OBSERVATIONS OF SOLAR ENERGETIC PARTICLES AT A SYNCHRONOUS ORBIT

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1. INTRODUCTION

The Space Environment Monitors (SEM) on board the Japanese geostationary meteorological satellites (GMS-1 and GMS-2) observed energetic protons, alpha particles and electrons continuously for February 1978 to September 1984. The satellites were at 6.6 earth radii above 140°E equator. Observational items are shown in Table 1 [1].

In the propagation studies of solar energetic particles, statistical analyses for many events revealed on averaged picture of the propagation such as was reported by Reinhard et al.[2] and Van Hollebeke et al.[3]. They showed the existence of the fast propagation region (FPR:45°W $\pm\sim60°$, on an average) or the preferred connection region (PCR:20° W - 80° W) in the heliolongitude. We tried to study some characteristics of the propagation process of solar energetic particles by using the data provided by the GMS/SEM's for February 1978 to February 1983. Some preliminary results of the data analyses are reported in the present paper.

Table 1. Observational items of the GMS/SEM's.

GMS-1/SEM			GMS-2/SEM		
Channel Name	Particle Type	Energy Range (MeV)	Channel Name	Particle Type	Energy Range (MeV)
P1	protons	1.2 - 4	P1	protons	0.8 - 4
P2	protons	4 - 8	P2	protons	4 - 8
P3	protons	8 - 16	P3	protons	8 - 16
P4	protons	16 - 34	P4	protons	16 - 30
P5	protons	34 - 80	P5	protons	30 - 60
P6	protons	80 - 200	P6	protons	60 - 100
P7	protons	200 - 500	-	-	-
A1	alphas	9 - 70	A1	alphas	8 - 66
A2	alphas	30 - 70	A2	alphas	32 - 66
A3	alphas	65 - 170	A3	alphas	64 - 120
A4	alphas	130 - 250	A4	alphas	120 - 240
A5	alphas	320 - 370	A5	alphas	270 - 370
EL	electrons	> 2	EL	electrons	> 2

The data were obtained by the GMS-1/SEM for Feb 1978 to Dec.1981 and by the GMS-2/SEM for Dec.1981 to Feb 1983.

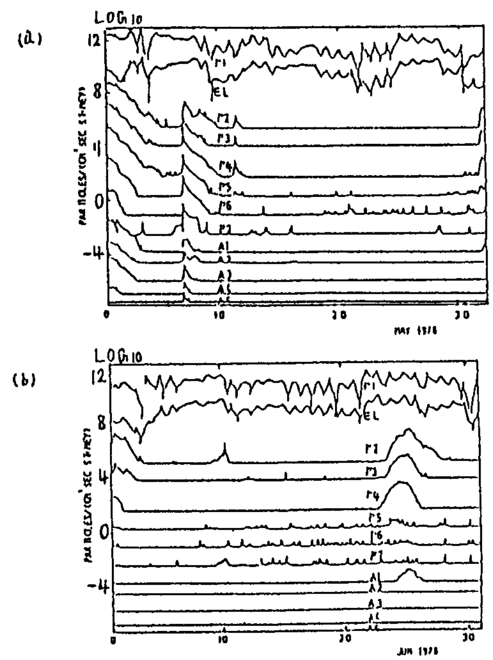

Fig 1 Two examples of the SEP events Hourly averaged SEM data are plotted for May 1978 (a) and Jun 1978 (b) The event of May 7,1978 is classified as an SRT event, and Jun 23,1978 event as an LRT event Each channel is separated from others by multiplying factor 10

2. DISTRIBUTION OF THE SEP EVENTS

Sometimes, the GMS/SEM's observed the solar energetic particle (SEP) events at their synchronous orbits. Two examples of the SEP events are shown in Fig.1(a) and 1(b). As seen in the figures, there was apparent increase in each channel, except for the P1 and EL channels. These two channels are omitted from our analyses because they are contaminated dominantly by the geomagnetically trapped or quasi-trapped particles.

About 50 SEP events were observed by the GMS/SEM's for the period (Fig.2). Hourly plots of the SEM data, first, indicate that the time profiles of flux intensities of the SEP events are different from event to event. It seems, however, that they are able to be classified roughly into two groups. One of them is the short rise time (SRT) event group. The rise time of

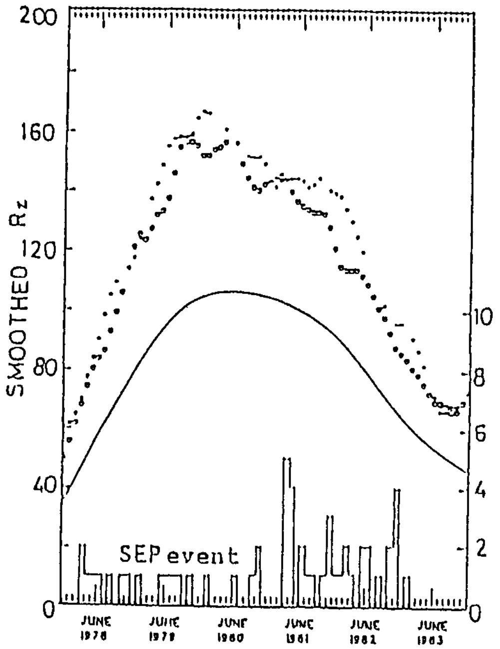

Fig 2. Distribution of the SEP events observed by the GMS/SEM's for the period of Feb 1978 to Feb 1983 This period just coincides with the maximum phase of solar activity cycle 21 (Sun spot data were taken from the SOLAR-GEOPHYSICAL DATA.)

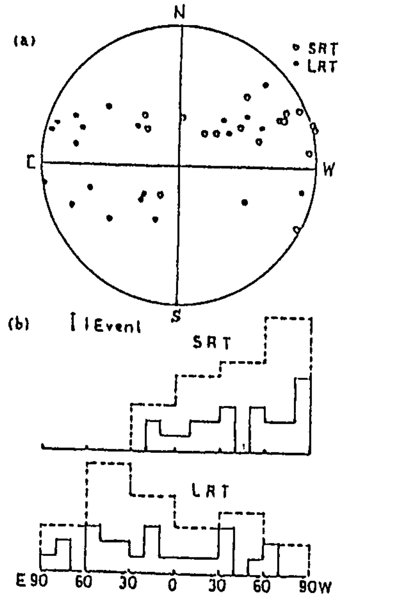

Fig 3 Distribution of the SEP events in the heliolongitude. The parent flares are plotted on the solar disk (a). In the figure (b), heliolongitudinal bin is taken by 10° (solid line) or 30° (broken line)

an SRT event is relatively short. It has a clear peak, as shown in Fig.1(a). (Here the rise time is defined as the time from onset to maximum flux intensity.) The other group is composed of several events, alternatively, which do not belong to the SRT event group (such as in Fig.1(b)), that is, it includes long rise time events, those which have no clear peak, and those which have somewhat complex time profiles. We called the second group the long rise time (LRT) event group. The distributions of the SRT and the LRT events are shown in Fig.3. These figures indicate that the SRT events distribute dominantly on the western hemisphere and many of the LRT events on the eastern.

3 CORRELATION BETWEEN THE SRT EVENTS AND THE PRECEDING SSC's Temporal situation of the interplanetary space will become a very important factor in addition to the steady and averaged configuration of the space, when we consider the interplanetary propagation of solar energetic particles. Shock waves are one of the most dominant sources which affects the temporal situation of the space such as the IMF. Shocks also disturb the geomagnetic situation as sometimes observed as storm sudden commencement (SSC).

We examined the correlation between the SEP events and preceding SSC's. Fig.4 shows the frequency distribution of events which were accompanied by the SSC several days prior to onset of event. In the figure, τ_0 is the time needed for the sun to rotate 180°; it is considered to be nearly double scale of the broadness of interplanetary shocks [5]. It can been seen in the figure that a reasonable correlation exists between the SRT events and their accompanied preceding SSC's, while no correlation exists for the LRT events. And τ is considered as a limit of the correlation.

4 TIME VARIATION OF P/α -RATIO It would be interesting to find tendencies of time variation of the proton-alpha ratio in the context of propagation study, because it is expected that there are some qualitative differences in the effects suffered during the propagation. We plotted

three ratios corresponding to three energy (per nucleon) ranges, R(L), R(M) and R(H) defined as

$$R(L;t) = [P2(t)+P3(t)]/A1(t),$$
$$R(M;t) = P4(t)/A3(t),$$
$$\text{and } R(H;t) = P5(t)/A4(t).$$

Examples of these plots for an SRT and an LRT events are shown in Fig.5. In the figure, plots of R(H), which is the one of highest energy, fluctuate significantly, because of poor statistics on P5 and A4. From the plots of many events, we may be able to say that R(L) has a constancy in its value during a event for both the SRT and the LRT events but the values are different from event to event. And, for the SRT events, R(M) and R(H) have a tendency to decrease with time, while they were nearly constant for the LRT events. These tentatively identified tendencies are represented in Fig.5 by broken lines.

5.DISCUSSION

5.1 Coronal Propagation: The SEM data are hourly averaged ones and can not provide any information about anisotropy. Hence, it is not possible to discuss coronal propagation in detail. However, we can draw some suggestions about coronal propagation from the data. It is not natural that the mechanism of solar flare responsible for particle acceleration and release would change depending on the heliolongitude of flare position. Therefore, Fig.3 suggests as follows. The differences between the SRT and the LRT events are attributed to the differences of the propagation effects suffered during the propagation between the sun and the earth for each group. As is well known, the region of good connection is 40° - 50° W in the heliolongitude. According to Reinhard et al., the predominantly well guided region is not so narrow, in fact, it is rather more wide; that is the FPR has a size of ~100°. In section 2, we found that the width of distribution of the SRT event was about 100°. This may imply that the solar energetic particles, generated by the flare at a heliolongitude λ, fill up the region with a center of λ and radius of ~50° in heliolongitude, and when the root of the IMF passing the earth is lying in this region, that event will be observed as an SRT event at 1AU. Fig.3 is an evidence of the existence of the FPR. Thus, we would be able to state that the SRT events are distributing in the FPR and many of the LRT events are far from this region. We should, here,

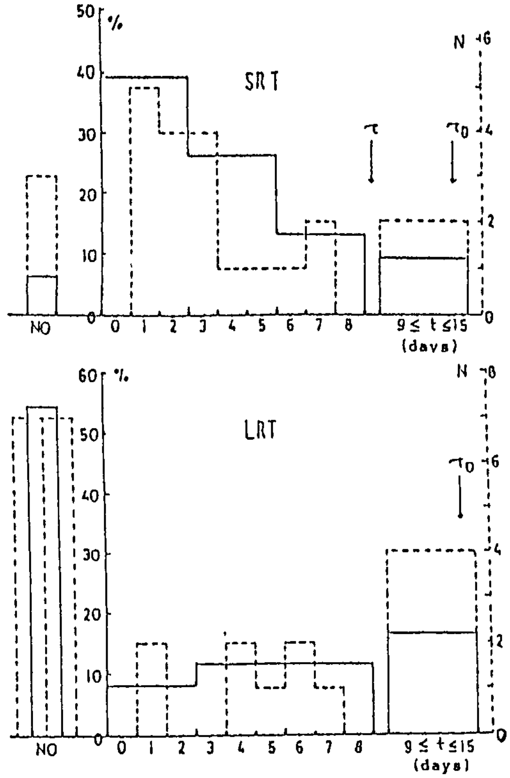

Fig 4 Correlation between the SEP events and their accompanied preceding SSC's The frequency distribution is shown The abscissa in the figure represents how many days does occur SSC prior to SEP event And τ is a limit of the correlation Diagram indicated by broken line with right hand side ordinate represents the distribution of event number.

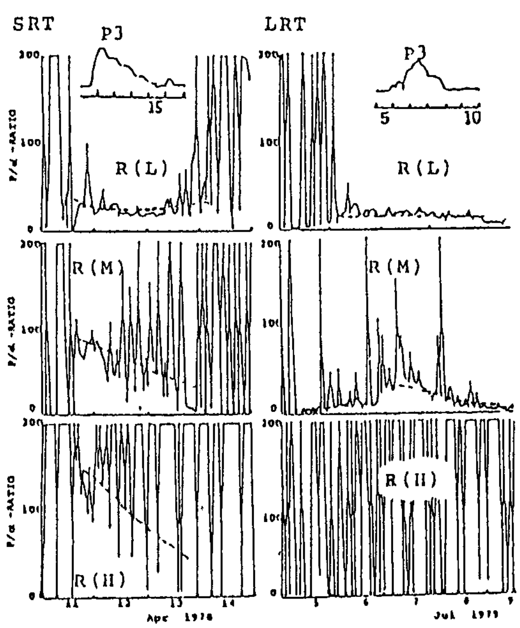

Fig.5 Time variation of P/α -ratio Three ratios corresponding to three energy ranges are plotted Tentatively identified tendencies are drawn by hand as broken lines

note the fact that there are a few exceptions for both groups, and the statement is valid in the sense of averaged picture.

5.2 Interplanetary Propagation: Let us consider the space with distance less than 1AU when a shock has just passed, i.e., immediately after an occurrence of SSC. Observations show that, when a shock has passed in the space, the solar energetic particles propagate in the interplanetary space; then these particles are observed predominantly as an SRT event. This means that, for such an event, most of the energetic particles have suffered only little scattering through their propagation in the space. Therefore, the result is that mean free path, hence diffusion coefficient, is large for the energetic particles with energy (or rigidity) under consideration. And this may suggest the number density of scattering centers in the space decreased after passage of shock. When a shock wave that triggered off an SSC has propagated through the space, the irregularities of magnetic field which are scattering centers were swept out. Thus the density of scattering centers is minimized within several days after an occurrence of a SSC. At this time, it is considered that some region of the interplanetary space which has been swept out by a shock is a "clean space". The cleanness of the space will decay in two ways. One is due to the rotation of the sun . The other is due to the random motion of the roots of the IMF on the solar surface. Therefore, it is inferred that an upper limit in time between the SRT events and preceding SSC's. According to the statistics in Fig.4, this upper limit is 7-10 days.

We should, however, remember the following argument. If the interplanetary shock that is observed as a preceding SSC and the solar flare that generates an SRT event occur in the same active region, then another possibility may exist other than the above mentioned. The active region that is responsible for a SRT event has been in the eastern hemisphere several days before. At this time, it is possible to imagine that such active region has generated a shock wave that is responsible for a SSC. In this case, the correlation between a western hemisphere event and its preceding SSC necessarily exists. Then, the essential condition of the occurrence of SRT events is that the parent flare occurs in the western hemisphere; and the correlation between SRT events and their preceding SSC's is not the cause but a result If it were a result, it becomes more interested because subsequent occurrences of shock ejection and flare provides informations of prediction of an occurrence of flare and of flare mechanism itself. Continuous measurements of the power spectrum of the IMF will be able to solve this problem.

The time profiles of the LRT events significantly differ from each other Moreover it is not possible that the LRT events can be understood by using one propagation model only (e.g., anisotropic diffusion model). These two facts may suggest that the interplanetary propagation effects modulate significantly the time profile. For example, when we tried to fit the time profiles by using an anisotropic diffusion model (e.g., Burlaga's ADB model [5]), fitting curve was in good agreement with the appropriate parameters for the SRT events, but for the LRT events, no reasonable agreement was obtained. In the case of the SRT event, time variations of P/α -ratio for R(L),R(M) and R(H) are able to be understood by introducing appropriate energy (or rigidity) dependence of the mean free path of particles. On the other hand, for the LRT event, it is not possible to explain the time variation of P/α by using diffusion theory only because it is considered that this kind of events was suffered the propagation effects other than diffusion effect. Though, it seems that constancy in P/α restricts these effects such as that protons and alphas were modulated in a same manner.

The SEM data used in the present study were provided from the Meteorological Satellite Center, the Japanese Meteorological Agency.

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