Quiescence of GLE-Producible Solar Proton Eruptions during the Transition Phase of Heliomagnetic Polarity Reversal near the Solar-Activity-Maximum Period

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By using data of the ground-level-enhancement (GLE), of solar cosmic rays observed with the neutron and muon monitors in the period 1942–1990, it is shown that the solar proton eruptions producible GLE are forbidden during the transition phase of the heliomagnetic polarity reversal, near the period of the maximum solar activity. It is suggested that the quiescence of GLE is not due to the suppression effect of the proton eruption from the Sun by the strong solar magnetic field, but is due to the deterioration of the proton acceleration efficiency by the structual change of the field during the transition period.

The relativistic solar protons sometimes produce the enhancement of the cosmic-ray intensity observable with the neutron and muon monitors on the ground (e.g. ELLIOT, 1952; CARMICHAEL, 1962; DUGGAL, 1979; SMART and SHEA, 1990; and references therein). We call this phenomenon the ground-level-enhancement (GLE) of solar cosmic rays. The occurrence of GLE is mainly in the period of the enhanced solar activity, but according to KODAMA (1962) it is forbidden in the maximum-activity period of the solar cycle when the sunspot number (R) is greater than some critical value (R_c) such as about 100. This suggests that the relativistic protons cannot escape from the Sun owing to the strong magnetic field in the extremely active period even though they might be accelerated to the relativistic energy. With the increase of GLE-events, his statement, however, has become an unsafe criterion for ascertaining the forbidden period of the occurrence. We propose here an alternative criterion as expressed by the title of the present paper.

Data used for the analysis are 43 events observed in the period 1942–1990, as shown in Table 1. The occurrence time (T_i) of GLE is shown by the vertical line in Fig. 1, together with the sunspot number. As can be seen in the figure, his criterion in the above seems effective before the present solar cycle (#22). But, in the present cycle, many GLEs have been observed even in the maximum period for $R > R_c$. Figure 2 shows the distribution of the relative occurrence time (ΔT_R) of GLE which is measured from the epoch (T_{max}) of the maximum sunspot number of the respective solar cycles shown at the bottom. As anticipated, the distribution does not show any depression near the period of the maximum solar activity and furthermore it rather

Table 1. Ground-based-enhancement (GLE) of solar cosmic rays observed with the neutron and muon monitors in the period 1942–1990. ΔI is the hourly average of peak intensity of neutrons (unless specified) at high latitude station. Alphabetical symbol in the remaks represents the reference of the data source written below.

GLE No.	Solar Cycle	GLE Start Y	M	D	H	Max. Intensity $\Delta I(\%)$	Smoothed R_Z	Ref-erence
1	17	'42	FEB	28	11.7	~ 7 (muon)	37	a
2	"	"	MAR	7	4.7	~ 9 (")	36	a
3	18	'46	JUL	25	17	~ 20 (")	95	a
4	"	'49	NOV	19	10.8	~ 40 (")	118	a
5	19	'56	FEB	23	3.8	~ 4500	99	b, c
6	"	"	AUG	31	12.8	2	154	c
7	"	'59	JUL	17	0.1	10	154	"
8	"	'60	MAY	4	10.5	280	116	"
9	"	"	SEP	3	2.5	4	96	"
10	"	"	NOV	12	13.5		86	"
	"	"	"	12	19	120		"
11	"	"	NOV	15	2.5	80	86	"
12	"	"	NOV	20	21.0	5	84	"
13	"	'61	JUL	18	10.2	12	53	"
14	"	"	JUL	20	16.2	4	53	"
15	20	'66	JUL	7	0.8	2	50	"
16	"	'67	JAN	28	8.2	17.6	75	d
17	"	'68	NOV	18	10.6	3.7	111	"
18	"	'69	FEB	25	9.3	4.8	110	"
19	"	'71	JAN	24	24	11.2	80	"
20	"	"	SEP	1	21	12.8	66	"
21	"	'72	AUG	4	13	7.4	66	"
22	"	"	AUG	7	16	6.3	66	"
23	"	'73	APR	29	22	2.2	43	"
24	"	'76	APR	30	22	2.2	13	"
25	21	'77	SEP	19	12	1.1	39	"
26	"	"	SEP	24	7	6.9	39	"
27	"	"	NOV	22	11	15.2	52	"
28	"	'78	MAY	7	4	9.9	83	"
29	"	"	SEP	23	11	5.8	108	"
30	"	'81	OCT	12	8	7.5	142	"
31	"	'82	NOV	26	4	3.7	95	"
32	"	"	DEC	7	24	18.5	95	"
33	"	'84	FEB	16	10	4.7	56	"
34	22	'89	JUL	25	10	4.0	159	"
35	"	"	AUG	16	2	9.0	158	"
36	"	"	SEP	29	12	340.4	157	"
37	"	"	OCT	19	14	39.9	157	"
38	"	"	OCT	22	19	16.6	157	"
39	"	"	OCT	24	19	85.8	157	"
40	"	"	NOV	15	8	1.4	158	"
41	"	'90	MAY	21	23	~ 9	148	"
42	"	"	MAY	24	22	~ 6	148	"
43	"	"	MAY	26	22	~ 5	148	"

No. 1~4: CHELTENHAM Ion Chamber, No. 5: LEEDS, No. 6~15: DEEP RIVER, No. 16~33: 1/2 (ALERT + McMURD), No. 34~43: THULE.

Data sources:

a: FORBUSH and LANGE (1942), FORBUSH (1946), FORBUSH et al. (1950) and ELLIOT (1952),
b: SITTKUS et al. (1956) and MEYER (1956),
c: ŠVESTKA and SIMON (1975),
d: *WDC-C2 for Cosmic Rays, and Solar-Geophysical Data.*

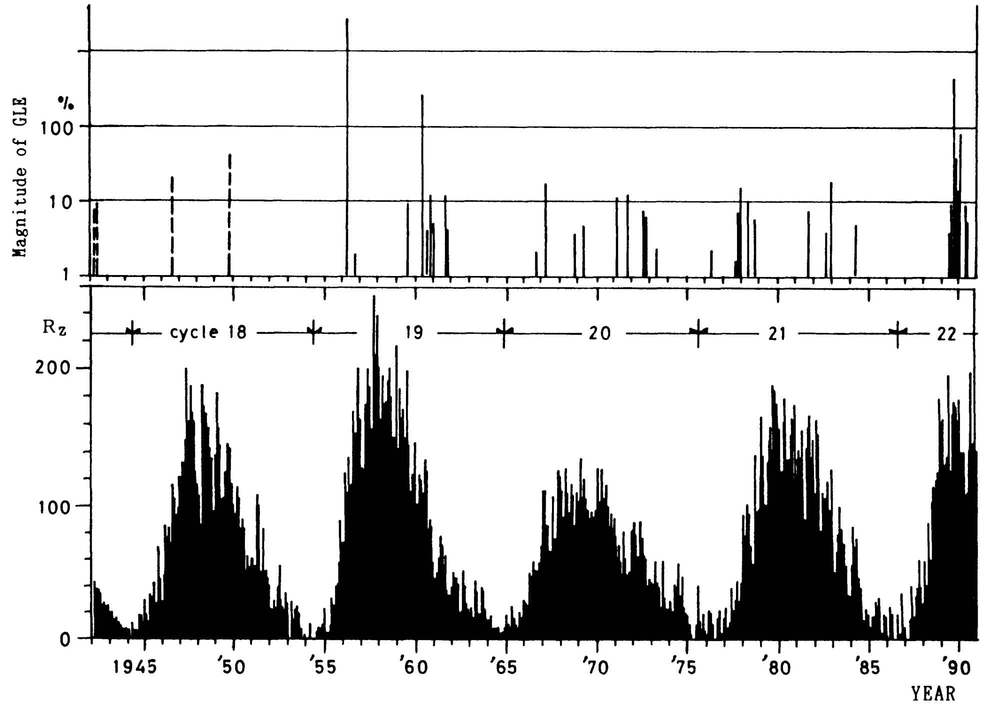

Fig. 1. Occurrence times and magnitudes of the ground-level-enhancement (GLE) of solar cosmic rays expressed with the vertical lines and the sunspot number (R) during the period 1942–1990.

shows a peak in the period. This implies that the criterion in the above cannot be adopted any more. The quiescence of GLE seems to be related to the polarity reversal of the solar magnetic field. Figure 3 shows the distribution of the occurrence time (ΔT_P) of GLE which is measured from the initial time (T_P) of the transition phase of the heliomagnetic polarity reversal in each solar cycle. We have defined the transition phase as follows; it starts from the time of the sign change of the magnetic field in one of the polar regions (north or south) and ends at the time of the sign reversal of the magnetic field in another polar region. The period of transition phase in each solar cycle is shown by the horizontal bar in the figure and listed in the caption of the figure with references. In the early period, as there was no observation of the polarity reversal, the transition in the solar cycle #17 has been assumed to have started near the maximum solar activity and continued about one year, and the transition in the cycle #18 has been inferred from the polarity dependence of the long term variation of cosmic-ray intensity (cf. NAGASHIMA and MORISHITA, 1980; BABCOCK, 1959). Such assumption and inferrence does not give any decisive influence on the distribution, as the GLE-events reported in these cycles (#17, #18) are very few. As can be seen in Fig. 3, the occurrence frequency is maximum just before the period of the transition phase, becomes zero during the period and increases gradually afterwards.

It is noted that the absence of the proton events in this period is limited only in the high energy region. According to the analysis of space probe data in the period

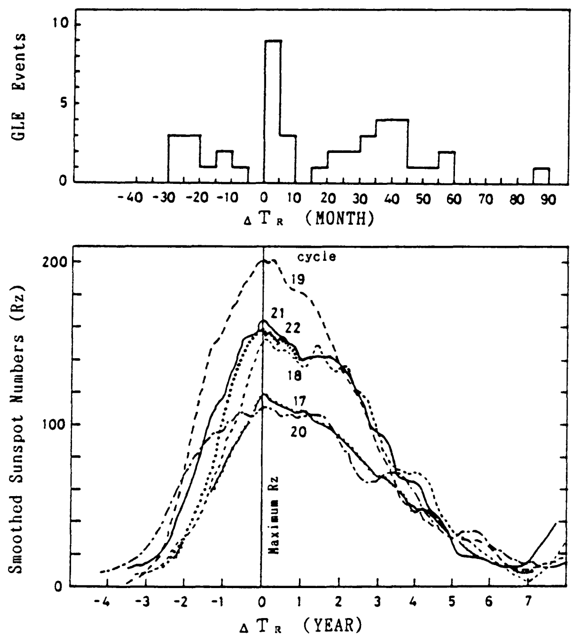

Fig. 2

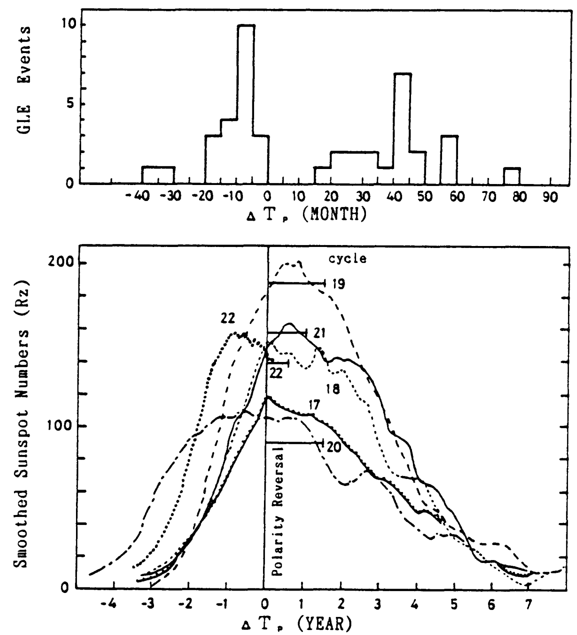

Fig. 3

Fig. 2. Occurrence frequency of GLE as a function of the time ΔT_R which is measured from the time (T_{max}) of the maximum of the smoothed sunspot number in each solar cycle. T_{max}'s are respectively Apr., 1937, May, 1947, Nov., 1957, Nov., 1968, Dec., 1979 and Jul., 1989 for the solar cycles #17–22. The figure at the bottom is the superposition of the sunspot numbers for these solar cycles.

Fig. 3. Occurrence frequency of GLE as a function of the time ΔT_P which is measured from the initial time (T_P) of the transition phase of the heliomagnetic polarity reversal in each solar cycle. The transition phase are respectively Apr., 1937(?)–? (solar cycle #17), Jun., 1947(?)–? (solar cycle #18), May, 1957–Nov., 1958 (solar cycle #19; cf. HOWARD (1974)), Sep., 1969–Feb., 1971 (solar cycle #20; cf. HOWARD (1974)), May, 1979–May, 1980 (solar cycle #21; cf. *Solar Geophysical Data*) and Jun., 1990–Dec., 1990 (solar cycle #22; cf. *Solar Geophysical Data*). The superposed sunspot numbers for these solar cycles are also shown. The period of the transition phase is indicated by a horizontal bar.

of solar cycles #19 $\sim$ #21 by SMART and SHEA (1990), the low-energy proton events are observed even in the periods of the transition phase, although we can find, in the Fig. 2 in their paper, some slight indication of the depression of the occurrence frequency of the events in these periods. This indicates that the absence of GLE is not due to the suppression effect of the proton eruption from the Sun by the strong solar magnetic field. As can be seen in Fig. 3, the sunspot number does not show any abrupt change at the bounds of the transition phase in the same solar cycle, and the sunspot activities in the period in different solar cycles are considerably different from each other. These facts indicate that the quiescence of GLE-producible solar proton eruption during the transition phase is not due to the change of the solar activities represented by the sunspot number, the solar radio flux and the like. The principal cause of the quiescence would be to be sought in the structural change of the solar magnetic field in the period, which could induce at least one of the following deteriorations of the particle acceleration efficiency; (1) the shortage of energy supply for the acceleration of the solar protons, (2) the reduction of the efficiency of the particle acceleration and (3) the shortening of the storage time of particles inside the source region for the acceleration to the relativistic energy.

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