Major Solar-Energetic Particles and the Associated GLEs

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Abstract

The hourly-averaged of measurements of solar proton fluxes (from Jan' 73 to May 01) have been scanned to select the major intensities. We have identified 58 of extremely high solar energetic particle (SEP) events (with flux of over 10 protons (cm2 sec ster)-1 with energy $\geq$ 60 MeV). Nearly 40 % of these events shed ground level enhancements (GLEs) of cosmic rays. Furthermore, high GLE was not a necessarily comes as a sequence of major SEP event and also, it was not a condition for creating major SEP fluxes. Some proposal factors are presented for production SEP and GLE together.

1. Introduction

Solar energetic particles (SEPs) often generate during powerful solar flares, allow us to obtain unique information; e.g., the Sun's flare process and the particles-acceleration mechanism. The study of [1] examined higher 21 SEP events, for which the intensity of 48.0-96.0 MeV protons exceeded 1 (cm2-sec-ster)-1. The events were associated with fast coronal mass ejections (CMEs) that originated from the central meridian to western longitudes on the Sun. In addition, major SEPs seem to be associated with solar activity that occurred within a narrow range of solar longitudes between 30 E and 30 W [2, 3]. SEPs propagate through interplanetary medium and can be detected at large distances from the Sun. These particles accelerate locally in the solar coronal by either solar flares or interplanetary (IP) shock-waves driven by CMEs [4,5]. Recent study [6] has given an evidence that the flares associated with SEP events were influenced by the storm sudden commencements (SSC). Being the most powerful SEP events, GLEs are always accompanied by powerful solar flares, with exception of events associated with active regions behind the limb. On the other hand, solar flares and other magnetic phenomena at the Sun may give rise to GLEs. In the present work, major intense event is defined as one having $\geq$ 10 particles (cm2-sec-ster)-1 $\geq$ 60 MeV. We have found 105 SEP days of 58 "significant" events. Twenty-three GLEs have associated with these events. The distributions of time-intensity profile and magnitude of SEPs have been compared elsewhere [7], with the associated

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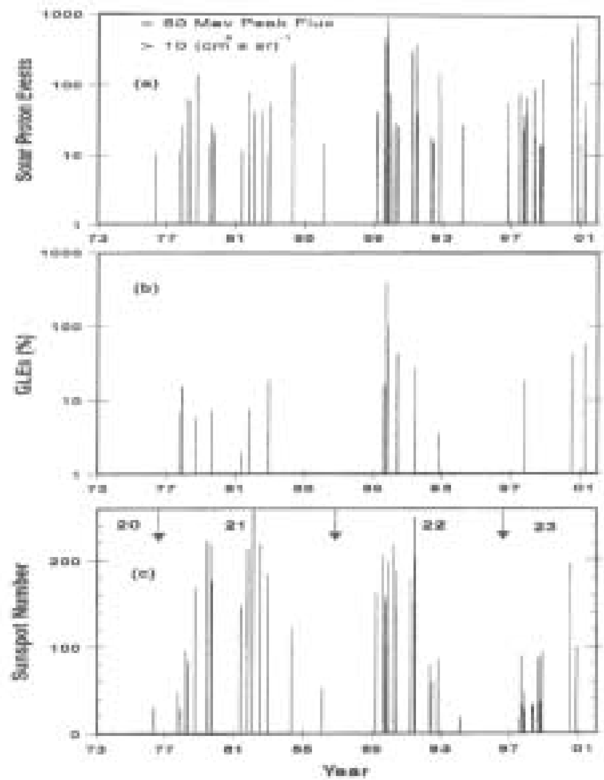

Fig. 1. The daily average magnitudes of major 105 SEPs (top) and the corresponding GLEs of solar cosmic rays (middle) plotted as individual vertical lines. Note that, there are 13 GLEs that did not produced RSPs. Plot 1c displays the international sunspot numbers

features for GLEs. The factors responsible for creating a couple of GLE and high SEP events, have been discussed.

2. Observations of Major Solar Energetic and Relativistic Particle Events Throughout the Period Jan' 73-May 01

The hourly averages of solar energetic proton intensities recorded near the Earth's orbit between Jan' 73 and May 01, which were provided by the National Space Science and Data Center (NSSDC), have been used. We have scanned the proton intensities to select the events with energies $\geq$ 60 MeV proton fluxes $\geq$ 10 particles / (cm2 sec ster). Our database included 105 days with 58 of major SEP events. Twenty-three major SEPs have associated with GLEs. Approximately 40 % of the obtained major events contained relativistic solar protons as recorded by ground-based neutron monitors (NMs).

Figure 1 shows the magnitudes (based on daily-averages) of major 105 solar energetic proton days (top) and the corresponding ground level enhancements of solar cosmic rays (middle) expressed with the individual vertical lines. The bottom graph (1c) displays the international sunspot numbers between 1973 and May 01. Arrows indicate the start of each SAC (from 21 to 23). Note that, there are 13 GLEs which did not produced relativistic solar protons (RSP). Generally,

Table 1. Distribution of the major energetic proton intensities (based on daily averages) and ground level enhancements observed over the solar cycles 21-23.

Solar Cycle	SEP Events			GLE Events			Relativistic
	#	Max. Peak/Date	R_Z	#	Max. Peak/Date	R_Z	Percent (%)
21 (Jul' 76-Sep' 86)	16	198.2/26 Apr' 84	124	8	18.5/ 7 Dec' 82	184	50
22 (Oct' 86-May 96)	24	847.3/19 Oct' 89	140	11	340.4/ 29 Sep' 89	134	45.8
23 (Jun' 96-May 01)	17	712/9 Nov' 00	95	4	57.1/ 15 Apr' 01	75	23.5

major proton events occur between the 2nd and 6th- year of the solar cycle. In addition, there are 48 % of events with at least two or more consecutive days (0.05 % of four-day duration). Nearly half of the individual SEP events (52 %) with one-day duration. Major SEPs were completely absent during the years of sunspot minima toward the end of solar cycle, the decaying phase of SAC 20 (1973-74), and the rising phase of SC 22 (1987-88). There is no predicable pattern in the occurrence of SEP events from one solar cycle to the next [8]. Several events have observed in 1989 (21 events): four of them (one in Sep' 89 and three in Oct' 89) originated from the same active region [9]. The largest five high-energy peak flux events observed in 1989 and 2000 (29 Sep' 89, 19 and 22 Oct' 89, 14 Jul' 00, and 9 Nov' 00). High SEPs were not a necessary condition for the creation of GLE events (e.g., 14 Feb' 78, 30 Apr' 78, 8 Dec' 82, 1 Dec' 89, 23 Mar' 91, 9 Jul' 97, 20-21 Apr' 98, 5 Nov' 98, and 6 Nov' 00). Although the existing of the flare or/and the interplanetary shock driven by CME are essential factors for the particle acceleration efficiency and to produce high SEPs, we think there are another factors should be associated with producing of GLE. In addition, larger GLEs were not condition for creating high SEPs flux/fluence (13 GLEs were not accompanied by SEPs). So, we think there are multiple factors help in increasing of the protons-acceleration efficiency, prevent particles from escaping in the inner heliosphere and, ..etc., should be available in producing SEP and GLE together. We think, the detailed studies of the following factors, may be give more explanations; the complex structures of both the heliospheric magnetic field and geomagnetic activities during the producing of SEP and GLE events, the coronal mass ejection in association with B-, N-, and F-type solar flares, as well as, the types of sudden commencement followed by a magnetic storms. Table 1. shows the distribution of the major energetic proton intensities (based on daily averages) and ground level enhancements observed over the solar cycles 21-23.

Table 1 shows the distribution of major SEP (based on daily averages) and GLE events over the solar cycles 21-23. The number of observed events (SEPs and GLEs) for each cycle, as well as the maximum peak and date for each event, are listed with the corresponding sunspot number (RZ). The relativistic solar protons percent is noted in the last column. There are 17 discrete solar proton events during the first 60 months of cycle 23 (from 1 Jun' 96 to 31 May 01). So, the distribution of SEPs, GLEs and RZ throughout the first-five years of cycle 23 may be following the similar pattern of cycle 20, as recently noted [3]. Four solar events during the solar cycle 23 have shed GLEs with considerable high increases in cosmic rays. Generally, the rate of relativistic solar protons that produced GLEs remained relatively constant during the two cycles 21 and 22 (50 % and 45.8 %, respectively). The solar cycle 22 has the largest SEP and GLE ever (19 Oct' 89 and 29 Sep' 89, respectively). Also, it has the greater number of events than those occurred in solar cycle 21. The Mar' 89-Jul' 91 period (29 months) of cycle 22 has a larger proton events (magnitude and fluence) than those recorded in cycle 21 or even those from Jan' 73 throughout the 194 months. The observed peak flux (based on daily-averages) in cycle 22 is larger by a factor of four than that happened in cycle 21, implying to different mechanisms of solar particle acceleration and subsequent propagation through the interplanetary space, and in turn to different forms of energy spectra. The extremely high SEP in cycle 23 (9 Nov' 00) was not recorded by ground-based neutron detectors.

3. Discussions and Conclusions

Solar energetic particle events refer to the most powerful signatures of solar activity cycle. Nearly 40 % of events shed RSP events. We found that high GLE was not a necessarily comes as a sequence of major SEP event. Although the existing of solar flare or/and IP shock driven by CME are essential requirements for the particle accelerating efficiency and to generate high SEPs, there are another factors should be associated to produce GLE. In contrast, high GLEs were not condition for creating major SEPs fluxes. We think that, there are multiple factors to create a couple of SEP and GLE.

4. Acknowledgement

Acknowledgments The author acknowledges the NSSDC for energetic proton data.

5. References

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