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Effect of Some Solar Energetic Events on Cosmic Ray (CR) Ground Level Enhancement (GLE)

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Abstract: Ground Level Enhancements (GLEs) are sudden and short-lived increases in cosmic rays intensities registered by neutron monitors and usually associated with powerful solar explosive events. This work examines the key features of forty-nine (49) Ground level enhancement (GLE) events with a view to understanding the possible link to their solar sources. These constitute the 22nd -71st GLE as recorded by the Oulu Neutron monitor. We have computed the increase rates of the GLE and have compared them with the associated solar activity parameters. It is observed that GLEs are more associated with Solar flares than CMEs during the minimum and ascending phase of the 11 year solar cycle when compared with GLEs that occurred during the maximum phase of the solar cycle. In general, more GLE events were associated with solar flares originating from the Northern hemisphere of the solar disk as compared with the southern hemisphere flares. 80% of GLE with percentage increase rate (PIR) <10% were linked with strong flares. There was no/weak statistical association between intensity of solar energetic events (solar flares, CMEs, etc) and increase rate of GLE. The harder solar energetic fluxes seem to be responsible for GLEs with high PIR and that the softer fluxes may be responsible for those with low PIR. These results have important implications for our present understanding of potential solar drivers of the GLEs.

Keywords: Cosmic Rays, Ground Level Enhancement, Solar Activity, Solar Flares

1. Introduction

Ground level enhancement (GLE) are a consequence of the most energetic (~GeV) solar particles accelerated during solar explosive events such as flare processes and CMEs. The importance of understanding the variability of GLEs and their association with their solar origin cannot be overemphasized. Consequently, much studies have been dedicated to understanding specific events [21, 2, 18, 19], and the main properties of many events [22, 3, 9, 10, 1].

In general GLE is a result of secondary cosmic rays formed from the original (or primary cosmic rays) from the sun. The primary cosmic rays initiate a complicated nuclear-electromagnetic –moun cascade in the atmosphere generating large variety of secondary particles resulting in an ionization of the ambient air. In such a cascade a small fraction of initial primary particle energy reaches the ground as high energy secondary particles. Most of the primary energy is released in the atmosphere by ionization and excitation of the air molecules [7, 23]. However in some cases, solar energetic particles (SEP) can be accelerated to greater energies up to a few GeV and can penetrate deep into the atmosphere or even reach the ground leading to ground level enhancements [19]. Being able to associate SEPs and flares to specific GLEs is more like an act rather than a science. This is because a number of flares and SEP show enigmatic properties that does not conform to known signatures. For example, impulsive SEP events without accompanying shocks and energetic storm particle events detected by spacecrafts near earth are concrete proof for the reality of flares and shock acceleration processes [14]. In addition both processes (SEP and flares) are expected to operate during major eruptions such as those involved in GLE events. It is important to note that SEP are a major source of ionization in the atmosphere especially in high latitudes. It is customary to represent the increment of GLEs by the % of enhancement of the neutron monitors count rates above the background. The time window of GLE are generally considered within 24hrs covering backgrounds before and after the GLE peaks [9].

Many authors have attempted to understand the associations and relationships between GLEs and various solar activity proxies [12 6, 3, 9, 10 14, 18]. Some of these works [10, 14] have suggested that solar flares are primarily responsible for the GLE properties, while other works [6, 9, 18] believe that solar energetic particles (SEP) including CMEs and associated shocks are major candidates. Solar energetic particles (SEPs) which are accelerated during explosive energy releases on the sun can reach energies of the order of a few tens of MeV [19]. Since the first documented GLE in 1942, many studies have continued to provide useful information for specific and generalized properties of GLEs occurrence. Firoz et al. [9] studied GLEs that occurred between 1986 and 2006 and associated solar flares. Their result showed that in general the GLE event that were associated with flares were much stronger than those that did not have an associated flare. A similar result was obtained by Firoz et al. [10], when only very intense GLEs were considered. It was suggested that the intensive portions of solar flares should be responsible for causing GLEs. On the other hand some authors (e.g [16, 20]) had argued that GLE constitute the relativistic counterpart of solar energetic particles (SEP) which have the requisite hard spectra to drive such high flux of cosmic rays at high latitude. This appears not to be the case as some relatively strong solar flares do not have associated GLEs. GLES are consequently known to be sporadic and much work is currently underway to better understand the conditions that give rise to its occurrence and properties. For Instance, Cohen et al., [4] studied several extreme solar energetic particle (SEP) events and observed that many had harder spectra and higher fluences than some GLEs measured on earth.

Belov et al. [3] studied the 16 GLEs of the last solar cycle (cycle 23), they also observed that the flares associated with the GLEs were mostly in the western part of the solar disk He also reported that the CME followed by the GLE will most probably lead to a very large Forbush decrease on the Earth. Firoz et al., [9] studied the characteristics of 32 GLEs and their associations with solar eruptions. They observed that CMEs associated with GLE were much faster than the average speed of CME that were not associated with GLEs. They observed from their sample that 82% of GLEs were associated with X-class flares and nearly all GLE associated with flares originated from the western hemisphere of the Sun. It was consequently concluded that CMEs alone does not cause GLE and that the variations of the GLEs may depend on a combination of the magnitude of the flare, solar energetic particle and CME driven shock and possibly other geophysical parameters. In addition, the way solar energetic particles are accelerated to GeV energies, and at what height in the corona are they released are not yet fully understood [14]. The spatial and temporal information on the release of GLE particles provide important details that may distinguish between two particle acceleration mechanism (flare reconnection and shock) that operate in distinct spatial locations in a solar eruption [13]. Cohen and Mewaldt [5] studied the GLE event of September 10, 2017 which was the second in the cycle 24, observed that Fe/O ratio was lower than average and hence concluded that this may be a feature of the suprathermal population having a lower Fe/O ratio in cycle 24.

Mishev et al. [18] analyzed the data of the first GLE of the solar cycle 24. They observed that the event had an anisotropic onset in addition to a complicated pitch angle distribution. The pitch angle is defined as the angle between the anisotropic direction and the axis of anisotropy. They suggested that the interplanetary magnetic field structure which could have been associated with a previous CME could be responsible. Gopalswamy et al. [14] also analyzed the first GLE of the 24th solar cycle which was associated with a moderate flare, they found that the flare size for this GLE is smaller than that in all cycle 23 GLEs and suggests that the flare size us not a good indicator of GLE production because there were half a dozen well connected eruptions with larger flare size and faster CMEs during cycle 24 that lacked GLEs. Similar discrepancy in the measured GLE was reported by Liu et al. [17] who studied GLEs across Canada during the Jan 20, 2005 solar event. Not much work has been done to understand the less subtle GLEs with less than 10% relative count rate increment (Ir%). This study has become important in the light of observation by Kataoka et al., [15] that solar energetic particle events affect humans at about 12km altitude for (weak) non GLE associated SEP event. Therefore the objectives of this study is to understand the time series of weak GLEs (Ir<10%)in terms of their general properties, and their relationship to associated solar flares and CMEs.

2. Sources of data and Method of Analysis

The cosmic ray data used in this work consists of cosmic ray intensity ground based data obtained from neutron monitor (NM) stations which are a part of the world wide network and covering GLE 15-71. The solar particles events data include information on the start time, peak time and end time of the events in addition to location on the solar disk from 1971-2012. These data were collected from the IZMIRAN group data base (http://cosray.phys.uoa.gr/index.php/data/solar-proton-events-database), and complimented by published data by Belov et al., [3], and, Firoz et al., [9]. The data constitute 1-minute data (and sometimes 5-mins data). Data for OULU NM data contained significant intermittent down time which on removing such data points did not significantly affect the GLE profiles considered. To understand the association between the GLEs and their solar explosive drivers, data for individual events were synthesized from the different sources. The increase rate I_r (%) of the cosmic ray intensity (CRI) during the GLE is computed after Firoz et al. [9] as;

$$I_r(\%) = \left[\left(I_j - I_p\right) \times 100\right]/I_p$$

Where I_j is the CRI time series from the pre-increase value to the value at which the CRI decreases to minimum or to the background level. I_p is the average pre-increase CRI (i.e before the onset of the sharp increase) see figure 1 for details of the method of determining the I_r (%).

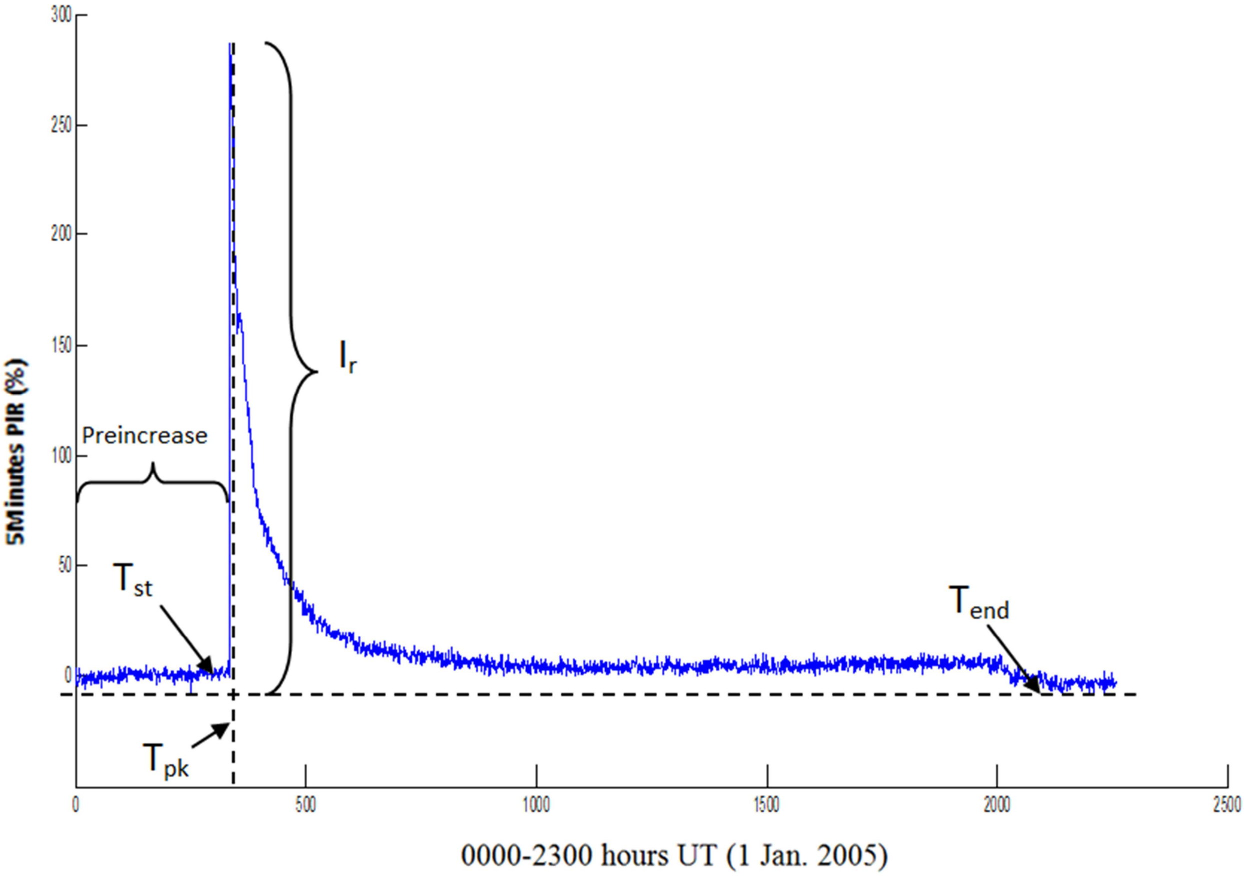

Figure 1. *5 min CRI at ONM for GLE69@OULU on Jan. 1, 2005.*

MATLAB program was employed to plot the cosmic ray intensity Peak Increase Rate PIR (%) for the station over the period 1971-2012. The program was used to deduce the 5 min peak increase rate of the cosmic ray intensity of the Oulu station in Figure 1. The statistical association between GLEs and some solar energetic events i.e. solar flares (SFs), solar energetic particle events (SEPs), and coronal mass ejections (CMEs) were performed and the summary of results are presented in table 1. Column 1 of Table 1 is the event of GLE (number of event). Column 2: the corresponding date of GLE event, Column 3 - the PIR, peak increase rate or (I_r%), Column 4 -*X-ray Flux* events which include flare class, optical importance of flare, flare position and flare intensity, Column 5- the peak flux unit of SEP, the natural log. of PFU and fluence of SEP (particle flux PF>10MeV/ cm^2 data), Column 6- CME event which include the velocity (km/s), CPA (central position angle in deg.) and the AW (angular width in deg.)

Table 1. *Summary of GLE observation and associated solar energetic events.*

GLE Event	Date	PIR	X-ray Flux (w/m^2)					SEP Event			CME		
No.	**D. M. Y**	**(%)**	**Class**	**Opt Imp**	**Location Lat. Long**	**Flare Int. (W/m^2)**	**Nlog Flare Int (W/m^2)**	**Peak_pfu cm^{-2} sec^{-1} sr^{-1}**	**NLog Peak_pfu**	**Fluence PF > 10 MeV (per cm^2)**	**Vcme (km/s)**	**CPA (deg)**	**AW (deg)**
22	24.01.71	16	X5.0	3B	N18W49	5.0 x 10^{-4}	-7.6	1000	6.9	--	--	--	--
23	01.09.71	14	--	--	OverWLimb	--	--	450	6.1	--	--	--	--
24	04.08.72	10	--	2B	N14E28	--	--	55000	10.9	--	--	--	--
25	07.08.72	5	>X5.0	3B	N14W37	5.0 x 10^{-4}	-76	1300	7.2	--	--	--	--
26	29.04.73	4	X2.0	2B	N14W73	2.0 x 10^{-4}	-8.5.	40	3.7	--	--	--	--
27	30.04.76	4	X2.0	2B	S09W47	2.0 x 10^{-4}	-8.5.	130	4.9	1.01E+08	--	--	--
28	19.09.77	3	X2.0	3B	N08W57	2.0 x 10^{-4}	-8.5.	400	5.9	3.50E+08	--	--	--
29	24.09.77	7	--	--	Over Limb	--	--	100	4.6	8.82E+07	--	--	--
30	22.11.77	13	X1.0	2B	N27W40	1.0 x 10^{-4}	-9.2	300	5.7	3.00E+08	--	--	--
31	07.05.78	84	X2.0	1N	N23W72	2.0 x 10^{-4}	-8.5.	110	4.7	2.35E+09	--	--	--

GLE Event	Date	PIR	X-ray Flux (w/m^2)					SEP Event			CME		
No.	**D. M. Y**	**(%)**	**Class**	**Opt Imp**	**Location Lat. Long**	**Flare Int. (W/m^2)**	**Nlog Flare Int (W/m^2)**	**Peak_pfu cm^{-2} sec^{-1} sr^{-1}**	**NLog Peak_pfu**	**Fluence PF > 10 MeV (per cm^2)**	**Vcme (km/s)**	**CPA (deg)**	**AW (deg)**
32	23.09.78	7	X1.0	3B	N35W50	1.0×10^{-4}	-9.2	1000	6.9	3.32E+09	--	--	--
33	21.08.79	4	C6.0	2B	N17W40	6.0×10^{-6}	-12.0	750	6.6	6.40E+08	--	--	--
34	10.04.81	1	X2.5	2B	N07W36	2.5×10^{-4}	-8.3	40	3.7	--	--	--	--
35	10.05.81	2	M1.3	1N	N03W35	1.3 x 10-5	-11.3	120	4.8	--	--	--	--
36	12.10.81	11	X1.3	2B	S18E31	1.3×10^{-4}	-8.9	2800	7.9	--	--	--	--
37	26.11.82	4	X4.5	2B	S12W87	4.5×10^{-4}	-7.7	150	5.0	--	--	--	--
38	07.12.82	26	X2.8	1B	S19W86	2.8×10^{-4}	-8.2	800	6.7	--	--	--	--
39	16.02.84	15	C2.3	--	Over limb	2.3×10^{-6}	-12.9	100	4.6	--	--	--	--
40	25.07.89	2	X2.6	2N	N25W84	2.6×10^{-4}	-8.3	30	3.4	1.60E+06	--	--	--
41	16.08.89	12	X20.0	2N	S18W84	2.0×10^{-3}	-6.2	1000	6.9	1.20E+08	--	--	--
42	29.09.89	174	X9.8	2N	S32W90	9.8×10^{-4}	-6.9	--	7.6	1.00E+08	--	--	--
43	19.10.89	37	X13.0	4B	S27E10	1.3×10^{-3}	-6.6	40000	10.6	5.40E+07	--	--	--
44	22.10.89	17	X2.9	3B	S27W31	2.9×10^{-4}	-8.1	5000	8.5	--	--	--	--
45	24.10.89	94	X5.7	3B	S30W57	5.7×10^{-4}	-7.5	2512	7.8	1.40E+08	--	--	--
46	15.11.89	5	X3.2	3B	N11W28	3.2×10^{-4}	-8.0	30	3.4	1.40E+06	--	--	--
47	21.05.90	13	X5.5	2B	N35W37	5.5×10^{-4}	-7.5	410	6.0	8.10E+04	--	--	--
48	24.05.90	8	X9.3	1B	N36W76	9.3×10^{-4}	-6.9	199	5.3	8.20E+05	--	--	--
49	26.05.90	6	X1.4	--	N33W104	1.4×10^{-4}	-8.9	80	4.4	4.00E+06	--	--	--
50	28.05.90	5	M1.3	F	S15W44	1.3×10^{-5}	-11.3	45	3.8	1.80E+06	--	--	--
52	15.06.91	24	X12.0	3B	N33W69	1.2×10^{-3}	-6.7	1400	7.2	4.10E+07	--	--	--
53	25.06.92	5	X3.9	1B	N09W69	3.9×10^{-4}	-7.8	300	5.7	7.10E+05	--	--	--
55	06.11.97	11	X2.0	2B	S14W33	2.0×10^{-4}	-8.5	72	4.3	8.50E+06	1556	Halo	360
56	02.05.98	7	X1.1	3B	S15W15	1.1×10^{-4}	-9.1	150	5.0	2.40E+06	938	Halo	360
57	06.05.98	4	X2.7	1N	S11W65	2.7×10^{-4}	-8.2	290	5.7	--	--	--	--
58	24.08.98	3	X1.0	3B	N35E09	1.0×10^{-4}	-9.2	100	4.6	--	--	--	--
59	14.07.00	30	X5.7	3B	N22W07	5.7×10^{-4}	-7.5	24000	10.1	2.30E+08	1674	Halo	360
60	15.04.01	57	X14.4	2B	S20W85	1.4×10^{-3}	-6.6	951	6.9	2.10E+07	1199	245	167
61	18.04.01	5	M1.3	2B	S 20Wlimb	1.3×10^{-5}	-11.3	321	5.8	1.20E+07	2465	Halo	360
62	04.11.01	3	X1.0	3B	N06W18	1.0×10^{-4}	-9.2	31700	10.4	2.00E+07	1810	Halo	360
63	26.12.01	5	M7.1	1B	N08W54	7.1×10^{-5}	-9.6	779	6.7	2.10E+06	1446	281	>212
64	24.08.02	5	X3.1	1F	S08W90	3.1×10^{-4}	-8.1	317	5.8	1.70E+07	1913	Halo	360
65	28.10.03	5	X17.2	4B	S16E08	1.7×10^{-3}	-6.4	30000	10.3	1.80E+08	2459	Halo	360
67	02.11.03	6	X8.5	2B	S14W56	8.5×10^{-4}	-7.1	1570	7.4	1.50E+07	2598	Halo	360
68	17.01.05	3	X3.8	--	N15W25	3.8×10^{-4}	-7.9	6040	8.7	1.30E+07	2547	Halo	360
69	20.01.05	269	X7.1	3B	N14W61	7.1×10^{-4}	-7.3	1860	7.5	5.20E+07	882	Halo	360
70	13.12.06	92	X3.4	3B	S06W23	3.4×10^{-4}	-7.9	1980	7.6	2.70E+07	1774	Halo	360
71	17.05.12	16	--	--	N65W25	--	--	--	--	--	--	--	--

3. Discussion

3.1. Properties of GLE-Associated Solar Flare

Solar flare is usually produced in large solar eruptions. It is spewed out as a sudden flash of electromagnetic radiation emission from the active region of the intensely luminous part of the Sun. We investigated GLE-associated solar flare events and it was observed that most of the GLEs were associated with strong flares (Table 1). In most cases, an X-class solar flare occurred just before GLE events. We have instances where M-class flares or even C-class flares with optical importance >1N were also found associated with GLE events. This is an indication that irrespective of class, a flare with high optical brightness may as well be strong enough to cause a GLE event.

From our observation in Table 1, about 86% of the GLE-associated flares were X-class flares, whereas 9% were M-class flares, and 5% were C-class flares. 95% of flares had optical importance within the range of 1N to 4B. The flares whose classes are C or M having less optical importance less than 1N did not seem to cause GLE. However, we found that, for example, the GLE50-associated M-class (M1.3) flares had very low optical importance of 1F (very faint flare). Thus, the GLE50 was perhaps not generated by a solar flare.

Solar flares erupts from the active regions of the Sun. It is found that out of the 47 events under observation, 3 were over the limb and from the remaining 44 events 52% of GLE event-associated flares originated from the North-West active region, whereas 36%of GLE event-associated solar flares originated from the South-West, while a few percent 7% of the GLE event-associated flares came from South-East region and only 5% of GLE event-associated flares noticed to have originated from North-East active region. Although the strongest GLE event-associated solar flare came from the Northern hemisphere, there is no clear indication that powerful solar flares came out only from the Northern hemisphere. This result contradicts earlier work by Firoz et al. [9] who found majority of GLE-associated flares to have originated from the South-West active region. Almost 89% GLE-associated X-ray flares are from the Western hemisphere: (Table 1) and (Figure 2), suggesting that the greater possibility for a GLE is connected with the Western X-class flares. This view agrees with earlier work of Belov et al. [3].

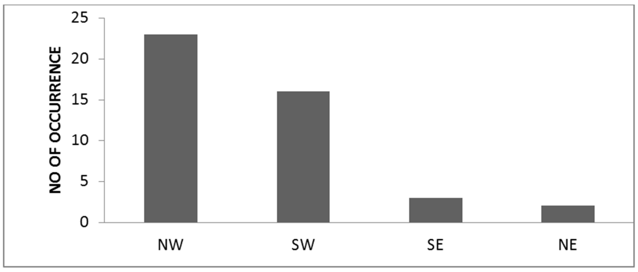

Figure 2. *Distribution of associated solar flares according to their location on the solar disk.*

We investigated the type of flare optical importance that associated with GLE, we found that 80% were extremely bright, whereas, 15% GLEs were associated with normal flare and only 5% were found to be faint flare type. For those with PIR < 10%, we found that majority (78%) of the GLEs were associated with brighter flare, 9% were observed to associate with normal flare whereas, 13% GLEs were discovered to be associated with faint flare. For those with PIR ≥ 10%, we discovered that 83% of the GLEs were brighter, only 17% were found to be associated with normal flares. This result suggests that most of the GLEs were generated from the brighter part of the Sun (in all the three cases). Furthermore, we investigated the association of GLE with class of flare. Our observations shows that for all the 43 GLE events, 86% were extremely strong, whereas, only 9% of the GLEs were discovered to be associated with moderate flare and very few GLEs, just 5%, were found to be associated with common flare. We equally noticed that for the events with PIR <10%, almost 80% of the GLEs were discovered to be associated with strong flare, whereas, 16% were observed to be associated with moderate flare, only 4% GLEs were found to have been associated with common type of flare. Also, for the events with PIR ≥ 10%, we found that majority (94%) of GLEs were also associated with strong flare, while only 6% were observed to be associated with common flare. None were found with moderate flare. Result shows that in all the cases considered (Figure. 4), GLEs seems to be generated from the intense or harder portion of X-ray fluxes where particle acceleration is taught to be effectual. Also, since particle acceleration in solar flares plays an important role in GLE production, we establish that solar flares seem to be the main agent that might produce enhancement in cosmic ray intensity. This view agrees with earlier works (e.g [6]).

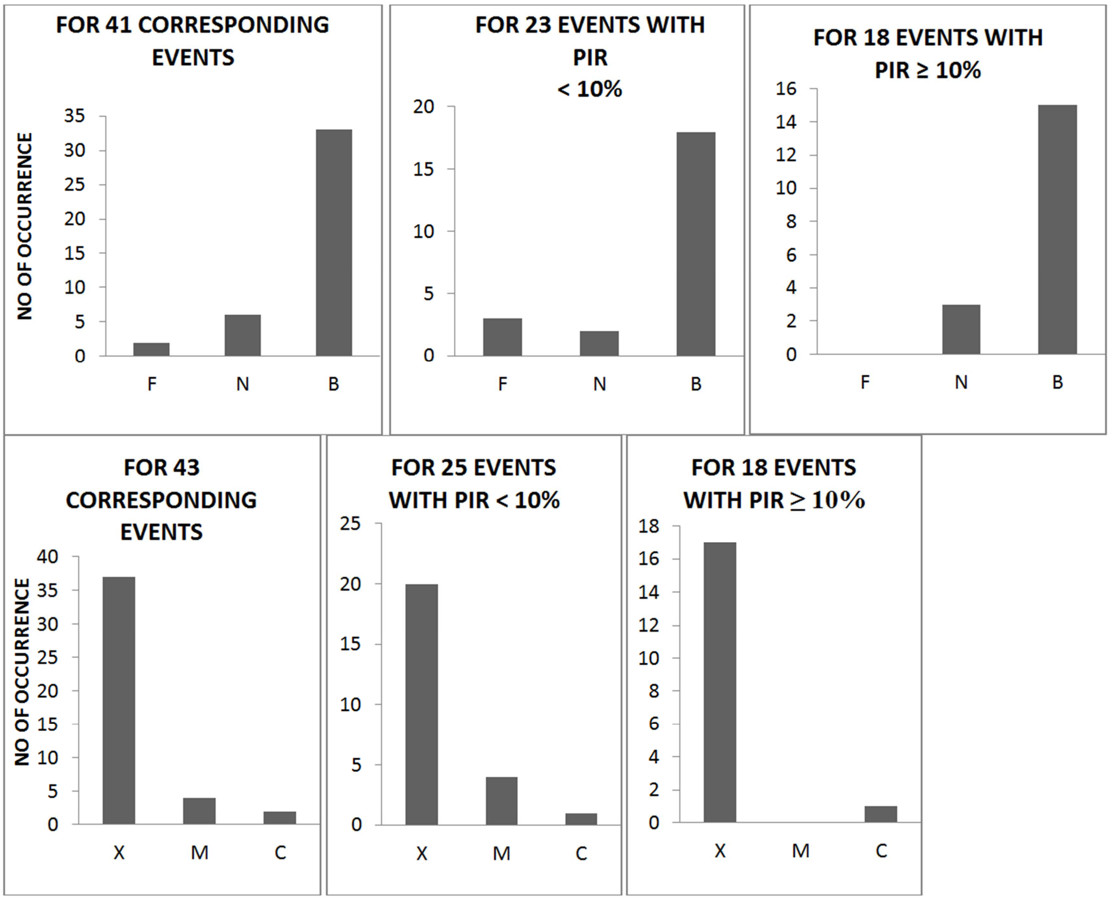

Figure 3. *(top): Chart of the distribution of the different flares according to optical brightness and (bottom): distribution of the different classes of flares.*

We observed that no single GLE was associated with any Eastward flare that occurred outside the central meridian but notable GLE could be associated with Westward flares outside the central meridian. This orientation effect could be attributed to the nature of the interplanetary space condition which will tend to favour Westward flares as candidate for

GLEs since the Sun rotates anticlockwise (Westward to Eastward), thus making it possible for Westward flares to reach the Earth in record time. On the other hand the Eastward events would have to acquire higher than average SEP ejections to cause GLEs (Table 1 and Figure 2).

3.2. Properties of GLE-Associated CME

CME is the release of large quantity of matter through the solar corona, caused by the eruption of local solar magnetic field. When the ejected plasma reaches the Earth, it may have an impact on the modulation of CRI. With this fact, we investigated GLE associated CMEs (Table 1). Almost 85% of the GLEs were associated with very fast CMEs, whereas, only very few GLEs (namely GLE 56 and 69) which corresponds to only 15% GLEs were associated with slow CME as shown in Figure 4.

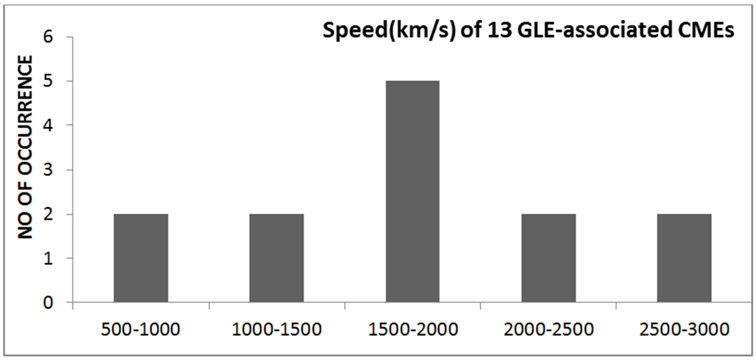

Figure 4. *The distributions of the speeds of CMEs associated with GLE events.*

We further looked into other properties of CMEs since the efficiency of the ejection of plasma on the modulation of cosmic rays may also depend on its position angle and not only on its speed. Whether a CME is able to intercept the Earth depends on the propagation direction in the heliosphere, a Halo CME (360° AW) is likely to have a component moving along the Sun-Earth connection line. A Halo is a projection effect, it happens when a CME is initiated close to the disk center and thus moves along the Sun-Earth connection line. Therefore, a Halo CME is probably geo-effective. Since the propagation of Halo CME is known to be directed toward the Earth, which can modulate cosmic ray intensity at the Earth. We investigated the angular width (AW) of CME associated GLEs and we found that 85% GLEs were associated with Halo (360°AW) CMEs, whereas 15% of the GLEs were associated with partial Halo CMEs having angular width >166° (Table 1). Since GLE is often associated with Halo CMEs, geomagnetic disturbances in the Earth's magnetosphere can cause cosmic ray modulation depending on the magnitude of the compression caused by CME and other geomagnetic agents. Our results suggest that most of the GLE-associated CMEs had very fast speeds (e.g. GLE55, 59, 60, 61, 62, 63, 64 65, and GLE70), whereas a few of them were extremely fast (e.g. GLE67 and 68). Our work agrees with earlier work by Firoz et al., [10].

Knowing fully well that the fast CME can accelerate the interplanetary shock waves during their propagations through the interplanetary medium, CMEs eventually drive shock waves ahead as they propagate, and the acceleration in large SEP fluxes starts at the arrival of the CME-driven shock wave. The acceleration of particles is believed to take place by the shock. The propagation of the shock is perhaps controlled by the ambient solar wind plasma and aerodynamic drag force. Although shock acceleration occurs widely at sites throughout the heliosphere, the process may have an impact on SEP fluxes near the Earth's space. The conjunction between flares having strong optical signatures and fast CME-driven shocks seems to produce GLEs.

3.3. Properties of GLE-Associated SEP

During large solar eruptions, solar energetic particle fluxes are thought to be generated. Energy released at a solar flare site or shock waves associated with CMEs are the other origin of SEP fluxes. Particles producing GLEs are widely believed to have been primarily accelerated by CME-driven shocks. Our observations revealed that SEP fluxes are one of the main perpetrators causing GLE. Most of the GLE-associated SEP fluxes shows that there are two parts to the patterns of fluxes, (the softer part and the harder part), that may modulate cosmic rays differently. The harder part refers to the extreme intensity, while the softer part refers to the weak intensity. There are three classes of >10MeV (i.e. the minor events which ranges from 0-10pfu, the moderate events from 10-100pfu and the large events are those >100pfu). We used the moderate events with >10pfu in the flux of >10MeV because events exhibiting these are likely to be located close to the disk center. In this context, we studied corresponding fluencies of SEP fluxes under case 1 fluence of particle flux associated with PIR ≥10% and (2) fluence of particle flux associated with PIR <10% and we found that in case 1 92% of SEP fluences related to GLEs were very strong. Whereas only few (corresponding to just 8%) were observed to be relatively softer particle fluence. We investigated case 2 and we found that 89% of SEP fluences related to GLEs were strong, while only 11% were considered to be softer particle fluences, namely, GLE48 and GLE53 respectively (Table 1). As seen from our observations, there is no glaring difference between the first and the second case as we observed a close range of value between them (i.e. 92% and 89%, against 8% and 11%) but still the first case is observed to be slightly harder than the second, and the weak intensity is noticed to be more associated with the second case compared to the first case thereby suggesting that (a) the extreme intensity is likely associated with the first case (particle flux associated with PIR ≥ 10%) compare to the second case (particle flux associated with PIR <10%) and thereby produces GLEs with high PIR value ranging from 10%-270% (see Table 1), (b) We also noticed that the weak intensity is most likely associated with the second case (particle flux associated with PIR <10%) which may eventually produce GLEs with low PIR value (ranging from 1-9%) as seen in Table 1. Although we noted that in both cases, we had very fast speed halo CME and followed by strong X-class flare e.g. in the first case (GLE55), 6, Nov. 1987 had a very fast halo CME of 1556km/s with strong X-class flare at 13:15 (UT), in like manner, the second case (GLE65) had a fast halo CME speed of 2459km/s with a strong X-class flare at 11:50 (UT), but we cannot say whether or not that this contributes to the hardening/softening of SEP fluence. This argument agrees with the earlier reports of Uddin et al. [24], Firoz and Kudela [8]. Thus, it is suggested that the harder SEP fluxes seemed to be causing GLEs with high PIR and that the softer may be responsible for those with low PIR values.

We further performed correlation coefficient between GLE (PIR) and PFU (Natural log. PFU) see figures 5 and 6 and we observed a weak correlation (r=0.05) in the case of all 46 correspondent events (Figure 5). The correlation becomes weaker (r=0.06) for the 20 events with PIR ≥ 10% and the 26 events with PIR <10% (r=0.01). Also, between GLE and flare intensity, we equally noticed weak correlation (r=0.01) from the plot of all the 43 correspondent events, also, weak correlation was observed for the 20 events with PIR ≥ 10% (r=0.38) as well as the 26 events with PIR <10% (r=0.16). The result of our correlations indicates that there is no direct physical association between GLEs and SEPs.

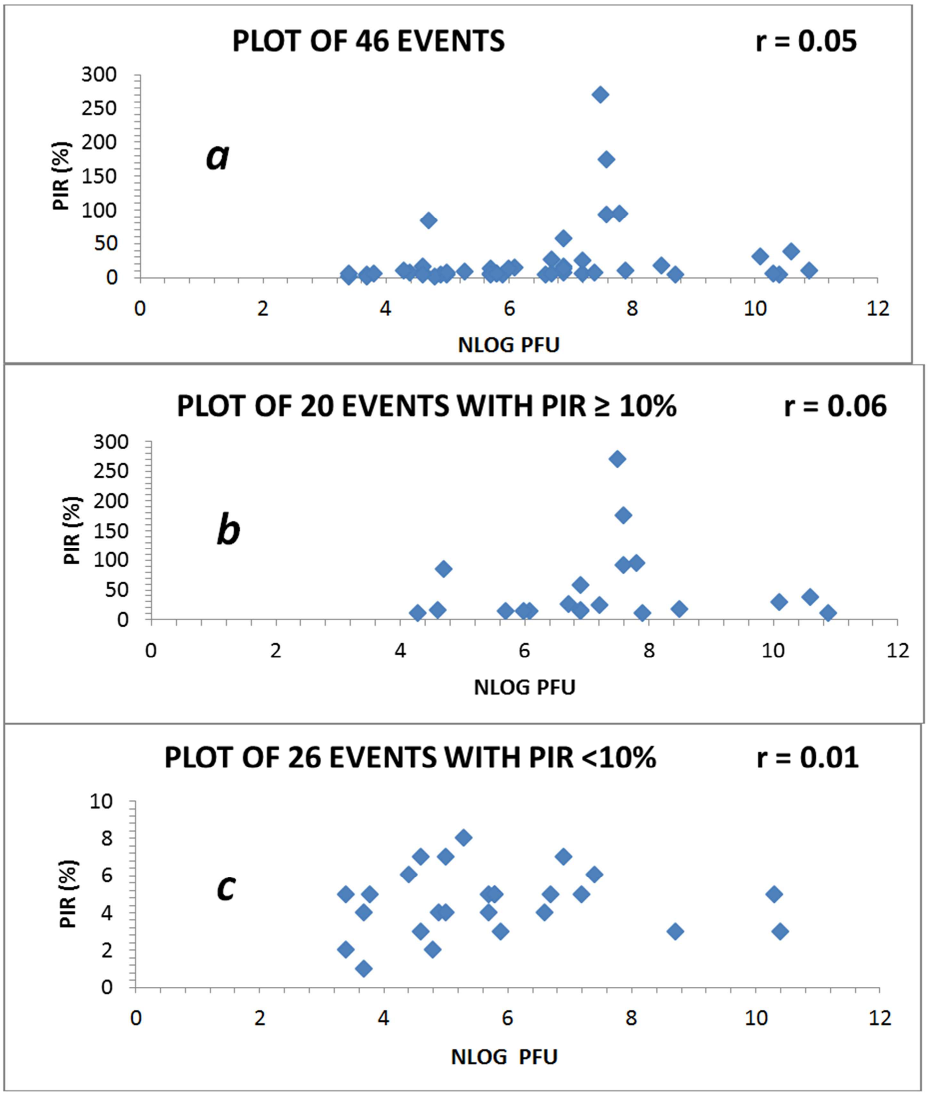

Figure 5. *Plot of PIR (%) versus natural logarithm of proton flux unit (PFU), a-all 46 events; b-20 events with PIR >10% and c-26 events with PIR <10%.*

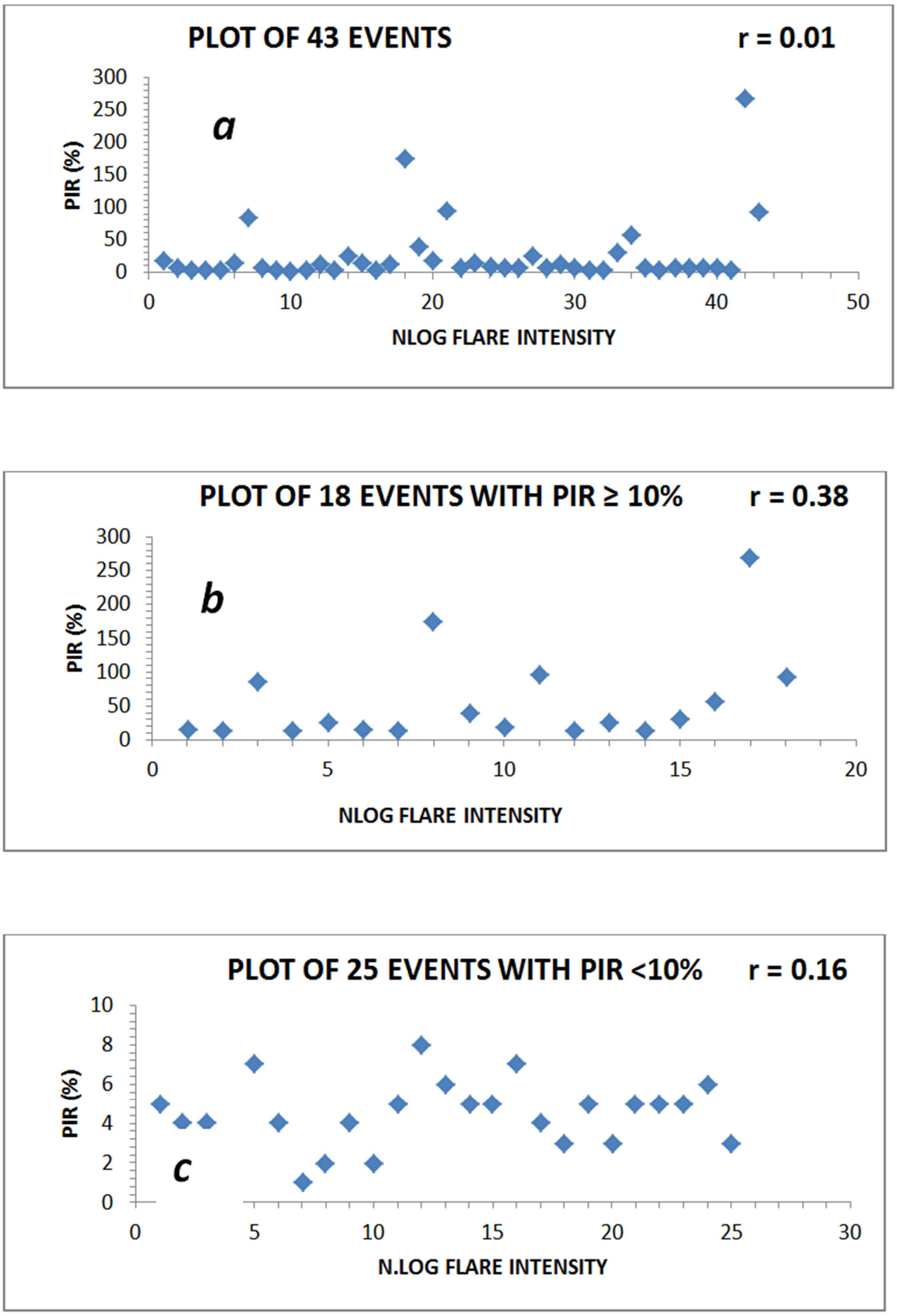

Figure 6. *Plot of PIR (%) versus natural logarithm of flare intensity, a-all 46 events; b-20 events with PIR >10% and c-26 events with PIR <10%.*

4. Conclusion

The effect of some solar energetic phenomena on ground level enhancement of cosmic rays have been studied. Majority of GLE associated flares were from North Western and South Western region of the solar disk. GLEs were equally associated with relatively strong solar flares. It is suggested that GLEs may arise from the harder portion of X-ray fluxes where particle acceleration is thought to be effective. The orientation effect could is a plausible factor moderating the association of the GLE with the intensities of the solar energetic phenomena causing them. It is observed that GLEs are more associated with Solar flares than CMEs during the minimum and ascending phase of the 11 year solar cycle when compared with GLEs that occurred during the maximum phase of the solar cycle. The direct role of the interplanetary space condition on the intensity of the GLE has not been studied here in this paper. However, there may also be a link between the nature of the interplanetary space conditions and the occurrence of GLE. Since they tend to favour westward flares as candidates for GLEs as the sun rotates west to east, making it possible for westward flares to reach Earth more effectively.

Declarations

Funding

Not Applicable.

Conflicts of Interest/Competing Interests

Not Applicable.

Availability of Data and Material

Data used in this work is available from the IZMIRAN group data resource: (http://cosray.phys.uoa.gr/index.php/data/solar-proton-events-database.

Code Availability

Not Applicable.

Authors' Contributions

All authors contributed to each aspect of this paper including the final manuscript.

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