Ground-level enhancements during solar cycle 23: results from SVIRCO, LOMNICKY STIT and LARC neutron monitors

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Abstract

The list of Ground-Level Enhancements (GLEs) occurring during the on-going solar cycle (no. 23) is used to show that they are absent during a time interval of the maximum phase in which a relative reduction in the sunspot area extent occurs. This period refers to October 2000 to March 2001 and it is associated with the concept of the Gnevyshev Gap, introduced 10 years ago by the Rome cosmic ray group. Also, effects of the Gnevyshev Gap in the solar cycle modulation of the atmospheric attenuation coefficient for Rome neutron monitor during the past solar cycle (no. 22) are illustrated. Moreover, it is suggested that GLE data files should be prepared by using the appropriate attenuation coefficient for each level of solar activity.

Keywords: Relativistic solar particles; Solar cycle; Gnevyshev gap

1. Introduction

The sporadic emission of solar relativistic charged particles causes Ground Level Enhancements (GLEs) in the terrestrial cosmic ray records. They appear as intensity increases – from a few percent up to 1000 percent, and beyond, on a small time scale basis (see, for instance Pomerantz and Duggal, 1974), depending on the measurement site and on the energy/flux of the arriving particles – superposed on the background level of the galactic cosmic radiation. Such kind of events were discovered many years ago before the Space Age (Forbush, 1946). Even if satellite- and spacecraft-based measurements are able to monitor the different outflows of solar particles, the ground-based and underground cosmic-ray measurements remain the only tool to know the maximum energy acquired by the particles in the related production/acceleration mechanisms.

GLE information is relevant not only for Cosmic Ray Physics but also in the terrestrial environment context. Since the start (1936) of systematic and continuous cosmic ray measurements 67 GLEs have been identified. The last event occurred on November 2, 2003 and the largest one, very probably, on February 23, 1956 (GLE05). While, GLE42 (September 29, 1989) was the most intense event observed with contemporary in situ measurements.

There exist many reviews covering theoretical, experimental, descriptive and statistical aspects of solar particle events (e.g. Carmichael, 1962; Cliver et al., 1982; Dorman and Venkatesan, 1993; Duggal, 1979; Shea and Smart, 1990; Smart and Shea, 1989; Stoker, 1994 among others). Nevertheless, no one of the past studies was able to give the occurrence probability of GLE events during the Schwabe cycle evolution. In this paper we give a contribution to this topic (Section 2) and

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discuss the best way to estimate the solar particle contribution to ground-based cosmic ray records (Section 3).

2. GLEs during the on-going Schwabe cycle

During the on-going Schwabe cycle (no. 23) 13 GLEs occurred. By using data reported by the NOAA/Boulder Web site we have compiled the Table 1, which summarizes the relevant associated solar parameters. From this list it is confirmed the preferred position of the GLE-associated solar flare in the western side of the Sun (in this cycle the location is always less than 10°E; see the top of Fig. 1). In the middle panel of Fig. 1 we report the monthly number of grouped Hα solar flares and sunspot numbers together with the GLE occurrence (arrows with the GLE number). It is seen that GLE events tend to appear when the monthly flare number has a relative maximum. On the other hand, not all the relative maxima correspond to a GLE. We cannot derive a rule from that, but we notice that most of the GLE events are related to energetic phenomena in Hα and soft X rays (Table 1).

Several years ago, analyzing solar-terrestrial parameters for cosmic ray modulation studies, the Rome cosmic ray group identified in the time history of such parameters a double peak morphology during each Schwabe cycle (Feminella and Storini, 1997; Storini, 1995, 1998; Storini and Felici, 1994; Storini and Pase, 1995; Storini et al., 1997). Furthermore, the separation between the two peaks resulted to be different in the different analyzed cycles. In some cases this separation (called Gnevyshev Gap to honor the solar astronomer who discovered the two maxima in the green corona data of cycle 19) is large and easy to identify (as in cycle 22) in others more difficult (see also Bazilevskaya et al., 2000). The performed work brought to the conclusion that the double-peak morphology is more distinct when the time history of intense and/or long-lasting solar events are considered, because low-energy and short-

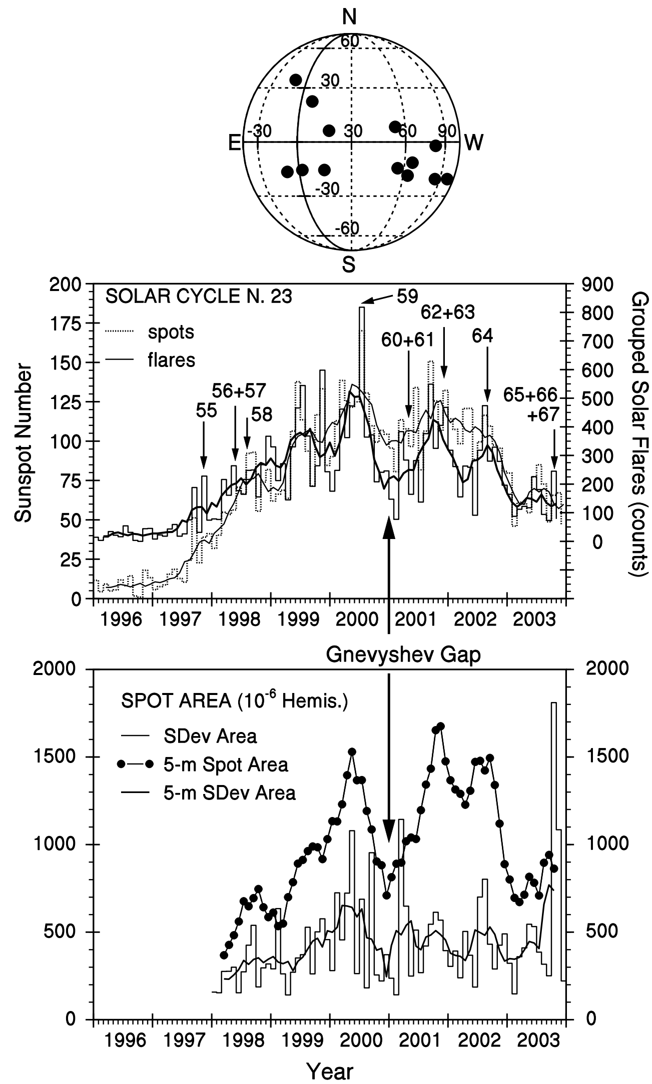

Fig. 1. Solar flare location for the 13 GLEs occurred during the on-going Schwabe cycle (top), time history of the monthly records of grouped Hα solar flares and sunspot numbers (middle; continuous curves are 5-month running averages and arrows indicate the GLE occurrence) and the 5-month (5-m) running averages of the sunspot area together with the corresponding standard deviation derived from daily values (bottom).

Table 1
GLE list for the on-going Schwabe cycle 23, together with some solar parameters

Year	Ev. No – dd mm	Lat – Long	Region	Hα Max	Hα Imp	X Imp
1997	55 – 06 11	18S – 63W	8100	11.55	2B	9.4 X
1998	56 – 02 05	15S – 15W	8210	13.42	3B	1.1 X
1998	57 – 06 05	11S – 65W	8210	08.09	1N	2.7 X
1998	58 – 24 08	35N – 09E	8307	22.12	3B	1.0 X
2000	59 – 14 07	22N – 07W	9077	10.24	3B	5.7 X
2001	60 – 15 04	20S – 85W	9415	13.50	2B	14.4 X
2001	61 – 18 04	20S – >Wlimb	9415	02.14	?	2.2 C
2001	62 – 04 11	06N – 18W	9684	16.20	3B	1.0 X
2001	63 – 26 12	08N – 54W	9742	05.40	1B	7.0 M
2002	64 – 24 08	02S – 81W	10069	01.12	1F	3.1 X
2003	65 – 28 10	16S – 08E	10486	11.10	4B	17.2 X
2003	66 – 29 10	15S – 02W	10486	20.49	2B	10.0 X
2003	67 – 02 11	14S – 56W	10486	17.17	2B	8.3 X

duration events tend to follow a single-peaked 11-year cycle. In other words, the Gnevyshev Gap should be seen as a time period in which a reduction of large-scale and intense solar dynamical phenomena occur.

In the GLE context Nagashima et al. (1991) noted that GLE events are absent during the inversion of the general heliomagnetic field (i.e., around the period characterized by the maximum sunspot numbers). Indeed, they seem to be absent during the Gnevyshev Gap. We have analyzed the daily sunspot area reported in the NOAA/Boulder Web pages and computed its monthly means together with the corresponding standard deviations. Also the 5-month running averages were evaluated. Results are shown in the lower panel of Fig. 1, where an absolute minimum (or strong reduction of the sunspot area) during the maximum solar activity phase can be identified in December 2000. No comparable values are present till 2003. We suspect that it is the mark of the Gnevyshev Gap for cycle 23. From the computed data trends we extracted a nearly quiescent solar activity period spanning at least from October 2000 to March 2001 (being the 5-month running averages of the sunspot areas practically at the same level for October–November 2000 and February–March 2001). We infer no GLE events in such a period. Looking data summarized in Table 1 we confirm the absence of GLE events.

Neutron monitor records from three measurements sites (LARC, LS and SVIRCO; see Table 2) were used to compute the monthly means of the nucleonic intensity (normalized to the average counting rate of January–February 1997) from 1987 to 2002. For what concerns the SVIRCO neutron monitor (Rome) it is necessary to recall to the reader that the data here used, and made available at the URL http://www.fis.uniroma3.it/svirco/, is the counting rate of a neutron monitor located at the La Sapienza University site (60 m a.s.l.). Reason for that is to ensure data continuity, being in May 1997 the detector moved to the Roma Tre University (about s.l.). As can be seen in Fig. 2, the described period of quiescent solar activity corresponds also to a relative minimum in the cosmic ray modulation of galactic cosmic rays. This period is shorter than the one observed for cycle 22.

We are not able to estimate the GLE occurrence probability along the Schwabe cycle, but our results exclude the possibility to record a GLE event during the Gnevyshev Gap. This confirms the GLE connection with intense and large-scale solar activity phenomena.

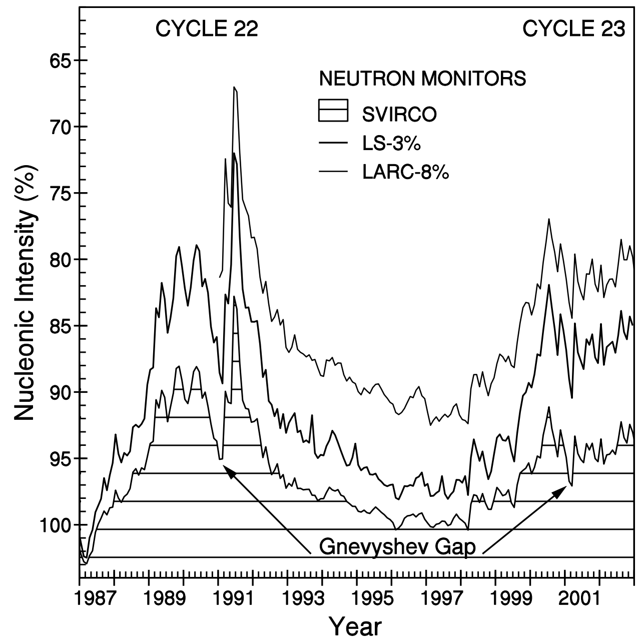

Fig. 2. Time evolution of the nucleonic intensity registered from 1987 to 2002 by three neutron monitors SVIRCO (Rome – Italy), Lomnický Štít (LS – Slovak Republic) and LARC (King George Island – Antarctica).

3. To improve the GLE data base

Neutron monitor data sets for GLE events are prepared by the scientific community on the smallest available time scale and they are maintained for comprehensive analyses of GLEs at the international data centers. However, aiming to estimate the correct solar particle contribution to the records of each measurement site some problems arose.

To have ready GLE data files as soon as possible they are generally prepared by using a constant attenuation coefficient (α) to eliminate induced pressure variations at the standard pressure (P_0) of the detector location. For example, GLE data from LS are derived by using $P_0 = 550.0$ mm Hg ($\sim$733.27 hPa) and $\alpha = 0.95\%$/mm Hg (0.71%/hPa) and those for LARC using $P_0 = 980$ hPa ($\sim$735 mm Hg) and $\alpha = 0.74\%$/hPa ($\sim$0.99%/mm Hg). Nevertheless, it was demonstrated that the long-term α variability undergoes an 11-year

Table 2
Characteristic parameters of used cosmic ray measurement sites

Name	Lat	Long	Height	Cut-off (GV)	Detector
LARC (King George Island)	−62.20	301.04E	40 m	~3	6-NM64
LOMNICKY STIT (LS)	+49.20	20.22E	2634 m	~4	8-NM64
SVIRCO (Rome – La Sapienza)	+41.90	12.52E	60 m	~6	17-NM-64
SVIRCO (Rome – Roma Tre)	+41.86	12.47E	s.l.	~6	17-NM-64

cycle modulation (e.g. Bachelet et al., 1972 for an early work). Hence, we are evaluating the yearly α-values for our measurements, aiming to improve GLE files.

Here we report results for SVIRCO detector for a complete solar cycle (no. 22). The used techniques were described by Massetti et al. (2001) in detail. Briefly, α was estimated by using:

- the daily averages of the pressure-uncorrected counting rates of Rome neutron monitor (N_i), and the ones of the corresponding atmospheric pressure (P_i). Only days with data coverage greater than 75% (i.e. >18 h) were considered;
- the daily values of the pressure-corrected counting rates registered by Hermanus neutron monitor (auxiliary data).

Each year data set was divided into quarters: January–March, April–June, July–September, October–December to estimate α values for shorter periods and to compute the yearly α average, using the standard error derived from every subset as a weighting factor. The computations were performed by using:

(i) the standard method (i.e. by calculating the linear regression of an adequate amount pairs of values $\ln[N_i - N_0]$ and $[P_i - P_0]$, being N_0 and P_0 the averages of the corresponding values);
(ii) the difference method (as above but after subtracting the corrected data of an auxiliary detector, in our case Hermanus data);
(iii) the auto-regressive method (applied after knowing the self-correlation first coefficient of the residuals from the standard method).

Fig. 3 shows in its upper panel the yearly α-values obtained as weighted averages of the four quarters. The middle panel reports the average pressure level and the number of days used in the analyses (the ±standard errors of the atmospheric pressure are lesser than the size of the symbols). The lower panel gives results from the complete yearly data set without the quarter division for the difference and auto-regressive techniques. We notice that the second and third methods give better results. In particular, for the yearly data sets of SVIRCO they give practically coincident values, except for 1990 (where α-values are more similar when quarter division is considered, upper panel). As it is known from past studies, during the 1990 year the Gnevyshev Gap was present (see also Fig. 2). The quarter division helped to avoid the different quarter intensity levels existing during the year. Effects of the Gnevyshev Gap on the error of the atmospheric attenuation coefficient for neutron monitor data were already discussed (Storini et al., 2000).

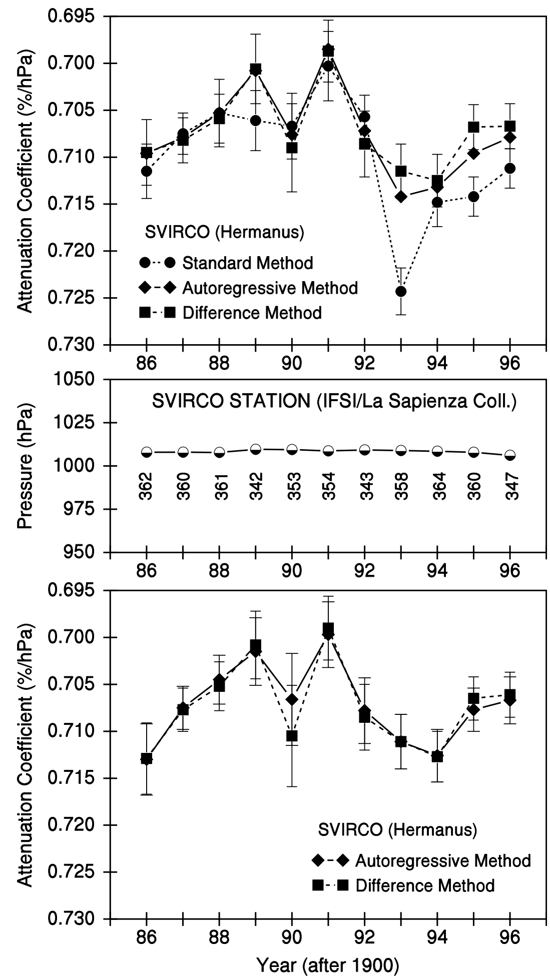

Fig. 3. Yearly attenuation coefficient for SVIRCO neutron monitor data (up and down) together with the average pressure level and number of days used in the evaluation (center). The upper panel shows the weighted value of the four quarters in which each year was divided to apply the reported techniques. The lower panel gives results from the complete yearly data set (see the text for details).

We conclude that during cycle 22 the difference between maximum (low solar activity level) and minimum (high solar activity level) SVIRCO α-values is about 0.013%/hPa. At high latitudes, a similar work performed for Oulu detector (Massetti et al., 2001) gave a difference of 0.025%/hPa, which is two times higher. This implies that to apply the appropriate attenuation coefficients during the different stages of the Schwabe cycle is relevant for GLE files. More information on the α-variability are reported by other authors (Dorman et al., 1997; Raubenheimer and Stoker, 1974; Shatashvili and Rogava, 1995 among others).

We are performing α evaluations for SVIRCO, LS and LARC for the current Schwabe cycle to correct the GLE files. Moreover, for each GLE the reference level of the atmospheric pressure will be the one of the time interval in which the maximum increase is observed.

4. Conclusions

We have investigated the GLE occurrence during the current Schwabe cycle (no. 23) and identified the time interval from October 2000 to March 2001 for the Gnevyshev Gap period (i.e., the time interval of the maximum phase of the Schwabe cycle in which the relative solar activity quietness occurs). No GLEs are found inside that interval, confirming results from the study of the past cycles.

To better evaluate GLE effects in the terrestrial environment, the evaluation of the long-term variability of the atmospheric attenuation coefficient is in progress for three measurements site: Rome (SVIRCO), Lomnický Štít (LS), and King George Island (LARC). We exemplified results for SVIRCO detector during a complete solar cycle (no. 22). Results show the failure of the standard method for the α evaluation and the success of the so-called difference and auto-regressive techniques.

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