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The Gnevyshev Gap Effect in Solar Cosmic Rays

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Abstract

The phenomenon of the double-peak solar cycle structure (Gnevyshev, 1963) is used to study the solar cosmic ray origin. Solar proton events are diminished in number and energetic particle intensity during the maximum solar activity phase. It is shown that during the same time periods the Ground Level Enhancements disappeared almost simultaneously with solar flares of large area and long lasting X-ray emission. Averaged solar proton (E>10 MeV) intensity of the non-relativistic events also suffers depressions which correlate with depletions in proxies for interplanetary disturbances.

1 Introduction:

It is known from long ago that the most powerful solar proton events avoid the period close to the solar maximum (e.g., Hakura, 1974). Actually, many parameters of solar and solar-terrestrial domain changing generally in phase with solar activity suffer temporary depressions close to the solar maxima (e.g., Feminella & Storini, 1997, and references therein), which we call Gnevyshev Gaps after the astronomer who initiated investigation of the double peaked structure of the solar activity cycle (Gnevyshev, 1963, 1967, 1977). The nature of the complicated structure of solar cycle maximum is still obscure. Nevertheless, the Gnevyshev Gap (GG) effect can be used to look for relations between various solar/interplanetary parameters with the aim to improve the understanding of the physical processes involved.

It is widely accepted that solar energetic particles (SEPs) associated with impulsive events are generated close to the site of a solar flare whereas SEPs associated with gradual solar events are accelerated mostly by coronal and interplanetary shocks (Cane et al., 1986, Kahler, 1994, Reames, 1995). However, Bazilevskaya & Sladkova (1997) showed that the most powerful SEP events with relativistic protons, so called Ground Level Enhancements (GLEs), are closely related to solar flares without regard to their impulsiveness. In this paper we discuss the GG effect in solar cosmic rays (SCRs) during the two last solar cycles. We try to trace the origin of the GG effect in GLEs and non-GLEs.

2 Data and results:

We consider the homogeneous data series on SCRs for 1975-1996 (Akiniyan et al., 1983, Bazilevskaya et al., 1990, Sladkova et al., 1998) including the SEP events with maximum solar proton intensity J_{10}= J(E≥10 MeV) ≥ 1 cm^{-2} s^{-1} sr^{-1}. No event selection was made with respect to the flare association. Information on the grouped solar flares, X-ray bursts and interplanetary characteristics were taken from NGDC NOAA Solar-Terrestrial Physics Division via Internet.

All the data series were examined with the aim to consider their time-structure near the solar activity maxima around 1980 and 1990. Figure 1 presents the yearly number of the SEP events and the yearly averaged intensity J_{10} for the two last solar cycles. The number of grouped optic flares and the sunspot number Rz are given for comparison. We are interested in the periods A and B close to the solar maximum marked by horizontal bars at the top of the figure. The boundaries of the maximum solar activity phase were taken from Ivanov, (1995). The most prominent GG effect is observed in J_{10} in 1980 and 1990. The GG effect in the SEP event number is also clearly seen, but in cycle 21 it was observed one year earlier. The GG effect cannot be seen in Rz and in the flare number in cycle 21 but it can be noticed in cycle 22. It is clear that the reason of the GG effect in SCRs is not caused by a GG effect in the occurrence frequency of optic flares. However, it was found that the GG effect is more distinctive for the more energetic phenomena (Gnevyshev, 1967), and in particular for the flares of higher importance (Feminella & Storini, 1997). For the further analysis the H-alpha grouped flares were separated by their brightness, area and duration. The X-ray bursts of different importance were also treated separately.

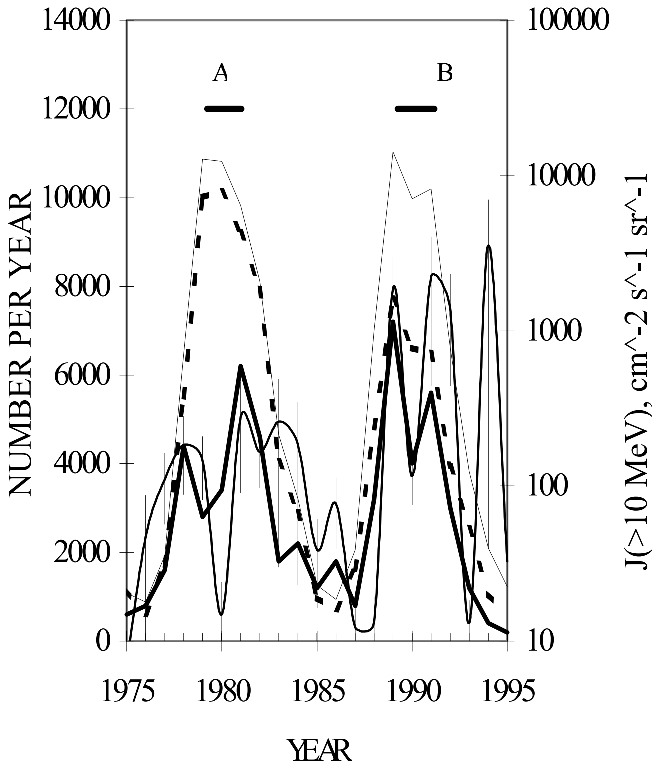

Figure 1: Yearly number of grouped solar flares (dotted curve) and of SEP events (multiplied by 200, thick curve), averaged R_z (multiplied by 70, thin curve) and J_{10} (thin curve with error bars, right axis) vs. time. The periods of the maximum solar activity phase are marked by horizontal bars labeled “A” and “B”.

The detailed time histories for SEP events and some relevant phenomena are given in Figure 2. In the top panels of the figure each GLE is plotted as a vertical bar with a height equal to J_{10}. No GLEs at all were recorded from 22.08.1979 to 09.04.1981 and from 29.05.1990 to 10.06.1991. The same drastic effect was found only for the H-alpha flares with largest area (importance 3, corresponding to an area >1200 m.s.d.). On the other hand, GLEs usually occur after powerful X-ray bursts. Therefore, we looked at the behavior of X-ray bursts of importance “M” and “X” associated with optic flares of large area. The duration of such events is presented by the diamonds in the upper panels of Figure 2. The gaps in the occurrence of X-ray bursts associated with flares of large area are clearly seen, and they roughly coincide with the periods where GLEs are absent. One should not expect a one-to-one correspondence between the flares shown in Figure 2 and GLEs because it is known that a small part of GLEs is observed after flares with an area of importance <3. In addition, GLEs are preferably associated with flares on the western hemisphere of the Sun. Considering the list of flares occurring inside the GGs for GLEs we found only two western large area flares with X-burst duration >100 min. - 14.10.80 (3B, X3.3, S09W07, duration 112 min.) and 20.04.91 (3N, X1, N08W50, duration 177 min.). It can be concluded that the disappearance of GLEs coincides with a strong reduction in the occurrence rate of X-ray bursts associated with flares of large area and lasting >100 min.

The lower panels of Figure 2 show the non-GLE time histories. For non-GLEs the GG effect is not as obvious as for GLEs. Even when GLEs were absent non-GLEs were observed, a few of them with J_{10} up to ~100 cm^{-2} c^{-1} sr^{-1}. The GG effect in J_{10} in cycle 21 can be defined as the absence of events with J_{10} > 25 sm^{-2} s^{-1} sr^{-1} from 16.11.1979 to 9.04 1981 (with one exception for 18.07.1980). In cycle 22 the GG effect lasted from 31.07.1990 till 30.01.1991, when only events with $J_{10} < 5$ cm^{-2} s^{-1} sr^{-1} were observed. We examined a number of solar/interplanetary parameters looking for the best correlation with the GG effect in non-GLEs. Although clear GG effects can be observed in the bright H-alpha flares with large area and duration as well as in the number of the X-ray bursts of importance “M” and “X”, all these parameters poorly correspond to the time history of J_{10}.

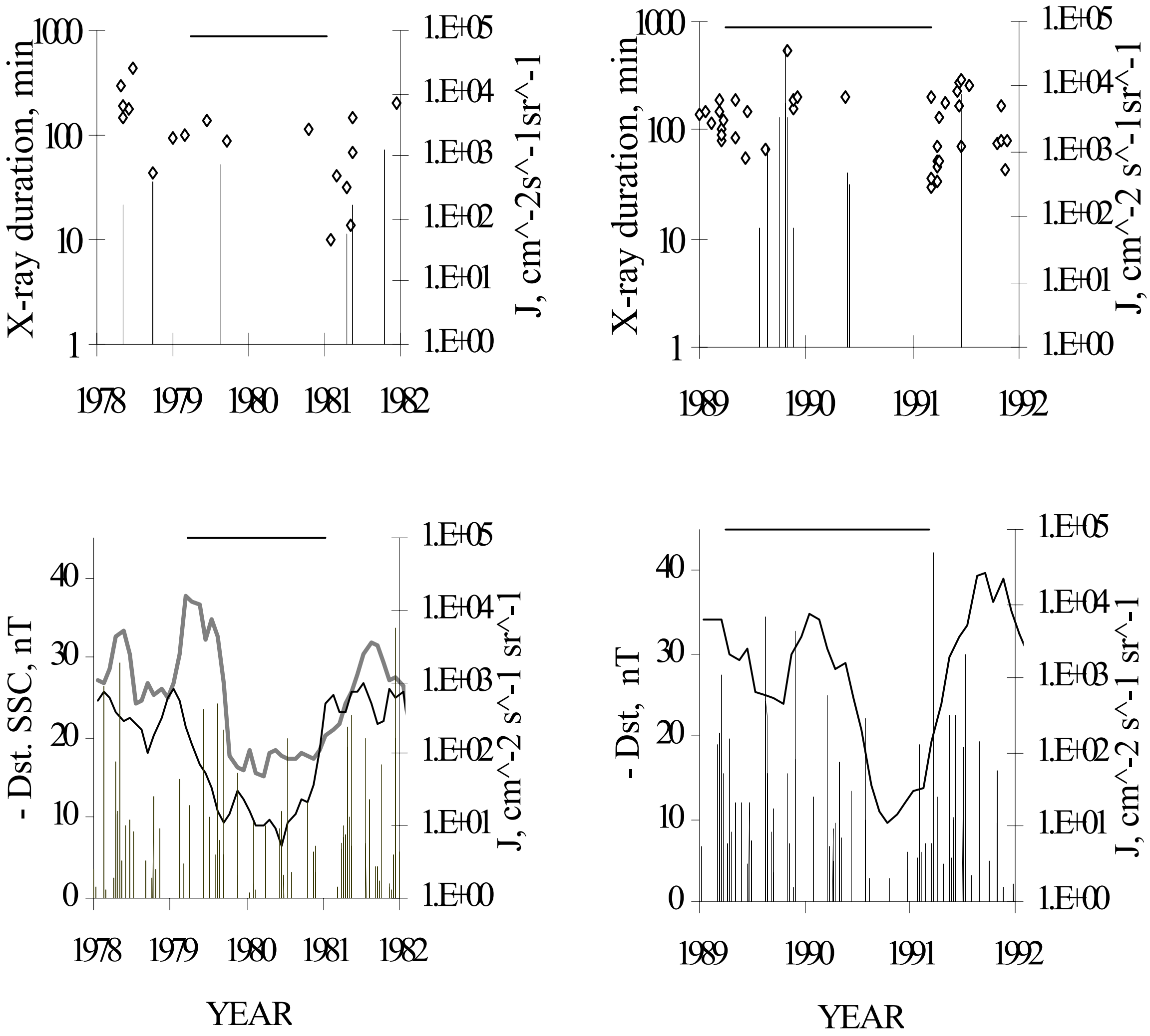

Figure 2: Upper panel: J_{10} for GLEs (vertical bars) and duration of X-ray bursts associated with optic flares of large area (diamonds) during maximum solar activity phases. Lower panel: J_{10} for non-GLEs (vertical bars) and 7-point smoothed SSC (thick curve) and -D_{st} (thin curve) amplitudes. Horizontal bars correspond to periods A and B of Figure 1.

Bearing in mind the role of interplanetary shocks in particle acceleration the data on SSC and Dst were considered as proxies for interplanetary disturbances. Intense SSC events are certainly associated with interplanetary shocks. Unfortunately, data on SSC amplitudes were available to us only for cycle 21. For cycle 22 we therefore used the Dst data. We found no GG effect in the number and duration of SSCs. But the amplitudes of SSC and –Dst correlated fairly well with the envelope of J_{10} for non-GLEs. This result is shown in the lower panels of Figure 2.

3 Discussion and conclusion:

The behavior of SCRs during the maximum phase of the two last solar cycles demonstrated depressions in the occurrence rate of events and in the solar proton intensity which are clearly identified as the Gnevyshev gap effect. The typical feature of GG as being more distinctive for more powerful events was confirmed: while J_{10} for non-relativistic events decreased by an order of magnitude during 0.5-1.5 years, the GLEs just disappeared for periods of 1-1.5 years. At the same time the most powerful solar flares of large area with long lasting X-ray emission also disappeared. The time history of the non-GLE particle intensity during GG roughly correlated with the amplitude of strong interplanetary disturbances which were used as proxies for interplanetary shocks. This can be understood since strong interplanetary shocks are continuations of coronal shocks and are related to coronal mass ejections. Disappearance of intense shocks from August 1979 to December 1980 was found by Rodriguez-Pacheco et al. (1997) while the number of less powerful shocks did not change. The latter finding is in agreement with the absence of the GG effect in the SSC number. However, we cannot agree with the conclusion of Rodriguez-Pacheco et al. (1997) that there was “no anomalous behaviour“ of the long duration X-ray bursts during this period. From our research it follows that actually the X-ray bursts with large H-alpha area were absent at all from 20.09.1979 to 13.10.1980 and from 16.05.1990 to 4.03.1991.

It can be concluded that during the two last solar cycles solar proton events with and without relativistic protons reflected the reduced solar activity during GGs in different ways. While GLEs were absent, non-GLEs continued to occur, but with smaller particle intensity. Our study of the GG effect in SCRs confirms a direct relation between GLEs and powerful solar flares. Non-relativistic SEP events are more closely correlated with the amplitude of proxies for strong interplanetary disturbances.

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