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Galactic Cosmic Ray Modulation and Solar X-ray Parameters During the Maximum Phases of Sunspot Cycles 20 and 22

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Abstract. A daily-basis cross–correlation analysis between the galactic cosmic ray intensities from the Calgary Neutron monitor and the occurrence of long duration event (LDE) type flares, together with the solar x-ray background (the daily average of the unresolved full-Sun soft x-ray flux – XBG), is outlined for the maximum phases of sunspot cycles 20 and 22.

1. Introduction

A good knowledge of the relationship between galactic cosmic ray (CR) modulation and the solar–activity parameters is relevant for Solar–Heliospheric Physics. We have been investigating such daily correlations. In a previous paper (Jakimiec at al. 1995) we had addressed the issue of cross-correlations between CR intensities and XBG, and between CR intensities and the East-West distribution of LDE-type solar flares, during the maximum phase of sunspot cycle 20. The CR intensities are obtained from the Calgary neutron monitor (type: IQSY-NM-64; location: N 51.°1, W114.°1, 1128 m above sea level; cutoff-rigidity about 1GV). The LDE-type solar flares are characterized by a long lasting x-ray flux.

Here, we continue the analysis of such correlations for the 22nd cycle (Antalová et al. 1994; Storini et al. 1995) and extend our discussion to the period 1 January 1988 – December 31, 1992. Fig. 1 shows the sunspot and H-alpha flare numbers, together with the 13-month running average of Calgary neutron monitor intensity, to illustrate solar activity features during the analyzed epochs. In this study, we emphasize the role of solar x-ray parameters in cosmic ray modulation.

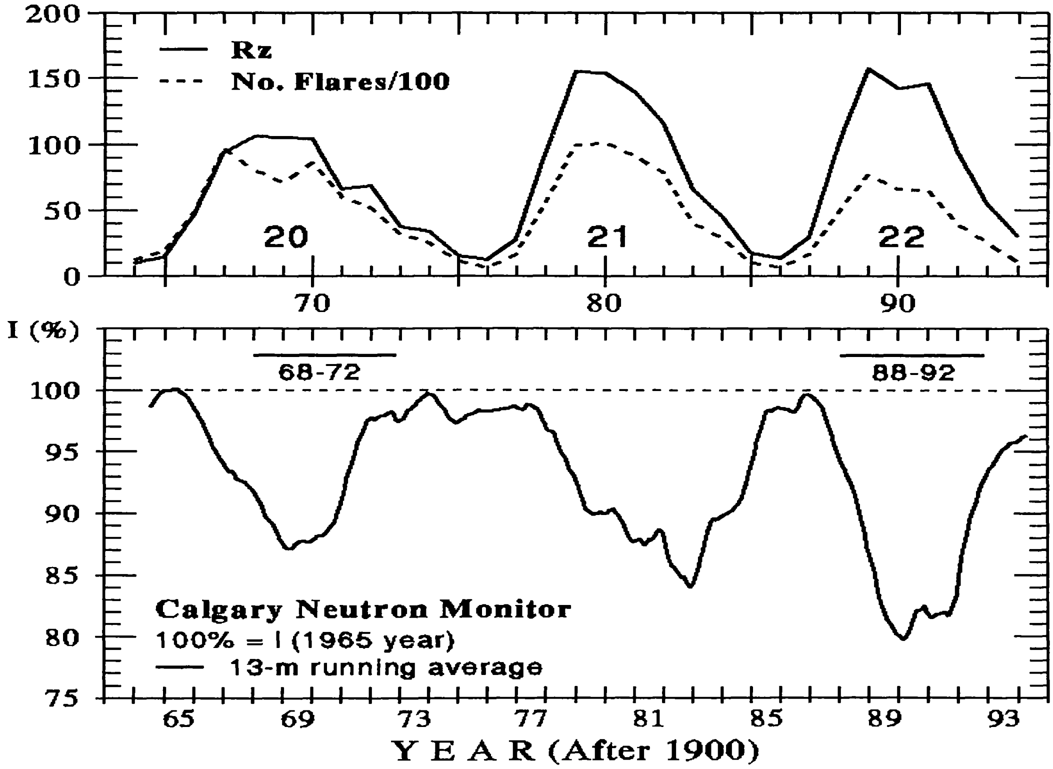

Figure 1. The sunspot and H–alpha flare numbers (upper panel) together with the 13–month running average of Calgary neutron monitor intensity (lower panel) for the years 1964 – 1993. Horizontal bars mark the investigated epochs.

2. Data sets

A detailed description of our parameters is given in Storini et al. (1995) as well as in Antalová et al. (1995a, b). Briefly they are as follows:

CR - the daily pressure-corrected data from Calgary neutron monitor (Venkatesan et al. 1989) updated to 1993 (data are in per cent of the May 1965 counting rate: 284.544 counts/hour).

XBG - the daily average of the unresolved full-Sun x-ray flux from SOLRAD (cycle 20) and GOES (cycle 22) as published in Solar Geophysical Data.

TSF - the daily index of the total LDE-type flares observed in the visible disk of the Sun. Table 1 summarizes the yearly averages of the studied parameters with standard errors in parenthesis, while Figs. 2 – 4 report daily and 15-day running trends.

Table 1. The yearly averages (their standard errors are in parenthesis) for the three analyzed parameters. The last column gives the number of 'LDE-free' days.

year	CR	XBG	TSF	N_0
1968	87.60 (0.15)	77 (03)		
1969	86.18 (0.10)	104 (06)	66 (09)	31
1970	87.00 (0.09)	132 (11)	68 (09)	13
1971	93.69 (0.14)	42 (02)	14 (03)	47
1972	96.40 (0.12)	51 (03)	23 (03)	31
1988	91.97 (0.08)	59 (02)	9 (03)	209
1989	82.82 (0.19)	158 (04)	82 (10)	26
1990	82.25 (0.14)	98 (02)	36 (04)	7
1991	82.71 (0.29)	142 (03)	89 (10)	6
1992	90.42 (0.52)	67 (03)	20 (03)	28

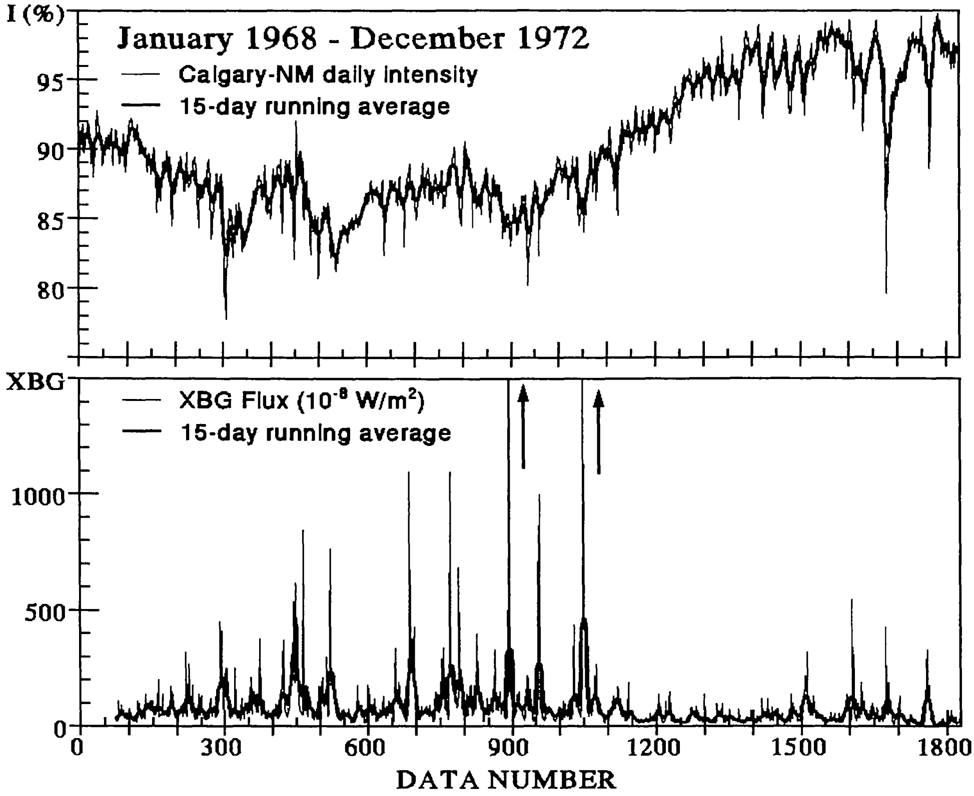

Figure 2. Daily and 15-day running values of Calgary neutron monitor intensity data (I, as a percentage of the May 1965 average intensity) and the unresolved full-Sun x-ray flux from SOLRAD satellite (XBG) during 1968–1972.

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Table 2. The yearly extreme values of the CR – XBG cross-correlation functions, preceded by the corresponding time lag (in days).

year	lag	CR–XBG	year	lag	CR–XBG
1968	3	-0.33	1988	3	-0.41
1969	5	0.00	1989	4	-0.14
1970	4	-0.24	1990	6	-0.10
1971	4	-0.34	1991	4	-0.07
1972	4	-0.44	1992	5	-0.26

Table 3. The yearly extreme value of the CR – TSF cross-correlation function preceded by the corresponding time lag (in days).

year	lag	CR–TSF	year	lag	CR–TSF	lag	CR–TSF
1969	5	-0.04	1988	6	-0.01	13	-0.02
1970	6	-0.33	1989	4	-0.14	8	-0.15
1971	4	-0.17	1990	9	-0.22	22	-0.24
1971	7	-0.17	1991	4	-0.25	7	-0.25
1972	4	-0.40	1992	4	-0.08	9	-0.09

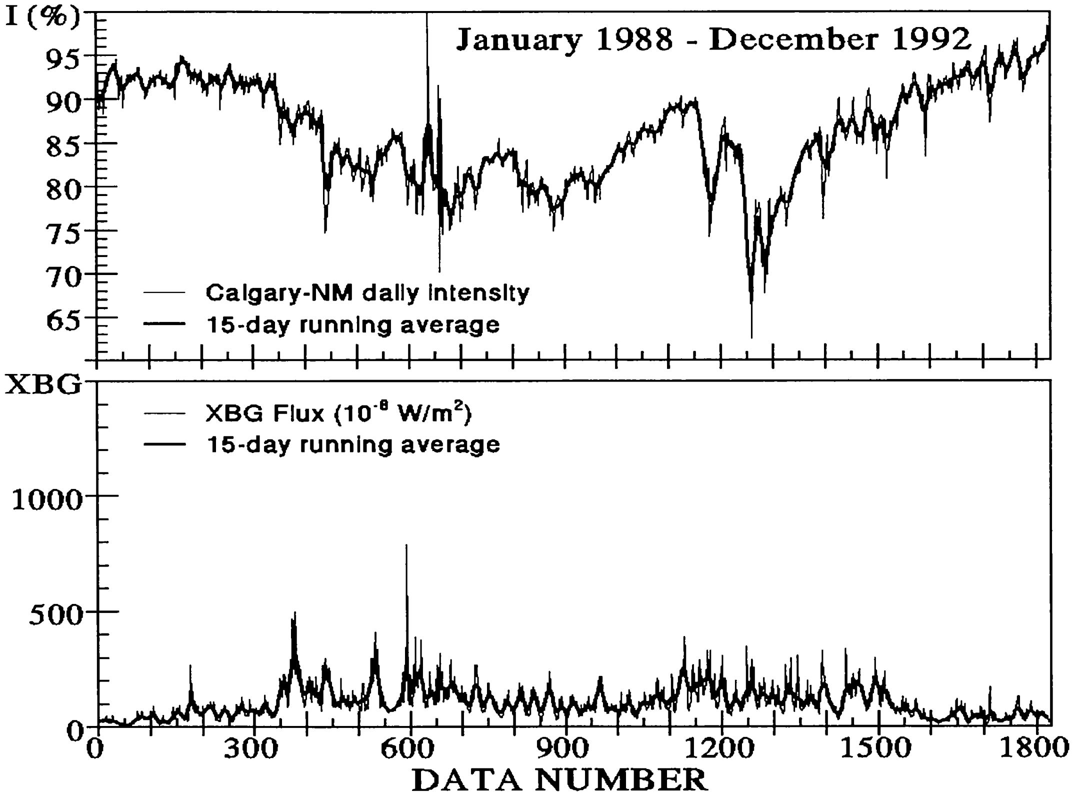

Figure 3. As in Fig. 2 but for the years 1988–1992. The XBG flux is from GOES.

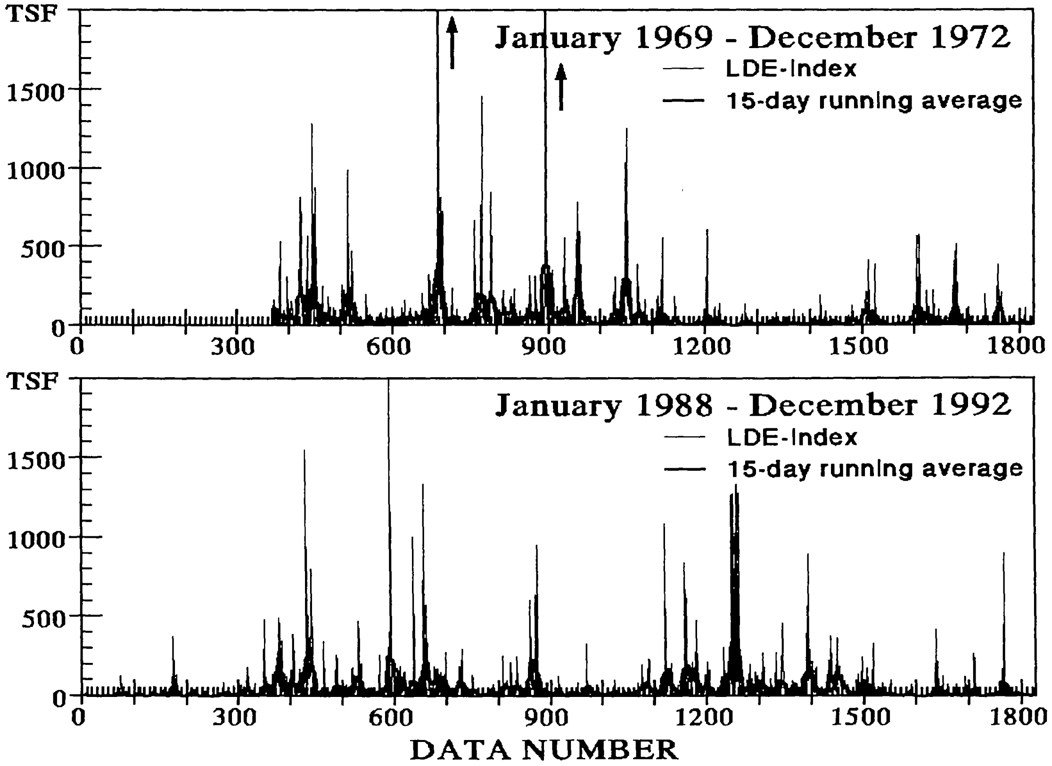

Figure 4. Daily and 15-day running trends of the LDE index (TSF) during time intervals 1969–1972 and 1988–1992.

3. Data Treatment and Results

We have undertaken cross-correlation analyses between cosmic ray intensities and each of the above mentioned x-ray parameters. We have estimated the cross-correlation function and have searched for its extremum. Tables 2 – 4 show the extremal values of the cross-correlation functions obtained for time intervals 1968–1972 and 1988–1992 introducing an appropriate time-lag between the correlated data-sets. We have obtained the following results:

(i) We obtained the degree of the anti-correlation between the CR and non-flare corona (XBG) changes during solar activity phases of two solar cycles (Table 2). We notice that the CR–XBG anti-correlation is more significant in the years preceding and following the maximum phase of solar activity (i.e., during the years 1968, 1971, 1972, and during the years 1988, 1992), while during the years 1969, 1990 and 1991 we find no CR–XBG correlation. Is is of particular interest to note that the recovery of the CR modulation in both cycles corresponds to a low level of activity in XBG (see Figs. 2 – 3). An average lag of about 4 days is needed to obtain the best CR–XBG correlation coefficients.

(ii) Both periods of the data sets are characterized by low anti-correlations between CR and LDE–type flare indices (Table 3). A higher correlation coefficient is found for 1972 (−0.40) with a lag of 4 days. We notice that during sunspot cycle 22 there is no stable lag between the two parameters. A systematic separation of isolated flares from those coming from the same active region is needed to gain further insight.

(iii) For the cross-correlations between XBG and TSF, in general, we found stronger correlations during sunspot cycle 20 than in cycle 22 (Table 4); in the former cycle, an average zero-time lag seems to be appropriate. Moreover, the degree of correlation in the correlation coefficients switches switches from high to low or vice-versa as one goes from one year to the other.

Table 4. The extreme values of XBG – TSF cross-correlation functions preceded by corresponding time lag (in days).

year	lag	XBG–TSF	year	lag	XBG–TSF
1968	-	–	1988	2	0.33
1969	0	0.67	1989	0	0.59
1970	0	0.87	1990	0	0.37
1971	0	0.47	1991	0	0.42
1972	0	0.67	1992	0	0.31

4. East-West Distribution of LDE-type Flares

Following our previous papers (Storini et al. 1995; Jakimiec et al. 1995) we consider the East-West distribution of the solar LDE-type flares. For the years 1990 and 1991 prepared three additional parameters:

E - the daily flare index for LDE-type flares located from E90° to E45°;

C - the same as above but for LDE-type flares located from E44° to W44°;

W - the same as above but for LDE-type flares located from W45° to W90°.

These parameters were correlated with the CR values (Table 5). Performing an analysis of these correlations for cycle 22 and published elsewhere (Storini et al. 1995), we found a significant lag between the occurrence of LDE flares and CR intensity depressions only for the 12-month sequence covering the period 1 July 1988 – 30 June 1989, whereas for cycle 20 a significant lag was obtained for all the investigated years, in agreement with expectations of a changing connection between an observers field line and a respective flare position. In other words, only in that cycle the CR response to LDE flares is properly delayed.

However, it is worth mentioning that in the past this result was obtained not only analyzing galactic cosmic ray intensities, but also solar proton fluxes (e.g., Iucci et al. 1979; Sarris 1982; Sarris et al. 1984; Sarris et al. 1989). Moreover, a similar behavior is emerging from multi-spacecraft measurements of CMEs (Reames 1994) through the interplanetary protons (accelerated by CME shock). This supports the hypothesis that the CME phenomenon is partly interrelated with some, but not all, LDE–type flares. This hypothesis is also in agreement with results obtained from a direct comparison of the 1986 GOES SXR events with Coronal Mass Ejections (Burkepile et al. 1994).

Table 5. The yearly extreme values of cross-correlation functions between CR intensity and flare indices for LDE events located in the eastern **E**, central **C** and western **W** belts of the solar disk, preceded by the corresponding time lag (in days).

year	lag	CR–E	lag	CR–C	lag	CR–W
1969	6	-0.11	4	-0.01	0	-0.02
1970	6	-0.27	4	-0.19	3	-0.20
1971	4	-0.10	4	-0.08	5	-0.19
1972	7	-0.18	3	-0.40	0	-0.12
1990	6	-0.10	8	-0.18	6	-0.07
1990	19	-0.10	25	-0.16	22	-0.11
1991	10	-0.19	2	-0.29	0	-0.12
1991	20	-0.07	14	-0.41	21	-0.08

5. Conclusions

Cross-correlations between galactic CR intensities and solar x-ray parameters on daily basis suggest that these parameters are not capable of explaining all the intensity depressions observed during the maximum phases of sunspot cycles. However, they seem to be related with a dynamical component of solar activity working throughout the sunspot cycle (Storini et al. 1995). Clearly, much more work is needed to get a better understanding of their role on galactic cosmic rays.

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