Rigidity Dependence and Correlations with Solar Parameters of Galactic Cosmic Ray Intensity as Seen by Neutron Monitors

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Abstract

We analyze the cosmic ray intensity detected by neutron monitors (NM) located ad high altitudes from 1990-2000. The set of monitors covers a wide range of geomagnetic cutoff rigidities (gcr). We calculate the rigidity dependence of several periods during the cycle and determine correlations with solar activity phenomena and IMF.

1. Introduction

Our understanding of solar cycle modulation of cosmic rays (CR) is still limited and a continuation of the research in this line is important. An example of the work developed in this line is the continued effort of Ahluwalia and co-workers (e.g. Ahluwalia, 2000) they studied different aspects of the evolution of the CR modulation over the last solar cycles and searched for the best indicators of solar activity producing modulation. Belov et al. (1999) and Cane *et al.* (1996, 1999) tried to produce an empirical model that reproduced CR intensities based on the evolution of the solar magnetic field and the heliospheric current sheet tilt.
In the present study we analyze the cosmic ray modulation cycle (CRMC) observed by six NM around the world, and its correlation with the evolution of representative parameters of the solar activity cycle (SAC) and with IMF variations. We also studied the dependence of CRMC on gcr of NM for different modulation levels.

2. Observational Data

The NM whose daily corrected data were used in this work are: Climax, with gcr 2.93 GV; Lomnicky Stit, gcr 3.88 GV; Alma Ata, gcr 6.45 GV; Mexico City, gcr 8.02 GV; Tsumeb, gcr 9.06 GV; and Huancayo-Haleakala, gcr 12.76 GV. The period covered is from 1990 to 1999, i.e., the descending and ascending phases of the CRMC 22 plus the start of CRMC 23. There are some data gaps clearly seen in figure 1(left panel) where we present intensity vs time plots normalized

pp. 4107–4110

Table 1. Percentage of variation in the CR intensity for each NM.

Neutron Monitor	Decrease 3-6/91(%)	Recovery phase Fast stage: 6/91-8/92(%)	Recovery phase Slow stage: 8/92-12/95(%)	Minimum to Maximum 6/91-9/97(%)
Climax	16.7	21.5	7.1	29.6
Lomnicky Stit	17.9	20.6	4.8	26.4
Alma Ata	13	14.6	3.8	20.6
México	11.5	11.8	2.2	15.6
Tsumeb	10.3	11.6	1.7	13.7
Haleakala	8.2	9.7	1.9	12.4

respect to the maximum intensity for all six NM, reached in September 1997. Solar parameters chosen are: the 27 days mean values of sunspot number(SSN), Q index of Hα emission of solar flares, the solar microwave flux in 10.7 cm (2800 MHz). We also use the magnitude of the interplanetary magnetic field (IMF) at 1AU from OMNIWeb reports. Figure 1 (right panel) and figure 2 show the temporal evolution of solar parameters and magnitude of IMF.

3. Data Anlysis

If we compare figures 1 and 2 we find the following:
1. A long two year maximum in CRMC 22. This behavior confirms the importance of magnetic drifts in cosmic ray modulation.
2. A double peak in CR during 1990-1991. This structure is present in every of the last five CRMC. We believe that it is associated with the Gnevyshev gap. Feminella and Storini (1997) found this double maxima in many parameters of solar activity. Our analysis indicates that it affects CR in a wide range of rigidities.
3. From March to June of 1991, a series of important Forbush decreases, after that the recovery phase of CRMC 22 starts (see table 1). The depth of this decrease, is comparable with the fast recovery phase that lasted around 14 months.
4. The CR intensity recovery phase has two stages: fast until August 1992, and slow to December 1995 (see table 1). Solar indexes present two stages too. The four month lag between the end of the slow stage in microwave and flares to the end of the slow stage of CR indicates that the associated interplanetary disturbances filled a substantial volume of the heliosphere before the CR flux could sense the changes.
5. The recovery phase of CRMC 22 ends in January 1996. It extends approximately 4.5y. Ahluwalia and Wilson (1996) observed that the recovery phase is completed in 5 to 8y for odd cycles and is less than half for even cycles. On the other hand, this cycle of modulation is the deepest CRMC ever observed.

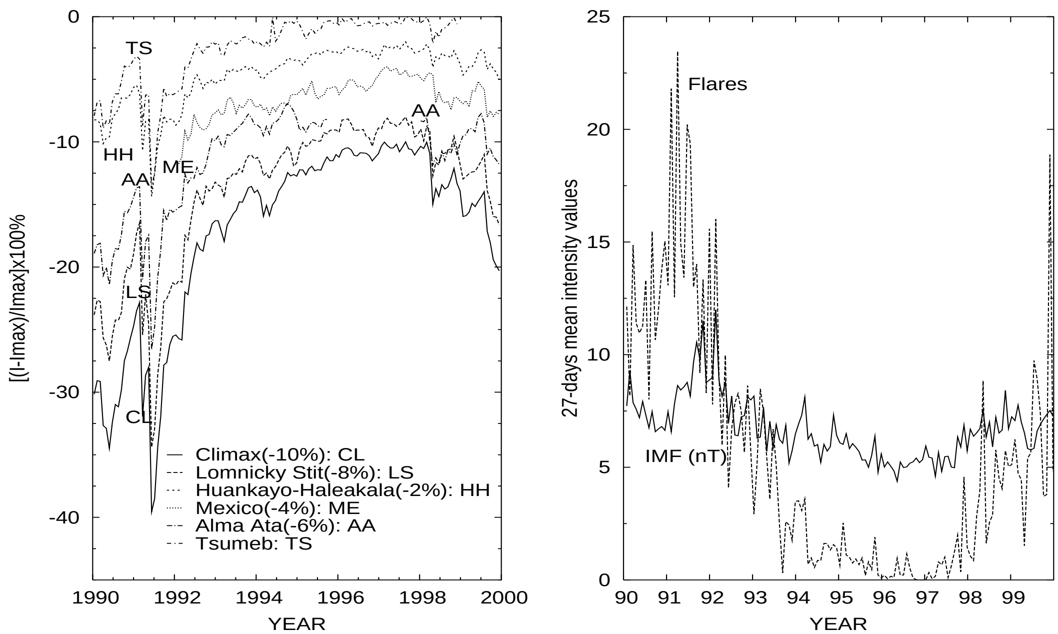

Fig. 1. 27-days mean intensity values of neutron monitors (left panel) from 1990 to 1999. Right panel: the same for Q index of the flares and the magnitude of IMF.

The recovery phases for cycles 18 and 20 presented a similar two stage behavior, shorter than cycle 22.
6. The onset of CRMC 23 is simultaneous at all NM in March 1998, one year and five months after the onset of SAC 23. Solar parameters other than SSN start activity in the second half of 1997. Sunspot onset appears to be of little significance in CR intensity.
7. Two steps are recognizable at the beginning of CRMC 23: both are more signifi-cant for monitors with smaller gcr. The second step is larger. Aluwhalia (1991) found a more significant first decrease for Huancayo than for Deep River in CRMC 21.

4. Geomagnetic Rigidity Dependence

The depth of CRMC is different for each NM. The decrease in 1991 is more significant at smaller gcr stations. Also the recovery phase presents a similar rigidity dependence. NM located at high geomagnetic latitude (low gcr) are more sensitive to changes in the solar activity.
We assume that the variation in table 1 is anticorrelated with gcr in GV. Also we assume an empirical power law relation with n as the power spectral index that we can calculate by the correlation between CR variations and gcr for each of the three periods defined above. The value of the index n depends on the spectrum of

Table 2. Results of correlation between variations in CR intensity and gcr.

	Decrease 3-6/91	Fast stage 6/91-8/92	Slow stage 8/92-12/95	Min.to Max. 6/91-9/97
n	0.52	0.59	0.98	0.64
Corr. Coef.	0.96	0.99	0.95	0.98

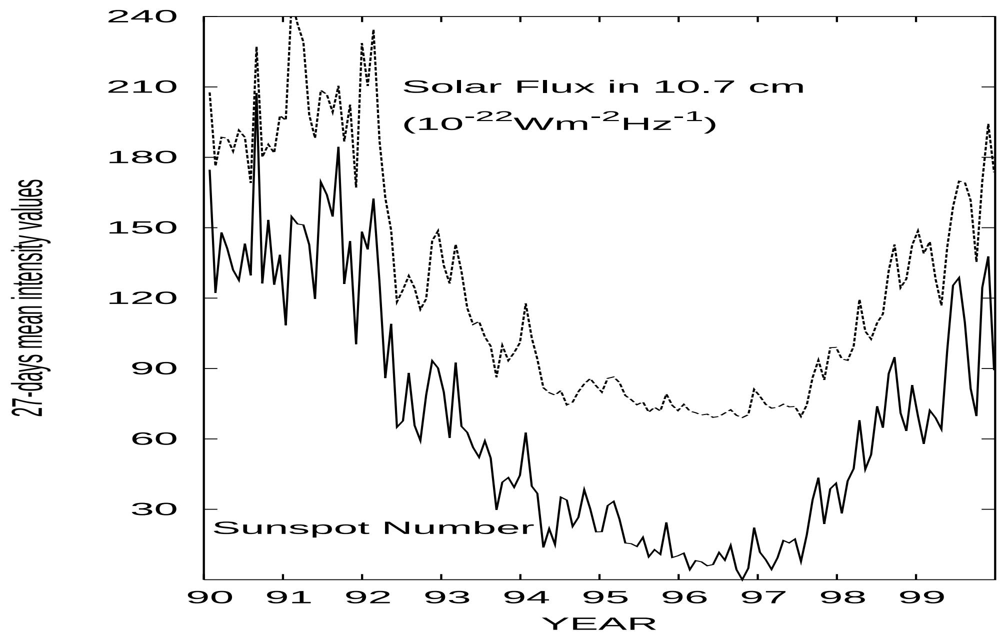

Fig. 2. 27-days mean values of sunspot number and solar flux.

primary CR. Because all stations analyzed here are mountain altitude monitors, this index approximately describes the spectral changes of primary CR. In table 2 we present the calculated parameters for the periods of table 1. The values of n increase with the decrease in solar activity. At maximum solar activity conditions, changes in solar activity affect CR particles primary spectrum up to large rigidities. At solar minimum conditions the changes in the solar activity affect mainly the small energy CR.

5. References

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