On the Shape of Cosmic Ray Modulation during Even- and Odd-numbered Solar Activity Cycles

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Abstract

Data from several neutron monitors are used to investigate the cosmic ray modulation for different rigidity intervals in the period 1953-2002. From the shape of the cosmic ray modulation it turns out that the ∼1.3-yr periodicity, identified also by the use of the wavelet technique, results highly significant during the second stage of cosmic ray modulation in even/odd heliomagnetic semicycles.

1. Introduction

Many research efforts, spent over the years, tried to analyse, characterise and interpret the changing shape of the cosmic ray (CR) modulation at the Earth's location during successive solar activity cycles (e.g. Belov, 2000 and references therein). More precisely, past studies indicate that the CR modulation presents systematic analogies during sunpot cycles of the same type (even- or odd-numbered) but clear discrepancies during cycles of different type. Moreover, by comparing the long-term trend of the CR intensity for the energy interval of 3–13 GeV with the one of the Crimea/Stanford heliomagnetic field intensity it was underlined the existence of a close relationship between them (Storini, 1997, 1998). Clues for this relationship were discussed later on by Cane et al. (1999).

In this paper CR data from several neutron monitors are used to identify the variability of the CR modulation pattern for 4.5 solar activity cycles (from January 1953 to December 2002).

2. Data used and time history of cosmic ray modulation

The monthly averages of the nucleonic intensity registered by Climax (CLI: $R_c \sim 3$ GV), LARC ($R_c \sim 3$ GV), Lomnicky Stit (LS: $R_c \sim 4$ GV), Rome (RM: $R_c \sim 6$ GV), Huancayo/Haleakala (HU/HA: $R_c \sim 13$ GV) NMs in the available time intervals are under study to derive the long-term time history of cosmic ray modulation for different rigidity intervals. Fig. 1, shows such trends for the CR

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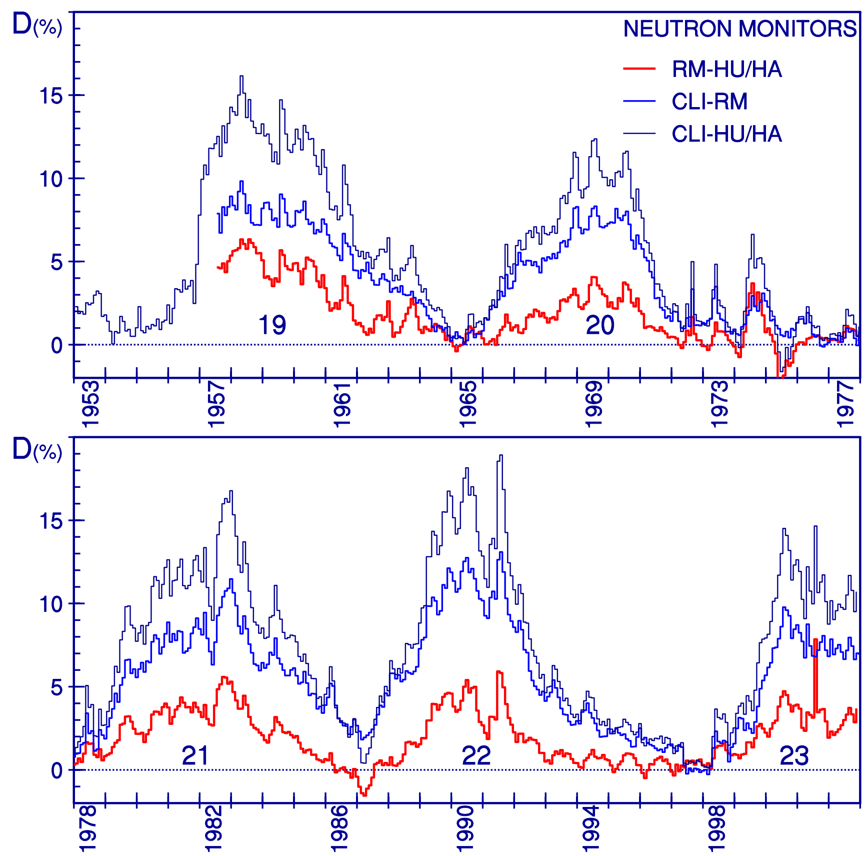

Fig. 1. Time history of CR modulation for different rigidity intervals (from top to bottom in each panel: 3-13 GV, 3-6 GV, 6-13 GV).

stations with longer data acquisition (CLI-HU/HA: 3–13 GV, CLI-RM: 3–6 GV and RM-HU/HA: 6–13 GV).

Looking at solar activity minima (1954, 1964, 1976, 1986, 1996) we can observe distinct steps of CR modulation when going from an even-numbered to an odd-numbered cycle and vice versa. When we have an even/odd minimum the time interval in which the CR modulation (D) is low belongs to the long-lasting type (several months), while it is short for an odd/even minimum.

More precisely: - (i) during the descending phase of odd cycles, D tends to decrease continuously towards the solar activity minimum (*one-stage CR modulation*), while during even cycles the D-decrease is made up by two consecutive steps, being the first one a sudden decrease towards low values and the second one a fluctuation around the minimum level (*two-stage CR modulation*); - (ii) during the ascending phase of even cycles the D-increase begins shortly after the solar activity minimum and goes on (*one-stage CR modulation*), instead during odd cycles the D enhancement is soft for several months (first step) and it is followed

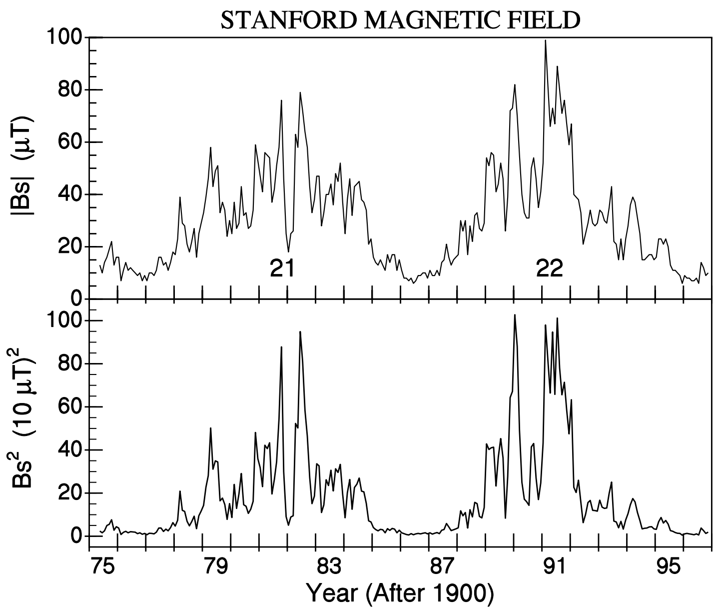

Fig. 2. The $|Bs|$ (top) and Bs^2 (bottom) trends derived from the mean solar magnetic field measurements of the Wilcox Solar Observatory (see the text for details).

by a sharp rising phase (second step), i.e. it progresses with the *two-stage CR modulation*.

Are there differences in the long-term solar magnetic dynamics during consecutive sunspot cycles? To answer the question the mean solar magnetic field (Bs), as observed in the integrated sunlight by means of the Zeeman effect (Wilcox Solar Observatory; Scherrer et al., 1977a,b) was considered for cycles 21 and 22. The daily values of Bs, published by NOAA in the SGD issues, were analysed. Fig. 2 shows the obtained monthly averages of the $|Bs|$ and Bs^2, for the period May 1975 - December 1997. We notice that there exits a fairly good correspondence between D and $|Bs|$ trends, able to explain the two underlined CR modulation types: *one-stage CR modulation* for the odd-even heliomagnetic semicycle and *two-stage CR modulation* for the even-odd one. Moreover, Bs^2 is going down 20 $(10\ \mu T)^2$ only from 1984 in cycle 21, and from 1992 in cycle 22. Certainly, the solar magnetic dynamics is more longer active during the odd cycle.

3. Cosmic ray modulation for different rigidity intervals

In a recent paper Kudela et al. (2002) explored the time evolution of low-frequency periodicities in the cosmic ray intensity. They found that the $\sim$ 1.3-year periodicity is a characteristic feature for the decreasing phases of cycle 20 and 22. The modulation shape reported in Fig. 1, clearly shows that such periodicity is highly significant during the second step of the CR modulation for each even/odd heliomagnetic semicycle and less relevant in the odd/even ones, where the second step is missing.

Finally, from the same figure, it can be noticed that the lowest D (< 2 %) values occur for the following time intervals: $\sim$ 1964-1966, 1971-1977, 1985-1987 and 1992-1997 in the 6-13 GV particle rigidity range, in coincidence with the lowest Bs^2 levels (Fig. 2). The close connection between the solar magnetic field and the CR modulation is further confirmed. Moreover, the short or long time intervals of low CR modulation can be explained in terms of predominance of flare/CME activity or either by the enhanced number of medium/low latitude coronal holes (Storini and Hofer, 1999). The latter seem to be the responsibles of the second step modulation during even/odd heliomagnetic semicycles.

4. Conclusion

The CR modulation for different particle rigidity ranges was evaluated by using several neutron monitor datasets (Fig. 1) and discussed. It resulted a fluctuating trend, in which the $\sim$1.3-yr periodicity play an important role. Work is in progress for a detailed study of such periodicity in the CR modulation as observed at different particle rigidity intervals.

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