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Galactic cosmic ray modulation for sunspot cycle 23

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Abstract

We present a study of the galactic cosmic ray modulation for sunspot cycle 23. We use the monthly and the annual mean hourly, pressure corrected, data from neutron monitors of the global network (monthly rate is calculated as the average of the hourly pressure corrected values). We draw attention to an asymmetry in the galactic cosmic ray (GCR) recovery during odd and even cycles for the monthly mean hourly rate data. For over half a century of observations, we find that the recovery for the odd cycles is to a higher level than for the even cycles. Qualitatively the effect is ascribed to charged particle drifts in inhomogeneous interplanetary magnetic field. Even so it has not been possible to arrive at a quantitative, self-consistent, explanation in terms of drifts at higher and lower GCR rigidities. We also study the rigidity dependence of the amplitude of 11-year modulation over a wide range (1–200 GV) of GCR spectrum; it is a power law in rigidity with an exponent −1.22. We discuss the implication of these findings on quasi-linear diffusion theories of modulation. We reflect on GCR recovery pattern for 2006–2009.

Keywords: Galactic cosmic rays; Solar modulation; Sunspot cycle 23

1. Introduction

Measurements made at Wilcox Solar Observatory (WSO) indicate that solar polar field strength for cycle 23 is ~50% lower than for previous three cycles; see Fig. 1 in Schatten (2005), it also shows that north solar polar field reversed near 2000 and the south polar field in 2001, see also Wang et al. (2002) for a discussion of this topic. McComas et al. (2006) infer that the structure of the heliosphere is significantly different from that observed for cycles 21 and 22 during the decay phase of sunspot cycle 23; the monthly mean smoothed sunspot numbers (SSNs) for cycle 23 reached a minimum value in December 2008. McKinnon (1987) states that SSN data before 1848 are questionable; the reader may also refer to a review of long-term solar activity by Usoskin and Kovaltsov (2005). The duration of 151 months for cycle 23 makes it the longest cycle in the Wolf series. It is interesting to enquire whether GCR modulation for the prolonged sunspot cycle 23 is different from that observed for the previous cycles.

We compare cycle 23 modulation features with the prior odd ($A < 0$) – the solar polar field in the northern hemisphere points toward sun – and even ($A > 0$) cycles – the solar polar field points away from sun; cosmic ray recovery pattern is related to solar magnetic (Hale) cycle. We use hourly, pressure corrected rates obtained with the global network of neutron monitors (NMs), ion chamber (ICs), muon telescopes (MTs) at underground sites, and detectors carried on board the satellites (Ahluwalia, 2003, 2005; Ahluwalia and Fikani, 2007; Ahluwalia and Lopate, 2008; and references therein). These detectors respond to time variations of galactic cosmic ray (GCR) spectrum over a wide range of rigidities (1–200 GV); data from MT at Mawson (Antarctica), deployed at 31 m water

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equivalent (mwe), are used for the study of the 11-year modulation for the first time to show that diffusion approximation (Parker, 1965) is valid at high rigidities for long-term changes in GCR differential rigidity spectrum.

2. Climax neutron monitor data

Climax neutron monitor (CL/NM) has operated continuously, at the same site, at an altitude of 3000 m, since 1950 (see Table 1 in Pyle, 1993). It is of international geophysical year (IGY) design, with two sections of six tubes each. A great care is taken to maintain the stability of atmospheric pressure measurements. Although the geomagnetic vertical cut-off rigidity (Ro) is 3 GV, the monitor is 16% more sensitive to GCR modulations (because of its altitude) than the sea-level monitor at Deep River (DR/NM) with a (lower) cut-off rigidity of 1.1 GV (see Fig. 2 in Ahluwalia and Wilson, 1996b). Moreover, the Ro value for CL/NM has been stable for a long time (Smart et al., 2000).

Fig. 1 shows a plot of the monthly mean hourly rate (monthly average of hourly pressure corrected values) for CL/NM for 1951 to November 2006; the rate is normalized to 100% in May 1965. The positions of solar activity maxima (M) and minima (m) are shown in the diagram. The period covers four complete solar cycles (19–22) and parts of the other two (18 and 23) as well as five epochs of solar polar field reversals, marked by the vertical dashed lines drawn through the middle of the epochs. After November 2006, CL/NM data is available but remains unprocessed for lack of financial support to its PI.

3. Comments on CL/NM data

In addition to the inverse correlation between NM rate and sunspot activity, first noted by Forbush (1954), the following additional features stand out in Fig. 1.

(1) Recovery from 11-year modulation occurs following the epoch of the solar polar field reversal in the first two cycles (19 and 20) but not in the last three (21, 22, and 23).
(2) Unusual variations are seen for $A > 0$ epoch (1973–1975) during recovery from cycle 20, they are discussed in detail by Ahluwalia (2003).

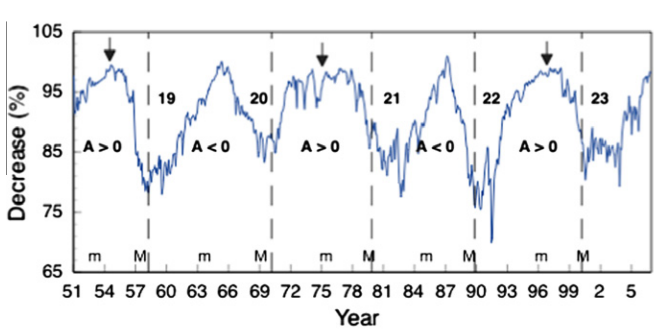

Fig. 1. CL/NM monthly mean data are plotted for 1951 to November 2006. See text for details.

(3) For cycle 21, minimum GCR intensity occurs in 1982, nearly 3 years after sunspot activity maximum in 1979. A similar situation happens for cycle 22; GCR intensity in 1991 was the lowest ever observed since continuous monitoring began by CL/NM. These features are not expected from the original Forbush analysis; see a detailed discussion by Ahluwalia (2000a).
(4) A repeating pattern of inverted 'V' (2) followed by broad (3) maxima is seen in the recovery from modulation; the former pattern is termed negative (odd) cycle ($A < 0$) and latter a positive (even) cycle ($A > 0$). Ahluwalia (1980) uses ion chamber (IC) data obtained at Cheltenham–Frederiksburg, to show that GCR intensity for cycle 19 takes 7 years to recover to solar minimum value, but for cycle 20 the recovery from modulation occurs in only ~2 years. Furthermore, Ahluwalia (1994) shows that this pattern repeats every 22 years in the data obtained with NMs and ICs at other global sites; during odd cycles (17, 19, and 21), when magnetic polarity in the solar northern hemisphere is negative ($A < 0$), recovery from modulation takes twice as long for the even cycles (18 and 20). A similar pattern is clearly seen in CL/NM data in Fig. 1 for an extended period. These patterns are explained qualitatively by Kota and Jokipii (1983); they show that during $A > 0$ epochs, positive charges drift from higher helio-latitudes towards the heliospheric neutral current sheet (HNCS) while for $A < 0$ cycles positive charges drift along HNCS toward higher helio-latitudes, driven by the symmetric particle density gradients (with respect to HNCS) which change sign every 11 years (Ahluwalia, 1996a).
(5) Downward pointing arrows on broad maxima ($A > 0$), draw attention to the fact that recovery during a positive cycle is to a lower level than for a negative cycle, as noted earlier by Ahluwalia (1994) as well as Webber and Lockwood (1988); the latter authors note that GCR intensity measured by NMs for the broad maximum is ~1.5% lower (for ICs the difference is about 0.3%, see Fig. 3 in Ahluwalia, 1997). The recovery for cycle 23 is still in progress as of November 2006 for which CL/NM data are available. A similar difference is observed in composite IC data (Rm = 67 GV) plot for 1937–1987 (see Fig. 3 in Ahluwalia, 1997).

Kota and Jokipii (1983) show that charged particle drifts in the inhomogeneous IMF (with warped HNCS included) lead to a "pointy" and a "broad" maximum in the recovery phase of the 11-year modulation for a 1.6 GeV proton, the pointy peak is higher than the broad peak (see their Fig. 6). These patterns are expected to recur during alternate sunspot cycles. On the other hand, Potgieter and Moraal (1985) are unable to reproduce this effect in a self-consistent simulation for NM data (at an order of