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The onset of sunspot cycle 24 and galactic cosmic ray modulation

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Abstract

The annual mean sunspot number (SSN) has a minimum value in 2008, while the monthly mean SSN has a value of zero in August 2009. The galactic cosmic ray modulation for cycle 24 began at earth orbit in January 2010. We study the onset characteristics of the new modulation cycle using data from the global network of neutron monitors. They respond to time variations in different segments of the galactic cosmic ray rigidity spectrum. The corresponding temporal variations in the interplanetary magnetic field intensity (B) and solar wind velocity (V) as well as the tilt angle of the heliospheric current sheet are also studied. There is a lag of 3 months between a large, sharp increase of the tilt angle of the heliospheric current sheet and the onset of modulation. Some neutron monitors are undergoing long-term drifts of unknown origin.

Keywords: Galactic cosmic rays; Sunspot cycle 24 onset; Modulation; Neutron monitors; Heliospheric current sheet; Solar wind

1. Introduction

The long decay phase of sunspot number (SSN) cycle 23 reached a monthly mean SSN of zero in August 2009; the smoothed SSN minimum was reached in December 2008. The sunspot cycle 24 has set in. It is rising slowly towards its maximum. Ahluwalia and Jackiewicz (submitted for publication, and references therein) predict that cycle 24 will be significantly less active than cycle 23 and will peak in 2013.

The frequency of the coronal mass ejections (CMEs) closely follows the sunspot cycle (Ahluwalia, 1992a and references therein; Webb and Howard, 1994; Gopalswamy et al., 2003). The CMEs modulate galactic cosmic ray (GCR) intensity in the heliosphere (Newkirk et al., 1981; Ahluwalia, 2000 and references therein), explaining the inverse correlation between GCR intensity and SSNs observed by Forbush (1954) at earth orbit; later Smith (1990) showed that heliospheric current sheet (HCS) also contributes to the solar modulation of GCRs.

Although 11-year modulation has been studied for sunspot cycles 17–23, we still do not understand its intricacies. Even so, we have begun to appreciate the pivotal role played by the time variations of the interplanetary magnetic field (IMF) intensity (B) in modulating GCRs (Barouch and Burlaga, 1975; Ahluwalia, 1992b; Perko and Burlaga, 1992; Burlaga and Ness, 1998; Cane et al., 1999). An advancement of our understanding of 11-year modulation has come about due to the fact that a variety of instruments are now available to the heliophysics community to monitor different parts of the GCR rigidity spectrum, at different locations in the heliosphere. These global sites lie on the surface of the Earth, underground at different depths, at mountain tops, on the satellites, and the space probes; Voyagers 1 and 2 are now making measurements in the heliosheath.

Several theoretical models have been advanced to understand GCR solar modulations. Morrison (1956) proposed that certain features of the Forbush decreases could be explained in terms of charged particle diffusion in the tangled magnetic fields pervading the heliosphere. Ahluwalia and Dessler (1962) proposed a physical process for the convection of GCRs away from the sun by means of an electric drift ($E \times B$, $E = B \times V$) in the Parker IMF spiral, leading

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to a diurnal anisotropy (in solar time) observed by a detector on the spinning earth. These insights led to the development of the Parker equation (1965); a corollary of it is the successful diffusion–convection model in which convection is the driver of observed modulations. As details of IMF structure and its evolution with time were understood (Forman and Gleeson, 1975) it was clear that the Parker equation contains information about all features of GCR modulations, e.g. it includes contributions from other drifts in the inhomogeneous IMF; an appreciation of their role for the helio-latitudinal transport of GCRs came much later (Kota and Jokipii, 1983). In the meantime, Jokipii (1971) presented an alternate theory of cosmic ray transport in the solar wind containing random magnetic irregularities proposed by Morrison; GCRs are scattered as they diffuse into the heliosphere from the interstellar medium, causing modulations.

The Parker equation can only be solved numerically. Besides, it points to no preferred choice of transport parameters or the configuration of IMF. A spherical symmetry solution of the Parker equation (Gleeson and Urch, 1973) is often invoked to understand modulation in terms of a force field parameter ϕ; it represents a GCR rigidity loss in the heliosphere. The appeal of this approach lies in the fact that observed modulation, over a range of rigidities (R), can be described in terms of a single parameter (ϕ); it is a charge-less potential (volts), and GCR species behave as if they are all positively charged, see Ahluwalia (2005) for a discussion of this approach. The model retains much of the physics of the Parker equation, e.g. diffusion, convection, and adiabatic energy loss, only drifts are left out. Although this approach is quite successful in explaining features of GCR modulations at higher rigidities ($R > 1$ GV), it fails to account for the measurements made by Voyagers 1 and 2 near the termination shock and in the heliosheath (Ness et al., 2005), at lower rigidities. So, improvements have been made to the diffusion theories over the last several years by including perpendicular diffusion and non-linear effects; see an excellent summary by Shalchi (2009). These improved theories need to be tested at higher GCR rigidities (Ahluwalia et al., 2010a,b).

2. Cycle 24 onset

Fig. 1 shows a plot of the monthly mean hourly Oulu NM data and smoothed SSNs for 1965–2010 May; NM data are normalized to 100% in May 1965. The following are the noteworthy points:

- The data cover four SSN cycles (20–23), two positive ($A > 0$) and two negative ($A < 0$); for a positive epoch, the solar polar field in northern hemisphere points outward from the sun.
- The GCR intensity recovers to a higher level for a negative ($A < 0$) epoch (in an inverted V form) in a matter of months. However, the recovery for cycle 23 negative epoch is to the highest level ever since Climax NM began operations in 1951. Also the recovery takes a much longer time than for cycle 22.
- The inverse correlation between the GCR intensity and the SSNs stands out.
- In 2009, the solar activity reached a deep and prolonged minimum for cycle 23.
- A vertical dashed line marks the onset of the GCR modulation (in January 2010);

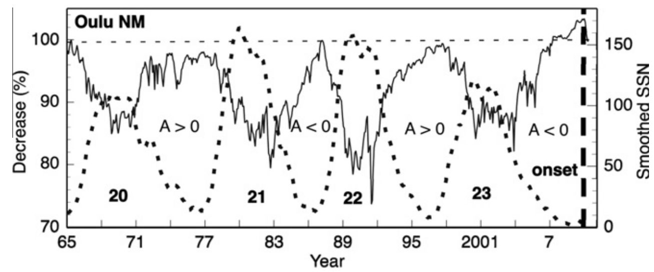

Fig. 1. Oulu NM monthly mean hourly data plot for 1965–2010, normalized to 100% in May 1965; cycle 24 modulation onset (January 2010) is shown by a vertical dashed line, the dotted curve represents the smoothed sunspot numbers.

Ahluwalia et al. (2010a) discuss the subtle features of GCR modulation for the prior cycles. In this paper, we only describe the solar-terrestrial connections related to the onset of cycle 24 modulation.

Fig. 2 shows a plot of the heliospheric parameters (B, V) for October 1963–May 2010 (cycles 20–23). The following features may be noted:

- The values of V undergo solar cycle variations and fluctuate about the nominal mean level (the horizontal dashed line) of 450 km/s.
- The values of B also undergo solar cycle variations. But, B decreases systematically during cycle 23 to the lowest value ever measured ($\sim$3 nT) by the end of 2009, well below the IMF “floor” value of 4.6 nT proposed by Svalgaard and Cliver (2007). Also, the annual mean value (3.9 nT) of B in 2009 may correspond to its value in 1912, indicating that we are returning close to the geomagnetic and solar conditions near the early part

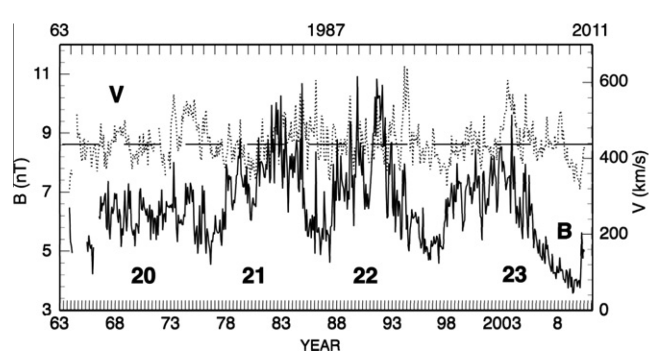

Fig. 2. Monthly mean values of B and V are plotted for October 1963 to May 2010.