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Observed galactic cosmic ray 11-year modulation for cycle 23

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Abstract: We present a preliminary study of the observed 11-year modulation of galactic cosmic rays (GCRs) for cycle 23. The detectors selected for the analyses have a track record of stable operations and have median rigidities of response (Rm) covering a wide range of GCR spectrum. They are located at global sites and on IMP-8 satellite. The onset of modulation occurred at the earth's orbit following a number of coronal mass ejections in April- May 1998, as an active region moved across the solar disc from the east to west limb. The recovery is not complete yet. We examine the features of the observed modulation thus far and compare it with those seen for previous cycles at a comparable stage of development.

Introduction

In situ observations of the solar wind in space show that 3-D structure of the heliosphere can differ significantly from one solar cycle to the next. In particular, heliospheric structure for cycle 23 seems to be significantly different from that observed for cycles 21 and 22 [1]. So, it is interesting to see how GCR modulation for cycle 23 compares with the previous observations, over a range of rigidities. The rigidity dependence of modulation arises from the local as well as global GCR contributions. To explore this dependence, one uses data obtained with a variety of detectors at sea level and mountain sites, as well as on balloons, satellites, and space probes. For such studies to be meaningful, it is important to have a clear understanding of the response characteristics of the detectors involved. We characterize detectors in terms of their median rigidity of response (Rm) to GCR spectrum; 50 % of detector counting rate lies below it [2]. Some colleagues define effective rigidity of modulation for neutron monitors (NMs) in an ad hoc manner. For example, Lockwood and Webber [3] give values of Rm = 5.4 / 7.0 GV, for cycles 21 / 22, for Mt. Washington NM compared to our value of 10 GV. Later still, Lockwood, et al. [4] give Rm = 14 GV for Mt Washington NM which exceeds our value. Recently, we made an attempt to understand the physical basis of the wide divergence in the reported Rm values for NMs; we consider them to empirical attempts that did not pan out in the long run. We showed that solar cycle variation in Rm values is small for the NMs [5].

Climax neutron monitor data: 1951-2006

Figure 1 shows a plot of the 27-day mean Climax neutron monitor (CL/NM) hourly rate and the 27-day mean smoothed sunspot numbers (SSNs) for 1951 to 2006 (November); the rate is normalized to 100 % for the month of August 1954. The period covers four complete cycles (19 to 22) and parts of the other two (18, 23) as well as five epochs of the solar polar field reversals. An inverse correlation exists between NM rate and the smoothed SSNs, as noted by Forbush [6]. Additional features are noted below.

1. A repeating pattern is observed in the recovery phase of NM rate; it consists of a broad maximum for A > 0 (positive) cycle followed by an inverted 'V' recovery for A < 0 (negative) cycle, indicating that GCR intensity undergoes a long term modulation over a solar magnetic (Hale) cycle. In each case the recovery follows the solar polar field reversal except for cycle 21; the reader is

referred to Ahluwalia [7] for a detailed discussion of this phenomenon.

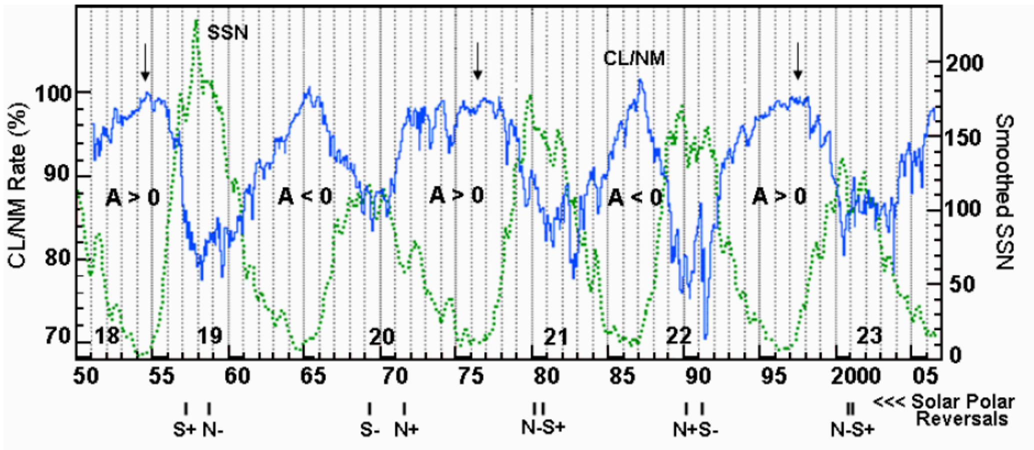

Figure 1

2. Downward pointing arrows indicate that recovery during A > 0 cycles is to a level lower than those for the A < 0 cycles; recovery for (negative) cycle 23 is still in progress. We looked at McMurdo NM data, available until 30 June 2007 (http://neutronm.bartol.udel.edu), to ascertain the present state of cycle 23 recovery. We find that a very rapid recovery is underway at high latitude NM site in the last few months to a level higher than the preceding A > 0 cycle recovery in 1997, as one would expect from earlier observations obtained with CL/NM. Similar situation exists at other high latitude NM sites at Oulu and Apitity (private communications from Usoskin and Vashenyuk at ICRC). Webber and Lockwood [8] and Ahluwalia [7] also noted this effect. Potgieter and Moraal [9] state that they are unable to reproduce this effect in their simulations for NMs that incorporate drifts. Lockwood and Webber [10] suggest that this difference in intensities on recovery may result from a modulation in the heliosheath (see their Fig. 7). Earlier, Webber and Lockwood [11] argued similarly (see their Fig. 2). We argue that heliosheath related effects are minimal at earth's orbit at rigidities greater than 3 GV [12]; the geomagnetic cut off for CL/NM is 3 GV. A recent numerical simulation supports our view (Potgieter, private communication at COSPAR, Beijing, China, 2006). Reinecke et al., [13] present an alternate explanation. They interpret the phenomena in terms of 'crossovers' of GCR spectra during positive and negative cycles at 6 to 10 GV indicated by latitude surveys with their NMs (see their Fig. 1). This effect is also seen at lower rigidities in the spacecraft data for different particle species (protons and helium) but with opposite phase i.e. one observes a suppression of particles with rigidities below ~ 1 GV in negative cycles (1965 and 1987) compared to positive cycles (1977 and 1996); see their Figs. 2 and 3. For spacecraft data 'crossovers' are accounted for in the simulations that include drifts. However, Reinecke et al. [13] are unable to reproduce observed 'crossovers' in NM data using the same modulation model. They concede that the two 'crossovers' may have different (unspecified) physical causes. Dorman et al., [14] dispute the existence of 'crossovers' in their latitude survey data. So, this effect remains unexplained at this time.

3. Unusual variations are seen for the A > 0 epoch, for 1973-1975, during recovery from cycle 20. The reader is referred to Ahluwalia [15] for a detailed discussion of this.

4. For cycle 21, the minimum in GCR intensity occurs in 1982, nearly three years after the solar

activity maximum in 1979. A similar situation is observed for cycle 22; SSN maximum is in 1989 and GCR intensity minimum is in 1991; the intensity minimum in 1991 was the lowest ever observed, since continuous monitoring began. This is not expected from the analyses carried out by Forbush. It turns out that the intensity (B) of the interplanetary magnetic field (IMF) attains very large values in 1982 and 1991. These observations point to the dominant role played by IMF in causing GCR modulation [16].

5. The modulation profile for cycle 23 is very different from that observed for the prior cycles; it develops a shoulder during its recovery phase. McComas et. al., [1] report that Ulysses spacecraft observed a very different heliospheric structure during the declining phase of cycle 23 compared to the previous cycles.

Features of cycle 23 modulation

Figure 2 shows a plot of the annual mean hourly

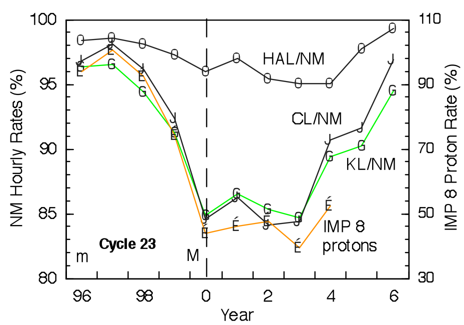

Figure 2

rate obtained with NMs at Haleakala (Rm = 33 GV), Kiel (Rm = 17 GV), and Climax (Rm = 11 GV); rates are normalized to 100 % for the month of May 1965 [17]. Also plotted are IMP 8 penetrating proton channel annual mean rate. The IMP 8 (Explorer 50) satellite was launched on 26 October 1973 to measure the magnetic fields, solar wind plasma, and energetic charged particles at the orbit of the earth; it quit in October 2006 (private communication from Bruce McKibben). The annual mean penetrating proton channel (> 100 MeV) rate on IMP 8 was normalized to 99 % in 1997 [18] to match the annual mean rate of > 0.1 GeV Gieger counter telescopes on board the high altitude balloons flown at high latitude locations in USSR [19] for over three decades (1957-1989) to obtain a continuous record of the time variations of low energy GCR from IGY period to date, spanning five solar cycles (19 to 23). Unlike NMs, Rm value for the IMP 8 penetrating proton channel changes for different cycles [20]. The years of solar activity maximum (M), minimum (m) and polar field reversal (vertical dashed line) are shown in the figure. The following features are easily noted.

1.The onset of modulation for all detectors occurs in 1997, a year after the 'm' epoch.

2. For NMs the lowest GCR intensity is reached at the M epoch, coincident with the solar polar field reversal given by Wang et al. [21].

3. For IMP 8 protons GCR intensity minimum occurs in 2003, three years after M epoch. According to Gopalswamy et. al [22] the field reversal in the southern hemisphere is not complete until May 2002, with several temporary reversals in between. This may be the cause of irregular variations in all NMs for 2001 and 2002.

4. For all detectors, the recovery sets in after 2003. A shoulder in the recovery phase is clearly visible in all NM data between 2004-2005. It may be due to a pick up in solar activity in solar southern hemisphere late in cycle 23.

The above results are preliminary; details are being studied using data from a variety of other detectors of the global network. The results will be reported elsewhere.

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References

[1] McComas, D.J. et al., 2006. Geophys. Res. Lett., 33, L09102.

[2] Ahluwalia, H.S., and J.H. Ericksen, 1971. J. Geophys. Res., 76, 6613.
[3] Lockwood, J.A., and W.R. Webber, 1996. J. Geophys. Res.,101, 21573.
[4] Lockwood, J.A., W.R. Webber, and H. Debrunner, 2001. J. Geophys. Res., 106, 10635.
[5] Ahluwalia, H.S., and M.M. Fikani, 2007. J. Geophys. Res., 112, A08105, doi:10.1029/2006JA011958.
[6] Forbush, S.E., 1954. J. Geophys. Res., 59, 524.
[7] Ahluwalia, H.S., 1994. J. Geophys. Res., 99, 11561.
[8] Webber, W.R., and J.A. Lockwood, 1988. J. Geophys. Res., 93, 8735.
[9] Potgieter, M.S., and H. Moraal, 1985. Astrophys. J., 294, 425.
[10] Lockwood, J.A., and W.R. Webber, 1997. J. Geophys. Res., 102, 24221.
[11] Webber, W.R., and J.A. Lockwood, 1987, Astrophys. J., 317, 534.
[12] Ahluwalia, H.S., 2005. J. Geophys. Res., 110, A10106, doi:10.1029/2005JA011106.
[13] Reinecke, J.P.L., et al., 1997. 25th ICRC, Durban, South Africa. Conf. Pap., 2, 49.
[14] Dorman, L.I., et al., 2000. J. Geophys. Res., 105, 21047.
[15] Ahluwalia, H.S., 2003. Geophys. Res. Lett., 30, 1133, doi:10.1029/2002GL016017.
[16] Ahluwalia, H.S., 2002. Geophys. Res. Lett., 27, 1603.
[17] Ahluwalia, H.S., and M.D. Wilson, 1996. J. Geophys. Res., 101, 4879.
[18] Ahluwalia, H.S., and C. Lopate, 2001. Proc. 27th ICRC., 8, 3837.
[19] Bazilevskaya, G.A., et al., 1991. J. Geomag. Geoelectr., 43, 893.
[20] Ahluwalia, H.S., and C. Lopate, 2007. In these ICRC Proceedings.
[21] Wang, Y.M. et al., 2002. J. Geophys. Res., 107, 1465, doi:10.1029/2002JA009463.
[22] Gopalswamy, N., et al., 2003. Astrophys. J., 598, L 63.