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Onset of Galactic Cosmic Ray Modulation for Cycle 23

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Abstract

We have followed the long term, steady state, modulation of galactic cosmic ray (GCR) intensity for almost two decades and have reported on its observed characteristic features at the international cosmic ray conferences (ICRC) fairly regularly. The data obtained with a variety of detectors on earth (neutron monitors and ion chambers), located at different global sites, are analyzed for this purpose. We reported on the near recovery of GCR modulation for cycle 22 up to April 1997 at the 25th ICRC, Durban, South Africa; the mathematical minimum for the cycle 22 was reached a month later in terms of the smoothed sunspot numbers (SSN). The onset of GCR modulation for cycle 23 occurred last year. We discuss it's observed characteristics at higher rigidities along with implications for the modulation theories.

1 Introduction:

The study of inverse correlation between solar as well as geomagnetic activity and galactic cosmic ray (GCR) modulation has been carried out over an extended time period (Ahluwalia and Wilson, 1996 and references therein). A variety of GCR data obtained with several different types of cosmic ray detectors are used for this purpose because they respond to different parts of GCR rigidity spectrum. Sunspot numbers (SSN) solar microwave (2800 MHZ) flux (F 10.7), coronal green line (5303A) intensity, tilt (alpha) of the heliospheric current sheet (HCS) and coronal mass ejections (CME) have been used as the measures of the solar activity. These indices are related amongst themselves which makes it more difficult to draw clear cut conclusions as to the nature of the physical processes involved. A new GCR modulation cycle started last year. We comment on its observed characteristics in relation to others.

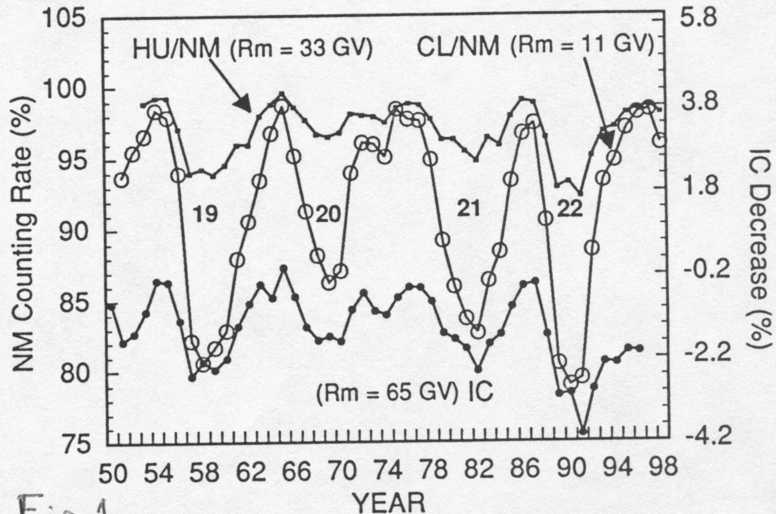

Fig. 1

2 Data Analysis:

Available GCR annual mean data for the period 1950 to 1998 are plotted in Fig. 1. The median rigidity of response (Rm) to GCR spectrum is listed in the figure alongside the labels for the detectors. It lies in the range 11 GV < Rm < 65 GV. Neutron monitor (NM) data are normalized to 100% in May 1965 and ion chamber (IC) data to 100% for the year 1965. The time period covers four cycles (19 to 22) and parts of other two (18, 23). As we pointed out at the 25th ICRC, Durban, South Africa (Ahluwalia and Wilson, 1995), the recovery after 1994 is very slow. It reaches a maximum very close to 1954 and 1976 levels in 1997 (but below 1965 level). The recovery profile looks more like that for cycle 18 than for cycle 20 in NM data.

Note that GCR recover to the highest level in 1965 when the annual mean value of IMF measured at earth's orbit is the lowest (Ahluwalia, 1999b). The progressively lower levels to which GCR recover in 1976 and 1986 seems to tie in well to progressively higher levels observed for the annual mean values of IMF at earth's orbit for the corresponding years. So it may well be a manifestation of the three cycle quasiperiodicity in GCR recovery mode at earth's orbit. Previously the "pointy" GCR recovery in 1965 was ascribed to the charged particle curvature and gradient drifts in the heliosphere (Kota and Jokipii, 1983). A question arises as to whether 1996-1997 peak will be "pointy."

The details of GCR modulation onset phase in 1998 for CL/NM is shown in Fig. 2 which gives a plot of hourly rate averages for the year 1998. One notes that GCR intensity never recovered after the Forbush decrease (FD)

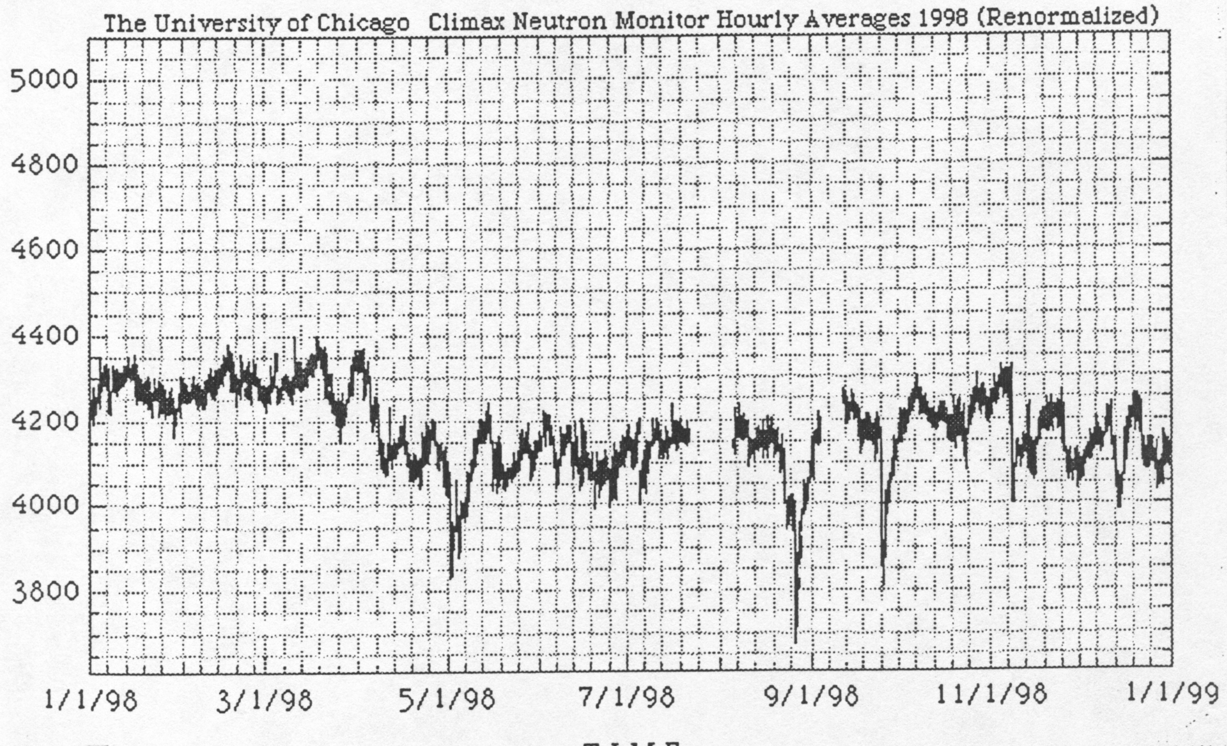

Fig. 2

in late April followed by other FD later in the year. The fact that HU/HA neutron monitor annual mean rate is also depressed in 1998 makes it more likely that GCR modulation for cycle 23 has begun. This view is further supported by the data presented in Fig. 3 for the 1959 to 1998 period. It depicts a plot for the 12 month running averages of GCR intensity at DR/GB (scale on the left) and F10.7 (scale on right); the scale for latter is inverted because of the inverse correlation between two datasets. The pattern for the onset phase of GCR modulation for cycle 23 is similar to that for cycle 21. So we expect solar activity to increase more rapidly than the accompanying decrease in GCR intensity during the descending phase of the cycle. Elsewhere we have predicted that SSN cycle 23 will be more modest compared to cycles 22 and 21 (Ahluwalia, 1998, 1999a). The physical cause responsible for the observed time lag during the declining phase of an odd cycle is being investigated.

3 Discussion:

Since SSN cannot influence GCR in the heliosphere just by themselves, we have to look for the physical cause(s) for GCR modulation elsewhere. It must follow the change in SSN on the photosphere and alter the electrodynamics of the heliosphere in such a way that GCR respond to the changes in the observed manner. In other words, the signature of the physical cause is likely to be imprinted on the solar wind. Two obvious candidates are CME and HCS tilt angle (alpha); both are highly correlated with SSN. Lockwood (1960) showed that GCR modulation arises from a superposition of shocks (CME in contemporary terminology) each of which produces FD at earth's orbit depressing GCR intensity and forming a heliocentric barrier further out in the

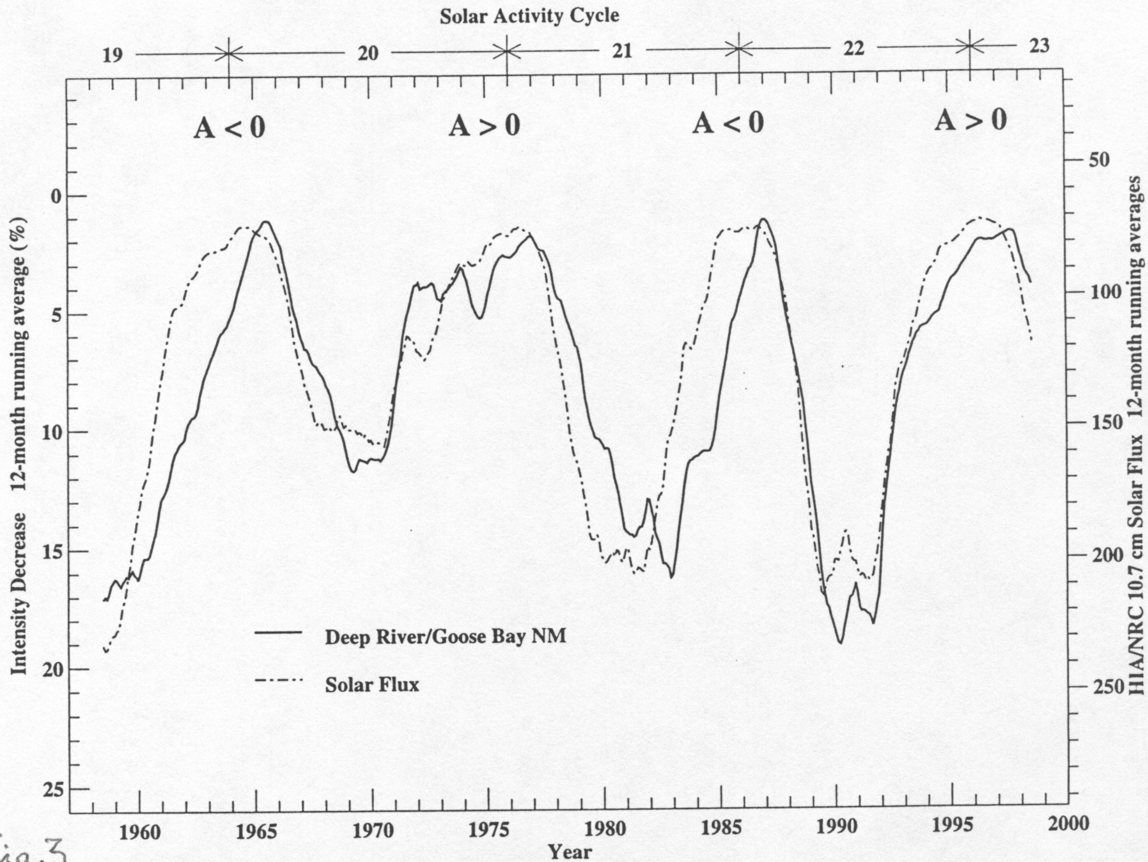

Fig.3

heliosphere--global merged interaction regions (GMIR) in the present day terminology (Burlaga et al, 1993)--so that GCR intensity never quite recovers at earth's orbit. Gosling et al (1991) showed that the largest geomagnetic storms during cycle 21 maximum (1978-1982) were triggered by CME. Their further study over an extended time period (1978-1990) led to the inference that the frequency of occurrence of CME varies in phase with SSN cycle (Gosling et al, 1992), confirming an earlier result by Webb (1991) whose data came from the coronagraphs in space. The interplanetary scintillation measurements made between 1986 and 1991 (ascending phase of the cycle 22) reconfirmed and extended this important inference (Manoharan, 1997). This study delineated the heliolatitudinal distribution of CME, indicating that near solar minimum (1986-1988) the CME activity starts at the solar equatorial region and progresses to higher heliolatitudes reaching the polar regions at solar maximum (1989-1991) for cycle 22. HCS tilt angle (alpha) exhibits a similar behavior (Ahluwalia, 1992). We posit that the locus of CME activity moves in concert with alpha across the heliolatitudes. One can then explain the observed close relationship between alpha and GCR modulation over a wide rigidity range (Smith and Thomas, 1986; Saito and Swinson, 1986) as being caused by CME. Some support for this hypothesis comes from an inference drawn by Hundhausen (1993) who found that in 1984 when $\alpha \sim 30°$, CME heliolatitudes were clumped about the HCS rather than the heliographic equator. This result has been reconfirmed recently with a limited experience with the Large Angle Spectrometic Coronagraphs (LASCO) on board the Solar & Heliospheric Observatory (SOHO) launched in December 1995. The observations suggest that CME tend to be deflected towards HCS (private communication from D. Michels and R. Schwenn). Time will tell whether this is also true at higher heliolatitudes.

In Fig. 4 we have plotted the annual mean values of CL/NM hourly rates and the annual mean values of the tilt angle (alpha) for the 1976 to 1998 period. The epochs of the cycle maxima and minima are indicated by M and m respectively, and those of the solar polar field reversals in the northern hemisphere by the vertical dashed lines. The timeline covers two cycles (21, 22). For cycle 21 (1976-1986) the minimum in CL/NM data occurs two years after M, well past the epoch of the polar field reversal. This is unlike our previous experience (Ahluwalia, 1994) which indicated that recovery starts during or immediately following the reversal of the solar polar field as is the case with recovery for cycle 22. However, we note that solar activity remained high for more than a year after the polar field reversal. There is no correlation between the amplitude of alpha and GCR modulation during the two cycles. This implies that alpha is not a reliable index of GCR modulation. Webb and Howard (1994) have inferred that the frequency of CME occurrence tends to track SSN in amplitude as well as phase. Their result would have to be reconfirmed for cycle 23 which is being tracked by more sensitive instruments with full sun in view all the time.

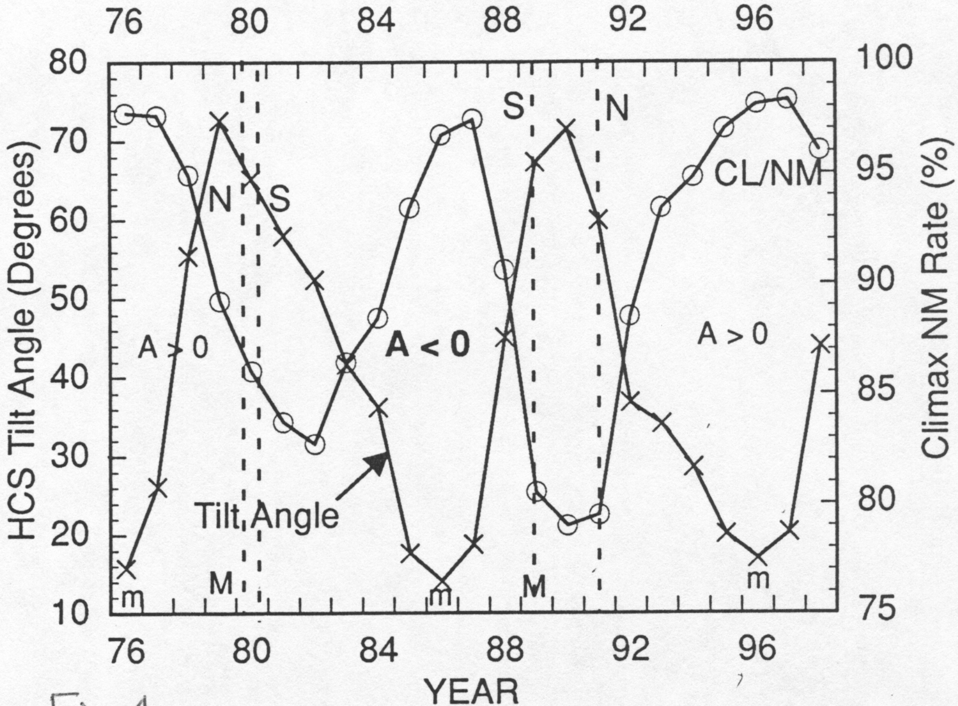

Fig. 4

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