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Gnevyshev gap in the annual frequency distribution of cosmic ray decreases and Ap index

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Abstract: We present preliminary results of a study of the annual frequency distribution of cosmic ray decreases (amplitude ≥ 3.5%) for five solar cycles (19 to 23). We use Climax neutron monitor hourly counting rate data for 1952 to 2006. We confirm the main result of an earlier study for a shorter time interval (cycles 20, 21, 22); it showed that there is a gap (Gnevyshev gap) in the distribution, near the sunspot maximum of each solar cycle during the epoch of the solar polar field reversal. A similar study with yearly averages of the Ap index leads to a similar result. Ap is constructed from the global mid-latitude magnetograms; it is a measure of how disturbed the magnetosphere is at any given time.

Introduction

This work is an extension of an earlier study of the frequency distribution of the Forbush decreases (FDs) that we reported at the 35th COSPAR Scientific Assembly at Paris in July 2004 [1]. That study is based on the catalog of FDs published by Cane et al. [2]; we use annual frequencies to minimize contributions from seasonal effects. In earlier study we found that FD frequency distribution varies in step with the solar cycle but it has a gap near the sunspot maximum, leading to two peaks per cycle in the distribution; second peak occurs well before the onset of high-speed streams (HSS) during the descending phase of the cycle, indicating that HSS are not the main cause of FDs, but they do contribute to a peak in the annual mean value of the Ap index. Our results were significant at a little over 1σ level. So, we decided to repeat the study using data obtained with the Climax neutron monitor (CL/NM) which is the oldest continuously operated instrument (1951-2006) in the world; Cane et al. used Deep River neutron monitor data over a shorter time interval (cycles 20, 21, 22) for their catalog of FDs with an amplitude ≥ 4%. We set the threshold at ≥ 3.5% decreases, in the hourly counting rate of CL/NM in a 24-hour interval. Our list includes most of the FDs in the Cane et al. catalog. Our list will be published later, elsewhere. The study is ongoing. Preliminary results are presented in this paper.

Results

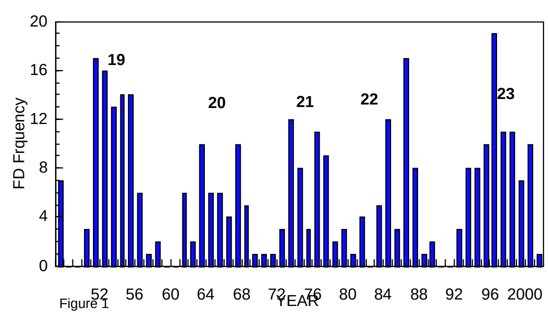

Figure 1

Figure 1 shows a histogram of the annual frequency distribution of the observed decreases in the CL/NM hourly rate for 1952-2006; we discarded the data for 1951 because of too many breaks and enhanced variance in the data. Our study found about 350 events compared to 180 FDs listed in the Cane et al. catalog. Our study covers five solar cycles (19 to 23). The cycle characteristics vary a lot; cycle 19 is the most active cycle ever and the declining phase of cycle 23 is different from other cycles [3]. Like moderate cycle 20 before it, cycle 23 may span a period of 12 years; the southern hemisphere of the sun became active in 2005, it is moving very slowly to a level closer to a minimum in late 2007 (or early 2008). The maximum sunspot activity for the cycles occurred in 1957, 1968, 1979, 1989, and 2000. The gaps in the distribution near sunspot maxima vary from being almost non-conspicuous for cycle 19 to more striking for cycles 20, 21, and 22, while for cycle 23 the frequency of decreases increases dramatically after sunspot maximum in 2000.

recovery of GCR intensity from 11-year modulation always happens after SPFR is complete.

- There is an increase in the frequency of decreases after each epoch M, sometimes quite striking (cycle 23) and sometimes not so conspicuous (cycle 19). The peak before M epoch behaves similarly. For example, there is no peak before the epoch of SPFR for cycle 23 although there is a plateau at a higher frequency. The occasional lack of clarity in the separation of the peaks on either side of SPFR epoch may be due to poor statistics (small sample size) or there may be a physical cause [8]. In any case, our previous suggestion that there may be a hint of an even/odd cycle effect in the relative heights of the peaks is not substantiated by this study. Below we attempt to understand if there is a physical basis for the position of the kinks in the distribution.

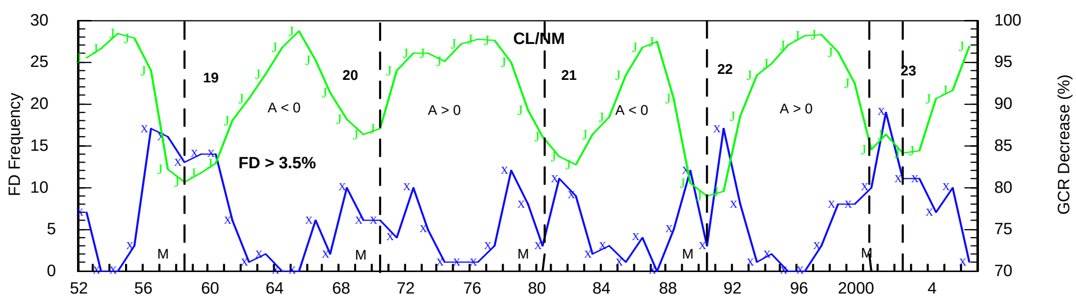

Figure 2

Figure 2 depicts the percent decrease in CL/NM annual mean hourly rate for five solar cycles (19 to 23); the rate is normalized to 100% in May 1965; the errors are comparable to the dot size. Also shown are the annual frequency of decreases with an amplitude ≥ 3.5% in a 24-hour interval for five cycles as well as the position of sunspot activity maximum (M). The vertical dashed lines are drawn through the epochs of the solar polar field reversal (SPFR); the reversal for cycle 23 took place over an extended time interval, from 2000 to 2002 [4]. The graph covers 5 epochs of SPFR and two epochs each of positive (A > 0) and negative (A < 0) cycles; galactic cosmic ray (GCR) intensity undergoes a modulation over a 22-year period, called the Hale cycle [5]. One notes the following features.

- Although the inverse correlation between GCR intensity and sunspot activity is seen clearly [6], the position of the minimum intensity does not always lie at the position of sunspot maximum (M). This is very conspicuous for cycle 21 where the minimum occurs 3 years after the sunspot maximum in 1979 [7]. The

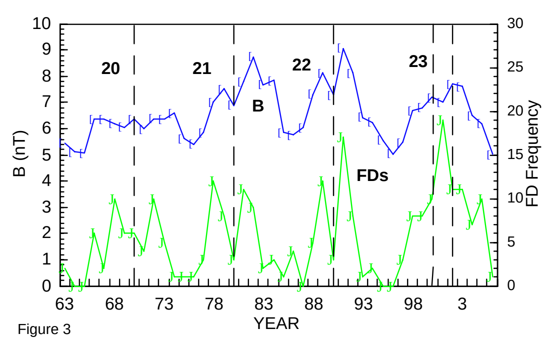

Figure 3

Figure 3 shows a plot of the annual mean value of the interplanetary magnetic field (IMF) intensity (B) for 1963-2006; in situ measurements of the solar wind in space started in late 1963. The error for each B point is 0.1 nT (negligible). Also plotted are the FD frequencies for the corresponding year. The vertical lines are drawn through SPFR epochs. They define a local minimum for FD frequency for cycles 20, 21, and 22. However, for cycle 23 the FD frequency is notably larger within the confines of SPFR epoch. In fact, the year 2001 recorded the largest number of decreases in this study. This is a surprising result not anticipated from our previous study; we have no explanation for this observation at present.

Figure 4 is a plot of the annual mean values of B

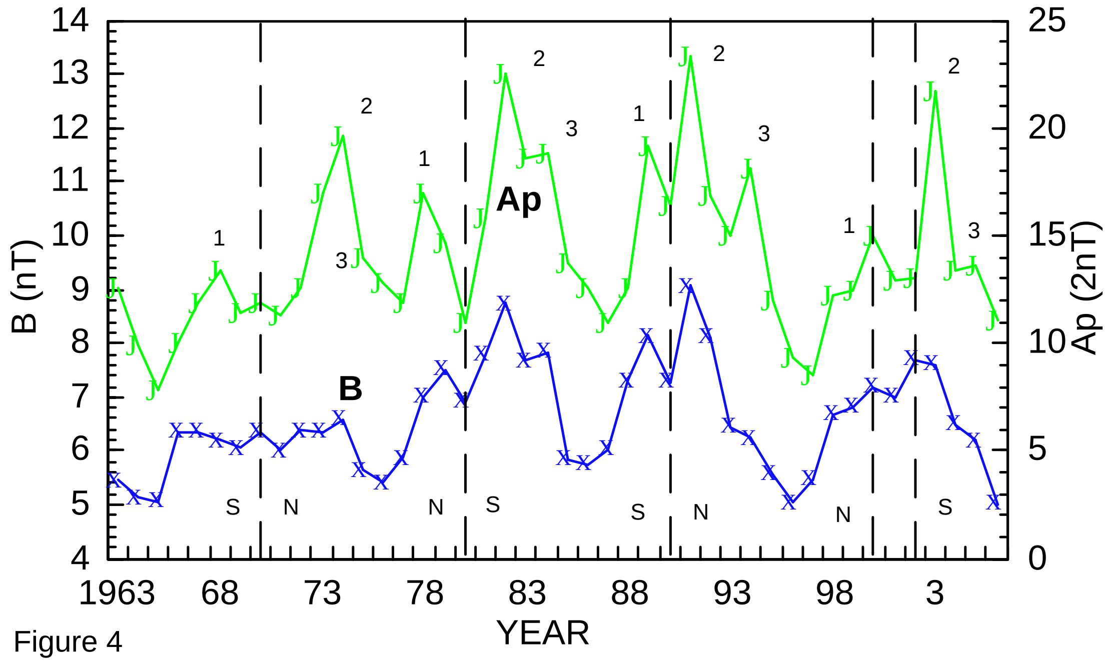

Figure 4

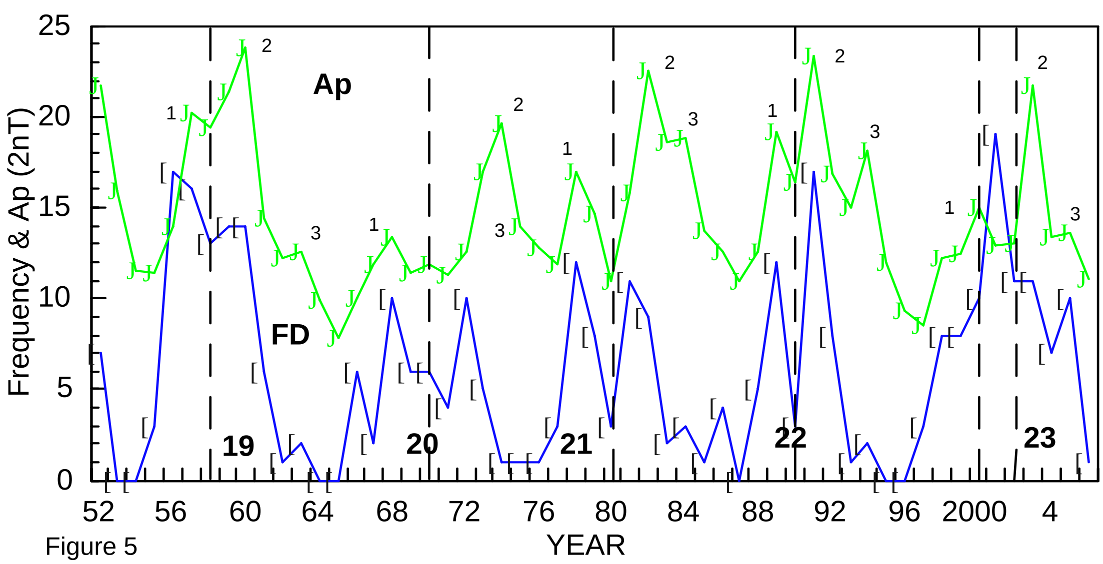

Figure 5

and index Ap, for the common period 1963-2006; the error in each plotted Ap point is less than one half Ap unit which makes the position of each kink significant. The vertical dashed lines are drawn through SPFR epochs; the polarity of the magnetic field in the solar northern hemisphere before and after each reversal is indicated at the bottom. One notes that each SPFR epoch represents the local minimum in B as well as in Ap for the four cycles (20 to 23), consistent with our previous studies [1, 9]. Furthermore, one notes that there are three identifiable peaks in B and Ap plots for each cycle, labeled 1, 2, and 3, the last peak occurs late in the declining phase of the cycle. In the earlier study we established this result for cycles 20, 21, and 22. It is gratifying to see that cycle 23 (nearing its end) also conforms to this notion. So there are three Ap peaks per solar cycle; common belief is that there are only two Ap peaks per cycle [10], peak 1 is due to ICMEs and peak 2 to HSS. It would be very interesting to verify if this result applies to the entire Ap time series since 1932. The cause of Ap peak 3 is not known at present and its physical significance not appreciated yet.

Figure 5 shows a plot of the annual mean values of Ap and the annual frequencies of cosmic ray decreases for 1952-2006, covering five solar cycles (19 to 23); note Ap for cycle 19 has three peaks too as one would expect from previous discussion. Note also that peak 3 is associated with the minimal number of FDs for four cycles (19 to 22) but for cycle 23 the number is larger. It looks like cycle 23 has a distinct identity of its own unlike others in this study. Normally, Ap peak 2 corresponds to the onset of HSS in a cycle and occurs well after the second FD peak. But for cycle 22 it corresponds to the position of second FD peak, perhaps because the value of B is also large then (see Fig. 4).

Acknowledgements

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