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Gnevyshev Peaks in the CME Average Speeds in Cycle 23

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Abstract Sunspots have a major 11-year cycle, but the three to four years near the maximum may show two or more peaks called Gnevyshev peaks. Earlier, it was reported that in Solar Cycle 23, the double peak in sunspot numbers was reflected in the electromagnetic radiations and coronal mass ejection (CME) frequencies in the solar atmosphere, but with phase differences. In this article, it is shown that the average CME speeds also show Gnevyshev peaks but with phase differences.

Keywords Gnevyshev peaks · Coronal mass ejections · Cycle 23

1. Introduction

Among the characteristics of coronal mass ejections (CME's), the speed of the CMEs has long since received attention (Gosling *et al.*, 1976; Howard *et al.*, 1985). Further, the solar cycle variation of CME speed was reported by Hundhausen, Burkepile, and St. Cyr (1994), St. Cyr *et al.* (2000), Yashiro *et al.* (2004), and Gopalswamy *et al.* (2008). Sunspots have a major 11-year cycle; however, the maximum is not smooth but structured. Two or more peaks can be identified during the solar maximum years. This splitting of activity was identified for the first time in the green corona line intensity data by Gnevyshev (1967, 1977) and later in several solar and interplanetary phenomena (see details in the review by Storini *et al.*, 2003). In recent publications (Kane, 2006, 2007, 2008a, 2008b, 2008c), it was pointed out that these Gnevyshev peaks have a solar latitude dependence, with peaks shifting with time from higher to lower latitudes as in the Maunder butterfly diagram. The peaks in sunspots are similar to those in other electromagnetic radiations (2800 MHz flux, X-ray background, *etc.*), but may differ in number and time location for some other parameters, such as CMEs, solar open magnetic flux, and so on. Recently, Mittal *et al.* (2009) reported the distribution of CME speeds in Solar Cycle 23. They found that the speeds were low (below 300 $\mathrm{km\,s^{-1}}$) in the rising phase 1996 – 1997, increased to about 500 $\mathrm{km\,s^{-1}}$ or more during 1999 – 2004,

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had two peaks during 2000 and 2003 with a minimum in 2001, and decreased after 2004. Since they studied only annual values, the minimum in 2001 was only roughly detected and they did not mention anything about Gnevyshev peaks and gaps. We feel that their minimum in 2001 depicts a Gnevyshev gap. In the present article, we examine the CME speed data on finer time scales (monthly values instead of annual values), locate the Gnevyshev peaks and gaps more accurately, and find out if these coincide with the peaks in other solar parameters during Solar Cycle 23. The data are obtained from the National Oceanic and Atmospheric Administration (NOAA) website, Space Physics Interactive Data Resource (SPIDR), and from the NASA website http://cdaw.gsfc.nasa.gov/CME_list/ Large Angle and Spectrometric Coronagraph (LASCO) CME catalogue.

2. Plots of Monthly Values

Figure 1 shows the plots of the monthly values and their running means. Figure 1(a) shows the annual values (Mittal *et al.*, 2009) of the average CME speeds, where the annual value for 2001 is smaller than the annual values for 2000, 2002, and 2003. Figure 1(b) shows the

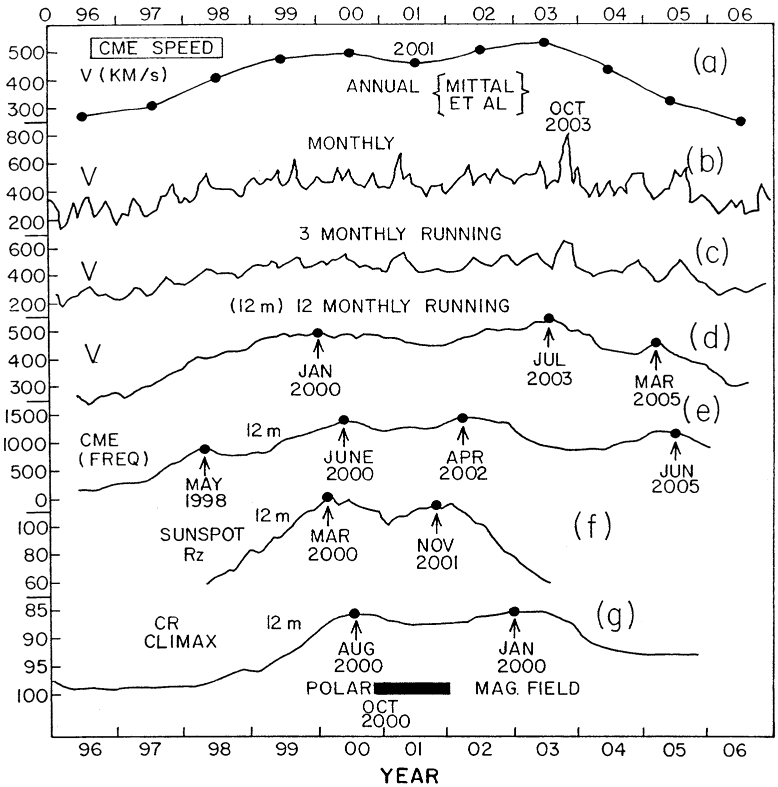

Figure 1 Plots of the monthly values and 3-month and 12-month running means for cycle 23 (1996 – 2006). (a) Annual values for CME average speeds, (b), (c), (d), monthly, 3-month and 12-month running means for CME average speeds. (e), (f), (g), 12-month running means for CME occurrence frequency, sunspot number *Rz*, cosmic ray neutron monitor counts at Climax, Colorado. In (g), the rectangle shows the reversal of solar polar magnetic field in October 2000.

monthly values. Here, the month-to-month values vary considerably (large scatter). At least some of the scatter is due to the fact that in some months strong events occurred with speeds exceeding 1000 km s^{-1}; these increased the average value for that month (notable example, the Halloween events of 29 – 30 October 2003, with speeds exceeding 2000 km s^{-1}). To reduce this scatter, three-month running means were calculated. These are shown in Figure 1(c). The scatter has reduced, but clear-cut peaks and gaps are not yet easily identifiable. As a result, 12-month running means were calculated. These are shown in Figure 1(d). Now, the CME speeds show two clear peaks, one centered at January 2000 and another at July 2003, with a gap in between. Thus, CME speeds show two Gnevyshev peaks clearly. However, there also is a minor peak later on, centered at March 2005, well in the declining phase of solar activity. Ivanov and Obridko (2001) also reported a similar peak in the declining phase of the previous cycle.

Further plots are for 12-month running means of other parameters. Figure 1(e) refers to the CME occurrence frequency. It shows a minor peak centered at May 1998 (still in the rising phase of solar activity), two prominent peaks centered at June 2000 and April 2002, and a minor peak later at June 2005. All these are phase shifted by several months with respect to the CME speed peaks.

Figure 1(f) shows the plot of the 12-month running means of sunspot number *Rz*. Here, there are only two prominent peaks, centered at March 2000 and November 2001. These do not match the peaks in CME speeds or CME occurrence frequencies (they differ by several months). Figure 1(g) shows the 12-month running means of the cosmic-ray neutron-monitor counts at Climax, Colorado (midlatitude). The scale is upside down so that peaks imply cosmic ray intensity depressions. There are two peaks centered at August 2000 and January 2003. Again, these differ from the peaks of other parameters by several months. For cosmic rays, the modulation near sunspot maximum is often claimed to be due to solar polar magnetic field reversals that occur sometime during solar maximum years. In Solar Cycle 23, the reversal at the North Pole started during October 2000 and lasted up until October 2001, while at the South Pole it started a few months later. In Figure 1(g) the black rectangle indicates this interval. As can be seen, the cosmic ray modulation started a few months earlier than the polar magnetic field reversal month and cannot have been caused by the magnetic field reversal (effect cannot precede the cause).

3. Conclusion and Discussion

Sunspot maximum does not occur as a single peak. There are often multiple peaks during the three to four years around sunspot maximum. These peaks are called Gnevyshev peaks. Different solar parameters show two or more peaks, but do not match between them, *i.e.*, not occurring simultaneously in the same months. In the present article, it is shown that, in Solar Cycle 23, CME average speeds also showed Gnevyshev peaks; two peaks centered at January 2000 and July 2003, not matching in phase with the Gnevyshev peaks in sunspot numbers; CME occurrence frequency; and cosmic ray neutron monitor counts at Climax, Colorado, which had a phase mismatch between them.

The Gnevyshev gap (GG) was reported as coinciding with the period of solar polar heliomagnetic reversal, during which somewhat decreased activity is reported to occur for intense and long-lasting solar events. Its association with a similar cosmic ray gap is interpreted as a temporary weakening of the cosmic ray modulation process (Feminella and Storini, 1997; Storini *et al.*, 1997). Using Obridko and Shelting's (1992) findings, clues for a link between outstanding activity phenomena and the strength of the heliomagnetic field energy were reported to be found. On this ground, during the inversion of the polar heliomagnetic field, a decrease (or a gap) in the number of high-energy events occurs (GG). Alania *et al.* (1999) stated that in the course of the Sun's polar magnetic field reversal, a part of the Sun's energy is used up for the magnetic reversal process. This implies that during such periods the interaction between "local magnetic fields" (particularly those connected with the processes involved in the development of large and complex active regions, Bumba and Howard, 1965) and the "background magnetic field" is suppressed. Consequently, large-scale dynamical phenomena of the photosphere cannot reach the solar corona, and hence they are not able to affect the interplanetary medium. The long-term behavior of the average current helicity of active regions shows the GG's (Bao and Zhang, 1998; Storini *et al.*, 1999a, 1999b) in agreement with Bieber and Rust's (1995) computations on the long-term magnetic flux released from the Sun (Feminella and Storini, 1997), as well as the observation of Cane *et al.* (1999) that during GG intervals the solar open magnetic flux attains the minimum value in each cycle (see more details and contradictions in Kane, 2006). Feminella and Storini (1997) demonstrated that during GG periods, intense solar activity is missing or it really is lower. It was also claimed that the solar atmospheric GG interval is more easily identified when parameters of energetic activity phenomena are considered. Moreover, the bimodal behavior of solar activity was stated to occur separately in each solar hemisphere (Feminella and Storini, 1997), which implies that using solar parameters for the Sun as a star, the GG valley can be masked by the different GG time occurrence in each hemisphere. On the other hand, during the past Solar Cycle 22, the GG occurrence was reported to be practically synchronous in both hemispheres and the dual-peak solar activity cycle was shown by several researchers (Feminella and Storini, 1997; Storini, Massetti, and Antalová, 1997; Storini *et al.* 1997, 1999a; Ataç and Özgüç, 1998; Bao and Zhang, 1998; Krainev *et al.*, 1998; Bazilevskaya *et al.*, 2000 among others).

However, all this is only roughly true. In Figure 1(g), the long rectangle corresponds to the starting of solar polar field reversal in Solar Cycle 23, first at the North Pole at the end of 2000 and later at the South Pole by the middle of 2001 (Vernova *et al.*, 2002). As can be seen, the beginning of the magnetic field reversal does not coincide exactly with any Gnevyshev peak or gap as such. In fact, most of the Gnevyshev peaks and the starting of the Gnevyshev gaps occurred several months before the month (about October 2000) of the North Pole heliomagnetic field reversal. Thus, the magnetic field reversal cannot be a cause of the other phenomena (effect occurring before cause). There is obviously some basic mechanism in solar dynamics that is affecting different solar parameters in roughly the same way, but with different phases; therefore, the magnetic field reversal is just one of these parameters, not the basic cause of anything.

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