SH.1.5.11

Present Status of Our Prediction for Solar Cycle 23 Maximum Activity

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Abstract

Our recent review of the data for the observed sunspot numbers (SSN) and the planetary index Ap, for the period January 1932 to February 1998, led to the discovery of a linear correlation between the amplitudes of the last six solar cycles (17 to 22) and the annual mean values of Ap one year into the new cycle. Based on the annual mean value of Ap = 8.5 for 1997, we predicted that cycle 23 will be a moderate cycle (more like cycle 17) notwithstanding the early exuberant predictions of some solar astronomers that cycle 23 "may be one of the greatest cycles in recent times, if not the greatest." The data upto March 1999 is added to our analysis. The continued development of cycle 23 activity is reviewed and it's effect on galactic cosmic ray modulation is discussed. We have traced the major source of three cycle quasiperiodicity discovered by us in Ap data to the off-ecliptic component of the interplanetary magnetic field.

1 Introduction:

Recently, the solar astronomers have come to believe that sun may indeed by sending out a subtle signal as to its level of activity for the new cycle, during the descending phase of the preceding cycle. Several schemes have been proposed in the last three decades to decode this advance warning from the sun. The most successful schemes are those based on the behavior of the geomagnetic indices aa and Ap. Recently, we reviewed SSN and Ap data for the 1932 to 1998 period. We discovered that a linear correlation exists between the amplitudes of the last six SSN cycles (17 to 22) and the annual mean values of Ap one year into the new cycle (Ahluwalia, 1998, 1999a). Based on the annual mean value of Ap = 8.5 for 1997, I predicted that cycle 23 will be a moderate cycle (more like cycle 17) notwithstanding the early exuberant predictions of some solar astronomers (Wilson, 1992) that cycle 23, "may be one of the greatest cycles in recent times, if not the greatest."

A successful prediction technique would be of practical importance to NASA in planning the launch schedules of expensive low altitude spacecrafts, such as the international space station. In fact, any future program of active space exploration may depend very critically upon the availability of a credible capability for forecasting solar activity, both in the short- and the long-term. The short-term forecasts are of extreme importance in defining a quality of life index for the earthlings. For example, the coronal mass ejection (CME) of May 1998 led to an eerie moment for the electronic pager owners (45 million of them in North America) when it shorted out an earth orbiting communications satellite. Also, it caused the first large Forbush decrease (FD) of cycle 23 resulting in the onset of a new galactic cosmic ray (GCR) modulation cycle.

2 Data Analysis:

In Fig. 1 we have plotted the entire Ap data in existence (1932 to 1998) along with the corresponding SSN data. Yearly mean values are plotted for the two indices. The period covers six complete cycles (17 to 22) and parts of the other two (16, 23). One notes the following features.

1. There are two Ap maxima per cycle. The smaller one occurs near SSN maximum and a larger one during the descending phase of the cycle. The separation between the two peaks varies with a cycle; it is appreciable for some (18, 20, 21) and not so for others (17, 19, 22). The first peak is attributed to CME activity and the second peak to the contributions from the high speed solar wind streams (Hundhausen, 1979) which contribute to GCR modulation (Ahluwalia, 1997b) also.

2. Ap minimum for a cycle typically occurs one year after SSN minimum, the 1980 Ap minimum near SSN maximum appears to be anomalous.

3. There is a definite trend in Ap minima over the three succeeding cycles at a time, as indicated by the dashed lines in the lower half of Fig. 1. This serendipitious discovery of three cycle quasiperiodicity was reported by us at the 25th ICRC, Durban, South Africa (Ahluwalia, 1997a). We suggested that the effect may be related to as yet undiscovered property of the source regions of the solar wind (Ahluwalia, 1998).

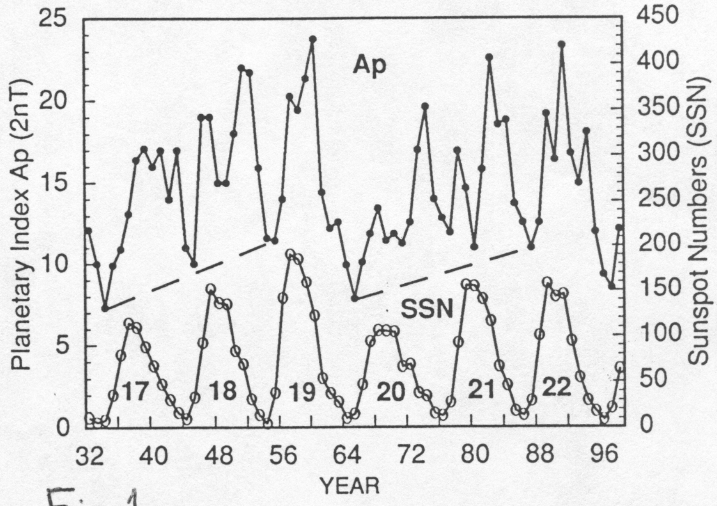

Fig. 1

3 Correlation With IMF:

It occurred to me that if the three cycle quasiperiodicity is an intrinsic property of the solar wind source regions, its signature may also be found imprinted on the interplanetary magnetic field (IMF). In Fig. 2 we have replotted the annual mean values of Ap in the upper half of the figure. In the lower half we have plotted the annual mean values of IMF obtained from OMNIWeb, National Space Science Data Center (NSSDC), Greenbelt, MD. The dataset is a composite of the multispacecraft observations obtained over different time periods, beginning November 27, 1963. King (1976, 1979, 1981) discusses the quality of early data. The coverage is very uneven for some time periods (Ahluwalia and Xue, 1993). Even so, the correspondence between the two data strings is very impressive. The following features may be noted.

1. The anomalous minimum of Ap in 1980 corresponds to a dip in the IMF data when the solar polar field changed its polarity in less than a year. In fact there are dips in both data strings for the three epochs of the solar polar field shown in the diagram. The large scale rearrangement of IMF, following a reversal, has a noticeable effect on Ap data. The two Ap maxima per cycle, noted earlier, might indeed be an artifact of the global rearrangement of IMF. So Hundhausen's inference may have to be revised.

2. The featureless period in the late sixties and early seventies is apparent in both data sets.

3. The steep decline in Ap from its peak value in 1991 corresponds to the steep decline in the magnitude of IMF from its highest value ever recorded in 1991.

4. The signature of the three cycle trend in the IMF minima corresponds to the trend in Ap data noted earlier. Therefore, our hunch that the three cycle quasiperiodicity is an inherent feature of the source regions of the solar wind and IMF may be considered confirmed.

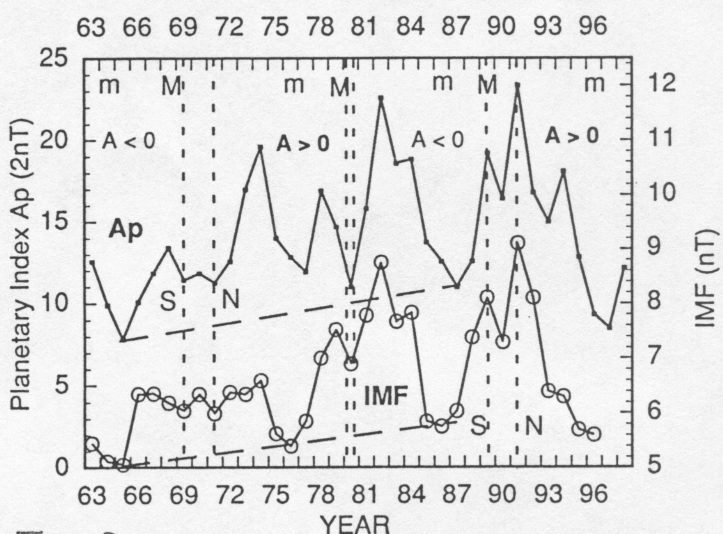

Fig. 2

Fig. 3 depicts the linear correlation analysis between Ap and IMF data for the 1963 to 1996 period. The correlation coefficient (cc) of 0.79 is quite high at the confidence level (cl) > 95%. The fit parameters are given by the regression equation,

$$\text{IMF} = 0.22\ \text{Ap} + 3.5,\ \text{nT}$$

In view of our preceding discussion, the result shown in Fig. 3 is not surprising. It's physical significance is considerably enhanced because of our previous work involving a systematic study of the solar diurnal anisotropy of cosmic rays. I showed that the limiting GCR rigidity (R_c) applicable to the steady state diurnal anisotropy is correlated (cc = 0.68) with the magnitude of IMF, measured in situ at earth's orbit, but not with the bulk velocity (V) of the solar wind (Ahluwalia, 1992 and references therein). It should be pointed out that a correlation also exists between V and Ap data strings (cc = 0.77) at cl > 95% (Ahluwalia et al, 1994). However, no clear three cycle quasiperiodicity is seen in the data string for V. But $|B_z|V^2$ has a very high correlation (cc = 0.9) with the Ap data string (Feynman, 1980; Crooker and Gringauz, 1993), where $|B_z|$ is the off-ecliptic component of IMF. Hapgood et al (1991) have shown that $|B_z|$ varies in concert with IMF for cycles 20 and 21. Our analysis over an extended time period (1963-93) confirms their result (Ahluwalia and Fikani, 1995).

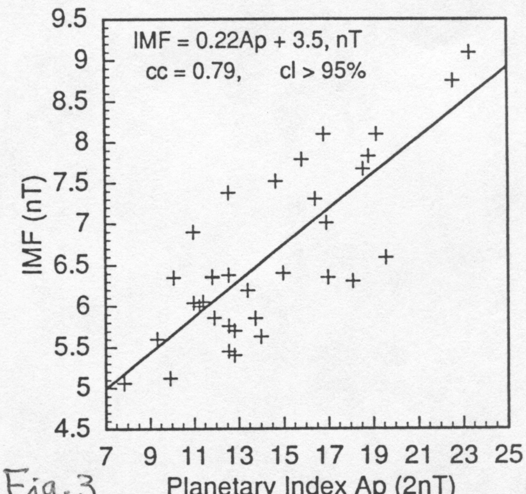

Fig. 3

They also showed that the magnitude of B_z is scaled down by a factor of about 2.5 compared to IMF (see their Fig. 2). They argue that this is a real (time invariant) effect. Therefore, it follows that the source of three cycle quasiperiodicity in Ap is to be attributed to $|B_z|$.

4 Solar Cycle 23 Development Todate:

In Fig. 4 we compare the ascending phases of the last six solar cycles (17 to 22) with the present development of cycle 23. The cycles are followed from their onset month for 30 months using the smoothed SSN to reduce the variance contributed by the transients. Preliminary data are available upto March 1999. It is clear that cycle 23 is a slow riser. It has mimicked cycle 20 since its onset. For the last six months, it has swerved off of the time line for cycle 20 towards that for cycle 17 and is showing a sign of flattening. Our original prediction anticipated this situation (Ahluwalia, 1998). This is gratifying indeed. The reader may note that the time line for cycle 23 is well below that for the three most active cycles (19, 21, 23) ever recorded in the last three centuries.

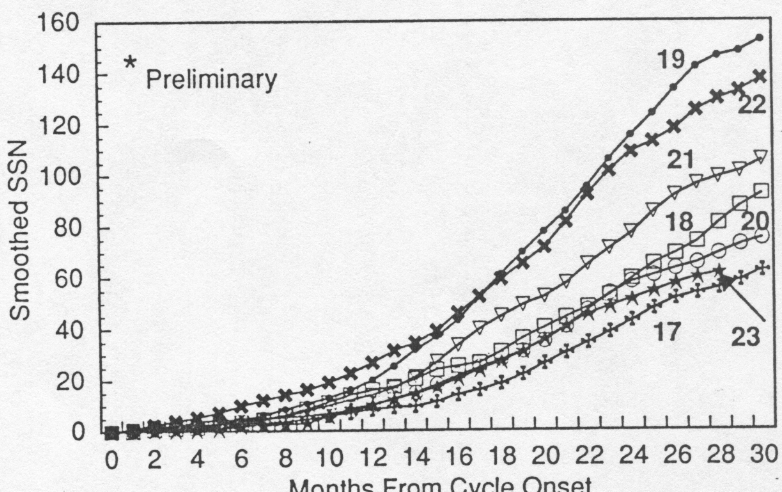

Fig. 4

5 Acknowledgments.

I am grateful to Helen Coffey, NGDC/NOAA, for the solar and geophysical data. Support from Research Allocation Committee of the University of New Mexico is appreciated.

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