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The forecast for solar cycle 23 activity: A progress report

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Abstract. At the 25th International Cosmic Ray Conference (ICRC) at Durban, South Africa, I announced the discovery of a three cycle quasi-periodicity in the ion chamber data string assembled by me, for the 1937 to 1994 period (Conf. Pap., v. 2, p. 109, 1997). It corresponded in time with a similar quasi-periodicity observed in the dataset for the planetary index Ap. At the 26th ICRC at Salt Lake City, UT, I reported on our analysis of the Ap data to forecast the amplitude of solar cycle 23 activity (Conf. Pap., v. 2, pl. 260, 1999). I predicted that cycle 23 will be moderate (a la cycle 17), notwithstanding the early exuberant forecasts of some solar astronomers that cycle 23, "may be one of the greatest cycles in recent times, if not the greatest." Sunspot number data up to April 2001 indicate that our forecast appears to be right on the mark. We review the solar, interplanetary and geophysical data and describe the important lessons learned from this experience.

1. Introduction

Ohl (1971) was the first to realize that Sun may be sending us a subliminal message as to its intent for its activity (Sunspot Numbers, SSN) in the next cycle. He posited that the message was embedded in the geomagnetic activity (given by sum Kp). Schatten at al (1978) suggested that Ohl hypothesis could be understood on the basis of the model proposed by Babcock (1961) who suggested that the high latitude solar poloidal fields, near a minimum, emerge as the toroidal fields on opposite sides of the solar equator. This is known as the Solar Dynamo Model. One can speculate that the precursor poloidal solar field is entrained in the high speed solar wind streams (HSSWS) from the coronal holes which are observed at Earth's orbit during the descending phase of the previous cycle. The interaction between HSSWS and Earth's magnetosphere somehow transfers a vital information to the magnetosphere which manifests itself in the changes observed in the geomagnetic indices Kp, Ap, and aa. It is a matter of record that geomagnetic precursors provided the closest prediction for cycle 22 (Brown, 1992). This encouraged many researchers to make predictions for cycle 23 activity based on geomagnetic indices and other parameters but using different methods of analyses. In particular, Schatten and Pesnell (1993) developed a solar dynamo amplitude (SODA) index, related to the buoyant magnetic flux trapped within Sun's convection zone. They claimed that SODA index should be insensitive to the phase of a cycle, thereby making it possible to predict the amplitude (Rmax) of a solar cycle several years in advance. They predicted that cycle 23 will have a large amplitude (Rmax = 170 ±25), confirming a suggestion made by Wilson (1992) that cycle 23 may "potentially be one of the greatest cycles in recent times, if not the greatest." Recently, Schatten et al (1996) realized that their earlier claim about the phase independence of SODA index was much too exuberant (SODA index has been declining steadily since the early nineties) and revised their forecast downwards to Rmax = 138 ±30.

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2. An Alternate View

A review of the solar and geophysical data, conducted by us in the early nineties (Ahluwalia et al 1994; Ahluwalia, 1997, 1998), indicated to us that most of the early forecasts for Rmax (based on Ohl's method) were overly optimistic; in particular we discovered a new solar frequency in Ap data, namely the three cycle quasi-periodicity in Ap annual mean minima which typically occur one year after SSN annual mean minima. We inferred (Ahluwalia, 1998) that "cycle 23 will be more modest (a la cycle 17), with activity well below that for cycle 19." Our inference was questioned by Wilson and Hathaway (1999) who reiterated their earlier predictions to the contrary and stated, "It seems incontrovertible that cycle 23 is destined to be a larger than

average sized cycle, commensurate with the largest cycles of the modern era, (i.e. cycles 18, 19, 21, and 22), and that it is consequently should be a fast rising cycle, peaking probably in late 1999 to early 2000." Notwithstanding the use of non-scientific words in Wilson and Hathaway's reiteration, we defended our earlier forecast (Ahluwalia, 1999) and concluded that, "WH may turn out to be better solar astrologers, but that remains to be seen." Our prediction stands at Rmax = 126 +29/-21 for annual mean SSN and Rmax = 131.5 +33/-20 for smoothed SSN.

3. Sun – Magnetosphere Connection

We were indeed very surprised that planetary index Ap data are a good fount of the solar activity development indicator. After all, Ap is only a range index; not a physical measurement. So it was clear to us that solar wind must be the carrier of the weak solar signal. Therefore, we carried out a detailed analysis of the available solar wind data (1963-98) pertaining to the Sun – Magnetosphere connection and Ap's role in it (Ahluwalia, 2000). We discovered that the three-cycle quasi-periodicity in Ap minima may be ascribed to the corresponding time variations in the baseline of the flux of the open field lines (B) of the solar magnetic field measured in-situ at Earth's orbit; in our view B is a more fundamental parameter than solar wind bulk speed (V). The pertinent information carried by B from the source regions of the solar wind on the Sun is transferred to the magnetosphere via the temporal fluctuations of the interplanetary electric field and shows up in the corresponding time variations of the geomagnetic indices, such as Ap.

4. Cycle 23 Timeline

Figure 1 is a plot of the ascending phases of the last six cycles for 53 months from the onset in terms of the smoothed SSN (to suppress the transients and reduce variance in the data). The value of the smoothed SSN at the start of a cycle is decreased from the value for a given month and the difference is plotted along the y-axis. Thus all solar cycles are normalized at the origin (y = 0, x = 0) in Fig. 1. After about a year from the onset, the developmental curves for the cycles that rise slowly (17, 20) begin to separate from those cycles which rise faster (18, 19, 21, 22); the latter represent more active cycles, with cycle 19 being the most active ever. For cycle 23, preliminary data are available up to April 2001. The following characteristic features may be noted.

1. Cycle 23 is clearly a slow rise cycle, in contrast to the prediction made by Wilson and Hathaway (1999).

2. Cycle 23 mimicked cycle 20 (a long cycle) since its onset in May 1996; the timelines of the two cycles overlap for 21 months after the onset. Afterwards, the timeline for cycle 23 starts to veer off that for cycle 20 towards lower values i.e. closer to the timeline for cycle 17, and settles at a level lower than both cycles 20 and 17 after 33 months. The timeline for cycle 23 reaches out to that for cycle 20 after 40 months and edges closer to that for cycle 17. After 46 months it crosses over the timeline for cycle 17 and settles at higher values above that for cycle 17 and begins to follow the timeline for cycle 17 which reached its maximum 43 months after its onset in September 1933; cycle 23 may have reached a maximum (Rmax = 120.8) in April 2000, 46 months after its onset in May 1996. This preliminary inference is supported by continued recovery of the galactic cosmic ray (GCR) flux from 11 year modulation (Ahluwalia, 2001). Cycle 23 may be ready to enter the history books as a moderate cycle.

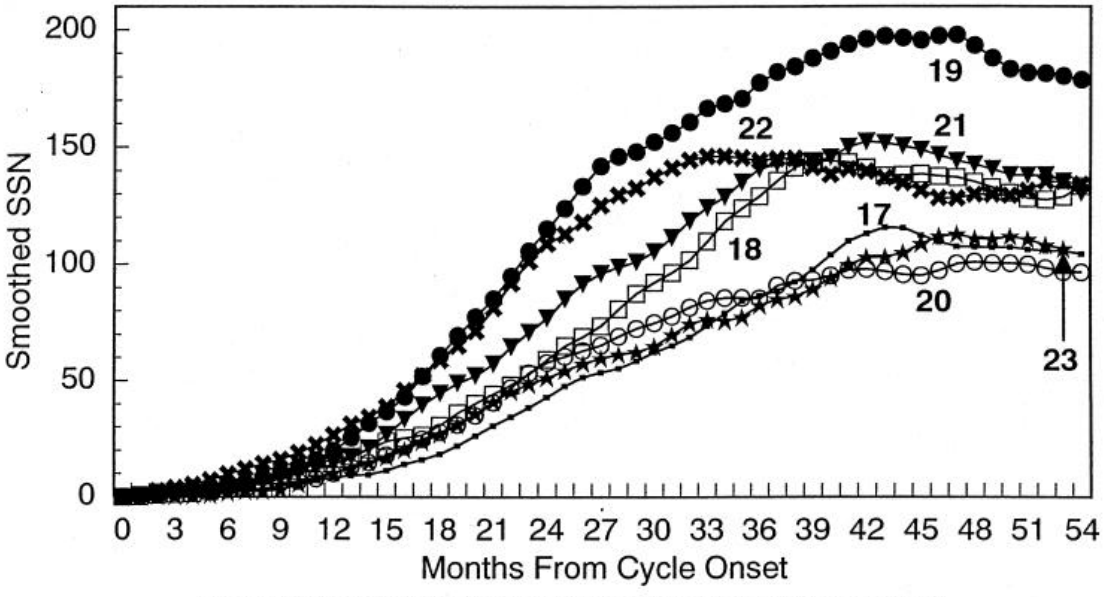

Fig. 1. Ascent of cycle 23 is compared to six prior cycles for 53 months after onset

3. If the present trend continues, cycle 23 will be significantly less active than cycles 21 and 22. It may thereby violate the popular (but little understood) rule that odd cycles are more active than the preceding even cycles (Wilson, 1992). However, Waldmeier Effect (Bracewell, 1988) continues to remain valid i.e. slow rise cycles attain modest values of Rmax. Also, a moderate cycle 23 will continue the tradition, noted by Silverman (1992), that epochs of prolonged solar activity minima occur around the beginnings of each century (1500, 1600, 1700, 1800, 1900).

5. Comments on the SODA Index

The SODA index proposed by Schatten and Posnell (1993) for an early prediction of activity in a new solar cycle has to be abandoned for the following reasons.

1. It does not live up to its advertised virtue of being independent of the phase of a SSN cycle; it has declined steadily since 1993.
2. It relies on 10.7 cm solar radio flux as a proxy of the solar toroidal field buried inside the Sun. This is a questionable proposition in the absence of a credible modeling based on self consistent computations.
3. Solar polar fields estimated in the SODA index may be questionable; they are notoriously very hard to measure. On the other hand, B which is a good indicator of the flux of the open field lines of the solar magnetic dipole moment (M) is very easy to measure in situ at Earth's orbit (Ahluwalia, 2000). At a solar minimum, the measured B may also be a very good indicator of the solar polar field strength at high heliolatitudes (Hoeksema, 1991). We recommend that use of SODA index be discontinued.

6. Discussion

We suggest that it is not necessary to follow Ohl's complex procedure to compute the q index which represents "the relative intensity of recurrent disturbances in the 11 year cycle." We know that HSSWS are responsible for the recurrent disturbances in the declining phase of a solar cycle (Nolte et al, 1976). In practice, some workers have invoked Ohl's recipe to look for a late Ap peak (the one that occurs just before the onset of the new cycle) and correlate its magnitude with the size of the unfolding SSN cycle. This procedure led Wilson and Hathaway (1999) to the conclusion, "that cycle 23 will have Rmax very close to that which was seen for cycles 18, 21, and 22;" the reader is referred to Fig. 1 and Fig. 3 in their paper. In retrospect, this expectation of theirs is unlikely to be met. Brown (1992) noted earlier that "precursor" methods, (similar to the one pursued by Wilson and Hathaway) were biased towards predicting higher values of Rmax for cycle 22. Our method of using annual mean Ap minimum (one year after SSN minimum) as the precursor is straight forward to use. Moreover, it provides a reasonable lead time for planning purposes. Furthermore, we have shown that it has a physical basis through B (measured at Earth's orbit) to the solar magnetic field at high heliolatitudes during the declining phase of a solar cycle, even though the physical process for the observed three cycle quasi-periodicity in the baseline of B still remains unidentified.

The results obtained by us appear to be in qualitative agreement with Babcock's Solar Dynamo Model. Therefore, an effort should be made to make it more quantitative by solving MHD equations in a self consistent manner. One would think that this challenging problem should be tractable, with the availability of super computers and helioseismology data. The need for a Physics-based model is great in light of the fact that a statistical approach (Wilson, 1992) has not been successful to date in providing a reliable activity forecast for the amplitude of a solar cycle.

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