Solar Cycle 23 Activity Forecast: A Look Back

H.S. Ahluwalia
Department of Physics and Astronomy, Univ of New Mexico, Albuquerque, NM 87131, USA

Abstract.

Solar activity has a bearing on the quality of life issues on Earth. In this high-tech era, it is important that its level be forecast in a reliable manner, well ahead of time to minimize the ensuing adverse economic consequences on Earth. We predicted a moderate cycle 23 with a smoothed sunspot number (SSN) at its maximum (in early 2000): 131.5+33/-20. The status of our forecast was reported at the 27th ICRC, Hamburg, Germany (2001). The maximum smoothed SSNs occurred in April 2000, as predicted. We review the solar and geophysical data as of the end of March 2003 and compare cycle 23 with those observed earlier as well as the lessons learned by us from this exercise.

1. INTRODUCTION

At the 25th ICRC, Dublin, South Africa, we announced the discovery of a three-cycle quasi-periodicity in the ion chamber data (1937–94); it corresponds in time with a similar trend in the planetary index Ap data [1]. Next, we reviewed the available data for Ap (1932–1997) and aa (1868–1997); these indices are commonly used as precursors for forecasting the size of a new cycle [2]. A procedure was devised for computing the annual mean SSNs at the maximum (Rmax) for cycle 23; we predicted that it would be a moderate cycle. Our prediction was criticized as being overly on the low side and unlikely to come true [13]. We defended our forecast [3].

At the 27th ICRC, Hamburg, Germany, we presented a progress report on the forecast using smoothed SSN data up to April 2001. We noted that the forecast was right on the mark [5]; the maximum occurred in April 2000 with smoothed Rmax = 120.8, well within our forecast of $131.5 + 33/-20$.

2. Data

The aa index data (1844–2001) are depicted in the upper half of the Figure 1; also shown are the corresponding SSNs from cycle 9 onwards. The aa index was devised by Mayaud [8] to study the long term changes in the "intensity" of magnetic activity on planet Earth by combining data from the two

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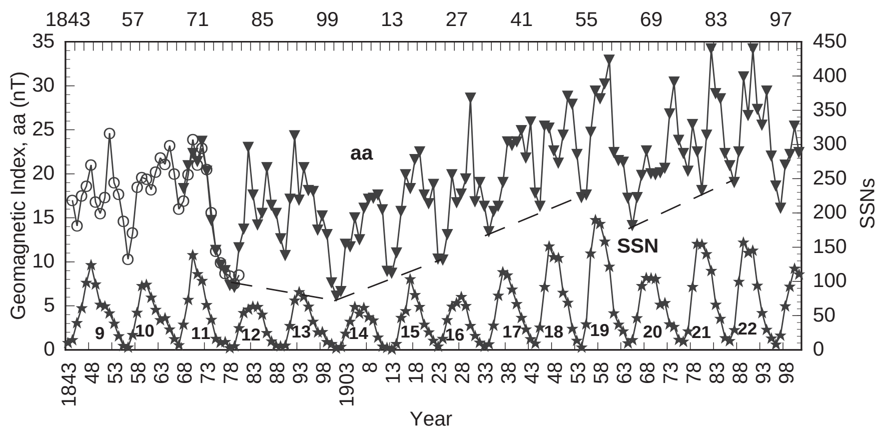

Fig. 1. SSN and aa index data (1844–2001)

antipodal magnetic observatories to cancel the observed daily and seasonal variations in the record, leading to the variations of a planetary character from 1868 onwards. Nevanlinna and Kataja [9] extended Mayaud's series back in time for two additional cycles (1844 onwards) using the magnetic declination observations made at the Helsinki magnetic observatory in Finland. The two data strings overlap nicely for the common period. The following features may be noted.

1. After 1901, the aa index seems to be riding on a line of a positive slope. A question arises whether this rise will continue indefinitely. Feynman [7] ascribed this trend to the rising phase of the long solar cycle with an average period of 87 years (Gleissberg cycle). This interpretation implies that aa indices should have decreased rapidly after 1950s. This did not happen, indicating that longer periods may be present in the time series. For example, Silverman [12] noted that recurring minima near the turn of a new century are typical of the auroral occurrence from 1500 onwards.

2. The three-cycle quasi-periodicity in the annual mean aa index (near solar cycle minima) are highlighted by the dashed lines; no such trend is present in SSN time series. Note that the slope of the dashed line is negative prior to 1901. A question arises whether the quasi-periodicity will continue after the solar minimum circa 2006 and in what direction. Our forecast for cycle 24 will be greatly influenced by what happens then.

3. Since the slope of the line must turn negative eventually, the data suggest the presence of a cyclic variation of greater than 100 years in aa index.

4. Beginning with cycle 10, one observes a pattern where even cycles of the even-odd pairing are less active; it disappeared after cycle 21. The physical cause for this pattern (and its disappearance) is unknown. One wonders whether this pattern will manifest itself again in the future.

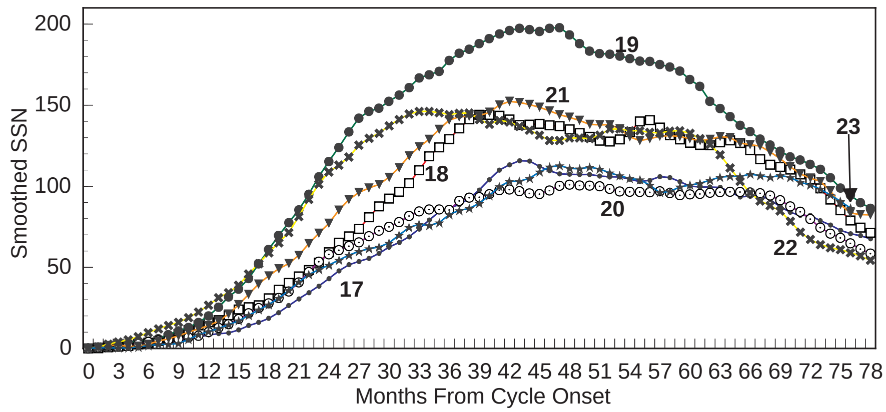

Fig. 2. Timeline of cycle 23 is compared to those of 6 prior cycles for 78 months.

3. CYCLE 23 TIMELINE

In Figure 2, the timeline for cycle 23 is compared to those for 6 prior cycles (17 to 22) for 66 months after onset; cycles are normalized at the origin by subtracting SSN at onset from those for the subsequent months. The following features may be noted.

1. The timelines may be classified into 2 groups; cycles 18, 19, 21, 22 exhibit above average activity (19 was the most active cycle ever observed in nearly 400 years of SSN observing period), while cycles 17 and 20 exhibit moderate activity. A clear separation occurs between the two groups 30 months after their onsets; cycle 17 starts out less active than 20 but its timeline settles at a higher level after 39 months. On the other hand, cycle 22 starts out more active than 19 but became less so after only 18 months.

2. cycle 23 starts out mimicking cycle 20 for 21 months, drifting closer to cycle 17 timeline settling below it after 33 months, rising above cycle 20 timeline after 42 months and that for cycle 17 after 45 months and lingering at the higher level afterwards, reaching a broad maximum 47 months (April 2000) after onset. It is came off its second maximum as of the end of May 2002; all solar and geophysical phenomena exhibit two maxima, known as the Gnevyshev gap [4].

3. The only suspense left for cycle 23 is whether it would again mimic cycle 20 in its declining phase and end up being a long cycle, with a length of 12 years or be a short cycle (∼ 10 years) like others in recent times.

4. HISTORIC RECORD

Figure 3 is a 300-year record (1700–2000) of the annual mean SSNs. The following points may be noted.

1. There is a tendency for the solar cycles to be less active at the start of a new century. About six cycles in each century are moderate (Rmax ∼ 100 or

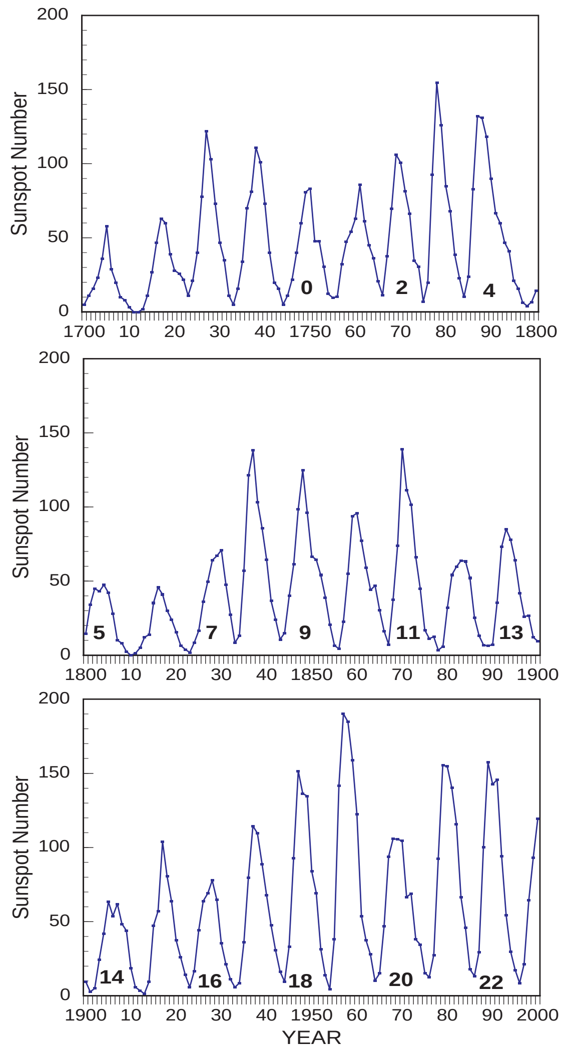

Fig. 3. Annual mean SSNs (1700–2000)

less). Four most active cycles (18, 19, 21, 22) all occurred towards the later half of the 20th century. One wonders whether this fact has a bearing on the cycles to come in the 21st century. No clear answer is available yet.

2. For the 18th and 19th centuries the average cycle length is about 11 years, since there are nine cycles per century present. However, for the 20th century more than nine cycles are present, including the rising phase of the cycle 23. This may be indicative of the presence of a cyclic variation of greater than 100 years in SSN data.

3. As noted earlier, one observes a pattern where an even cycle of the even-odd pairing is less active, beginning with cycle 10 and ending with cycle 21. It is not clear how this is linked to the workings of the solar dynamo.

5. DISCUSSION

Ohl [10] was the first to realize that sun advertises in advance what to expect by way of its activity (SSNs) in a new cycle. He posited that Sun's message is conveyed to Earth via geomagnetic indices; he used sum Kp data. However, he could not explain how this incretion of Sun's message actually occurs. We suspected that solar wind must be the carrier of the weak solar signal. So, we carried out a detailed analysis of the available solar wind data (1963–1998) to understand the Sun-magnetosphere relationships and Ap's role in it [4]. We discovered that the three-cycle quasi-periodicity in the annual mean Ap minima in a solar cycle may be ascribed to the corresponding time variations of the flux of the open field lines of the solar magnetic field carried by the high speed solar wind streams (HSSWS) from the coronal holes (measured in situ at Earth's orbit), late in the declining phase of a cycle. We suggested that the pertinent information from the Sun is transferred to the magnetosphere via temporal fluctuations of the induced interplanetary electric field, leading to the appropriate temporal variations of the planetary indices. These results appear to be in qualitative agreement with Babcock's Solar Dynamo model [6] which outlines a scheme whereby high latitude solar poloidal fields near solar minimum appear as toroidal fields on the opposite sides of the solar equator in the new cycle. We speculate that the precursor solar poloidal fields are entrained in HSSWS and brought to Earth's orbit. It is not clear whether the three-cycle quasi-periodicity is generated on the surface of the Sun at high latitudes where Babcock's dynamo operates or whether it has to do with an intrinsic property of the circulation pattern in the convection zone under the solar surface.

6. SUMMARY

Our simplified operational procedure for forecasting the rise time and the amplitude for a new cycle appears to have been vindicated for cycle 23. For the first time, in 400 years of observations of SSNs, a forecast was made, it was defended against peer criticism and has turned out to be right. The only mystery left is whether cycle 23 will follow the timeline for cycle 20 in its declining phase and be a long cycle or end up with a duration $\sim$ 10 years like other more recent cycles. It is too early to make a forecast for cycle 24 in view of the uncertainties discussed in this paper. We have to wait for about 3 years more for cycle 23 to have run its course.

7. REFERENCES

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