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Sunspot cycle 23 descent to an unusual minimum and forecasts for cycle 24 activity

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Abstract

The decay phase of the sunspot cycle 23 exhibited two unusual features. First, it lasted too long. Second, the interplanetary magnetic field intensity at earth orbit reached the lowest value since in situ measurements in space began in October 1963. These physical anomalies significantly altered the early forecasts for the sunspot activity parameters for cycle 24, made by several colleagues. We note that there was a significant change in the solar behavior during cycle 22. We discuss the observed trends and their effect on our empirical solar activity forecast technique, leading to our prediction for cycle 24 parameters; cycle 24 will be only half as active as cycle 23, reaching its peak in May 2013. We speculate on the possible implications of this outcome on future earth climate change and the ensuing socio-economic consequences.

Keywords: Sun; Solar activity; Cycle 24; Predictions; Helioseismology

1. Introduction

Sunspot cycle 23 started in May 1996 and produced no sunspots in August 2009. The duration of 159 months (151 months if smoothed sunspot numbers are used) makes cycle 23 the longest cycle in the Wolf series. An earlier cycle 4 (1784–1798) had a length of 164 months with a prolonged descent of 123 months, leading into the Dalton minimum. McKinnon (1987) states that sunspot number (SSN) data before 1848 are questionable. Usoskin et al. (2009) argue that SSN count is poor in the late eighteenth century, it may have lost count of a short cycle in 1790s, i.e. cycle 4 may consist of two short cycles lumped together; Petrovay (2010) considers this conjecture still an open issue, also see (Sonett, 1983).

A new tool to investigate solar cycle processes inside the sun is called helioseismology. It has made a rapid progress since the launch (in 1996) of the SOlar and Heliospheric Observatory (SOHO), with the Michelson Doppler Imager (MDI) package on board. For an excellent review of the history and present status of the helioseismology the reader is referred to Howe (2009). A theoretical explanation is not available yet for the so-called torsional oscillations, even so it has been well established that thin bands of faster and slower rotation than the overall solar rotation, exist throughout the convection zone. The bands of faster rotation migrate from mid-latitude regions toward the equator during the course of a solar cycle, resembling the path that sunspots travel to produce the butterfly diagram. This is thought to be a signature of an internal dynamo process.

Helioseismic measurements made during the recent unusual solar minimum (Howe et al. 2009) show that the faster band (at about 7000 km beneath the photosphere) has begun its migration toward the equator at a much slower rate than at a similar stage in the previous minimum. When sunspots first appear in a new cycle, they typically are located between 20°–25° latitude in both hemispheres. Thus, since the sunspots follow the torsional oscillation pattern that migrates from about 45°, this critical latitude

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was not reached until about 13 years after the previous minimum because of the flatter slope, signaling a delay in the onset of cycle 24. Some believe this will also cause a weaker maximum as well. However, Dikpati et al. (2010) have studied statistically the correlation between the length of a cycle minimum and the following and preceding cycle peaks. They conclude that the length of the previous minimum is a poor predictor of the amplitude of the next sunspot cycle.

The frequency of interplanetary remnants of coronal mass ejections (ICMEs) is tied to the level of the solar activity (Ahluwalia, 1992 and references therein; Webb and Howard, 1994; Gopalswamy et al., 2003). In turn, they determine the space weather, affecting the quality of life on earth (Ahluwalia and Ygbuhay, 2010, and references therein). If solar astronomers can start to predict the arrival of ICMEs at earth orbit, steps may be taken in advance to prevent damage on earth assets; satellites could be reoriented, instruments that are sensitive to the effects of the magnetic storms could be turned off, air travel could be diverted or delayed, etc. The solar activity may also have implications for the future climate on earth. Therefore, it is most desirable to acquire the knowledge and skills to be able to forecast the solar activity at any time in the future, a very challenging task indeed.

2. Some forecasting methodologies

Several statistical techniques have been employed over time to forecast the parameters of a SSN cycle; for details the reader is referred to Hathaway and Wilson (2006), Kane (2008), de Jager and Duhau (2009) and references therein. A distinct class of forecasting techniques (based on the use of the geomagnetic precursors) was inspired by the work of Ohl (1966, 1976). The predictions made by the practitioners of this technique have been remarkably accurate for the last two solar cycles (Brown, 1992; Kane, 2001). Schatten et al. (1978) provided a physical basis for Ohl's analysis by linking it to an unquantified Babcock solar dynamo (1961). New ideas have been put forward to understand the operations of the solar dynamo (Dikpati et al., 2006; Choudhuri et al., 2007; Schatten, 2007). But, the physical foundations for making the solar activity forecasts theoretically remain shaky (Hathaway, 2009). Pesnell (2008) and Petrovay (2010) list several early forecasts made for cycle 24; none of them anticipated the long descent to minimum for cycle 23.

Ahluwalia (1998) discovered a three-cycle quasi-periodicity (TCQP) in the planetary index Ap, devised by Bartels (1962) to measure the geo-effectiveness of the solar corpuscular radiation (now the solar wind). He showed that the minimum in the annual mean value of Ap (observed typically one year after the SSN minimum) predicts the peak SSN for the next solar cycle. Ahluwalia predicted that the activity in the sunspot cycle 23 shall be moderate (a la cycle 20) as opposed to the (Wilson, 1992) view that cycle 23 will be more active than cycle 22. The former view prevailed (Ahluwalia, 2003), cycle 23 not only turned out to be less active like cycle 20 before it but a long cycle as well (it has a length of 140 months). According to Petrovay (2010), "Even though the evidence presented for the alleged triadic pattern (*by Ahluwalia*) is not overwhelming, this method resulted in one of the few successful predictions for the amplitude of cycle 23".

At the time of the COSPAR meeting at Montreal, Canada (2008), cycle 23 SSNs seemed close to the minimum value. Ahluwalia and Ygbuhay (2009) decided to hazard a preliminary forecast for the peak of solar activity in cycle 24, knowing full well that the method is strictly applicable to the data obtained one year after Ap minimum is reached. With these reservations, they concluded that cycle 24 may be about 20% less active than cycle 23. Their report ruled out the forecasts at the higher end (Hathaway and Wilson, 2006; Dikpati et al., 2006).

In contrast, at the time of the 12th International Solar Wind Conference at St. Malo, France (2009), the monthly mean SSN for August 2009 reached zero and the smoothed SSN (used in our analysis) attained a minimum value of 1.7 in December 2008. Ahluwalia and Ygbuhay (2010) made another attempt to forecast sunspot cycle 24 parameters, fully aware that this time they were very close to SSN minimum for cycle 23. For this attempt, they decided to use SSN data from cycle 14 onward, to improve the statistics and cover the whole of the 20th century. Since Ap data are not available before 1932, they decided to compute the annual mean Ap values from the corresponding aa indices for three cycles (14, 15, and 16); both have a linear scale and are highly correlated ($cc = 0.94$, at $cl > 99\%$). Ahluwalia and Ygbuhay concluded that the smoothed SNN at cycle 24 peak would be 78 in June 2013 ± 6 mos.

3. Data analysis

We use the time series of the monthly mean data for SSNs, the smoothed SSNs and the planetary indices Ap/aa. The data are readily available at the National Geophysical Data Center website (SPIDER) of the National Oceanic & Atmosphere Agency (NOAA) at Boulder, CO, as well as the Solar Influences Data Analysis Center (SIDC) website at the Royal Observatory of Belgium, Brussels (http://sidc.oma.be/Data/monthssn.data).

Fig. 1 shows a plot of the annual mean values of the aa index and SSNs for 15 solar cycles (1843–2009); the aa data for 1844–1868 are from (Nevanlinna and Katja, 1993), they may not be as reliable as the data after 1868 derived by (Mayaud, 1972). Here we use only the aa data from 1901 (cycle 14) onwards, covering the 20th century. In addition to the 11-year (Schwabe) cycle in the two time series, the following features are also noted.

- Beginning with cycle 10, Gnevyshev and Ohl (1948) noted that there is a pattern such that even cycles of the even–odd pairing are less active; the pattern disappears after cycle 21. Also, every third sunspot cycle is