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An empirical approach to predicting the key parameters for a sunspot number cycle

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Abstract

The common methodologies used to predict the smooth sunspot number (SSN) at peak (Rmax) and the rise time (Tr) for a cycle are noted. The estimates based on geomagnetic precursors give the best prediction of Rmax for five SSN cycles (20–24). In particular, an empirical technique invoking three-cycle quasi-periodicity (TCQP) in Ap index has made accurate predictions of Rmax and Tr for two consecutive SSN cycles (23 and 24). The dynamo theories are unable to account for TCQP. If it endures in the 21st century the Sun shall enter a Dalton-like grand minimum. It was a period of global cooling. The current status of the ascending phase of cycle 24 is described and the delayed reversal of the solar polar field reversal in the southern hemisphere in September 2013 is noted.

Keywords: Sunspot number, Solar cycle 24

1. Introduction

In early 1600s, Galileo discovered sunspots with a newly invented telescope. In 1800s, Wolf devised a formula for computing the relative sunspot numbers (SSNs), forming a time series used extensively for contemporary heliophysics investigations. The sunspots form and dissolve on the solar disc (photosphere), leading to a (Schwabe) cycle with an average period of 11.2 y; actual periods have ranged from 7 to 14 y (Kane, 2008). They are sites of intense magnetic fields, brought to the surface from the solar interior (Wang et al., 2005). The SSN data since 1700 are available from the Solar Influences Data Analysis Center (SDIC) in Belgium. Currently, efforts are underway to assess the long-term stability of the absolute scale of SSN time series, leading to ~10 to 20% adjustments (Lefevre and Clette, 2013). The results of this study may be altered as a result (see Fig. 1).

Sunspot activity impacts the quality of life issues for humans in several detrimental ways. It controls the space weather mainly through coronal mass ejections (CMEs) creating the radiation hazard for human activities in space, impeding operation of geosynchronous and low Earth-orbiting satellites for varied communication needs and automatic high frequency stock market trading, affecting the safety of expensive transformers at high latitude sites, etc. The gigantic CME observed by Carrington in 1859 (Carrington, 1860) could easily cause a global blackout if it were to happen today. An unprecedented CME did occur in July 2012 (detected by the STEREO satellites). Fortunately, it was directed away from Earth; the March 1989 CME led to a geomagnetic storm that caused the collapse of the Hydro-Quebec power grid in Canada and left millions of people without electricity for up to 9 h. The CME frequency closely follows SSN cycles (Ahluwalia, 1992; Webb and Howard, 1994; Gopalswamy et al., 2003). The steady increase in CMEs reminds us that we are near the peak of cycle 24 as of late summer 2013. With the launch of the twin STEREO spacecraft (Kaiser et al., 2008) on 25 October 2006, an analysis of the concurrent images from it and SOHO allows for an accurate determination of CME parameters.

The heliophysics community and the society at large have a strong interest in acquiring a capability to predict

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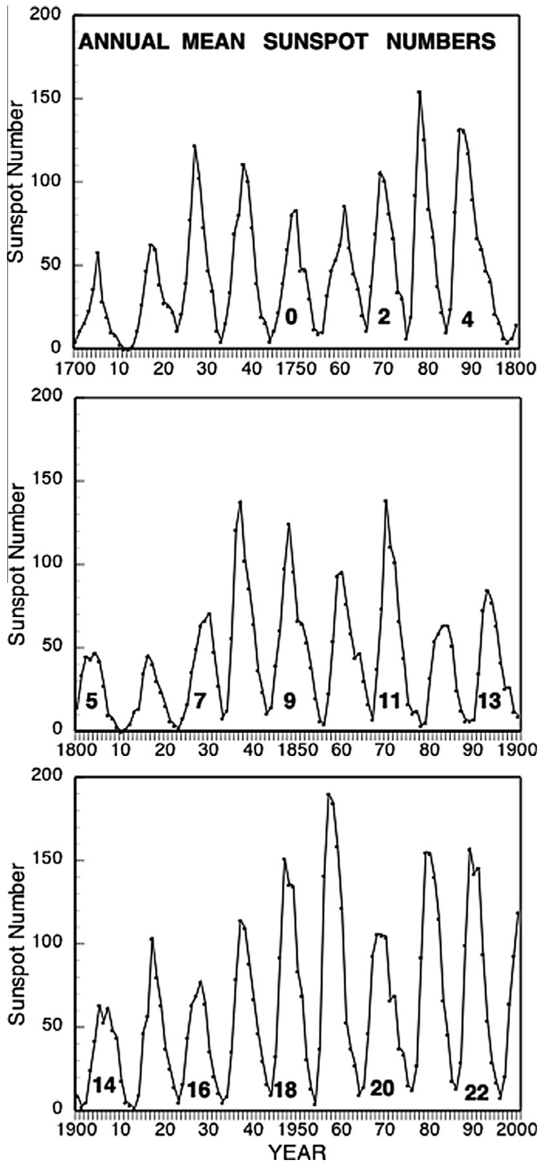

Fig. 1. Annual mean SSNs are plotted for 1700–2000 (27 cycles and the rising phase of cycle 23); low value of SSNs at the start of a century (1700, 1800, etc.) indicates ~100 y period in the time series.

the key parameters (Rmax, Tr) for a SSN cycle. Also, there is a fervent hope that this exercise may help us understand the workings of the solar dynamo. Pesnell (2012) presents a summary of the techniques used for forecasting Rmax for a cycle and an analysis of 75 predictions of Rmax for cycle 24; the values lie between 0 and 185, a dismal record indeed. Even so, there is a general impression that predictions based on the geomagnetic precursors (Ohl 1966, 1976) have yielded the best prediction of Rmax for five SSN cycles (20–24).

Ahluwalia (1998, 1999, 2000, 2003) discovered the three-cycle quasi-periodicity (TCQP) in the planetary indices Ap/aa and developed an empirical methodology to predict key parameters for a SSN cycle, leading to the best prediction for cycle 23 (Kane, 2008; Petrovay, 2010). Ahluwalia and Jackiewicz (2012) – AJ12 hereafter – used the same method to obtain Rmax = 56.4 ± 4.4, Tr = May 2013 ± 6 months for cycle 24, implying that flux transport models (Dikpati et al., 2006) do not yet have a predictive capability.

2. Periodicities in SSNs

The known periods in SSN time series are 11 y (Schwabe cycle), 22 y (Hale cycle), 33 y (Silverman, 1992; Ahluwalia, 1998), 55 y (Yoshimura, 1979; Silverman, 1992; Du, 2006), 77 y (Schove, 1955), 88 y (Gleissburg cycle), 100 y (Kane, 2002; Ahluwalia, 2003), 200 y (de Vries/Suess cycle). The 11 y, 22 y, 33 y, and 88 y cycles also exist in aa index, interplanetary magnetic field (IMF) intensity (B) at Earth's orbit and galactic cosmic rays (GCRs) (McCracken, 2007; Ahluwalia, 2012). The 77 y cycle corresponds to a radial eigen mode in solar oscillations (Gilliland, 1981) but the 55 y period has not yet been detected in other data. Sonett (1982) argues that observed SSN periods can be reproduced by a model involving 22 y period, amplitude modulated by the Gleissberg cycle. In addition, the radionuclide data indicate the presence of a solar period ~2000 y (Sonett, 1984; McCracken et al., 2013).

Fig. 2 shows an updated plot of the annual mean SSNs for 1700–2012, every fourth cycle is labeled bold. One notes that beginning with cycle 10, there is a pattern where even cycles of the even–odd pairing are less active; it disappears after cycle 21. Also, every third cycle is less active (cycles: 14, 17, 20, and 23). We have no understanding of the *physical processes* leading to these solar features. The thick black line is 11 y mean, showing that Sun is a variable magnetic star, with phases of enhanced activity followed by periods of low activity. The grand minima are labeled bold, namely the 70 y Maunder minimum (1645–1715, MM), the 40 y Dalton minimum (1790–1830, DM), and the 13 y Gleissburg minimum (1889–1902, GM). The Sun has emerged from a grand maximum for SSN cycles; it includes cycle 19, the most active cycle ever observed in 400 y. The grand minima are associated with cooler Earth temperatures (Eddy, 1976, 1981). The trend line indicates that we have entered a period of low solar activity; AJ12 suggest that we are at the advent of a Dalton-like minimum. The Earth was cooler then, made worse by Mt Tambora volcanic eruption on 5 April 1815 (http://en.wikipedia.org/wiki/MountTambora). The minimum phase for cycle 23 has an unprecedented long duration of 159 months (151 months if smooth SSNs are used); four prior minima occurred in 1966, 1976, 1986, and 1996.

One may think that SSN periodicities may be used to predict the key parameters (Rmax, Tr) for a new cycle. This has not come to pass (Cole, 1973; Cohen and Lintz, 1974; Kane, 2008), only TCQP methodology has been successful in predicting key parameters for two consecutive cycles (23, 24); AJ12 opine that if TCQP endures in the 21st century, cycles 25 and 26 will be successively less active than cycle 24 i.e. we are on the brink of a Dalton-like grand minimum in mid-21st century. It was a period of global cool-