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Revisiting the prediction of solar activity based on the relationship between the solar maximum amplitude and max–max cycle length

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Abstract

It is very important to forecast the future solar activity due to its effect on our planet and near space. Here, we employ the new version of the sunspot number index (version 2) to analyse the relationship between the solar maximum amplitude and max–max cycle length proposed by Du (2006). We show that the correlation between the parameters used by Du (2006) for the prediction of the sunspot number (amplitude of the cycle, R_m, and max-max cycle length for two solar cycles before, $P_{max\text{-}2}$) disappears when we use solar cycles prior to solar cycle 9. We conclude that the correlation between these parameters depends on the time interval selected. Thus, the proposal of Du (2006) should definitively not be considered for prediction purposes.

Keywords: Sun; Solar cycle; Solar activity prediction

1. Introduction

The prediction of future solar activity levels is an important challenge owing to the impact they can have on Earth and our surrounding space. During the planning of Earth-orbit satellite missions, the solar activity indices are a tool employed to evaluate the future behaviour of solar activity (Mugellesi and Kerridge, 1991). Along with other parameters, these indices are used as input in an atmospheric model to predict the orbital decay. The greatest uncertainty for this model is found in the errors associated with the predicted values of the solar activity. We would emphasise that solar and geomagnetic activity can cause major problems in daily life due to our dependence on technological systems. Some effects of this phenomenon are saturation of transformers, disturbances in communication systems, corrosion in pipelines, etc. (Lanzerotti, 2001; Pulkkinen, 2007).

The attempts to predict the level of solar activity can be grouped in several ways (Petrovay, 2010). Pesnell (2012) presented a summary of 75 predictions of the maximum amplitude for the current solar cycle 24, classified into different categories – climatology, dynamo models, spectral, etc. Since the sunspot number series is the longest observational series available (Clette et al., 2014), it is the index most used to predict solar activity. However, several authors (Hathaway et al., 1999; Petrovay, 2010; Pesnell, 2012) have noted that prediction methods based on cycle characteristics from sunspot numbers are less reliable than methods based on geomagnetic precursors or polar fields (Svalgaard et al., 2005).

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Two notable parameters related to the solar cycle used in prediction tasks are the solar maximum amplitude (R_m) and the cycle length (P). Several relationships have been found involving these parameters. Du (2006) proposed a prediction method based on the relationship between R_m and P_{max} (cycle length defined from maximum to maximum) at lag -2 after analysing the correlations of these parameters at different lags for the old version of the sunspot number (version 1) considering data from solar cycle 9 onwards. Carrasco et al. (2012) demonstrated that previous solar cycles can be considered for the analysis because they have good temporal coverage, and showed that the correlation used by Du (2006) between R_m and P_{max} at lag -2 from solar cycle 6 onwards disappears, and therefore the proposal of Du (2006) must not be used for prediction purposes. Moreover, other authors (Hathaway et al., 1994; Solanki et al., 2002) found that the strongest correlation between the solar maximum amplitude and the cycle length defined from minimum to minimum is at lag -1.

There exist other well-known relationships between parameters of the solar cycle used for prediction tasks, for example, amplitude – rise time. This relationship is known as the "Waldmeier Effect" (Waldmeier, 1935), and it states that solar cycles with greater maximum amplitudes have shorter rise times. This effect is significant in the sunspot number series, but several authors have shown that the correlation between these parameters is weaker in the sunspot area series (Kane, 2008; Karak and Choudhuri, 2011; Carrasco et al., 2016).

Since certain problems have been detected in the sunspot number series, mainly in the historical part (Vaquero, 2007), they are being revised (Clette et al., 2014). As a consequence, new versions of the sunspot number have recently been published (Clette et al., 2015; Usoskin et al., 2016; Svalgaard and Schatten, 2016; Lockwood et al., 2016), and a new revised collection of sunspot group numbers is available (Vaquero et al., 2016). The objective of the present work is to revise the works of Du (2006) and Carrasco et al. (2012) using the new version of the sunspot number (http://www.sidc.be/silso/, version 2) to provide a definitive analysis of Du's prediction method. In Section 2, we present the methods employed in this revision (weighted average epochs of maxima, and Gaussian filter), and we analyse the relationship between R_m and P_{max} for all data of the new version of the sunspot number. The analysis and results are shown in Section 3 and, finally, Section 4 is devoted to the conclusions.

2. Methods

In order to analyse the relationship between the solar maximum amplitude and max–max cycle length, previous work used the old versions of the sunspot number index. While Du (2006) employed the international sunspot number (Clette et al., 2014), Carrasco et al. (2012) used both the international sunspot number and the group sunspot number (Hoyt and Schatten, 1998). For the present work, we used the new version of the sunspot number published recently (Clette et al., 2015) and available on the Web (www.sidc.be/silso/datafiles).

We performed the analysis in two ways. On the one hand, we followed the method of Du (2006) to calculate the weighted average epochs of maxima. For this purpose, we employed the 13-month smoothed values corresponding to the new version of the sunspot number. To obtain the epoch of the maximum of a given solar cycle, we selected all values lying within the range R_m–d to R_m, with R_m being the maximum value for the cycle and $d = 0.1{\cdot}(R_m - R_0)$, where R_0 is the minimum value of the cycle. The maxima are defined by:

$$E_m = \frac{1}{\sum_{i=1}^{n}\omega_i}\sum_{i=1}^{n} E_i\omega_i$$

where E_i are the dates and ω_i ($\omega_i = 1/(R_m - R_i)$) the weights of the range selected previously. Here, R_i is the value of the sunspot number for each point of that interval, and, in the case of $R_i = R_m$, ω_i is taken as $3\omega'$, with ω' being the maximum weight for $R_i \neq R_m$ (Du et al., 2006a, 2006b). Finally, the max–max cycle length is calculated by $P_{max}(i) = E_m(i) - E_m(i-1)$, where $E_m(i)$ and $E_m(i-1)$ are the weighted average epochs of the maxima for cycles i and $i-1$, respectively. Table 1 lists the parameters used in the analysis of the relationship between R_m and P_{max} following this method.

On the other hand, we applied a Gaussian filter to the sunspot number index in order to establish the maxima and the cycle lengths for this series. Hathaway (2015) showed that the 13-month running mean does not work well for high-frequency variations. In contrast, the Gaussian filters are preferable because they remove these variations. A suitable Gaussian filter is given by:

$$W(t) = e^{-t^2/2a^2} - e^{-2}(3 - t^2/2a^2)$$

with $-2a + 1 \leqslant t \leqslant +2a - 1$, where t is the time from the centre of the filter and $2a$ is the Full Width at Half Maximum (FWHM) of the filter. The significant variations in solar activity on time scales of one to three years are filtered by a 24-month Gaussian filter. Table 2 shows the parameter used for the analysis applying the Gaussian filter. Note that: (i) it is not possible to calculate the cycle length for solar cycle 1 due to there being no previous data and (ii) for the Gaussian filter, there is not enough data to calculate the parameters corresponding to solar cycle 24.

The analysis of Du (2006) included data from solar cycle 9 to 23, arguing that these cycles are the most reliable for the sunspot number data. However, Carrasco et al. (2012) demonstrated that solar cycles 6, 7, and 8 have good temporal coverage, and therefore should be considered for the analysis. In this present study, we analysed the relationship between the solar maximum amplitude and max–max cycle length given for the two methods presented above from: (i) solar cycle 2, (ii) solar cycle 6, and (iii) solar cycle