Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Reassessing the Predictions of Sunspot Cycle 24

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Abstract. Predictions of sunspot cycle are important due to their space weather effects. Bhatt *et al.* (2009) predicted sunspot cycle 24 (Maximum amplitude: 92.8±19.6; Timing:October 2012±4 months) using relative sunspot number (International Sunspot Number), and average geomagnetic activity index *aa* considering 2008 as the year of sunspot minimum. Owing to the extended solar minimum till 2009, we re-examine our prediction model. Also, the newly calibrated international sunspot number reduces many discrepancies in the old dataset and is available from Solar Influences Data Center (SIDC) website. Considering 2009 as sunspot minimum year and newly calibrated international sunspot number, (i) The annual maximum amplitude of cycle 24 = 118.5±24.4 (observed = 113.3±0.1), (ii) A smoothed monthly mean sunspot number maximum in January 2014±4 months (observed in February 2014). Our prediction method appears to be a reliable indicator for the predictability of cycle 25.

Keywords. (Sun:) sunspots

1. Introduction

Prediction of solar activity is important as solar outbursts sometimes cause extreme space weather conditions. Following Jain (1997), Bhatt *et al.* (2009) employed the precursor technique for the prediction of sunspot cycle 24 using the long term dataset of the International Sunspot Number R_i, as well as average geomagnetic activity index aa from 1868. Owing to the extended solar minimum in 2009 (Owens *et al.* 2011), we re-examine our prediction model. Recent studies have shown that there are many inconsistencies in the old dataset of R_i which has been used as a basis for many predictions till now (Clette & Laure 2016, Pesnell 2016). We re-assess our predictions in the light of this newly calibrated improved version of international sunspot number S_N.

2. Reassessment of Predictions and Discussion

2.1. $(R_{24})^{max}$ Employing R_i. Bhatt *et al.* (2009) employed the precursor technique for the prediction of sunspot cycle 24 (considering 2008 as the sunspot minimum year). They predicted $(R_{24})^{max}$ = 92.8±19.6 using the relation: $(R_{n+1})^{max} = 7.44\ (aa_n{}^*)_{dsc}$ - 44.12. Considering 2009 as sunspot minimum, the revised prediction for $(R_{24})^{max}$ = 71.2±19.6 which is in good agreement with the observed amplitude of 79.

2.2. $(S_N\ (24))^{max}$ Employing S_N. The newly calibrated international sunspot number S_N reduces many discrepancies of the old dataset of R_i. We determine $(aa_n{}^*)_{dsc}$, an average of the geomagnetic aa index for the sunspot minimum year and preceding four years of the n^{th} cycle and compare it with the observed maximum annual mean sunspot number $(S_N(\text{n+1}))^{max}$ of the next, $(\text{n+1})^{th}$ cycle. For cycles 11-23, the variation of $(S_N(\text{n+1}))^{max}$ is plotted as a function of $(aa_n{}^*)_{dsc}$ as shown in Figure 1a. The best fit (exponential) to

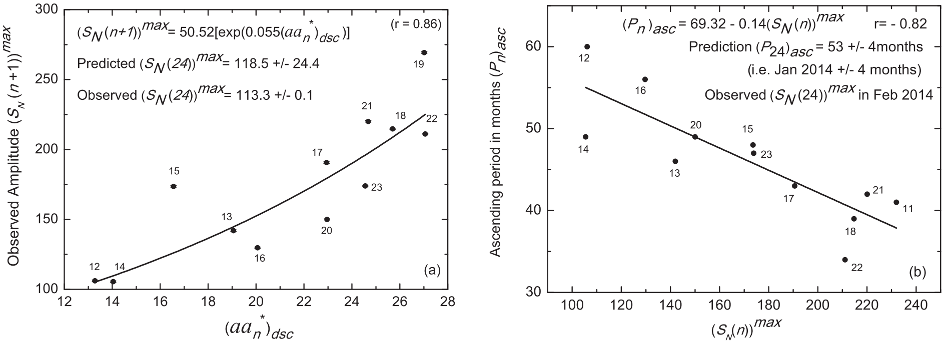

Figure 1. Cycles 11 to 23: (a) Plot of $(S_N\,(\mathrm{n+1}))^{max}$ as a function of $(aa_n{}^*)_{dsc}$ (b) $(P_n)_{asc}$ (in months) is plotted as a function of $(S_N\,(\mathrm{n}))^{max}$ (Cycle 19 omitted)

the data (r= 0.86) is given by: $(S_N\,(\mathrm{n+1}))^{max}$ = 50.52 [exp(0.055$(aa_n{}^*)_{dsc}$)]. Using this equation, and considering 2009 as sunspot minima, predicted $(S_N\,(24))^{max}$ = 118.5±24.4 which is in good agreement with the observed $(S_N\,(24))^{max}$ = 113.3±0.1.

2.3. $(P_{24})_{asc}$ Employing R_i. To predict the ascending period for solar cycle 24 $(P_{24})_{asc}$, Bhatt *et al.* (2009) studied the relationship between $(P_n)_{asc}$ (the elapsed time in months from sunspot minimum amplitude to sunspot maximum amplitude) and $(R_n)^{max}$. They predicted the maximum of cycle 24 in October 2012±4 months [$(P_n)_{asc}$= 66.14 - 0.18 $(R_n)^{max}$]. Considering the revised prediction for $(R_{24})^{max}$ = 71.2±19.6, the revised prediction $(P_{24})_{asc}$ = 53±4 months (i.e. January 2014±4 months) which is in very good agreement with the observed monthly maximum of 102.3 in February 2014.

2.4. $(P_{24})_{asc}$ Employing S_N. The statistical relation between $(S_N\,(\mathrm{n}))^{max}$ and the corresponding $(P_n)_{asc}$ for the cycle 11 to 23 (excluding cycle 19 to improve correlation) is shown in Figure 1b (manifestation of Waldmeier effect). Figure 1b is the best linear fit (r= - 0.82) expressed as $(P_n)_{asc}$ = 69.32 - 0.14 $(S_N\,(\mathrm{n}))^{max}$. Considering the newly predicted $(S_N\,(24))^{max}$ = 118.5±24.4 (cf. section 2.2) gives predicted $(P_n)_{asc}$ = 53±4 months (i.e. January 2014±4 months). The maximum amplitude occurred in February 2014 (monthly mean=146.1±0.6). Our reassessment results strongly suggests that our prediction method appears to be a reliable indicator for the prediction of the following solar cycle. At this point of time, we have not yet reached sunspot minima of cycle 25. Hence, considering the provisional *aa* index from 2014-2017, we make a preliminary prediction of the upper limit for maximum amplitude of cycle 25: $(R_{25})^{max} < 101$; $(S_N\,(25))^{max} < 147$). We acknowledge the NGDC,SIDC and UKSSDC website for sunspot and geomagnetic data.

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