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Attachment(s):
(1) "Article Kane Annales 2010-28-1463-1466-Size comimg solar cycle",
.   536 KB pdf, 4 pages.
(2) "Article Kane IJRSP 2011-40-72-75-Prediction solar cycle 24_1",
.   76 KB pdf, 4 pages.
(3) "Article Kane SP-2013-282-87-90 Prediction cycle 24_2",
.   469 KB pdf, 6 pages.

:   Re:
:   Solar Max 2013
:   Three papers by Prof. Kane,
:   who participated in the
:   2008 UN/Bulgaria Workshop on IHY

Dear ISWI Participant:

Attached are three papers by Prof. Kane -- all related to the upcoming Solar Max of 2013; these papers were kindly provided by the author and can be freely distributed.

If you sent email to me between 01 September 2012 and 13 December 2012 there is a high chance that I have not yet seen it due to a very intense travel schedule. I hope to clear this backlog during the upcoming holidays.

Wishing you a Joyeux Noel,
:   George Maeda
:   The Editor
:   ISWI Newsletter

Ann. Geophys., 28, 1463–1466, 2010
www.ann-geophys.net/28/1463/2010/
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Annales Geophysicae

Size of the coming solar cycle 24 based on Ohl's Precursor Method, final estimate

R. P. Kane

Instituto Nacional de Pesquisas Espacias, INPE C.P. 515, 12201-970 São Jose dos Campos, SP, Brazil

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Abstract. In Ohl's Precursor Method (Ohl, 1966, 1976), the geomagnetic activity during the declining phase of a sunspot cycle is shown to be well correlated with the size (maximum sunspot number *Rz*(max)) of the next cycle. For solar cycle 24, Kane (2007a) used *aa*(min)=15.5 (12-month running mean), which occurred during March–May of 2006 and made a preliminary estimate *Rz*(max)=124±26 (12-month running mean). However, in the next few months, the *aa* index first increased and then decreased to a new low value of 14.8 in July 2007. With this new low value, the prediction was *Rz*(max)=117±26 (12-month running mean). However, even this proved a false signal. Since then, the aa values have decreased considerably and the last 12-monthly value is 8.7, centered at May 2009. For solar cycle 24, using *aa*(min)=8.7, the latest prediction is, *Rz*(max)=58.0±25.0.

1 Introduction

Prediction of the magnitude of the sunspot maximum *Rz*(max) is important for planning satellite launching For cycle 23, NOAA's Space Environment Center (SEC) recruited a scientific panel to assess the likely development of cycle 23 and their report entitled "Solar Cycle 23 Project: Summary and Panel Findings," later published as Joselyn et al. (1997), mentioned (i) a range of 160–200 of *Rz*(max) of cycle 23 as obtained by considering the even/odd behavior and (ii) a range 110–160 of *Rz*(max) by other methods. The panel gave the greatest weight to precursor methods, since they have proved to be the most successful technique for solar activity predictions in the past. The precursor methods invoke a solar dynamo concept, whereby the polar field in the declining phase and at minimum is the seed of future toroidal fields within the Sun that will cause solar activity (e.g., Schatten and Pesnell, 1993). In one of the precursor methods (Ohl's method), geomagnetic *aa* indices at solar minimum are seen to be well correlated with the succeeding *Rz*(max) (Ohl, 1966, 1976; Brown and Williams, 1969; Ohl and Ohl, 1979; Sargent, 1978). Since then, Kane (1978, 1987, 1992, 1997, 1998), Wilson (1988a, b, 1992), and Wilson et al. (1998) have been studying this aspect for the past three decades. For cycle 24, Kane (2007a) evaluated *Rz*(max) as 124±26 using *aa*(min)=15.5 which seemed to be a minimum at that time. However, some workers (notably L. Svalgaard, private communication) were apprehensive that since *aa*(min) usually occurs a few months later than *Rz(*min), and *Rz*(min) had not yet occurred in 2006, the *aa*(min)=15.5 in March 2006 could be a false alarm. A Solar Cycle 24 Prediction Panel composed of international scientists and presided by D. Biesecker, (details given in http://www.sec.noaa.gov/SolarCycle/SC24/index.html), issued on 25 April 2007, a consensus opinion that cycle 24 would commence in March 2008 (±6 months) and two consensus opinions, that the solar maximum would be 140±20 in October 2011 or 90±10 in August 2012. As it happened, the sunspot minimum was nowhere near the range March 2008 (±6 months) mentioned by them, and the old cycle 23 seems to have ended and the new cycle 24 commenced only in the end of 2009. The sunspot numbers seem to have gone through a minimum of zero in August 2009. In this note, the situation of *Rz*(max) vis-a-vis *aa*(min) is reexamined to see whether a final estimate can be given for *Rz(*max) of cycle 24.

Correspondence to: R. P. Kane
(kane@dge.inpe.br)

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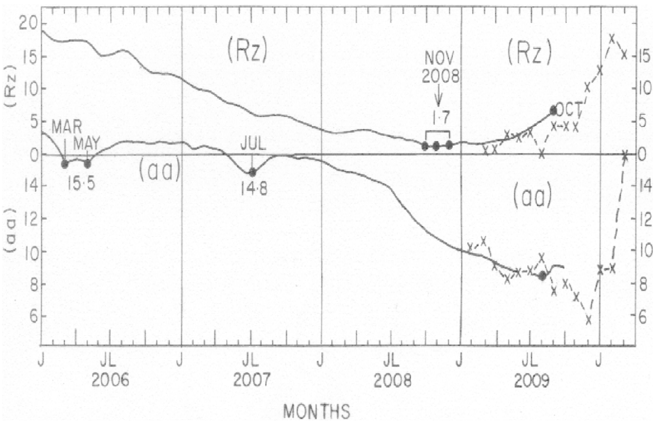

Fig. 1. Plot of the 12-month running means of sunspot number *Rz* and geomagnetic index *aa* for January 2006 onwards. Vertical lines mark the month January. Minima are shown by big dots and the corresponding months are indicated.

2 Data

The data used are the geomagnetic *aa* indices (the antipodal amplitudes deduced from the K index of Greenwich, England, and Melbourne, Australia; Mayaud, 1973) available at NOAA ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/RELATED_INDICES/AA_INDEX/ and international sunspot numbers *Rz* (McKinnon, 1987, and further data from NOAA websites ftp and ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS). For *aa* indices, data are available from 1868 onward only (cycle 11). However, for 1844–1880, Nevanlinna and Kataja (1993) generated an "equivalent" *aa* index based on the declination data from Helsinki and, for the overlapping period of 13 years 1868–1880, they found a very high correlation (0.99). Hence, we have now *aa* index data for cycle 9 and 10 also (annual values) and for cycle 11 onward (monthly values).

3 Present situation

The origin and development of sunspot numbers are described recently in Clette et al. (2007) and Vaquero (2007). The monthly values of *Rz* and *aa* indices vary erratically from month to month. Hence, 12-month running means were evaluated and used. (This is simple average of 12 consecutive monthly values. The centering is half-a-month displaced. To get the centering correct, some workers use 13 consecutive monthly values, with half weight for the first and last values. However, the difference between the two estimates is negligibly small). As shown in Kane (2007a), for cycles 12–23, the *Rz*(min) occurred earlier than *aa*(min) by 3, 5, −2, 2, 14, 8, 16, 12, 7, 7, 4, 16, 9 months. Thus, except for cycle 14 where *Rz*(max) occurred later by 2 months (−2 italicized), the *aa*(min) have occurred with delays ranging from 2 to 16 months. Figure 1 shows the plots of the 12-month running means of *Rz* and *aa* indices for January 2006 onwards. The following may be noted:

1. The 12-month running mean *Rz*(min) seems to have occurred only recently. The mean 1.7 occurred in three successive months October, November, December 2008, followed by values 1.9, 1.9, 2.2, 2.3, 2.3, 3.1, 4.1, 5.5, 6.7 till September 2009. Further, the actual monthly values for July 2009–March indicate that the sunspot activity has started rising. For January–March 2010, monthly values were 13.1, 18.6, 15.4

2. The 12-month running mean *aa*(min) seemed to have occurred first centered at March 2006 and May 2006 with a value 15.5. In Kane (2007a), this value was used in the regression equation *Rz(*max)=(−24.9±18.1)+(9.6±0.1.2)*aa*(min) and yielded the preliminary estimate prediction *Rz*(max)=124±26.

3. However, in retrospect, this seems to have been a false alarm. The *aa* values increased in the next few months but decreased later considerably, and attained a second minimum centered at July 2007, *aa*(min)=14.8, smaller in magnitude than the first minimum and 15 months later. This also has proved a false signal and after rising for the next six months, the aa values have decreased considerably. The last 12-monthly running mean for aa index is 8.7, centered on June 2009. If this value 8.7 is used as aa(min), the prediction becomes *Rz*(max)=58.0±25.0.

4 Conclusion and discussion

In Ohl's Precursor Method, the geomagnetic activity during the declining phase of a sunspot cycle is shown to be well correlated with the size (maximum sunspot number *Rz*(max) of the next cycle. Kane (1997, 1998, and references therein) and Wilson, Hathaway and Reichmann (1998 and references therein) have been using the *aa* index during the sunspot minimum year as representative of the geomagnetic activity. For solar cycle 24, using *aa*(min)=8.7, the latest prediction is *Rz*(max)=58.0±25.0.

Recently, Du et al. (2008, 2009) examined the Ohl method more critically, and pointed out that a higher correlation does not necessarily mean a successful prediction, In their analyses, a higher correlation often yielded a failure prediction. Therefore, they suggest that when a prediction is obtained, its rationality should be analyzed. As one test, they suggest that the prediction could be considered reliable if the prediction lies very near the regression line and the correlation increases. We tried this criterion. For cycles 9–23, the correlation was +0.918. When the value 8.7 for *aa*(min) in May 2009 was used with predicted *Rz*(max) as 58, the correlation was slightly higher (+0.931). Thus the predicted value

Rz(max)=58±25 for cycle 24 should be fairly reliable, and it is in the low *Rz*(max) category.

For cycle 24, there are predictions in a very wide range (see list and references in Kane, 2007a), namely, (a) <70 (three predictions), (b) 70–90 (eight predictions), (c) 90–110 (eight predictions), (d) 110–130 (ten predictions), (e) 130–150 (seven predictions), (f) 150–170 (three predictions), and (g) >170 (four predictions). Our latest prediction of *Rz(*max)=58±25 is in the (a) range of <70, much lower than the average of all predictions (∼115). Thus, if our prediction comes true, predictions in the high range (g) like *Rz*(max) 150–180 (Dikpati et al., 2006), *Rz*(max)=180 (Tsirulnik et al., 1997), *Rz*(max)=185 (Horstman, 2005) would prove grossly erroneous, while predictions in the very low range (a) *Rz*(max)=42±34 (Clilverd et al., 2006) and *Rz*(max)<50 (Badalyan et al., 2001) would prove to be true.

Incidentally, the present author published predictions for cycle 24 by using other methods also and got the results as (i) Kane (2007b) based on solar activity at different solar latitudes, *Rz*(max)=130, (ii) Kane (2007c) based on extrapolation of spectral components, *Rz*(max)=92, (iii) Kane (2008a) based on solar cycle lengths, *Rz*(max)=94, and (iv) Kane (2008b) based on the Ohl-Kopecky rule and the three-cycle periodicity scheme, *Rz*(max)=106. Almost all these (except 130 in Kane, 2007b) are below the statistical average of ∼115 for the 23 cycles. Thus, cycle 24 is likely to be below average. Recently, a review on this solar minimum has been published by Russell et al. (2010).

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Prediction of the size of coming solar cycle 24 based on solar parameters during sunspot minimum between cycles 23 and 24

R P Kane
Instituto Nacional de Pesquisas Espacias, INPE C P 515, 12201-970 São Jose dos Campos, SP, Brazil
E-mail: kane@dge.inpe.br

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The dependence of Rz(max) on preceding two solar parameters, namely length of sunspot minimum and the values of Rz(min), has been examined in the present paper. The results indicate a prediction of Rz(max) = ~90±20 for cycle 24. The average of cycles 1-23 is about 115. So, the prediction here indicates sunspot activity below normal.

Keywords: Sunspot minimum, Solar cycle size, Solar parameters
PACS No.: 96.60.*qd*

1 Introduction

In recent decades, several attempts have been made to predict the magnitude of the sunspot maximum Rz(max) with antecedence [references in refs (1,2)]. For solar cycle 23, NOAA's Space Environment Center (SEC) recruited a scientific panel to assess the likely development of cycle 23 and their published report[3] mentioned: (i) a range of 160 – 200 of Rz*(*max*)* of cycle 23 as obtained by considering the even/odd behavior and (ii) a range 110 – 160 of Rz(max*)* by other methods. The panel gave weightage to precursor methods since these have proved to be the most successful techniques for solar activity predictions in the past. A Solar Cycle 24 Prediction Panel, composed of international scientists and presided by D Biesecker (ref. 4), issued consensus opinion on 25 April 2007 that: cycle 24 would commence in March 2008 (±6 months); and the solar maximum would be 140±20 in October 2011 or 90±10 in August 2012. The sunspot minimum was nowhere near the range March 2008 (±6 months). The old cycle 23 ended and the new cycle 24 commenced only in the end of 2009. The sunspot numbers went through a minimum of zero in August 2009. The predictions of Rz(max) for cycle 24, based on various methodologies and physical models, have a very large range, from as low as 40 to as high as 150 or more[2,4].

The precursor methods invoke a solar dynamo concept, whereby the polar field in the declining phase and at minimum is the seed of future toroidal fields within the Sun that will cause solar activity[5]. In one of the precursor methods (Ohl's method), geomagnetic *aa* indices at solar minimum are seen to be well correlated with the succeeding Rz(max) (refs 6,7).

The recent sunspot minimum lasted for more than two years, unusually long as compared to all previous cycles 1-23. This induced Dikpati *et al.*[8] to see whether a prediction could be made using the length of the minimum (not length of the whole solar cycle, which has been examined earlier by Kane[9], who gave a prediction Rz(max) = 98±44). It was found that the length of the minimum had a reasonably good correlation of -0.75, with Rz(max) values of the succeeding cycles. However, Dikpati *et al.*[8] did not do a regression analysis, as they noticed that the length of the minimum had a moderate correlation of -0.59 with the Rz(max) of the previous cycles, thus putting in doubt the reliability of the relation between length of minimum and Rz(max) of the succeeding cycles.

In the present paper, the regression equations of length of the minimum (L1, L2, L3) and actual sunspot minimum R(min) have been examined with the succeeding Rz(max) values.

2 Data analysis

Table 1 gives the values of solar parameters, lengths of sunspot minimum, sunspot minimum R(min) and the succeeding Rz(max) values. L1 refers to the series used by Dikpati *et al.*[8], defined as the interval during which sunspot number dropped below

Table 1 — Solar parameters: Length of the minimum L1, L2, L3; sunspot minimum R(min); and the succeeding Rz(max) values for cycles 1-23

Minimum between cycles	Length minima L1 (Rz<15), months	Depth of minima R(min)	R(max) following peak	Length minima L2 R(min)*2, months	Length minima L3 Rmin+5 months
0-1	32	8.4	86.5	33	22
1-2	8	11.2	115.8	20	9
2-3	18	7.2	158.5	17	15
3-4	14	9.5	141.2	20	13
4-5	47	3.2	49.2	12	36
5-6	79	0	48.7	13	40
6-7	58	0.1	71.5	5	18
7-8	22	7.3	146.9	21	17
8-9	15	10.6	131.9	23	15
9-10	27	3.2	98	16	18
10-11	17	5.2	140.3	12	12
11-12	49	2.2	74.6	11	19
12-13	49	5	87.9	30	32
13-14	46	2.7	64.2	20	25
14-15	48	1.5	105.4	10	36
15-16	24	5.6	78.1	17	16
16-17	38	3.5	119.2	8	17
17-18	16	7.7	151.8	14	12
18-19	19	3.4	201.3	8	12
19-20	15	9.6	110.6	21	14
20-21	18	12.2	164.5	28	20
21-22	11	12.3	158.5	29	18
22-23	19	8.3	120.8	19	18
23-24	42?	1.7	Prediction	17	23+

15 (criterion chosen arbitrarily). The series L2 is defined as the interval when Rz values were below the double of Rz(min). The series L3 is defined as the length when Rz values equal to five sunspots above Rz(min).

Figure 1 shows plots of Rz(max) versus: (a) L1 and (b) Rz(min). The regression lines are shown. In (a), the correlation is good (-0.75) and the regression equation is

$$Rz(max) = (163.88 \pm 11.01) - (1.66 \pm 0.32)*(L1) \quad \ldots (1)$$

If the length L1 is 42 months, plugging this value on the right side of Eq. (1), one gets the estimate Rz(max) = 97 ± 17 for cycle 24.

For (b), the regression equation is:

$$Rz(max) = (89.7 \pm 16.7) + (2.04 \pm 1.22)*Rz(min) \quad \ldots (2)$$

Since Rz(min) is 1.7, the prediction for cycle 24 is of Rz(max) = 94 ± 17

3 Bivariate analysis

Since the Rz(max) is correlated with two parameters, namely length L1 and Rz(min), a bivariate analysis[10] could be conducted.. The result was:

$$Rz(max) = (186.23 \pm 32.86) - (1.99 \pm 2.82)*Rz(min) - (2.00 \pm 0.57)*L1 \quad \ldots (3)$$

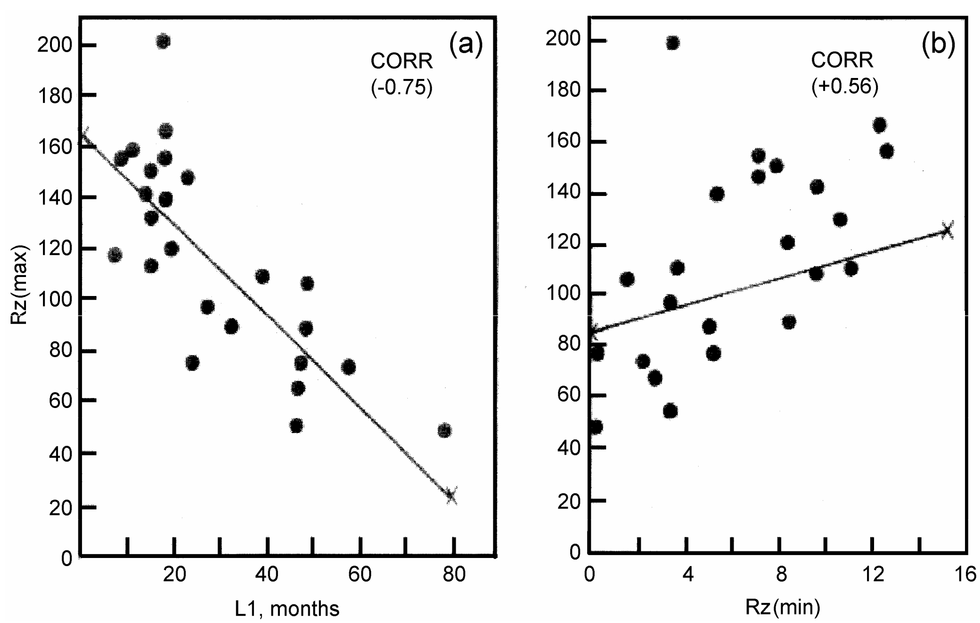

Fig. 1 — Plot of Rz(max) *vs:* (a) L1 (months); and (b) Rz(min). The regression lines are indicated and correlations mentioned.

Using Rz(min) = 1.7 and L1 = 42 months and plugging these in the right side of Eq. (3), one gets Rz(max) = 99±27, almost the same as in Eqs (1) and (2).

4 Other values for L

For a reliable bivariate analysis, the two independent variables L1 and Rz(min) need to be really independent, i.e. the correlation between L1 and R(min) should be almost zero. In the present case, the correlation was very high negative, -0.82. Thus, L1 and Rz(min) could be expressed as functions of each other and Eq. (3) becomes just a simple equation with one independent variable. No wonder that predictions in Eqs [(1), (2) and (3)] are almost the same.

In search of an independent estimate of the length of the sunspot minimum, two more series have been tried. In series L2, the criterion, that the length is defined as the interval when Rz values were below the double of Rz(min), has been used. For example, if the Rz(min) was say 1.7, the interval when Rz values were below 3.4 was considered as the length. These values are given in Table 1. However, with this series, the correlation between L2 and Rz(min) was +0.70. In contrast to the correlation -0.82 between L1 and Rz(min), the correlation +0.70 was slightly smaller; but it was still substantial, certainly far from the expected value zero.

Another series L3 has been tried where the length was defined as Rz values equal to five sunspots above Rz(min). For example, if Rz(min) was 1.7, the length was defined as when Rz dropped below 6.7 to when Rz rose above 6.7. In this case, the correlation between L3 and Rz(min) was smaller, -0.53, still far from the expected value zero. Thus, so far, one has not been able to create a series of length which has a very low correlation with Rz(min).

Using L2 and Rz(min), and L3 and Rz(min) in bivariate analyses, the estimates of Rz(max) were ~90±20. The correlation of Rz(max) with Rz(min) was about +0.56, not very high; but the bivariate analysis takes care of this by introducing larger standard errors in the coefficients, as also in the standard error of the estimated Rz(max). If one standard deviation is considered, Rz(max) would be in the range 70-110. If a very rigorous two standard errors criterion is considered, the Rz(Max) would be in the range 50-130.

In single variate analysis (Eqs 1 and 2), the computer program gives the standard errors of the coefficients (indicated) and the correlation is also known. In a bivariate analysis, the standard errors of the coefficients are known (as indicated) but there is no single correlation. As an overall correlation, the expected value of R(max) has to be obtained by inserting the observed values of Rz(min) and L1 in the right-hand side of Eq. 3 and the series R(max)-expected is to be plotted against Rz(max)-observed. This correlation tells how good the Eq. 3 is. In the present case, the value of the overall correlation was 0.70, indicating that the bivariate analysis results were not better than the single variate results.

5 Conclusions and discussion

In the last two decades, several researchers have been using different methods for predicting the Rz(max) for cycle 23 and 24. Among these, the precursor methods have proved to be most promising[3]. In this paper, the dependence of Rz(max) on two parameters, namely length of sunspot minimum and the values of Rz(min), is examined. The results indicate a prediction of ~90±20 for cycle 24. The average of cycles 1-23 is ~115. So, the prediction here indicates cycle 24 sunspot activity below normal.

Dikpati *et al.*[11], based on a modification of a calibrated flux transport solar dynamo model, predicted that cycle 24 will have a 30–50% higher peak than cycle 23 [which had Rz(max) as 122]. Thus, a value in the range 160–185 is predicted. However, using the solar dynamo concept, where the polar field in the declining phase of a cycle n is the seed of future sunspot fields (toroidal fields) within the sun in cycle $n+1$ that will cause solar activity, Svalgaard *et al.*[12] and Schatten[13] predict a value of 70 – 80. The analysis presented here agrees with the low values.

Besides the several references given in Pesnell[4] and Kane[2] for predictions of R(max) of cycle 24, some more have appeared recently[14-17].

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An Estimate for the Size of Sunspot Cycle 24

R. P. Kane

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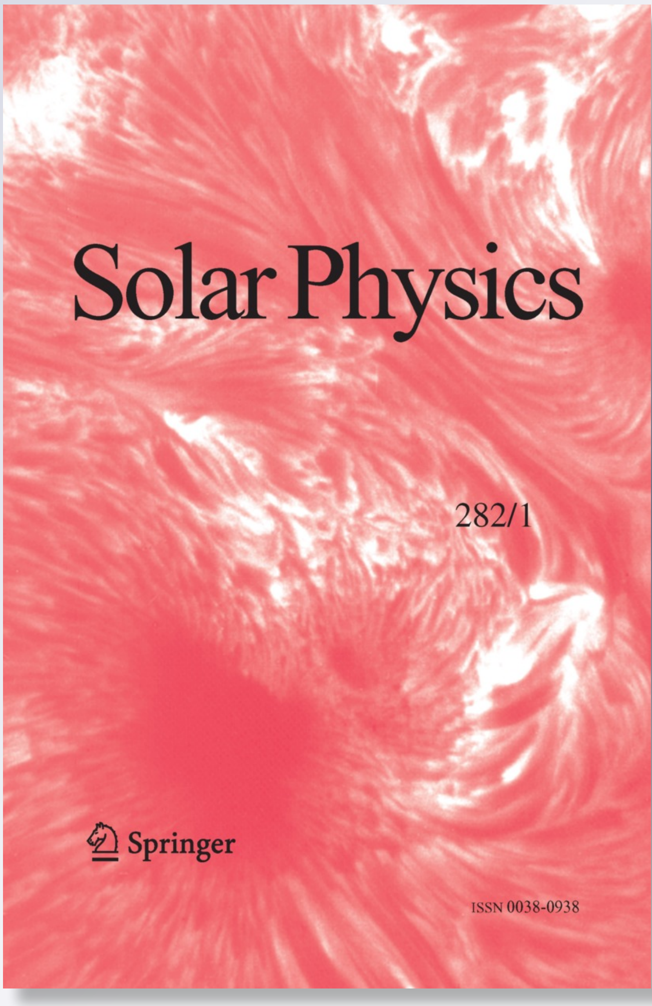

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An Estimate for the Size of Sunspot Cycle 24

R.P. Kane

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Abstract For the sunspot cycles in the modern era (cycle 10 to the present), the ratio of $R_Z(\text{max})/R_Z(\text{36th month})$ equals 1.26 ± 0.22, where $R_Z(\text{max})$ is the maximum amplitude of the sunspot cycle using smoothed monthly mean sunspot number and $R_Z(\text{36th month})$ is the smoothed monthly mean sunspot number 36 months after cycle minimum. For the current sunspot cycle 24, the 36th month following the cycle minimum occurred in November 2011, measuring 61.1. Hence, cycle 24 likely will have a maximum amplitude of about 77.0 ± 13.4 (the one-sigma prediction interval), a value well below the average $R_Z(\text{max})$ for the modern era sunspot cycles (about 119.7 ± 39.5).

Keywords Prediction · Sunspot cycle

1. Introduction

Sunspots vary in number over an approximately 11-year cycle, where each cycle is determined on the basis of using 12-month moving averages of monthly mean sunspot number, the so-called smoothed monthly mean sunspot number. Conventionally, a sunspot cycle begins at the time of a minimum amplitude ($R_Z(\text{min})$) of the 12-month moving average value, rises to a maximum amplitude ($R_Z(\text{max})$) and ends at a subsequent minimum amplitude that marks the conventional start of the next sunspot cycle. Each sunspot cycle is numbered, with the present sunspot cycle being 24, and cycle 10 and onwards are here collectively called the modern era sunspot cycles. Prediction of the maximum amplitude and timing of a sunspot cycle is of vital importance, especially as related to the potential for damage to electronic components aboard earth-orbiting satellites (Dyer *et al.*, 2003) and to the possible health hazards for astronauts (Lockwood and Hapgood, 2007).

For the current sunspot cycle 24, a number of predictions previously have been made for its size, with the predictions spanning a large range of values from < 70 to > 170 (Kane, 2007a; Pesnell, 2008). Using aa(min) $= 8.7$ of geomagnetic aa index in conjunction with

R.P. Kane (✉)
Instituto Nacional de Pesquisas Espacias, INPE C.P. 515, 12201-970 São Jose dos Campos, SP, Brazil
e-mail: kane@dge.inpe.br

the Ohl precursor method (Ohl, 1966, 1976), Kane (2010) previously predicted $R_Z(\max) = 58.0 \pm 25.0$ for cycle 24, a value considerably below the mean for the modern era sunspot cycles (about 120). If this predicted value proves to be correct, then the predictions calling for cycle 24 to be a large maximum amplitude cycle (*e.g.*, Dikpati, de Toma, and Gilman, 2006) will prove to be utterly erroneous. Other predictions of below average $R_Z(\max)$ for cycle 24 include those of Clilverd *et al.* (2006) and Badalyan, Obridko, and Sykora (2001).

In addition to the prediction by Kane (2010), Kane (2007b, 2007c, 2008a, 2008b) made several earlier predictions regarding $R_Z(\max)$ for cycle 24. Kane (2007b) predicted cycle 24 to have $R_Z(\max) = 130$, based on solar activity at different solar latitudes; Kane (2007c) predicted $R_Z(\max) = 92$, based on the extrapolation of spectral components; Kane (2008a) predicted $R_Z(\max) = 94$, based on cycle lengths; and Kane (2008b) predicted $R_Z(\max) = 106$, based on the Gnevyshev–Ohl–Kopecky rule (Gnevyshev and Ohl, 1948; Kopecky, 1950) and the three-cycle periodicity scheme. More recently, based on the long-term changes in solar activity and the unusual quietness associated with the early rising portion of cycle 24, Lockwood *et al.* (2012) estimated that cycle 24 would have maximum amplitude near 60, probably in mid 2012.

In this study, the ratio of $R_Z(\max)/R_Z(36\text{th month})$ is investigated to determine its predictive power for estimating $R_Z(\max)$, where $R_Z(36\text{th month})$ is the smoothed monthly mean sunspot number 36 months after cycle minimum. Indeed, the ratio strongly suggests that $R_Z(\max)$ for cycle 24 will be well below average in size.

2. Data

The data employed in this study are the 12-month moving averages of monthly mean sunspot number, the so-called smoothed monthly mean sunspot numbers, given at ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/INTERNATIONAL/smoothed/. The 36th month following minimum amplitude occurrence (November 2008) corresponds to November 2011 and measures 61.1.

3. Results

Table 1 gives the data for the modern era sunspot cycles that are considered pertinent for this study. Columns from left to right give the cycle number, the year and month of minimum, the value of $R_Z(\min)$, the timing of 36 months past minimum, the value of R_Z at 36 months past minimum, the year and month of maximum, the value of $R_Z(\max)$, the elapsed time from $R_Z(\min)$ to $R_Z(\max)$ in months, and the ratio $R_Z(\max)/R_Z(36)$. Also included in Table 1 are the observed values of $R_Z(\min)$, $R_Z(36)$, and the dates of their occurrence for cycle 24, as well as its estimated $R_Z(\max)$ based on the mean ratio for the modern era cycles (*i.e.*, 1.26 ± 0.22) by applying the observed $R_Z(36)$ for cycle 24 (= 61.1). Clearly, the one-sigma prediction interval for cycle 24 $R_Z(\max)$ is equal to 77.0 ± 13.4, which suggests that it will be considerably below the mean $R_Z(\max)$ for the modern era sunspot cycles ($= 119.7 \pm 39.5$).

4. Conclusion and Discussion

In this brief study, the ratio of $R_Z(\max)/R_Z(36)$ has been used to estimate the size of the ongoing sunspot cycle 24. Using the observed value of $R_Z(36) = 61.1$ and the mean ratio

Table 1 Details of sunspot number R_Z (12-month moving averages), their ratios, and their occurrence dates for individual sunspot cycles 10 – 23.

Column								
1	2	3	4	5	6	7	8	9
Cycle No.	Month of R_Z(min)	R_Z(min)	36th month	R_Z at 36th month	Month of R_Z(max)	R_Z(max)	Months, R_Z(min) to R_Z(max)	Ratio, R_Z(max)/ R_Z(36 mon)
10	1855(12)	3.2	1858(12)	75.5	1860(02)	98.0	50	1.30
11	1867(03)	5.2	1870(03)	121.5	1870(08)	140.3	41	1.15
12	1878(12)	2.2	1881(12)	62.4	1883(12)	74.6	60	1.20
13	1890(02)	5.0	1893(02)	79.8	1894(01)	87.9	47	1.08
14	1901(05)	2.8	1904(05)	41.5	1906(02)	64.2	57	1.55
15	1913(06)	1.5	1916(06)	56.3	1917(08)	105.4	50	1.87
16	1923(02)	5.9	1926(02)	64.1	1928(04)	78.1	62	1.22
17	1933(09)	3.5	1936(09)	90.3	1937(04)	119.2	43	1.32
18	1944(02)	7.7	1947(02)	136.8	1947(05)	151.8	39	1.11
19	1954(04)	3.4	1957(04)	181.0	1958(03)	201.3	47	1.11
20	1964(10)	9.6	1967(10)	95.0	1968(11)	110.6	49	1.16
21	1976(06)	12.2	1979(06)	153.0	1979(12)	164.5	42	1.21
22	1986(09)	12.3	1989(09)	156.6	1989(07)	158.5	34	1.01
23	1996(05)	8.0	1999(05)	90.5	2000(04)	120.8	47	1.33
24	2008(11)	1.7	2011(11)	Obs.61.1	Estimated	77.0		1.26
					std. deviation	± 13.4		± 0.22

$R_Z(\max)/R_Z(36) = 1.26 \pm 0.22$ found for the modern era sunspot cycles, one can estimate $R_Z(\max) = 77.0 \pm 13.4$ for cycle 24 (with the one-sigma prediction interval). Hence, it appears highly likely that R_Z(max) for cycle 24 will be below the mean R_Z(max) value found for the modern era sunspot cycles, with only a 5 % chance of it being about 106 or more, thus negating the predictions of Dikpati, de Toma, and Gilman (2006; $R_Z(\max) = 180$) and Tsirulnik, Kuznetsova, and Oraevsky (1997; $R_Z(\max) = 185$). The finding reported here is in agreement with that of Lockwood *et al.* (2012), who indicated that long-term solar changes appear to be happening and suggested the likely occurrence of another Maunder-like minimum in solar activity later this century. They further stated that the unusual quietness of sunspot cycle 24 suggests that it will have R_Z(max) near 60 in mid 2012. The finding reported here also is in agreement with that of Duhau and de Jager (2010), who argue that the solar variability is presently entering into a long grand minimum, longer than a century, with cycle 24 having R_Z(max) near 55.

Additionally, the finding reported here agrees with that of Wilson (2011), who using the Hathaway–Wilson–Reichmann shape-fitting function (Hathaway, Wilson, and Reichmann, 1994), found that the early rise of cycle 24 (the first 18 months) was consistent with it having $R_Z(\max) = 70$, peaking about 56 months after the minimum (about mid 2013). He also noted that the expected R_Z(max) for cycle 24 deduced using the minimum value of geomagnetic aa index gave only a 1 % chance of R_Z(max) exceeding 100.5. Wilson (2011) also included in his study a formulation for predicting R_Z(max) on the basis of the maximum month-to-month rate of growth in smoothed monthly mean sunspot number, which was unknown at the time of his publication but now appears to be known (5.8), a value suggesting $R_{\mathrm{Z}}(\max) = 103.4 \pm 21.3$ as applied to cycle 24.

In conclusion, although the present technique appears to have limited use for predicting the size of the sunspot cycle well in advance, it obviously can be used to confirm earlier predictions and differentiate between those that appear to be reasonable and those that appear to be unreasonable.

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