Indian Journal of Radio & Space Physics
Vol 40, April 2011, pp 72-75

# 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

*Received 22 July 2010; revised received and accepted 24 February 2011*

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:

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

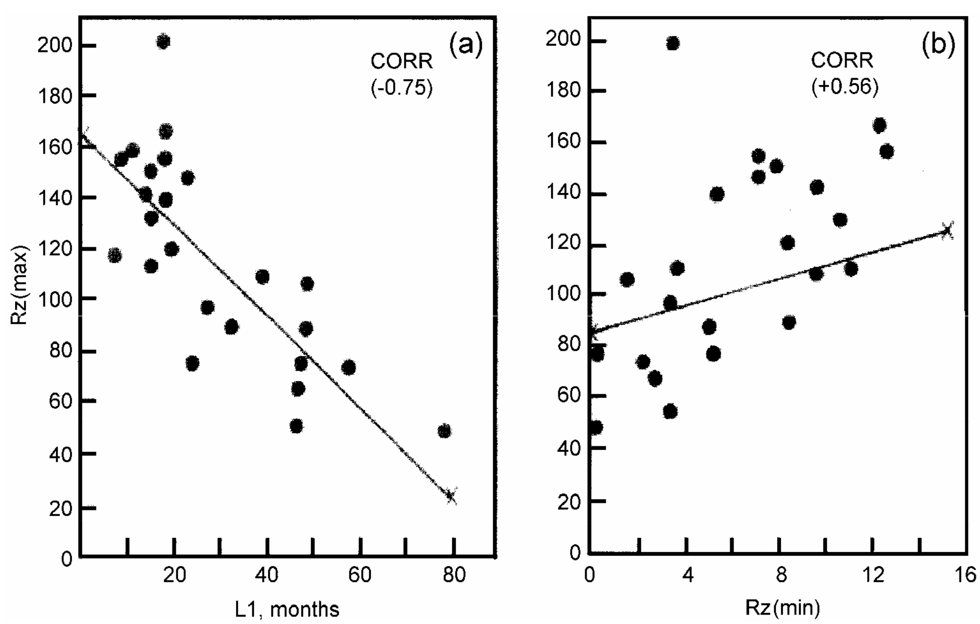


Fig. 1 — Plot of Rz(max) *vs:* (a) L1 (months); and (b) Rz(min). The regression lines are indicated and correlations mentioned.

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].

## Acknowledgements

The author gratefully acknowledges the partial support by FNDCT, Brazil under Contract No FINEP-537/CT for the study.

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