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(NASA-CR-157320) A PHYSICAL MECHANISM FOR THE PREDICTION OF THE SUNSPOT NUMBER DURING SOLAR CYCLE 21 (Stanford Univ.) 13 p HC A02/MF A01 CSCL 03B
N78-29028
Unclas
G3/92 27356

A PHYSICAL MECHANISM FOR THE PREDICTION OF THE SUNSPOT NUMBER DURING SOLAR CYCLE 21

By

K.H. Schatten, P.H. Scherrer,
L. Svalgaard and J.M. Wilcox

Office of Naval Research
Contract N00014-76-C-0207

National Aeronautics and Space Administration
Grant NGR 05-020-559

National Science Foundation
Grant ATM77-20580

and

The Max C. Fleischmann Foundation

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SUIPR Report No. 736

February 1978

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER
SUIPR Report No. 736

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
A Physical Mechanism for the Prediction of the Sunspot Number During Solar Cycle 21

5. TYPE OF REPORT & PERIOD COVERED
Scientific; Technical

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
K.H. Schatten, P.H. Scherrer,
L. Svalgaard, J.M. Wilcox

8. CONTRACT OR GRANT NUMBER(s)
N00014-76-C-0207

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Institute for Plasma Research
Stanford University
Stanford, California 94305

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Office of Naval Research
Electronics Program Office
Arlington, Virginia 22217

12. REPORT DATE
February 1978

13. NO. OF PAGES
11

14. MONITORING AGENCY NAME & ADDRESS (if diff. from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from report)

18. SUPPLEMENTARY NOTES
Tech; Other.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
sunspot cycle
solar activity
solar magnetic fields

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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Abstract

On physical grounds it is suggested that the sun's polar field strength near a solar minimum is closely related to the following cycle's solar activity. Four methods of estimating the sun's polar magnetic field strength near solar minimum are employed to provide an estimate of cycle 21's yearly mean sunspot number at solar maximum of 140 ± 20. We think of this estimate as a first order attempt to predict the cycle's activity using one parameter of physical importance.

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Introduction

A variety of methods have been used by many scientists to predict solar activity (Sargent, 1978). Often they rely on time series analyses which assume implicitly that the solar dynamo has basic periodicities. These methods are questionable in that the basic periodicities, if any exist other than the 11-year cycle, can not be determined with the current uncertain set of sunspot numbers (Mayaud, 1977).

Other methods, such as that of Ohl (1976), are based upon some apparent precursor of sunspot number which the author has noted fits past solar cycles. These methods will work if there is some underlying, but as yet obscure, physical connection between the two. The method may not work, or will break down some time in the future, if it depends only upon the researcher's ability to notice an apparent high statistical but not necessarily physical correlation.

We would like to discuss a method based upon the physical grounds of our understanding of the solar dynamo process. One aspect which is central to the solar activity cycle is that the magnetic flux from sunspots in a given cycle cancels the existing polar magnetic flux causing the polar fields to reverse (Babcock, 1961; Leighton, 1969; Parker, 1977 and Howard, 1977). Furthermore, it is the polar flux, wound by differential rotation into a subsurface toroidal flux, which emerges as the next cycle's sunspots. Thus, on physical grounds, we believe the strength of the sun's polar magnetic field at minimum is related to the next cycle's sunspot activity. In this paper we test this hypothesis by several graphs which are basically a plot of the polar field strength, measured at solar minimum in various ways, versus

the next cycle's maximum sunspot number, as determined during the past several sunspot cycles. We then use these graphs with our estimate of the polar field strength during the present sunspot minimum to ascertain a best estimate of this cycle's sunspot maximum.

Polar Field Strength

Estimates of the polar magnetic field strength near sunspot minimum may be obtained from the shape of the corona at the time of solar eclipses, or by the amount of flattening of the "warped current sheet" at 1AU as obtained from interplanetary magnetic field measurements analysed in accordance with the methods of Rosenberg and Coleman (1969). A further and more direct estimate of polar field strengths is obtained by observing the number of polar faculae.

The shape of the corona at eclipses may be used to obtain a measure of polar field strength in the following two ways. The Ludendorf index (Billings, 1966) may be used as a measure of coronal flattening and hence of polar field strength. Figure 1a shows the mean sunspot number versus the Ludendorf index. Each point represents the Ludendorf index of an eclipse near sunspot minimum (listed) versus the yearly mean sunspot number at the following solar maximum. The straight line through the origin is chosen as a best fit to the observations with the theoretical assumption that if there is a zero polar field at solar minimum corresponding to a zero Ludendorf index, the next solar maximum will have few, if any, sunspots. The June 1954 solar eclipse was remarkable in the flattening of the corona due to the symmetrical plumes over each pole and the huge equatorial streamers. It was also marked by a very high amount of solar activity the next cycle, suggestive that these ideas for predicting solar activity may have some validity.

It should also be noted that some of the scatter of the points near Ludendorf index 0.23 may be related to the possibility (Svalgaard, 1978) that the interplanetary and coronal fields may have increased progressively by a factor of two from 1900 to the present time. The Ludendorf flattening would not reflect an overall change in solar field

strengths, thus the rise in R_m from 1900 to 1922, to 1933, and to 1944 along nearly the same flattening index could be due to an increase in polar field strengths, not reflected in the flattening index. This can occur because the flattening index only measures the polar magnetic pressure relative to low latitude field and plasma pressure. The October 23, 1976 solar eclipse (Waldmeier and Weber, 1977) with a Ludendorf index equal to 0.36 was used to estimate a maximum yearly mean sunspot number of 155 ± 25, with the uncertainty based upon the spread of the points near the index 0.23.

A second similar measure of polar field strength and subsequent solar activity may be obtained from the bending of high latitude polar plumes. This assumes that a higher polar field strength will bend the high latitude plumes more toward the solar equator (where the polar magnetic field pressure is balanced by low latitude field and coronal plasma pressure). The bending of the polar plumes was obtained by taking an average of the angle of the coronal plumes from the radial just above the photosphere at 60° latitude in the four quadrants seen at solar eclipses. Only those eclipse drawings near solar minimum where these angles could be determined were used in this study. In Figure 1b, the bending angle is plotted against the mean sunspot number of the following maximum. The line shows a best linear fit, again through the origin, assuming a zero bending angle corresponds to a zero following sunspot cycle. One can see a relation emerging between polar field strength (as determined by the bending angle) and the subsequent maximum's mean sunspot number. The value for the October 23, 1976 eclipse bending angle was obtained directly from eclipse photos and also from Waldmeier's (1977) eclipse drawing. These two estimates shown in Figure 1b provide an estimate for the next maximum's mean yearly sunspot number of 110-140.

The third estimate of polar field strength utilizes the model of a "warped current sheet" in interplanetary space, whose geometry depends upon the polar field strength (see Svalgaard and Wilcox, 1976). For a few years prior to and spanning sunspot minimum the dominant polarity

of the interplanetary magnetic field as observed at the earth - which through the year is travelling $\pm 7^{o}$ out of the solar equatorial plane - shows an annual variation. This is due to the fact that the sector boundary in interplanetary space is very nearly in the east-west direction. This flattening of the current sheet results from strong solar polar fields controlling coronal and interplanetary field configurations. Thus the stronger the flattening the stronger are the polar fields and hence the ensuing sunspot maximum.

The flattening, Δ , may be obtained from interplanetary field measurements near solar minimim by determining the number of days of toward-the-sun field polarity throughout one or more years. The amplitude of this curve, in days, throughout the year (as the earth swings between $\pm 7^{o}$ heliographic latitude) is Δ. In Figure 1c, Δ near solar minimum is graphed with the following sunspot maximum yearly mean sunspot number, R_m. The curve is assumed to go through zero as with revious graphs. The range of Δ near 1976 (shown as arrows) provide an estimate for the next sunspot maximum's mean yearly sunspot number of 135 ± 20. Again, the ability of the 1964 and 1954 data to fit a line through the origin is seen as supporting the view that subsequent sunspot peaks are related to polar field strengths.

Sheeley (1964,1966,1976) has suggested that the sun's polar field strengths may be estimated by a fourth method - counting the numbers of faculae at the poles. Annual averages of the polar fields from Mt. Wilson synoptic magnetic charts for the years available (1967 through 1975) confirm Sheeley's results. Sheeley also points out that the polar field magnitude tends to lag the sunspot number and that this is consistent with the model that the polar fields are produced by the poleward transport of flux that originates in bipolar magnetic regions in the lower latitude zones of solar activity. In our model, the polar fields near sunspot minimum are the source of the fields to generate the next activity maximum We have compared the sum of north and south polar faculae counts (from Sheeley 1976, Figure 1 but without his polarity determination) with the sunspot number. We found a better correlation between the polar faculae counts

and the following sunspot maximum than with the preceding one. This supports the idea that the polar fields near minimum (when the polar fields are usually the greatest) predict the peak of the following cycle. To attempt a numerical estimate we have computed 3-year averages of the polar faculae counts centered about sunspot minimum and plotted them with the maximum yearly mean sunspot number of the next cycle. Figure 1d shows the result. The faculae count was a maximum at sunspot minimum for all minima except 1923 and 1954 when it was largest in the declining phase of the cycle. The faculae count for the 1923 minimum may be biased by an unusually large count just after the 1917 maximum. As a rough estimate of the coming maximum we estimate a sunspot number of 120-160 by this method.

Further suggestion of a fairly high sunspot cycle comes from the work of Brown (1976) who noticed a correlation between solar activity at solar minimum with the following maximum. Utilizing such a correlation, with the added fact that this past minimum had the highest ever recorded value for mean sunspot number (13), suggests the new cycle could have a mean value of 150 ± 25, near solar maximum.

Prediction of the Sunspot Number of Solar Cycle 21

Utilizing the previous estimate of polar magnetic field strength obtained near solar minimum, we have four estimates of cycle 21's maximum mean yearly sunspot number. These are 155 ± 20, 125 ± 20, 135 ± 20, and 140 ± 20. Averaging these two together we get a value of 140 ± 20 for the mean yearly maximum sunspot number of cycle 21. We have kept the ± 20 uncertainty rather than reducing its value because the four methods are based on the same physical principles, and any uncertainties in the four methods may not be independent.

An estimate of the time of rise of the solar activity cycle may be found from Waldmeier's (1935) formulae, which gives the rise time as 3.4 ± 0.5 years. Placing the solar minimum in April 1976 gives the time of maximum to be September 1979, to within half a year.

Figure 2 shows our estimate of sunspot number for cycle 21 as a solid line with dashed lines around it to indicate the limits of our estimate. The mean of cycles 8-20, shown as a dotted line, indicates that we predict cycle 21 to be significantly larger than average.

It is important to add that we are making a prediction of the size of solar cycle 21 using estimates of the polar field strength together with our assumption that this relates to the size of the next cycle's activity. We also believe that more than just this one parameter governs the behavior of the solar activity cycle. We would thus like to think of this paper as a first order attempt to predict the cycle's activity using one parameter of physical importance. If this method succeeds to some degree, it may be possible to establish other solar parameters which will improve the prediction.

The prediction of cycle 21's yearly mean sunspot maximum to be 140 ± 20 is close to Sargent's (1978) prediction of 154 but significantly larger than most other predictions listed in Sargent's paper If we err in the prediction, we feel we have erred on the side of being too conservative. Waldmeier and Weber (1977) point out that this cycle had the largest value of sunspot number at solar minimum ever recorded. Thus it is possible that solar maximum may exceed our stated limits.

Acknowledgements

This work was supported by the Office of Naval Research under Contract N00014-76-C-0207, by the National Aeronautics and Space Administration under Grant NGR 05-020-559, by the Atmospheric Sciences Section of the National Science Foundation under Grant ATM77-20580 and by the Max C. Fleischmann Foundation.

Figure Captions

Figure 1a (top) Sunspot number at maximum vs. the Luedendorf isophote flattening index at an eclipse near the preceding solar minimum (used as a measure of polar magnetic strength).

1b (2nd down) Sunspot number at maximum vs. the polar field bending angle at an eclipse near the preceding solar minimum.

1c (3rd down) Sunspot number at maximum vs. Δ, a measure of the yearly variation of the predominant polarity of the interplanetary field near earth. This is used as a measure of polar magnetic field strength.

1d (bottom) Sunspot number at maximum vs. faculae count in polar regions, and related polar field strength, at the preceding solar minimum.

Figure 2 Predicted smoothed sunspot number from 1976 to 1983 (solid curve). A maximum of 140 ± 20 near September, 1979 is significantly above the mean of cycles 8-20 (dotted curve).

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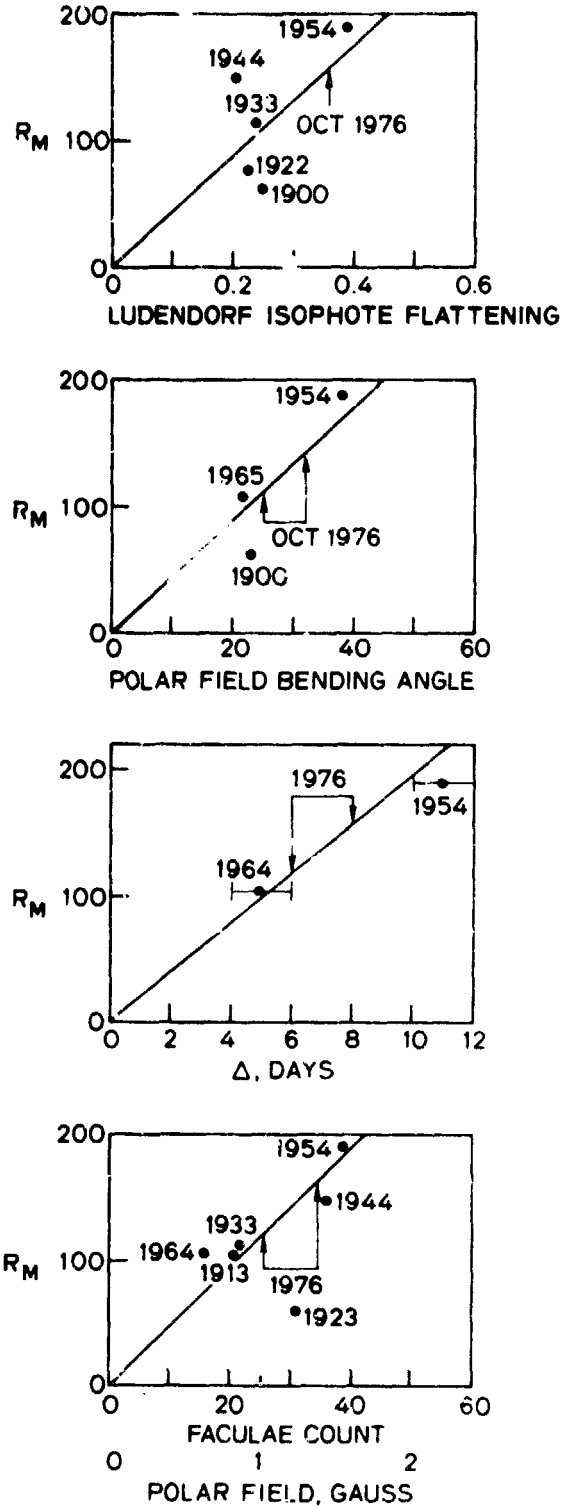
200
100
0
R_M
1954
1944
1933
OCT 1976
1922
1900
0
0.2
0.4
0.6
LUDENDORF ISOPHOTE FLATTENING
200
100
0
R_M
1954
1965
OCT 1976
1900
0
20
40
60
POLAR FIELD BENDING ANGLE
200
100
0
R_M
1976
1954
1964
0
2
4
6
8
10
12
Δ, DAYS
200
100
0
R_M
1954
1944
1933
1964
1913
1976
1923
0
20
40
60
FACULAE COUNT
0
1
2
POLAR FIELD, GAUSS

Figure 1

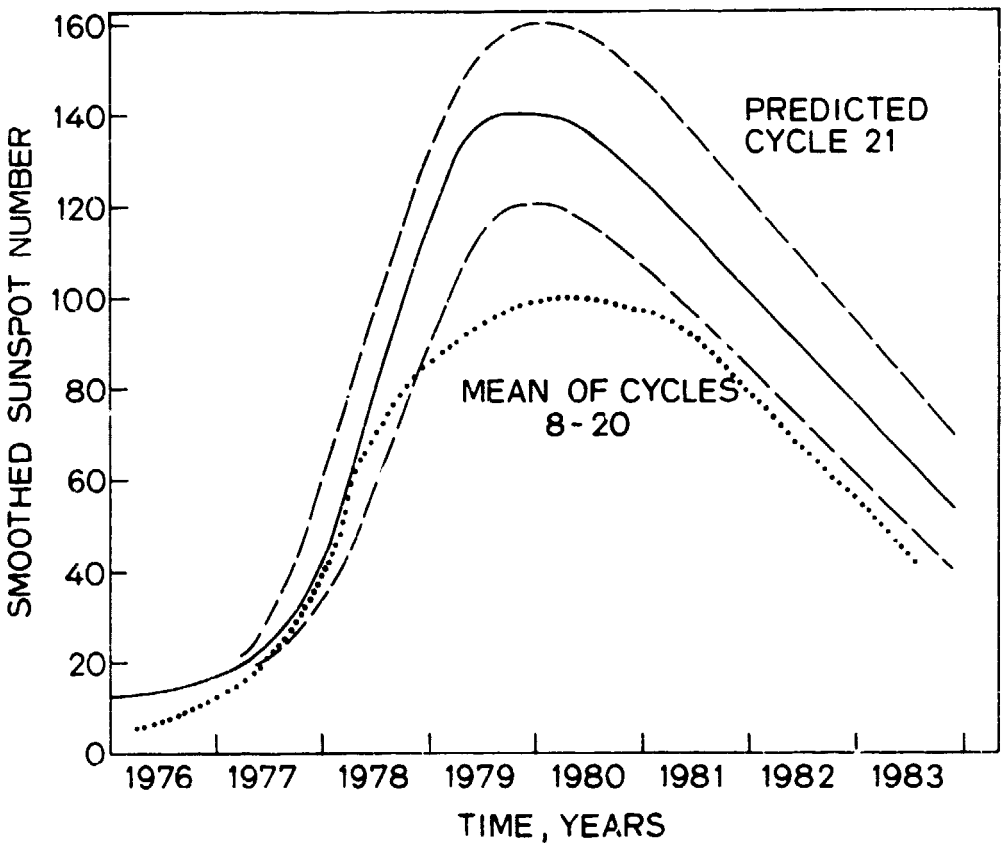
160
140
120
100
80
60
40
20
0
SMOOTHED SUNSPOT NUMBER
PREDICTED
CYCLE 21
MEAN OF CYCLES
8-20
1976
1977
1978
1979
1980
1981
1982
1983
TIME, YEARS

Figure 2