# Large-Scale Photospheric Magnetic Field: The Diffusion of Active Region Fields

by

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13. ABSTRACT

The large-scale photospheric magnetic field has been computed by allowing observed active region fields to diffuse and to be sheared by differential rotation in accordance with the Leighton (1969) magnetokinematic model of the solar cycle. The differential rotation of the computed field patterns as determined by autocorrelation curves is similar to that of the observed photospheric field, and poleward of $20^{\circ}$ latitude both are significantly different from the differential rotation of the long-lived sunspots (Newton and Nunn, 1951) used as an input into the computations.

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# LARGE-SCALE PHOTOSPHERIC MAGNETIC FIELD: THE DIFFUSION OF ACTIVE REGION FIELDS


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## Abstract

The large-scale photospheric magnetic field has been computed by allowing observed active region fields to diffuse and to be sheared by differential rotation in accordance with the Leighton (1969) magneto-kinematic model of the solar cycle. The differential rotation of the computed field patterns as determined by autocorrelation curves is similar to that of the observed photospheric field, and poleward of $20^{\circ}$ latitude both are significantly different from the differential rotation of the long-lived sunspots (Newton and Nunn, 1951) used as an input into the computations.



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# LARGE-SCALE PHOTOSPHERIC MAGNETIC FIELD: THE DIFFUSION OF ACTIVE REGION FIELDS

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## Introduction

The large-scale photospheric field has a differential rotation (Wilcox and Howard, 1970) that differs significantly from that of the long-lived sunspots analyzed by Newton and Nunn (1951). Furthermore, the large-scale photospheric field, aside from exhibiting a differential rotation pattern, shows variations that are suggestive of rigid rotation with a period of 27 days (Bumba and Howard, 1969, and Wilcox, et al., 1970.) Spectroscopic observation of the differential rotation by Howard and Harvey (1970) shows considerably different results from those of Newton and Nunn (1951).

A magneto-kinematic model of the solar cycle has been developed by Leighton (1969). Leighton (1964) proposed that the radial component of the photospheric magnetic field is dispersed by a random walk resulting from the supergranulation motions. The present paper investigates whether the Leighton (1969) mechanism is able to account quantitatively for the formation of the large-scale patterns of the photospheric field.

Certainly other models for the solar cycle could also be tested. Alfven (1945) developed the first magnetohydrodynamic model of the solar cycle. Cowling (1953), Babcock (1961), Parker (1955, 1970), and Steenbeck and Krause (1969) have all contributed significantly to our understanding of the sun's dynamo.

## Analysis

In the present investigation we compute the photospheric magnetic field using observed active regions as sources of the field. The random walk mechanism and the shearing effects of differential rotation are applied to the resulting magnetic flux. This computation is applied over ten consecutive solar rotations. The resulting magnetic field patterns are compared with the photospheric field observed at the same time with the Mount Wilson Observatory solar magnetograph.

The field was computed as follows. The flux from active regions was placed within areas of the photosphere extending $40^{\circ}$ in longitude by 0.4 units in the sine of the latitude in one case, and within $20^{\circ}$ by 0.2 units in a second case. The large area allowed a more exact representation of the tilt of the magnetic axis of each sunspot group. The smaller area more closely represents the actual size of an active region. No significant difference was found between the results of the two cases. Only the results obtained from considering the larger area will be discussed here. The strength of each observed active region was represented by numbers varying from 1 to 5, such that the flux was proportional to the square of the number. Thus fluxes of equal and opposite strength proportional to the square of this number were placed in each active region. The active regions were placed in position in Carrington rotations 1421 to 1430 (November 1959 - August 1960), on a grid system of $10^{\circ}$ in longitude and 0.1 in sine of latitude. Initially the photospheric magnetic field was set equal to zero. For each Carrington rotation consecutively the effects of the random walk mechanism and of the shearing due to differential rotations were applied. The input differential rotation for the computation was from Newton and Nunn (1951), which is shown as the solid curve in Figure 4.

## Results

Figure 1 shows the polarity of the computed field for four rotations. Initially the polarity of the computed background field (that field present at a particular solar rotation excluding the new active region field added during that rotation) forms irregular patterns. This is seen in Figure 1 for rotations 1422 and 1423, which are near the start of the analysis. During the initial three rotations the computed flux increases. Eventually, however, the diffusion and differential rotation processes cause merging of magnetic flux, thus tending to partially cancel the new flux added. Thus the flux level increases to a value where the flux merging process and the added flux cancel. When this happens the computed flux forms more stable patterns which slowly vary depending upon the new flux added. The patterns seen in rotations 1429 and 1430 have a characteristic backwards "C" shape, similar to the "UMR"s (Unipolar Magnetic Regions) and ghost "UMR"s discussed by Howard (1967). Thus the calculated background field appears to show some of the qualitative behavior of the observed photospheric field (see Howard, et al., 1967).

A quantitative comparison may be obtained by examining correlations of the observed photospheric field and the computed field. Figures 2 and 3 show autocorrelations of the observed photospheric field and the computed field. Correlations for each $5^{o}$ in latitude are shown for heliographic latitudes from $40^{o}$ south to $40^{o}$ north. For each latitude the horizontal line adjacent to the label on the left represents a correlation coefficient of 0., the horizontal line above it represents a correlation coefficient of 1.0 and the line below it a coefficient of -1.0. The autocorrelations of the observed and computed photospheric fields are similar, with major peaks at approximately every 27 days at almost all latitudes. The recurrence peaks have a narrow width near the low latitudes and a broader width at the higher latitudes. The sizes of the peaks are also comparable. The positions of the subsidiary peaks do not correspond, indicating that although the large-scale patterns are somewhat similar in the two analyses, the smaller scale features are not.

Cross-correlation of the observed and computed fields results in a small but positive correlation at all latitudes. It is not possible to decide whether the lack of closer agreement is due to insufficient accuracy in assignment of source strengths and positions or to some shortcoming in the model.

We now make a quantitative comparison of the differential rotation of the computed field and of the observed field. Figure 4 shows the differential rotation of long-lived sunspots (solid curve from Newton and Nunn, 1951), the field observed with the Mount Wilson Observatory solar magnetograph (open circles) and the computed field (solid squares). At latitudes poleward of $20^{\circ}$ there is good agreement between the differential rotations of the computed and the observed photospheric fields, and both are significantly different from the differential rotation of long-lived sunspots that was used as an input in the computations. The model thus seems to modify the differential rotation of the assumed source of photospheric fields (sunspots and active regions) in a manner in agreement with observation of the large-scale photospheric fields. The fact that the rotation curve for the model falls below the Newton-

Nunn curve at all latitudes is not expected on the basis of the random walk model, but small displacements as a function of latitude might result from the rotation-by-rotation method of computations.

The lack of agreement in the structure of the subsidiary peaks in Figures 2 and 3 indicates that the smaller scale features are not well represented in this analysis. This may indicate: 1) that the active region fields are not being properly represented; 2) that the interval of the analysis (ten solar rotations) is not sufficiently long to allow the solution to reach equilibrium; 3) that other sources of magnetic flux exist (nonactive region sources or regions that appear and decay on the hidden side of the sun); or 4) that other processes are occurring which are not being accounted for in the model.

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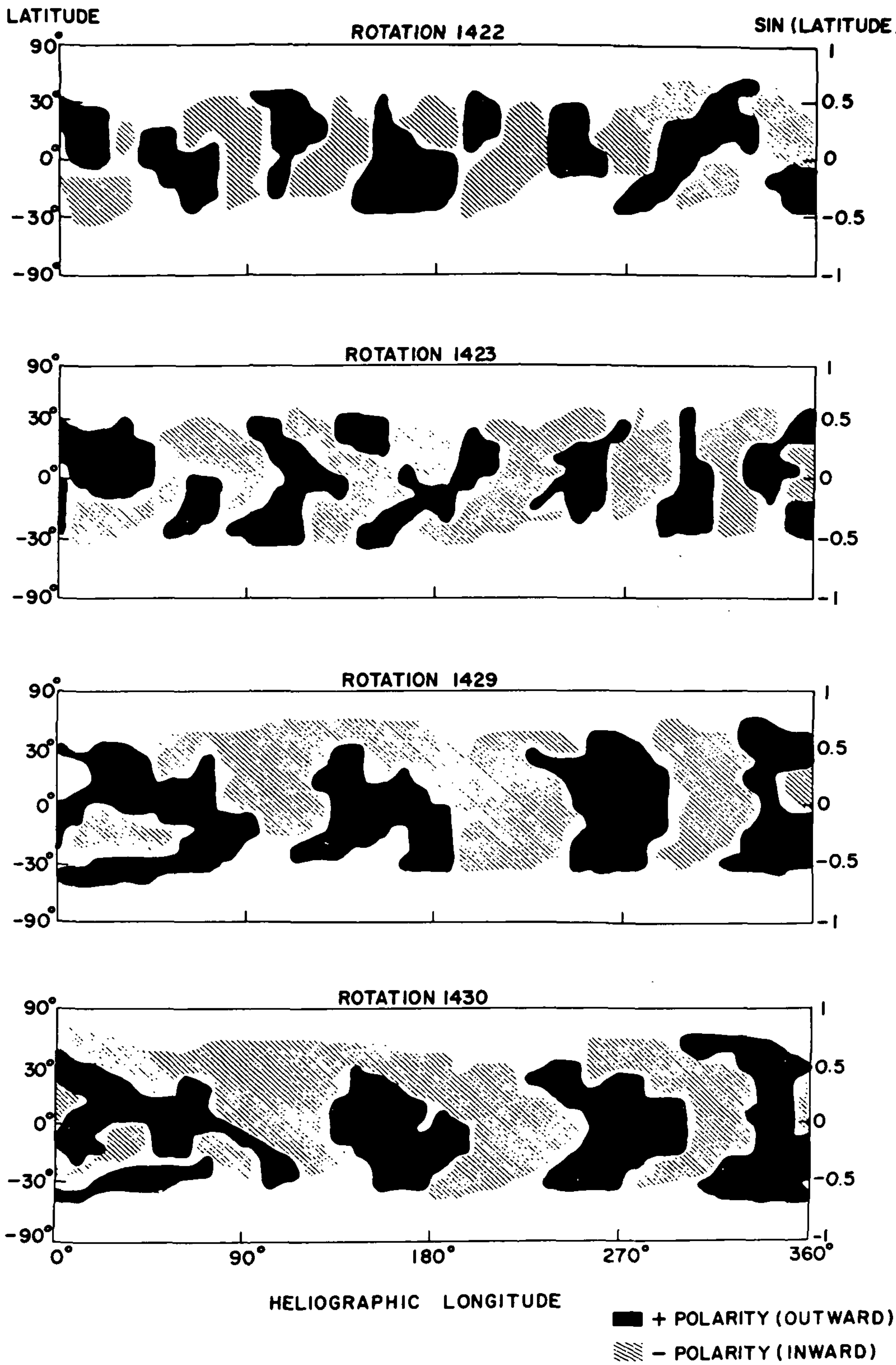


Figure 1. Polarity of the computed background photospheric magnetic field for Carrington rotations 1422, 1423, 1429, and 1430.

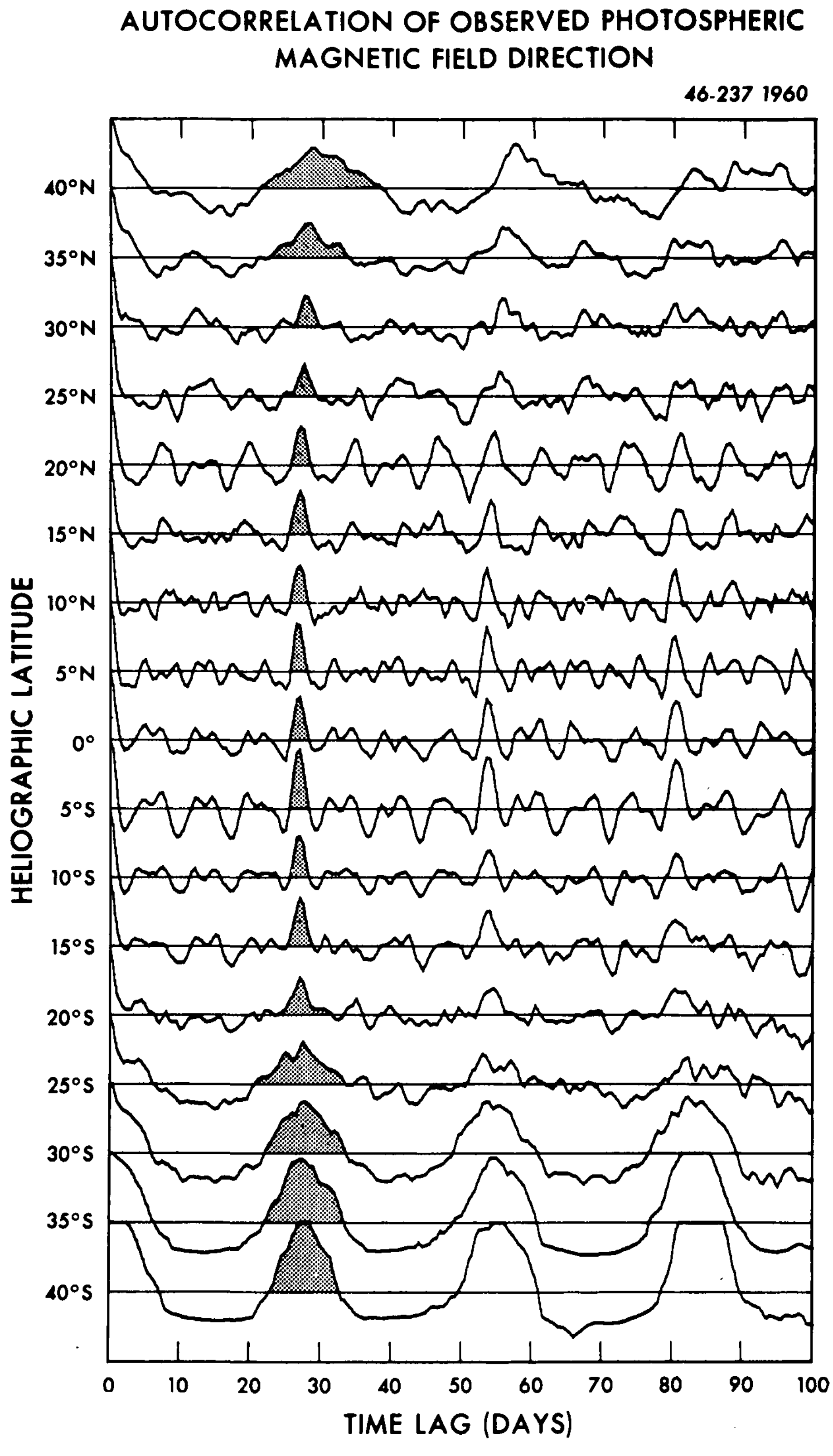


Figure 2. Autocorrelations of the observed photospheric magnetic field as a function of time lag for latitudes 40° N to 40° S. For each latitude a correlation of 0.0 is represented by the horizontal lines associated with it. A coefficient of 1.0 is represented by the line above, a coefficient of -1.0 by the line below. The peaks plotted in Figure 4 are indicated by shading.

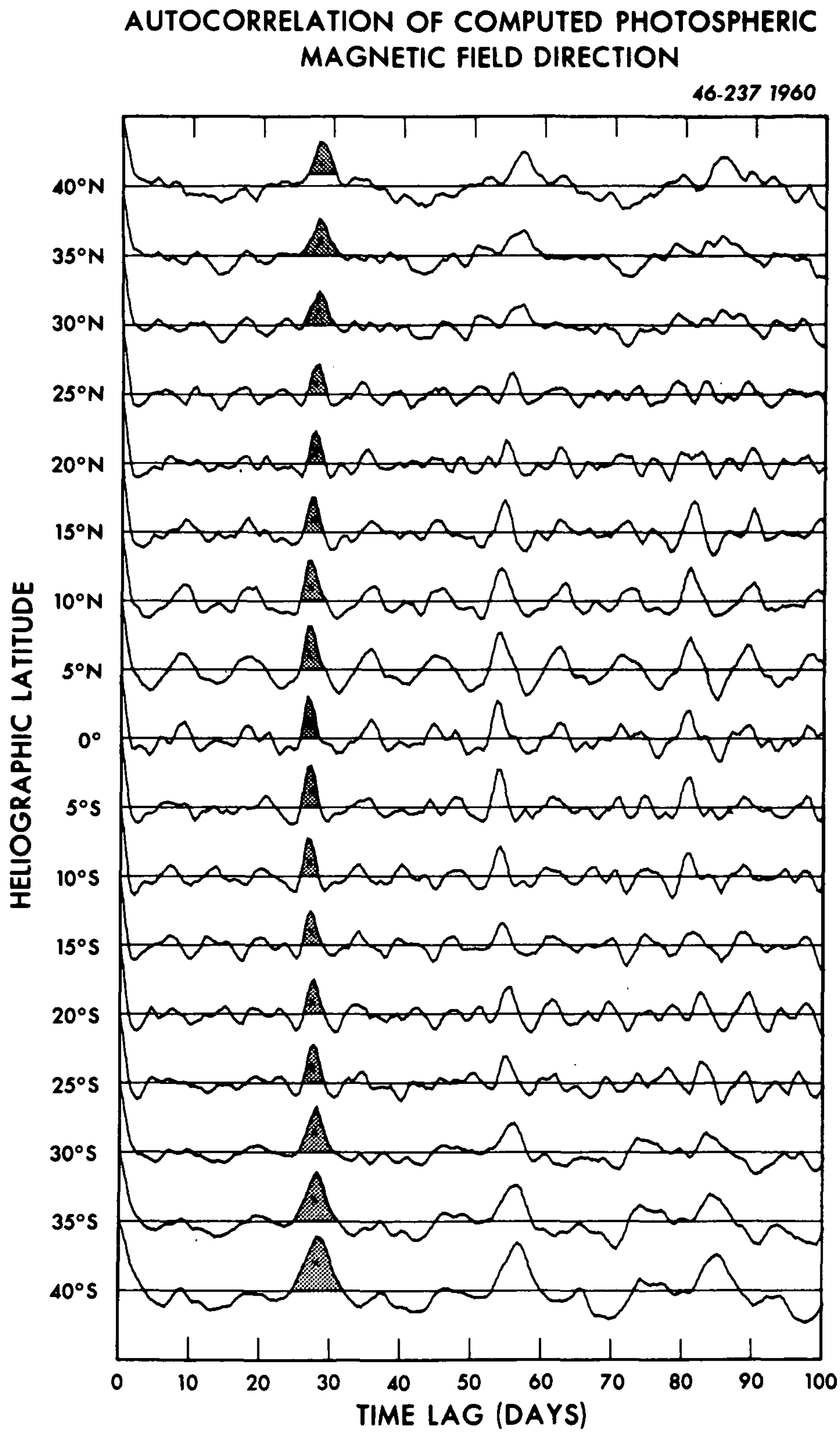


Figure 3. Autocorrelation curves of the computed photospheric magnetic field in the same format as Figure 2.

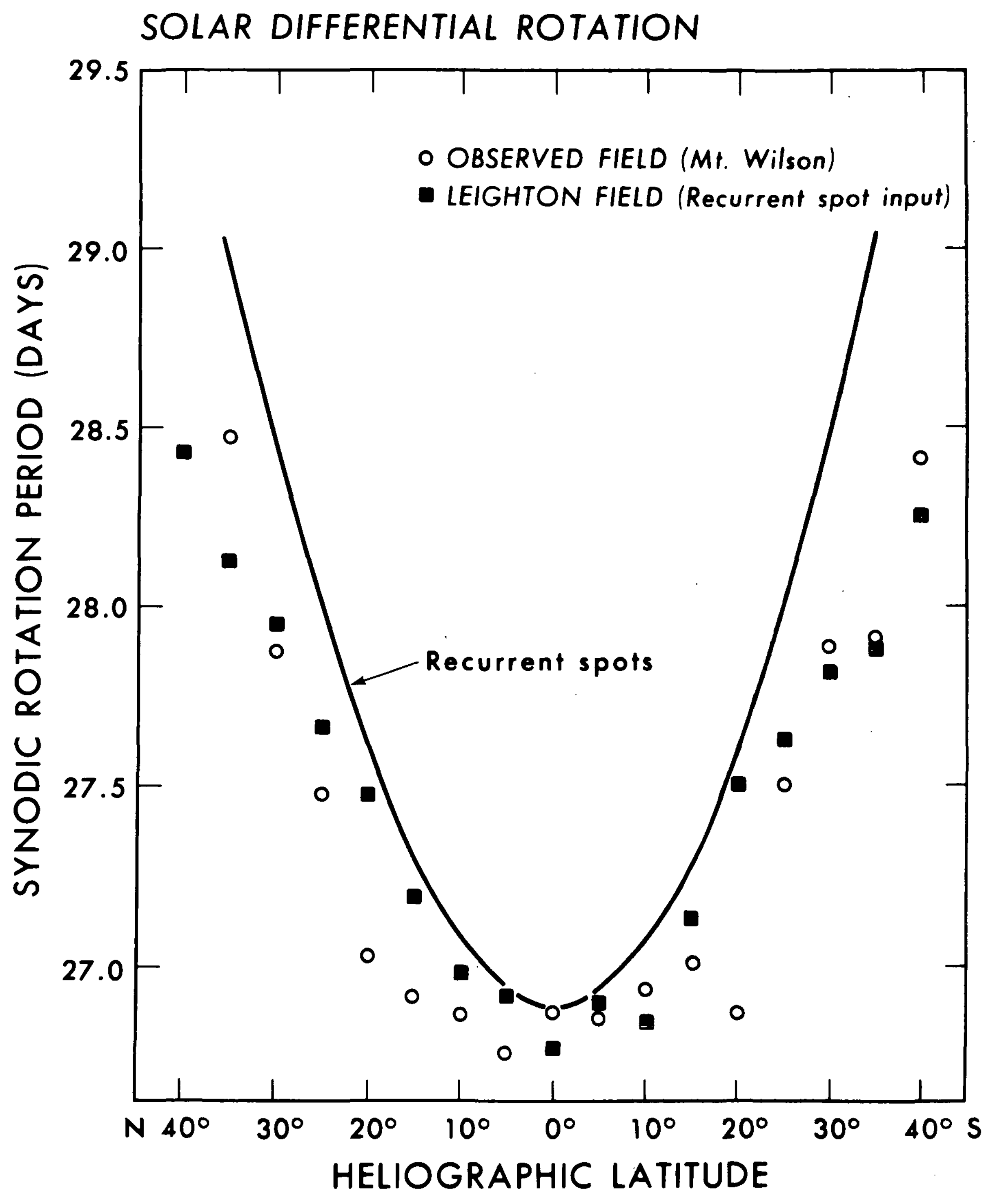


Figure 4. Differential rotation curves of long-lived sunspots (Newton and Nunn, 1951) solid curve; the observed photospheric field from the autocorrelation peaks in Figure 2 (open circles), and the computed photospheric field from Figure 3 (solid squares).