STUDIES OF SOLAR MAGNETIC FIELDS

I: *The Average Field Strengths**

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(Received 15 May; in revised form 22 July, 1974)

Abstract. The telescope, spectrograph, and magnetograph at the 150-ft Tower Telescope are described, and a chronology of changes in the instrumentation is given. The average magnetic field strengths over the last seven years are discussed. The changes in polarity at the poles of the Sun are described. The characteristics of these polarity reversals at both poles are similar. A reversal is not seen in the sunspot latitudes ($\lesssim 40°$) but is observed to start in the 40–50° zone and proceed slowly poleward, reaching the pole within 12 to 18 months. At the time of the polarity reversal at the pole, field strengths over a large portion of the disk show similar behavior. Rapid changes of solar magnetic fields over large portions of the solar disk are discussed. Two possible models are suggested to explain the frequent 'monopole' appearance of the solar fields. The poleward drift of the magnetic field reversals in each hemisphere was not closely in phase with the polar filament migrations or the variations in mean latitude of high-latitude coronal activity. The behavior of the low-latitude field strengths with phase in the cycle follows earlier correlations of activity with predominantly negative magnetic fields.

1. Introduction

The principle of the modern solar magnetograph was first developed by Babcock (1953). At that time regular observations of full-disk magnetic fields were started in Pasadena. Since the Summer of 1957 such observations have been obtained at the 150-ft Tower Telescope at Mount Wilson. The early Mount Wilson system was described by Howard and Babcock (1960).

Starting late in 1966, the magnetograph signals have been digitized and recorded on magnetic tape for subsequent analysis on a digital computer. Since that time the data have been preserved both as raw data and in a condensed format.

This paper will describe the instrument, the data system, and the reductions of the magnetic data. In addition, the average magnetic fields as a function of latitude and time will be described and discussed.

2. The Instrument

2.1. The telescope and spectrograph

The 150-ft Tower Telescope has been described in detail elsewhere (Hale and Nicholson, 1938). The objective lens was a 30-cm achromatic air-spaced doublet, *f*/150. (On December 16, 1971, a new cemented triplet apochromat was installed – also 30 cm, *f*/150.) Above the lens is a coelostat mirror system. Fused quartz coelostat and second flat mirrors were replaced by cervit mirrors on November 7, 1970. Image size: 42 cm.

* For Part II: *The Magnetic Flunes*, see this volume, pp. 59–67.

Solar Physics **38** (1974) 283–299. *All Rights Reserved*

The spectrograph is a 22.5-m *f*/150 Littrow type in a vertical pit. The original Littrow lens was an air-spaced doublet – replaced on June 8, 1971, by a cemented triplet apochromat. Both the new objective and the new Littrow lenses were designed by I. S. Bowen. The dispersion is provided by a Babcock grating, 16×26 cm, 610 grooves mm^{-1}, blazed in the fifth order green. Dispersion in the fifth order is 11 mm $Å^{-1}$, This grating was installed in December, 1962.

Beause the spectrograph is located in a deep pit, the air is extremely steady, and the spectrograph seeing is negligibly small. Very slow low-amplitude wavelength drifts may result from variations in barometric pressure or other unknown causes.

2.2. The Guider

Guiding of the 42-cm image is done near the focus. A guiding ring slightly larger than the image supports four small boxes at separations of 90° around the circumference. These light-collecting boxes may be moved in the radial direction so that each intercepts only a small amount of light near the solar limb. The length of each box along the limb is 125″. Fiberoptic bundles transmit the diffused light within each box to a photocell nearby. The light from each pair of boxes along an image diameter is aimed at the photocathode of one tube, and a mechanical chopper admits the light alternately from one or the other box. This provides an a.c. error signal when the image is not centered on that axis. A servoamplifier nulls this signal by running a servomotor to tip slightly the second flat mirror at the top of the tower, and thus correct the image position. Care must be taken that the image motion introduced by tipping the mirror is parallel to the axis defined by the corresponding light-collection boxes near the image. This system has the advantage that the image position does not depend on the brightness of the image. In practice, the light boxes subtract only five or ten arc secs from the image at the limb. Image motion for scanning with the magnetograph is accomplished by translating the guiding ring in a two-axis system. This guider was installed in the summer of 1965.

2.3. The Magnetograph

The solar magnetograph at the 150-ft Tower Telescope is basically the same as that described by Babcock (1953). In place of the glass block beneath the exit slits to compensate for the Doppler motion of the spectrum line, the exit slit assembly is mounted on a precision screw, and the Doppler servo keeps the spectrum line centered on the exit slit by translating the slit mechanism. The digital Doppler signal comes from a shaft encoder coupled to the screw.

In the original version of the Mount Wilson magnetograph, which was used for two years starting in the summer of 1957, the field was mapped on a cathode-ray tube in the same manner as was described in the original Babcock (1953) paper. In the summer of 1959 a new display device, also using a CRT, was installed (Howard and Babcock, 1960). The new display was considerably simpler to interpret than the original one, but still in complicated active regions it was often difficult to see the magnetic patterns.

The display was again improved in June, 1963 with the installation of an X-Y servo-plotter with two colored pens. In principle, many levels of both polarities could be distinguished with this instrument, and it was quite effective for large-scale fields in quiet regions. However, in active regions it was still often difficult to detect complicated magnetic patterns. The *Atlas of Solar Magnetic Fields* (Howard *et al.*, 1967) consisted of synoptic charts drawn mostly from these X-Y plotter observations.

In order to provide a better display of the magnetic-field distribution and to preserve the quantitative data for subsequent analysis, a digital data system was installed in 1965. The first regular observations with this instrument were obtained in the summer of 1966. This system provides digital magnetic, velocity, intensity, position, and time signals. The observer selects an integration time which is available in steps from 0.1 to 10 s. The signals from the magnetograph amplifier are converted to electrical pulses during this interval by voltage-to-frequency converters, and these pulses are counted and scaled to give the digital signals. The velocity signal comes from a shaft encoder on the screw that drives the exit slit as described above, and is read by the data

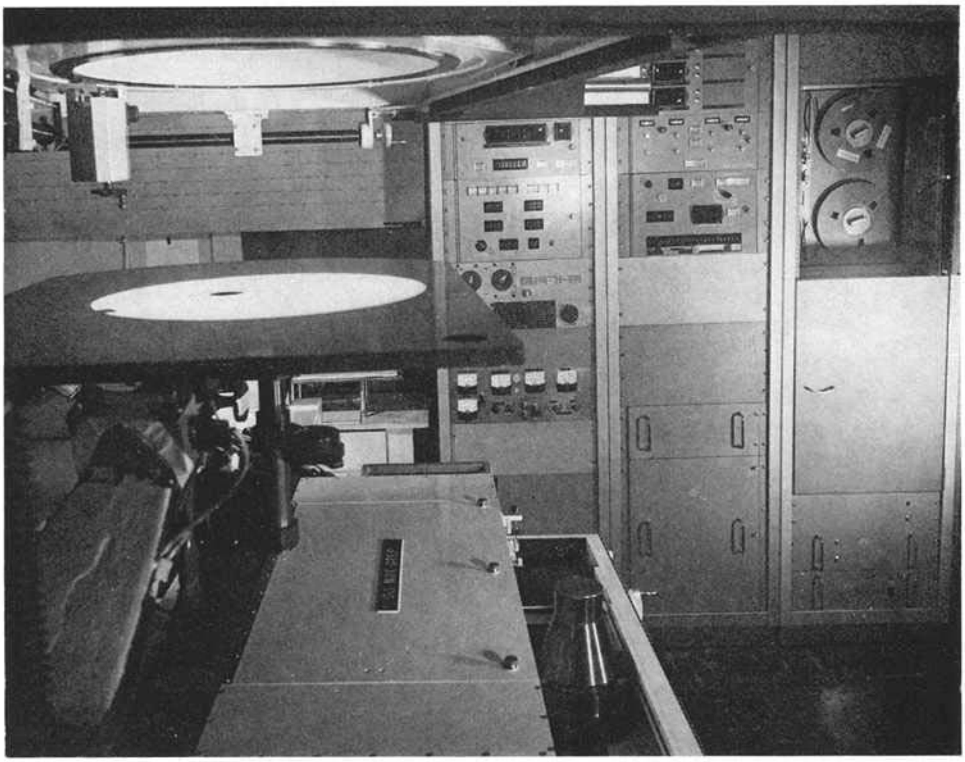

Fig. 1. A view of the observing room at the base of the 150-ft Tower Telescope at Mount Wilson. The solar image is formed on the table at the left. The guiding ring is seen in the upper left above the image, and the lead screws that move the image may also be seen. The light from a portion of the image passes through a hole in the center of the table and through the analyzing crystal to an image slicer. The exit slit assembly is in the white box in the lower center. The electronic racks seen on the right contain the magnetograph amplifier, digitizing circuits, and tape recorder as well as the scan control logic.

system at the end of each integration interval. These data are then recorded on magnetic tape for later analysis. Portions of this system have been described already (Howard *et al.*, 1968). Figure 1 shows some of the instrumentation at the focus of the 150-ft Tower Telescope.

In recent years the noise level of the magnetic signal has been less than 2 G. Figure 2 shows a 2-G magnetogram. This observation was selected at random and is typical of recent data. Clearly most of the 2-G features are real, as can be seen from the large-scale pattern that is evident. Such patterns are reproducible from observations on the same day or on sequential days. We do not publish 2-G magnetograms regularly –

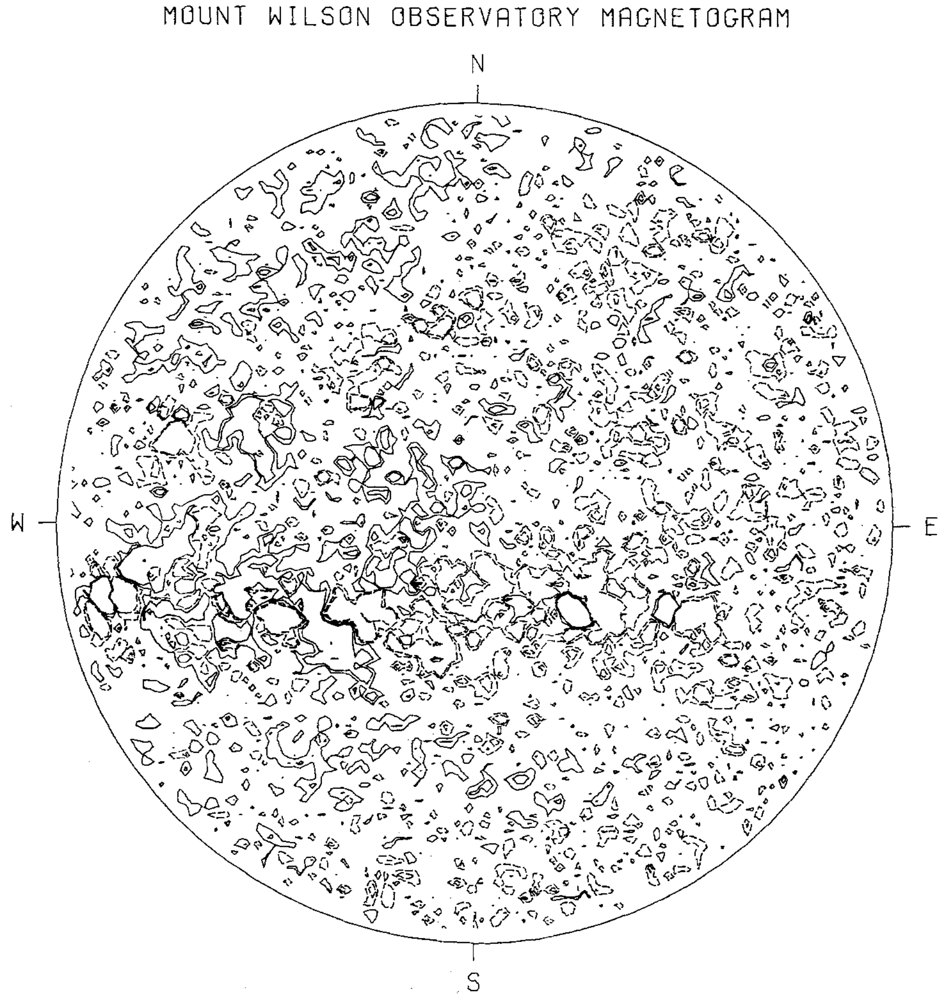

Fig. 2. A computer-plotted isogauss magnetogram for February 16, 1974. Solid lines represent positive magnetic fields (magnetic vector pointed toward the observer), and dashed lines represent negative fields. The Gauss levels are ± 2 and ± 5 G. The scanning aperture was 17″ square. The spectrum line used was Fe I λ5250.2, and the time of the observation was 15.9–17.4 UT. The pole markers represent the rotation pole of the Sun.

5 G is normally the lowest level – because it is difficult to discern the active regions on a 2-G plot. Figure 3 shows a normal plot made for the same day as the plot in Figure 2.

Raster scanning of the solar image is accomplished by moving the guiding ring in a raster pattern. A digital logic system uses parameters entered by the observer at the

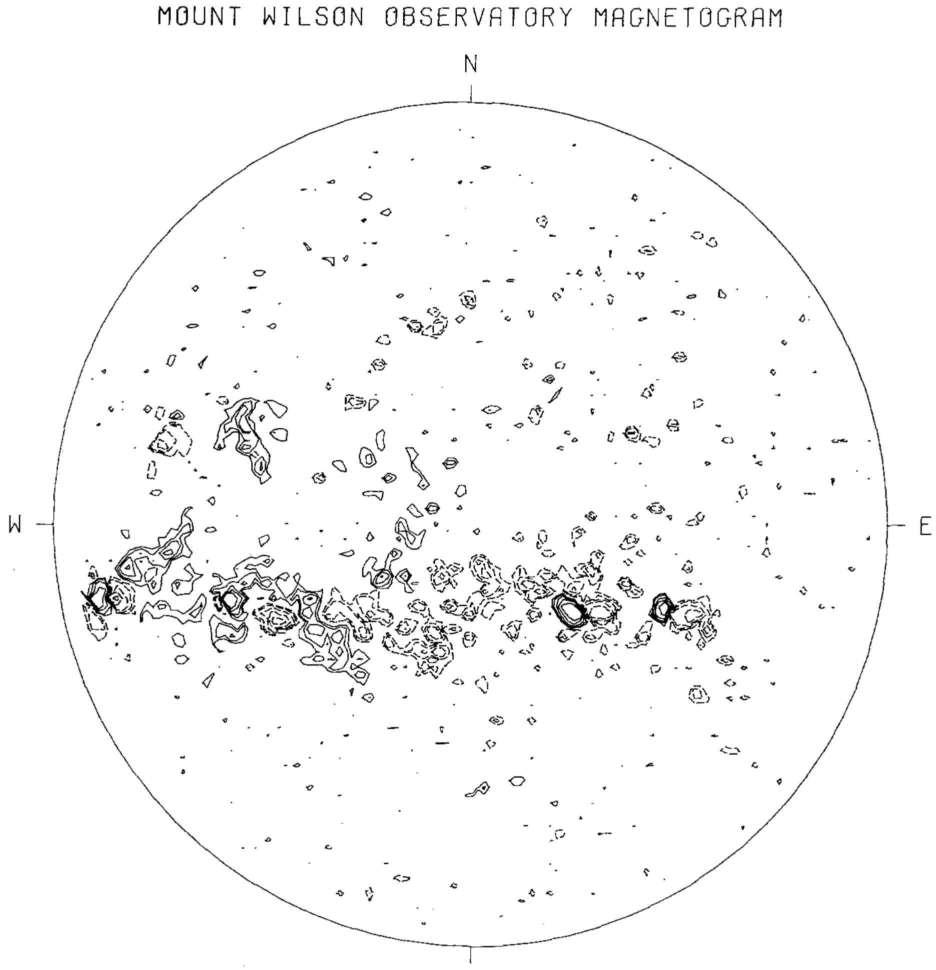

Fig. 3. A computer-plotted isogauss magnetogram for February 16, 1974. This is from the observation as Figure 2, but the isogauss levels are ± 5, ± 10, ± 20, ± 40, and ± 80 G.

front panel of the instrument to construct the raster pattern. The speed, step size, and scan limits are entered before each observation. Control of the scan is by means of three buttons which enable the observer to start, hold, and stop the observation – both scanning and data collection. The hold is a temporary stop, for example for clouds.

An image slicer is located at the focus of the telescope so that a square aperture may be used. The size of this aperture was 23″ until mid-July, 1966, after which it was

17.5″. The separation of the raster scan lines is the same as the aperture size so that the whole solar disk is covered.

A normal magnetogram observation is run with an integration interval of 0.4 s and a scanning speed of about 35″ s^{-1}. In this way the full disk of the Sun is scanned in about 90 min of time, and about 11 000 data points are accumulated.

Calibration of the magnetic signal is obtained with essentially the same technique used in the early days (Babcock, 1953). A circular polarizing analyzer is inserted before the KD*P crystal, which cuts out one of the Zeeman components and gives an a.c. signal for a line shift. Then a known shift of the spectrum line is introduced, and the difference in the Zeeman readings for the two line positions may be used to calibrate the signal. The zero setting of the magnetic signal is obtained by covering the aperture and adjusting the Zeeman signal to zero voltage by balancing the amplifier outputs from the two channels. The line-shift calibration is done by measuring the difference between the positions of two spectrum lines with the Doppler encoder readout. This is essentially a measure of the spectrograph dispersion, which shows only slight seasonal variations. The information from the calibrations is entered into the system in a digital form and is written by the system on the magnetic tape as the first record of an observation. Included in this record are the date, observer identification, and other similar information.

The first exit slit arrangement was described by Babcock (1953). This was replaced in April, 1966 by a new system described by Howard *et al.* (1968). Prisms intercept the light from the spectrograph and deflect it to the sides. Slit size is determined by the separation of the prisms and the location of the masks. Light from these long prisms is then deflected downward and focussed on the photocathodes by lens-prism combinations. The photomultipliers are 1P21 tubes, which have S-4 photocathodes.

The spectrum line λ5250.2 Fe I has been used almost exclusively in recent years for the daily observation. All the data used for this analysis have come from this line. Al measurements are of the line-of-sight component of the magnetic field.

3. Data Reduction

The data from each observation are written on a magnetic tape. Normally about a week is required to fill a tape with data, then the tape is transported to Pasadena for the data reduction. The analysis is done with a digital computer.

The magnetic signal is converted to Gauss units using the calibration information written in the first record of the observation. A magnetogram plot is drawn by the computer. An example is shown in Figure 3. These magnetograms are published monthly in the bulletin *Solar-Geophysical Data* by the Environmental Data Service of the U.S. National Oceanic and Atmospheric Administration. Computer-drawn synoptic charts are published in the IAU *Quarterly Bulletin on Solar Activity*.

The velocity data are reduced at the same time to determine the differential rotation of the Sun. This process is described in detail in the paper presenting the first results (Howard and Harvey, 1970).

As a regular part of the reduction program for each day's observation, various quantities derived from the raw data are averaged or totaled over a number of latitude zones in each quadrant. These data are then punched on data cards and stored for later analysis. For each quadrant (defined by the central meridian and the equator) the latitude zones used were: equator to 40°, 40° to 50°, 50° to 60°, 60° to 70°, and 70° to the pole. The quantities punched on cards were: the total positive magnetic flux, the number of data points contributing to the positive flux, the total negative flux, the number of these data points, the average magnetic field strength, and the total number of data points contributing to this average field.

All of the data cards generated in this way are routinely saved; however, before the start of this analysis a small amount of hand editing was done. This consisted of discarding from the deck those cards representing days for which an examination of the magnetogram indicated clearly that the quality of the observation was poor. This represented only a few percent of the total number of observations.

No corrections were made to these data except for the usual correction for brightness. In particular, the effects of any inclination to the line of sight of magnetic fields were not accounted for. The effects of weakening of the Fe I $\lambda 5250$ line in magnetic regions (Howard and Stenflo, 1972) were also not accounted for. This amounts to a correction of approximately a factor 2 at the disk center, i.e., the measured fields are too weak by nearly a factor 2.

In general the quality of the data improved steadily with time. It is difficult to establish the errors precisely, but probably in the later years the accuracy of a single magnetic field determination was around 10 or 15%. The zero level is also an important quantity that is even more difficult to ascertain. Inspection of magnetogram plots reveals that from time to time the fields over most or all of the solar surface seem biased toward one polarity by as much as 1 or 2 G. But such observations are rare, and for the vast majority of cases the zero error is much less than that. Plots such as that shown in Figure 2 indicate that for most days the zero uncertainty is less than about 0.3 G. For data averaged over some time interval, the zero uncertainty should be less than that unless there are systematic effects.

Since the results presented in this paper refer to fields integrated over relatively large zones of solar latitude and longitude, the effect of the large (17.5″) aperture used is negligible. In fact, for the purpose of this paper it would have been more efficient to observe with a much larger aperture. The average field strengths presented here almost certainly represent rather good averages of the true fields. Naturally if some magnetic elements have larger field strengths than others, and there is considerable magnetic saturation because of the splitting of the line profiles, then the simple correction determined by Howard and Stenflo (1972) does not apply, and the situation is much more complicated. In this case all magnetograph measurements made with apertures larger than the tiniest magnetic elements may be in error. But it seems unlikely that this could be the true situation, and evidence presented by Howard and Stenflo (1972) suggests strongly that the field strengths are rather uniform.

Sunspots contribute very little to these mean fields for several reasons. From the observational aspect, they are dark and have widely split Zeeman profiles. In any case, they are short-lived compared to the other magnetic features and simply do not contribute much to the integrated fields. A typical value for the total measured flux of the Sun over the visible disk ($|F_+|+|F_-|$) for the period of these observations is 5×10^{23} Mx. During the same period a typical value for the umbral area of sunspots is 500×10^{-6} of the visible hemisphere. For an average spot field strength of 1000 G, this corresponds to a total flux of 3×10^{22} Mx, or about 6% of the total soltar flux.

The fields measured below 40° latitude will be strongly influenced by active-region (plage) magnetic fields. The fields poleward of 40° will consist of old remnants of these active region fields.

4. Average Magnetic Fields

Average magnetic field strengths over various portions of the solar disk are easily computed and constitute a simple means of visualizing an important parameter of the field distribution. Field strengths averaged over the polar regions have been discussed recently (Howard, 1972). The same raw data have been used in computing the field lines in the potential approximation for the *Atlas of Coronal Magnetic Fields* (Newkirk *et al.*, 1973). In a related analysis, the Legendre polynomials from a harmonic analysis

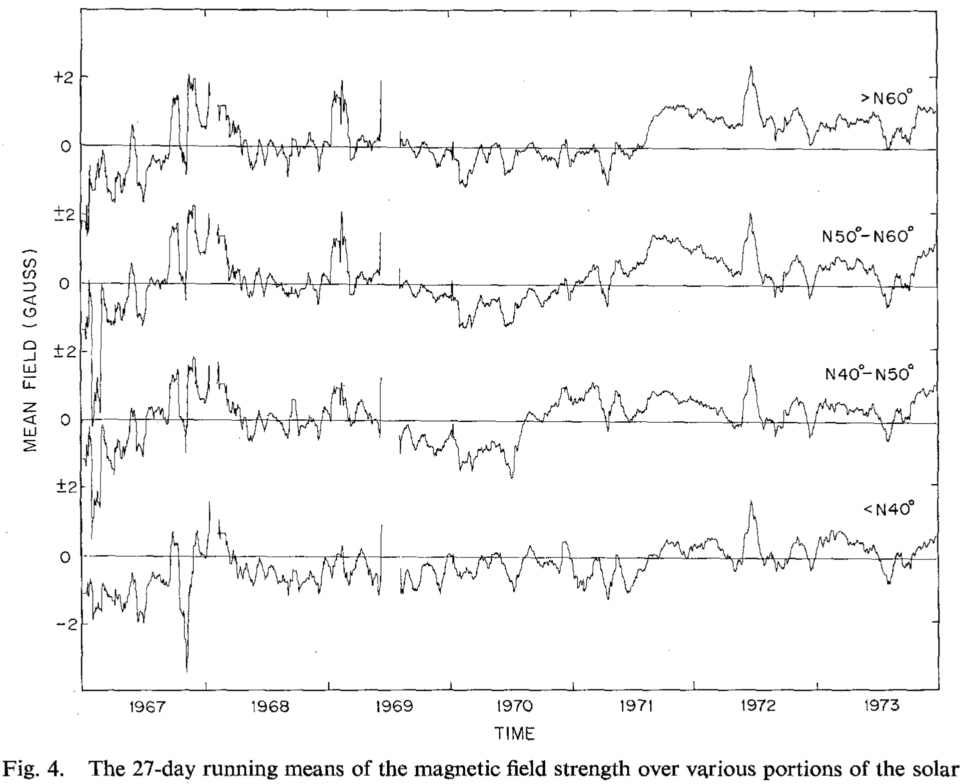

Fig. 4. The 27-day running means of the magnetic field strength over various portions of the solar disk in the northern hemisphere.

for the solar surface give results that are in good agreement with the average field data (Howard *et al.*, 1974).

Figures 4 and 5 show the average magnetic fields as functions of time for the various latitude zones. The field averages are running means over 27 days.

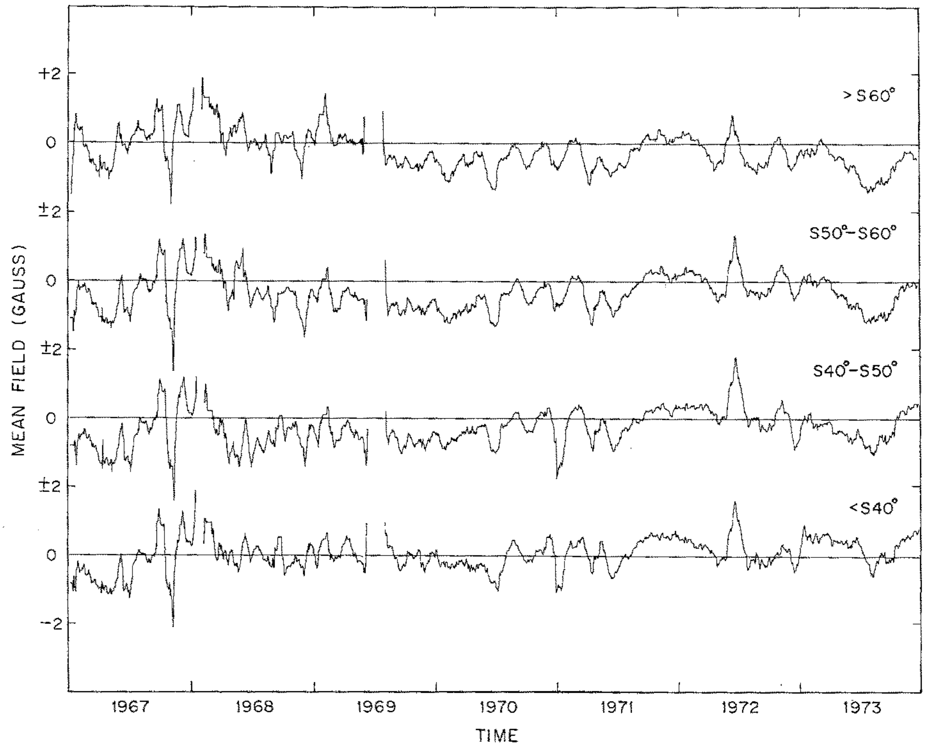

Fig. 5. The same as Figure 4 but for the southern hemisphere.

At times the fields appear to behave in the same way over the entire solar disk or a large portion of it. An example of this is the large positive 'spike' in the middle of 1972. This actually is caused by only a handful of days' observations in which there was a strong positive bias. The 27-day running mean has stretched this into a larger feature. There was no reason to reject the data from these days except that the fields were strongly positive. In general, data were omitted from this study only when it was clear that instrumental problems had affected the results. Thus features such as that in the middle of 1972 may or may not represent what was on the Sun, and the fact that they appear in the figures in this paper does not insure that they represent the Sun. In the past similar appearing biases in polarity of the solar magnetic field have at times been coincident with biases in the interplanetary magnetic field (Wilcox, 1972), which at least suggests that such events could be real. Sudden variations in magnetic field strength over large portions of the solar surface have been observed since the earliest observations (H. W. and H. D. Babcock, 1955). This phenomenon has been discussed by Severny (1971). We seem to be no closer to an explanation of this effect now than we were 20 yrs ago.

4.1. Activity-cycle-related field sign reversals

An earlier paper (Howard, 1972) described the high-latitude sign reversal in the northern hemisphere. Now that more time has passed and more data have accumulated it is possible to view this sign change with more perspective.

It does indeed appear that the fields poleward of N60° latitude made a significant and rather permanent change of sign around August, 1971. Before that time these fields were weak and variable. They had been largely positive for a period of about six months centered on the start of 1968, and there was another positive surge around the start of 1969. This latter sign change was seen in the northern high latitudes only and lasted for about two months.

The August, 1971 sign reversal poleward of N60° was preceded by a more gradual reversal in January, 1971 in the 50–60° zone. In the 40–50° zone in the north, the sign reversal took place in about September, 1970. There is no comparable sign reversal to be seen in the zone equatorward of 40°. Thus the polar sign reversal started in the 40–50° zone and took nearly one year to reach the zone poleward of 60°. Figure 6 shows the northern zones 60–70° and >70°. There is about one month separating the polarity reversal in these two zones.

The polarity reversal in the zone above 70° in the north was accompanied by a rather general positive surge in fields in all latitudes, even in the south.

No south polar field reversal was reported in the earlier paper (Howard, 1972). Somewhat later I reported the reversal of these fields in early 1972 (Howard, 1973). This reversal can be seen in Figure 5, but after an examination of this plot for the entire interval, I conclude that there is instead evidence, albeit weak, that the real activity-cycle related polar field reversal in the south was in mid-1969. This reversal has the same characteristics as the reversal more than two years later in the north. The actual field reversal (to negative polarity) poleward of 60° in the south occurred in about June or July, 1969. The exact date is hard to determine because of a large gap in the data at that time caused by instrumental problems. The reversal in the 50–60° zone occurred in about June, 1968, and in the 40–50° zone in about March, 1968. It is not clear whether there was a comparable change for the fields equatorward of 40° in the south. These fields certainly did not become very negative during this period. Figure 6 shows the >70° and 60–70° zones for this period, and, as in the north, the higher-latitude reversal followed the lower-latitude reversal. The polar fields in the south were strongly negative in early 1967 and went positive occasionally following the reversal, so the situation is not as clear as in the north. If this truly represents the south polar field reversal, then the south polar field reversed significantly earlier than did the north polar field, which was also the case at the previous solar maximum (H. D. Babcock, 1959).

Stenflo's (1970) detailed study of the small-scale fields in the polar regions referred to the interval in the summer of 1968, which was during the course of the polarity

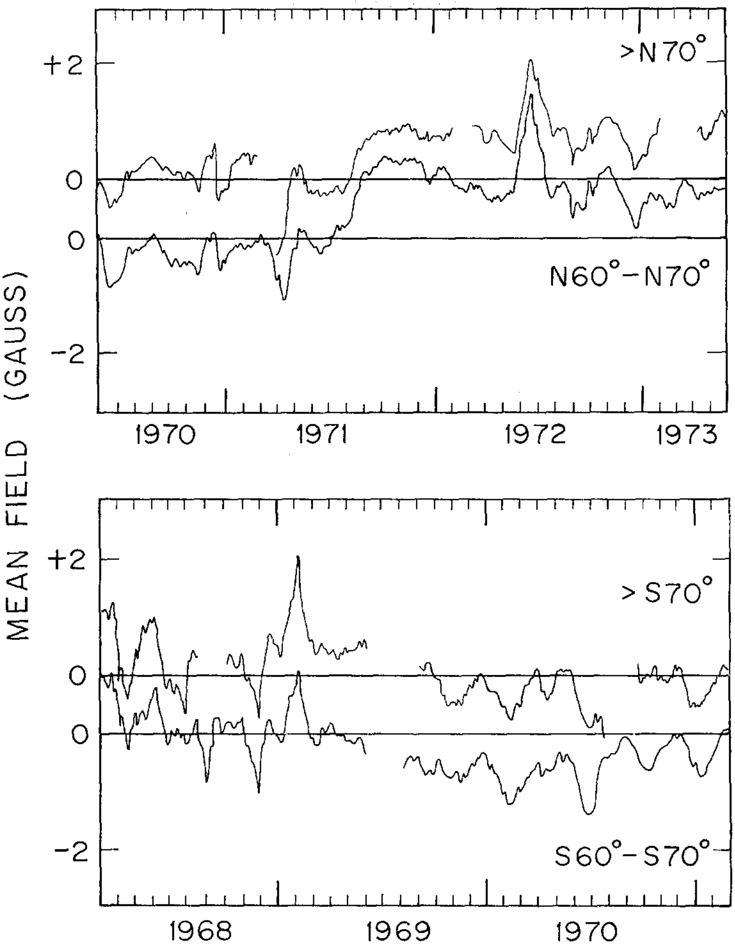

Fig. 6. The 27-day running means of the polar fields in the north (top) and south (bottom). The intervals are chosen to show the times of polarity reversal.

reversal in the south. It is clear now that when the high-latitude fields are as weak as they have been in this cycle one must examine data over a very long period of time to be certain when a reversal has taken place.

A further similarity in the south with the later field reversal in the north is the general tendency for high-latitude fields in both hemispheres to show a negative surge about the time of the south field reversal. This is not so marked as for the north polar field reversal and not so sudden, but the same tendency is clearly there. Equatorward of 40° this is not seen, or only very weakly.

There is only very weak evidence from Figures 4 and 5 that there is any polarity reversal equatorward of 40° that is comparable with the high-latitude reversal. Any such reversal that might be present is largely masked by the short-term variations seen over wide latitude ranges.

4.2. The seven-year averages

In view of the strong variability of the average field strengths in all parts of the solar disk during the seven-year period under consideration, it may not be very meaningful to examine the average field strengths integrated over the entire period. In particular, this exercise might be moιe useful when we have an entire activity cycle over which to integrate. Nevertheless Table I gives the full-period averages for each of the latitude zones. The total number of observed points for each zone is also listed. The total number of observed points for the whole interval is somewhat over 1.7×10^7.

From Table I we note that equatorward of 40° in each hemisphere the average field is the polarity of the leadings spots. In each hemisphere the polarity of the high-latitude fields is the one that was predominant after the polarity reversal. This is true even in the north where the change in polarity occurred at most latitudes well after the middle of the seven-year interval.

TABLE I

Average magnetic field strengths over the interval 1967–1973

	N		S	
Latitude	Ave. field (G)	No. of pts (1000)	Ave. field (G)	No. of pts (1000)
>70°	+0.166	98	−0.082	83
60°–70°	+0.250	313	−0.282	295
50°–60°	+0.194	610	−0.342	592
40°–50°	+0.113	949	−0.283	939
<40°	−0.200	6662	+0.053	6639

In the south the fields poleward of 70° and equatorward of 40° are quite weak – less than 0.1 G. In the north the field strengths in the same zones are relatively strong.

The average field strength for the whole solar disk for the seven-year period is +0.071 G. This mean value was found by weighting each average field strength by the number of points in that zone. Judging from Figures 4 and 5, it is probably fortuitous that the average for the entire period is so small. Certainly intervals of a few months can be found when the average fields at almost all latitudes are strongly positive or negative.

Note that in Table I there are more observed points in the north than in the south. This is simply due to the fact that the north latitudes of the Sun are tipped toward the Earth in the summer months when there are relatively more days during which the Sun can be observed from California. It is possible that an observational bias of this sort may affect other results reported in this and subsequent papers.

5. Summary and Discussion

5.1. Summary

The results of the analysis of average magnetic field strengths over various portions of the solar disk during the interval 1967–1973 may be summarized as follows:

(1) At times field strengths over large portions or all of the solar disk vary in unison. It is not possible at this time to establish which of such events may be due to instrumental or other non-solar causes.

(2) The north polar fields ($>70°$ latitude) changed sign from weakly negative to rather strongly positive in August, 1971.

(3) This high-latitude reversal was accompanied by a rather general positive surge in field strengths over the whole solar disk.

(4) Fields at successively lower latitudes in the north changed sign earlier, as if there were a positive 'wave' starting in the 40–50° zone and reaching the pole in about one year.

(5) No evidence could be found for a related reversal in the zone equatorward of N40°.

(6) In the south the same events occurred except that the reversal was a weaker one. The polar fields reversed in about September, 1969, and the 40–50° zone reversed in March, 1968.

(7) The average fields poleward of 40° in each hemisphere over the whole period have the sign of the follower spots, and the fields equatorward of 40° have the sign of the leader spots.

5.2. Global Field Changes and the Solar 'Monopole'

Sufficient evidence has accumulated from several observatories and from magnetic field measurements in interplanetary space to indicate that rapid fluctuations of solar magnetic fields on a large scale can occur, leading on occasion to what may appear to be a strong preponderance of one magnetic polarity over the whole Sun (cf. Wilcox, 1972). Such observations pose a difficult problem for theorists, but the fact that such observations exist does not necessarily imply that the Sun is indeed at times a magnetic monopole. Two models are suggested below which can explain the observations.

(1) Almost all magnetograph measurements are of the longitudinal component of the magnetic field on the Sun. All the observations reported here are longitudinal measurements. If fields of one polarity were inclined systematically toward the ecliptic more than the fields of the other polarity, we could see a strong bias in the fields.

(2) There is evidence that most magnetic fields on the Sun are confined to small areas where the field strengths are quite high (Howard and Stenflo, 1972; Frazier and Stenflo, 1972). If at times the field strengths depended upon polarity, the effects of saturation would differ between the two polarities, and we could expect on the average a bias in the net field strength.

In either case there remains the problem of explaining why the biased fields exist on a global scale. If the strong positive bias seen early in 1965 repeats itself at the next activity minimum, as suggested by Svalgaard (1972), then we will have an opportunity to examine an occurrence again within a few years.

A recent study by Stix and Wiehr (1974) suggests that optical retardation in mirror reflections in the Mount Wilson Tower Telescope may be responsible for polarity biases in the magnetic signal. The effects that they describe may exist, but as described they are an order of magnitude lower in amplitude than is required to explain the puzzling 'monopole' results discussed above.

5.3. Polar Field Reversals and Polar Filaments

As was mentioned above and can be seen from Figures 4 and 5, the polar field reversals were accomplished in a wavelike pattern that originated in the 40–50° zone and moved to the poles. The north pole reversed in 1971 and the south pole in 1969. It has long been recognized that filaments lie between magnetic fields areas of opposite polarity. It has also been known for a long time that the polar crown filaments move poleward in each hemisphere during the early years of a cycle and disappear near the pole around the time of solar maximum.

The polar filaments of this cycle have been studied by Waldmeier (1973). He found that there was a second 'anomalous' advance of filaments to the pole in the northern hemisphere. Figure 7 shows Waldmeier's results and the magnetic field results from

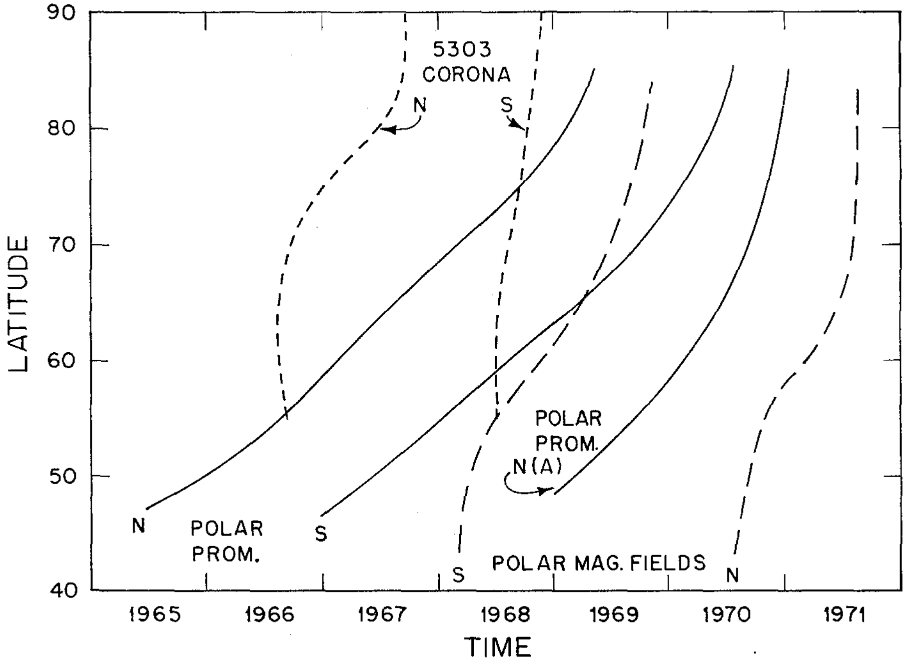

Fig. 7. The poleward migration of magnetic field reversals (large dashes) from the data of this paper, and the solar prominences (solid lines) and λ5303 corona (small dashes) from Waldmeier (1973). The solar prominences labeled 'N(A)' represent Waldmeier's 'anomalous' migration of northern prominences.

this paper. Here the field reversal is plotted at 45°, for example, when the field in the 40–50° zone changes sign.

The agreement between the filaments and the magnetic fields is not as good as we might expect. It appears that the 'anomalous' filament motion found by Waldmeier in the north refers to the true field reversal. There is no comparable field reversal for the first northern filament migration, which reached the pole in 1969.

As in the previous polar polarity reversal (H. D. Babcock, 1959), the south polar fields changed sign significantly earlier than did the north polar fields. The most striking polarity reversal, that in the north, occurred approximately two years after the activity maximum. Wilcox and Scherrer (1972) have shown from interplanetary field data, which was inferred by Svalgaard (1972) from polar geomagnetic data, that a change in phase of the predominant polarity of the interplanetary field (compared with the heliographic latitude of the Earth) occurs on the average $2\frac{2}{3}$ yrs after activity maximum. Whether one should expect the interplanetary field polarity reversal to be associated with the high-latitude or low-latitude polarity reversals on the Sun is not clear.

The coronal green-line activity migration given by Waldmeier is also plotted in Figure 7. This seems to precede both the filaments and the fields. The white-light coronal activity at high latitudes also shows a migration toward the poles (Hansen *et al.*, 1969), but this seems to precede the green-line migration.

The general picture of a poleward migration of a magnetic-field neutral line during a cycle, accompanied by filaments and coronal enhancements, is an attractive one that combines a number of divers observations. The detailed timing of these migrations does not appear to be in good coincidence; however, the model is still probably quite valid. If the strongest magnetic fields of opposite polarities lying on either side of the polar filaments are separated by some 10 or 15 degrees in latitude from the filaments, then there could be a delay in the strengthening of the new magnetic polarity in the polar zone, causing a phase shift between the filaments and the fields.

5.4. Comparison with the spherical harmonic analysis

Spherical harmonic analyses of the magnetic fields on the solar surface have been published for the intervals 1959–66 and 1967–72 (Altschuler *et al.*, 1971, 1974). These analyses used the same raw data from the Mount Wilson magnetograph as were used in this paper. The harmonic $P_n^m(\theta)\cos m\varphi$ was determined for the various intervals. In the case of systematic polarity reversals with latitude such as that seen in Table I, where reversals occurred at the equator and at $\pm 40°$, one should expect strong harmonics with $n-m=3$. However $n-m=3$ has not been a major harmonic in any of the results above.

One possible explanation for this is that in the harmonic analysis it is necessary to subtract the 'monopole' component of the magnetic signal, which implicitly assumes that any variation of this component results from a zero offset of the instrument. In fact, as may be seen from Figures 4 and 5, often when the whole Sun assumes a 'monopole' appearance, the changes in field strength are not uniform over the whole disk. Thus subtracting the monopole, although a mathematical necessity, may at times mask real large-scale magnetic features.

5.5. The large-scale distribution of field strengths and solar activity

Ambrož *et al.* (1971) have found that within the sunspot latitudes solar activity is generally correlated with the presence of predominantly negative magnetic fields. In Table I it can be seen that negative fields predominate in the zone between $\pm 40°$ latitude. In the south in this zone the fields are positive but considerably weaker than in the north. Solar activity has been stronger in the north in this cycle than in the south.

In the north there may be seen in Figure 4 a tendency for the field strengths equatorward of 40° to be negative centered roughly on the time of the activity maximum in mid-1969. For the rest of the interval, with the exception of early 1967, these fields are positive. In the south there is only very slight evidence of a similar effect.

Acknowledgements

The success of the magnetograph observations at the 150-ft Tower Telescope at Mount Wilson is due to the devoted efforts of many people. Dr E. W. Dennison and the Astro-Electronics Laboratory played a key role in planning, designing, installing and maintaining the scanning and data systems at the telescope. The observing has been handled ably over the years by Thomas A. Cragg, John M. Adkins, Thomas S. Gregory and Merwyn G. Utter. Much of the later computer programming was done by John E. Boyden. The entire effort would not have been possible without the advice and support of Dr H. W. Babcock. Financial support for the continued operation of the system and the data reduction was provided in part by the U.S. Office of Naval Research and the National Aeronautics and Space Administration. Funds for some of the later equipment came from the Air Force Cambridge Research Laboratories and the National Science Foundation.

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