POLEWARD MIGRATION OF THE MAGNETIC NEUTRAL LINE AND THE REVERSAL OF THE POLAR FIELDS ON THE SUN

I: *Period 1945–1981*

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Abstract. Poleward migration of the magnetic neutral line on the Sun has been calculated for the periods 1945–1950 and 1955–1981 using synoptic charts based on Hα observations. Epochs of sign reversal of the solar magnetic field at latitudes 50° to 90° have been determined for these periods. During the cycles 19 and 20 a threefold sign reversal took place in the northern hemisphere. During all the above cycles both the solar poles were of one polarity for a period ranging from 0.5 to 1 year. The poleward drift velocity of the magnetic neutral line varies from 6 to 29 m s^{-1} and seems to depend on the strength of the cycle.

1. Introduction

In an earlier paper (Makarov *et al.*, 1982) dealing with the morphology of filaments and filament channels, we have emphasised the importance of these features as effective tracers for studying the evolution of large-scale magnetic fields on the solar surface. On the basis of an analysis of the polar filament band motion Makarov and Fatianov (1981) studied the sequence of the sign reversal of the polar field for the 20th solar cycle and also gave a forecast for the 21st cycle. This analysis has established that the filament band could be used as a dependable tracer for studying the movements of large-scale magnetic regions and that the polar field reversal exhibited by the Sun can be detected with equal accuracy and ease as from full disc magnetograms. The use of the filament bands as tracers has also been established independently by Topka *et al.* (1982) from a similar study covering a period of 13.5 years (1967–1980). The above paper appeared in print while we were at the final stages of the present analysis.

When the Hα features can be clearly identified, they show the neutral line pattern of these large-scale fields in more detail and in greater accuracy than what can be inferred from magnetograms (Duvall *et al.*, 1977). In this paper using the filament and filament channels we have attempted to portray the reversal of the polarity of the polar field of the Sun for the cycles 18 through 21. In Section 2 we describe the method of reduction of the data. In Section 3 we discuss in detail the sequence of changes associated with each cycle and compare our results with those derived from Mount Wilson full-disc magnetograms, wherever the overlap exists. Our results provide the information on the

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reversal of polarity for the other cycles which have no magnetograph measures. In the last Section 4 we present a summary of our results for the four cycles.

2. Reduction of Observations

The epoch of the sign reversal of the solar magnetic field at high latitudes and around the poles can be derived once the drift trajectory of the neutral line of the large-scale magnetic field is worked out (Makarov and Fatianov, 1980). This contour is outlined by filaments and filament channels best seen on Hα spectroheliograms (McIntosh, 1972; Makarov *et al.*, 1982). The Hα synoptic charts (McIntosh, 1979, for the period 1964–1974; *Solar Geophysical Data*, for 1974–1978; and *Soln. Dann.*, for 1979–1981) formed the starting point for computing the trajectory of the neutral line drift. For the periods 1945–1950 and 1955–1963 similar charts were constructed from an examination of the Hα and Ca^+ K_{232} spectroheliograms of the Kodaikanal Observatory and by transferring these observations onto the Meudon charts of filament distribution (*Cartes Synoptiques de la Chromosphere Solaire*) for these years. The Meudon charts show only the distribution of filaments. Prominences with optical depths along the line of sight less than unity, when on the disc do not show up as filaments but only as filament channels (Makarov *et al.*, 1982). Such prominences appearing day after day were noted down from the spectroheliograms and from these the filament channels were drawn on the Meudon charts. We then closely followed McIntosh's methods for assigning polarity to the large scale magnetic regions on these charts. This procedure brought the Meudon charts on par with McIntosh's synoptic charts.

The appearance and evolution of active regions at the beginning of the cycle is such that the eastern part of the active region is outlined as an island of the opposite polarity relative to the background field, by the filament and filament channel contour. On the ascending branch of the solar cycle, with the increase in number of new active regions the number of independent islands of opposite polarity also increases (Figure 1a). As a result the polarity dividing line of the background field becomes longer, sometimes extending from one hemisphere to another. In course of time the poleward boundaries of these islands are connected by filaments or filament channels forming the poleward filament band. By the epoch of maximum of solar activity the filament bands in the two hemispheres would be closer to the poles (Figure 1b). Soon they reach the respective poles and reverse the polarity. If there are the second and third waves, they can be seen migrating to the poles in a similar way. When the reversal of the polar field is completed the conditions look similar to Figure 1c.

The synoptic charts show that the deduced polarity of the large-scale magnetic field for any longitude alternates in sign at several latitudes between the equator and the poles, the lines of demarcation being the filament bands that run approximately east to west. This makes it necessary to assign a mean latitude for every filament band over each solar rotation. This value which is the mean of all the latitude values which themselves are averages over 20° intervals of longitude provides one data point on the drift trajectory curve. We plot all such points for each filament band as a function of time and obtain

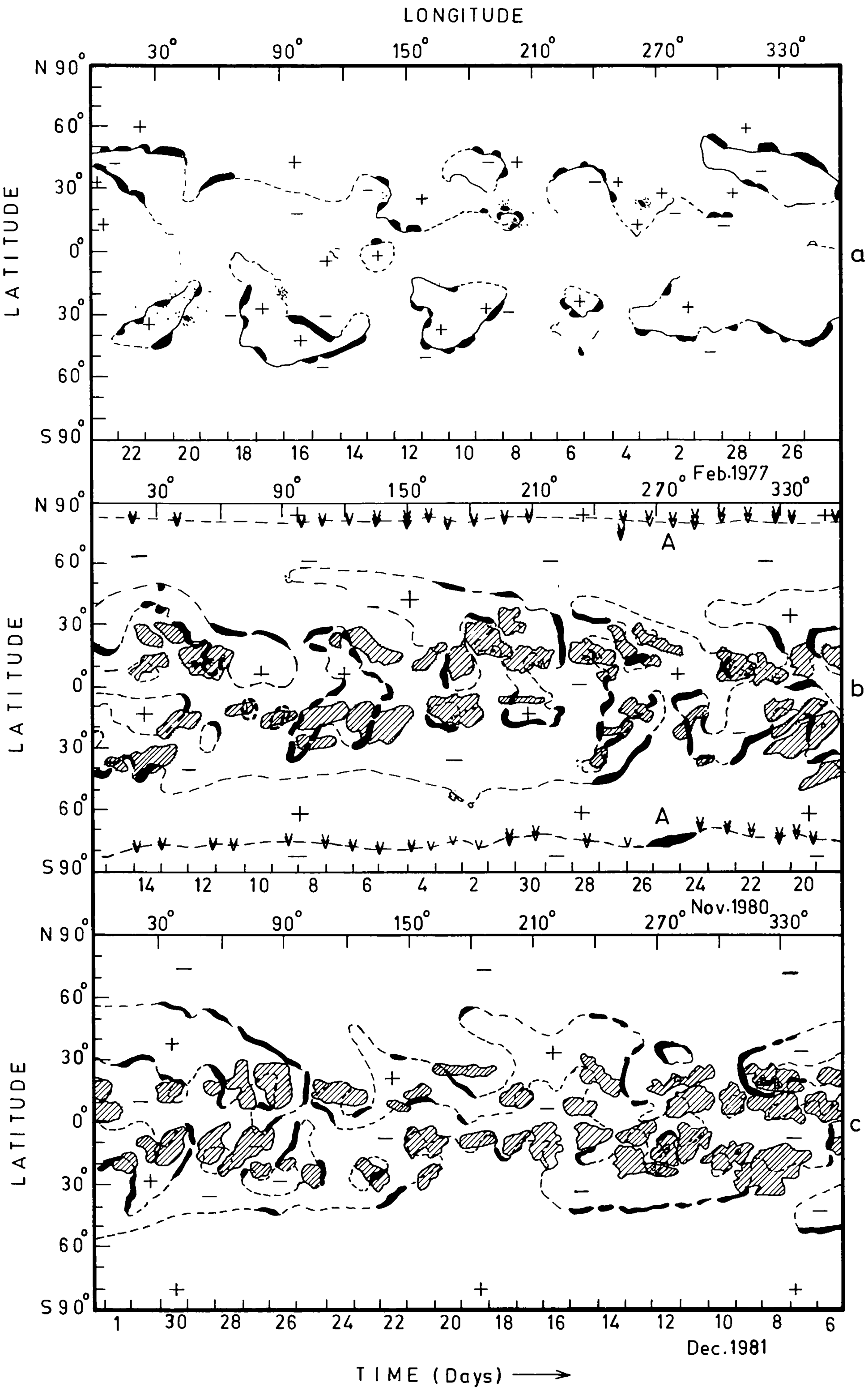

Fig. 1. Samples of synoptic charts corresponding to three epochs of solar activity for cycle 21. (a) shows the start of activity. Notice the islands enclosing the following polarity. The polarity of the N-pole is positive at the start of this cycle. (b) At the phase of maximum activity, the filament band has migrated and reached the polar region (*A*). The filaments constituting the filament band are seen as prominences on the E and W limb at these high latitudes. Prominences are shown by the symbol ⩔. (c) shows the distribution of filaments after the polarity reversal. The hatched areas represent active regions. For a detailed description of the features represented here see McIntosh (1979).

the trajectory of the poleward boundaries of magnetic regions of one dominant polarity as they migrate to high latitudes with progress of solar activity. We present such curves derived for the solar cycles 18 to 21 in Figures 2 to 6. The mean scatter of each data point in the latitude belt 30°–70° is ±10° and near the poles the maximum error is ±5°.

The motion of prominences analysed by Ananthakrishnan (1954) and also by Waldmeier (1973) shows that their drift mimics the above pattern. However, the poleward drift of prominences without the knowledge as to which filament band they are associated with does not help to map the trajectory of its drift unambigously and also does not reflect the dynamics of the background field at various latitudes during the cycle.

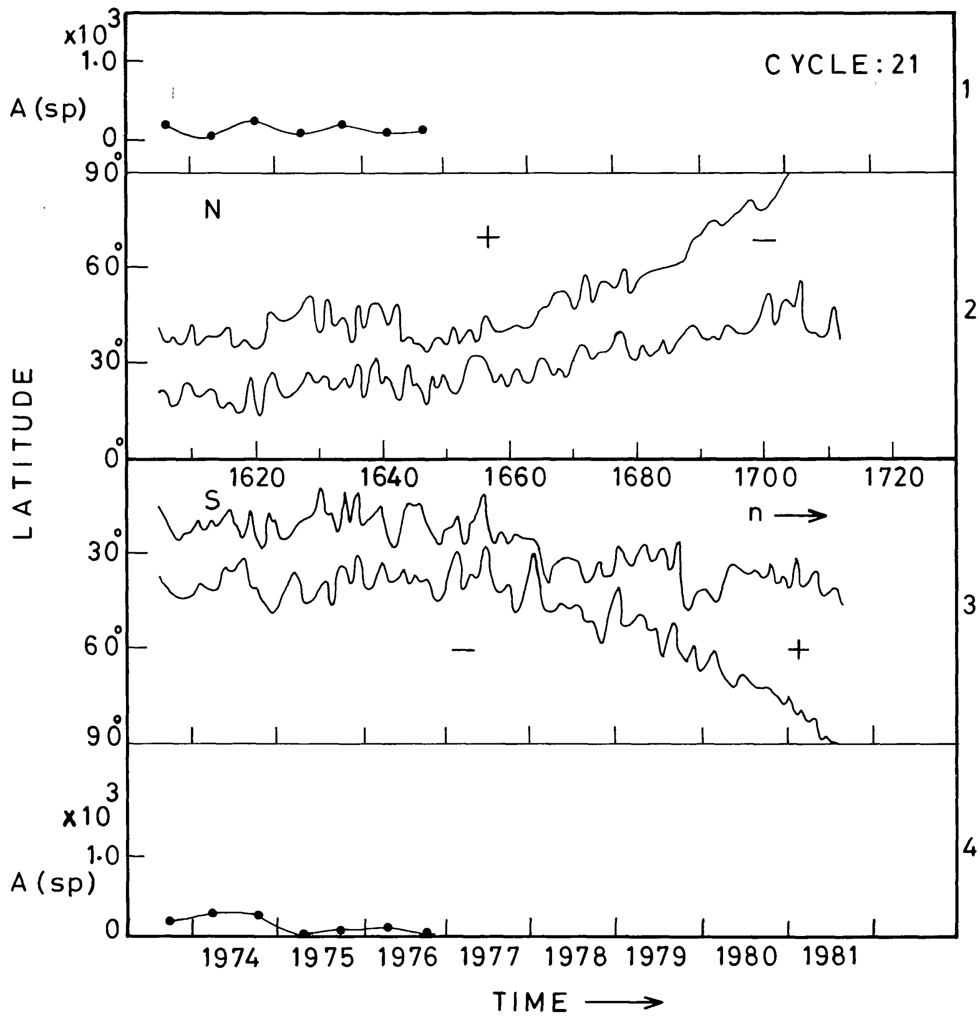

Fig. 2. The trajectory of the migration of the mean latitude of the neutral line of the large-scale magnetic field for solar cycle 21. N – northern hemisphere; S – southern hemisphere; + and – stand for polarity sign of the magnetic field in the conventional way; *n* – number of the Carrington solar rotation. Time is in years. Curves in boxes 1 and 4 are the plots of the six monthly means of the mean daily areas of sunspots *A*(sp) expressed in millionths of the visible hemisphere for this cycle for the northern and southern hemispheres respectively. These areas are extracted from *Greenwich Photoheliographic Results* published till 1976.

3. Results: Sign Reversal of the Polar Fields

3.1. Solar cycle 21

Figure 2 shows the poleward migration of the mean latitude of the inversion line in the N and S hemispheres for solar rotations 1605 to 1712 (1973.7–1981.6). Since mid 1972

TABLE I

The figures inside the table represent the epochs of polarity reversals expressed in years correct to a decimal

Northern hemisphere

Cycle	21	20			19			18
Polarity change φ_N	(+/−)	(−/+)	(+/−)	(−/+)	(+/−)	(−/+)	(+/−)	(−/+)
90°	1981.0	1969.7	1971.1	1971.5	1958.0	1958.8	1959.7	1950.2
80°	1980.8	1968.9	1971.0	1971.4	1957.7	1958.7	1959.5	1949.1
70°	1980.0	1968.6	1970.8	1971.3	1957.6	1958.5	1959.3	1948.2
60°	1979.8	1967.2	1970.4	1971.1	1956.7	1957.8	1958.7	1947.0
50°	1978.7	1966.6	1970.0	1971.0	1956.1	1957.6	1958.6	1946.4
V (m s^{-1})	6.4	5.4	13.4	29.4	7.7	12.3	13.4	4.5
T_{min}	1976.0		1964.5			1954.2		1944.2
T_{max}	1979.8		1969.0			1959.2		1946.8
S(sp)			5.8×10^3			8.8×10^3		6.2×10^3

Southern hemisphere

Cycle	21	20	19	18
Polarity change φ_S	(−/+)	(+/−)	(−/+)	(+/−)
90°	1981.8	1970.6	1959.5	1949.0
80°	1981.2	1970.2	1958.1	1948.8
70°	1980.6	1969.8	1957.8	1948.0
60°	1979.9	1968.6	1957.0	1947.3
50°	1979.3	1968.2	1956.6	1946.9
V (m s^{-1})	5.9	6.1	6.7	6.7
T_{min}	1976.5	1964.6	1954.4	1944.0
T_{max}	1981.0	1970.1	1958.8	1947.2
S(sp)		4.1×10^3	6.1×10^3	6.2×10^3

φ_N – latitudes in the north hemisphere.
φ_S – latitudes in the south hemisphere.
V is the velocity of migragion of the filament bands in m s^{-1}.
T_{min} is the epoch of the minimum of solar activity preceding the cycle in question.
T_{max} is the epoch of solar maximum. T_{min} and T_{max} are based on unsmoothed six monthly means of the mean daily areas of sunspots.
S(sp) is the early mean of the mean daily areas of sunspots summed up over the one solar cycle and expressed in millionths of the visible hemisphere.

the polar magnetic field in the northern hemisphere remained positive, which was opposite in sense to that of the Earth. The final reversal at the north pole (from + to −) took place in December 1980, and at the south pole (from − to +) in September 1981 when it became similar to the Earth's field. For 9 months the fields of both the polar regions remained negative. Here as well as in all future discussions the terms positive or negative polarity at the polar latitudes will stand for the sign of the predominant polarity in this region.

A ring-like polar filament in each hemisphere at the latitude $\sim 70°$ was formed when the filament and filament channels drifted to high latitudes. In the northern hemisphere the filament band was formed in August 1980 as a continuous optically thick filament at all longitudes, asymmetric with respect to the pole and inclined at an angle of about 10°. In September–October 1980, while still moving polewards, the filament band became a system of filament channels, which showed up as prominences on E and W limbs at latitudes 70°–80° seen every day. The ring-like polar band of filaments and filament channels were asymmetric with respect to the solar rotation axis, the normal of the ring plane being inclined at 5° with reference to the rotation axis.

The mean velocity of drift of the filament band in the northern hemisphere was 6.4 m s^{-1} and 5.9 m s^{-1} in the southern hemisphere as computed from the beginning of 1978 to the end of 1980. Between the latitudes 50° and 90° the field in the north changed sign about half a year earlier than the field in the southern hemisphere. In Table I, we present the results on the sign reversal of the background field between latitudes 50°–90° for this cycle along with others.

3.2. Solar cycle 20

In Figure 3 we show the drift trajectories of the neutral line for solar rotations 1482–1602 (1964.4–1973.5) computed by us. According to this, the polarity change close to the south pole was single fold and ended by 1970.6. In the northern hemisphere, the process was more involved and at latitudes higher than 50° the polarity change took place in three stages that ended by 1971.5. Thus the monopole on the Sun was observed twice, 1969.7–1970.6 and 1971.1–1971.5. In the former period the field at both the poles were positive and in the latter both showed negative polarity.

For the 20th cycle (1964–1976), the Mount Wilson magnetograms obtained by Howard (1974) provide direct information on the nature of the polar fields. In Figure 4, we compare the neutral line drift trajectory computed by us with Howard's observations. In the northern hemisphere ($> 60°$) the magnetograms show the first reversal (− to +) in the latter half of 1969 (marked A) and this corresponds precisely to the arrival of the first 'wave' of the neutral line at this latitude in our diagram. The magnetograms show a positive polarity till the reversal at B, which took place by early 1970. This is represented by the second wave in our drift diagram and the epoch is marked B. The magnetic field poleward of 60° continued to be negative from B till August 1971 when it reversed once again (− to +; marked C) which agrees closely with the third wave of our drift diagram. Similarly in the southern hemisphere the field poleward of 60° reversed in mid 1969 and this is precisely what we note from our neutral line drift

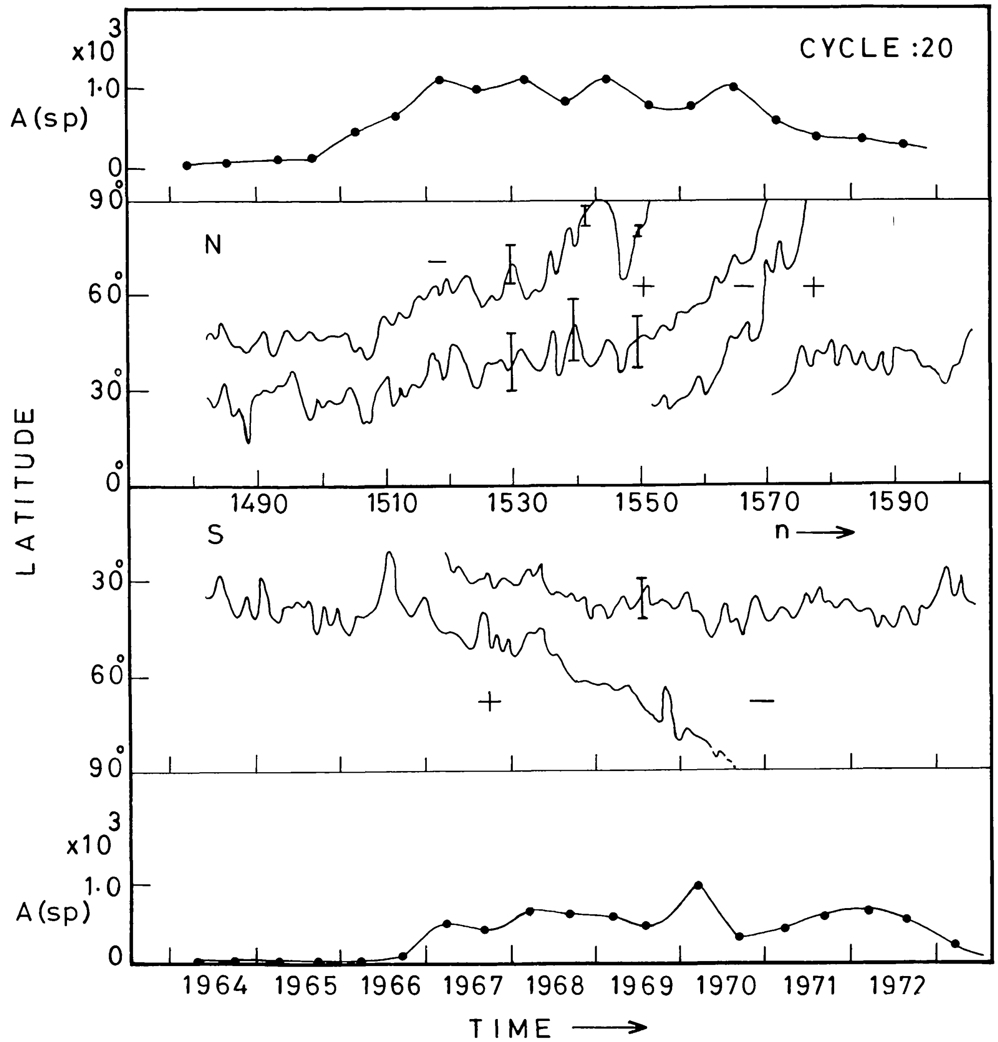

Fig. 3. Same as Figure 2 for solar cycle 20. The error bars for typical data points are also shown. These hold good for other figures too.

diagram also. We thus identify the one to one correspondence between the polarity reversals reckoned from our drift trajectory diagrams and those from Howard's magnetograms. This strengthens our approach of using similar diagrams for the remaining cycles to establish the polarity reversal.

We note that the final polarity change took place 2.7 years and 0.5 years after the solar maximum in the northern and southern hemispheres, respectively. The first filament band, outlining the negative polarity at the latitudes 50° began its drift with the mean velocity of 6.4 m s^{-1} by mid of 1966. Nearly simultaneous latitude variations were observed in the second filament band and its poleward migration started by the start of 1970 with a mean velocity of 13.4 m s^{-1}. The third one which appeared towards the close of 1971 migrated from 50° to 90° within half a year with a mean velocity of 29.4 m s^{-1}. Table I gives a detailed picture of the time of the polarity change in the 20th solar cycle.

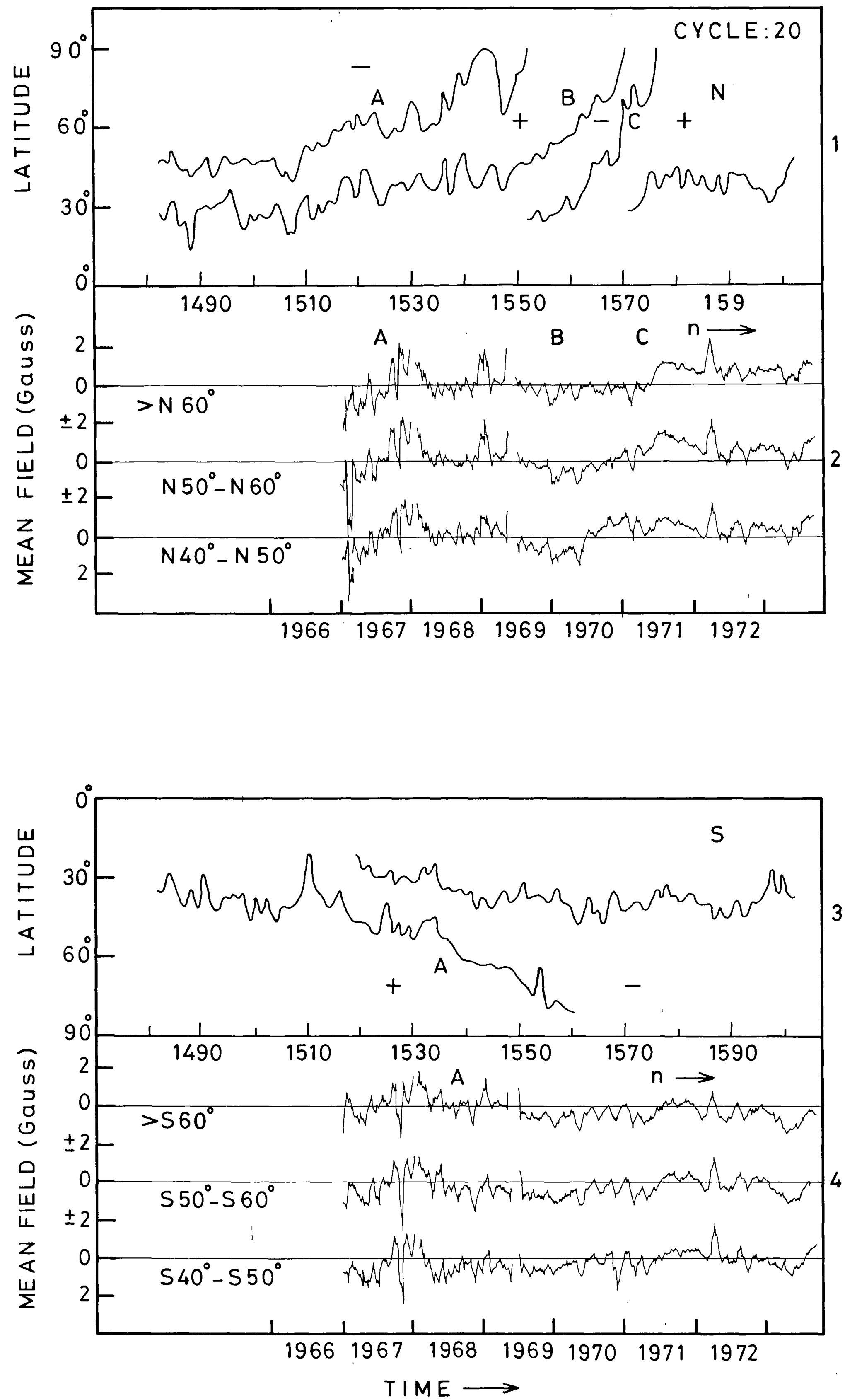

Fig. 4. Comparison of the drift trajectory curves for cycle 20 with Howard's (1974) magnetograph observations for the two hemispheres. Parts 2 and 4 are Howard's Figures 4 and 5.

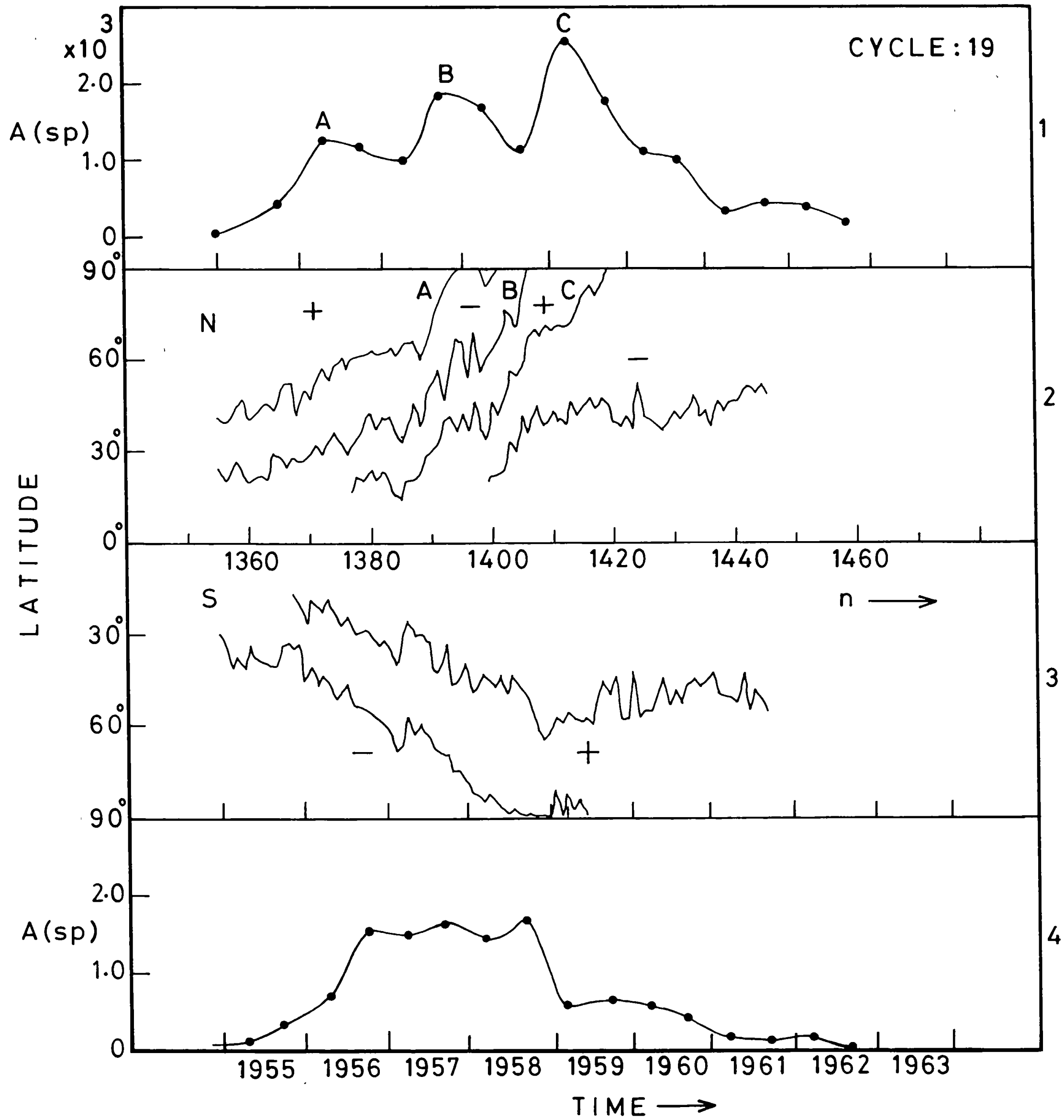

Fig. 5. Same as Figure 2 for solar cycle 19.

3.3. Solar cycle 19

In Figure 5 we give trajectories of the migration of the filament bands for rotation 1355–1445 (1955.0–1961.7). The process of the polarity change of the background field was identical to that in the 20th cycle. In the southern hemisphere a single fold polarity change was observed and at latitudes poleward of 85°, this process lasted for more than a year finally ending by mid 1959, 0.7 year after the maximum of solar activity in this hemisphere. In the north, a three-fold polarity reversal of the field took place between latitudes 50°–90° and the reversal was completed in 1959.7, about 0.5 year after the epoch of maximum of activity in this hemisphere.

According to magnetograph observations in the first half of this cycle (1954–1958) the polarity of the high-latitude magnetic field was of opposite sense to that of the Earth.

The polarity change was first observed near the south pole in the spring of 1957 (Babcock, 1959) and until November 1958 both the poles were of the same polarity. The 1959 magnetograms showed that the polar field of the Sun was oriented in the same way as the Earth's field. The sign reversal in the south in mid 1957 and in the north in November 1958 observed by magnetograph really corresponded to the polarity change at the latitude 65° (see Table I). The onset of the poleward drift in the north coincides with the enhancement of solar activity. For 2.2 years it moved from 50° to 90° with the average velocity 7.7 m s^{-1}. The second filament band was at latitude 25° till early 1956 and its poleward drift also coincided with the enhancement of solar activity. This filament band passed latitudes from 50° to 90° one year after the first one, with a velocity of 12.3 m s^{-1}. The third filament band appeared in the mid 1956 at the latitude 15° and reached high latitudes 1.6 years after the first filament band. The velocity of its drift was 13.4 m s^{-1}. The 'monopole' character of the high latitude magnetic field in the 19th cycle was the result of the multifold polarity change of the field.

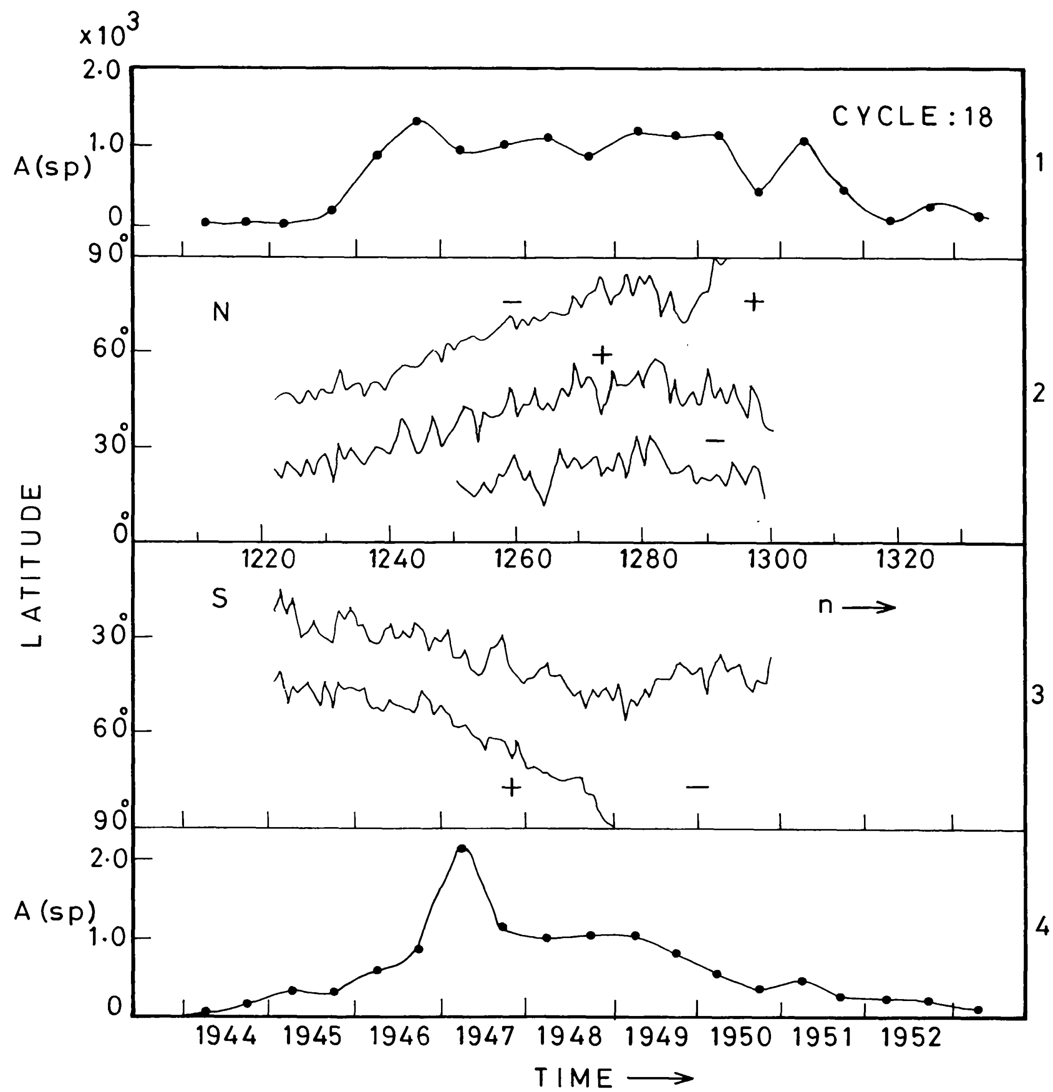

Fig. 6. Same as Figure 2 for solar cycle 18.

3.4. Solar cycle 18

To obtain the progress of the sign reversal of polar field for this and earlier cycles one has to depend entirely on the neutral line drift diagram (Figure 6). In the southern hemisphere the high latitude filament band began its poleward migration at the beginning of 1945 and reached the pole in 1949.0, thereby changing the polarity of the field from + to −, about 1.8 years after the maximum of solar activity in the southern hemisphere. The mean velocity of the drift was 6.7 m s^{-1}. In the northern hemisphere, the neutral line poleward of 80° showed latitude fluctuations lasting over a year. From 1949.0 to 1950.2 both the poles were of negative polarity and the final reversal took place in 1950.2 about 3.4 years after the maximum burst of solar activity. The mean velocity of drift of the neutral line was 4.5 m s^{-1}.

4. Summary and Discussion

(1) There is a close agreement of the polarity reversals derived from the drift trajectory of the neutral line and those from magnetograph observations.

(2) In cycles 19 and 20, in the northern hemisphere, the migration of the filament bands consists of three waves. Box 1 of Figure 5 shows the three peaks A, B, C in the six monthly areas of sunspots illustrating that the activity in this hemisphere took place in three bursts. The increasing magnitude of activity from A to C, gives a positive slope for the line drawn touching the points of maxima of these three peaks. With the positive slope in mind if we examine the migration trajectory, a qualitative correlation between the bursts of activity and the three waves of migration seems to exist. The northern hemisphere in the cycle 20 also shows a similar correlation although the positive slope is not as unmistakable as in cycle 19. Whereas if the sunspot area plot shows only one prominent peak as in the southern hemisphere for all the cycles, then there is only one wave of migration of the filament band.

(3) Also, the drift velocity of the filament bands, seems to be related to these bursts of activity. If $C > B > A$, then the drift velocity of the 3rd wave corresponding to the activity burst C is the highest. This holds good for cycle 20 too.

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