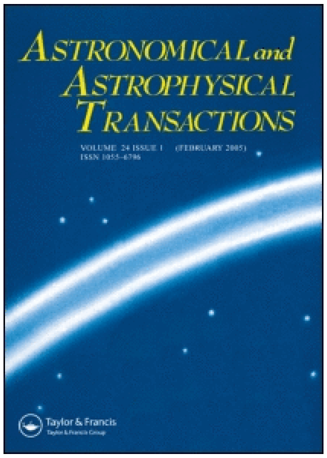

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GENERAL MAGNETIC FIELD REVERSAL IN THE SOLAR CYCLE 22 PERIOD: 1986–1992

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The zonal structure of the magnetic field radial component B(r) has been determined using the mean latitude of magnetic neutral lines, $\theta(B_r = 0, t)$, on the Kislovodsk magnetic H-alpha charts for 1986–1992. At the minimum activity (m) in 1986, the latitudes of the zonal boundaries in the N-hemisphere were $\theta(N, 2m) = 39^\circ$ and $\theta(N, 1m) = 18^\circ$ and those in the S-hemisphere, $\theta(S, 2m) = -42^\circ$ and $\theta(S, 1m) = -15^\circ$. The high-latitude boundary $\theta(N, 2m)$ of the "−" polarity field at the latitudes higher than 40° reached the pole in 1991.0 and that moment corresponded to the reversal of the poloidal component $B(p)$ to "+". In the S-hemisphere, the boundary of the zone of "+" polarity $\theta(S, 2m)$ reached the pole in 1992.0 and that corresponded to the reversal of the $B(p)$ to "−" at the latitudes higher 40°. From 1991.0 to 1992.0, the solar polar magnetic field had the same "+" polarity in both hemispheres.

It is shown that the magnetic field reversal in the n-cycle is caused by the poleward migration of the magnetic field zones from the $n-2$ cycle in the case of a single reversal.

KEY WORDS Sun, magnetic field reversal

1 INTRODUCTION

H. W. Babcock and H. D. Babcock (1955) were the first to use a new method of observations of the solar magnetic field and to proove rather convincingly that a magnetic field reversal took place in the mid of the solar cycle 19 (1955–1965). Then, according to magnetographic observations, a reversal of the Sun's polar magnetic field took place during the cycles 20 and 21 (1965–1986). It was shown that at the boundaries of unipolar regions, where the radial component of the magnetic field is zero, prominences are observed. During the last decade, a great number of papers have been dedicated to a study of the solar magnetic field reversal using the poleward migration of filaments and prominences starting from 1870 (Makarov, 1983; 1984; Makarov and Sivaraman, 1989a; 1989b). A new phenomenon has been discovered – that is a three-fold polar magnetic field reversal in one of the solar hemispheres, that was observed mainly in even 11-year cycles (Makarov, 1986; Makarov and Sivaraman, 1989). In that case, all 3 zones of the magnetic field of alternating polarities in both hemispheres reach the pole and have a three-fold polarity reversal. That happened in solar cycles 12, 14, 16, 18, 19 and 20. When there was a single field reversal, only one high-latitude zone reached the pole in each hemisphere. That happened in cycles 11, 13, 15, 17, 21.

Although the polar fields are weak, their reversal seems to be a "beginning" of a new global solar cycle. The time of the field reversal is the epoch of the completion and restructing of the large field after which a new zonal structure is formed and preserves itself until the beginning of the next cycle. After the reversal of the field, the regular poleward migration of the latitudinal zones stops and the first events of the global solar cycle appear at high latitudes, showing polarity patterns similar to those expected for sunspot pairs of the cycle that follows (Makarov *et al.*, 1988; Wilson *et al.*, 1988). The latitudes of the two boundaries of the zones at the minimum of the cycle determine the maxima of two succeeding cycles (Makarov and Mikhailutsa, 1992).

Since the poloidal field $B(p)$ is an essential component of a model cycle, it is important to understand how the opposite poloidal field is formed.

The present paper describes peculiarities of the polar field reversal in the solar cycle 22, the formation of new latitude zones, their migration and the correspondence of these to the Babcock (1961) and Leighton (1969) models.

2 OBSERVATIONS AND REDUCTIONS

The structure of the Sun's magnetic field is determined by the distribution of unipolar regions which are evident on magnetograms. These unipolar regions can be identified on H-alpha charts because filaments outline their boundaries where $B(r) = 0$ (McIntosh, 1972; Makarov, 1984)

The radial component $B(r)$ of the magnetic field may be expanded in terms of the spherical harmonics $Y_L^M(0,\varphi)$ as

$$B(0,\varphi,t) = \sum_{L=0}^{\infty} \sum_{M=-L}^{L} A_L^M(t) Y_L^M(0,\varphi). \tag{1}$$

The coefficients $A_L^M(t)$ characterize the magnetic field distribution at time t. In case $M = 0$,

$$A_L^0(t) = \sqrt{\pi(2l+1)} \int_{-1}^{1} \overline{B}(x,t) P_L(x)\, dx, \tag{2}$$

where $x = \cos\theta$ and $\overline{B}(x,t) = \frac{1}{2\pi} \int_{-\pi}^{\pi} B(x,\varphi,t)\, d\varphi$.

Synoptic charts show that the 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-West.

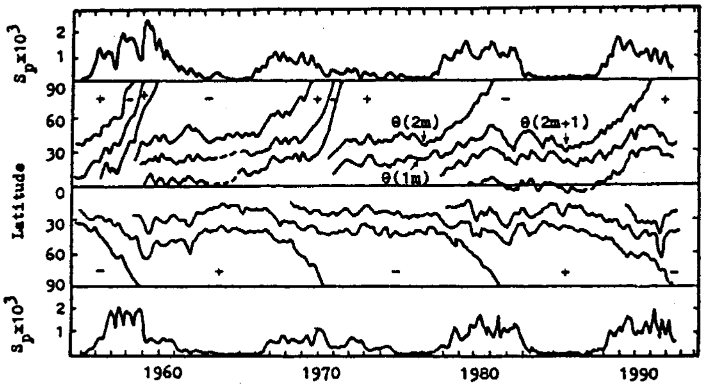

Figure 1 Curves in boxes II and III are the migration trajectories of the mean latitude (averaged over three rotations) of magnetic neutral lines in the solar cycles 19–22 (Northern and Southern hemispheres). "+" and "−" stand for the magnetic field polarity signs in the conventional way. Curves in boxes I and IV are plots of daily sunspot areas averaged over three rotations (Northern and Southern hemispheres, respectively). $S(p)$ are expressed in 10(-6) of the visible hemisphere, (Soln. Dann. Bull., 1955–1992).

It is possible to determine the mean latitude for each filament band over each solar rotation on H-alpha charts:

$$\theta(+/-,t) = \frac{\sum^{n} \theta_n(+/-,t)}{n}; \quad \theta(-/+,t) = \frac{\sum^{k} \theta_k(-/+,t)}{k}, \qquad (3)$$

where $\theta_n(+/-,t)$ and $\theta_k(-/+,t)$ are the latitudes of the boundaries of unipolar n and k regions of "+" and "−" polarity, respectively, and $\theta(+/-,t)$ is the latitude of the zone boundary.

Kislovodsk H-alpha charts have been plotted on the basis of the observations of the Sun in the H-alpha and K-Ca(11) lines and of sunspot magnetic fields for the period 1986–1992 (Soln. Dann. 1986–1992, NN 1–12).

From a plot of such points versus time, the trajectories of the boundaries of the poleward migration of the magnetic regions of the dominant polarity were obtained, Figure 1.

3 THE ZONAL STRUCTURE OF THE MAGNETIC FIELD AFTER THE REVERSAL IN 1981 UNTIL THE BEGINNING OF THE SOLAR CYCLE 22 IN 1986

The reversal of the polar magnetic field of the Sun in the solar cycle 21 as incurred from H-alpha charts was over in the North and South in 1981.0 and in 1981.7, respectively (Makarov and Fatianov, 1982). The unsimultaneity of the polarity reversal was very well seen on the eclipsing frames of the corona on 31 July 1981.

In the South, at a latitude about 80° a polar ring of filament–prominences was observed. That ring detected the region of the "previous" background field of the "–" polarity about 10° in width. That structure of the "previous" field showed up as a coronal helmet-like streamer (Stellmacher *et al.*, 1986).

After the magnetic field reversal in the solar cycle 21 in 1981 to the beginning of the cycle 22 in 1986, the zonal structure of the magnetic field was characterized predominantly by $L = 5$, when $M = 0$. The latitudes of the boundaries of the alternating polarity zones were calculated from H-alpha charts. At minimum activity in 1986, the field zones were located between $\theta = 39°$ and $\theta = 18°$ in the North and $\theta = -42°$ and $\theta = -15°$ in the South. At the beginning of the cycle 22, a poleward migration of the zone boundaries of the magnetic field was observed. The mean velocity of the poleward migration was 4 m/s, although at certain periods it reached 13 m/s.

It is important to note that the latitude boundary of the zone at the minimum of activity does not depend on the intensity of the preceding cycle, as it should be in the Babcock and Leighton model (Babcock and Leighton, 1969). According to Makarov and Mikhailutsa (1992) the latitude θ(2m) foreshadows the intensity $W(n)$ of the succeeding cycle n,

$$W(n) = 605 - 10.45 \langle \theta(2m) \rangle \, , \; r = -0.87 \qquad (4)$$

and

$$\theta(2m + 1) = \theta(1m) + 23\overset{\circ}{.}5, \qquad (5)$$

where W(n) is the maximum Wolf number in the cycle n, and r is the correlation coefficient.

The dependence (4) reflects the fact that the toroidal component $B(\varphi)$ is formed from the poloidal component $B(p)$. The larger is the magnetic flux of the poloidal component $F(p)$, the larger is the flux of the toroidal component. According to (5), there is an inverse relation between the toroidal component $B(\varphi)$ of the cycle n and the poloidal component $B(p)$ of the cycle $n + 1$. Actually the smaller is the latitude $\theta(2m)$ at the minimum m, the larger are $F(p)$ and $F(\varphi)$ in the succeeding cycle n. But the larger is $F(\varphi)$ in the cycle n, the larger is $\theta(1m)$ in the following minimum $m + 1$, i.e. $\theta(2, m + 1)$. But again the larger is $\theta(2, m + 1)$ the smaller are $F(p)$ and $F(\varphi)$ in the $n + 1$ cycle.

The zone structure of the field during the reversal of $t(rev)$ in 1981 until the beginning of a new cycle $t(s)$ in 1986 can be given by

$$B(\theta, t_s - t_r) \approx B(0, t_s - t_r) \cos\theta (a \cos^2\theta - 1)(b \cos^2\theta - 1),$$

where $a = 2.4$ and $b = 12.4$

Evidently, the coefficients a and b determine the latitude of the boundaries $\theta(2, m)$ and $\theta(1, m)$ after the reversal, and vary from cycle to cycle.

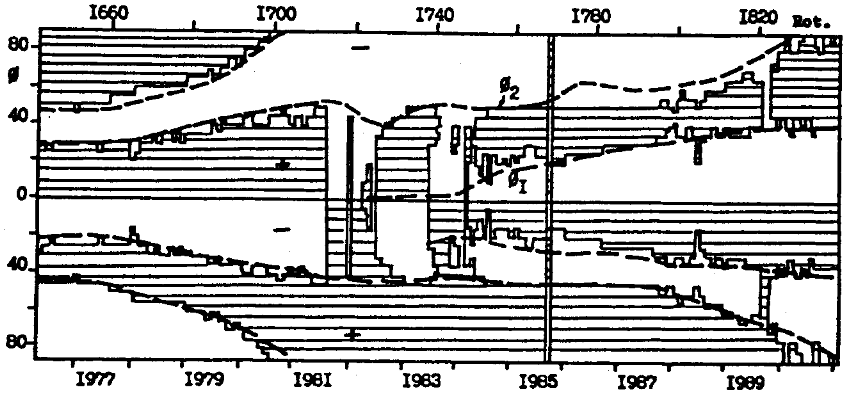

Figure 2 Formation of a new zonal structure of the large scale magnetic field in the equatorial zone and its poleward migration in the global activity cycle according to magnetographic data (Hoeksema and Scherrer, 1986) and H-alpha chart data (dashed lines). One can observe a polarity reversal in the polar zone during 1980–1981 and in the equatorial zone, in 1983–1984.

4 FORMATION OF A NEW LOW-LATITUDE ZONE

Figure 1 shows the dynamics of a latitude zone of the magnetic field in the solar cycles 19–22 (1955–1992). The middle latitude zone became a polar zone, the low latitude zone shifted to middle latitudes and a new zone was formed at the latitudes from 0° to 20° by fusion (enlargement) and polar motion of separate unipolar regions of the magnetic field. Simultaneously, the zone boundary $\theta(2m)$ shifted to the pole, the boundary $\theta(1m)$ shifted to the boundary $\theta(2m)$ and became $\theta(2m+1)$ after the magnetic field reversal. The zone outlined by the latitudes $\theta(1m)$ and $\theta(2m)$ at the minimum became a polar zone after the polar field reversal. In the case of a single reversal, the magnetic fields migrate consecutively poleward during the two succeeding cycles, Figure 1.

Zonal structures were constructed for 1976–1990 using data of H-alpha charts according to (1), (2) and (3) and those of the spherical axisymmetric modes $L = 1,3,5$ according to Hoeksema and Scherrer (1986). It can be seen from Figure 2 that the summarized modes $L(1,3,5)$ follow H-alpha chart data, and two large-scale magnetic field reversals take place in the polar and in the equatorial zone. This means that a magnetic cycle begins with a reversal in the equatorial zone and it is completed at the poles.

5 CONCLUSIONS

The results obtained and described above enable us to make some conclusions on the solar magnetic field reversal in the cycle 22. It was completed at the N-pole in 1991.0 and at the S-pole in 1992.0. In both hemispheres the polar solar magnetic field had the same "+" polarity from 1991.0 to 1992.0. The cycle 22 is characterized by a single polarity reversal in both hemispheres.

A magnetic field reversal is the epoch of completion and restructuring of the large-scale field after which a new zonal field structure is formed and preserves itself until the beginning of the succeeding cycle. After the reversal, the regular poleward migration of the zone boundaries stops and this epoch is the beginning of a new global cycle showing up as the appearance of a magnetic structure of a new magnetic field in Hale's sense. The velocity of migration of the zone boundaries varied from 4 m/s to 13 m/s in the period 1986–1992.

The aim of the present note is to draw attention to this interesting feature of solar activity and to stimulate future theoretical studies.

One can hope that intensive work in this field will help in understanding unsolved problems of the solar cycle.

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