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Solar Differential Rotation of Compact Magnetic Elements and Polarity Reversal of the Sun

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Abstract. The differential rotation of the compact elements of the large-scale magnetic fields is studied using Solar Synoptic Charts (1966–1986). It is revealed that compact magnetic elements with the similar polarity of the polar magnetic field of the Sun have a larger rotation rate than the elements with the opposite polarity at all stages in the cycle.

From the comparison of the experimental measuring data of the solar magnetic elements there are received the results: a) The differential rotations of the compact magnetic elements with negative and positive polarities have the similar behavior for the solar 20 and 21 cycles; b) It is established that in the rotation rate of compact magnetic elements there are present some variations at the time of polarity reversal of the Sun.

There is assumed that the physical understanding of the connections of differential rotation of compact magnetic elements and polarity reversal of the Sun depends upon establishing a connection between the temporal variability of spatially resolved solar magnetic elements and polar reversals.

Keywords. Differential rotation, magnetic fields, polarity reversal.

1. Introduction

Special attention has always been paid to the study of the solar differential rotation and the solar magnetic field, because they are key to understanding the physical processes in the solar atmosphere. Sunspots have been used as tracers of solar rotation since they were first recognized as features on the Sun (Newton 1924). Other features used are faculae (Newbegin & Newton 1931) and hydrogen filaments (D'Azambuja & D'Azambuja 1948; Japaridze & Gigolashvili 1992; Gigolashvili *et al.* 1995; Gigolashvili *et al.* 2005). Another class of features used for tracking the large-scale solar patterns is neutral lines of the magnetic fields in filtergrams and spectroheliograms (Durrant *et al.* 2002; Gigolashvili *et al.* 2005/2006; Japaridze *et al.* 2006; Japaridze *et al.* 2007). The variations of characteristics of time-varying processes occurring in the solar atmosphere are tightly connected with prolonged large-scale manifestation of solar activity. The interaction between the solar rotation and magnetic fields is indisputably the reason for such activity.

Within the solar interior the surface manifestation of magnetic fields exhibits an unexpected degree of regularity despite such fields being embedded in an extremely turbulent medium. The largest magnetic fields observed at the surface follow episodic patterns of emergence and evolution that collectively form each activity. There is also evidence that smaller-scale magnetic fields also possess an imprinting of such cyclic behavior. Two specific aspects of the coupling between small and large scale structures on the Sun are discussed by DeRosa (2005). McIntosh and coauthors made Carrington maps of H-alpha solar synoptic charts and the results were published in the form of the atlas of stackplots

(McIntosh *et al.* 1991). Large-scale stackplots for the entire range of data for 1966-1986 include the series of plots displaying 10°- zones of solar latitude in the range of 70°. Snodgrass (1992) finds patterns that appear to show features at the same latitude which are moving at different rotation rates. It is also possible to observe the poleward drift of the large-scale unipolar regions and the evolution of the polar cap as well as a variety of other apparent meridional and vertical motions. For compact magnetic elements with negative and positive polarities separately the average values of statistics were calculated for the minimum periods 1964–1966 and 1973–1978, as well as for maximum periods 1967–1972, 1979–1983 for the northern and the southern hemispheres with the 90 % confidence level (Gigolashvili *et al.* 2007). In this paper, we study the differential rotation of compact magnetic elements during solar activity cycles 20 and 21 using the McIntosh's stackplots (McIntosh *et al.* 1991).

2. Data, Method of Treatment and Results

To study the differential rotation of compact magnetic elements for solar activity cycles 20-21 (1966-1986) we used the McIntosh's atlas of synoptic maps. We have chosen only the visually symmetric compact elements with significant angle of a deviation that is possible to be measured at least for 3 days. This is necessary for determination of differential rotation of the features with high accuracy.

For 335 chosen compact magnetic elements, 1675 measurements have been made. In cycles 20 and 21, 990 measurements for 198 features and 685 measurements for 137 features, respectively have been carried out.

We measured the angle between the symmetry axis of a chosen magnetic element and the horizontal line parallel to the horizontal edge chosen among five identical plots. The average slope of long-lived patterns generally varies in a regular way as a function of latitude. Since the frame of reference is the Carrington system of solar longitudes, a vertical pattern in a stackplot represents a pattern rotating at the Carrington synodic rate of 27.2753 days; positive slopes indicate apparent rotation rates slower than the Carrington rate. Negative slopes indicate rotation rates faster than the Carrington rate and these usually occur at latitudes less than 20° (McIntosh, Willock, and Thompson, 1991). The rotation rates for compact magnetic elements were calculated with the help of the empirical formula (Japaridze *et al.*, 2006): $\Omega(\phi) = 1000/(36.664\text{-}\cot\alpha)$, where α is the angle of the slope, ϕ is latitude and $\Omega(\phi)$ is the rotation rate in deg/day. By a method developed by us (Japaridze *et al.*, 2006) measurement of the rotation rates of large-scale features is impossible because of an uncertainty in the determination of the angle of their deviation from the solar central meridian.

As the patterns in McIntosh's stackplots are displayed in both longitude and latitude, we can trace a wealth of various details. Calculated rotation rates of magnetic elements with the positive and negative polarity for low (10°) and middle (60°) latitudinal zones separately for both hemispheres of the Sun are presented on the Figure 1.

The diagrams for every 10°-zone were constructed separately for the northern and southern hemispheres for compact magnetic elements with the positive and negative polarities. In the figure −CE and +CE are rotation rate for the whole cycle of magnetic elements with negative and positive polarities, respectively. Arrows point to the epochs of the polarity reversals of the circumpolar regions of the Sun for northern (big arrows) and southern hemispheres (small arrows). The polarity reversal occurred in 1969, 1971.1, 1974.1 (three-fold polarity reversal) and in 1970.5 for cycle 20 and in 1981.0 and 1981.7 for cycle 21 in the northern and southern hemispheres, respectively (Makarov *et al.*, 1977; Makarov and Sivaraman, 1989a, b).

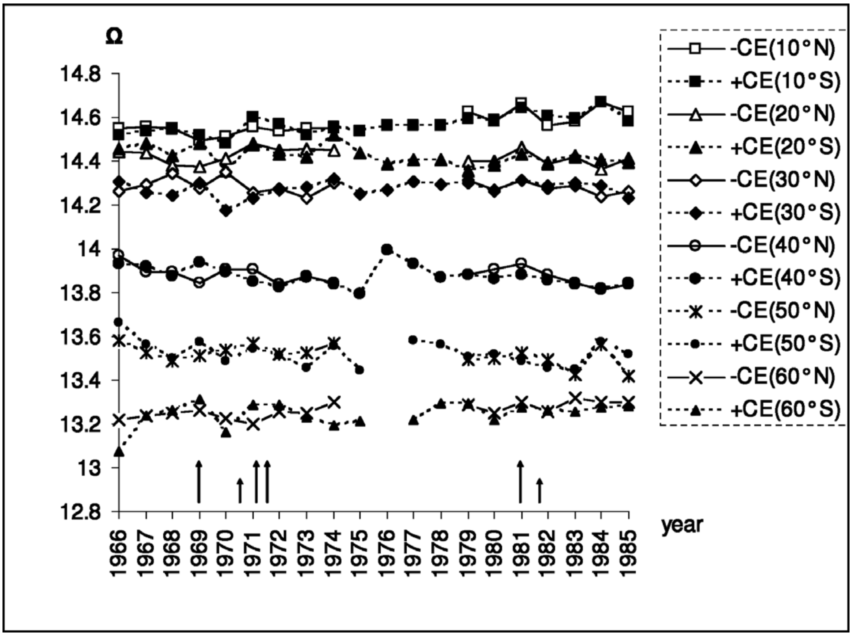

Figure 1. Rotation rate of magnetic elements with the positive and negative polarities for 10°-zones of the northern and southern hemispheres.

From figure 1 we can see that the differential rotations of the compact magnetic elements with negative and positive polarities have the similar behavior for cycles 20 and 21. In the rotation rate of compact magnetic elements some variations are present at the time of the polarity reversal of the Sun.

3. Discussion

It is known that the polar magnetic fields reverse their polarity at maxima of solar cycles. Using homogenous data of hydrogen filaments a quasi-biennial pulse propagation from high latitudes to the equator was found. A pulse drift was observed in the northern hemisphere during 1968–1970, 1979–1981, 1988–1990 and in the southern one during 1969–1971, 1979–1981, 1989–1991. If the polarity reversal is three-fold the residual velocities are great and have secondary peaks at relatively high latitudes. If the polarity reversal is simple, propagation of a quasi-biennial pulse occurs almost simultaneously in both hemispheres and the amplitude of residual velocities is minimal (Gigolashvili *et al.* 2005).

Pulkkinen & Tuominen (1998) found that the solar rotation is continuously changing not only in the course of a cycle but also over a longer time period. They also found strong fluctuations in the equatorial rotation in the course of solar activity.

According to Seeley *et al.* (1987) small-scale compact magnetic elements are parts of larger structures. They have rotation rates different from motions of large-scale structures. Symmetric large-scale magnetic elements (chosen by visual examination) with negative and positive polarity have the same behavior of the rates of differential rotation. During the first polarity reversal of the three-fold changing of circumpolar magnetic field in northern hemisphere the rotation rates of compact magnetic elements with negative and positive polarities change in an anti phase, while all other cases show collective variations of rates.

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We investigated the differential rotation of the large-scale magnetic elements during solar activity cycles 20–21. For these cycles the differential rotations of the compact magnetic elements with negative and positive polarities have similar behavior. In the rotation rate of compact magnetic elements some variations are present at the time of polarity reversal of the Sun.

A physical understanding of the connections of differential rotation of compact magnetic elements and polarity reversal of the Sun depends on establishing a connection between the temporal variability of spatially resolved solar magnetic elements and polar reversals.

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