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VARIATIONS OF THE SOLAR DIFFERENTIAL ROTATION ASSOCIATED WITH POLARITY REVERSAL

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Abstract. Variations of solar differential rotation have been studied using observations of solar quiescent Hα filaments obtained during 1965–1993 at the Abastumani Astrophysical Observatory.

In both hemispheres of the Sun, propagation of a quasi-biennial pulse of residual rotation velocities of filaments was found. There is a pulse drift from high latitudes to the equator in the northern hemisphere in 1968–1970, 1979–1981, 1988–1990 and in the southern one in 1969–1971, 1979–1981, 1989–1991.

Propagation of a pulse starts near the time of the polarity reversal of the circumpolar regions of the Sun. High-latitude double peaks of rapid motion were found in the northern hemisphere for cycle 20 and in the southern hemisphere for cycle 22. The relation of the appearance of suggested double pulse peaks of residual velocities with the threefold polarity changing of the circumpolar areas is suggested.

1. Introduction

The variation of differential rotation with cycle is not well understand (Beckers, 1981; Howard, 1984; Schröter, 1985; Zirin, 1988; Stix, 1989). Observational studies of the large-scale motion fields on the Sun and tracer measurements are discussed by Snodgrass (1992). Some authors found an increase in the rotation speed with decreasing latitude at activity minimum (Isksanov and Vitinskij, 1982; Lustig, 1983; Balthasar, Vázques, and Wöhl, 1986; Lustig and Schroll, 1989). Pulkkinen and Tuominen (1998) found that rotation is continuously changing not only in the course of a cycle but also in a longer time period. They also found strong fluctuations in the equatorial rotation in the course of the solar activity. Photospheric facula rotation showed a little time-dependence throughout the solar cycle (Meunier *et al.*, 1997).

During some years of cycles 21 and 22 investigation gave drastically different results (Brajša *et al.*, 1997). Helioseismic observations have detected small temporal variations of the rotation rate below the solar surface (Howe *et al.*, 2000). For cycles 21 and 22, from sunspot group data it was found that the southern hemisphere rotates faster than the northern hemisphere (Javaraiah, 2003).

In contrast, it is found that the northern hemisphere rotates faster during the even cycles while the rotation of the southern hemisphere dominates in odd ones (Gigolashvili, Japaridze, and Mdzinarishvili, 2003; Gigolashvili *et al.*, 2003).

Quiescent filaments are aligned with inversion lines of the large-scale magnetic field, and thus reveal rotation of global magnetic field patterns. In particular, continuous observations of Hα quiescent filaments can be useful when studying the variations of global circulation over a broad range of heliographic latitudes in the solar atmosphere.

2. Observational Data

The differential rotation of the Sun has been studied by many authors using Hα filaments. D'Azambuja and d'Azambuja (1948) and Bruzek (1961) were the first to measure rotation rates near the poles using filaments as tracers. Followed by Adams and Tang (1977) have measured the rotation of short-lived Hα filaments as a function of their latitude. Brajša *et al*. (1991), Bruzek, (1961) and Mouradian *et al*. (1987), by using filaments as tracers, found that limited solar areas of rigid rotation are observed: these are "pivot points" around which the filaments rotate during two or more successive solar rotations. The velocity field was derived for many filaments during a few consecutive days and for different Carrington rotations (Ambrož and Schroll, 2002).

We used the long-term, homogeneous data on Hα filaments obtained at Abastumani Astrophysical Observatory during 1965–1993.

From all the filaments observed during this period we have chosen relatively stable ones, separate fragments of which could be identified during the whole time of observation. The chosen filaments were not connected directly with active regions. Filaments which exist less than three days were considered as unstable and were eliminated.

Filaments are large structures. We mainly determined the rotation rate of individual structural patterns of various filaments as seen on the background of the chromosphere, but we did not determine their height. It would certainly be much better to take into a account height correction, using the method described in Brajša *et al*. (1991) and Vršnak *et al*. (1999). However, as we determined the rotation rate for a set of structural elements of filaments for statistical processing, we have ignored distinctions in height at the present stage of our research and considered that we measure the average height of a filament, which does not depend on latitude and does not change in time. We are planning to make a more detailed study of the dependence of filaments on height in future.

In this paper we investigate the rotation of 619 filaments which was measured in about 13000 points. The rotation rates of accurately identified segments of filaments were measured for the latitude interval of 50°N–50°S and in the range of longitudes ±60° from the central meridian. Beyond these limits measurements were not made, as there were difficulties because of uncertainty arising near the edge of the disk. Our method of evaluation of observational data has been previously published by Japaridze and Gigolashvili (1992).

The differences

$$\triangle\Omega = \Omega_c - \Omega_i$$

were calculated, where Ω_c is the average value of the rotation velocity of filaments. Average annual velocities have been determined for 5° separated latitudinal intervals at cycles 20–22.

Time dependence of residual velocities of Hα filament rotation as a function of heliographic latitude was constructed for solar cycles Nos. 20–22 in Figure 1. Time (in years) is plotted on the X-axis and heliographic latitude with 5°-intervals along the Y-axis. Residual velocities of Hα filaments are plotted along the Z-axis.

Propagation of a quasi-biennial pulse (propagation of rotation residual pulses lasts around 2 years) of rotation residual velocities occurred in 1968–1970, 1979–1981, 1988–1990 in the northern hemisphere of the Sun and in 1969–1971, 1979–1981, 1989–1991 in the southern one.

Figure 2 shows distribution of rotation residual as a butterflydiagram. Observation time in years is plotted along the X-axis and latitude along the Y-axis. The amplitudes of residual velocities of Hα filaments $\triangle\Omega$ vary from -0.2 to $+0.2$ deg/day.

It appears that propagation of a quasi-biennial pulse of residual velocities starts near the moment of polarity reversal of the circumpolar regions of the Sun. Actually, the polarity reversal occurred in the northern hemisphere in 1969, 1971.1, 1971.4 (three-fold polarity reversal) and in the southern one in 1970.5 (cycle No. 20); in 1981.0 and 1981.7 (No. 21 cycle) and in 1990.7 and 1991.7 (No. 22 cycle) in the

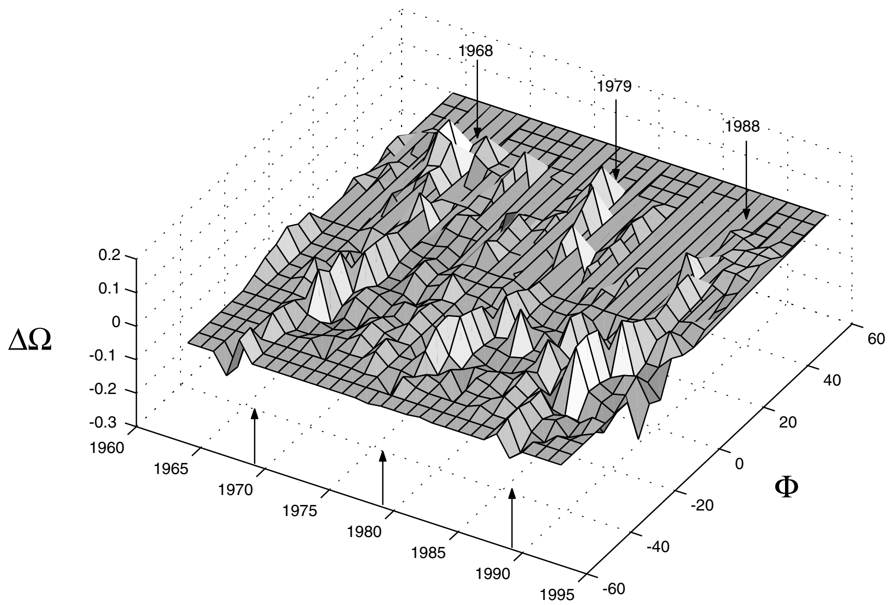

Figure 1. Time variation of the rotation residual of Hα filaments for both solar hemispheres.

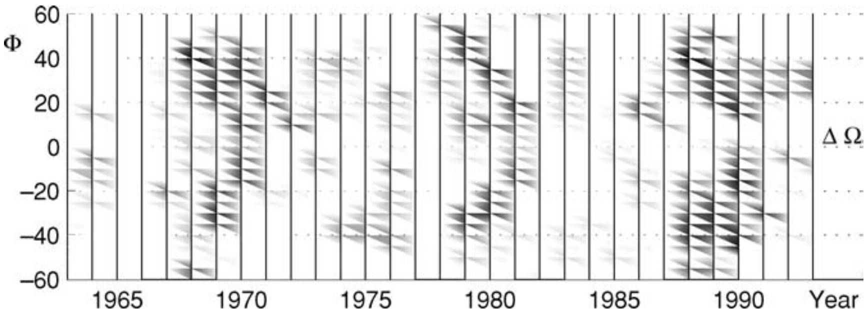

Figure 2. Grey-scale plot of the rotation residual as a function of latitude and time.

northern and southern hemisphere of the Sun respectively (Makarov, Tlatov, and Callebaut, 1977; Makarov and Makarova, 1996). In cycle 22 the polar field reversals present a complicated pattern. First the old polarity becomes isolated at the southern pole, then the polar field shows both polarities. After that the old polarity restored in polar region, but when the isolation of this field is re-established, it declines both in area and strength. The polar field reversal is completed in the north by December 1990, and in the south by March 1992 (Snodgrass, Kress, and Wilson, 2000).

The amplitudes of pulses vary both in the southern and the northern hemispheres. The impression is that propagation of pulses both in the southern and northern hemispheres begins from the mid-latitudes of 40–50° and when reaching the equator they coalesce, sometimes enhancing and sometimes extinguishing each other.

3. Discussion

The study of the differential rotation and its variations in time is an important task of solar physics. Balthazar, Vázques, and Wöhl (1986) found that the differential rotation velocity of sunspot groups is the highest around minima; at the beginning of activity maximum there is a secondary velocity maximum.

During the two recent decades there has been a great interest in quasi-biennial variations. They have been found in various characteristics of solar formations as well as in geophysical phenomena (Predeanu, 1991, and references in it). Quasi-biennial variations were revealed in torsional drift (Howard and LaBonte, 1982; Singh and Prabhu, 1985; Stojanova and Tsap, 1989), in flares (Ikhsanov, Miletsky, and Peregud, 1988) and in circular flocculi (Singh Jagdev and Prabhu, 1985; Stojanova and Tsap, 1989). Two types of the meridional poleward drift of magnetic fields with the characteristic times of travel from the equator to the poles equal to 16–18 and 2–3 years were found (Ivanov and Obridko, 2002). The results obtained by Benevolenskaya (1995, 1998) emphasize that a quasi-biennial component is the most pronounced in the periods of sign changing of the polar magnetic field, especially during a threefold polarity reversal. The intensity of the biennial component is somehow lower than that of basic 22-year component and its intensity varies with time. According to magnetographic data, the biennial component is the most pronounced in the northern hemisphere in cycle 20 and in the southern one in cycle 21. In cycle 22 its value was considerably lower (Benevolenskaya, 1998).

Using homogeneous data of Hα filaments for 1965–1993 we have revealed that a quasi-biennial pulse of residual rotation velocities propagates from relatively high latitudes to the equator in both hemispheres of the Sun. The excitation and distribution of a quasi-biennial pulse (Gigolashvili *et al.*, 1995, 1996) are connected with the magnetic field polarity reversal (Japaridze and Gigolashvili, 1992).

4. Conclusion

On the base of homogeneous data on Hα filaments obtained during 1965–1993 the authors have found that quasi-biennial pulse propagation from high latitudes to the equator happens almost simultaneously in both hemispheres of the Sun (Figures 1 and 2). A pulse drift from relatively high latitudes to the equator was observed in the northern hemisphere in 1968–1970, 1979–1981, 1988–1990 and in the southern one in 1969–1971, 1979–1981, 1989–1991. If the polarity changing is threefold (cycle No. 20 – northern hemisphere, cycle No. 22 – southern hemisphere), the residual velocities are great and have secondary (collateral) peaks at relatively high latitudes. If the polarity reversal is simple (single peak), as in cycle No. 21, propagation of a quasi-biennial pulse occurs almost simultaneously in both hemispheres and the amplitude of residual velocities is minimal.

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