Investigation of Solar Differential Rotation by Means of Long-Lived Features of the Solar Magnetic Field

D. Japaridze, M. Gigolashvili, V. Kukhianidze

Georgian National Astrophysical Observatory, Georgia, marinagig@yahoo.com

The differential rotation of the large-scale magnetic features by using Solar Synoptic Charts (1965-1976) is investigated. Variations of the rotation rate of the large-scale formations both in the northern and southern solar hemispheres for various latitudinal intervals are revealed. The large rotation rate of magnetic formations is obtained for patterns having the sign of the global magnetic field. The change of rotation rate of magnetic features studied in all latitudinal intervals coincides with the sign reversal of the global magnetic field.

Introduction

Large-scale motions are velocity field on a scale larger than supergranulation. The velocity fields observed on the surface include rotation meridional flows, vertical motion, differential rotation and, perhaps, vertical flows.

The observations by which large-scale motion patterns are determined fall into three main categories: a) measurements of Doppler shifts for selected Fraunhofer lines, b) tracking of various tracers such as sunspots and magnetogram-determined magnetic field patterns, and c) analysis of k-ω diagrams from helioseismology [1].

Sunspots have been used as tracers for solar rotation since they were first recognized as features on the Sun [2]. Other features visible on the solar surface that has been used as tracers of solar motion fields and, in particular, rotation, are faculae [3], hydrogen filaments [4] and plages [5].

Another class of features that have been used to track the large-scale solar motion fields are neutral lines in filtergrams and spectroheliograms.

A study of the differential rotation of large-scale magnetic elements

To record and study the co-evolution of neutral lines by the long-term program was carried out by P.S. McIntosh et al. [6]. The observations used to determine the neutral lines are Hα – filtergrams.

McIntosh and co-workers made Carrington maps of these features and the results were published in the form of the atlas of stack plots [6].

As the patterns in McIntosh's stack plots are displayed in both longitude and latitude, one can trace a wealth of details. In addition to the patterns expected from the differential rotation, one finds patterns that appear to show features at the same latitude, which are moving at different rotation rates. One can watch 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 [1].

Large scale stackplots for the entire range of data for solar cycle No 20 (1966-1975) include a series of plots displaying 10°- zones of solar latitude, stepped from 60°N through the solar equator to 60°S. Five identical plots have been placed side-by-side, each stepped up by one row and displaced to the left. This improves the visibility of the features that drift beyond the edge within 360° of solar longitude. Several types of stackplots are included in this collection. Grids to measure rotation rates of drift patterns accompany the plots. These allow a quick determination of the synodic rate of rotation for patterns.

Segmentation of the charts into stackplots with narrow latitude zones is a valuable method of isolating the differential rotation of the Sun. This differential rotation causes long-lived features at same latitude to move relative to those at adjacent latitude, resulting in complicated interactions among large-scale patterns [6].

Observational data and method of treatment

To study the differential rotation of large-scale magnetic elements for Solar Cycle 20 (1966-1975) we used the atlas of synoptic maps, but instead of using grids for determination of rotation velocity, we have developed the following method: we measured the corner between the symmetry axis of a chosen magnetic element and the horizontal line parallel to the horizontal edge chosen among five identical sites and calculated the rotation rate for a given magnetic element with the help of the formula: $\Omega(\varphi) = 1000/(36.664 - \mathrm{ctg}\alpha)$, where α is the angle (measured) and Ω is the rotation rate.

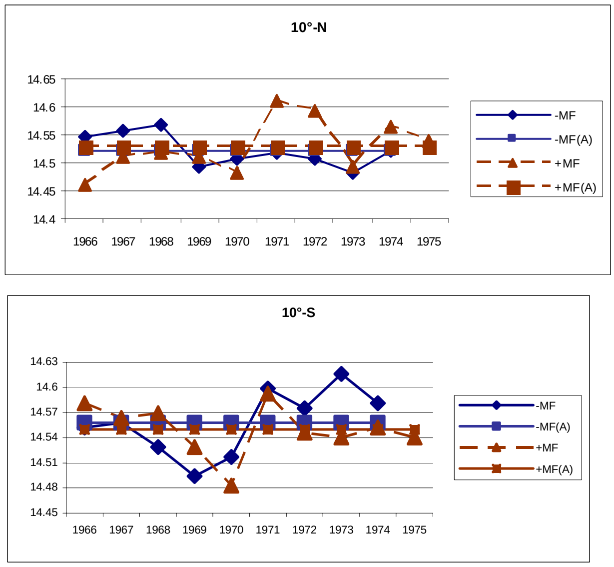

Fig. 1. Rotation rate of magnetic elements with the positive and negative polarity for the northern and southern hemisphere for 10°-zones.

A choice of magnetic elements for measuring the differential rotation is performed by the following method: we have chosen symmetric structural formations from many magnetic data in order to have the best possibility to measure rotation rates by identifying the structural elements chosen by us with the synoptic maps we fined that the structures chosen really correspond to the regions with the same sign of polarity. The characteristic details of the structural elements chosen were also noticed. In most cases they were separated from the surrounding field with the opposite polarity by quiescent Hα filaments having sometimes the same sign of polarity as the magnetic elements and sometimes - the opposite sign [7].

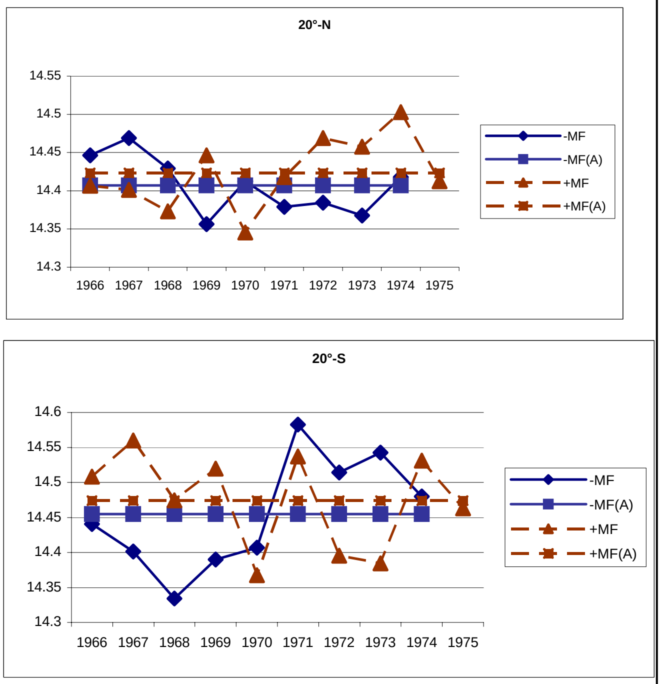

Fig. 2. Rotation rate of magnetic elements with the positive and negative polarity for the northern and southern hemisphere for 20°-zones

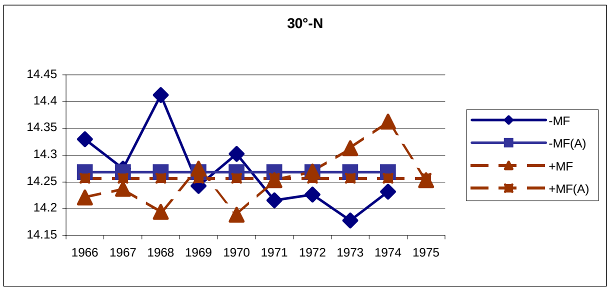

Fig. 3. Rotation rate of magnetic elements with the positive and negative polarity for the northern and southern hemisphere for 30°-zones

For each chosen magnetic element five measurements have been made and an average velocity has been calculated. 990 measurements have been carried out for 198 large-scale magnetic elements.

The diagrams for every 10º zone were constructed separately for the northern and southern hemispheres for magnetic elements with the positive polarity and negative polarity (Fig. 1, 6). As seen from these figures, magnetic elements, which have the same sign of the general magnetic field of the sun, have a larger speed of rotation than those with an opposite sign. In all 10º- zones the average rotation rate of magnetic elements with the negative sign of polarity is little higher than that of magnetic elements with the positive sign of polarity, except for 20º -zones of both hemispheres and 10º- zones of the north hemisphere (in this zone the difference is very small) (Fig. 7).

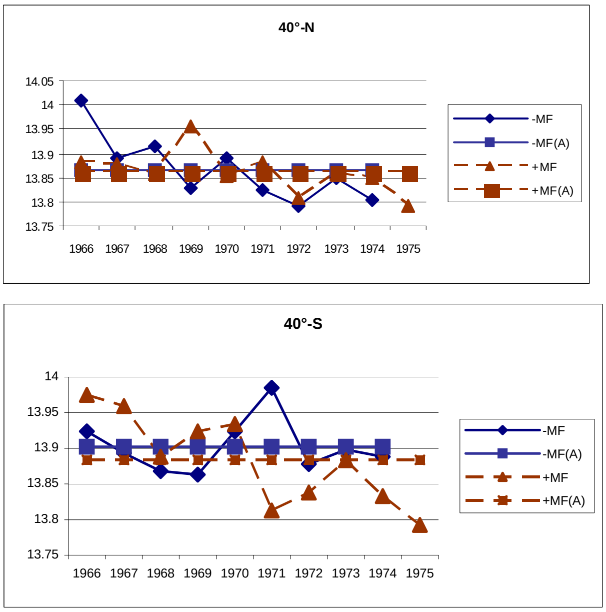

Fig. 4. Rotation rate of magnetic elements with the positive and negative polarity for the northern and southern hemisphere for 40°-zones.

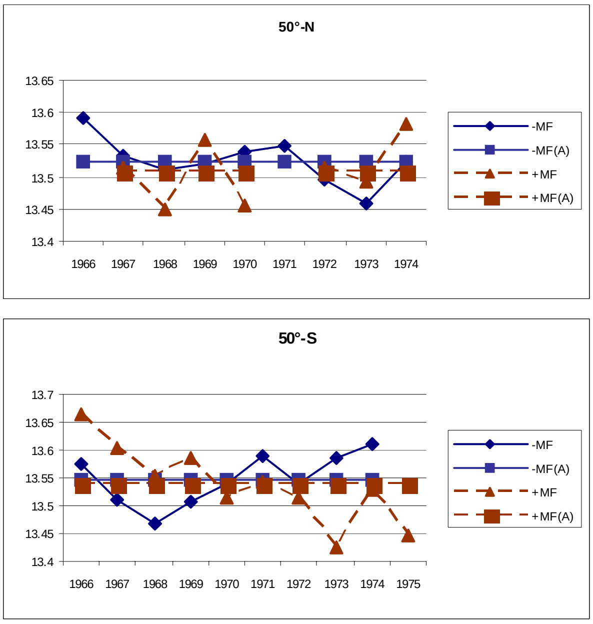

Fig. 5. Rotation rate of magnetic elements with the positive and negative polarity for the northern and southern hemisphere for 50°-zones.

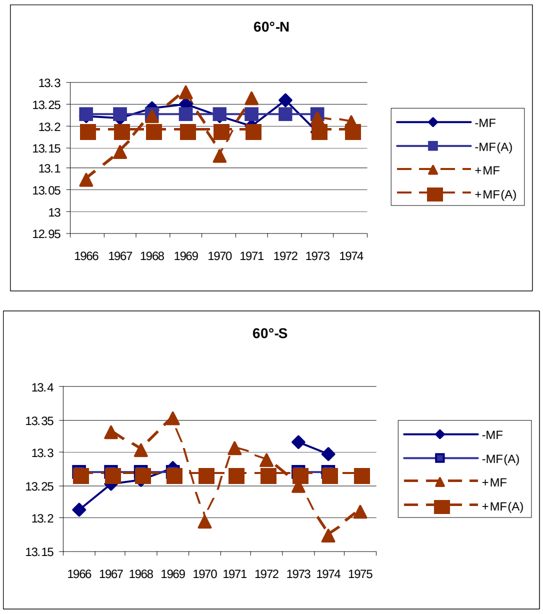

Fig. 6. Rotation rate of magnetic elements with the positive and negative polarity for the northern and southern hemisphere for 60°-zones.

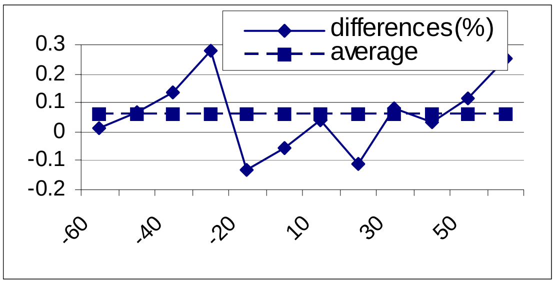

Fig. 7. Difference (in percent) between the average rotation rates for the northern and southern hemispheres.

The rotation rate varies at reversal time of the general magnetic field of the Sun. As three-multiple reversal has taken place in Solar Cycle 20 in the northern hemisphere, in 1969-1970, for each 10^{o}- zone of the northern hemisphere variations of the rotation rate for magnetic elements both with the positive and negative polarity can be noticed.

Discussion

Many authors measured both the average magnetic field of the Sun and large-scale magnetic fields, obtaining different results.

Beckers and Canfield [8] gave a review of the large-scale motion, a recent overview has been given by Howard [9-10] and Schröter [11], who concentrated on the solar rotation, and by Beckers [12] in discussion of the overall dynamics of the photosphere.

Measurements of the solar mean magnetic field showed the presence of three groups of stable peaks connected with rotation of two-, four- and six-sector structures of the solar magnetic field (periods are about 26.^{d}9, 13.^{d}6 and 9.^{d}0). The data also show a temporal change of the mean period of rotation of the solar mean magnetic field within the range of 26.^{d}6 - 27.^{d}4, which clearly indicates a motion of the magnetic pattern to the solar equator during the 11-year cycle of solar activity. The solar mean magnetic field measurements also reveal the presence of a 22-year wave, which coincides in phase with changes in the predominant polarity of the interplanetary magnetic field. This 22-year periodicity can rather be explained by so-called north-south asymmetry of the magnetic field of the Sun [12-14].

An auto-correlation analysis was performed using digitized synoptic charts of the photosphere magnetic fields for the past three solar activity cycles (1965–1994). It is shown that the large-scale system of the solar magnetic fields is rather complex and comprises at least three different systems. The first one is a global rigidly rotating system. It determines the cyclic variation of magnetic fields and is probably responsible for the behaviour of magnetic fields in the polar zones. The second one is a rigidly rotating 4-sector structure in the central (equatorial and mid-latitude) zone. The third one is a differentially rotating system that determines the behaviour of the LSSMF structure elements with a size of ~ 30–60° and less. This one is the most noticeable in the central zone and absent in the polar zones [15].

Comparison of polar plots of the solar magnetic fields with the available Hα filtergrams shows that the polarity boundaries are consistent in these two data sets where they overlap. The polar field reversal involves a complex sequence of events. Although the details differ slightly, the basic patterns are similar in each hemisphere. First the old polarity becomes isolated at the pole, shortly thereafter the isolation is broken, and the polar field includes unipolar regions of both polarities. Then the old polarity moves to the polar region, but when the isolation of this field is established for the second time, it declines in both area and strength [1].

The rotation characteristics of large-scale (global) magnetic fields and their relation to the activity of the local fields are studied over a long time interval (1915–1996). The large-scale magnetic fields rotation rates and local magnetic fields activity vary in ant correlation. Both variations have similar periods (11 years and a quasi-secular period of about 55–60 years), but are shifted relative to each other by half an 11-year cycle. The large-scale magnetic fields rotation rate increases at the minimum of the 11-year cycle of local magnetic fields activity. The large-scale magnetic fields rotation rate is faster in a less active hemisphere. The large-scale magnetic fields rotation period slows down at the maximum of the secular local magnetic fields [16].

The global solar cycle is considered as a manifestation of 3 type magnetic activity: polar, sunspot and large-scale magnetic field cycles. The polar activity cycle is not dependent on sunspot activity [17].

The cycle of the large-scale magnetic field begins during the polar field reversal. At the beginning of the large-scale magnetic field cycle, a narrow bridge connects the polar and mid-latitude magnetic field systems, but later they evolve independently. The polar field has completely open configuration latitude above 60^{o} and fills the whole area of the polar caps near the cycle minimum of the local fields. At this time, essentially all open solar flux comes from the polar caps. The mid-latitude open field regions occur at latitudes of 30-40^{o} away from the solar minimum and drift slowly toward the equator to form a typical ‘butterfly diagram’ at the periphery of the local field zone. The regions with open magnetic fields have more rigid rotation than the sunspots. The rotation characteristics are shown to depend on the phase of the solar cycle [18].

Conclusions

Magnetic elements, which have a sign of the general magnetic field of the sun, have a larger speed of rotation than the elements with an opposite sign. In all 10º- zones the average rotation rate of magnetic elements with the negative sign of polarity is little higher than that of magnetic elements with the positive sign of polarity, except for 20º- zones of both hemispheres and 10º- zones of the north hemisphere (in these zones the difference is very small).

The rotation rate varies at reversal time of the general magnetic field of the Sun. As three-multiple reversal has taken place in Solar Cycle 20 in the northern hemisphere in 1969-1970. For each 10º- zone of the northern hemisphere variations of speed of rotation can be noticed for magnetic elements both with positive and negative polarity.

REFERENCES

[1] H.B. Snodgrass, *ASP Conference Series*, Vol. 27, Karen L. Harvey (ed.), 1992, pp. 262-271.
[2] C. Scheiner, *Rosa Ursini sive solis*: Book 4, part 2, 1630.
[3] H. W. Newton, *MNRAS*, Vol. 84, 1924, p. 431.
[4] D’Azambuja, D’Azambuja, *Ann. Obs. Paris*, Vol. 6, 1948, pp. 1-278.
[5] G. Belvedere, R. M. Pidatella, M. R. E. Proctor, *Geophys. Ap. Fluid Dyn.*, Vol. 51, 1990, pp. 263-286.
[6] P.S. McIntosh, E.C. Willock, R.J. Thompson, “Atlas of stackplots derived from solar synoptic charts”, National Geophysical Data Center, 1991, p. 196.
[7] Solar Geophysical Data, (J.), 1966-1975.
[8] J. M. Beckers, R. C. Canfield, CNRS Colloquium No 250, AFGL-TR-0131, *Env. Res. Papers No. 586*, 1976, p. 207.
[9] R. Howard, *Rev. Geophys. Space Phys.*, Vol. 16, 1978, pp. 721-732.
[10] R. Howard, *ARAA,* Vol. 22, 1984, pp. 131-155.
[11] E. H. Schröter, *Solar Physics*, Vol. 100, 1985, pp. 141-168.
[12] J. M. Beckers, *NASA Conference Publication SP-450*, Vol. 11, S. Jordan (ed.), 1981, p. 11.
[12] V.I. Haneychuk, *Izvestiya KRAO*, Vol. 96, 2000, pp.176-187.
[13] M. Sh. Gigolashvili et al., *New Astronomy*, Vol. 8, 2003, pp. 529-536.
[14] M. Sh. Gigolashvili, D. R.Japaridze, T. G.Mdzinarishvili, *Bull. Abastumani Astrophys. Observ.*, Vol. 76, 2003, pp. 181-192.
[15] E.V. Ivanov, V.N. Obridko, I.V. Ananyev, *Solar Physics*, Vol. 199 (2), 2001, pp. 405-419.
[16] V.N. Obridko, B.D. Shelting, *Solar Physics*, Vol. 201 (1), 2001, pp. 1-12.
[17] V.I. Makarov, et al., 1st Solar & Space Weather Euroconference, “The solar cycle and terrestrial climate”, Santa Cruz de Tenerife, Spain, 25-29 September 2000, *ESA SP-163*, 2000, pp. 367-370.
[18] V.N. Obridko, B.D. Shelting, *Solar Physics*, Vol. 187 (1), 1999, pp. 185-205.