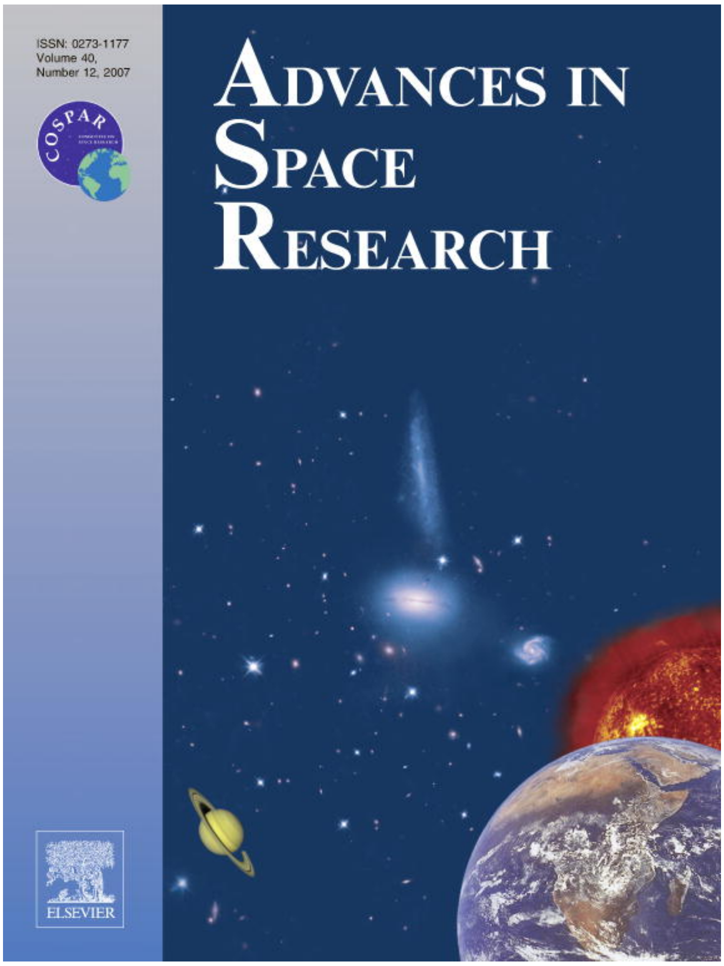
ISSN: 0273-1177
Volume 40,
Number 12, 2007
COSPAR
ADVANCES IN
SPACE
RESEARCH
ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 40 (2007) 1912–1916
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Investigation of the differential rotation of the large-scale magnetic elements for the solar activity cycles 20 and 21

D.R. Japaridze, M.Sh. Gigolashvili *, V.J. Kukhianidze

Georgian E. Kharadze National Astrophysical Observatory of Ilia Chavchavadze State University, A. Kazbegi Ave 2a, Tbilisi 0160, Georgia

Received 3 December 2006; received in revised form 21 May 2007; accepted 10 June 2007

Abstract

The differential rotation of the patterns of the large-scale solar magnetic field during solar activity cycles 20 and 21 is investigated. Compact magnetic elements with the polarity of the general solar magnetic field have larger speed of rotation than the elements with the opposite polarity. The surface of the Sun was divided by 10°-zones. In all of them the average rotation rate of the magnetic elements with negative polarity is little higher than that of the magnetic elements with positive polarity, except for 50°-zone of the south hemisphere and at the 10° latitude of the north hemisphere.

The rates of differential rotation for large-scale magnetic elements with negative and positive polarities have similar behavior for both cycles of the solar activity.

The rotation rate varies at polarity reversal of the circumpolar magnetic fields. For the cycle No 20 in 1969–1970 the threefold reversal took place in the northern hemisphere and variations of rotation rate can be noticed for magnetic elements both with positive and negative polarity for each 10°-zone in the same hemisphere.

Keywords: Sun; Large-scale magnetic patterns; Differential rotation

1. Introduction

Sunspots have been used as tracers for solar rotation since they were first recognized as features on the Sun (Scheiner, 1630). Other features visible on the solar surface that has been used as tracers of solar motion fields and, in particular, rotation, are faculae (Newbegin and Newton, 1931) and hydrogen filaments (D'azambuja and D'Azambuja, 1948).

Another class of features used for tracking the large-scale solar patterns motion fields are neutral lines of the magnetic fields in filtergrams and spectroheliograms (Durrant et al., 2002; Japaridze and Gigolashvili, 1992; Gigolashvili et al., 1995).

The large-scale system of solar magnetic fields is very complex. Some authors consider that it comprises at least three different systems: (1) A global rigidly rotating system determined by the cyclic variation of magnetic fields, probably responsible for the behavior of magnetic fields in the polar zones; (2) A rigidly rotating 4-sector structure in the central (equatorial and mid-latitude) zone; (3) A differentially rotating system that determines the behavior of the elements of the large-scale solar magnetic fields' structure with the size of ~30–60° and less (Ivanov et al., 2001).

Obridko (2001) studied the rotation characteristics of large-scale (global) magnetic fields and their relation to the activity of local magnetic fields during the long time interval (1915–1996). They found that rotation rates of the global magnetic fields and local fields' activity variations are in anticorrelation.

Derosa (2005) found that the surface manifestation of magnetic fields within the solar interior exhibits an unexpectedly high degree of regularity, despite such fields being embedded in an extremely turbulent medium. The largest magnetic fields observed at the surface follow episodic

* Corresponding author.
E-mail address: marinagig@yahoo.com (M.Sh. Gigolashvili).

0273-1177/$30 © 2007 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2007.06.076

patterns of emergence and evolution that collectively form each activity. Though there is also the evidence that smaller-scale magnetic fields possess an imprinting of such cyclic behavior.

Study of the evolving magnetic nature of coronal dimming regions can be used to probe the large-scale magnetic structure involved in the eruption of a coronal mass ejection and analyze the intensity evolution of coronal dimming regions using 195 Å data (Attrill et al., 2006).

In dynamo model with algebraic nonlinearity, the increase continues, however, to higher latitudes and is more gradual. This could be due to the neglect of the coupling between small-scale and large-scale current and magnetic helicities and the latitudinal drift of the activity belts in the model (Kuzanyan et al., 2006).

McIntosh and coworkers made Carrington maps of these features and the results were published in the form of the atlas of stackplots (McIntosh et al., 1991). 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.

In this paper, we study the differential rotation of the patterns of the large-scale solar unipolar magnetic elements during solar activity cycles 20 and 21 using the McIntosh's stackplots.

2. Observational data, method of treatment and analysis

A number of various details can be traced on the patterns in McIntosh's stackplots. Large-scale stackplots for the entire range of data for solar cycles 20–21 (1966–1986) include a series of plots displaying 10°-zones of solar latitude, stepped from 60°N through the solar equator up 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. Grids to measure rotation rates of the drift patterns accompany the plots. This allows us to quickly determine the synodic rate of rotation for patterns (Fig. 1).

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 the same latitude to move relative to those at adjacent latitude, resulting in complicated interactions among large-scale patterns (McIntosh et al., 1991).

To study the differential rotation of large-scale magnetic elements for cycle of solar activity 20–21 (1966–1986) we used the atlas of synoptic maps. Instead of using the grid for determination of rotation rate, we have developed the following method: 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 sites. 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 with the Carrington synodic rate of 27.2753 days; positive slopes indicate apparent rotation rates slower that the Carrington rate. The rotation rate for a given magnetic element we have calculated with the help of the empiric formula (Japaridze et al., 2006):

$$\Omega(\phi) = 1000/(36.664 - \mathrm{ctg}\alpha),$$

where α is the measured angle (Fig. 2), ϕ is latitude and Ω is the rotation rate $\Omega(\phi)$, measured in deg day^{-1}.

To select the magnetic elements for measuring the differential rotation we have chosen visually symmetric structural formations from a large set of magnetic data for the best possibility to measure rotation rates (Fig. 2). By identifying the structural elements by us chosen on the synoptic maps we found that the chosen structures really correspond to the regions with the similar polarity. In most cases, they were separated from the surrounding field with the opposite polarity by quiescent Hα filaments having sometimes the same polarity as the magnetic elements and sometimes – the opposite one (Solar Geophysical Data, 1966–1986).

3. Results

For each chosen magnetic element five measurements have been made and the average velocity has been calculated. 1675 measurements (990 for the cycle No 20 and 685 for the cycle No 21) have been carried out for 335 large-scale magnetic elements (198 for the cycle No 20 and 137 for the cycle No 21). Calculated rotation rates of magnetic elements with the positive and negative polarity for low (10°) and middle (50°) latitudinal zones separately for both hemispheres of the Sun are presented on the Figs. 3–6. 10°-zones are divided this way: 0–10°, 10–20°, 20–30°, and so on. The diagrams for every 10°-zone were constructed separately for the northern and southern hemispheres and magnetic elements with positive and negative polarities.

On the figures "−MF" denotes the rotation rate of magnetic elements with negative polarity, "+MF" – that with positive polarity, "−MF(A)" and "+MF(A)" are the average rotation rates of magnetic elements with negative and positive polarity, respectively. The triangle markers "RT" on the horizontal axes correspond to the epochs of polarity reversals of the solar circumpolar magnetic fields.

As we see from these figures, magnetic elements with the same polarity of the general magnetic field of the Sun, have larger rate of rotation than those with the opposite polarity. In all 10°-zones the average rotation rate of magnetic elements with the negative polarity is little higher than that of magnetic elements with the positive polarity, except for 50°-zone of the south hemisphere.

4. Discussion

For cycles 20 and 21 the rotation rate of large-scale magnetic elements varies at the reversal time of the general

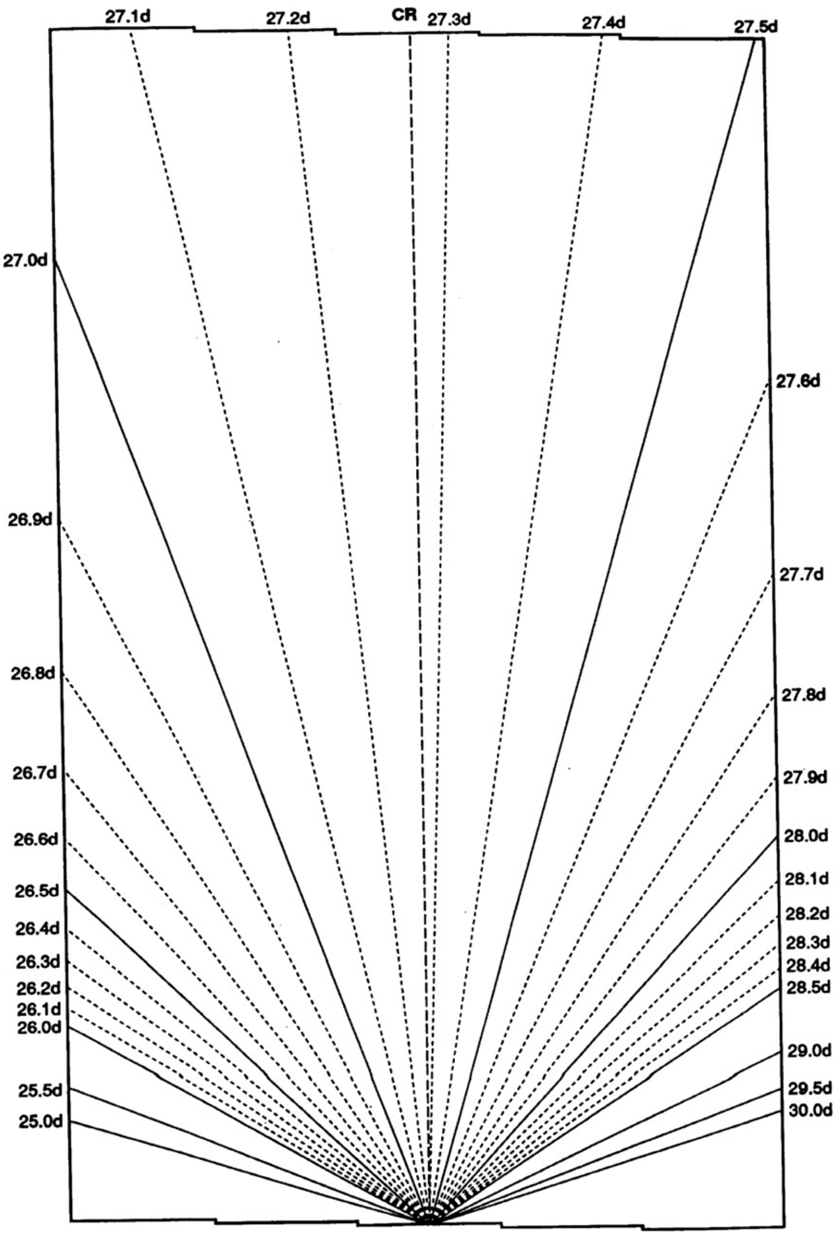

Fig. 1. Grids for determination of rotation rate for large-scale stackplots.

magnetic field of the Sun. The general magnetic field, producing the Sun's north and south magnetic poles, reverses polarity at each cycle. The polarity reversals of the circumpolar regions of the Sun typically occur 3 years after sunspot minimum.

In solar cycle No 20 in the northern hemisphere during 1969–1970 has taken place three-multiple reversal (Makarov et al., 1997; Makarov and Makarova, 1996; Gigolashvili et al., 2005). As we see from our Figs. 3–6, magnetic elements with the same polarity of the general magnetic field of the Sun, have larger rate of rotation than those with the opposite polarity. In all 10°-zones the average rotation rate of magnetic elements with the negative polarity is little higher than that of magnetic elements with the positive polarity, except for 50°-zone of the south hemisphere.

For large-scale magnetic elements with negative and positive polarity there were constructed the curves of differential rotation for both north and south hemispheres for cycles 20 and 21 separately (Figs. 7 and 8) and together (Fig. 9). The rates of differential rotation for large-scale magnetic elements with negative and positive polarity have similar behavior.

5. Conclusions

The differential rotation of the large-scale magnetic elements during solar activity cycles 20–21 is investigated.

Magnetic elements, which have a sign of the general magnetic field of the Sun, have a larger rate of rotation than the elements with an opposite sign. The aver-

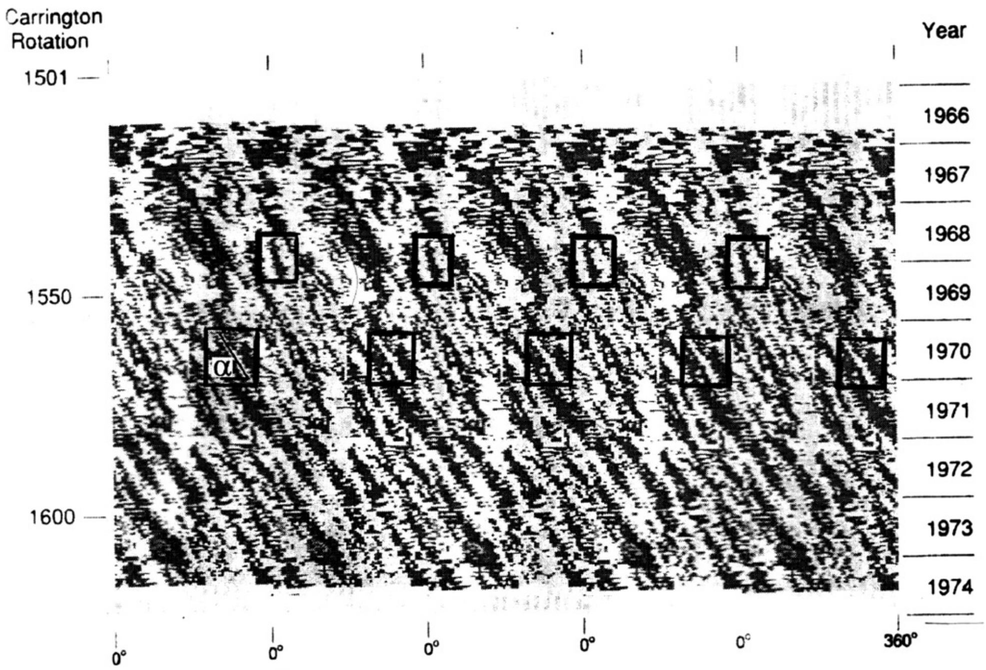

Fig. 2. Large-scale stackplot: south 1 to south 10, for 1966–1975. In the figure there are marked features selected by us for measure (black patterns correspond to negative magnetic elements and white one to positive magnetic element). α is the angle between the symmetry axis of a chosen magnetic element and the horizontal line parallel to the horizontal edge.

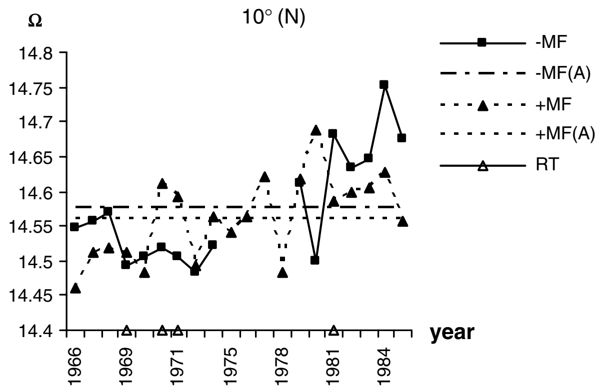

Fig. 3. Rotation rate of magnetic elements with the positive and negative polarities for 10°-zone of the northern hemisphere.

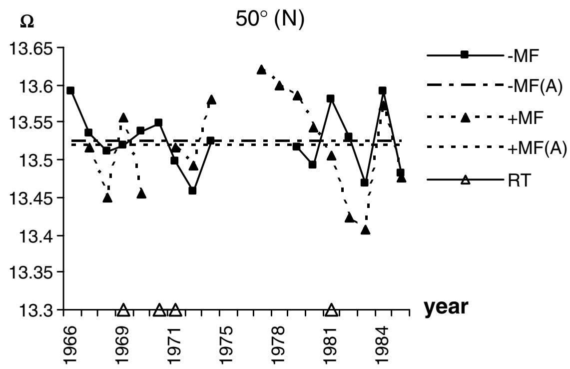

Fig. 5. Rotation rate of magnetic elements with the positive and negative polarities for 50°-zone of the northern hemisphere.

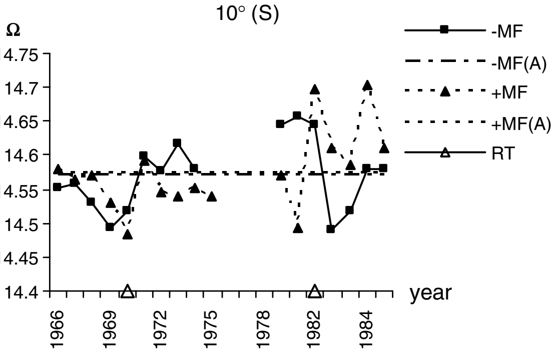

Fig. 4. Rotation rate of magnetic elements with the positive and negative polarities for 10°-zone of the southern hemisphere.

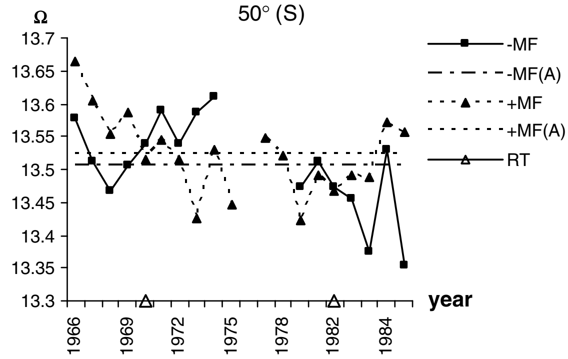

Fig. 6. Rotation rate of magnetic elements with the positive and negative polarities for 50°-zone of the southern hemisphere.

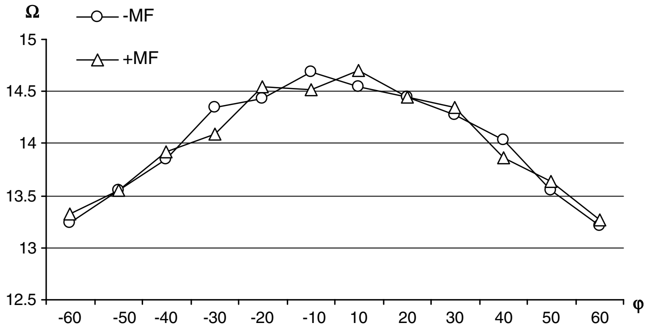

Fig. 7. Rotation rate of magnetic elements with the positive and negative polarities for the northern and southern hemispheres for cycle No 20. The average square deviations $\sigma = 0.65$.

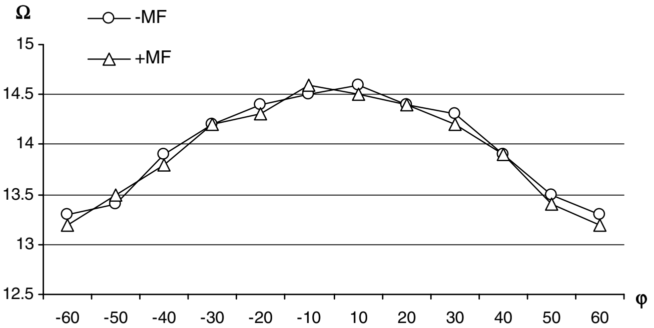

Fig. 8. Rotation rate of magnetic elements with the positive and negative polarities for the northern and southern hemispheres for cycle No 21. The average square deviations $\sigma = 0.75$.

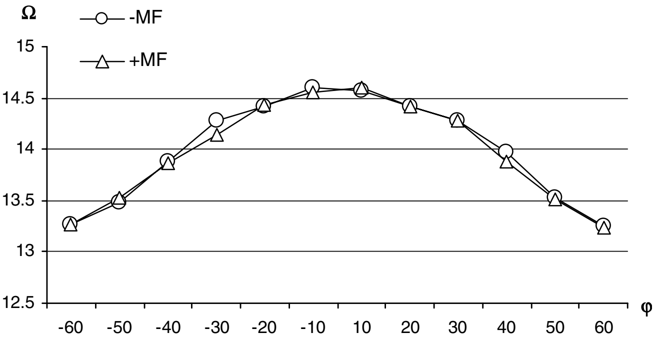

Fig. 9. Rotation rate of magnetic elements with the positive and negative polarities for the northern and southern hemispheres. For both cycles 20 and 21 together the average square deviation $\sigma = 1.14$.

age rotation rate of the magnetic elements with negative polarity is little higher than that of the magnetic elements with positive polarity, except for 50°-zone of the south hemisphere and at the 10° latitude of the north hemisphere (in these zones the difference is very small).

The rates of differential rotation for large-scale magnetic elements with negative and positive signs have similar behavior for the solar cycles 20 and 21.

The rotation rate changes at the polarity reversal of the circumpolar magnetic fields. For the cycle No 20 in 1969–1970 the threefold reversal took place in the northern hemisphere and variations of rotation rate can be noticed for magnetic elements both with positive and negative polarity for each 10°-zone in the same hemisphere.

Acknowledgement

We are grateful to Prof. R.Kiladze for important advices, as well as to unknown referees for useful critical remarks.

References

Attrill, G., Nakwacki, M.S., Harra, L.K., van Driel-Gesztelyi, L., Mandrini, C.H., Dasso, S., Wang, J. Using the evolution of coronal dimming regions to probe the global magnetic field topology. Solar Phys. 238 (1), 117–139, 2006.

D'azambuja, M., D'Azambuja, L. Etude D'Ensemble Des Protuberances Solaireset De Leur Evolution. Ann. Obs. Paris 6, 1–278, 1948.

Derosa, M.L. Influence of small-scale dynamics on large-scale solar activity, large-scale structures and their role in solar activity, in: Sankarasubramanian, K., Penn, M., Pevtsov, P. (Eds.), Proc. Conf. in Sunspot, 18–22 October, 2004, New Mexico, USA, ASP Conference Series, vol. 346, pp. 337–352, 2005.

Durrant, C.J., Turner, J., Wilson, P.R. Bipolar magnetic fields emerging at high latitudes. Solar Phys. 211 (1–2), 103–124, 2002.

Gigolashvili, M.Sh., Japaridze, D.R., Kukhianidze, V.J. Variations of the solar differential rotation associated with polarity reversal. Solar Phys. 231, 23–28, 2005.

Gigolashvili, M.Sh., Japaridze, D.R., Pataraya, A.D., Zaqarashvili, T.V. Propagation of a quasi bi-annual impulse close to the moment of the solar magnetic field polarity changing. Solar Phys. 156, 221–228, 1995.

Ivanov, E.V., Obridko, V.N., Ananyev, I.V. Sector structure, rotation, and cyclic evolution of large-scale solar magnetic fields. Solar Phys. 199, 405–419, 2001.

Japaridze, D.R., Gigolashvili, M. Sh. Investigation of the solar differential rotation by hydrogen filaments in 1976–1986. Solar Phys. 141, 267–274, 1992.

Japaridze, D., Gigolashvili, M., Kukhianidze, V. Investigation of the solar differential rotation by means of long-lived features of the solar magnetic field. Sun Geosph. 1 (1), 31–34, 2006.

Kuzanyan, K.M., Pipin, V.V., Seehafer, N. The alpha effect and the observed twist and current helicity of solar magnetic fields. Solar Phys. 233 (2), 185–204, 2006.

Makarov, V.I., Makarova, V.V. Polar faculae and sunspot cycles. Solar Phys. 163, 2267–2289, 1996.

Makarov, V.I., Tlatov, A.G., Callebaut, D.K. Long-term variations of the torsional oscillations of the Sun. Solar Phys. 170, 373–388, 1997.

McIntosh, P.S., Willock, E.C., Thompson, R.J. Atlas of Stackplots derived from Solar Synoptic Charts. National Geophysical Data Center, Boulder, CO, USA, pp. 196, 1991.

Newbegin, A.M., Newton, H.W. Dark hydrogen flocculi and motion forms. The Observ. 54, 20–21, 1931.

Obridko, V.N. Rotation characteristics of large-scale solar magnetic fields. Solar Phys. 201 (1), 1–12, 2001.

Scheiner, C. Rosa Ursina sive Solis, Bracciano (Ed.), Book 4, Part 2, 17–18, 1630.

Snodgrass, H.B. Synoptic Observations of Large Scale Velocity Patterns on the Sun, in: Karen L. Harvey (Ed.), ASP Conference Series, 27, pp. 205–240, 1992.

Solar Geophysical Data, National Geophysical Data Center, Boulder, Colorado, 1966–1986.