VARIATION OF THE SOLAR ROTATION DURING THE ACTIVITY CYCLE APPLYING THE RESIDUAL METHOD TO GREENWICH DATA

R. BRAJŠA, H. WÖHL, D. RUŽDJAK and K. SCHAWINSKI-GUITON

1 Hvar Observatory, Faculty of Geodesy, University of Zagreb, Kačićeva 26, HR-10000 Zagreb, Croatia
2 Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D-79104 Freiburg, Germany
3 Department of Physics, Cornell University, Ithaca, NY 14853 U.S.A.

UDC 523-327-56
Conference paper

Abstract. The Greenwich data set consisting of positions of sunspot groups was used for the investigation of possible cycle-related variations of the solar rotation in the years from 1874 to 1976. The measurements were extended with the USAF/SOON and NOAA data for the years 1977–1981. The residual method providing yearly deviations from the mean rotation velocity (averaged over all years) for each 5-deg latitude band was applied. These deviations were averaged over latitudes and yearly residuals were calculated. A dependence of the rotation velocity residual on the phase of the solar cycle was found and compared with results from the literature.

Key words: solar rotation - solar cycle - sunspots

1. Introduction

Different manifestations of the solar activity strongly depend on the phase of the activity cycle. Among the global properties of the Sun having indications of cycle-related variations we mention here the solar irradiance (Lang, 2000; Floyd, 2003), measured solar neutrino flux (Bahcall, 1989; Fukugita and Yanagida, 2003), and as a controversial and less significant result the observed radius of the solar disc (Noël, 2003; Delmas, 2003).
The solar differential rotation is an important factor of the solar activity, since the mechanism of the magnetohydrodynamical dynamo action on the Sun arises from the interaction between rotation and convection. Solar differential rotation changes constantly (Howard, 1984) and investigation of its variation may provide additional comprehension of the solar MHD dynamo (Stix, 2002).

Analysing Doppler measurements of the solar rotation, Howard (1976) suggested the existence of cycle-related variations of the solar rotation. Later on, variations of the solar rotation determined tracing sunspots were reported (Lustig, 1983; Gilman and Howard, 1984; Balthasar, Vázquez, and Wöhl, 1986; Khutsishvili, Gigolashvili, and Kvernadze, 2002).

In this paper we analyse variations of the solar rotation determined by tracing sunspot groups in the years 1874–1981, applying the residual method to Greenwich data. The residual method was originally developed by Gilman and Howard (1984) and applied to Mt. Wilson data.

2. The Data Set and Reduction Method

In the years 1874–1976 positions of sunspot groups were measured on photographic plates taken at the Royal Greenwich Observatory on a daily basis. To provide as many measurements as possible, additional measurements from external observatories were also used. The results were published in the catalogue ”Greenwich Photoheliographic Results” (GPR). In the catalogue there are 161714 position measurements. Geometrical midpoints of sunspot groups were taken as positions of the groups and the given precision of the position measurement of 0.1 deg is a rather optimistic estimate, as discussed by Balthasar and Wöhl (1980).

The GPR are available as the printed and electronic versions. The electronic version is extended with the measurements provided by the Solar Optical Observing Network (SOON) of the US Air Force and the National Oceanic and Atmospheric Administration (NOAA). In the present analysis we use 18308 additional measurements from the years 1977–1981, so that the total number of data used here amounts to 180022.

Rotation rates were determined with the daily shift method, i.e., from the daily differences of the Central Meridian Distance (CMD) and the elapsed time (t):
\[
\omega_{\text{syn}} = \frac{\Delta CMD}{\Delta t}. \tag{1}
\]

The synodic rotation rates (\(\omega_{\text{syn}}\)) obtained in this way were then transformed into the sidereal ones (\(\omega\)) applying the procedure described in the papers by Graf (1974) and Roša et al. (1995). In the present analysis only measurements performed at CMD values less than 75 deg east and west were taken into account. In addition, sidereal rotation rates larger than 19 deg/day and less than 8 deg/day were excluded from the analysis. These constraints left 132519 rotation rates which were further reduced.

The residual method (Gilman and Howard, 1984) provides yearly deviations \(\Delta \omega(\phi, i)\) from the mean rotation velocity, averaged over all years, for each latitude band:

\[
\Delta \omega(\phi, i) = \bar{\omega}(\phi, i) - \frac{\sum_{i=1}^{n} \bar{\omega}(\phi, i)}{n}, \tag{2}
\]

where \(\bar{\omega}(\phi, i)\) is the annual (for the year \(i\)) averaged rotation rate for a latitude band centred at the latitude \(\phi\). The total number of years under consideration is denoted by \(n\). These deviations are averaged over latitudes and yearly rotation rate residuals \(\overline{\Delta \omega}(i)\) are calculated yielding a single number for each year:

\[
\overline{\Delta \omega}(i) = \frac{\sum_{\phi=0}^{90} \Delta \omega(\phi, i) \cdot m(\phi, i)}{\sum_{\phi=0}^{90} m(\phi, i)}, \tag{3}
\]

where \(m(\phi, i)\) is the number of rotation rates in a latitude band centred at the latitude \(\phi\) in the year \(i\). A positive rotation rate residual indicates a higher velocity than the average and a negative rotation rate residual indicates a lower velocity than the average. In the present analysis we used a 5-deg latitude band’s width. The data reduction was performed with computer programs written in JAVA and IDL.

3. Results

In Figure 1 rotation rate residuals are presented as a function of time for the period 1874–1981. The first four residuals, from the years 1874–1877, are systematically lower than the rest of the data, very probably due to some systematic error. Up to now we have not found any other plausible
explanation and do not know which kind of error might be responsible for this result. Let us now consider the rest of the data, i.e., rotation rate residuals for the years 1878–1981. Periodical variations of the rotation rate residual, superposed on a systematic decrease of rotation velocity (secular deceleration) can be seen.

![Solar rotation variation, Greenwich sunspot groups](image)

*Figure 1*: Rotation rate residual as a function of time for the years 1874–1981. Typical standard errors around the activity minima are in the range $0.001 - 0.04$ deg/day (in one extreme case $0.1$ deg/day) and around activity maxima in the range $1 - 5 \times 10^{-4}$ deg/day.

To analyse the periodical behaviour of the rotation rate residual (Figure 1) we now present in Figure 2 rotation rate residuals, again as a function of time, but averaged according to the year relative to the nearest sunspot minimum which occurred in the years: 1878, 1889, 1901, 1913, 1923, 1933, 1944, 1954, 1964, 1976, and 1986. Rotation rate residuals were averaged for all years with the same solar cycle phase. Error bars represent simply the standard errors of the mean values. As can be seen in Figure 2, the maximum of the rotation rate residual takes place in the minimum of activity and the minima of the rotation rate residual are in the 2nd and 8th (–4th) years of the cycle. A secondary maximum of the rotation rate residual takes
place in the maximum of activity.

![Graph showing solar rotation variation](image)

*Figure 2*: Dependence of the rotation rate residual on the phase of the solar cycle for the years 1874–1981.

In averaging rotation rate residuals for all years with the same phase of the solar cycle (Figure 2) the number of measurements in each year was not taken into account. Data from different solar cycles were simply averaged together. For this reason the error bars in Figure 2 are relatively large. To reduce the errors we now apply the statistical weights procedure associating the rotation rate residual of every year with the corresponding statistical weight. To the rotation rate residual obtained from the minimal number of measurements ($n = 44$ in the year 1913) the statistical weight $w = 1$ is assigned and residuals from all other years are then normalized to that value. The rotation rate residual as a function of the solar cycle phase obtained in this way is presented in Figure 3. Indeed, the errors are reduced, the qualitative behaviour remained partly similar, but the amplitude of the variation is now smaller (Figure 3), as compared to the procedure without statistical weights (Figure 2).
4. Discussion and Conclusion

In this work indications of the cycle-related changes of the solar rotation determined by sunspot groups from the Greenwich data set were found. The pattern of the variation reveals a higher rotation rate than the average in the minimum of activity and perhaps also in the maximum of activity. This result is mostly consistent with the result of Gilman and Howard (1984), who applied the same residual method to sunspot data from Mt. Wilson and to a lesser extent with the result of Khutsishvili, Gigolashvili, and Kvernadze (2002), who applied a similar method to sunspot data from Abastumani. Further, a secular deceleration of the solar rotation was found, in a qualitative agreement with the results of Balthasar, Vázquez, and Wöhl (1986), who also analysed sunspot group data from Greenwich, but with another method, and partly with the results of Kitchatinov et al. (1999), who analysed Hα synoptic charts.

For any interpretation of the obtained results it is important to under-
stand whether the rotational variations measured by tracers, in our case sunspot groups, represent global changes of the solar plasma, or are just some effect of the used tracers. Our work is still in progress and in the present paper only preliminary results are presented.

Acknowledgements

R. B. acknowledges the support of the A. v. Humboldt Foundation.

References

PROMJENE SUNČEVE ROTACIJE TIJEKOM CIKLUSA AKTIVNOSTI PRIMIJENJUĆI POSTUPAK REZIDUUMA NA GREENWICH-KE PODATKE

R. BRAJŠA1*, H. WÖHL2, D. RUŽDJAK1 i K. SCHAWINSKI-GUITON3

1Hvar Observatory, Faculty of Geodesy, University of Zagreb, Kašićeva 26, HR–10000 Zagreb, Croatia
2Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D-79104 Freiburg, Germany
3Department of Physics, Cornell University, Ithaca, NY 14853 U.S.A.

UDK 523-327-56
Izlaganje sa znanstvenog skupa


Ključne riječi: rotacija Sunca - Sunčev ciklus - Sunčeva pjege

*Stipendist Zaklade Alexander von Humboldt