Astronomical Notes
Astronomische Nachrichten

On the solar rotation and activity

R. Brajša[1], **H. Wöhl**[2], **D. Ruždjak**[1], **B. Vršnak**[1], **G. Verbanac**[3], **L. Svalgaard**[4], and **J.-F. Hochedez**[5]

[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] Geophysical Institute, Faculty of Science, University of Zagreb, Horvatovac bb, HR-10000 Zagreb, Croatia
[4] Easy Toolkit, Inc., Houston, Texas, USA
[5] Observatoire Royal de Belgique, Ave. Circulaire 3, B-1180 Bruxelles, Belgium

Received 2007 Aug 31, accepted 2007 Oct 25

Key words Sun: activity – Sun: rotation

The interaction between differential rotation and magnetic fields in the solar convection zone was recently modelled by Brun (2004). One consequence of that model is that the Maxwell stresses can oppose the Reynolds stresses, and thus contribute to the transport of the angular momentum towards the solar poles, leading to a reduced differential rotation. So, when magnetic fields are weaker, a more pronounced differential rotation can be expected, yielding a higher rotation velocity at low latitudes taken on the average. This hypothesis is consistent with the behaviour of the solar rotation during the Maunder minimum. In this work we search for similar signatures of the relationship between the solar activity and rotation determined tracing sunspot groups and coronal bright points. We use the extended Greenwich data set (1878–1981) and a series of full-disc solar images taken at 28.4 nm with the EIT instrument on the SOHO spacecraft (1998–2000). We investigate the dependence of the solar rotation on the solar activity (described by the relative sunspot number) and the interplanetary magnetic field (calculated from the interdiurnal variability index). Possible rotational signatures of two weak solar activity cycles at the beginning of the 20th century (Gleissberg minimum) are discussed.

Astron. Nachr. / AN **328**, No. 10, 1013 – 1015 (2007) / **DOI** 10.1002/asna.200710867

WILEY-VCH

Astron. Nachr. / AN **328**, No. 10, 1013 – 1015 (2007) / **DOI** 10.1002/asna.200710867

On the solar rotation and activity

R. Brajša[1,⋆], **H. Wöhl**[2], **D. Roždjak**[1], **B. Vršnak**[1], **G. Verbanac**[3], **L. Svalgaard**[4], and **J.-F. Hochedez**[5]

[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] Geophysical Institute, Faculty of Science, University of Zagreb, Horvatovac bb, HR-10000 Zagreb, Croatia
[4] Easy Toolkit, Inc., Houston, Texas, USA
[5] Observatoire Royal de Belgique, Ave. Circulaire 3, B-1180 Bruxelles, Belgium

Received 2007 Aug 31, accepted 2007 Oct 25

Key words Sun: activity – Sun: rotation

The interaction between differential rotation and magnetic fields in the solar convection zone was recently modelled by Brun (2004). One consequence of that model is that the Maxwell stresses can oppose the Reynolds stresses, and thus contribute to the transport of the angular momentum towards the solar poles, leading to a reduced differential rotation. So, when magnetic fields are weaker, a more pronounced differential rotation can be expected, yielding a higher rotation velocity at low latitudes taken on the average. This hypothesis is consistent with the behaviour of the solar rotation during the Maunder minimum. In this work we search for similar signatures of the relationship between the solar activity and rotation determined tracing sunspot groups and coronal bright points. We use the extended Greenwich data set (1878–1981) and a series of full-disc solar images taken at 28.4 nm with the EIT instrument on the SOHO spacecraft (1998–2000). We investigate the dependence of the solar rotation on the solar activity (described by the relative sunspot number) and the interplanetary magnetic field (calculated from the interdiurnal variability index). Possible rotational signatures of two weak solar activity cycles at the beginning of the 20th century (Gleissberg minimum) are discussed.

1 Introduction

The interaction between differential rotation and magnetic fields in the solar convection zone was discussed by Brun (2004), who describes the three-dimensional numerical simulations of compressible convection under the influence of rotation and magnetic fields in spherical shells. One consequence of the model is that the Maxwell stresses can oppose the Reynolds stresses and in this way contribute to the transport of the angular momentum towards the solar poles. This leads to a reduced differential rotation. So, when magnetic fields are weaker, one can expect a more pronounced differential rotation yielding a higher rotation velocity at low latitudes on the average.

The Maxwell stresses are associated with the correlations of the fluctuating magnetic field components which arise from tilts and twists within magnetic structures (Brun, Miesch & Toomre 2004). They originate from the reaction on the flow through the Lorentz forces (e.g. Sturrock 1994; Parker 1996; Mestel 2003).

As proposed by Brun (2004), an observational test for the above described hypothesis can be the behaviour of the solar rotation during the Maunder minimum. Based on observations by Hevelius, a higher rotation velocity at low latitudes during the Maunder minimum was reported by Eddy, Gilman & Trotter (1976). However, this result was criticized by Abarbanell & Wöhl (1981), who found still a slightly more differential rotation during the Maunder minimum as compared to modern values, which was later confirmed by Ribes & Nesme-Ribes (1993). Additional data on the solar rotation velocity during and around the Maunder minimum were discussed by Mendoza (1999), Vaquero, Sánchez-Bajo & Gallego (2002), as well as by Casas, Vaquero & Vazquez (2006).

In the present work we investigate possible implications of the above described interaction between differential rotation and magnetic fields for modern research. In the solar cycle minimum one should expect a more differential rotation profile with a higher velocity at low latitudes, as earlier indicated by Gilman & Howard (1984) and by Balthasar, Vázquez & Wöhl (1986). Also, possible rotational signatures of weak solar cycles will be searched for.

2 The data sets and reduction methods

Positions of sunspot groups were measured on photographic plates taken on a daily basis at the Royal Greenwich Observatory in the years 1874–1976. Additional measurements from other observatories were also used to provide as many measurements as possible. The results were published in the catalogue “Greenwich Photoheliographic Results” (GPR). Midpoints of sunspot groups were taken as positions of the groups. The GPR are available in the printed and electronic

---

[⋆] Corresponding author: romanb@geof.hr 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 used additional measurements from the years 1977–1981. The rotation velocity values from the years 1874–1877 are systematically lower than the rest of the data, most probably due to some yet unknown systematic error. For this reason we exclude the data from the years 1874–1877 and resume the analysis only with the data from the years 1878–1981.

Rotation velocities were determined by the daily shift method, i.e., from daily differences of the central meridian distance (CMD) and the elapsed time. Then we applied the residual method originally proposed by Gilman & Howard (1984). It provides yearly deviations from the mean rotation velocity, averaged over all years under consideration, for each latitude band. These deviations are averaged over latitudes and rotation velocity residuals are calculated yielding a single number for each year. A positive rotation velocity residual indicates a higher velocity than the average, and a negative rotation velocity residual indicates a lower velocity than the average. The rotation residual is higher if the differential rotation is stronger, since sunspots are observed at lower latitudes.

Further details concerning the analysis of the Greenwich data set were given in the paper by Brajša, Ruždjak & Wöhl (2006). In that paper also the power spectrum of the rotation velocity residuals for the years 1878–1981 was analysed and the periods of 32.6, 10.6, 5.2, and 3.5 years were identified. It is interesting to note that a period of about 5 years in sunspot relative numbers was also found by Balthasar (2007), while a period of the "flip-flop" oscillation in sunspot activity of about 3.7 years was reported by Berdyugina & Usoskin (2003).

Coronal bright points were traced in SOHO-EIT full-disc solar images obtained at 28.4 nm (Brajša et al. 2001; 2002). The automatic method of data reduction based on the IDL procedure "Regions of Interest (ROI) segmentation" was applied to triplets of images taken every 6 hours during the period 1998–2000. The numerical ROI parameters (sharpness of the subimages, their circumference range and intensity range of their brightness) were adjusted according to the interactive (visual) method.

As a proxy for the solar activity, yearly and monthly values of the relative sunspot number, provided by the SIDC, were used, and as a proxy for the interplanetary magnetic field strength (B), the interdiurnal variability (IDV) index (Svalgaard & Cliver 2005). From the IDV index the values of B were calculated for time periods also before the measurements from space (Svalgaard & Cliver 2005), and these values were used in the present work.

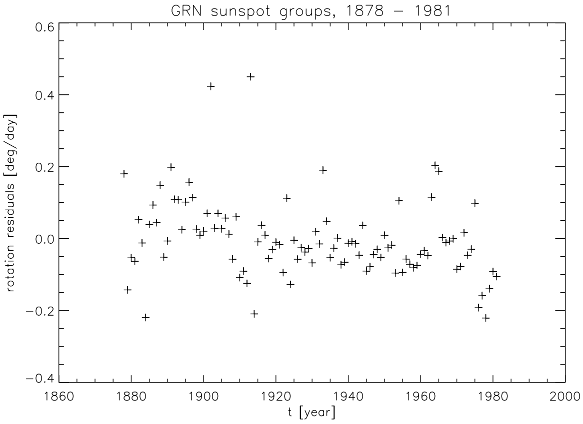

Fig. 1 Rotation velocity residual of sunspot groups as a function of time for the years 1878–1981. All latitudes up to ±60° were taken into account and the CMD cut-off was fixed at ±60°. The secular slope of the least-square fit through the data points amounts to -0.0011 ± 0.0003.

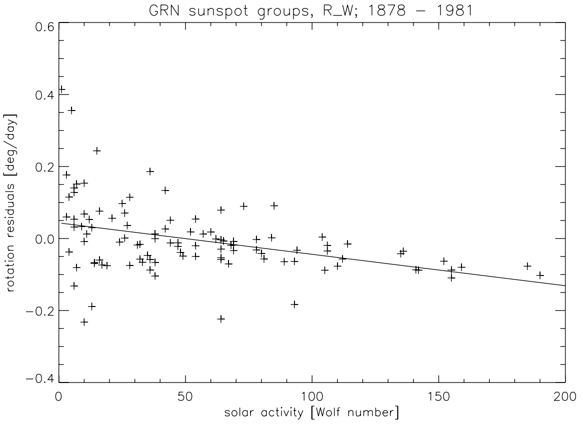

Fig. 2 Rotation velocity residual of sunspot groups (the CMD cut-off was fixed at ±75°) as a function of relative sunspot number for the years 1878–1981. The correlation coefficient amounts to -0.40 for the case without an application of the SW and to -0.45 for the case with an application of the SW. For these two cases the slopes of the straight line are -0.0009 and -0.0007, respectively, with the error of 0.0002 in both cases.

3 Results and discussion

Results are presented in Figs. 1–4. Rotation velocity residuals of sunspot groups as a function of time for the period 1878–1981 are presented in Fig. 1. Superimposed on a systematic decrease of the rotation velocity (secular deceleration) a finer modulation connected with the 11-year solar activity cycle can be seen. This type of variation was discussed in more detail by Brajša, Ruždjak & Wöhl (2006).

A dependence of the rotation velocity residual determined by sunspot groups is presented as a function of the solar activity and the interplanetary magnetic field in Figs. 2 and 3, respectively. The correlation coefficients and the slopes of the straight lines fitted through the data points are given in the captions for the cases with and without an ap-

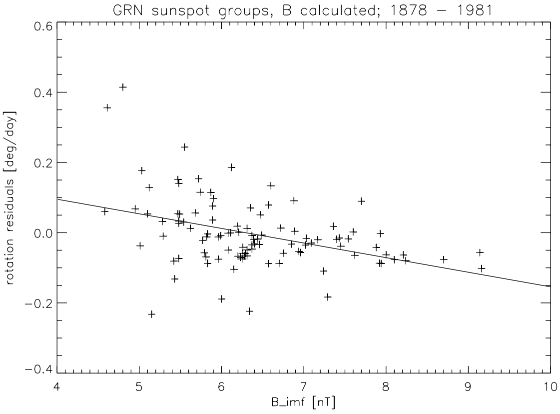

Fig. 3 Rotation velocity residual of sunspot groups (the CMD cut-off was fixed at ±75°) as a function of the interplanetary magnetic field for the years 1878–1981. The correlation coefficient amounts to -0.41 for the case without an application of the SW and to -0.36 for the case with an application of the SW. For these two cases the slopes of the straight line are -0.042 ± 0.009 and -0.025 ± 0.001, respectively.

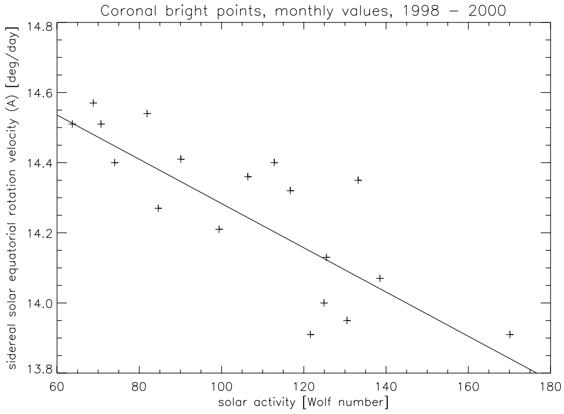

Fig. 4 Solar sidereal equatorial rotation velocity of coronal bright points as a function of relative sunspot number (monthly values) for the period June 1998–October 2000. The correlation coefficient amounts to -0.74 and the slope of the straight line is -0.006 ± 0.001.

plication of the statistical weights (SW). In Figs. 2 and 3 the straight lines are presented only for the case without an application of the SW procedure. The SW procedure was described in detail in the paper by Brajša et al. (2006). We note that in Fig. 1 and in Figs. 2 and 3 not the same CMD cut-off was used; however the rotation velocity residuals do not depend significantly on the CMD cut-off.

Finally, in Fig. 4 we present a dependence of the solar equatorial rotation velocity, determined tracing coronal bright points using the automatic method of data reduction, as a function of the solar activity, in a preliminary form. Within the period June 1998–October 2000 monthly values were used, but not all of the consecutive months were analysed due to some lack of the data. The correlation coefficient and the slope of the straight line are given in the caption.

4 Conclusions and an interpretation

A secular deceleration of the mean solar rotation in the 20th century was found by tracing sunspot groups. This variation also shows a finer modulation indicating a connection with the phase of the 11-year solar cycle. In the years 1902 and 1913 we have found possible rotational signatures of two weak solar activity cycles (Gleissberg minimum). The rotation velocity residual increased in these years for about 0.4 °/day. This is in a qualitative and quantitative agreement with a similar rotational behaviour during the Maunder minimum. A qualitatively similar behaviour was also found on a shorter time scale for the period 1998–2000. As solar activity was increasing, the equatorial rotation velocity determined tracing coronal bright points was decreasing (in this part of analysis monthly values were used).

A dependence of the solar rotation velocity measured by magnetic tracers and solar activity and interplanetary magnetic field was found. An interplay between the Reynolds and the Maxwell stresses is proposed for the interpretation. As stated by Rüdiger & Hollerbach (2004), the more magnetic the Sun is, more rigid is its rotation.

Acknowledgements. We thank E. Cliver (AFRL, Hanscom, MA) for motivating this work, K. Schawinski-Guiton (then Dept. of Physics, Cornell Univ., Ithaca, NY) for taking part in the first phase of data reduction during his research stay at the KIS, Freiburg in 2001 and J. de Patoul (ROB, Bruxelles) for preparing the SOHO-EIT data. The attendance of R.B. at the 5th Potsdam Thinkshop was sponsored by the A.v. Humboldt Foundation.

References

Abarbanell, C., Wöhl, H.: 1981, SoPh 70, 197
Balthasar, H.: 2007, A&A 471, 281
Balthasar, H., Vázquez, M., Wöhl, H. 1986, A&A 155, 87
Berdyugina, S.V., Usoskin, I.G.: 2003, A&A 405, 1121
Brajša, R., Ruždjak, D., Wöhl, H.: 2006, SoPh 237, 365
Brajša, R., Wöhl, H., Vršnak, B., Ruždjak, V., Clette, F., Hochedez, J.-F.: 2001, A&A 374, 309
Brajša, R., Wöhl, H., Vršnak, B., Ruždjak, V., Clette, F., Hochedez, J.-F.: 2002, A&A 392, 329
Brun, A.S.: 2004, SoPh 220, 333
Brun, A.S., Miesch, M.S., Toomre, J.: 2004, ApJ 614, 1073
Casas, R., Vaquero, J.M., Vazquez, M.: 2006, SoPh 234, 379
Eddy, J.A., Gilman, P.A., Trotter, D.E.: 1976, SoPh 46, 3
Gilman, P., Howard, R.: 1984, ApJ 283, 385
Mendoza, B.: 1999, SoPh 188, 237
Mestel, L.: 2003, *Stellar Magnetism*, Clarendon Press, Oxford
Parker, E.N.: 1996, in: T. Roca Cortés, F. Sánchez (eds.), *The Structure of the Sun*, p. 299
Ribes, J.C., Nesme-Ribes, E.: 1993, A&A 276, 549
Rüdiger, G., Hollerbach, R.: 2004, *The Magnetic Universe*, Wiley-VCH, Weinheim
Sturrock, P.A.: 1994, *Plasma Physics*, Cambridge University Press
Svalgaard, L., Cliver, E.W.: 2005, JGR 110, A12103
Vaquero, J.M., Sánchez-Bajo, F., Gallego, M.C.: 2002, SoPh 207, 219