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22-Year Periodicity in the Solar Differential Rotation

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Abstract. Using the data on sunspot groups compiled during 1879-1975, we determined variations in the differential rotation coefficients *A* and *B* during the solar cycle. The variation in the equatorial rotation rate *A* is found to be significant only in the odd numbered cycles, with an amplitude ~ 0.01 μrads^{-1}. There exists a good anticorrelation between the variations of the differential rotation rate *B* derived from the odd and even numbered cycles, suggesting existence of a '22-year' periodicity in *B*. The amplitude of the variation of *B* is ~ 0.05 μ rad s^{-1}.

Key words. Sunspot group—solar cycle—solar rotation.

1. Introduction

Study of solar cycle variations of the Sun's differential rotation is important for understanding the solar cycle mechanism and has been studied by several authors using the Greenwich data on sunspot groups (for references see Javaraiah & Gohkale 1995). Recently, we determined periodicities in the solar differential rotation through the power spectrum analysis of the differential rotation parameters derived from the data on sunspot groups compiled from Greenwich Photoheliographic Results (GPR) during 1879-1976 and from Mt. Wilson velocity data during 1969-1994 (Javaraiah & Gokhale 1995, 1997a; Javaraiah 1998; Javaraiah & Komm 1999). A periodicity at 18.3 ± 3 year was found to be dominant in *B* determined from the spot group data. This periodicity might be related to the solar magnetic cycle (Gokhale & Javaraiah 1995; Gokhale 2000). Hence, it is interesting to study, in detail, the temporal behavior of the differential rotation in the adjacent solar cycles. We have now analyzed the upgraded GPR sunspot group data during 1879-1975 and study variations of the differential rotation coefficients *A* and *B* during the odd numbered solar cycles (ONSCs) and during the even numbered solar cycles (ENSCs). This study is carried out by using the method of superposed epoch analysis (see Balthasar *et al.* 1986). This method provides adequate samples of spot groups in different phases of the solar cycle.

2. Data and analysis

We have used the data on sunspot groups compiled from GPR during 1879-1975. This data is compiled by the National Geophysical Data Center, USA and include the observation time (the date and the fraction of the day), heliographic latitude and longitude, central meridian longitude (CML), etc., for each day observation. We have computed the sidereal rotation velocities (ω) for each pair of consecutive days in the life of each spot group using its longitudinal and temporal differences between these days. We fitted this data to the standard formula of differential rotation, $\omega(\lambda) = A + B\sin^2\lambda$, where $\omega(\lambda)$ is the solar rotation rate at latitude λ, the parameters A and B are measures of the equatorial rotation rate and latitude gradient of rotation rate, respectively. We have excluded the data corresponding to the $|CML| > 75°$ on any day of the spot group life span and also did not use the data from non-consecutive days of spot groups life span. Further, we excluded the data corresponding to the

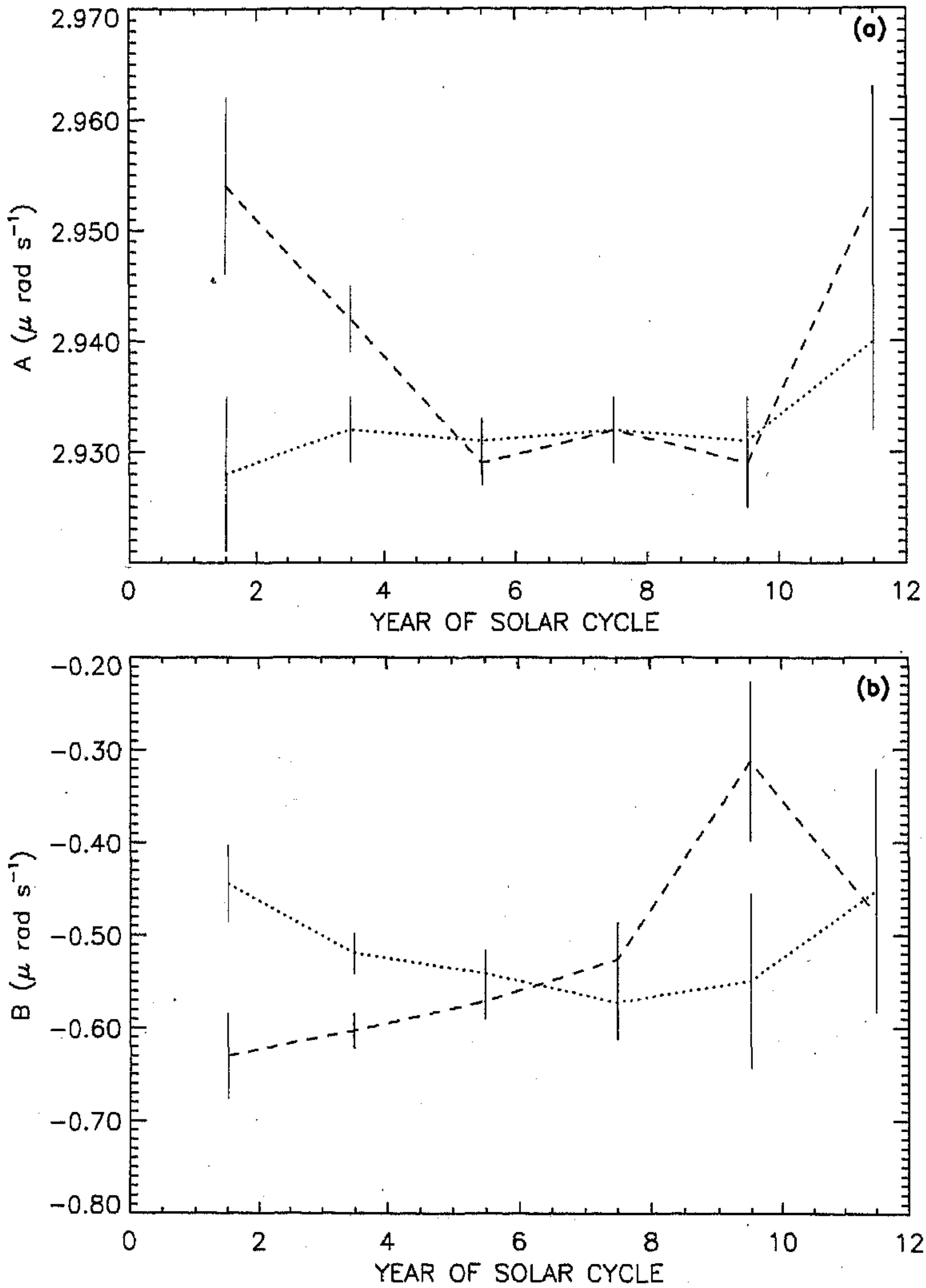

Figure 1. The mean variations of A and B during ONSCs (dashed curves) and ENSCs (dotted curves). Averages taken over 2-year intervals. Activity maximum is around 4-5 years.

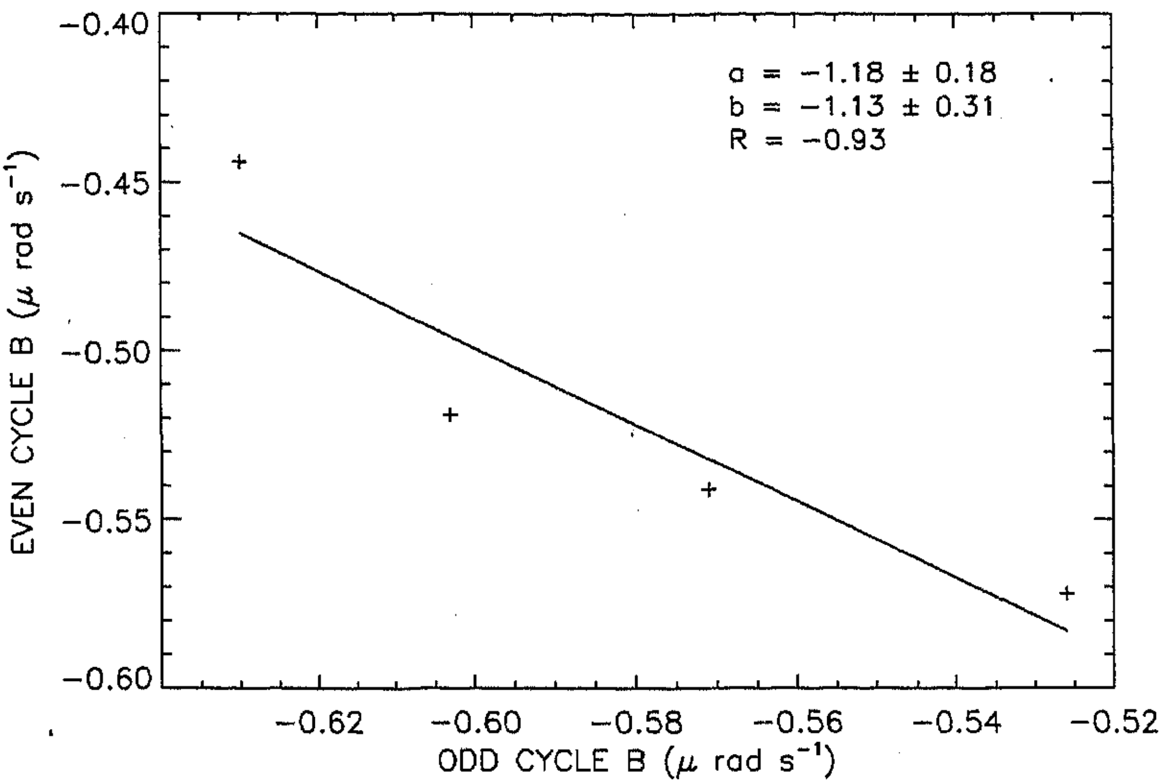

Figure 2. Correlation between B of ONSCs and that of ENSCs during the first eight years of the cycles. The solid line represents the values of B of ENSCs obtained from the linear regression analysis. The values of intercept a, slope b and correlation coefficient R are also given.

'abnormal' motions, e.g., displacements exceeding 3° day^{-1} in the longitude or 2° day^{-1} in latitude. This precaution substantially reduces the uncertainties in A and B (cf., Javaraiah & Gokhale 1995). We have determined the variations of A and B by superposing the data during 1879-1975, according to the years relative to the nearest sunspot minimum (1879, 1890, 1902, 1913, 1923, 1934, 1944, 1954, 1965, 1976).

3. Results and discussion

Fig. 1 shows the mean variations of A and B during the ONSCs (Waldmeier cycle numbers 13, 15, 17, 19) (dashed curves) and the ENSCs (12, 14, 16, 18, 20) (dotted curves). From this figure, it can be seen that the variation in A is significant only in the ONSCs, with amplitude ~ 0.01 μrads^{-1}. The variation in B is quite significant in both ONSCs and ENSCs with amplitude ~ 0.05 μrads^{-1}. There exists a good anti-correlation between the dashed and dotted curves (in Fig. 1(b)) suggesting existence of a '22-year' periodicity in B. However, the amplitude of the anticorrelation depends on the phase of the solar cycle. The value of the correlation coefficient (R) is only —0.33 from all the 6 points. Exclusion of the last point (average value of 11th and 12th years) yielded R = —0.53. The exclusion of last two points yielded R = —0.93 and this is shown in Fig. 2. The linear fit shown in this figure (solid line) suggests existence of a good inverse linear relationship between the B of ONSCs and that of ENSCs, in the first eight years of the cycles.

The so-called 'torsional oscillations' discovered by Howard & LaBonte (1980) and LaBonte & Howard (1982) using Mt. Wilson Doppler measurements during

1967-1982, consist of alternating bands of rotation, faster (or slower) than average, and moving in each hemisphere from the pole to the equator in ~ 22 years. In a given latitude, the velocity of torsional oscillation changes its direction from east to west and vice versa during 11 years with amplitude of about $3\,\mathrm{m\,s^{-1}}$. Teraullo (1990) has found evidence of equator-ward moving bands of torsional oscillation using the sunspot drawings made during cycle 21 at Catania Astrophysical Observatory. It is interesting to note that Ternullo used for each spot group only the data collected from the 4th day of observation until the last observation available (i.e., the data of old spot group). Using the anchoring depths of magnetic structures of spot groups of different life spans and age (Javaraiah & Gokhale 1997b), we suggested that the '22-year'and '11-year' periodicities in B might be dominant in the rotation perturbations near the base of the convection zone and near the surface, respectively (Javaraiah 1998).

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