CYCLE DEPENDENCE OF HEMISPHERIC ACTIVITY

M. Temmer[1], A. Veronig[1], J. Rybák[2], and A. Hanslmeier[1]

[1]Institute for Geophysics, Astrophysics and Meteorology, University of Graz, Universitätsplatz 5, A-8010 Graz, Austria, E-mail: manuela.temmer@uni-graz.at
[2]Astronomical Institute/SAS, SK-05960 Tatranská Lomnica, Slovak Republic

ABSTRACT

Data of daily hemispheric Sunspot Numbers are analyzed including the time span 1975–2001. The study of north-south asymmetries concerning solar activity and rotational behaviors is in particular relevant, as it is related to the solar dynamo and the generation of magnetic fields. As diagnostic tools we use wavelets and autocorrelation functions in combination with statistical significance tests that are applied separately to the northern and southern hemisphere. Pronounced differences between the northern and southern rotational periods are obtained. The northern hemisphere shows a rigid rotation of ~27 days which can be followed up to ~15 periods in the autocorrelation function. The signal of the southern hemisphere is strongly attenuated after 3 recurrences showing variable periods in the range ~26–28.5 days. The presence of these periods is not permanent during a cycle suggesting activity pulses in each hemisphere. For the northern hemisphere strong relations to the motions of deeper lying convective structures building up long-living 'active zones' are suggested.

1. INTRODUCTION

The Sun's differential rotation is an important element of the solar dynamo which is responsible for the solar activity cycle. Thus, the increase in knowledge of phenomena that constitute a part of the cyclic mechanism is of tremendous importance. Numerous studies concerning sunspots as well as other activity phenomena, such as flares, coronal mass ejections, filaments, etc. have shown that these activity phenomena are not distributed symmetrically with relation to the solar equator. The physical causes are not well known. Besides the activity evolution also the rotational periods show an asymmetric behavior. Periodical occurrence rates in the range of ~27 days (all periods stated in this paper are synodic) for the northern and ~28 days for the southern hemisphere were obtained from the analysis of hemispheric Sunspot Numbers for the time span 1975–2000 (Temmer et al. 2002; hereafter referred to as Paper I). In Paper I the rotational periods were calculated from the whole observational time range applying periodograms. The present study is a continuation of Paper I in such a way, that we analyze the periodical occurrence of hemispheric Sunspot Numbers with respect to their changes in time using wavelets.

2. DATA AND METHODS

The data of daily northern and southern Sunspot Numbers are taken from the hemispheric Sunspot Numbers Catalogue[1] provided in Paper I and from the SIDC (World Data Center for the Sunspot Index, Royal Observatory of Belgium). Wavelets and autocorrelation functions are applied to the daily hemispheric Sunspot Numbers in order to identify dominant rotational periods.

The wavelet transform can be used to analyze time series that contain non-stationary power at many different frequencies (Daubechies 1990). Therefore, wavelets are an appropriate tool to investigate the temporal evolution of dominant periods in time series. For this purpose several types of wavelets can be used. However, if the signal is sinusoidal (cf. Fig. 1), the wavelet should be also sinusoidal. Thus, we have chosen the Morlet wavelet (Grossman & Morlet 1984) representing a sinusoidal oscillation contained within a Gaussian envelope as the analyzing wavelet function $\psi(\tau)$, where τ is a non-dimensional time parameter. The continuous wavelet transform is defined as the convolution of a time series, x_n, with equal spacing in time, δt, and $n = 0, 1, ..., N-1$ observation points. It can be written as

$$W_n(s) = \sum_{k=0}^{N-1} \hat{x}_k \hat{\psi}^*(s\omega_k) e^{i\omega_k n\delta t}\,, \qquad (1)$$

where $\hat{x}_k$ is the discrete Fourier transform of x_n and $\hat{\psi}^*(s\omega_k)$ is the scaled and translated version of $\psi(\tau)$,

[1]More details are given within these proceedings: 'Catalogue of hemispheric Sunspot Numbers Rn and Rs: 1975–2000' by Temmer M., Veronig A., & Hanslmeier A.

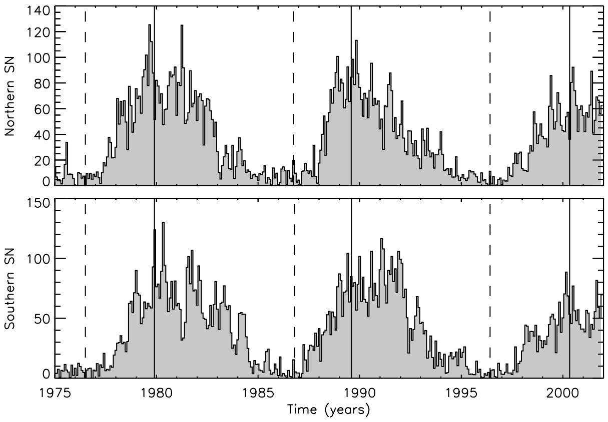

Figure 1. Monthly mean values of northern (top) and southern (bottom) hemispheric Sunspot Numbers for the time span 1975–2001. Dashed/solid lines indicate the minima/maxima of a solar cycle.

and (*) indicates the complex conjugate. By varying the scale s and translating along the localized time index n one can construct a descriptive two-dimensional plot showing both the amplitude of any features versus the scale and how this amplitude varies with time. The angular frequency ω_k is defined as

$$\omega_k = \begin{cases} \frac{2\pi k}{N\delta t} & : k \leq \frac{N}{2} \\ -\frac{2\pi k}{N\delta t} & : k > \frac{N}{2} \, . \end{cases} \tag{2}$$

All wavelet power spectra presented in this paper are calculated for the period range from 10–38 days. As significance tests confidence levels at 90% and 99% are applied. Since the daily hemispheric Sunspot Numbers are not independent from each other but correlated with a typical correlation time of about 7 days (Oliver & Ballester 1995), the background spectrum is modeled with red noise. Regions where edge effects become apparent due to dealing with finite-length time series, such as the beginning and the end of the wavelet spectrum, are labeled as cone of influence (COI). The computation of all these parameters is performed in the way as described by Torrence & Compo (1998).

The autocorrelation function $R_x(L)$ measures the dependence of time series values at one time on the values at another time. Given the time series x_n, with $n = 0, 1, ...N$, the autocorrelation function at lag L is defined as:

$$R_x(L) = \frac{\sum_{n=0}^{N-L-1} (x_n - \overline{x})(x_{n+L} - \overline{x})}{\sum_{n=0}^{N-1} (x_n - \overline{x})^2} \, , \tag{3}$$

with $\overline{x}$ as the mean of x_n.

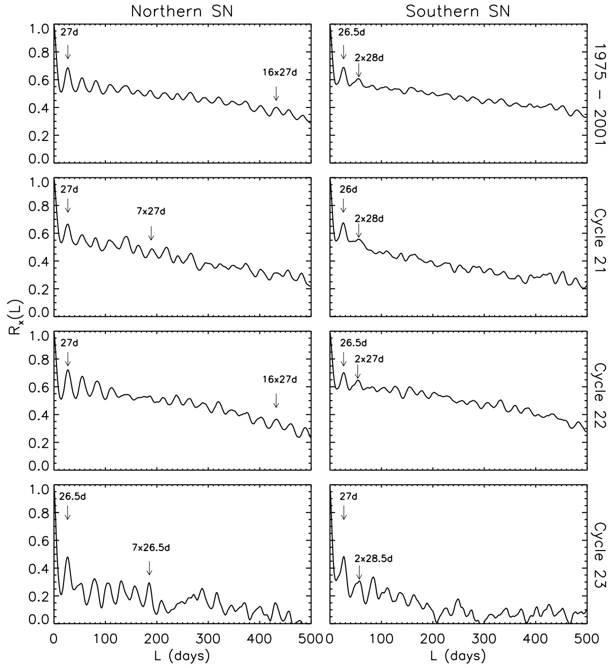

Figure 2. Autocorrelation analysis separately applied to daily northern (left panels) and southern (right panels) Sunspot Numbers. Various time ranges are analyzed up to a time lag of 500 days.

3. RESULTS

Fig. 1 represents the monthly hemispheric Sunspot Numbers from 1975–2001. It is obvious that both hemispheres are very different in their activity behavior during a solar cycle. Especially, the peak times considering the northern and southern hemisphere separately, do not render those of the entire solar disk. In Paper I, the differences are investigated in detail, such as the predominance of one hemisphere over the other for different phases of the cycle. In general, during solar cycles 21 and 22 the cumulative activity is higher for the southern hemisphere. This pronounced N-S asymmetry is not restricted to the distribution of activity but also observed in the rotational periods.

In Fig. 2 autocorrelation coefficients calculated for the total period 1975–2001 as well as separately for the cycles 21, 22 and 23 (rising phase), are plotted. The plots show periodical occurrence rates for the northern and southern hemisphere, respectively, which are cycle-dependent. For the northern hemisphere, the different time ranges that are studied reveal a maximum of the autocorrelation, $R_x(L)$, at a lag of $\sim$27 days. Multiples of this 27-day period can be followed up to $\sim$15 times. For the southern hemisphere the first maxima of the $R_x(L)$ values vary from $\sim$26 to 27 days. However, the southern hemispheric Sunspot Numbers do not show a periodical recurrence of these values. Already the second peak of $R_x(L)$ is observed at the doubling of another period which features a slower period in the range 27–28.5 days. In summary, one can say that both

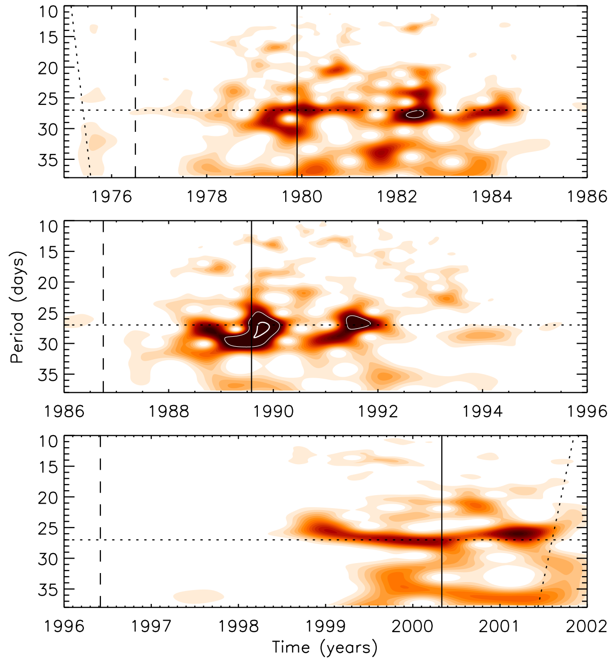

Figure 3. Wavelet power spectra calculated for the northern hemispheric Sunspot Numbers including the time span 1975–2001. Grey-scale coding from white to black represents the square root of power in a linear scale. The COI is given as skew dotted lines. Dashed and solid vertical lines indicate the solar cycle minima and maxima. Dashed horizontal lines indicate a 27-day period. White thin/thick contour lines show the 90%/99% confidence level.

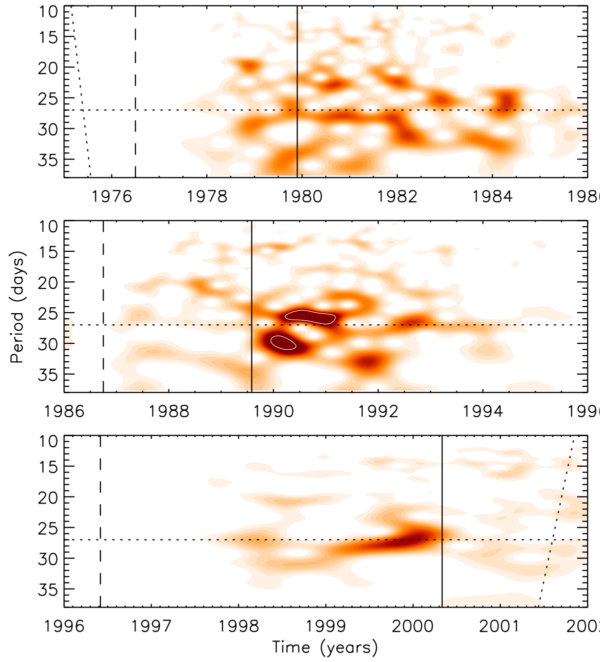

Figure 4. Same as in Fig. 3 but for the southern hemispheric Sunspot Numbers.

hemispheres contain more than one period which are likely to interfere among one another. Separate calculations for solar cycles 21 and 22, as well as for the observed time span of cycle 23, reveal a regular behavior of the northern hemisphere, whereas the signal of the southern hemisphere is strongly attenuated after 2–3 periods.

Figs. 3 and 4 show the results of the wavelet analysis for the daily northern and southern hemispheric Sunspot Numbers, respectively. Multiple periods and their variations close to the rotational periods are obtained. The interrelation of more than one periodical rate may strongly influence each other which is also indicated by Fig. 2. Generally, cycles 21 and 23 smoothly change periods showing significantly lower power than cycle 22.

For the northern hemisphere we get much higher power than for the southern (ratio of about 3:2) ranging from 25 to 30 days centered around the 27-day period. For solar cycle 21 the power is primarily focused on the maximum phase of the cycle, and after ascending it recurred a few years later above the 90% level of significance. For solar cycle 22, where most of the power is revealed, distinct differences of the northern and southern hemisphere can be identified. For the northern hemisphere regions of amplitudes around 27 days that are well defined above the 90% and even 99% significance level appear from 1989.5–1990.25 and above a 90% level from 1991.5–1992.

On the other hand, the southern hemisphere is dominated by significant periods around 29–32 days and at about 26 days which appear intermediate to the dominance of the northern periods during cycle 22 (1990–1991.25). Furthermore, over the entire cycle 21 a rather diffuse 'periodical picture' is obtained for the southern hemisphere, i.e. the power is low and may be not solely centered at one period.

4. CONCLUSIONS AND DISCUSSION

The predominant rotational periods of 27 and 28 days for the northern and southern hemisphere, respectively, which were obtained in Paper I over the time span 1975–2000 are in the present study revealed as strongly cycle-dependent. Moreover, these dominant periods are only apparent during certain phases of a solar cycle and their variability lies in the time range of several days. Especially the southern period at 28 days is much less pronounced which we want to remark as clear deviation from Paper I probably due to the different mathematical techniques applied and the partition of the calculations into several time ranges in the present study.

The apparent diversity of periods originates most probably from the migration of sunspots in latitude during the solar cycle together with the differential rotation of the Sun. Nevertheless, the northern hemispheric Sunspot Numbers seem to be less addicted to this fact than the southern. Applying an autocorrelation analysis, we observe for the northern hemisphere a rather stable rotation in the range of about 27 days which can be followed up to more than 15 times. This periodical recurrence cannot be explained by long-living sunspots that are observed maximally up to 4–5 solar rotations. It provides strong evidence that during the considered periods a preferred zone of activity is present at the northern hemisphere rigidly rotating with 27 days, whereas the behavior of the southern hemisphere is mainly dominated by individual long-lived sunspot groups, which are not (or only weakly) grouped at preferred longitude intervals. A similar outcome for the autocorrelation function of the daily Sunspot Numbers of the entire disk was obtained by Bogart (1982) for the time range 1850–1977. Our analysis separately done for both hemispheres reveals that the persistent 27 day period occurs only for the northern hemisphere. Pojoga & Cudnik (2002) obtain from studying longitudinal distributions of solar magnetic active regions for the first part of cycle 23 (1996–2001), that active regions tend to cluster. These so called activity nests last for 14 rotations in the northern hemisphere, while for the southern the lifetime was shorter. A 27-day period is also found by Henney & Harvey (2002) by investigating magnetic data from the Kitt Peak Observatory concluding its origin from long-lived 'complexes of activity' (Bumba & Howard 1965) in the northern hemisphere at a latitude of approximately 18 degrees. They interpret this quasi-stationary magnetic patterns as flux transport phenomena.

A more detailed picture on how the rotation rate varies with time during the solar cycle can be inferred from wavelet analysis. Therein, the northern hemisphere reveals again a rather coherent signal around the 27-day period for the whole considered time span with significant amplitudes during the maximum phase of a cycle and some years afterwards. On the contrary, the southern hemisphere reveals only after the maximum phase of solar cycle 22 two significant dominant periods near 30.5 and 25.5 days appearing sequentially. First the longer period and after its disappearance the shorter one is pronounced. Both periods seem to increase by at least one day during their appearance. This could be a manifestation of the magnetic flux and convection in the subphotospheric layers. In Paper I it was found that during the phase after the solar cycle maximum the southern hemisphere shows significantly enhanced activity.

A study by Erofeev (1999) shows that the modal structure of the sunspot activity agrees well with that of the large-scale magnetic field. We therefore suggest that the northern hemispheric activity is driven by active zones originating from the underlying magnetic field that must not be considerably disrupted by differential rotation up to several years. Also the southern hemisphere might be dominated over certain smaller time and latitude ranges by such zones at least for the phase after the maximum of cycle 22. Some kind of deep-seated activity pulses are suggested, and active zones are build up stabilized by strong magnetic flux. Recently Beck et al. (1998) pointed out that the magnetic fields of solar activity are generated at the bottom of the convection zone, and long-lived cells, so called 'giant convective cells' (Bumba & Howard 1965), that are connected to this layer could explain the persistence of solar activity at the same location. Thus, giant convective cells probably provide the physical link between the solar interior and active zones at the solar surface.

However, these active regions, or giant convective cells seem to emerge differently in both hemispheres. Therefore and due to the observed N-S asymmetry of both activity distribution and rotational periods, we agree that the evolution of the northern and southern solar hemispheres during a solar cycle are magnetically only weakly coupled as it was inferred by Antonucci et al. (1990). Thus, the study of the northern and southern hemisphere separately on a variety of parameters like the solar magnetic field, activity, rotational periods, flux transport, complexes of activity, etc., and their interrelation will give us relevant results to the solar dynamo theory.

ACKNOWLEDGMENTS

M.T., A.V. and A.H. gratefully acknowledge the Austrian *Fonds zur Förderung der wissenschaftlichen Forschung* (FWF grant P15344) and J.R. the Slovak grant agency VEGA (2/7229/20) for supporting this project. Wavelet software was provided by C. Torrence and G. Compo, and is available at URL: `http://paos.colorado.edu/research/wavelets/`.

REFERENCES

Antonucci E., Hoeksema J.T., Scherrer P.H., 1990, ApJ 360, 296

Beck J.G., Duvall Jr. T.L., Scherrer P.H., 1998, Nature 394, 653

Bogart R.S., 1982, Sol. Phys. 76, 155

Bumba V., Howard R., 1965, ApJ 141, 1502

Daubechies I., 1990, IEEE Trans. Inform. Theory 36, 961

Erofeev D.V., 1999, Sol. Phys. 186, 431

Grossman A., Morlet J., 1984, SIAM J. Math. Anal. 15, 723

Henney C.J., Harvey J.W., 2002, Sol. Phys. 207, 199

Oliver R., Ballester J.L., 1995, Sol. Phys. 156, 145

Pojoga S., Cudnik B., 2002, Sol. Phys. 208, 17

Temmer M., Veronig A., Hanslmeier A., 2002, A&A 390, 707

Torrence C., Compo G.P., 1998, Bull. Am. Meteorol. Soc. 79, 61