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Hemispheric sunspot numbers R_n and R_s from 1945–2004: catalogue and N-S asymmetry analysis for solar cycles 18–23*

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ABSTRACT

From sunspot drawings provided by the Kanzelhöhe Solar Observatory, Austria, and the Skalnaté Pleso Observatory, Slovak Republic, we extracted a data catalogue of hemispheric Sunspot Numbers covering the time span 1945−2004. The validated catalogue includes daily, monthly-mean, and smoothed-monthly relative sunspot numbers for the northern and southern hemispheres separately and is available for scientific use. These data we then investigated with respect to north-south asymmetries for almost 6 entire solar cycles (Nos. 18−23). For all the cycles studied, we found that the asymmetry based on the absolute asymmetry index is enhanced near the cycle maximum, which contradicts to previous results that are based on the normalized asymmetry index. Moreover, the weak magnetic interdependence between the two solar hemispheres is confirmed by their self-contained evolution during a cycle. For the time span 1945−2004, we found that the cycle maxima and also the declining and increasing phases are clearly shifted, whereas the minima seem to be in phase for both hemispheres. The asymmetric behavior reveals no obvious connection to either the sunspot cycle period of ∼11- or the magnetic cycle of ∼22-years. The most striking excess of activity is observed for the northern hemisphere in cycles 19 and 20.

Key words. catalogs – Sun: activity – Sun: sunspots – Sun: photosphere

1. Introduction

The well-known north-south (N-S) asymmetry of solar activity was observed and studied extensively in the past from a variety of solar activity indices. Historically seen, the most outstanding manifestation of an asymmetrical behavior was observed during the Maunder minimum (1645−1715) with almost no spots on the northern hemisphere (Sokoloff & Nesme-Ribes 1994). It has been suggested that the magnetic field systems originating in the two hemispheres and their evolution in the course of the solar cycle are only weakly coupled (e.g. Antonucci et al. 1990).

The most widely studied indices with respect to their hemispheric distribution, as well as periodicities, are sunspot areas (e.g. Newton & Milsom 1955; Vizoso & Ballester 1990; Carbonell et al. 1993; Oliver & Ballester 1994; Krivova & Solanki 2002; Vernova et al. 2002; Ballester et al. 2005), sunspot groups (e.g. Waldmeier 1961; Li et al. 2001; Brajša et al. 2002; Li et al. 2002; Berdyugina & Usoskin 2003; Forgács-Dajka et al. 2004), the flare occurrence/index (e.g. Ružičková-Topolová 1974; Garcia 1990; Verma 1993; Ataç & Özgüç 1996; Li et al. 1998; Ataç & Özgüç 2001; Temmer et al. 2001; Joshi & Joshi 2004; Joshi & Pant 2005), coronal green-line intensity (Waldmeier 1971; Özgüç & Ücer 1987; Tritakis et al. 1988; Storini & Sýkora 1995; Sýkora & Rybák 2005), prominences/filaments (e.g. Hansen & Hansen 1975; Duchlev 2001; Gigolashvili et al. 2005), and photospheric magnetic fields (e.g. Antonucci et al. 1990; Mouradian & Soru-Escaut 1991; Knaack et al. 2004, 2005). On the basis of these activity features, significant N-S asymmetries were revealed. As a result, it is very important to analyze the behavior of solar activity separately for the two hemispheres. Indices representing solar activity for the entire disk are the superposition of northern and southern hemispheric activity, which may smear out distinct features as, e.g., the Gnevyshev gap (Gnevyshev 1963).

In contrast to the numerous investigations based on the above listed activity phenomena, relative sunspot numbers subdivided into the two hemispheres were only partially exploited for this purpose, due to the lack of suitable data sets. The International Sunspot Number (or relative sunspot number), R_i, provided since 1818 by the Solar Influences Data Analysis Center (SIDC) in Belgium, is a measure of solar activity on the entire disk of the Sun. Hemispheric Sunspot Numbers (SN),

* The catalogue is available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/447/735

R_n and R_s, have been included since 1992 but not before (Cugnon 1997; Vanlommel et al. 2004). Studies using hemispheric SN were performed by Swinson et al. (1986) using data provided by Koyama & Yallop (1985) for the period 1947−1983 (data coverage of ∼59%) and Temmer et al. (2002) who prepared a data catalogue of northern and southern relative sunspot numbers for the time span 1975−2000 for this purpose. The data were extracted from daily sunspot drawings made at the Kanzelhöhe Solar Observatory (KSO) in Austria (cf. Steinegger et al. 2001), which have been provided since 1947 on a regular basis within the framework of solar surveillance programs (available online through the Central European Solar ARchive `http://cesar.kso.ac.at/`). However, the KSO data set did not steadily cover the overall period, since 27% of the daily values were missing due to bad weather conditions. Extracting sunspot drawings from another observatory would increase the data coverage and likewise enhance the statistical significance.

Rybák et al. (2004) present first results on a merged data set from KSO and the Skalnaté Pleso Observatory (SPO), Slovak Republic. For the sample's time span 1977−1978, it was shown that the data coverage could be increased from 73% (including only KSO data) up to 86% for KSO and SPO data together. Thus, we aim to produce an extended and improved catalogue (based on KSO and SPO data) that includes hemispheric SN for the time span 1945−2004, which will cover almost 6 entire solar cycles. This also implies an extension and upgrade of the already existing data catalogue for the time span 1975−2000 (Temmer et al. 2002). In order to provide evidence for/against significant patterns in the N-S asymmetry behavior and to perform mid-term studies on the basis of relative sunspot numbers, a validated and consistent data set that is available to the scientific community is needed.

The plan of the paper is as follows. In Sect. 2 the gathering and merging of the two data sets for deriving the hemispheric SN is described. For data validation, a comparison with the international hemispheric SN for the period 1992−2004 was made, as well as a cross-check of data quality between the two observatories. Section 3 contains a brief description of the online catalogue. In Sect. 4, we present an analysis of the N-S asymmetry based on the derived hemispheric SN for solar cycles 18−23. In Sect. 5 we discuss our results and finally, in Sect. 6 the conclusions are drawn.

2. Data gathering and data validation

2.1. Extracting and merging

From daily sunspot drawings provided by KSO and SPO we extracted the northern and southern relative sunspot number for each observatory. The SPO drawings were taken for the entire time span 1945−2004; from 1988 on data were taken from the Stará Lesná Observatory, while thereafter we refer only to SPO, which also includes data from Stará Lesná. Drawings from the KSO were usable from 1952 on; before that time, chromospheric features were indicated on the drawings as well, which inhibited reliable extraction of SN. The KSO as well as SPO/Stará Lesná, are part of collaborating observatories all over the world at which provisional SN are collected and averaged in an advanced form to be published by the SIDC. The data coverage for SPO in the time span 1945−2004 is ∼58%, and for KSO over the period 1952−2004 ∼72%. For KSO and SPO data together, the coverage is ∼84% including ∼38% of days within the entire time span 1945−2004, where drawings from both observatories are available (cf. Rybák et al. 2004).

For each observatory, we counted the SN separately for the northern and the southern hemisphere. The merging of both data sets is then achieved as follows: for dates where SPO data but no KSO data are available, the data are taken only from SPO and vice versa; for common days, i.e. observations from both observatories SPO and KSO are available, their average is simply taken. After this merging step, for each available day the relative fraction of the northern and southern component, n and s, is calculated (i.e. normalized to the activity of the entire disk). The final hemispheric SN, R_n and R_s, are then calculated by multiplying n and s with the total SN R_i from SIDC, for that day, i.e.

$$R_n = n \times R_i, R_s = s \times R_i. \tag{1}$$

With this procedure we ensure that the derived hemispheric SN are normalized with respect to the international SN (cf. Temmer et al. 2002), i.e. $R_n + R_s = R_i$. Finally, dates without any observation are linearly interpolated with the derived R_n and R_s time series.

2.2. Cross-validation with SIDC (1992–2004)

To validate the procedure described in Eq. (1), we compared the derived hemispheric SN, R_n and R_s, with the international hemispheric SN, $R_{n,\mathrm{SIDC}}$ and $R_{s,\mathrm{SIDC}}$, for the overlapping period 1992−2004. For comparison, we utilized the daily, the monthly-mean, and the smoothed-monthly (13 months running average) values of the international hemispheric SN provided by SIDC, online available at `http://sidc.oma.be/`. A detailed description of the SIDC data sets and the methods that are used for its determination are given in Cugnon (1997) and Vanlommel et al. (2004).

The top panels in Fig. 1 show the scatter plots of the derived daily hemispheric SN, R_n and R_s, versus the corresponding international SN for the northern and southern hemisphere provided by the SIDC, $R_{n,\mathrm{SIDC}}$ and $R_{s,\mathrm{SIDC}}$, covering the period 1992−2004. The scatter plots clearly reveal that no systematic difference exists between the derived and the international daily hemispheric SN. Moreover, the scatter turns out to be rather small. The results of the regression analysis are summarized in Table 1. The slope derived from a linear least-squares fit to the data, as well as the cross-correlation coefficients, are very close to 1. For the standard error between the fitted and the original data, we obtain ∼4.0. For the old catalogue Temmer et al. (2002) obtained an outlier for May 2000 due to the low data coverage (5 days of observation that month), which does not show up in the new combined data. A comparison with the regression analysis presented in Temmer et al. (2002) also confirms the high quality of the new data set gathered from the two observatories.

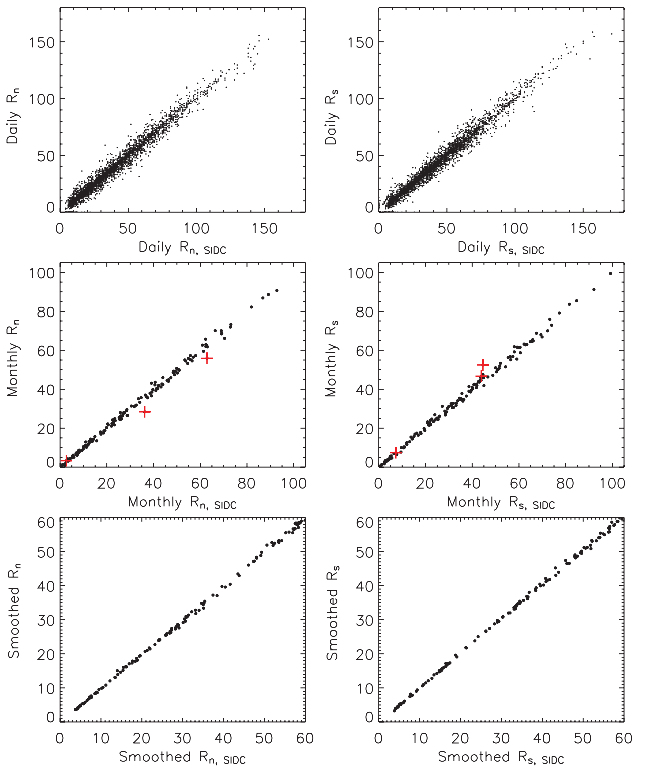

Fig. 1. Scatter plots of the daily (*top panels*), monthly-mean (*middle panels*), and smoothed-monthly (*bottom panels*) hemispheric SN for the northern (*left panels*) and the southern (*right panels*) hemisphere. Calculated hemispheric SN from KSO/SPO, R_n and R_s, are plotted against the international hemispheric SN provided by the SIDC, $R_{n,\mathrm{SIDC}}$ and $R_{s,\mathrm{SIDC}}$, for the period 1992–2004. Crosses in the middle panel indicate months with a data coverage < 18 days.

Table 1. Summary of the regression analysis of the merged KSO/SPO and SIDC hemispheric SN 1992−2004. The analysis was performed for the daily, the monthly-mean, and the smoothed-monthly northern (N) and southern (S) relative sunspot numbers. We list the cross-correlation coefficients (*Corr.*), the parameters obtained from the linear least-squares fit (*intercept, slope*), and the standard error between the fitted and original data (*StE*).

	Corr.	Linear Fit		StE
		intercept	slope	
daily N	0.990	−0.170 ± 0.094	1.000 ± 0.002	4.027
daily S	0.990	−0.034 ± 0.098	1.000 ± 0.002	4.010
monthly N	0.998	−0.021 ± 0.196	0.992 ± 0.005	1.437
monthly S	0.998	+0.130 ± 0.204	1.002 ± 0.005	1.423
sm.mon. N	0.999	−0.192 ± 0.070	0.997 ± 0.002	0.451
sm.mon. S	0.999	−0.038 ± 0.077	1.009 ± 0.002	0.462

For the monthly hemispheric SN, we obtained a few points that lie slightly outside the main regression line (indicated as crosses in the middle panels in Fig. 1), which are due to low data coverage with <18 observing days for the corresponding month. We want to stress that, for the entire time span (1945−2004), only 25 out of 720 months contained <18 observing days, and 10 months had <15 observing days. Figure 2 shows the course of the derived hemispheric SN, together with the international hemispheric SN from SIDC for the period

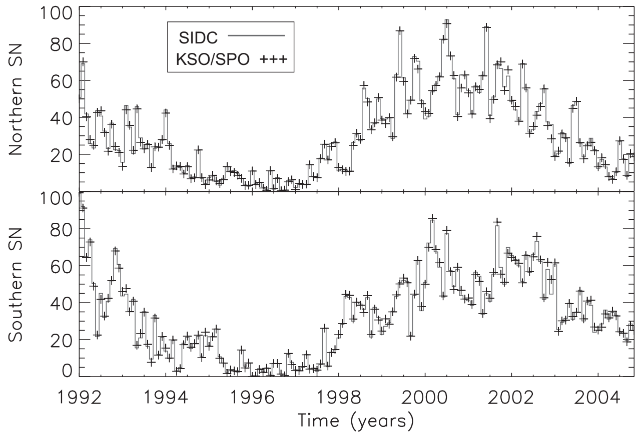

Fig. 2. Monthly hemispheric SN from SIDC (dotted line) and KSO/SPO data (crosses) for the overlapping time span 1992−2004. Northern/southern SN are given in the top/bottom panel.

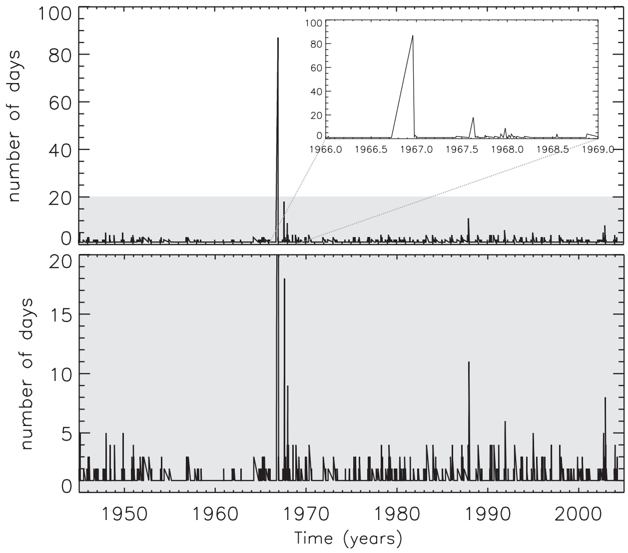

Fig. 3. *Top panel*: continuously missing days within the data set of sunspot drawings from KSO and SPO during the time span 1945−2004; the clipping shows in detail the two longest gaps of 88 and 18 days for the years 1966−1969. The gray shaded area indicates the zoomed part shown in the bottom panel.

1992−2004. In general, the derived hemispheric SN render the international ones (cf. Figs. 1 and 2; Table 1) very well.

2.3. Completion of the data set (1945–2004)

For about 16% of the days within the period 1945−2004, no observations were available, i.e. neither from KSO nor from SPO. For these intervals it is necessary to check their length and randomness. Figure 3 shows the number of continuously missing days in the merged data set of sunspot drawings. As can be seen in the bottom panel, the major part has a length well below 5, and only three gaps are longer than 10 days, namely 11, 18, and 88 days. The long gap of 88 continuously missing days is due to repairs of the KSO instrument and building that were performed from 26-Jun.-1966 until 19-Dec.-1966, as well as similar repairs at SPO from 23-Sep.-1966 until 21-Dec.-1966.

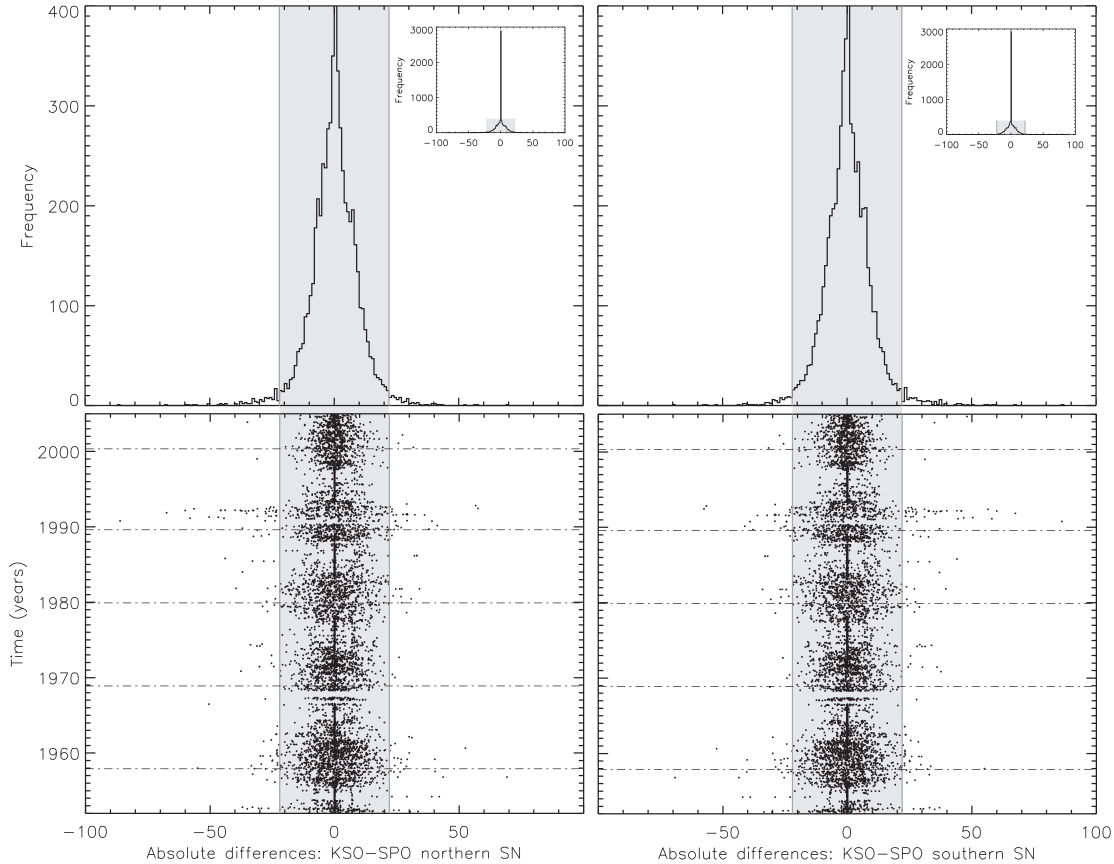

Fig. 4. *Top panels*: histogram of the deviations between daily hemispheric SN derived from KSO and SPO sunspot drawings available on common days. For details the histogram is cut at a frequency number of 400. The inset shows the full range of the histogram. *Bottom panels*: temporal evolution of the differences between daily KSO and SPO SN during the time span 1952−2004. *Left panels*: northern SN. *Right panels*: southern SN. The grey shaded area between ±22 includes ~98% of the calculated differences. Dashed-dotted lines indicate the solar maximum of a cycle.

Therefore, data from neither KSO nor SPO were available for an overlap in time of 88 days. Linear interpolation over this interval is useless, as well, since it covers several solar rotations.

Thus, we have to fill this interval with external data that are provided separately for the northern and southern solar hemispheres. Since sunspot drawings for this time span are not easily available from other observatories, we decided to use data from sunspot areas (Greenwich) that are separately given for both hemispheres. As a substitution, the northern and southern fraction derived from sunspot areas for the specific time span is multiplied with the international SN. Thus we ensure again that the sum of the derived R_n and R_s is equal to the international SN.

Here the question arises why we need to extract hemispheric SN from drawings to study long-term N-S asymmetries and not take sunspot areas instead? Temmer et al. (2002) showed that, in general, the correlation between sunspot areas and relative sunspot numbers is far from being one-to-one. Especially during the maximum phase of the solar cycle they found significant differences. Moreover, Pettauer & Brandt (1997) stressed that the reliable measurement of sunspot areas is not an easy task and that results might differ by an order of magnitude due to the different techniques and instruments used. For a short time span, as here to fill our data gap, these facts are negligible, although for mid- and long-term investigations of solar activity, the difference might be significant.

A further cross-check was made in order to validate the data quality among the KSO and SPO sunspot drawings. For this purpose the relative sunspot numbers for the northern and southern hemispheres are calculated separately for KSO and SPO for the days they have in common. The ratios $n_{\rm KSO}$, $s_{\rm KSO}$ and $n_{\rm SPO}$, $s_{\rm SPO}$ extracted from sunspot drawings of each observatory are multiplied by the international SN $R_{i,\rm SIDC}$ for the respective days. The left and right panels in Fig. 4 show the deviation for each day, i.e. $R_{n,\rm KSO} - R_{n,\rm SPO}$ and $R_{s,\rm KSO} - R_{s,\rm SPO}$, respectively. For each hemisphere, the histogram of the differences is shown, along with their temporal evolution. Both histograms reveal that ~98% of the calculated differences are located within the range ±22 (~85% have a difference ≤10). Differences in that range might be easily achieved according to the definition of the relative sunspot number $R_i \approx 10g+f$ (without correction factor), where g indicates the number of sunspot groups and f the number of sunspots. Thus, one sunspot group that is not identified by one of the observatories gives a difference of at least 11 in the relative sunspot number. Differences in defining groups which strongly depends on the observer as well as instrument capabilities would give a deviation of 10 such as when two spots are measured as one group versus when two

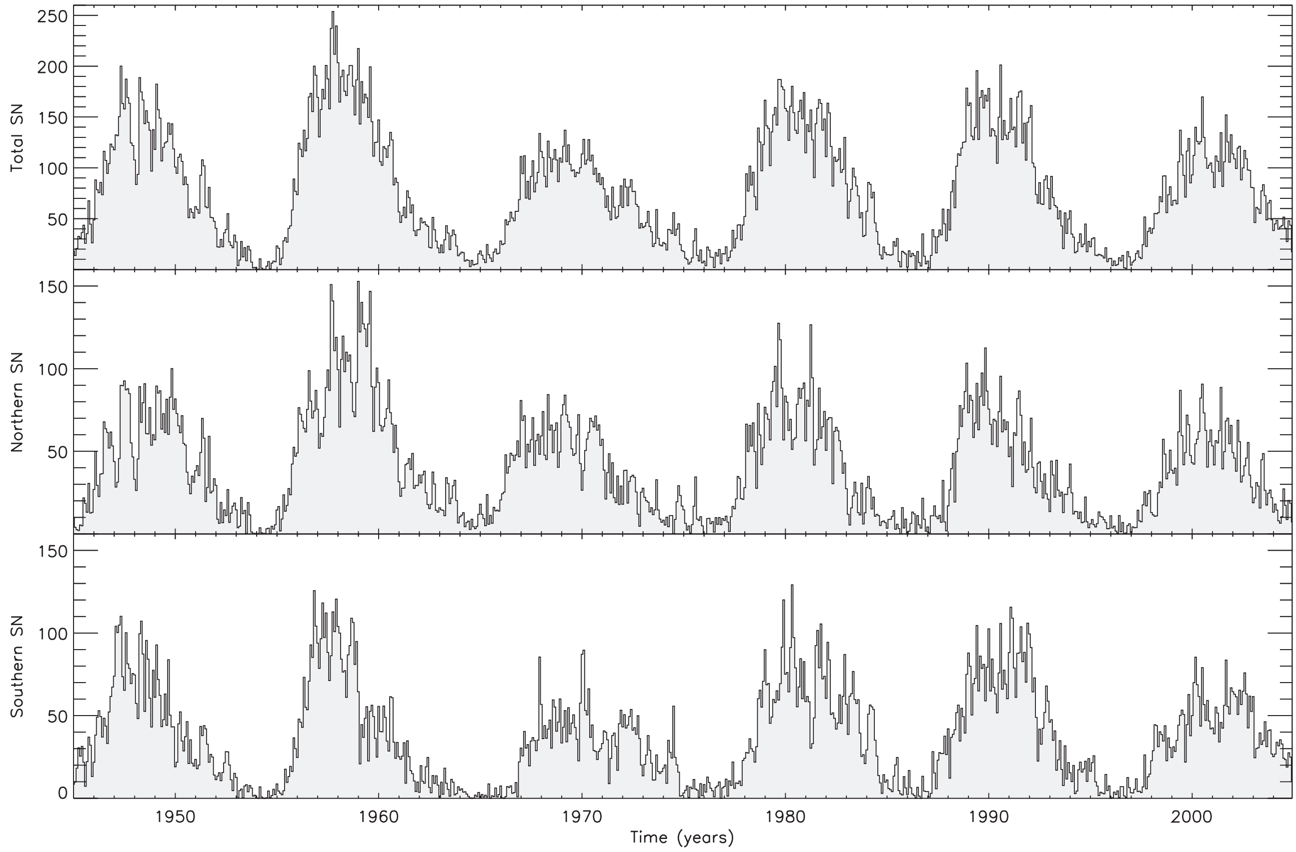

Fig. 5. *Top panel*: monthly relative sunspot numbers for the entire disk (from SIDC); *middle panel*: derived monthly northern relative sunspot numbers; *bottom panel*: derived monthly southern relative sunspot numbers.

spots are measured as two separate groups. The temporal evolution of calculated differences (cf. bottom panels in Fig. 4) shows that those differences are enhanced during times of high solar activity.

In conclusion, no systematic differences are observed, whether between the two observatories (check range 1952−2004) or between the derived data and SIDC (check range 1992−2004). Thus, we can confirm that the merging of KSO and SPO data and derivation of northern and southern hemispheric SN together result in a consistent data set that is convenient for scientific use which can be extended by the SIDC hemispheric SN available since 1992. Finally, the derived monthly hemispheric SN are presented in Fig. 5 for the time span 1945−2004, i.e. almost fully covering solar cycles 18−23.

3. The catalogue

The derived data for the period 1945−2004 has been compiled into a catalogue consisting of two parts, including a) daily hemispheric SN and b) monthly-mean and smoothed-monthly mean hemispheric SN. The catalogue is available online at the CDS. The organization of the catalogue is described in the following (for details see the `ReadMe` file).

a)

- 1st column: year, month, and day (interpolated days are marked with an asterisk (∗));
- 2nd column: daily northern SN;
- 3rd column: daily southern SN;

b)

- 1st column: year and month (months with less than 18 observation days are marked with an asterisk (∗) to note that the statistical significance of the derived monthly data is lowered);
- 2nd column: monthly mean northern SN;
- 3rd column: monthly mean southern SN;
- 4th column: smoothed monthly northern SN (13 months running average);
- 5th column: smoothed monthly southern SN (13 months running average).

4. North-south asymmetry

In the following we perform statistical studies concerning the N-S asymmetry of solar activity, exclusively using the derived hemispheric SN.

Figure 5 shows the course of solar cycles 18−23 based on monthly relative sunspot numbers, which clearly points out the importance of separating the northern and southern hemispheres when analyzing solar activity. It can be seen that the shape of a cycle based on the total SN is the result of the overlapping activity of both hemispheres. For all cycles studied, N-S asymmetries are found for the declining and increasing phases, as well as times of maxima. The N-S activity peaks are

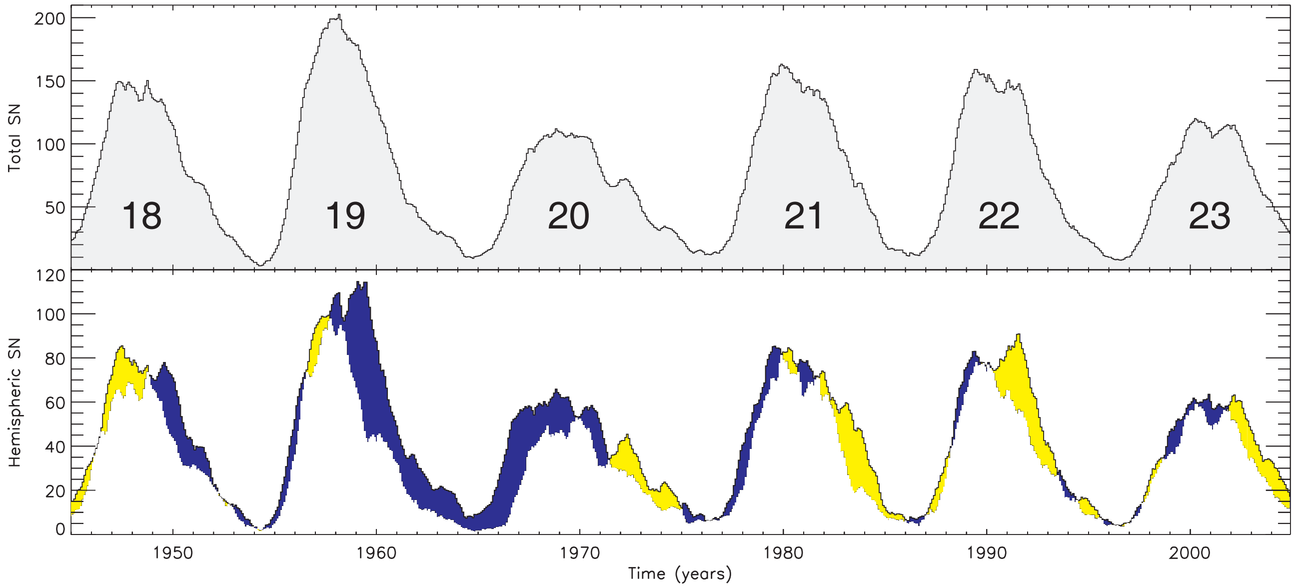

Fig. 6. Smoothed monthly relative sunspot numbers for the entire disk (from SIDC, *top panel*) and excesses of one hemisphere over the other (*bottom panel*) based on smoothed-monthly hemispheric SN. Excess of the southern hemisphere is gray shaded (online edition: yellow) and dark shaded (online edition: blue). The time span covers the years from 1945 until 2004 which corresponds to solar cycles 18−23. See the electronic edition of the Journal for a color version of this figure.

shifted in time from several months up to ~2 years, whereas their minima are more or less in phase. Particular features of a cycle, like the Gnevyshev gap (Gnevyshev 1963), are more striking when regarding the hemispheres separately (see also Fig. 6).

The Gnevyshev gap (GG) means a sudden decrease in activity during the maximum time of a cycle – manifesting itself in a double/multiple peak structure – which is supposed to indicate the restructuring of the global magnetic field due to the polar field reversal (Feminella & Storini 1997) and/or the superposition of two oscillating processes in solar activity (Bazilevskaya et al. 2000). These gaps do not occur simultaneously in the northern and southern hemispheres, and by measuring only the SN for the total disk it may even be smeared out. This also implies that the formation of the GG is not the result of superposing the shifted activity observed in northern and southern hemispheres (see also Gnevyshev 1977; Feminella & Storini 1997).

We found no difference between the total and hemispheric relative sunspot numbers when studying the Gnevyshev-Ohl (GO) rule (Gnevyshev & Ohl 1948), which states that the even-numbered solar cycles are followed by ones that are higher in amplitude odd-numbered. Also, the total, as well as the northern and southern SN, revealed a violation of the GO rule during the current low active solar cycle 23.

Figure 6 shows the monthly relative sunspot numbers that were derived and smoothed for the entire disk (top panel) and for the northern and southern hemispheres (bottom panel), where the excess of one hemisphere over the other is emphasized by shaded areas. For the time span 1945−2004, the variation in the excesses does not seem to follow a pattern connected to the 11-year sunspot cycle or the 22-year magnetic cycle. Solar cycle 18 reveals an excess for the activity of the southern hemisphere during the increasing phase, whereas for cycles 20−23 the south starts major activity during the declining phases after solar maximum. This is almost the opposite for the northern hemisphere with the exception of a striking asymmetry observed for the time span 1959−1970 featuring an outstanding excess of the northern hemisphere (see also Table 2).

Table 2. Number of months that are found to be significant in the activity excess of one hemisphere over the other, separately for each solar cycle. The calculation was performed on a 99%-level applying the Student's t-test given in Eq. (3).

Cycle	fraction of asymmetry per cycle %	months of excess per cycle North no. (%)	South no. (%)
cycle 18	50	25 (25)	25 (25)
cycle 19	58	69 (50)	11 (8)
cycle 20	63	60 (43)	28 (20)
cycle 21	50	30 (24)	32 (26)
cycle 22	52	21 (18)	40 (34)
cycle 23	47	17 (17)	31 (30)

As quantification of the activity excess of one hemisphere with respect to the other, we calculated the absolute asymmetry index of activity defined by

$$\Delta = R_n - R_s. \tag{2}$$

This representation of asymmetry is supposed to reproduce variations in the activity better than the traditional asymmetry index $\delta = \frac{N-S}{N+S}$ normalized by the overall activity (cf. Ballester et al. 2005). In order to assess the significance of the activity asymmetry, we applied the paired Student's t-test:

$$\hat{t} = \frac{\bar{D}}{s_{\bar{D}}} = \frac{(\Sigma D_i)/n}{\sqrt{\frac{\Sigma D_i^2 - (\Sigma D_i)^2/n}{n(n-1)}}}, \tag{3}$$

where D_i is the difference of paired values (here, daily R_n and R_s), $\bar{D}$ the mean of a number of n differences, and $s_{\bar{D}}$ the respective standard deviation with $n-1$ degrees of freedom. Since we want to test the significance of the monthly value, n is given by the number of days of the considered month. The calculated test value, $\hat{t}$, based on the degrees of freedom, is compared to the corresponding $\hat{t}_{n-1,\alpha}$ given in statistical tables on a preselected error probability α. We chose $\alpha = 0.01$, i.e. if $\hat{t} > \hat{t}_{n-1,\alpha}$, the difference between the paired values is statistically significant at a 99% level. Thus for each month, the paired Student's t-test is utilized to determine the significance of the difference between the northern and southern SN.

In Fig. 7 the course of the asymmetry index (Eq. (2)), together with the outcome of the paired Student's t-test (Eq. (3)), is presented separately for each solar cycle studied. Excesses of the northern/southern hemisphere are marked by crosses/circles if obtained at a 99% significance level. From the shape of the asymmetry index, it is obvious that for all solar cycles the asymmetry is enhanced near the maximum and declining phase of a cycle. The most striking asymmetry lasting over several months is obtained for solar cycle 19 about two years after solar maximum. Table 2 summarizes the number of months revealing a significant excess for each solar cycle. From this the extreme asymmetric behavior of cycle 19 is again demonstrated. During the time span 1954–1964, 69 months (i.e. 50% of cycle 19) of highly significant activity excesses are obtained for the northern hemisphere, whereas for the south only 11 months. For solar cycle 20, this kind of extreme asymmetry in favor of the northern hemisphere is sustained, however, but not all that striking. A comparison to the old catalogue covering the time span 1975–2000 (Temmer et al. 2002) confirms the outcome for solar cycles 21 and 22; note that the Student's t-test was performed at a 95% significance level, thus it is not fully comparable. Solar cycle 23, which was covered for the rising phase until 2000, showed clear asymmetry for the northern hemisphere, which is not obtained when analyzing the data up to 2004. This provides clear evidence that the southern hemisphere started its major activity after the maximum in 2000.

5. Discussion

Our results confirm the weak magnetic interdependence of the northern and southern hemisphere that was already found in previous studies dealing with that subject (e.g. Antonucci et al. 1990). Most prominent evidence for the self-contained evolution of each solar hemisphere during a cycle is given by time-shifted maxima, the Gnevyshev gaps that do not occur simultaneously, and different lengths of increasing and decreasing phases. During the investigated period, the most striking asymmetry is observed for the time span 1959–1970 with more predominant activity in the northern hemisphere (cf. Swinson et al. 1986), which also manifests itself in the statistical results obtained from a Student's t-test.

To analyze the asymmetry behavior over a cycle, we calculated the absolute asymmetry index, Δ, and found an enhanced asymmetry index for all cycles studied during the maximum phase of a cycle: about one year before and up to three

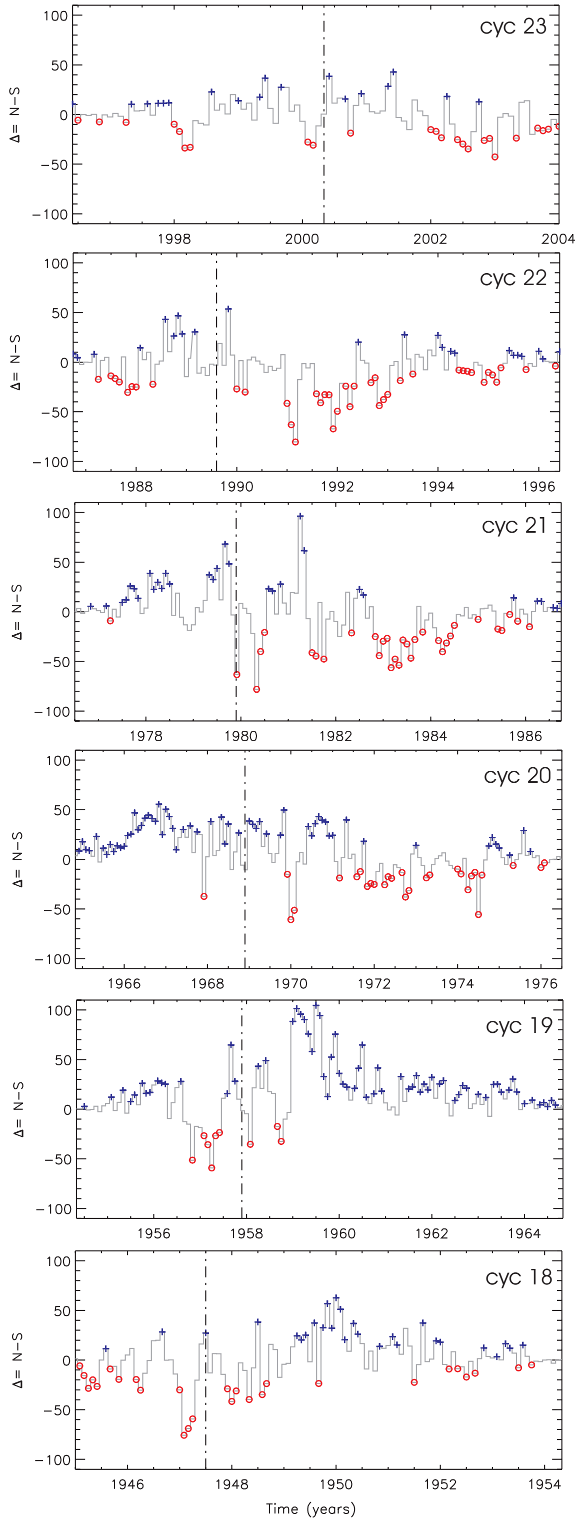

Fig. 7. Activity asymmetry (Eq. (2)) plotted for each solar cycle 18–23 on the basis of monthly hemispheric SN. The results from a Student's t-test with a significance level of 99% are marked (cf. Eq. (3)) as crosses/circles for a significant excess of the northern/southern hemisphere. Dashed-dotted lines indicate the solar cycle maximum.

years after. These results contradict those obtained by, e.g., Swinson et al. (1986); Vizoso & Ballester (1990); Carbonell et al. (1993); Ataç & Özgüç (1996); Joshi & Joshi (2004), who investigated sunspot areas, flare indices, as well as prominences/faculae, and found that the N-S asymmetry is higher when approaching the minimum of a cycle. However, contrary to our analysis, these works are all based on normalized asymmetry indices, δ, which is biased at the time of low solar activity. During the minimum phase only a few isolated spots (or flares, prominences, etc.) are observed in one of the hemispheres. The monthly hemispheric relative sunspot number, as shown in Fig. 5, might be fixed in a range between 0 and ~20 for more than three years which corresponds roughly to two sunspots. From this it is obvious that a 100% difference between the hemispheres, which corresponds to a δ of 1, could be achieved very easily during times of low activity. Thus different results are revealed using the normalized and the absolute asymmetry index, which should be considered when analyzing all the varieties of N-S asymmetry. Thus, we might extend the conclusions drawn by Ballester et al. (2005), who advised the correct application of the absolute asymmetry index Δ when studying periodic behaviors of the N-S asymmetry, to the studies of N-S asymmetry itself.

The asymmetric behavior reveals no clear evidence of a dependence on the 11-year sunspot cycle or the 22-year magnetic cycle. The N-S asymmetries might be caused by phase differences between the magnetic activity in both hemispheres (cf. Waldmeier 1971; Swinson et al. 1986). However, the minima are in phase, which might reveal a kind of "cross-talk" between the hemispheres at the end of the cycle. In the frame of dynamo theories, this might be explained by the interference between the dominant dipolar mode and modes with quadrupolar symmetry with respect to the solar equator (excitation could be reached through nonlinear or stochastic effects) that may strongly enhance the N-S asymmetry between the hemispheres (Ossendrijver 2003). In principle, such models can explain the average of N-S asymmetries observed over a solar cycle. On a shorter time scale, stochastic components have to be taken into account, such as the formation and appearance of sunspots at the solar surface which is a random process and might substantially contribute to the asymmetry behavior (Ossendrijver et al. 1996). Long-term asymmetries, as obtained during the years 1949−1951 and 1959−1970, might also be related to the tendency of the solar magnetic field to cluster at "preferred longitudes" (so-called active longitudes/zones/regions) and contain large, complex active regions of sunspots that can persist for several solar rotations up to several solar cycles (e.g. Bumba & Howard 1965; Bai 1988; Neugebauer et al. 2000; Henney & Harvey 2002; Bigazzi & Ruzmaikin 2004). From flare distribution analyses, Bai (1988) obtained three very active regions in the northern hemisphere during cycle 19 and two for cycle 20, whereas in the southern hemisphere only two regions of moderate activity were present. This would also confirm the outcome of the Student's t-test in the presented analysis, where we found an extreme asymmetry for the northern hemisphere during cycle 19 and a sustained, but less striking, asymmetry during cycle 20.

Compared to the hemispheric smoothed-monthly SN, calculated from sunspot areas and provided by SIDC for solar cycles 19−23 (cf. Vanlommel et al. 2004), we get a very similar outcome, as shown in Fig. 6; but when going into detail, some clear differences are pointed out. From a comparison between northern and southern activity behavior on the basis of relative sunspot numbers and sunspot areas, respectively, Temmer et al. (2002) found between the two activity indices, significant deviations especially during the maximum phases. Although the sunspot areas would give a more direct connection to the physical conditions of the underlying photospheric magnetic field, their reliable measurements might contain substantial errors. Variable measuring techniques of sunspot areas could differ in the results by an order of magnitude (Pettauer & Brandt 1997).

6. Conclusion

A solar cycle is not symmetric when considering the distribution of activity features separately in the northern and southern solar hemisphere. This intrinsic feature poses an important constraint for dynamo model calculations and has consumed the attention of solar physicists for many years now. Due to a lack of suitable data for relative sunspot numbers given separately for the northern and southern hemispheres, we prepared a data catalogue over the time span 1945−2004. These data are being made available to the community for scientific use.

By analyzing the N-S asymmetry behavior over almost 6 entire solar cycles (1945−2004), we demonstrate the application of the derived hemispheric SN. We confirm the self-contained evolution of each solar hemisphere, i.e. a weakly magnetic coupling between the hemispheres, with highly significant asymmetries during the solar cycle maximum and a kind of "cross-talk" during solar minima. No systematic pattern that could be connected to the 11-year sunspot cycle and/or the 22-year magnetic cycle is obvious. An outstanding behavior of asymmetry is obtained for the northern hemisphere during cycles 19 and 20. By calculating the absolute asymmetry index, we found that the degree of asymmetry is higher near the solar maxima, which contrasts with previous results based on the normalized asymmetry index.

We would like to stress that investigating the northern and southern hemispheres separately should always be considered when studying solar activity. The traditional asymmetry index, as normalized to the overall activity, results in different outcomes compared to the absolute asymmetry index, which should also be considered when analyzing all the varieties of N-S asymmetry.

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