

# HEMISPHERIC SUNSPOT NUMBERS $R_N$ AND $R_S$ FROM 1945–2004: EXTENDED AND IMPROVED CATALOGUE

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## ABSTRACT

We present the extended and improved catalogue of hemispheric Sunspot Numbers  $R_n$  and  $R_s$  covering the time span 1945–2004. The data set is based on sunspot drawings from the Kanzelhöhe Solar Observatory (KSO) and the Skalnaté Pleso Observatory (SPO). Results from a cross-validation with the international hemispheric sunspot numbers provided by the Sunspot Index Data Center and available for the time span 1992–2004, confirm the high quality of the merged data set compared to the original catalogue based solely on KSO data (Temmer et al. 2002). The application of the data is presented for investigations concerning possible N-S asymmetries including solar cycles 18–23.

Key words: catalogs; sunspots; solar cycle; N-S asymmetry.

## 1. INTRODUCTION

The relative sunspot numbers  $R$  are a measure of solar activity on the entire disk of the Sun. The relevance of the relative sunspot numbers lies in particular in the fact that they represent one of the longest time series of solar activity indices available. Thus, relative sunspot numbers provide the foundation of a continuous data set for research on the solar cycle and its long-term variations.  $R$  is defined by

$$R = k(10g + f), \quad (1)$$

where  $g$  is the number of observed sunspot groups,  $f$  the number of spots and  $k$  is an observatory-related correction factor (the details depending on the actual seeing conditions, the instrument used and the observer).

In contrast to the relative sunspot numbers, which are compiled on a regular basis by the Sunspot Index Data Center (SIDC), the hemispheric Sunspot Numbers  $R_n$  and  $R_s$  were not included before 1992 (see Cugnon 1997;

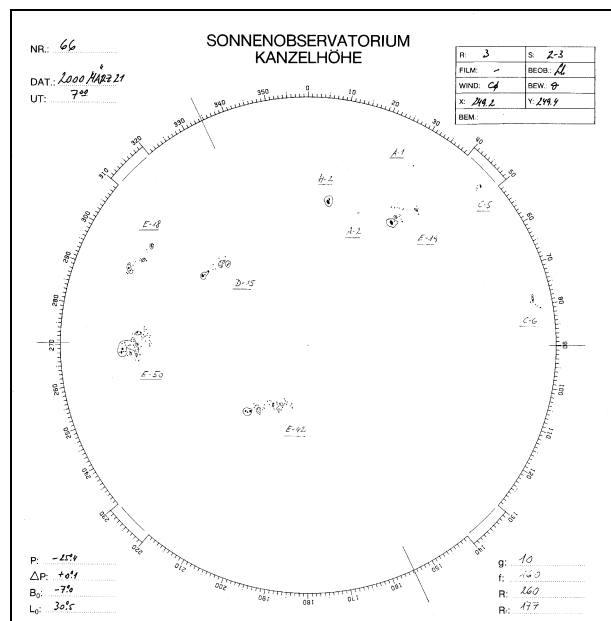


Figure 1. Sunspot drawing from which hemispheric Sunspot Numbers are extracted. (The presented example is taken from KSO of March 21, 2000.)

Vanlommel et al. 2004). However, as it is known from many studies, solar activity occurs not symmetrically with relation to the solar equator, and the northern and southern hemisphere tend to evolve separately (e.g., Antonucci et al. 1990; Temmer et al. 2002, 2003, and references therein). By the separation into northern and southern activity, overlapping effects which are obtained when we study the whole disk, can be avoided. These facts were the motivation for preparing a catalogue from daily sunspot drawings provided by the Kanzelhöhe Solar Observatory (KSO), Austria, for the time span 1975–2000 (Temmer et al. 2002). However, the KSO data set did not steadily cover the overall period but, 27% of the daily values were missing (due to bad weather conditions). Rybák et al. (2004) presented first results on a merged data set

from KSO and the Skalnaté Pleso Observatory (SPO), Slovak Republic. For the time span 1977–1978 it was clearly shown that the data coverage could be increased from 73% (including only KSO data) up to 86% for KSO and SPO data together. In order to provide evidence for/against significant patterns within 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 entirely available for the scientific community is needed.

In the following we describe the compilation of the data from KSO and SPO drawings for the time span 1945–2004. Furthermore, as a quality check of the derived hemispheric data we present a regression analysis and comparison to the international hemispheric sunspot numbers from SIDC for the time span 1992–2004. First results from the application of the data performing north-south asymmetry analyses on the basis of a Student’s t-test are given.

## 2. DATA GATHERING AND VALIDATION

From daily sunspot drawings provided by KSO and SPO (cf. Fig. 1) we extracted for each observatory the northern and southern relative sunspot number,  $R_{n,s\ KSO}$  and  $R_{n,s\ SPO}$ , respectively. SPO drawings were taken for the entire time span 1945–2004 (from 1988 on data were taken from the Stara Lesna Observatory). Drawings from KSO were usable from 1952 on; before that time chromospheric features were indicated on the drawings as well which inhibited the reliable extraction of sunspot numbers.

Subsequently the obtained daily “raw” hemispheric Sunspot Numbers from KSO,  $R_{n,s\ KSO}$ , and SPO,  $R_{n,s\ SPO}$ , respectively, are merged separately for each hemisphere. If data from both observatories are available simply the mean value is calculated otherwise available data from the respective observatory are taken. Out of this the relative fraction of the northern and southern component,  $n$  and  $s$ , is calculated. The final hemispheric Sunspot Number,  $R_n$  and  $R_s$ , was then obtained by multiplying the northern and southern fractions with the definitive International Sunspot Number,  $R_i$ , of the day (see Equ. 2).

$$R_n = n \times R_i, R_s = s \times R_i. \quad (2)$$

With this procedure we ensure that the derived hemispheric Sunspot Numbers are normalized with respect to the International Sunspot Numbers (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.

As a quality check of the derived hemispheric sunspot numbers we made a regression analysis with corresponding data from SIDC for the overlapping period 1992–

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

	Corr.	Linear Fit slope	StE
daily N	0.990	1.000±0.002	4.027
daily S	0.990	1.000±0.002	4.010
monthly N	0.998	0.992±0.005	1.437
monthly S	0.998	1.002±0.005	1.423
sm.mon. N	0.999	0.997±0.002	0.451
sm.mon. S	0.999	1.009±0.002	0.462

2004. In Table 1 the results of the regression analysis are summarized. 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  $\sim 4.0$ . From this, it can be inferred that the derived hemispheric Sunspot Numbers very well render the International ones.

About 16% of days within the period 1945–2004 are missing. For these intervals it is necessary to check their length and randomness. By calculating the intervals of continuously missing days we get values well below 5 and there are only three gaps that are longer than 10, namely of 11, 18, and 88 days. The longest gap is due to repairs on KSO instrument and building which were performed from 26-Jun-1966 until 19-Dec-1966 as well as similar repairs at SPO during 23-Sep-1966 until 21-Dec-1966. Therefore, we have an overlap in time of 88 days where neither data from KSO nor from SPO are available. Linear interpolation over this interval is useless since the interval covers several solar rotations. The gap is filled with external data that are provided separately for the northern and southern solar hemisphere. Due to the lack of relative sunspot numbers for that time span as substitution the north/south ratio from Greenwich sunspot areas is taken.

The catalogue of hemispheric Sunspot Numbers for the time span 1945–2004 will be made available as daily, monthly, and monthly smoothed  $R_n$  and  $R_s$ , via CDS at <http://cdsweb.u-strasbg.fr>.

Finally, in Fig. 2 the derived smoothed monthly hemispheric sunspot numbers are presented for the time span 1945–2004, i.e. almost fully covering solar cycles 18–23.

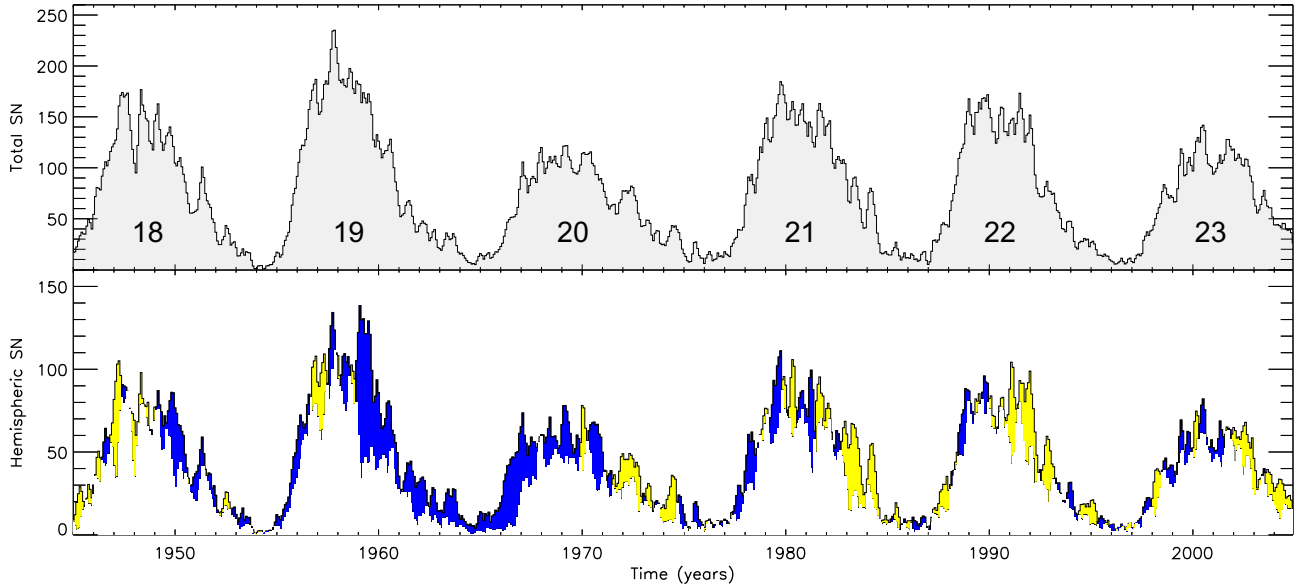


Figure 2. Smoothed monthly relative sunspot numbers for the entire disk (from SIDC, top panel) and excesses of one hemisphere over the other (bottom panel) based on smoothed monthly hemispheric Sunspot Numbers derived from KSO/SPO. Excess of the southern hemisphere is yellow shaded and for the northern hemisphere blue shaded. The time span covers the years from 1945 until 2004 which corresponds to solar cycles 18–23.

### 3. RESULTS APPLYING THE DERIVED DATA SET

To analyze numerically the north-south asymmetry behavior over a cycle we calculated the absolute asymmetry index,  $\Delta = R_n - R_s$ . In order to assess the significance of the asymmetry, i.e. activity excess of the northern or southern hemisphere, respectively, we applied the paired Student's t-test on a significance level of 99% (a detailed description can be found in Temmer et al. 2002). For each month, the paired Student's t-test is utilized to determine the significance of the difference between the northern and southern Sunspot Numbers.

In Fig. 3 the course of the asymmetry index together with the outcome of the paired Student's t-test is presented separately for each solar cycle studied. 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.

### 4. DISCUSSION AND CONCLUSION

In contrast to the relative sunspot numbers, the hemispheric sunspot numbers are not provided on a regular basis. Hemispheric Sunspot Numbers, in addition to the historical Sunspot Numbers that describe the activity of the whole Sun, provide important information on solar activity and also give necessary constraints on dynamo theories.

As the extension and improvement of an already existing catalogue (Temmer et al. 2002) we aim to provide data of hemispheric Sunspot Numbers for the time span 1945–2004 with enhanced data coverage. A previous study showed that the quality of such a data set could be significantly improved by merging data from two observatories (Rybák et al. 2004). In the present paper the extracting and merging of data from the Kanzelöhe Solar Observatory (KSO), Austria, and the Skalnaté Pleso Observatory (SPO), Slovak Republic, is described. Moreover a quality check of the data is performed. From a regression analysis with the International hemispheric Sunspot Numbers provided by SIDC since 1992 it is revealed that our data are in very good agreement with those from SIDC. No systematic offset or scatter between the two data sets could be observed.

By calculating the absolute asymmetry index,  $\Delta = R_n - R_s$ , we found that the degree of N-S asymmetry is higher near the solar maxima which is in contrast to previous results that found increased asymmetry when approaching the minimum of a cycle (Swinson et al. 1986; Vizoso & Ballester 1990; Carbonell et al. 1993; Ataç & Özgüç 1996; Joshi & Joshi 2004). Contrary to our analysis these works are all based on normalized asymmetry indices,  $\delta = \frac{N-S}{N+S}$ , which seems to give a bias at the time of low solar activity. So 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 (see also Ballester et al. 2005).

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## REFERENCES

- Antonucci, E., Hoeksema, J. T., & Scherrer, P. H. 1990, *ApJ*, 360, 296
- Ataç, T. & Özgüç, A. 1996, *Sol. Phys.*, 166, 201
- Ballester, J. L., Oliver, R., & Carbonell, M. 2005, *A&A*, 431, L5
- Carbonell, M., Oliver, R., & Ballester, J. L. 1993, *A&A*, 274, 497
- Cugnon, P. 1997, *Ciel et Terre*, 113, 67
- Joshi, B. & Joshi, A. 2004, *Sol. Phys.*, 219, 343
- Rybák, J., Bendík, P., Temmer, M., Veronig, A., & Hanslmeier, A. 2004, *Hvar Observatory Bulletin*, 28, 63
- Swinson, D. B., Koyama, H., & Saito, T. 1986, *Sol. Phys.*, 106, 35
- Temmer, M., Veronig, A., & Hanslmeier, A. 2002, *A&A*, 390, 707
- Temmer, M., Veronig, A., Rybák, J., & Hanslmeier, A. 2003, *Hvar Observatory Bulletin*, 27, 59
- Vanlommel, P., Cugnon, P., Linden, R. A. M. V. D., Berghmans, D., & Clette, F. 2004, *Sol. Phys.*, 224, 113
- Vizoso, G. & Ballester, J. L. 1990, *A&A*, 229, 540

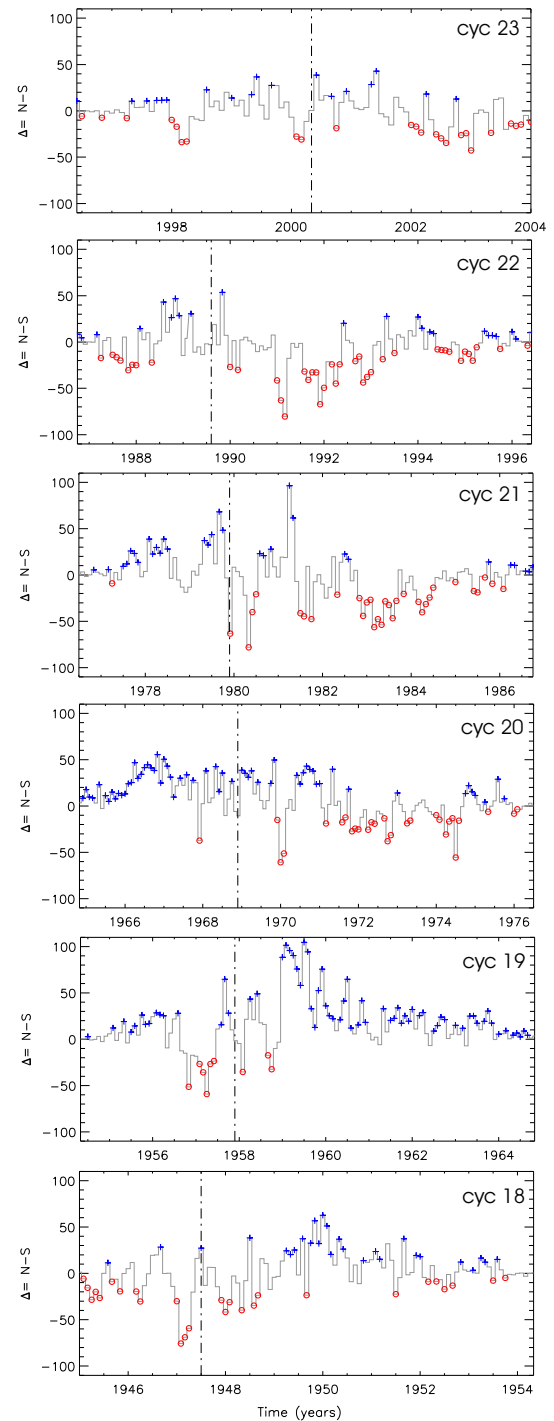


Figure 3. Quantification of activity asymmetry plotted for each solar cycle 18–23 on the basis of monthly hemispheric Sunspot Numbers. The results from a Student's *t*-test with a significance level of 99% are marked as crosses/circles for a significant excess of the northern/southern hemisphere. Dashed-dotted lines indicate the solar cycle maximum.