

## HEMISPHERIC SUNSPOT NUMBERS 1945–2004: DATA MERGING FROM TWO OBSERVATORIES

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**Abstract.** For the time span 1945–2004 from daily sunspot drawings northern and southern relative sunspot numbers are extracted using drawings provided by Kanzelhöhe Solar Observatory, Austria, and Skalnaté Pleso Observatory, Slovak Republic. The derived data will be used to improve and extend an already existing catalogue of hemispheric sunspot numbers (Temmer *et al.*, 2002). Since northern and southern solar hemispheres do not evolve in phase during the cycle, hemispheric data are very important for activity studies. In the present paper the compilation of the data for the period 1945–2004 is described. Furthermore as a quality check of the derived hemispheric data a regression analysis and the comparison to the international hemispheric sunspot numbers from the Sunspot Index Data Center for the time span 1992–2004 is presented.

**Key words:** catalogue - sunspot numbers - solar cycle

### 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

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

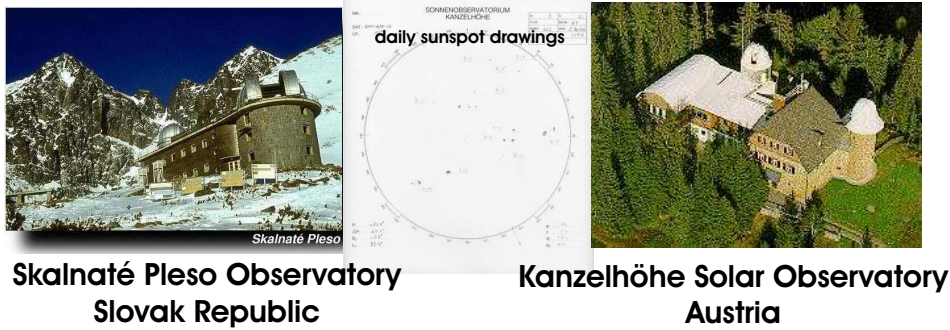


Figure 1: Sites of the two observatories (left panel: SPO - right panel: KSO) and a sample sunspot drawing taken from KSO (middle panel).

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, the hemispheric Sunspot Numbers  $R_n$  and  $R_s$  were not compiled on a regular basis by the Sunspot Index Data Center (SIDC) (see Cugnion, 1997; Vanlommel *et al.*, 2004) before 1992. Solar activity occurs not symmetrically with relation to the solar equator, moreover the northern and southern hemisphere tend to evolve separately (e.g., Antonucci *et al.*, 1990; Temmer *et al.*, 2002, 2003, and references therein). Due to 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). Extracting sunspot drawings from another observatory would increase the data coverage and, moreover, enhance the statistical significance. Rybák *et al.* (2004) presented first results on a merged data set from KSO and the Skalnate Pleso Observatory (SPO), Slovak Republic. For the 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. In order to perform long-term studies on, e.g., north-south asymmetry features, we aim to produce an extended and improved catalogue (based on KSO and SPO

data) including hemispheric sunspot numbers for the time span 1945–2004. This would cover almost 6 entire solar cycles.

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.

## 2. Data and Methods

From daily sunspot drawings provided by KSO and SPO (cf. Figure 1) we extracted for each observatory the northern and southern relative sunspot number,  $R_{n,s} \text{ KSO}$  and  $R_{n,s} \text{ SPO}$ , 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,  $R_{n,s} \text{ KSO}$ , and SPO,  $R_{n,s} \text{ SPO}$ , respectively, are merged separately for each hemisphere. If data from both observatories are available simply the mean value is calculated (Equation 2) otherwise available data from the respective observatory are taken (Equation 3 and 4). Out of this the relative fraction of the northern and southern component,  $n$  and  $s$ , is calculated. If neither KSO nor SPO drawings are available the data are linearly interpolated after the merging process.

$$n, s = (R_{n,s} \text{ KSO} + R_{n,s} \text{ SPO}) / (R_{\text{SPO}} + R_{\text{KSO}}) \quad (2)$$

$$n, s = \frac{R_{n,s} \text{ KSO}}{R_{\text{KSO}}} \quad (3)$$

$$n, s = \frac{R_{n,s} \text{ SPO}}{R_{\text{SPO}}} . \quad (4)$$

The final hemispheric Sunspot Number,  $R_{n,\text{KSO/SPO}}$  and  $R_{s,\text{KSO/SPO}}$ , was then obtained by multiplying the northern and southern fractions with the definitive International Sunspot Number,  $R_i$ , of the day. With this procedure we ensure that the derived hemispheric Sunspot Numbers are normalized with respect to the International Sunspot Numbers, fulfilling

**Table I:** Summary of the regression analysis of the KSO/SPO and SIDC hemispheric Sunspot Numbers 1992–2004. The analysis was performed for the daily ( $d$ ), the monthly mean ( $m$ ) and the smoothed monthly mean ( $sm$ ) northern (N) and southern (S) Sunspot Numbers. We list the cross-correlation coefficients and the slope parameter obtained from the linear least-squares fit with a standard error.

	Regression Analysis	Linear Fit slope
$N_d$	0.990	$1.000 \pm 0.002$
$S_d$	0.990	$1.000 \pm 0.002$
$N_m$	0.998	$0.992 \pm 0.005$
$S_m$	0.998	$1.002 \pm 0.005$
$N_{sm}$	0.999	$0.997 \pm 0.002$
$S_{sm}$	0.999	$1.009 \pm 0.002$

the relation

$$n \times R_i + s \times R_i = R_{n,\text{KSO/SPO}} + R_{s,\text{KSO/SPO}} = R_i. \quad (5)$$

### 3. Results

As a quality check of the derived hemispheric sunspot numbers we made a regression analysis with corresponding data from SIDC for the overlapping period 1992–2004. From Table I it can be shown that the slope derived from a linear least-squares fit to the data as well as the cross-correlation coefficients are very close to 1. Figure 2 shows the scatter between derived daily hemispheric Sunspot Numbers from KSO/SPO drawings,  $R_{n,\text{KSO/SPO}}$  and  $R_{s,\text{KSO/SPO}}$ , and corresponding International Sunspot Numbers provided by the SIDC,  $R_{n,\text{SIDC}}$  and  $R_{s,\text{SIDC}}$ , for the period 1992–2004 (top panels). The middle and bottom panels in Figure 2 shows the dependence between monthly and monthly smoothed hemispheric Sunspot Numbers from KSO/SPO and SIDC data, respectively. The scatter plots clearly reveal that no systematic difference exists between the derived and the International hemispheric Sunspot Numbers. Extreme outliers as observed for monthly hemispheric Sunspot Numbers (indicated as crosses in the middle panels in Figure 2) are due to a low data coverage with  $< 18$  observing days for the corresponding month. For the entire time span (1945–2004) only 25 out of

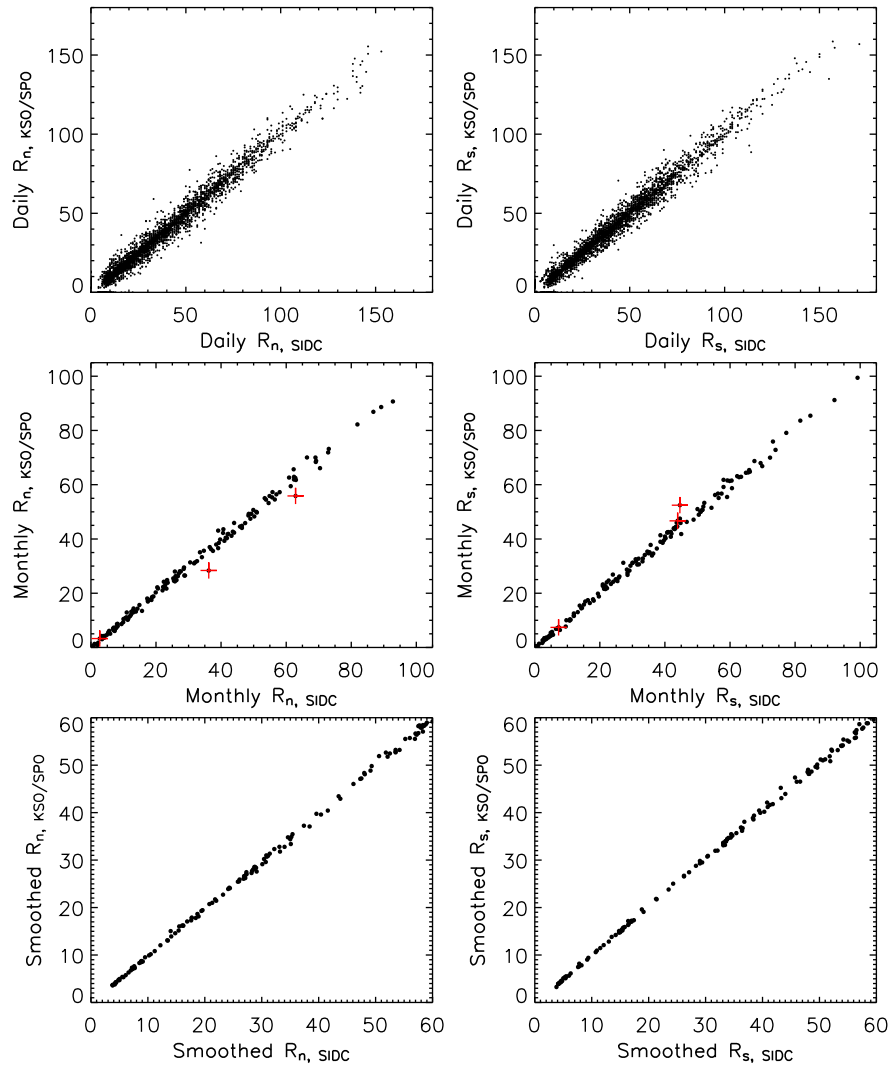


Figure 2: Top, middle and bottom panels show the daily, monthly and monthly smoothed hemispheric Sunspot Numbers, respectively. Crosses (middle panel) indicate months with a data coverage  $< 18$  days.

720 months contain  $< 18$  observing days (10 months with  $< 15$  observing days) with an overall data coverage of 84%. Thus, it can be inferred that the derived hemispheric Sunspot Numbers very well render the International ones.

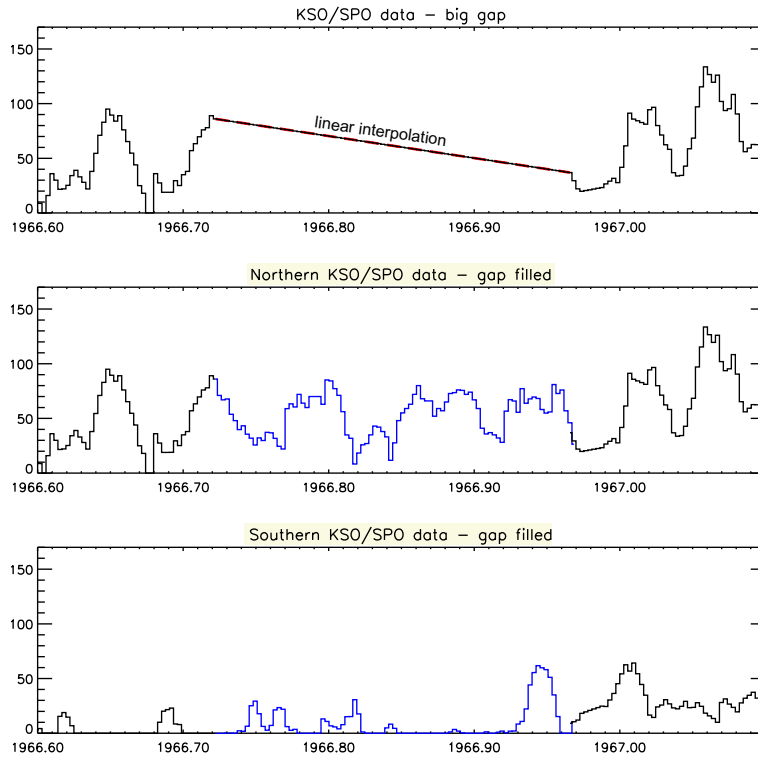


Figure 3: Top panel: gap linearly interpolated (shown for northern hemispheric sunspot numbers); middle/bottom panel: gap of northern/southern hemispheric sunspot numbers filled using Greenwich sunspot area data;

However, by calculating the length of continuously missing days we get a peak value of 88 days; only two are longer than 10 days (18 and 11 days); some smaller ones are well below 10 days. This long 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 (see Figure 3 - top panel).

Thus, we have to fill this interval with external data that are provided separately for the northern and southern solar hemisphere. 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 substitution the north/south ratio from sunspot areas for the specific time span is multiplied with the International Sunspot Number ( $n, s_{area} \times R_{i,SIDC}$ ). The result of this procedure is shown in Figure 3.

Here the question arises why to extract in a wasteful manner hemispheric sunspot numbers from drawings to study long-term north-south asymmetries and not take sunspot areas instead? Temmer *et al.* (2002) showed that the relationship between sunspot areas and relative sunspot numbers is far from being one-to-one with significant differences especially during the maximum phase of the solar cycle. Moreover, Pettauer and Brandt (1997) stressed that the reliable measurement of sunspot areas is not an easy task and results might differ by an order of magnitude due to different techniques and instruments used. For a short time span, like here to fill our data gap, these facts are negligible but for mid- and long-term investigations of solar activity these might pose problems.

#### 4. Conclusion and Outlook

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. The overall data coverage amounts to 84%. However, one big data gap of 88 continuously

missing days is obtained due to simultaneous repairs at KSO and SPO. In order to avoid errors, this gap is filled using ratios of hemispheric sunspot areas which are considered to be suitable for such short-term substitutions.

In a next step the data will be investigated with respect to north-south asymmetry studies. The extent of data covers almost 6 entire solar cycles over the time span 1945–2004. This will be used to analyze trends and periodic features of the N-S activity asymmetry. The derived hemispheric Sunspot Numbers will be published and provided to the solar physics community as a catalogue for scientific use (Temmer *et al.*, 2005).

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## HEMISFERSKI BROJEVI SUNČEVIH PJEGA OD 1945. DO 2004.: SPAJANJE PODATAKA DVAJU OPSERVATORIJA

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Izlaganje sa znanstvenog skupa

**Sažetak.** Koristeći dnevne crteže Sunčevih pjega načinjene na Solarnom Opservatoriju Kanzelhöhe, Austrija i Opservatoriju Skalnaté Pleso, Slovačka određuju se relativni brojevi pjega posebno za sjevernu i južnu hemisferu za razdoblje od 1945. do 2004. godine. Dobiveni podaci koristit će se za poboljšanje i nadopunu već postojećeg kataloga hemisferskih brojeva Sunčevih pjega (Temmer *et al.*, 2002). Podaci po hemisferama su vrlo značajni pri istraživanju aktivnosti Sunca, jer se tijekom ciklusa sjeverna i južna hemisfera ne razvijaju u fazi. Daje se kompilacija podataka za razdoblje od 1945. do 2004. godine. Nadalje se u svrhu kvalitativne provjere dobivenih hemisferskih podataka prikazuje regresiona analiza i usporedba sa međunarodnim hemisferskim brojevima Sunčevih pjega prikupljenim u Sunspot Index Data centru za razdoblje od 1992. do 2004. godine.

**Ključne riječi:** katalog - brojevi Sunčevih pjega - ciklus Sunčeve aktivnosti