

# Deriving a Sunspot Number Scaling Factor from 30 Years of White-Light Solar Observations

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## Abstract

Sunspot numbers derived from the author's white-light observations spanning 30 years (1996–2025) are compared with the International Sunspot Number ( $R_i$ ) to determine an observer scaling factor,  $k$ . Monthly values are analysed using linear regression, with an additional correction applied to account for incomplete daily coverage within individual months. The derived scaling factors are  $k = 1.280$  for uncorrected data and  $k = 1.284$  for corrected data, the latter showing improved agreement with  $R_i$ . The results demonstrate that consistent long-term amateur observations can produce sunspot numbers closely aligned with the International Sunspot Number.

## 1. Introduction

The relative sunspot number is a long-standing measure of white-light solar activity. It is derived from the number of sunspot groups and individual sunspots observed on the solar photosphere each day, using the expression:

$$R = k(10g + f)$$

where  $k$  is a scaling factor,  $g$  is the number of sunspot groups, and  $f$  is the number of individual sunspots. The parameter  $k$  depends on factors such as the observer, the observing equipment, and environmental conditions.

The primary source of sunspot numbers is the Solar Influences Data Analysis Center (SIDC) of the Royal Observatory of Belgium, which provides the International Sunspot Number ( $R_i$ ). Daily sunspot numbers are available from 1818 onwards, and monthly sunspot numbers from 1749. Version 2 of  $R_i$  was released in 2015 (ref. [1]).

The purpose of this paper is to compare  $R_i$  with sunspot numbers derived from the author's own observations since 1996, and to determine the corresponding scaling factor  $k$ . The method presented also accounts for the fact that observations are not possible on every day.

## 2. The author's white-light observations

The author is a solar observer using an 80 mm f/11 refractor with a custom-built projection box to produce white-light full-disk drawings with a diameter of 6 inches (152 mm). The same equipment, including the same eyepiece, has been used since the early 1990s in order to maintain a consistent series of daily drawings over a long period. In addition, the same method for assigning sunspots to groups has been used throughout (ref. [2]).

Over the thirty-year period from January 1996 to December 2025, a total of 5,568 drawings were made, corresponding to an average of 186 observing days per year. Missed observations were due to weather conditions (South-East England), work commitments, or holidays.

Measurements obtained from these drawings include the number of sunspot groups and individual sunspots (both hemispheric and whole-disk totals), and the resulting sunspot number,  $R_m$ . These data are submitted monthly to the British Astronomical Association (BAA) Solar Section and to the SIDC. The latter combines these observations with those from approximately 70 other professional and

amateur observers to derive  $R_i$ . While the author's observations are therefore not strictly independent of  $R_i$ , the contribution of any individual observer is sufficiently diluted that the author's data may still be treated as effectively independent for the purposes of this analysis.

### 3. Calculation of $k$

Two approaches are given for the calculation of the author's  $k$  value:

- Using the linear relationship between the monthly averaged  $R_m$  and  $R_i$  values as shown in Figure 1 (blue points).
- Because daily observations are not always possible, the author's monthly mean sunspot number ( $R_m$ ) may be biased if solar activity varies significantly during a given month. To compensate for this, the **ratio** of the monthly  $R_i$  to the mean of the daily  $R_i$  values corresponding only to the days on which observations were made is used to scale the author's monthly means. This adjustment accounts for within-month variability in solar activity and is also shown in Figure 1 (green points). The resulting corrected monthly sunspot number is denoted  $R_m^*$ . Further details of the ratio calculation, together with examples, are given in Appendix A.

The calculated  $k$  values for the above two approaches (with  $R^2$  in parentheses) are:

- $R_m$ :  $1.280 \pm 0.012$  (0.966)
- $R_m^*$ :  $1.284 \pm 0.008$  (0.986)

Despite the different approaches, the two  $k$  values are very similar. However, as Figure 1 shows, the corrected monthly sunspot numbers ( $R_m^*$ ) exhibit a reduced spread. This is also reflected in the smaller standard error and higher  $R^2$  value. A  $k$  value greater than unity indicates that the author's raw sunspot numbers are systematically lower than  $R_i$ .

Note that the value of  $k$  is calculated using the mean of the gradient from linear fits of  $R_m$  versus  $R_i$  and the reciprocal of the gradient from fits of  $R_i$  versus  $R_m$ .

### 4. Relationships with the International Sunspot Number

Figure 2 shows the monthly values of  $R_i$ ,  $R_m$ , and  $R_m^*$  after applying the corresponding  $k$  factors. Also shown are the residuals ( $R_i - k.R_m$  and  $R_i - k.R_m^*$ ). The mean and standard deviation of these differences are:

- $R_m$ :  $0.3 \pm 10.7$
- $R_m^*$ :  $-0.1 \pm 6.9$

The mean differences are small, at less than 1. The standard deviations are also smaller than the sunspot number contribution of a single isolated sunspot (i.e.  $g = 1$  and  $f = 1$ ). The remaining  $R_m^*$  residuals are likely to arise from differences in assigning sunspots to groups, identification of individual sunspots and from environmental factors such as seeing conditions.

### 5. Conclusions

A comparison of the monthly International Sunspot Number ( $R_i$ ) with monthly sunspot numbers derived from the author's long-term white-light observations over a 30-year period shows no significant systematic differences or long-term trends.

Including an adjustment for within-month variations in daily  $R_i$  has only a small effect on the derived  $k$  scaling factor. However, this adjustment reduces the standard error of  $k$ , improves the goodness of

fit between  $R_i$  and  $R_m$ , and reduces the standard deviation of the residual differences between  $R_i$  and  $R_m^*$ . These residuals are comparable to those obtained using sunspot numbers derived from SOHO and SDO continuum images and calculated from USAF/NOAA Solar Region Summary data (ref. [3]). This demonstrates that experienced amateur solar observers are able to derive long-term sunspot numbers with accuracy comparable to that of professional datasets.

### Acknowledgements

The International Sunspot Number v2 data are provided by the World Data Center SILSO, Royal Observatory of Belgium.

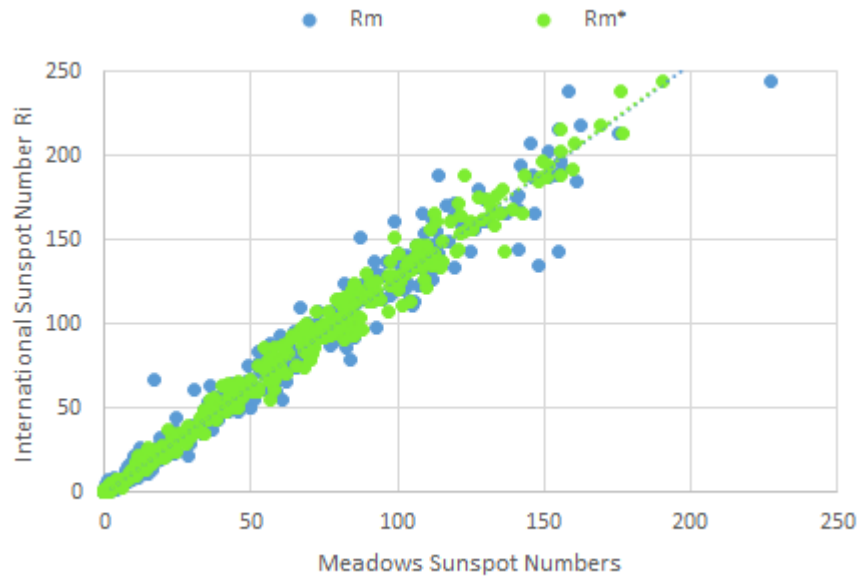


Figure 1. Relationship between the author's monthly sunspot numbers,  $R_m$  and corrected  $R_m^*$ , and the International Sunspot Number,  $R_i$ . Blue points show uncorrected  $R_m$  values, and green points show the corrected  $R_m^*$  values. Linear fits are also indicated.

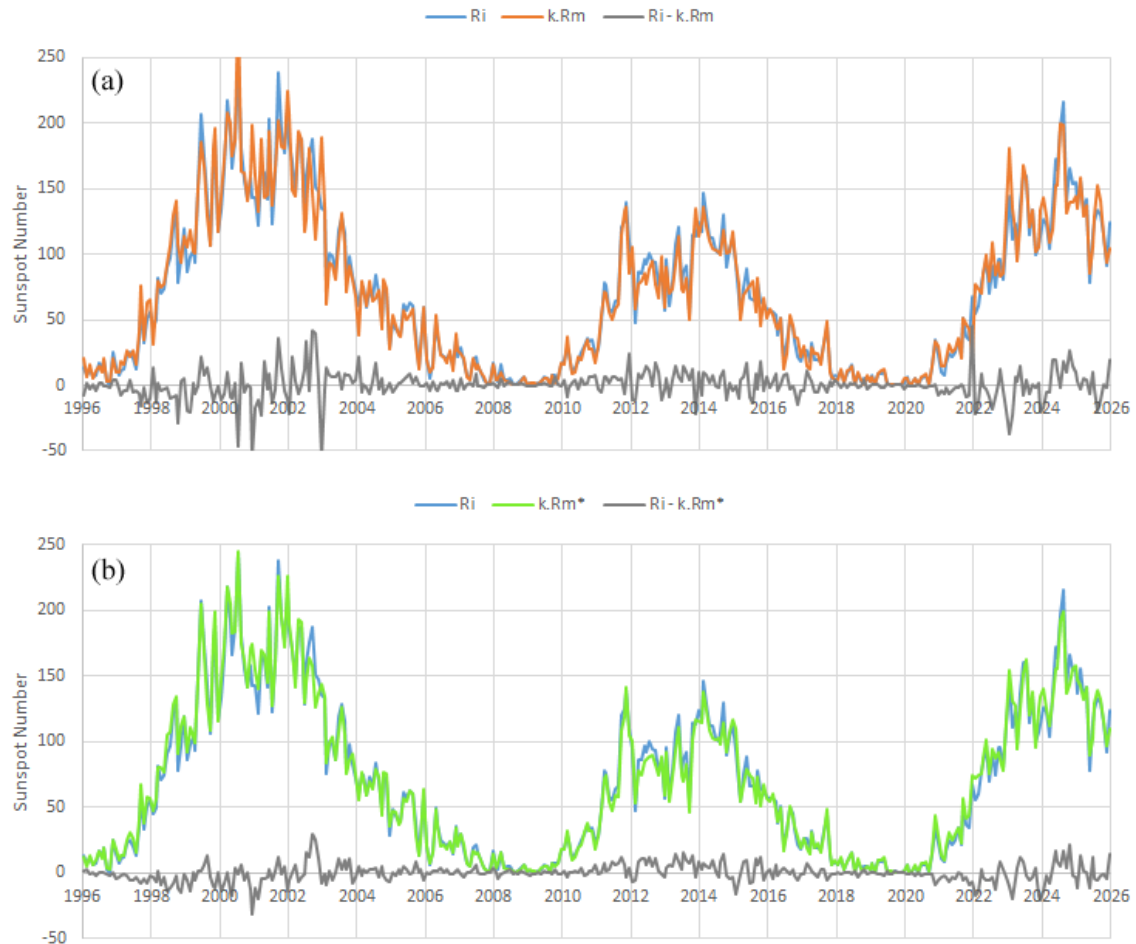


Figure 2. Monthly International Sunspot Number ( $R_i$ ) compared with the author's scaled sunspot numbers: (a)  $k.R_m$  and (b) corrected  $k.R_m^*$ . The residuals ( $R_i - k.R_m$  and  $R_i - k.R_m^*$ ) are also shown.

## References

1. Clette, F., Svalgaard, L., Vaquero, J.M. *et al.* 'Revisiting the Sunspot Number', *Space Sci Rev*, **186**, 35–103, 2014. <https://doi.org/10.1007/s11214-014-0074-2>
2. Based on the BAA guidelines whereby sunspots are counted as a separate group if it has a separation of more than  $10^\circ$  in longitude and  $5^\circ$  in latitude from its neighbours. Occasionally there may be exceptions when closer sunspots may be separated into more than one group.
3. Meadows, P.J. 'An Independent Assessment of the International Sunspot Number since 1996', *Res. Notes AAS*, **9**, 304, 2025, <https://iopscience.iop.org/article/10.3847/2515-5172/ae1cbb>

## Appendix A. Within-month sunspot number adjustment

The adjusted monthly sunspot number  $R_m^*$  is calculated as:

$$Rm^* = Rm \frac{Ri}{\frac{1}{n} \sum_{i=1}^n Ri(i)}$$

where  $Ri$  is the monthly International Sunspot Number,  $n$  is the number of observing days in the month, and  $Ri(i)$  is the daily  $Ri$  value for each of those observing days. The correction factor is therefore a ratio, not of absolute values, of the monthly mean  $Ri$  to the mean of the daily  $Ri$  values corresponding to the author's observing days. This ensures that the adjusted monthly values more accurately represent overall solar activity during each month.

A fictional example illustrating the calculation of  $Rm^*$  is shown in Figure A1 for a 30 day month where:

- $Ri$  has a value of 120 for the first 15 days and 20 for the remaining 15 days (blue points). The monthly average  $Ri$  is therefore 70 (blue horizontal line).
- Only four observations are made during the month, all within the first 15 days when activity was high (orange dots). Assuming  $k = 1$ , the average monthly  $k.Rm$  is 124 (orange line).
- The ratio of the monthly  $Ri$  (70) to the average of daily  $Ri$  for the four observations days (120) is 0.5833.
- Applying this ratio to the four  $k.Rm$  values and averaging gives a corrected monthly value  $k.Rm^*$  of 72.3, shown by the green points and line.

Applying this ratio brings the monthly  $k.Rm^*$  value much closer to the monthly  $Ri$  (72.3 compared with 70). Without this correction, the unadjusted monthly  $k.Rm$  value of 124 would significantly over-represent solar activity during the month.

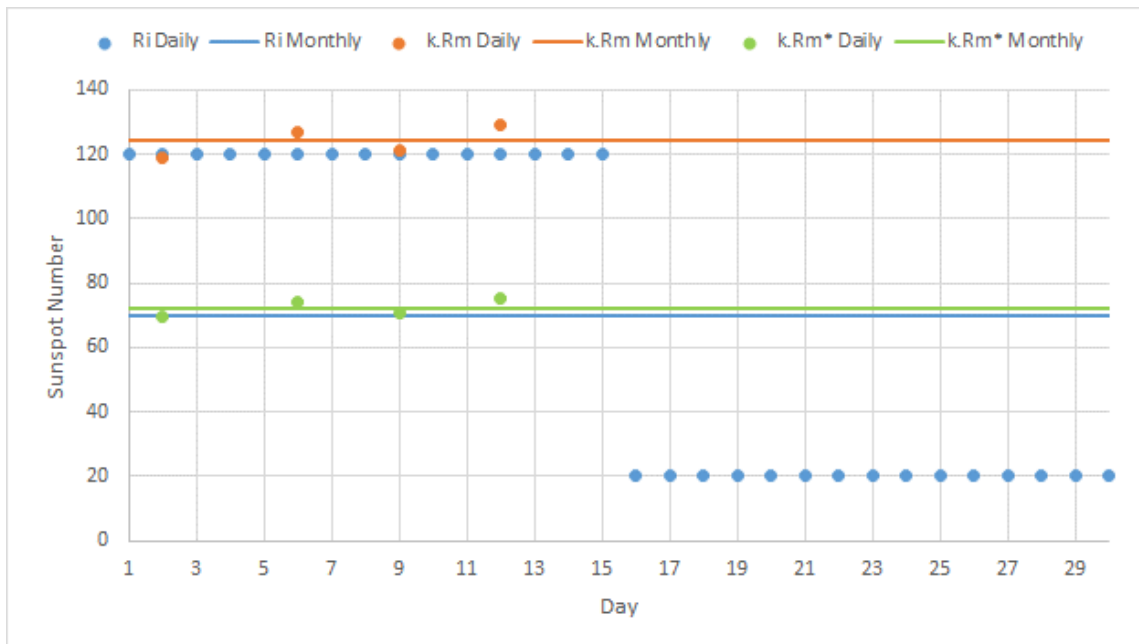


Figure A1. Daily and monthly  $Ri$ ,  $k.Rm$  and  $k.Rm^*$ . The monthly  $Rm^*$  values are corrected for incomplete observing days using the ratio of the monthly  $Ri$  to the mean daily  $Ri$  on observation days.

A more realistic example, based on the author's own observations, is shown in Figure A2 for 2023 January, during which the majority of the 11 observations were made when solar activity was relatively high:

- As before, the daily and monthly  $R_i$  values are shown in blue. The monthly  $R_i$  has a value of 144.4.
- The observation  $k.Rm$  values ( $k = 1.28$ ) are shown in orange points, together with the monthly average of  $k.Rm$  (181.1).
- The ratio of the monthly  $R_i$  (144.4) to the average of daily  $R_i$  for the 11 observations days (181.1) is 0.7973.
- Applying this ratio to the 11  $k.Rm$  values and then averaging yields a corrected monthly value,  $k.Rm^*$ , of 154.2, shown by the green points and line.

Applying this ratio again produces a monthly  $k.Rm^*$  value that is much closer to the corresponding  $R_i$  (154.2 compared with 144.4). Without this adjustment, the uncorrected monthly  $k.Rm$  value would be 181.1 and would substantially overestimate the level of solar activity during the month.

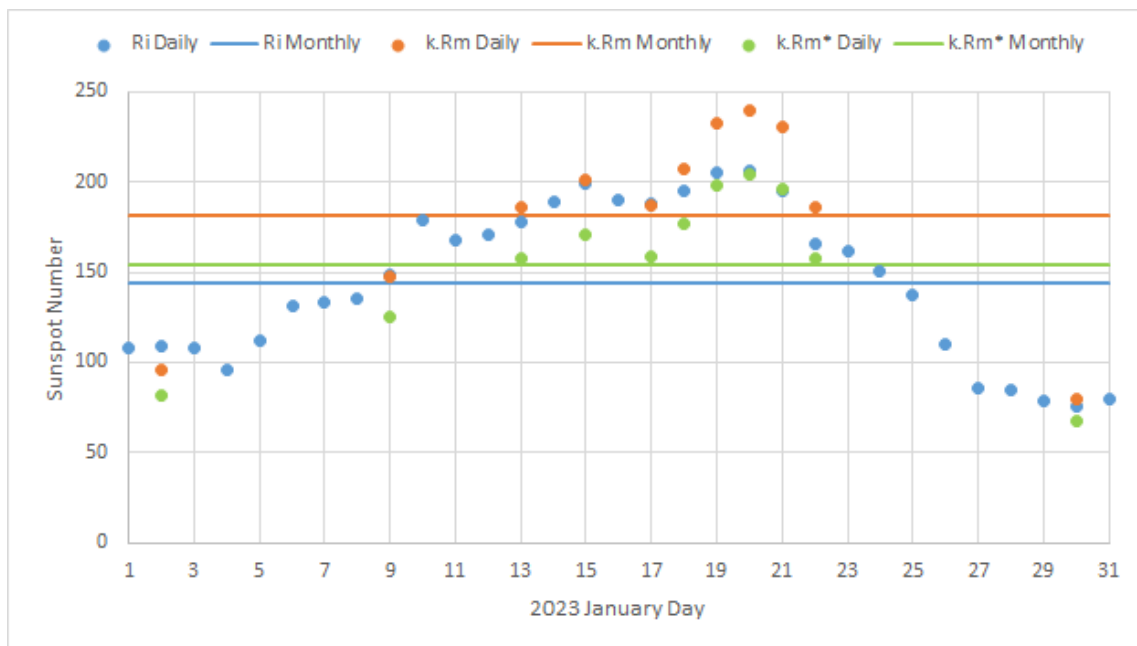


Figure A2. Daily and monthly  $R_i$ ,  $k.Rm$  and  $k.Rm^*$  for 2023 January.

Note that in both examples presented in this appendix, the sunspot numbers have been multiplied by  $k$ . This has been done to ensure the observation  $Rm$  values are on the same scale as the  $R_i$  values to illustrate the impact of applying the  $R_i$  ratio to compensate for variations in the sunspot numbers throughout a month.

Solar observers who submit their observations to the BAA should continue using a  $k$  value of 1 (rather than deriving and applying their own  $k$  value).