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# A Comparison of Rome Observatory Sunspot Area and Sunspot Number Determinations With International Measures, 1958–1998

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***November 2005***

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## LIST OF ACRONYMS

| | |
|---|---|
| NOAA | National Oceanic and Atmospheric Administration |
| RGO | Royal Greenwich Observatory |
| SIDC | Solar Influences Data analysis Center |
| SOON | Solar Optical Observing Network |
| USAF | United States Air Force |

## NOMENCLATURE

| | |
|---|---|
| $A$ | total corrected area in millionths of solar hemisphere |
| $f$ | number of individual discernible spots |
| $G$ | number of groups; also designated by $g$ |
| $k$ | personal-reduction coefficient; ratio $s/s_R$ |
| $n$ | number of daily observations available for study |
| $R$ | relative sunspot number; also Rome designated by subscript |
| $r$ | linear correlation coefficient |
| $s$ | derived sunspot number using the same days that $s_R$ is determined |
| $se$ | standard error of estimate |
| $s_R$ | derived sunspot number based on observed values for $G_R$ and $f_R$ |
| $x$ | RGO data for 1958–1976 and to USAF/NOAA for 1977–1998 |

TECHNICAL PUBLICATION

# A COMPARISON OF ROME OBSERVATORY SUNSPOT AREA AND SUNSPOT NUMBER DETERMINATIONS WITH INTERNATIONAL MEASURES, 1958–1998

## 1. INTRODUCTION

Existence of the sunspot cycle, the somewhat regular waxing and waning of the number of dark spots on the Sun, was first established more than 160 years ago by Samuel Heinrich Schwabe, an apothecary and amateur astronomer who observed the Sun for more than four decades from Dessau, Germany in the early to mid-19th century.[1–9] On the basis of annual counts of spotless days and clusters of spots, he asserted that the Sun's spottedness displayed a minimum and maximum of activity about every 10 years.

Schwabe's simple method for monitoring sunspot activity, however, was soon superceded by another measure of sunspot activity called "relative sunspot number." This method was introduced in 1848 by Rudolf Wolf and is given by the expression $R = k\,(10g + f)$; where $R$ is relative sunspot number; $g$ is the number of groups (similar to Schwabe's clusters of spots); $f$ is the actual number of discernible individual spots; and $k$ is a personal reduction coefficient dependent upon the observer's method of counting spots and groups, the size of the telescope and magnification employed, and on seeing conditions at the observing site. On the basis of relative sunspot number, Wolf was able to approximately reconstruct past sunspot activity in terms of monthly estimates back to 1749 and yearly averages back to 1700, and he estimated epochs of minima and maxima back to the beginning of telescopic observations of the Sun in 1610.[3] More importantly, he established a continuing international effort for monitoring sunspot activity on a daily basis. Based on Wolf's relative sunspot number, the average length of the sunspot cycle is found to be ≈11 yr, although individual cycle lengths are found to vary considerably about this mean.[9-12] Countless studies of the sunspot cycle are based on these numbers.

For his own observations of sunspots, Wolf used a value of $k = 1$. This value was continued to be used up until 1882 when Wolf's successors at the Swiss Federal Observatory in Zurich changed the counting method and began using $k = 0.60$, which reduced the new observations to the old scale.[3,4] Wolf counted each spot singly, regardless of size, ignoring very small spots, which are visible only during good seeing conditions. Typically, the observations of a "primary" observer were used unless they were unavailable, filling in the missing days with observations from a "secondary" observer.

More recently, Douglas Hoyt and Kenneth Schatten developed another measure of sunspot activity as an alternative to Wolf's relative sunspot number, called "group sunspot number," which appears to more accurately portray sunspot activity, especially prior to 1882.[13–15] The group sunspot number is normalized to make it agree with Wolf's sunspot number during the years 1874–1976 when the Royal Greenwich Observatory (RGO) provided daily reports on the number and characteristics of sunspot groups (see below). Wolf's relative sunspot number and Hoyt and Schatten's group sunspot number are more or less virtually identical since 1882. Using group sunspot number, a statistically significant upward secular trend is discerned of the maximum amplitudes of individual sunspot cycles, one that extends from the end of the Maunder minimum in 1715 to the present, with cycles of late being among the largest on record.[15] (Hoyt and Schatten used averages from multiple observers when available rather than a primary/secondary observer system.)

Because the definition of $R$ is somewhat arbitrary with observers reporting different values for both $g$ and $f$—given identical instruments and seeing conditions—with the use of photography one possibly could achieve a more objective measure of sunspot activity by measuring sunspot area. This technique was introduced in 1874 at the RGO, where systematic observations at Greenwich, England; Cape Town, South Africa; and Kodaikanal, India were compiled to form a list of the numbers and positions of sunspot groups and their areas on a daily basis taken directly from photographs by means of reticules divided into small squares, all measured relative to Sun center.[2,4] The RGO dataset—actually called the "Greenwich Photoheliographic Results"—spans the years 1874–1976 and is available online at http://science.nasa.gov/ssl/PAD/SOLAR/greenwch.htm. This Web site also contains an extension from 1976 to the present using United States Air Force/National Oceanic and Atmospheric Administration (USAF/NOAA) measurements of numbers, positions, and areas of sunspot groups from the Solar Optical Observing Network (SOON).

In addition to the change at the end of 1976 in observatories used for the time-consuming and tricky job of accurately measuring spot areas, another perhaps important change occurred at the start of 1981. Beginning in January 1981, the task of providing daily values of sunspot number was shifted from the Swiss Federal Observatory in Zurich, Switzerland to the Royal Observatory of Belgium in Brussels—the Solar Influences Data analysis Center (SIDC). It may be that these seemingly unimportant changes might have had subtle but measurable effects on the numerical records of solar activity since 1976. Such a change, in fact, has previously been mentioned at the aforementioned Web site, based on a comparison of Mt. Wilson area measurements against the RGO dataset and its extension, through 1982, and conflicting findings have been reported using Rome Observatory and other observatory area data.[16,17]

In this study, sunspot area and sunspot number measurements—from numbers of groups and individual spots—from the Rome Observatory in Italy are compared against the RGO dataset and its extension and the Zurich and now SIDC datasets for the interval January 1958 through June 1998 to determine the relative behaviors of these measures of solar activity. Such a study seems necessary because it might provide greater confidence as related to the accuracy of the overall sunspot record, in particular, since 1976. The sunspot record often is employed as a proxy for predicting changes in space weather and climate change on Earth.[6,12,16,18,19]

## 2. RESULTS

### 2.1 The Rome Observatory Dataset (1958–1998)

The Rome Observatory dataset is comprised of selected parametric values, extracted from readily available copies of their publication *Solar Phenomena*, spanning January 1958 through June 1998, the last available issue in our collection. For this study, these values include daily listings of observed numbers of groups, estimated numbers of spots, and total corrected area in millionths of the solar hemisphere. Only days when each of these parameters was known are used, neglecting those additional days when some group areas were noted to have been omitted from the daily area determinations (from notes contained in the Rome Observatory publication). Also, two specific time intervals could not be used because appropriate copies of the Rome Observatory publication were missing from our collection. These intervals included January through April 1972 and the entire year of 1995.

Figure 1 depicts the number ($n$) of daily observations available for study that met the above criteria. Thus, for our study there were 6,590 daily observations of $G_R$, $A_R$ and, $f_R$ over 449 available months of observations, where $G$, $A$, and $f$ refer, respectively, to number of groups, total corrected area in millionths of solar hemisphere, and number of individual discernible spots, and the subscript $R$ designates Rome.

In figure 1, three specific instances of time are identified (1, 2, and 3), these three referring to times when possibly important changes occurred in the record. For example, time tick 1 marks the end of the RGO dataset and the beginning of USAF/NOAA observations; time tick 2 marks the end of the tenure of Professor Massimo Cimino and the beginning of the tenure of Maria Torelli at the Rome Observatory; and time tick 3 marks the end of the Swiss Federal Observatory (Zurich) sunspot values and the beginning of SIDC (International) sunspot values. A legend appears to the right describing the various intervals when data were excluded from the study, as well as the meaning of the time ticks. The thin and thick vertical lines refer, respectively, to the epochs of sunspot minimum and maximum, based on the 12-mo moving average of monthly mean sunspot number (smoothed monthly mean sunspot number), and the numbers along the bottom (19, 20, 21, 22, and 23) refer to specific sunspot cycles. Observations are found to extend from the maximum of cycle 19 though the rising portion of cycle 23.

Figure 2 shows the variation of monthly means of $G_R$, $A_R$, $f_R$, $s_R$, $s$, and $k$, where $G_R$, $A_R$, and $f_R$ are defined as before, and $s_R$ is the derived sunspot number based on the observed values for $G_R$ and $f_R$ given by the equation $s_R = 10\ G_R + f_R$. The symbol $s$ was chosen to represent sunspot number because the symbol $R$ has been used to designate Rome. The symbol $s$ (without subscript) represents the derived sunspot number using the same days that $s_R$ is determined (from Zurich through 1980 and from SIDC after 1980). The symbol $k$ represents the ratio $s/s_R$. The thin and thick vertical lines and the numbers at the bottom have the same meanings as before in figure 1 and in all remaining figures.

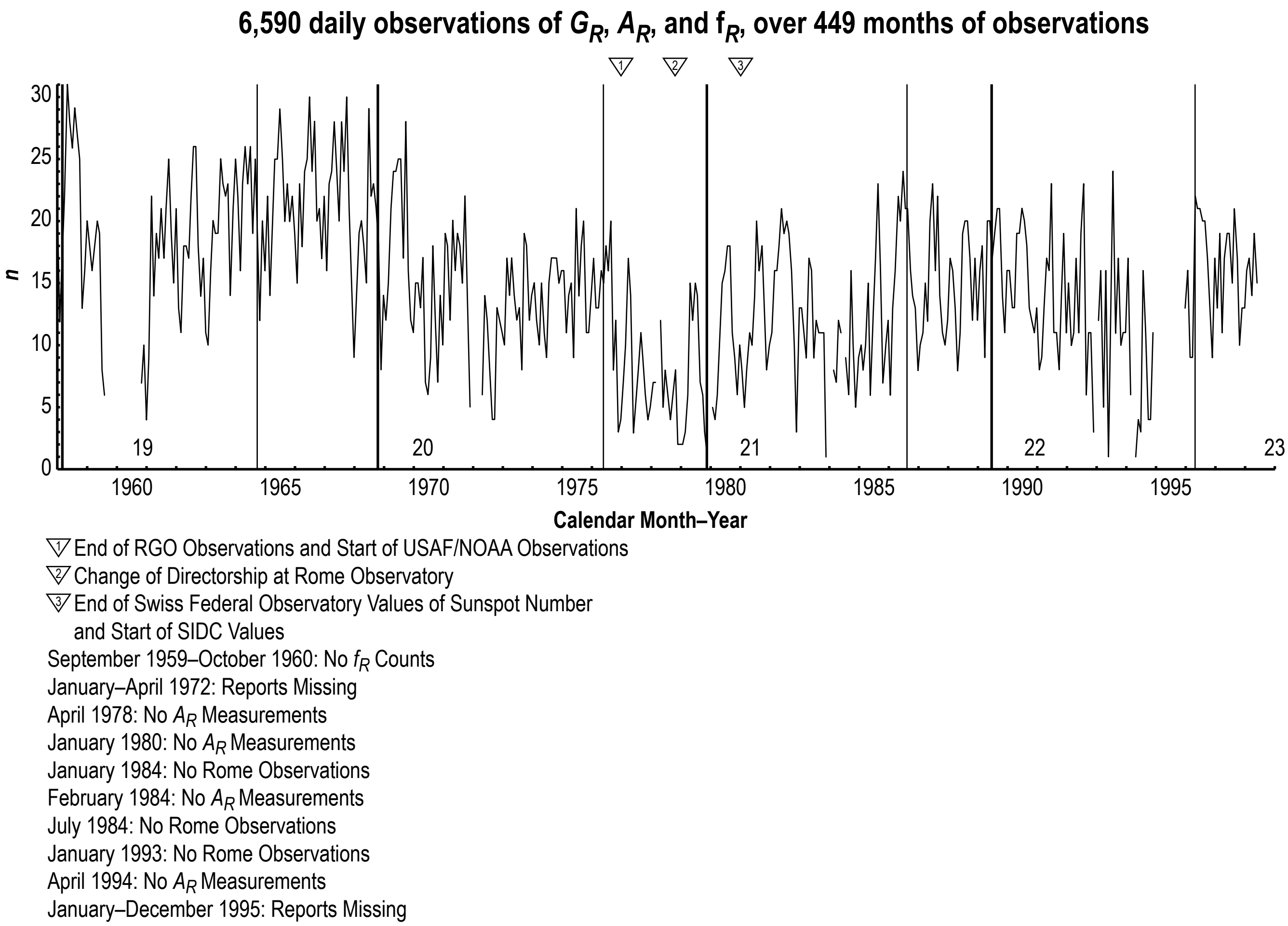


Figure 1. Variation of *n*.

Examination of figure 2 reveals that the variation of $G_R$ over a solar cycle is much smoother than for $A_R$ and $f_R$, with cycle 19 having the highest values and cycle 20 having the lowest values at maximum amplitude of the measured parameters ($G_R$, $A_R$, $f_R$, $s_R$, and $s$). Also, cycle maximum is better viewed as a broad interval of time rather than a specific instant of time, with a strong hint of double peaking in cycles 20–22, especially cycle 22. A sharp curtailment of $f_R$ is suggested in cycle 22 after maximum amplitude, which also is mimicked in $A_R$ and $s_R$, although a recovery is seen in $A_R$ due to a continued rise in $G_R$. Most interesting is the relative constancy of $k$, averaging ≈0.975, during the interval 1958–1980 and the relative inconstancy of $k$, averaging ≈1.178 during the interval 1981–1998 (the interval of SIDC measurements). This suggests perhaps that while the change of directorship at Rome Observatory had no noticeable effect, the change from Zurich to SIDC values may have resulted in slightly inflated values now as compared to prior years.

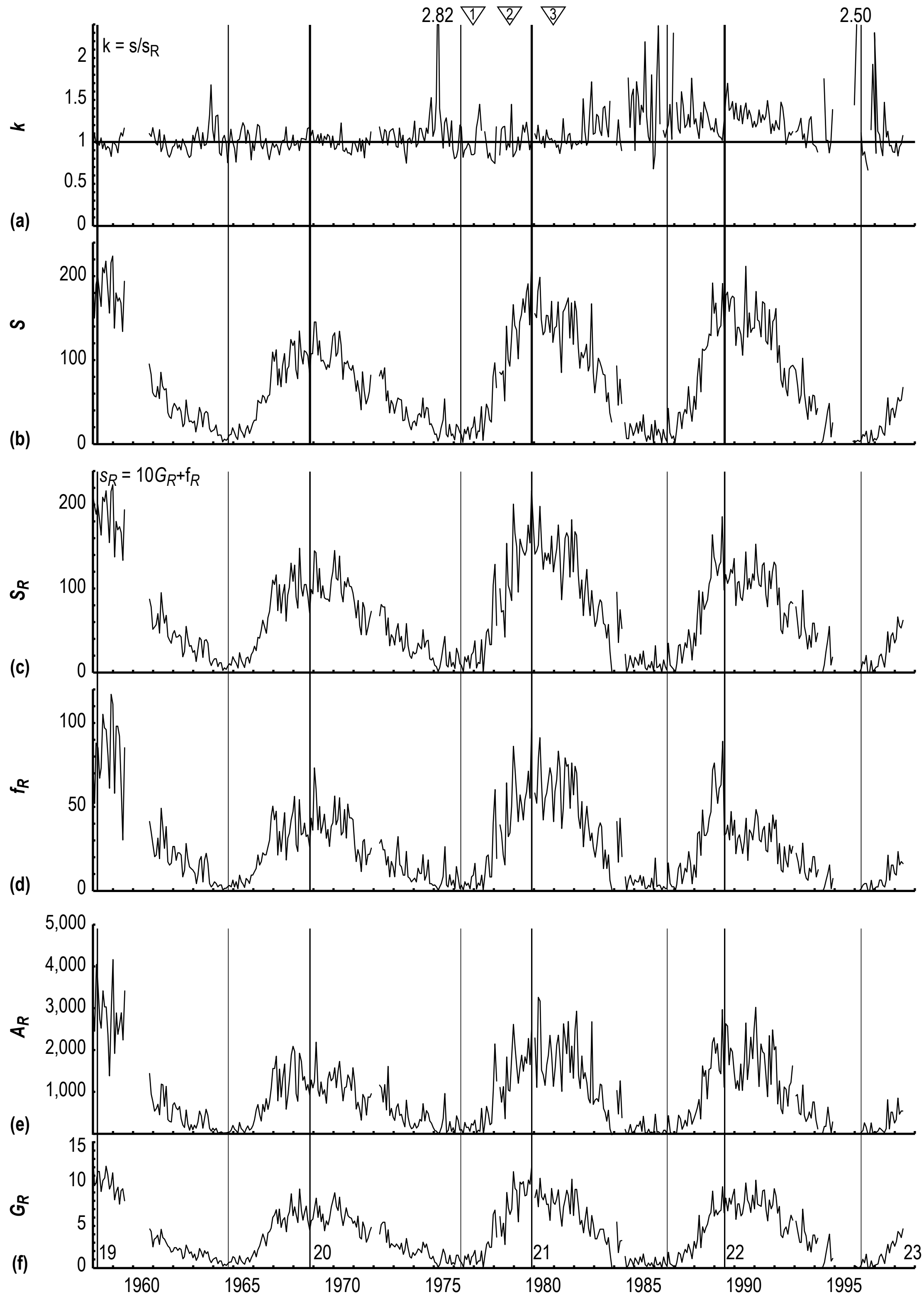


Figure 2. Variation of (a) $k$, (b) $s$, (c) $s_R$, (d) $f_R$, (e) $A_R$, and (f) $G_R$.

## 2.2 The RGO and USAF/NOAA Datasets (1958–1998)

Figure 3 depicts the variation of monthly means of $G_x$ and $A_x$, calculated using the same observing days used in figure 2 for the Rome Observatory. The subscript $x$ refers to the Greenwich Royal Observatory data for 1958–1976 and to USAF/NOAA data for 1977–1998.

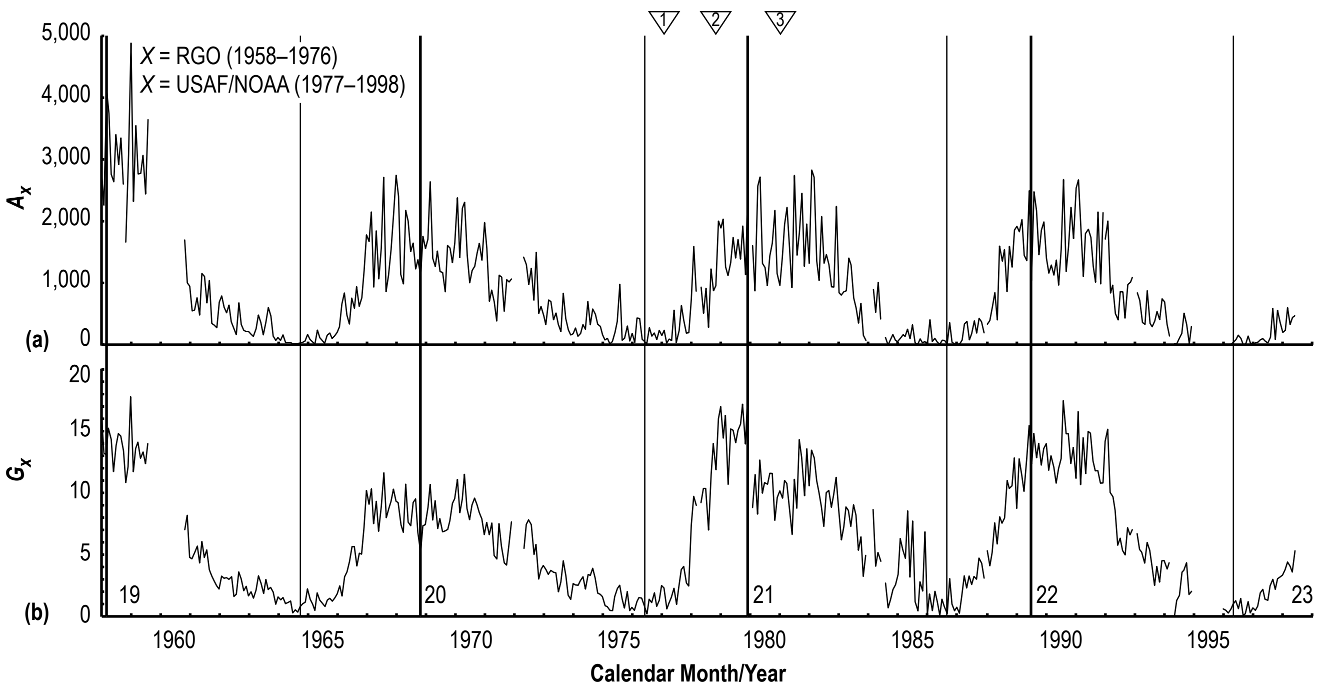


Figure 3. Variation of (a) $A_x$ and (b) $G_x$.

Casual inspection of figure 3 suggests that it compares quite favorably with figure 2, with the possible exception that sunspot areas during cycles 21 and 22 appear slightly smaller with respect to cycle 20 than is the case for figure 2 (Rome Observatory data). Also, the double peaking found in figure 2, especially during cycle 22, is seen in figure 3.

It may be important to recall that group and area measures for both the RGO and Rome Observatory datasets are based on photographic records, while the USAF/NOAA values are based on sunspot drawings. Hence, one probably should expect close agreement between Greenwich and Rome data, but not necessarily between Rome and USAF/NOAA data.

According to Baranyi et al.,[17] the SOON system consists of a worldwide network of solar observatories located so that 24-hr synoptic coverage can be achieved. Sunspot drawings on an 18-cm diameter projected image of the Sun are made daily at each site, including Boulder, Holloman, Learmonth, Palehua, Ramey, San Vito, and occasionally Culgoora. Because SOON operates in real time, providing early warning of potentially disruptive solar events at Earth, extremely accurate measurements, particularly, of sunspot areas are not possible. The scaling of positions and areas of sunspots are performed routinely by hand, using Stonyhurst disc overlays for positions and circle/ellipse overlays for sunspot area starting in 1981 (grids were used to estimate sunspot area prior to 1981). Sunspot areas less than 10 millionths of the solar hemisphere generally are not reported. Also, areas are rounded. This same procedure is followed at all of the sites, giving an internal consistency, but no further screening, for outliers or errors, is done. Thus, it appears that there may be a tendency to underestimate sunspot area using the drawings from SOON; this is especially true near sunspot maximum when many small spots contribute to the overall sunspot number estimate but are not counted in the area estimate. Such an explanation seems consistent with what has been found in the comparison of figures 2 and 3.

To better show this possible effect, the ratios of $G_R/G_x$ and $A_R/A_x$ are given in figure 4. For the interval of 1958–1976 (Rome/RGO data), these ratios are found to vary about means of 0.72 and 0.89, respectively, while they are found to vary about means of 0.66 and 1.15, respectively, for the interval of 1977–1998 (Rome/USAF/NOAA data). The means given here are not the simple averages of the monthly values, but instead are the weighted means, weighted according to the number of daily observations. Clearly, the behavior of the ratios changes beginning in 1977, with the ratio of groups decreasing and the ratio of areas increasing, this being consistent with an increase in the number of groups (hence, an increase in overall sunspot number $s$) and a decrease in sunspot area in the latter portion of the record (USAF/NOAA). For the RGO timeframe $G_R$ averaged 3.9, $G_x$ averaged 5.4, $A_R$ averaged 860.2 and $A_x$ averaged 963.3, while for the USAF/NOAA timeframe averaged, respectively, 4.6, 7.0, 995.0, and 868.6 (where these averages are again the weighted mean averages based on the number of daily observations). For convenience, table 1 is included to summarize these averages for the time intervals 1958–1976, 1977–1998, 1958–1980, 1981–1998, and 1958–1998.

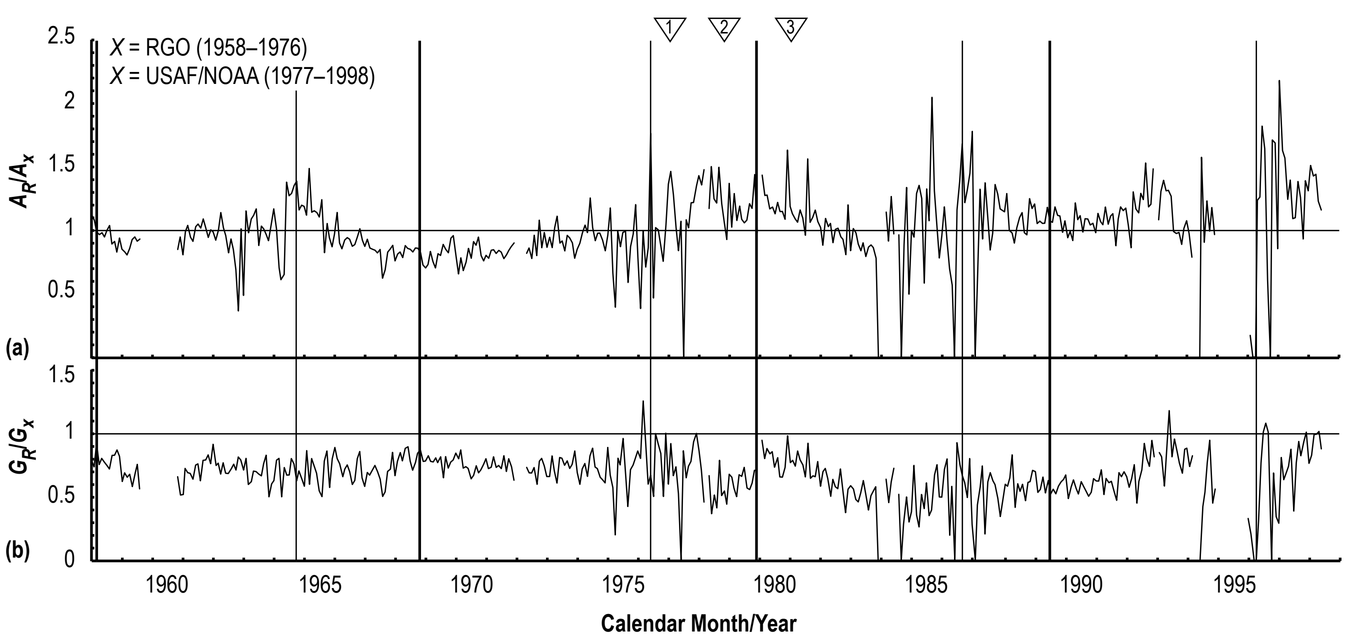


Figure 4. Variation of (a) $A_R/A_x$ and (b) $G_R/G_x$.

Table 1. Weighted mean averages of observed parameters for specific time intervals.*

| Parameter | 1958–1976 | 1977–1998 | 1958–1980 | 1981–1998 | 1958–1998 |
|---|---|---|---|---|---|
| $G_R$ | 3.9 | 4.6 | 4.3 | 4.2 | 4.2 |
| $A_R$ | 860.2 | 995.0 | 897.7 | 956.3 | 920.7 |
| $f_R$ | 26.8 | 26.1 | 28.1 | 23.9 | 26.5 |
| $s_R$ | 65.8 | 72.1 | 71.1 | 65.9 | 68.5 |
| $G_X$ | 5.4 | 7.0 | 5.7 | 6.6 | 6.1 |
| $A_X$ | 963.3 | 868.6 | 977.3 | 839.9 | 920.8 |
| $s$ | 65.5 | 81.2 | 69.3 | 77.6 | 72.4 |

*Weighted by number of observations per months (*n*). $G_X$ and $A_X$ are, respectively, the number of groups and sunspot areas from the RGO for 1958–1976 and from the USAF SOON/NOAA for 1977–1998. *S* is the sunspot number from the Swiss Federal Observatory for 1958–1980 and from SIDC for 1981–1998. $G_R$, $A_R$, $f_R$, and $s_R$ are, respectively, the number of groups, sunspot area, number of individual spots, and sunspot number from the Rome Observatory. For 1958–1976, *n* equals 210 monthly observations (3,633 daily observations). For 1977–1998, *n* equals 239 monthly observations (2,957 daily observations). For 1958–1980, n equals 256 monthly observations (4,004) daily observations). For 1981–1998, *n* equals 193 monthly observations (2,586 daily observations). For the entire interval, 1958–1998, *n* equals 449 monthly observations (6,590 daily observations).

Table 2 compares linear regression fits for $A_x$ versus $A_R$ for the two time intervals of 1958–1976 and 1977–1998, and it compares linear regression fits for $s$ versus $s_R$ for the two time intervals of 1958–1980 and 1981–1998. Plainly, for each time interval strong correlations are found, although the *y* intercepts and slopes are slightly different. Given an $A_R$ of 1,000 millionths of the solar hemisphere, such a value suggests a value of about 1,122 millionths of the solar hemisphere during the RGO timeframe and a value of only 899 millionths of the solar hemisphere during the USAF/NOAA timeframe, a difference of 223 millionths of the solar hemisphere. Thus, areas after 1976 appear to be slightly underestimated as compared to earlier years.

Table 2. Linear regression fits for $A_X$ versus $A_R$ and $s$ versus $s_R$.*

| Parameters | Time Interval | Linear Regression ($y = a + bx$) | $r$ | $se$ |
|---|---|---|---|---|
| $A_X$ versus $A_R$ | 1958–1976 | $y = 24.599 + 1.097x$ | 0.988 | 143.9 |
| | 1977–1998 | $y = 9.602 + 0.889x$ | 0.983 | 141.6 |
| $s$ versus $s_R$ | 1958–1980 | $y = 1.937 + 0.974x$ | 0.986 | 9.4 |
| | 1981–1998 | $y = 2.958 + 1.132x$ | 0.967 | 14.7 |

*Notes:

- For interval 1958–1976, $A_X$ is the sunspot area from the Royal Greenwich Observatory.
- For interval 1977–1998, $A_X$ is the sunspot area from the U.S. Air Force SOON/NOAA.
- For interval 1958–1980, *s* is the sunspot area from the Swiss Federal Observatory in Zurich, Switzerland.
- For interval 1981–1998, *s* is the sunspot area from the SIDC in Brussels, Belgium.
- For all intervals, $A_R$ and $s_R$ are the sunspot area and sunspot number, respectively, from the Rome Observatory.
- The linear correlation coefficient is "*r*" and the standard error of estimate is "*se*."

Similarly, given an $s_R$ of 100, such a value suggests a value of about 99 during the Zurich timeframe and a value of 116 during the SIDC timeframe, a difference of 17 units of sunspot number. Thus, sunspot numbers after 1980 appear to be slightly overestimated as compared to earlier years.

### 2.3 Area-per-Group Ratios (1958–1998)

The ratio of spot area to number of groups is not constant over the solar cycle, as evinced from figure 5. Instead, its variation appears to mimic the general shape of the sunspot cycle, with higher values near sunspot maximum and lower values near sunspot minimum. Additionally, the double peaking in cycle 22 is replicated in the ratios and a moving average of the values (not shown) suggests that the peak in cycle 21 occurred post cycle sunspot maximum in 1981–1982. More interesting is that the long-term behavior of the two ratios appears to differ, with the ratio determined from Rome observations being relatively flat and the ratio determined from Greenwich and USAF/NOAA observations suggesting a downward shift. In other words, the peaks associated with cycles 21 and 22 are too low in comparison to cycles 19 and 20. This can be easily explained if the overestimate of sunspot number (due to a slightly inflated value of number of groups) and the underestimate of sunspot area, noted above, associated with the post-RGO and post-Zurich timeframes are real.

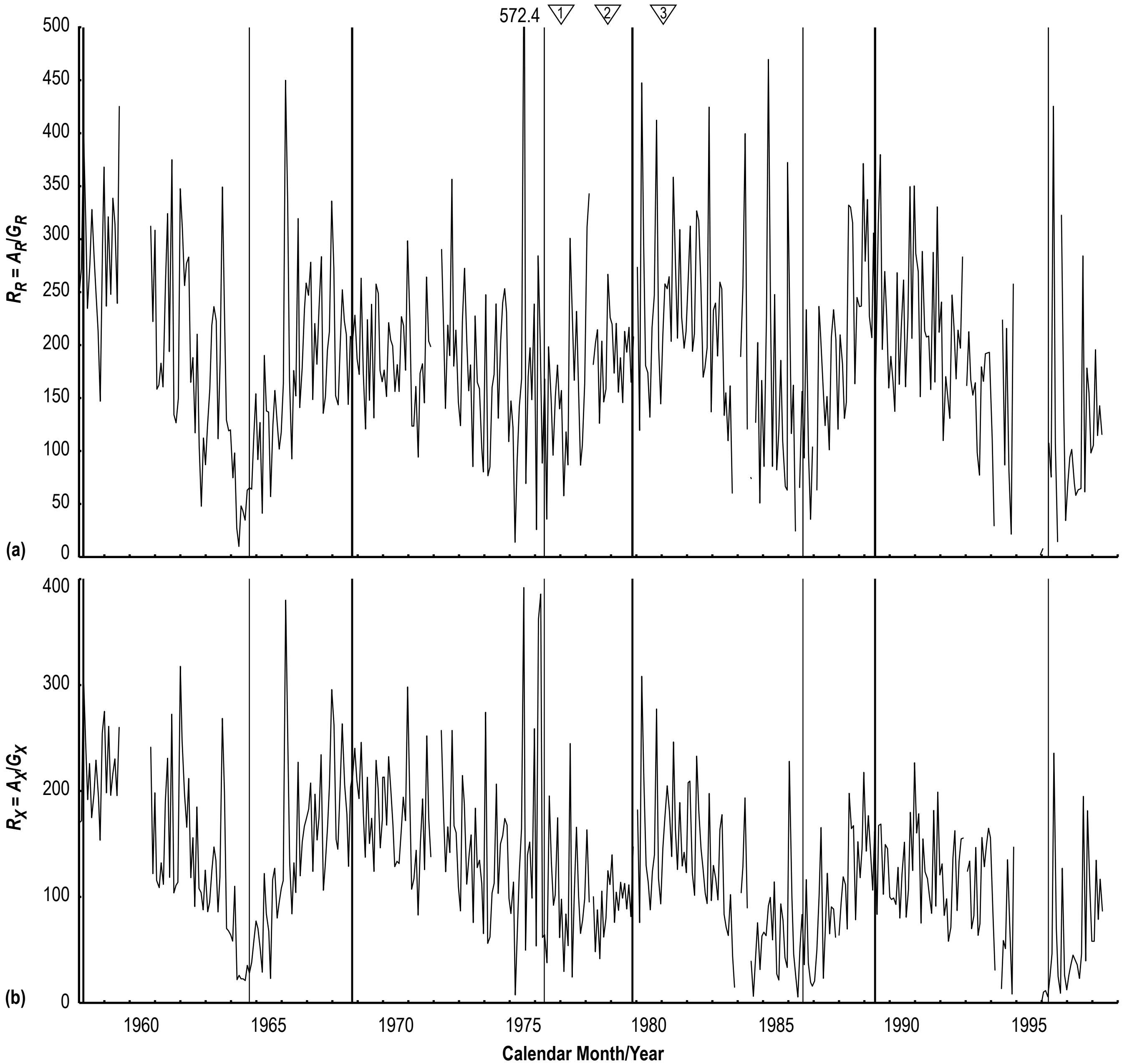


Figure 5. Variation of (a) $R_R = A_R/G_R$ and (b) $R_x = A_x/G_x$.

## 3. DISCUSSION AND CONCLUSION

Previously, Fligge and Solanki[16] reported a significant disagreement between RGO and Rome Observatory area measurements, suggesting that the RGO values are between 15 and 25 percent larger than sunspot areas measured at Rome Observatory. Later, Baranyi et al.[17] reported that the photographic databases of sunspot areas for both the RGO and Rome Observatory provide nearly the same areas if the random errors and the constant deviations are neglected. Hence, they argue that the areas from these observatories are in good agreement with each other, seemingly in contradiction with the result of Fligge and Solanki. Baranyi et al. went on to note that Fligge and Solanki–plotted daily sums of RGO and Rome Observatory areas versus Zurich sunspot number, without correcting for the omission of some areas in the Rome dataset. Hence, some of the daily sums reported by the Rome Observatory may be smaller than their actual values.

In this study, sunspot areas, numbers of sunspot groups, and sunspot numbers were derived using the RGO, USAF/NOAA, Zurich, and SIDC datasets for same-day observations as reported by the Rome Observatory, with the further requirement that the only days used were those in which $G_R$, $A_R$ and $f_R$ (hence, $s_R$) were documented and there was no indication that any sunspot area was omitted on those days in the Rome dataset. These derived values were then compared directly with the Rome Observatory measures during specific intervals of time; namely, 1958–1976, 1977–1998, 1958–1980, and 1981–1998. The weighted mean averages of the various parameters were computed and are summarized in table 1.

During the interval 1958–1976, the weighted mean averages of $A_R$ and $A_x$ are, respectively, 860.2 and 963.3 millionths of the solar hemisphere, suggesting that RGO values are about 12.0 percent higher than those measured by the Rome Observatory. For the interval 1977–1998, the weighted mean averages are, respectively, 995.0 and 868.6 millionths of the solar hemisphere. This suggests that the USAF/NOAA estimates of sunspot areas are ≈12.7 percent lower than those measured by the Rome Observatory or ≈22 percent lower than an equivalent area for the RGO had it still been reporting areas. Thus, it appears the extended database, 1977 through present, based on USAF/NOAA sunspot reports has underestimated sunspot areas, on average, by ≈22 percent.

Similarly, for the interval 1958–1980, the weighted mean averages of $s_R$ and $s$ are 71.1 and 69.3, respectively, suggesting that Zurich sunspot numbers are ≈2.5 percent lower than that derived for the Rome Observatory. For the interval 1981–1998, the weighted mean averages are 65.9 and 77.6, respectively, suggesting that the SIDC values are ≈17.8 percent higher than those measured by the Rome Observatory or ≈18.2 percent higher than an equivalent sunspot number for Zurich had it been reporting sunspot number. Thus, it appears the extended sunspot number database, 1981 through present, based on SIDC values has overestimated sunspot numbers, on average, by ≈18.2 percent.

The overestimate in sunspot number may be due to more groups being counted, on average, since 1980. From table 1, the interval of 1958–1980 saw weighted mean averages of 4.3 and 5.7, respectively, for $G_R$ and $G_x$, and the interval of 1981–1998 saw weighted mean averages of 4.2 and 6.6, respectively, for

$G_R$ and $G_x$. Thus, whereas the weighted mean average of number of groups remained essentially the same during the two intervals for $G_R$, there was an increase in $G_x$, beyond what the equivalent Zurich number of groups would have been (a difference of ≈1 group or 10 units of sunspot number, which compares favorably to the difference of 11.7 units of sunspot number that actually is observed).

Area-per-group behavior is found to mimic the general shape of the solar cycle, with lowest values near solar minimum and highest values near solar maximum. However, the long-term behavior of values based on USAF/NOAA observations appears to differ from those based on RGO (for earlier years) and Rome Observatory observations (over the entire interval). Since 1976, area-per-group values determined using USAF/NOAA observations seem too low, easily explained by the inferred overestimate of numbers of groups and the inferred underestimate of spot areas.

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