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A cross-calibrated sunspot areas time series since 1874

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Abstract.
A complete and homogeneous historical record of sunspot areas is a valuable proxy of solar variability, and is widely used, e.g., to understand the behaviour of total and spectral solar irradiance at earlier times. Since 1874, the Royal Greenwich Observatory (RGO) regularly carried out these and other measurements until December 1976. After that time the records from a number of different observatories are available. These, however, show some systematic differences and often have a lot of gaps. In order to compile a complete and cross-calibrated time series we compare the data from different observatories when they overlap and find the corresponding correction factors. The Greenwich data set is used as a basis until 1976, the Russian data (stations from the former USSR) between 1977 and 1985 and the Mt. Wilson data since 1986. Other data sets (Rome, Yunnan, Catania) are used to fill in the remaining gaps.

Key words. Sun: activity – Sun: magnetic fields – sunspots

1. Introduction

The total area of all sunspots visible on the solar hemisphere is one of the fundamental indicators of magnetic activity in the Sun. Measured since 1874, it provides the most complete database of solar activity over more than 130 years. Consenquently, a reliable and complete series of sunspot areas is essential. Since no single observatory made such records over this whole interval of time, different data sets must be combined after an appropriate intercalibration. In this sense, several comparative studies have been carried out in order to get reliable and complete sunspot areas data set (see, for instance: Sivaraman et al. 1993; Fligge & Solanki 1997; Baranyi et al. 2001; Foster 2004). In this work, we compare data from Russian stations in addition to the data from Mt. Wilson (US Air Force) and other sources with RGO. This combination provides a good set of observations almost free of gaps after 1976. Combining them appropriately improves the sunspot area time series available at present.

2. Observational Data

Data from RGO is the longest and most complete record of sunspot areas measured by a small network of observatories. It has provided information about sunspot areas between 1874 and 1976, thus covering nine solar cycles. Positions and distance from center of solar disk are also available. The second data

Send offprint requests to: L. Balmaceda set is completely independent and is known as Russian books — Solar Data from the ex-USSR stations. The stations, belonging to the former USSR, provided sunspot areas corrected for foreshortening with the position (latitude, longitude) and radial distance to Sun center for each sunspot group. US Air Force (USAF) started compiling data from its own Solar Optical Observing Network (SOON). This network consists of solar observatories located in such a way that 24-hour synoptic solar monitoring can be maintained. The basic observatories are Boulder and the members of the network of the US Air Force (Holloman, Learmonth, Palehua, Ramey and San Vito). Their work was continued with the help of the US National Oceanic and Atmospheric Administration (NOAA) with the same information being compiled through to the present. For this reason, this data set is called USAF/NOAA although sometimes it is also called USAF/Mt. Wilson. A number of further observatories have also regularly measured sunspot areas during the past decades. Rome Astronomical Observatory, whose measurements began in 1958, has several years of observations in common with Russia and Mt. Wilson as well as with RGO. This is perhaps the only source of data with a long period of overlapping with all three prime data sets. Therefore, the database from Rome is used to compare the results obtained from the other observatories and also to fill some remaining gaps. Unfortunately, its coverage is limited by the weather conditions and instrumentation problems. All the data used in this work were extracted from http://www.ngdc.noaa.gov/stp/SOLAR/.

3. Analysis

Daily values for sunspot areas from different observatories are directly compared in those periods where they overlap. It is necessary to find a factor to multiply the data from each observatory in order to have the final data consistent with the information provided by RGO. A linear fit forced to pass through the origin is applied to the data so that the value for the slope b is the factor to correct the different data sets (see left panels of Fig. 1 for two examples of such regressions). The value of b is found from the equation:

$$A_s^{bas} = b \cdot A_s^{aux},$$

where A_s^{bas} is the area published by the observatories that are taken as basis, while A_s^{aux} is the area published by the observatories whose data needs to be recalibrated. First, this analysis is applied to all the points and without assigning any weights to them. The obtained b_1 is taken to be the initial estimate for a second analysis where not all the points are taken into account. Only measurements larger than 2σ (σ being the standard deviation of all the points) are considered, so that points close to the origin are excluded since they introduce a bias. Table 1 shows the results of the comparison between the sunspot areas, both corrected for foreshortening (CA) and directly observed ones (OA), measured by different observatories. The observatories whose data is taken as the basis are indicated as Obs1, while the observatories whose data is recalibrated are indicated as Obs2. As a second diagnostic, we also compare the 12-month running means of all sunspot area records (see right panels of Fig 1). The final factor in this case is then an average over time.

4. Discussion

The comparison between RGO and Russia is made for the period from 1968 to 1976 when the data series overlap. As can be seen from Fig. 1 (top panels) the measurements from RGO and Russia agree rather well with each other. The factor calculated from the comparison between these two observatories is very close to unity, although the trend in the difference is not monotonous. Because, before 1970, areas from RGO are larger (5 – 6%) than Russian measurements and after that vice versa.

In the comparison between Russian and Mt. Wilson areas, more significant differences arise (see Fig.1, bottom panels). The overlap covers the period from 1982 to 1991, cycles 21 and 22. During the whole time interval, Mt.

Table 1. Calibration factors for the different observatories

Obs1	Obs2	Period	Calibration Factor OA	Calibration Factor CA
Mt. Wilson	Rome	1982 – 1999	0.7716980 ± 0.1408438	0.8076460 ± 0.2180137
RGO	Rome	1958 – 1976	1.0815642 ± 0.1098725	1.0690922 ± 0.1038753
Russia	Rome	1968 – 1990	1.1160067 ± 0.0743860	1.1689711 ± 0.1319131
Mt. Wilson	Yunnan	1982 – 1992	0.8976687 ± 0.1445133	0.8792276 ± 0.1658460
Russia	Mt. Wilson	1982 – 1990	1.3491828 ± 0.1348256	1.3866438 ± 0.1415974
RGO	Russia	1968 – 1976	1.0160007 ± 0.0665799	1.0125098 ± 0.0794502
Russia	Yunnan	1968 – 1990	1.2664820 ± 0.0665799	1.3113281 ± 0.0794502

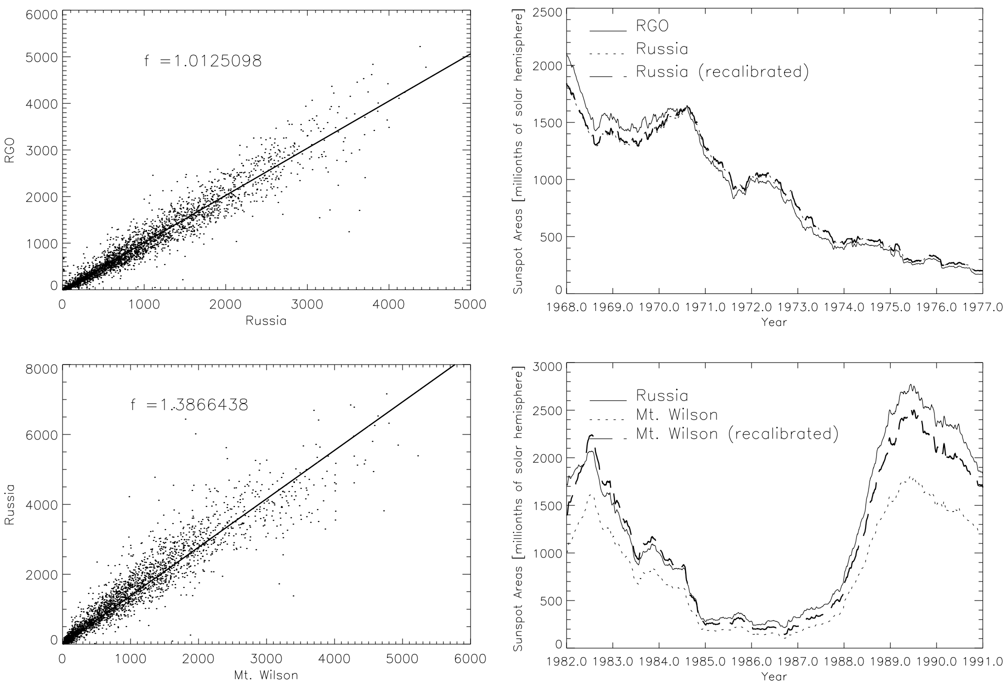

Fig. 1. Comparison of sunspot areas obtained by the different observatories. Top: RGO vs. Russia, bottom: Russia vs. Mt. Wilson. Left: linear regressions, right: 12-month running means of sunspot areas vs. time.

Wilson areas appear to be smaller (35 – 39%) than that of the Russian data.

Mt. Wilson and Rome measurements overlap between 1982 and 1999 covering three solar cycles: parts of cycles 21 and 23 and the whole of cycle 22. The variation of the differences between the data sets do not follow any systematics. During the declining phase of cycle 21, both observatories present similar values for the areas. However, Mt. Wilson areas in cycle 22 are about 20% smaller than Rome data while during the ascending phase of cycle 23 they are about 40% smaller. Rome and RGO measurements overlap during the declining phase of cycle 19 and the whole of cycle 20. During this period, Rome provides

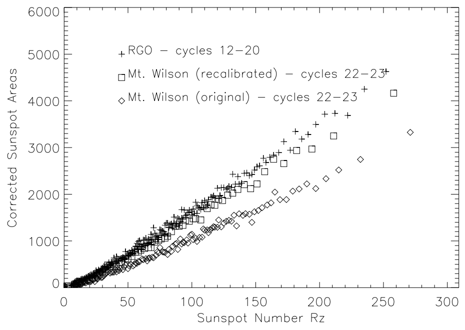

Fig. 2. Sunspot areas vs. sunspot number, Rz, for measurements made by RGO and Mt. Wilson. Each symbol represents an average over bins of 50 points. The original data from Mt. Wilson lie significantly below the ones from RGO. These data have to be multiplied by a correction factor of 1.4 in order to match RGO data.

smaller areas than RGO. The difference is only about 8 – 11%, which is somewhat smaller than 15–20% found by Fligge & Solanki (1997). Russia and Rome present the longest period of overlap from 1962 to 1985, covering also three solar cycles. The difference between these two data sets vary from cycle to cycle from about 12 to 17%.

Mt. Wilson measurements started in 1981, so there is no period of overlap with RGO. For this reason, the correction factor for this data set with respect to RGO is calculated by multiplying the correction factors from Mt. Wilson to Russia and from Russia to RGO. Fig. 2 shows the comparison between sunspot areas measured by RGO and Mt. Wilson and sunspot number. We have binned the data from each observatory every 50 points according to the sunspot number. We can notice that the original areas from Mt. Wilson lie significantly below the ones from RGO. In order to match RGO data, it is then necessary to multiply Mt. Wilson data by a correction factor of 1.37–1.40, which agrees well with the value found by combining the Mt. Wilson to Russia and Russia to RGO factors from Table 1.

We propose the following combination of databases to obtain a consistent sunspot areas time series:

1874 - 1976	RGO
1977 - 1985	USSR
1986 - present	Mt. Wilson

We have chosen to use the USSR data set until 1985 for the simple reason that this year corresponds to the solar minimum. In this way, each data set describes a different solar cycle. This is only aproximately correct since sunspots from consecutive cycles overlap during a short period of time, but this is only a second order effect.

5. Summary and conclusions

We have investigated here the relationship between sunspot areas from different observatories. We used more recent data, covering mainly the critical period after RGO stopped providing information about this parameter. We found a good agreement between sunspot areas measured in Russian stations and RGO. Unfortunately, this data is only available until 1991, so for this reason the relationship with Mt. Wilson, which extends to the present, was also explored. In this case, the comparison with Russian data shows a difference of about 35–39% between sunspot areas measured in both places. When combining this data set with the RGO data, it is then necessary to multiply the sunspot areas from Mt. Wilson by a factor of 1.37 in the case of observed areas and 1.40 in the case of corrected areas. By using these results, a complete sunspot areas database can be produced, contributing to the improvement of studies on longer time-scales of, e.g., total and spectral solar irradiance.

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