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Remeasurement of Solar Observing Optical Network sunspot areas

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ABSTRACT

The United States Air Force solar observing optical network (SOON) sunspot areas have been reported by several researchers over many years to be underestimated by as much as 50 per cent. Here, the areas of sunspots from scanned SOON disc drawings have been accurately remeasured for a period of two months from 2014 October and November – this being near the peak of Solar Cycle 24 and which includes the largest sunspot group of that cycle. The remeasured sunspot areas are now comparable with areas in sunspot catalogues.

Key words: methods: data analysis – sunspots.

1 INTRODUCTION

The joint United States Air Force (USAF)/National Oceanic and Atmospheric Administration (NOAA) Solar Region Summary (SRS) report is issued daily at 01:30 UT online[1] and via email. An example is shown in Fig. 1 where information of sunspot groups is given for the previous day. This includes an active regions number (last four digits), the heliographic location, area, group type, longitude extent, number of sunspots, and magnetic type. The AR number is the primary reference used for individual groups. The SRS report is compiled from reports prepared by the SOON observatories of which there are currently three. These are located in Learmouth in Western Australia, San Vito in Italy, and Holloman in New Mexico, USA thus enabling solar observations to be made throughout each 24-h period.

Various studies have indicated that the USAF/NOAA sunspot areas have been underestimated over a period of at least 40 yr. No clear reason for this discrepancy has been provided in the literature although there are only two possibilities – the drawings themselves and/or the area measurement approach. Here, the area of sunspots from SOON Observatory scanned drawings have been remeasured by creating a sunspot mask followed by the area calculation of each pixel in the mask.

A description of SOON observations is given below followed by a summary of previous studies before a description is given of the remeasurement approach. The remeasured areas results are then shown for the largest group of Cycle 24, AR 12192, and for daily areas from SOON drawings for a two-month period of high solar activity in 2014 October and November. Comparisons have been performed with the Debrecen Photoheliographic Data Sunspot Catalogue[2] (Győri, Ludmány & Baranyi 2016) and the catalogue recently compiled by Mandal et al. (2020)[3].

2 SOON OBSERVATIONS

Giersch, Kennewell & Lynch (2018) give an overview of the SOON and how the disc drawings are made. Briefly, the white-light drawings use an 18-cm diameter projected disc with the outline of sunspots drawn. The average time (UT) between the start and end of the drawing is noted. Subsequent analysis using a Stonyhurst overlay enables the heliographic latitude and longitude of each sunspot group to be determined and added to a Sunspot Analysis Worksheet. The area of individual groups is measured using two overlays. The first one consists of a number of different sized circle and ellipses from 10 millionths of the Sun's visible hemisphere (μHem) up to 1000 μHem. These are placed over the sunspots to estimate an uncorrected area. The second overlay shows the foreshortening correction required for any sunspot that is located away from the middle of the disc. The smallest sunspots are assigned an area of 2 μHem. Finally, the total area of a group is reported to a precision of 10 μHem. Giersch et al. (2018) indicate that prior to 1987 October a mm grid was placed over each group to calculate the area, such as used by Meadows (2002).

The procedures used by the SOON Observatories, including sunspot areas are described in the USAF Air Force Weather Agency document AFWAMAN 15-1 dated 2013 December – this is available online[4]. The overlays are also available online[5].

3 PREVIOUS STUDIES

Hathaway (2015) states that in 1977 NOAA began reporting sunspot area and position in its SRS reports and that the areas have a significantly different relationship with the International Sunspot Number (R_I)[6] than previously derived by the Royal Greenwich Observatory (RGO)[7]. The RGO ceased reporting solar positions and areas at

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[1] http://www.swpc.noaa.gov/products/solar-region-summary
[2] http://fenyi.solarobs.csfk.mta.hu/en/databases/DPD/
[3] http://www2.mps.mpg.de/projects/sun-climate/data.html
[4] http://ngdc.noaa.gov/stp/space-weather/online-publications/miscellaneous/afrl_publications/afwaman15-1_space-environmental-observations.pdf
[5] ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_REGIONS/USAF_MWL/docs/miscellaneous/
[6] http://sidc.be/silso/
[7] http://fenyi.solarobs.csfk.mta.hu/GPR/index.html

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:Product: Solar Region Summary
:Issued: 2014 Oct 25 0030 UTC
# Prepared jointly by the U.S. Dept. of Commerce, NOAA,
# Space Weather Prediction Center and the U.S. Air Force.
#
Joint USAF/NOAA Solar Region Summary
SRS Number 298 Issued at 0030Z on 25 Oct 2014
Report compiled from data received at SWO on 24 Oct
I.  Regions with Sunspots.  Locations Valid at 24/2400Z
Nmbr Location  Lo   Area  Z    LL   NN Mag Type
2187 S08W93    321  0070 Hax  02    01 Alpha
2192 S12W21    249  2510 Fkc  20    62 Beta-Gamma-Delta
2193 N07W59    287  0070 Cao  06    03 Beta
2194 S12E19    208  0070 Cao  05    03 Beta
2195 N08E47    180  0070 Cso  10    06 Beta
2196 S03E66    161  0020 Hsx  01    01 Alpha
2197 S12E62    164  0010 Axx  00    01 Alpha
IA. H-alpha Plages without Spots.  Locations Valid at 24/2400Z Oct
Nmbr  Location  Lo
2190  N22W79    307
2191  S11W79    307
II. Regions Due to Return 25 Oct to 27 Oct
Nmbr Lat    Lo
None
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Figure 1. USAF/NOAA SRS report for 2014 October 24.

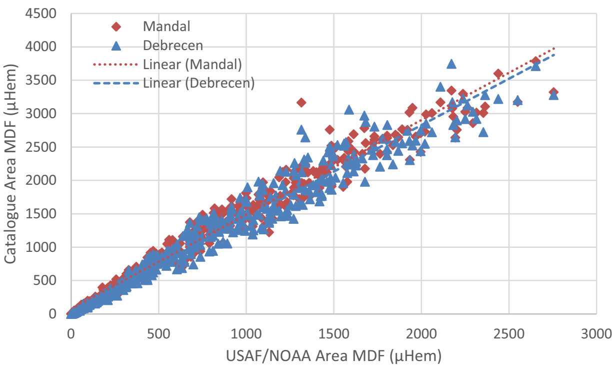

Figure 2. Relationship between USAF/NOAA and Debrecen and Mandal Area MDF from 1977 to 2016.

the end of 1976 (this activity was then transferred to the Debrecen Observatory). Hathaway (2015) shows that the constant of proportionality between area and R_I is 16.7 for smoothed RGO sunspot areas (from 1874 to 1976) and 11.2 for smoothed USAF/NOAA sunspot areas (from 1977 to 2014). Thus, the USAF/NOAA areas need to be multiplied by a factor of 1.49 to match with the RGO areas. Hathaway (2015) cites various papers dating back to 1997 that report on the discrepancy between RGO and USAF/NOAA sunspot areas.

Giersch et al. (2018) also describe previous studies into the underestimation of USAF/NOAA sunspot areas. They also perform a comparison between USAF/NOAA and Rome Observatory[8] derived areas but acknowledge there is a discrepancy of 34 per cent in Cycle 22 and that the problem worsened in Cycle 23. They state that if the mm grid method of measuring area were used instead of the circle/ellipse template, this would account for some of the discrepancies. This is also the case if area correction overlay extended all the way to the limb (it ceased for a foreshortening factor of 3). Finally, Giersch et al. (2018) conclude that their analysis does not completely account for all the shortcomings of the USAF/NOAA analysis, which are a contributing factor to the underreporting of sunspot area.

Fig. 2 illustrates the underestimation of USAF/NOAA areas. This shows the monthly Mean Daily Frequency (MDF) areas of the USAF/NOAA areas and those from the Debrecen and Mandal sunspot catalogues. Table 1 shows the underestimates are a factor of 1.39 and 1.42 for the two catalogues based on data from 1977 to 2016. Given that these are average underestimates over 40 yr, Fig. 3 shows the ratio of the USAF/NOAA monthly MDF with the Debrecen MDF as a function of date. The upper vertical lines show the date of solar cycle maxima (cycles 21–24) while the lower vertical lines are for solar minima (as determined by the smoothed monthly R_I). This shows that the underestimate varies from a factor of 1.1 (9 per cent underestimate) to 1.9 (48 per cent). Note that Fig. 3 should not be used to apply a correction to the USAF/NOAA measurements. This is due to the variability of sunspot activity throughout a month and throughout solar cycles.

Table 1. Linear fit parameters for USAF/NOAA versus Debrecen and Mandal area MDFs.

	Gradiant	Intercept	R^2
Debrecen	1.39 ± 0.01	45 ± 12	0.96
Mandal	1.42 ± 0.01	74 ± 11	0.97

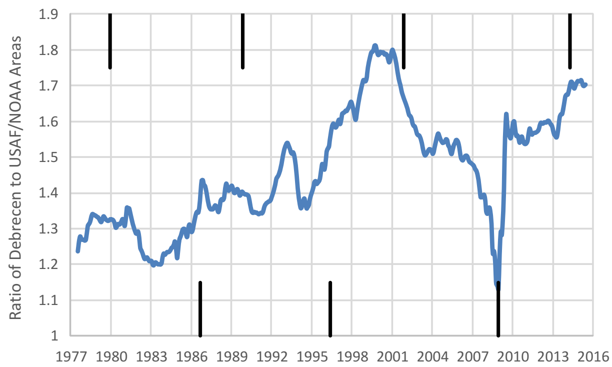

Figure 3. Ratio of Debrecen to USAF/NOAA Area MDF.

4 MEASUREMENT PROCEDURE

The approach taken here to calculate the area of sunspots from the SOON disc drawings is to:

(i) crop the solar disc from the Sunspot Analysis Worksheets[9];
(ii) determine the edge of the drawing disc;
(iii) make a photosphere/sunspot mask;
(iv) calculate the area of each pixel containing a sunspot; and
(v) sum the area of each sunspot pixel to give either the area of a particular group or all the sunspots on the disc.

The SOON drawings have a white background (the photosphere) while the disc edge, sunspots umbra, and edge of penumbral are shades of grey or black. For the disc edge determination, the location of the dark edge pixels are found around the disc by using a pixel intensity threshold followed by a least-square fit to a circle. This gives the pixel coordinates of the middle of the disc and the disc radius. The mask is created by assigning all non-white pixels of a sunspot to a specific mask colour and then filling in all the resulting white regions within penumbral sunspots. Fig. 4 (upper right-hand side) shows an example of a sunspot mask for AR 12192. Note that

[8] ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_REGIONS/Rome/

[9] ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-imagery/photosphere/sunspot-drawings/soon/

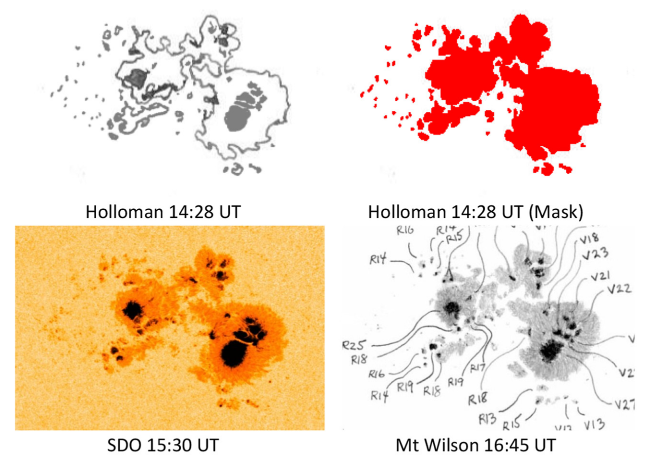

Figure 4. AR 12192 on 2014 October 24 from the SOON Holloman Solar Observatory, Mt Wilson Observatory, and the Solar Dynamics Observatory (SDO).

no distinction is made between sunspot penumbra and umbra and that the area of a penumbral sunspot includes its edge.

Once the mask has been created, the whole drawing is searched to find each pixel with the mask colour. Knowing the disc radius (in pixels) and calculating angle from the middle of the disc (ρ) to the pixel from the mask pixel coordinates with respect to the middle of the disc, the projected and corrected areas are calculated as explained in Appendix A. The SOON disc drawings have a radius of 710 pixels, which corresponds to a pixel size of 1.3 arcsec and a corrected area of 0.3 μHem at the middle of the disc (i.e. for $\rho = 0°$). The smallest sunspots in the SOON drawings occupy between 6 and 10 pixels and thus have an area of 2 or 3 μHem. The final step is simply to add the mask pixel areas for a particular group or for the all the sunspots in the whole disc.

5 AR 12192 GROUP AREA

This group was first seen on 2014 October 18 close to the eastern limb at latitude 12°S as an Fkc type where the follower was the largest penumbral sunspot. On the following day, more of the large irregular follower could be seen which included a main umbra and several smaller sunspots. Its total area was 2800 μHem (based on the Debrecen catalogue). By October 21, AR 12192 became much more complex with many umbrae and several regions of photosphere within the main penumbral sunspot and its area grew to 3250 μHem. Over the next few days, the main penumbral sunspot continued to grow such that on the 24th it obtained its maximum size of 4420 μHem. On the 26th, the main sunspot started to split into several penumbral sunspots. This was evident on the 27th when the area had reduced to 3600 μHem. AR 12192 was last seen on October 28. Throughout its passage across the solar disc, AR 12192 remained type Fkc. This was the largest sunspot group of Cycle 24 (Meadows, Smith & Cook 2019). The group returned on the next rotation, as AR 12209, between November 14 and 26 still of type Fkc for most of its passage across the disc but with a reduced maximum passage size of 1690 μHem.

Fig. 4 shows AR 12192 on October 24 based on the disc drawing from the SOON Holloman Solar Observatory, the Mt Wilson Observatory, and the Solar Dynamics Observatory (SDO) satellite. Note that the Mt Wilson drawing is made using a 40-cm disc diameter. The time-span between the three images is just over 2 h and all three are shown with the same scale. There is a good correspondence between them including structure, outline of the penumbrae, the position and size of the umbrae and the presence of pores at the leading (west) part of the group (although they appear slightly larger in the Holloman drawing than in the Mt Wilson drawing and the SDO image).

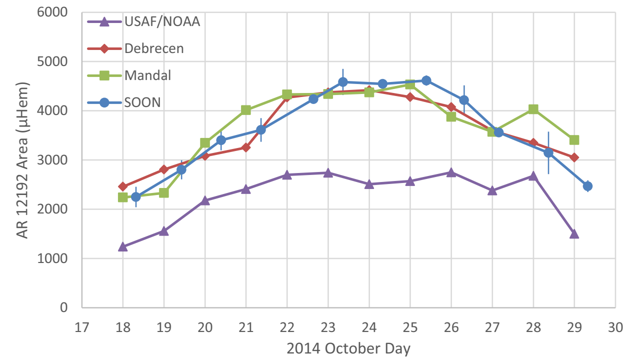

Figure 5. Daily area of AR 12192 during 2014 October.

Table 2. Daily SOON area for AR 12192 between 2014 October 18 and 29 and ratio with USAF/NOAA, Debrecen, and Mandal areas.

Day	SOON (μHem)	SOON/ USAF	SOON/ Debrecen	SOON/ Mandal
18	2250	1.81	0.92	1.00
19	2802	1.80	1.00	1.20
20	3404	1.56	1.10	1.02
21	3611	1.50	1.11	0.90
22	4239	1.57	0.99	0.98
23	4586	1.67	1.05	1.06
24	4549	1.81	1.03	1.04
25	4616	1.80	1.08	1.02
26	4218	1.53	1.03	1.09
27	3558	1.49	0.99	1.00
28	3146	1.17	0.94	0.78
29	2470	1.65	0.81	0.73
		1.61 ± 0.19	1.00 ± 0.09	0.98 ± 0.13

The area of AR 12192 from October 18 to 29 has been calculated using the pixel mask approach described above for the Learmonth, San Vito, and Holloman SOON sites (31 drawings). The average daily area is shown in Fig. 5 (referred to as the SOON area) together with the areas from the USAF/NOAA SRS reports, the Debrecen Catalogue and the Mandal Catalogue. There is very good agreement in area between the SOON, Debrecen, and Mandal areas as also indicated in Table 2. The USAF/NOAA areas are underestimated by a factor of 1.6 (cf. 1.7 from Fig. 3).

6 DAILY TOTAL AREAS

Table 3 gives the remeasured average daily area from Learmonth, San Vito, and Holloman disc drawings from 2014 October and November (164 drawings). During this period drawings were available from all three observatories on 43 d, from two observatories on 17 d and from one observatory on one day (October 22). The days with the largest SOON error bars (the standard deviation of the SOON areas for the same day) occur where a large sunspot group is rotating on or off the disc.

The Debrecen and Mandal catalogues also give daily sunspot areas. These have been compared with the remeasured average daily areas

Table 3. Average daily SOON area during 2014 October and November.

Day	October SOON Area (μHem)	November SOON Area (μHem)
1	1364 ± 125	304 ± 48
2	693 ± 258	511 ± 104
3	536 ± 62	536 ± 161
4	594 ± 55	564 ± 84
5	440 ± 52	962 ± 81
6	485 ± 40	976 ± 82
7	454 ± 105	765 ± 73
8	646 ± 46	810 ± 179
9	712 ± 135	735 ± 115
10	651 ± 24	667 ± 121
11	521 ± 55	704 ± 53
12	620 ± 140	745 ± 28
13	607 ± 105	898 ± 124
14	623 ± 96	1818 ± 452
15	651 ± 21	1823 ± 86
16	606 ± 35	1790 ± 79
17	1146 ± 613	1663 ± 18
18	2796 ± 181	1665 ± 41
19	3394 ± 191	1475 ± 28
20	3975 ± 357	2278 ± 162
21	4175 ± 304	2358 ± 112
22	4896	2375 ± 147
23	5305 ± 362	2263 ± 108
24	5085 ± 60	2558 ± 309
25	5073 ± 11	2269 ± 277
26	4633 ± 301	1624 ± 222
27	3812 ± 118	1822 ± 563
28	3394 ± 512	1888 ± 485
29	2635 ± 281	2063 ± 76
30	715 ± 527	2066 ± 435
31	232 ± 16	

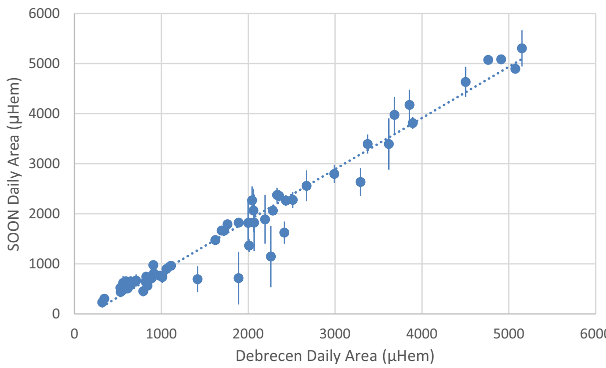

Figure 6. Comparison between the remeasured SSON and Debrecen daily areas for 2014 October and November.

as shown in Figs 6 and 7 with linear regression parameters given in Table 4. As with the remeasured areas for AR 12192, there is good agreement with the daily Debrecen and Mandal catalogues areas.

7 CONCLUSIONS

This paper has shown that by using a sunspot mask and pixel-by-pixel calculation of sunspot area, the areas measured from SOON disc drawings are comparable to the areas given in the Debrecen and Mandal catalogues. Thus, the source of the long-standing underestimate of the USAF/NOAA sunspot areas is only related to the measurement approach.

It is recommended that USAF/NOAA and the SOON observatories update their sunspot area procedures to that used here by developing a software tool. Such a tool would also replace the need for the manual use of Stonyhurst discs for heliographic latitude and longitude measurement. It is suggested that the time to determine the inputs for the SRS reports using scanned SOON disc drawings and a software tool would not be any longer than the current manual approach.

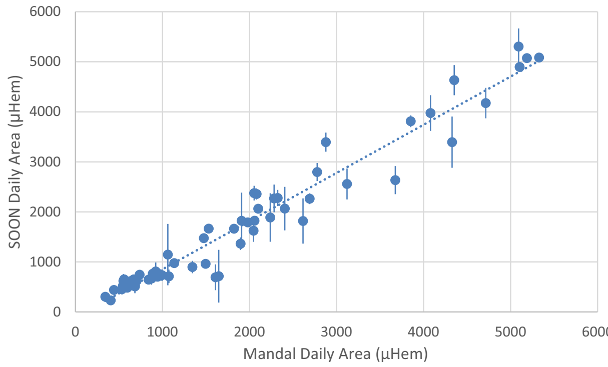

Figure 7. Comparison between the remeasured SSON and Mandal daily areas for 2014 October and November.

Table 4. Linear fit parameters for USAF/NOAA versus Debrecen and Mandal catalogues.

	Gradiant	Intercept	R^2
Debrecen	1.02 ± 0.03	−179 ± 63	0.96
Mandal	0.96 ± 0.03	−108 ± 66	0.95

ACKNOWLEDGEMENTS

The referee is thanked for useful comments. This paper includes data from the synoptic program at the 150-Foot Solar Tower of the Mt. Wilson Observatory. The Mt. Wilson 150-Foot Solar Tower is operated by UCLA, with funding from NASA, ONR, and NSF, under agreement with the Mt. Wilson Institute. The Solar Dynamics Observatory (SDO) Helioseismic and Magnetic Imager (HMI) Continuum image is Courtesy of NASA/SDO and the HMI science team. The NOAA National Centers for Environmental Information is thanked for providing the SOON sunspot drawing archive.

DATA AVAILABILITY

The data underlying this paper will be shared on reasonable request to the corresponding author.

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APPENDIX A: PROJECTED AND CORRECTED SUNSPOT AREAS

Sunspot databases, such as the Debrecen and Mandal catalogues, give two types of sunspot areas: projected and corrected. The projected area assumes the Sun is a disc of area πR^2 with the area of a sunspot group expressed in millionths of the disc area (R being the radius of the drawing). The corrected area has two components: (i) the surface area of a hemisphere of the Sun and (ii) a correction for foreshortening away from the middle of the drawing. This area is expressed in millionths of the Sun's visible hemisphere (μHem) and thus is given by $2\pi R^2/\cos(\rho)$ where ρ is the angle from the middle of the drawing to the sunspot as viewed from the centre of the Sun (i.e. along the surface of the Sun). The angle ρ is given by $\sin^{-1}(\rho_1/\mathrm{S}) - \rho_1$ where ρ_1 is the angle from the middle of the disc to the sunspot as viewed from Earth and S is the apparent angular radius of the Sun (in degrees). The angle ρ_1 is given by $\mathrm{S}(r/R)$ where r is the distance of the sunspot from the middle of the drawing in the same units as R, the drawing radius – see Smart (1971) and Duffett-Smith (1988).

The USAF AFWAMAN 15-1 document and Giersch et al. (2018) give an approximation to $\cos(\rho)$ of $\sqrt{(1-(r/R)^2)}$. This overestimates the sunspot area near the solar limb by 0.9 per cent for r/R of 0.90, 1.3 per cent for r/R of 0.95 and 3.2 per cent for r/R of 0.99.

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