The measurement of sunspot area

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This paper explains various methods for measuring sunspot area and gives results obtained from the author's own disk drawings to show that sunspot area can be used to illustrate the development of sunspot groups. The paper also shows that long term trends in sunspot areas can be derived to complement other white light observer-derived measures of solar activity.

Introduction

For white light solar observers there are a variety of quantities that can be determined or measured. These include the number of active areas, the sunspot number and the quality factor.[1] The former two quantities are determined daily by contributors to the BAA Solar Section, while monthly averaged values of all three quantities are determined by solar contributors to *The Astronomer* magazine.[2] For those solar observers who obtain white light images of the Sun via disk drawings, photographs or via electronic devices such as CCDs, there is a further quantity that can be measured - sunspot area. Unlike quantities such as sunspot number, sunspot area is a physical property of the solar photosphere.

Warning: never look at the Sun with the naked eye or with any optical instrument unless you are familiar with safe solar observing methods.

Sunspot area

The area of a sunspot, or any other feature on the surface of the Sun, is usually expressed in millionths of the Sun's visible hemisphere. Thus, if a sunspot occupies 0.1% of the Sun's visible hemisphere, it would have an area of 1000 millionths. The expression to calculate sunspot area, A_M, including the correction for foreshortening, from an image or drawing is given by:

$$A_M \pm A_S 10^6 / 2\pi R^2 \cos(\rho) = 2A_S 10^6 / \pi D^2 \cos(\rho)$$

where A_S is the measured size of a sunspot in the image, R and D are the radius and diameter of the image respectively and ρ is the angular distance on the surface of the Sun from the centre of the disk to the sunspot. The sunspot size can be measured using a square grid by placing the grid over a sunspot and counting the number of squares covering it (both the umbra and surrounding penumbra).

In the case of a sunspot group, the area of all sunspots within the group will need to be calculated. For a given solar image diameter and grid size, the above expression can be simplified to:

$$A_M = A_F n / \cos(\rho)$$

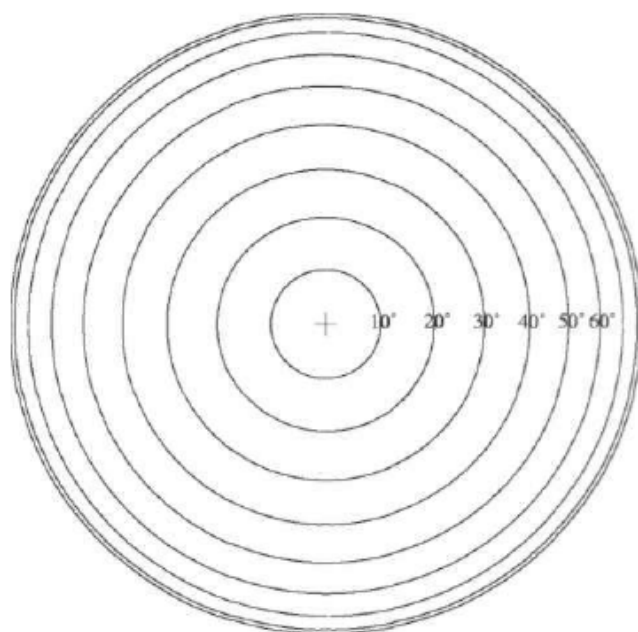where A_F is a factor that depends on the diameter of the solar

Figure 1. An example ρ chart.

image and the grid size used and η is the number of grid squares covering the sunspot. Table 1 gives values for A_F for various disk diameters and grid sizes. For example, with a disk diameter of 150mm and all the sunspots in a group covering ten 1mm by 1mm grid squares (i.e. $A_F = 28.3$ and n = 10) and assuming all the spots in the group have an angular distance from the centre of the Sun of 27.5°, then the corrected area is 320 millionths of the Sun's visible hemisphere.

Graphical methods to calculate ρ

To calculate the sunspot area it is necessary to determine the angular distance of a sunspot from the centre of the Sun (i.e. angle ρ). Two graphical methods are now described to calculate this angle. The first uses a ρ chart while the second uses Stonyhurst disks.

It is possible to construct a chart that gives ρ as a function of distance from the centre of an image or drawing. Figure 1 shows an example ρ chart with intervals of 10°. Placing the chart of the correct diameter over the image enables ρ to be determined and used in the above equations.
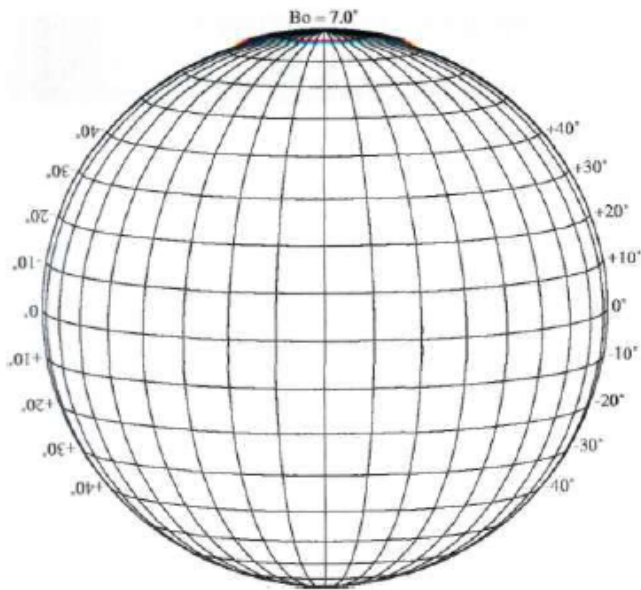
Figure 2. An example Stonyhurst disk (for Bo = +7.0° and -7.0°).

Stonyhurst disks are used to determine the heliographic latitude and longitude of a solar feature and are usually available in a set of 8 covering, in steps of 1°, the range of heliographic latitudes of the centre of the solar disk (Bo). Bo varies from -7.25° to 7.25° during a year due to the solar equator being inclined to the ecliptic by 7.25°. Figure 2 gives example Stonyhurst disks for heliographic latitudes of the centre of the disk (Bo) of +7.0° and -7.0°. They are used by placing the disk, with the nearest Bo value to that of the observation, on the image and rotating the top of the Stonyhurst disk so that it is aligned with the north end of the solar axis of rotation (as given by the position angle P). The latitude scale to the right gives the latitude of a sunspot (B). The longitude difference from centre of the disk (ΔL) can be measured and with the heliographic longitude of the centre of the disk (Lo), the longitude of a spot (L) can be calculated (L = Lo - ΔL when AL is positive for sunspots to the east of the central meridian). The latitude and longitude difference of a sunspot can then be used to calculate ρ from the following expression:

$$\text{Cos}(\rho) \quad = \quad \text{sin(Bo)sin(B)} + \text{cos(Bo)cos(B)cos}(\Delta L)$$

Table I. A_F calculated for some disk diameters and grid sizes

Disk diameter	Grid size	
100 mm	1 x 1 mm	63.7
125 mm	1 x 1 mm	40.7
150 mm	1 x 1 mm	28.3
4 inch	1/25 x 1/25 inch	63.7
5 inch	1/25 x 1/25 inch	40.7
6 inch	1/25 x 1/25 inch	28.3

or by the following approximation given that Bo is small:

$$\text{Cos}(\rho) \quad \approx \quad \text{cos(B)cos}(\Delta L)$$

The accuracy of the approximation depends on the values of Bo and the heliographic latitude and longitude of the sunspot.

The ρ chart approach is the simpler of the two graphical methods and it can be used even when the orientation of the image is not known.

Software method to calculate ρ

In order to improve the accuracy and reduce the time taken to calculate sunspot areas, the author has written a free-ware Windows program, *Helio*,[3,4] as shown in Figure 3. The observer simply inputs the date and time of the observation, sets the disk diameter and orientation and finally inputs the horizontal and vertical position of a sunspot (as shown by the location of the black spot) with respect to the centre of the disk. This gives the heliographic latitude and longitude of the sunspot and, with the size of the sunspot, its area in millionths of the Sun's visible hemisphere. Given the observer's location, the altitude and azimuth of the Sun is displayed together with the other information about the Sun at the time of observation (right ascension, declination, the heliographic parameters Bo, Lo and P together with the solar diameter and Carrington rotation number).

Practical considerations

When measuring the area of a sunspot group it is not practical individually to measure the area of each sunspot within the group. In this case, the location of the centre of the group is used together with the size of all the sunspots in the group to give the group area. The only exception to this is when the longitudinal extent of the group is particularly large. Then the group can be separated into segments and the area of each segment calculated before adding these to obtain the group area.

One problem encountered when using small disk diameters are measurement inaccuracies towards the disk limb due to foreshortening. Any slight inaccuracy in the location of the sunspot will have a far greater impact on sunspot area
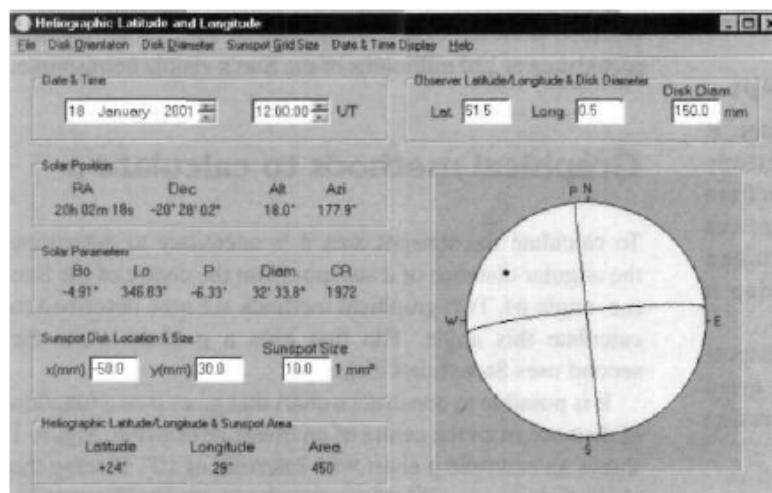

Figure 3. The *Helio* v2.0 software.

towards the limb than in the centre of the disk. For the standard 152mm (6in) disk diameter, a 1mm inaccuracy in position for a sunspot at the centre of the disk gives a 0.01% area inaccuracy while the same position inaccuracy for a sunspot at 60° from the disk centre gives a 4.98% area inaccuracy. For this reason, it is not recommended that sunspot area be measured for sunspots more than 60° from the disk centre (i.e. for $\rho > 60°$). The *Helio* program shows the sunspot area in red text for $\rho > 60°$ as a warning to the user.

For groups comprising sunspots without any penumbra (types A and B) it is not possible to calculate a sunspot area. For these groups an area of 0 is assigned.

To assist observers, ρ charts and Stonyhurst disks for the various disk diameters together with the two grids given in Table 1 are available from the author's Web site.[3]

Sunspot group development

The measurement of sunspot group area enables the development of the group to be shown. For example, Figure 4 shows the change in area for the large sunspot group seen in September 2000. The group was initially seen as a B type group (bipolar without penumbra) on August 24, as a C type group (bipolar with one main spot with penumbra) on August 25 and 27, as a D type group (bipolar with largest spots having penumbra) between August 28 and 30 and as an E type group (large bipolar at least 10° in longitude) on September 2 before rotating off the solar disk. During this period the group began to grow in size up to 130 millionths of the Sun's visible hemisphere. When next seen on September 20, after reappearing from the averted side of the Sun, the group had increased in size considerably to just over 2000 millionths and was of type F (very large bipolar at least 15° in longitude). As shown in Figure 4, the group then began to decay such that its areas was 1310 millionths of the Sun's visible hemisphere on September 26. The group continued to decay, as on its third rotation it was seen as a single penumbral spot (type J) on 2000 October 15.

Figure 5 shows the development of another larger group over two rotations in March and April 2001. An observation on March 29 showed the large F type group having an area of 2300 millionths near the central meridian. Unlike the large group of 2000 September, which mainly consisted of one large penumbral spot, this group consisted of several large irregular penumbral spots stretching over 20° of longitude. On the next and final rotation, the group had reduced in size.
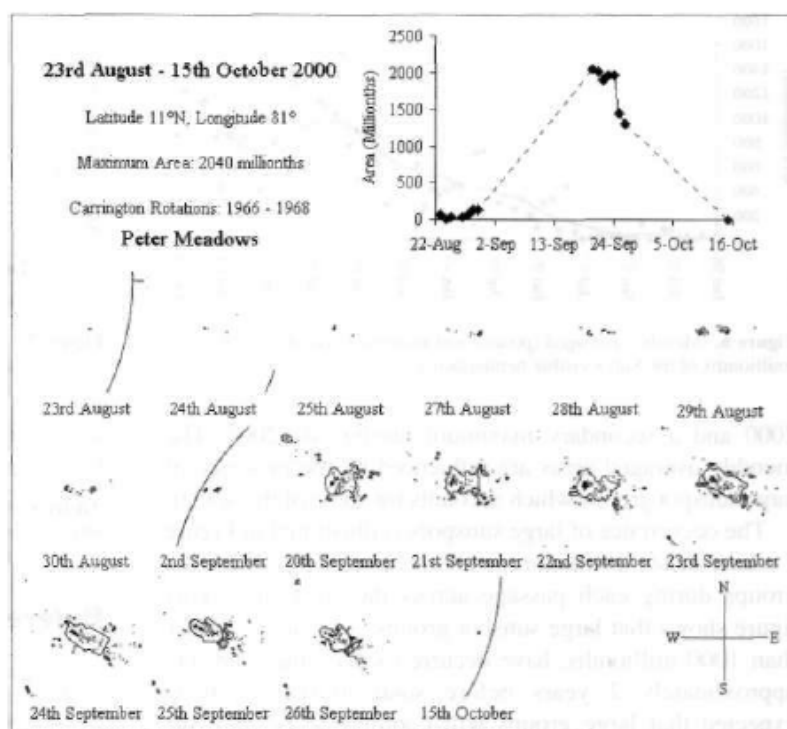

Figure 4. Development of the large sunspot group during August to October 2000 at a mean latitude 11 °N and longitude 81°.

Long term trends

As with the measurement of the number of active areas, the sunspot number and the quality factor, daily and monthly averaged sunspot areas can be calculated. For the daily area, this is achieved by calculating the area of each group and summing over all groups for a particular observation. Similarly, the monthly averaged area is the average of all daily areas during a month. Figure 6 shows the monthly averaged sunspot area and smoothed sunspot area (the running mean over a 13 month period) for the current solar cycle. As expected, the monthly area has increased from solar minimum in 1996 towards solar maximum in early
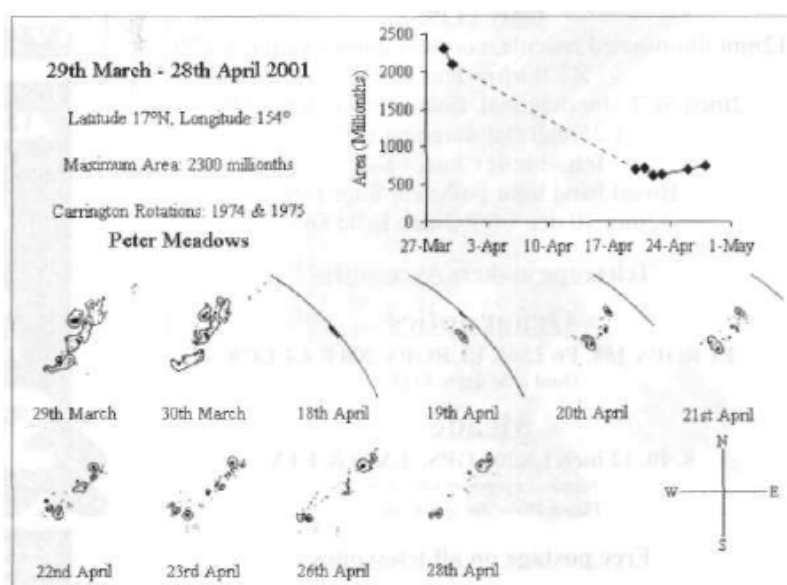

Figure 5. Development of the large sunspot group during March and April 2001 at a mean latitude 17°N and longitude 154°.
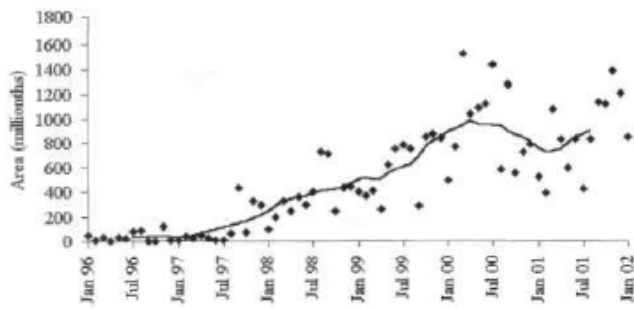
Figure 6. Monthly averaged (points) and smoothed (curve) sunspot area (millionths of the Sun's visible hemisphere).

Figure 7. Maximum sunspot group areas (millionths of the Sun's visible hemisphere).

2000 and a secondary maximum during late 2001. The monthly averaged areas are influenced by the presence of large sunspot groups which accounts for some of the scatter.

The occurrence of large sunspots is illustrated in Figure 7 which shows the maximum area measured for individual groups during each passage across the solar disk. This figure shows that large sunspot groups, with areas greater than 1000 millionths, have occurred since mid-1998, i.e. approximately 2 years before solar maximum. It is expected that large groups will continue to be seen for about 2 years after solar maximum. It will also be interesting, over the remainder of th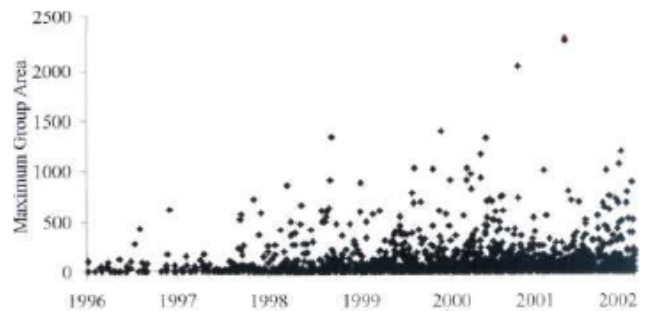is solar cycle, to see if there is any asymmetry in the distribution of the larger groups before and after solar maximum.

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References

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3   Meadows P. J., 'Solar Observing', http://www. meadows3.demon.co.uk
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