Leibniz-Institut für Astrophysik Potsdam

Sunspot group areas, tilt-angles and magnetic-field reconstruction for historical cycles

V. Senthamizh Pavai, Rainer Arlt

Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

Introduction:

The relation between the solar dynamo and surface magnetic fields, polar fields and open flux can be better understood with the long term properties of the sunspots. The magnetic surface flux of the Sun for earlier centuries can be obtained from analysing historical observations of the Sun.

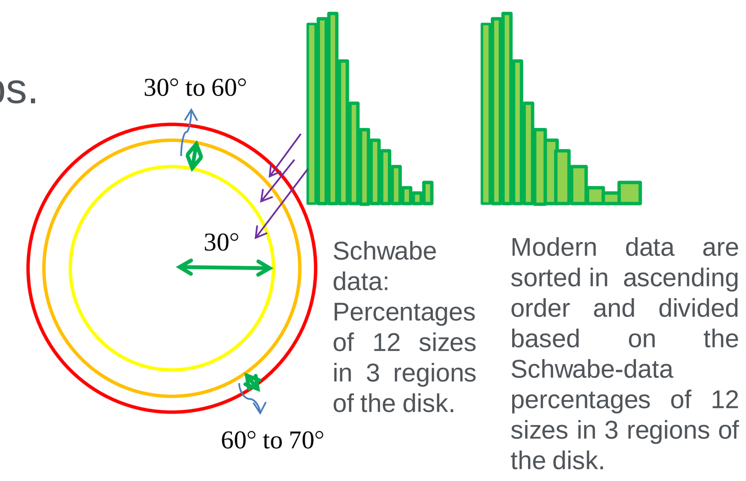
A very long period of observations of the Sun has been recorded as drawings by Samuel Heinrich Schwabe during 1825 – 1867. His observations have been digitized and the positions and sizes of sunspots were measured. The sizes of the sunspots were determined using 12 different circular-shaped cursors. The problem is that the sunspot areas are not drawn to-scale and require a conversion to true areas in km^2 or millionths of a solar hemisphere (MSH).

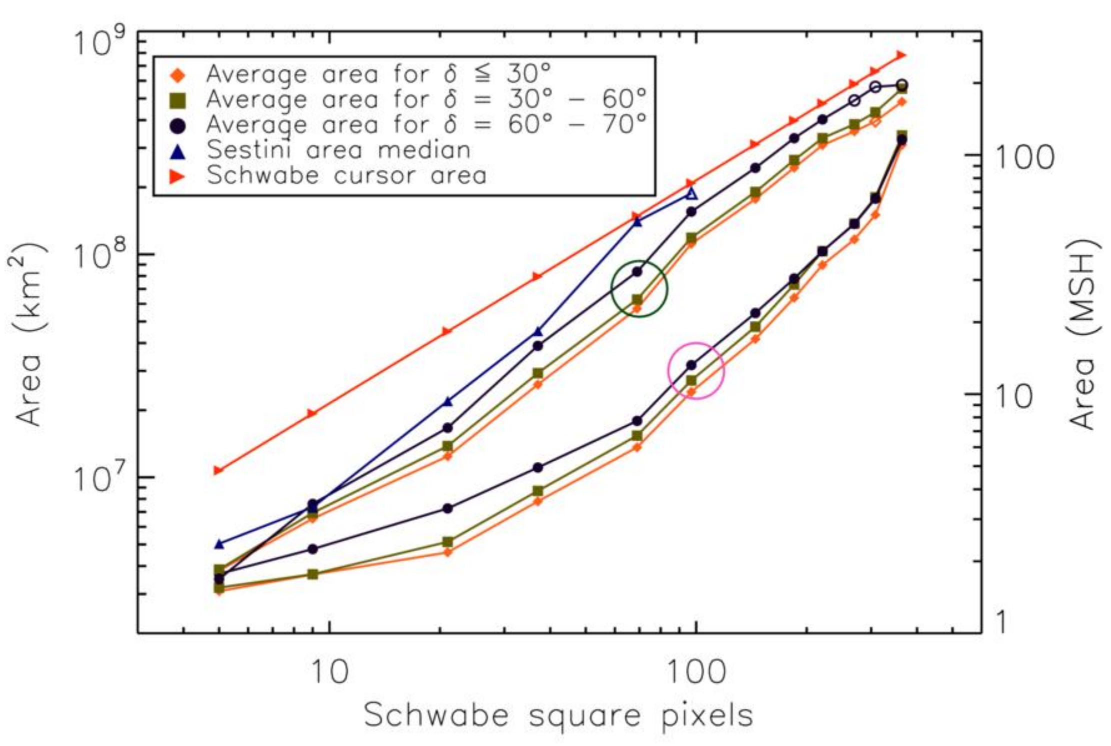
Aims:

- ➢ Estimation of true umbral area values for 12 different sized cursors.
- ➢ Regrouping of sunspot groups.
- ➢ Calculation of tilt angles of the sunspot groups.

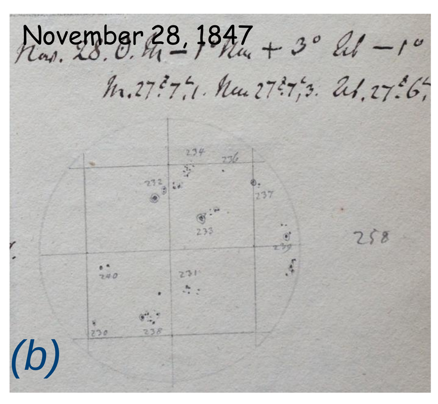
Area Estimation:

To estimate the area of Schwabe size classes, which were used to measure the sunspots, the percentages of 12 sizes in 3 regions of disk-center distances were calculated.

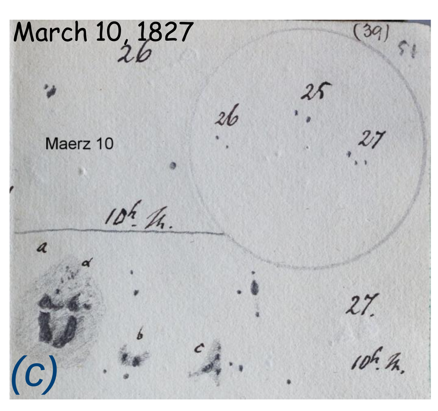




(a)



(b)



(c)

Fig. 1. (a) Average area plots for each size class in three regions of the disk. The curves passing through green circle and pink circle corresponds to the average areas for 1831 – 1867 and 1825 – 1830 repectively. A direct comparison of area values can been seen from the Sestini (1853) average area curve. (b) Schwabe's style of sunpot drawing since 1831 showing penumbrae. (c) Schwabe's style of sunspot drawing before 1831 showing combined penumbrae and umbrae.

Umbral area for 1831 – 1867:

The umbral areas were estimated using Debrecen, Kodaikanal, Mt. Wilson and MDI data. The data were divided on the basis of percentages of 12 sizes in 3 regions and the average of all data sources for each class in each region gives area for 12 sizes.

Umbral area for 1825 – 1830:

Only the Debrecen data was used to estimate the area values. The only difference from the above method is that the Debrecen data was divided on the basis of umbra+penumbra areas and the corresponding umbra area values are considered for size classes. The spots drawn during these years include penumbrae and nearby spots (see in Fig.1(c)).

Area Calculation:

The area is calculated using the equation , $A_i = a_i + b_i / \cos\delta$, where a_i and b_i are the coefficients from a linear fit of areas of i^{th} class and δ is the disk-centre distance of the sunspot.

The comparison of calculated area values with modern data sources can be seen in Table 1. Another comparison of area values with group sunspot number is shown in Fig. 2(a).

Schwabe has assigned number to each group but his definition often contains more than one group. Those groups were split and renamed through manual inspection. Fig 2(b). shows the number of new groups formed in a year normalised with the number of old groups present before regrouping. The average number of spots per group before and after regrouping is shown in Fig. 2(c).

Cycle	Average area per day in a cycle (MSH)					
	Schw.	Debr.	Kod.	Grnw.	Mt.W.	Rome
8	118					
9	93					
10	131					
11						
12				110		
13				127		
14				97		
15			56	135		
16			59	147	48	
17			66	197	57	
18			83	216	68	
19	Taipei		86	256	85	
20	276		66	141	63	222
21		163	91			268
22	MDI	159				210
23	78	130				

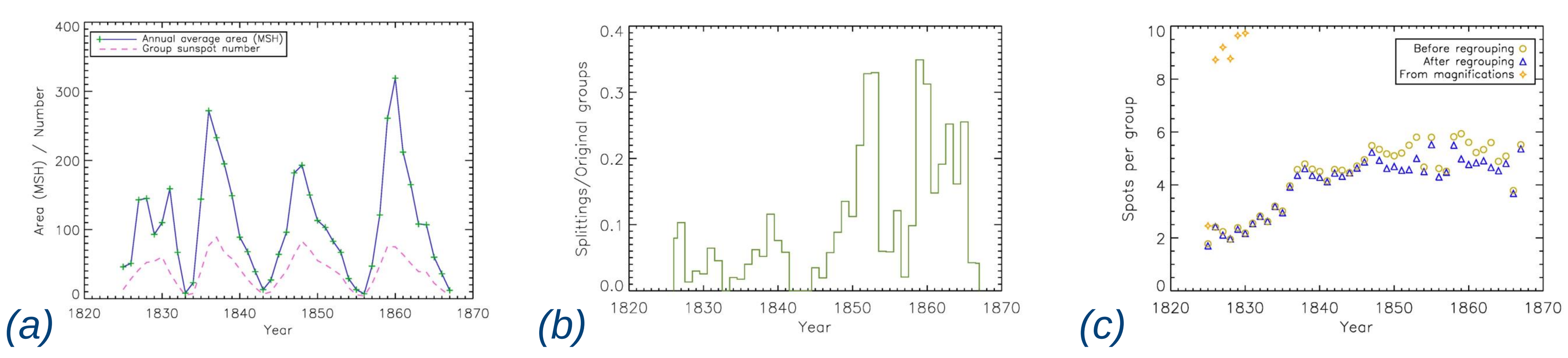


Fig. 2. (a) The annual average of total-disk umbral area of the sunspots and the group sunspot number. (b) The number of new groups defined normalised with the number of groups before regrouping. (c) The average number of spots per group before regrouping, after regrouping and manually calculated from the magnification drawings of sunspot groups. The jump near 1836 cannot be removed.

Tilt angle Calculation:

With the positions and areas of the sunspots, the tilt angles of the sunspot groups can be calculated. The groups were divided into leading and following polarities by finding the lowest positional variance with which it can be divided. Then the tilt angles of the groups were calculated in its tangential planes using the equation, $\theta = \arctan(\Delta P_x / \Delta P_y)$, where ΔP_x and ΔP_y are the differences in x and y device-coordinates of the area-weighted centers of the following and leading polarities. Fig. 4. shows the distribution of tilt angles. The average tilt angle for groups with polarity separation > 3° is 4.25 deg.

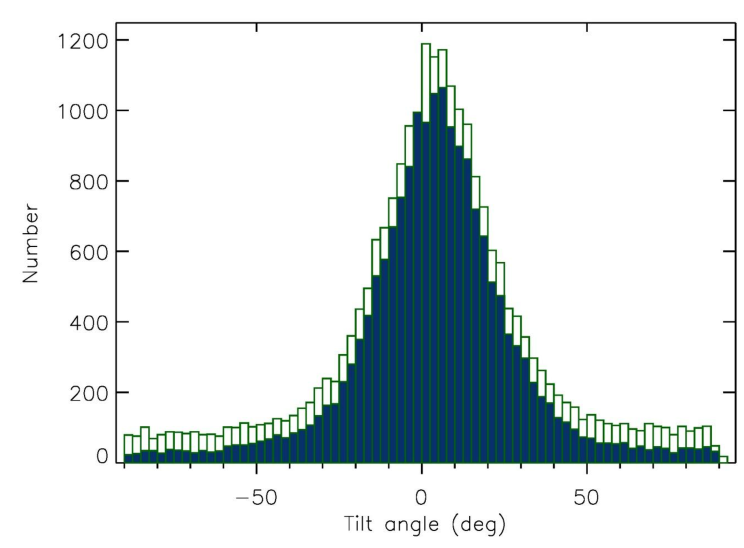
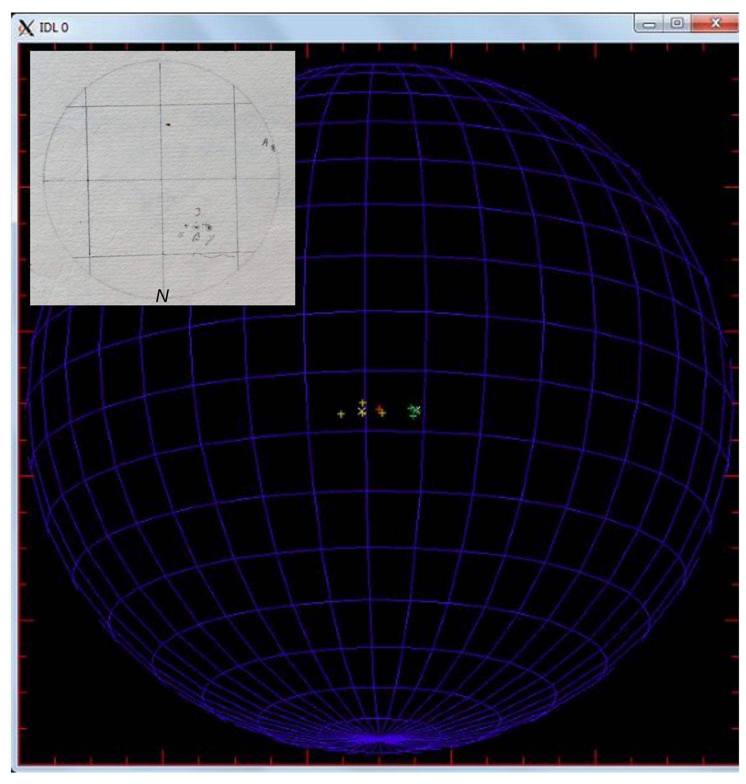


Fig. 4. Histogram of the tilt angles of all groups (open). The filled histogram shows the distribution of tilt angles of groups with polarity separation > 3°.



Conclusion:

- ➢ The area values for 12 Schwabe size classes were estimated through statistical comparison with the modern data sources.
- ➢ The tilt angles of the sunspot groups were calculated.
- ➢ With the positions, areas and tilt angles; we are planning to reconstruct the open-flux of earlier cycles.

Reference:

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