Centuries of Sunspot Observing

We have observed sunspots with telescopes for 400 years

Galileo Galilei

June 23, 1613

Thomas Hariott 1610

Galileo’s Telescope

Sunspots observed by Spacecraft

SOHO

March 29, 2001

January 7, 2005

The sunspot number is always determined using small telescopes

Galileo Galilei

Rudolf Wolf 1816-1893

Wolf’s Telescope

Still used today
The Galilean Telescope

Stopped down because of spherical aberration

Lens is cracked
Technical Details about Galileo’s Telescope

A typical Galilean telescope was configured as follows. It had a plano-convex objective (the lens toward the object) with a focal length of about 30-40 inches, and a plano-concave ocular with a focal length of about 2 inches. The ocular was in a little tube that could be adjusted for focusing. The objective lens was stopped down to an aperture of 0.5 to 1 inch, and the field of view was about 15 arc-minutes (about 15 inches in 100 yards). The instrument's magnification was 15-20. The glass was full of little bubbles and had a greenish tinge (caused by the iron content of the glass); the shape of the lenses was reasonable good near their centers but poor near the periphery (hence the restricted aperture); the polish was rather poor.
The Sunspot Number ~1856

- Wolf Number = $k_w (10^* G + S)$
- $G =$ number of groups
- $S =$ number of spots
- $k_w =$ telescope aperture + site seeing + personal factor + learning curve

Rudolf Wolf (1816-1893)
Observed 1849-1893
1849-1855 Bern
1856-1893 Zürich

The breakthrough was that sunspot activity could be quantified.
Principal Actors and Observers

Directors of Zürich Observatory

1825-1980 the Sunspot Number (SSN) was derived mostly from a single observer. Since then, the SSN is determined by SILSO in Brussels [Belgium] as an average of ~60 observers normalized to Cortesi in Locarno.
Wolf initially used 4’ Fraunhofer telescopes with aperture 80 mm [Magn. X64]

Still in use today [by Thomas Friedli] near Bern, continuing the Swiss tradition [under the auspices of the Rudolf Wolf Gesellshaft]

This was the ‘Norm’ Telescope in Zürich
Wolf occasionally [and eventually – from 1860s on - exclusively] used much smaller handheld, portable telescopes [due to frequent travel], leaving the large 80mm telescope for his assistants.

These telescopes also still exist and are still in use today to safeguard the stability of the series.

Wolf estimated that to scale the count using the small telescopes to the 80mm Standard telescope, the count should be multiplied by 1.5 (The k-factor)
Table 2. $k$-factors as a function of seeing for Kandilli Observatory (Atlas et al., 1998)

<table>
<thead>
<tr>
<th>Seeing</th>
<th>1(worst)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5(best)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>244</td>
<td>473</td>
<td>812</td>
<td>682</td>
<td>126</td>
</tr>
<tr>
<td>$k$</td>
<td>0.96</td>
<td>0.95</td>
<td>0.90</td>
<td>0.83</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Douglas Hoyt and Ken Schatten devised the Group Sunspot Number ~1995 as $R_{\text{Group}} = 12 \, G$ using only the number, $G$, of Groups normalized [the 12] to $R_{\text{Wolf}}$.

The rationale was that with the inferior telescopes of the first 250 years of sunspot observations Groups of spots would be easier to count and fewer would be missed.
The Problem: Discordant Sunspot Numbers

Group and Wolf Sunspot Numbers

Hoyt & Schatten, GRL 21, 1994
The Ratio Group/Zürich SSN has Two Significant Discontinuities

At ~1947 (After Max Waldmeier took over) and at 1876-1910 (Greenwich calibration drifting)

As we found problems with the H&S normalization, we (Svalgaard & Schatten) decided to build a new Group Series ‘from scratch’
The SSN Workshops. The Work and Thoughts of Many People

http://ssnworkshop.wikia.com/wiki/Home

Sunspot, NM, 2011
Brussels, BE, 2012
Sunspot, NM, 2012
Tucson, AZ, 2013
Locarno, CH, 2014
Brussels, BE, 2015
A New Approach: The Backbones

Wolfer

Schwabe

1876

1928
For each Backbone we regress each observers group counts for each year against those of the primary observer, and plot the result [left panel]. The slope gives us what factor to multiply the observer’s count by to match the primary’s.

The Backbone is then constructed as the average normalized counts of all observers that are part of the backbone.

The right panel shows a result for the Wolfer Backbone: blue is Wolf’s count [with his small telescope], pink is Wolfer’s count [with the larger telescope], and the orange curve is the blue curve multiplied by the slope.
Harmonizing Schwabe and Wolfer Backbones

- Harmonizing Schwabe and Wolfer Backbones
  - Schwabe scaled by 1.48
  - Wolfer BB

- Reducing Schwabe BB to Wolfer BB
  - \( y = 1.4007x \)
  - \( R^2 = 0.9938 \)

- Group Count Combining Schwabe and Wolfer Backbones
The Modern Backbones

Ms. Hisako Koyama, 小山 ヒサ子 (1916-1997)

Mr. Sergio Cortesi, Locarno.
Combined Backbones back to 1800

The Standard Deviation falls from 30% in 1800 to a rather constant 8% from 1835 onwards.

By choosing the middle Wolfer Backbone as the reference, we minimize ‘daisy chaining’ errors.
In 1940s Waldmeier in Zürich began to ‘weight’ larger spots and count them more than once. When the auxiliary station ‘Locarno’ became operational in 1957 they adopted the same counting rules as Zürich and continue to this day.

Weighting Rules: “A spot like a fine point is counted as one spot; a larger spot, but still without penumbra, gets the statistical weight 2, a smallish spot with penumbra gets 3, and a larger one gets 5.” Presumably there would be spots with weight 4, too.

When the auxiliary station ‘Locarno’ became operational in 1957 they adopted the same counting rules as Zürich and continue to this day.
The Effect of the Weighting can even be seen in Rumrill’s Observations

Fig. 35 Ratio of monthly means $R_Z/(\text{Rumrill SSN})$. Data taken with small telescopes are plotted as small “+” symbols

Space Science Reviews, 5 Aug, 2014
DOI 10.1007/s11214-014-0074-2

Revisiting the Sunspot Number: A 400-Year Perspective on the Solar Cycle
Frédéric Clette · Leif Svalgaard · José M. Vaquero · Edward W. Cliver
J.C. Staudach’s Drawings 1749-1799

Wolf undercounted the number of groups on the Staudach drawings by 25%. We use my re-count in building the backbone (see later).
How do we combine the Staudach and Schwabe Backbones?

Examine the data for the decades surrounding the year 1800. It becomes evident that the group counts reported by the observers during that interval separate into two categories: ‘low count’ observers and ‘high count’ observers. It is tempting to lump together all observers in each category into two ‘typical observers’ for the now overlapping categories.

And now we can regress one category against the other and scale the low category to the high category, which now overlaps sufficiently with the Schwabe Backbone.
‘Brightest Star Method’

In Edwin Hubble’s (1929) landmark paper showing the galaxy velocity-distance relation he used, of necessity, the brightest star in nebulae and the brightest galaxy in clusters as distance indicators, calibrated against the few nebulae whose distance could be ascertained by more reliable methods. We could apply the same procedure here and use the **highest group count** in each year by *any* observer as a rough indicator of solar activity (which still needs to be suitably calibrated)

This may be our only way of assessing the data before ~1730
We now find the reduction factor that will best match the backbones (red curves) that we have established. For the time before 1800 that factor is 0.88 and we apply it all the way back to 1610 having no other purely solar data. R. Muscheler 14C Cosmic Ray Proxy provides some support for the calibration.
Hoyt & Schatten used the Group Count from RGO [Royal Greenwich Observatory] as their Normalization Backbone. Why don’t we?

Because there are strong indications that the RGO data is drifting before ~1900. And that is a major reason for the ~1885 change in the level of the H&S Group Sunspot Number.
New series: http://www.sidc.be/silso/home

This is a major (and long-needed) advance.

The result of hard work by many people.

A Topical Issue of ‘Solar Physics’ is devoted to documenting, discussing, opposing, and criticizing the new series.

We have a SOI of 54 papers as of today.

New SSN = Old SSN / 0.6
Opposition and Rearguard Action

Solar activity has generally been decreasing the last ~3000 years.

The non-existing Grand Modern Maximum is not based on 14C, but on the flawed H & S Group Number reconstruction and is not seen in 10Be data.

Muscheler (thin red line) and Usokin’s (black line) 14C values are aligned.

Usoskin 2014 from 14C

‘14C’ Earlier version

"Highest in 10,000 years"
Conclusions from SSN Workshops

• Both the International Sunspot Number and the Group Sunspot Number had serious errors
• Correcting the errors reconciles the two series and new sunspot series have been constructed
• The new pure solar series are confirmed by the geomagnetic records and by the cosmic ray records
• There is no Grand Modern Maximum, rather several similar maxima about 120 years apart
• There is still much more work to be done, and a mechanism has been put in place for updating the sunspot record as needed
Where is the Weak Link in the Above Conclusions?

It is here: the **Staudach Backbone** is ‘floating’ and is not firmly calibrated to link up with the neighboring Schwabe Backbone.
Counting Groups on Staudach’s Drawings

Wolf’s Groups
Modern (i.e. My) Count

Groups on Staudach’s Drawings

Wolf
Svalgaard
We are Hostages to the Drawings

The drawings are today stored in the library of the Astrophysikalisches Institut Potsdam, Germany, and are in very good condition. Arlt (2008) has recently photographed the drawings, one by one. Arlt also draws some inference about the telescope used by Staudach. In the material there is a single mention of a telescope (18 February 1775: “when I turned round with my 3-foot sky tube…”) hence we may assume that the focal length of the telescope was 3 feet. Achromatic telescopes with a focal length of 92 cm were manufactured by John and Peter Dollond from the late 1750s. With such a telescope, however, the distinction between umbra and penumbra should have been possible, and the Wilson effect (elongated spots near the limb) should have been visible. Both were not noted and not drawn by Staudach (using projection onto a sheet of paper).

An average telescope used by an amateur at the time probably suffered from fairly strong spherical aberration. Because of a couple of mirrored solar-eclipse drawings, Arlt (2008) suggests that Staudach was using a Keplerian refractor with a non-achromatic objective and that he most likely missed all the tiny A and B spot groups (according to the Waldmeier (1938) classification). Such groups make up 30-50% of all groups seen today. To convert a group count without A and B groups to a full count of groups of all classes, one must thus multiply by 1.65, which incidentally is the same factor it takes to reduce the group count obtained by Wolf using his small, but superb, 2½-foot Fraunhofer refractor to the count by his successor Wolfer, using the 4-foot norm-telescope. Taking into account that Staudach’s telescope likely suffered from both spherical and chromatic aberration, the actual factor is likely to be somewhat larger. But we don’t know how much larger, and that is the problem...


Groups of Class A or B

<table>
<thead>
<tr>
<th>A</th>
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<tbody>
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<td>B</td>
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<td>H</td>
<td></td>
<td></td>
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<tr>
<td>J</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What would Staudach have drawn?

No. 208
2015. X 6.585
09:15 T.U.
Osservatore: S. Cortesi
Immagini: 3, 800, 3 brevi schiele

specola solare ticinese
locarno monti

L = 338.1
B = 46.5
pC = 26.5

What would Staudach have drawn?
The Plan

- Find telescopes (from the 18th century if possible) with similar characteristics as Staudach’s
- Find people willing to observe, i.e. make drawings of what they see (high precision of positions not needed)
- Make systematic observations over some time (months) perhaps one drawing per week
- If we can find several people, they can share the load (and also make it possible to assess the ‘error bar’)
- Scan the drawings and communicate them to me (leif@leif.org). Website: http://www.leif.org/research
- I’ll process the drawings and produce a scientific paper with the observers as co-authors publishing the result
- Benefits: Exposure of ATS and providing an important calibration point for the Sunspot Series (real science)
Perhaps something like this

(b) 1957-10-07 09:23  1957-10-08 11:05  1957-10-09 12:34  1957-10-10 12:41  1957-10-11 09:18  1957-10-12 10:03
(c) 1975-02-04 09:30  1975-02-05 13:43  1975-02-06 09:50  1975-02-07 09:50  1975-02-08 14:42  1975-02-09 09:15
Any Takers?

• Thanks to Bart Fried for inviting me and serving as an interface to ATS
• And to John Koester for photocopying Rumrill’s notebooks
• Questions or Comments?
The new sunspot series - a reconstruction and a project.

Abstract

We have reconstructed the sunspot group count, not by comparisons with other reconstructions and correcting those where they were deemed to be deficient, but by a reassessment of original sources. The resulting series is a pure solar index and does not rely on input from other proxies, e.g. radionuclides, auroral sightings, or geomagnetic records. “Backboning” the data sets, our chosen method, provides substance and rigidity by using long-time observers as a stiffness character. Solar activity, as defined by the Number of sunspot groups, appears to reach and sustain for extended intervals of time the same level in each of the last three centuries since 1700 and the past several decades do not seem to have been exceptionally active, contrary to what is often claimed in support of a large solar role in Global Warming.

The data for the 18th century rely to a large extent on the observations of a German amateur astronomer, Johann Caspar Staudach, who made 1130 drawings of the sun during 1749-1799. The drawings still exist and the number of groups and spots can be determined from the drawings. The drawings were made using a helioscope (the helioscope for observing sunspots was first used by Galileo’s student Benedetto Castelli (1578-1643). The method involves projecting a telescopic image of the sun onto a white sheet of paper in a darkened room). . In the material there is a single mention of a telescope (18 February 1775: “when I turned round with my 3-foot sky tube…”) hence we may assume that the focal length of the telescope was 3 feet. Achromatic telescopes with a focal length of 92 cm were manufactured by John and Peter Dollond from the late 1750s. With such a telescope, however, the distinction between umbra and penumbra should have been possible, and the Wilson effect should have been visible. Both were not noted by Staudach and were not clearly present. An average telescope used by an amateur at the time probably suffered from fairly strong spherical aberration. Because of a couple of mirrored solar-eclipse drawings we suggest that Staudach was using a Keplerian refractor with a non-achromatic objective and that he most likely missed all the A and B spot groups (small groups of spots with no penumbra). Such groups make up 30-50% of all groups seen today. To convert a group count without A and B groups to a full count of groups of all classes, one must thus multiply by 1.65, which incidentally is the same factor it takes to reduce the group count obtained by Wolf using his small, but superb, 2½-foot Fraunhofer refractor to the count by his successor Wolfer, using the 4-foot norm-refractor. Taking into account that Staudach’s telescope likely suffered from both spherical and chromatic aberration, the actual factor is likely to be somewhat larger. We don’t know how much larger, but if a series of drawings be made today with a telescope similar to Staudach’s we might be able to get a better estimate of the factor. As Staudach was an amateur it is important that the modern series also be made by non-professionals.

I propose that a project be started to accomplish this.