Building a Sunspot Group Number Backbone Series

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Why a Backbone? And What is it?

Building a long time series from observations made over time by several observers can be done in two ways:

• Daisy-chaining: successively joining observers to the ‘end’ of the series, based on overlap with the series as it extends so far [accumulates errors]

• Back-boning: find a primary observer for a certain [long] interval and normalize all other observers individually to the primary based on overlap with only the primary [no accumulation of errors]

When several backbones have been constructed we can join [daisy-chain] the backbones. Each backbone can be improved individually without impacting other backbones.
The Backbones

- SIDC Backbone [????-2013]
- Waldmeier Backbone [????-????]
- Wolfer Backbone [1841-1945]
- Schwabe Backbone [1794-1883]
- Staudach Backbone [????-????]
- Earlier Backbone(s) [1610-????]
Sources of Data

• The primary source is the very valuable tabulations by Hoyt and Schatten of the ‘raw’ count of groups by several hundred observers

• In some cases [especially Wolf and Schwabe] data has been re-entered and re-checked from Wolf’s published lists, as some discrepancies have been found with the H&S list
Alfred Wolfer observed 1876-1928 with the ‘standard’ 80 mm telescope. Rudolf Wolf from 1860 on mainly used smaller 37 mm telescope(s) so those observations are used for the Wolfer Backbone.
Normalization Procedure, I

What we do not do:

- Compare only days when both observers actually observed. This is problematic when observations are sparse as during the early years.
- Compare only days when both observers actually recorded at least one group. This is clearly wrong as it will bias towards higher activity.

What we do:

- We compute, for each observer, the monthly mean of actual observations [including days when it was indeed observed that there were no groups].
- We compute, for each observer and for each year, the yearly mean of the average counts for months with at least one observation.
For each Backbone we regress each observer’s group counts for each year against those of the primary observer, and plot the result [left panel]. Experience shows that the regression line almost always very nearly goes through the origin, so we force it to do that and calculate the slope and various statistics, such as $1-\sigma$ uncertainty and the $F$-value. The slope gives us what factor to multiply the observer’s count by to match the primary’s. 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. It is clear that the harmonization works well [at least for Wolf vs. Wolfer].
Schmidt, Winkler

Number of Groups: Wolfer vs. Schmidt

Yearly Means 1876-1883

Wolfer = 1.311±0.035 Winkler
R² = 0.9753

F = 2062

Wolfer

Schmidt

Number of Groups: Wolfer vs. Schmidt

Wolfer = 1.313±0.029 Schmidt
R² = 0.9971

F = 1241

Wolfer

Schmidt

Number of Groups: Wolfer vs. Winkler

Yearly Means 1882-1910

Wolfer = 1.311±0.035 Winkler
R² = 0.9753

F = 2062

Wolfer

Winkler
Weber, Spörer

Number of Groups: Wolfer vs. Weber

Wolfer = 1.510±0.145 Weber
$R^2 = 0.9476$

Wolfer
Weber
$F = 109$

Number of Groups: Wolfer vs. Spörer

Wolfer = 1.416±0.145 Spörer
$R^2 = 0.9504$

Wolfer
Spörer
$F = 347$
Tacchini, Quimby

**Number of Groups: Wolfer vs. Tacchini**

- Wolfer: Yearly Means 1876-1900
- Wolfer = 1.130±0.030 Tacchini
- \( R^2 = 0.9835 \)
- \( F = 1379 \)

**Number of Groups: Wolfer vs. Quimby**

- Wolfer: Yearly Means 1889-1921
- Wolfer = 1.284±0.034 Quimby
- \( R^2 = 0.9771 \)
- \( F = 1352 \)
Broger, Leppig

**Number of Groups: Wolfer vs. Broger**

Wolfer = 1.016±0.018 Broger  
$R^2 = 0.99$  
$F = 3003$

**Number of Groups: Wolfer vs. Leppig**

Wolfer = 1.264±0.041 Leppig  
$R^2 = 0.9956$  
$F = 953$
Konkoly, Mt. Holyoke

Number of Groups: Wolfer vs. Konkoly
Yearly Means 1885-1905

Wolfer = 1.562±0.034 Konkoly
$R^2 = 0.9916$

$F = 2225$

Number of Groups: Wolfer vs. Mt. Holyoke
Yearly Means 1885-1905

Wolfer = 1.562±0.034 Konkoly
$R^2 = 0.9916$

$F = 2225$

Etc… Dawson, Guillaume, Bernaerts, Woinoff, Merino, Ricco, Moncalieri, Sykora, Brunner,…
The Wolfer Group Backbone

If we average without weighting by the F-value we get very nearly the same result as the overlay at the left shows.
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

Could this be caused by Wolfer’s count drifting? His $k$-factor for $R_z$ was, in fact, declining slightly the first several years as assistant (seeing fewer spots early on – wrong direction). The group count is less sensitive than the Spot count and there are also the other observers…

José Vaquero found a similar result which he reported at the 2nd Workshop in Brussels.

Sarychev & Roshchina report in Solar Sys. Res. 2009, 43: “There is evidence that the Greenwich values obtained before 1880 and the Hoyt–Schatten series of Rg before 1908 are incorrect”.

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Schwabe received a 50 mm telescope from Fraunhofer in 1826 Jan 22. This telescope was used for the vast majority of full-disk drawings made 1826–1867.

For this backbone we use Wolf’s observations with the large 80mm standard telescope.
Wolf, Shea

Number of Groups: Schwabe vs. Wolf

Schwabe = 0.990±0.008 Wolf
$R^2 = 0.9992$

Number of Groups: Schwabe vs. Shea

Schwabe = 1.284±0.052 Shea
$R^2 = 0.937$

Too good?
Mixing records!

F = 16352

F = 493

Number of Groups 1849-1860

Number of Groups 1847-1865
Schmidt, Carrington

Number of Groups: Schwabe vs. Schmidt

Schwabe = 0.830±0.059 Schmidt
R² = 0.8789

Number of Groups: Schwabe vs. Carrington

Schwabe = 1.017±0.048 Carrington
R² = 0.988
Spörer, Peters

Number of Groups: Schwabe vs. Spörer

Schwabe = 0.867±0.075 Spörer
$R^2 = 0.9619$

Number of Groups: Schwabe vs. Peters

Schwabe = 0.659±0.079 Peters
$R^2 = 0.9411$
Pastorff, Weber

**Number of Groups: Schwabe vs. Pastorff**

Schwabe: Yearly Means 1825-1833

Schwabe = 0.816±0.064 Pastorff

$R^2 = 0.9635$

$F = 158$

**Number of Groups: Schwabe vs. Weber**

Schwabe: Yearly Means 1860-1867

Schwabe = 0.844±0.054 Weber

$R^2 = 0.9746$

$F = 234$


Hussey, Stark

**Number of Groups: Schwabe vs. Hussey**

Schwabe: 0.970±0.083 Hussey  
$R^2 = 0.9114$  
$F = 116$

**Number of Groups: Schwabe vs. Stark**

Schwabe: 0.862±0.044 Stark'  
$R^2 = 0.9324$  
$F = 289$
Tevel, Arago

Number of Groups: Schwabe vs. Tevel

Schwabe = 1.029±0.3 Tevel
\[ R^2 = 0.4807 \]
\[ \frac{\text{Schwabe}}{\text{Tevel}} = 1.007 \]

Number of Groups: Schwabe vs. Arago

Schwabe = 1.56 Arago
\[ R^2 = 0.5427 \]

Number of Groups

Schwabe = 1.029±0.3 Tevel
\[ R^2 = 0.4807 \]
\[ \frac{\text{Schwabe}}{\text{Tevel}} = 1.007 \]

F = 2.3

F = 8.3
Flaugergues, Herschel

Number of Groups: Schwabe vs. Flaugergues

Schwabe

Schwabe = 1.958±0.9 Flaugergues

F = 0.1

Number of Groups

Flaugergues*

1790 1800 1810 1820 1830 1840

Number of Groups: Schwabe vs. Herschel

Schwabe

Schwabe = 0.79 Herschel

F = 2.3

Number of Groups

Herschel*

1790 1800 1810 1820 1830 1840

Etc… Lindener, Schwarzenbrunner, Derfflinger…
The Schwabe Group Backbone

Schwabe Group Backbone

Schwabe Backbone Groups

Weighted by F-value

Number of Observers

Standard Deviation

Comparing Schwabe Backbone with Hoyt & Schatten Group Number

Groups

Schwabe Backbone

H&S Groups

1790 1800 1810 1820 1830 1840 1850 1860 1870 1880 1890

1790 1800 1810 1820 1830 1840 1850 1860 1870 1880 1890
Joining two Backbones

Comparing Schwabe with Wolfer backbones over 1860-1883 we find a normalizing factor of 1.55
Comparison **Backbone** with **GSN** and **WSN**

Sunspot Group Numbers 1790-1945

Heliospheric Magnetic Field at Earth

**Groups = GSN/13.149**

**Groups = WSN/12.174**
How do we Know HMF B?

The IDV-index is the unsigned difference from one day to the next of the Horizontal Component of the geomagnetic field averaged over stations and a suitable time window. The index correlates strongly with HMF B [and not with solar wind speed].
Staudach Observations

Number of Groups: Staudach

Monthly Means 1749-1799
Zucconi, Horrebow

**Number of Groups: Staudach vs. Zucconi**

Staudach Yearly Means 1754-1760

Staudach = 1.070 Zucconi

\[ R^2 = 0.7509 \]

**Number of Groups: Staudach vs. Horrebow**

Staudach Yearly Means 1761-1776

Staudach = 0.551 Horrebow

\[ R^2 = 0.7365 \]