Scale Transfer in 1849: Heinrich Schwabe to Rudolf Wolf

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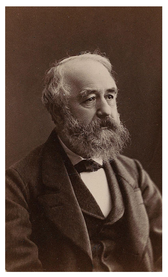
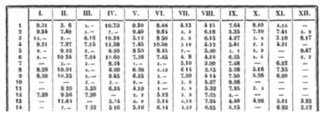
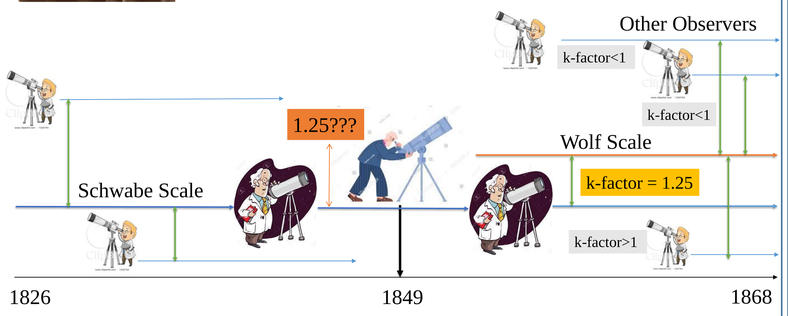
INTRODUCTION



In 1843, Professor **Rudolf Wolf** founded a **journal** called the **"Mittheilungen der Natur-forschenden Gesellschaft** in Berne" where he published yearbooks with all of his findings, including sunspot observations as far back as Galileo (Wolf, 1861).



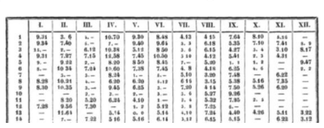


R. **Wolf** started his own **observations** from **1849** and maintained the sunspot series in **his scale ever since**, but **before 1849**, from 1818 to1848, the Sunspot Number series was **scaled to Schwabe's observations (1826-1868)**.
In **1859** Wolf **introduced** the notion of calibration factors or ***k-factors*** (Wolf, 1850) which he used (Clette et al., 2007; Mathieu et al., 2019) to **calibrate** all other observers to **his own observations** scale.

Schwabe's *k-factor* was calculated based on **observations from 1849-1868** when **Wolf received** them to **fill gaps** in his own series. Therefore, it remained **controversial** if this **same k-factor** was suitable for Schwabe's observations for the period **1826-1848** when he was the **primary observer** (Friedli, 2016).

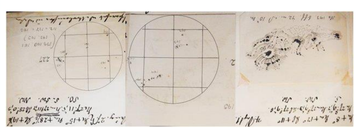
DATA COMPARISONS

We use the following series for our comparison studies:



ID	DATE	GROUPS	SUNSPOTS	WOLF
14219	1861-01-03	4	9	49
14220	1861-01-06	4	5	45
14221	1861-01-18	2	3	23
14222	1861-01-19	2	3	23
14223	1861-01-23	4	8	48
14224	1861-01-26	4	13	53
16767	1861-02-05	3	6	36
16768	1861-02-06	3	9	39
16769	1861-02-07	1	1	11
16770	1861-02-15	6	16	76
16771	1861-02-16	7	16	86

the WDC-SILSO, (Royal Observatory of Belgium) conducted a mission between 2017 and 2019 to digitize all the data contained in the published *Mittheilungen*. We call Schwabe's data from **1826-1848 – SCP1** and data from **1849-1868 – SCP2.**



Arlt et al.,2013 **(A2013)**

ID	DATE	GROUPS	SUNSPOTS	WOLF
14219	1861-01-03	4	9	49
14220	1861-01-06	4	5	45
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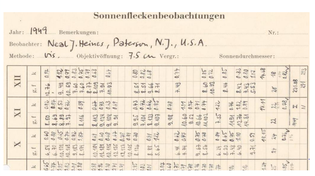
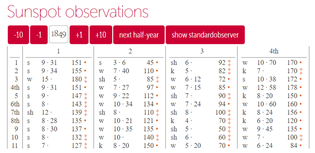
Arlt et al. (2013) provides a detailed record on Schwabe's drawings including sunspots' positions and sizes. They analyzed about 135 000 sunspots on Schwabe's drawings.



Thomas Friedli **(SSB)**



Wolf's own handwritten records on loose (unbinded) pages were recovered at the ETH Library in Zürich in 2015. We call them the "Source Books" and they were digitized by Thomas Friedli (Friedli, 2016) on the period from 1849 to 1877. Some of the data Wolf recorded in his Source Books he did not use, and thus might not have had them printed in the *Mittheilungen*

Note: Between 1849-1859, Wolf combined all the observers in the *Mittheilungen* but they can be distinguished in the Source Books.

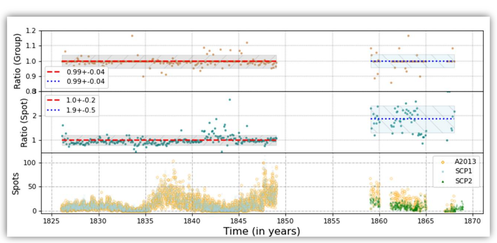


Figure 1: The **upper panel** shows the monthly smoothed ratio of **A2013/SCP1 and A2013/SCP2** for number of **groups**, the **middle panel** shows the same for **spots**. The dashed and dotted lines in both the panels show the mean ratio of the respective timelines and the shaded region corresponds to 1σ standard deviation. The **lower panel** shows **the daily spot counts in A2013, SCP1 and SCP2.**

From Figure 1, it seems the **group numbers** are **identical** between the A2013 and the numbers present in the *Mittheilungen* for Schwabe (SCP1+SCP2). However, **the numbers of spots differ** by almost a **factor of 2** after 1859.

ANALYSES

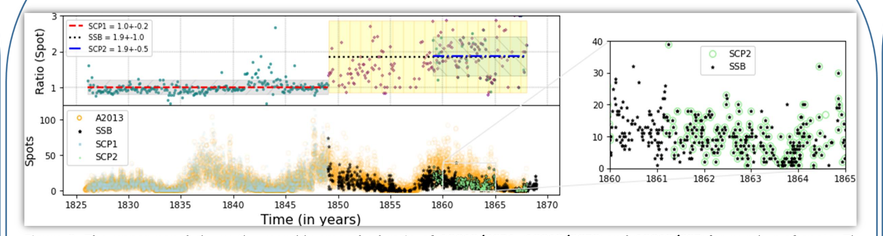
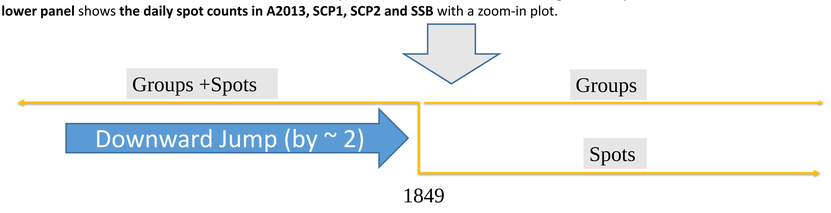


Figure 2: **The upper panel** shows the monthly **smoothed ratio of A2013/SCP1, A2013/SCP2 and A2013/SSB** for number **of spots**. The dashed and dotted lines show the mean ratio of the respective timelines and the shaded region corresponds to 1σ standard deviation. **The lower panel** shows **the daily spot counts in A2013, SCP1, SCP2 and SSB** with a zoom-in plot.



From Figure 2 **zoom-in** plot it is evident that **SCP2 is actually a subset of SSB** found in the Source Books, hence **they are identical.**

In Mittheilungen X (Wolf, 1850b), (p247) **Wolf writes**: ***Schwabe's sunspot observations in the years 1826 to 1848**; The following communication contains observations, which **I have made from the observation books of Mr. Heinrich Schwabe** * concerning the years 1826 to 1848, **following exactly the same principles** which guided me in the earlier numbers when I communicated **my own observations from the years 1849 to 1858**, kindly supplemented by Mr. Schwabe.*

1826-1848 → The **early Schwabe data** was **recounted** by Wolf himself in 1859, **therefore *k-factor* ~ 1**

1848-1868 → The **later part** was added **"in real time"** from **Schwabe's correspondence , therefore k-factor ~ 1.25.**

K-factor applied?

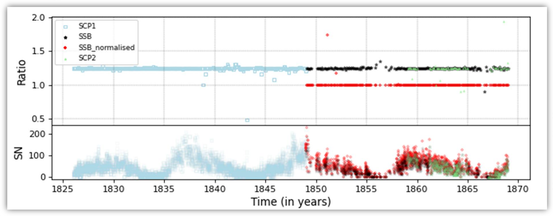
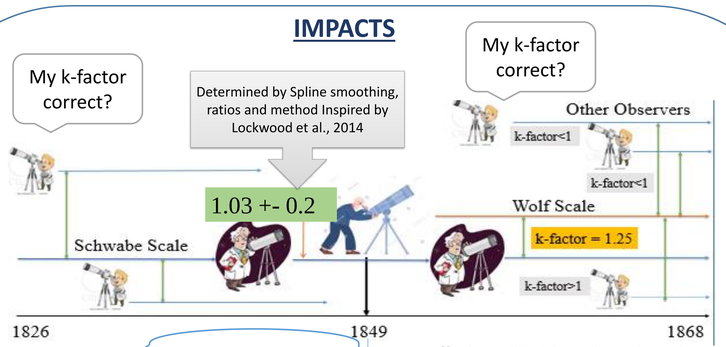


Figure 3: The **upper panel** shows the **monthly ratio of SN Version 1 (SNV1) versus Schwabe Mittheilungen** (blue squares)**, SNV1 versus source tables** for raw Schwabe data (black stars) and **normalized (x 1.25) Schwabe data** (red diamonds). The **lower panel** shows the **daily SN for SCP1, SSB, SCP2 and normalized SSB** in the y-axis.

This **long-standing issue** in 1849 in SN (Version 1) seems to have **one origin** : as can be seen in Figure 3, Wolf **applied** the **same *k-factor of 1.25*** to the 2 datasets of Schwabe that were **NOT counted in the same way**.

IMPACTS



Wolf writes for one of the important observers from 1819-1836, C. Tevel : *The comparison of these last observations by Tevel's with those of Schwabe at the same time yields, for 20 days in the years 1828, 1830 and 1832: the average group number: 5.0 Schwabe = 6.4 Tevel ; relative number: 61.6 Schwabe = 80.7 Tevel*

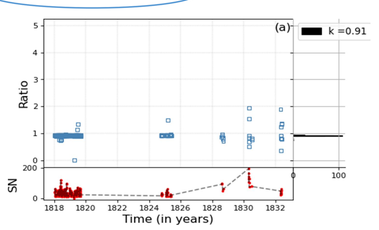


Figure 5: The blue squares in the figure represent the daily ratio between SNV1/ Tevel. The lower panel gives the daily SN of Tevel's observation days. The right panel of both figures show the distribution of the ratio SNV1/Tevel, with the maximum frequency or mode indicated in the legend.

This implies, Tevel's *k-factor* respect to Schwabe should be **61.6 x 1.03/80.7 = 0.78.** However as seen in the above Figure, the most probable applied k-factor is 0.91 in the current SNV1.

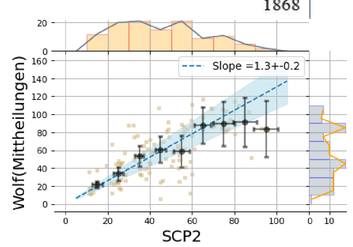


Figure 6:The central panel gives the mean monthly smoothed values in squares with a regression line in blue with error as the shaded region and error bars in black. The upper panel gives the distribution of monthly smoothed values mentioned in the x-axis and the right panels give the distribution of the monthly smoothed values mentioned in the y-axis.

We compute the k-factors applied to the observers after 1849 by calculating a monthly ratio of the observer with that of Wolf and there is **no significant impact of the jump on SNV1 after 1849**.

SCP2's k-factor is also validated as seen in Figure 6.

We assess the *k-factors* for all the identified observers before 1849 and indeed, a SN reconstruction is necessary with the corrected k-factors before 1849 and therefore, we present *Sunspot Series Version 2.1*

RECONSTRUCTION

The daily Sunspot Number (SN) is available from 1818, but there is no clear distinction in the *Mittheilungen* tables of which observer is being used for which day until 1859.

Identifying the observer for each day is a crucial step for implementing the corrected k-factors for each observer, to recreate a correct a daily version of SNV1 without the jump of 1849, from 1818-1849.
Our **adopted methodology** for identifying the **associated observer** for a particular **day data in SNV1** is shown in Figure 7.

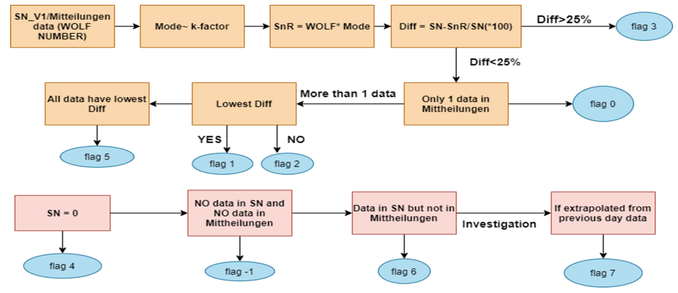


Figure 7: The flowchart of assigning observer to daily Sunspot Number data.

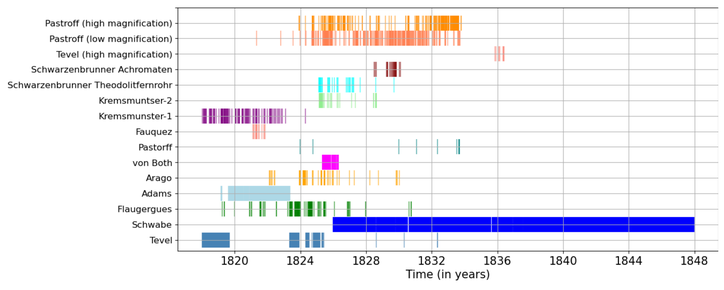
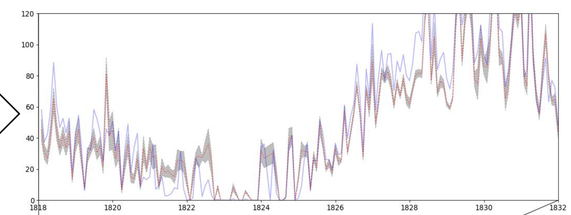


Figure 8: The data used of each observer for each day identified by the above method in the construction of SN (Version 1).

CONCLUSIONS

We Introduce **Daily Errors**/ Confidence bands in **SN Version 2.1** from **1818-1849.**



Errors
$SN=k_i x SN_i$
$\triangle SN^2=ki\triangle SNi^2 + \triangle ki\ SNi^2$

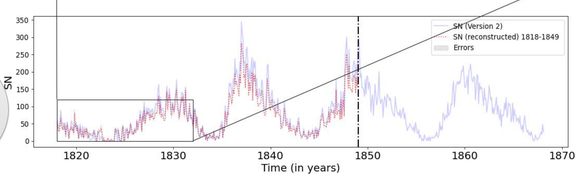


Figure 9: Monthly smoothed SN (Version 2) and re-constructed SN (Version 2.2) spanning from 1818-1868 .The zoom in plot is for easy comparisons, with SN in the y-axis and time (in years) in the x-axis.

We **present SN Version 2.1**, in which SNV1 has been **reconstructed** from all the available **raw data** of the observers with **revised k-factors**, along with the **confidence band associated with k-factor** of each observer. We maintain the newly reconstructed version at the scale of SN Version 2.

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