# Recalibrating the Sunspot Number (SN): The 3rd and 4th SN Workshops

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**Abstract.** At the XIIth Hvar Astrophysical Colloquium in 2012, we reviewed the progress of an effort begun in 2011 to recalibrate the sunspot number (SN). That work is now nearing completion and we review the motivation, approach, and results of this process which was conducted via a series of four international workshops. Previously we discussed the principal results of workshops at Sunspot in 2011 and Brussels in 2012. These involved the identification of discontinuities circa 1885 in the Hoyt and Schatten Group SN and 1945 in the International SN. Subsequently, workshops were held in Tucson (2013) and Locarno (2014). Key results during the time of these two workshops included: (1) development of an independent "backbone" method for determining the Group sunspot number; (2) identification of post-1970 inhomogeneities in the Group SN and the International SN; (3) construction of preliminary revisions of the Group SN from 1610-present and the International SN from 1700-present; (4) reassessment (ongoing) of the Hoyt and Schatten Group SN data base from 1610-present; and (5) establishment of a SN archive at the University of Extremadura. The release of the new International and Group SN series is anticipated during the second half of 2015 and procedures are being put in place both to maintain the calibration of these two series and to produce subsequent revisions should more historical data be unearthed or new inhomogeneities in the series be uncovered or arise.

**Key words:** Sun – sunspot number – solar dynamo – climate change

## 1. Introduction

Charbonneau (2010) noted that, "The various incarnations of the sunspot number time series (Monthly [SN], 13-month smoothed SN, yearly SN, etc.) are arguably the most intensely studied time series in astrophysics, as measured by the number of published research paper pages per data points." The SN is widely used in studies of the solar dynamo, terrestrial climate change, and space climate.

There is a serious problem with the SN, however, in that there are two of them. The original SN is often referred to as the Wolf SN, after its creator Rudolf Wolf (Wolf, 1851, 1856) or the Zürich number because Wolf worked there from 1855 until his death in 1893. After the curatorship of the SN moved from ETH in Zurich to the Royal Observatory of Belgium (ROB) in Brussels in 1980 (Berghmans et al., 2006; Clette et al., 2007), Wolf's time series was designated the International SN. Following Wolf's definition, the International number ($R_I$) is given by

$$R_I = k\ ((10 \times G) + S) \qquad (1)$$

where the R stands for relative, G is the number of sunspot groups, S is the number of individual spots (counted at a given time on a given day), and k is a normalization factor for each observer because of differences in such factors as telescope aperture, seeing conditions, and visual acuity. $R_I$ extends from 1700, based on Wolf's pioneering work, to the present day as constructed by the World Data Center for the Sunspot Index and Long-term Solar Observations (SILSO) at ROB.

An alternative to $R_I$ arose in the 1990s when Hoyt et al. (1994) and Hoyt & Schatten (1998a,b) created a Group SN ($R_G$) based entirely on the number of sunspot groups (G), ignoring the count S of individual sunspots within a group. This was done in part because as one goes back in time before ~1750, only group counts are generally available. Thus Hoyt and Schatten were able to extend $R_G$ back to the beginning of sunspot observations (from 1610-1612 by Harriot, Scheiner, and others) to encompass the Maunder Minimum (1645-1715; Eddy, 1976; Ribes & Nesme-Ribes, 1993). To do so, Hoyt and Schatten conducted an extensive search of the scientific archives (e.g., Hoyt & Schatten, 1996) and greatly expanded the sunspot number data base.

For most of the period from 1874-1976, for which Hoyt and Schatten normalized RG to $R_I$, the agreement between $R_G$ and $R_I$ is very good (Figure 1). Before ~1885, however, the Group SN is systematically lower, by ~45% on average for the interval of overlap. This disparity of the $R_I$ and $R_G$ numbers and the lack of consensus as to which

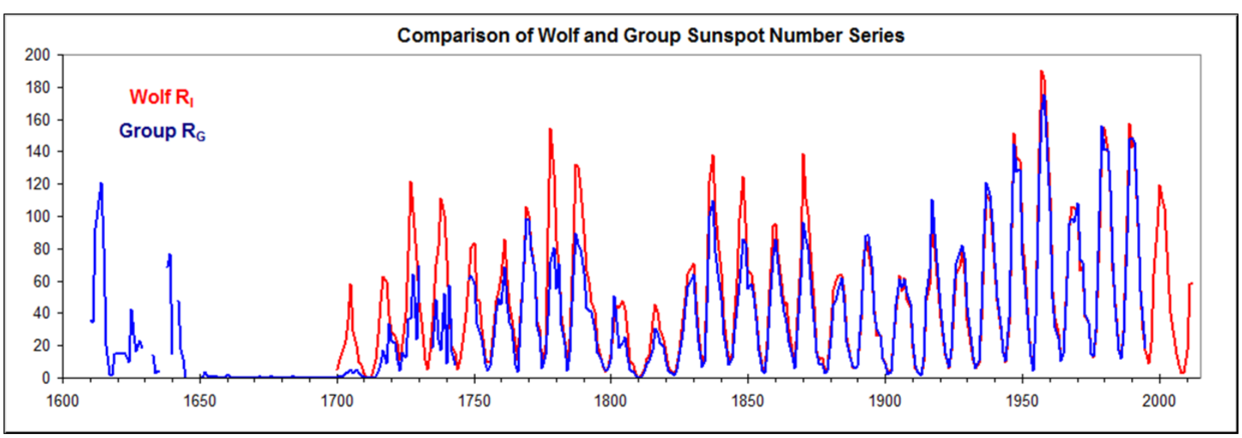


*Figure 1:* Comparison of yearly mean values of the International (red) and Group (blue) SNs (adapted from Hoyt & Schatten, 1998b; reproduced from Cliver et al., 2013).

is better as a measure of solar activity has made the SN a free parameter in solar and solar-terrestrial studies. Results are dependent on which series is used.

To address this undesirable situation, we organized, beginning in 2011, a series of workshops on the sunspot numbers (Cliver et al., 2013). Our goal was to reconcile the two SNs or, at minimum, to understand the differences between them. Because of the centrality of the SN in solar and solar-terrestrial physics, we decided at the outset that the effort would have to be community-wide. Thus we scheduled alternating workshops on both sides of the Atlantic and solicited participants from Asia and South America. We anticipated that the SN reconciliation/recalibration would take some time, but under-estimated just how much was needed. For independent oversight, for each workshop we invited participation by senior solar scientists: Sunspot 2011 (Phil Judge), Brussels 2012 (Hugh Hudson), Tucson 2013 (Jack Harvey), and Locarno 2014 (Jan Stenflo). Their critiques were frank, ranging from Phil Judge's comment that it would be difficult to get scientists to commit to work on this project over the two years we considered necessary at the time to Jack Harvey's one-slide summation of the Tucson meeting (Figure 2).

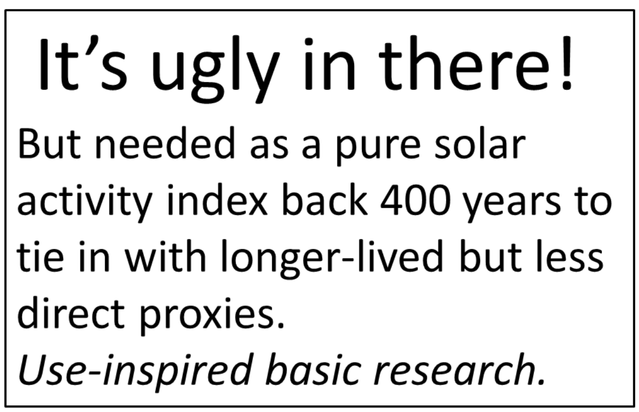


*Figure 2:* Jack Harvey's overview slide of his summary talk at the NSO Tucson workshop in January 2013.

As can be seen from Figure 2, there is a larger issue at hand, beyond the important goal of rectifying studies based on the last 400 years of sunspot observations. The archive of cosmosgenic nuclide data, specifically $^{10}$Be trapped in ice cores and $^{14}$C sequestered in tree rings, represents a measure of solar activity that extends for tens of millennia (Beer, McCracken, & von Steiger, 2012). Calibration of this time series is complex, however, and is subject to variations caused by Earth's magnetic field, terrestrial climate, and volcanic activity. Thus it is necessary to have as long and as accurate a record of solar activity as possible to characterize the effect of these other variables on a long-term cosmogenic-nuclide-based SN.

In section 2 we give the highlights of the 1st and 2nd SN Workshops and in section 3 we review progress during the time of the 3rd and 4th Workshops. Section 4 gives a look back and a look ahead, including the anticipated release of the revised Group and International SN time series during the second half of 2015.

## 2. Highlights of the 1st and 2nd SN Workshops

As discussed in Cliver et al. (2013; for more detail, see Clette et al., 2014), the principal findings associated with the first two SN workshops were the identification of the Waldmeier Discontinuity or Jump (Svalgaard, 2010, 2012) in the International SN in 1947 and the discontinuity circa 1885 in the Group SN (Svalgaard, 2010). The Waldmeier Jump is attributed to the weighting of individual sunspots that apparently began shortly after Waldmeier succeeded Brunner as the curator of the SN at Zürich. This resulted in a ~20% increase in the International SN beginning in 1947 (cf., Lockwood et al., 2014). The decrease in $R_G$ relative to $R_I$ before ~1885 is primarily due to a flaw in the Hoyt & Schatten (1998a,b) normalization (k-factor) scheme (Clette et al., 2014). Hoyt and Schatten chose as their primary reference observer the Royal Greenwich Observatory (RGO) which observed sunspots from 1874-1976. As can be seen in Figure 3, the RGO sunspot group counts before ~1915 are inhomogeneous.[1] Recent work by Cliver & Ling (in preparation) demonstrates that correcting for this inhomogeneity in the RGO record and comparing overlapping observers directly with RGO (not done by Hoyt and Schatten for 1874-1883) removes the major discrepancy between $R_I$ and $R_G$ seen before ~1885.

In Cliver et al. (2013), we reported that Wolf used the "magnetic needle", i.e., measurements of the daily range of geomagnetic variability, to make adjustments to Staudach's (a 100% increase) and Schwabe's (25% increase) sunspot counts. A closer reading of Wolf's *Astronomische Mittheilungen* indicates that Wolf based the increase to Schwabe's counts on comparisons with his own observations as well as those of

[1]Inspection of the metadata in the *Greenwich Photo-Heliographic Results* series for the 1874-1928 period of overlap with Wolfer reveals possible causes, in addition to observer learning curve, for this inhomogeneity: (1) change from Kew 3.6" aperture refractor to Dallmeyer 4" photoheliograph in September 1875; (2) change from wet to dry photographic plates in November 1882; (3) addition of secondary magnifier changes image of Sun on plate from ~4" to ~8" in April 1884; (4) new enlarging lens for Dallmeyer installed in December 1892; (5) the 4" object glass of the Dallmeyer was replaced by a Grubb photographic objective in 1910; (6) comment added in 1913 that Dallmeyer aperture of 4" is "usually stopped down to 2.9"; plate vendor changed; (7) intermittent use of 9" Thompson refractor after 1891 including: (a) 1891-1894; (b) gradual transition from Dallmeyer to Thompson from 1898-1901; (c) primary use of Thompson from 1902 to June 1912 (followed by exclusive use of the Dallmeyer until July 1924); (d) from July 1924 through 1928 the Thompson was used for "intervals of good definition" or "during the winter months when the Sun's disk was reddish".

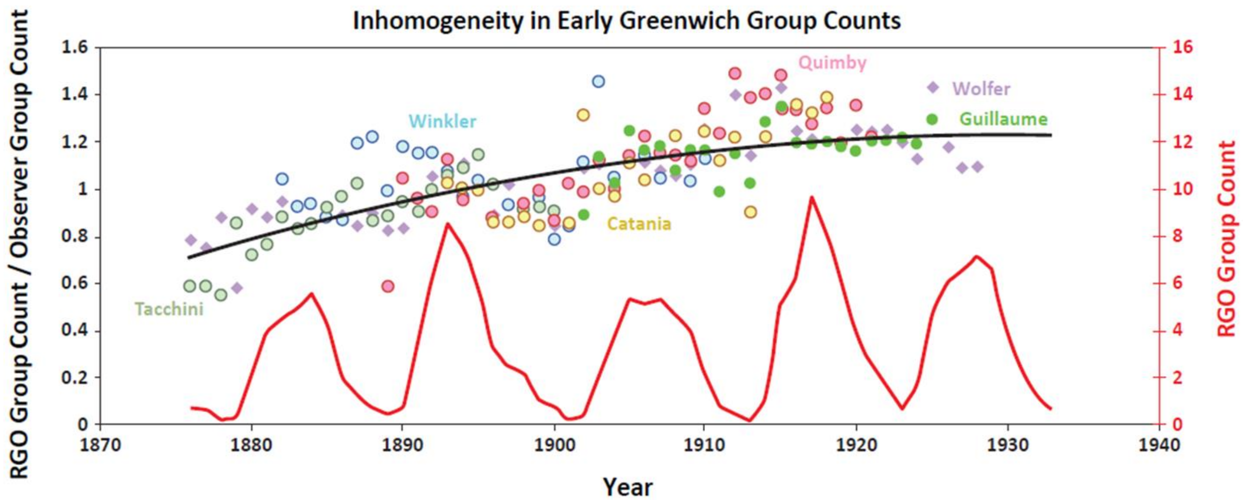


*Figure 3:* Ratio of mean annual RGO group counts to those of Tacchini, Winkler, Catania, Quimby, Wolfer, and Guillaume from 1876-1928, with a second order fit through all points. The ratio does not stabilize until ~1915.

Hornstein and Carrington (Clette et al., 2014), and hints that the doubling of Staudach's count was based on a comparison with Hagen for 1750-1751. That said, there is evidence (Loomis, 1873) that Wolf adjusted the sunspot number for 1870 (downward) following a comparison with magnetic observations and it seems likely that such observations influenced his revisions elsewhere in the SN series.

## 3. Progress during the Time of the 3rd and 4th SN Workshops

Participants at the 3rd and 4th Sunspot Number Workshops are pictured in Figures 4 and 5.

### 3.1 An Independent "Backbone Method" for Determining the Group SN

The Hoyt and Schatten k-factor method for normalizing observers relies on "daisy chaining" individual observers to go back in time before the observing interval of their primary observer (RGO). This results in a proliferation of links, an error in any one of which can be propagated back in time. Although Hoyt and Schatten took steps to mitigate this effect, such as using only high quality observers to link back in time and multiple pathways, the major discontinuity in 1885 still resulted.

As an alternative method to constructing a group SN, Svalgaard (Svalgaard, 2013; Clette et al., 2014) devised a "backbone" approach in which several long-term primary observers are identified (e.g., Schwabe (who observed from 1826-1867), Wolfer (1876-1928), Staudach (1749-1799)). Then, instead of linking individual observers, overlapping backbones based on multiple observers are joined. Hoyt & Schatten (1998a,b) employed a somewhat similar scheme for the years before 1800. The


*Figure 4:* Participants at the 3rd SN Workshop, Tucson, Arizona, 22-25 January 2013. Left to right: O.R. White, J. W. Livingston, A. Pevtsov, M. Penn, G. de Toma, G. Chapman, L. Lefèvre, S. Oatney, O. Hérent, A. Muñoz-Jaramillo, L. Balmaceda, L. Wauters, J. Alvestad, F. Clette, D. Hathaway, D. Webb, E. Cliver, J. Love, J. Muraközy, M. Laurenza, J. Harvey, A. Ludmány, P. Hejda, L. Bertello, R. Howe, L. Svalgaard.

*Figure 5:* Participants at the 4th SN Workshop, Locarno, Switzerland, 19-23 May 2014. Left to right: R. Ramelli, F. Marenzi, C. Kiess, D. Supriya, L. Belluzzi, G. Travaglini, R. Howe, C. Fröhlich, T. Dudok de Wit, J. Vaquero, P. Hejda, J. Beer, R. Arlt, J. Stenflo, M. Bianda, L. Svalgaard, S. Cortesi, D. Willis, E. Cliver, O. Hérent, L. Lefèvre, A. Kilcik, A. Bulling, J. Alvestad, F. Clette, J. Javaraiah.

backbone method also has its shortcomings. From 1610-1750, one is forced to rely on a series of short backbones, more like vertebrae. In addition, the overlap between observers on the Schwabe and Staudach backbones is rather tenuous. Nonetheless, the "backbone" method provides an alternative observer normalization scheme – the result of which can be compared with $R_G$ and $R_I$. Figure 6 gives this comparison for the 1749-1995 interval. In the figure, it can be seen that before ~1885, the Group SN is consistently below both the International SN and Svalgaard's backbone-based Group SN ($R_{BB}$). To corroborate the behavior of the $R_{BB}$ and $R_I$ time series across the 1885 discontinuity in $R_G$, we plotted the scaled daily range (rY) of the eastward component of geomagnetic activity from 1840-2013 in Figure 7. This independent EUV-driven parameter which is highly-correlated with F10.7 also indicates that $R_G$ is too low before ~1885 (Svalgaard, 2013).

### 3.2 Identification of Post-1970 Inhomogeneities in the International and Group SNs

#### 3.2.1 An Increase in the Group SN (1974-1982)

Clette et al. (2014) report an increase from 0.97 to 1.08 over the interval 1974-1982 in the ratio of the monthly group count rate constructed from WDC-SILSO archived observations to that obtained from Hoyt & Schatten (1998a,b). Corresponding discontinuities in spot areas associated with the 1976-1977 transition from RGO to the USAF ISOON system for their measurement have been noted (e.g., Hathaway et al., 2002; Balmaceda et al., 2009; Foukal, 2013). Clette et al. (2014) suggest that the change in the ratio in group counts is due to the use of a group-splitting-rule by USAF observers that resulted in more groups than reported by RGO.

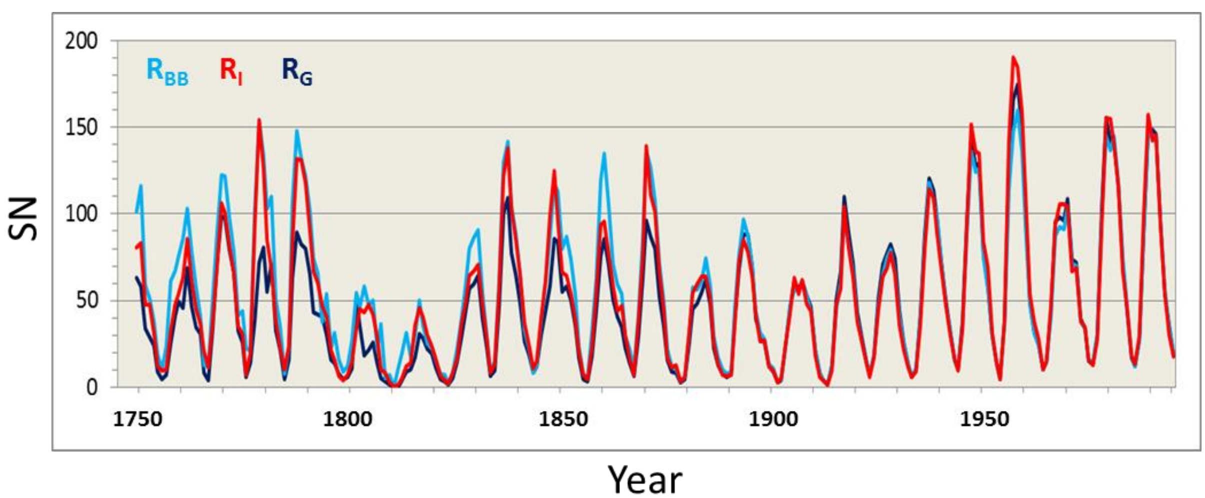


*Figure 6:* Comparison of $R_{BB}$ (Svalgaard, 2013; Clette et al., 2014) with $R_I$ and $R_G$.

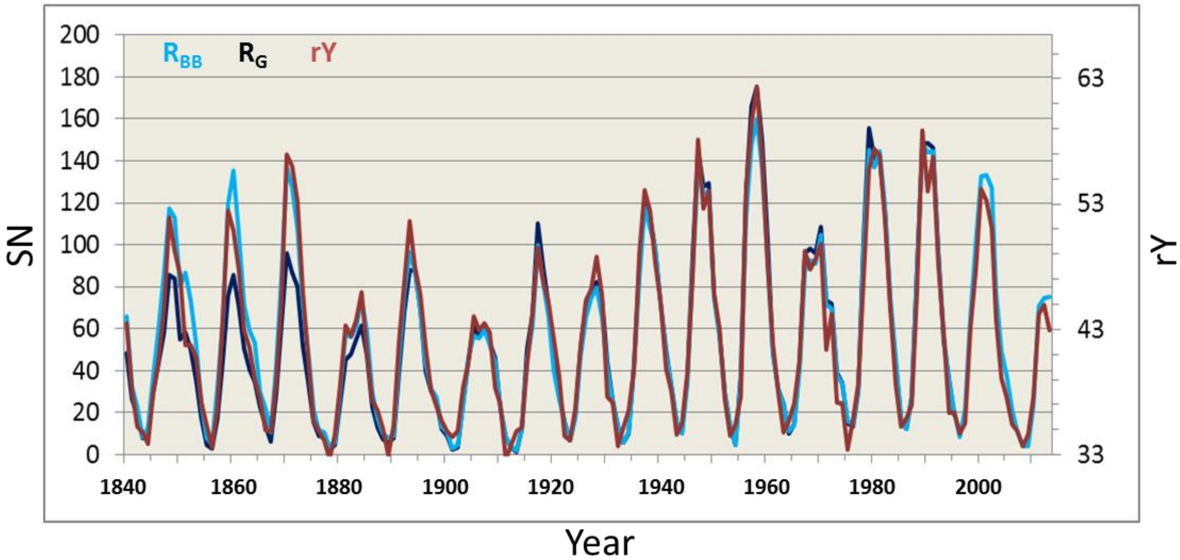


*Figure 7:* Comparison of $R_{BB}$ (Svalgaard, 2013; Clette et al., 2014) with $R_G$ and rY.

### 3.2.2 A Drift in the International Number (1980-2014)

One of the surprises that arose from the SN workshops was the discovery that the most recent segment of the $R_I$ series, dating from the Zürich to Brussels transition in 1980, was inhomogeneous (Clette et al., 2014). Even more surprising was the finding that the drift in $R_I$ resulted from a variation of the sunspot counts at Locarno, the pilot station for the SILSO network of observers. Figure 8, taken from Clette et al. (2014), shows smoothed k-factors for long-running SILSO network stations relative to the pilot Locarno station for which the k-factor is 0.6 by definition. The figure shows that either the network stations drifted in concert or that, more plausibly, the Locarno station was drifting from 1981-2013. The current interpretation of the apparent Locarno drift is that when Locarno took over from Zürich it began to overcount leading to an increase in k-factors for the network stations. The subsequent decline in k-factors beginning in 1987 is attributed to the natural eyesight degradation of the principal Locarno observer, Sergio Cortesi, who had begun observing in 1957. As Locarno reported fewer spots, the k-factors of the network stations accordingly decreased until 2008 when they began to rise again reflecting the increasing fraction of observations made by a younger Locarno observer, Marco Cagnotti. Cagnotti, the new Director of the Specola Observatory and Cortesi's effective replacement as the lead observer, began observing in 2005. As the above variations are only based on data after 1981, the absolute scale of the correction relative to the preceding Zürich series is still approximate and needs to be determined more accurately using long-duration stations active before and after the 1980 transition.

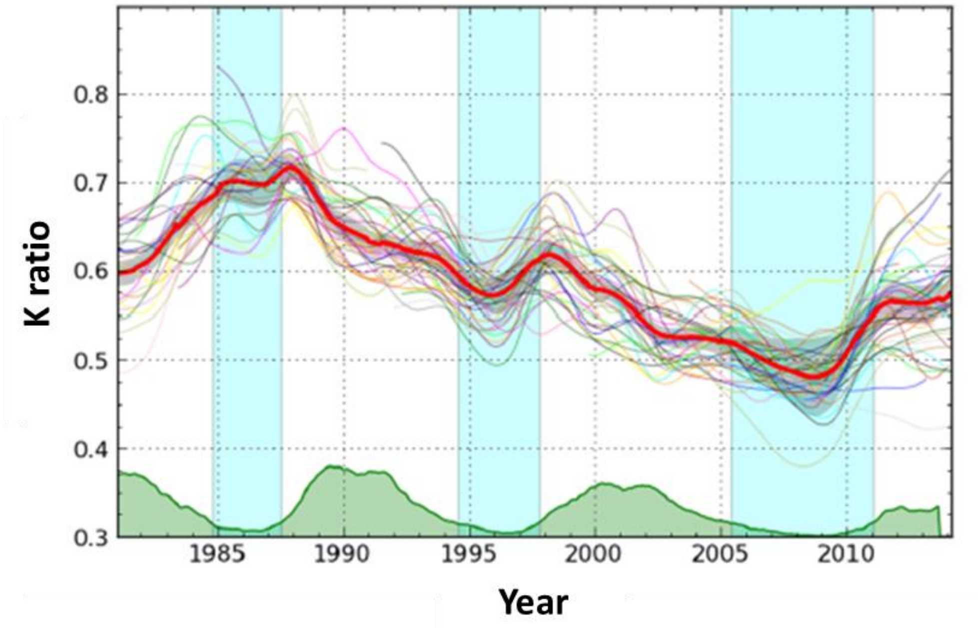


*Figure 8:* Plot of 20-month smoothed k-factors for long-running SILSO network stations from 1981-2013. The gray shading around the red curve gives the standard error on the average k-value (from Clette et al., 2014).

3.3 Preliminary Revisions of the International SN and Group SN

The various inhomogeneities identified in the International and Group SNs during the time of the SN workshops and their corresponding corrections ($R_I$: Waldmeier jump (-20% correction after 1946), Locarno drift (-10% and +10% corrections between 1981-2014); $R_G$: 1885 discontinuity (40% graduated increase from 1915 to 1880), RGO/USAF offset (10% decrease after 1970)) are summarized in Figure 9 taken from Clette et al.

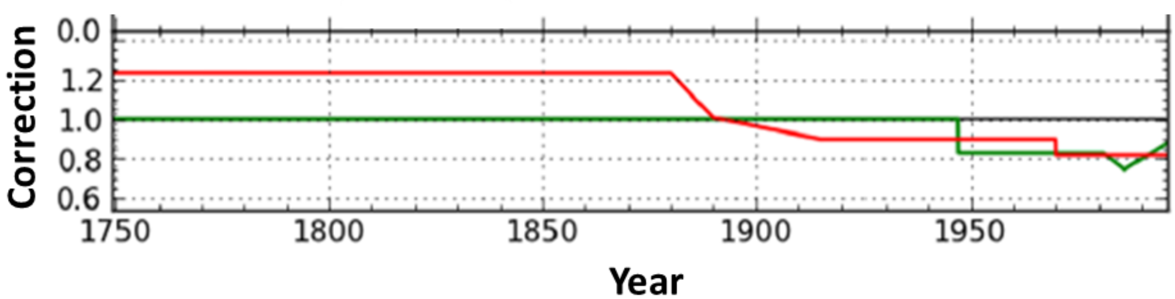


*Figure 9:* Corrections to $R_G$ (red) and $R_I$ (Green) identified during the SN workshops (from Clette et al., 2014).

(2014). Figure 10 shows the resulting corrected $R_I$ and $R_G$ series, labelled $R_{IC}$ and $R_{GC}$, along with the $R_{BB}$ series. The agreement between these three series is reasonably good after 1800 until about 1985 when $R_{BB}$ is high compared to $R_{GC}$ and $R_{IC}$, for as yet unknown reasons. Before 1800, however, $R_{GC}$ is low compared to $R_{IC}$ and $R_{BB}$. A comparison of $R_{GC}$ with $R_{BB}$ over the 1749-1799 Staudach interval indicates an upward correction for $R_{GC}$ of 24% which we apply from 1610-1799 in Figure 11. Now the agreement between all three series is adequate during the 18th century, given the apparent noise in the data, except for the cycle with maximum in 1705 for which $R_{IC}$ and $R_{GC*}$ differ by a factor of 6 (for a cause that remains to be determined). Given the weakness of the link between the Staudach and Schwabe backbones, i.e., the absence of a prolific observer overlapping with these two observers, it would be very useful, if possible, to use geomagnetic data to substantiate the normalization between these

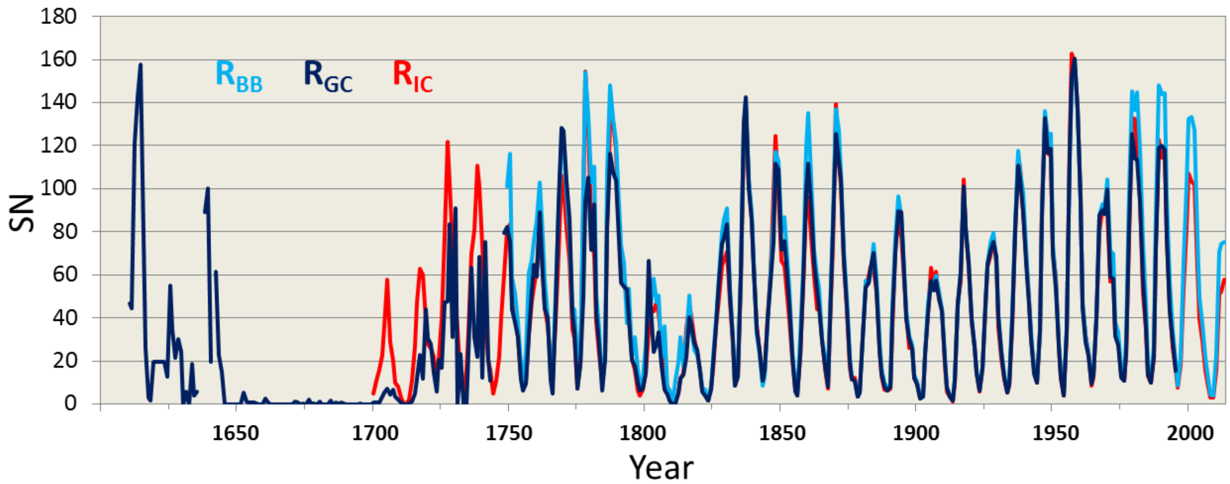


*Figure 10:* Provisionally corrected (based on Figure 9) International ($R_{IC}$; 1700-2013) and Group ($R_{GC}$; 1610-1995) SN series along with the backbone-based Group SN ($R_{BB}$; 1749-2013).

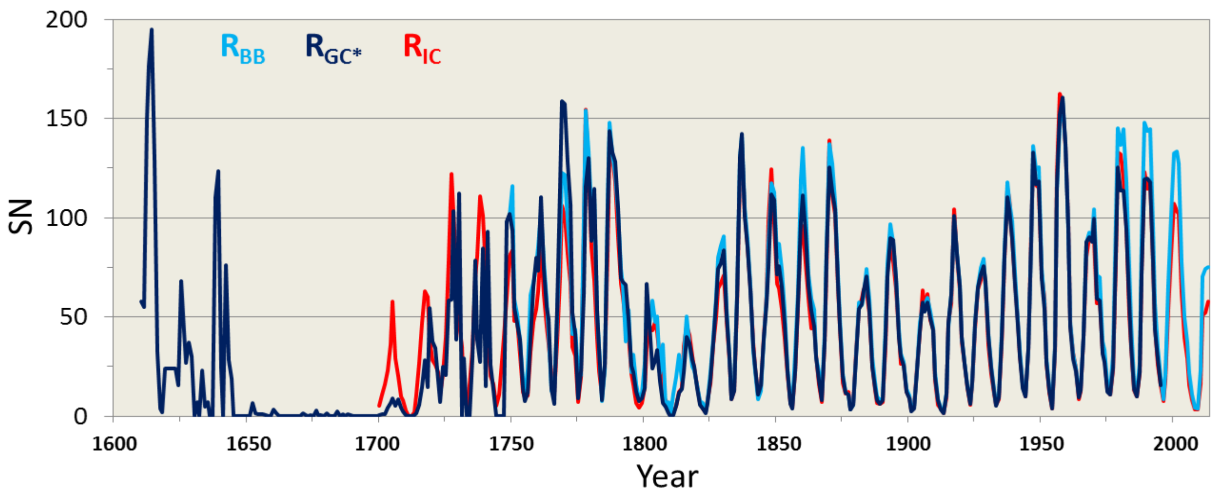


*Figure 11:* Same as Figure 10 but with an additional upward correction of 24% to $R_{GC}$ (to yield $R_{GC*}$) before 1800.

two backbones – and our resulting correction to $R_{GC}$ before 1800. With that caveat, the time series in Figure 11 argue against the need for a systematic 20% decrease in $R_I$ before 1848 as proposed by Leussu et al. (2013).

The 11-yr maximum of $R_{GC*}$ in 1614 is higher than any observed since. The SN for this year is based on a single observation and has large uncertainty. The calculated $R_{GC*}$ values of 149.2 and 176.4 for years 1612 and 1613, however, are based on 394 observations (six observers) and 90 observations (four observers), respectively, so the peak of the first observed solar cycle is at least comparable to the largest cycles of subsequent centuries. Figure 11 calls into question the notion that solar cycles 17-23 (1933-2008) constituted a modern Grand Maximum (Usoskin et al., 2003; Solanki et al., 2004; cf., Clette et al., 2014).

### 3.4 $R_I$ and $R_G$

Our goal in the sunspot number workshops was not to create a third SN time series in addition to the original International and Group SNs (Cliver et al., 2013), but rather a single reconciled time series that would replace both of them. This goal of reconciliation of the two SNs was countered by criticism from the community that the two series did not measure the same thing. Point taken, but at the same time, we expected – as shown in Figure 11 – that the two series would track each other more closely than was the case in Figure 1.

During the time of the first two workshops, the Livingston-Penn effect (Penn & Livingston, 2006, 2011; Livingston & Penn, 2009; Livingston et al., 2012) was gaining increasing prominence. This observational effect indicated that the magnetic field strength in sunspots was undergoing a secular decrease from 1998-2012. An extrapolation of the trend implied that sunspots would disappear by 2015. Questions arose: Is this what happened during the Maunder Minimum? Did the decrease in sunspot field strengths presage a descent into another Grand Minimum? Was the SN a moving target? In addition, after the solar minimum of 1996, the strong correlation between the SN and the F10.7 cm flux (e.g., Kundu, 1965) appeared to be breaking down (Svalgaard & Hudson, 2010) and the long-term ratio of the number of spots to groups was decreasing from its nominal value of ~10 (Clette at al., 2014).

Subsequently, several authors have variously attributed the secular decline in the magnetic field in sunspots reported by Livingston and Penn to a gradual decrease in the number of large sun spots and a steady increase in the number of small spots from 1998-2011 (Nagovitsyn et al., 2012; cf., Lefévre & Clette, 2011), 11-yr and longer term cyclic effects (Pevtsov et al., 2011; Rezaei et al., 2012; Pevtsov et al., 2014), and a data selection effect (Watson et al., 2014). The post-Zürich inhomogeneity in $R_I$ was found to be responsible for about half of its divergence from F10.7 (Clette et al., 2014). In sum, the interpretation of the Livingston-Penn effect, the SN-F10.7 divergence, and the variable spot-to-group ratio remains unsettled. What we know for certain is that the sunspots did not disappear in 2015 and that $R_I$ and $R_G$ track each other reasonably well over a range of solar activity levels (Figure 11). That said, it is clear that the construction of both $R_I$ and $R_G$ should continue because they measure different quantities and also because the data do not permit, as Wolf first discovered, a reliable determination of the number of individual sunspots and thus an extension of $R_I$ before 1700 (at best).

3.5 Reassessment of the Hoyt and Schatten Group SN Data Base from 1610-1800

The last decade has seen a renewal of interest in historical sunspot observations (e.g., Vaquero, 2007). In an ongoing effort, Vaquero and colleagues have undertaken a systematic re-evaluation of the 1610-1825 portion of the Hoyt and Schatten data base (see Clette et al., 2014). Key results include: (1) elimination of ~50 observer years (all from central Europe) with only zeroes reported for more than 330 days of observations during the Maunder Minimum; (2) elimination of ~2300 zero values for sunspot groups reported in conjunction with solar meridian observations at the Basilica of San Petronio in Bologna (Vaquero & Gallego, 2014); (3) reduction of the amplitude of the solar maximum in 1639 immediately preceding the Maunder Minimum (Vaquero et al., 2011); (4) reassessment of the unusual multiple-peak solar maximum circa 1740 (Vaquero et al., 2007a,b; Vaquero & Trigo, 2014); and (5) recovery of sunspot counts from D.E. Hadden (Carrasco et al., 2013) and the Madrid Observatory (Aparicio et al., 2014). Arlt and colleagues have digitized/analyzed the sunspot observations of Staudach (Arlt, 2008), Schwabe (Arlt, 2011; Arlt et al., 2013) and Spörer (Diercke et al., 2014). In the Hoyt and Schatten data base, Svalgaard separated Wolf into two observers (Svalgaard, 2013; Clette et al., 2014): (1) Wolf, large telescope (1848-1860 and 1865-1867; 80 mm Fraunhofer refractors at Bern and Zürich), and (2) Wolf, small telescope (1861-1864 and 1868-1893; three portable refractors with 30-40 mm apertures). In addition, Svalgaard has uncovered and digitized observations for several sunspot observers from the $20^{th}$ century that are not in the Hoyt and Schatten data base (e.g., Hedewig, Kanzelhöhe, Luft, Rumrill) and reassesssed the Staudach group counts, increasing them by 24% on average. A revised Hoyt and Schatten data base incorporating these various deletions, additions, and corrections will be released along with the correspondingly revised Group and International SN series.

The revised $R_G$ and $R_I$ time series in this paper are based on the original $R_I$ and $R_G$ time series as taken from the NGDC and SILSO websites.[2] The final revised series

[2]Note that the online version of the Hoyt and Schatten Group SN data base (http://www.ngdc.noaa.gov/nndc/struts/results?t=102827&s=1&d=8,4,9)) is slightly different from that published in Appendix 2 of Hoyt & Schatten (1998a).

will need to take into account the above changes to the Hoyt and Schatten data base. Other than specific instances, viz., the solar maximum near 1740 and the not-yet-examined discrepancies for the 1705 and post-1985 maxima, we do not anticipate that the final series for the 1700-present interval will be significantly different from those shown in Figure 11. For the 17th century, the maximum in $R_G$ circa 1640 will be reduced in accordance with Vaquero et al. (2011) and the removal of observer years with all zeroes will result in gaps (no data) for years 1646, 1647, 1649, 1650, and 1651 during the Maunder Minimum.

Recently, Zolotova & Ponyavin (2015) have challenged the reality of the numbers of reported sunspots during the Maunder Minimum. They argue that 17th century reports of sunspots reflected, at least in part, searches for interior planets which would have appeared as round shadows on the disk, and thus that less regular blemishes on the Sun's disk may have been ignored (perhaps in keeping with contemporary religious views). In agreement with Vaquero & Gallego (2014; as reported in Clette et al., 2014), Zolotova and Ponyavin discounted null observations of spots associated with solar meridian observations. Similarly they excluded reports of continuous zeros over periods of several months to years. Zoltova and Ponyavin concluded that the Maunder Minimum was not the radical departure from normal solar behavior that it is generally thought to be today, and speculate that during the 1645-1700 depth of the Maunder Minimum, 11-yr peak sunspot counts ranged from ~30 to ~100 rather than the 0.1 to 2.0 range inferred from Appendix 2 in Hoyt & Schatten (1998a). From an analysis of cosmogenic nuclide ($^{10}Be$) concentrations in ice cores, McCracken & Beer (2014) obtained an independent estimate of solar activity during the Maunder Minimum. They concluded that the "periods of highest solar activity during the Maunder Minimum approximated those near the sunspot minima between 1954 and 1996." The International SNs at 11-yr minima during this period range from 3.5 (1954) to ~11 (1986) (after reduction for the Waldmeier Jump), above those of Hoyt and Schatten's 0.1 to 2.0 values, but still an order of magnitude below Zolotova and Ponyavin's range of ~30 to ~100. A recent paper by Carrasco et al. (2015) suggests 11-yr peak Group SNs of ~10 during 1653-1675 based on a revisitation of the observations made by Hevelius. These various studies will need to be taken into account when determining the uncertainties in the Group SN during the Maunder Minimum.

### 3.6 Historical Archive of Sunspot Observations (HASO)

A valuable off-shoot of the SN workshops was the creation of a physical and virtual Historical Archive of Sunspot Observations (HASO) by the Universidad de Extremadura, Mérida, Spain. The physical archive is located in the library of the Centro Universitario de Mérida and the virtual archive can be accessed at: http://haso.unex.es. Quoting from the website:

"Successive great compilations by Wolf in the 19th century and Hoyt and Schatten in the 20$^{th}$ century have highlighted the importance of the recovery of the historical record to reconstruct the best sunspot number series.

The objective of HASO is to collect and preserve all documents in any format (original, photocopy, photography, microfilm, digital copy, ...) with sunspot observations that can be used to calculate the sunspot number in the historical period or related documents."

The archive will thus provide a specified home for sunspot-number related material beyond that routinely saved at WDC-SILSO. It will serve as a repository for working materials (e.g., computer programs and data bases) associated with the SN workshops, subsequently uncovered sunspot records, as well as material related to any future revisions of the sunspot record.

## 4. A Look Back and a Look Ahead

When we began this effort to recalibrate/reconcile the sunspot number(s), some gave us the impression that we were tinkering with sacred texts. In the event, even we were surprised by the inhomogeneities/uncertainties in the $R_I$ and $R_G$ series and the amount of work needed to correct/specify them.

Much remains to be done. The revision of the Hoyt and Schatten group sunspot record needs to be completed and the annual $R_G$ and $R_I$ time series in Figure 11 recomputed accordingly, with stated uncertainties. The release of the revised $R_I$ and $R_G$ time series is scheduled for the second half of 2015. The revised Group and International SNs will be maintained by the SILSO Data Center and published on their website. At SILSO, the homogeneity of these series will be monitored by reference to a subset of key stations, rather than to a single pilot station (Locarno) as was done in the past. Finally, procedures are being put in place for possible future revisions of $R_G$ and $R_I$ as new historical observations of sunspots are uncovered and as our understanding of the sunspot number evolves.

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