The New Sunspot Numbers

The new SILSO numbers will affect many calculations using sunspot numbers.

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In early March of this year, Wayne Mills, N7NG, was browsing the WM7D solar website[1] and noticed that the smoothed sunspot numbers on the Sunspot Index and Long-term Solar Observations (SILSO) plot from the Royal Observatory of Belgium, and the smoothed sunspot numbers on the International Space Environment Service (ISES) plot from the Space Weather Prediction Center in Boulder, did not agree. Figures 1A and 1B show these two plots.

The smoothed sunspot number on the SILSO plot (the red line) at the second peak of Solar Cycle 24 (early 2014) was around 120, while the smoothed sunspot number on the ISES plot (the blue line) at the same point in time was around 80.

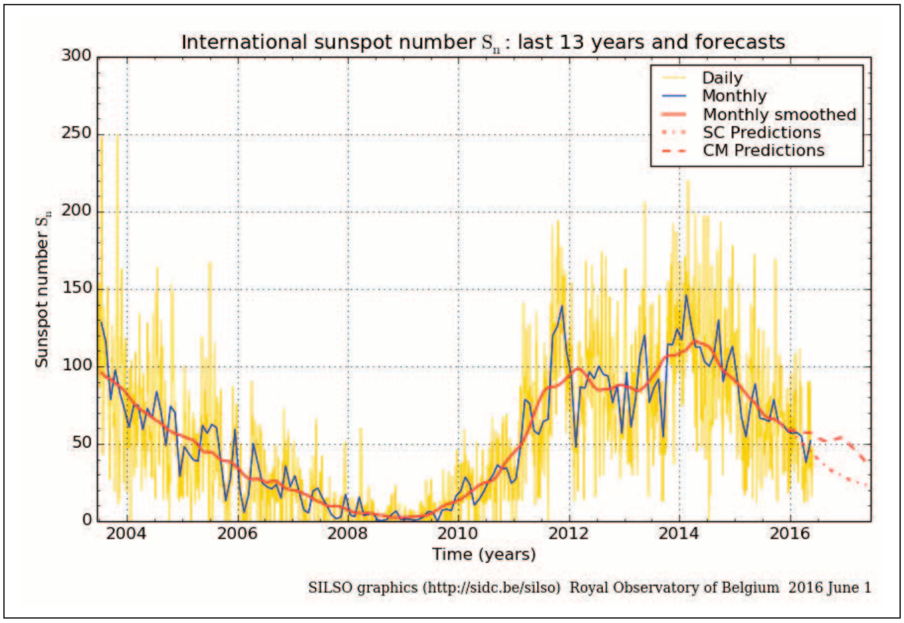

Figure 1A — International sunspot numbers for the last 13 years and forecasts.

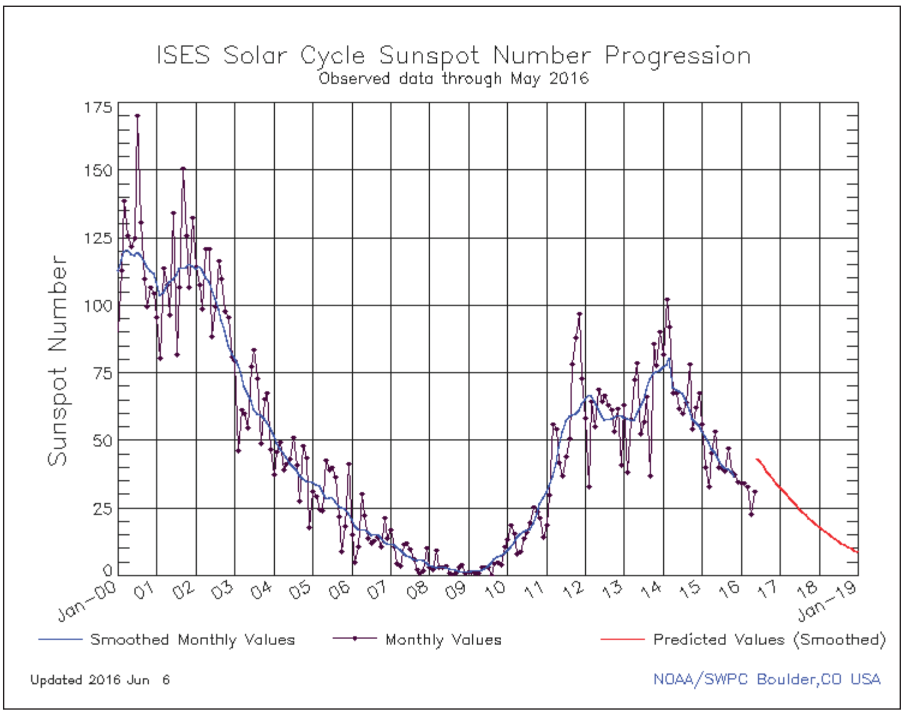

Figure 1B — ISES solar cycle sunspot number progression.

Why Is There a Difference?

The simple answer to the question Wayne posed is, we have a new set of sunspot numbers that the SILSO plot reports. The more involved answer is that counting sunspots is subjective — there's human interpretation involved. Let's see how we ended up with "new" sunspot numbers.

The sunspot number is calculated according to the following equation:

$$R = (10G + S) \times K_{Wolf}$$

where R is the Wolf sunspot number — named for Rudolph Wolf, who devised this equation in 1848. G is the number of sunspot groups, S is the total number of individual spots in all the groups, and K_{Wolf} is a variable scaling factor that indicates the combined effects of observing conditions, the telescope used, and the bias of the solar observers. This equation reflects the importance of sunspot groups as well as the importance of individual sunspots. The Wolf sunspot number has also been known as the Zurich sunspot number, and now it's known as the International sunspot number, determined by the Royal Observatory of Belgium.

The above equation is for the daily sunspot number. Monthly mean sunspot numbers are an average of the daily values for a

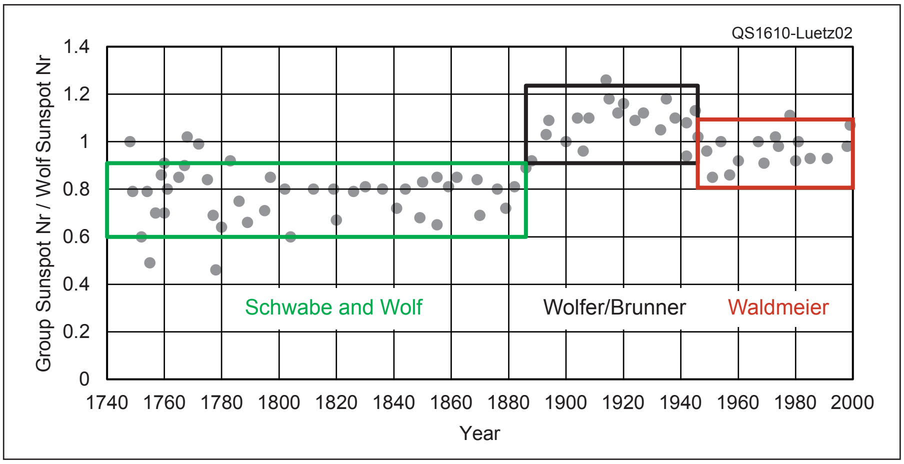

Figure 2 — Yearly values of ratio of Group Sunspot Number, and Wolf Sunspot Number.

month. A smoothing calculation is applied using 13 months of monthly mean data to give the smoothed sunspot number, which is the official measure of a sunspot cycle. These calculations apply to 10.7 centimeter solar flux as well.

Including the scaling factor makes it easy to understand why counting sunspots is subjective. Just the advances in telescopes over the years could affect the count. Then throw in the fact that there have been many official observers: Schwabe up to 1849, Wolf from 1849 – 1893, Wolfer from 1876 – 1928, Brunner from 1929 – 1944, and Waldmeier from 1945 – 1995.

It is important to get the sunspot numbers right for solar cycle models and climate studies — as well as Amateur Radio propagation predictions. Beginning in September 2011, there have been four Sunspot Number Workshops — sponsored by the National Solar Observatory, the Royal Observatory of Belgium, and the Air Force Research Laboratory — discussing the quality of the sunspot data. The last Workshop reviewed the corrected time series of sunspot numbers from 1610 to the present, and reached an agreement to publish the new data.

So how did solar scientists conclude that the old data may have a problem? The concern began in the early 1990s when Douglas Hoyt and Kenneth Schatten asked the question, "Do we have the correct reconstruction of solar activity?" Their question came from the problem of counting the number of individual sunspots — the observing conditions, the telescope used, and the observer's bias play a big part in this determination. To get around individual sunspot numbers, Hoyt and Schatten devised the Group Sunspot Number (GSN), which is based solely on the number of sunspot groups (sunspot areas) and normalized by a factor of 12 to match the Wolf numbers from 1874 to 1991.

Hoyt and Schatten found and tabulated many more early sunspot records than were available to Wolf. Unfortunately, a fudge factor is also needed in the GSN. Regardless of this, solar scientists divide GSN by *R* expecting 1.00 if the correlation between GSN and *R* was perfect. If the ratio changed abruptly, that would signify something changed in visually counting sunspots. Figure 2 shows the ratio of GSN to *R* from about 1745 to 2000.[2]

The most obvious observation is the two steps in the data around 1885 and around 1946. Another observation is that the most recent data has a higher ratio of GSN to *R* than most of the historical data. Thus something changed in counting sunspots.

The upward step around 1885 appears to be due to Wolfer reporting more groups than Wolf — and Brunner continued this. This was largely confirmed using a technique involving geomagnetic activity.

The downward step around 1946 appears to be due to Waldmeier assigning different weighting to the sunspot count. This issue has largely been confirmed based on other solar indices: sunspot areas, calcium II spectral lines, diurnal variations of day-side geomagnetic field activity, and ionospheric F2 region critical frequencies (foF2).

The net result is the GSN to *R* is now scattered about 1.00 with no significant up or down steps. There certainly is more scatter in the early years, but that is expected due to the more crude equipment back then.

New Data Compared to Old Data

The new data (designated Version 2.0), along with the old data (designated Version 1.0), is available at **sidc.oma.be/silso/datafiles**. Figure 3 shows the difference in the old data and new data from January 1950 through the present.

The old data in this range has been shifted up, by approximately 40%; and the difference is most pronounced around the peak of a solar cycle. There is still that shift around the solar minimum periods, but it is not as noticeable.

I can't stress enough that the corrected data isn't just to make the data "look better." The corrected data is what solar scientists actually believe happened in terms of sunspots.

SWO Data

You may have wondered about some of the data in the National Oceanic and Atmospheric Administration's (NOAA) Recent Solar Indices monthly report.[3] Figure 4 shows an excerpt of this data.

In the columns under the Sunspot Numbers category there are two sunspot numbers reported: SWO and RI. The *SWO* data comes from Space Weather Operations, a part of the Space Weather Prediction Center at NOAA. The *RI* data is the International sunspot number from Belgium.

The data is different because the two organizations count sunspots differently. If you download a large sample of the smoothed SWO and RI numbers, you'll see that the SWO numbers are about 40% higher than the RI numbers. It says SWO has been reporting something close to the new data for quite some time, while the RI data is the old data from Belgium. What the Space Weather Prediction Center will report in the future is unknown.

Impact of New Sunspot Numbers — Correlation to 10.7 cm Solar Flux

One of the major issues is that sunspot numbers are used in many other calculations. One calculation is the correlation between the smoothed sunspot number and the smoothed 10.7 centimeter solar flux. Figure 5A shows this correlation from 1950 to the present using old sunspot numbers, while Figure 5B shows this for the new sunspot numbers.

Our propagation predictions are based on the correlation between monthly median ionospheric parameters and a smoothed solar index. It doesn't matter which smoothed sunspot numbers we use — old or new — as both give very high correlation factors to the smoothed 10.7 centimeter solar flux. Thus the new smoothed sunspot number and smoothed 10.7 centimeter solar flux are still interchangeable in our prediction programs. But the equation in the ionospheric literature that ties the smoothed sunspot number to the smoothed 10.7 centimeter solar flux will have to be slightly modified.

Also note the anomalous data after the peak of Solar Cycle 23 in both figures. There is an obvious trend that decreases the correlation factors.

This anomalous behavior suggests that the Sun somehow changed after the peak of Solar Cycle 23. One reasonable explanation is the concept that sunspots are disappearing because their magnetic field strength has been decreasing. For more details read the update on my web page.[4]

Impact of New Sunspot Numbers — Propagation Predictions

For most Amateur Radio operators, the most important use of the sunspot number is in our propagation predictions. Let's see how it impacts our predictions.

The original worldwide database of ionospheric characteristics came from 5 years: 1954, 1955, 1956, 1957, and 1958.[5] Looking back at Figure 3, we see that this range of years covered solar minimum through solar maximum (but only the rising phase — the assumption was that the declining phase was identical). Data from the 1964 solar minimum period supplemented the 1954 data.

Using this data, scientists developed a model of the ionosphere — see my web page.[6] The model correlated monthly median ionospheric parameters — the F2 region critical frequency foF2 for vertical incidence and the multiplying factor M(3000)F2, which gives us the maximum usable frequency for a 3000 km hop — to a smoothed sunspot number from solar minimum to solar maximum — with a linear interpolation in between solar min and solar max.

The easiest way to show the difference between the old and new sunspot data is to go through an example. We'll analyze October 1968, which is around the peak of Solar Cycle 20. The data in Figure 3 says the old smoothed sunspot number is around 110 and the new smoothed sunspot number is around 155.

Select an ionosonde, download the data, and determine the monthly median foF2 — the critical frequency for the F2 region — at a given time. This will be the "truth." I'll use the Boulder ionosonde in Colorado. That exercise results in the monthly median foF2

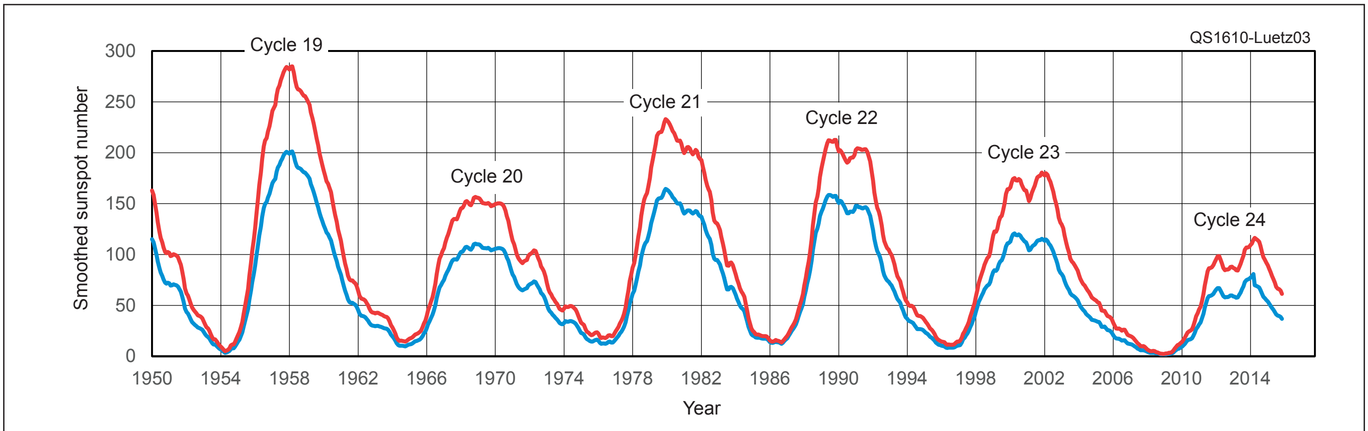

Figure 3 — New (red) and old (blue) sunspot data compared.

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#                              Recent Solar Indices
#                        of Observed Monthly Mean Values
#
#       -----------Sunspot Numbers--------- ----Radio Flux--- ---Geomagnetic---
#       ---Observed---- Ratio   --Smoothed- Observed Smoothed  Observed Smoothed
# YR MO    SWO     RI   RI/SW    SWO    RI    10.7cm  10.7cm      Ap        Ap
#--------------------------------------------------------------------------------
1991 01   213.5   136.9  0.64   220.5 147.6   229.4    205.5         8      17.4
1991 02   270.2   167.5  0.62   221.5 147.6   243.0    206.3        10      18.4
1991 03   227.9   141.9  0.62   220.7 146.6   230.0    205.9        27      19.1
1991 04   215.9   140.0  0.65   220.7 146.5   198.8    206.8        17      20.0
1991 05   182.5   121.3  0.66   219.6 145.5   190.3    207.1        18      21.7
1991 06   231.8   169.7  0.73   218.9 145.2   206.8    207.4        44      23.0
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Figure 4 — An excerpt of a recent solar indices monthly report.

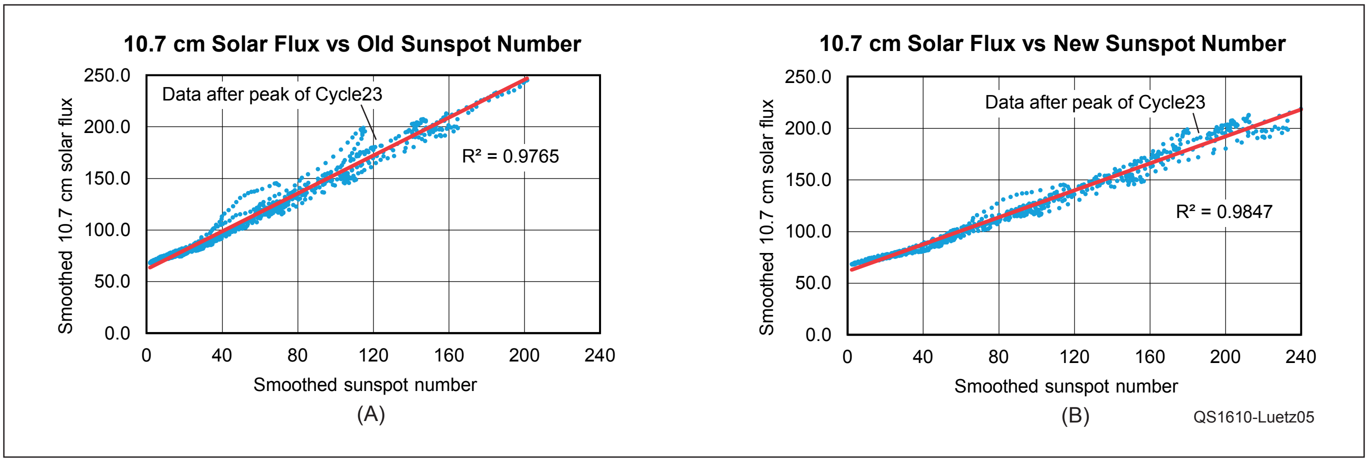

Figure 5 — Correlation of 10.7 centimeter solar flux to sunspot number.

Table 1
Predicted foF2. The measured "truth" from the Boulder ionosonde is 11.5 MHz.

Sunspot numbers	From *Proplab Pro V3*	From Ionospheric Predictions
Old	11.9 MHz	10.7 MHz
New	14.0 MHz	12.3 MHz

of 11.5 MHz over this ionosonde at 2000 UTC — about when the amount of ionization at Boulder maximizes on a typical day.

Next I looked at worldwide foF2 predictions for October 1968 at 2000 UTC using a smoothed sunspot number of 110. Then I looked at similar data using a smoothed sunspot number of 155. I did this using *Proplab Pro V3* and the *Ionospheric Predictions* from the 1971 hard-bound volumes of ionospheric data from the Institute for Telecommunication Science to compare two models of the ionosphere. Table 1 gives the result of this exercise for foF2 over Boulder for October 1968 at 2000 UTC.

The old sunspot numbers with *Proplab Pro V3* give a monthly median foF2 that is 0.4 MHz higher than the actual 11.5 MHz monthly median foF2 measured by the Boulder ionosonde. The old sunspot numbers with the *Ionospheric Predictions* give a monthly median foF2 that is 0.8 MHz lower than the actual 11.5 MHz monthly median foF2 measured by the Boulder ionosonde.

Considering the day-to-day variability of the F2 region, those errors aren't bad at all. For oblique propagation at low elevation angles, the maximum usable frequencies would be off by a couple MHz — which translates to an error less than one band up or down.

The predicted monthly median foF2 values using the new sunspot numbers are, of course, higher than the actual 11.5 MHz value — 2.5 MHz higher with *Proplab Pro V3* and 0.8 MHz higher with Ionospheric Predictions. Again, for oblique propagation at low elevation angles, the maximum usable frequencies would be off by up to several MHz, which translates to an error of one band. Much more data would be needed to properly analyze this.

One last topic with respect to predictions: the saturation effect in the F2 region. The ionization in the ionosphere may level off at some high smoothed sunspot number. Unfortunately, there's no consensus among scientists on this.

Lacking consensus, the F2 region model in *Proplab Pro V3* — the 2007 version of the International Reference Ionosphere — and the F2 region model in W6ELprop (Raymond Fricker's 23 equations) limit the foF2 values at smoothed sunspot numbers greater than about 150. But the F2 region model of the ionosphere in *VOACAP* doesn't do this. It very well could be that the saturation effect is at a much higher level than a smoothed sunspot number of about 150 as the old 150 value translates to a new smoothed sunspot number of around 210.

Summary

We have new sunspot numbers, and the Royal Observatory of Belgium began reporting these new numbers as of July 1, 2015. These new numbers will affect many calculations using sunspot numbers. With respect to our HF propagation predictions, the error looks to be on the order of one band up or down. I'm sure we'll see more discussion of the new sunspot numbers as time passes.

Notes

[1]**www.wm7d.net/hamradio/solar**
[2]Figure 2 based on data from Frederic Clette, Leif Svalgaard, Jose Vaquero, Edward Cliver; "Revisiting the Sunspot Number – A 400-Year Perspective on the Solar Cycle," *Space Science Review* (2014) *186*, pp 35 – 103.
[3]**ftp://ftp.swpc.noaa.gov/pub/weekly/RecentIndices.txt**
[4]**k9la.us/Jun14_Update_On_Disappearing_Sunspots.pdf**
[5]Report 340, *CCIR Atlas of ionospheric characteristics*, International Radio Consultative Committee (CCIR), 1983.
[6]**k9la.us/Feb16_Development_of_the_Model_of_the_Ionosphere.pdf**

Carl Luetzelschwab, K9LA since 1977, was first licensed in October 1961 as WN9AVT. His interests include propagation, contesting (he was Editor of *NCJ* from 2002 – 2007), DXing (he's on the top of the Honor Roll), antennas, and vintage gear. He and his wife Vicky, AE9YL, were team members of the 2001 YK9A DXpedition to Syria. They have operated from OJØ (Market Reef) and they enjoy the ARRL 10 Meter Contest from ZF (Cayman Islands). Carl can be reached at **k9la@arrl.net**.

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