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The NEW Sunspot Numbers

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In early March of this year I received a great question from Wayne Mills N7NG. He was browsing on WM7D's solar web site (http://www.wm7d.net/hamradio/solar/) and noticed that the smoothed sunspot numbers on the SILSO plot (Sunspot Index and Long-term Solar Observations from the Royal Observatory of Belgium) and the smoothed sunspot numbers on the ISES plot (International Space Environment Service from the Space Weather Prediction Center in Boulder) did not agree. Figures 1A and 1B show these two plots.

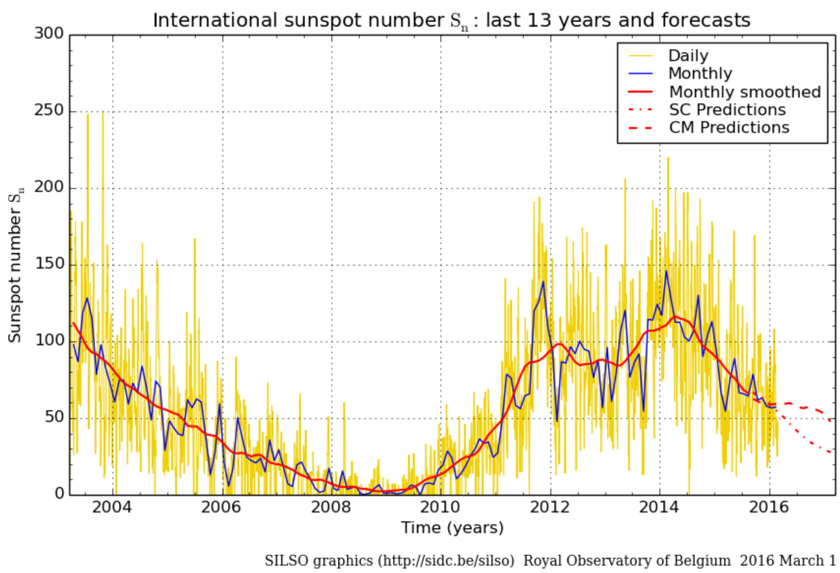

Figure 1A – SILSO plot

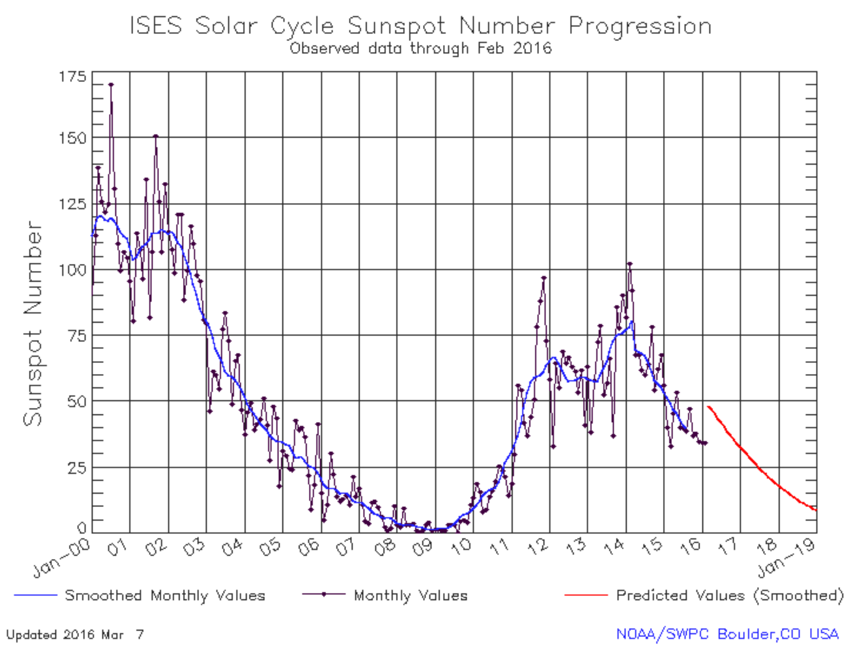

Figure 1B – ISES plot

For example, looking at the data indicates the smoothed sunspot number on the SILSO plot (the red line) at the second peak of 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.

Why Is There A Difference?

The simple answer is that we have a new set of sunspot numbers, and the new numbers are what the SILSO plot reports. The more involved answer is that counting sunspots is subjective – there's human interpretation involved. Having said that, let's start at the beginning and we'll see how we ended up with "new" sunspot numbers.

The sunspot number is calculated according to the following equation:

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

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.

As a reminder, the above equation is for the daily sunspot number. When the daily sunspot numbers are averaged for a month, we have monthly mean (monthly average) sunspot numbers. Unfortunately the monthly mean sunspot numbers are still spiky, and more averaging is applied to determine the smoothed sunspot number (this calculation uses 13 months of monthly mean data). The smoothed sunspot number is the official measure of a sunspot cycle. These calculation apply to 10.7 cm solar flux, too.

Including the scaling factor in the above equation makes it easy to understand why counting sunspots is subjective. Just the advances in telescopes over the years could affect the count, especially in trying to "see" small individual sunspots. 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. With at least five people determining the sunspot count, you can see possible trouble brewing.

Because of the importance of getting the sunspot numbers right for solar cycle models and climate studies (and Amateur Radio propagation predictions!), this issue has attracted much attention. 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 come to the conclusion that the old data may have a problem? There has always been some concern about the data, and the serious effort to understand the existing data started in the early 1990s when Douglas Hoyt and Kenneth Schatten asked the simple question “Do we have the correct reconstruction of solar activity?” Their question came from the problem of counting the number of individual sunspots – as mentioned earlier, the observing conditions, the telescope used and the observer’s bias plays a big part in this determination. To get around individual sunspot numbers, Hoyt and Schatten devised the Group Sunspot Number, 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 Group Sunspot Number. Regardless of this, the Group Sunspot Number enabled solar scientists to divide GSN (the group sunspot number) by R (the Wolf sunspot number). The resultant expectation was 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. The plot of Figure 2 (from reference 1) shows the ratio of GSN to R from about 1745 to 2000.

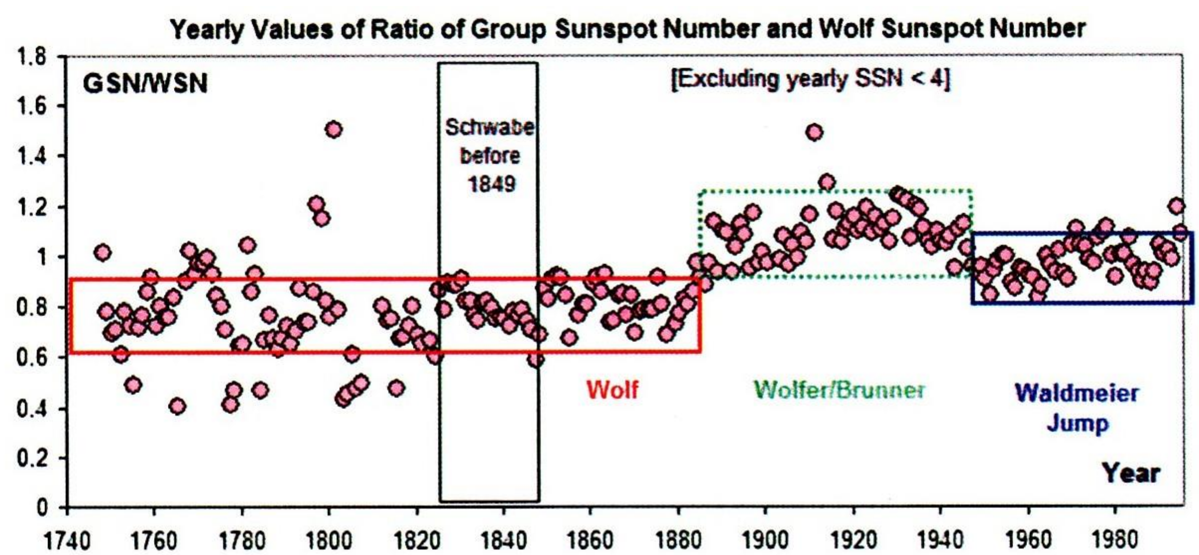

Figure 2

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 (actually more than one thing) changed in counting sunspots.

The upward step around 1885 appears to be due to Wolfer reporting more groups than Wolf (and his assistant Brunner continued this). This issue has largely been 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).

There are a couple other small corrections that came out of this concentrated study, and the total result is the ratio of GSN to R now being scattered about 1.00 with no significant step-ups or step-downs. There certainly is more scatter in the early years, but that is expected due to the more crude equipment back then.

The New Data Compared to the Old Data

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

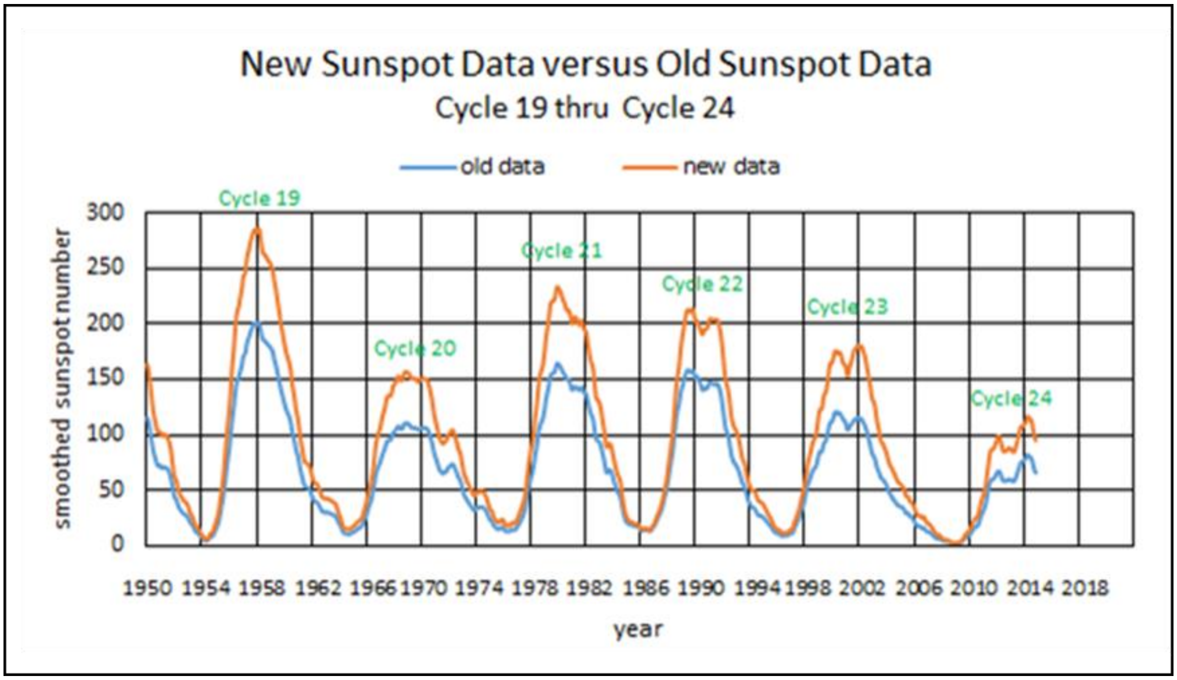

Figure 3

The old data in this range of years has been shifted up by around 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 NOAA's Recent Solar Indices monthly report (ftp://ftp.swpc.noaa.gov/pub/weekly/RecentIndices.txt). Figure 4 shows an excerpt of this data.

```
#                              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
```

Figure 4

Note that in the columns under the Sunspot Numbers category there are two sunspot numbers reported: one labeled SWO and the other labeled RI. The SWO data comes from Space Weather Operations, which is 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 and play with 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. Does that value sound familiar? It should, and 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 with the new sunspot numbers is that sunspot numbers are used in many other calculations. One relevant calculation is the correlation between the smoothed sunspot number and the smoothed 10.7 cm solar flux. Figure 5A shows this correlation from 1950 to the present using the old sunspot numbers, while Figure 5B shows this for the new sunspot numbers.

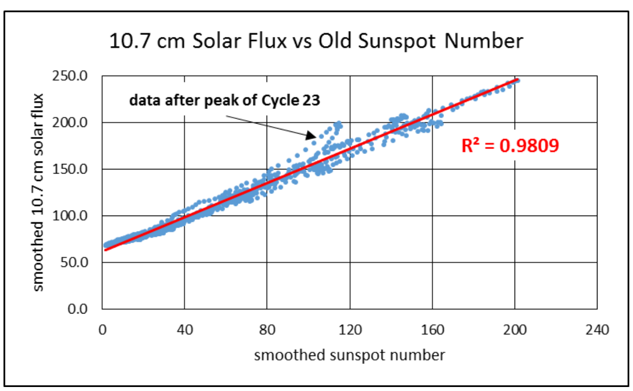

Figure 5A

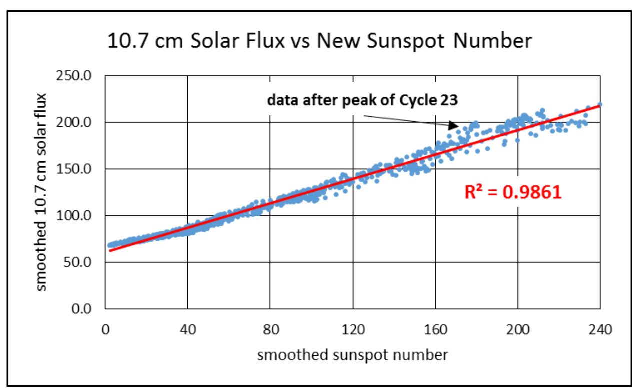

Figure 5B

Our propagation predictions are based on the correlation between monthly median ionospheric parameters and a smoothed solar index. The plots tells us that it doesn't matter which smoothed sunspot numbers we use – smoothed old sunspot numbers or smoothed new sunspot numbers – as both give very high correlation factors to the smoothed 10.7 cm solar flux (the new sunspot numbers are a bit better in this respect). Thus the new smoothed sunspot number and smoothed

10.7 cm 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 cm solar flux will have to be slightly modified.

Also note the anomalous data after the peak of Cycle 23 in both figures (it is annotated on both figures). There is an obvious trend that decreases the correlation factors. It's not as obvious with the new smoothed sunspot numbers – but it's still there.

This anomalous behavior suggests that the Sun somehow changed after the peak of Cycle 23. One of the most reasonable explanations is the concept that sunspots are disappearing because their magnetic field strength has been decreasing. For more details on this interesting topic, download and read http://k9la.us/Jun14_Update_On_Disappearing_Sunspots.pdf from my web site.

Impact of New Sunspot Numbers – Propagation Predictions

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

The original worldwide database of ionospheric characteristics came from five years: 1954, 1955, 1956, 1957 and 1958 (reference 2). 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). I should point out that data from the 1964 solar minimum period supplemented the 1954 data.

Using this data, scientists developed a model of the ionosphere (you can read about that endeavor at http://k9la.us/Feb16_Development_of_the_Model_of_the_Ionosphere.pdf). 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 useable 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 sunspot data and the new sunspot data is to go through an example. We'll select October 1968 for the month to analyze. This is around the peak of Cycle 20. Eyeballing the data in Figure 3 says the old smoothed sunspot number for October 1968 is around 110 and the new smoothed sunspot number is around 155.

The first order of business is to 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". The Boulder ionosonde in Colorado is one that always has a good data set, so I'll use it. Going through that exercise results in the monthly median foF2 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 (http://www.spacew.com/proplab/index.html) 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.

Table 1

	foF2 prediction from Proplab Pro V3	foF2 prediction from Ionospheric Predictions	The "truth" from the Boulder ionosonde
Old sunspot numbers	11.9 MHz	10.7 MHz	11.5 MHz
New sunspot numbers	14.0 MHz	12.3 MHz	

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 useable 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 useable frequencies would be off by up to several MHz – which translates to an error of one band.

I'll leave it at this for now, since this analysis was only at one time at one location for one old sunspot number and one new sunspot number. Much more data would be needed to properly analyze this.

There is one last topic with respect to predictions that is tied to the increased sunspot numbers in the new data. It's the saturation effect in the F2 region. In other words, the ionization in the ionosphere may level off at some high smoothed sunspot number. Unfortunately there doesn't appear to be consensus among scientists on this.

As a result of the lack of a 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 twenty-three 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 times passes.

References

1. Frederic Clette, Leif Svalgaard, Jose Vaquero, Edward Cliver; Revisiting the Sunspot Number – A 400-Year Perspective on the Solar Cycle; Space Science Review (2014) 186:35-103

2. Report 340; CCIR Atlas of ionospheric characteristics; CCIR (International Radio Consultative Committee); 1983