

This short document describes the two algorithms used on this site (spawx.nwra.com) for converting between observations of the solar 10.7 cm solar radio flux and various versions of sunspot number. Two algorithms are needed because the international community has decided to rescale the sunspot number series (see references within this paper), and there appears to have been a change in the relationship between the radio flux and sunspot number indexes since the original algorithm was developed (in 1972).

Original Relationship

What will be referred to as the “original” relationship is from *Stewart and Leftin (1972)*, in which they derived the following relationship between the 13-month smoothed 10.7 cm solar radio noise flux (SF10) and the 13-month smoothed sunspot number (SSN) using data from Nov 1947 (descending side of Cycle 18) through Nov 1968 (ascending side of Cycle 20):

$$SF10 = 63.7451 + 0.728015 \times SSN + 0.000890443 \times SSN^2 \quad (1)$$

(from their Equation 1). Figure 1 shows this relationship (green circles) plotted with the data from the fit interval (black circles), and Figure 2 shows the same data plotted as a function of date (same color scheme as Figure 1). This relationship has been used in many ionospheric models, including the current International Reference Ionosphere (IRI) model (*Bilitza, 2018*), typically with the number of significant digits in the constants reduced to three or four.

New Relationship

During the decade of 2010 to 2020 two changes came about that require the development of a new relationship between SF10 and SSN: (1) in a series of workshops from 2011 through 2014 the international community of solar observers re-examined the historic sunspot number series and determined that a rescaling was required (SSN-Workshop Wiki, 2015; *Clette and Lefèvre, 2015*), and (2) the solar radio community found that the relationship between SF10 and SSN was different in Cycles 23 and 24 had changed from the relationship as represented by Equation (1) (*Tapping and Morgan, 2017*).

We have developed a new relationship using data from Cycles 23 and 24 based on the rescaled sunspot number (referred to by the community as sunspot number version 2.0, referred to here as SSN_2). In looking at the changed relationship between SF10 and SSN_2 *Tapping and Morgan (2017)* noted that there appears to be a knee, or break, in the relationship around SSN_2 of 20. They postulate that this might indicate a change in the predominate source of the 10.7cm solar flux. Following this, we have developed a simple relationship using two linear fits, one over the range $SSN_2 = 0$ to 20, and the second over $SSN_2 = 20$ to 200 (past the highest observed SSN_2) using data from Cycles 23 and 24 (May 1996 through December 2019):

$$SF10 = \begin{cases} 67.90 + 0.447 \times SSN_2 & \text{for } SSN_2 \leq SSN_b \\ 62.98 + 0.678 \times SSN_2 & \text{for } SSN_2 > SSN_b \end{cases} \quad (2)$$

where SSN_b is where the two linear segments intersect ($SSN_b = 21.30$ for the equations shown). Figures 3 and 4 are repeats of Figures 1 and 2 using the relationship in Equation (2) covering the

interval May 1996 through December 2019. Note that in Figure 3 the red circles are the new model (Equation (2)) and the green circles are the old model (Equation (1)).

Use on This Site

With one exception this site will use the relationship shown in Equation (2) to calculate estimates of SF10 from observations of SSN₂ or of SSN₂ from observations of SF10. The one exception is the multi-Cycle plot of effective SSN (URL <https://spawx.nwra.com/spawx/ssne-cycle.html>). The effective SSN (SSN_e) parameter is derived by fitting a model of the ionosphere foF2 parameter to observations of foF2. That model was derived initially using observation from 1958 (the first half of Cycle 20), which is within the interval covered by Equation (1), and the model is based on the old sunspot number series (sunspot number version 1.0) (*Jones and Obitts, 1970*). For a meaningful comparison between a proxy SSN and an SSN derived from solar observations we are retaining the use of Equation (1) to generate what is referred to as SSN_f from the observed F10.7 for this one plot.

Also with one exception all plots and listings of sunspot number and F10.7-based sunspot number will use the V2.0 sunspot number scaling, and all plots and listings of the effective sunspot number will use the V1.0 sunspot number scaling. That one exception is the sunspot number comparison plot (URL <http://spawx.nwra.com/spawx/comp.html>) in which the effective sunspot number is adjusted to the V2.0 scaling to be consistent with the other indexes used in the plot. All plot axis labels for sunspot numbers will specify which scaling has been used.

References:

Bilitza, D. (2018), IRI the International Standard for the Ionosphere, *Adv. Radio Sci.*, 16, 1-11.

Clette, F., and L. Lefèvre (2015), The new sunspot number: assembling all corrections, *Solar Phys.*, 291, DOI:10.1007/s11207-016-1014-7.

Jones, W. B., and D. L. Obitts (1970), Global Representation of Annual and Solar Cycle Variation of foF2 Monthly Median 1954-1958, *Research Report OT/ITSRR 3*, U.S. Institute for Telecommunication Sciences, COM 75-11143/AS, National Technical Information Service, Springfield, Virginia, 1970.

SSN-Workshop Wiki (2014), URL <https://ssnworkshop.fandom.com/wiki/Home>.

Stewart, F. G., and M. Leftin (1972), Relationship Between Ottawa 10.7 cm Solar Radio Noise Flux and Zurich Sunspot Number, *Telecomm. J.*, 39, 159-169.

Tapping, K., and C. Morgan (2017), Changing relationship between sunspot number, total sunspot area, and F10.7 in Cycles 23 and 24, *Solar Phys.*, 292:73, DOI 10.1007/s11207-017-111-6.

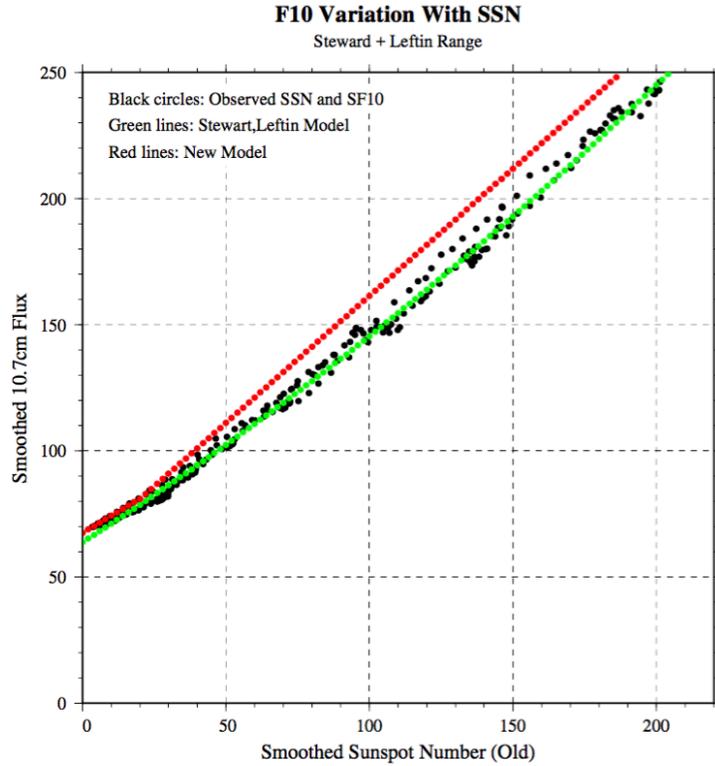


Figure 1. Variation of SF10 with SSN (old version, version 1.0) showing observations from the period Nov 1947 through Nov 1968 (black circles), the Stewart and Leftin model (green circles), and the new model (red circles). Note that the results from the new model have been scaled to the v1.0 sunspot number scaling.

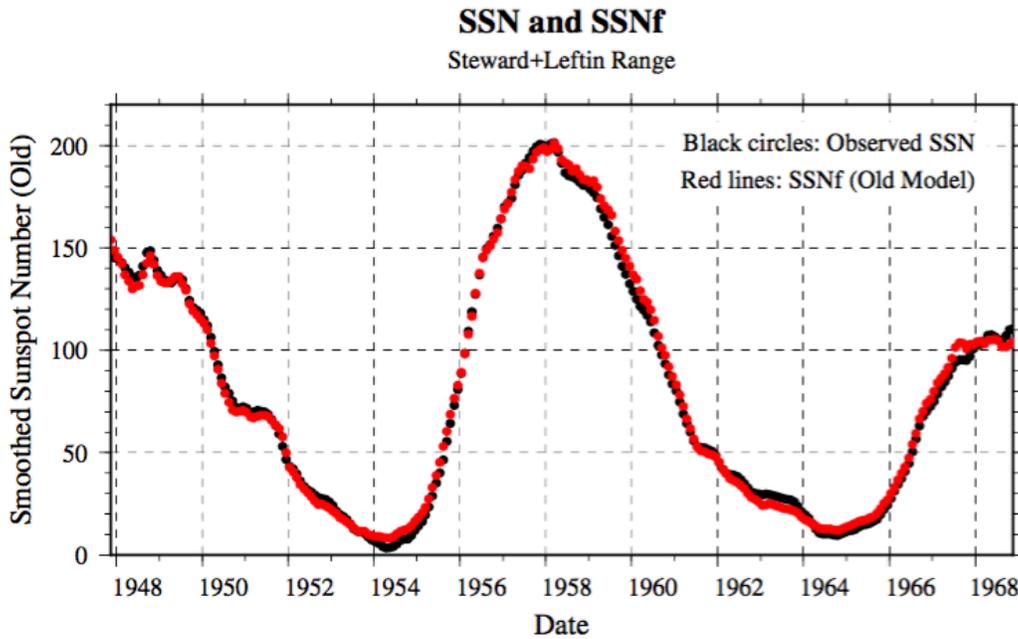


Figure 2. SSN (version 1.0) for the Nov 1947 through Nov 1968 period (black circles) showing the SSN derived from SF10 observations using the Stewart and Leftin model (red circles).

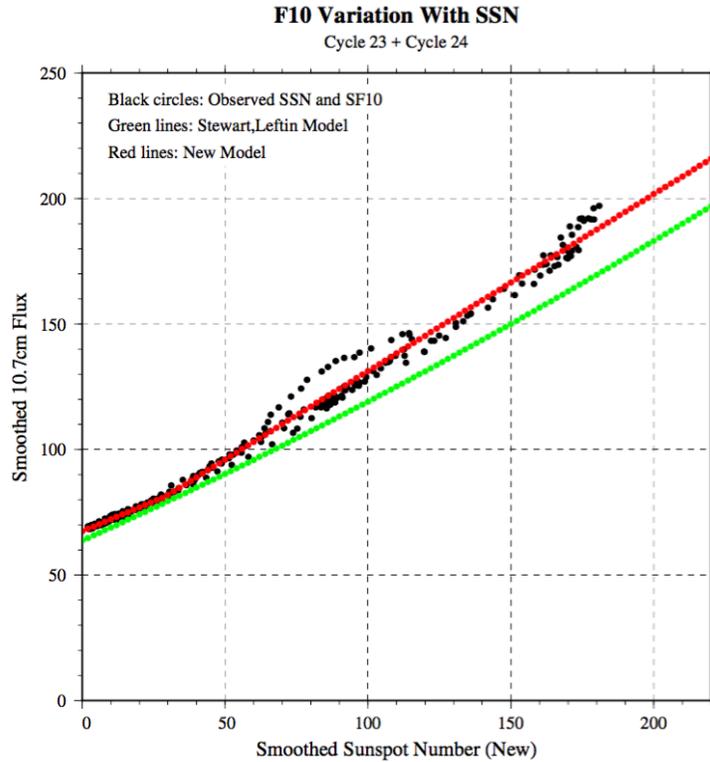


Figure 3. Variation of SF10 with SSN (new version, version 2.0) showing observations from the period May 1996 through Dec 2019 (black circles), the Stewart and Leftin model (green circles), and the new model (red circles). Note that the results from the Stewart and Leftin model have been scaled to the v2.0 sunspot number scaling.

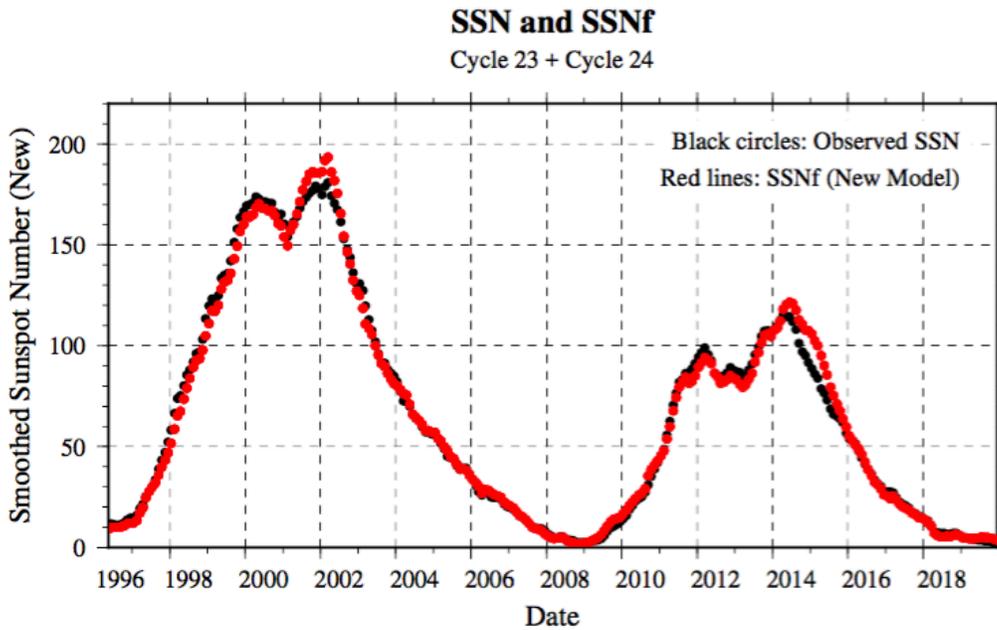


Figure 2. SSN (version 2.0) for the May 1996 through Dec 2019 period (black circles) showing the SSN derived from SF10 observations using the new model (red circles).