Cycle 25 Predictions

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I'm writing this at the end of July, and at this time I'm aware of 27 predictions for Cycle 25. There are probably some predictions out there that I missed, and I'm sure there will be more predictions in the near future.

An important issue here is that we have to make sure we understand which sunspot record the prediction is for. Remember that in July 2015 the Royal Observatory of Belgium began reporting the new V2.0 sunspot numbers (see the April 2016 Monthly Feature at https://k9la.us for a discussion of this important issue). The revision of the old V1.0 sunspot numbers to the new V2.0 sunspot numbers goes all the way back to July 1749. The revision to the old record is significant enough to make sure we know which version of the sunspot record we're talking about.

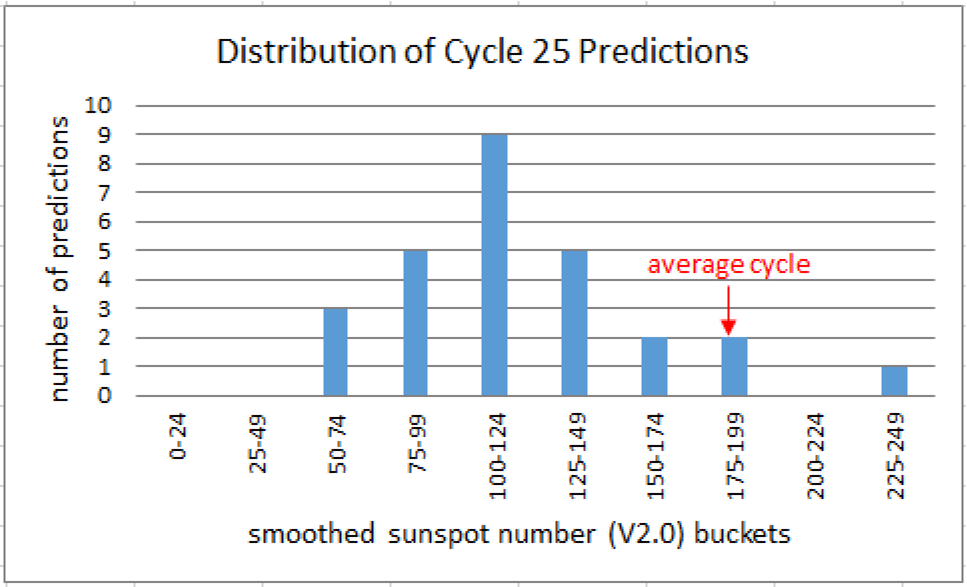
The following table lists the 27 predictions that I'm aware of, and they are in ascending order of the predicted maximum smoothed sunspot number. These predictions are in terms of the new V2.0 sunspot record (those predictions converted from the old sunspot record are noted).

	minimum date	maximum date	maximum (V2.0)	author(s)	prediction date
1			50 +/-7 (converted from V1.0)	Javaraiah	2017
		2022-2023	57 +/-17	Covas, et al	2019
			71 (converted from V1.0)	Javaraiah	2014
			78	Upton and Hathaway	2017
5			85 +/-5	Bisoi and Janardhan	2019
	2020.5 +/- 0.12	2027.2 +/1 1.0	89 +29/-14	Labonville, et al	2019
	2019-2020	2024 +/- 1	90 +/-15	Kitiashvili	2016
			94 (converted from V1.0)	Shepherd, Zharkov, Zharkova	2014
		2024	excess of 100	Bhowmik and Nandy	2018
10		2024 +/- 0.6	103 +/-25	Singh and Bhargawa	2017
	2020.9		110	Upton and Hathaway	2018
	April 2020 +/- 6 months	July 2025 +/- 8 months	115	NOAA/NASA Solar Cycle 25 Prediction Panel	2019
			117	Hawkes and Berger	2018
			117 +/-15	Petrovay	2019
15		2025.2 +/- 1.5	120 +/-39	Pesnell and Schatten	2018
			121.5 +/-32.9	Miao, et al	2020
			124 +/-31	Jiang, et al	2018
		2022	130 (converted from V1.0)	Attia, et al	2013
	2019.4	2024.8	130	Petrovay	2018
20			134	Bisoi, Janardhan, Ananthakrishnan	2020
			136	Svalgaard	2017
			136 +/-48	Pesnell and Shatten	2018
		2023.2 +/- 1.1	154 +/-12	Sarp, et al	2018
			169 (converted from V1.0)	Helal and Galal	2012
25	2019.9	2023.8	175 (154-202)	Li, et al	2015
		2023.4	188 (converted from V1.0)	Rigozo, et al	2011
			229 +/-25 (68% confidence)	McIntosh, et al	2020

There's quite a range to the predictions – from a low of 50 +/-7 to a high of 229 +/- 25. What this tells us is that we still don't fully understand the process that makes sunspots.

If you recall, the predictions for Cycle 24 also had a wide range. In fact, initially the NOAA/NASA Solar Cycle 24 Prediction Panel was split down the middle, and they issued two predictions for Cycle 24 – one low and one high. As the duration of the solar minimum period between Cycles 23 and 24 increased, solar scientists came to a consensus that the prediction of a low cycle would be the one most likely – and, indeed, it turned out to be the most accurate one.

What does the distribution of the Cycle 25 predictions look like? Are they all over the map like the Cycle 24 predictions? Or is there some consensus among solar scientists? Here's a plot of the distribution.



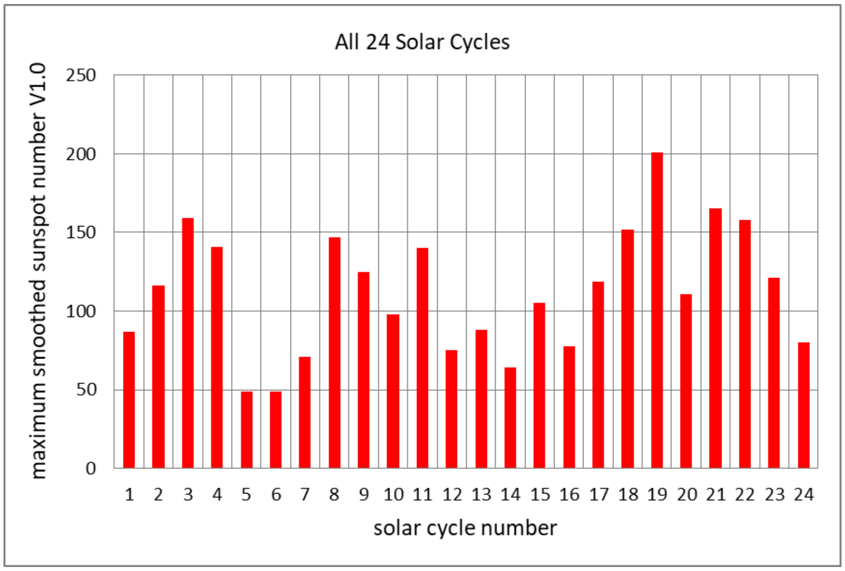
There seems to be a consensus for Cycle 25 among solar scientists. Nine of the twenty seven predictions (33%) are for a maximum smoothed sunspot number in the 100-124 bucket. Nineteen of the twenty seven predictions (70%) are for a maximum smoothed sunspot number between 75 and 149. And twenty six of the twenty seven (96%) predict that Cycle 25 will be equal to or smaller than an average cycle, which is 179 for all twenty four cycles in terms of the V2.0 sunspot number (the average is around 120 in the old V1.0 sunspot numbers).

Now let's look at the lowest and highest predictions in the table – the one for a maximum smoothed sunspot number of 50 +/-7 (V2.0) that is in the 50-74 bucket and the prediction for a maximum smoothed sunspot number (V2.0) of 229 +/- 25 that is in the 225-249 bucket.

<u>The 50 +/-7 prediction</u>

This prediction comes from J. Javaraiah in 2017 (formerly of the Indian Institute of Astrophysics). Note from the table that this is the second of his two predictions (the first was in 2014).

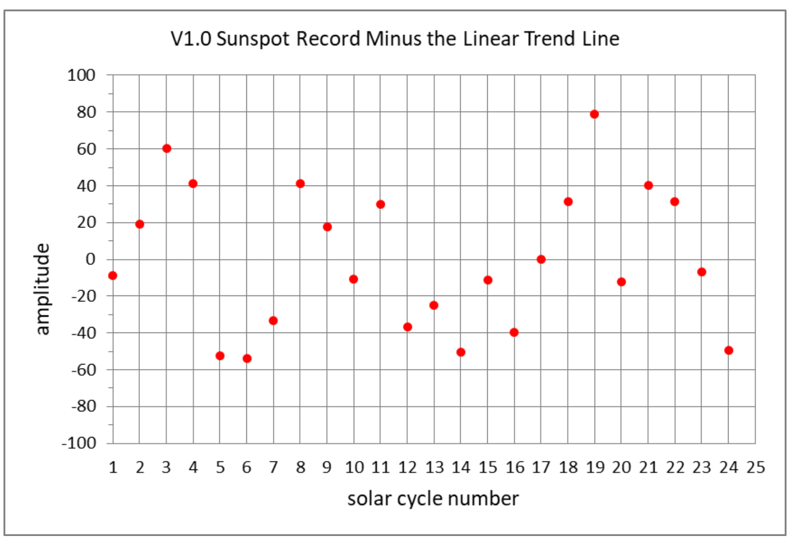
The fundamental basis for his prediction is the Gleissberg cycle in our sunspot records. Here's a plot of the maximum old V1.0 smoothed sunspot numbers for all 24 cycles. This plot is in terms of the old V1.0 sunspot record as the paper was in terms of the V1.0 sunspots. A plot of the maximum new V2.0 smoothed sunspot numbers shows the same cyclic trend – just higher amplitudes.



The cyclic trend is quite obvious. We started with several big cycles, then we had several small cycles, then again several big cycles, then again several small cycles, then again several big cycles and finally we appear to be in (or headed towards) a period of several small cycles. Cycle 19 is an "anchor point" of the old V1.0 record – its maximum smoothed sunspot number was 201 in March 1958.

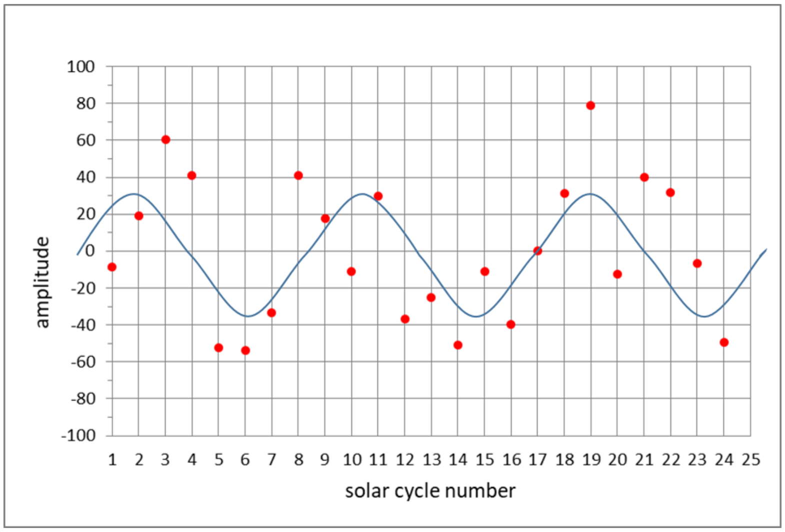
The period of these ups-and-downs is approximately 88 years, and is named the Gleissberg cycle after M.N. Gleissberg due to his observation of this trend in 1939.

What Javaraiah did was fit a linear trend line to the 24 years of sunspot data. Then he subtracted this linear trend line from the V1.0 record. The result was as follows, with the maximum smoothed sunspot numbers plotted as dots rather than in column format.



As you can see, the sunspot record is now vertically centered on 0.

Then Javaraiah fit a cosine function to the data, and it looks like this.



Now we can follow the cosine curve to the Cycle 25 marker on the horizontal axis. Adding the linear trend line back to the -10 value on the plot gives a Cycle 25 maximum of 119 in terms of the V1.0 sunspot number, which translates to 170 in terms of the V2.0 sunspot number. So where did the much lower prediction of 50 +/-7 come from?

Javaraiah recognized that the cosine fit to the 24 data points was not very good. So he looked at two other parameters: the Gnevyshev-Ohl rule [reference 1] and the orbital angular momentum of the Sun about the center of mass of the solar system [reference 2]. Bringing these two parameters into the picture resulted in the V1.0 prediction of 35 +/-5, which translates to the V2.0 prediction of 50 +/-7.

If you'd like to dig deeper into Javaraiah's paper, you can download it and read it here: https://arxiv.org/abs/1711.04117.

The 229 +/-25 prediction

We generally think of solar minimum as the month and year when the smoothed sunspot number numerically minimizes [reference 3]. Accepting that assumption, we then usually think of the old cycle ending and the new cycle beginning at this definition of solar minimum.

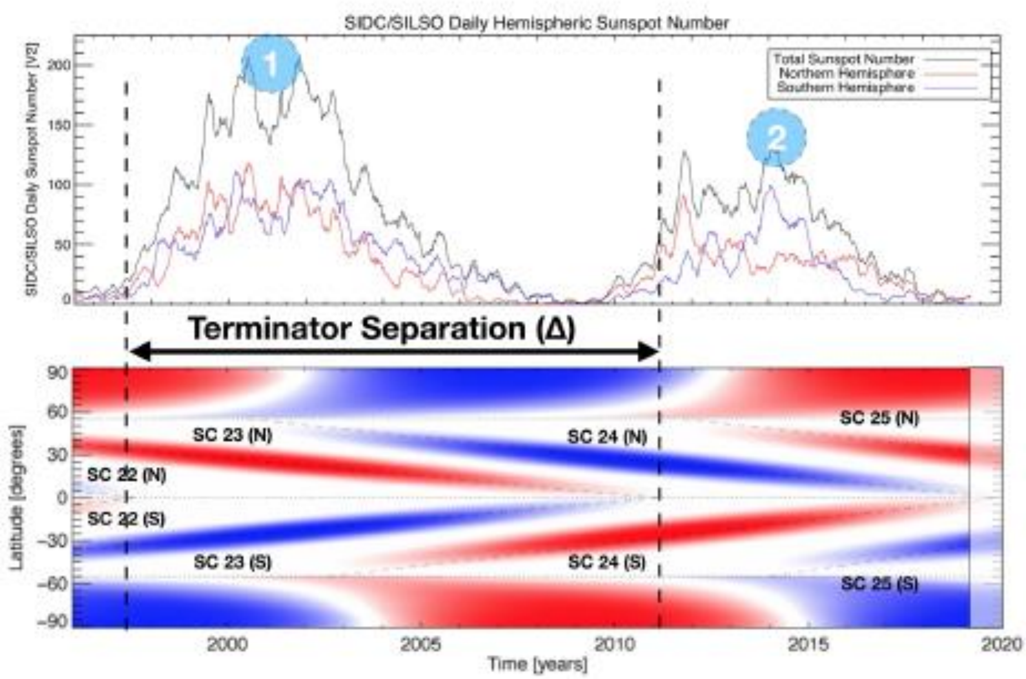
There is a problem with this. The numerical minimum of the smoothed sunspot number between Cycles 24 and 25 will likely be around the early months of 2020. But the first official Cycle 25 sunspot region was in July 2019 – it was large enough and lasted long enough to be assigned an Active Region number. This was almost a year before the anticipated numerical minimum. More importantly, there were even earlier Cycle 25 sunspots. For example, on November 19, 2018, a Cycle 25 sunspot region emerged in the northern solar hemisphere but it was so small and so short-lived that it wasn't assigned an Active Region number. But it was a Cycle 25 sunspot.

And on July 11, 2020, we saw a Cycle 24 sunspot region, which will likely be after the month/year of solar minimum. These dates suggest that Cycle 24 ended in July 2020 (maybe even later if some more Cycle 24 sunspots still show up) and Cycle 25 started in November 2018. Although some of the date are tentative, it doesn't look like they're going to line up with the common definition of solar minimum.

Thus solar minimum does not necessarily indicate when sunspots from the old cycle end and when sunspots from the new cycle start. The authors of the 229 +/-25 prediction (McIntosh, et al) focused on the fact that a complete solar cycle is actually around 22 years [reference 4}, and they inferred that the sunspot cycle could be described in terms of the magnetic interactions of the oppositely-polarized overlapping toroidal bands of this 22-year magnetic activity cycle.

An earlier paper in 2014 (McIntosh, et al) worked through all this for the last 60 years of solar activity. The 2020 paper, with the 229 +/-25 prediction, expanded the analysis back to Cycle 1.

The result of all this work was their Figure M1 in the 2020 paper (McIntosh, S.W., Chapman, S.C., Leamon, R.J., Egeland, R. and Watkins, N.W., *Overlapping Magnetic Activity Cycles and the Sunspot Number: Forecasting Sunspot Cycle 25 Amplitude*, Solar and Stellar Astrophysics, arXiv:2006.15263v1). This paper is available for download at https://arxiv.org/abs/2006.15263).



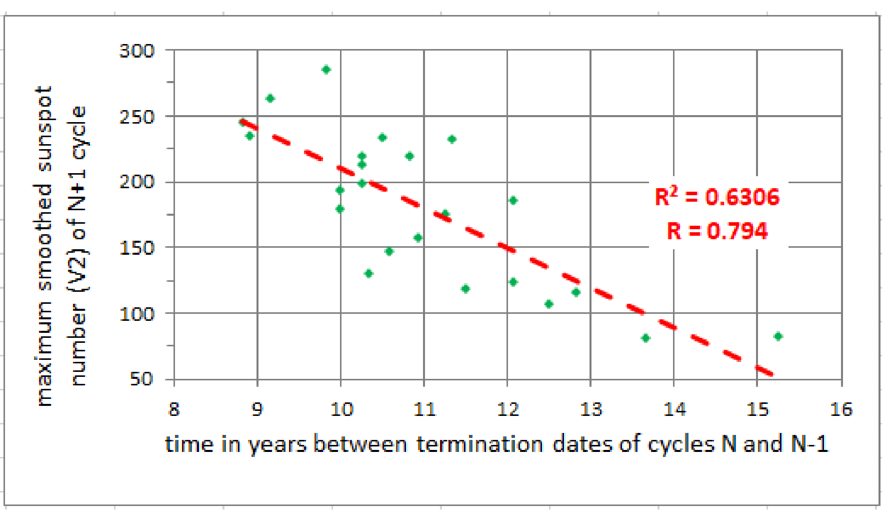
The upper plot is the daily hemispheric sunspot numbers for Cycle 23 (annotated with the number 1) and Cycle 24 (annotated with the number 2). Note that the sunspot numbers versus time in both solar hemispheres were somewhat similar for Cycle 23, but were much more out-of-sync in Cycle 24.

The bottom plot is the meat of the analysis. What the authors are showing are the inferred magnetic activity bands for the end of Cycle 22 (kind of tough to see way on the left, but they are there) and the full bands for Cycles 23 and 24 (well, almost the full band for Cycle 24). The magnetic end of Cycle 22 is when the colored bands converge at the solar equator – early 1997 (this is identified by the dashed vertical line). Similarly, the magnetic end of Cycle 23 is early 2011 (also identified with a dashed vertical line). The magnetic end of Cycle 24 is expected to have occurred in early 2020.

These colored bands begin around a latitude of +/- 55^{o}, and are the inferred start of the magnetic cycle for a solar cycle. They are not necessarily in-sync timewise for the two hemispheres, as confirmed by the upper plot of sunspots. Also note that the end of a magnetic cycle (the old cycle) is after the time when the sunspot number minimized numerically. The data also suggest that sunspots from the new cycle may occur well before the time the sunspot number minimized numerically. These two observations agree with my comments on the last Cycle 24 sunspot (so far) and the first Cycle 25 sunspots. Finally, note that these inferred magnetic bands reverse polarity from Cycle 23 to Cycle 24 – thus indicating the 22-year Hale cycle.

The authors provided tabular data of the time from the end of one magnetic cycle to the end of the next magnetic cycle. They called the end of a magnetic cycle the 'termination date'. They listed the termination dates for all the cycles. Their prediction comes from the correlation between the amplitude of the next cycle and the termination dates of previous cycles. Mathematically speaking, their method predicts the maximum smoothed sunspot number of cycle N+1 versus the time between the termination dates of cycle N and cycle N-1.

I took their tabular data and did a scatter plot. Here's that correlation. To reiterate, this prediction method for a solar cycle is based on the magnetic cycle end dates of the previous two cycles.

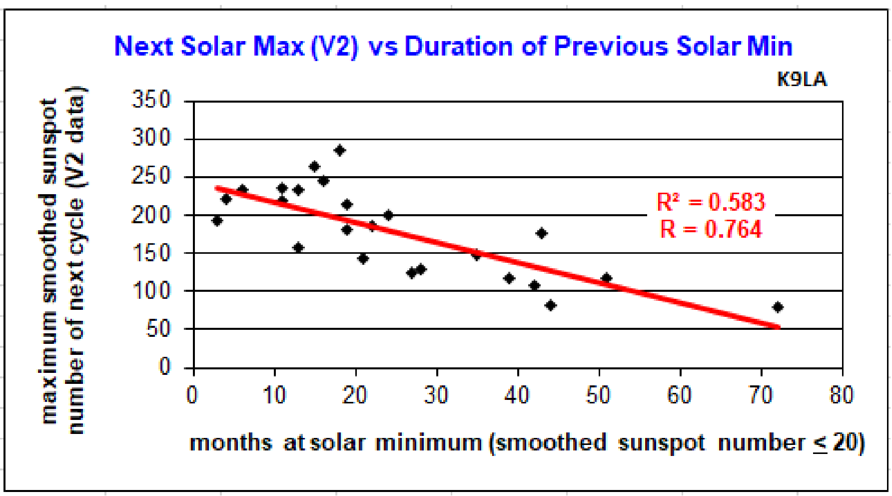


The correlation coefficient of 0.794 of the dashed red linear trend line is very high, indicating a strong correlation. The shorter the time between termination dates (between the ends of the magnetic cycles), the stronger the cycle. Their estimate for the time between the end of the Cycle 24 magnetic cycle and the end of the Cycle 23 magnetic cycle is 9.29 years, which gives the prediction for Cycle 25 of 229 +/- 25.

The authors acknowledged that the value of 9.29 years for the difference between termination times of Cycles 23 and 24 would be a severe outlier with respect to the behavior of previous sunspot cycles. The determination of the actual date for the Cycle 24 termination date (it's just an estimate at the moment) will permit higher fidelity on their prediction.

A Contradiction

For many years I've used a plot of the correlation between the duration of a solar minimum period (how many months the smoothed sunspot number was less than or equal to 20) and the magnitude of the next cycle. Here's that plot.



This says the longer the previous solar minimum period, the smaller the next cycle. The correlation coefficient of this plot is very high, too. With our current solar minimum on target for at least 50 months by my definition, the above plot suggests that Cycle 25 is going to be small.

One of these two scatter plots may be a great example of two parameters being highly correlated, but with no true cause-and-effect. So which one of these scatter plots is going to be more accurate? The 'termination date' plot or the 'solar minimum duration' plot? I'll let you know around 2024!

A final comment

What we're seeing in all 27 predictions is the scientific method. You propose a hypothesis, and then validate or shoot down the hypothesis. Predicting a football game, and then waiting several hours to validate your prediction is very common.

But a solar cycle, being on the order of 11 years, means the validation could be a long way off. Even a prediction at solar minimum may take 4 years to validate since the average rise time of a solar cycle is around 4 years.

References

1) The Gnevyshev-Ohl rule states that the sum of the annual international sunspot number during an odd-numbered cycle exceeds that of the preceding even-numbered cycle. However, the Gnevyshev-Ohl rule is occasionally violated.

2) The orbital angular momentum of the Sun about the center of mass of the solar system has been decreasing steadily since about 1600 (four centuries ago), and it appears to factor into the times when the Gnevyshev-Ohl rule is violated.

3) But you have to watch it here. Not all solar parameters minimize when the smoothed sunspot number minimizes. Other considerations may be involved when defining "solar minimum".

4) The 22-year cycle is called the Hale cycle after G.E. Hale and his colleagues. The Sun's magnetic field flips polarity at solar maximum, and thus it takes two 11-year cycles to get back to the original magnetic field orientation.