The Solar Cycle and F2 Propagation

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F2 Propagation – There are a number of different, solar-related, ionospheric radio-propagation mechanisms that can be available in the HF and lower VHF ranges. Generally speaking, the major players are those that involve creating ionospheric refraction in the E Region (typically 105 km), the F1 Region (typically 200 km), and the F2 Region (typically 300 km).

F2 propagation can be especially exciting for many. At F2 heights, single-hop signals can travel 4,000 km or more. So, multihop F2 paths can really stretch out the distance. At F2 heights, solar ultraviolet radiation (UV) produces free electrons by ionizing O_1. If the amount of ionization is great enough, the resulting free electrons can provide propagation up to the maximum usable frequency (MUF) – and the more free electrons, the higher the MUF. This is especially important for DX at 6 meters (and 10 and 5 meters). The key driver is the amount of solar *activity*, which peaks during solar *maximum*. So, having advanced knowledge of when solar maximum will occur, and how intense it will be, would be useful to take best advantage of the opportunities. *Unfortunately*, this is very difficult to do.

Sunspots – In late 1610 and early 1611, Galileo and two other different observers became aware of the existence of sunspots – by using a then-new invention – the telescope. Later on, a useful set of sunspot records was assembled from late 1610 through 1750. These were then added to the newer records kept since then. (The current sunspot-cycle numbering system begins with 1750). This activity summary is shown in Figure 1. Of course, lots of vigorous active sunspots are required to make F2 propagation work.

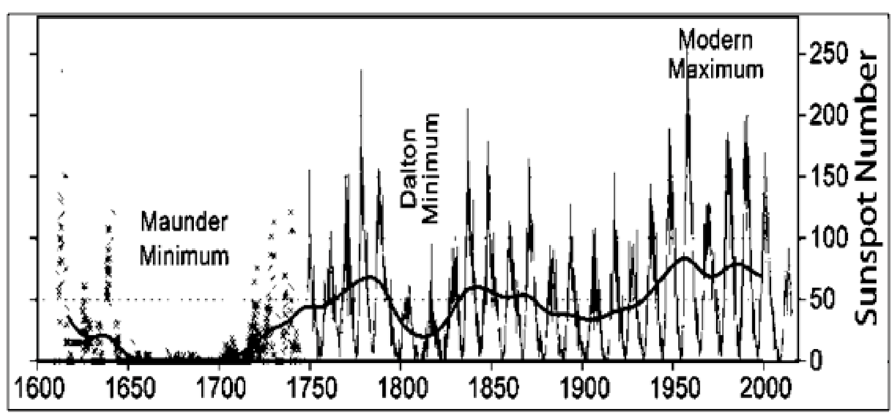

Figure 1: This shows a summary of the known, 400-year, history of solar cycles. Note the quite prolonged Maunder and Dalton Minimums. *Credit: NASA-MSFC*

Sunspots are born after a *long* gestation, ranging from 18 to 28 years. A key ingredient is the *leftover* magnetic fields from earlier solar cycles. (Yes, the Sun *recycles*.) Shards of leftover magnetic fields become firmly attached to small "chunks" of Sun. These are bunches of highly ionized hydrogen atoms, with some helium atoms. The chunks move solar magnetic material from the recently worn out sunspots near the surface, and sweeps them towards the nearest pole. Sunspot birthing starts, as the magnetic fields grow larger – until they finally appear as new sunspots.

Two Kinds of Cycles? **–** Yes, there are *two*, related, solar cycles. They are both found in the outer one-third of the Sun, and they are intimately connected. The first cycle is the 22- to 28-year *Magnetic Cycle* (the "gestation period"). During this cycle, the Sun's prominent magnetic structures actually *reverse* polarities about halfway through the Magnetic cycle. The second cycle is the *Activity Cycle*. This is the traditional Sunspot Cycle, ranging from 9 to 14 years, that is, *one half* of a Magnetic Cycle.

Solar *Magnetic* Cycle – Mechanically, the solar cycle results from two, powerful, heat-driven, north-south *convection* loops in the upper one-third of the Sun. One loop is in the Sun's northern hemisphere, and the other in its southern hemisphere (Figure 2). Starting at the Sun's visible surface, close to the equator, the flow first moves toward the nearest pole. Much closer to the pole, the convection flow loops *downward*, deeper into the Sun. Further down, at that lower level, it loops back toward the equator. Near the equator, it loops back *upwards* toward the surface. When it completes a full loop, it starts moving back toward the pole again. Meanwhile the opposite solar hemisphere does the same thing – more or less in step. In the process, the poleward surface flow *recycles* the magnetic leftovers from the current cycle, *and* the leftovers of the immediately *previous* solar cycle, in each of the northern and southern hemispheres, at the same time.

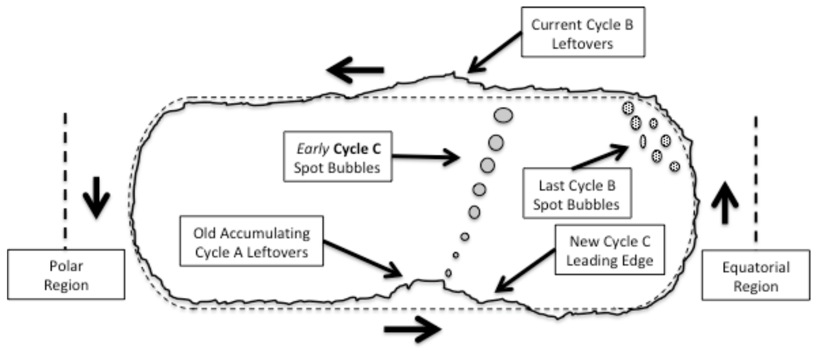

Figure 2: Active **Cycle B** is well past maximum, a few magnetic bubbles still rising. Old, now *enhanced*, **Cycle A** bubbles float to the surface. Some will become the earliest *new* **Cycle C** sunspots. On average, the whole magnetic loop takes about 22 years. This is two 11-year Activity cycles.

So, as if moving on a conveyor belt, the solar chunks (and their "old" magnetic fields) move around the loop. Over time, they also attract and *collect* additional fields from other chunks, as they pass them by. As a result, they collect more and more additional magnetic field. About three-quarters of the way around the loop, deeper in the Sun, and now moving toward the equator, a dynamic interaction between the motion of given chunk, and its magnetic field, causes it to begin to *spin*. The spinning chunk's magnetic field makes its physical size begin to *expand*, and *increases* its field strength. Some of the other nearby chunks also do the same thing. They each become buoyant, and they begin to rise like *bubbles*. As they rise, they continue to expand, the spinning speeds up, the magnetic field, and energy of the upward motions increases. Then, much later nearer the end of the loop, the remaining chunks circle back toward the surface, with added force of the conveyor belt motion, and many more magnetic bubbles are spawned, moving toward *new* cycle solar maximum.

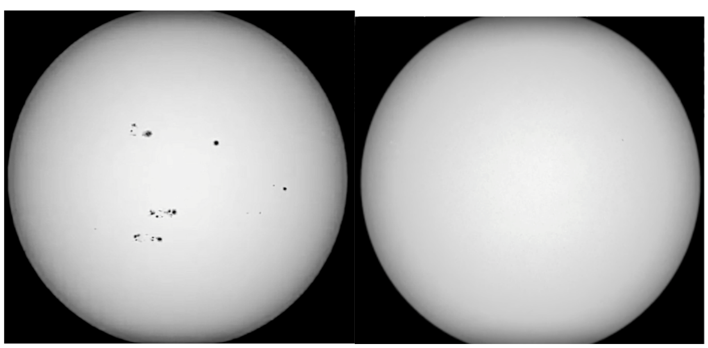

Figure 3: Cycle 24 sunspots. *Left*: Near solar maximum (June 2014); *Right*: Near solar minimum (December 2016). Note the difference between max and min. *Credit: NASA Goddard - SDO*

Making Sunspots – Switching now to the solar *surface*, it is important to know that near the solar equator, the normal *surface* magnetic field lines are organized along east-west lines, basically *parallel* to the equator. Their field strengths are *quite intense*. On the other hand, the rising bubbles are like gigantic magnetic hurricanes. They are extremely powerful and tightly focused, rather like a cannon ball. So, when the two different fields collide, a very violent event occurs.

As the bubbles arrive at the surface, they crash into, and even through, the Sun's *surface* magnetic field. This forces the surface field to bend outwards, and even break, releasing enormous amounts of energy into space. Much of this is in the form of short-wavelength radiation, including a lot of UV. If the angles are right, the UV travels outward, and arrives at the Earth's atmosphere and ionizes the upper regions, leading to radio propagation opportunities (Figure 4).

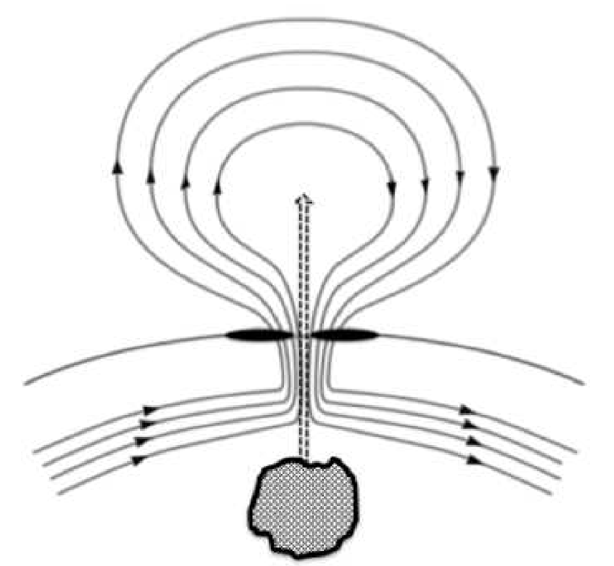

Figure 4: The rising "bubble" of magnetic energy reshapes the *surface* magnetic field, and releases UV radiation that ionizes the F2 Region that can produce high MUF propagation. The two dark ovals at the solar surface are the positive and negative polarity spots of the sunspot pair.

When sunspots occur, they actually show up in *bipolar pairs* of sunspots. That is, one member of the pair has one magnetic polarity and the other member has the opposite polarity. Then many other pairs are then nestled in larger, also bipolar, structures called magnetic regions (Figure 5). Each magnetic region is commonly made up of multiple sunspot pairs.

Switching Hemispheric Polarities – Typically, the *magnetic* cycle lasts between 18 and 28 years (about 22 years on average). This contains *two* regular *activity* cycles. During the first activity cycle, the magnetic polarity is east-west in one hemisphere, and west-east in the other hemisphere. At the conclusion of the first activity cycle, the next activity cycle will *reverse* the polarities for that next activity cycle to west-east and east-west. So, a single solar *activity* cycle usually lasts between 9 and 14 years (averaging 11 years), while the full magnetic cycle takes twice as long.

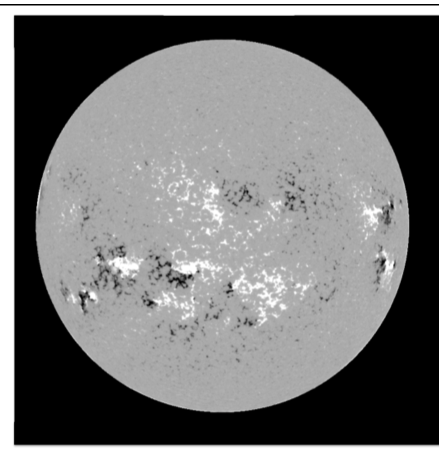

Figure 5: This solar magnetogram (from Cycle 24 maximum) shows two bands of magnetic regions – one north, the other south, of the solar equator. The white patches (one polarity) are to the left in the north, and the right in the south. Dark patches are the "other" polarity. Higher magnification would show the actual sunspot pairs. Each of the many pairs has one spot in one of the larger white and dark regions. *Credit: NSO/AURA/NSF*

Solar Activity Cycles – Within the current understandings, the accurate detailed predictions of solar-cycle performance are very elusive. As work continues regarding the Sun's internal workings, there is still some way to go to understand the Sun's subtle interactions in the deeper solar interior.

Many different prediction techniques have been applied over the years. Most have been based on various kinds of statistical patterns, as seen over many previous cycles. A key disappointment here has been that, using *different* statistical factors, very often leads to very *different* results – when trying to predict the *same* future cycle. This is especially so, when it gets down to answering specific questions like "when", and "how much". Nevertheless, work continues to improve statistical models.

In the meantime, the solar physics community continues to develop better pictures of the solar interior, to enable *physics-based* mathematical models, which could show how the Sun works, in detail. Hopefully, in some near-future cycle, this will lead to a much more elegant and deeper understanding of the Sun (and a wide range of other stars as well). In addition, it should provide far more accurate solar-cycle predictions. There are some hints as to the "*how*" of activity, even if the full "*why*" is still unclear.

Phase Shifts Within a Cycle – Although the cause is unclear, many cycles have shown that the amplitudes of northern and southern solar hemispheres are free to wander for a number of degrees *out of phase* with each other. In addition, the hemispheric phases often *progressively* shift over several contiguous cycles, and not always in the same patterns. So, even if the *peak* magnetic energy, in each hemisphere, occurs sometime during the same activity cycle, if the two hemispheres do not reach their individual activity maximums at the *same time*, the combined solar maximum is reduced (Figure 6).

Amplitude Shifts Over Cycles – Going back to the first direct sunspot counts in the 1600s, there is a direct *amplitude* component that changes, more or less equally, both the northern and southern solar hemispheres with time (see Figure 1).

Solar Cycle Predictions – So, most forecasts have been based on the predictor's hypothesis that a certain set of specific characteristics, seen in earlier cycles, can be used to predict a specific future cycle, or even a group of cycles. These are actually experiments. For example, the *first* step might be to take a group of *already known*, past cycles, and then try to predict the very next *already known* cycle. All this is to see if it will work. This is often referred to as "hindcasting".

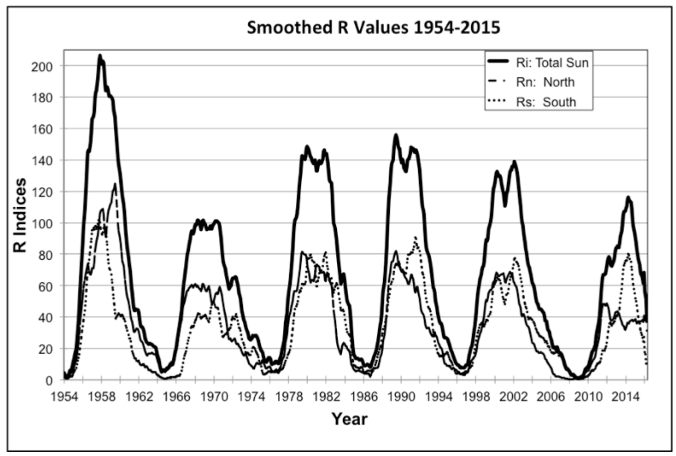

Figure 6: At a given in point time, the total activity is the sum of both hemispheres. If the two don't peak at the same time, the maximum total activity is diminished. *Data Credit: SILSO*

If it works when the correct answers are already known, the next step is to apply the tweaked procedure to an upcoming *real-time* cycle, *before* it actually happens. However, so far there doesn't seem to be a robust, reliable, repeatable solution for future cycles. So far, this has been a "hard problem" to solve.

Cycle 25 Maximum Predictions – A recent professional review of some 30 different recent Cycle 25 forecasts found that the resulting predictions were all over the map [2]. The predictions of the maximum sunspot index (R_{max}) ranged from 60 to 136 – for the same solar cycle. This is an uncertainty range of 113%. With no broad agreement among the various predictions, the precise range of possible F2 MUF values is very unclear.

On another hand, one thing that stands out is that *radical* changes in activity, from one cycle to the next, are not common – especially if the previous cycle was relatively low. In this spirit, one researcher noted that the patterns of Cycle 23 and the current Cycle 24 look very much like Cycles 15 and 16. However, the next old cycle (17) was noticeably stronger than Cycle 16. So, that might imply that Cycle 25 also would be a stronger cycle. However, many people do not expect that. Many are concerned that Cycle 25 will be very low, and stay low, for a much longer time than usual, based on a weakening trend in sunspot magnetic fields over the last two or three cycles.

No Cycle 25 at All? – Starting from a different direction, another group looked at the history of the sunspot magnetic-field strengths over Cycle 23 *and* the first year of Cycle 24 (in total, 1998-2010). They found that, during that time, the average sunspot field strength was consistently declining in a more or less *straight-line* fashion. They noted that, *if* that trend continued unabated, there might be very few, if any, sunspots by the middle of Cycle 25. Of course, this is the same time that one would (otherwise) expect to see Cycle 25 at solar *maximum* [3].

This launched a concern that Cycle 25 might be the beginning of an extended number of very weak cycles, such as the Maunder Minimum, or the *less* profound, Dalton Minimum, which can both be seen in Figure 1. Like everything else, time will tell.

When Will Cycle 25 Begin? – Despite the problem with *full-cycle* predictions, once the current cycle has gone well past maximum, it *is* possible to make much shorter-term predictions of the *end date* of that same cycle. So, as Cycle 24 is winding way down, there are some reasonable procedures to estimate the end date. That is to say, when will the Cycle 24 sunspots reach minimum. Of course, the end of Cycle 24 is *also* when Cycle 25 actually begins as the *dominant* source of overall solar activity.

Two recent predictions are in close agreement. The McNish-Lincoln Method concludes that the January 2019 should be the Cycle 25 start date, while the Combined Method says the start date will be about two months later, about March 2019. These predictions suggest that Cycle 25 will be about a year shorter than most previous predictions. This is still within the normal 9- to 14-year range (Figure 7).

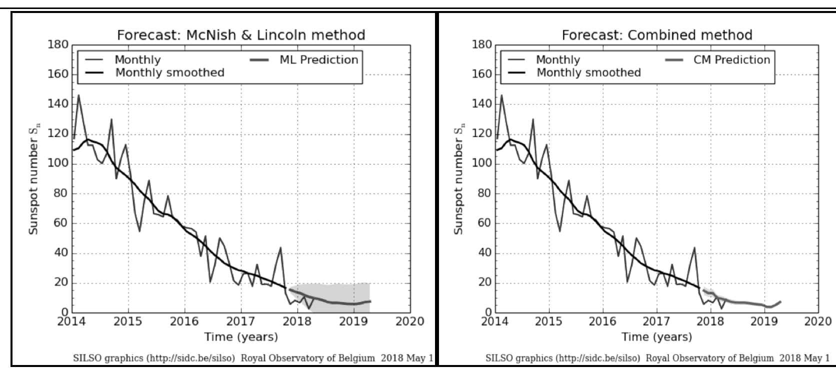

Figure 7: These two forecasts of the new Cycle 25 starting date show very similar results. One is about January 2019 and the other is about March 2019.
Credit: SILSO/ Royal Observatory of Belgium, Brussels

Summary – There is a lot that is not clear about solar activity projections. Sadly, one *known* thing is that solar science has *not yet* achieved the intended goal of providing accurate predictions of future solar-cycle activity. However, there are some things that *are* real and some others that are, perhaps, at least likely at some level.

Technically, Cycle 25 Already Started – In connection with Figure 2, it was pointed out that very early bubbles float upward, to the surface, from the lower part of the convection loop. These bubbles lead to the first *next-cycle* sunspots. They *first* appear far from the equator. Then over time, the "conveyor belt" brings the bubbles closer and closer to the equator. These sunspots are *not* made from current-cycle magnetic scraps, but from the cycle *before* it. So, the polarities of these new sunspot pairs are reversed from the current cycle's sunspots. Thus, during this gradual transition from one cycle to the next, sunspots from two different cycles can be seen on the Sun at the same time, at least for a while.

This raises a semantic question: Which cycle-name does one use for the *overall* situation? The answer is simple: Until the current solar-cycle activity reaches its minimum, the overall cycle is named for the original solar cycle. When the new cycle becomes the *dominant* activity source, then the new cycle takes on its own name. So, when the first sunspots of Cycle 25 showed up in mid April 2018, the *dominant* cycle was *still* called Cycle 24. After Cycle 24 minimum, it will be known as Cycle 25.

Some Good News – The recent news is that Cycle 25 spots have *actually shown up* (at least for now). So, Cycle 25 activity *is* off to a start – at least with real sunspots – and *not without* them (as some had previously feared). Still, one must wait to see where it goes from here.

Some Unlikely Things – Historically, most of the modern record shows that the amount of activity can vary widely from cycle to cycle. However, the changes between two *adjacent* cycles rarely exceed a 50% change, and most cycle-to-cycle fluctuations are less than half of that (see Figures 1 and 6). However, the two historical periods, with significantly extended solar minima, seem to be an exception. So, if a new extended minimum were about to occur, all bets would be off.

Closing Speculation – Taken as a whole, there seems to be a good chance that Cycle 25 will *not* suddenly become a very strong and active cycle. That suggests that it will not be an especially good F2 cycle. (Fairly persistent 6m F2 needs an R_{max} of about 100). Hopefully, it will not suddenly get much worse, either. At the same time, the new digital modes have been making some outstanding differences in what can be done with weak signals.

Acknowledgements

The author expresses his appreciation to: The NASA Solar Dynamics Observatory (SDO) for sunspot images, SILSO at the Royal Observatory of Belgium (Brussels) for the raw data for the activity plots, my former associates at NSO/AURA/NSF for additional solar images, and most especially to Linda Kennedy, WH6ECQ, for her always careful and effective proof reading of the various manuscripts.

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