Jim Kennedy, 2007, “Solar Cycles and Cycle 24 Predictions”, *Proc. 41st Conference of the Central States VHF Society*, pp 1-13, ARRL

Solar Cycles and Cycle 24 Predictions

Jim Kennedy KH6/K6MIO
Gemini Observatory Hilo HI

F Layer and the Sun – F_2 propagation can produce dramatic results on six meters. The F layer is ionized primarily by extreme ultraviolet (EUV) radiation from the Sun. The intensity of solar EUV is strongly dependent on the phase of the solar activity cycle. Unfortunately, the average level of solar EUV is not sufficient to raise the *muf* above 50 MHz. Consequently, six-meter F-layer propagation is confined almost entirely to the *peak* years of the solar activity cycle[1].

Managing radio propagation, satellite health, and power-grid issues all lead to an interest in predicting future solar activity, on both short and long timescales. There are actually *two*, intimately related, “solar cycles”: the *activity* or “sunspot” cycle, and the solar *magnetic* cycle.

Solar Activity Cycle – The sunspot cycle peaks roughly every 11 years. Sunspots are always found in pairs or groups. The spots and groups occur in two latitude bands, one north and the other south of the solar equator (Fig. 1). They come and go within those latitude bands with end-to-end lifetimes of a few days to several weeks.

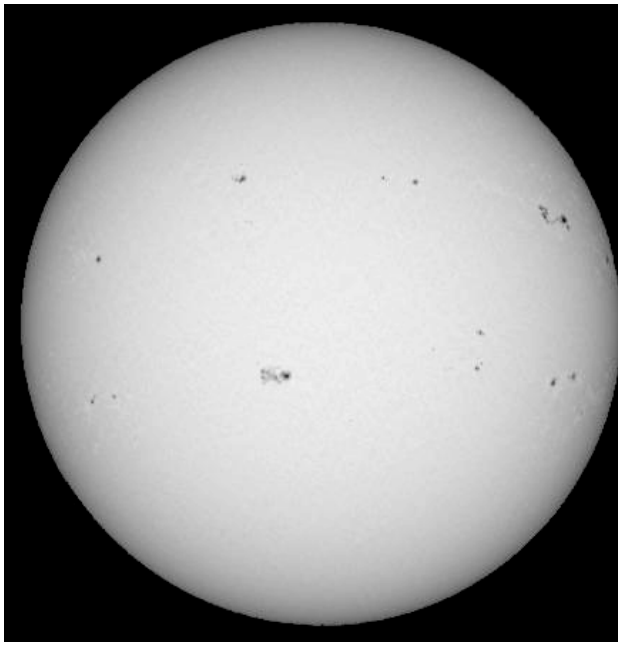

Figure 1: The Sun as seen by the National Solar Observatory (NSO) at Kitt Peak near Cycle 23 solar maximum on 3 April 2000. Note the two bands of sunspots north and south of the solar equator. (Credit: NSO/AURA/NSF)

As will be shown shortly, sunspots are the visible effects of loops of powerful magnetic fields arising from within the Sun that have then floated up and bulged out above the Sun’s visible surface (Fig. 2).

The east-west leading spot(s) in a pair (or group) have the opposite magnetic polarity from that of the trailing spot(s). If the leading spots in the southern hemisphere band have one polarity, then the leading spots in the northern hemisphere band have the opposite polarity – that is, the direction of the field between the leading and following spots in the south are opposite of those in the north (Fig. 3).

As the Sun rotates on its axis every 27 days or so, sunspot pairs and groups appear to march across the Sun from east to west, being visible for up to 14 days as they travel from limb to limb and then rotate out of sight around the farside. If they live long enough, they return to the near side about 14 days later.

---

[1] *50 MHz F2 Propagation Mechanisms*, Kennedy, J.R., 2000, in Proc. 34th Conf. Central States VHF Soc, (ARRL Pub. **257**), 87-105

Old Cycle, New Cycle – Each "new" activity cycle begins at the *minimum* after the preceding solar maximum. Near the minimum, the few remaining "old-cycle" spots are found in their two latitude bands, now very near the solar equator (about 5 degrees north and south).

On the almost spotless Sun, the new cycle begins when spots begin to appear in two *new* bands about 30 degrees north and south– with opposite *polarities* from the old-cycle spots. So, the old and new cycles actually *overlap each other* for a period of time. Their latitude bands and polarities distinguish between the old- and new-cycle spots. Curiously, new-cycle spots generally do *not* appear at the *same time in both the northern and southern hemispheres* (more later).

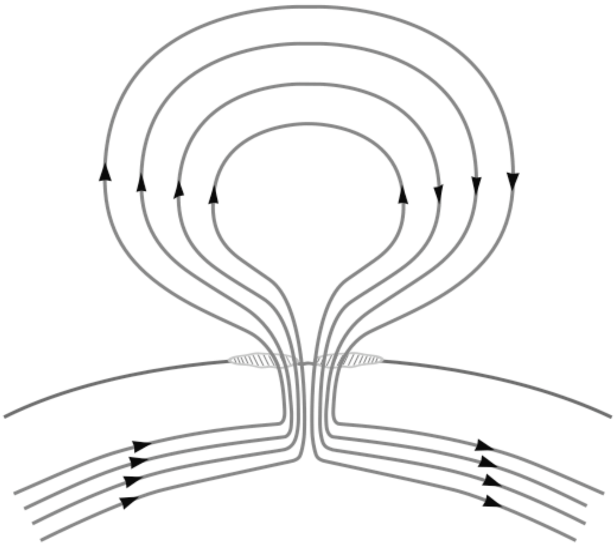

Figure 2: When magnetic field lines within the Sun erupt through the surface, they form loops creating sunspot pairs. The leading spot at the surface has one polarity and the following surface spot has the other polarity, as indicated by the direction of the arrows.

As the cycle progresses, the new-cycle spots appear in increasing numbers, with their higher latitude bands slowly moving closer and closer to the equator. By solar maximum, the bands are centered on about 15 degrees north and south latitude. As the cycle wanes, the old-cycle spot count decreases and the two bands move to within about 5 degrees of the equator.

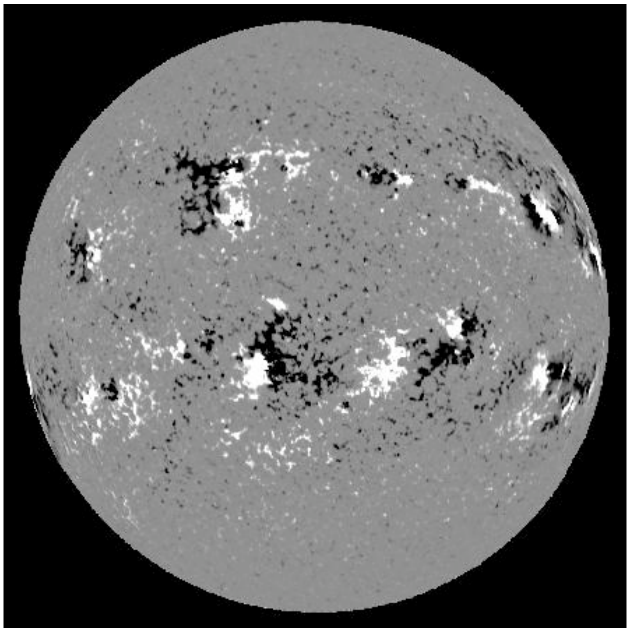

Figure 3: An NSO solar magnetogram, also from 3 April 2000. It shows the magnetic strength at the surface. White is polarity pointing out of the Sun, and black pointing into the Sun. Note that the northern and southern leading-trailing patterns are reversed. (Credit: NSO/AURA/NSF)

Cycle Strength – The amplitude of a cycle is measured by various indices. The most common one today is the international sunspot index[2], R_i. Another common index is the 10.7 cm radio flux, F10.7. Both indices are quite valid, but have different values. Only R_i will be discussed here, just to simplify the presentation.

Solar Magnetic Cycle – The *activity* cycle, with its sunspots, solar flares, and coronal mass ejections (CMEs) is the result of an *underlying* cycle of *magnetic* activity *within* the Sun. The period of the solar *magnetic* cycle averages about *22-years*.

---

[2] The value of R_i is essentially the same as the historical R_z (Zurich) sunspot number index, by deliberate design.

On very large scales, the Sun has a global average magnetic field of about 1 gauss. It is basically a *dipole with its axis passing through the poles*. During solar maximum, every 11 years or so, the polarity of the *polar* field flips direction. As a result, it goes through a complete cycle, pointing from north to south and then back to north again about every 22 years. Each *magnetic half-cycle* produces a peak in solar activity, producing the 11-year *activity* or sunspot cycle.

The magnetic cycle is the result of the recurring evolution of large-scale plasma flows inside the Sun. These flows of charged particles interact to produce a kind of *dynamo*. By concentrating the small overall magnetic field into relatively small volumes, the dynamo produces locally intense magnetic fields, typically a few thousand gauss and sometimes greater than 6,000 gauss. These strong local fields lead to solar activity in the form of sunspots, flares, and other particle and radiant emissions.

Understanding the *details* of these complex interactions and *why* they lead to *cyclic* solar activity has been a "holy grail" in solar physics for a long time. Thanks to the evolution of some very clever technologies, much progress has been made in the last two or three decades in shedding light on these mysterious processes. *Any successful solution to the problem must account for all the effects described above*.

Convection Zone – The outer 30% of the Sun is a seething convection layer. As heat moves up from the fusion core, it reaches a level where the gases are convectively unstable (like the hot air rising in a summer thunderstorm). Giant updrafts within the convection zone carry heat up to the surface of the Sun where it is released into space. Then the cooled gas sinks back down, to be reheated and rise again.

Since the convection zone is gaseous, it does *not* rotate as if it were a *solid object*. The equatorial regions rotate faster than the polar regions. Thus, the gases at the equator take about 25 days to rotate all the way around the Sun; but it takes about 35 days near the poles. This effect is called *differential rotation*.

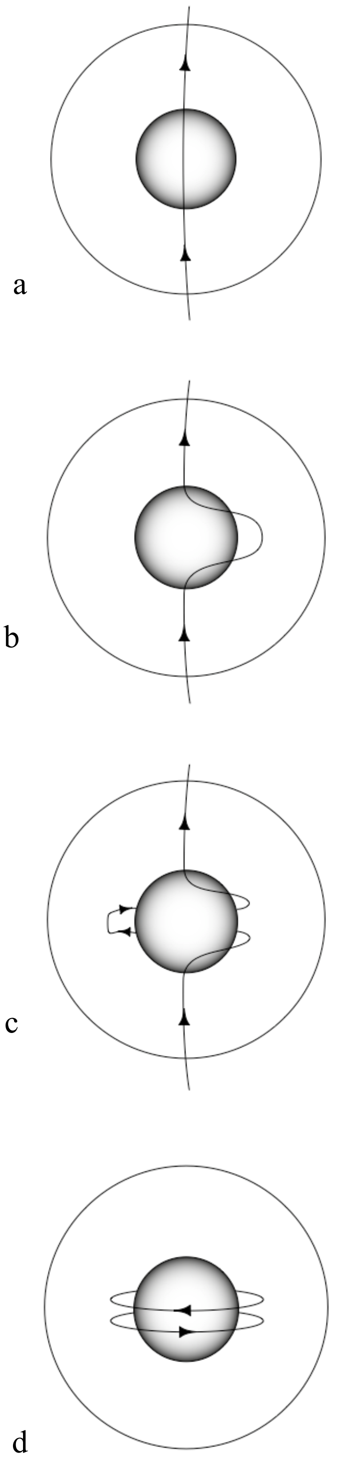

Figure 4: Frames a through d show how convection-zone differential rotation wraps the polar dipole magnetic-field lines into oppositely-sensed toroidal field lines at low latitudes north and south of the equator.

Rising Cycle – At the beginning of a cycle the Sun's whole magnetic field is essentially the polar dipole. However, the lines of force that flow through the Sun, from pole to pole, cannot long remain as simple straight north-south lines.

Differential rotation in the convection zone drags the embedded magnetic fields in *equatorial regions* westward, out ahead of the same lines of force nearer the poles, eventually wrapping them around in the interior parallel to the equator, like string around an axle (Fig. 4).

After a few months, this transforms the north-south polar magnetic field into two east-west *toroidal* field bands, one north and the other south of the equator (Fig. 4d). These two bands have opposite polarities; one is pointed around in an east-west direction and the other in a west-east direction.

Thus, the reason that the sunspots are found in two latitude bands is that they are spawned from the two toroidal fields that lie beneath the sunspot bands. Eventually, fragments of the toroidal fields float up and break out above the surface in big loops, as shown in Figs. 2 and 5. At each foot of the loop is a sunspot, together forming a sunspot pair. Multiple fragments sometimes result in very complex sunspot groups.

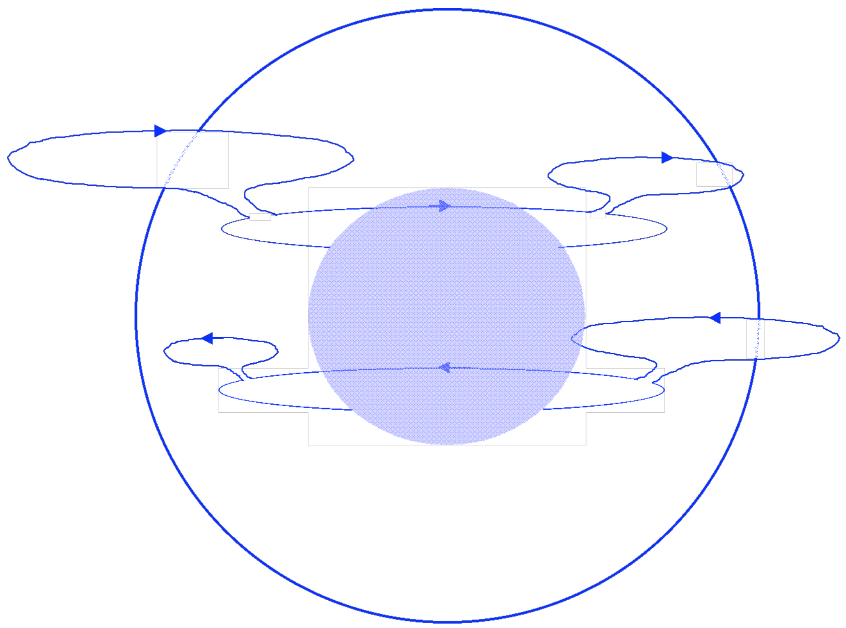

Figure 5: When bulges in the two toroidal field rings become large enough to break through the solar surface, they expand into large loops above the surface and leave a sunspot pair at the points where the field punches through the surface. For simplicity, only one toroidal field-line loop is shown in each hemisphere.

Solar Maximum – As the cycle continues toward maximum, more and more of the polar field is converted into the two toroidal fields, and they and their sunspot bands move closer to the equator. When the toroidal field is at maximum strength, so also is the amount of energy "leaking" upwards into the sunspot-causing above-surface field loops.

Solar maximum occurs when all the available polar-field energy has been converted to the two toroidal fields. At this point, having been sucked down to zero, the polar field passes through zero and *reverses* its polarity to produce a very weak field in the opposite direction. Thus, the *polar-field reversal* is closely associated with the solar maximum.

North Cycle, South Cycle – The northern and the southern polar-field reversals can occur many months apart. The two hemisphere's toroids usually don't reach solar maximum at the same time. One hemisphere often leads the other (see Fig. 9). This is the reason that new-cycle spots don't appear at the same time in both hemispheres

So, each hemisphere has its own cycle and timetable. The periods are similar, but the phases are not exactly the same. The two phases shift in time, but they resynchronize from time to time, since they are coupled through their reliance on the same pool of total solar magnetic energy. When the time lag is long between the north and south peaks, a *double-peaked maximum* occurs.

The double peak in Cycle 23 is a consequence of the northern hemisphere peak leading the south by about a year. When north and south are *in* phase, a single peak occurs. When they are in phase and both north and south peaks are strong, one gets a powerful cycle, as in Cycle 19 in 1958 ($R_i = 201$[3]), see Fig. 6.

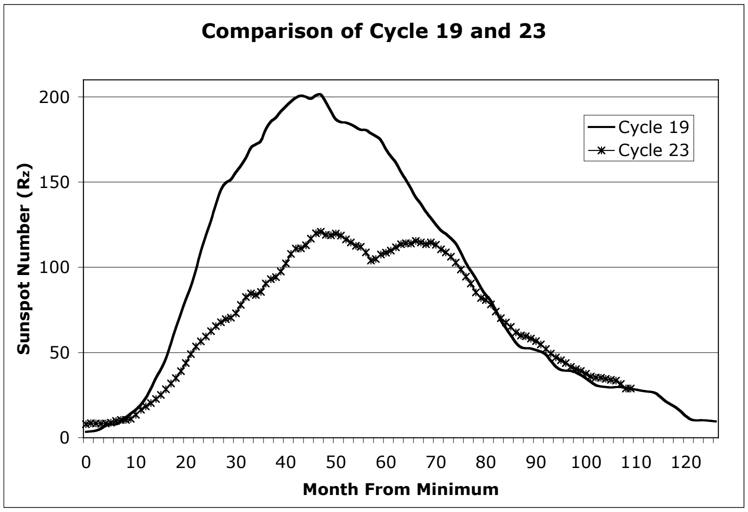

Figure 6: Cycles 19 and 23, respectively, are good examples of single and double peaked cycles. Notice the delay in even the first peak of Cycle 23 with respect to Cycle 19.

Declining Cycle – Once solar maximum is reached, the respective toroidal fields at the root of the sunspots begin to *weaken*, and the strength of the now-reversed polar field begins to *increase* in strength. The two magnet toroids continue to move closer to the equator taking their families of sunspots with them, but in ever *decreasing* numbers.

Finally, as the current activity cycle nears an end and its two magnetic toroids are about to fade out, *new toroids* appear much further north and south. The first few furtive spots of a new cycle flash briefly into existence, and Nature's cycle begins to repeat. The National Solar Observatory (NSO) saw the first unequivocal instance of a Cycle 24 sunspot pair on July 23, 2006, although little else has been seen since.

Conveyor Belt – Still, key questions remain. Why does the polar field actually reverse sense and then build up? Why doesn't the activity just remain at maximum for all time after that?

Although the cause is not clear, observations show significant north-south plasma flows in the convection zone *between the equator and the poles*. There is a large-scale upwelling of plasma near the equator that then flows near the surface both north and south toward the poles. Near the poles the gas sinks, and then flows back toward the equator again, now deep in the convection zone. Since these circulation patterns flow along longitude meridians, they are referred to as *meridional flows*, shown schematically in Fig. 7.

The meridional flows are the conveyor belts that drive the solar cycle. They drag leftover surface fields from old sunspots toward the poles and then suck them down deep in the convection zone and back toward the equator. These "old" fields will form the *nuclei* for the next generation of sunspots. *Curiously, the southern-hemisphere conveyer belt flow has been running much slower than the northern flow for a number of years now.* This is the apparent reason that the southern polar reversal has trailed the north for the last two or three cycles.

---

[3] See www.ips.gov.au/Educational/2/3/1.

The Sun's Magnetic Memory – It takes 30 to 50 years for the conveyor belt to make one complete circuit. Since the new-cycle spots reappear at about 30 degrees latitude, they only ride the conveyor part way around. Even so, it takes something like twenty years before some of them reappear. Thus, the "remembered" field fragments from at least the last two cycles (and maybe more) "seed" the current cycle's sunspots and active regions.

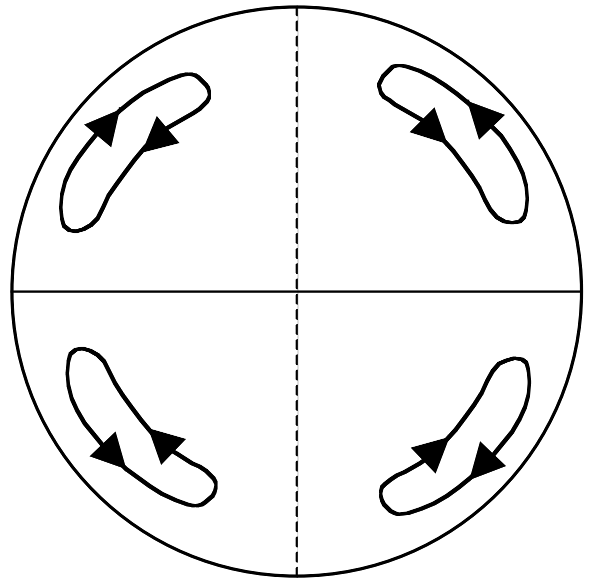

Figure 7: The meridional circulation currents of near-surface plasma from the equator to the poles traps residual magnetic fields from "dead" sunspots that are recycled into future solar cycles, perhaps one to three cycles later.

Predicting Cycles – Since the past history of solar activity seems to play a role in the evolution of future activity, today it is reasonable to assume that one could find ways to make accurate long-range forecasts.

This has been an underlying assumption in the past prediction efforts as well. However, without understanding *how* the past and future were *physically* connected, there has been much disagreement about which of the measurable characteristics are the most important.

In principle, there are two broad approaches to predicting future solar cycles: statistics and physics. The parameters one might predict would include: the maximum amplitude of the cycle (e.g. the smoothed sunspot number R_i), the date of the peak, and the length of the cycle. Table 1 shows some actual values from the last five peaks.

Until the last couple of cycles, very little was directly known about the details below the visible surface of the Sun, simply because those regions could not be seen or measured. For decades the only prediction approaches were based on statistical relationships seen in previous cycles. This still remains the most common approach today. However, today there is one novel method that applies actual solar interior data to a physical model of the Sun's interior structure.

Table 1
Comparison of Recent Cycles

Cycle	Date Max	R_i Max
19	Mar 1958	201
20	Nov 1968	111
21	Dec 1979	166
22	Jul 1989	159
23	Apr 2000	121
24	?	?

Currently there are more than twelve different published professional predictions of the characteristics of Cycle 24 – almost all are of the statistical variety. These various methods produce answers that range from a very strong maximum, perhaps a year earlier than expected, to one of the weakest on record – and everywhere in between.

Statistical Methods – One approach is to amass a database of the solar and terrestrial observables from as many past cycles as possible. These might include the length of the cycle, the rate of rise and fall of the cycle amplitude, peak amplitude of cycle maximum, amplitude and polarity of the global field, intensities of the local magnetic fields, and various geomagnetic indices.

Then, one could look for statistical correlations between these different factors in different cycles. If a dependable set of correlated factors were found, then one could use those relationships to predict the values of a future cycle.

The 240 Year "Cycle" – As an example of a *statistical* approach, there seems to be a pattern in the solar cycle *lengths* with a period of roughly 240 years. With some fluctuations, cycles tend get shorter for about 120 years and then tend get longer for about 120 years, and then the pattern appears to repeat. Since Cycle 14 (beginning in 1902) the trend generally has been toward shorter cycles. *If* this pattern persists*,* Cycle 24 could be a "short" cycle, i.e., less than 11 years. *However*, Cycle 24 could also be close to the 120-year *turning poin*t toward longer cycles. The slowing of the southern meridional flow could be suggesting that this is the case.

Weighted Averages – Another straightforward example of the statistical approach is that of John Kennewell at Australia's IPS Radio and Space Services. He currently uses a system based on weighted averages of the characteristics of a few recent cycles.

Wilson's "Rule" – Predicting the date of the next maximum could also depend on the date of the *preceding minimum*. Known as "Wilson's Rule", recent solar cycle minimums usually occurred about 34 months *after* the first full day with *no visible spots* on the Sun.

Dave Hathaway, at NASA's Marshall Space Flight Center, notes that the first spotless day of Cycle 23 occurred on January 28, 2004. Based on Wilson's Rule, the Cycle 23 minimum should have occurred in November or December 2006. This date is consistent with the recent trend toward short cycles, mentioned above. *However*, the minimum did *not* occur in 2006. If it had, it would have suggested that the Cycle 24 maximum would occur in late 2010.

Four Years from Minimum – The solar minimum date is also important because the next *maximum* usually occurs *four years* after the minimum. In any case, almost all prediction methods get pretty good once the new cycle actually starts and a little *real data* starts to accumulate some trends.

Precursor Methods – Several seasoned researchers hold that the *precursor* prediction methods are among the best. These methods are based on the hypothesis that the configuration of the Sun during one cycle determines the major features of the Sun during either the next cycle or the one after that. Without access to the details of the Sun's current internal configuration, precursor methods look for gross measurable indices as "proxies" for the real physical details.

Geomagnetic Precursors – Some of these methods rely on variations of the geomagnetic aa[4] index at the preceding solar minimum as a predictor of the following maximum, such as one by Joan Feynman at NASA's Jet Propulsion Laboratory. Richard Thompson, recently retired from IPS Radio and Space Services in Australia, uses the number of days during the previous cycle

---

[4] This index is derived from the three-hour averages of the K index at two antipodal earth-based observing stations.

that the geomagnetic field was disturbed. More recently, Hathaway and Wilson have developed a hybrid method that incorporates parts of both the Thompson and Feynman approaches.

Solar Precursors – Some time ago, Ken Schatten, at Ai-Solutions, Inc., constructed an index relating to the Sun's buried dynamo fields. He assumed that if geomagnetic effects have some prediction success, then actual solar magnetic fields measurements should work *even better*. He uses an index that tracks the total magnetic field, including both the polar and toroidal components. Leif Svalgaard, at ETK, uses a somewhat similar method based only on the polar field strength at solar minimum.

Magnetohydrodynamic Models – Developments permitting actual observation of the *interior* of the Sun are beginning to offer intriguing new possibilities in solar cycle prediction. The study of helioseismology uses sound waves, traveling through the inside of the Sun, to visualize the structure and dynamics of the solar interior, something like a medical CT scan. Collaborative research projects at the National Solar Observatory[5] and Stanford's Wilcox Solar Observatory[6] have collected a full solar cycle of data on the evolution of the Sun's internal structure.

These techniques have yielded many key pieces of information in understanding the processes that take place inside our nearest star. They also have led to practical short-term predictive tools, including the visualization of active regions on the farside of the Sun, away from the Earth. This is enabling prediction of when new or returning activity will rotate back into view and become geoeffective (Fig. 8).

Armed with these and other data, one could construct magnetohydrodynamic predictive models that start from first principles, the *physics* of the Sun itself. One such model has been developed by Mausumi Dikpati and her collaborators at NCAR's High Altitude Observatory. While still being fine-tuned, they insert structural data from previous cycles in a computer model of the flow interactions, and predict what a subsequent cycle should look like. It has been very successful in reproducing previous cycles, including the double maximum in Cycle 23.

This sort of approach might be quite accurate at predicting one or two cycles in the future. *However*, there is an important caution. There is good reason to believe that the fine details of the solar flows are basically chaotic processes.

Figure 8: A GONG "image" of near-surface active regions on the Sun's farside. Clever data processing of seismic waves within the Sun permit this "x-ray" view through to its farside. The large feature on the right just below the equator emerged as a nearside sunspot group four days later. Credit: GONG/NSO/AURA/NSF

---

[5] The Global Oscillation Network Group (GONG).

[6] The Michelson Doppler Imager (MDI) experiment on the SOHO spacecraft.

Thus, like the weather on Earth, short-term predictions might be fairly accurate, but longer-term predictions would be progressively less reliable.

Hindcasts and Forecasts – No matter what kind of method or model one uses, the fine tuning of the approach is based on applying the scheme to *past* cycles, where "what happened" is already known, and then adjusting the details for the best match. This is a process known as *hindcasting*. Most methods work pretty well when you already know the answer! In the past, the use of those methods to *forecast* has met with very mixed results.

Table 2
Comparison of Several Prediction Methods

Lead Researcher	Method	Cycle 23 Min Date	Cycle 23 Min R_i	Cycle 24 Max Date	Cycle 24 Max R_i
Dikpati	Flux Transport Dynamo	Late 2007-Early 2008		Jan 2012	169 ±12
Hathaway	Super Geomag Precursor	Aug-Sep 2006	7.2	Jun 2010	147 ±24
Wilson	Wilson's Rule	Nov-Dec 2006		Nov-Dec 2010	
Kennewell	Recent Cycle Statistics	Oct 2007	8.5	Aug 2011	134 ±50
Schatten	Solar Precursor SODA Index			Oct 2011	100 ±30
Svalgaard	Solar Precursor Polar Field	Oct 2006		2011	75 ±10
NOAA Committee	High Consensus	Mar 2008		Oct 2011	140 ±20
NOAA Committee	Low Consensus	Mar 2008		Aug 2012	90 ±10

So, Who to Believe? – Table 2 shows a comparison of the predictions by six respected forecasters, and a consensus committee. These are *samples* of the available methods, chosen to reflect the diversity of predictions based on the various general approaches. It will be noticed that they *range from awful to terrific*. (The same has been true of past predictions for previous new cycles.)

In the current case, the two solar precursor methods are making very pessimistic predictions, while the two geomagnetic precursor methods are making optimistic predictions.

One would think that the solar precursor methods, based on parameters closer to the root source – the solar magnetic field – would be more reliable. *But*, the Dikpati model, *if correct*, should be the most accurate. Curiously, it disagrees with the solar precursors, and produces the most optimistic prediction of all, even exceeding those of the geomagnetic methods. Whatever actually happens, we should *learn* something.

The NOAA Committee – The National Oceanic and Atmospheric Administration convened a committee of experts to try to reach a consensus prediction. In late April 2007, the committee issued a report saying that they were evenly split into two camps. One group steadfastly believes that the cycle will be good (but not great), and the other group feels that there will be rather poor cycle. The only thing they agreed on is that the minimum was likely to be about March 2008.

Beware the Error Bars – Another caution about predictions is their error estimates. They are often quite large. Each method is predicting not one value, but a *range* of values. For example, a value of $R_i = 150 \pm 50$ might appear to predict a fairly good cycle. But, it actually predicts R_i to be anywhere between 100 (a very poor cycle) and 200 (a rival for the amazing Cycle 19).

Predictions with large error bars reflect a lack of confidence in the precision of the method's predictive capability (usually based on previous experience). In any case, large error bars don't provide a very precise *quantitative or qualitative* picture of the predicted activity.

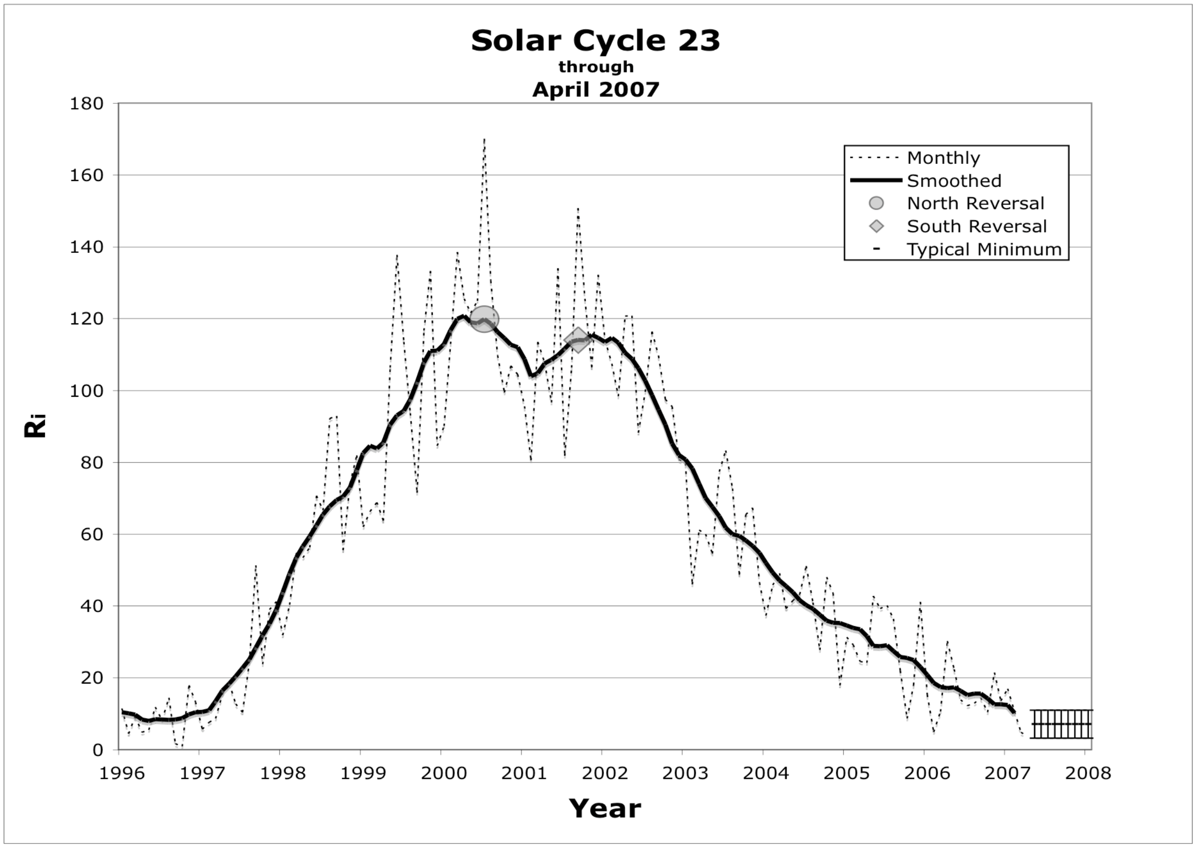

Figure 9: This plot of the Cycle 23 R_i overlays the monthly and 12-month running-average smoothed values. The shaded circle and diamond show the points of north and south polar-field reversal, respectively. The line with error bars in the lower right corner shows the mean and one sigma range of the smoothed R_i as seen at solar minimum for the last 100 years.

A Reality Check – As noted, there was a brief appearance of what appeared to be new Cycle 24 activity in middle and late 2006. However, this hopeful flurry of activity quickly dissipated. Fig. 9 shows the progress of Cycle 23 from the previous minimum in 1996 through April 2007. The slope of the smoothed R_i was clearly still negative[7].

---

[7] For the last few data points only, the smoothing span has been shortened from the traditional 12 months.

- **It does *not* appear that solar minimum had occurred by the end of April 2007.**

The shape of the plot suggests that the curve may round out to reach minimum by late 2007. But, if R_i minimum is much lower than 10, it could even be Dikapti's prediction of early 2008.

This would be quite in line with the solar minimum prediction dates of Dikpati and Kennewell. On the other hand, the target dates predicted by Hathaway and Svalgaard *have already passed*.

When Will the DX Start? – From a DX perspective, the crucial question isn't: "When is the solar maximum?". Rather, it is: "When will solar activity be high enough for good propagation?".

My own experience shows that once the smoothed R_i rises above about 60, the F_2 *muf* will start peaking above 50 MHz – subject to the usual seasonal effects (i.e., *no* F_2 during local summer). This will generally show up first as north-south transequatorial propagation (TEP), taking advantage of the ionization boost of the equatorial anomaly. As R_i rises to about 100, east-west F_2 will also start to show up. *Depending on the cycle strength*, TEP and linked TEP can start as early as about 18 month after *solar minimum*, and east-west F_2 about a year after that.

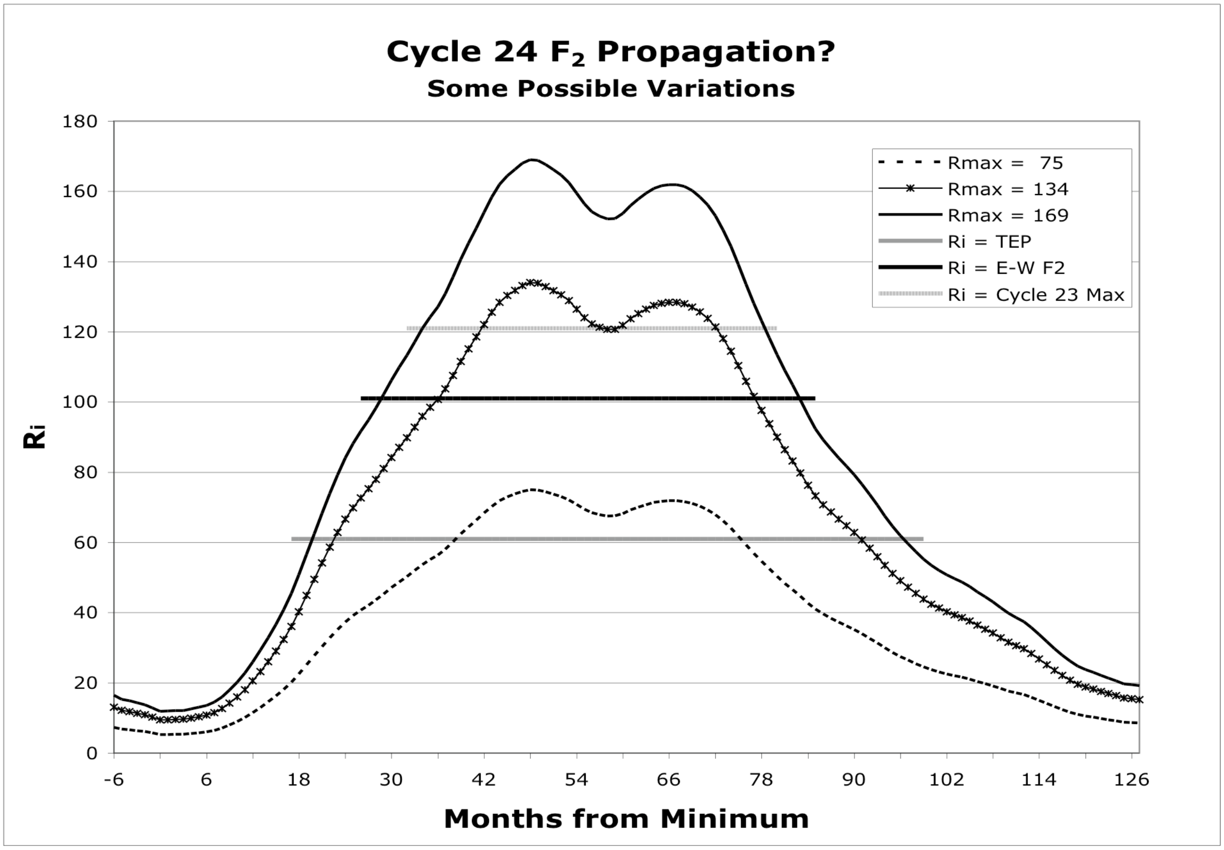

Figure 10: These are three realizations of an R_i model scaled to the maximums predicted by Svalgaard, Kennewell, and Dikpati respectively. It assumes that the slow down in the southern-hemisphere meridional flow "conveyer" will lead to another doubled-peaked maximum, much like Cycle 23. It shows the time relationship between the preceding minimum and the onset and duration of Cycle 24 TEP at R_i about 60, east-west F_2 at about 100, and the period above Cycle 23 at R_i = 121.

To illustrate this, Fig. 10 shows an *example* of three different *possible* Cycle 24s. The current evidence is that the slow down in the southern meridional flow, which probably led to the double peaks in Cycles 22 and 23, is continuing. So the shape of the curves is based on a highly smoothed version of Cycle 23 and is identical in each case, except for the scale factor. The curves are then scaled to the maximum R_i predicted by Svalgaard, Kennewell, and Dikpati and shown in Table 2[8]. These were chosen as representative examples of low, medium, and high cycles. Note that all the curves are *based on the date of solar minimum*, not a calendar date.

While no representation is made for the *detailed* accuracy of the Figure-10 models, if one focuses narrowly on the date of the *onset* of propagation, once the *actual date of solar minimum* is established, they should be useful in tracking toward the start of good propagation.

The time between the previous minimum and the new maximum is right about four years, based on many previous cycles. With the actual minimum date and an estimate of the R_i at maximum, even a straight line drawn from the minimum to the maximum R_i four years later will be a good estimate of the ramp up of activity in between those two dates, *if* the maximum R_i estimate is about right. Figure 10 gives three choices that bracket the range of R_i maximum predictions.

For example, *if* Kennewell's prediction of solar minimum in October 2007 and his mean R_i value are on target, the cycle will peak in August 2011 at 134. This shows that R_i should hit levels comparable to the peak of Cycle 23 (121) around February 2011, and then get even better. If this is the case, then the smoothed R_i could pass up through 60 in July 2009, with the return of transequatorial propagation as early as October 2009.

Curiously, even though Dikpati's model predicts that solar maximum will occur seven or eight months *later* than Kennewell's, because the Dikpati model must rise more steeply to reach its higher predicted peak within the four-year period, the same back-of-the-envelope calculation suggests the Dikpati's R_i will also exceed 60, with the return of TEP, around October 2009. Table 3 shows a comparison of these very rough estimates.

TABLE 3
Possible Interpretations of Two Models

	R_i			
Model	**60**	**121**	**134**	**169**
Kennewell	Jul 2009	Feb 2011	Apr 2011	NA
Dikpati	Oct 2009	Jan 2011	May 2011	Jan 2012

These are ***just examples***, not really predictions (and remember the error bars, too!). The real point here is that, unless the cycle is very poor, the DX will start *before* the maximum.

So when will the DX really start? We'll have to wait and see.

Cycle 25 and Beyond – Some people are even beginning to think about Cycle 25. The 240-year pattern in cycle lengths suggests that Cycle 24 might be shorter than other recent cycles, *or* it

---

[8] Note that the models used here are *not* the detailed models of Svalgaard, Kennewell, and Dikpati, but a different model merely scaled to their nominal predictions for the maximum R_i.

may be the first of several cycles to get systematically longer. In either case, this would suggest that *Cycle 25 will be longer*, and some say weaker.

Supporting that idea, Dikpati predicts that Cycle 24 will arrive "late". Similarly, since the meridional conveyor belt is slowing down, especially in the south, this should lead to a longer cycle – if not now, then probably in Cycle 25. Hathaway notes that statistically, slow conveyor belts lead to poor cycles and he expects that effect to be very noticeable in Cycle 25.

So, it could be that *all* of the predictions in Table 2 are more or less correct, but it isn't clear whether *they relate to Cycle 24 or Cycle 25*.

Acknowledgements

The author appreciates comments and suggestions by Jack Harvey at NSO, and the graphics skills of Kirk Pu`uohau-Pummill at Gemini in producing the renderings for Figures 2 and 4. The sunspot data used here are from the compilations by the Solar Influences Data Analysis Center (SIDC) at the Royal Observatory of Belgium (www.sidc.be).