LONG-RANGE SOLAR ACTIVITY PREDICTIONS:
A REPRIEVE FROM CYCLE #24'S ACTIVITY

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ABSTRACT

We discuss the field of long-range solar activity predictions and provide an outlook into future solar activity. Orbital predictions for satellites in Low Earth Orbit (LEO) depend strongly on exospheric densities. Solar activity forecasting is important in this regard, as the solar ultra-violet (UV) and extreme ultraviolet (EUV) radiations inflate the upper atmospheric layers of the Earth, forming the exosphere in which satellites orbit. Rather than concentrate on statistical, or numerical methods, we utilize a class of techniques (precursor methods) which is founded in physical theory. The geomagnetic precursor method was originally developed by the Russian geophysicist, Ohl, using geomagnetic observations to predict future solar activity. It was later extended to solar observations, and placed within the context of physical theory, namely the workings of the Sun's Babcock dynamo. We later expanded the prediction methods with a SOlar Dynamo Amplitude (SODA) index. The SODA index is a measure of the buried solar magnetic flux, using toroidal and poloidal field components. It allows one to predict future solar activity during any phase of the solar cycle, whereas previously, one was restricted to making predictions only at solar minimum. We are encouraged that solar cycle #23's behavior fell closely along our predicted curve, peaking near 192, comparable to the Schatten, Myers and Sofia (1996) forecast of 182 ± 30. Cycle #23 extends from 1996 through approximately 2006 or 2007, with cycle #24 starting thereafter. We discuss the current forecast of solar cycle #24, (2006-2016), with a predicted smoothed F10.7 radio flux of 142 ± 28 (1-sigma errors). This, we believe, represents a reprieve, in terms of reduced fuel costs, etc., for new satellites to be launched or old satellites (requiring reboosting) which have been placed in LEO. By monitoring the Sun's most deeply rooted magnetic fields; long-range solar activity can be predicted. Although a degree of uncertainty in the long-range predictions remains, requiring future monitoring, we do not expect the next cycle's + 2-sigma value will rise significantly above solar cycle #23's activity level.

INTRODUCTION

This paper will focus on long-term solar activity predictions. We focus on the present condition of the Sun's activity, and how we may expect it to vary over the next decade. The reason for considering present and future levels of solar activity is their importance to the National Aeronautics and Space Administration (NASA) in its Low Earth Orbit (LEO) satellite programs. Since the LEO satellites do not orbit in a total vacuum, but rather the extended terrestrial atmosphere (the exosphere) which have scale heights of various atmospheric constituents, determined, to a large extent, by the ultra-violet (UV) and extreme ultraviolet (EUV) outputs of the Sun, these aspects are of particular of interest to NASA. The drag of the satellites in LEO, and hence their orbital path and lifetime are strongly affected by atmospheric drag, and thus the Sun's varying output.

The varying solar output is affected by the Sun's "activity," and thus we shall concentrate on methods of predicting future solar activity. We first discuss general methods, which have been employed, and later focus on the SOlar Dynamo Amplitude (SODA) index method. This SODA index method is used to predict solar activity, based upon generating an index that is a measure of the strength of the Sun's dynamo. This method has a physical basis, rather than a purely numerical (or unphysical) basis.

The method was first tested with 8 prior solar cycles before first being published. Since then, it has predicted 3 solar cycles quite well. Figure 1 shows F10.7 radio flux data over the past 50 years, along with the past three predictions (refs. 1-3), including cycle #23. Cycle #23 extends from 1996 through approximately 2006 or 2007, with cycle #24 starting thereafter. Examining Figure 1, one notes that timing of earlier cycles was off by ± 1 year roughly. We have, however, developed methods of improved cycle timing, consequently this cycle seems to have been much closer to the predictions. Additionally, although perhaps fortuitously, the accuracy of the smoothed peak

prediction also seems to have improved, namely cycle #23's prediction fits the observed data better than the earlier predictions.

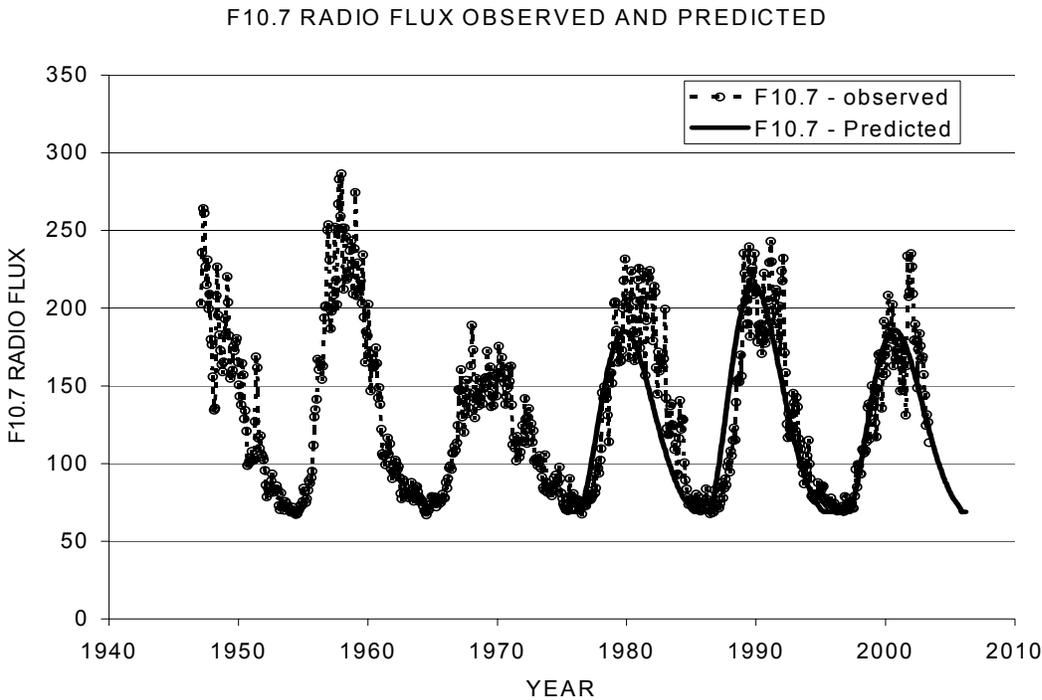## F10.7 RADIO FLUX OBSERVED AND PREDICTED

Figure 1: Observed F10.7 Radio Flux (open circles) and Schatten et al. Solar Flux Predictions (solid lines) prior to the last 3 cycles

Let us first briefly review the connection between solar activity and the density of the Earth's exosphere and then go on to solar forecasting. The Sun, whose nearly constant energy source provides a very stable harbor for life on Earth, provides a very unstable environment for satellites in orbit. The reason is that the solar UV and EUV irradiances vary dramatically with solar activity (showing changes at certain wavelengths of more than 100%), and this energy inflates the upper atmospheric layers of the Earth, forming the exosphere in which satellites orbit. Thus, the satellites in LEO have paths that depend strongly on exospheric densities. Of course, satellite and orbital properties (ballistic coefficient related to drag vs. mass, orbital properties, etc.) are also important. Although the LEO densities are primarily affected by the Sun's short wavelength output (UV and EUV), these parameters of solar activity are difficult to monitor, hence the longer (radio) F10.7 cm wavelength is often used as a proxy indicator.

The solar UV radiation ionizes oxygen, forming ozone in the Earth's stratosphere, and above this, the more intense EUV forms the hotter thermosphere and exosphere, in which terrestrial satellites orbit. Solar activity energy, as opposed to the more constant solar luminosity, thus inflates the Earth's atmosphere into its upper layers. These upper layers vary exponentially with the exotic forms of solar radiation, making them more sensitive to the some of the most variable forms of solar radiation. Hence satellite drag is greatly magnified by solar activity. Consequently, solar activity forecasting is a valuable tool for orbit predictions. This exospheric behavior contrasts greatly with tropospheric behavior, where meteorologists traditionally, yet safely, ignore solar irradiance changes. The solar irradiance is called as a misnomer, the "solar constant," since its changes are about 0.1%, much smaller than the EUV variations, which often exceed 100%. Let us now discuss how solar activity is predicted.

A NASA-funded National Oceanic and Atmospheric Administration (NOAA) panel investigated a number of the methods of solar activity prediction several years ago (see Joselyn et al. (ref. 4)). These methods of prediction rely upon knowledge of the many cycles of solar activity known, seen in Figure 2. The graph also shows the numbered cycles #s 1-23.
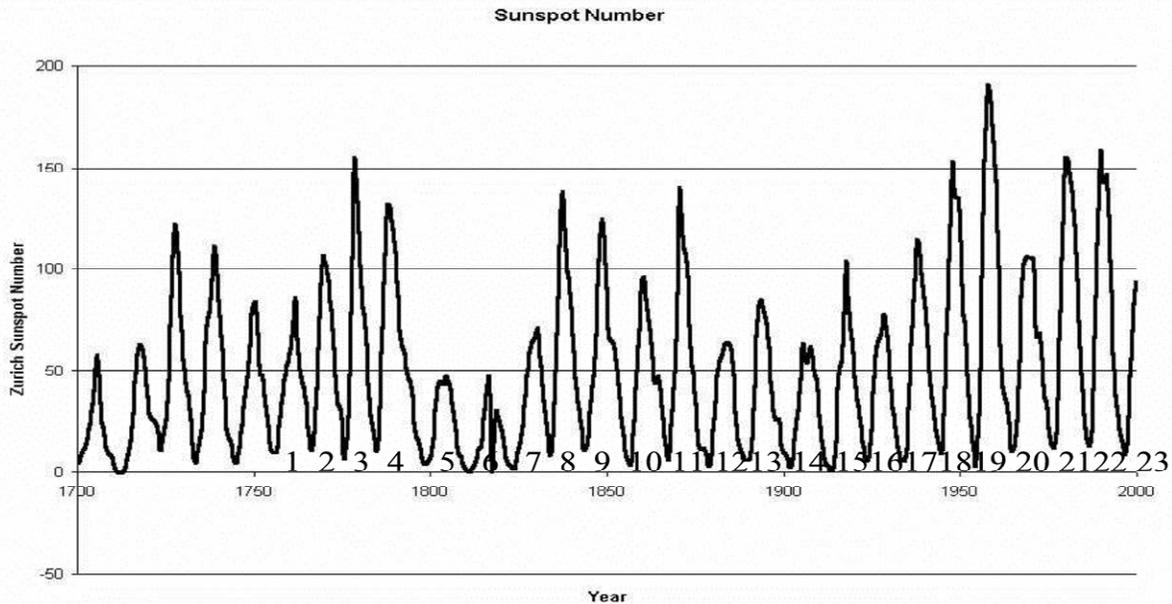
Figure 2: Sunspot Number Vs. Time For The Past Few Centuries

The figure shows "power" in a wide variety of periods beyond the famous 11-year Schwabe periodicity. Additionally, major variations exist both on longer and shorter timescales. Further, amplitudes of the cycles vary by more than 100%, in a rather chaotic manner. Epochs occur, such as during the "Maunder minimum," when solar activity dropped precipitously to near 0. The numbering on the chart shows the "Even/Odd" effect, where this century's odd numbered cycles have always been larger than the previous even numbered cycle (e.g. cycle #19 > cycle #18).

The NOAA panel (ref. 4) chose the following general solar forecasting categories: Even/Odd Behavior, Spectral, Recent Climatology, Climatology, Neural Networks, and Precursors. Briefly, these categories, seen in Table 1 indicate the following:

1. Even/Odd Behavior - uses the relationship that for the 20th century, and for most of the 19th century as well, the Odd numbered cycles have been larger than the preceding Even Numbered cycles.
2. Spectral - analyzing activity by spectral methods, such as Fourier analysis.
3. Recent Climatology - simply averaging recent cycles, say the last 5.
4. Climatology - using statistics of the longest duration of solar cycles (although usually leaving out the Maunder Minimum – a time period in the 17th century, when there was a 50+ year dearth of sunspots) to obtain a mean cycle and standard deviation to obtain a simple mean and uncertainty.
5. Neural Networks - using AI - artificial intelligence methods on solar activity, most commonly on sunspot number.
6. Precursors - physical phenomena related to future solar activity levels. The Precursor category has been subdivided into geomagnetic and solar magnetic branches, since they gave slightly different prediction levels for this cycle(ref. 3).

The above methods suggest the values for solar cycle #23's smoothed peak sunspot numbers, (Zurich sunspot numbers, Rz), shown in Table 1. It now appears from the behavior of this cycle that it has peaked near a smoothed sunspot number near 120.8 in April 2000. Although, the smoothed F10.7 cm radio flux peaked early in 2000, in 2002, a second peak later formed above 180. Surprisingly, this later peak, although higher in F10.7 than the previous values, was lower in the more traditional sunspot number, making argumentative which was the "larger peak." From an examination of Table 1, one sees the solar cycle behavior, for this cycle, supports the Climatology, Neural Networks, and Solar Precursor methods. Geomagnetic Precursors predicted too large a value, partially due to the Geomagnetic Precursors reaching their minimum values past solar minimum. Additionally, the Even/Odd behavior predicted much too large a value. Although the Climatology, Neural Networks, and the Solar Precursors have done

well this cycle, the first two have not done well for the past two cycles. Thus the solar precursor technique seems to be both the most reliable, as well as having a physical basis, rather than purely "numerical." Let us go through the Table 1 list, and provide some insight into these "traditional" methods.

Table 1. PREDICTED AND OBSERVED** ACTIVITY FOR
SOLAR CYCLE #23: SUNSPOT NUMBERS (Rz)* AND F10.7 Radio Flux

Technique	Smoothed Max: Rz	Smoothed Max: F10.7
Even/Odd Behavior	200	245
Spectral	155	198
Recent Climatology	155	198
Climatology	115	159
Neural Networks	140	183
Geomagnetic Precursor	160	203
Solar Precursor	138	182
Observed Values**	120.8	184

*Rz: Zurich sunspot number, based upon the NOAA panel report by Joselyn, et al.(ref. 4)
**The observed smoothed maxima in Rz and F10.7 occurred at different times during cycle #23

The first method, Even/Odd, wherein if one numbers the cycles (the present one is #23), then for this past century, all odd numbered cycles have been larger than the preceding even-numbered one (see Figure 2 for this numbering). This Even/Odd effect seems like a statistical fluke. Consider that there have been only 4 previous such pairs for the 20th century - cycles 14 through 21. If one takes the first pair, one or the other must be larger; hence one can't count the first pair to support any effect. Hence, there are only 3 matching subsequent pairs, the chance of these three agreeing with the first is only one in eight, or a significance of 87%, not highly significant. One would be fortunate not to believe in the Even/Odd effect. Since if one did, and then the present cycle #23 would be predicted to be the largest on record, having followed the largest even numbered cycle observed in the past 400 years. Namely, this enormous activity, as predicted by this method, did NOT occur.

The second method, Spectral, has seen the most attention throughout the history of solar activity predictions, since Fourier analyses have been readily available, and the methods generally useful for periodic phenomena. In recent times, however, with new knowledge of "chaotic" systems, it has become generally recognized that Fourier or generally spectral methods do not lend themselves to understandings of chaotic phenomena. The most obvious area where this is seen is in weather prediction. A weather forecaster would not be well received if s/he tried to forecast the weather at a location on Earth simply by taking parameters at that location and analyzing them using the Fourier technique. The reason, of course, is that knowledge in a chaotic system becomes "lost," whereas in a Fourier or spectral method, the coefficients are as dependent on what happened recently as on what happened in the distant past. Further, examination of long-term solar activity, using cosmogenic isotopes reveals that commonly accepted cycles (e.g. the Gleissberg cycle of 80-100 years); do not bear out over long periods, with significant power in the solar activity cycle over periods in the few hundred to thousand year ranges. This would be expected if one considers the "time constant" expected for changes, at the base of the convection zone, where magnetic fields are regenerated.

Next, we come to Recent Climatology, and Climatology. These basically, simply use the statistics of known solar cycles, with climatology using the last few hundred years, from after the Maunder Minimum to present. One obtains a mean and standard deviation to get the chances of any size cycle. Recent climatology recognizes the "chaotic nature" of solar activity, and thus eliminates the early data. One develops a "recent average" and "recent statistical behavior" from the last few cycles. This method relies strictly upon "persistence," and it has a certain amount of use, in geophysics. It is like saying tomorrow's weather will be the same as today's – a method which is not too bad, but which has been surpassed by other methods. One of the earliest solar activity prediction methods in this category is the curve fitting techniques of McNish and Lincoln. In this method the recent behavior gradually blends into the average behavior, however, the technique was to be utilized for no more than a year in advance.

The next set of methods is Neural Networks - using AI - artificial intelligence methods on solar activity. While AI is a powerful technique, however, this method has only been utilized with past activity (sunspot number), an

inadequate source to predict future activity from. Similar to the spectral methods, the technique suffers from an inadequate database to make long-term predictions from. Nevertheless, the AI technique seems to provide a curve fitting technique similar to that of the McNish-Lincoln method, which works for about 1-2 years in advance. Over a long time interval, this method reverts to the climatological method, and thus provides little more than an average.

The paper now discusses Precursor methods more fully, distinguishing solar from geomagnetic Precursor methods. In general, for more information on solar activity prediction methods including Precursor methods, the NOAA panel discussions (ref. 4) provide an excellent source. Further, other views including more detail on climatological and statistical methods may be found in Hathaway, et al. (ref. 5).

SOLAR AND GEOMAGNETIC PRECURSOR METHODS

The Precursor category may be subdivided into solar and geomagnetic varieties. This past cycle the solar precursors in 1996 suggested a peak value near a smoothed sunspot number of 138 ± 30 and F10.7 values of 182 ± 30 (ref. 3). This value was more accurate than the geomagnetic predictions, which gave too high a value. Nevertheless, since the geomagnetic precursors preceded the solar precursor method, let us briefly review how that method began.

Geomagnetic Precursors

The first to point out the significance of the geomagnetic Aa index (a geomagnetic index used as a planetary index, originated by Bartels) in tracking long-term solar activity were Feynman and Gu (ref. 6). Although Feynman never used the information for directly making predictions, it seems clear that the Ohls (refs. 7-8) and other Geomagnetic Precursor practitioners used the same or similar methods to predict activity. Feynman separated the geomagnetic Aa index into two components: one in phase with sunspot number, and one out of phase. This effectively led to "active" and "quiet" components. She found that this quiet signal tracked the sunspot numbers several years in advance, similar to the Ohl results. The maximum in this signal occurs at sunspot minimum and is proportional to the sunspot number during the following maximum. How this signal propagated or why it should be present, however, was not clear.

Precursor methods were developed by the Soviet geophysicists Ohl and Ohl (refs. 7-8) to make solar predictions and taken up by Brown and Williams (ref. 9), who later noticed an extremely high correlation (close to 1) between geomagnetic activity near solar minimum and the size of the next solar cycle. High correlations were found between the number of "geomagnetic abnormal quiet days" and the size of the next solar cycle. Although the abnormal quiet day geomagnetic index was an unusual one, later the correlations remained high when objective geomagnetic indices, such as Ap, and Aa were employed. Bartels (ref. 10) discusses these indices. Thompson (ref. 11) further improved upon the relationships between geomagnetically "disturbed" days and the amplitude of the next sunspot maximum.

The Precursor methods involved correlations found by the geophysicists; they were puzzling because the Sun's activity might cause a terrestrial effect, but not vice-versa. So the order of the causality seemed to be reversed. Trying to unravel the mystery of how the Sun could broadcast to the Earth, in advance, the level of its future activity, Schatten et al. (ref. 1) searched for a physical mechanism to understand the phenomena. To place these puzzling correlations in a physical context meant relating these geomagnetic effects somehow to solar dynamo theory. Let us briefly review how this is done.

Solar Dynamo Theory and Solar Precursors

Figure 3 shows the Babcock dynamo, a classical, generally well accepted view for the Sun's dynamo, as there are many observed solar features explained by this model. Namely, in this model the Sun's polar fields near solar minimum are wrapped up by differential rotation to form the toroidal fields, which later float to the Sun's surface and erupt to form active regions. As these fields dissipate, they then regenerate the polar field allowing the solar cycle to recur. Modern helioseismological studies have shed new light on the Sun's dynamo; nevertheless, the broad view outlined by Babcock still remains valid. Figure 3 thus shows an "oscillation" between the Sun's toroidal field (the East-West fields which erupt to form sunspot fields) and "poloidal" field (which extends through the Sun's polar regions). Let us now see how making key observations and processing them, based on this dynamo paradigm,

allows us to gain an understanding of the Sun's buried magnetic flux and to better predict solar activity. The dynamo process outlined is neither as simplified nor "perfect," in terms of perfectly reproducing itself, as outlined, but rather is subject to the vagaries of field magnification within the turbulent convection zone of the Sun. Hence, during an 11-year solar cycle, the amplification sometimes regenerates more polar field and sometimes less, leading to a growth or decay of the solar cycle.
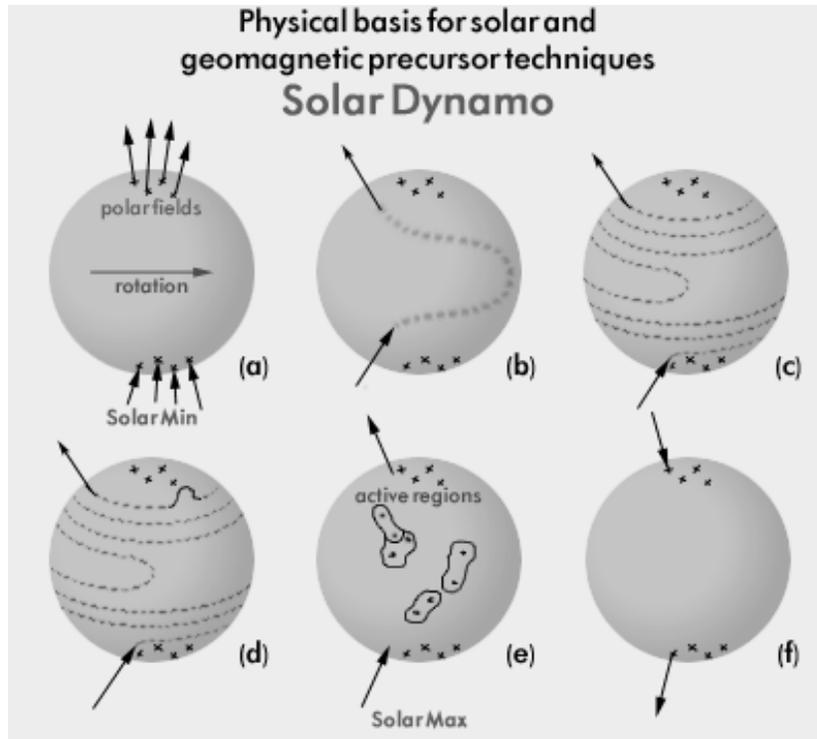

Figure 3: The Babcock Dynamo: the Sun's polar fields near solar minimum (a) are wrapped up by differential rotation (b) to form toroidal fields (c). These fields, later in the cycle, float to the Sun's surface and erupt (d) to form active regions containing sunspots (e). The breakup of these active region fields regenerates the Sun's polar field with a reverse sign (f), allowing the process to repeat anti-symmetrically.

If the Sun's dynamo is fairly linear, then one expects a direct correlation between the numbers of active regions formed in that cycle with the strength of the Sun's polar field near the cycle's solar minimum. In this view, since the polar field of the Sun is later amplified into the sunspot fields, one can use it as a precursor or predictor of solar activity, for that cycle. Namely, by monitoring the observed magnetic fields of the Sun, one can use these observations to predict future levels of solar activity. This is similar to the way meteorologists monitor atmospheric pressure regions to predict cloud formation. Hence it is the first "physics-based" forecasting technique.

To test this hypothesis we used 8 solar cycles of historic data, and found reasonable correlations, although not as good as those found by the geomagneticians (refs. 6-8). Nevertheless, we placed more faith in this method, as it was tied to solar measurements directly, and the geomagnetic methods found correlations based solely upon some indices, which were qualitative. Until recently, solar magnetic measurements could not be used directly, and instead solar "proxy" fields were used (estimated from numerous solar indices, ranged from solar polar faculae, to the shape of the Sun's corona) which were not as well measured as the geomagnetic indices. Nevertheless, the correlations were reasonable. At present we can measure directly the Sun's polar fields; Schatten and colleagues have been basing their predictions primarily from solar magnetism (the so-called "Solar Precursor method")

The Solar Dynamo Amplitude Index

When "precursor" methods of predicting solar activity were first developed, it was only possible to assess the state of the Sun's dynamo near each solar minimum, when the Sun's buried magnetic fields poke through the Sun's surface at the poles and these fields may directly be observed. Schatten and Pesnell (ref. 12) developed a more sophisticated method for undertaking the analysis than was done in the early days of this field. This now allows an estimation of the "magnetic state" of the Sun to be ascertained during any phase of the solar cycle, rather than only at solar minimum. As the solar cycle progresses, there is an interchange between poloidal and toroidal magnetic field (see Figure 4 – the poloidal field is the "polar field", and the toroidal field is that which erupts to form sunspots.). This interchange is similar to the interchange between the kinetic and potential energies of a pendulum. One can measure both, and obtain a measure of the total energy of the pendulum, at any time, rather than measuring only one, when that one maximizes, thus allowing the energy of the pendulum to be estimated at ANY TIME, rather than only when one of its energy components maximizes. Utilizing this idea allowed Schatten and Pesnell to capitalize on all the aspects of solar activity magnetism to obtain a combined index, the SODA index. Just as with the pendulum, use of this index can be updated during any phase of the Sun's solar cycle. Through a combined measure, the SODA index, the strength of the Sun's buried magnetic flux is obtained. Figure 4 shows the 11-year oscillations of the poloidal and toroidal fields, plus their secular (long-term) changes. By using both indices, the combined SODA index, shows less 11-year variation, but <u>retains</u> the Sun's secular changes, thereby capturing the slowly varying strength of the Sun's dynamo fields while allowing the state of the dynamo to be monitored continuously. Note that it is important that removing the 11-year variation is <u>not</u> done with spectral filtering, as this would require having current conditions dependant upon old temporal variations, and hence would completely <u>mitigate</u> the benefits gained by updating conditions with the latest information (it would smooth the data out).
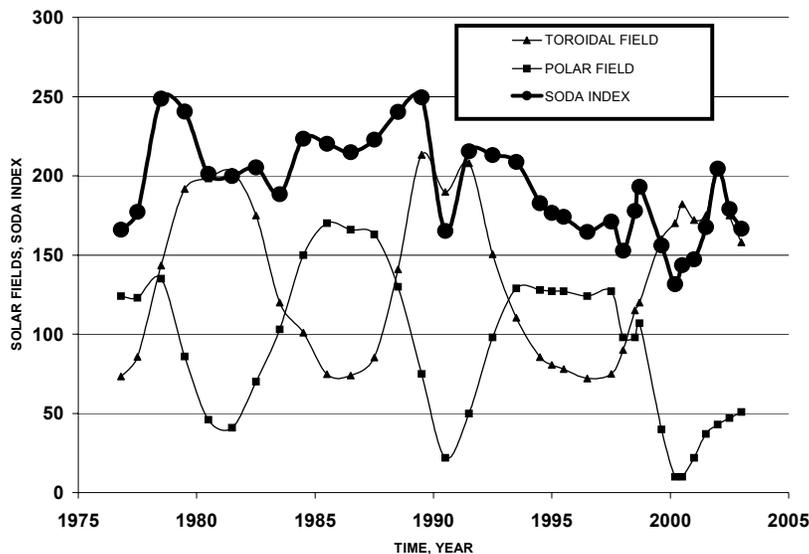

Figure 4: The SODA index is a composite index attempting to combine the changing toroidal and poloidal fields of the Sun. As these fields vary with time, the combined SODA index allows us to monitor the "buried magnetic flux" present in the Sun's ever-changing dynamo.

Let us discuss other properties of the SODA index. Firstly, it provides a continuous measure of the strength of the magnetic field buried within the Sun's interior. Additionally, since the magnetic field in the interior of the Sun is "buoyant" (as the magnetic field pressure excludes plasma), the field acts like a gas in a liquid (e.g. carbon dioxide inside a carbonated drink). Hence, the SODA index terminology is not only an acronym, but also a descriptor of the amount of magnetic "fizz" inside the Sun's interior. Figure 4 shows the SODA index in recent times. It has been somewhat down from cycle #22, suggesting (several years ago) that cycle #23 would be somewhat reduced (which has been born out). This incidentally goes against the Even/Odd behavior mentioned earlier about cycles this century. Using the SODA index we predicted a value at the lower end of the Precursor methods (ref. 3), namely a smoothed sunspot number of 138 ± 30 in 1996 and F10.7 values of 182 ± 30, as shown in Table 1. This is

significantly less than the NOAA panel estimate (ref. 4), and agrees more closely with the observed values of 120.8 for Rz, and 184.2 for smoothed F10.7. Let us now see how cycle #23 has progressed.

SOLAR CYCLE #23 FORECASTS AND OBSERVED BEHAVIOR

Solar cycle #23 is now past its peak activity for this cycle. As with many recent cycles, the "peak" was actually a "double peak." Figure 5 shows our past prediction (ref. 3), as well as the solar radio flux for this past cycle. The double peak aspect is due to the variations in sunspot activity on monthly and yearly time-scales, considered "short-time scales" for the purposes of understanding long-term solar cycle. This is usual as solar activity is not a monotonically varying function. In any case, a good estimate for the size of the current cycle can now be ascertained from the observed data. The two peaks seen were near 180 and 192 in F10.7. In sunspot number, the second peak was smaller than the first peak, and near about 120. Thus choosing which the official peak is depends upon which index one "trusts" more. The sunspot index is more commonly used, because it has the longest history, however, for the purpose of studying the Earth's exosphere, radio flux is more commonly used. One may simply examine the curves themselves, to examine how the cycle compares with a particular prediction. Figure 5 shows the prediction compared with radio flux, commonly used as a proxy indicator for the Sun's UV and EUV. A different set of curves would apply if one were comparing sunspot number.
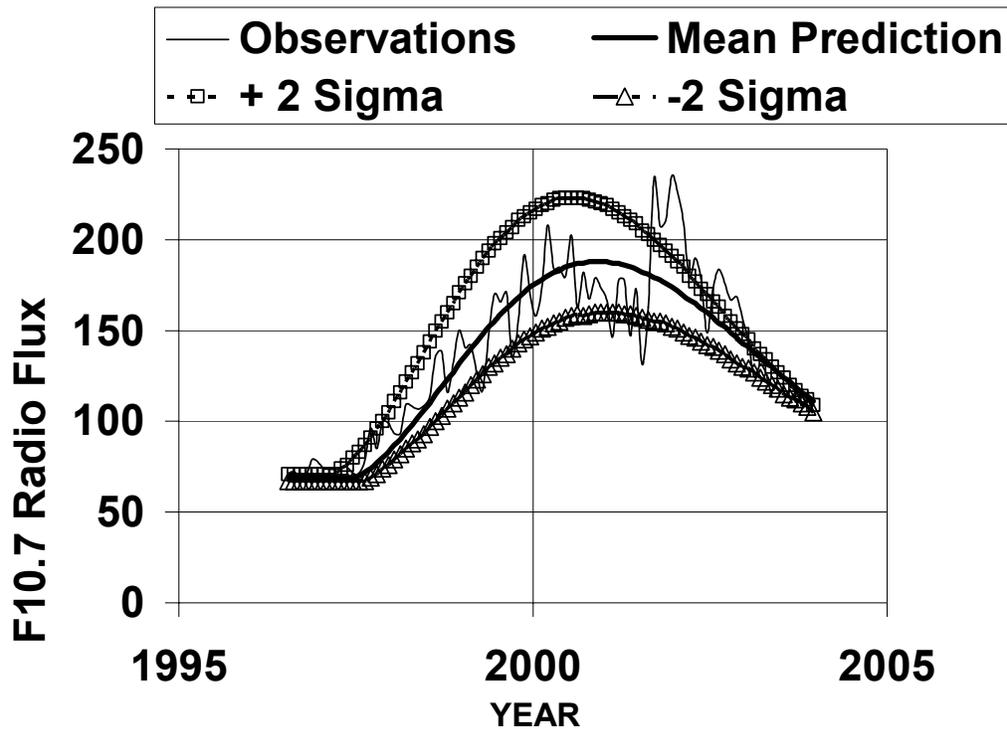

Figure 5: 1997 Prediction of Solar Activity and observations Of Solar Cycle #23; also +, and – 2 sigma curves.

A PROSPECTIVE ON CYCLE #24

Let us end with a prospective on solar activity for cycle #24 (years 2006 - 2016). The Sun's polar field reversed near the peak activity of cycle #23, and begun its growth towards a new peak. The Wilcox Solar Observatory polar field strength measured in the pole-most 3' aperture shows magnetograms averaged each 10 days. They provide the following behavior (ref. 13). Early in 2000, after polar field reversal, the smoothed mean polar field rose quickly from zero to 0.22 Gauss, compared with only 0.12 Gauss over a similar period for the last cycle, a decade earlier.

The initial quick rise in the Sun's polar field was followed by a virtual abstinence of field increase. We believe this reduction was the result of low latitude coronal holes (which are like polar fields, but falling in equatorial latitudes). This allowed the "normal reversal" of the Sun's polar field to be shut down. In this case, at the lower latitudes, the high differential rotation of the Sun can destroy unipolar fields through flux diffusion and consequent destruction of oppositely oriented flux.

Regardless of the reason for the lack of polar field rise, the current levels of polar field strength do not bode well for a fully active sunspot cycle #24. The current estimated activity level (for the next cycle) could be estimated from the levels of the SODA index seen in Figure 4. With values significantly below levels a decade ago, our prediction for solar cycle #24, is that of a similarly stunted cycle. Thus our prediction for cycle #24 is shown in Figure 6 for the future levels of activity based upon utilizing the current and projected SODA index, and possible growths. This figure shows radio flux, F10.7, with a mean peak value (for cycle #24), near 142, and a 2-sigma uncertainty of 50. Nevertheless, it would be wise to observe future levels of the Sun's magnetic field and thus further monitor changes in the Sun's dynamo. This would allow an improved prediction as well as a reduced uncertainty.
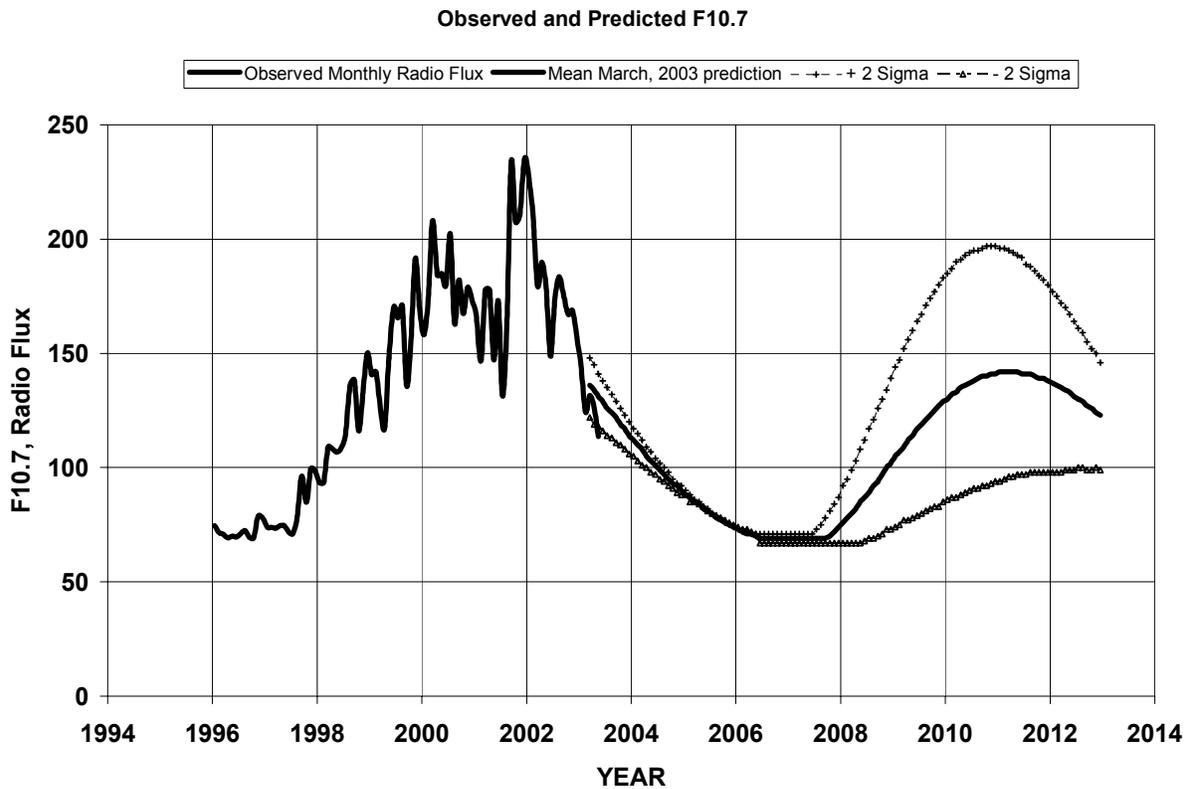
Observed and Predicted F10.7

Figure 6: Prediction for the new Solar Cycle # 24, as well as data for past Solar Cycle #23, until present. The + and – 2 Sigma curves are dashed lines shown with +'s and triangles, respectively. The mean prediction is the solid line.

Let us briefly discuss the use of different activity indicators since it affects the prediction estimates. As mentioned there have been two different indicators for the "size" of the solar cycle: radio flux and sunspot number. Both these indicators are not full or complete indicators of the solar cycle, and the use of ill-defined indices which only approximate what really is needed, is a stumbling block to predictors of spacecraft orbits. Namely, for flight dynamics as an example, one often uses F10.7 radio flux, but one adds geomagnetic activity levels to calculate exospheric densities. The added index helps deal with the inadequacy of using F10.7 radio flux alone. The real exospheric densities are affected by upper atmospheric processes and their interaction with solar UV and EUV fluxes, as well as geomagnetic storm energy supply. If one were to search for improvements in satellite orbital prediction on short time scales, one might find that that the overall indexing scheme (e.g. F10.7) is inadequate to quantify the solar flux, and one would need better ways to quantify solar activity. Tobiska (ref. 14) and colleagues

are making progress in this area, using an "E10.7" index to better measure how the Sun's flux affects the Earth's exosphere.

SUMMARY AND CONCLUSIONS

This paper discussed predicted levels of activity for the current solar cycle (#23), how the cycle has behaved, and future levels of solar activity for cycle #24. Currently, solar cycle #23 seems to have reversed the trend this past century of odd numbered cycles having larger amounts of solar activity than even numbered cycles. At present, the peak smoothed sunspot number for this cycle is near 120 and F10.7 radio flux had a double peak with the larger peak near 192. For this cycle, climatological, neural network prediction methods and the solar precursor method have given reasonably good values, but the first two did not provide good predictions for past cycles.

For solar cycle #24, the Sun's polar field reversed at the previous solar maximum, and has yet to rise to its formally large values. As a result the SODA index, has not risen significantly, and thus using solar precursor methods suggests cycle #24 will be smaller than cycle #23, with a current prediction of 142 ± 50 (± 2-sigma uncertainties).

This, we believe, represents a reprieve, in terms of reduced fuel costs, etc., for new satellites to be launched or old satellites (requiring reboosting) which have been placed in LEO. By monitoring the Sun's most deeply rooted magnetic fields; long-range solar activity can be predicted. Although a degree of uncertainty in the long-range predictions remains, requiring future monitoring, we do not expect the next cycle's + 2-sigma value will rise significantly above solar cycle #23's activity level.

Thus, the field of solar activity predictions is interesting both scientifically and pragmatically. It provides valuable information concerning the Sun's dynamo and it garners useful data for NASA and other agencies interested in solar activity related phenomena, ranging from power grid spikes, to communication blackouts, to satellite orbital dynamics.

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