Space Weather: What *IS* the Sun Doing?

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Introduction

Now in the depths of solar minimum, space weather should be quiet, well-behaved and basically, non-existent. In fact, the Sun is now fairly featureless and somnolent, but even with a weak pulse, it continues to surprise those who watch it closely. Space weather experts are searching for hints of what is to come during the next period of high activity – Solar Cycle 24 – and are also astonished to see short-lived but strong eruptions punctuate this period of calm. In December of 2006 a solar eruption included a radio burst that interfered with GPS to such a degree that it caused many dual-frequency receivers on the dayside of the earth to lose lock suddenly and unexpectedly. All of this stellar intrigue is causing us to ask" What *IS* the Sun Doing?"

Solar Cycle

Data and observations over many years have shown that the Sun gives/takes the more spectacular types of space weather on roughly an 11 year cycle. At the height of the solar cycle, the most recent maximum phase being near 2000-2001, there were numerous eruptive events that caused ionospheric storms that impacted Loran and GPS. These events usually last for a few days, and cause rapid changes in the amount and distribution of free electrons. Think of the maximum phase of the solar cycle as being analogous to the hurricane season – it is a time of strong space weather activity with periodic pulses that have profound effects.

A more subtle but significant contributor to the solar cycle variability seen in the ionosphere is the fact that the Sun's output in the Extreme Ultraviolet (EUV) wavelengths increases by a factor of 4-5 from solar minimum to maximum (Figure 1).

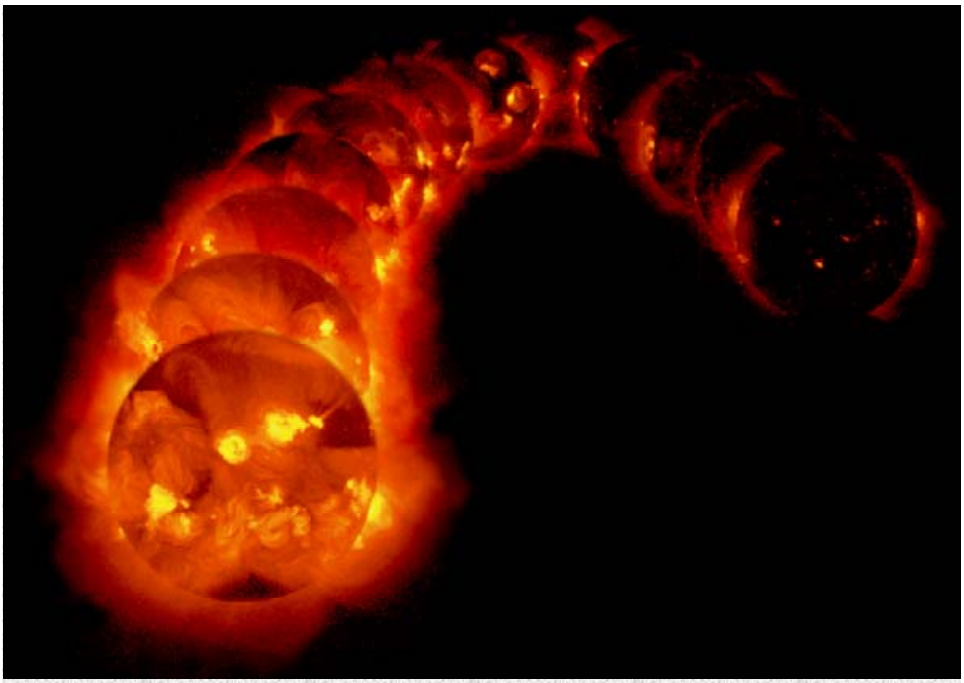


Figure 1: The variability of the Sun's output from solar minimum (right) to solar maximum (left) in X-rays. (Yohkoh mission, courtesy ISAS, Japan, and Lockheed-Martin).

Literally the Sun brightens and dims in its output of EUV, and it is the EUV that is the primary driver of photo-ionization in middle ionosphere. The ionosphere is seen to "bulk up" when the Sun is providing more EUV to increase the amount of free electrons that affect the GPS signal.

In the case of Loran the solar cycle variability is less dramatic. The lower level of the ionosphere, where the sky wave is reflected, is created by a different physical process. The solar Lyman-alpha emission, at 121.6 nanometers in the Far Ultraviolet (FUV), also varies over the solar cycle, but increases only about 10% from minimum to maximum. That translates to the problematic events for Loran more likely to be the storms, and not just due to the ionosphere being increasingly ponderous at times, as it is for GPS.

Currently Solar Cycle 23 is near its end and signs of the beginning of new Cycle 24 are anxiously anticipated. The solar EUV flux is low, the eruptive events are rarely occurring, and the ionosphere is generally well-behaved for Loran and GPS users. What is the latest prediction for the coming solar cycle, Cycle 24? A blue-ribbon panel has been convened and has had serious, lively deliberations on the prediction for the magnitude of Solar Cycle 24, and, at this writing, the panel is split. The reasons for the divergence of opinion are very interesting.

One faction of the prediction panel argues that the seed magnetic flux available for Solar Cycle 24 is found by measuring the strength of the solar polar magnetic fields. The idea

is that those fields will be drawn into the solar interior and percolate to the surface in the next few years as sunspots. Sunspots are the metric by which solar cycles are measured. The solar polar fields (Figure 2) over the past thirty years, shows a relationship between the strength of the solar polar magnetic fields and the magnitude of the next solar cycle.

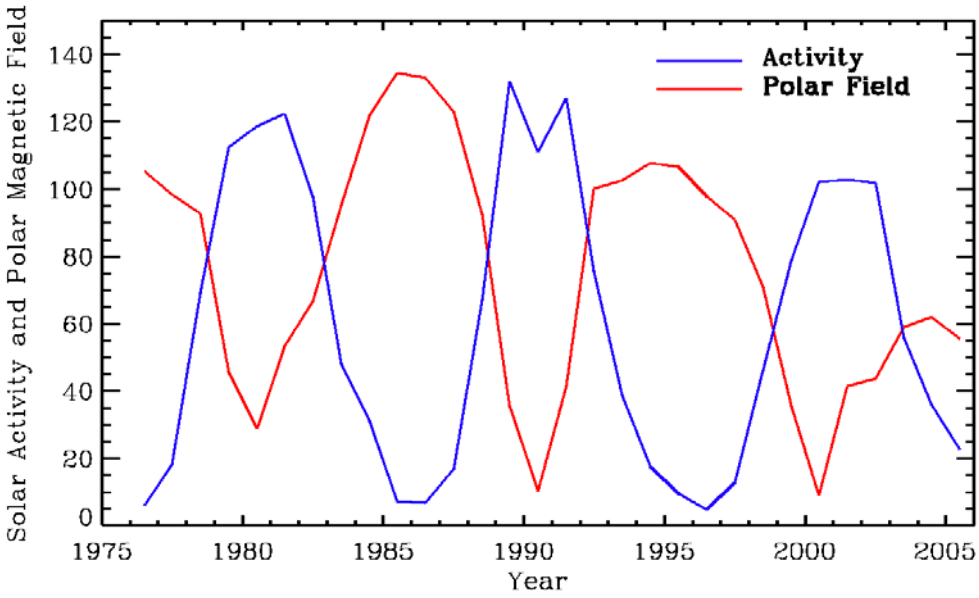


Figure 2: Solar Polar Magnetic Field and smoothed sunspot number. (W.D. Pesnell, NASA).

If there is a cause and effect relationship in these data, it is clear that a prediction of a small Solar Cycle 24 is reasonable, given that the solar polar fields are very weak at the appropriate time of the solar cycle, approximately 2005.

On the other hand, the other faction of the prediction panel believes that a more relevant and necessary observable that foretells the size of the next solar cycle is the strength of the meridional flow seen at the solar surface, over the time period of the past two solar cycles, i.e., the Sun has a memory and given what has recently occurred will indicate what is soon to come. What is most intriguing about this new model (Dikpati et al, GRL, 2006) is that the model has faithfully replicated the past 8 solar cycles with these assumptions (Figure 3).

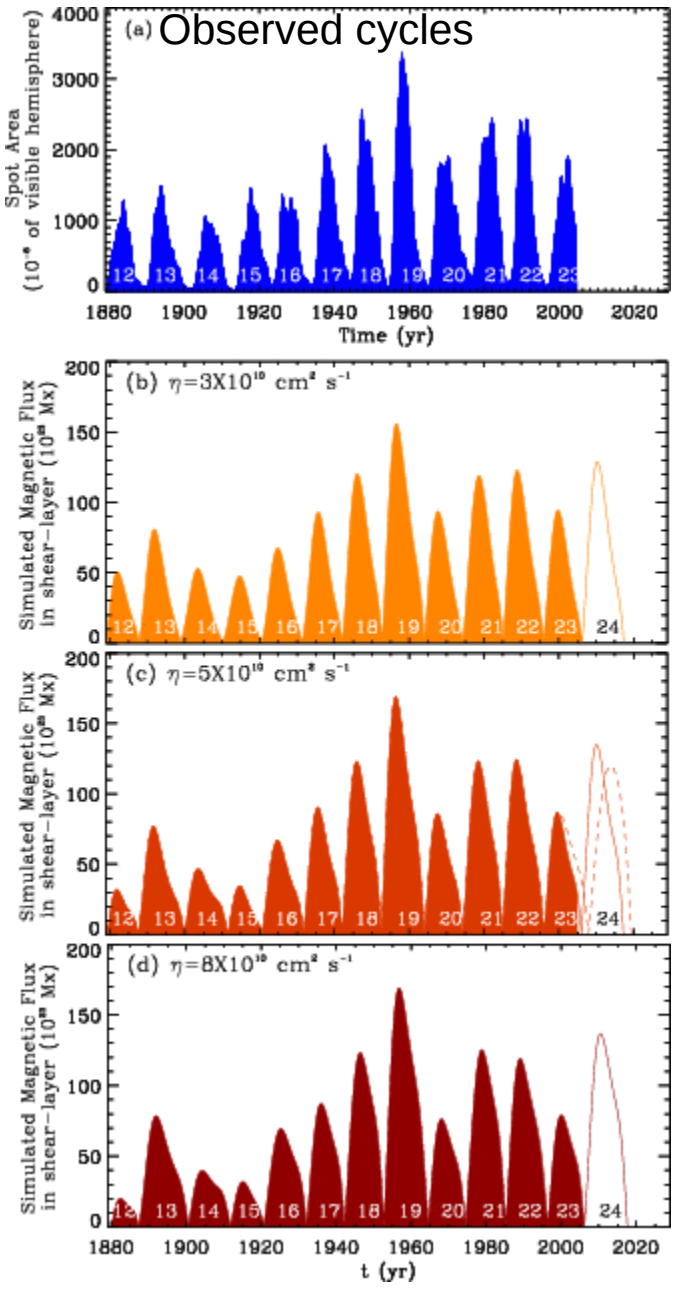


Figure 3: A comparison of the observed magnetic flux (a) – solar cycle – with model predictions (b-d), with different assumptions of solar magnetic diffusivity. Note that all assumptions replicate the observations. (Dikpati et al., 2006).

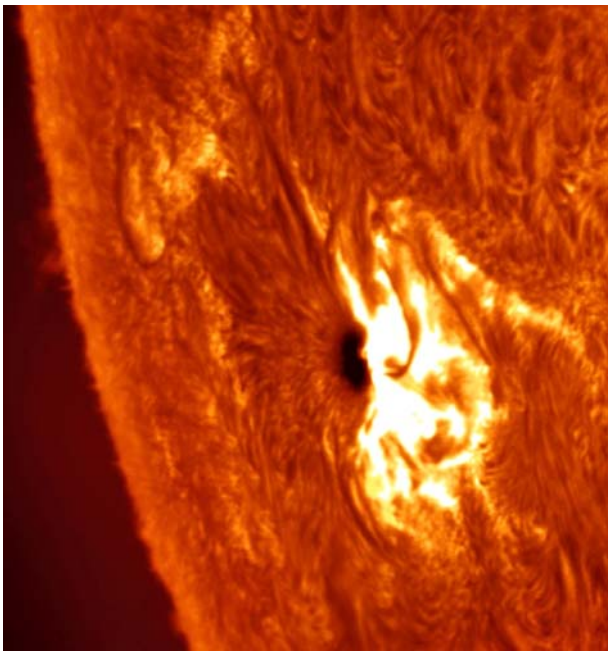
If this model truly captures the relevant physics, then a prediction of Solar Cycle 24 being 30-50% larger than Solar Cycle 23 is reasonable; hence the debate among the scientific community.

The electronic navigation community has a need to know how Solar Cycle 24 will play out as a strong cycle bodes for both more ionospheric storms in the context of a “bulked

up” ionosphere. A weak cycle means fewer ionospheric storms against a backdrop of a more svelte ionosphere.

December 6, 2006 Solar Eruption

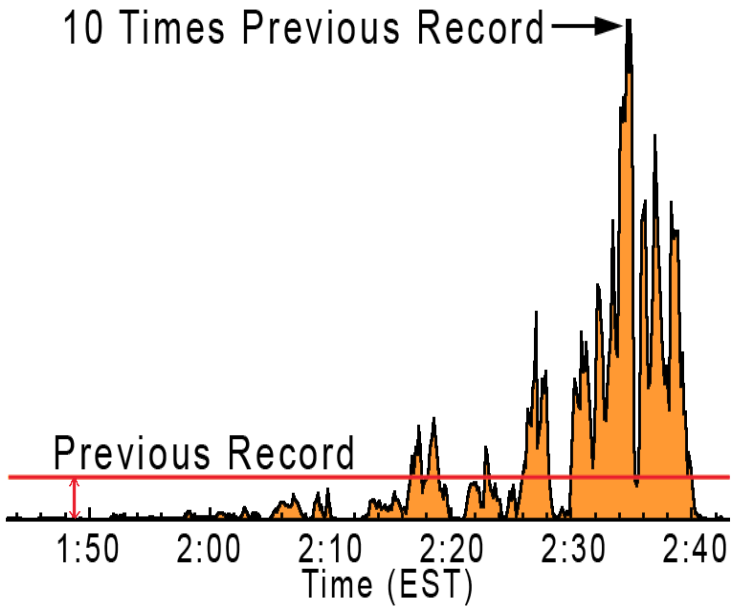
Even in the depths of solar minimum in 2006, the Sun can produce some extraordinary activity. A large sunspot group came into view from earth in early December and erupted periodically with solar flares. Flares are rapid releases of energy that affect all frequencies across the electromagnetic spectrum to varying degrees.



Courtesy G. Palmer

On December 6, a flare erupted around 1930 UTC (Figure above), and was monitored at various frequencies both from satellites and the ground. The New Jersey Institute of Technology operates a radio-telescope at Owens Valley California, capable of making polarization and intensity measurements at 1.6 GHz, near the GPS L1 frequency.

Remarkably, this radio burst was so powerful – 10 times stronger than the previous record – and so highly right-hand circularly polarized (RHCP) – GPS antennas are predominantly RHCP – that it caused a sudden malfunction of dual frequency GPS receivers over the sunlight side of the earth for a few minutes time.



Courtesy D. Gary (photo and chart)

This event is so interesting as it clearly shows the Sun being a noise source that overwhelms GPS at times, and this unprecedented activity occurred during solar minimum, the "quiet" time for space weather activity.

Conclusions

Space weather is mostly invisible to the human eye, but at times a blinding beacon to Loran and GPS. It can render Loran unusable during strong space weather storms. It is a major contributor to GPS error budgets, and can, with little warning, cause total loss of one's ability to use GPS or other GNSS systems.

Space weather has both a cyclical component as well as a spontaneous component. A great debate is now taking place about the likely characteristics of the upcoming Solar Cycle 24.

Be it large or small, events such as the one seen on December 6, 2006, do occur and can dramatically affect both Loran and GPS operations. The NOAA SWPC is in close consultation with the electronic navigation user community, to design and produce products and services, in cooperation with other partner organizations with NOAA. There's no other route – to improve Loran and GPS services requires improved space weather products and services.