Lab Notes

Prepared by the ARRL Laboratory Staff

Here Comes the Sun!

Solar activity can aid or hamper HF propagation beyond line-of-sight range. Many information sources can help us keep up with solar conditions. This month, ARRL Laboratory Technician Mike Gruber, WA1SVF, assisted by Senior Technical Editor Dean Straw, N6BV, answers some questions about how Ol' Sol influences the propagation of radio signals.

Q I've only been on the air on HF for a year. I've heard about the Sun's 11-year sunspot cycle and would like some details. Can you help?

A I'd be delighted. First, let me state that the interactions between the Sun and our Earth are incredibly complex. Even scientists who have studied the subject for years do not completely understand everything that happens on the Sun. I will try to give you some general background about how the Sun affects radio propagation here on Earth.

The Sun emits electromagnetic radiation of all kinds, ranging in frequency from below HF all the way to the X-ray region. Much of the energy is emitted as heat. Some solar radiation ends up here on Earth, providing the energy needed to sustain all activity here—including HF radio propagation. Although our Sun is not a particularly large or spectacular star, it still radiates an almost unimaginable amount of energy into space. The total power radiated by the Sun is estimated at 4×10^{23} kW—that is, the number four followed by 23 zeroes. At its surface, the Sun creates about 60 *megawatts* per square meter. Now that is some transmitter!

The Sun also is constantly ejecting material from its surface in all directions into space. This makes up the so-called *solar wind*. Under relatively quiet solar conditions the solar wind blows around 200 miles per second—675,000 miles per hour—taking away about two million tons of solar material each second from the Sun. Don't worry: the Sun is not going to shrivel up anytime soon. It's big enough that it will take many billions of years before that happens.

A 675,000-mph wind sounds like a pretty stiff breeze, doesn't it? Lucky for us, the density of the material in the solar wind is very tiny by the time it has been spread out into interplanetary space. Scientists calculate that the density of the particles in the solar wind is less than that of the best vacuum they've ever achieved on Earth. However, even such a low density of solar particles can have immense effects here on Earth.

For years scientists have used different filters on their optical telescopes to observe various aspects of solar activity. Starting in the 1930s, observations began at radio frequencies and now we have satellites that specialize in watching what happens at the Sun and in space.

One of the best known gauges of overall solar activity is the number of *sunspots* seen on the Sun's surface. Sunspots are relatively cool areas that appear as dark spots. (CAUTION: Do not look at the Sun with the naked eye or a telescope; you could *permanently* damage your eyes.) Surprisingly, sunspots are not really dark, but appear so only because the surrounding surface is even hotter and brighter. A large sunspot can be up to 80,000 miles in diameter.

Systematic study of solar activity began around 1750. Long-term sunspot activity varies in *cycles*. On average, the number of sunspots reaches a maximum every 11 years, but the period has varied from 7 to 17 years. The first cycle to be completely and scientifically observed began in 1755; we know it as Cycle 1. We are now just starting Cycle 23. Solar activity also follows a 27-day cycle: the sun's rotational period.

Sunspot activity changes continuously. A sunspot can vary in size and appearance, or even vanish, within a single day. Large areas of sunspot activity usually last through several rotations of the Sun, some as long as two years. To offset the confusing effects of short-term changes, we average (or *smooth*) solar data. HF propagation predictions commonly use Smoothed Sunspot Numbers (SSN), which are monthly sunspot counts averaged over a 12-month period.

Solar-flux readings are another measure of solar activity. The average intensity of solar emissions also varies slowly over the 11-year solar cycle. A solar flux reading is a measure of power received, per unit area, per unit frequency. The Dominion Radio Astrophysical Observatory in Penticton, British Columbia, measures 2800-MHz (10.7-cm) solar-flux data daily at local noon. Solar flux correlates well with the intensity of ionizing UV and X-ray radiation. Smoothed Sunspot Numbers range from 0 to over 200 and solar-flux numbers range from 60 to 300.

Q That's really interesting stuff. But how can I use the Smoothed Sunspot Number to tell whether 10 meters will be open today for

DX?

A Long-time users have found that the upper HF bands are reliably open for propagation only when the average number of sunspots is above certain minimum levels. For example, from mid-1988 to mid-1992 during Cycle 22, the SSN stayed higher than 100. The 10-meter band was open then almost all day, every day, to some part of the world.

Nowadays, in mid-1996, few if any sunspots show up on the Sun, and the 10-meter band is rarely open. Even 15 meters, normally a workhorse DX band when solar activity is high, is closed most of the time during this low point in the solar cycle. Sunspots are associated with increased solar *ultraviolet* (UV) radiation. UV acting on the ionosphere is what makes radio propagation exciting on the upper HF bands.

Scientists believe that we are in the transition to Cycle 23 right now. The first sunspots from the new cycle were identified and reported on August 12, 1995. Solar activity however has remained very low since that time. Sorry, but it will be at least several years before we return to the days of hot 10-meter DX again.

Q Wait a minute. My Elmer told me that several years ago, when sunspot numbers were really high, sometimes conditions were still really “rotten.” What gives?

A Let’s try to keep something in perspective the Sun is a very large, very hot, thermonuclear ball of flaming gases. The Sun and its effects on earthly propagation can be described in “statistical” terms—that’s what the 11-year solar cycle does. However, you may experience vastly different conditions on any particular day compared to what a long-term, 11-year average would suggest.

Have you ever gazed into a blazing campfire and been surprised when a flaming ember or a large spark was ejected in your direction? The Sun can also do unexpected and sometimes very dramatic things. Disturbances of propagation conditions here on Earth are caused by disturbed conditions on the Sun.

There are three general types of major disturbances on the Sun that can affect radio propagation, and almost invariably they do so in a negative manner. You may hear people complaining about *Solar Flares*, *Coronal Holes* or *Sudden Disappearing Filaments*, especially when propagation conditions are “rotten.” Just like the weather, there’s not a lot we can do about solar disturbances, except perhaps to know they’re coming and then to endure the effects. Each disturbance causes both electromagnetic radiation and ejection of material from the Sun.

Solar flares are cataclysmic eruptions that suddenly release huge amounts of energy, including sustained, high-energy bursts of radiation from VLF to X-ray frequencies and vast amounts of solar material. Most solar flares occur around the peak of the 11-year solar cycle. The first earthly indication of a huge flare is often a visible brightness near a sunspot group, along with increases in UV and X-ray radiation and VHF radio noise. If the geometry between the Sun and Earth is right, intense X-ray radiation takes eight minutes to travel the 93 million miles to Earth at the speed of light.

The sudden increase in X-ray energy from a large flare can immediately increase RF absorption in the Earth’s lowest ionospheric layers, sometimes causing a phenomenon known as a *Sudden Ionospheric Disturbance* (SID). An SID affects all HF communication on the sunlit side of the Earth and signals in the 2 to 30-MHz range may disappear entirely. Even background noise may cease in extreme cases. When you experience a big SID, your first inclination may be to look outside to see if your antenna fell down! SIDs may last up to an hour before ionospheric conditions temporarily return to normal.

Typically, several hours after a flare erupts at the Sun, particles begin to arrive at the Earth in the form of a *plasma*, a highly ionized gas made up of electrons, protons and neutral particles, traveling at speeds up to 300 miles per second. This may interact violently with the Earth’s magnetic field. Really high-energy protons may even disable satellites orbiting high above the atmosphere.

Another possible effect of a high-energy particle bombardment during a flare may be high absorption of HF signals propagating through the polar regions. This is called a *Polar Cap Absorption* (PCA) event and it may last for several days.

A second major solar disturbance is a so-called “coronal hole” in the Sun’s outer layer (the *corona*). Temperatures in the corona can be more than four million °C over an active sunspot region but more typically are about two million °C. A coronal hole is an area of somewhat lower temperature. Solar-terrestrial scientists have a number of competing theories about how coronal holes are formed. Matter ejected through this “hole” becomes part of the solar wind and can affect the Earth’s magnetic field, but only if the Sun-Earth geometry is right. [1]

Statistically, coronal holes tend to occur most often during the declining phase of the 11-year solar cycle and they can last for a number of solar rotations. This means that a coronal hole can be a “recurring coronal hole,” disrupting communications for several days about the same time each month, for as long as a year or even more.

The Sudden Disappearing Filament (SDF) is the third major category of solar disturbance that can affect propagation. SDFs take their names from the manner in which they suddenly arch upward from the Sun's surface, spewing huge amounts of matter as plasma out into space in the solar wind. They tend to occur mostly during the rising phase of the 11-year solar cycle.

Thus, when the conditions are right, a flare, coronal hole or an SDF can launch a plasma cloud into the solar wind, resulting in an *Ionospheric Storm* here on Earth. Unlike a hurricane or a Nor'easter in New England, an ionospheric storm is not something we can see with our eyes or feel on our skins. We can't easily measure things occurring in the wispy ionosphere some 200 miles overhead. However, we can see the indirect effects of an ionospheric storm on magnetic instruments located on the Earth's surface, because disturbances in the ionosphere are intimately related to disturbances in the Earth's magnetic field.

During a *geomagnetic storm* ("geo" means Earth, in Greek), we may experience extraordinary radio noise and interference, especially at HF. You may hear solar radio emissions as increases of noise at VHF. A geomagnetic storm generally adds noise and weakens or disrupts ionospheric propagation for several days. Transpolar signals at 14 MHz or higher may be particularly weak, with a peculiar hollow sound or flutter—even more than that which is normal for transpolar signals. [2]

Q Okay, I understand more about solar disturbances. Now, what do the A-Index and K-Index numbers broadcast by WWV mean?

A Scientists measure geomagnetic activity with a device called a *magnetometer*. It detects minute changes in the Earth's magnetic field, and may be as simple as a magnetic compass rigged to record the appropriate movement. Since geomagnetic activity can vary with location, a world-wide network of magnetometers monitors it. Two scales, the A and K Indices, quantify geomagnetic variations

A Index The A Index is a daily average of data (from observatories around the world) that reflects the state of the Earth's magnetic field for the preceding 24 hours. The index can be revealing because geomagnetic disturbances due to phenomena such as recurring coronal holes tend to recur at 27-day intervals as the Sun rotates.

K Index: The K Index broadcast by WWV reflects the instability of the geomagnetic field at Boulder, Colorado, over the last three hours. Such frequent updates can indicate K Index trends. A decreasing K Index is good, especially for propagation paths at greater than 30° latitude. Some VHF operators like to see an increasing K Index, because aurora is possible at K Index values of 3 and greater. Such values also warn that conditions associated with degraded HF propagation were present in Boulder, Colorado. Note: the K Index is a Boulder measurement—it may not correlate well to conditions in other areas.

The A Index range is from 0 to 400, while the K Index ranges from 0 to 9. Lower indices indicate better HF propagation conditions. Tables relating index readings and geomagnetic activity appear in an earlier *QST* discussion of WWV and WWVH propagation broadcasts. [3]

Q Now that I have some idea what the numbers mean, how can I get them?

A There are many sources

1) National Institute of Standards and Technology (NIST) stations WWV and WWVH broadcast propagation information on 2.5, 5, 10, 15 and 20 MHz (WWV only) at 18 and 45 minutes past each hour, respectively.

2) The NIST in Boulder provides a telephone voice recording of the WWV/WWVH propagation message at 303-497-3235. There's also a continuous audio rebroadcast at 303-499-7111 (Colorado) and 808-335-4363 (Hawaii). NOAA provides the WWV solar-terrestrial data via several on-line services Gopher service is available by telephone bulletin board (303-497-7788; up to 28.8 kbps; login: gopher), telnet (telnet **gopher.sel.noaa.gov**; login: gopher) and the World Wide Web (**http://www.sel.noaa.gov).** Files are available by FTP at **ftp.sel.noaa.gov**

3) When time permits, W1AW broadcasts a weekly propagation forecast as part of the normal, daily bulletins. The W1AW schedule appears monthly in *QST*.

4) Local *PacketClusters*. Use the command SH/WWV/*n*, where *n* is the number of spots you wish to see (five is the default).

5) There are numerous sources for solar and propagation data and information on the World Wide Web. (A search for WWV yielded several hundred hits.)

HF propagation is a complicated, fascinating topic. To further your knowledge of the ionosphere and solar-terrestrial interactions, I highly recommend a book called *Radio Amateur's Guide to the Ionosphere*, by Leo F. McNamara. [4]

Notes

[1]A plasma has a very interesting and somewhat bizarre ability. It can lock-in the orientation of the magnetic field where it originates and carry it outward into space. However, unless the locked-in magnetic field orientation is aligned properly with the Earth's

magnetic field, even a large plasma mass may not severely disrupt our ionosphere. Presently, we don't have the ability to predict very well when a particular event on the Sun will result in an ionospheric or geomagnetic storm, although new satellites now being built should help us in the future.

[2]Other modes of propagation, such as sporadic E, may provide sky-wave propagation on the 6 and 10-meter bands, especially during the summer. The mechanisms behind these propagation modes vary considerably from what we've discussed here, but they can offer exciting DX opportunities. Lower HF bands, such as 80 and 40 meters, are less susceptible to sunspot activity, and can provide good propagation possibilities even at the "bottom" of a cycle.

[3]Tables relating the A and K Indices to each other and to geomagnetic activity appear in "Propagation Broadcasts and Forecasts Demystified," *QST*, Nov 1991, pp 20-24.

[4]Leo F. McNamara, *Radio Amateur's Guide to the Ionosphere* (Malabar, FL: Krieger Publishing Company, 1994). Excellent, quite-readable text on HF propagation.