Understanding Disturbances to Propagation

Carl Luetzelschwab K9LA

[this article appeared in the November/December 2005 issue of The DX Magazine]

On September 7 a large complex sunspot group rotated into view of Earth-based observatories, and it was numbered Region 808. This region was not a new one – it had been around about a month earlier (because the Sun rotates about every 27 days), and was numbered Region 798 back then.

Region 808 was a very active region (as it was the last time around). From September 7 through September 15, Region 808 produced many solar flares (including the fourth largest in recorded history) and several coronal mass ejections (CMEs). Before looking at specific events during this period, let's first take a look at how solar flares and CMEs impact propagation.

Disturbances to propagation

The best way to do this is to summarize the information put out by the National Oceanic and Atmospheric Administration (NOAA). In March 2002, NOAA changed the format of the WWV alert (at 18 minutes past the hour) to better align it to the current understanding of disturbances to propagation. This summary is shown in Table 1 (full details are at **www.sec.noaa.gov/NOAAscales**).!

NOAA designator	Description	Source	Results	Comments (from K9LA)
G	Geomagnetic storm	Shock wave from **CME** or high speed solar wind from **coronal hole** affecting the Earth's magnetic field	Bad: auroral absorption, decreased F2 ionization at high and mid latitudes, skewed paths at the main trough Good: auroral-E, may increase F2 ionization at low latitudes	Generally the worst of all three due to the duration of the storm and the recovery time of the ionosphere
S	Solar radiation storm	Energetic protons from a large **solar flare**	Additional absorption in the polar cap	Low probability of happening since there are only about six events per year
R	Radio blackout	Electromagnetic radiation at x-ray wavelengths (0.1-1 nm) from a large **solar flare**	Blackout on daylight side of Earth due to increased D region absorption	Generally of short duration, with the higher frequencies affected last and recovering first

Table 1 - Disturbances to Propagation

Note that there are three general categories for disturbances to propagation: G for geomagnetic storms, S for solar radiation storms, and R for radio blackouts. Further note (by the words in bold in the third column) that CMEs (and coronal holes) are tied to geomagnetic storms, and solar flares are tied to both solar radiation storms and radio blackouts. Each of the three categories (G, S, and R) has a scale of 1 to 5, with 1 being ‘minor’ and 5 being ‘extreme’.

CME and solar flare comments

Not all CMEs cause geomagnetic storms. The most important parameter for a CME to eventually impact the ionosphere is that it has to be Earth-directed. When a CME is Earth-directed, it is called a halo event because the explosion on the Sun can be seen all around the occulting disk of a coronagraph (a telescope that artificially produces an eclipse to see the Sun’s corona). If the CME isn’t directed towards Earth, the explosion is only seen coming from one location around the Sun’s circumference.

Even among those CMEs that are Earth-directed, some will affect us more than others. The different qualities of a CME that can determine its “geo-effectiveness” include the amount of material ejected, the speed at which it travels, and the strength and direction of the magnetic field carried by the cloud of charged particles.

In a like manner to CMEs, not all solar flares cause solar radiation storms and radio blackouts. In general only the large solar flares are involved in these disturbances – X-class flares and M-class flares (see the sidebar How Solar Flares Are Measured on the last page). Now let’s look at the specific events of September 7 through 15.

Events of September 7-15

Table 2 summarizes the X-class flares for this period. Also included are columns indicating whether a specific flare had a concurrent CME and the daily planetary magnetic index Ap.

Date	Flare magnitude & begin/max/end time	Concurrent CME?	Ap
Sep 7	X17 1724/1728/1847 UTC	yes	15
Sep 8	X5.4 2052/2105/0042 UTC	yes	8
Sep 9	X1.1 0243/0300/0307 UTC X3.6 0942/0959/1008 UTC X6.2 1913/1946/2328 UTC	no no yes	17
Sep 10	X1.1 1634/1643/1651 UTC X2.1 2130/2211/2243 UTC	no yes	30
Sep 11			105
Sep 12			66
Sep 13	X1.5 1922/1923/2313 UTC X1.7 2315/2322/2330 UTC	Yes (from these twin flares)	51
Sep 14			25
Sep 15	X1.1 0836/0837/0936 UTC	no	43

Table 2 – CMEs and X-class solar flares for September 7-15

The period began with the fourth largest x-ray flare in recorded history – the X17 event on September 7. It had a CME associated with it. Two more CME-producing flares followed: an X5.4 flare on September 8 and an X6.2 flare on September 9. The effects of these three CMEs drove the Ap index up to 105 on September 11, and Ap remained high through September 13 due to an additional CME (from the X2.1 flare) on September 10. The Ap index quieted down on September 14, but then increased to 43 on September 15 due to the CME associated with the twin X1.5/X1.7 flares on September 13.

The impact of a geomagnetic storm

The best way to assess the impact of these geomagnetic storms is to look at a typical mid latitude ionosonde during the September 7-15 period. The Wallops Island ionosonde at 37° North geographic latitude falls into this category, and Figure 1 shows its F2 region critical frequency foF2.

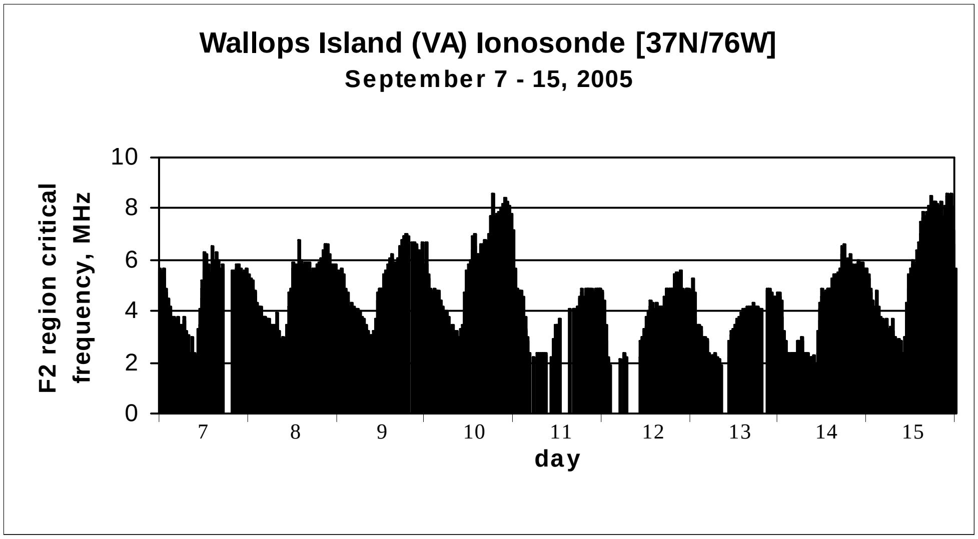


Figure 1 – Wallops Island foF2 data

The F2 region critical frequency is a vertical incident (straight up) measurement, and the Earth-ionosphere geometry works out such that the MUF (maximum usable frequency) for a 3000km low elevation angle path will be approximately three times higher than the critical frequency.

Up through September 10 the F2 region over Wallops Island could support propagation on 17m (and maybe even on 15m on the 9th and on 12m on the 10th) if Wallops Island was the midpoint of a 3000km hop. But on September 11 and the following couple days, propagation could only be supported on 20m. The decrease in foF2 (and thus the MUF) on September 11 and after was due to those three CMEs on September 7, 8, and 9.

The impact of a solar radiation storm

As stated in Table 1, sometimes a large solar flare can send out very energetic protons. These protons are guided into the polar cap (the area inside the auroral oval and centered on the magnetic pole) and cause additional absorption. The amount of additional absorption can be measured by a riometer (*r*elative *i*onospheric *o*pacity *meter*). A riometer measures the signal strength of cosmic noise at the upper end of the HF spectrum (usually around 30MHz). A ‘quiet’ time plot is determined, and then the additional absorption is calculated from the decrease in signal strength during an event (which is commonly known as a PCA – a Polar Cap Absorption event). Figure 2 shows the absorption on September 8 (the times on the horizontal axis are UTC) from a riometer in the polar cap (the riometer at the Sodankylä Geophysical Observatory in Finland).

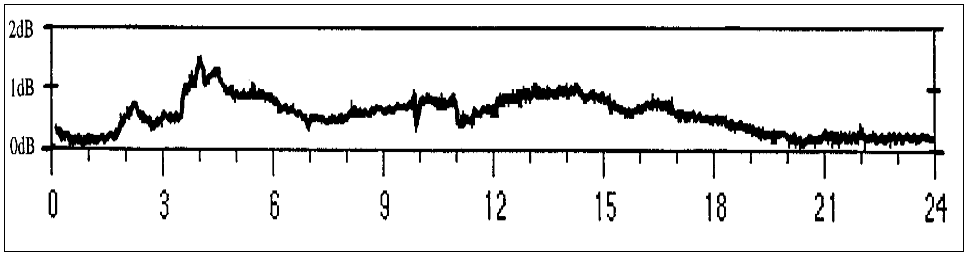


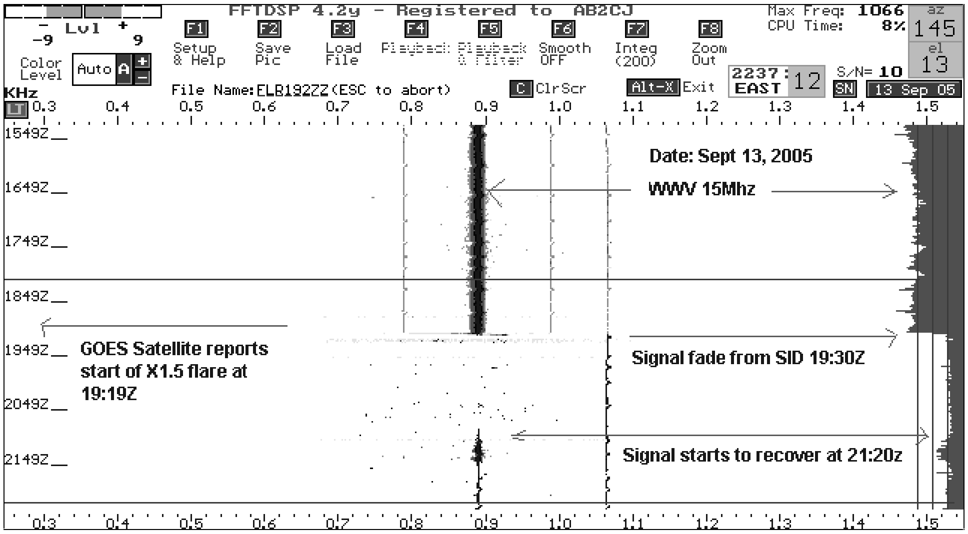
Figure 2 – Absorption due to solar radiation storm

The absorption is at quiet-time levels until just after 0200 UTC, when it spikes up to about 0.8dB absorption. It then settles back down a bit until it spikes up to about 1.5dB around 0400 UTC, and then stays elevated throughout most of the day. The cause of this additional absorption on September 8 starting around 0200 UTC is the energetic protons sent out by the big X17 flare that began at 1724 UTC on September 7.

The 1.5dB absorption may not sound like much, but it’s for a 30MHz signal passing through the D region only once from straight above. For a 3000km one-hop path on 20m across the polar cap, the 1.5dB translates to greater than 10dB.

<u>The impact of a radio blackout</u>

A great way to see the impact of a solar flare in relation to radio blackouts is to look at WWV signal strength during a flare. Figure 3 does this for the path from WWV on 15MHz to New York for the X1.5 flare on September 13.



Date: Sept 13, 2005

WWV 15Mhz

GOES Satellite reports start of X1.5 flare at 19:19Z

Signal fade from SID 19:30Z

Signal starts to recover at 21:20z

Figure 3 – WWV signal strength in NY (thanks KT2Q)

The WWV signal level is on the right side of the plot, and it is fairly steady up until the flare starts – after which it takes a big dive. The amount the signal strength decreases and the duration of the decrease depend on the peak flare intensity (even M-class flares can decrease the signal strength a bit), the solar zenith angle at the two locations where the electromagnetic wave goes through the D region (the most absorption occurs when those two locations are directly under the overhead Sun), and the duration of the flare.

The flare in Figure 3 was of long duration, so the signal strength didn't come back right away. Since the amount of absorption is inversely proportional to the square of the frequency, WWV on 20MHz would have been affected to a lesser extent – but WWV on 10MHz would have been affected to a greater extent.

Advanced notice of Region 808

An interesting question to ask is "did we have advanced warning of Region 808?" Since the Sun rotates approximately every 27 days, knowing that Region 798 was large and active the last time around hinted that it could come around again about a month later and cause more propagation problems. As a side note, the Sun's 27-day rotation period is an average, as the Sun is a ball of gas and is not rigid like the solid planets and moons. The Sun's equatorial regions rotate faster (about 24 days) than its polar regions (more than 30 days).

Thanks to space-age technology, we have a more elaborate method of forecasting sunspot regions before they rotate into view. It's called helioseismic holography. It's an acoustic imaging process that allows us to see sunspot regions on the far side of Sun. The details for this are at **spaceweather.com** (on the left side of the web page). Figure 4 shows soon-to-be Region 808 on the far side of the Sun.

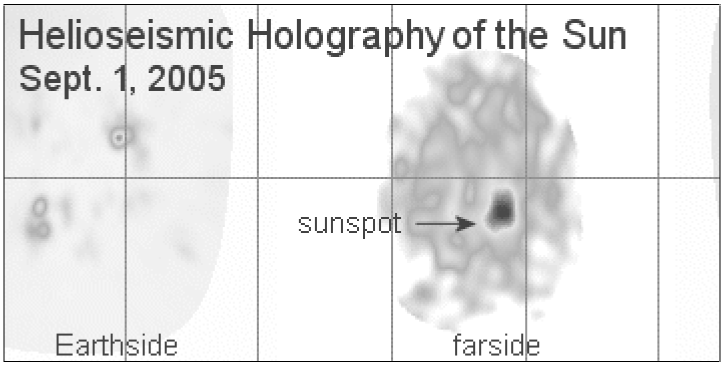


Figure 4 – Region 808 on the far side of the Sun

Note that Figure 4 is dated September 1 – that's a week before Region 808 rotated into view. Figure 4 doesn't tell us if we're going to get hit with disturbances to propagation, but it does tell us that a large sunspot region *capable of producing disturbances to propagation* is coming around.

Summary

This article reviewed disturbances to propagation, and showed how each of the three categories of disturbances affects propagation. Hopefully you've come away with a better understanding of these important events.

How Solar Flares Are Measured

When we talk about solar flares causing radio blackouts, we're interested in the electromagnetic radiation at x-ray wavelengths – which causes additional absorbing ionization in the D region.

The units for the intensity of a flare are watts per square meter (watts/m^2). To facilitate reporting of flare intensity, letters have been designated per the accompanying table. The letters are referred to as the *class* of the flare – for example, a flare of intensity greater than or equal to 10^{-5} watts/m^2 but less than 10^{-4} watts/m^2 is an M-class flare.

Intensity (Watts/m^2)	**Letter designation**
intensity $< 10^{-7}$	A
$10^{-7} \leq$ intensity $< 10^{-6}$	B
$10^{-6} \leq$ intensity $< 10^{-5}$	C
$10^{-5} \leq$ intensity $< 10^{-4}$	M
intensity $\geq 10^{-4}$	X

Classes of x-ray flares

Using Table 1, we can report the peak intensity of a flare in shorthand. A flare of peak intensity 3.5 x 10^{-5} watts/m^2 is an M3.5 flare (with the M in front designating its class, and thus designating the power of ten to be multiplied by).

Note that the scale is 'open' above 10^{-4}. A really big flare (like the X17 flare on September 7 noted in Table 2 in the main text) cannot go into a higher class than X, so the number after the letter will be greater than 10.