Day-to-Day Variability of the Ionosphere

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from my Propagation column in WorldRadio for August 2004

One of the most important concepts to understand about propagation predictions is the fact that the outputs are monthly median values. For example, when your favorite prediction program says the F2 region MUF (maximum usable frequency) is, say, 23MHz, it doesn't mean the MUF is 23MHz right now today. It means that over a month's time frame, half the days of the month will have an actual MUF greater than 23MHz and half the days of the month will have an actual MUF less than 23MHz. Similarly, the prediction of signal strength follows the same concept.

How did we end up with a monthly median model? Why don't we have a daily model to answer the question "what is the MUF predicted to be right now today?" The model of the ionosphere for prediction purposes comes from many years of observing daily sunspots and measuring daily 10.7cm solar flux. While these efforts were going on, measurements (with ionosondes) of ionospheric critical frequencies (foF2, for example), heights of the peak electron densities (hmF2, for example), and other parameters were concurrently underway. Thus the task came down to determining the best correlation between what the ionosphere was doing and what the Sun was doing.

Obviously it would have been nice if the daily sunspot number or daily 10.7cm solar flux on a given day correlated well to what the ionosphere was doing on that given day. Unfortunately that correlation didn't turn out too good. The best correlation turned out to be between the smoothed sunspot number or smoothed 10.7cm solar flux and monthly median ionospheric parameters. Since the model of the ionosphere is a monthly median model, the outputs of our prediction software are monthly median values – they are statistical in nature over a month's time frame.

The lack of correlation between the daily sunspot number (or daily 10.7cm solar flux) and what the ionosphere is doing today can be seen by downloading the daily sunspot number and daily 10.7cm solar flux for an entire month, along with daily ionosonde data for the same month. I did this for December 2003 using the data from the Millstone Hill (Westford, Massachusetts) digital ionosonde. I will focus on F2 region data (critical frequency foF2 and the F2 region MUF for a 3000km path), as the F2 region is the most important for our DXing efforts.

Using this data, I made scatter diagrams of daily solar flux/daily foF2, daily sunspot number/daily foF2, daily solar flux/daily 3000km MUF, and daily sunspot number/daily 3000km MUF. I also added a linear regression line to each scatter diagram to determine the correlation (the R^2 value in the upper right corner of each plot) between the pairs plotted. Figure 1 summarizes these results. I only used data on days when the Ap index was less than or equal to 15 to eliminate geomagnetic field activity as a variable.

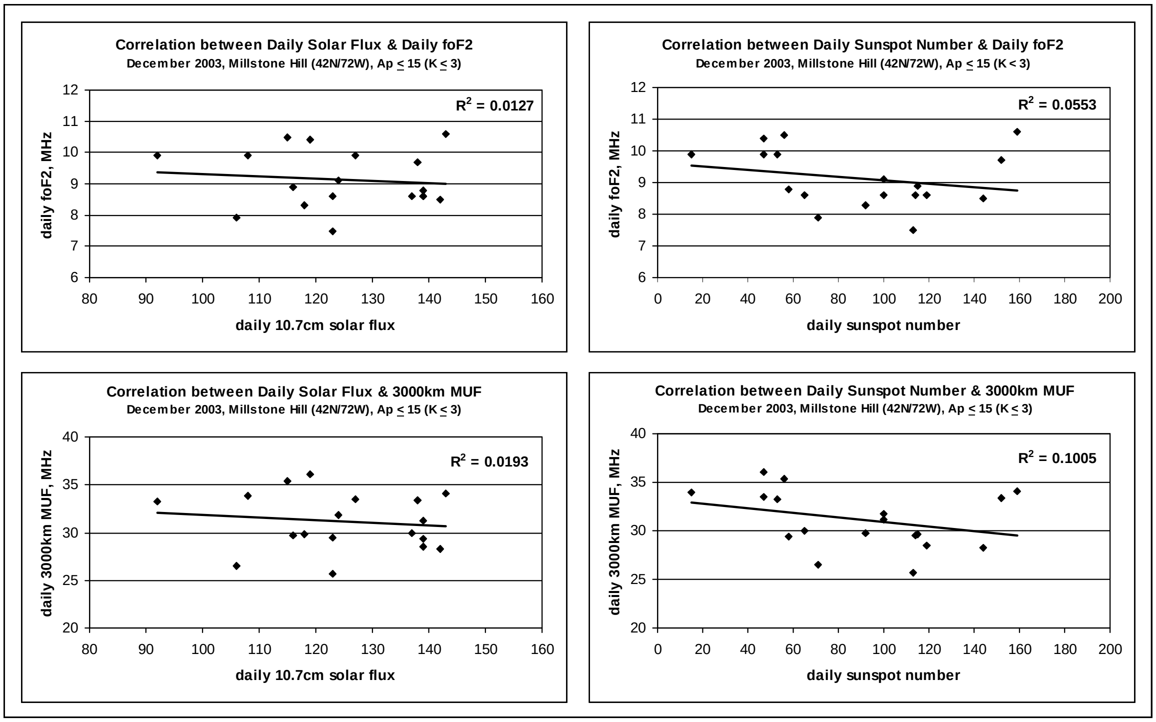

Figure 1 Correlation between the Sun and the Ionosphere

With an R^2 value of 0 indicating no correlation and an R^2 value of 1 indicating perfect correlation, it is easy to see why we don't have a daily prediction model. There is very little correlation on a day-to-day basis between what the ionosphere is doing and what the Sun is doing.

Why doesn't the day-to-day variability of the ionosphere correlate to the daily sunspot number or daily solar flux? We can gain some insight into this question by reviewing a recent technical paper that appeared in the Journal of Atmospheric and Solar-Terrestrial Physics (Volume 63, 2001, pp 1661-1680). The title of the paper is *Patterns of F2-layer variability*. The authors are H. Rishbeth and M. Mendillo, and are with the Center for Space Physics at Boston University.

The authors started by listing the possible causes of ionospheric F-layer variability. These causes fell into three broad categories: solar ionizing radiation, solar wind/geomagnetic activity/electrodynamics, and neutral atmosphere. The first category (solar ionizing radiation) consists of issues with respect to the sunspot number and 10.7cm solar flux. The second category (solar wind/geomagnetic activity/electrodynamics) consists of issues with respect to the K and A indices. The third category (neutral atmosphere) consists of issues with respect to processes in the lower atmosphere (remember the troposphere, stratosphere, and mesosphere from the May column?). Table 1 lists details under each broad category.

Solar ionizing radiation	Solar wind/geomagnetic activity/electrodynamics	Neutral atmosphere
Solar flares	Day-to-day 'low level' variability	Solar and lunar tides
Solar rotation (27 day) variations	Substorms	Acoustic and gravity waves
Formation and decay of active regions	Magnetic storms	Planetary waves
Seasonal variation of Sun's declination	IMF/Solar wind sector structure	Quasi-biennial oscillation
Annual variation of Sun-Earth distance	Energetic particle precipitation	Lower atmosphere coupling
Solar cycle variation (11 and 22 yrs)	Fountain effect at low latitudes	Surface phenomena (earthquakes)
Longer period solar epochs	Magnetospheric electric fields	Surface phenomena (volcanoes)
	Plasma convection at high latitudes	
	Field-aligned plasma flows	
	Electric fields from lightning	

Table 1 Three General Categories Causing Day-to-Day Variability

Then the authors analyzed 34 years of F2-layer critical frequency data (1957 – 1990) from the 1994 NGDC/WDC-A Ionospheric Digital Database (CD-ROM). They used data from 13 stations chosen to represent a range of latitudes and geographic/geomagnetic relationships. From this, they defined 'variability' as a percentage calculated by dividing the standard deviation of foF2 by the monthly mean value of foF2 and multiplying by 100. Doing this showed that the day-to-day variability of the daytime F region, averaged over all 13 stations, was 20%.

Next they dug down into the data, sorting by hour, season, where we were in a solar cycle, geomagnetic field activity, and so forth. The result of all this was determining the day-to-day variability of each of the three broad categories: solar ionizing radiation came in at around 3%, solar wind/geomagnetic activity/electrodynamics came in at around 13%, and neutral atmosphere came in at around 15%.

If you're wondering how 3%, 13%, and 15% can add up to 20%, note from the definition of variability that it is equivalent to a standard deviation. Thus the sum of squares of the separate standard deviations equals the square of the total standard deviation. Indeed $(3\%)^2 + (13\%)^2 + (15\%)^2 = (20\%)^2$.

In light of solar ionizing radiation being a small contributor to the daily variation of the F2 region of the ionosphere, it's no wonder that there is a poor correlation between daily sunspot number and solar flux and the daily ionospheric parameters. That's unfortunate, but it's a fact of life.

How do we tell what the F region is doing right now? I think one of the best ways, at least on the higher bands, is to take a quick listen to the IARU/NCDXF beacons (www.ncdxf.org/beacons.html). That will give you a great picture of what 20m, 17m, 15m, 12m, and 10m are doing right now to all areas of the world. Click on 'Tools for Listeners' on the referenced website to see a list of beacon software to help identify the time slots of the various beacons.

Will we ever see honest-to-goodness real-time predictions? Although we have a good handle on the solar ionizing radiation category and we're making strides in the solar wind/geomagnetic activity/electrodynamics category, there's still a lot to be done in the neutral atmosphere category. With physical models of the ionosphere being developed and computing power increasing, this may just happen some day in the future.