

All Things Digital

Amateur Radio for the 21st Century

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Amateur Radio Science 101

Introduction

“Much of Amateur Radio has been plagued by a lot of pseudo-science and even worse, some entirely unscientific folklore and opinion. To be a credible and reliable investigator, everything you observe must be confirmed through valid, verifiable, and repeatable measurements.”—Eric P. Nichols, KL7AJ from “Radio Science for the Radio Amateur”. Today, one really important radio science question to answer is about the future fate of the solar magnetic field activity cycle—solar cycle for short (see Figure 1A).

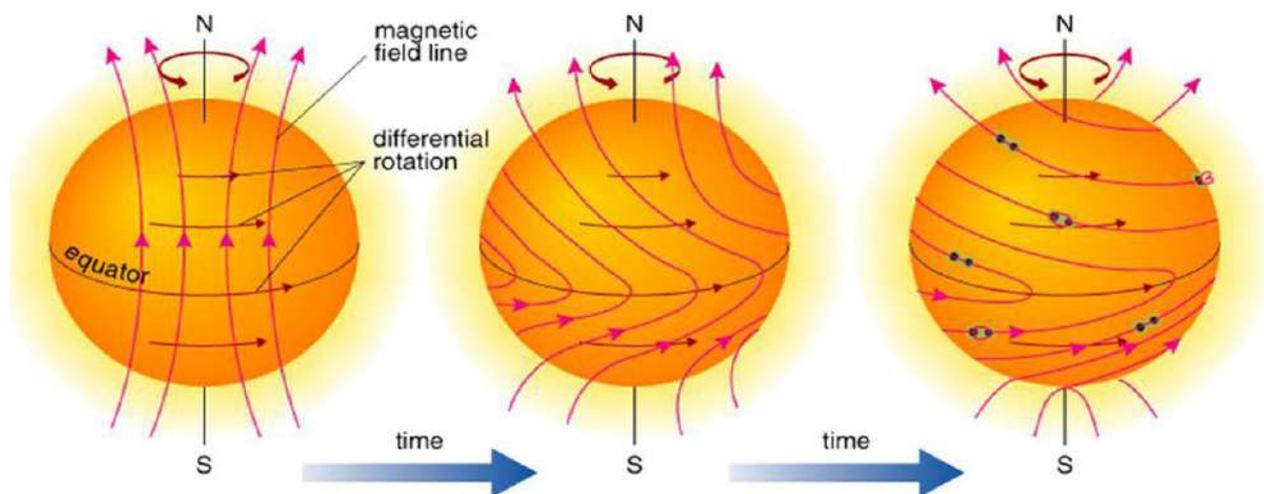


Figure 1A: Babcock solar cycle model. Every 11 years (on average) areas of the Sun’s surface are encircled by magnetic field loops trapping plasma that become cooler and therefore darker in colour (“sunspots”). Credit: “Sunspots and the Scientific Method: Models”, Singleton (2015).

Past, Present, Future Solar Activity and Its Possible Effects

In 2014, Usoskin et al. published a paper in *Astronomy and Astrophysics* titled “Evidence for distinct modes of solar activity” using 3000 years of historical and current data based on Carbon-14 (increases at solar maximums) and Beryllium-10 (increases at solar minimums) radioactive isotope levels (tree ring growth patterns and ice core samples) plus visual sunspot counts from 1609 and the measured 10.7 centimetre (cm) solar magnetic flux since 1947 (see Figure 1B).

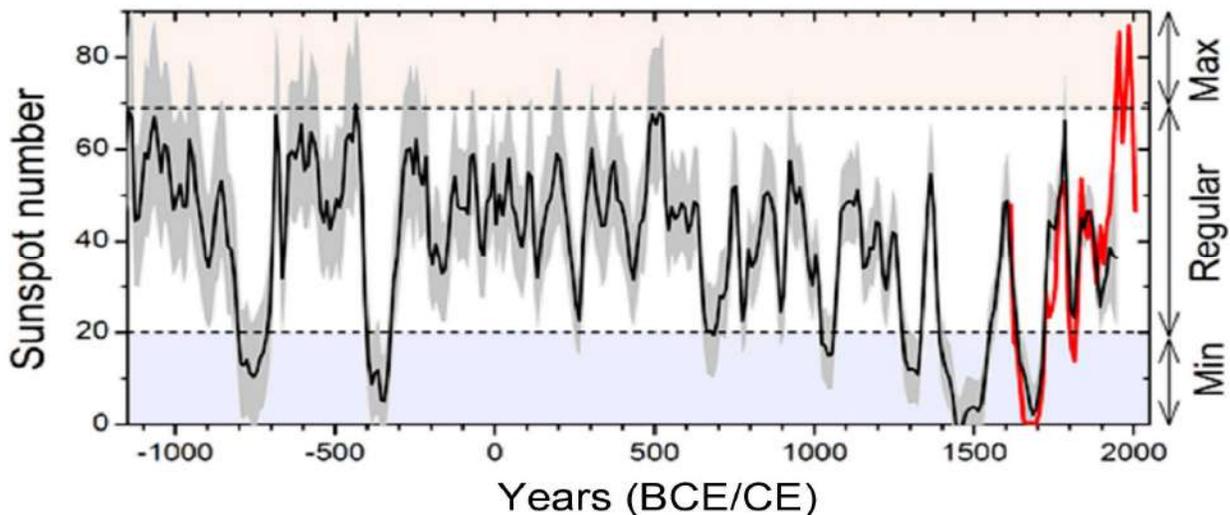


Figure 1B: Three millennia of solar cycle activity. Dashed upper and lower horizontal lines indicate the reconstructed smoothed sunspot number range. The normal range has been between 20 and 67 except for the present period (red line). Credit: “Evidence for distinct modes of solar activity”, Usoskin et al. (2014).

In this paper, the period from 1950 to 2009 is called “the rare and unique Grand Solar Maximum”, and the evidence seems to indicate that Sol is returning to its historically average activity level, but it could also be entering a prolonged solar minimum. Even well into the 21st century, solar scientists still don’t fully understand all of the processes involved resulting in widely ranging predictions with large plus/minus errors of probability. Regardless of either outcome, the data indicates that we’ve had it too good for too long in so far as high band radio propagation is concerned. The days of working the world with “a watt and a wet noodle” will probably become the stuff of legend told to our great-grandchildren.

Besides poor to no high band shortwave radio propagation because of the lack of sunspots, there's a less obvious but far more insidious side effect occurring during any solar minima—Earth's upper atmosphere (thermosphere) cools and contracts as ionization levels drop in the ionosphere (a region of the thermosphere). The Sun sends us both “good” and “bad” radiation but Earth's magnetosphere and atmosphere fortunately filters out most of the bad stuff. But Sol also shields us from the really, really bad incoming cosmic radiation generated “out there” by supernova explosions and other catastrophic cosmic events. But at solar minima, Sol's electromagnetic (EM) magnetic field shield contracts, allowing much higher levels of cosmic radiation to bombard the Earth, which tears through the magnetosphere and travels deeper down to the lower atmosphere (stratosphere). And this may affect Earth's climate causing global droughts, ice age events, biological life extinctions and/or mutations, etc. The Earth to Sky Calculus student group launches regular high altitude balloon (HAB) telemetry gathering flights to measure cosmic ray levels across the U.S., and the data shows a constant upward trend in the stratosphere as this current solar minimum deepens (see Figure 2).

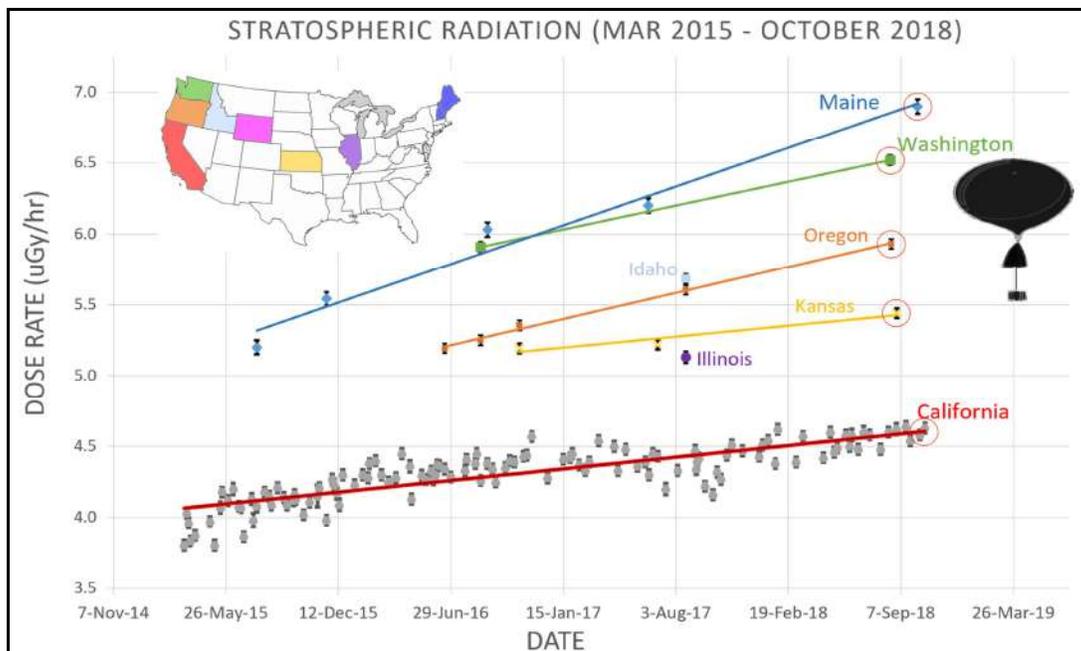


Figure 2: Atmospheric cosmic ray radiation levels. Plot of increasing cosmic ray radiation levels measured in micrograys (μGy) per hour as collected by HAB telemetry flights. *Note: The gray is a unit of ionizing radiation dose, defined as the absorption of one joule of energy per kilogram of matter.* Credit: spaceweather.com.

Note: Ionization is the process whereby electrons are blasted free from neutral atoms (oxygen and nitrogen) in the upper atmosphere (ionosphere). It's caused by solar extreme ultraviolet (EUV) ionizing radiation. This creates an electrically charged, super hot form of matter called "plasma" having regions of different densities of free negatively charged electrons (responsible for shortwave refraction) and free positively charged ions. After sunset, the plasma cools and free ions and electrons recombine into neutral atoms.

Thermosphere Climate Index

A new metric called the "thermosphere climate index" (TCI), invented by Martin Mlynczak and his team at NASA's Langley Research Centre, uses a special NASA satellite to monitor the thermosphere's radiated infrared (IR) power into space (in watts) as it reacts to changes in the solar cycle, solar flares, geomagnetic storms and other types of space weather. And it can be worked backwards in time, too! Graphing the Canadian recorded 10.7 cm solar magnetic flux index records going back to 1947 (almost seven solar cycles) with the TCI reveals the relationship between the two (see Figure 3).

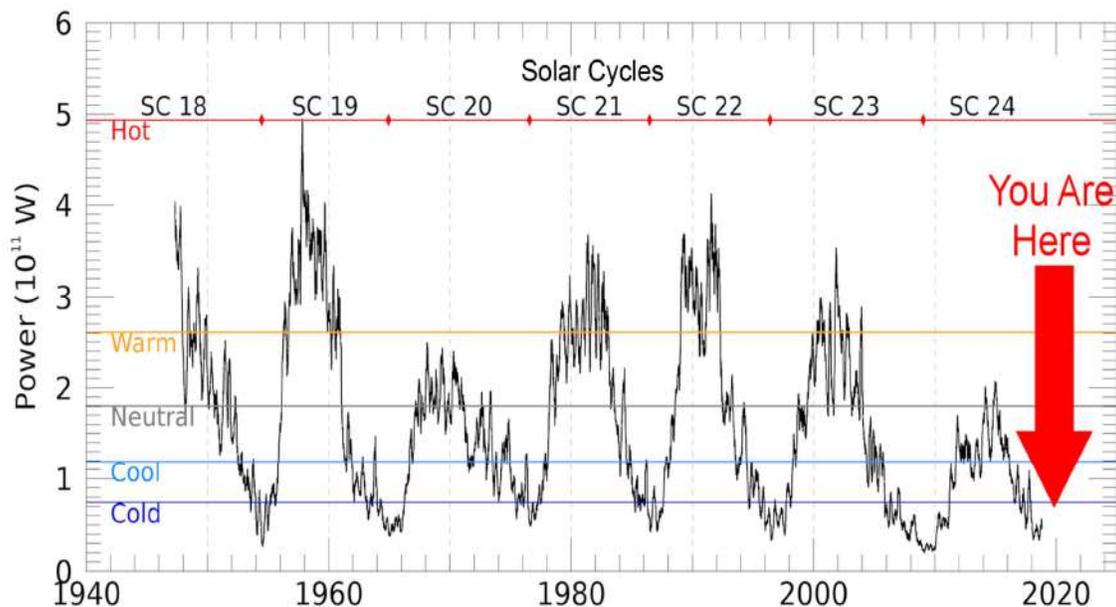


Figure 3: Thermosphere climate index chart. Only the weak-signal digital data modes can thrive and survive in the current "cold" temperatures. The daily TCI is available from the spaceweather.com website. Credit: spaceweather.com.

Amateur Contributions Past, Present and Future

The Radio Amateurs of the 1920's, using the supposedly "useless" shortwave radio bands to where they had been "exiled" in 1912, quickly discovered that world-wide communication was possible using the modes available to them: spark gap (damped wave) then continuous wave (CW) Morse code plus amplitude modulated (AM) voice. They conducted well-organized transcontinental and later transoceanic experiments, and kept detailed logs that provided the data needed by scientists of the day to explain long distance (DX) radio wave propagation, and then prove the existence of the long theorized upper atmosphere's "E-region" (Kennelly-Heaviside layer theory, 1902), and then identify its three major regions (D, E and F) along with their different characteristics.

The Radio Amateurs and other "citizen scientists" of the 2020's can now help answer the current solar cycle conundrum question (along with other ones) using today's digital data modes such as the weak signal propagation reporter (WSPR), Franke-Taylor 8 (FT8), phase shift keying (PSK), radio teletype (RTTY), Jordan Sherer 8 (JS8), etc., plus good old Morse code, used in combination with their web servers: WSPRnet, PSKReporter and the Reverse Beacon Network (RBN). Each day, megabytes of real-time "ripples in the ether" are collected by digital data mode transmitting and receiving stations around the world across a wide swath of the radio frequency (RF) spectrum, and their data is streamed to the respective internet "collectives"; this invaluable data is being used by today's professional scientists and amateur citizen scientists.

Some of us have personal weather stations (PWS) streaming telemetry to Weather Underground, etc., and this data can help prove or disprove theories about whether or not solar activity (or inactivity) has any direct short or long term effect on Earth's climate. Some of us are amateur astronomers (optical and/or radio) and make observations of the Sun. But a few are also professional academics with various degrees in science, technology, engineering and mathematics (STEM) whose hobby just happens to be Amateur Radio, and they create/design and the digital signal processing (DSP) software and/or the hardware we use.

A few Tools and Techniques

1. Alex Schwarz, VE7DXW has written a program called the “RF Seismograph” and designed and sells a radio filter module used with it to scan various digital data mode Amateur Radio bands and determine the band specific signal to noise ratios (SNR) of any received signals, which are displayed on an electronic strip chart (see Figure 4). The software supports various computer operating systems plus the Raspberry Pi micro-controller. Alex theorizes that earthquakes can be detected by his system because the ionosphere can be affected by the powerful shock waves produced that travel rapidly out and upward into the atmosphere.

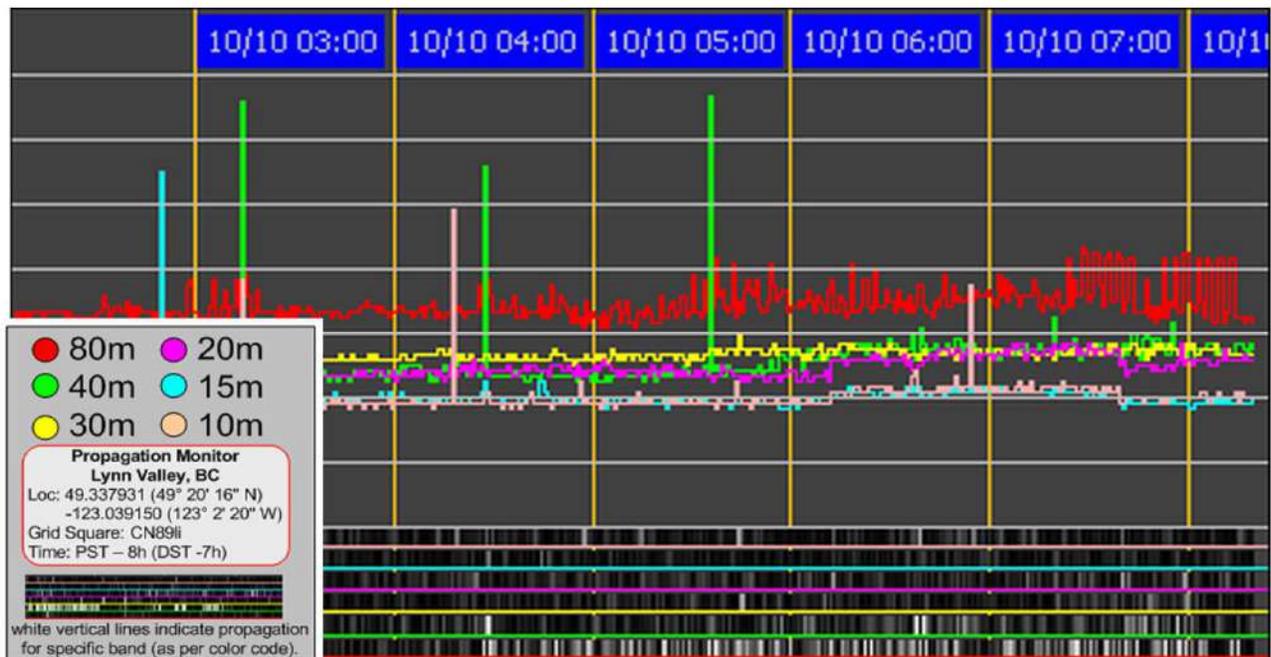


Figure 4: RF Seismograph display. Credit: Alex Schwarz, VE3DXW.

2. Another interesting technique is used by retired physicist Steve Cerwin, WA5FRF who wrote a *QEX* article called “Ionospheric Disturbances at Dawn, Dusk, and during the 2017 Eclipse”. One section of his article describes using the WWV time signal carrier in combination with Spectrum Laboratory (a free audio spectrum analyzer program) to monitor and record the subtle frequency shifts caused by real-time ionospheric conditions (see Figure 5, next page).

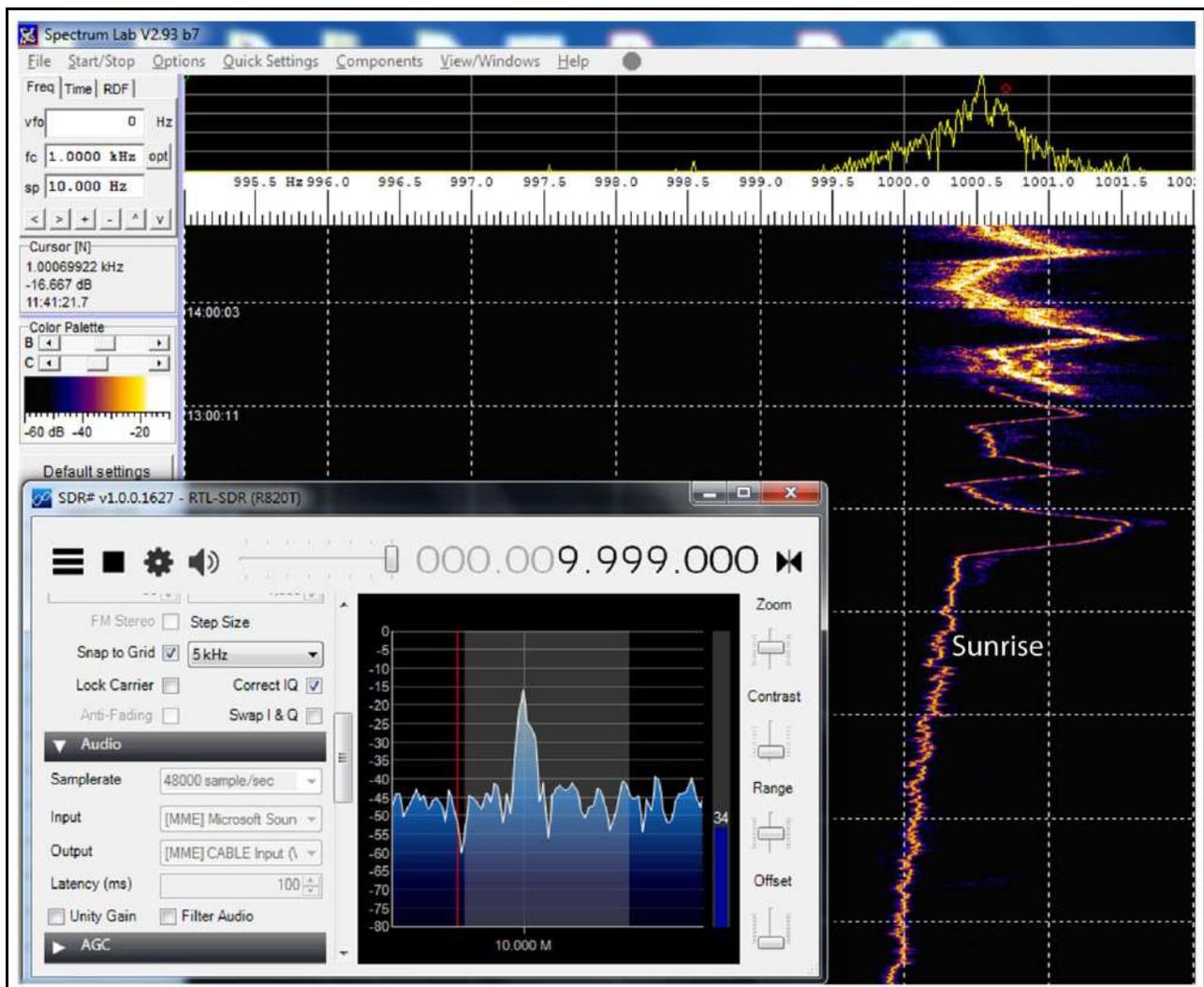


Figure 5: Diurnal ionospheric effects on the WWV time signal carrier. Using WA5FRF’s direct conversion (DC) method to create a 1000 hertz (Hz) audio beat note with the WWV carrier, you can image the ionosphere’s real-time effects on the signal. Vertical scale is time in UTC; horizontal scale is frequency in Hz.

The ionosphere isn’t a flat or homogeneous region; it has “clouds” of free ions and electrons with ripples, different densities and tilt angles, and they can bob and weave like a knuckleball! I emailed Steve and he helped me setup the software, and provided simplified explanations (no physics!). Not only can you study the ionosphere during its diurnal (day/night) cycles, or during solar eclipses and other solar weather events, you can also determine any radio’s transmit or receive frequency error, and/or drift characteristics to within fractions of Hz!

3. The Radio JOVE school project (developed by NASA and the University of Florida) is a combination of radio and astronomy whereby teachers and students, groups or individuals can monitor solar and/or Jovian (planet Jupiter) radio activity using an optimized 20.1 MHz DC receiver and a one or two-element dipole antenna. Jupiter's radio emissions are far more regular and easier to predict, but they don't usually occur during daytime school hours. Of course Sol is always around in the day for monitoring, but since we are at the bottom of a solar cycle there are often month-long gaps between its radio "outbursts". A set of teacher/student lesson plans was developed to provide a structured study course in learning about solar (and Jovian) radio astronomy, the solar cycle and sunspots, etc. There's a central server that collects and archives data streamed to it using a multifaceted program called "Radio-SkyPipe" available from Sky Publishing (see Figure 6). The program graphs activity on an electronic strip chart, and it can also connect to various radio astronomy observatories ("pro" version).

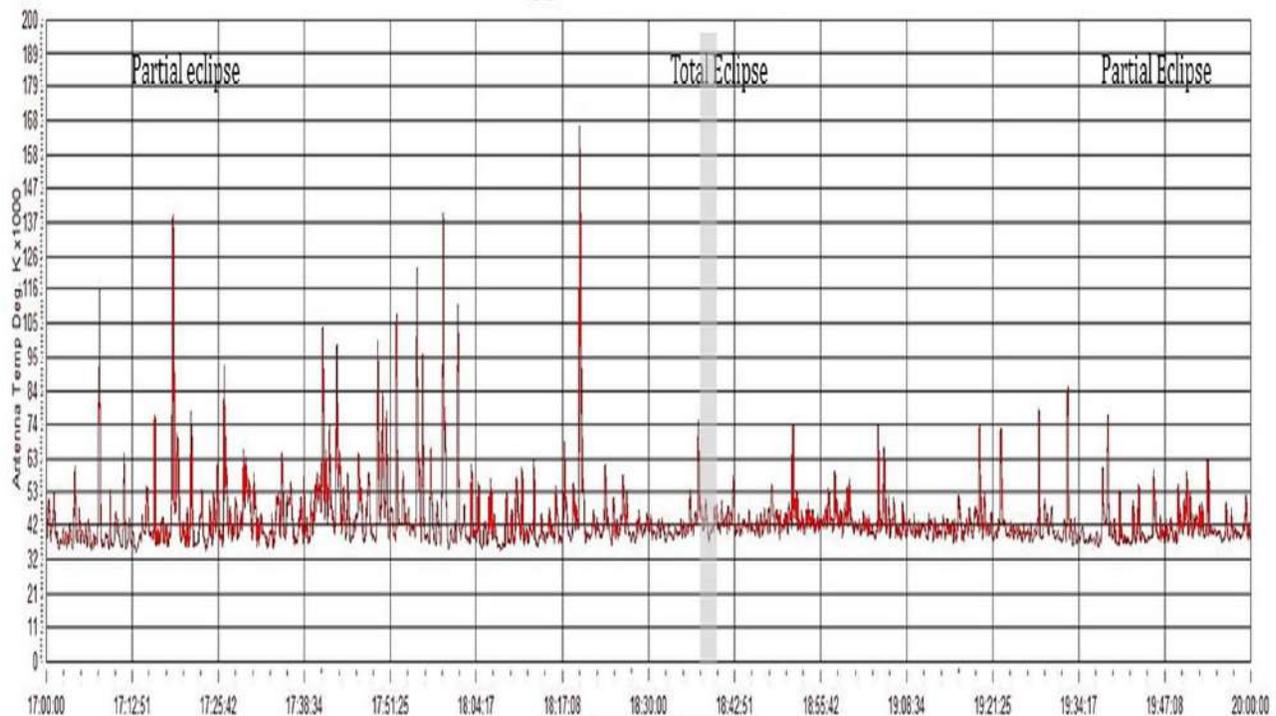


Figure 6: Radio-SkyPipe monitoring a solar eclipse. Solar radio activity was very high on the day of the "Great American Solar Eclipse" (21 August 2017). There were strong 20.1 MHz radio outbursts during the day leading up to totality, but their number and intensity died down afterwards. Credit: John Cox via the Radio JOVE bulletin (July 2018).

4. The WSPRlite antenna and propagation tester (two different versions) is a multi-band WSPR mode only, very low power (QRPP) transmitter designed by Richard Newstead, G3CWI and sold by his company SOTABEAMS. It's used in combination with the SOTABEAM DXplorer website, which hooks into the WSPRnet server to extract the received time, frequency, drift and SNR reported ("spotted") by WSPR receiving stations of your signal. It then analyses the raw data and presents processed information in various ways (see Figure 7).

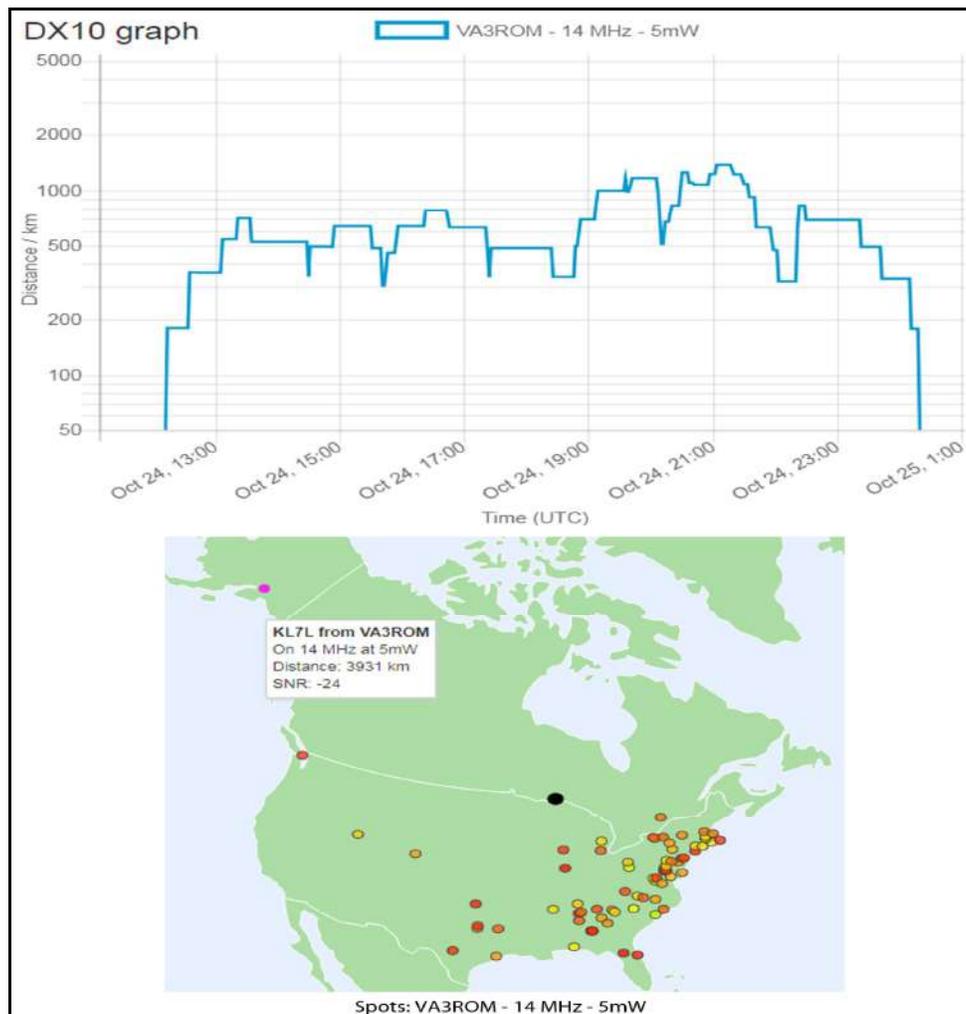


Figure 7: DXplorer and WSPRlite transmitter/antenna performance. Question: "Can a 20 m band five milliwatt (mW) WSPR beacon using a ground mounted quarter-wave vertical antenna travel any great distance in poor propagation conditions?" "Yes, it can!" according to the DXplorer graph (top) of smoothed mean spotted distances and the map (bottom) of stations spotting my beacon. Notice that it's only heard between my local sunrise and sunset times with the majority of spotting stations clustered in the same (Eastern) time zone.

Accidental Introduction to Amateur Radio Science

My original plan was to use FT8 (and WSPR) with WSJT-X and GridTracker (Sep-Oct 2017 *TCA* column refers) for testing the performance of various radios and antenna systems continuously monitored the 40 metre (m) FT8 sub-band. But after a few days, I quickly realized that this technique can also be used for ionospheric “imaging” (see Figure 8).

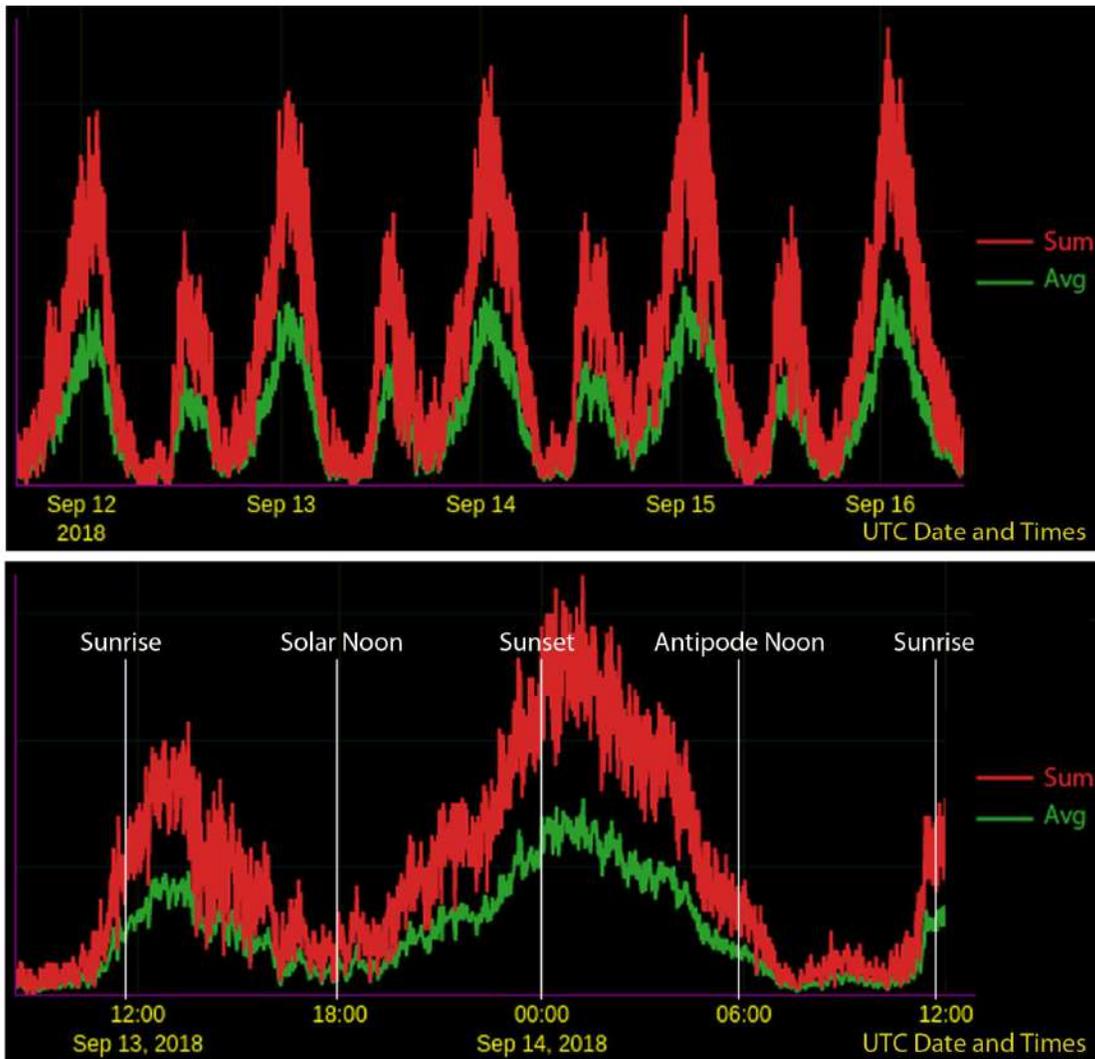


Figure 8: FT8 40 m sub-band local ionosphere imaging. GridTracker plot (top) of decoded FT8 signals taken over several days. There appears to be two distinct radio peaks or “tides” (as I call them), repeating daily. GridTracker can zoom in to analyze any portion of a larger plot so I overlaid my local solar times for sunrise, solar noon and sunset over 24 hours (bottom). There appears to be a definite solar/diurnal radio reception relationship divided into four equal periods. *Note: Antipode [solar] noon occurs on the opposite side of the world from my location.*

“So what the heck’s going on ‘up there’?” To help answer my question, I found and read several excellent *QST* articles and books written by Eric P. Nichols, KL7AJ. What he has to say is a revelation for many radio hobbyists because it’s very counterintuitive to our widely held and cherished misconceptions, and therefore very hard to accept—at first. Highly recommended are his two books “Receiving Antennas for the Radio Amateur” and “Propagation and Radio Science” (read in that order), followed up with “Radio Science for the Radio Amateur”.

My Final

Amateur citizen scientists far outnumber the professional scientists (physicists, astronomers, meteorologists, climatologists, etc.), who all have limited funding, staff, time and resources. But we can help them out and contribute to the continued advancements to be made in science today, tomorrow and beyond. To paraphrase Napoleon, “As in other things, amateurs are often better than professionals.”—73