What Solar Eclipses Have to Tell Us

HamSCI reports on what citizen scientists observed on the HF, MW, and LF bands during an eclipse and explains how amateur observations become scientific findings.

Gary Mikitin, AF8A, and
Dr. Nathaniel A. Frissell, W2NAF

Project Origins: The Great American Eclipse of 2017

The Ham Radio Science Citizen Investigation (HamSCI) successfully encouraged hams to operate during the North American total solar eclipse of August 2017. Thousands of Solar Eclipse QSO Party (SEQP) contacts made on the 6 – 160-meter bands were monitored and later used to prove that amateur radio volunteers — citizen scientists — could play a valuable role in space physics research. Hams helped prove that solar eclipses affect the ionosphere by temporarily modifying its ability to refract radio waves from one point to another on Earth's surface. The complete study, authored by Dr. Frissell et al., in 2018, is available at **www.doi.org/10.1029/2018GL077324**.

Fast-Forward to 2023

A near-total solar eclipse, categorized as an annular eclipse, transited North and South America on October 14, 2023. This not only presented an opportunity for a second running of the SEQP, but it was also the ideal time for hams to put new hardware, software, and monitoring techniques into place. New equipment and methods conceived by HamSCI community members were designed to record expected changes in the ionosphere during this major solar event. Additionally, this eclipse provided practice for the next big event: the North American total solar eclipse of April 8, 2024.

Grape Personal Space Weather Station

The new equipment became known as a Grape Personal Space Weather Station (PSWS). Its components include a compact, single-frequency shortwave receiver, a GPS-disciplined oscillator, and a Raspberry Pi single-board computer. Most participants in the Grape network built their own receivers, assembled the components, configured software, and erected an antenna. Once their Grape was powered up and tested, they connected their systems to the internet so data from their receivers could be uploaded daily to a central server for later examination by scientists and amateurs. Eventually, all Grape data will be available for download on a public site.

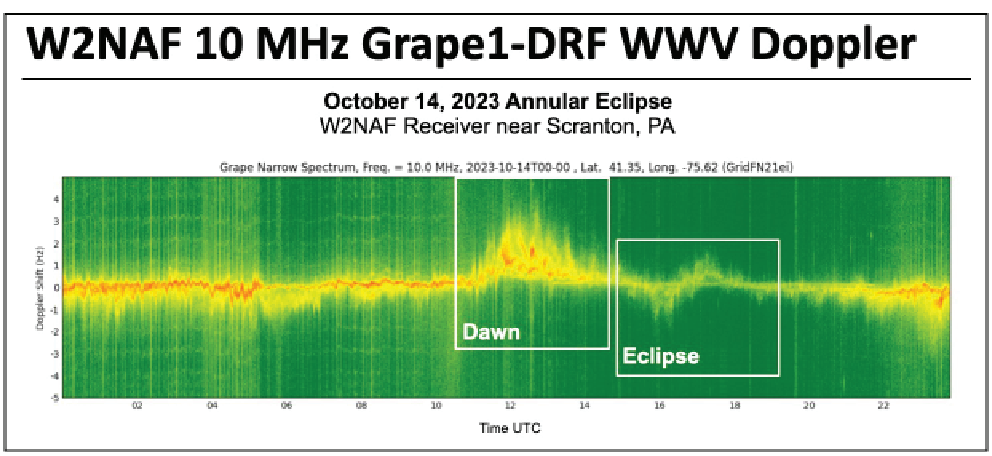

Figure 1 — Dr. Nathaniel Frissell's, W2NAF, Grape data plot for the October 2023 eclipse. The reddish line moving away from 0 indicates frequency shift. A positive shift indicates the bottom side of the ionosphere is moving down toward Earth's surface, while a negative shift indicates it is moving upward. Note the similarities between dawn (beginning at hour 12) and the period just after the eclipse (between hours 16 and 18). In both cases, the ionosphere is transitioning from being "in the dark" to being fully illuminated by the sun.

Grape PSWSs are used to monitor standard time and frequency stations such as WWV, WWVH, or CHU on a 24/7/365 basis. Those stations' transmitters are extremely precise — accurate to the microhertz (millionths of a Hertz). Despite the many factors that impact a radio signal as it travels hundreds or even thousands of

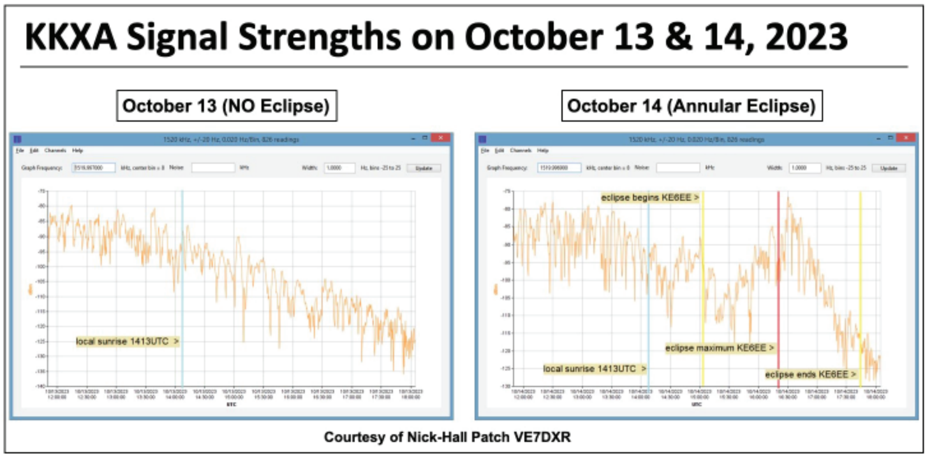

Figure 2 — Nick Hall-Patch, VE7DXR, compiled this illustration showing that a signal from station KKXA (Snohomish, Washington), received by Richard Cook, KE6EE (Fair Oaks, California), varied relatively little on the day prior to the eclipse. On eclipse day, Cook's station recorded a significant jump in signal strength.

miles, it is possible for a Grape PSWS to receive and accurately measure those signals with millihertz (thousandths of a Hertz) precision. In fact, Grape systems make receive frequency measurements so well that their output data can be used to sense changes in the height of the bottom of the ionosphere. The bottom side not only rises and falls, but it experiences ripple-like effects known as *traveling ionospheric disturbances*. Scientists hope to use Grape data to develop theories about bottom-side motion and how it is linked to solar, magnetospheric, and atmospheric events. Figure 1 shows a Grape PSWS data plot for the October 2023 eclipse. Learn how the Grape PSWS makes its measurements at **www.hamsci.org/grape**.

Monitoring the Medium-Wave Band

The medium-wave (MW) band, from roughly 500 to 1700 kHz, is used for professional AM radio broadcasts around most of the world. When it is nighttime at an operator's location, distant stations (DX) can be received from across the continent. When the sun is up at that same location, almost all signals are from local stations. The lack of daytime DX can be explained by a well-known phenomenon known as *D-layer signal absorption*. The D layer forms in the ionosphere at sunrise and dissipates at sunset.

We know that nighttime brings better DX conditions when there is no D layer to absorb MW signals. Of course, night occurs every 24 hours, though its length varies based on location and time of year. Of current interest to HamSCI are the brief conditions resembling night that occur thanks to a solar eclipse.

During a solar eclipse, the moon passes between the sun and Earth. For those in or near the eclipse's path, a brief period of near-darkness occurs because much of the sun's radiation is blocked from reaching Earth. The period of near-darkness resembles a very brief "night" perhaps 3 – 5 minutes in length. HamSCI members, knowledgeable about MW propagation and curious about how the short period of eclipse-generated night might affect radio signals, monitored AM broadcast stations before, during, and after the October eclipse. Figure 2 shows how the eclipse impacted signals from station KKXA. Researchers are eager to review their data, and they looked forward to having more receiving stations participate around the April 2024 eclipse. Further details are at **www.hamsci.org/MW-recordings**.

Moving to the Low-Frequency Band

HamSCI member Steve Cerwin, WA5FRF, monitored the signal from WWVB in Fort Collins, Colorado, during the 2017 and 2023 eclipses. WWVB's frequency (60 kHz) is in the low-frequency (LF) band (30 – 300 kHz). WWVB transmits the signal received by atomic clocks, which are consumer devices that self-correct when able to receive WWVB for short periods each day. In true ham spirit, Steve used a homebrew peak-detecting superheterodyne receiver designed for receiving WWVB. His antenna was a square loop with 2 meters on each side. Steve's setup allows us to compare results from similar eclipse events, 6 years apart. When looking at Figure 3, one can plainly see that there was enhanced reception of WWVB at Steve's Texas location when solar eclipses passed over his station — first in 2017, and again in 2023.

Observations and Findings

We can see *what* happened, but when will we know *why* it happened? Before we answer that question, it would be helpful to explain the difference between observations and findings. Described above are observations: data presented in formats that clearly depict what was observed (for example, changes in the height of the ionosphere and the enhancement of MW and LF signals during an eclipse). Scientific findings — explanations for the observations — will develop over time. In short, observations are what we saw, and findings are why we saw them.

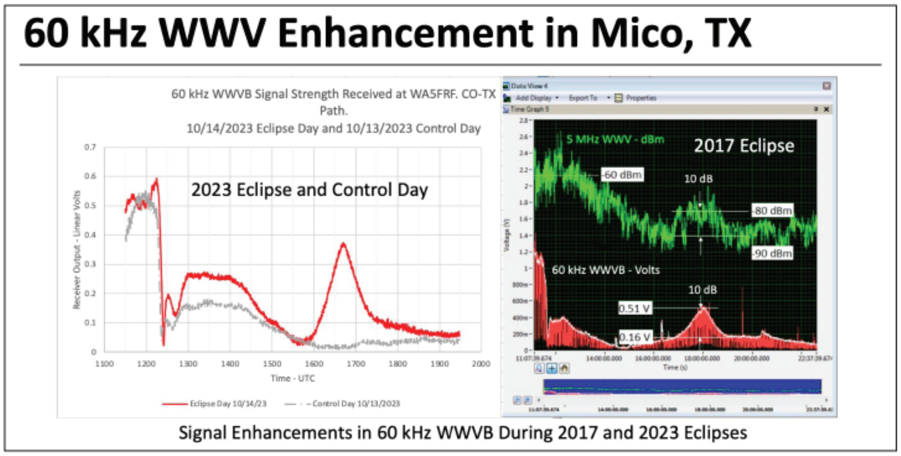

Figure 3 — These plots indicate receiver output, with voltage following signal strength. On the left, Steve Cerwin, WA5FRF, obtained control data (in gray) 1 day prior to the 2023 eclipse, and then he repeated his measurements (in red) on eclipse day. Note the signal enhancement beginning at 1600 UTC and continuing through 1730 UTC. On the right, plots have a similar shape in data recorded during the August 21, 2017, North American total solar eclipse.

More Citizen Scientist Eclipse Data

HamSCI sponsored two radiosport events as part of the 2023 Festivals of Eclipse Ionospheric Science. Results are available for both events:

- Solar Eclipse QSO Party: A 10-hour on-air contest using CW, SSB, and digital modes. **www.hamsci.org/2023-SEQP-results**
- Gladstone Signal Spotting Challenge: A competition for digital modes, such as WSPR, FST4W, and PSK31. **www.hamsci.org/foeis-results**

Findings will first appear in scholarly articles, which may be published in scientific journals or presented at scientific conferences. A scholarly author and co-author(s) spend a great deal of time studying data, formulating hypotheses, discussing and debating, and finally writing their conclusions into articles. Articles are submitted to journals, which use the peer-review process. Reviewers look for gaps in the data and errors in logic or calculations. They consider originality, methodology, and significance of the work while providing constructive criticism to the authors, who then revise their article to answer reviewers' criticisms. The process can take anywhere from months to years.

Recognizing Participants, Partners, and Sponsors

HamSCI's solar eclipse studies began in 2017, continued in 2023, and will carry on into 2024 and beyond. Each eclipse passes over North America for only a few hours. During those brief events, hams contribute to scientific knowledge as part of a tradition that dates back to the Transatlantic Tests. HamSCI and the space physics community are grateful to the hams and shortwave listeners who participate. All contributions are important; for example, see the sidebar, "More Citizen Scientist Eclipse Data," for links to the scores of two HamSCI-sponsored radiosport events.

The HamSCI community is led by The University of Scranton Department of Physics and Engineering Amateur Radio Club, W3USR, in collaboration with Case Western Reserve University Amateur Radio Club, W8EDU; the University of Alabama; the New Jersey Institute of Technology Center for Solar-Terrestrial Physics Amateur Radio Club, K2MFF; the Massachusetts Institute of Technology Haystack Observatory; TAPR in Arizona; additional collaborating universities and institutions, and volunteer members of the amateur radio and citizen science communities. We are grateful for the financial support of the US National Science Foundation, NASA, and Amateur Radio Digital Communications.

Gary Mikitin, AF8A, has been licensed since 1977. He is a retired electrical engineer, and he enjoys ragchewing, DXing, and contesting on HF CW. He currently volunteers as the Amateur Radio Community Coordinator for HamSCI.

Dr. Nathaniel A. Frissell, W2NAF, is an Associate Professor of Physics and Engineering at The University of Scranton. He was introduced to space physics in middle and high school through amateur radio, where he was fascinated by long-distance radio propagation and the variability imposed on it by the geospace system. His interests led to the founding of the Ham Radio Science Citizen Investigation (**www.hamsci.org**), a citizen science collective that aims to bring together the professional research and the amateur radio communities.

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