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HamSCI: The Future of Ham Radio is Here

Nathaniel A. Frissell, W2NAF

Since the beginning of amateur radio, amateurs have significantly contributed to the advancement of technology and radio science. This is no accident, as the people who make up the amateur radio community are driven by a profound curiosity and passion. Equally passionate, the professional radio science community consists of scientists and engineers working to advance our understanding of the world around us. These communities share many common goals and interests, but each group has unique capabilities, resources, cultures, and perspectives. HamSCI combines these strengths.

HamSCI gathering at the 2025 Dayton Hamvention.

What is HamSCI?

Founded in 2015 in preparation for the 2017 Solar Eclipse QSO Party, the Ham Radio Science Citizen Investigation, or HamSCI, was created to bring the amateur and professional communities together for mutual benefit. HamSCI has three primary objectives. First, to advance scientific research and understanding through amateur radio activities. Second, to encourage the development of new technologies to support this research. Third, to provide educational opportunities for the amateur community and the general public. Today, the HamSCI community is engaged in multiple publicly funded projects and is recognized as an official NASA Citizen Science project.

Who Makes Up HamSCI?

HamSCI is a cooperative forum spanning both the amateur and professional communities. A number of academic institutions are represented along with amateur radio organizations (see the Acknowledgments at the end of this article). The real power of HamSCI is the ability for any individual, licensed or not, to join the community. Participation ranges from joining the group to learn something new, to helping collect and analyze data, to presenting at conferences. Participants might contribute to papers, design and build instrumentation, or even propose scientific campaigns.

Where HamSCI Data Comes From

Currently, the primary source of HamSCI data comes from real-time, global, amateur radio observing networks, such as PSKReporter, WSPRNet, WSPR-Daemon, and the Reverse Beacon Network (RBN). As an example, Figure 1 illustrates how space weather can be observed in this data. Here, a solar flare-induced HF radio blackout was observed by the RBN and WSPRNet. Figure 1a shows the 15-minute period before the flare, while Figure 1b shows the 15-minute period after. An 82% decrease in the number of HF communications paths was observed!

HamSCI members are also building a network of Personal Space Weather Stations (PSWS). A complete PSWS includes an HF receiver, a VLF receiver, and a ground magnetometer. The radio receivers utilize GPS disciplined oscillators (GPSDOs) to allow for precision frequency measurement. This capability allows the PSWS receivers to observe HF Doppler shifts.

Figure 2 illustrates one mechanism that can cause HF Doppler shift, using the 10 MHz signal from WWV in Colorado. Ionospheric processes cause the ionosphere to lower and rise in height. As the ionosphere lowers (as it does at dawn), the path length decreases causing a positive (blue) shift. As the ionosphere rises (as it does at dusk), the path length increases, causing a negative (red) shift. HamSCI PSWS HF receivers are designed to measure these shifts, which are often on the order of +/- 5 Hz or less.

PSWS HF receivers were developed at Case Western Reserve University's Case Amateur Radio Club, W8EDU, including the single-channel GRAPE 1 (See Figure 3a) and the more sophisticated three-channel

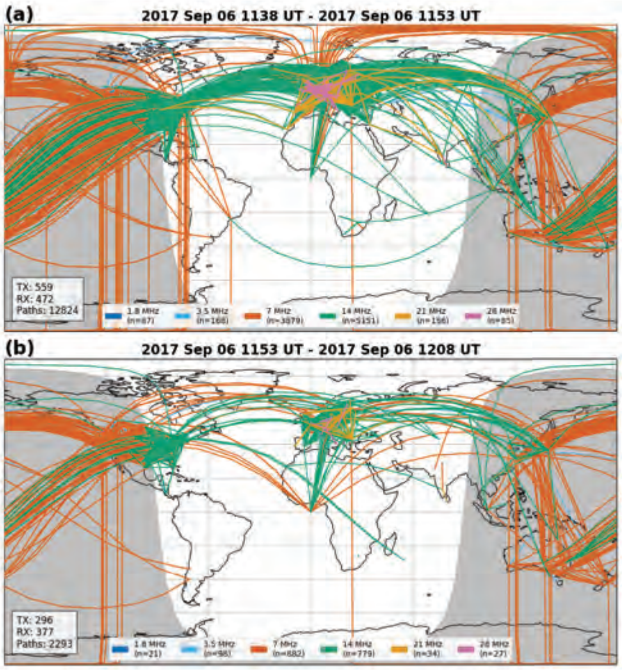


Figure 1

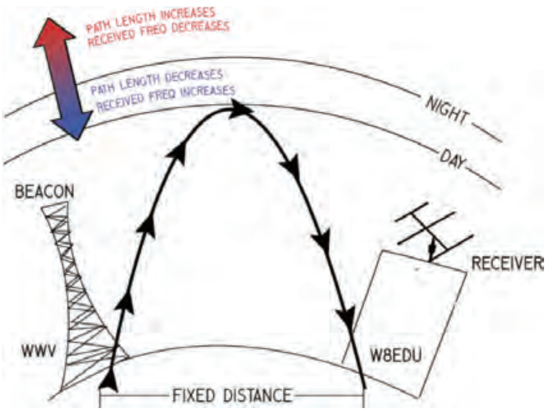


Figure 2

Figure 1 — An HF radio blackout observed by the RBN and WSPRNet on September 6, 2017. From *Frissell et al.* (2019, **https://doi.org/10.1029/2018SW002008**).

Figure 2 — A drawing showing one mechanism for HF Doppler shift. Blue indicates a positive shift and red indicates a negative shift. HamSCI PSWS HF receivers are designed to measure these shifts routinely. From *Collins et al.* (2022, **https://doi.org/10.1109/LGRS.2021.3063361**).

Figure 3a

Figure 3b

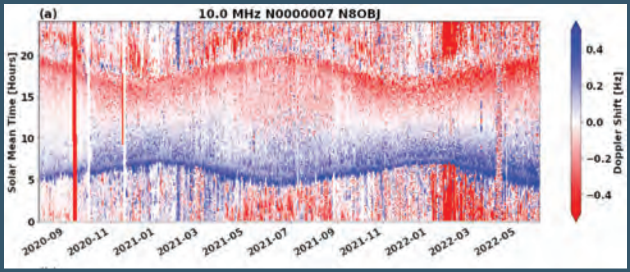


Figure 3c

Figure 4a

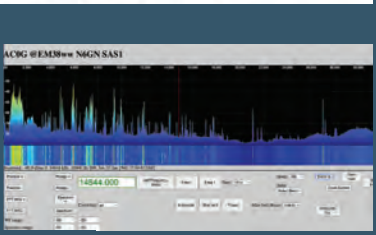


Figure 4b

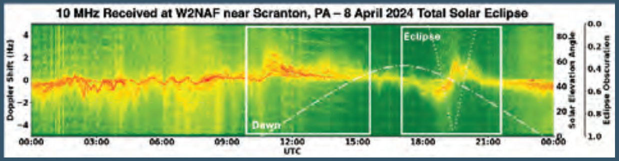


Figure 4c

Figure 3 — The (**a**) GRAPE 1 and (**b**) GRAPE 2 are receivers designed to measure the Doppler shift of signals received from stations such as WWV and CHU. (**c**) Two years of data from N8OBJ showing the Doppler shift of the 10 MHz signal produced by WWV near Fort Collins, Colorado received using a GRAPE 1. From *Collins et al.* (2023, **https://doi.org/10.5194/essd-15-1403-2023**).

Figure 4 — (**a**) An SDR-based Personal Space Weather Station consists of a Leo Bodnar GPSDO, a RX-888 SDR receiver, and a Linux computer running the *KA9Q-radio* and *WSPRDaemon* software. (**b**) The *KA9Q-web* interface allows the system to simultaneously be used as a general-coverage SDR receiver operating from 0.1 to 60 MHz. (**c**) 10 MHz observations at W2NAF on April 8, 2024, a day with a total solar eclipse traversing North America.

GRAPE 2 (See Figure 3b). Figure 3c shows almost 2 years of continuous 10 MHz Doppler observations from N8OBJ in Ohio.

HamSCI has adopted SDRs for newly deployed PSWS HF receivers, as shown in Figure 4a. This system uses the *KA9Q-radio* software by Phil Karn KA9Q, the *WSPRDaemon* data collection software by Rob Robinett, AI6VN, and the RX-888 SDR. The Linux-based system can decode WSPR/FT8 spots and observe HF Doppler shifts simultaneously across all relevant bands and channels from 0.5 – 60 MHz. The system can also be used as a web-based general coverage SDR receiver, thanks to the *KA9Q-web* interface (See Figure 4b). Figure 4c shows 10 MHz Doppler observations made using a RX-888-based PSWS receiver at W2NAF as part of the HamSCI Festivals of Eclipse Ionospheric Science (FoEIS).

How to Get Involved

First, visit **hamsci.org** and click the big, blue "Join HamSCI" button. From there, you can join the HamSCI Google Group, an open forum that facilitates discussion between the amateur and professional communities. That web page also gives links to multiple open, weekly Zoom telecons HamSCI hosts to support its various projects. You can join HamSCI on the air by participating in events such as the Meteor Scatter QSO Party (**hamsci.org/msqp**), or help collect data by installing a Personal Space Weather Station (**hamsci.org/psws**).

Acknowledgments

HamSCI gratefully acknowledges the support of the following government and academic institutions and organizations: National Science Foundation (NSF), NASA, Amateur Radio Digital Communications (ARDC), University of Scranton (W3USR), New Jersey Institute of Technology (K2MFF), Case Western Reserve University (W8EDU), University of Alabama, Massachusetts Institute of Technology Haystack Observatory, Dartmouth College, Andrews University/Princeton Plasma Physics Laboratory, and Virginia Tech. HamSCI also collaborates with amateur radio organizations, including TAPR, Frankford Radio Club (FRC), Yasme Foundation, Radio Society of Great Britain (RSGB), and ARRL.

About Traveling Ionospheric Disturbances

Ethan Miller, K8GU, and
Nathaniel A. Frissell, W2NAF

On the basis of publicly available ionosphere maps, one might conclude that the ionosphere is relatively smooth in space and time. However, if you have spent much time operating on the HF bands, you know that reality is quite different — the bands are constantly changing where the openings are, fading causes signals to come and go. This article is about the science behind a common source of short-period (15-minute to several-hour) variability observed in the ionosphere: the *traveling ionospheric disturbance*, or *TID*. TIDs are an important source of variability, particularly for HF propagation, and they represent a larger source of variability that is often overlooked: the (neutral) atmosphere. (Hines 1974, **https://doi.org/10.1029/GM018p0014**)

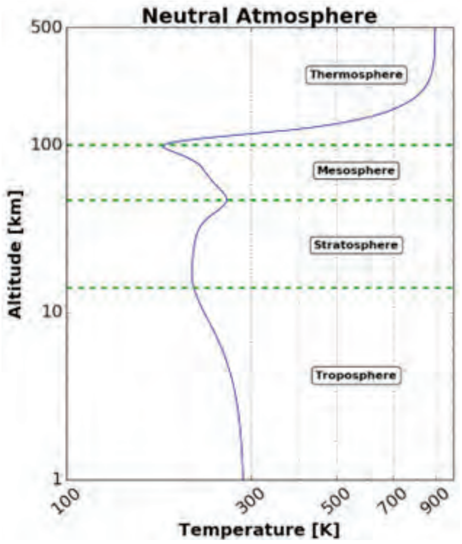


Figure 1 — Neutral atmosphere temperature profile generated using the MSIS (Emmert et al. 2020, **www.doi.org/10.1029/2020EA001321**) model for 1200 UTC 21 Jan 2013, 40°N, 80°W. Atmospheric regions are defined by the inflection points of the temperature profile.

To understand TIDs, we need to review the processes that govern the state of the ionosphere and radio wave propagation through the ionosphere. Scientists divide the neutral atmosphere into four different regions (see Figure 1). The region boundaries are defined by the temperature profile inflection points; each region has several characteristic physical properties. For example, the *troposphere*, the region closest to the surface of the Earth, is warm, moist, and subject to convective instabilities. The *stratosphere* above it is cold, dry, and very stable. The *mesosphere* above the stratosphere is still well-mixed like the layers below it — for example, in the troposphere, the relative concentrations of nitrogen, oxygen, and carbon dioxide are relatively constant no matter where you are in the layer. As the atmosphere transitions from the mesosphere to the *thermosphere*, this mixing transitions to stratification (layering) by the mass (density) of the molecules, with larger molecules at low altitudes transitioning to atomic (single) hydrogen at the highest altitudes as the atmosphere transitions into space.

Introducing Hams to the TID Phenomenon

HamSCI is interested in any physical process that impacts radio wave propagation. Amateur radio operators typically hear about the sun and space weather impacts, including those caused by solar cycles, solar flares, coronal mass ejections, geomagnetic storms, auroras, and more. In this article, we highlight the ionosphere's connection to the neutral atmosphere and discuss a propagation phenomenon likely less familiar to amateur radio operators: *traveling ionospheric disturbances*, or *TIDs*.

The Role of Ionospheric Plasma

None of the foregoing discussions has treated the key parameter for skywave radio propagation: the ionospheric plasma. The ionosphere, illustrated in Figure 2, coexists alongside the mesosphere and thermosphere at altitudes from 70 km to over 700 km. A small fraction (about 3%) of the neutral atmosphere is ionized by solar EUV (extreme ultraviolet) radiation that has such high energy that it knocks loose one electron (usually, sometimes more) from the gases in the mesosphere and lower thermosphere. Unlike a neutral gas, the plasma also has electrical conductivity and behaves like a circuit, in addition to behaving like a gas. This enables skywave propagation because the index of refraction (parameter that controls the bending of a radio wave's path) in the plasma becomes a function of plasma density and radio frequency. The 14 MHz ray trace simulation shown in Figure 3 illustrates how ionospheric refraction can enable communications of 1500 km or more. (Davies 1965, **www.nvlpubs.nist.gov/nistpubs/Legacy/MONO/nbsmonograph80.pdf**)

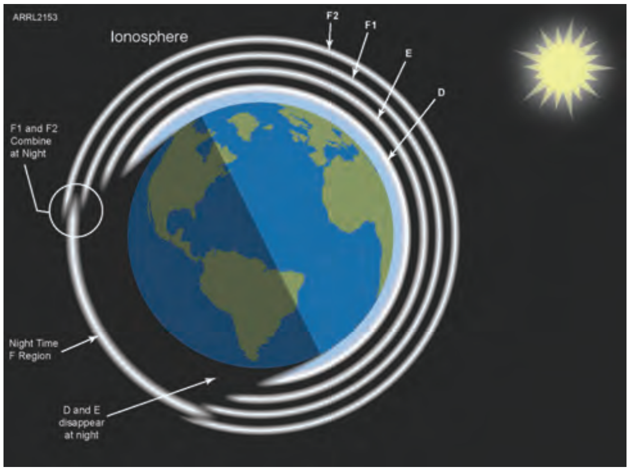


Figure 2 — The ionosphere, created primarily by a balance between photoionization, recombination, and transport, coexists alongside the mesosphere and thermosphere at altitudes from 70 km to over 700 km. It is separated into several regions of ionized particles at different heights above the Earth. At night, the D and E regions disappear and the F1 and F2 regions combine to form a single F region. While illustrations like this one make the ionosphere look smooth and stable, reality is quite different.

The amount of plasma at a given location in the ionosphere is governed by a balance or continuity equation. The continuity equation for the ionosphere states that the change in electron density at a point is increased by production (ionization from the sun), decreased by loss (recombination — electrons and ions coming back together), and either increased or decreased by transport (motion of plasma from place to place).

Most of the literature available to radio amateurs focuses on the production (ionization) term because it controls the maximum amount of plasma available and, therefore, the peak maximum usable frequency (MUF) for a specific path. Production is driven by solar EUV emissions for which the smoothed sunspot number (SSN) and 10.7-centimeter solar radio flux index (SFI) are easily observed proxies. Recombination is a more complicated function of local ion and electron densities and recombination rates (essentially probabilities) of plasma loss for different kinds of ions. Introduction of recombination into this discussion serves two purposes: 1. awareness of the process; 2. recombination produces weak light emissions (similar to the auroras, but much lower energy and much weaker) from the ionosphere that may be used as tracers for ionospheric structures. These "airglow" emissions are not shown in this article, but they are a popular way to study nighttime TIDs.

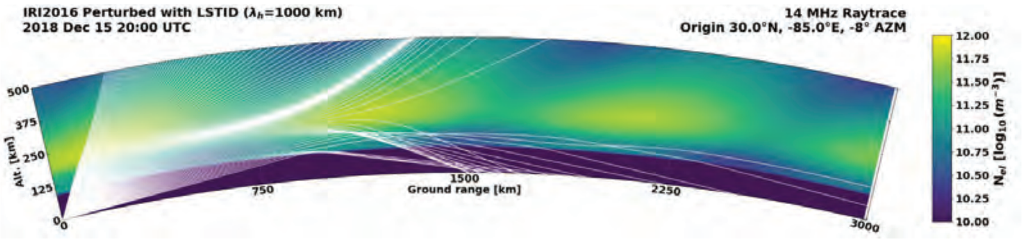


Figure 3 — Illustration of the mechanism in which Traveling Ionospheric Disturbances can cause HF fading (i.e., QSB). This simulation shows 14 MHz radio waves transmitted through an International Reference Ionosphere (IRI) model run perturbed with a TID (Bilitza et al. 2022, **www.doi.org/10.1029/2022RG000792**). The ionospheric variations caused by the TID will either focus rays (i.e., strong signals, as seen around 1500 km ground range) or defocus rays (i.e., weak signals, as seen between about 1700 and 3000 km ground range). The TID will move overhead with time, causing stations on the ground to experience periodic fading as the skip focusing distance moves with the TID.

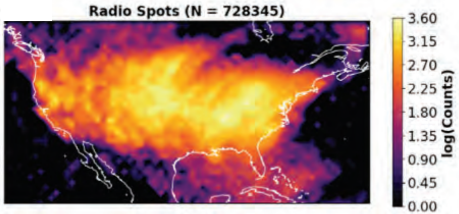
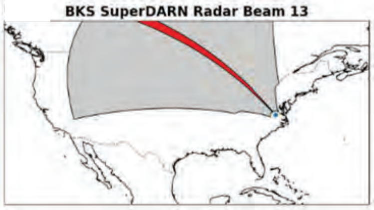


Figure 4a



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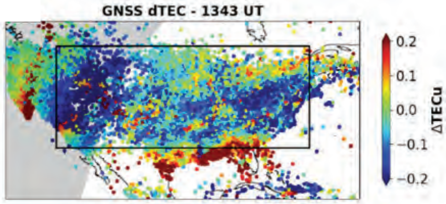

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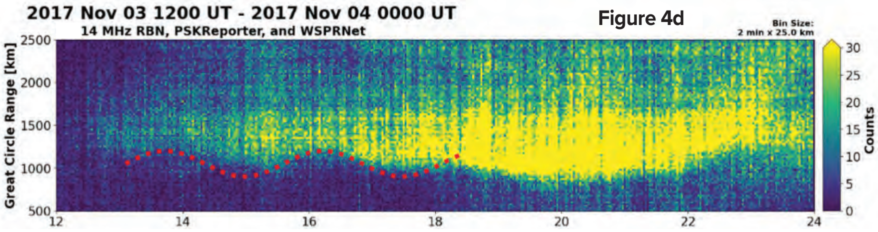

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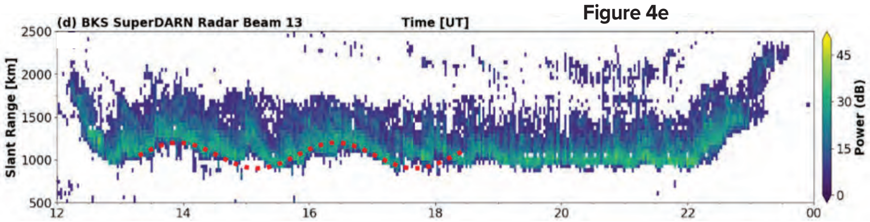

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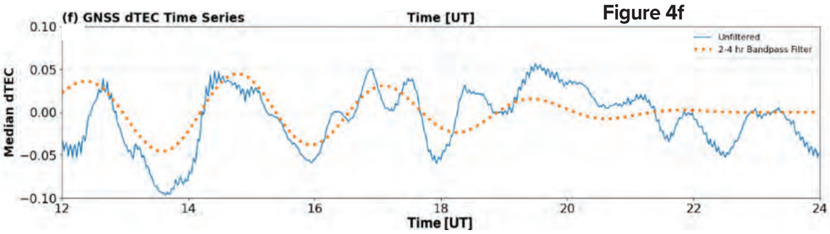


Figure 4f

Figure 4 — Example of Large Scale Traveling Ionospheric Disturbances (LSTIDs) observed using (**a** & **d**) amateur radio networks, (**b** & **e**) the Blackstone (BKS) SuperDARN radar, and (**c** & **f**) Global Navigation Satellite System (e.g., GPS) differential Total Electron Content (dTEC). Dots overlaid on (**d**) and (**e**) show a sinusoidal 2.5 hr oscillation in skip distance common to both the amateur radio and SuperDARN observations. (From Frissell et al., 2022, **https://doi.org/10.1029/2022GL097879**).

The Matter of Transport

The final term of the continuity equation is transport. As we discussed previously about the atmosphere, the layers of the ionosphere also have key physical characteristics: the D region (70 – 90 km) is dominated by collisions between ions and neutral atoms — this is what produces the absorption we observe on lower frequencies during daylight; the E region (90 – 120 km) is dominated by collisions between electrons and ions, as well as electrons and neutrals; the F region (above 120 km) transitions from the E region properties to being almost completely collision-less at altitudes above the F-region peak density around 300 – 350 km. Collisions between plasma constituents (ions and electrons) result in recombination described previously; collisions between the neutral constituents and the plasma result in one form of transport: neutral wind. Winds in the mesosphere and lower thermosphere “push” plasma around. In the D and E regions, the collision rates are great enough that the plasma follows the flow of the wind faithfully. In the F region, the collision rates are lower, and the plasma tends to move easily only along the geomagnetic field.

Atmospheric Gravity Waves

Revisiting the neutral atmosphere (no charged particles) for a moment, the atmosphere is a fluid; so, like bodies of water, it supports buoyancy waves — a displacement of the fluid is restored by gravity, for example, a rock thrown into a calm pond or puddle. Likewise, for the atmosphere, tropospheric winds blowing over a mountain range, for example, produce buoyancy waves in the atmosphere. These are called “atmospheric gravity waves” because gravity is the restoring force. (These should not be confused with “gravitational waves” produced by black holes, which are a completely different and unrelated process.) Like waves at the beach, many gravity waves produced in the lower atmosphere “break” as the atmosphere becomes “thinner” (less dense) in the stratosphere and mesosphere. Breaking gravity waves are responsible for wind shears thought to

contribute to the formation of sporadic-E layers. Gravity wave breaking can occur at multiple different altitudes in the atmosphere, each time creating new, higher-order gravity waves that continue propagating upward. Ultimately, these gravity waves can reach the thermosphere and interact with the plasma of the lower F region via the collisional process described previously.

The gravity waves in the thermosphere appear in the ionosphere as a TID that produces observable effects on HF skywave communications channels. This is illustrated in the Figure 3 ray trace. Because more than one path frequently connects stations communicating by skywave, and each path's length is affected differently by the passage of the TID, constructive and destructive interference between the waves on multiple paths produce potentially strong peaks and deep fades on some paths. Furthermore, the orientation of TID wavefronts with respect to the geomagnetic field introduces gradients that focus and defocus bundles of waves. This can also control whether the waves penetrate into the ionosphere at all. This produces the spotlight effects contest operators experience while running population centers (for example, Europe, Asia, or even parts of the US during a 160-meter contest).

The Study of TIDs

Professional instrumentation, such as the Super Dual Auroral Radar Network (SuperDARN, **http://vt.superdarn.org/**) often used to study TIDs, and climatological studies can sometimes produce new insights into underlying mechanisms. For instance, Frissell et al. (2016, **https://doi.org/10.1002/2015JA022168**), used a climatology of SuperDARN MSTID observations to show that midlatitude medium scale TIDs (MSTIDs) primarily occur when the polar vortex is strong, which is typically during the late fall and early winter. MSTIDs are less likely when the polar vortex is weak, such as following a Sudden Stratospheric Warming (SSW) and during the spring and summer. For amateur radio operators, this means that 15- to 60-minute HF QSB (fading) is more likely in the fall and winter months.

It is possible to see TIDs affect amateur radio communications. Figure 4 shows a large-scale TID, which can have a period of 1 to 3 hours, observed in RBN, PSKReporter, and WSPRNet data. This observation is corroborated with independent measurements by a SuperDARN radar and Global Navigation Satellite System (e.g., GPS) differential Total Electron Content (dTEC). This figure introduces amateur radio as a novel method for studying TIDs that is not only complementary to traditional techniques, but also directly shows the impact of TIDs on real communications systems. A major HamSCI effort is under way to automate the detection of these amateur radio-observed TIDs and see what their climatology tells us. Current progress was presented at the 2025 HamSCI Workshop by Diego Sanchez, KD2RLM (see "Amateur Radio as a Scientific Tool for Understanding the Climatology of TIDs" below for more information).

While this article barely scratches the surface of the deep and complex subject of TIDs, the authors hope that readers now have a better appreciation for what the ionosphere is doing when they experience deep QSB or a long run of German stations that slowly moves to Poland and the Czech Republic.

Amateur Radio as a Scientific Tool for Understanding the Climatology of TIDs

At the 2025 HamSCI Workshop held in March, Diego Sanchez, KD2RLM, a graduate student in software engineering at University of Scranton, presented "Climatology of Large-Scale Traveling Ionospheric Disturbances Observed with 14 MHz Amateur Radio Using a Novel Automated Detection Technique." This oral session described how KD2LRM and his colleagues used data from WSPRNet, the Reverse Beacon Network, and PSKReporter, as well as ham radio data from 14 MHz to detect phenomena of ionospheric variability and magnetosphere-atmosphere coupling processes. The oral session, which can be viewed at **https://hamsci.org/publications/climatology-large-scale-traveling-ionospheric-disturbances-observed-14-mhz-amateur**, presents a multi-year climatology of Large Scale Traveling Ionospheric Disturbance period oscillations.

2025 HamSCI Workshop: Oral Sessions Sampler

Expanding the HamSCI PSWS Network

Gary Mikitin, AF8A

HamSCI has long studied the ionosphere using data collected during rare events such as solar eclipses. However, data collection also occurs daily, thanks to volunteers hosting Great Radio Amateur Propagation Experiment (GRAPE) receivers, monitoring standard frequency stations such as WWV (**hamsci.org/GRAPE-science**). Today, over 50 GRAPEs are operating a network of receivers — formally known as a Distributed Array of Small Instruments (DASI), aka the HamSCI PSWS network (**hamsci.org/psws**).

HamSCI hopes to use data collected by the PSWS to gain a better understanding of the local-, regional-, and global-scale processes influencing the ionosphere and how radio waves propagate over great distances. This may lead to improved propagation predictions, new tools to predict radio wave behavior during solar storms, and new insights into solar cycles and other heliophysical phenomena.

Increasing HamSCI's research efforts requires a more capable PSWS network, with broader geographic coverage and greater technical capabilities. HamSCI seeks hams to host DASI2 stations, consisting of an SDR for recording the HF spectrum, a VLF receiver, and a ground magnetometer for monitoring changes in the Earth's magnetic field. Planning for 30 new PSWS sites is under way (see Figure 1).

You can learn more about the site selection process, determine if you might be a candidate, and join the mailing list at **hamsci.org/site-search**.

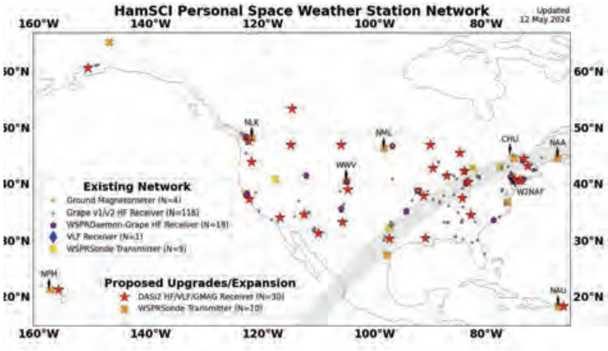


Figure 1 — A map displaying the existing HamSCI PSWS Network, as well as proposed points for DASI2 receivers and WSPR transmitters to further enhance the current network.

HamSCI Solar Eclipse QSO Party (SEQP): Observations & Modeling on Ionospheric Effects

Kuldeep Pandey, PhD, New Jersey Institute of Technology, et al.

Ham radio volunteers across the contiguous United States reported over 52 million spots during the April 2024 Great American Solar Eclipse. For this study, we obtained those logs from PSKReporter, WSPRNet, and RBN, including timestamps, frequency, transmitter and receiver grids, transmitter-receiver midpoints, and transmitter-receiver great circle distances. Using this dataset, we investigated how the solar eclipse affected radio wave propagation and ionospheric conditions.

The data show that the eclipse increased the range of radio communications across the contiguous United States, though not uniformly — frequencies up to 7 MHz showed a symmetrical response, with the increase in communication range peaking around the time of totality, while frequencies above 14 MHz exhibited an asymmetrical response, with increased range occurring about 45 min after totality. These observations suggest that the ionospheric D and E regions responded symmetrically to solar obscuration, while the F region had a delayed response.

The results from the 2024 solar eclipse are similar to those from the 2017 eclipse, reported by Nathaniel, W2NAF, et al. (2018, **https://doi.org/10.1029/2018GL077324**), save for one key

difference: the 14 MHz band weakened during totality in 2017, but not in 2024. This difference likely stems from the eclipses occurring during different phases of the solar cycle — solar minimum in 2017 and solar maximum in 2024. The denser ionosphere in 2024, driven by higher solar flux levels, supported continued communication at the higher frequency of 14 MHz. These findings improve our understanding of how solar eclipses affect radio propagation and the ionosphere and can aid in future planning for ham radio contests. For the slide deck of this session, visit **https://hamsci.org/publications/hamsci-solar-eclipse-qso-party-seqp-observations-and-modeling-ionospheric-effects**.

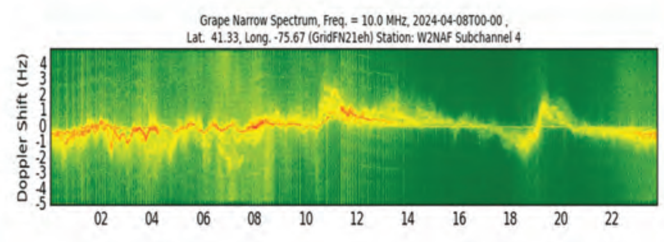


Figure 2 — 10 MHz Doppler observations using the PSWS receiver at W2NAF during the April 2024 solar eclipse — the Doppler shift occurring between 18:00 and 21:00 UTC represents the duration of the eclipse.

Analysis by Citizen Scientists of Doppler Radio Observations of the April 2024 Solar Eclipse

Mary Lou West, PhD, KC2NMC, Montclair State University, et al.

This project to evaluate Doppler radio observations of the April 2024 solar eclipse has three goals: visually categorize the solar eclipse radio data from the PSWS, identify correlations within the data set, and train five citizen scientists as data analysts. The first goal is completed, the others still in progress.

On eclipse day, 46 receiving stations uploaded 24-hour spectrum files to PSWSNet (**pswsnetwork.caps.ua.edu**). Eighteen stations heard eight different frequencies from WWV in Fort Collins, Colorado (5, 10, 15, 20, and 25 MHz) and CHU in Ottawa, Canada (3.33, 7.85, and 14.67 MHz), providing 139 files (see Figure 2).

We measured or estimated the maximum Doppler shift (Hz) at ingress (when the moon started to cover the sun), the maximum shift at egress (when the sun started to become visible again), the number of multipath modes (one, two, or more hops), and the observation's symmetry. Demographic and midpath data were also determined.

We found that the Doppler shifts were primarily dependent on the sun's obscuration at the midpoint, but also on the carrier frequency and the distance between the transmitter and the receiver. At closer distances, radio waves measured a greater change in the path length as the bottom of the ionosphere retreated skyward, then returned at egress.

We are currently investigating correlations between the spectrum outputs and radio frequency, distance from transmitter, time of day, midpoint location, depth of obscuration, and direction. Five CHU observations and one WWV observation proved invaluable because they probed path midpoints that experienced totality. Discussion of the science behind Doppler observations can be found on the HamSCI website (**hamsci.org/GRAPE-science**). For the slide deck of this session, visit **https://hamsci.org/publications/analysis-citizen-scientists-doppler-radio-observations-april-2024-solar-eclipse**.

More Workshops Online

The 2025 HamSCI Workshop featured oral sessions, as well as several invited tutorials and a poster session. Visit **https://hamsci.org/publications** to browse the full list, with links, under the "2025" heading.

An Invited Tutorial:
The Role of the Polar Vortex in Atmosphere-Ionosphere Coupling

Dr. V. Lynn Harvey

In this talk, presented at the 2025 HamSCI Workshop, I provided a comprehensive overview of how the polar vortex contributes to atmosphere-ionosphere coupling, with a focus on “bottom-up” processes that begin in the lower atmosphere and extend upward to affect geospace. The talk began with a tutorial on the polar vortex itself—what it is, why it forms, and how it varies across different spatial and temporal scales (see Figure 1). The wintertime polar vortex is a fast-flowing jet stream that forms in the stratosphere and mesosphere, encircling a region characterized by confined descent. While often discussed in the context of meteorology, the polar vortex is also a critical driver of space weather variability.

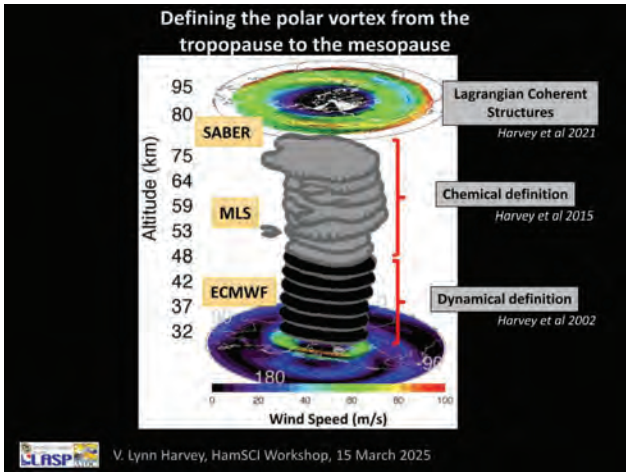
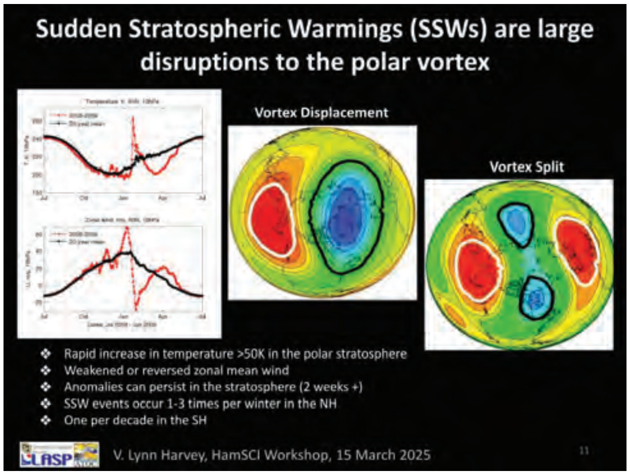


Figure 1 — A 3D perspective of the Arctic vortex in the stratosphere (black) and mesosphere (gray). The view is toward the North Pole from the Pacific. The vertical axis is altitude. The colored map on the bottom is MERRA-2 wind speed. The colored map on the top is SABER wind speed. In the stratosphere, the vortex is defined dynamically (see Harvey et al., 2002). In the mesosphere, the vortex is defined chemically (see Harvey et al.. 2015). [V. Lynn Harvey, photo]

Next, I introduced key atmospheric wave phenomena that interact with or are influenced by the vortex, including planetary waves (PWs), tides, and gravity waves (GWs). In particular, I highlighted how the breakdown of the polar vortex during sudden stratospheric

Dr. V. Lynn Harvey

Dr. Harvey received her doctorate in atmospheric and oceanic sciences from the University of Wisconsin in Madison in 2001. Her PhD focused on the numerical identification of stratospheric vortices, thus her scientific expertise is rooted in the neutral atmosphere. She did a postdoc at NASA Langley and for over 20 years she has been a Research Scientist at the Laboratory for Atmospheric and Space Physics at the University of Colorado in Boulder, where she is a world expert in studies of the polar vortices. She has published 120 peer-reviewed manuscripts on topics covering the general circulation, wave dynamics and transport of trace gases in the stratosphere, mesosphere, and lower-thermosphere. Her recent work focuses on how the polar vortex acts to couple the sun-Earth system from the top down via the descent of nitrogen oxides produced by energetic particle precipitation and from the bottom up via the upward propagation of waves that drive variability in the thermosphere and ionosphere.



Sudden Stratospheric Warmings (SSWs) are large disruptions to the polar vortex

- Rapid increase in temperature >50K in the polar stratosphere
- Weakened or reversed zonal mean wind
- Anomalies can persist in the stratosphere (2 weeks +)
- SSW events occur 1-3 times per winter in the NH
- One per decade in the SH

V. Lynn Harvey, HamSCI Workshop, 15 March 2025

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Figure 2 — A time series of 90 N (left), 10 hPa temperature and 60 N (top), 10 hPa zonal wind (bottom) during the 2009 SSW (red) compared to a 30-year climatology (black). NH polar map (middle) of MERRA-2 geopotential height at 10 hPa with anticyclone (bold white contour) and polar vortex (bold black contour) boundaries on a day during a displacement-type SSW. The figure on the right is the same as the middle panel, but on a day during a split-type SSW. [V. Lynn Harvey, photo]

warmings (SSWs)—typically triggered by upward-propagating PWs—can have dramatic impacts on the upper atmosphere, including changes in temperature, wind, and tidal patterns throughout the mesosphere and lower thermosphere (MLT), and even into the ionosphere.

Importantly, while SSWs (see Figure 2) are known to cause strong variability in the thermosphere-ionosphere system, recent findings suggest that strong polar vortex events cause anomalies of the opposite sign. These include reversed signatures in MLT temperatures, wind patterns, and the distribution of tides. This duality provides a pathway for improved predictability in upper atmospheric conditions, which has clear implications for space weather forecasting and systems like ham radio.

I then explored how the vortex influences GWs in two major ways. First, it modulates their propagation by altering the background wind field. GWs generated in the lower atmosphere must navigate these wind fields as they travel upward, and the vortex can filter or amplify different wave modes. Second, the vortex itself — particularly at its edge and in jet cores — acts as a source of GWs. Observations show enhanced GW activity at the vortex edge, and wave hotspots in the stratosphere have been linked to traveling ionospheric disturbances (TIDs) observed thousands of kilometers away.

This connection between the vortex, GWs, and TIDs is especially important for the ham radio community. While TIDs are often thought to originate from processes in the upper thermosphere or beyond, results show that many are “forced from below” by lower atmosphere dynamics. For example, GW hotspots in the polar stratosphere can initiate TIDs that propagate far from their origin, impacting communications unpredictably.

The talk concluded with a discussion of predictability and remaining research questions. The improved understanding of vortex-driven variability — both from strong vortex states and from SSWs — offers a path toward better forecasting of upper atmospheric conditions. However, many open questions remain, particularly regarding the quantification of GW sources and their spatiotemporal impacts on the ionosphere. As such, continued work is essential to further unravel the full extent of atmosphere-ionosphere coupling driven by the polar vortex. To view the slide deck for this tutorial, visit **https://hamsci.org/publications/role-polar-vortex-atmosphere-ionosphere-coupling**.

More Invited Tutorials Online

Access the Digital Edition of *QST* (**www.arrl.org/qst**) to read a summary of Steve Cerwin’s, WA5RF, invited tutorial, “Radio Wave Propagation and Antenna Fundamentals.” You can view the slide deck at **https://hamsci.org/publications/radio-wave-propagation-and-antenna-fundamentals**.

The 2025 HamSCI Workshop featured several invited tutorials, as well as oral sessions and a poster session. Visit **https://hamsci.org/publications** to browse the full list, with links, under the “2025” heading.

A Glimpse of the Workshop Poster Session

Effect of Near Total Solar Eclipse on Radio Propagation of HF, Weak-Signal Propagation Reporter (WSPR) Transmissions

Mindy J. Hull, MD, KM1NDY

This study investigates the variations in propagation across HF amateur radio bands during the duration of the April 2024 solar eclipse. Solar eclipses cause disruptions in the ionosphere. Citizen scientist amateur radio operators have explored this phenomenon using Weak Signal Propagation Reporter (WSPR), and researchers have relied on amateur radio operator transmissions during QSO parties for solar eclipse radio wave propagation analysis.

WSPR is a digital communication mode characterized by a 6-Hz, upper-side band, time-synchronized, four-tone, multi-frequency-shift-keying (MFSK) with forward error correction signal that can be accurately detected and decoded in low signal-to-noise situations. WSPR is a low-power amateur radio mode that demonstrates real-time propagation on specific 200 Hz band segments of frequencies ranging from 136 kHz – 1296.5 MHz. WSPR transmission data — including call signs of receiving and transmitting stations, grid square locators, time of transmission, signal-to-noise ratios, and transmission power output — are automatically uploaded to the internet, accessible at **WSPRnet.org**. Many entities utilize this data for various purposes, including WSPR Rocks! (**wspr.rocks**), which repackages WSPR data in a more accessible format.

Set up in a semi-rural New York field with a predicted 97.6% maximum sun obscuration, a Zachtek WSPR Desktop Transmitter outputted 200mW WSPR transmissions cyclically on 80- through 10-meter amateur radio bands before, during, and after the eclipse. Twelve multi-band transmission cycles, or "time slots," were completed during the experiment. Spot distances were obtained from the WSPR Rocks! online repository. For each band, propagation distance was compared between all time slots.

The data suggest that there are changes in propagation of 20- and 30-meter WSPR signals correlating to the obfuscation cycle of a near-total solar eclipse — particularly in the period before and leading up to maximum coverage, distances between the transmitting station within the eclipse path and receiving stations are shorter compared to the time of maximum coverage and later. While more work needs to be done on a larger controlled scale, this research suggests a solar eclipse nearing totality may cause transmissions around 20 and 30 meters to be received at greater distances at the peak of an eclipse and afterwards compared to those received prior to maximum solar obfuscation, as shown in Figure 1. To view the full poster, visit **https://hamsci.org/publications/effect-near-total-solar-eclipse-radio-propagation-hf-weak-signal-propagation-reporter**.

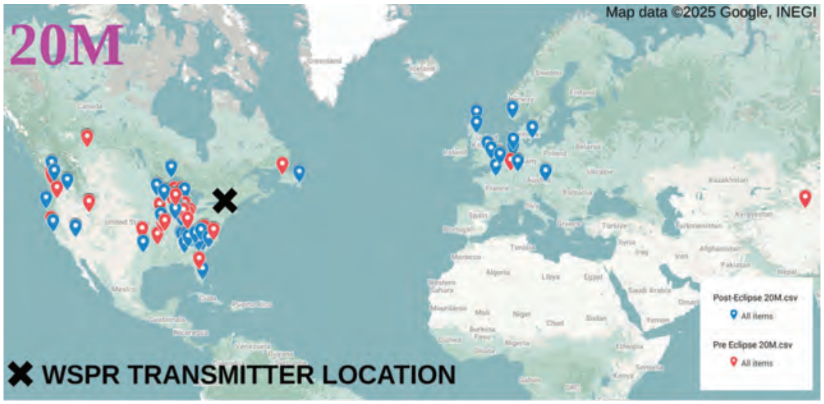

Figure 1 — A map illustrating WSPR transmission spots at 20 meters, before and after the April 2024 solar eclipse.

Development of a Contesting and DXing Dashboard for the HamSCI Personal Space Weather Station

Owen Ruzanski, KD3ALD, University of Scranton, et al.

This project aims to develop a dashboard display specifically for amateur radio HF contesting, DXing, and general operations using data from the HamSCI Personal Space Weather Station (PSWS), as well as other local and remote real-time data. The HamSCI PSWS is a multi-instrument system designed to measure space weather for scientific research and amateur radio operations. The core of the PSWS is the RX-888/KA9Q-radio WSPRDaemon-GRAPE HF software-defined radio (SDR), capable of capturing and analyzing signals across the 0.3-30 MHz range. While most PSWS development efforts thus far have focused on scientific objectives, this project aims to make data available to amateur radio operators with a dashboard designed to enhance real-time HF propagation assessments. By decoding WSPR spots and integrating with external space weather observations, the dashboard will offer propagation insights on an individual-station basis while contributing to a larger understanding of localized and global HF conditions. This should allow amateur radio operators to optimize transmissions based on real-time ionospheric conditions, improving contesting efficiency and DXing success.

This project aims to have a working prototype by the end of August 2025. Research and learning are being conducted on the HamSCI PSWS by experimenting with lab stations set up at the University of Scranton Amateur Radio Club, W3USR (see Figure 2).

To better understand the PSWS system, I will be setting up a PSWS at my home QTH. I started designing the dashboard with a basic implementation of a web mapping program for discovered WSPR spots uploaded to the web database. The next step is to utilize WSPRDaemon software to store discovered WSPR spots in a local database hosted on a PSWS system, then rewrite the web-mapping software to show those spots. After that, it will be critical for the dashboard to display band openings worldwide — showing band openings is one of the most important parts of the project, as it will improve contesters' and DXers' experience and efficiency by providing specific, localized information on changes to expected propagation, which may not be available from other sources. To view the full poster, visit **https://hamsci.org/publications/development-contesting-and-dxing-dashboard-hamsci-personal-space-weather-station**.

Figure 2 — The connections and basic layout of the HamSCI PSWS System. The core of the PSWS is the RX-888/KA9Q-radio WSPRDaemon-GRAPE HF SDR.

HamSCI's Meteor Scatter QSO Party 2025

McKenzie Denton, KO4GLN, Old Dominion University

The 2025 Meteor Scatter QSO Party (MSQP) is an innovative on-the-air experiment exploring the untapped potential of HF meteor scatter propagation using the digital mode MSK144 in WSJT-X. Organized by HamSCI and timed with the Perseid and Geminid meteor showers, this event invites amateur radio operators to contribute to cutting-edge ionospheric research while enjoying the thrill of meteor scatter communication. While some may think meteor scatter is an exotic mode, requiring expensive equipment or large antennas, the opposite is true — if you can transmit and/or receive FT8 on the 6- or 10-meter band, your station has what it takes to participate.

When meteors enter Earth's atmosphere, they create brief, ionized trails that can reflect radio signals, enabling contacts over distances of 1,000 – 2,000

Figure 3 — PSK Reporter map illustrating MSK144 reports across the US and Europe (**pskreporter.info/pskmap**).

km. While this phenomenon is well-studied on VHF bands, such as 2 meters, its behavior on HF frequencies (below 30 MHz) remains poorly understood. The MSQP aims to fill this gap by generating a dense dataset of 10- and 6-meter contacts during peak meteor activity. Topics for investigation may include:

- How long do meteor scatter band openings last on 6- versus 10-meters?
- Which geographic regions experience meteor scatter propagation during these showers?
- Does the Hourly Zenith Rate (visible meteors per hour) affect the distance between stations making QSOs? Is there a noticeable difference between 6- and 10-meter?

Participants will operate MSK144 for two 48-hour windows: August 11–12, 2025 (Perseids), and December 12–13, 2025 (Geminids). Stations will log contacts, recording QSO time, grid squares, and signal metrics. Data will be analyzed to map propagation patterns and compare HF/VHF performance. Websites such as **PSKReporter.info** and **DXMaps.com** can provide real-time visualization of QSO signals and reception reports, as illustrated in Figure 3.

Unlike traditional contests, the MSQP focuses on scientific discovery. Each logged contact may help future researchers map the geographic extent of meteor scatter effects, analyze the differences between 6- and 10-meter meteor scatter propagation, and develop predictive models for future operations.

If you want to participate, follow these steps:

1. **Prepare Your Station**: Familiarize yourself with WSJT-X's MSK144 mode, check your 6- and/or 10-meter antenna, and synchronize your computer's clock to an internet time server.
2. **Operate**: Call CQ on 6 or 10 meters during the event.
3. **Monitor**: Receive-only stations are welcome to contribute data to the event through uploads to PSKReporter.info.
4. **Log & Submit**: Upload ADIF logs to HamSCI for scoring and analysis. Bonus points are available for station photos or astronomy club collaborations!

Visit **HamSCI.org/msqp** for guidelines and registration details. Whether you're a seasoned contester or new to digital modes, your participation will showcase amateur radio's capacity to enhance our understanding of the ionosphere and help write the next chapter in the science of radio propagation. By turning our antennas skyward during these meteor showers, we're not just making contacts — we're making history! To view the full poster, visit **https://hamsci.org/publications/hamsci's-meteor-scatter-qso-party-2025**.

Browse the Poster Session Online

Access the Digital Edition of *QST* (**www.arrl.org/qst**) to read a summary of Steve Stroh's, N8GNJ, and Martin Alcock's, VE6VH, poster, "The IP400 Networking Project." You can view the full poster at **https://hamsci.org/publications/ip400-networking-project**.

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