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Solar Eclipse QSO Party Wrap-Up

Amateur Radio operators have long been fascinated with the changes to propagation caused by solar eclipses. On August 21, 2017, a total solar eclipse swept across the United States from Oregon to South Carolina in just over 90 minutes, presenting an opportunity for radio operation and scientific experiment that was just too good to miss. This led to the HamSCI Solar Eclipse QSO Party (SEQP), an international radio operating event and scientific experiment in which thousands of hams created the largest crowd-sourced dataset of eclipse radio science observations ever made. We summarize the SEQP experience, its results, and lessons learned in this article.

The history of solar eclipse radio propagation studies goes back over 100 years, starting in 1912 with the 55-kHz experiments of William Eccles, 2BA, a prominent radio physicist and past-president of the Radio Society of Great Britain (RSGB). Since then, numerous radio-eclipse studies by both professionals and amateurs have been conducted. Even so, there are still questions that remain unanswered about eclipse effects on radio propagation, and this field of study remains very active.

Recently, technological advancements have been made that enable experiments that could previously only be dreamt about. In particular, the development of software defined radios (SDRs) and automated receiving networks such as the Reverse Beacon Network (RBN, http://reverse-beacon.net), Phase Shift Keying Reporter (PSKReporter), **http://pskreporter.info**, and the Weak Signal Propagation Reporting Network (WSPRNet), **http://wsprnet.org**, allow for much easier monitoring of a vast number of Amateur Radio signals. Taken as a whole, the capabilities of these tools and the web-based nature of the collecting data sites mean that even routine ham radio operating can be used profitably for propagation studies, space weather, and space science research. Furthermore, by creating an attractive, contest-like operating event, a larger engagement of the amateur community can result with many benefits, including a significant increase in the number of data points (spots) collected and a degree of having some control over the signals on the air through QSO party rules.

HamSCI and the Eclipse

The Ham Radio Science Citizen Investigation (HamSCI), **hamsci.org**, is a collective of Amateur Radio operators and professional space scientists working together to foster collaborations between the two communities. The objectives of HamSCI are to (1) advance scientific research and understanding through Amateur Radio activities, (2) encourage the development of new technologies to support this research, and (3) provide educational opportunities for the amateur community and the general public. The HamSCI team is led by Dr. Nathaniel Frissell, W2NAF, a research professor at the Center for Solar Terrestrial Research at the New Jersey Institute of Technology (NJIT).

HamSCI sponsored three major experiments during the August 21, 2017 eclipse. The largest effort was the contest-like *SEQP*, which generated a quasi-randomly distributed set of QSO observations across the continental United States on multiple HF bands. Publicity for this effort was graciously provided by the American Radio Relay League (ARRL). Second, the *HF Frequency Measurement Experiment* monitored Doppler shifts of frequency standard stations such as WWV and CHU during the eclipse. Third, the *HF Wideband Recording Experiment* had amateurs record raw spectral data of the HF ham bands during the eclipse and post them to a public repository. Full experiment procedures and descriptions are available at **http://hamsci.org/eclipse**. User-contributed eclipse data is available from the HamSCI Zenodo Community Repository at **https://zenodo.org/communities/hamsci**.

SEQP Rules and Philosophy

The HamSCI SEQP was purposefully structured to feel like a normal ham radio contest, with a few twists, of course! The SEQP took place over 8 hours, 1400 – 2200 UTC on 21 August 2017. The start and end times coincided with 2 hours before partial eclipse began in Oregon to 2 hours after partial eclipse ended in South Carolina, respectively. SEQP activity was permitted on all standard HF contest bands (160, 80, 40, 20, 15, and 10 meters) plus 6 meters. CW and digital modes counted as 2 points, while phone QSOs counted as 1 point. CW and digital modes were incentivized because they could be detected by the RBN and PSKReporter networks. Multipliers were given for each 4-character grid square, counted once per band. Bonus points were awarded for a variety of activities, ranging from operation of RBN/PSKReporter/WSPRNet modes to operating outside in a place where you could watch the eclipse while operating. The new twist to contesting for SEQP was the awarding of explicit bonus points for those who were spotted by the major spotting networks. The complete final rules, as well as the peer-reviewed scientific results of the SEQP published in *Geophysical Research Letters*, are archived at **https://doi.org/10.1029/2018GL077324**. Look for the final contest rules in the "Supporting Information" section.

Table 1
SEQP Single-Operator Top 10

RBN Spots	618,623
WSPRNet Spots	630,132
PSKReporter Spots	1,287,962
Submitted Logs	566
Log QSOs	29,809
Log Unique Calls	4,929
Log 4 Character Grid Squares	649
Log DX Entities	80

To reach our scientific goals, we wanted to create a dataset that had large geographic coverage and significant frequency diversity. Although ionospheric eclipse effects have been studied for many years, never before has the infrastructure been in place to observe widespread shortwave radio traffic on a continental scale during a total solar eclipse. Most prior studies have relied on point measurements using a handful of frequencies. By creating a contest-like event that rewarded QSO rate, geographic multipliers, multi-band operation, and QSO modes that were detectable by the RBN and PSKReporter, we created a dataset that could "image" propagation changes across the entire continental United States. This dataset could then be compared against physics-based models of the eclipsed ionosphere to both aid in interpretation of the propagation measurements and provide validation of the model.

While keeping our scientific goals in mind, we also had very specific reasons for making the SEQP as contest-like as possible. First, we wanted to take advantage of the contest community's skill of making thousands of QSOs in a short period of time, while simultaneously utilizing newer ham radio community-developed technologies such as the RBN and PSKReporter networks. Next, ham radio contests are an extremely common and popular occurrence and have widespread community acceptance. In fact, Bruce Horn, WA7BNM, lists over 1,000 contests each year on his website, **www.contestcalendar.com**. Each of these contests could serve as a valuable data source for space weather and propagation research. By structuring the HamSCI SEQP in a manner similar to these contests, we could prototype tools and techniques that could be applied to other contests. Finally, we wanted to create a fun operating event that would involve hundreds to thousands of hams!

SEQP Participation and Path Coverage

In total, over 566 SEQP stations submitted logs containing over 29,000 QSOs with almost 5,000 unique call signs from 80 DX entities. This activity generated over 618,000 RBN spots, 630,000 WSPRNet spots, and 1.2 million PSKReporter spots. Full statistics are provided in Table 1. Some people set up portable stations right in the path of totality, such as the author and his friends who traveled to Gilbertsville, Kentucky. Others, such as the NJIT Amateur Radio Club K2MFF students at the United Astronomy Clubs of New Jersey Observatory in Hope, New Jersey, operated from areas of partial eclipse (see Figure 1). Some people also participated from their home stations as they would do with any other contest.

The end result of all of this participation was excellent spatial coverage of the eclipse path during the SEQP (see Figure 2). Almost 332,000 spots were observed over the US throughout the SEQP.

Eclipse Effects on the RBN

Fortunately, during the 2017 eclipse, HF propagation conditions were quite good for mid-August in the declining phase of the Solar Cycle. During the SEQP, the smoothed sunspot number (SSN) was 44, solar flux maximum was 83, and K_P was 3 or less. There were no major (M- or X-class) solar flares during the eclipse, and only a couple minor C-class flares during

Figure 1 — New Jersey Institute of Technology (NJIT – K2MFF) students Josh Katz, KD2JAO, and Josh Vega, WB2JSV, operate the SEQP from the United Astronomy Clubs of New Jersey (UACNJ) Observatory at Jenny Jump State Park in Hope, New Jersey. [Ann Marie Rogalcheck-Frissell, KC2KRQ, photo]

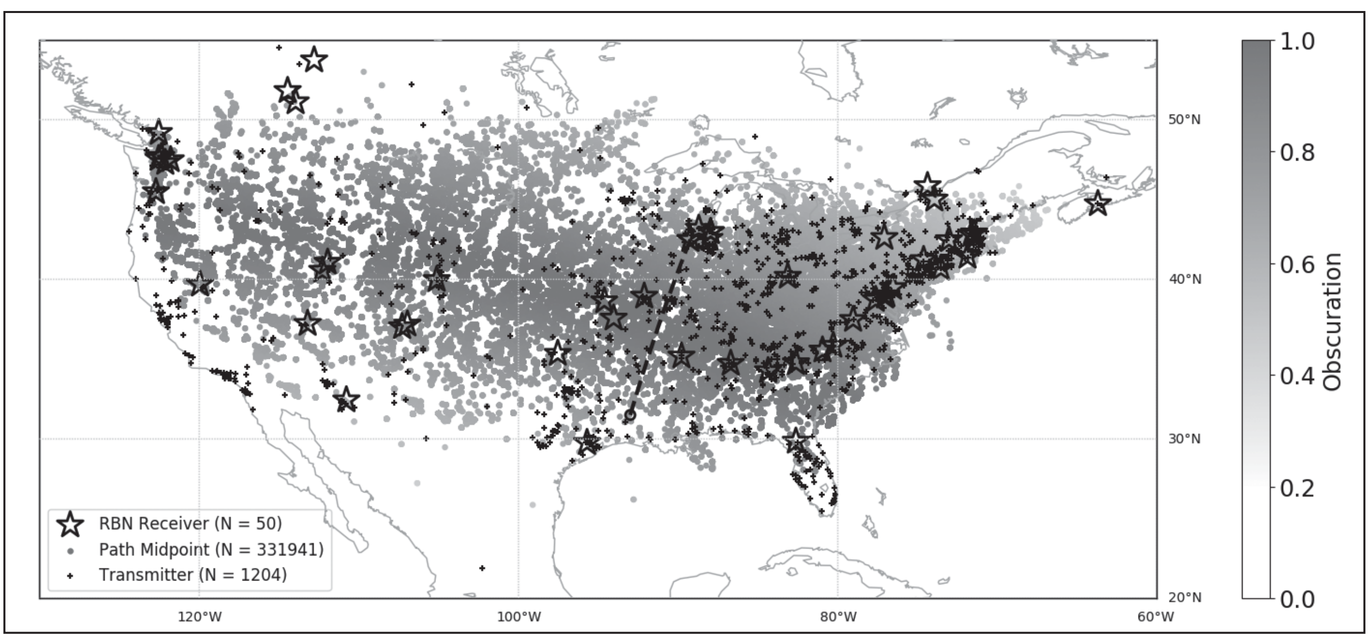

Figure 2 — RBN observations during the all-American total solar eclipse on 21 August 2017. Midpoints between transmitter and RBN receiver are color coded by their maximum obscuration. RBN receivers are marked as blue stars, and transmitters are represented by black dots. Note the dark path of totality from Oregon to South Carolina. (Frissell, et al., 2018)- (The color version is at www.ncjweb.com.)

the SEQP. These relatively quiet space weather conditions increased the probability that observed variations in propagation were more likely due to the eclipse and less likely due to geomagnetic conditions.

Figure 4 (color version is on **www.ncjweb.com**) shows the eclipse effects on propagation as observed during the SEQP, as originally published in Frissell et al., 2018. For initial analysis and peer-reviewed publication, we focused only on the RBN dataset. As shown in the map of Figure 4a, we further selected only spot midpoints with obscuration values ≥ 0.9. Panels (b) – (e) show contour histograms of the 14, 7, 3.5, and 1.8 MHz bands. Bands higher than 14 MHz did not produce enough RBN data for a meaningful analysis, due to prevailing ionospheric conditions (see Science Discussion, below). To organize the data on the X axis, relative time to maximum eclipse obscuration at each spot's location was calculated. The Y axis of each histogram shows the QSO great circle path length on a range of 0 to 3000 kilometers. This maximum range was chosen to primarily select for single-hop propagation. The color bar shows the spot number density with an underlying grid of 10 minutes by 500 kilometers. The white dashed line on each histogram shows the eclipse obscuration curve for the point (40° N, 100° W), roughly the center of the US and the path of totality.

All of the histograms of Figure 4 show clear evidence of eclipse effects. Figure 4b shows that the 14 MHz band was the most active during the SEQP, with 48,912 spots contributing to this figure. The band was open and activity was strong starting at 1.5 hours before eclipse maximum. During this time, most QSO distances were between 1,000 and 2,000 kilometers, with some even reaching out to almost 3,000 kilometers. Propagation changed when the eclipse obscuration values reached between 0.3 to 0.5, approximately 45 minutes before maximum eclipse. At this time, the 14 MHz band started to shut down, severely limiting the number of QSOs that were observed. Recovery started about 15 minutes after eclipse maximum, with propagation returning to near pre-eclipse levels by 1 hour after the eclipse.

Figure 4c shows that the 7 MHz band exhibited a very different response to the eclipse than the 14 MHz band. Instead of the band shutting down, QSO path lengths extended. 7 MHz was the second most active band during the SEQP, with 10,565 spots contributing to Figure 4c. Activity was again strong prior to the eclipse, but the QSO distances were now shorter, ranging primarily between 250 and 1,000 kilometers. At approximately 15 minutes before eclipse maximum, QSO distances

Table 2
SEQP Multioperator Top 10

Station	*QSOs*	*Grids*	*PSK*	*RBN*	*Cluster*	*Bonus*	*Score*
Bud Trench, AA3B Boyertown, PA	1360	296	76	584	5	1,415	403,975
John Laney, K4BAI Columbus, GA	902	248	31	470	5	806	224,502
Mitch Stern, W1SJ Essex Junction, VT	789	228	25	362	3	990	180,882
Karl Bretz, K9BGL Mascoutah, IL	795	216	18	432	2	752	172,472
Bob Patten, N4BP Plantation, FL	888	170	23	422	2	747	151,707
Jay Corriveau, W1UJ Webster, MA	696	169	21	371	0	742	118,366
Bob Johnson, W9XY Montello, WI	554	205	9	294	5	658	114,228
James Low, N6CY (@W6RDF) San Diego, CA	632	171	4	243	2	749	108,821
Bob Panek, K2DSW Indianola, IA	616	166	13	320	3	636	102,892
William H. Hannon, N8PW Canton, OH	792	113	9	194	5	608	90,104

Table 3
SEQP RBN 10,000+ Club

Station	*QSOs*	*Grids*	*PSK*	*RBN*	*Cluster*	*Bonus*	*Score*
WØECC Elayer Contest Club Steelville, MO	868	221	12	329	10	651	192,479
WØD The Eclipse Dogs DeSoto, MO	730	153	12	288	3	853	112,543
W5GAD Jefferson Amateur Radio Club Metairie, LA	557	167	7	257	1	615	93,634
W9S Southern Illinois University A.R.C. Carbondale, IL	312	109	341	42	3	886	34,894
W7O Wiillamette Valley Salem, OR	173	113	0	0	8	308	19,857
W8EDU Case Amateur Radio Club Cleveland, OH	222	73	5	74	1	430	16,636
W4E Ole Virginia Hams & Woodbridge Wireless ARC Lexington, SC	184	79	10	0	3	313	14,849
N9EP W9NXM, N9EP, & WB8BHN Deer Park, IL	187	68	7	117	0	1,224	13,940
WA5POK Blue Spring Cave Cavers Oak Ridge, TN	179	68	3	101	1	655	12,827
K8UTT Ford Amateur Radio League Dearborn, MI	109	62	0	0	0	400	7,158

began to extend in range to between 750 and 1,500 kilometers. A second band of spots ranging between 2,000 and 3,000 kilometers also appeared at this time. This continued until about 15 minutes after eclipse maximum, when propagation started to return to conditions similar to those prior to the eclipse.

Figure 4d and Figure 4e show the 3.5 and 1.8 MHz bands had similar characteristics during the eclipse, but on slightly different time scales. These lower bands were the least active during the SEQP, with 2,147 spots contributing to the Figure 4d 3.5 MHz plot, and 579 spots contributing to the Figure 4e 1.8 MHz plot. In both cases, there was little to no activity both before and after eclipse maximum. The 3.5 MHz band opening lasted longer than 1.8 MHz. On 3.5 MHz, activity was most significant from 45 minutes before to 45 minutes after eclipse maximum. On 1.8 MHz, the band opening lasted approximately ±20 minutes around eclipse maximum. On both bands, QSO distance extended from 0 to almost 2000 kilometers during eclipse maximum.

Table 4
North American RBN nodes with 10,000 or more spots during the SEQP.

Node	*Spots*	*Operator*	*QTH*
WE9V	54,874	Chad Kurszewski	Bristol, WI
AA4VV	40,574	Thomas Berry	Lexington, NC
KU7T	31,762	Andreas Hofmann	North Bend, WA
N4ZR-3	28,692	Pete Smith	Phoenix, MD
NC7J	28,564	Utah Contest Club	Layton, UT
W3OA	28,057	Dick Williams	Mooresville, NC
N2GZ	18,623	Greg Zenger	North Stonington, CT
NØTA	14,751	John Reilly	Loisville, CO

Raytrace Modeling

With the SEQP observations in hand, we contacted Dr. Joseph Huba of the Naval Research Laboratory to obtain a prediction of the eclipsed ionosphere generated with a first principles, multi-dimensional physics-based ionospheric model known as SAMI3 (Huba & Drob, 2017). By using this in combination with the PHaRLAP raytracing toolkit (Cervera & Harris, 2014), studies could predict whether or not a QSO should be possible at a particular time and frequency between a specified transmitter and receiver. We simulated the RBN observations of the SEQP by testing the viability of HF radio links on 1.83, 3.53, 7.03, and 14.03 MHz between each transmitter in a theoretical staggered 2° × 1° grid to every RBN receiver observed during the SEQP.

The modeling results were plotted in a format that could be compared directly with Figure 4, and are available at **https://doi.org/10.1029/2018GL077324**. In comparing the model results with the RBN observations, we found that the 14 MHz observations were consistent with model rays that refracted from altitudes less than 125 kilometers with takeoff angles less than 10˚. Conversely, the 1.8, 3.5, and 7 MHz observations were consistent with rays that refracted from altitudes greater than 125 kilometers and takeoff angles greater than 22˚.

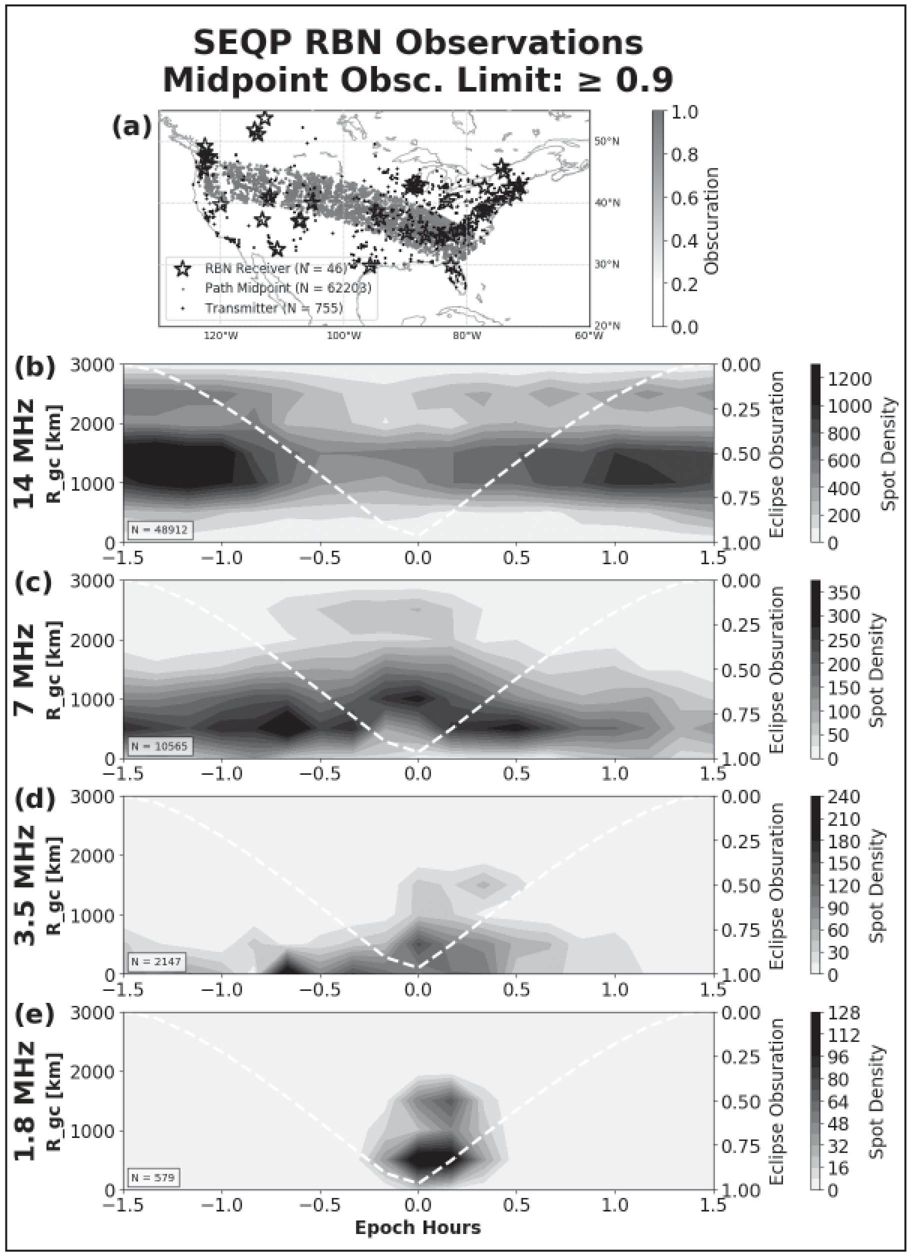

Figure 3 — RBN spot observations near the time of totality (maximum obscuration O300 ≥0.9). Location of midpoints on map of continental US (a). Great circle distance between transmitter and receiver versus epoch time for frequencies in the Amateur Radio bands (b) 14 MHz, (c) 7 MHz, (d) 3.5 MHz, and (e) 1.8 MHz color coded by spot density. For the contours, the underlying grid is 500 kilometers by 10-minute bins. The dashed white line shows obscuration at a representative point 40° N, 100° W. (Frissell, et al., 2018) (See www.ncjweb.com bonus content for the color images.)

Science Discussion

For the duration of the SEQP, the lack of observations above the 14 MHz ham band suggests that the maximum usable frequency (MUF) was between 14 and 21

MHz for most stations for the duration of the event. The model results showed that the majority of 14 MHz QSOs were completed with takeoff angles less than 10°, and this gave evidence that ionospheric densities were generally not high enough to support communications much above this frequency. The decrease in QSOs on 14 MHz, ±45 minutes around eclipse maximum, suggests that at this time the MUF dropped below 14 MHz and those rays escaped into space. The 7 MHz band showed a lengthening of QSO distance as a result of the eclipse. This behavior is also consistent with a reduction of ionospheric density, as reduced densities correspond with reduced bending of radio ray paths. Unlike the 14 MHz band, however, the 7 MHz band remained below the MUF for the entire SEQP.

The 3.5 and 1.8 MHz bands were closed as normal during daytime and were only open during high values of eclipse obscuration. The unavailability of these bands is consistent with low-altitude D region collisional absorption, as would be expected in daylight conditions. As both the moon's umbral and penumbral shadow traversed propagation paths, the D region recombined and absorption decreased, allowing these lower bands to propagate. The 1.8 MHz band was open for less time than the 3.5 MHz band, consistent with the fact that l.8 MHz suffered more D region absorption than 3.5 MHz. In general, the observations and modeling results at 80 and 160 meters were consistent with propagation changes similar to going from daylight to night and back again in a very short period of time.

Contest Results

None of the SEQP results would have been possible without the help and participation of hams on the air. Similar to Field Day, the SEQP was not really a contest, but in many ways it certainly felt like one. As such, we would like to recognize the top performers in both the single and multioperator categories, many of whom are well known to the contest community. In the Single-Operator category, Bud Trench, AA3B, of Boyertown, Pennsylvania, came out on top, followed by John Laney III, K4BAI, of Columbus, Georgia, and Mitch Stern, W1SJ, of Essex, Vermont. For multioperator, the top three were the Elayer Contest Club, WØECC, of Steelville, Missouri, The Eclipse Dogs, WØD (WBØSND and WBØTUA) of DeSoto, Missouri, and the Jefferson Amateur Radio Club, W5GAD, of Metairie, Louisiana. Table 2 and Table 3 show the top 10 stations in each category, along with a breakdown of grid multipliers, spotting network bonuses, and overall bonuses.

As the RBN results were key to success of the initially published SEQP results, we also would like to recognize the top performing RBN nodes during the SEQP. North American RBN nodes with more than 10,000 spots during the SEQP are recognized as being part of the RBN 10,000+ Club and are listed in Table 4. The top three RBN operators are Chad Kurszewski, WE9V, of Bristol, Wisconsin; Thomas Berry, AA4VV, of Lexington, North Caroloina, and Andreas Hofmann, KU7T, of North Bend, Washington. In addition to these, we would like to thank and recognize all who participated in the SEQP. Full contest results are available from **http://hamsci.org/seqp**.

Summary

The total solar eclipse of August 21, 2017 is definitely one for the history books. Rarely does a single astronomical event so engage an entire nation while simultaneously motivating the ham radio community to take to the airwaves for both pleasure and scientific experiment. The Solar Eclipse QSO Party was a great success, with over 29,000 QSOs and more than 2.4 million archived spots. This data shows eclipse ionospheric effects using HF radio on a truly continent wide scale, confirming previous results and continuing a long tradition of Amateur Radio experimentation.

The SEQP and ham radio eclipse work does not end here, however. The data from the SEQP has been archived and is now available for further analysis through **http://hamsci.org/** and **https://zenodo.org/communities/hamsci**. Discussions for future ham radio experiments are already under way for the American Total Solar Eclipse of April 8, 2024. The future is bright for Amateur Radio science!

Acknowledgments

We are especially grateful to the support of the ham radio community for its on-air participation in making the SEQP and other ham radio eclipse studies reality. Thank you to ARRL and to Ward Silver, NØAX, for the promotion of HamSCI and the SEQP, and thanks to the operators of the Reverse Beacon Network, PSKReporter, and WSPRNet for providing SEQP observations. We are also very grateful to National Science Foundation Grant AGS-1552188/479505-19C75, and to the New Jersey Institute of Technology Center for Solar Terrestrial Research for their support of this project.

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