On the use of solar eclipses to study the ionosphere

W. Liles[1,10], C. Mitchell[2], M. Cohen[3], G. Earle[4,10], N. Frissell[5,10], K. Kirby-Patel[6], L. Lukes[7], E. Miller[8,10], M. Moses[4,10], J. Nelson[7], J. Rockway[9]

[1]Independent Consultant, Reston, VA, USA

[2]University of Bath, Bath, UK

[3]Georgia Institute of Technology, Atlanta Georgia, USA

[4]Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

[5]New Jersey Institute of Technology, Newark, NJ, USA

[6]University of Massachusetts at Boston, Boston, MA, USA

[7]George Mason University, Fairfax, VA, USA

[8]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

[9]SPAWAR Systems Center Pacific, San Diego, CA, USA

[10]HamSCI.org

ABSTRACT

Exploring the effects of solar eclipses on radio wave propagation has been an active area of research since the first experiments conducted in 1912. In the first few decades of ionospheric physics, researchers started to explore the natural laboratory of the upper atmosphere. Solar eclipses offered a rare opportunity to undertake an active experiment. The results stimulated much scientific discussion.

Early users of radio noticed that propagation was different during night and day. A solar eclipse provided the opportunity to study this day/night effect with much sharper boundaries than at sunrise and sunset, when gradual changes occur along with temperature changes in the atmosphere and variations in the sun angle.

Plots of amplitude time series were hypothesized to indicate the recombination rates and re-ionization rates of the ionosphere during and after the eclipse, though not all time-amplitude plots showed the same curve shapes. A few studies used multiple receivers paired with one transmitter for one eclipse, with a 5:1 ratio as the upper bound. In these cases, the signal amplitude plots generated for data received from the five receive sites for one transmitter varied greatly in shape.

Examination of very earliest results shows the difficulty in using a solar eclipse to study propagation; different researchers used different frequencies from different locations at different times. Solar eclipses have been used to study propagation at a range of radio frequencies. For example, the first study in 1912 used a receiver tuned to 5,500 meters, roughly 54.545 kHz. We now have data from solar eclipses at frequencies ranging from VLF through HF, from many different sites with many different eclipse effects. This data has greatly contributed to our understanding of the ionosphere.

The solar eclipse over the United States on August 21, 2017 presents an opportunity to have many locations receiving from the same transmitters. Experiments will target VLF, LF, and HF using VLF/LF transmitters, NIST's WWVB time station at 60 kHz, and hams using their HF frequency allocations. This effort involves Citizen Science, wideband software defined radios, and the use of the Reverse Beacon Network and WSPRnet to collect eclipse-related data.

1. INTRODUCTION

In 1912, William Eccles had the idea of studying the influence of a solar eclipse on radio wave propagation. By that time, the diurnal effect on radio waves was known and Eccles was a proponent of the Kennelly-Heaviside theory positing the existence of a layer in the atmosphere that enabled long distance radio communications.

Eccles conducted an experiment using the solar eclipse of April 17, 1912, recording the amplitude of sounds of "strays" at a wavelength of 5,500 meters. He did not record signal amplitude change for any transmitter, but did record that a transmitter's signal in Clifden was loud when strays were loud and vice versa [1].

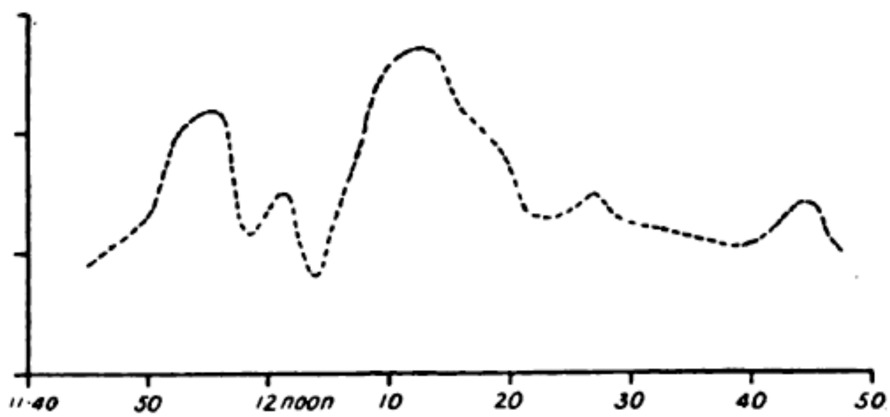


Figure 1. Eccles plot showing amplitude (y-axis) vs. time (x-axis). Maximum eclipse as viewed from London, UK was at 12:09:59.4 [1]

The plot in Figure 1 raises questions that are still being discussed today. For example, why are there two major humps and not just one? Why is there a hump before the maximum eclipse time? Why is the major hump the shape it is?

Since 1912 many attempts have been made using solar eclipses to study radio wave propagation at different frequencies using different transmitters and different receive locations. Comparing this data is difficult since it typically comes from one or a few receive sites for a given transmitter and not always with geometries that show all the conditions that one wishes to study.

During the 2015 partial solar eclipse north of the UK, the 711 kHz signal from France Info at Rennes-Thourie was received and collected at Wolverhampton, UK. Both transmit and receive sites were south of the eclipse path. Figure 2 shows the received signal strength and the eclipse path. On the signal strength plot, the slope of the increasing signal strength before the eclipse is more gradual than the slope for the decreasing signal strength after the eclipse. These differences might be associated with de-ionization and re-ionization rates.

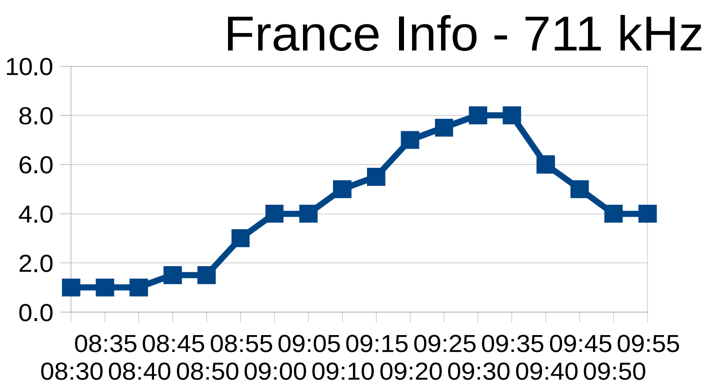
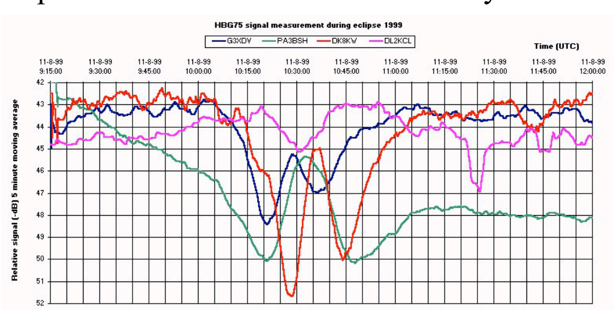


Figure 2. Received signal strength (in S units) at Wolverhampton, UK vs time (left) and eclipse path (right) for the transmitter located south of Wolverhampton at Rennes-Thourie, France [2]. Map from NASA shows the eclipse path.

The plot in Figure 2 looks straightforward with a low value early in the day when the signal cannot be heard, then rising signal strength during the eclipse and falling signal strength after the eclipse. But not all plots have been so straightforward. Figure 3 shows plots for reception of the 75 kHz time signal from Switzerland by four different receive sites during the 1999 solar eclipse. Notice that all signal paths cross the line of visual totality in the accompanying diagram.



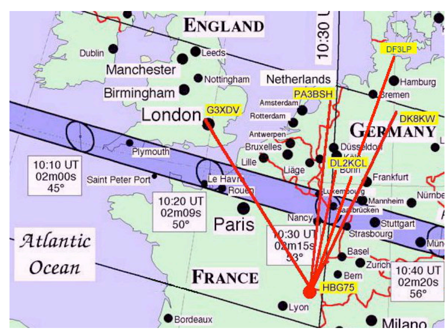


Figure 3. Relative signal strength from HBG Switzerland at 75 kHz during 1999 solar eclipse. https://misan.home.xs4all.nl/eclipse.htm

The signal strength variations depicted in Figures 2 and 3 reflect changes in the D layer. This layer has very complex chemistry. Ionosondes primarily measure E, Es and F layers, thus providing no insight into the D layer. While these figures show increased propagation strength during an eclipse, the F layer shows decreased propagation strength, as the critical frequency decreases during an eclipse.

During the 1920s and early 1930s, there was a serious debate as to what caused the ionization of the ionospheric layers. The diurnal effects were well known; as a result the sun was accepted as the main cause of ionization. However the ionization mechanism was unknown. The two main theories were either electromagnetic waves or neutral particles being emitted from the sun [3].

Questions regarding the ionization mechanism were the basis of an experiment using the solar eclipse. Since the moon would block both the electromagnetic waves traveling at 300,000 km/s and the particles traveling around 2,000 km/s, the delay in ionization after the passage of the eclipse could be computed. If the ionosphere was ionized quickly, it was due to high speed electromagnetic waves. If there was a significant delay in ionization, it was due to the slow speed of the particles. The results showed that electromagnetic waves were the agent [4].

2. Planned Studies during the North American Solar Eclipse of August 21, 2017

Multiple projects planned for the upcoming eclipse at variety of frequencies. This paper will discuss projects associated with terrestrial transmitters in the VLF, LF and HF frequency ranges.

As mentioned above, the first study done in 1912 suffered from the lack of a transmitter and thus reported only on atmospheric noises. Today there are many transmitters available.

The VLF/LF projects discussed below take advantage of two transmitter systems. One is WWVB in Fort Collins, CO, transmitting at a frequency of 60 kHz. This signal has complete coverage over the contiguous USA with an appropriate receiver and antenna. This addresses the issue of different receive sites reporting on different transmitters at different frequencies.

The second system uses the US Navy's transmitters for submarine communication. These stations have been used for years to study Sudden Ionospheric Disturbances (SIDs) and operate mainly at VLF with one transmitter at 40.75 kHz [5]. The Navy also has transmitters in Dixon, CA that may be active during the days around the 2017 eclipse event, transmitting signals at 55.1 kHz and 135.95 kHz.

The HF project will take advantage of the multiple frequency allocations to Amateur Radio distributed throughout the HF spectrum.

The projects below touch on the range of possibilities for experimentation during a solar eclipse event. For example, it has been shown that solar eclipses may generate traveling ionospheric disturbances [6]. Also, another tool now available to study eclipse effects uses GPS satellites to collect TEC data [6].

2.1 EclipseMob

EclipseMob is a crowdsourced project that invites participants throughout North America to record amplitude variation of signal strength from at least WWVB at 60 kHz and hopefully also US Navy transmitters on the VLF and LF bands. This effort focuses solely on VLF and LF.

The receiver consists of a single chip instrumentation amplifier, mixer chips and some external parts (capacitors, voltage regulators, batteries, etc.) feeding its output into a smart phone. The smart phone functions as a Software Defined Radio that also supplies location and time/date information. The electronics and antenna design, a balanced loop, are based on a paper by Tom Hagen [7].

Kits for building EclipseMob receivers are provided at no cost to educational institutions. Educational materials have also been prepared, including learning activities for K-12 students. The kits are easy to build, with no soldering required.

The data collected in the EclipseMob experiment will be uploaded to a web server, where it can be analyzed to address some of the questions raised in Section 1.

For more information, please see EclipseMob.org.

2.2 Georgia Institute of Technology

The Atmospheric Weather Electromagnetic System for Observation, Modeling and Education (AWESOME) is a magnetic field VLF/LF receiver currently built at Georgia Tech for lightning and ionospheric remote sensing, and other broadband VLF/LF observations [8]. It consists of two orthogonal air-core loop antennas, sampled at 1 MHz to capture the spectrum between 500 Hz and 470 kHz, with 16 bits of dynamic range. Sensitivity is as low as 0.03 fT/rt-Hz, enabling even weak 10 kA lightning strokes or VLF/LF beacons to be detected at global distances. The receiver is an improved version of the VLF AWESOME described by Cohen et al. [8], originally designed at Stanford University.

The timing accuracy of the new receiver is now 15 ns, allowing precise phase measurements of VLF and LF beacons (~0.16 degrees at 30 kHz). The receiver has long been used for VLF ionospheric remote sensing, in which the amplitude and phase of a beacon signal changes due to D-region ionospheric electron density changes. As the ionospheric layers respond to the eclipse, the beacon signals will scatter off the moving patch disturbance formed by what is effectively a nighttime ionosphere surrounded by daytime. The measured signal amplitudes and phases will then change as a result of this scattering process.

Current sites are: Toolik, AK; Juneau, AK; Burden, KS; Dover, DE; PARI, NC; Briarwood, GA; Baxley, GA; and Atlanta, GA. There are proposed sites for: Luthersville, GA; Marion, SC; Santa Cruz, CA; Port St Lucie, FL; and Arecibo, PR.

2.3 HamSCI

The HamSCI effort, unlike EclipseMob and Georgia Tech, is focused on HF band propagation effects, the Amateur Radio bands 160, 80, 40, 20, 15, 10 and 6 meters. This effort is run out of Virginia Tech, with support by NJIT and JHU/APL. This is also a crowdsourced project to involve many Radio Amateur operators and taking advantage of the Radio Amateur infrastructure, particularly WSPRNet and the Reverse Beacon Network [9; 10].

Participants in this activity will maintain logs so that propagation paths can be studied after the event. An additional set of Radio Amateurs will be operating their stations like an oblique sounder, with other hams recording the signal strength throughout the time period.

The Reverse Beacon Network [11] is a collection of receivers that record SNR for Radio Amateur Morse Code and Teletype transmissions along with the call sign of the transmitting station. This allows studies on SNR as a function of time throughout the eclipse.

For details of this effort and how to participate, even if not a Radio Amateur, visit HamSCI.org.

3. CONCLUSIONS

Since the solar eclipse of 1912, many professional and amateur experiments have been conducted to study the effects of solar eclipses on radio wave propagation. Although more has been learned about the ionosphere and radio wave propagation through these studies, but the results have been less than optimal for a variety of reasons, primarily equipment and logistics at the time the data was collected and analyzed.

The three projects presented here intend to overcome challenges related to previous experiments by taking advantage of the large landmass that the 2017 solar eclipse will traverse and combining modern technologies with distributed collection sites.

ACKNOWLEDGEMENTS

This material is based upon work supported in part by a NERC Knowledge Exchange Fellowship[2] and the National Science Foundation under Grant Nos. AGS-1638685[7], AGS-1638697[6], AGS-1451142[3] and AGS-1552188[4,5].

REFERENCES

[1] Eccles, W. H. (1912). The Propagation of Long Electric Waves during the Solar Eclipse. Nature, 89(2217), 191-192.

[2] Eclipse 2015 – RSGB Experiment downloaded from http://forums.thersgb.org/index.php?threads/early-results-from-eclipse-experiments.128/

[3] Chapman, S. (1932) "The Influence of a Solar Eclipse Upon Upper Atmospheric Ionization," MNRAS, March 1932, Vol 92, 413-422

[4] Appleton, E.V. and Chapman, S. (1935) "Report on Ionizaton Changes during a Solar Eclipse," Proc. IRE, June 1935, Vol 23(6) 658-669.

[5] List of VLF transmitters https://en.wikipedia.org/wiki/List_of_VLF-transmitters

[6] Verhulst, T.G.W., Sapundjiev, D., Stankov, S.M., (2016) "High-resolution ionospheric observations and modeling over Belgium during the solar eclipse of 20 March 2015 including first results of ionospheric tilt and plasma drift measurements," Advances in Space Research, Vol 57, 2407-2419.

[7] Hagen, T. "A Portable, Calibrated VLF Field Strength Measurement Receiver and Loop Antenna," Society of Amateur Radio Astronomers 2015 Western Conference, Stanford University, March 20-22, 2015.

[8] Cohen, M.B., Inan, U.S. and Paschal, E.W. (2010) "Sensitive Broadband EFL/VLF Radio Reception with the AWESOME Instrument, IEEE Transactions on Geoscience and Remote Sensing, January 2010, Vol. 48(1), 3-17.

[9] Silver, W. (2017). The Solar Eclipse QSO Party (HamSCI), QST, Feb. 2017, Vol 101(3), 82-84.

[10] Silver, W. ((2016). HamSCI: Ham Radio Science Citizen Investigation, QST, Aug. 2016, Vol 100(8), 68-71.

[11] Smith, P. and Silver, W. (2016) The Reverse Beacon Network. QST, Oct. 2016 Vol 100(10), 30-32.