Crowd-Sourced Radio Science at Marshall Space Flight Center

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INTRODUCTION

August 21, 2017 provided a unique opportunity to investigate the effects of the total solar eclipse on high frequency (HF) radio propagation and ionospheric variability. In Marshall Space Flight Center's partnership with the US Space and Rocket Center (USSRC) and Austin Peay State University (APSU), we engaged citizen scientists and students in an investigation of the effects of an eclipse on the mid-latitude ionosphere. Activities included fieldwork and station-based data collection of HF Amateur Radio frequency bands and VLF radio waves before, during, and after the eclipse to build a continuous record of changing propagation conditions as the moon's shadow marched across the United States. Post-eclipse radio propagation analysis provided insights into ionospheric variability due to the eclipse.

OBJECTIVES

- Observe the propagation of HF radio signals that may be influenced by changes in the ionosphere local to the eclipse shadow.
- Engage students and citizen scientists to participate in, and contribute to, a solar eclipse radio science investigation.
- "Continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art." (FCC 97. §97.1.b)
- Investigate the way eclipse radio propagation conditions evolve in a manner similar to day/night transition scenarios that occur at the dawn and dusk terminators (Smith and Silver, 2016).
- Explain changes in radio propagation in terms of evolving ionospheric conditions as the eclipse shadow marches across the U.S.
- Have Fun!

HYPOTHESIS

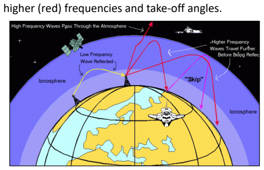
- It has long been known that the Earth's ionosphere responds to changes in solar illumination during a solar eclipse (e.g., Chapman, 1931; Hurlbert, 1941; Mitra, 1952; Davies, 1990).
- Changes in the ionosphere during an eclipse would influence the propagation of radio waves traversing the ionosphere, and could be explained by observing the behavior of radio propagation.
- The most dramatic changes in radio signal strength during the eclipse should occur in the ionospheric D Region (e.g., Nichols, 2015).

BACKGROUND

Radio propagation at low HF frequencies, 80 meters (80M, 3.5-4.0 MHz) and 40 meters (40M, 7.0 – 7.3 MHz), are typically good during the night, but during the day, the D-Region ionospheric density increases due to ionization, and the lower frequency waves are attenuated via radio wave absorption. In the ionospheric D region, radio wave absorption per unit path length is roughly proportional to $n_e \nu/(\nu^2+\omega^2)$, where n_e is electron density, ν is collision frequency, and ω is radio wave angular frequency.

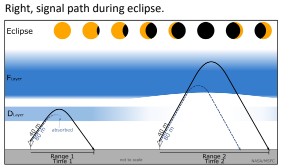
As solar illumination and ionization decrease in the shadow of the eclipse, electrons recombine with ions at a faster rate than they are produced. The result is a decrease in n_e and the product $n_e\nu$ during eclipse resulting in less absorption (Davies, 1990). Monitoring lower band HF propagation can help interpret and understand eclipse effects.

Propagation (radiowave path) at lower (white), higher (red) frequencies and take-off angles.

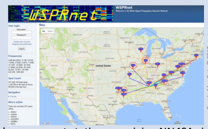


http://www.swpc.noaa.gov/phenomena/ionosphere

Left, normal day 80M and 40M signal paths. Right, signal path during eclipse.

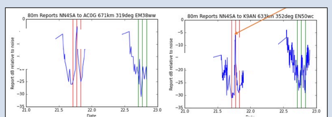


Weak Signal Propagation Reporter Network (WSPRnet) is a global amateur radio propagation reporting system, similar to RBN but with advantages (e.g., very low power, low error rates). Key to the success of the RBN and WSPR is the participation of hundreds of Amateur Radio volunteers who maintain these global propagation reporters.



Circles represent stations receiving NN4SA signals
WSPR Propagation Plot – 80m band (3.5 MHz)

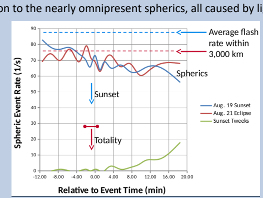
NN4SA WSPR Transmitter
NASA Marshall Space Flight Center
Huntsville, AL (34.64N, 86.68W)
Partial eclipse, 5 watt transmitters on 80M and 40M.

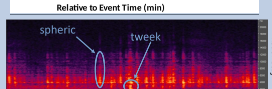


Reports of SNR on 80M by two WSPR stations showed clear enhancements of signals during the eclipse (red lines), but not on the day after (green lines). Figures indicates the range and azimuth from the NN4SA transmitter.

wsprnet.org / Google Map Data © 2017 Terms of Use

Thirteen students were sponsored by the **Interactive NASA Space Physics Ionosphere Radio Experiments (INSPIRE)** Project to monitor natural VLF noise to determine if an eclipse can enable nighttime-like VLF radio noise that is known to include tweeks and whistlers, in addition to the nearly omnipresent spherics, all caused by lightning.



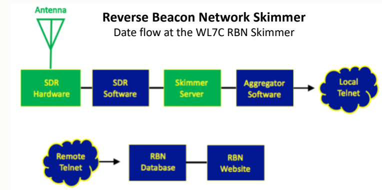


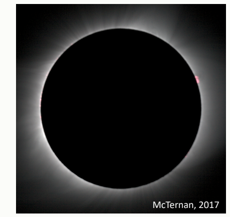
Representative frequency vs. time plot showing spherics and a tweek (hook-like feature).

No change from the typical midday local VLF noise was found for the shorter approximately 2 minute 40 second period of totality at the VLF observing site, only about 1.35 miles from the totality centerline. It is speculated that more night time like VLF noise may accompany the longest eclipse periods of totality that can last about 7 minutes.

Reverse Beacon Network (RBN) stations collect reports of received signals and send them back to central databases where they are archived and displayed in near-real time on the RBN website (reversebeacon.net). The RBN provides key information needed to characterize radio propagation conditions. RBN receiver "skimmer" servers generate reports ("spots") by decoding continuous wave (CW, e.g. Morse code), teletype and more modern digital format signals.

WL7C and K0DRK sites were very near Greatest Eclipse, Hopkinsville, TN.

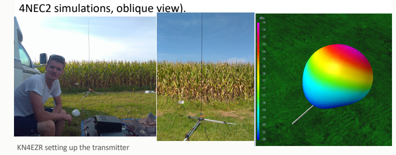




1000-mm Schmidt-Cassegrain, Canon Rebel XTi
1/125 shutter, 200 ISO, No filter

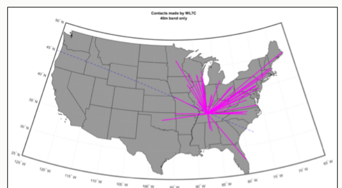
WL7C RBN Receive Node APSU Farm in Clarksville, TN (36.56N, 87.34W), South of eclipse centerline; 82-ft fan dipole antenna.

K0DRK RBN Transmitter North of Hopkinsville, KY (37.04N, 87.30W) on eclipse centerline; 80 watts feeding "L" antenna (gain pattern from 4NEC2 simulations, oblique view).

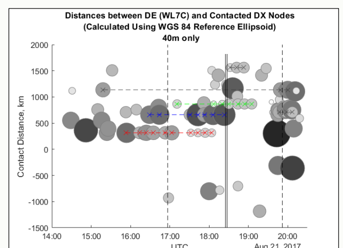


KN4EZR setting up the transmitter

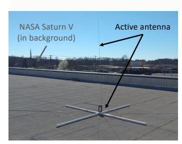
Parameterized Ionospheric Model (PIM) (Daniell et al., 1995) simulation of eclipse-like ionospheric conditions* using input parameters appropriate for solar and ionospheric conditions observed on the day of eclipse (GIRO; Reinisch and Galkin, 2011). Low angle propagation at 7 MHz (40 meter band) shows multiple hops. Near Vertical Incident Sky waves (NVIS) (red and green curves) do not return to the ground. [*PIM has no D Region].



Propagation paths of stations received by WL7C August 21, 2017 between 1400-2000 UT. WL7C is at the apparent radiant point.



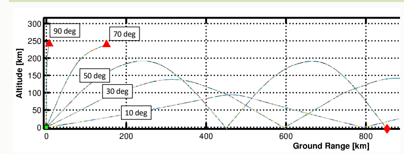
All 40M spots reported by WL7C on eclipse day. Bubble size represents Signal-to-Noise (SNR). Negative distances show stations south of WL7C. Colored lines: multiple spots from same stations.



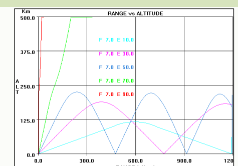
Active, receive only antenna for RNB, WSPR networks installed on the roof at MSFC. We are engaging other NASA facilities to install RBN and/or WSPR nodes as well.

PRELIMINARY RESULTS

Preliminary results from analysis of WL7C RBN data collected on eclipse day indicate an increase in propagation distance on the 40M band during the eclipse. On the 80M band, WSPR receivers from hundreds of kilometers away recorded NN4SA transmissions, whereas this was not the case on the day after the eclipse. These results point to decrease of absorption in the D region during the eclipse and suggest F region ionospheric propagation, and/or multi-hop modes. Numerical simulations using the PIM ionospheric model (Jones– Stephenson ray tracing) and IRI-2016 ionospheric model (IONORT raytracing) support these assumptions.



IONORT - Simulated 7-MHz rays pointed toward WL7C 60.6 km (37.7 miles) away at various elevations (electron density profiles via IRI-2016).



AF Geospace-simulated 7-MHz ray using Parameterized Ionospheric Model (PIM).

Why didn't WL7C hear K0DRK?

Three modes that enable propagation of radio waves between two nearby stations include Direct Wave (line of sight), Groundwave (follows the Earth's surface), and Near Vertical Incidence Sky Wave (NVIS) via ionospheric refraction. Of the three, on WL7C/K0DRK operating band of choice, 40M, NVIS would be the most likely mode because distance and terrain put the stations beyond the line of sight, and ground waves are rapidly attenuated. The UMass. Lowell GIRO database (Reinisch and Galkin, 2011), included 6 Digisonde ionospheric sounder stations operating in the mainland U.S. at 18:00 UT on August 21 (near peak eclipse at our field locations). Measured peak plasma frequencies in the F2 layer, *foF2*, were near 4.0 +/- 0.5 MHz, with the height of F2 layer peak, *hmF2*, ranging 196-244 km. NVIS propagation between WL7C and K0DRK (53 km separation) was unlikely because the high-angle sky wave would have punched through the ionosphere rather than returning to the surface.

CONCLUSIONS

Our eclipse radio science campaign during the 2017 total solar eclipse demonstrated that meaningful science can be done on a shoestring budget, while engaging citizen scientists. We look forward to exciting results from further analyses, and results from the broader HamSCI community. However, data quality can be impacted by the social nature of such crowd-sourcing observations due to uncertainties in the reliability of user-provided information: e.g., location, timing, and consistency of transmitter effective radiative power (ERP).

Next Steps:
We plan to install the RBN skimmer server at NASA Marshall Space Flight Center (MSFC) to fill a sorely needed gap in RBN observation coverage in the southeast U.S. to use as a teaching resource, and to enable new MSFC ionospheric and radio propagation research and public outreach. The experience and knowledge gained, and mistakes made, will better prepare us for future eclipse radio science campaigns. On to Chile in 2019!

ACKNOWLEDGEMENTS

We could not have accomplished this work without the Reverse Beacon Network (RBN). RBN is crowd-sourced by a dedicated and volunteer team of Amateur Radio operators and hosted on dxwatch.com. Weak Signal Propagation Reporter (WSPR) is open source software initially written by Joe Taylor,K1JT. HDSDR: High Definition Software Defined Radio is freeware by Mario Taeubel, DG0JBJ. http://www.hdsdr.de CW Skimmer is available from Afreet Software, Inc., Alex Shovkoplyas, VE3NEA. http://www.dxatlas.com/cwskimmer. Parameterized Ionospheric Model (PIM), see R. E. Danniell et al., 1995. IONOspheric Ray Tracing (IONORT) was developed at Istituto Nazionale di Geofisica e Vulcanologia, Rome, IT. We thank Prof. B. W. Reinisch, Global Ionospheric Radio Observatory (GIRO) Principal Investigator, for making Digisonde Data available via the GIRO. Ionosonde data is provided at http://spase.info/VWO/NumericalData/GIRO/CHARS.PT15M. See additional acknowledgements at http://umlcar.uml.edu/DIDBase/Acknowledgements.htm.

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