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 students and citizen scientists in an investigation of the eclipse effects on the mid-latitude ionosphere. Activities included implementing and configuring software, monitoring the HF amateur radio frequency bands and collecting radio transmission data on days before, the day of, and days after the eclipse to a 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. We report on results, interpretation, and conclusions of these investigations.

OBJECTIVES

• Engage students and citizen scientists to participate in, and contribute to, a solar eclipse radio science investigation.
• Observe the propagation of HF radio signals that may be influenced by changes in the ionosphere local to the eclipse shadow.
• 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, 2014).
• 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, 1933; Hurlburt, 1941; Mitra, 1952; Davies, 1990).
• Changes in the ionosphere during an eclipse would influence the propagation of HF radio waves traversing the ionosphere, and could be explained by observing the behavior of HF radio propagation.
• The most dramatic changes in radio signal strength during the eclipse should occur in the ionospheric D Region (e.g., Nichol, 2015).

BACKGROUND

Radio propagation at low HF frequencies (10 meters, 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 decreases 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

\[ \text{absorption} \propto n_e \text{ } \nu^2 \]

where \( n_e \) is electron density, \( \nu \) is radio wave angular frequency.

As solar illumination and ionization decreases 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 \( n_e \text{ } \nu^2 \) is radio wave angular frequency.

Propagation (radio waves) path at lower (white), left, normal day 80M and 40M signal paths. Right side: signal path during eclipse.

NLH: and KDDR reverse Beacon Network Transmitter

North of Hopkinsville, KY (37.04N, 87.30W)

On eclipse centerline: 80 watts feeding “L” antenna

KDDR Reverse Beacon Network Transmitter

North of Hopkinsville, KY (37.04N, 87.30W)

On eclipse centerline: 80 watts feeding “L” antenna

Radio volunteers who maintain these global propagation reporters.

PROPAGATION PATHS OF STATIONS RECEIVED BY WL7C AUGUST 21, 2017 BETWEEN 1400-2000 UT. WL7C IS AT THE APPARENT RADIANT POINT.

WLC7 Reverse Beacon Network Receive Node

AFSU Farm in Clarksville, TN (36.56N, 87.34W)

South of eclipse centerline, 82-foot dipole antenna


Daniell et al., 1995, Radio Sci., 30, 1499–1510.


E. P. Nichols, Global Ionospheric Radio Observatory (GIRO) Principal Investigator, for making Digisonde Data available via the GIRO database (Reinisch and Galkin, 2011), included 6 Digisonde ionospheric sounder 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 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 “reversed beacon (RBN) spots” by decoding continuous wave (CQ, e.g. Morse code), teletype and more modern digital format signals.

Weak Signal Propagation Reporter Network (WSPRnet) is also a global amateur radio propagation reporter network, similar to RBN but with advantages (e.g., very low propagation 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.

PRELIMINARY RESULTS

Preliminary results from analysis of WLC7/CN 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 PM model support these assumptions.

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)

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 reflection. Of the three, on WLC7/CN/C during low frequency choice, 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 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 “reversed beacon (RBN) spots” by decoding continuous wave (CQ, e.g. Morse code), teletype and more modern digital format signals.

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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 US, to serve 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 research campaigns. On to Chile in 2019!