Characterizing the Ionosphere Using a Commercial Off the Shelf Software Defined Radio System

M.L. Moses[1], S. Dixit[1], G.D. Earle[1], N.A. Frissell[2], L. Kordella[1], X. Han[1], C. Chitale[1]
[1]Virginia Tech, [2]New Jersey Institute of Technology

Introduction

Solar eclipses offer a way to study the dependence of the ionospheric density and morphology on incident solar radiation. There are significant differences between the conditions during a solar eclipse and the conditions normally experienced at sunset and sunrise, including the west-to-east motion of the eclipse terminator, the speed of the transition, and the continued visibility of the corona throughout the eclipse interval. Taken together, these factors imply that unique ionospheric responses may be witnessed during eclipses, reflected by changes in radio frequency (RF) propagation. In order to study these changes, we will establish four temporary field stations using software defined radios (SDRs) along the path of totality during the eclipse.

Motivation

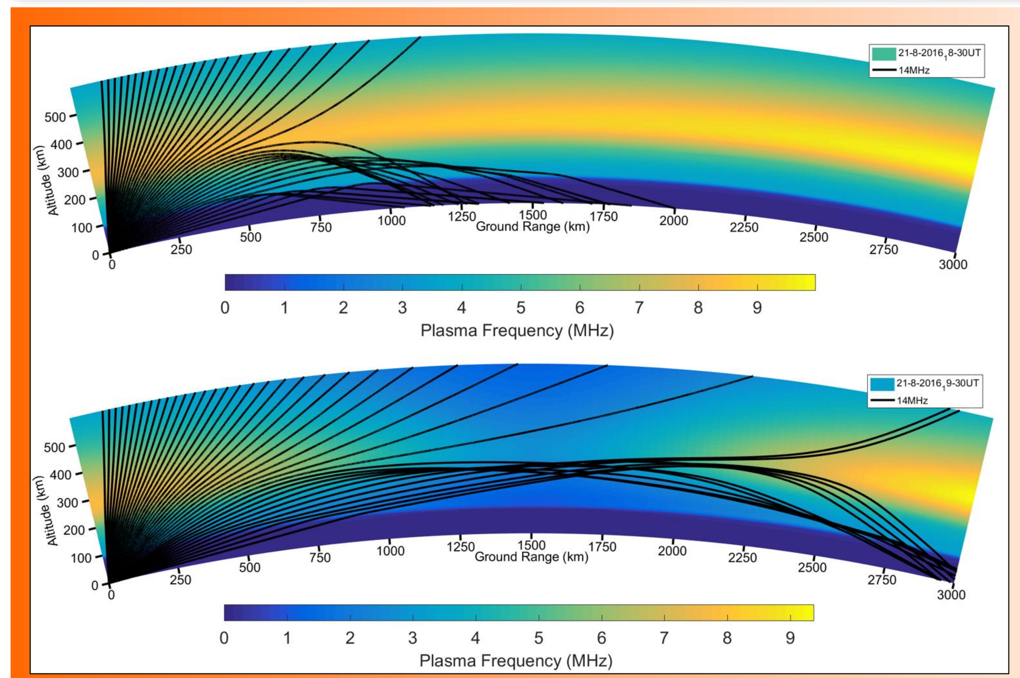

Figure 1. Raytrace on 14MHz ray through unperturbed ionosphere (top) and through eclipsed ionosphere (bottom)

- Our preliminary models (based on observations by Afraimovitch et al.) of the ionospheric response to the eclipse show a large decrease in electron density. We use the PHaRLAP ray tracer with our model to obtain the plot in Figure 1
- As Figure1 shows, the ray is ducted as it passes through the ionosphere's eclipsed region, resulting in a longer path than under pre-eclipse conditions.

In order to study these changes, we will establish four temporary field stations using software defined radios (SDRs) along the path of totality during the eclipse.

Instrumentation and Method

- We established two sites, one at the New Jersey Institute of Technology (NJIT) and the other at Virginia Tech (VT), in order to confirm that the SDRs are capable of inferring ionospheric conditions.
- The test consisted of one station transmitting a continuous tone while the other station recorded the received power from the display (Figure 2) and repeating the test in the other direction for every possible amateur radio band between 3-30MHz.
- We conducted these tests at various times of day from September through November.

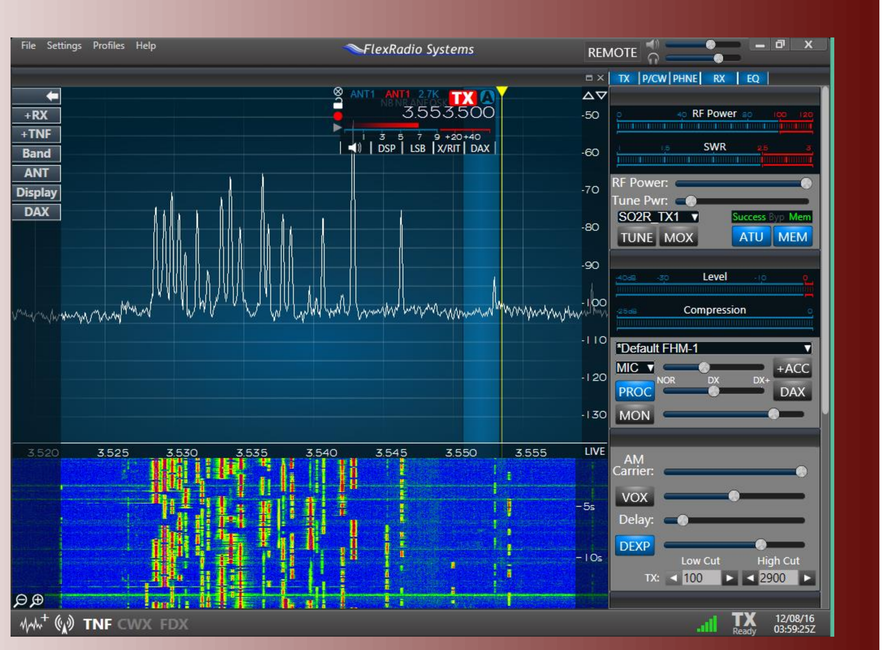

Figure 2. Flex 6300 SDR Control GUI

Observations

SNR Variations in Local Time

- From our recordings of the received signal and the noise floor powers (dBm), we obtained the signal-to-noise ratio (SNR) for each transmission. The figure on the right shows the SNR values by frequency band binned in 1 hour intervals.
- The 80 m (3.5 MHz) band shows significant variations versus local time, while the 40 m (7 MHz) band is less variable. These two frequency bands were most consistently able to communicate between NJ and VA during the 8 AM to midnight time window.

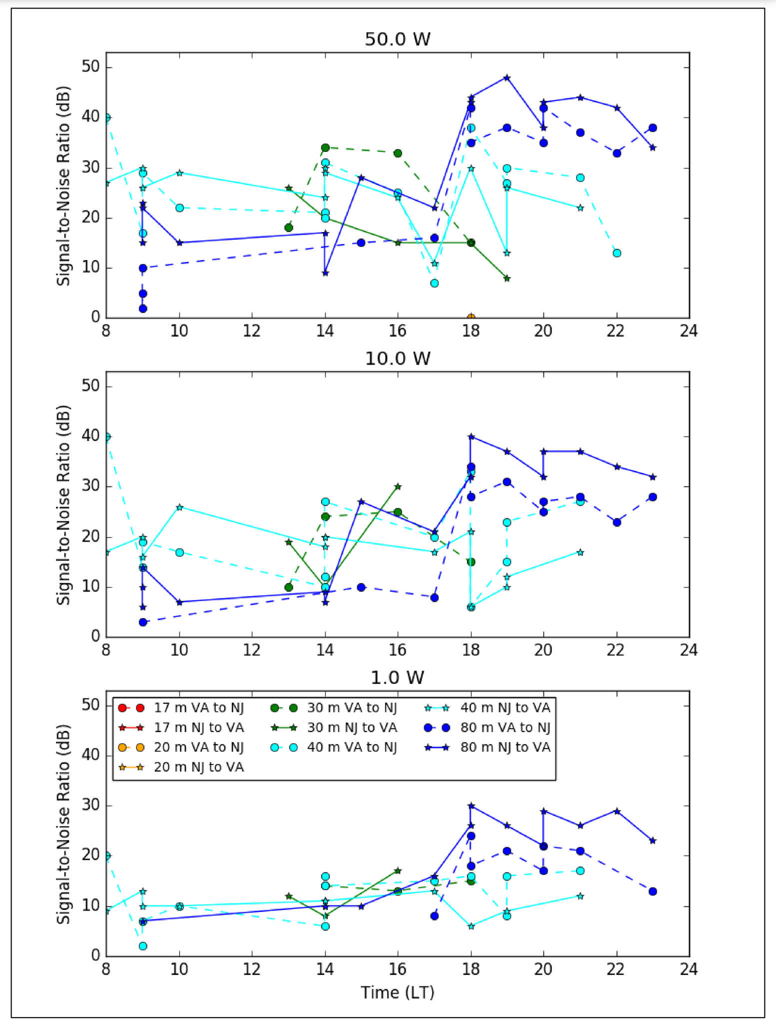

Figure 3. SNR data obtained by the system

Average SNR

- We bin the data from the two frequency bands in four hour intervals and take the average to obtain SNR trends over time. 80 m data are shown at three different power levels in Figure 4a.
- The same process for the data at 40 m yields Figure 4b.

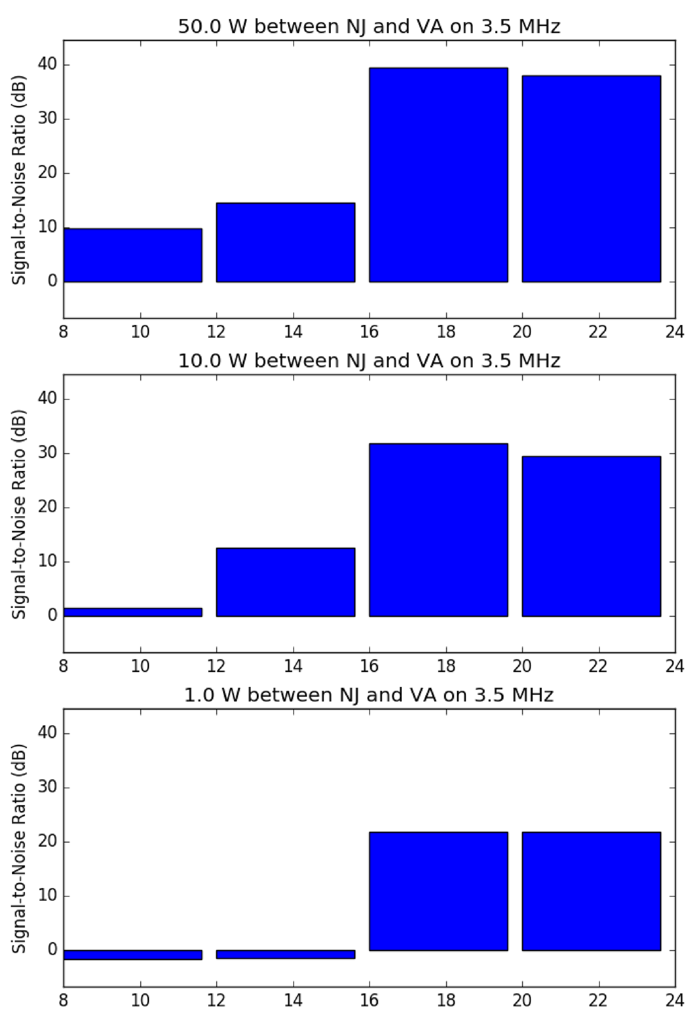

Figure 4a. Barplots of Average SNR between VT and NJIT on 3.5MHz

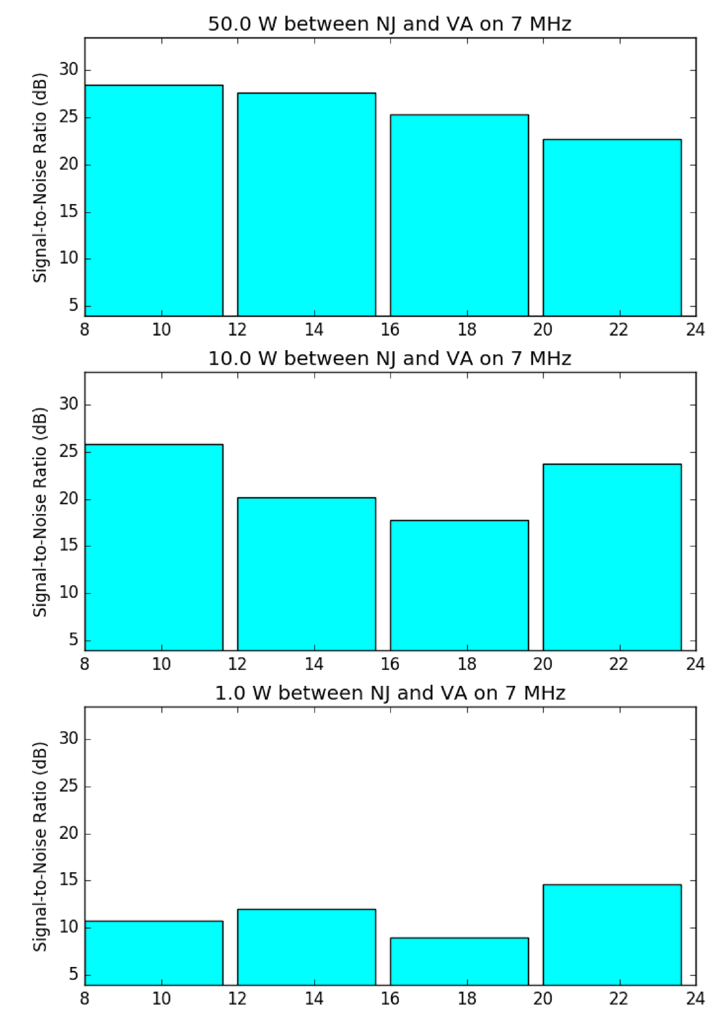

Figure 4b. Barplots of Average SNR between VT and NJIT on 7MHz

Discussion

- The maximum usable frequency (MUF) for RF propagation between two stations is related to the critical frequency (f_p) by $MUF = f_p * sec\theta$, where θ is the angle of incidence. Additionally, the relationship between the critical frequency in MHz and the plasma number density (N) in #/cm^3 is approximately given by $f_p = 9x10^3 * \sqrt{N}$. Hence, when the plasma density is greater as it is in the middle of the day, the MUF will also be larger. Our data in Figure 3 confirms this as in the early afternoon our stations were able to establish contact on higher frequencies than in the morning or at night.
- As shown in Figure 4, the measured SNR on the 3.5 MHz band shows a maximum variation of 30 dB over the course of the day, while the maximum SNR variation in the 7 MHz band is about 10 dB.
- When the plasma frequency of the plasma in a region of the ionosphere is greater than the frequency of the propagating RF signal, the electrons can extract energy from the signal. The electrons then lose this energy through collisions with the neutral gas; the process is most significant in the D and E regions. Losses are reduced near sunset as the D and E region electron densities rapidly decrease, as illustrated by the plot of the E layer plasma frequency (foE) from the International Reference Ionosphere (IRI) in Figure 5.

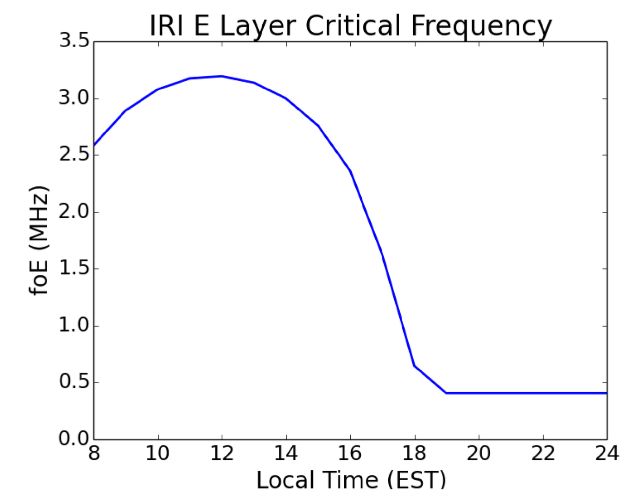

Figure 5. foE values over time obtained from the IRI

- Our results at 7 and 3.5 MHz are consistent with this interpretation, because the lower frequency data are more affected by sunset than are the higher frequency data.

Conclusions and Future Work

- This work demonstrates that software defined radio communication experiments can provide a useful tool for studying ionospheric propagation effects at HF frequencies (3-30 MHz).
- Our eclipse experiment will exploit this technique using point-to-point communications at sites distributed along the eclipse track across the entire US.
- Our future work will use the ray-tracing code to investigate azimuthal refraction during the eclipse.
- We will use our models to help interpret the HF propagation data we obtain during the eclipse experiment.

References and Acknowledgments

E. L. Afraimovich, E. A. Kosogorov, and O. S. Lesyuta, "Effects of the August 11, 1999 total solar eclipse as deduced from total electron content measurements at the GPS network," *Journal of Atmospheric and Solar-Terrestrial Physics,* vol. 64, pp. 1933-1941, 12/2002

This work was supported by NSF Grant # AGS-1552188.

The results presented in this poster were obtained using the HF propagation toolbox, PHaRLAP, created by Dr. Manuel Cervera, Defence Science and Technology Organisation, Australia (manuel.cervera@dsto.defence.gov.au). This toolbox is available by request from its author.

We acknowledge the use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python, iPython, matplotlib, NumPy, SciPy, scikit-learn,Davitpy, and others.

Contact: magda14@vt.edu

Fall AGU