Analysis of the HamSCI Solar Eclipse High Frequency Time Difference of Arrival Experiment Observations Using Automated Techniques

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Abstract

The objective of our research is to analyze the effects of a solar eclipse on High Frequency (HF) radio by extracting the time difference of arrival (TDOA) due to multiple ionospheric paths of ~3 kHz bandwidth chirp signals sent and received with unmodified commercial off-the-shelf (COTS) single sideband (SSB) amateur radio transceivers. We use programming techniques learned in the Digital Signal Processing course at The University of Scranton in the Python language to automate this process. On the day of the 14 October 2023 eclipse in Texas, WA5FRF transmitted a series of chirps every 15 minutes to receiving stations N5DUP and AB5YO on the 5.3 and 7.2 MHz amateur radio bands. Received signals were digitized, then squared and low-pass filtered to detect the waveform envelope. Correlation with a matched signal is then used to identify the start time of each chirp, after which a Fast Fourier Transform (FFT) is used to identify the beat-frequency (and TDOA value) generated by the multipath propagation. This TDOA value is then used to compute an ionospheric reflection height. On the WA5FRF-N5DUP path, this analysis shows that the F region reflection point raised from 262.5 km at 17:00 UTC to 300 km at eclipse maximum at 17:30 UTC and then returned to approximately 280 km at 18:00 UTC. This result is in good agreement with the hmF2 observations of the Austin ionosonde.

Introduction

- During a solar eclipse, the ionosphere loses solar radiation thereby affecting its layer height.
- Taking advantage of amateur radios allows us to measure the actual layer height of the F2 region.
- The standard amateur SSB mode allows us to facilitate the transmission of audio waveforms which are short audio pulses, audio chirps, and analog pseudorandom code sequences and then process these waveforms in .wav files. These files are data sets taken from two ground distances for approximately every fifteen minutes during the eclipse.

Fig 1a. Raw .wav file taken at 1215 UTC for the AB5YO ground distance

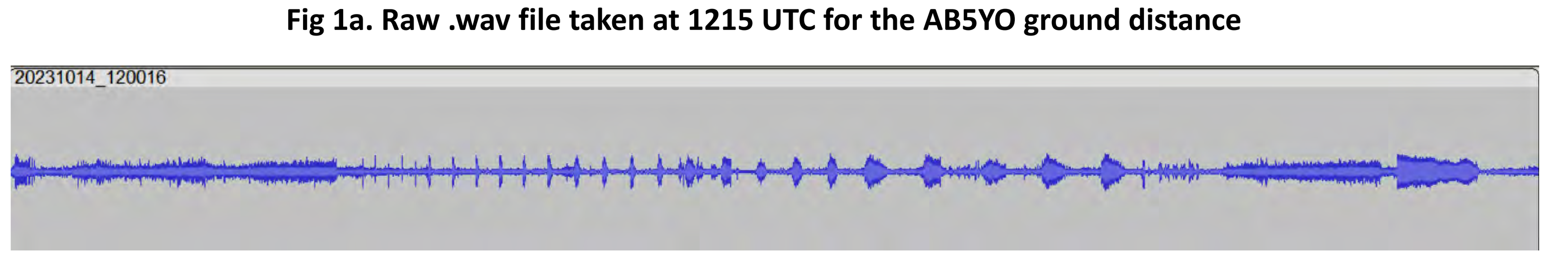

Fig 1b. Raw .wav file taken at 1200 UTC for the N5DUP ground distance

- Figure 1a-b above represents the time domain representations for the two ground distances. In these raw signals, the pseudorandom noise burst is seen first, followed by the 5 repetitive chirps, each having a different sweep rate.

Method/Experiment

- The analysis of the .wav files accomplished through DSP algorithms in python, in which the incoming signals were squared, enveloped, and zero averaged in the "**Processing**" function.
- Following this processing, we needed to **correlate** the .wav files with a given refined .wav file that assist us in determining repeating patterns seen between the chirps in the "**Find Starting Points**" function.

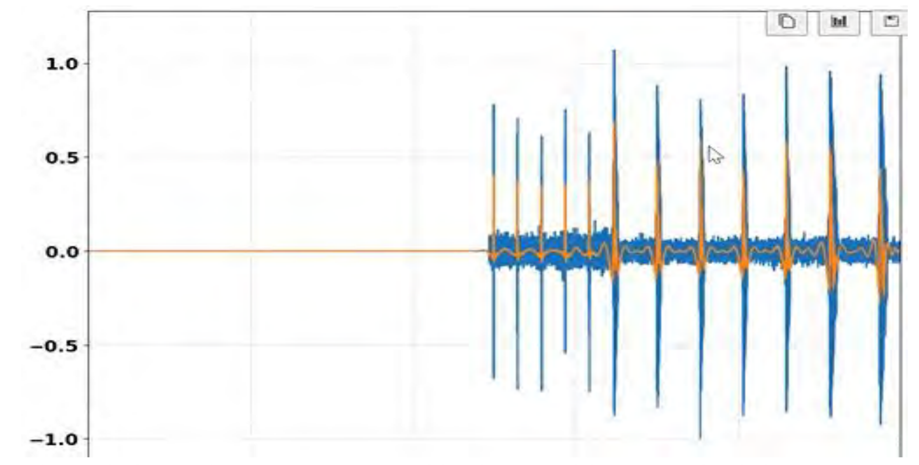

Fig. 2 The correlated result from the given tx3.wav file that enables us to find the starting point of each chirp

- The Fast Fourier Transform of each .wav file was then computed to return a maximum value called the "Beat Note Frequency". This maximum value is then computed with various implemented **for** loops to process each set of chirps (0-5), (6-10), etc. in the **"Find Beat Notes"** method. The ground distances AB5YO and N5DUP were sorted in their respective data sets and the proper range gating was applied to compute the maximum frequency observed.
- The "**Post Processing**" function accepted the above data to compute the respective **TDOA** values by dividing each set of chirps (5 per set) by their respective Sweep rate values (specifically 50, 25, and 10 Hz). We then plotted the average value seen for the different sweep rates across the time frame for the 14 October,2023 Solar Eclipse.

Data and Analysis

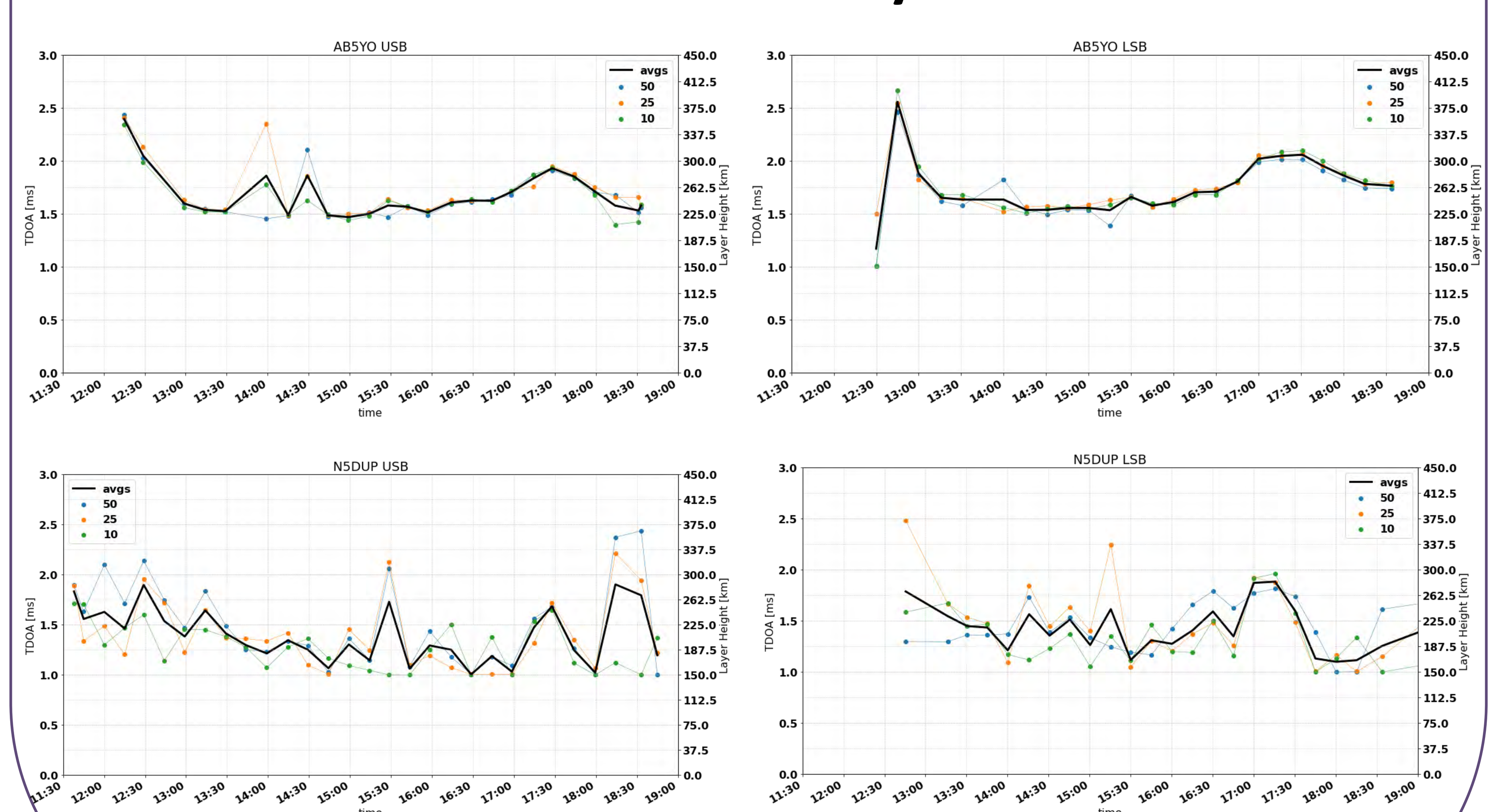

Fig 3. Resulting graphs for both pairs (N5DUP & AB5YO) for both 5.3 MHz and 7.2 MHz across the 50, 25, and 10 Hz/ms sweep rates

- The resulting graphs as seen in Fig. 3 coincide with the results gathered from the October 14,2023 Austin Ionosonde.
- There are significant consistencies for both ground distances around the 17:00 UTC time, with there being a bump in layer height for both N5DUP and AB5YO with a maximum bump at 17:45 UTC.
- Data acquired from autocorrelation analysis by K1FR from eclipse day for the Austin Ionosonde consist with the layer height analysis computed in this experiment, with the maximum layer height around 17:00 UTC matching approximately x ≈ 300 km for both the 40m and 60m bands.

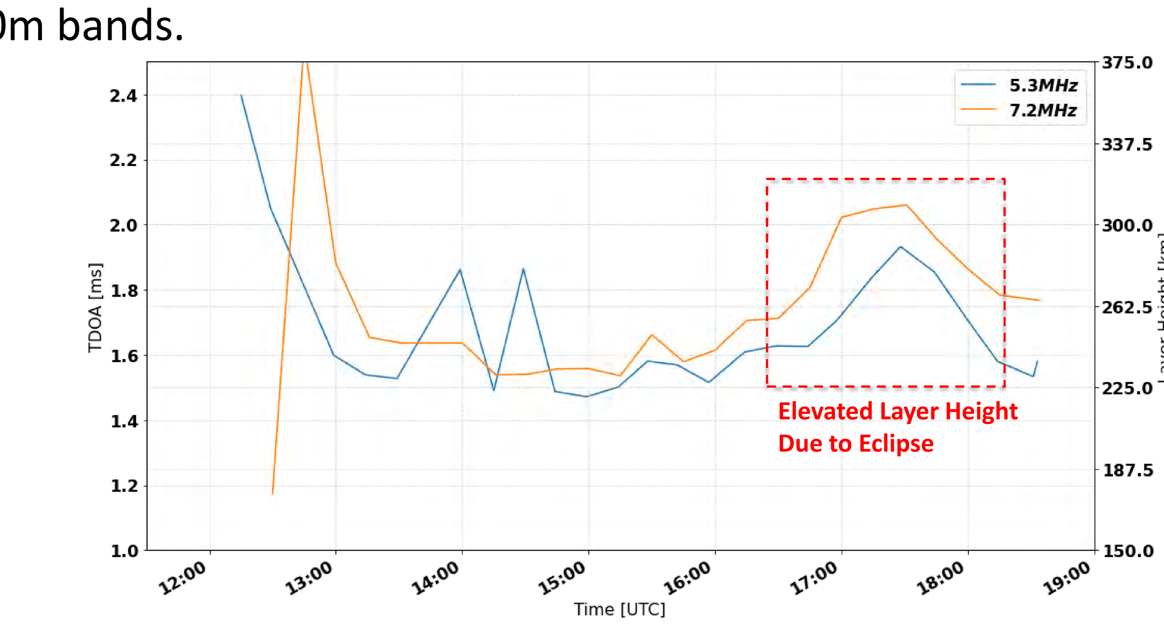

Fig 4. 5.3 and 7.3 MHz bands with their equivalent Layer Height. At 17:45 UTC the eclipse was at maximum annularity in Texas and the bumps correlate perfectly with the known times for the Austin ionosonde

Conclusion

- Digital signal processing analysis techniques have allowed us to compute results in layer height and TDOA values that correlate to values from the hmF2 Austin ionosonde.
- We initially considered the 1500 and 100 Hz/ms sweep rates for the averaging analysis seen in Fig. A, however due to the nature of radio technology, the audio filters may have difficulty with the fast sweep rates. We saw drastic averaging improvements when we considered the 50, 25, and 10 Hz/ms sweep rates.
- N5DUP had significant discrepancies in comparison to AB5YO specifically for the 50 Hz/ms sweep rate.
- Regarding future work, we would like to apply these signal processing techniques to other forms of solar disturbances such as solar flares to view the effects in the F region. We would also like to use this program for the 8 April 2024 solar eclipse specifically on the lower sweep rates to avoid inconsistencies

References

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Acknowledgements

This work is supported by NASA Grant 80NSSC23K1322 and NSF Grants AGS-2045755 and AGS-2230345

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HamSCI Workshop 2024