Pulse Shaping for Advanced Time Of Arrival Analysis at HAARP

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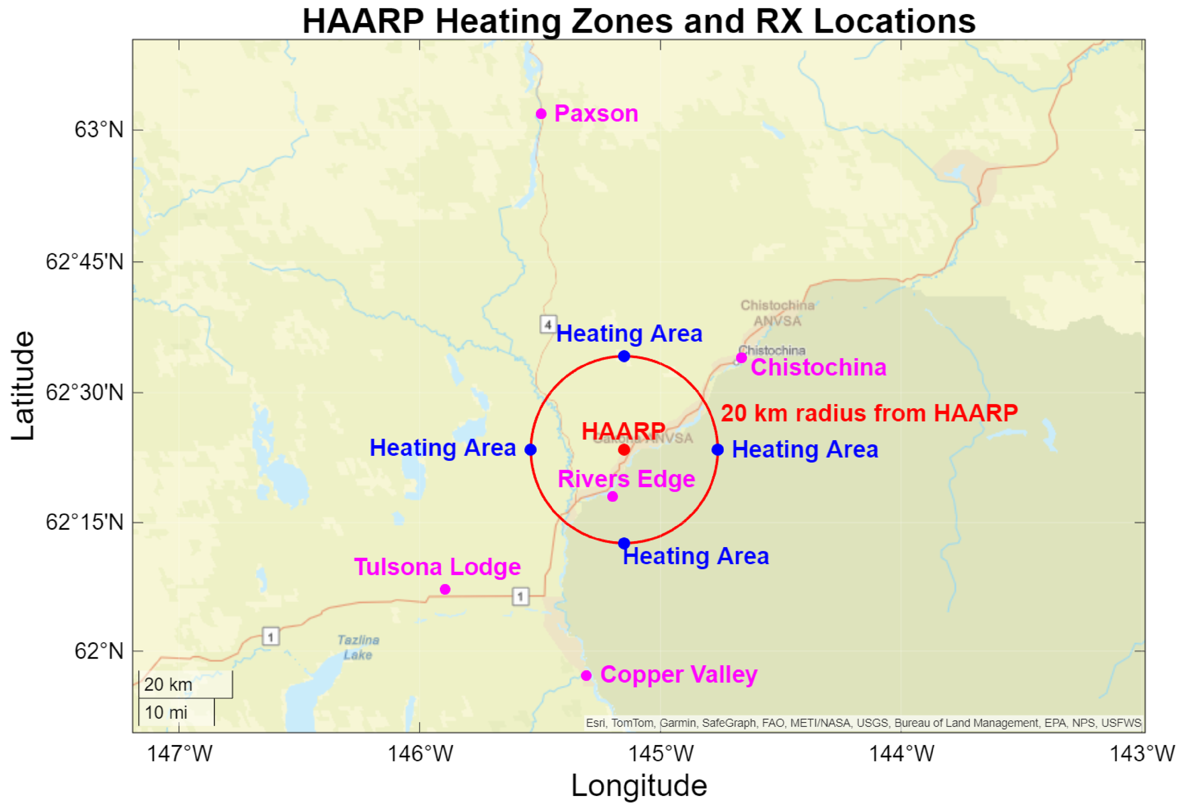
Introduction

- The High Frequency Active Auroral Research Project (HAARP) is an HF transmitter capable of modifying the conductivity of the ionospheric plasma via heating
- Electrical currents in the upper atmosphere (the electrojet, Pedersen and Hall currents) are produced by the interaction between solar wind and the geomagnetic field, and modulated by HAARP heating to produce a secondary radio wave at very low frequencies (<15kHz)
- Time of Arrival (TOA) is an established method of extracting subsequent radar returns or echoes of a chirp signal in a multipath environment ; here TOA methods are used to separate the effects of the electrojet current from those of the ionosphere on the received signal components
- TOA is accompanied by super-resolution curve fitting, least squares in this case, to determine timing differences beyond that of the signal bandwidth
- This work explores the use of pulse shaping to enhance the quality of data obtained from these methods in the presence of uncontrollable variables : Electrojet Strength, Shear wing at heating altitude, and environmental changes over the course of the experiment

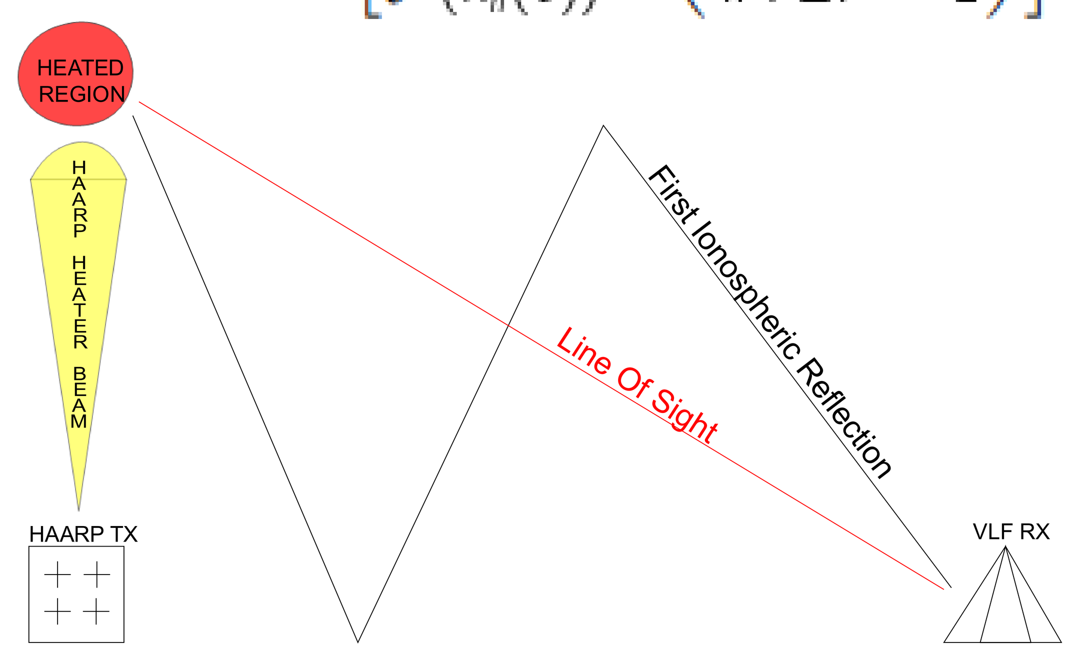
Data Collection and Experiment Design

- A set of VLF receivers (Purple) each comprised of two orthogonal channels of air-core magnetic loops.
- Heating Locations (Blue) approximately 75km in beam-waist at the D-Region altitudes .

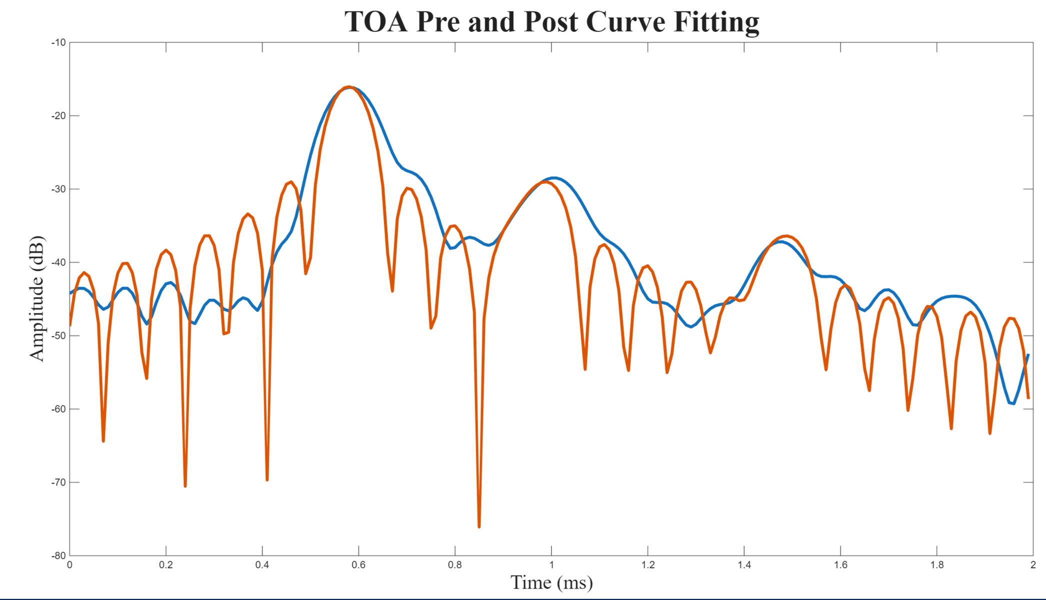


Time of Arrival Analysis

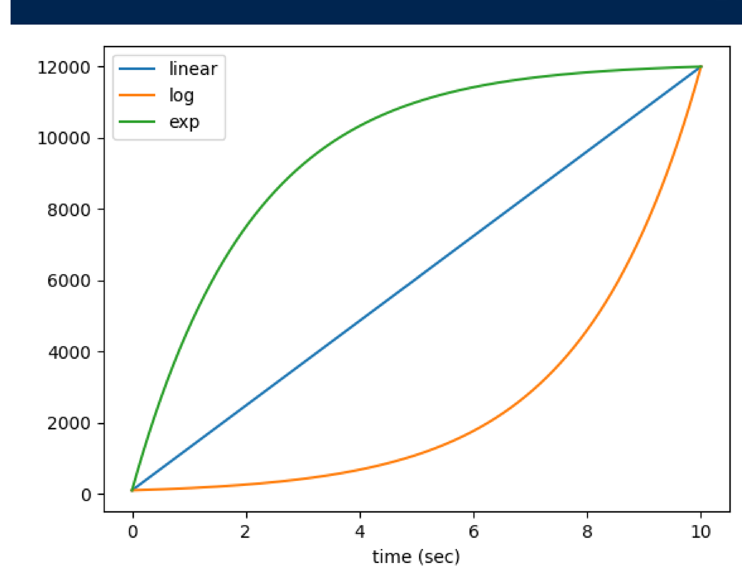
$$h_n(t) = \mathcal{F}^{-1}\left[\frac{\mathcal{F}(y_n(t))}{\mathcal{F}(x_n(t))}\sqcap\left(\frac{f-nf_0}{nT\Delta f}-\frac{1}{2}\right)\right]$$



Time of Arrival uses the ratio of the Fourier Transform of the received signal to that of the known transmitted chirp, windowed about its bandwidth . Then, given that the transmitter and receiver have absolute timing the delay can be assessed for each subsequent echo. This technique is limited by the bandwidth of the chirp, the sample rate of the receiver, and the SNR of the received wave. The goal of this experiment is to maximize both bandwidth and SNR across the chirp . The result of a perfect TOA analysis is a sum of sinc-convolved Dirac deltas. Knowing this we can curve fit to extract the pulse data with greater resolution than would be possible based on the bandwidth .



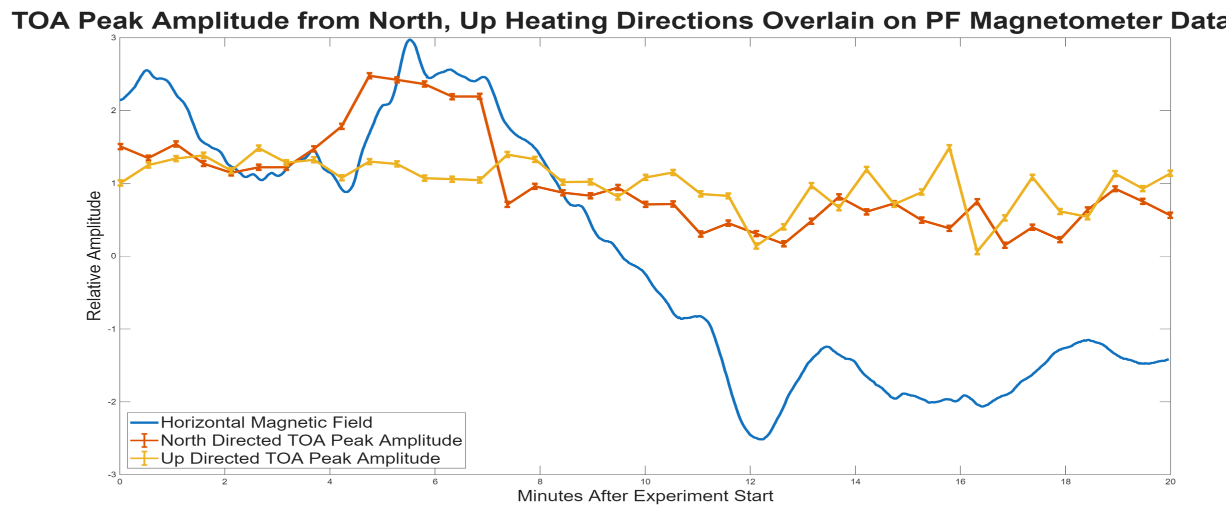
Pulse Shapes



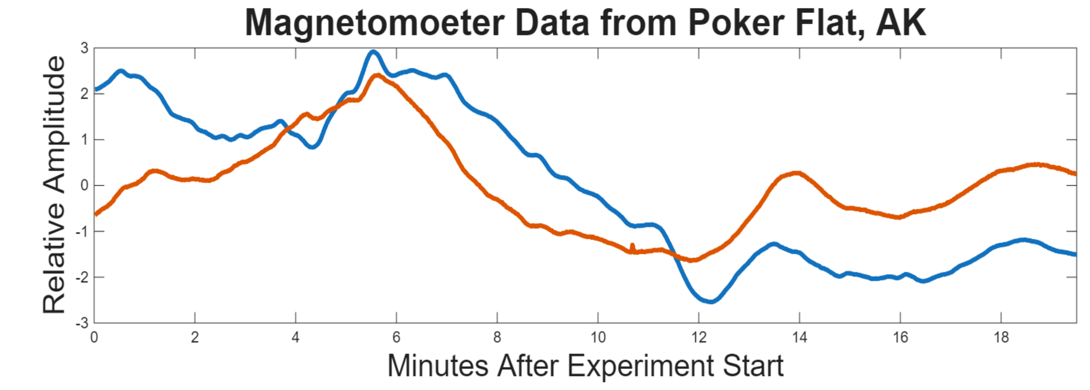
Three pulse shapes were chosen, each with the same band-width . Linear is the standard, logarithmic spends the most time at high SNR frequencies, and exponential has the most integrated power in the low SNR bands

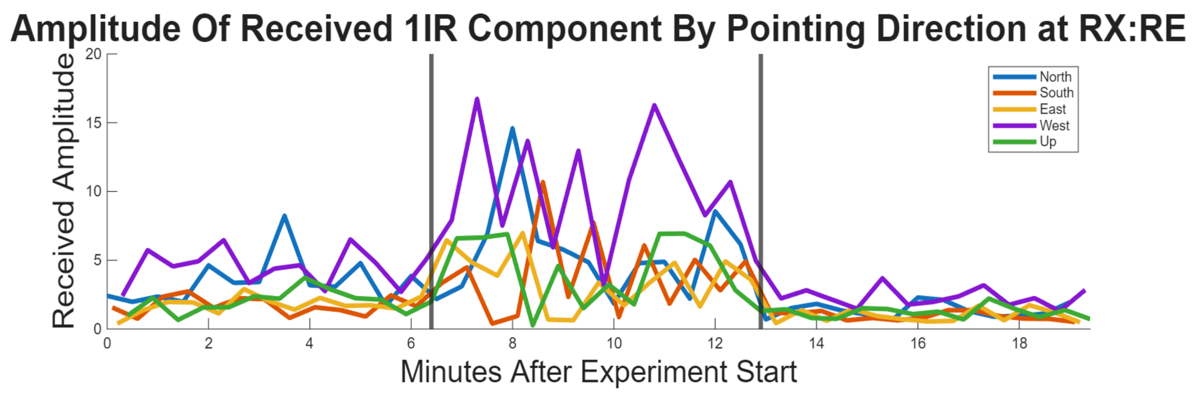
Line of Sight

The line of sight (LOS) component of the signal has been shown to correlate highly with the magnetometer readings over an area, [4]. This correlation means the LOS component is a diagnostic tool that can measure changes in total electrojet above an area with respect to a starting value .



First Ionospheric Reflection

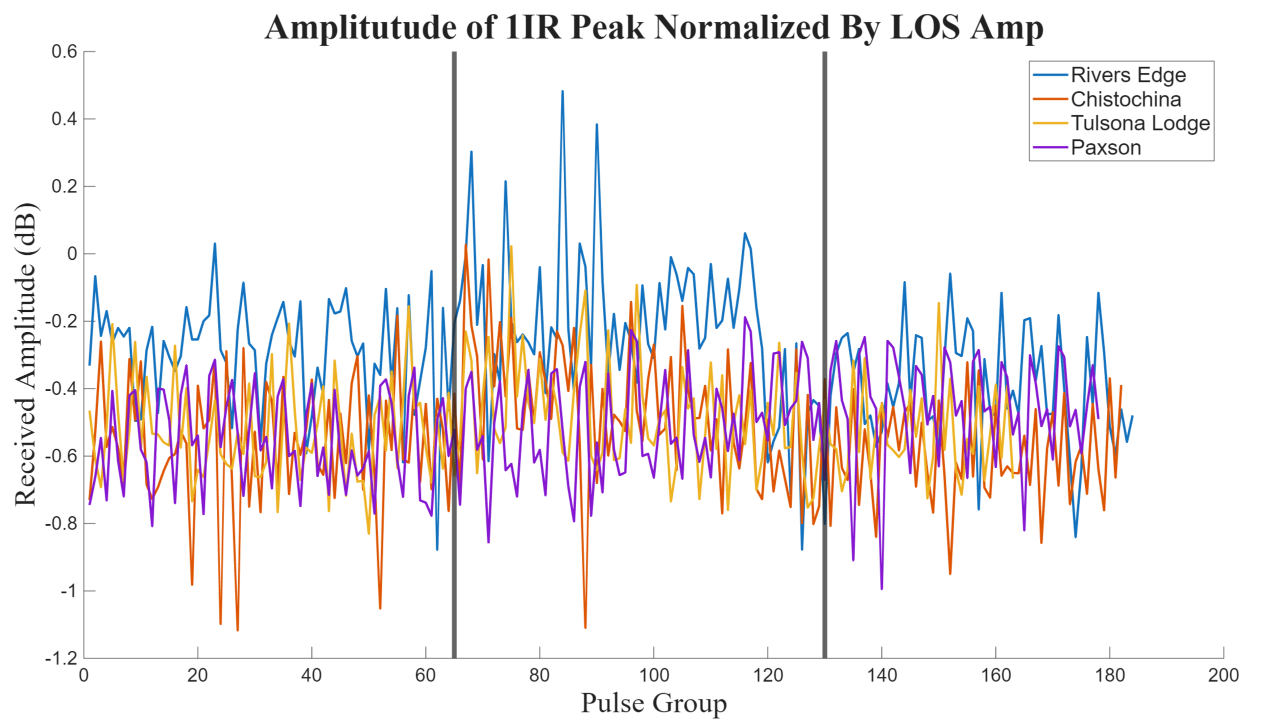




The first ionospheric reflection (1IR) is not correlated to electrojet strength. The height, conductivity, and distance to the transmitter play a much larger role in the amplitude of the 1IR. Given a fixed location receiver and transmitter, ionospheric changes could be mapped by tracking changes in average 1IR amplitude over time. This is the near field corollary to the modal method of ionospheric remote sensing as seen in [2]. The exponential chirps exhibit both higher amplitude on average as well as higher variability . This suggests that exponential chirps could provide higher specificity or could be more susceptible to measurement noise. Further experimentation is needed.

Contact, Résumé, and Other Work:

Spatial Variations



The traces in the above figure are arranged in ascending order of distance from the transmitter . The pulse shapes clearly influence the received peak amplitudes, but it is notable that the enhancement in received amplitude seems to have range limitations . This means that one of the best use cases is for near transmitter ionospheric sounding . Another use of linear time-ramp chirps is in ducting studies. The figure above also includes all pointing directions for each pulse type as it is only separated by receiver, meaning that much of the variation visible in the data is not simply noise but also induced by the experiment design. In a future study the pointing direction will be swept linearly toward and away from a receiver to help understand the roll-off seen with increasing distance .

Future Work

The work done to this point clearly shows that the pulse shape has some effect on the data extracted from TOA analysis. The next steps are to redesign the experiment with fewer dependent variables, limit the ambiguity induced by electrojet changes, and have a higher density of sensing instruments . All of these steps will provide statistically significant numbers of iterations from which relations between dependent variables can be derived and caried forward to broader applications in D-Region atmospheric sensing .

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References : [1] R. C. Moore, “ELF/VLF WAVE GENERATION BY MODULATED HF HEATING OF THE AURORAL ELECTROJET”.
[2] H. C. Burch, “ON THE ROLE OF WAVEGUIDE POLARIZATION IN VLF REMOTE SENSING OF THE LOWER IONOSPHERE”.
[3] S. Fujimaru , “TIME-OF-ARRIVAL ANALYSIS APPLIED TO THE SPATIALLY DISTRIBUTED ELF/VLF SOURCE REGION ABOVE HAARP”.
[4] T, J. Lindley VLF Wave Generation via HF Heating as a Plasma Diagnostic at HAARP