High Temporal and Spatial Resolution Mapping of the Auaroral Electrojet via VLF Wave Generation at HAARP

AUBURN Samuel Ginn College of Engineering

Taylor Lindley, Dr. Hunter Burch, Ben Smith – Auburn University

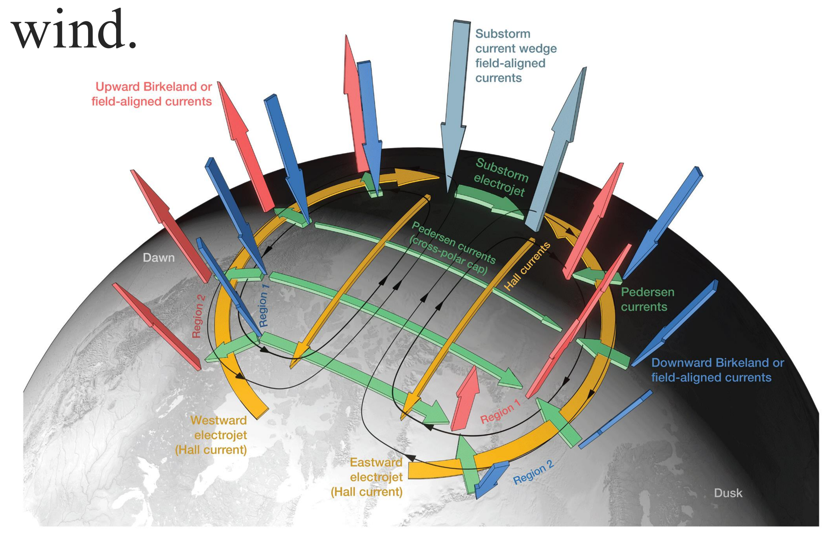
Dr. Rob Moore – University of Florida

Abstract

Historically, the auroral electrojet has been mapped using chains of flux gate magnetometers. This method has been useful for monitoring auroral activity; however, the resulting current density maps have low spatial resolution, on the order of, at best 100s of kilometers latitudinally. In this work we attempt to use time of arrival (TOA) analysis [3] to spatially map relative current densities of the lower D region via VLF wave generation at the High Frequency Active Auroral Research Program (HAARP) heating facility in Gakona, Alaska.

Background

The ionosphere contains naturally occurring electrical currents (electrojets) resulting from the interaction between the earths magnetosphere and solar wind.



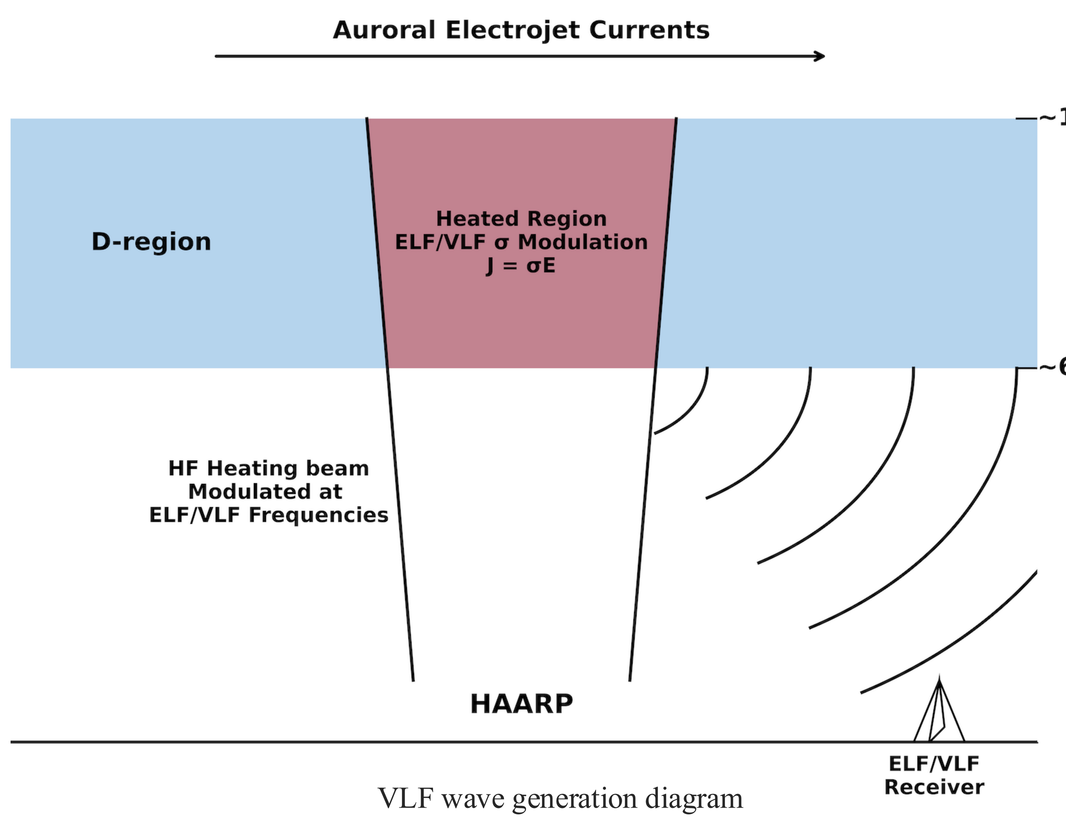
Electrojet Current Systems - Source: Palmroth et al. (2021)

Previous work [1] has determined the orientation of the electrojet using VLF wave generation. Magnetometers have also been used to create large scale maps electrojet map. These methods provide valuable insight into the electrojet; however, they lack the ability to resolve small scale structures. Additionally, there is a general lack of D-region data available for model creation

Experiment Design

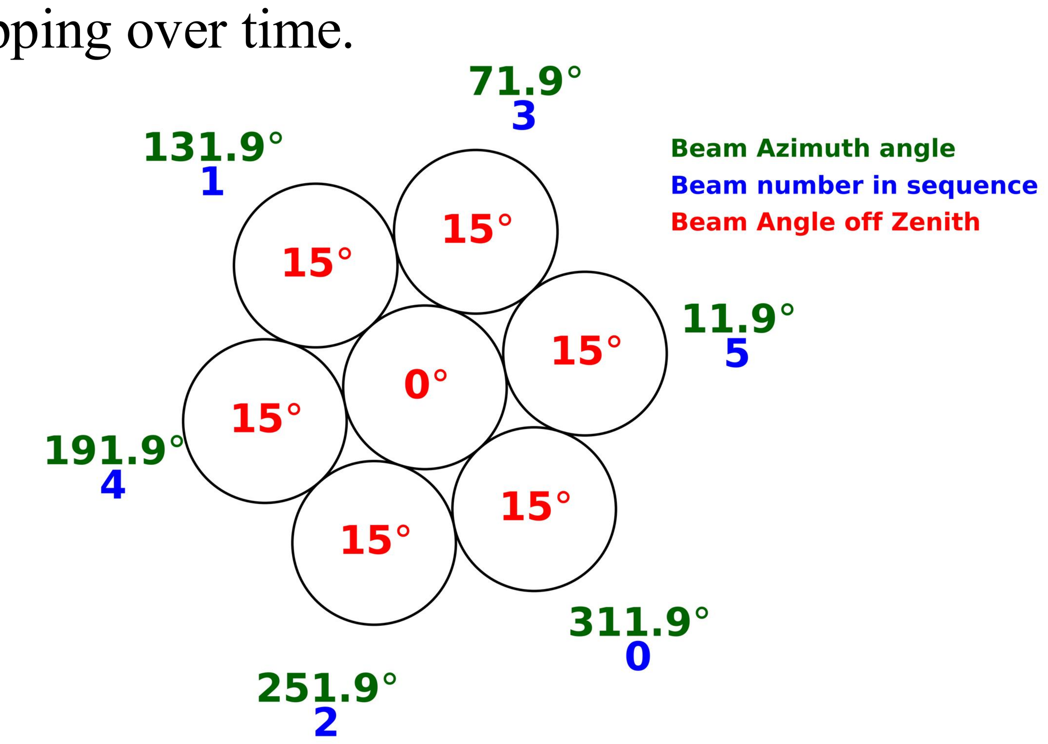
The 3.6 MW HF transmitter array at HAARP can be used to generate VLF waves via amplitude modulated HF heating of the electrojet current in the D-region ionosphere

Experiment Design Continued



VLF wave generation diagram

By repeatedly steering the HF beam to a sequence of locations, observation of the generated VLF amplitudes should enable source region current mapping over time.



Beam Pointing Locations

By using LFM pulses (1–10 kHz over 6s), time-of-arrival analysis can be used to separate the line-of-sight (LOS) and ionospherically reflected components of the signal [3]. This should allow for multipath-independent source region measurements.

Data collection

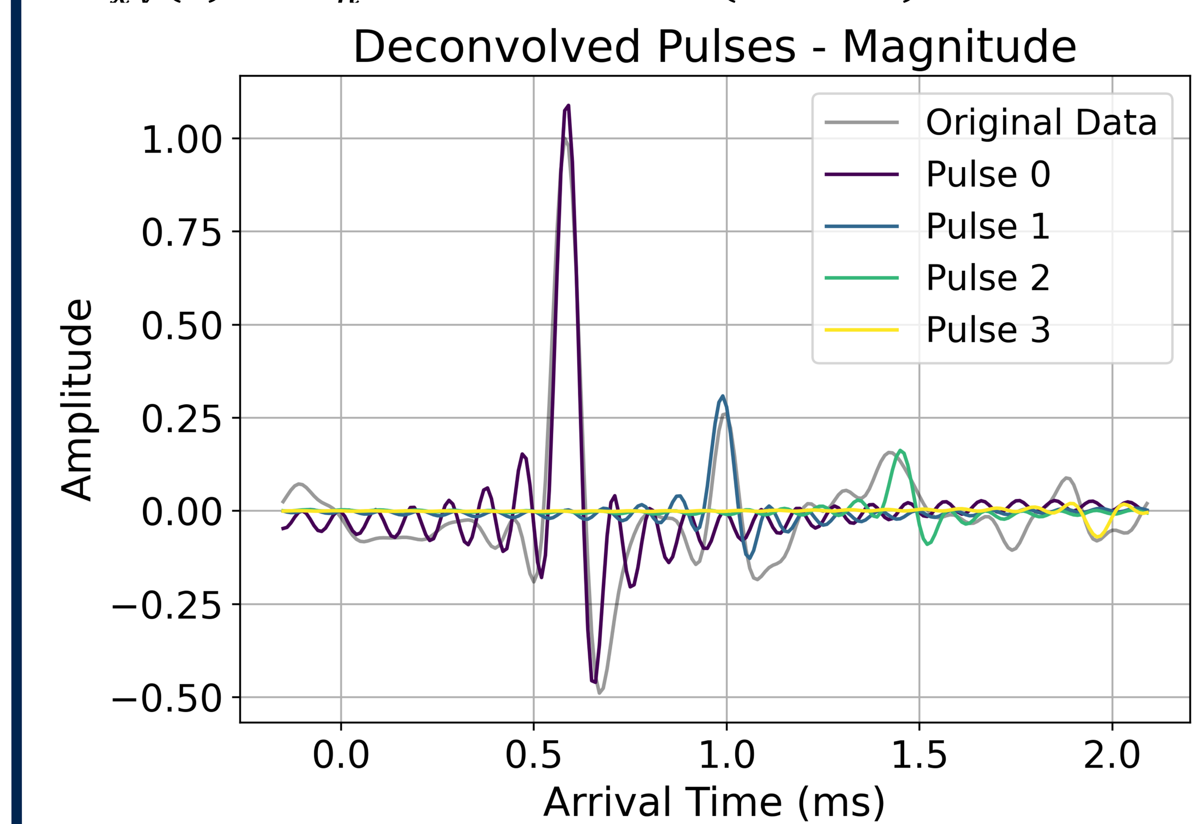
VLF data was collected using the University of Florida receiver located at Chistochina, roughly 36 km away. The data consists of magnetic field measurements from two orthogonal magnetic loop antennas oriented in the N/S and E/W directions, sampled at 100 kHz.

Signal Processing

The processing uses classical radar pulse compression techniques. LFM pulse convolution (with multiple returns) produces complex sinc functions that overlap in time.
Deconvolution via least squares fitting to an analytical sinc model (eqn 1.1) separates these overlapping signals, extracting individual phase, amplitude, and arrival time for each return pulse.

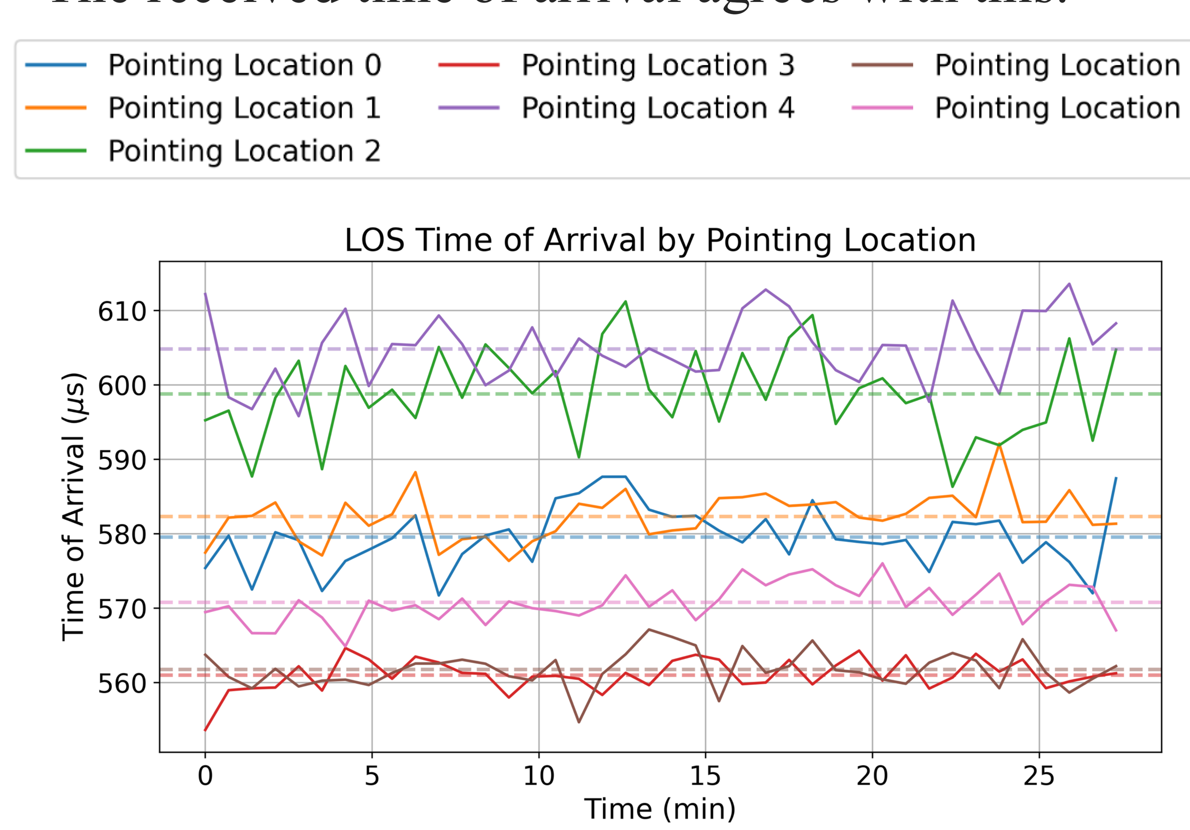
$$x(t) = e^{j2\pi n\left(f_0 t + \frac{mt^2}{2}\right)} \sqcap (t/T - 1/2) \tag{1.0}$$

$$R_{xv}(\tau) = A_n e^{j\phi_n} e^{j2\pi f_c \tau} \mathrm{sinc}(n\Delta T m\tau) n\Delta T m \tag{1.1}$$



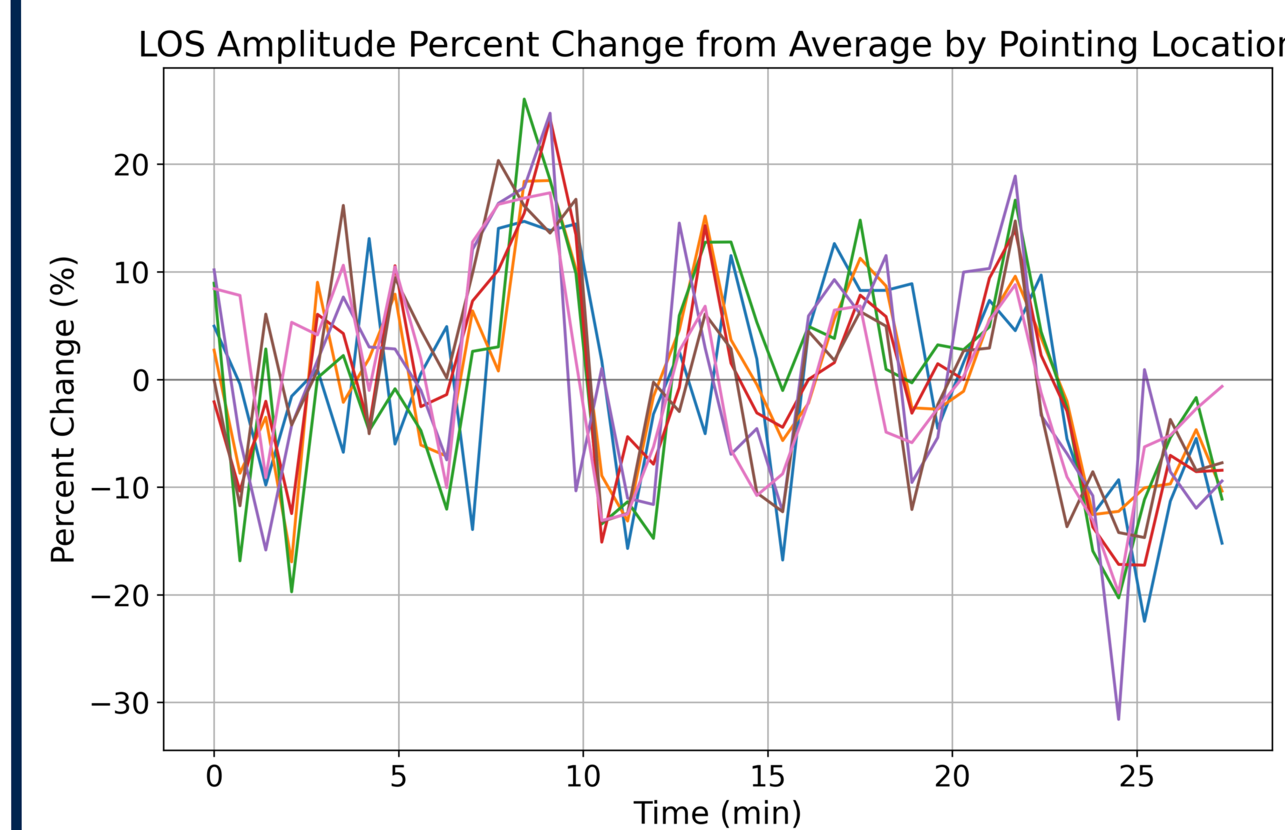
Results

The expected time of arrival, including HF propagation from the array to the source region, of the LOS component for beam location 2 is 588µs. The received time of arrival agrees with this.



Results Continued

Similarly, the LOS component amplitude can be plotted vs. pointing location to determine differences across the source regions. When plotted as a percent change from average, the plots show a common trend with deviations between source region locations. This suggests the presence of small scale electrojet structures.



Future Work

The time scale of the measurements are necessarily large due to the pulse compression techniques used. Future experiments could vary the time scale and pointing sequence to increase spatial or temporal resolution. The addition of multiple receivers at varying distances would also allow for verification through comparison of expected arrival times. Investigation into polarization effects may also yield valuable insights into source region characteristics

References

[1] Cohen, M. B., Golkowski, M., & Inan, U. S. (n.d.). Orientation of the haarp ELF ionospheric dipole and the auroral electrojet. Geophysical Research Letters 35 (2). doi: https://doi.org/10.1029/2007GL03242

[2] Cohen, M. B., & Golkowski, M. (2013). 100 days of elf/vlf generation via hf heating with haarp. Journal of Geophysical Research: Space Physics, 118 (10), 65976607. doi: https://doi.org/10.1002/jgra.50558

[3] Fujimaru, S. (2011). Time-of-arrival analysis applied to the spatially distributed elf/vlf source region above haarp (Doctoral dissertation)

Acknowledgments

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