Mapping the Fine Structure of the Auroral Electrojet via VLF Generation at HAARP

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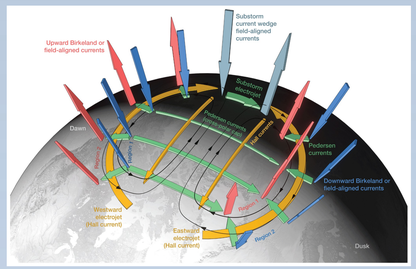
Abstract

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, single degrees (110 km) latitudinally. In this work we attempt to create a new method to spatially map relative current densities of the lower D region by performing VLF wave generation at the High Frequency Active Auroral Research Program (HAARP) heating facility in a cyclic spatial pattern of approximately 20km diameter spots. The findings and implications of this mapping technique are discussed along with plans for future work.

Introduction

The ionosphere contains naturally occurring electrical currents (electrojets) resulting from the interaction between the earths magnetosphere and solar wind. Understanding the structure of the electrojet could provide useful metrics to better understand various space phenomenon.



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 of the electrojet. These methods provide valuable insight into the electrojet structure; however, they lack the ability to resolve small scale structures.

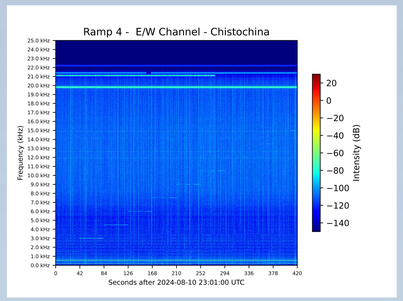
Experiment Design

The 3.6 MW HF transmitter array at HAARP can be used to generate VLF waves via amplitude-modulated HF heating of the electrojet currents. By steering the modulated beam to a series of locations in a cyclic pattern, the generated VLF waves should enable relative electrojet strength measurements. The transmission parameters were based on a comprehensive study of HAARP [2].

Transmission Parameters
- 2.75 MHz
- Square (100% depth) AM modulation
- Modulation frequency ranged from 1.5kHz to 15kHz in 1.5kHz steps
- Narrow beam configuration
- X mode

HAARP HF transmitter array (Source: Jessica Matthews)

Each pointing sequence at a given modulation frequency lasts 42 seconds. This can be seen as a stair step in the spectrogram below.

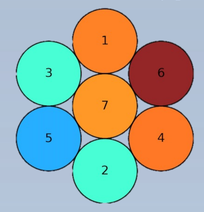


Experiment profile: spectrogram view

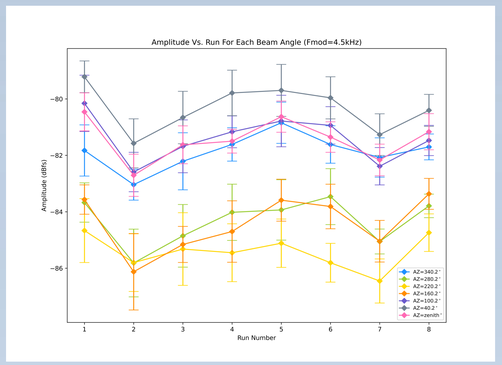
VLF data was collected using the University of Florida receiver located at Chistochina, roughly 36 km away. The data consists of magnetic field measurements from two orthogonal magnetic loop antennas oriented in the N/S and E/W directions. This data is sampled at 100 kHz, resulting in 50 kHz after Nyquist sampling.

Analysis and Results

The time-series VLF data was first processed to remove lightning sferics. With a 1 HZ bandwidth around the modulation frequency, the data was integrated over the six second dwell time of each beam. The resulting amplitude should now represent the strength of the electrojet in the source region. Below is an example of the received amplitude at a single modulation frequency. The effects of pointing the beam towards or away from the receiver can be clearly seen as an increased amplitude when the beam is pointed towards the receiver (spot 6).



By observing relative changes in VLF amplitude for a single beam location over multiple experiment runs (7 minutes apart) for a given frequency, changes in the source region current strength can be detected. In the figure below, deviations from the overall trend seem to indicate small-scale structures across the source regions.



Amplitude Vs. Experiment Run

- Large deviations in amplitude resulting from beam pointing effects
- Only able to create relative measurements due to pointing
- Data is usable but low SNR limits the resolution of relative measurements

Discussion

This method of observing relative changes in the VLF amplitude, as described earlier, confirms the existence of small-scale electrojet structures. The VLF generation amplitudes during the experiment run were relatively low compared to what is possible at HAARP. If ionospheric conditions had been more favorable for VLF generation, this method could have yielded higher-resolution data because of the increased SNR of the VLF data.

- Confirmed existence of small scale electrojet structures
- Ionospheric conditions have a large effect on the resolution of electrojet current measurements

Future Work

To better account for pointing effects, frequency time ramps could be used rather than a continuous VLF wave generation. This would allow for more accurate characterization of the source region by separating ionospherically-reflected and direct signal paths. This would eliminate some of the dependency on receiver location and modulation frequency [3].

Additionally, a VLF phased array could be used as a method to perform differential source region measurements.

- Frequency time ramps for time of arrival analysis
- VLF phased array to make differential source region measurements

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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