

# ELF/VLF WAVE-INJECTION INTO THE MAGNETOSPHERE VIA MODULATED HF HEATING OF THE IONOSPHERE

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## ABSTRACT

ELF/VLF wave-injection studies, using signals injected by ground-based VLF transmitters, in particular the Siple Station facility (closed since 1988) in Antarctica, has proven to be a highly effective means of probing the mechanisms and effects of magnetospheric wave-particle interactions. While the Siple Station VLF transmitter utilized long horizontal antennas on thick ice sheet to radiate waves in the range 2 to 6 kHz, another effective means of generation of such signals is modulated HF heating of the ionosphere in the presence of auroral electrojet currents. The relatively new establishment of the HAARP HF Heater, located on closed field lines (most of the time) presents a new opportunity to probe the magnetosphere via injection of ELF/VLF waves. If such a capability is realized, magnetospheric probing can be conducted from the ground at frequencies of a few tens of Hz (ULF/VLF) up to few kHz (VLF).

## ELF/VLF WAVE-INJECTION USING THE HAARP FACILITY

Modulated heating of the lower ionosphere in the presence of an auroral electrojet has long been successfully used to generate ELF/VLF waves. At present, a number of HF ionospheric heating facilities continue to be used around the world for ELF/VLF generation. Of these, the High-frequency Active Auroral Research Program (HAARP) facility in Gakona, Alaska is uniquely located at sub-auroral latitudes ( $L \sim 4.9$ ), lying in the immediate vicinity of the plasmapause, and on closed field lines, at least most of the time. As such, ELF/VLF wave-injection with HAARP should in principle be usable to probe the magnetosphere, and cyclotron resonant wave amplification and emission triggering processes, much in the same manner as the Siple Station ( $L \sim 4.2$ ) ELF/VLF wave-injection experiments. Recent ground-based observations in Alaska have shown that ELF/VLF signals are robustly produced by HAARP, in spite of the sub-auroral location of the facility. Although the ELF/VLF signal levels generated by the current HAARP facility ( $\sim 1$  MW total radiated power) are about an order of magnitude lower than the maximum signal levels produced by the Siple transmitter, stimulation of magnetospheric wave amplification and emission triggering should still be possible, based on Siple experiments conducted at reduced (as much as  $\sim 20$  dB) radiated power levels. Demonstration of the capability of magnetospheric probing with HAARP-induced ELF/VLF would facilitate a new range of wave-injection experiments, since modulated heating of the auroral electrojet can in principle be used to excite waves at frequencies ranging from tens of Hz to tens of kHz, as opposed to the 2-6 kHz range that feasible in Siple experiments. In terms of the practical conduct of ELF/VLF wave-injection experiments using the HAARP facility, an important limitation is the relative inaccessibility of the geomagnetically conjugate region, being located in the Southern Pacific ocean. However, based on successful observations of amplified two-hop (once reflected) signals (often with triggered emissions) in Siple experiments, and the well known multiply echoing nature of whistlers and VLF emissions, evidence for amplification of (and triggering by) HAARP-ELF/VLF signals can be searched for in the form of two-hop whistler-mode echoes. In this paper, we report on recent results of extensive ground-based observations aimed at detection of magnetospheric two-hop echoes of HAARP-induced ELF/VLF signals. Measurements have been conducted in two different campaigns (Fall 2001 and Spring 2002) at two different sites within  $\sim 100$  km of HAARP. ELF/VLF frequency-time patterns specifically designed for coherent amplification are used with duty cycles that would allow the easy identification of two-hop echoes when they are present. Very strong and well-defined ELF/VLF signals are often observed at both sites, and data analysis aimed at identification of two-hop echoes is currently underway. We also report on results of ELF/VLF observations on the CLUSTER satellites during their passes of the vicinity of the magnetic field lines which are expected to be illuminated by HAARP-ELF/VLF signals.