ELF/VLF Wave-injection and Magnetospheric Probing with HAARP

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Abstract

Located on closed sub-auroral field lines, the High-frequency Active Auroral Research Program (HAARP) heater in Gakona, Alaska is well positioned for conduct of ELF/VLF wave-injection experiments. With the completion of a major upgrade of the HAARP HF heating facility in 2007, campaigns are now carried out with data recorded at several sites in Alaska and in the conjugate hemisphere (on ships or Buoys). Initial results include observation of several episodes of one-hop and/or two-hop amplified whistler-mode signals/triggered emissions, initiated by constant frequency pulses and/or signals with other frequency-time shapes.

Summary

Wave-injection experiments with an HF heating facility such as HAARP, rather than with conventional ELF/VLF transmitters, presents several challenges and many opportunities. The interpretation of the highly complex magnetospheric response to injected ELF/VLF waves must be undertaken within the context of the complex physics of the generation of the waves as a result of modulated HF heating. When one-hop or two-hop whistler-mode signals and triggered emissions are observed, they are often quite intense and amplified (in cyclotron resonance interactions near the equatorial plane) and are thus easily observable. Since the timing of the transmissions are precisely known, the group time delay and dispersion (in the case of frequency-time ramps, for example) are accurately measured, so that the magnetospheric path of propagation (i.e., L-shell) and the equatorial electron density (and thus the resonant electron energy) can be determined. Important measurable also include the growth rate (in dB/s) and the total growth and saturation levels. Such determinations are crucially important in terms of theoretical models aimed at reproducing the observed exponential growth and saturation. The great advantage of a facility such as HAARP is the fact that waves at frequencies over the full range from ULF to ELF to VLF can be injected, although up to now conjugate region observations have not revealed any inter-hemispheric propagation at frequencies significantly below 1 kHz.

On the other hand, when magnetospherically amplified signals are not observed, it is generally not known whether the lack of a response is due to lack of generation (with HF modulated ionospheric currents) or due to lack of magnetospheric propagation paths or amplification conditions. Although the generated ELF/VLF signals are often easily observable at ground sites nearby (in the same hemisphere of HAARP and within several hundred km of it), it is not known whether such is an indication of effective injection of signals upward. In fact, recent simultaneous observations on DEMETER spacecraft and at Alaska ground sites indicate possibly an anti-correlation between injection upward and downward.

In this paper, we present results from recent ELF/VLF wave-injection experiments with the HAARP facility, including observations at distributed sites in Alaska, as well on ships and Buoys in the conjugate region.