Determination of Magnetospheric Propagation Paths of ELF/VLF Whistler-Mode Signals Excited by the HAARP HF Heater

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The HAARP HF heating facility is used to generate ELF/VLF waves for magnetospheric wave injection by modulating auroral electrojet currents. Recent observations of HAARP induced whistler-mode signals amplified by cyclotron-resonance interactions with radiation belt electrons include cases of wideband frequency-time 'ramps'. Ramps transmitted over a frequency range of 0.5-3.5 kHz yield observations of two-hop echoes in the northern hemisphere. The two-hop echoes result from whistler-mode propagation of HAARP signals to the conjugate hemisphere followed by reflection from the ionospheric boundary in the south and whistler-mode propagation back to the northern hemisphere of origin. The echoes have a frequency range of 1-3 kHz and exhibit multi-path propagation. The large frequency range of the ramp echoes as compared to single frequency tones allows for measurements of the wave dispersion resulting from propagation in the magnetospheric plasma. Whistler dispersion techniques are used to determine the L-shells and equatorial electron densities from the observations using the frequency dependent time delay of the signals. All magnetospheric paths of the two-hop echoes are located in the high density region inside the plasmapause. The dispersion results are combined with wave data from multiple ground stations in the vicinity of HAARP to estimate a simple model of HAARP induced whistler-mode wave injection and propagation. The two-hop echoes are observed primarily at Chistochina, Alaska, 35 km northeast of HAARP and Valdez, Alaska, 155 km south of HAARP. The signals are observed with low noise ELF/VLF receivers with air-core magnetic field antennas. Sampling is synchronized using GPS satellite clocks giving an inherent 200 nanosecond accuracy between sites.