Azimuth and Frequency Dependence of ELF/VLF Waves Generated at the HAARP Facility by Ionospheric Electrojet Modulation

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Modulated heating experiments at the High Frequency Active Auroral Research Program (HAARP) facility in Gakona, Alaska, for the purpose of extremely low frequency (ELF) and very low frequency (VLF) wave generation, have been successful under diverse ionospheric conditions. Here we analyze observations made at three different azimuths from the heating facility and at distances from 37 km to 99 km. The polarization and amplitude of the observed waves is analyzed as a function of modulation frequency and azimuth. It is found that waves radiated at azimuths northwest of the facility are generally lower and generated by a combination of modulated Hall and Pedersen currents, while waves observed at other azimuths are dominated by modulated Hall currents. At the same time, the polarization of the HF waves (X mode or O mode) has little effect on the ELF/VLF amplitudes other than a linear reduction of observed amplitudes for O mode heating. The ionospheric D region profile is known to have a significant effect on the amplitude of generated waves but is difficult to observe directly since it contains electron densities too low for standard HF radio sounding. Observed ELF/VLF amplitude peaks near multiples of 2 kHz are shown to result from vertical resonances in the Earth-ionosphere waveguide. The specific frequency of these resonances exhibits variations day to day and hour to hour. We show that the frequency of these resonances can be used to determine the D-region ionosphere electron density profile in the vicinity of the HF heater.