MULTI-HOP WHISTLER-MODE ELF/VLF SIGNALS AND TRIGGERED EMISSIONS EXCITED BY THE HAARP HF HEATER

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Modulated heating of the lower ionosphere with the HAARP HF heater in Alaska is used to excite 1-2 kHz signals, which are observed on a ship-borne receiver in the geomagnetic conjugate hemisphere after propagating as ducted whistler-mode signals. These so-called 1-hop echoes are believed to be amplified, and are accompanied by triggered emissions. Simultaneous observations near HAARP (~30 km) show 2-hop whistler-mode signals which travel back to the northern hemisphere upon reflection from the sharp lower ionospheric boundary in the south. Multiple reflected hops, up to tenth order (i.e., 10-hop) are detected, with the signal dispersing and evolving in shape, indicative of re-amplification and re-triggering of emissions during successive traversals of the geomagnetic equatorial interaction regions. Whistler-dispersion analysis methods were used to determine the L-shell of propagation of the ducted whistler-mode signals and the equatorial cold plasma density on the field line of propagation. The time delay (at each frequency over the range of observed frequencies of ~1 to ~2 kHz) between the time of origin of the original frequency-time ramp signal and the leading edge of the echo is measured and these data points are extrapolated to determine the 'nose' frequency $f_{\rm n}$ of minimum time delay and hence $f_{\rm Heq}$, the equatorial gyrofrequency along the field line, through the relation $f_{\rm n} \simeq 0.4 f_{\rm Heq}$, where $f_{\rm Heq}$ is the L-shell of propagation. The measured values are then used together with a diffusive equilibrium model of the cold plasma density distribution along the field line to infer the equatorial electron density $N_{\rm eq}$. This dispersion analysis revealed values of $L \simeq 4.9$ and $N_{\rm eq} \simeq 280$ cc, which are consistent with the empirical model of for the outer plasmasphere and with the results of previous wave-injection experiments carried out with the Siple Station VLF transmitter near 2 kHz. With the L-shell of propagation and the cold plasma density determined, the energy of the energetic electrons that would undergo first order cyclotron resonance interactions with the injected waves can be calculated in a straightforward manner. Analysis indicates that the relatively high-pitch-angle electrons which drive the gyroresonance instability and that the therefore likely to be involved in the amplification of the injected waves and the triggering of emissions have energies on the order of a few tens of keV. On the other hand, the energy of gyroresonant electrons in the vicinity of the loss-cone, which would be expected to be pitch angle scattered and precipitated by these waves, is estimated to only be a few keV.

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2. H - Waves in Plasma
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5. No special instructions