Artificial E-region field-aligned plasma density irregularities

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A hallmark of ionospheric modification experiments is the generation of field-aligned plasma density irregularities, sometimes termed "artificial" irregularities or AFAIs. The irregularities are generated by thermal parametric instabilities and, having entered nonlinear stages of development, by resonance instability. Thermal parametric instability involves the mode conversion of an electromagnetic O-mode pump wave into an electrostatic mode (upper hybrid waves primarily) in the presence of zero-frequency field-aligned plasma density irregularities (purely-growing modes) that grow in amplitude under the action of differential wave heating and thermal feedback. Wave trapping can ultimately occur, leading to resonance instability. Whereas the latter can be sustained with very low pump-mode amplitudes, the former only occurs when the pump mode amplitude exceeds a threshold. That threshold can be calculated precisely.

Most research has concentrated on F-region AFAIs, although irregularities can be generated in the E region by pump waves with sufficiently low frequencies during the daytime or in the presence of sporadic E layers. The relatively absence of variability in the daytime, quiet-time E region combined with the relative insensitivity of E region heating experiments to wave propagation effects make E region AFAI observations exceptionally consistent from event to event, day to day.

Coherent scatter from E-region AFAIs generated by HAARP have been observed using a 30 MHz radar imager located in Homer, Alaska. Observations permit accurate estimates of the threshold pump power for irregularity generation as well as the changes in threshold due to simultaneous X-mode heating at HAARP. As the E region critical frequency is just above the second electron gyroharmonic frequency ($2\Omega_e$), the effects of heating at the double resonance frequency (where the pump and upper-hybrid frequencies equal $2\Omega_e$) can readily be assessed. We have found that wave trapping occurs above and below the double resonance frequency and that irregularities are slightly suppressed precisely at this frequency, probably associated with coupling to electron Bernstein waves. An important role for waves with finite parallel wavenumbers is suggested by both findings.

While the horizontal structure of irregularities in the heated volume is often unremarkable, it is sometimes highly structured, mainly during geomagnetically active periods. The structuring seems to be indicative of natural aeronomic processes which can be investigated using ionospheric heating as a diagnostic tool. The threshold condition for AFAI generation is also a diagnostic tool, being sensitive to electron temperature, path-integrated absorption, and other ionospheric parameters.