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Spatiotemporal dynamics of HF-induced ionospheric turbulence revealed by diagnostic stimulated electromagnetic emission and test radio waves at HAARP

Investigation of the HF-pumped ionosphere using diagnostic electromagnetic emission (DSEE) generated by short-pulse test waves at frequencies shifted from the quasi-continuous pump wave were performed for the first time at the SURA heating facility [1, 2]. This report presents the results of similar experiments at the HAARP heating facility in March 2011. During these experiments, the transmitting schedule comprised several duty cycles as follows. For initial 30 s, the primary pump wave with the effective radiated power (ERP) Pef =400 MW was transmitted vertically at f0=5450 kHz in the low-duty diagnostic (D) regime, i.e., the pulse width τD=20 ms and the interpulse period TD=1 s. Next 60 s, the pumping continued in the high-duty quasi-continuous regime (QCP, with τQ=70 ms and TQ=100 ms). After that the pump wave was switched back to the D-rejime for 210 s. Concurrently, during all 300 s, the secondary pump wave at fD=f0–δf with the same ERP was radiated in D regime. Then both pump waves were switched off and switched on back in 60 s, but with exchanged primary and secondary pump wave frequencies (fD= 5450 kHz, f0=fD– δf). Then the sequence was repeated with δf increased by 200 kHz.

Overall, we successively used the frequency offsets δf=200, 400, 600, 800 and 1000 kHz. At δf=1000 kHz, the difference between the primary and secondary pump wave reflection altitudes was 30 km (205 km for f0,D=5450 kHz, 175 km for f0,D=4450 kHz). In addition, very short (τS=100 μs) pulses at the same carrier frequencies fS =f0 and fD were injected with the interpulse period TS=100 ms and a delay 90 ms for sounding (S) the pumped region. Due to the delay, during the QCP the S-pulses were transmitted within 30 ms pauses. The S-pulses created a wide spectrum of diagnostic waves (up to 300 kHz near each carrier frequency). All three modes, QCP, D and S, were ordinary polarized. The QCP and D regime is used, respectively, to create plasma turbulence, particularly magnetic field aligned small scale irregularities (striations) and to generate DSEE at different altitudes both with and without QCP. The S-pulses reveal anomalous absorption (AA) of the QCP, D and S vs. frequency due to scattering on striations into plasma (upper hybrid, UH) waves.

During the diagnostic regime, the DSEE spectra show only the so-called ponderomotive Narrow Continuum (NCp), which is generated near the reflection points of the primary and secondary pump waves. During QCP, the upper-hybrid related SEE (DSEE) features such as the Downshfted Maximum (DM), Broad Continuum (BC), and Upshifted Maximum (UM) are observed [3]. The DM, UM and BC can be attributed to the mechanism composed of three steps: (a) excitation of striations and UH waves near the UH resonance of the primary pump wave or scattering (at the developed stage) of the primary and secondary pump waves into UH waves on striations near the corresponding UH resonances, (b) formation of the red- and blue-shifted sidebands around f0,D in the UH spectrum, and (c) conversion of UH waves into electromagnetic waves on striations. These features are observed also at the relaxation stage of the striations lasting ~20 s after QCP is turned off.

After the QCP turn-on, the NCp suffers strong suppression due to anomalous absorption on striations. On the contrary, the DM and BC are amplified and exhibit an overshoot effect, i.e., the intensity drops after achieving the maximum. Even stronger overshoots of the DM and BC appear when QCP is switched to the D-regime. These overshoots are attributed to the competition between the increase (decrease) of the AA and growth (fall) of the SEE source due to developing (relaxing) striations after QCP is turned on (off) [1]. The obtained e-folding time of the DSEE relaxation after the reaching the maximum was 2-5 s. The maximum overshoot (the ratio of the SEE intensity at the maximum to that at the steady state) of 10-15 dB occurs in the central part of the pumped volume, i.e., at the primary pump frequency f0. For the D-waves with fD≠f0, the overshoots strongly decrease.

The AA GAA was estimated from the evolution of different spectral components of the S-pulses. GAA achieves ~20-30 dB in the center of the heated volume (fS~f0), while at the periphery (δf = 600-700 kHz) GAA drops to ~2-3 dB.

The data on the DSEE dynamics allow estimating the scales and the rates of growth and decay of striations at different distances from the center of the pumped volume as well as the contribution of striations to the SEE and DSEE generation [2,4]. Also, the DSEE measurements after QCP and D-pulses allow to determine the decay rates of plasma waves at different altitudes [2].

1. E.N. Sergeev et al., RQE, 1999, 42, 715.

2. E.N. Sergeev, S.M. Grach, RQE, 2014, 57, 81.

3. T.B. Leyser, Space Sci. Rev., 2001, 98, 223.

4. E.N. Sergeev, S.M. Grach, RQE, 2017, 60, in press.