THEORETICAL STUDY OF IONOSPHERIC MODIFICATION AND ELF/VLF WAVE GENERATION BY HAARP

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INTRODUCTION

HAARP (High Frequency Active Auroral Research Program) is a high power transmitter facility operating in the HF frequency range. After an upgrade to 3.6 MW power scheduled in 2006 it will have an effective radiated power (ERP) of the order of 2 GW in 2.8-10 MHZ range, only a factor of ten less than lighning. Powerful HF facilities are used to study various effects occuring throughout all regions of ionosphere. The emission at 3 MHZ, modulated at 2 kHz, will cause a modification of electron distribution at altitudes of 70-120 km. The resulting change in conductivity will modulate the polar electrojet current and lead to emission of ELF/VLF waves into the magnetosphere. The waves then propagate to a point geomagnetically conjugate to HAARP. We use a time-dependent kinetic equation solver, similar to ELENDIF [1], to calculate the electron distribution function $f(\mathbf{v})$. Since the modification of ionosphere affects the propagation of the HAARP radio wave, the power flux is found self-consistently with the solution of the kinetic equation at each altitude. The problem bears significant scientific interest because of (i) highly nonlinear dependence of elecrojet modulation on the applied HF power, and (ii) the geomagnetic field effects.

KINETIC EQUATION, PULSE PROPAGATION AND ELF/VLF WAVE GENERATION

The ELENDIF code [1] uses two-term spherical harmonic expansion of $f(\mathbf{v})$ to treat various electron gas processes, such as quasistatic electric field E, elastic scattering on neutrals and ions, inelastic and superelastic scattering, electron-electron collisions, attachment and ionization. We use the same expansion, but also include non-static (harmonic) E and geomagnetic field. The found $f(\mathbf{v})$ is somewhat similar to the ELENDIF solution with dc E, in that it also has a sharp drop at ~2.5 eV due to electron energy losses to N_2 vibrational excitations, and a high-energy tail for high values of E. However, similar shapes occur for different amplitudes, the oscillating value of E corresponding to static value $E_{eff} = E\Big/\sqrt{1 + \left(\omega_{eff}/\nu_{eff}\right)^2}$, where $\omega_{\mathrm{eff}}=\omega\pm\omega_{\mathrm{H}}$ for the clockwise (ordinary) and counter-clockwise (extraordinary) modes, correspondingly, and ν_{eff} is the average value of elastic collision frequency. The conductivity σ for both high-frequency and dc fields is then found using the anisotropic part of $f(\mathbf{v})$. The changes in high-frequency σ affect the pulse propagation, while the modulated dc σ results in the modulation of the elecrojet current.

DISCUSSION

Most of the previous models [e.g., 2] used Maxwellian electron distribution, characterized completely by T_e. In our case of a non-Maxwellian distribution, one can define effective T_e in terms of the average electron energy. The calculated ΔT_e as a function of altitude for static heating shows some similarities with Maxwellian models, but also has new features such as nonlinear saturation of T_e.

REFERENCES

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[2] K. Papadopoulos, T. Wallace, M. McCarrick, G. M. Milikh and X. Yang, "On the Efficiency of ELF/VLF generation using HF heating of the auroral electrojet", *Plasma Physics Reports*, vol. 29, pp. 561-565, 2003.