FDTD Modeling of Ionospheric HF Heating

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High-power electromagnetic waves propagating through the ionosphere can modify the background cold plasma substantially, producing significant changes in electron temperature and electron density. This heating in turn modifies the electron-neutral collision frequency of the plasma, which controls the rate of absorption and the phase propagation constant. The heating therefore changes the way that the waves propagate through the ionosphere and leads to non-linear effects such as self-absorption and cross modulation. The sources of these modifying waves under consideration are high-power, ground-based HF transmitters. Scientists have researched methods to model and understand the processes and interactions involved in high-power radio wave propagation through the ionosphere for decades.

The authors detail and implement a self-consistent FDTD model of HF heating of the lower ionosphere. A bilinear transform is used to complement a direct integration implementation for the FDTD. Implementation of the nonlinear components (i.e., the first- and second- order moments of the Boltzmann equation) requires detailed explanation, as the equations require the use of signals at the same time and place as the components being calculated. This model successfully simulates the time-evolution of heating within the D-region ionosphere for HF frequencies.

This new HF heating model is validated by comparing simulation results to observations performed during experiments at the High-frequency Active Auroral Research Program (HAARP) Observatory in Gakona, Alaska. Cross-modulation experiments were performed at HAARP on 15 November 2012 (J. Langston and R. C. Moore, *Geophys. Res. Lett.*, doi:10.1002/grl.50391). While excellent agreement between experimental observations and numerical simulations is demonstrated using the modulated signal magnitudes, the modulated phase does not perfectly align. We discuss these observations and simulations in detail.