ISR Spectra Simulations with Electron-Ion Coulomb Collisions

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Incoherent scatter radars (ISR) reflect radio waves in the MHz range off electrons in the ionosphere and measure the backscattered power spectra in order to generate altitude profiles of plasma density, electron temperature, ion temperature, and ion drift speed. These spectra result from the collective behavior of coupled ion and electron dynamics and, for most cases, existing theories predict these well. However, when the radar points nearly perpendicular to the Earth's magnetic field, the motion of the plasma across the field lines becomes complex and Coulomb collisions between electrons and ions become important in interpreting ISR measurements. This paper presents the first fully kinetic, self-consistent, particle-in-cell simulation of ISR spectra with electron-ion Coulomb collisions. We implement a grid-based Coulomb collision algorithm in the Electrostatic Parallel Particle-in-Cell (EPPIC) simulator, and obtain ISR spectra from simulations both with and without collisions. For radar directions greater than 5° away from perpendicular to the magnetic field, both sets of simulations match collisionless ISR theory well. For angles between 3° and 5°, the collisional simulation is well described by a simplified Brownian motion collision process. Between 1° and 3° away from perpendicular the Brownian motion model fails, but the collisional simulation is in agreement with previous single particle simulations. At angles between 0.2° and 1° away from perpendicular, the collisional particle-in-cell simulation produces qualitatively different results than either the Brownian motion model or single particle simulations. For radar directions exactly perpendicular to the magnetic field the simulated collisional spectra match those from the Brownian motion collision theory, in agreement with previous single particle simulations.