Electron-Electron Collision Effects on ISR Temperature Measurements

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Incoherent scatter radars (ISR) estimate the electron and ion temperatures in the ionosphere by fitting measured spectra of ion-acoustic waves to forward models. For radars looking at aspect angles within 5° of perpendicular to the Earth's magnetic field, the magnetic field constrains electron movement and Coulomb collisions add an additional source of damping that narrows the spectra. Fitting the collisionally narrowed spectra to collisionless forward models leads to errors or underestimates of the plasma temperatures. This paper presents the first fully kinetic particle-in-cell simulations of ISR spectra with collisional damping by velocity dependent electron-electron and electron-ion collisions. For aspect angles between 0.5° and 2° off perpendicular, the damping effects of electron-ion and electron-electron collisions are the same and the resulting spectra are narrower than what current theories predict. For aspect angles larger than 3° away from perpendicular, the simulations with electron-ion collisions match collisionless ISR theory well, but spectra with electron-electron collisions are narrower than theory predicts at aspect angles as large as 5° away from perpendicular. At all aspect angles the particle-in-cell simulations produce narrower spectra than previous results using single particle displacement statistics. The narrowing of spectra by electron-electron collisions between 3° and 5° away from perpendicular is currently neglected when fitting measured spectra from the Jicamarca and Millstone Hill radars, leading to underestimates of electron temperatures by as much as 50% at these radars. We compare the simulations to density and temperature profiles taken at small aspect angles by the fully steerable MISA antenna at Millstone Hill. The data from Millstone Hill show that current fitting routines fail to converge on accurate temperature measurements at aspect angles of 3.6° or smaller, in agreement with the results from particle-in-cell simulations.