Hybrid-PIC simulation of whistler mode wave-particle interactions in the Earth's radiation belts

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The Earth's magnetosphere is a complex plasma environment that is heavily influenced by the geomagnetic field. The plasma populations in the magnetosphere can be divided into a cold, dense component (~0.5 eV, 10~1000 el/cm^3) and a hot but rarified plasma referred to as the radiation belts (100 keV~10 MeV, 1 el/cm^3). The cold plasma acts like a linear background material that determines the wave modes that can propagate in the system of which whistler mode waves are particularly dominant. On the other hand, the radiation belts are responsible for amplification and generation of whistler waves via the Doppler shifted cyclotron resonance instability. The propagation and nonlinear dynamics of whistler mode waves has been challenging to model because of the spatial inhomogeneity that plays a vital role in the wave-particle interactions problem. In order to investigate the complex nonlinear interaction process, we have developed a hybrid simulation in which the cold plasma current is modeled by a fluid equation while the radiation belt particles are simulated with a Particle in Cell (PIC) code. Additionally, the finite-difference time-domain method (FDTD) is utilized to self-consistently determine the evolution of the wave electric and magnetic fields. This method provides a broad-band, time-domain numerical solution to the wave-particle interactions problem. The hybrid simulation method is an effective means to investigate self-consistent nonlinear wave phenomena such as the generation of magnetospheric chorus, nonlinear whistler wave amplification, and the triggering of free-running emissions. The acceleration and precipitation of radiation belt particles induced by wave-particle interactions can also be self-consistently determined. Using this hybrid simulation technique, several unanswered questions in magnetospheric physics can be quantitatively approached via numerical experiments.