Nonlinear pitch angle scattering of low pitch angle electrons caused by whistler mode chorus emissions

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Whistler-mode chorus emissions are defined as coherent emissions with frequency sweep, and are frequently observed by various satellites in the Earth's inner magnetosphere. Chorus emissions are generated by energetic electrons in the kinetic energy range from a few to tens of keV through nonlinear wave-particle interactions, and energetic electrons are scattered their pitch angle by generated chorus emissions. The pitch angle scattering is closely related to energetic electron precipitation into the ionosphere, contributing to diffuse and pulsating aurora. Conventionally, it has been considered that particles satisfying the cyclotron resonance condition are scattered toward the loss cone by whistler mode waves. Li et al. (2015) indicated, however, that low pitch angle particles tend to be scattered away from the loss cone by coherent whistler mode waves. Omura et al. (1991) reviewed the study of the motion of particles under the presence of coherent waves and represented the equation of motion of particle near the resonance condition as a pendulum equation. They assumed in the derivation of the equation that the pitch angle of particles is not small (Nunn, 1974).

In this study, we derive the equation of the motion of particles without the assumption of small pitch angle to consider pitch angle scattering near the loss cone in the velocity phase space. We clarify that electrons near the loss cone satisfying the cyclotron resonant condition are scattered away from the loss cone due to the Lorentz force caused by the wave magnetic field and the parallel velocity component of electrons. In order to reproduce the pitch angle scattering caused by chorus emissions, we carry out a test particle simulation using the simulation system along a dipole magnetic field line and a whistler mode wave model. Results of the test particle simulation are consistently explained by the nonlinear theory we derived, and the pitch angle variation due to the nonlinear effect strongly depends on the wave amplitude. In particular, for the case of the large amplitude wave, most of resonant electrons are trapped by the coherent wave and are efficiently scattered away from the loss cone, resulting in less precipitating electrons. Furthermore, assuming 20 keV electrons uniformly distributed in the pitch angle range from 0 to 90 degrees, we estimate the modulation of pitch angle distribution while electrons encounter one wave packet of chorus emissions. Our results indicate that most of low pitch angle electrons scattered away from the loss cone and build a bump of distribution at the moderate pitch angle satisfying the cyclotron resonant condition. These results suggest that the relation between chorus wave intensity and the flux of auroral electron precipitation is not straightforward and that the nonlinear effect newly proposed by the present study should be taken into account.

Keywords: chorus emissions, pitch angle scattering, wave-particle interaction

