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Evaluation of nonlinear effects in the pitch angle scattering process of energetic electrons into the loss cone by coherent whistler-mode waves

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Whistler-mode waves observed in the Earth's magnetosphere significantly contribute to the pitch angle scattering and cause the precipitation of high energy electrons into the atmosphere, which contribute to the diffuse/pulsating aurora in the polar ionosphere. Conventionally, the pitch angle scattering of energetic electrons has been considered as a diffusion process based on the quasi-linear theory. On the other hand, recent studies revealed that nonlinear effects play essential roles. Kitahara and Katoh (2019) theoretically and numerically clarified the peculiar nonlinear trapping process of resonant electrons near the loss cone by coherent whistler-mode waves. Further investigation has been required to reveal the nonlinear process in the pitch angle scattering of electrons into the loss cone.

To clarify the physical process of scattering electrons into the loss cone, we have updated the test particle code of Kitahara and Katoh (2019) in order to compute the motion of a large number of electrons by a massively parallelized supercomputer system. By using the developed code, we compute the motion of energetic electrons moving along a field line under the presence of a packet of monochromatic whistler-mode waves. We carry out three simulation runs by changing the wave amplitude B_w: 10^{-4}, 5×10^{-4}, and 10^{-3} of the background magnetic field intensity at the equator (B_{0eq}). The wave frequency is set to be 0.3 times of the electron gyrofrequency at the magnetic equator (f_{0eq}). The plasma frequency is assumed to be 4 f_{0eq} and uniform along a field line. We calculate the motion of 6,804,000 energetic electrons to investigate the behavior of precipitating electrons. The initial energies and equatorial pitch angles are assumed to be in the ranges from 10 to 90 keV and from 6 to 89 degree, respectively.

By analyzing trajectories of all electrons in the velocity phase space and counting the number of crossing of the resonance velocity during their nonlinear motion, we categorize 3 types of pitch angle scattering; resonant scattering, non-resonant scattering, and phase trapping. Simulation results show that electrons not only near the loss cone but also in the larger pitch angle range are scattered into the loss cone. In the case $B_w = 10^{-3}$ B_{0eq}, electrons with the pitch angle less than 20° are scattered into the loss cone. In the simulation results of both 5×10^{-4} and 10^{-3} B_{0eq}, electrons initially placed near the loss cone edge are mainly scattered into the loss cone by the non-resonant scattering but their contribution to the flux inside the loss cone is not significant. The electron flux inside the loss cone is dominated by electrons which are initially in the larger pitch angle range and are scattered into the loss cone through the large pitch angle change by the resonant scattering due to the expansion of the trapping region. We evaluate that the resonant scattering and the non-resonant scattering contribute to 97 % and 3 % of the loss cone flux when the wave amplitude is 10^{-4} B_{0eq}. The resonant and non-resonant scattering contribute to 87 % and 13% of the loss cone flux when the wave amplitude is 10^{-3} B_{0eq}.

We also investigate the temporal variation of the loss cone flux. The loss cone filling ratio is positively correlated with wave amplitude and the value reaches 0.6 when the wave amplitude is 5×10^{-4} B_{0eq} and exceeds 0.9 when the wave amplitude is 10^{-3} B_{0eq}. The obtained loss cone filling ratios are equivalent to those observed in the magnetosphere (Kasahara et al, 2019).

References

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