Theoretical and Numerical Analysis of Radiation Belt Electron Precipitation by Coherent Whistler Mode Waves: Phase-Trapping, Wave Amplitude Dependence, and Pulsing.

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The interaction between coherent whistler mode waves and energetic radiation belt electrons can result in pitch angle scattering of electrons into the bounce loss cone and subsequent precipitation. In studying the effects of VLF transmitters on particle precipitation, past modeling efforts have focused on computation of diffusion coefficients for a Fokker-Planck model. To capture the non-linear effects of large amplitude coherent waves, we evaluate particle precipitation using a Monte Carlo Model and a Vlasov-Liouville Model. The Monte Carlo Model consists of sampling the initial particle distribution function with a large number of test particles and tracking the rate at which particles fall into the loss cone. The Vlasov-Liouville model computes the particle distribution function directly using a characteristic based solution to the Vlasov equation; precipitation is then evaluated by computing the appropriate integrals over the particle distribution in phase-space. Previous work has shown that in the case of large amplitude coherent waves, phase-trapping can significantly perturb resonant particles from their adiabatic paths. In this study, the phase trapped and untrapped particle trajectories are separated to determine the relative influence of each on precipitation. We show that at large amplitudes, a significant number of particles can be phase trapped and contribute as much to precipitation as untrapped particles. However, due to the approximate symmetry of trapped trajectories around the geomagnetic equator, the maximum pitch angle change for trapped particles is the same as that of untrapped particles. The dependence of precipitated flux on wave amplitude is computed over a broad range of amplitudes (0-200 pT). Additionally, the effects of pulsed signals over CW signals are compared on maximizing induced particle precipitation. We show using 0.5 second pulses, that with the correct duty cycle, the pulsed signals can produce a higher integrated power ratio than CW signals. The results suggest that pulsing with the correct duty cycle can take advantage of the extended response time of the precipitated flux to effectively waste less power than CW signals. The plasma parameters and L-shell used in this study are typical of the Siple wave injection experiment.