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Short-term and long-term energetic electron precipitation induced by whistler-mode chorus waves

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Nonlinear wave-particle interaction with whistler-mode chorus waves is one of the processes that drive energetic electron precipitation in the Earth's inner magnetosphere. Using the Green's function method, we investigate the precipitation rates of electrons interacting with both parallel and oblique lower-band chorus emissions around the outer radiation belt. We analyze both short-term effects (within a single emission) and long-term evolution (˜tens of minutes) of electron precipitation. Our results confirm that when chorus waves propagate obliquely to the background magnetic field, electrons are generally more likely to be precipitated than in the case of parallel chorus waves. For short-term precipitation, namely the one-to-one correspondence between electron precipitations and chorus elements, we demonstrate that the majority of precipitation arises from nonlinear scattering (phase bunching) of cyclotron resonance, while smaller fractions result from Landau resonance and 2nd cyclotron resonance in the oblique chorus cases. For long-term precipitation, referring to the evolution of precipitation during events with consecutive chorus emissions, we find that oblique chorus waves are more effective than parallel waves at driving electrons toward low equatorial pitch angles, ultimately leading to enhanced precipitation. Additionally, we derive pitch angle scattering rates and verify precipitation processes governed by nth-order cyclotron resonances for both parallel and oblique chorus waves. The pitch angle scattering rates provide valuable insights for improving the prediction of space weather phenomena such as pulsating auroras and microbursts.