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Cyclotron acceleration of radiation belt electrons by whistler-mode waves with varying frequency

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We study the gyroresonant acceleration of radiation-belt electrons by quasimonochromatic whistler-mode waves, such as VLF chorus emissions, with account of partile trapping by the wave field. We perform and compare analytical estimates and numerical calculations for the net acceleration rate related to the particle motion in the trapped regime and energy diffusion related to the trapping and untrapping processes. Taking into account the nonlinear wave-amplitude modulation in a chorus element, we obtain that the electron energy diffusion rate can be comparable to that of the net acceleration rate, while it is by an order of magnitude smaller for an idealized wave packet with constant amplitude. Analytical estimates and numerical results for the acceleration parameters are in agreement with each other. Analytical estimates of the overall acceleration efficiency yield that a fraction of up to 10^{-3} of energetic particles can be involved in the regime of nonlinear acceleration for the plasma parameters corresponding to the region just outside the plasmapause.