Modulation of energetic electron distribution caused by toroidal mode ULF waves in association with periodic enhancement of chorus emissions

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Whistler-mode chorus emissions play significant roles in the acceleration and the loss of energetic electrons in the terrestrial magnetosphere. Previous studies revealed that chorus emissions satisfy the cyclotron resonance condition with electrons in the wide ranges of the kinetic energy and pitch angle and cause the periodic precipitations of energetic electrons into the atmosphere through wave-particle interactions, contributing to diffuse and pulsating auroras [e.g. Nishimura et al., 2010, S. Kasahara et al., 2018a]. While the mechanism controlling the periodicity of the chorus wave generation is one of essential problems unsolved in the magnetospheric physics, the roles of ULF waves have been discussed in several decades. In the present study, we analyze substorm-related toroidal mode ULF waves, chorus emissions, and energetic electrons simultaneously observed by the ERG satellite, and propose a model explaining how toroidal mode waves modulate energetic electrons. We focus on the event observed from 21:30 UT to 22:00 UT on March 27, 2017, the recovery phase of the CIR-driven storm. The ERG satellite traversed in the dawn sector of the ring current region, where the range of L-value was from 6.3 to 5.9, the magnetic local time from 04:00 to 04:12, and the magnetic latitude from -12.7 to -7.4 degrees during the analyzed event. From the observations of the Onboard Frequency Analyzer (OFA) of the Plasma Wave Experiment (PWE), the Magnetic Field Experiment (MGF), the Medium-energy particle experiments - electron analyzer (MEP-e) and the High-energy electron experiments (HEP), we find one-to-one correspondence among chorus emissions, toroidal mode ULF waves, and energetic electrons in the energy range 35-60 keV. We estimate the resonant energy to be about 30-300 keV, considering the first-order cyclotron resonance condition under the parameters determined based on the observations of the High Frequency Analyzer (HFA) and the OFA of the PWE and the MGF. Based on the results of analysis, we suggest that the intensity variations of chorus emissions are caused by the modulations of energetic electrons. The intensity of chorus emissions enhances at the timings when the toroidal component of the wave magnetic field has a peak in the westward direction as well as the enhancement of the flux and the temperature anisotropy of energetic electrons. From the observed phase relationship between the wave magnetic field of the ULF waves and the modulations of energetic electrons, it is expected that the locations corresponding to the wave phases when the flux enhancement (depletion) are expected to be the dense (sparse) region due to the concentration (divergence) of the E×B drift velocity between the wave electric field of the ULF waves and the ambient magnetic field. The azimuthal wave number and the wavelength of the observed ULF waves are estimated to be about 49-120 and 2000-4900 km, respectively, assuming that modulated energetic electrons satisfy the drift resonance condition with the ULF waves. The estimated m-numbers correspond to those reported as Transient Toroidal Waves [e.g. Takahashi et al., 1996], rather than the typical values of externally generated toroidal mode ULF waves observed in the inner magnetosphere.

Keywords: ULF waves, whistler-mode chorus, energetic electrons, inner magnetosphere