# Pi2 ULF modulation of energetic electron precipitations observed by using VLF/LF transmitter signals

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It has been expected that ULF (ultra low frequency, 1 mHz –1 Hz) magnetic pulsations modulate the precipitation of electrons in the magnetosphere [Coroniti and Kennell, 1970]. In this process, periodic change in the local magnetic field strength due to the ULF pulsations modulates the growth rate of whistler mode chorus waves and resultant pitch angle scattering rate. That is, flux of the precipitating electrons may depend on the strength of pitch angle diffusion coefficient at the same frequency as the ULF pulsations. There have been several studies of Pc5 (1.67–6.67 mHz, the periods: 150–600 s) ULF modulation of energetic electron precipitations (EEP) in the D-region ionosphere based on ground-based riometers and X-ray observations [e.g., Brito et al., 2012]. The EEPs associated with Pi2 pulsations (40-150 s) were reported [Asnes et al., 2004]. Auroral precipitations and energetic particle flux near the equator in nightside magnetosphere occur due to Pi2 modulation [Saka et al., 1999]. Precipitation of low energy electrons below 300 eV was reported when a Pi2 pulsation with short periods (less than 40 s) occurred [Tsunomura et al., 1990]. However, there have been few reports for the ULF modulation of high energy electrons that modulate the D-region ionosphere. In this study, we investigate the D-region signatures of the modulation due to the ULF waves using a network of VLF/LF transmitter signals in North America. The transmitter signals from NLK (USA, 24.8 kHz, L = 2.88), NDK (USA, 25.2 kHz, L = 2.98) and WWVB (USA, 60.0 kHz, L = 2.26) were observed by a receiver at ATHA (Athabasca, Canada, L = 4.31). We show the first observations of oscillations in intensities and phases on the NDK-ATH and WWVB-ATH paths with periods of 3-4 minutes during a small substorm at 05:25-05:50 UT on 4 June, 2017 (AE index = 140 nT). Based on ground-based magnetic observations, there were pulsations with the same periods with the VLF/LF oscillations both at high- and low-latitudes. The ground-based H-component magnetic field variations and Doppler velocity observed by the SuperDARN (Super Dual Auroral Radar Network) HF (high frequency, 8-20 MHz here) radars showed the same periodic changes as seen in the VLF/LF oscillations, suggesting that energetic electron precipitation over the WWVB-ATHA and NDK-ATHA paths was modulated by the ULF waves. Based on the ground-based magnetic field data, we conclude that the ULF wave was the Pi2 pulsations associated with the substorm, because propagation direction of the wave was westward (66.4 km/s) from the pre-midnight sector, the magnetic variations at low latitudes were in-phase over wide longitudes, and the magnetic variations at ATHA slightly preceded those at low latitudes. Rising-tone chorus emission was observed in the frequency range of 5-6 kHz at ATHA during the VLF/LF oscillations. Pitch angle scattering by the whistler-mode chorus wave is one of possible mechanism that accounts for the energetic electron precipitation. In this presentation, we will discuss possible causes of these VLF/LF oscillations.

 