Energetic electron precipitations showing ULF modulation observed by VLF/LF standard radio waves

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Possible mechanisms for how magnetospheric ULF magnetic pulsations modulate the precipitation of electrons have been proposed [Coroniti and Kennell, 1970]. Ionospheric modulation due to ultra low frequency (ULF) Pc5 waves has been observed by GPS-total electron content (TEC), high frequency (HF) Doppler sounders and SuperDARN HF radars. While modulation in the lower ionosphere has been reported based on riometer and X-ray observations [e.g., Pilipenko et al., 2014; Belakhovsky et al., 2016; Brito et al., 2012], there are few reports from observations of VLF/LF transmitter signals. We investigate the D-region signatures of the modulation due to the ULF waves using a network of very low frequency (VLF)/low frequency (LF) standard radio waves. Such VLF/LF propagation is a useful probe to detect energetic electron precipitation with energy of more than 100 keV. 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 ATH (Athabasca, Canada, L=4.31). During 5:25 - 5:50 UT on 4 June, 2017, oscillations of the VLF/LF intensity and magnetic field delta B_H, delta B_D and delta B_Z around the NLK-ATH, NDK-ATH and WWVB-ATH paths with periods of 180-240 s (the frequency: 4.2-5.6 mHz) were seen simultaneously. A weak signature of geomagnetic substorm was observed by ground magnetometers. Doppler velocity in ground scatter echoes observed by SuperDARN HF radars along the NDK-ATH and WWVB-ATH paths also showed the same periods of the 180-240 s simultaneously. The locations of SuperDARN HF radars are Christmas Valley East and West radars(CVE and CVW) and Fort Hays West radar(FHW). In this presentation, we will discuss the cause of these VLF/LF oscillations.