Energetic electron precipitations observed by VLF/LF sub-ionospheric propagation: ARASE and ground-based observation campaign

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Sub-ionospheric propagation of narrowband VLF/LF radio waves is a useful probe to observe energetic electron precipitation with energy of 100keV to MeV. Here, we show overview of observational characteristics of energetic electron precipitations at auroral and sub-auroral latitudes observed by a VLF/LF radio receiver network installed at Ny-Alesund(NAL), Athabasca(ATH) and Poker Flat Research Range, Alaska(PKR) during ARASE and ground-based observation campaign in the spring of 2017. The six sub-ionospheric propagation paths in total are available in northern America and three paths are available in Scandinavia; The ATH station is located at sub-auroral latitude (54.7N, 246.7E, L=4.45) and radio signals from mid-latitude transmitters (WWVB: 40.7N, 255.0E, 60kHz, NAA: 44.7N, 292.7E, 24.0kHz, NDK: 46.4N, 261.5E, 25.2kHz and NLK:48.2N, 238.1E, 24.79kHz) were recorded. PKR is located below the auroral latitude (65.1N, 212.5E, L=5.95) and received the signals from NDK and NLK. The NAL station is inside the northern polar cap (78.9N, 11.9E) and radio signals from mid-latitude transmitters (MSF: 54.9N, 256.3E, 60.0kHz, DCF: 50.0N, 9.0E, 77.5kHz, and NRK: 64.0N, 337.4E, 37.5kHz) are recorded. During the observation campaign, three magnetic storms occurred in March and April (Dst minima on Mar. 23, Mar. 27, and Apr. 4) and phase advances (available for WWVB, DCF, and MSF) and amplitude depressions of received radio signals were recorded during these periods. The phase advances are caused by lowering the ionospheric reflection height (70-90km) of radio waves due to energetic electron precipitation and subsequent enhancement of ionization in the lower ionosphere. The amplitude depressions are caused by attenuation of radio waves when they pass through the enhanced ionization region. These observational signature are proxies of energetic electron precipitation on radio propagation paths and the simultaneous multi-path observation enables us to investigate spatial structure of energetic electron precipitation region. Overview of the night time sub-ionospheric propagation of VLF/LF waves observed are summarized as follows: (1) Phase advances and amplitude depressions were observed at all received stations associated with storm time substorms. Substorm induced energetic electron precipitations were detected by the VLF/LF radio receiver network. (2) The energetic electron precipitation signatures sometimes show different start timing and duration depending on transmitter-receiver pairs, implying that spatial structure of energetic electron precipitation region is smaller than longitude separations of radio paths (~15 degrees in longitude). (3) The phase and amplitude variations with time scale of minutes were embedded inside the substorm induced energetic electron precipitation signatures. In some cases, the variations are corrected with magnetic field fluctuation in the Pc5 range observed by ground magnetometers. (4) The amplitude depressions associated with Pc1 were occasionally observed (Hirai et al. ibid).