Spread-Spectrum VLF Remote Sensing of LEP Events

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Lightning-induced electron precipitation (LEP) is one of the primary mechanisms for energetic electron loss from Earth's radiation belts. A newly developed spread-spectrum very low frequency (VLF) remote sensing technique is applied to recent experimental observations of VLF scattering during lightning-induced election precipitation (LEP) events. We provide a detailed overview of the spread-spectrum measurement technique, which can successfully be used to demodulate MSK-modulated VLF transmitter signals, yielding excellent approximations of the sum-of-modes amplitude and phase as a function of frequency before, during, and after transient events. For LEP events, the scattered field amplitude and phase both exhibit pronounced dependence on frequency, as do the event onset delays (relative to the causative lightning flash) the onset durations, and the recovery rates. The experimental observations are compared with the predictions of an Earth-ionosphere waveguide propagation and scattering model, using the latest version of the Whistler-Induced Particle Precipitation (WIPP) Code to calculate the magnitude of electron pitch angle scattering at each L-shell as a function of time and electron energy, thus generating the LEP-associated ionospheric disturbances as a function of time. The Long-Wave Propagation Capability (LWPC) code is used to demonstrate that the scattered field amplitude and phase depend sensitively on the electrical properties of the scattering body and the ionosphere between the scatterer and the receiver. The observed frequency-dependent onset times and durations, on the other hand, are attributed to the scattering source characteristics. As a result, we postulate that spread-spectrum measurements of VLF scattering may provide a means to estimate the spectral profile of energetic electrons precipitated from the Earth's radiation belts.