Master Thesis

EMIC wave-driven relativistic electron precipitation from outer radiation belt based on multi-instrument ground-based observations

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Abstract

Earth's outer radiation belt, which consists of high energy ions and electrons is highly dynamical region in the inner magnetosphere. The outer belt disappears during the main storm of geomagnetic storm. One of the loss mechanisms of electrons from the outer belt is precipitation into the atmosphere due to wave-particle interaction. Electromagnetic ion cyclotron (EMIC) waves are the left-hand polarized plasma waves in the Pc1-2 frequency range. EMIC waves can selectively scatter relativistic electrons and are considered to play an important role in the loss of the outer radiation belt electrons through pitch angle scattering.

However, there are still questions left in terms of contribution of EMIC waves to the loss of radiation belt electrons and conditions favorable to cause the pitch angle scattering. Theoretical studies predict nonlinear pitch angle scattering of protons and relativistic electrons due to EMIC triggered emissions. While one-to-one correspondence of pulsations of proton precipitation with Pc1 rising tone structure has recently been found, correspondence between a rising-tone structure and a burst of relativistic electron precipitation has not yet been confirmed by the observation. Also, recent study reported that not all types of EMIC waves accompany electron precipitation, but intervals of pulsations of diminishing periods (IPDP) are preferentially associated with electron precipitation. However, statistical relation between IPDP waves and the electron precipitation and the physical mechanism remain open issues.

In this thesis, we investigated EMIC waves and electron precipitation by combining multi ground-based instruments. Electron precipitation was observed by using VLF/LF radio waves. As modulation of the VLF signal shows ionization change in the lower ionosphere, we observed the modulation as occurrence of electron precipitation on the radio wave propagation path. We used proton aurora image to identify source location of the EMIC wave-particle interaction region in the magnetosphere. Also, EMIC waves were observed by induction magnetometers. Using combination with these instruments enables us to investigate both temporal and spatial relationship between EMIC waves and electron precipitation.

We conducted both case and statistical studies about EMIC waves and associated electron precipitation. In the case study, we investigated an EMIC wave-driven electron precipitation event occurred during the main phase of geomagnetic storms on 27 March 2017. Isolated proton aurora (IPA) was observed above the radio wave propagation path where electron precipitation was detected during the occurrence of EMIC waves. Also, we found similar temporal variation between bursts of electron precipitation and each element of EMIC waves with rising tone structure at a time lag of 24 s. This time lag is consistent with the difference of travel times between relativistic electrons and EMIC waves from the magnetic equator to the ionosphere. Calculated electron pitch angle scattering rate indicated that observed EMIC waves could scatter electrons with energies higher than 3.5 MeV. These results showed temporal and spatial correspondence among EMIC waves, electron precipitation, and IPA, and short time scale correspondence between relativistic electron precipitation (REP) and EMIC rising tone structure. In the statistical study, we investigated differences in characteristics between IPDP and other type Pc1 waves by using an induction magnetometer and VLF/LF radio wave data at subauroral latitude (Athabasca, Canada) from 1 November 2016 to 30 June 2018. In this period, we found 950 EMIC events, and 87 of total EMIC wave events were IPDP wave events (9.2%). Compared to normal Pc1 waves, IPDP waves often occur in the evening sector and during disturbed geomagnetic condition. Simultaneous observation of the magnetometer and VLF/LF radio waves were available for 286 days, and we found 163 EMIC wave events. 19 of 163 EMIC wave events were clearly associated with electron precipitation (12%). 15 of total 19 electron precipitation events were caused by IPDP waves (79%). Also, the electron precipitations were observed in the evening sector and has similar local time dependence as IPDP waves. This result suggests that IPDP waves are more likely to cause electron precipitation than other type Pc1 waves.