1 Introduction

Electromagnetic ion cyclotron (EMIC) waves are in the Pc1 frequency range of 0.2–5 Hz, which are believed to be generated due to temperature anisotropy \((T_\perp>T_\parallel)\) of energetic ions overlapping with cold, dense plasma.

**EMIC waves in the ionosphere** are primarily studied on their temporal and spatial distributions, relationship with geomagnetic storms, and influence factors of propagation. Ionospheric EMIC wave frequency differences with local time have recently been reported mainly based on Swarm observations. Previous studies have speculated about possible causes of EMIC wave frequency variations at different MLT regions, including that locations of the source region and concentrations of heavy ions may be different according to local time. However, no observational evidence was presented.

In this study, we discovered He+ band EMIC wave frequency differences in the ionosphere during a geomagnetic storm recovery phase, and then attempted to understand these frequency differences by joint analysis of EMIC waves in the magnetosphere. Pc1 pulsations on the ground and various parameters in the ionosphere.

2 Data and Methodology

- **Data**
  - In the ionosphere:
    - 50 Hz Magnetic field data (B) from the Swarm constellation
    - 125 Hz electric field data (E) from the China Seismo-Electromagnetic Satellite (CSES)
  - In the magnetosphere:
    - 64 Hz fluxgate magnetometer data from EMFISIS on Van Allen Probes
    - 64 Hz magnetic field data from MGF on Arase satellite

- **On the ground**
  - 20 Hz induction coil magnetometer data from CARISMA
  - 64 Hz induction magnetometer data from the PWING project

- **Methodology**
  - B from Swarm constellation and Van Allen Probes are transferred to mean field-aligned (MFA) coordinates
  - Residual B and E in the ionosphere are obtained by subtracting background field, which is defined by the Savityzk-Golay smoothing (order of 2 and length of 25s).
  - For B in the ionosphere and magnetosphere, performed FFT with a time segment of 20s and with a 30% overlapping between the adjacent segments to obtain power spectral density to have a fine spatial resolution. For B on the ground, performed FFT with a time segment of 60 s and with a 30% overlapping between the adjacent segments to have a frequency resolution less than 0.01 Hz.
  - For E, obtained their total cross-covariance power.
  - Use methodology of Means to calculate wave properties (wave normal angle and ellipticity).
  - Parameters for quantitatively determining EMIC wave frequencies

3 EMIC waves in the ionosphere, magnetosphere and on the ground

![Image of EMIC waves](image)

- Several substorms between 00 and 14 UT on August 28, 2018, which is during the recovery phase of a strong geomagnetic storm with the minimumDst = -175 nT on August 28, 2018.

4 Discussion

**Frequency-dependent attenuation of the ionospheric EMIC waves can be insignificant.**

**EMIC wave frequencies are higher at Swarm A#1 and CIES #1 when the magnetic field intensity is larger.**

![Image of EMIC waves](image)

(a) Average PSD during the same time, 03:26–03:39 UT.
(b) Average PSD observed by Arase during 03:26–03:39 UT and Swarm A during 03:26–03:40 UT.
(c) The ionospheric wave attenuation, obtained by the ratio between the average PSD of Arase and Swarm A.
(d) Ducting EMIC waves frequencies versus magnetic latitude.
(e) Total magnetic field, electron density and Alfvén speed in the ionosphere and orbit observed during EMIC waves.

5 Conclusions

- **EMIC waves are observed in the ionosphere, magnetosphere and on the ground in this case.**
- The duration of waves in the ionosphere and on the ground is similar, from about 01 to 10 UT.
- **Ionospheric EMIC waves show MLT differences in frequencies, i.e., frequencies in the post-midnight are higher than those in the pre-midnight.** We found that MLT differences in ionospheric wave frequencies are consistent with those MLT differences in the equatorial magnetosphere, which are related to the background magnetic field intensity at different locations.
- Besides frequency differences in MLT, ionospheric ducting EMIC waves tend to select upper or lower frequency ranges in the post-midnight. We found that frequency selection mainly depend on the local magnetic field intensity. When the magnetic field in the main part of the ionospheric waveguide is stronger, the frequency range is higher.