Revealing the EMIC wave frequency differences in the ionosphere via coordinated observations: A case study

Xin-Yan Ouyang[1], Chao Yue[2], Yong-Fu Wang[2], Jie Ren[2], Mu-Ping Yang[3], Ya-Lu Wang[1], Ying-Yan Wu[1], Xue-Min Zhang[1]

[1]Institute of Earthquake Forecasting, China Earthquake Administration, Beijing, China
[2]Institute of Space Physics and Applied Technology, Peking University, Beijing, China
[3]Liaoning Earthquake Agency, Shenyang, China

esa

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**.

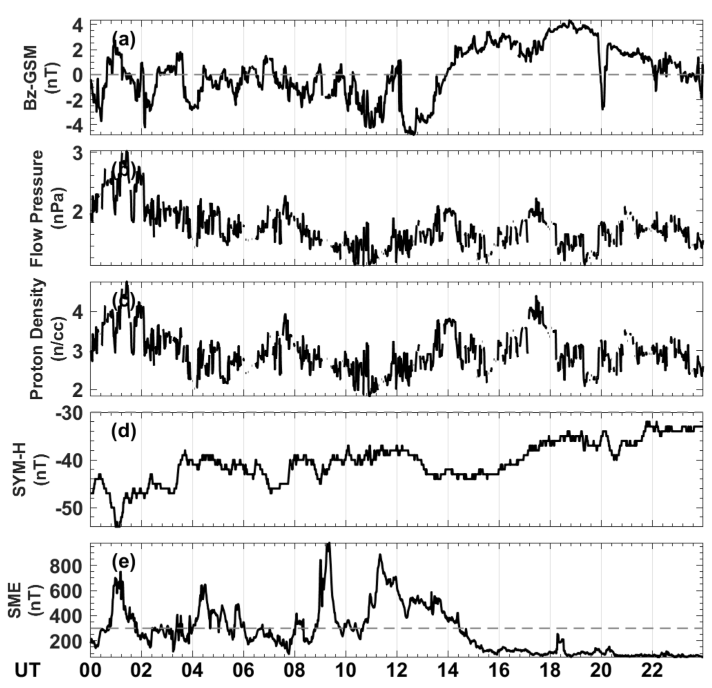
In this study, we discovered He+ band EMIC wave frequency differences in the ionosphere during a geomagnetic storm recovery phase, and then attempted to understand these frequency differences by conjoint analysis of EMIC waves in the magnetosphere, Pc1 pulsations on the ground and various parameters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

2 Data and Methodology

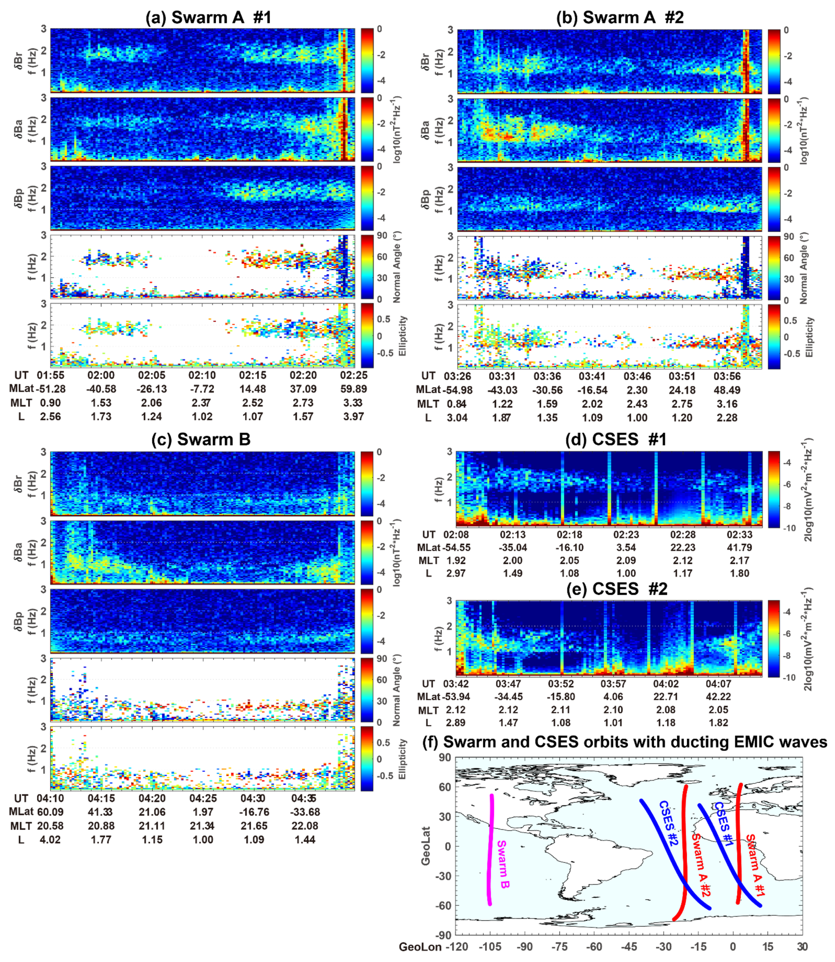
- **Data**
  - **In the ionosphere**
    50 Hz Magnetic field data (B) from the Swarm constellation
    125 Hz electric field data (E) from the China Seismo-Electromagnetic Satellite (CSES)
    (since CSES does not provide high sampling magnetic field data)
  - **In the magnetosphere**
    64 Hz fluxgate 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 Savitzky-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

	Start and end times (UT)	Lower and upper cutoff frequencies (Hz)	Thresholds
Swarm A #1	01:57–02:25	1.4–2.4	3×10^{-4} (nT^2/Hz)
Swarm A #2	03:26–04:00	0.8–2.0	3×10^{-4}
Swarm B	04:10–04:40	0.3–1.2	3×10^{-4}
CSES #1	02:09–02:35	1.4–2.4	10^{-9} ($(mV/m)^2$/Hz)
CSES #2	03:43–04:11	0.8–2.0	5×10^{-9}
Van Allen Probe A	01:16–01:30	0.4–1.2	10^{-3} (nT^2/Hz)
	07:20–07:40	1.0–2.8	10^{-3}
	07:22–07:25	3.0–4.6	10^{-3}
Van Allen Probe B	00:07–00:20	1.0–2.0	10^{-3}
	00:48–00:56	2.6–3.6	10^{-3}
	03:25–03:55	0.4–1.2	10^{-3}
Arase	03:24–03:39	0.2–2.5	5×10^{-2} (nT^2/Hz)
CARISMA-PINA	01:00–10:20	0.3–3.0	5×10^{1} (pT^2/Hz)
PWING-KAP	01:00–06:00	0.3–3.0	6×10^{-4} (nT^2/Hz)
	06:00–09:30	1.0–2.5	6×10^{-4}
	09:30–10:20	1.5–2.5	5×10^{-5}

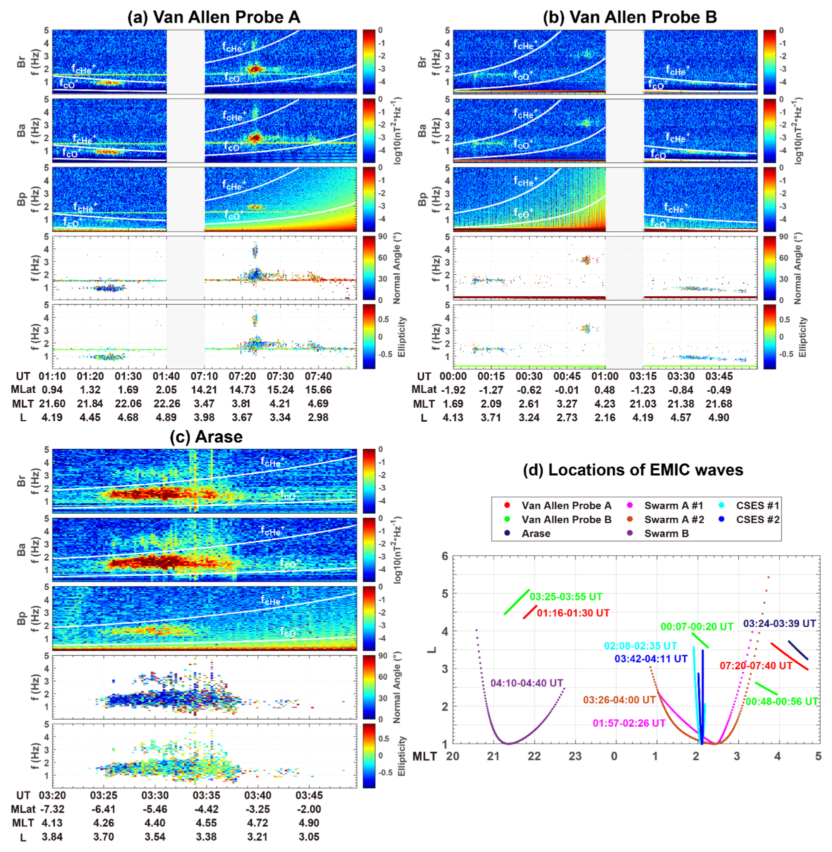
3 EMIC waves in the ionosphere, magnetosphere and on the ground



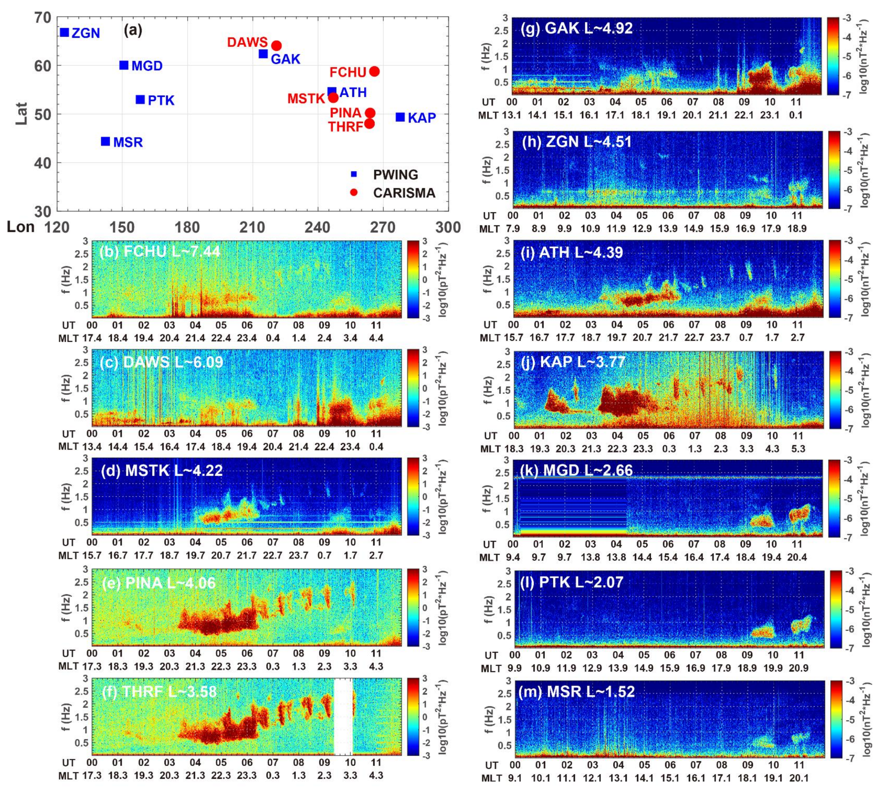
- Solar wind and geomagnetic indices on August 28, 2018.
- Several substorms between 00 and 14 UT on August 28, 2018, which is during the recovery phase of a strong geomagnetic storm with the minimum Dst = −175 nT on August 26, 2018.



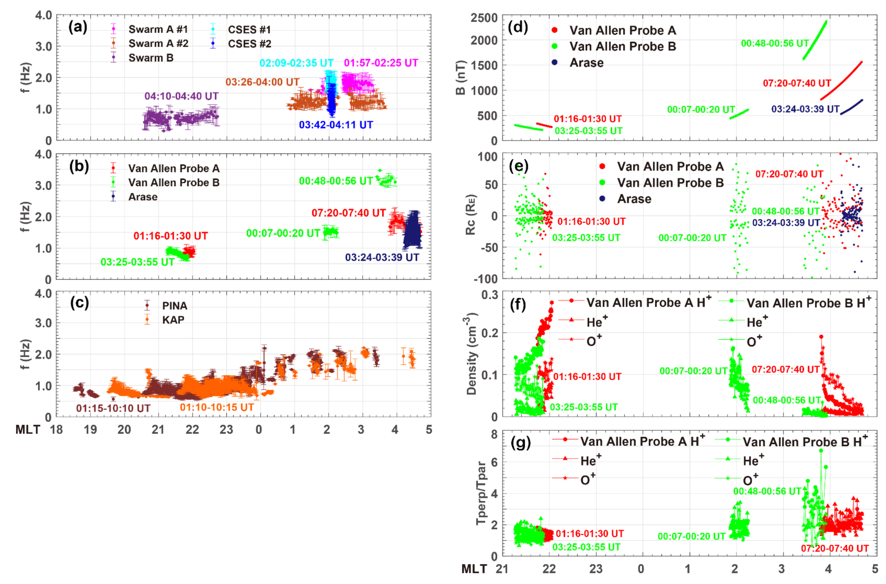
Ducting EMIC waves observed in the ionosphere and Swarm, CSES orbits with ducting waves during the recovery phase with substorms on August 28, 2018.
(a-c) Power spectral density of residual magnetic field from Swarm A and B, as well as the corresponding wave properties.
(d-e) Total cross-covariance power of residual electric field from CSES.
(f) Swarm and CSES orbits with ducting EMIC waves. The South Atlantic Anomaly region is approximately in −60–10° N latitude and −120–45° E longitude.



EMIC waves observed in the magnetosphere during the recovery phase with substorms on August 28, 2018 and locations of EMIC waves in the magnetosphere and ionosphere.
(a-c) Dynamic spectrogram of radial (Br), azimuthal (Ba) and parallel (Bp) magnetic field components from Van Allen Probe A, B and Arase, the corresponding normal angle and ellipticity.
(d) Locations of EMIC waves in the magnetosphere and ionosphere.



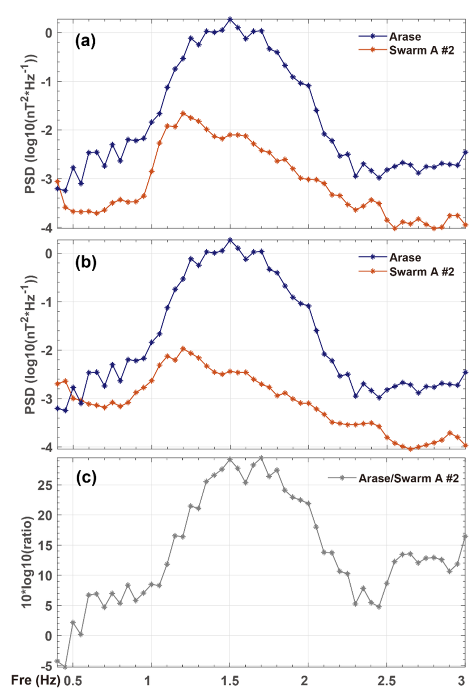
Pc1 waves on the ground on August 28, 2018.
(a) Locations of induction magnetometers from the CARISMA (red circle) and PWING project (blue square).
(b-m) Dynamic spectrogram of D component of magnetic field at the CARISMA (b-f) and PWING (g-m).



(a–c) **Quantitatively present EMIC wave frequencies in the ionosphere, magnetosphere (He+ band) and on the ground** during the storm recovery phase on August 28, 2018.
(d–g) **Major parameters, may affect EMIC wave generation and its frequency.** Background magnetic field shows a clear dependence on MLT, whereas other parameters' change with MLT can be negligible.

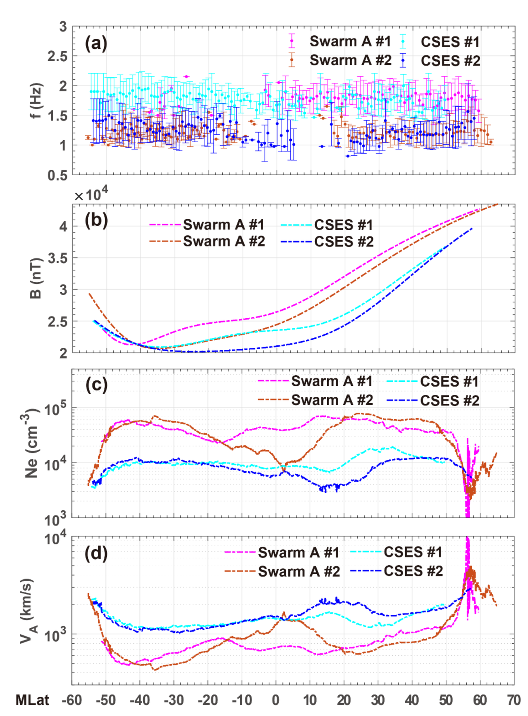
4 Discussion

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



(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 03:26-04:00 UT
(c) The ionospheric wave attenuation, obtained by the ratio between the average PSD of Arase and Swarm A.

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



(a) Ducting EMIC wave frequencies versus magnetic latitude.
(b)–(d) Total magnetic field, electron density and Alfvén speed in the ionosphere along orbits observed ducting EMIC waves.

5 Conclusions

(1) **EMIC waves are observed in the ionosphere, magnetosphere and on the ground** in the nightside for this case. The duration of waves in the ionosphere and on the ground is similar, from about 01 to 10 UT.

(2) **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.

(3) 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 selections 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.

SWARM 10 YEAR ANNIVERSARY SCIENCE CONFERENCE
08–12 April 2024 | Copenhagen, Denmark

Contact me
Email: oyxybj@qq.com; oyxy@ief.ac.cn