



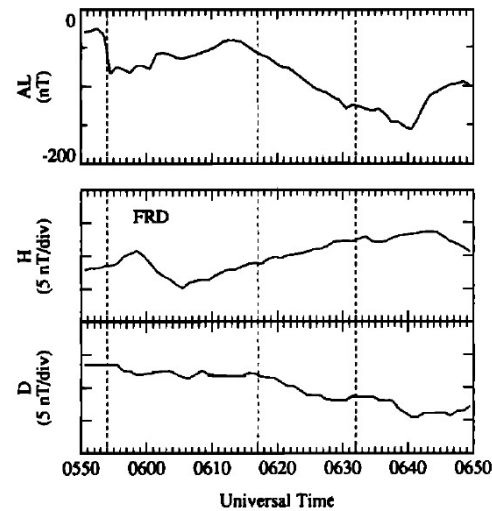
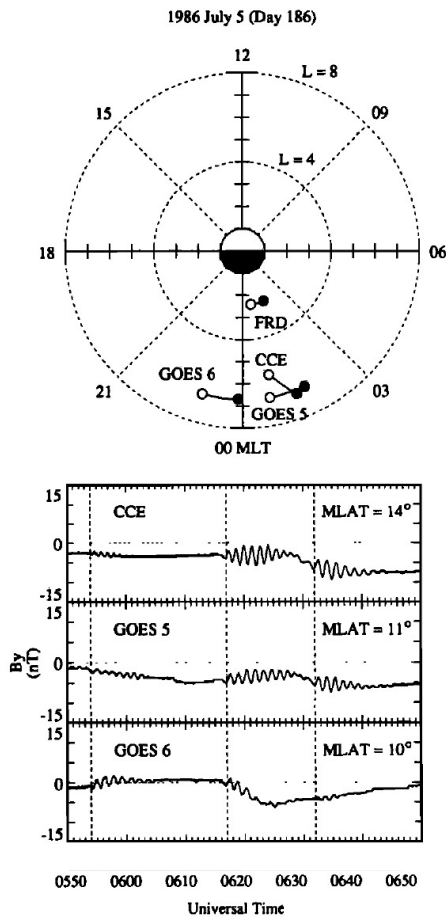
Preparation of Arase-SuperDARN conjunction event analysis to investigate the spatial structure of FLR excited by substorms

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Introduction: Transient Toroidal Waves

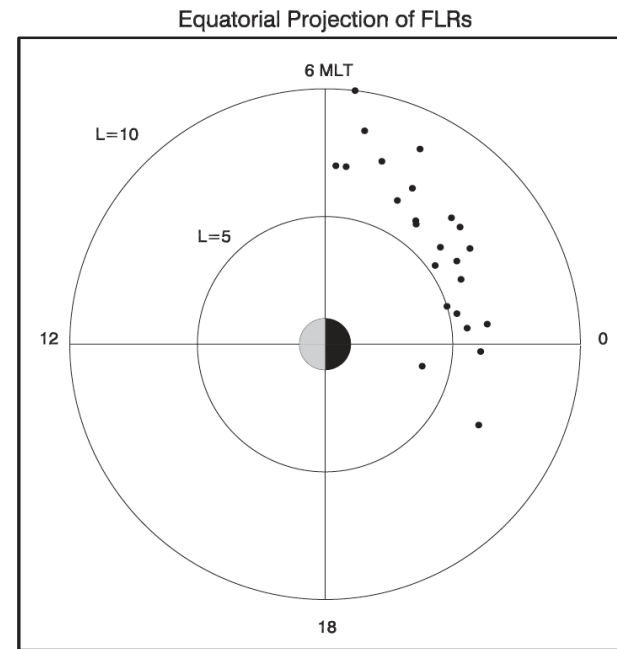
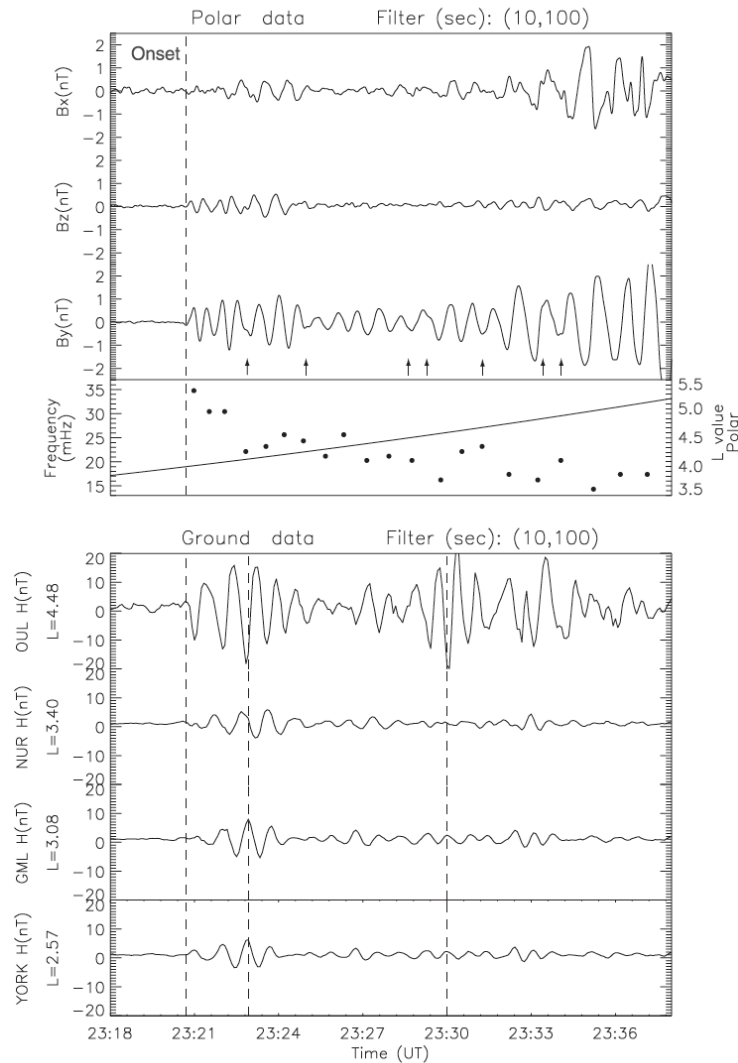


- Transient Toroidal waves (TTW) standing toroidal mode waves with Pc4 frequencies (6.7-20mHz), which are excited by the substorm onset [e.g. Takahashi et al., 1996].
- TTW and Pi2 pulsations are simultaneously observed in inner magnetosphere by satellites.

[Takahashi et al., 1996]

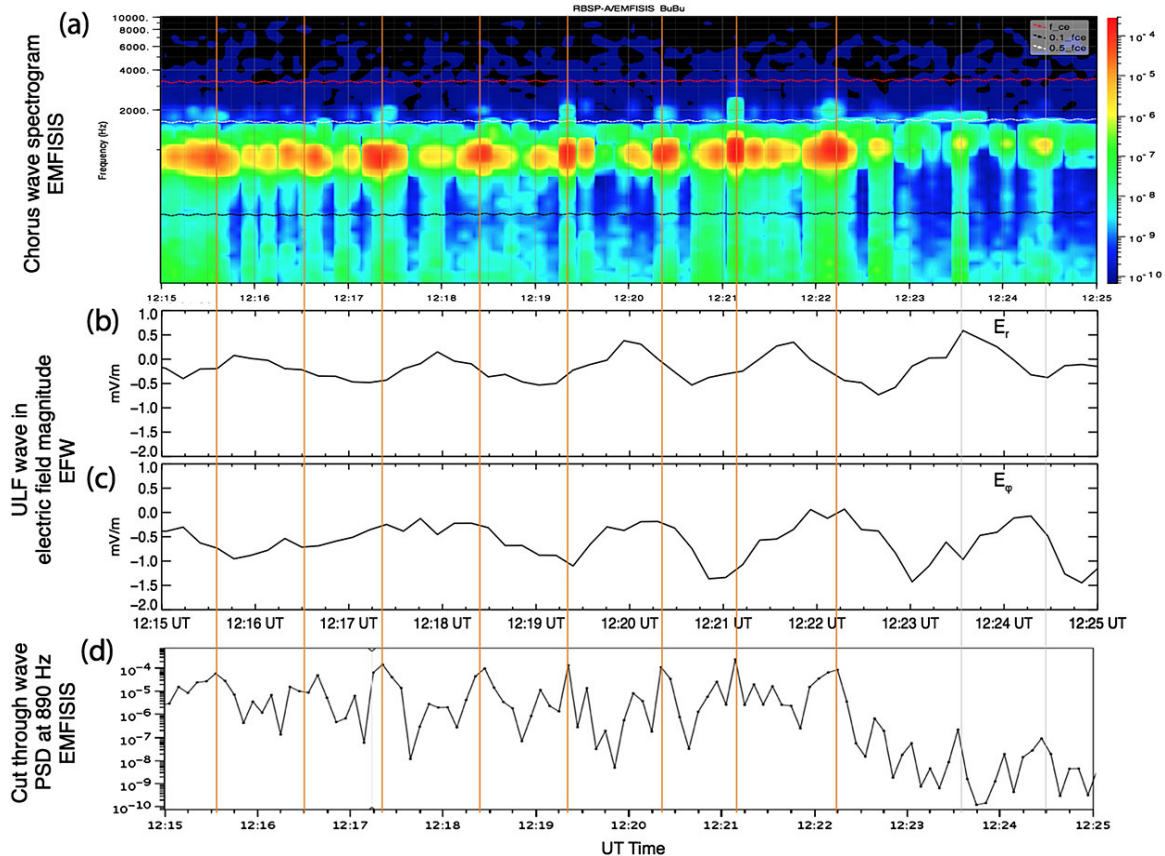
Spatial distribution of TTWs

- TTWs frequently occur at $4 < L < 7$ in the post-midnight sector [Keiling et al., 2003].
- Durational time of TTW (several minutes) is longer than that of Pi2 pulsations.
- Off-equatorial satellites can easily identify TTW.



[Keiling et al., 2003]

Substorm-related toroidal mode wave: Plasma and Plasma plasma waves interaction



[Jaynes et al., 2015]

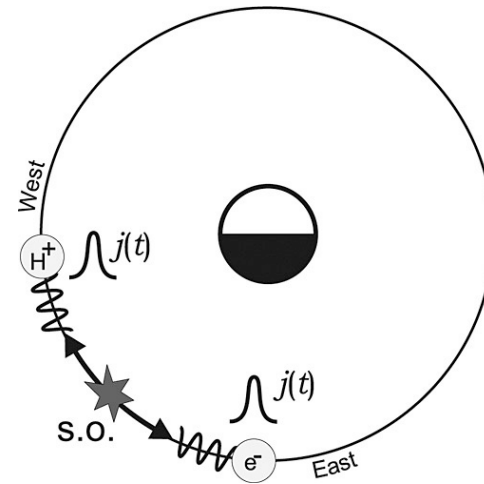
- The modulations of chorus emissions caused by poloidal and toroidal mode ULF waves are also reported [Jaynes et al., 2015; Liu et al., 2019; Zhang et al., 2019]
- Substorm-related toroidal mode ULF waves can modulate the distribution of energetic electrons via their spatial structure and cause chorus emissions [Ohno et al., to be submitted].

Motivation

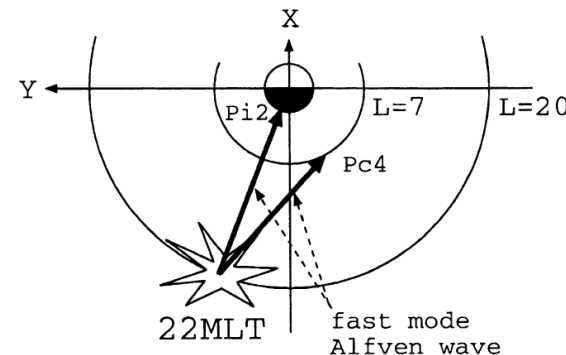
- Sinusoidal toroidal mode Pc4 waves associated with substorms have been reported in off-equatorial satellite observations. However, the spatial structure of these toroidal mode waves is not well understood.
- In order to investigate the spatial structure of transient toroidal mode waves and clarify their generation mechanisms and interactions with plasma waves, a detailed analysis using both ground-based (SuperDARN) and satellite observations is needed.

→ Investigate wave characteristics of TTWs by Arase satellite and ground (SuperDARN) observations.

Possible generation mechanisms



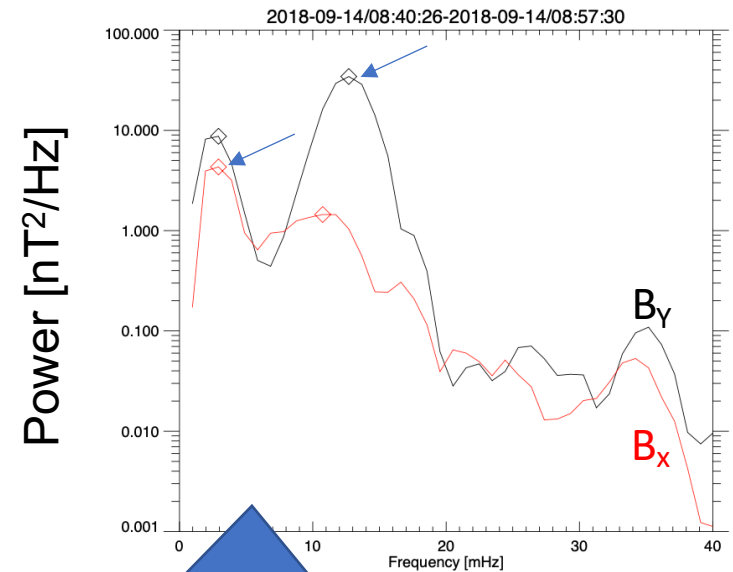
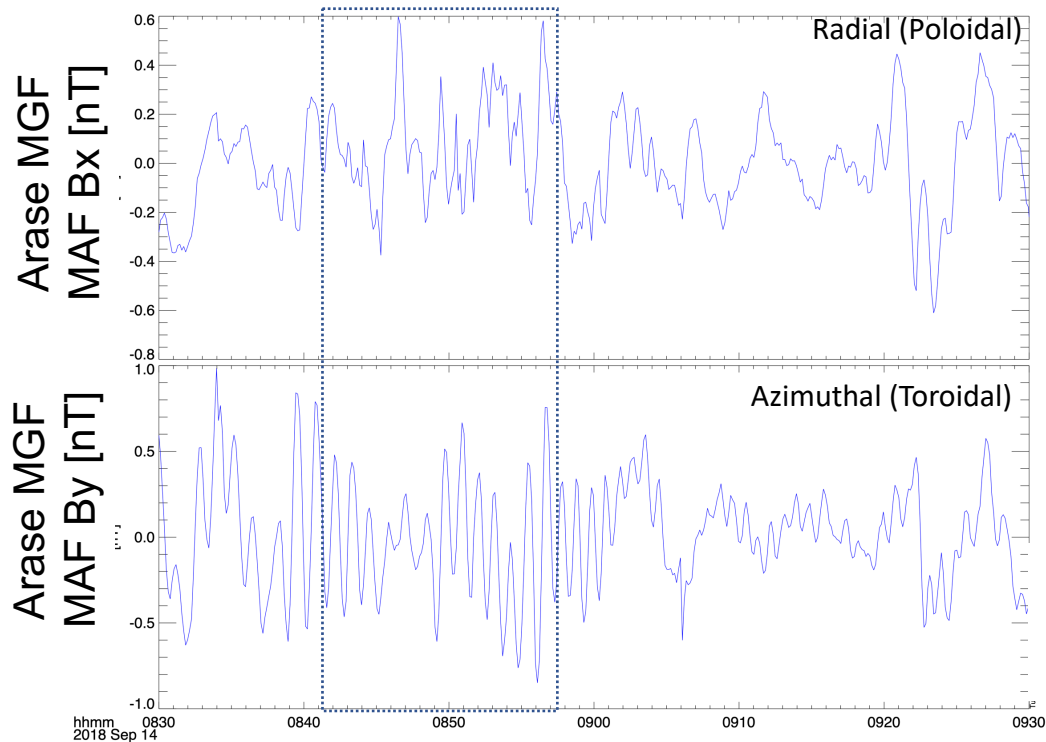
Moving-source theory
[James et al., 2013]



Coupling Alfvén waves

[Nose et al., 1998]

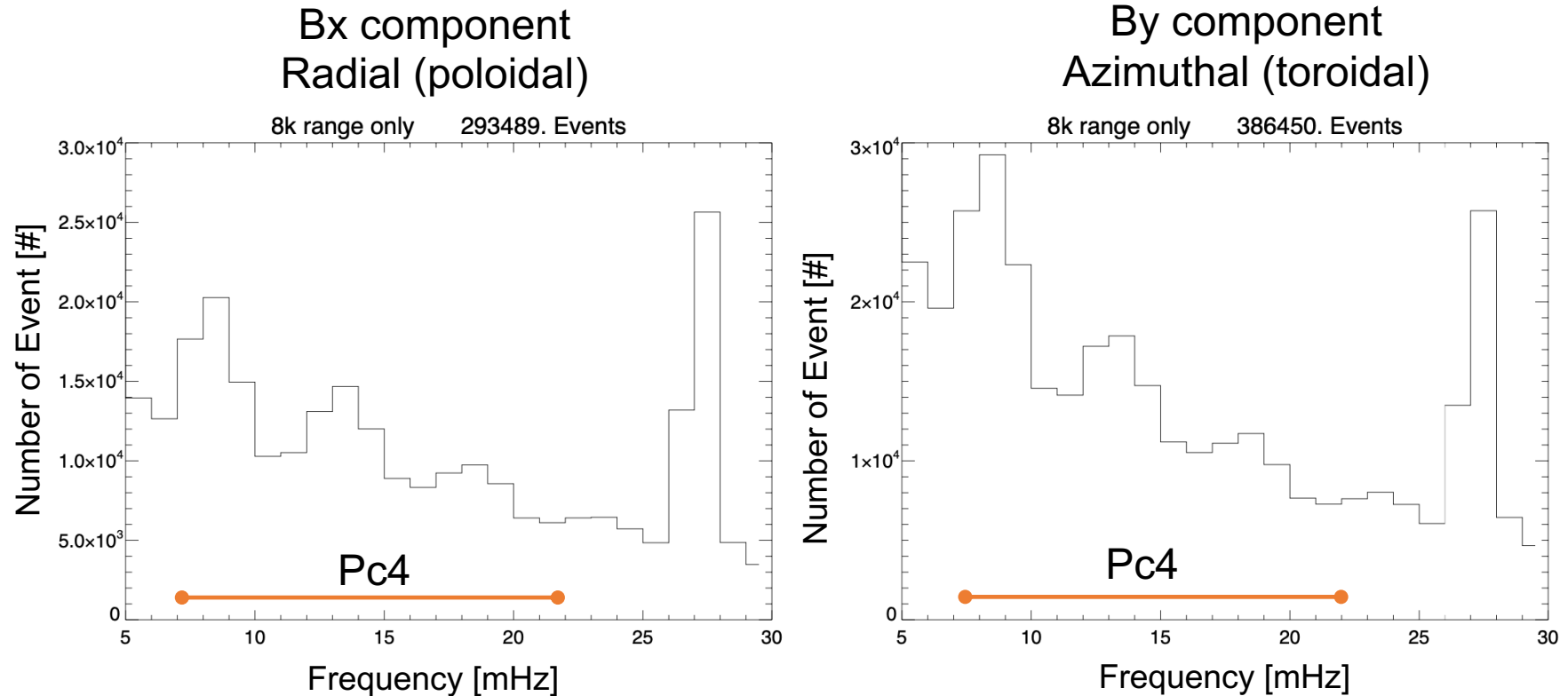
Event selection: sinusoidal ULF wave list



We identified sinusoidal ULF waves in the magnetic field observed by Arase satellite

- Use spin average data (8sec) for about 5 years (March 2017-December 2021).
- We utilized FFT with a 17-minute time window sliding every 1 minute to automatically check the peak power and frequencies of the azimuthal and radial components.

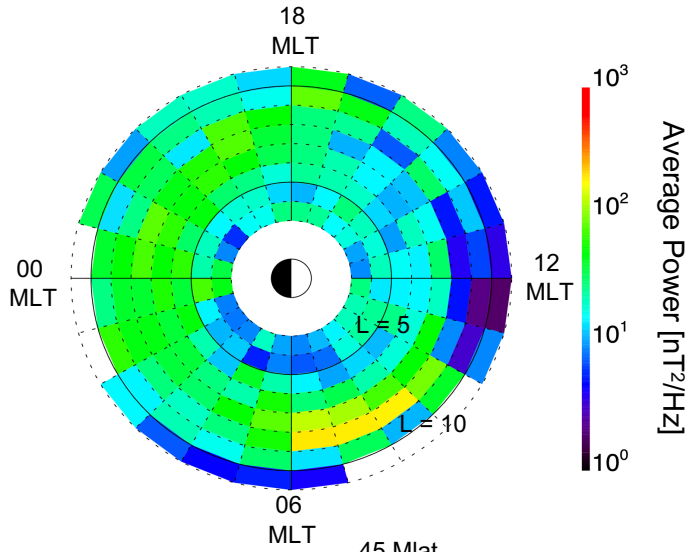
Frequency distribution of ULF observed by Arase



Arase observe toroidal mode Pc4 waves more frequently than poloidal mode waves.

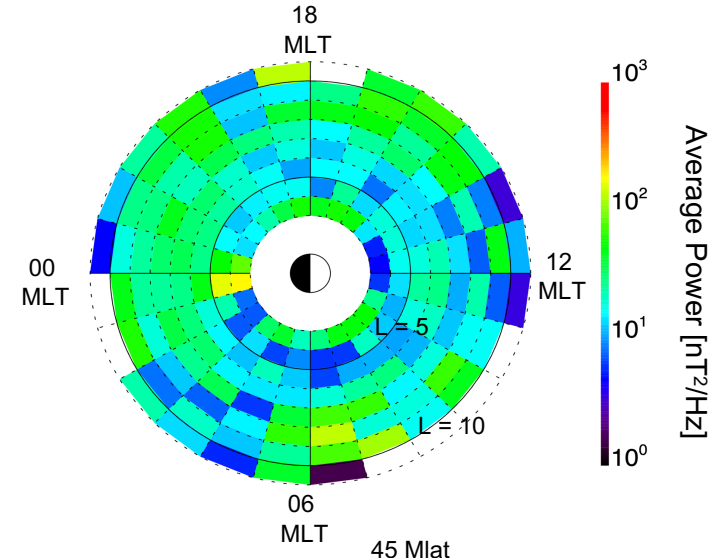
Power distribution on MLT-L and L-Mlat

Toroidal mode Pc4 $P_t(f_{Pc4})/P_p(f_{pc4}) > 1.5$

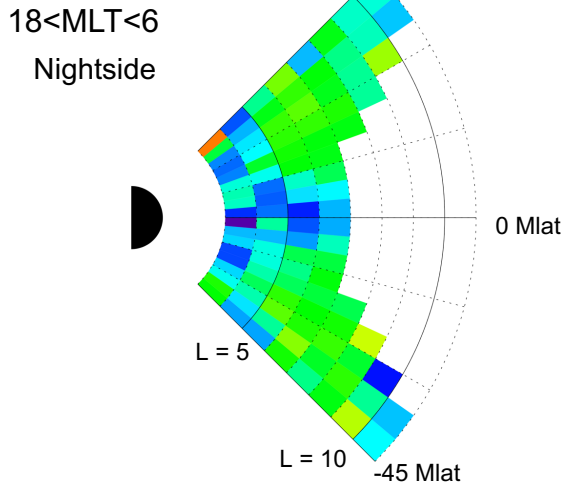


The power of the toroidal Pc4 waves is large on the nightside (18-06MLT) at L=5~8.

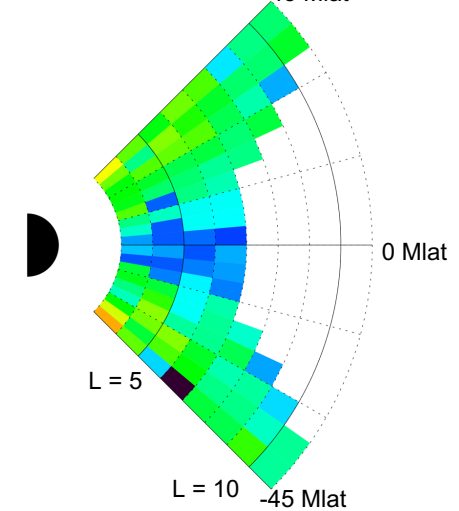
Poloidal mode Pc4 $P_p(f_{Pc4})/P_t(f_{pc4}) > 1.5$



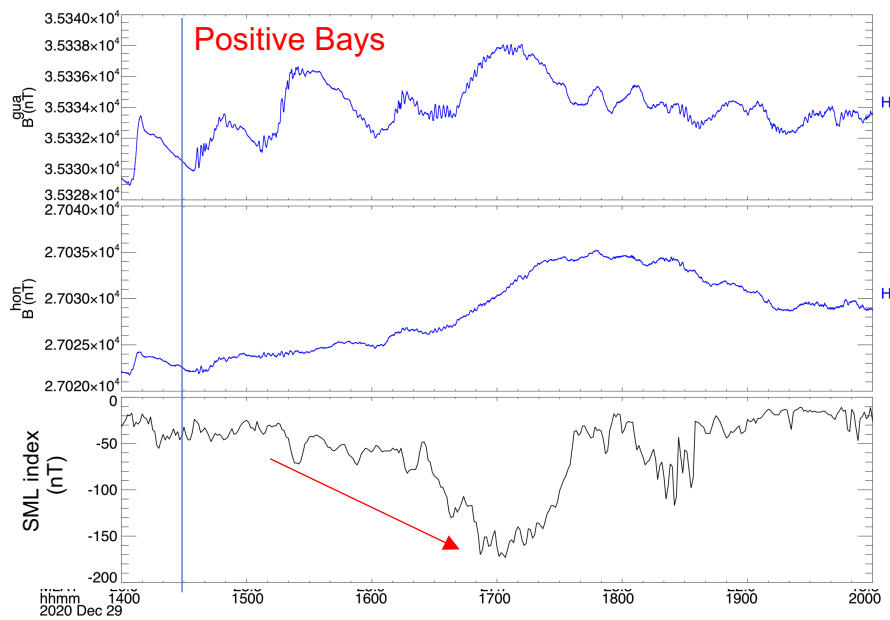
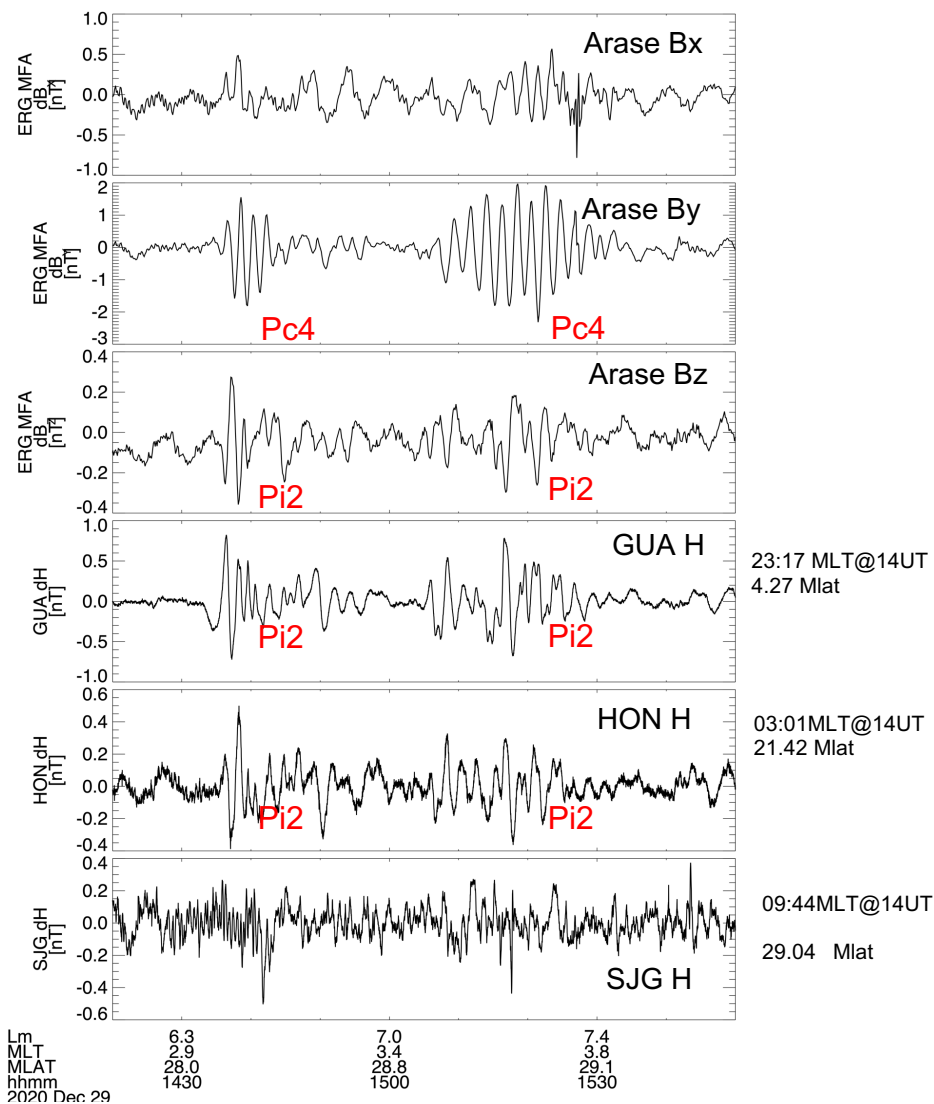
The average power is large off the magnetic equator (20>Mlat)



18<MLT<6
Nightside

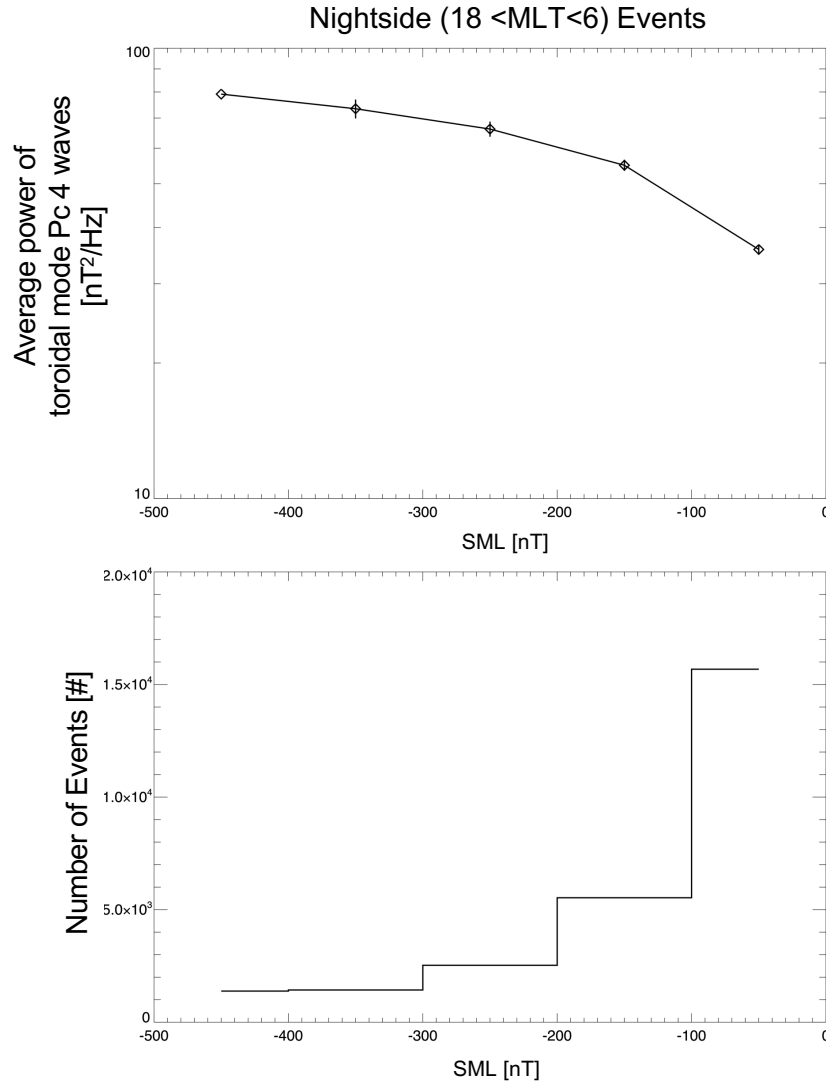


An Example of TTWs



- Arase simultaneously observed transient toroidal mode Pc4 waves and Pi2 pulsations at substorm onset.
- Waveforms of Pi2 pulsation observed by Arase are similar to those at ground station.

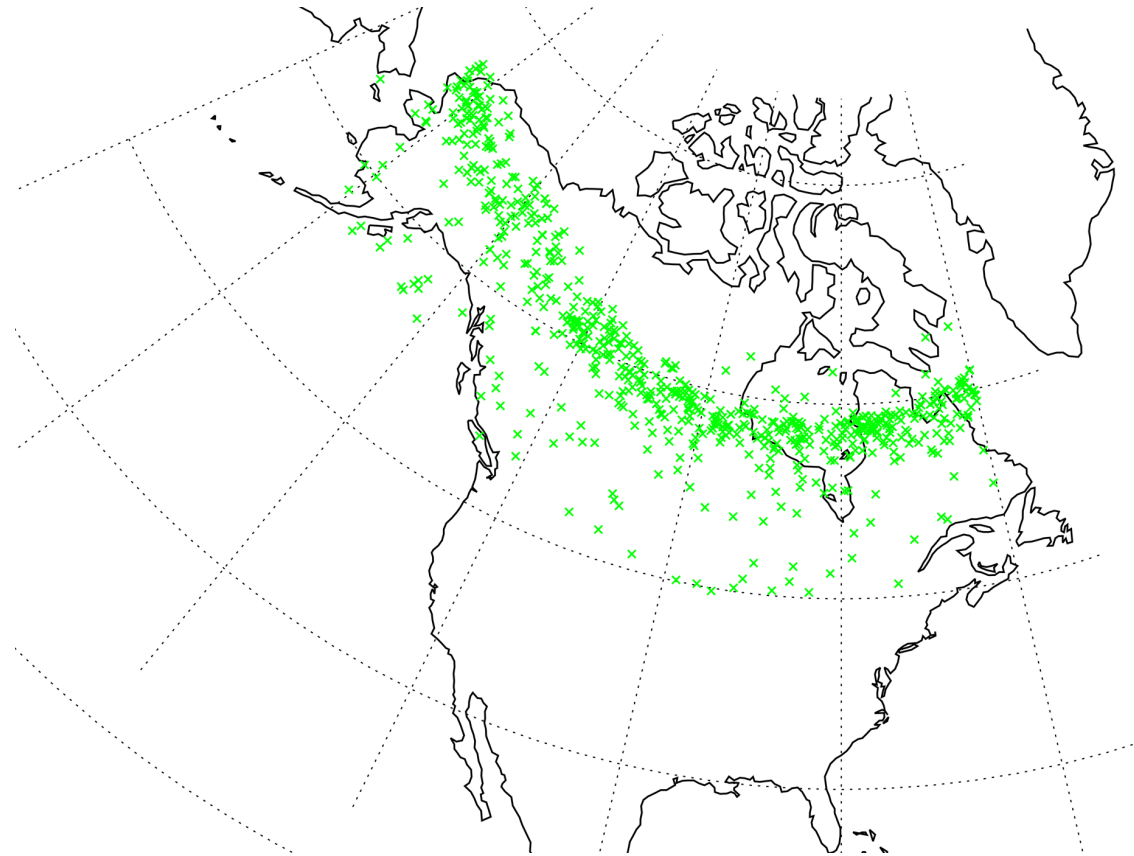
Comparison with SML index



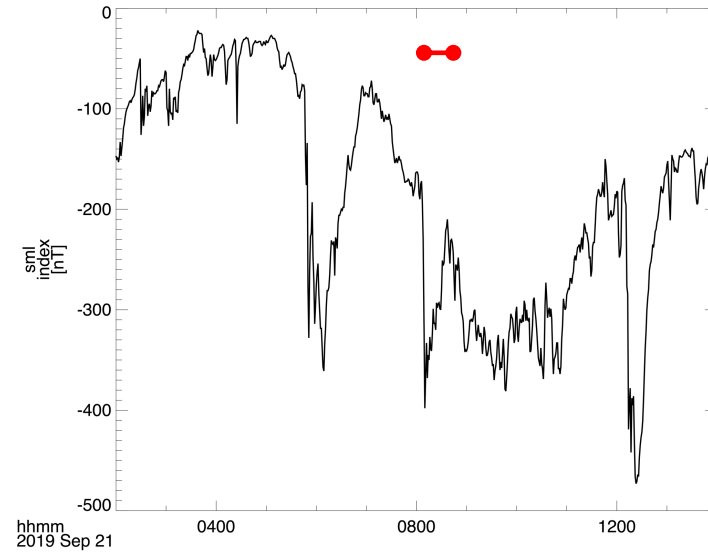
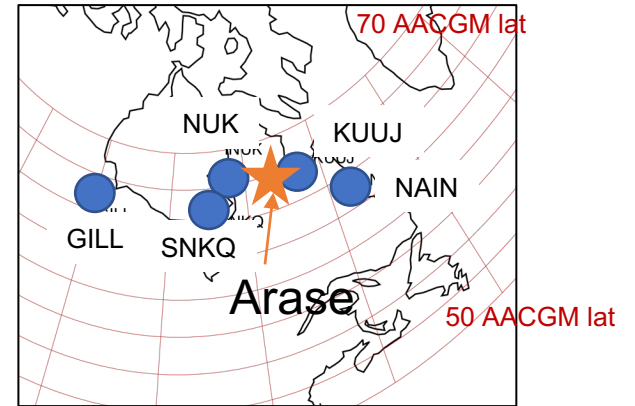
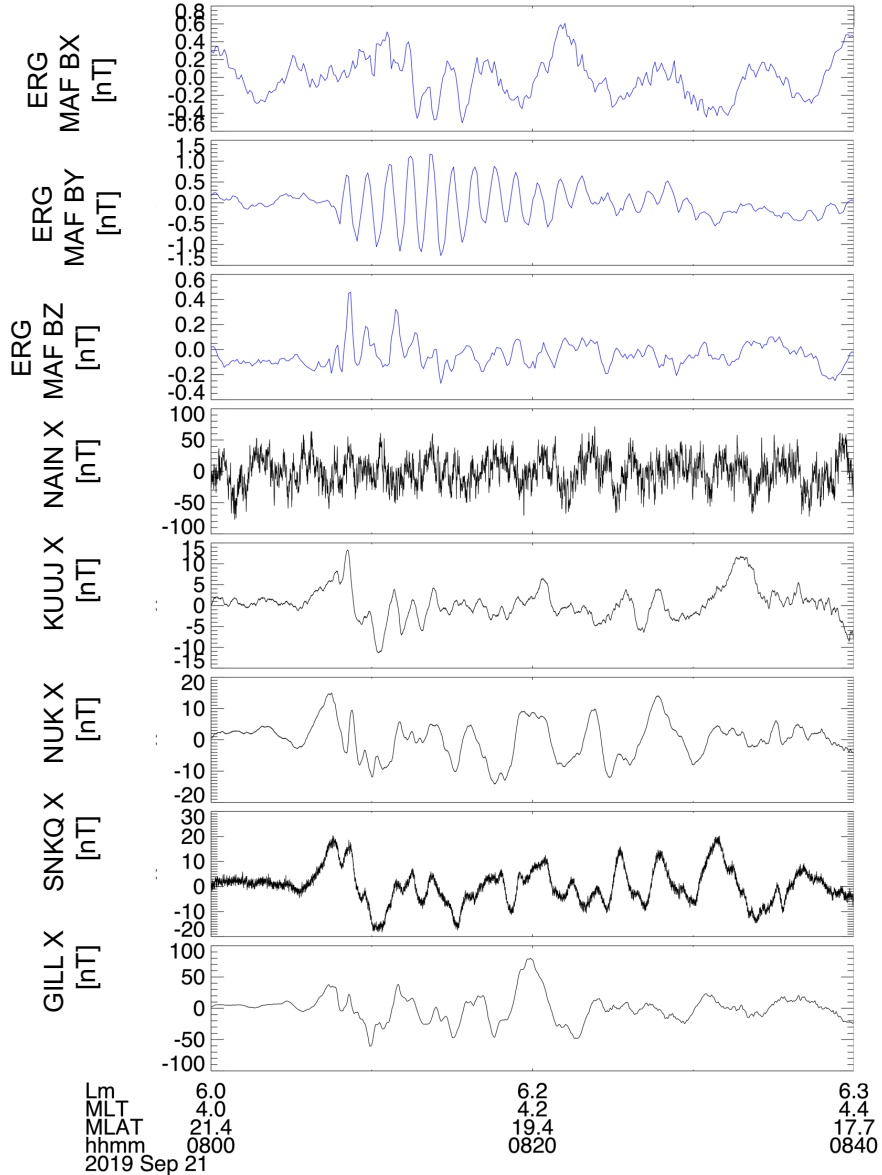
- Power of toroidal Pc4 waves increases as SML index decrease.
- Nightside toroidal waves frequently are excited at small SML values (SML < -100nT).
 - Nightside toroidal Pc4 waves can be excited during quiet or pseudo substorm periods.

Arase locations over the North America during nightside toroidal mode waves events

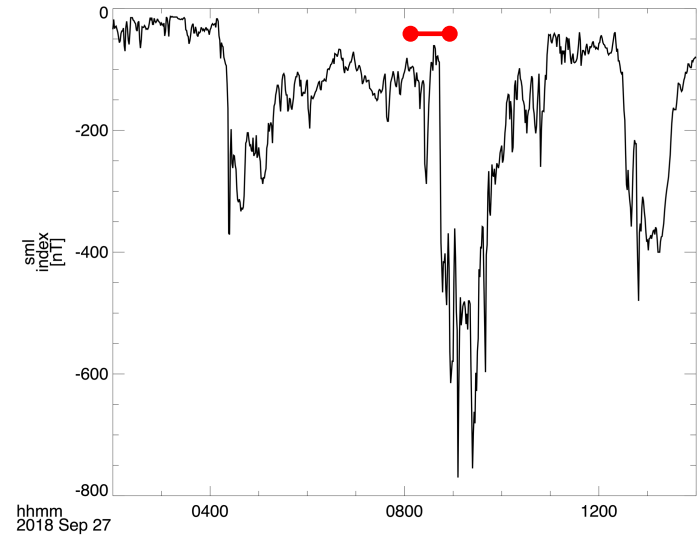
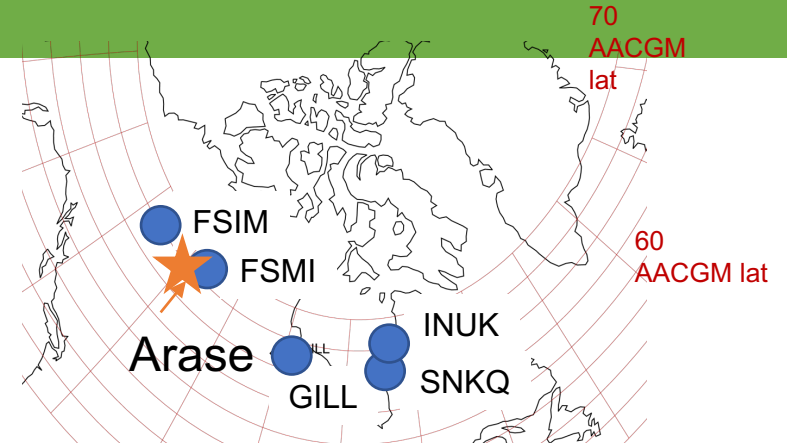
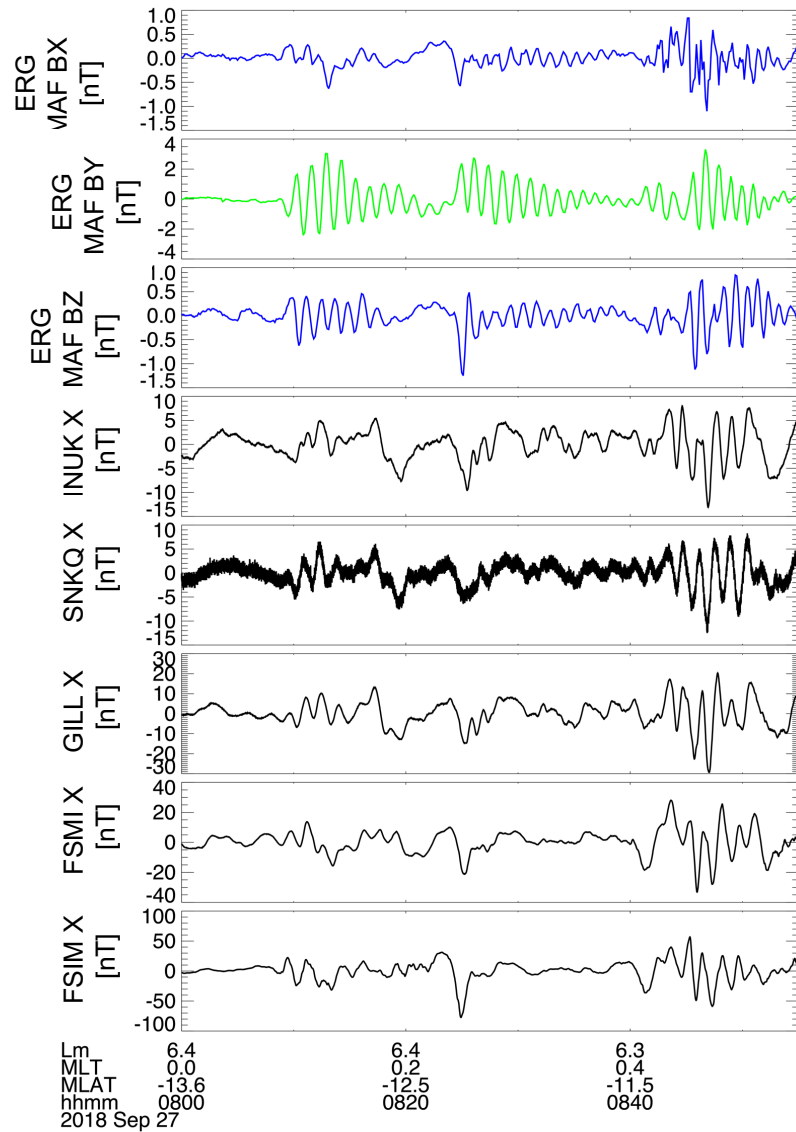
- From the ULF list, we identified 684 toroidal mode events when the Arase footprint was located over the North America and at 18-06 MLT.

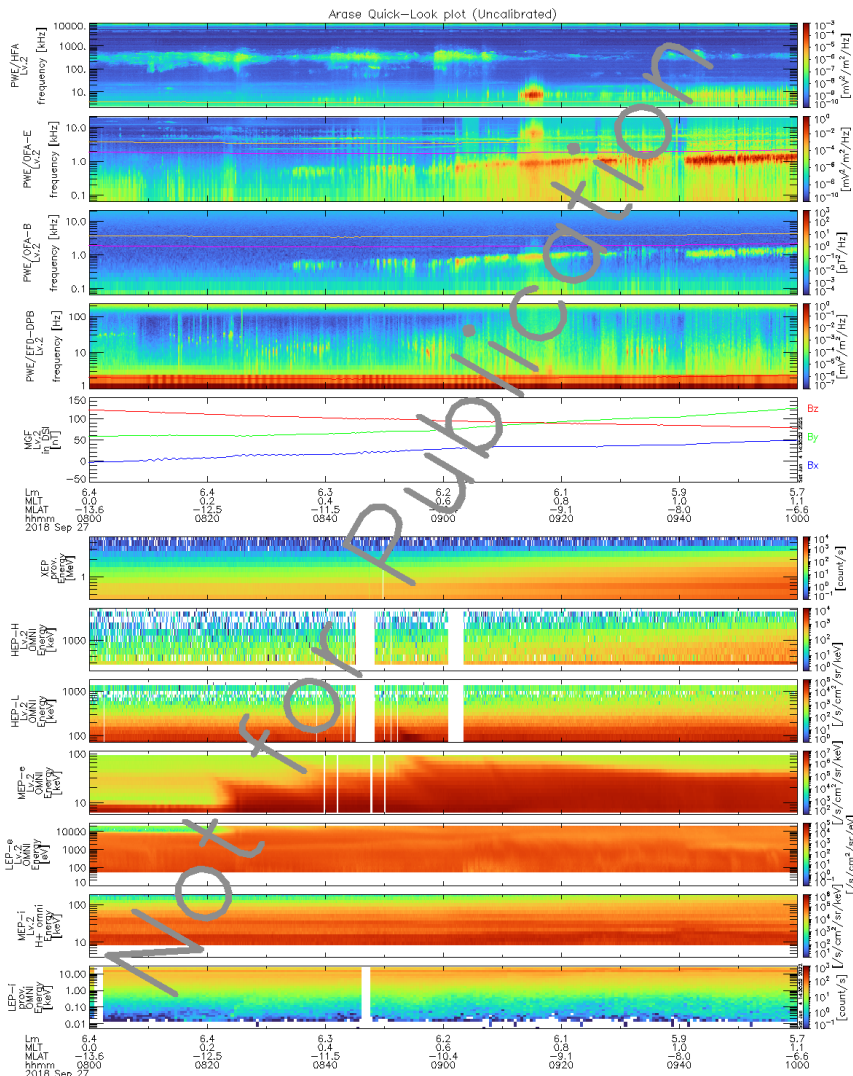


TTW events



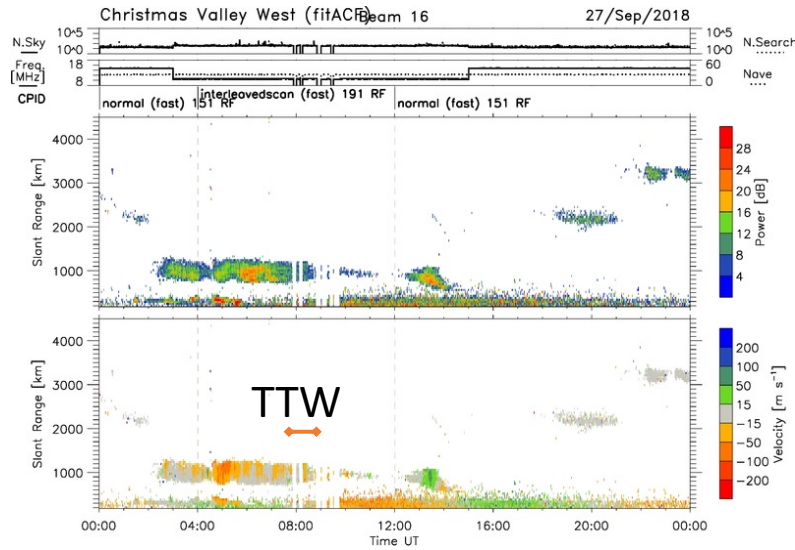
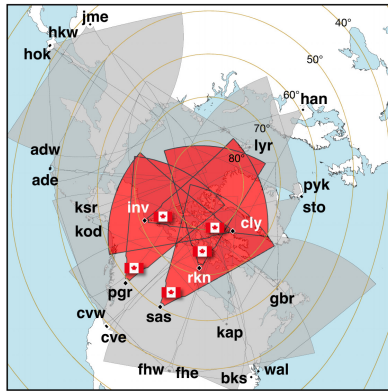
TTW event 2



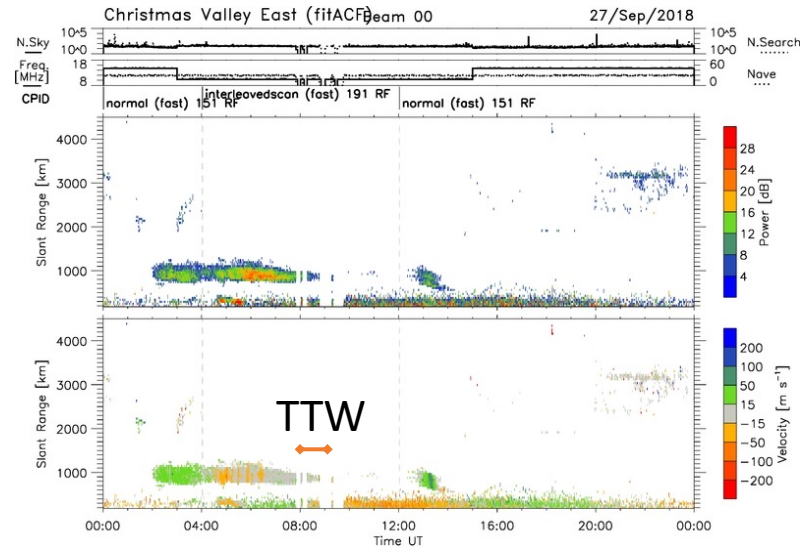
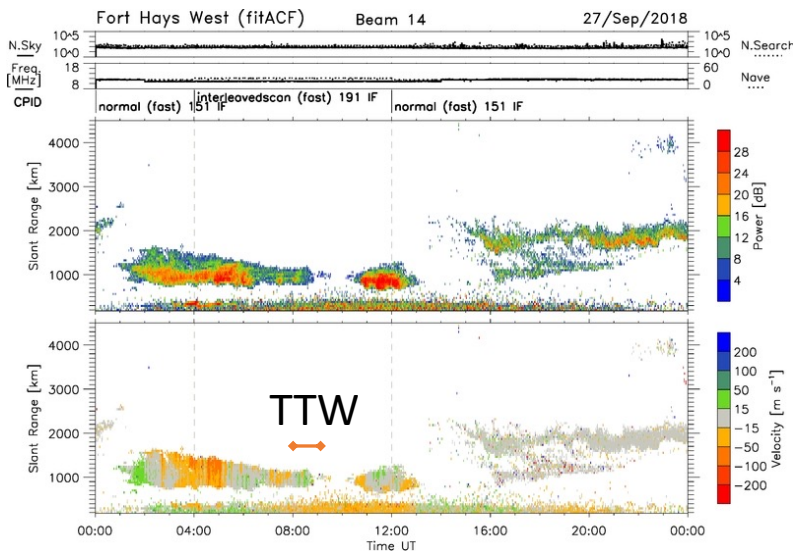


- Injection後にULF周期のchorusが発生
- Injectionがない状態だとULFが発生してもchorusはない。
- Electronがmodulationされる。
→freshなelectrons+ULFでchorusが起きる？

TTW Event 2



during the TTWs event, mid-latitude SuperDARN observed some echoes in interleaved scan mode. → We may investigate the spatial structure of the Pc4 waves by the radars.



<http://vt.superdarn.org/tiki-index.php?page=Range+Time+Browse>

Summary

- Arase orbit is advantage for the observation of toroidal (or/and) poloidal mode ULF in the magnetic field.
- To investigate the spatial structure of transient toroidal mode waves associated with substorm, we will examine the toroidal mode waves observed by Arase when its footprint was located over North America.
- We identified a significant toroidal mode wave event during interleaved scan operation mode of SuperDARN.
 - We will examine the wave signatures from the echoes and compare them with satellite observations.