“Caterpillar-like ULF waves” detected by SuperDARN during SuperDARN-Arase conjunctions in Fall 2022

2022 年秋の SuperDARN とあらせ衛星共役観測によって捉えられたイモムシ型 ULF 波動の特性

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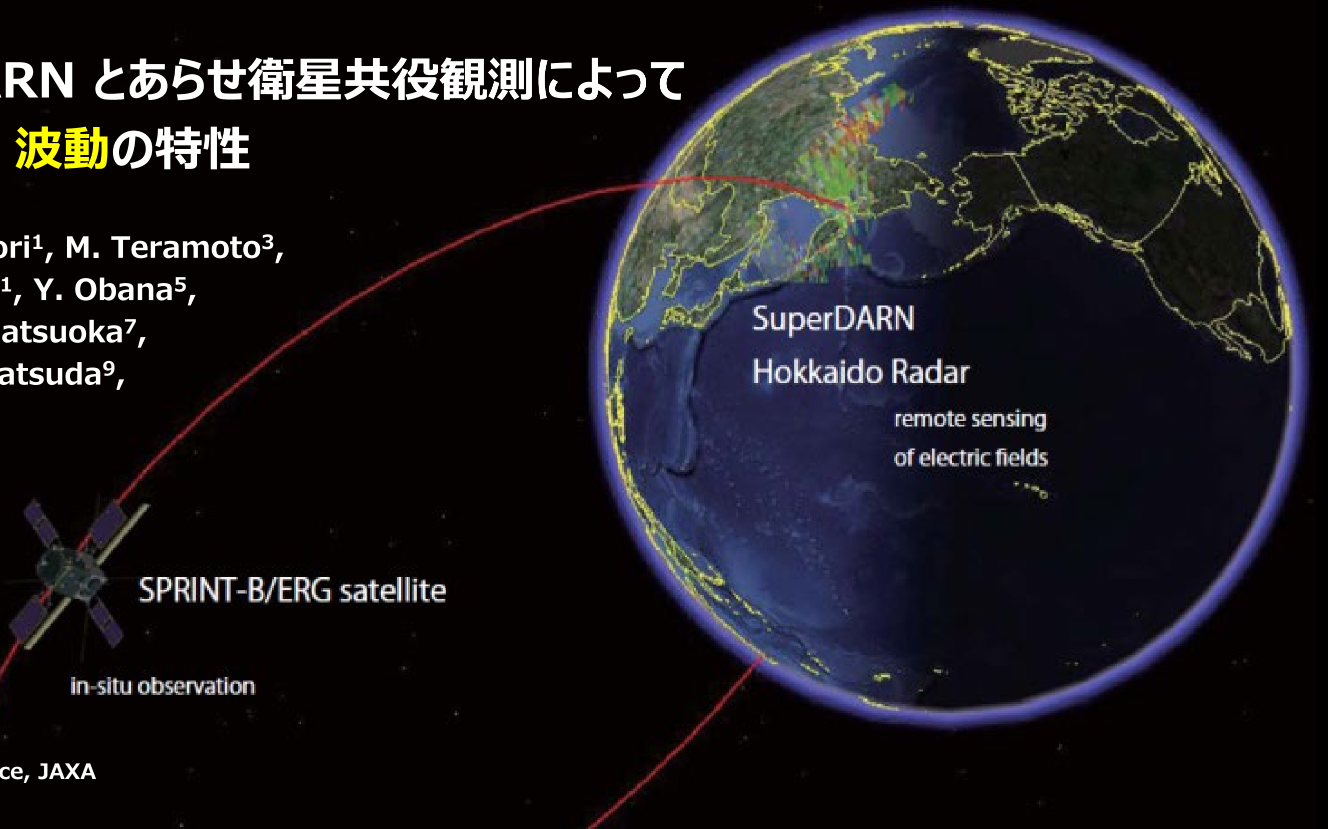
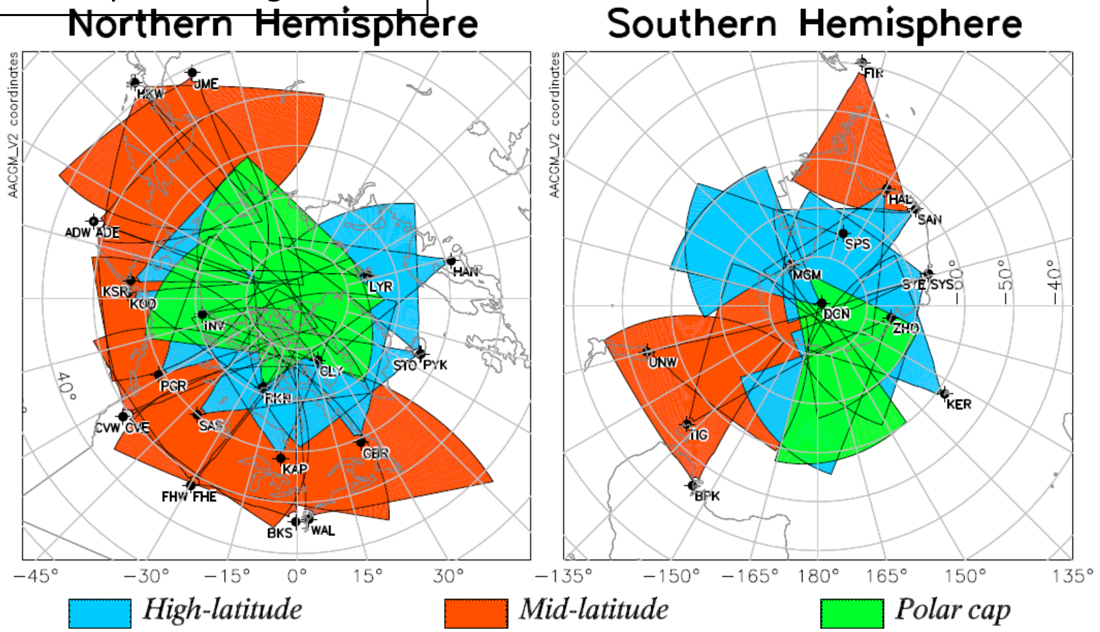


Super Dual Auroral Radar Network (SuperDARN)

From vt.superdarn.org website

Standard temporal resolution: 1-2 min

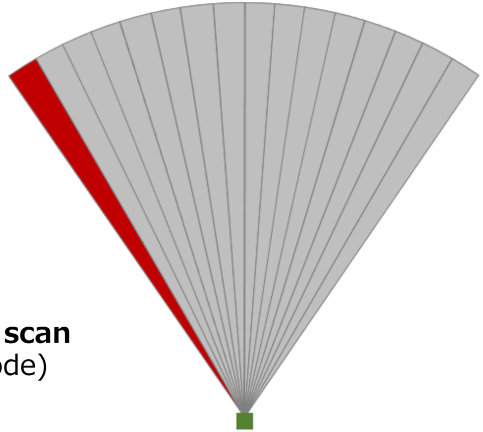


Number of operating HF radars: 38 (24 in the northern and 14 in the southern hemi-spheres) as of Nov 01, 2020, operated under the cooperation of about 10 countries

The radars use basically the same hardware architecture, same operation software, same schedule, same data format and same data analysis software, provide important information for the space weather / geospace dynamics studies.

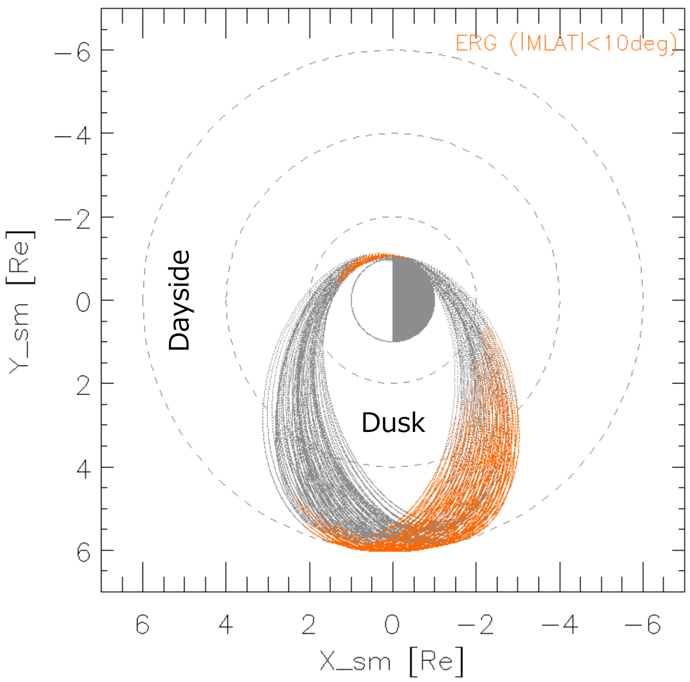
Conjunctions of SD with Arase in autumn 2022

- Arase covered the auroral/subauroral region on the dusk side which is a hot spot of irregularities (= source of radar echoes)
- Submitted special time requests for running interleaved_normalscan in support of Arase for 4 months from Sep to Dec, 2022
- Requests were approved for ~5 days/month
- May be able to track variations faster than the normal beam steering



Interleaved normal scan
(so-called Arase mode)

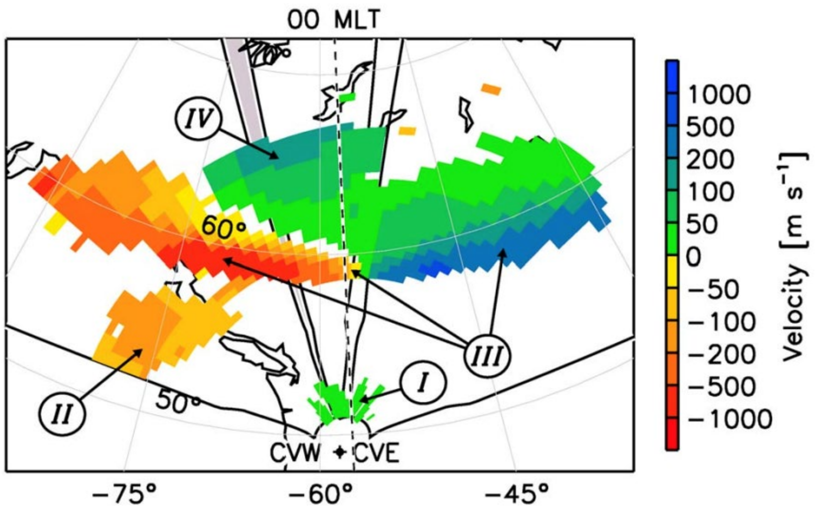
November 2022



Possible targets of special time observations

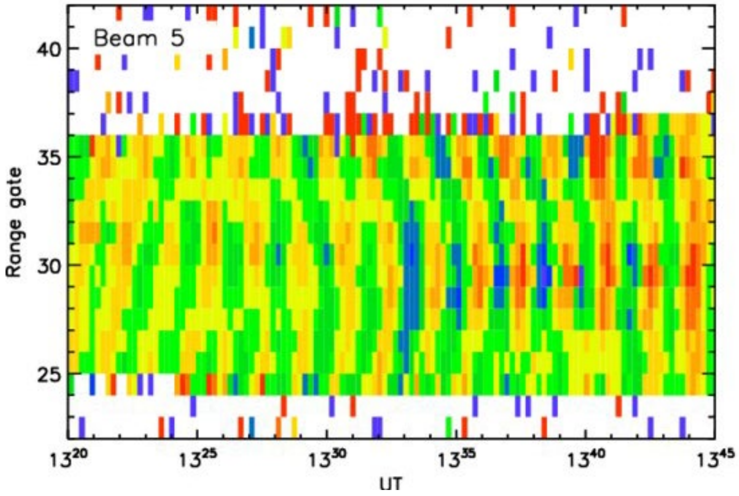
- Subauroral Polarization Stream (SAPS) – Hori et al. at poster on Sep 24
  ~= Subauroral Ion Drift (SAID)
- ULF waves at the auroral / subauroral latitudes in the dusk to pre-midnight sector

SAPS/SAID



Clausen et al. (2012)

ULF waves



Yeoman et al. (2012)

Majority of previous SuperDARN papers studied ULF waves during disturbed periods (Walker et al., 1992)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. A8, PAGES 12,187–12,202, AUGUST 1, 1992

Spatial and Temporal Behavior of ULF Pulsations Observed by the Goose Bay HF Radar

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A detailed analysis of HF radar data of a ULF pulsation event in the postmidnight sector on January 11, 1989, has been carried out using techniques which allow the instantaneous amplitude and phase to be determined as functions of geomagnetic latitude, longitude, and time. Field line resonances with several different frequencies occur simultaneously at different latitudes. These can be associated with cavity mode frequencies of 1.3 mHz, 1.9 mHz, 2.7 mHz, and 3.3 mHz. In addition there is a resonance at 0.8 mHz which does not fit well with a cavity picture. These frequencies are constant to better than 10% over a local time period of nearly 4 hours. They show a packet structure as would be expected if they were triggered by a succession of impulses. The phase changes arbitrarily from packet to packet, but the frequency remains constant. The position of the maximum of the resonance as a function of time changes systematically. It is shown that this arises as the length of the field line changes with time; the resonance remains on the field line having appropriate length and Alfvén speed. The field-aligned currents driven by the resonances can be as large as 5 $\mu A\ m^{-2}$ at ionospheric heights. The data support a picture of modes driven by solar wind impulses. It may be more appropriate to speak of a waveguide rather than a cavity with the phase velocity of the mode matching the velocity of the impulse along the magnetopause. A difficulty associated with this picture is that the great reproducibility of the frequencies is not consistent with the variability of the magnetopause, which forms one of the boundaries of the assumed resonator. It is, however, difficult to conceive of other resonators, for example in the magnetotail, which would provide a better explanation of the observations.

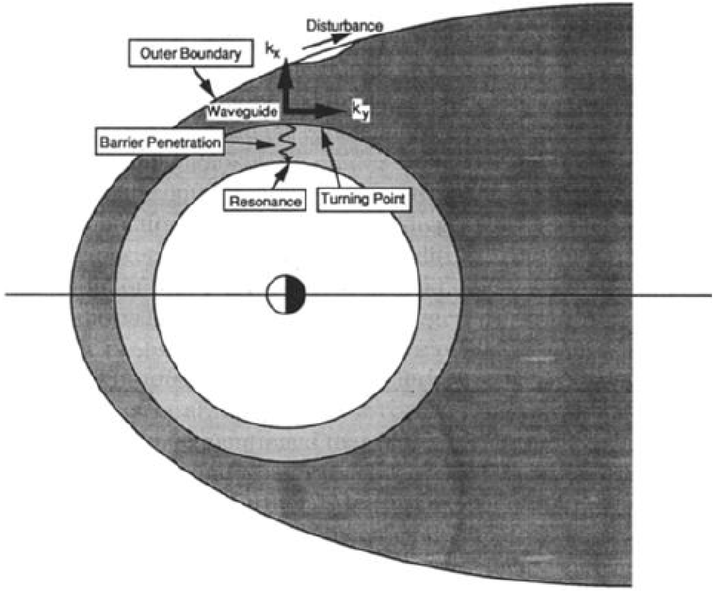

Fig. 1. Schematic diagram of the equatorial plane in the waveguide model.

Proposed waveguide mode disturbance triggered by SW Dp changes

Majority of previous SuperDARN papers studied ULF waves during disturbed periods (Samson et al., 1992)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. A6, PAGES 8495–8518, JUNE 1, 1992

Substorm Intensifications and Field Line Resonances in the Nightside Magnetosphere

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Magnetometer and HF radar data often indicate the presence of magnetohydrodynamic, field line resonances in the nightside magnetosphere. These resonances have frequencies of about 1.3, 1.9, 2.6, and 3.4 mHz and are due to cavity modes or waveguide modes which form between the magnetopause and turning points on dipolelike magnetic shells. Energy from these cavity modes tunnels to the field line resonances which are seen in the F region by the HF radar and on the ground by the magnetometers. The presence of these field line resonances gives us an excellent diagnostic tool for determining the position of the mechanism leading to the energetic electrons and field-aligned currents associated with substorm intensifications and auroral brightening. Using data from the Canadian CANOPUS array of magnetometers, meridian scanning photometers, riometers, and bistatic auroral radars and data from the Johns Hopkins University/Applied Physics Laboratory HF radar at Goose Bay in Canada, we have identified a number of intervals in which substorm intensifications occurred during times when field line resonances existed in the region of the magnetosphere where the intensification occurred. In the events that we have analyzed in detail, the ionospheric signatures of the substorm intensification began equatorward (earthward) of existing field line resonances. These observations give very strong evidence indicating that at least one component of the substorm mechanism must be active very close to the Earth, probably on dipolelike field lines in regions with trapped and quasi-trapped energetic particles. Furthermore, the auroral intensifications started near the position of one of the equatorward resonances, indicating that the field line resonances may play a role in triggering or producing the substorm intensifications. One possible scenario is mode conversion to kinetic Alfvén waves in the resonance.

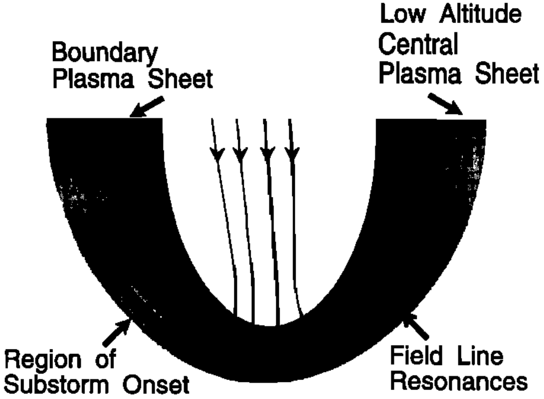
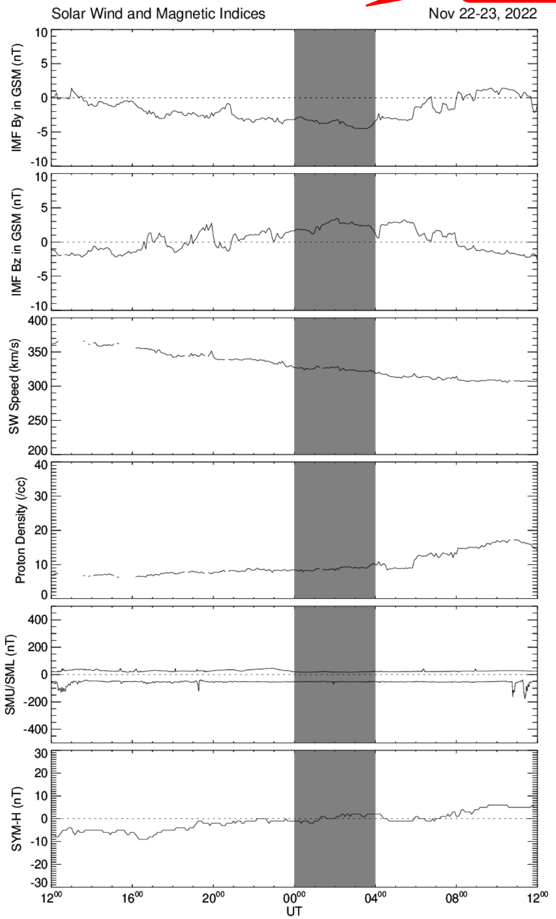


Fig. 31. An approximate schematic of the position of the onset of the substorm in the ionosphere. Convection cells are depicted by the thin lines with arrows giving the direction of flow.

Proposed that FLR leads to substorm intensifications

Example of Nov 23, 2022

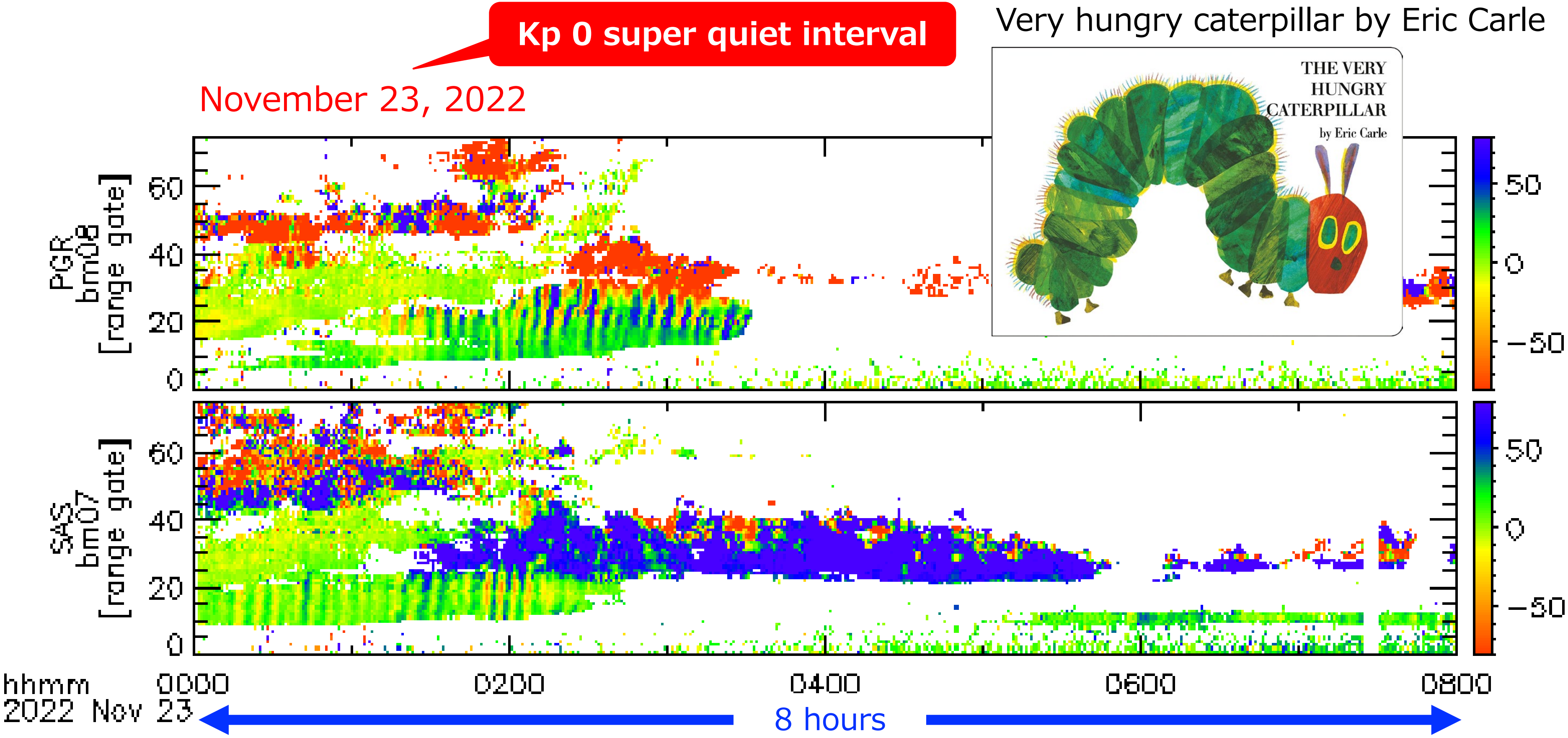
Kp 0 super quiet interval



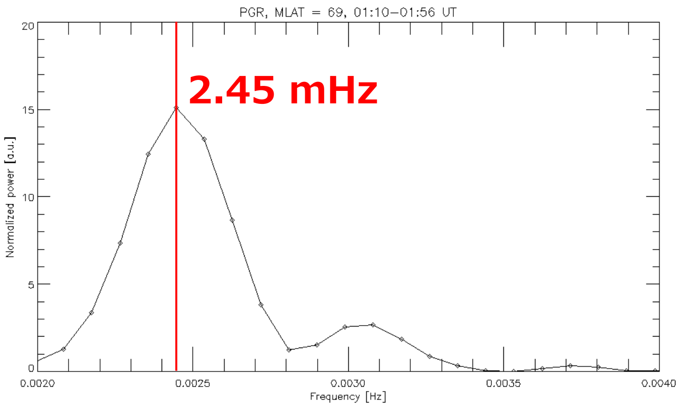
4 hours

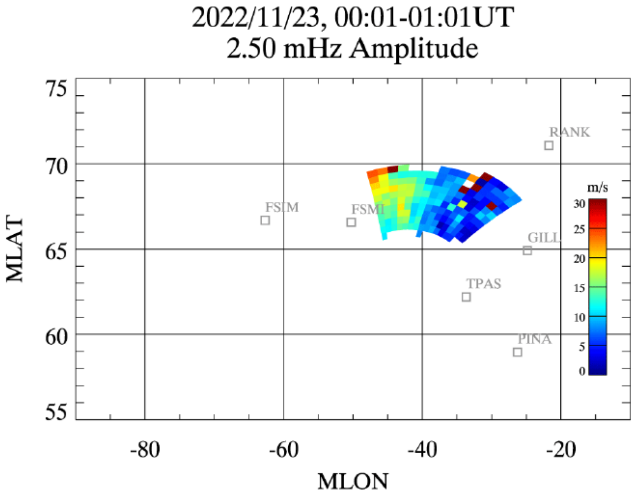
- IMF By/Bz, Plot: 2022 Nov 22 12 UT – Nov 23 12 UT
- Very quiet period
  - IMF Bz: ~ +2 - +3 nT
  - IMG By: -3 - -4 nT
  - SW velocity: 300 - 350 km/s
  - SW density: 7-8 /cc
  - SYM-H: ~0 nT

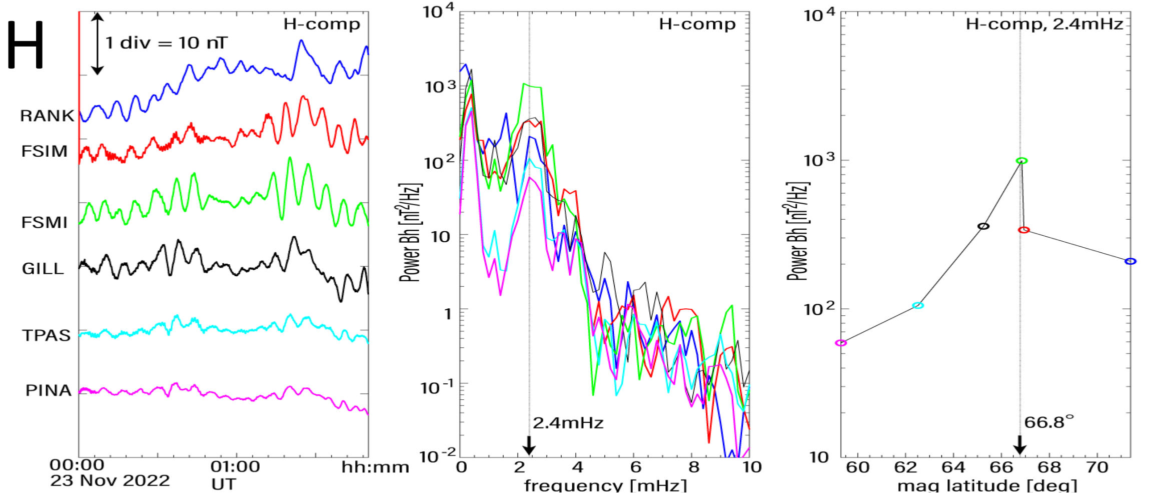
Caterpillar-like ULF signatures on Nov 23, 2022

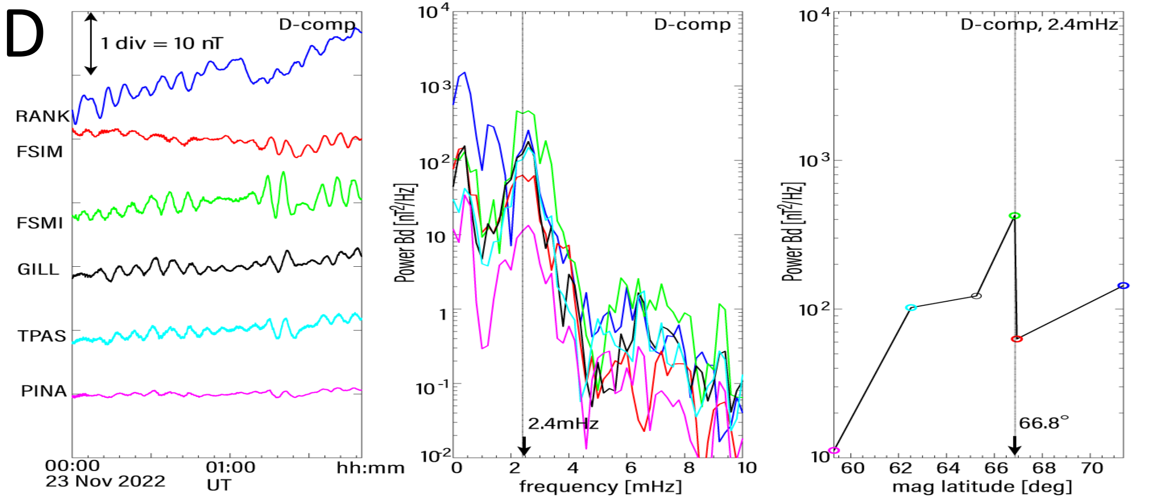


FLR signature?

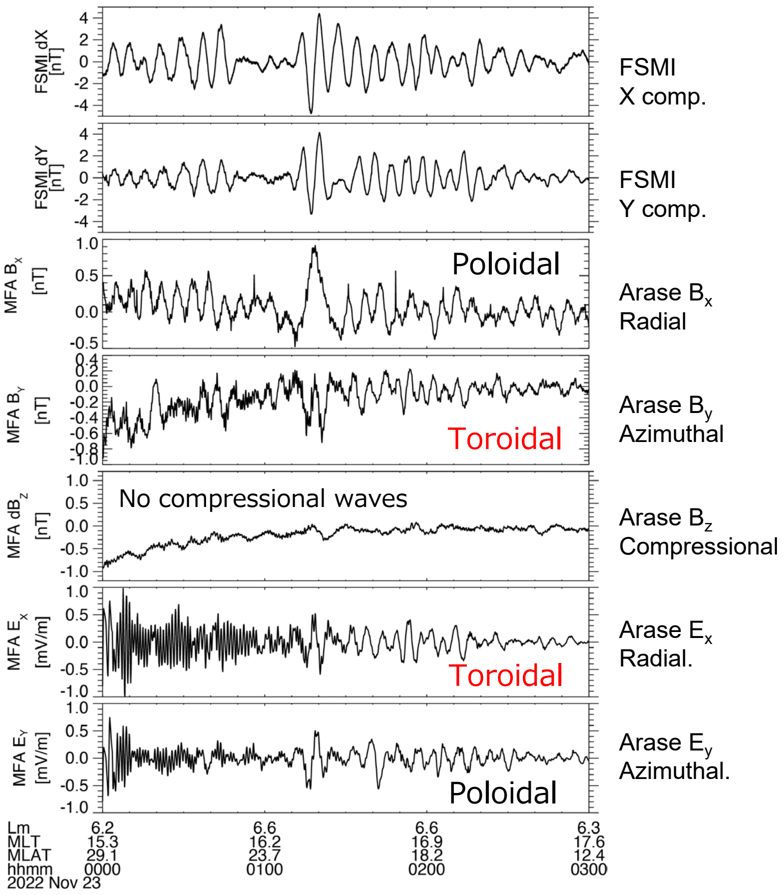




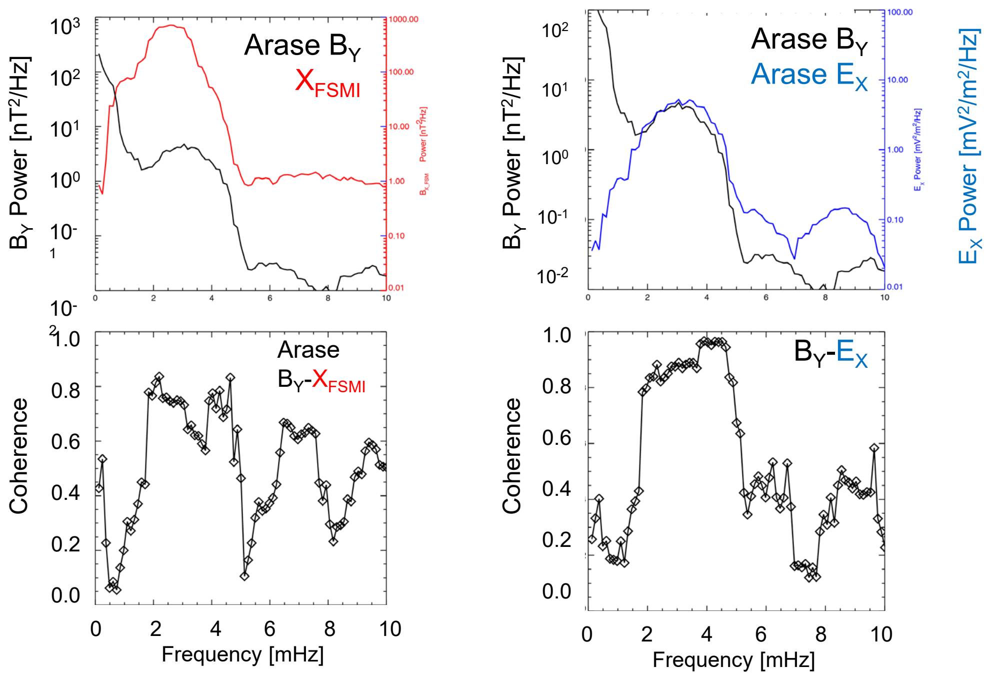




B & E-field from Arase

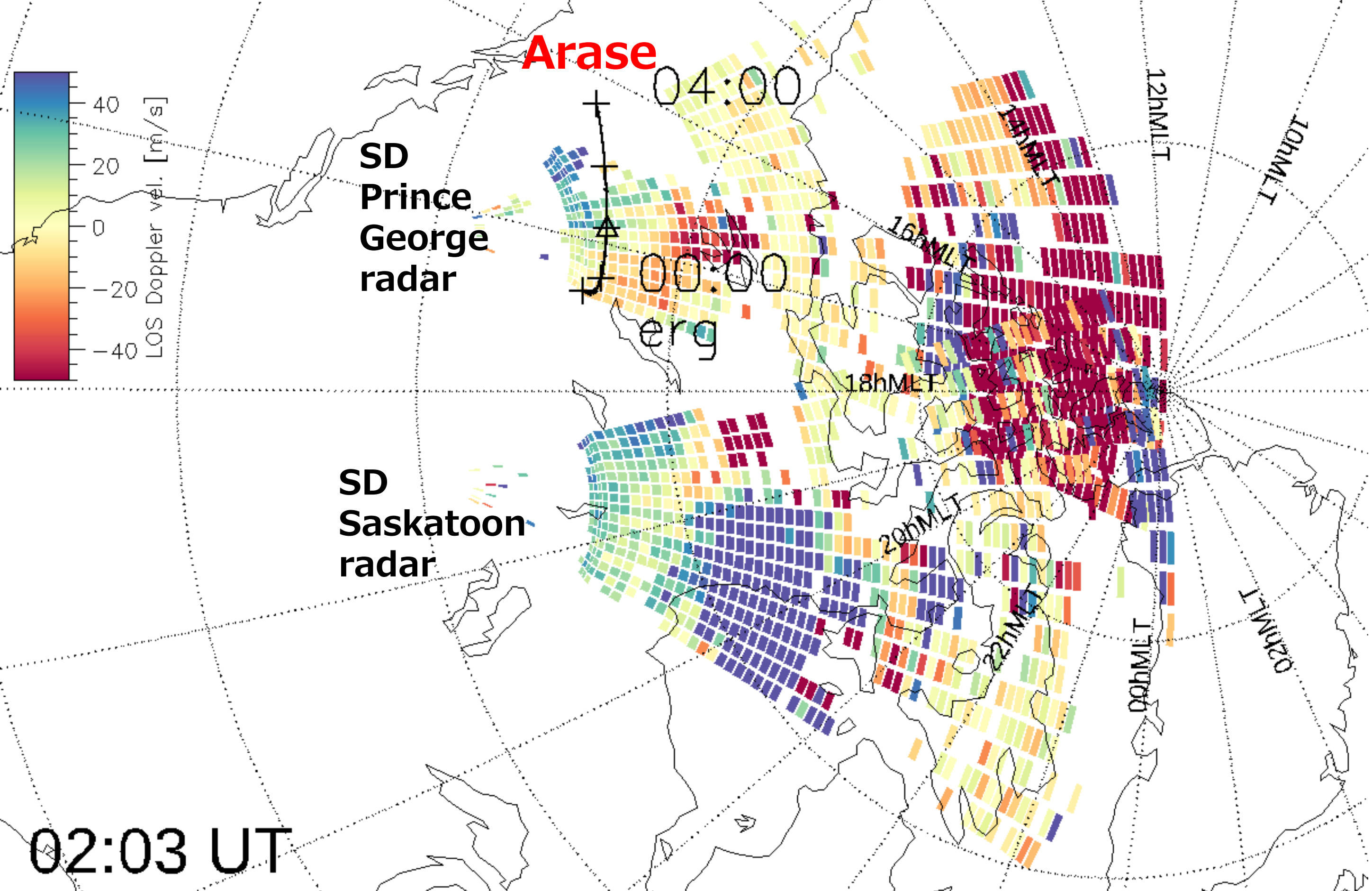


2022-11-22/23:59:59-02:16:23

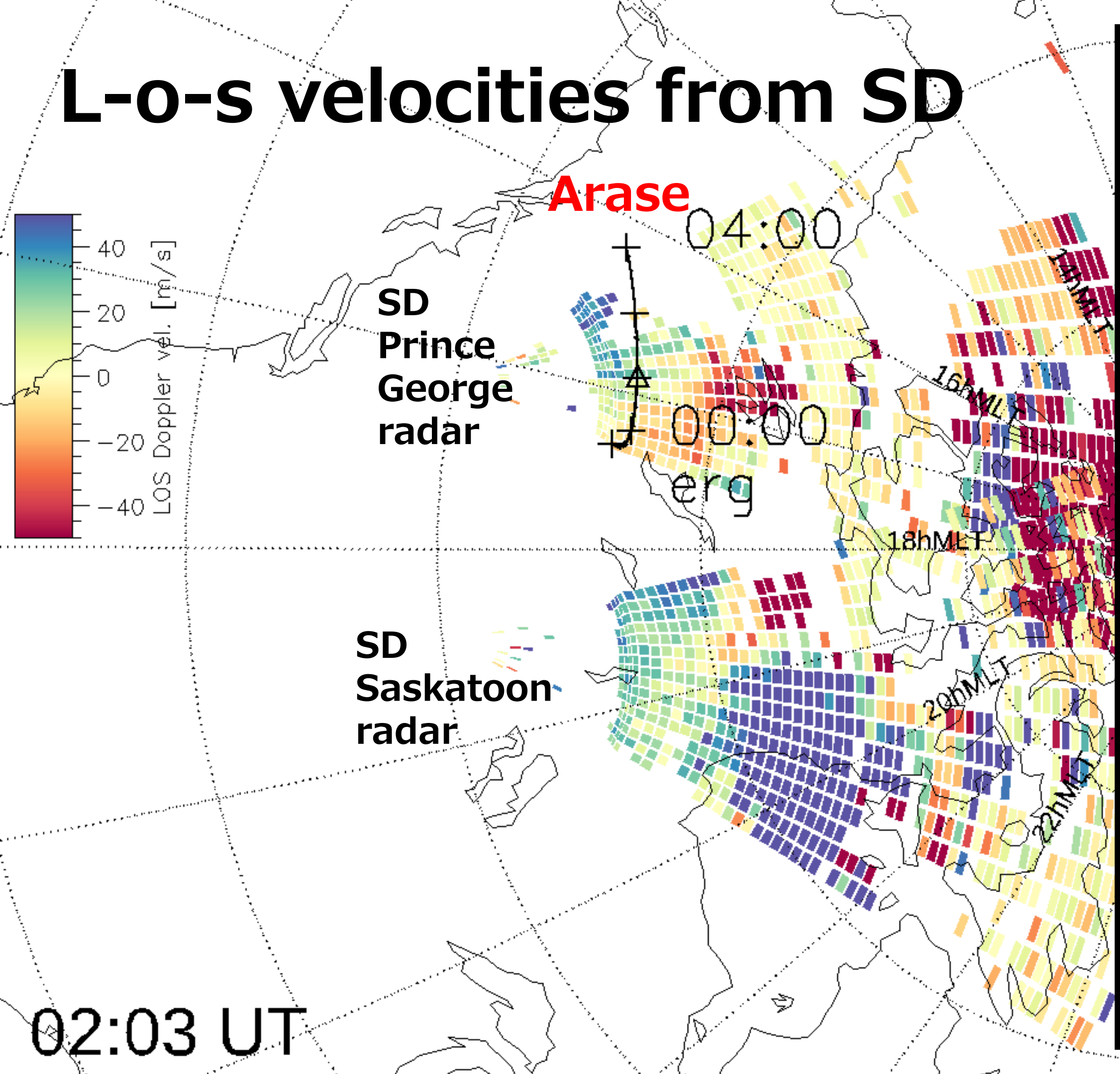


- Toroidal and poloidal mode waves were seen in the B & E fields of Arase
- Toroidal mode waves at Arase showed high coherence (>0.6) with Bx at FSMI

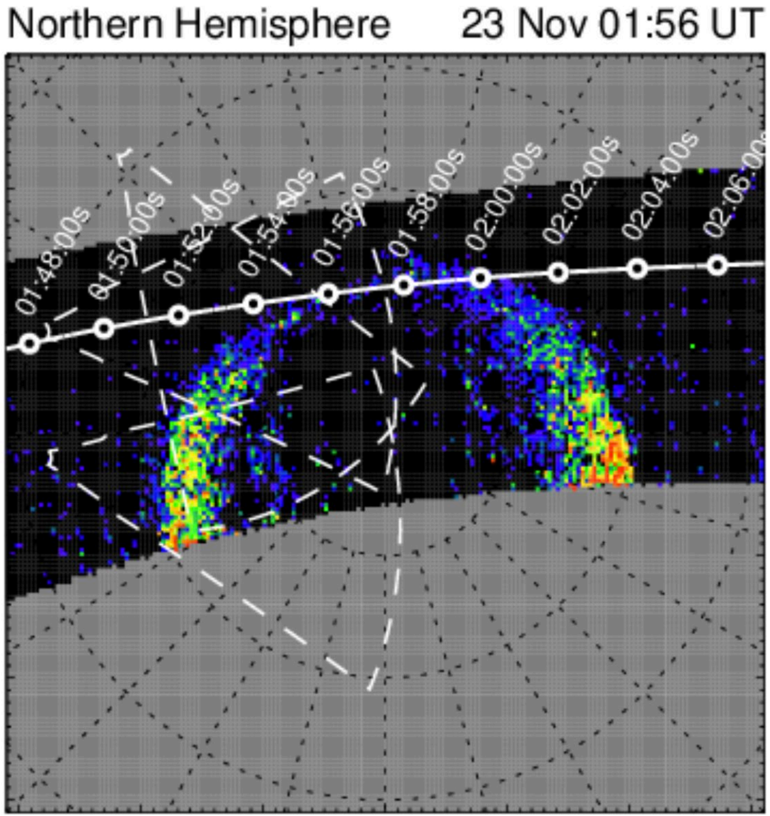
L-o-s velocities from SD

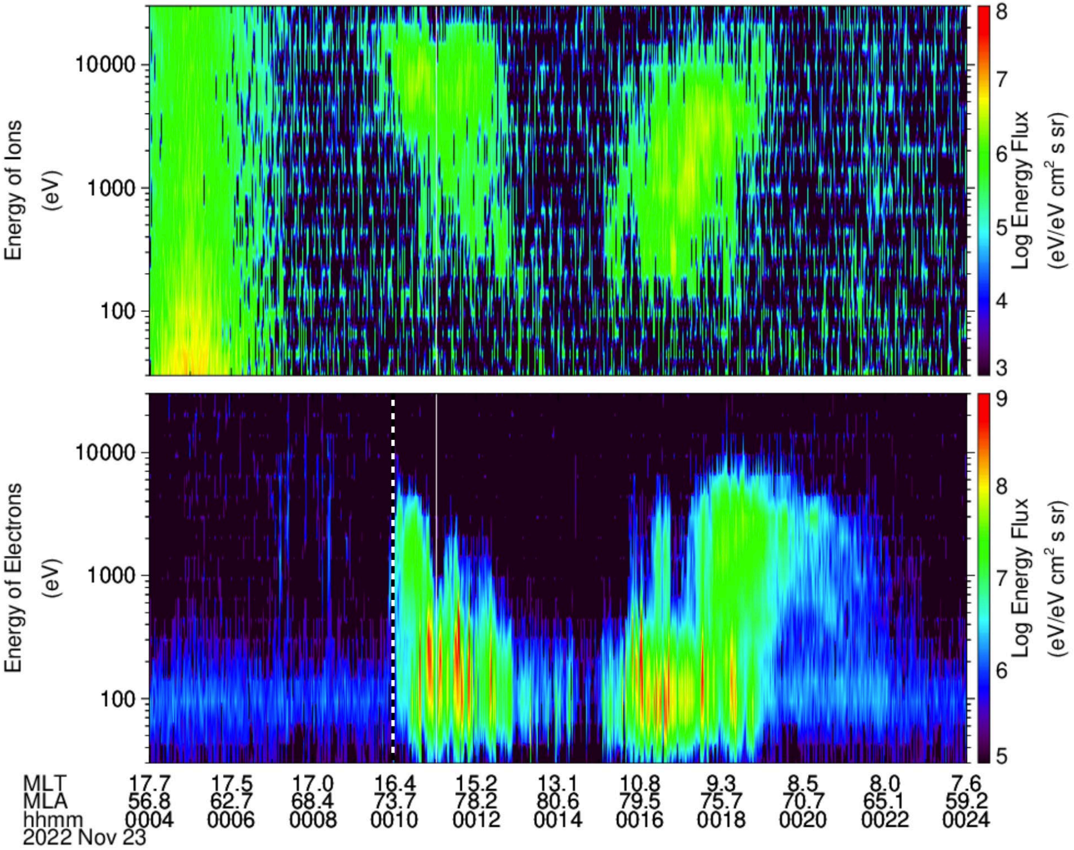


L-o-s velocities from SD



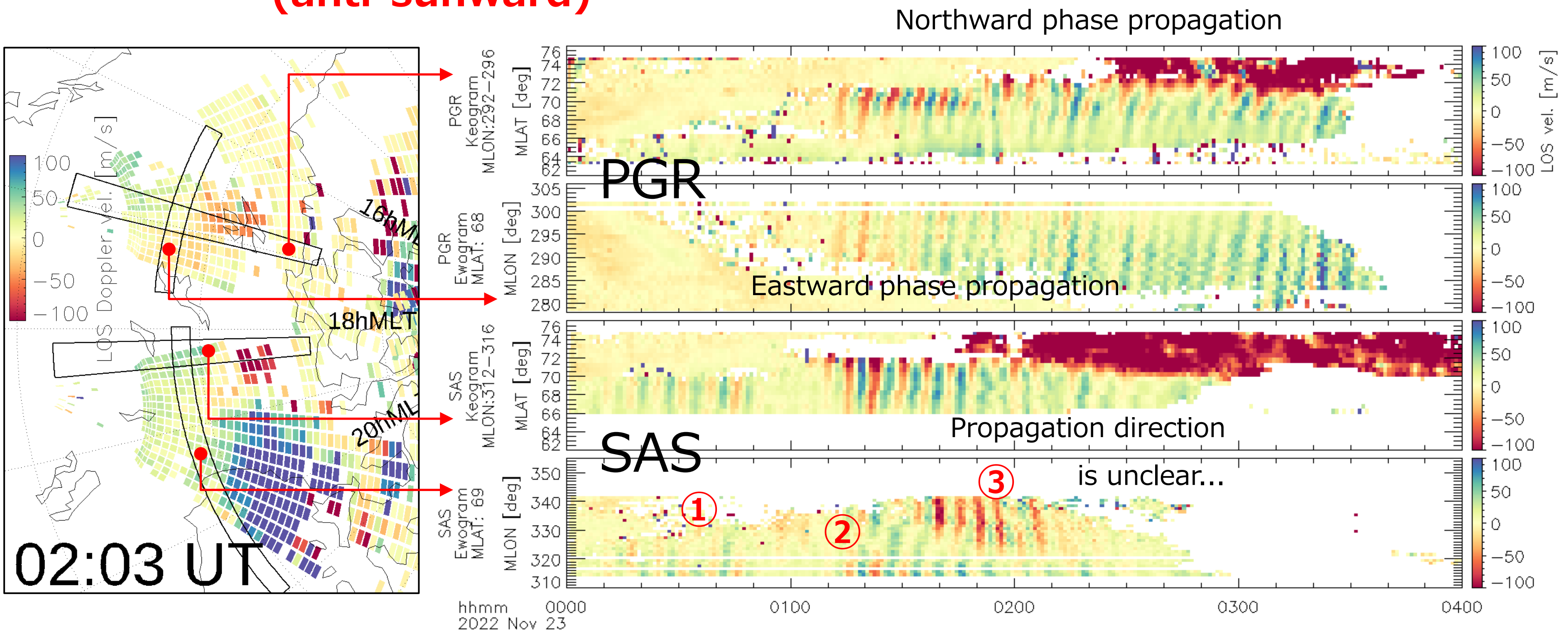
Magnetic latitude of auroral oval was ~72°





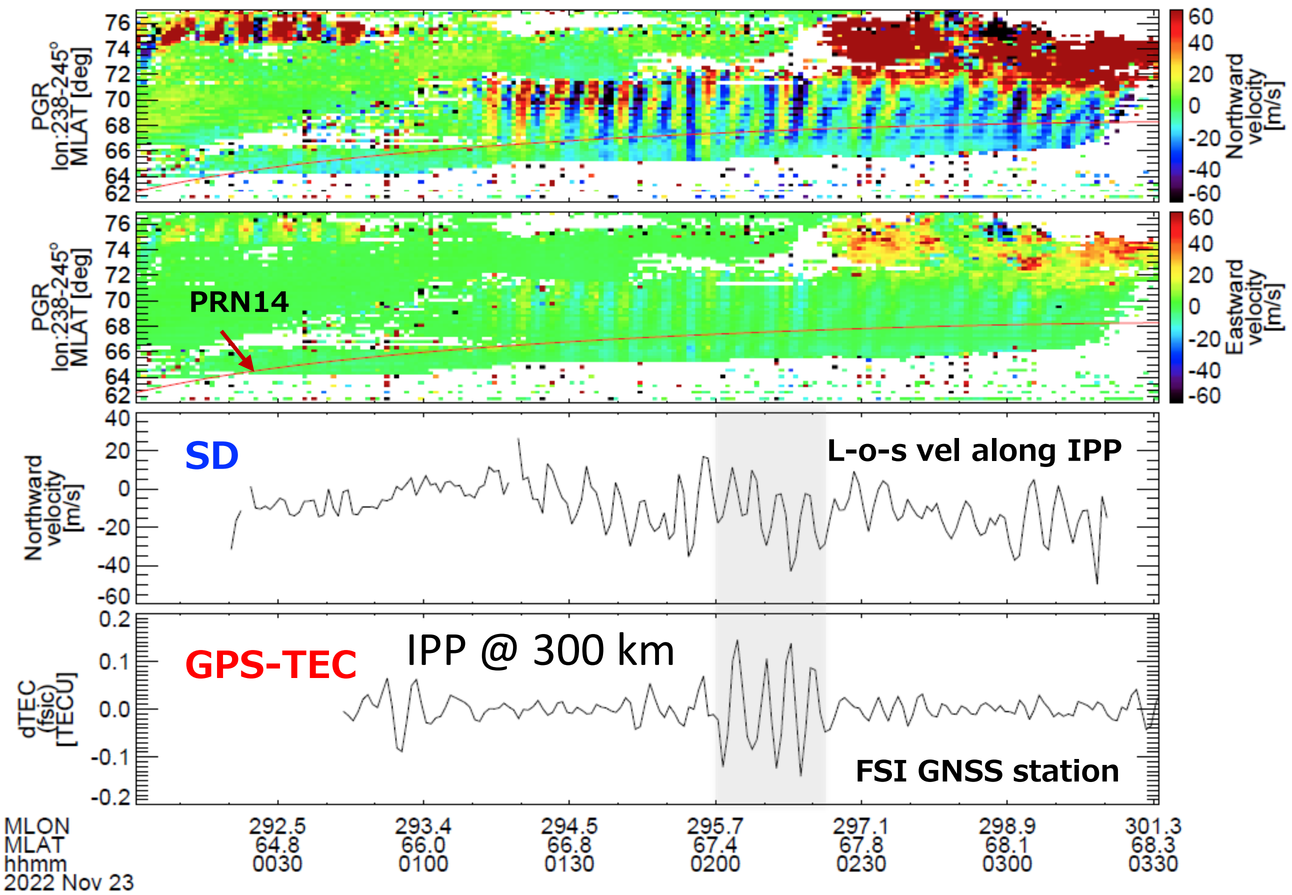
Propagation characteristics in keo/ewograms

- Northward / **eastward** phase propagation is obvious in the data from PGR **(anti-sunward)**



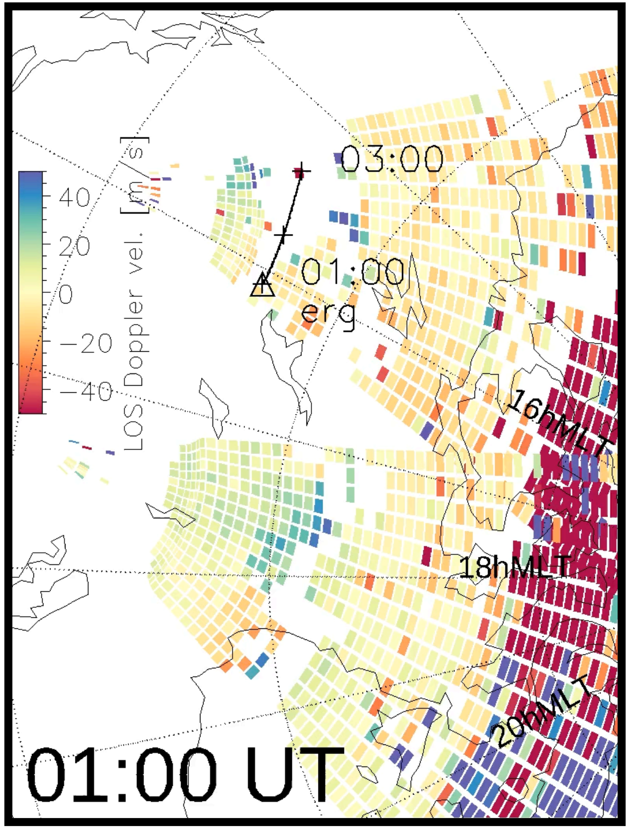
Corresponding variation in GPS-TEC

- The detrended TEC showed a periodic oscillation with the same period of ionospheric plasma flow perturbations
- The amplitude of the TEC oscillation was sporadically magnified during 02:00-02:20 UT



Summary and our plan this autumn/winter

- Captured "caterpillar-like" ULF waves during the SD-Arase campaign in autumn 2022 over the north American sector
- Latitudinal variation of the wave amplitude implies the existence of FLR
- Anti-sunward phase propagation seen in the 2D velocities suggests possible contribution of K-H instability to generate the ULF waves
- Arase detected the corresponding ULF signatures having toroidal/poloidal components (without compressional components). Toroidal waves are well correlated with the B-field variations on the ground
- Similar wavy feature was seen in GPS-TEC, indicating that the caterpillar-like ULF even modulated the ionospheric electron density
- ULF observations with SD allow us to visualize the 2D evolution of MHD waves from multiple sources in the M'sphere
- Analyses of ULF waves during "super quiet intervals" with in-situ satellite and ground-based observations would shed light on further understanding of the generation/propagation process of ULF waves
- Continue this effort in Oct, Nov, Dec, 2023



More caterpillars …

- Lots of other caterpillars indeed…