Case analysis of SAPS Wave Structure event observed by Arase and SuperDARN

あらせ衛星とSuperDARNで観測されたSAPS Wave Structureの事例解析

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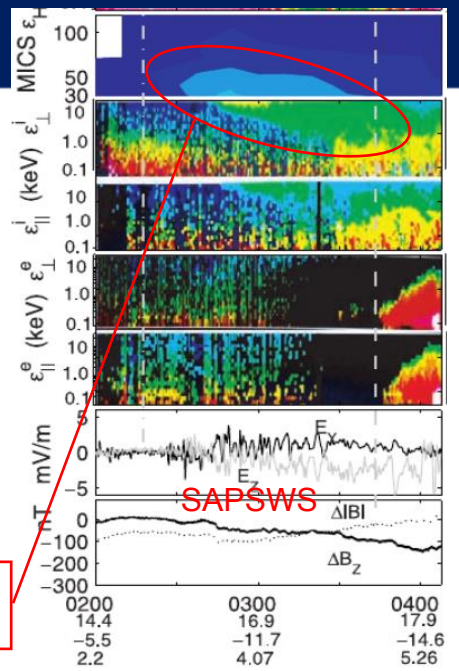
SAPSWS and plasma pressure

SAPSWS: SAPS wave structure

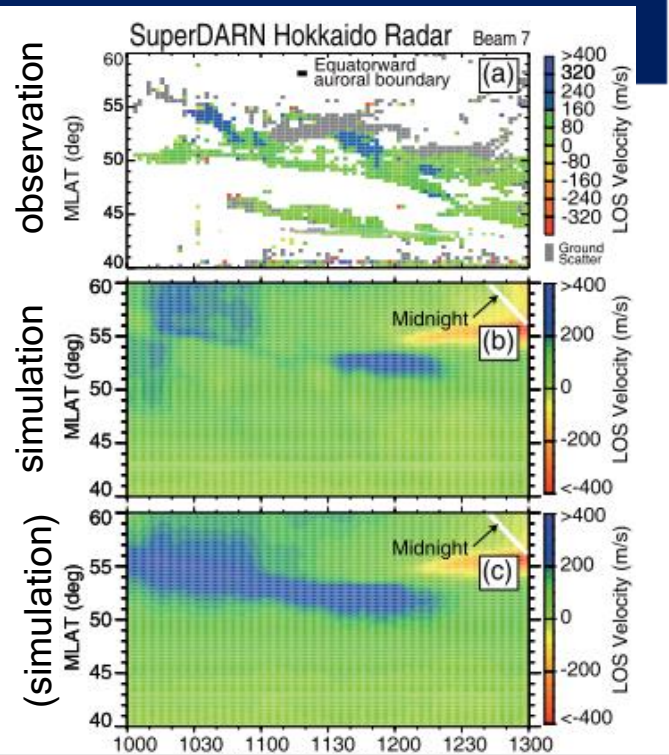
- SAPS-related electric and magnetic field oscillations and plasma density irregularities
- generation mechanism?
  - -Temporal variation or spatial one?
  - -Dominant wave mode?

[Mishin et al. (2003); Makarevich and Bristow (2014)]

Only hot ion
→ion nose structure



SAPSWS observation in magnetosphere
Mishin and Burke (2005)



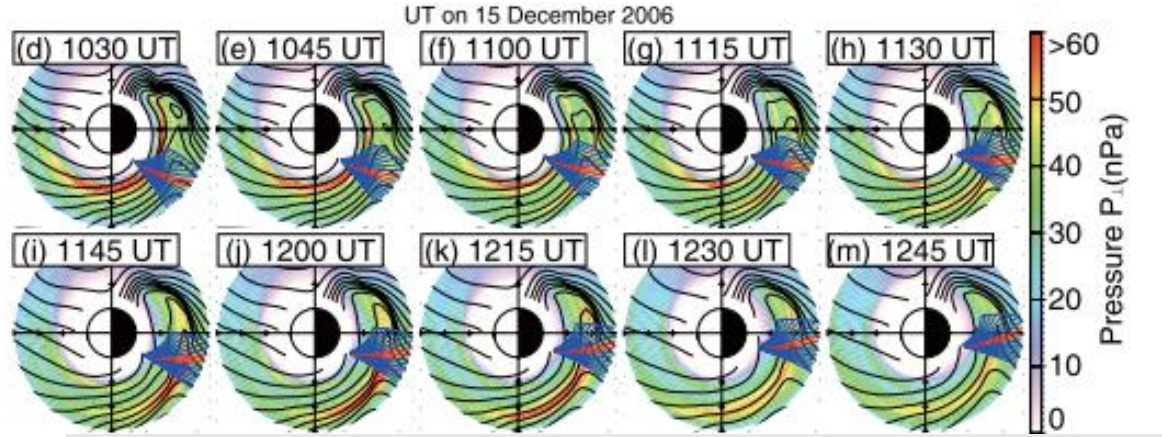
SAPS variation simulated by Ebihara et al. (2009)

Mishin and Burke (2005)

SAPSWS observed with ion nose structure in plasmasphere and ring current overlap region.

Ebihara et al. (2009)

Plasma pressure distribution contributes to the variation of ionospheric SAPS flow.



complex pressure distribution in magnetosphere simulated by Ebihara et al. (2009)

➢ Research the relation between
E & B variations and pressure of hot ion
by direct observation

Purpose of this study

Q: What is the physical driver of SAPSWS?

- Observations of SAPSWS in magnetosphere are limited
- There are no study focusing on relationship between phases of electric/magnetic field and hot (1-100 keV) ion's contribution

In this study,

To identify what drives SAPSWS by comparison between SAPSWS and SAPS without wave structure, ERG and SuperDARN data are analyzed, focusing on **hot ion's pressure**.

SAPS wave structure ⟺ SAPS without wave structure

Hot ion's contribution?

ERG (ARASE) satellite / SuperDARN

ERG satellite [Miyoshi et al., 2018]

- Orbit: perigee ~ 460 km, apogee ~ 32,110 km
- Spin period ~ 8 s

Table. Instruments of ERG

Instruments		Measurement	Coverage	Time resolution
Plasma Wave Experiment (PWE)	High Frequency Analyzer (HFA)	Electric field	10 kHz - 10 MHz	1 min
	Electric Field Detector (EFD)	Electric field	DC - 256 Hz	8 s
Magnetic Field Experiment (MGF)		Magnetic field	DC - 256 Hz	8 s
Medium-Energy Particle Experiments - Ion mass Analyzer (MEP-i)		Energetic ion	10 - 180 keV/q	8 s
Low-Energy Particle Experiments - Electron Analyzer (LEP-e)		Energetic electron	0.02 - 19 keV	8 s
Low-Energy Particle Experiments - Ion mass Analyzer (LEP-i)		Energetic ion	0.02 – 20 keV/q	8 s

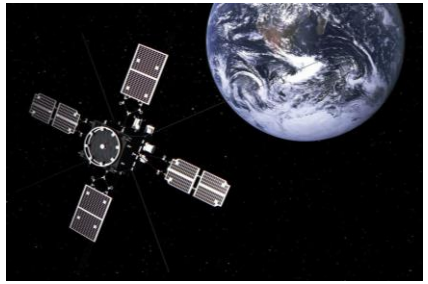


Fig. image of ERG satellite
http://www.isas.jaxa.jp/missions/spacecraft/current/erg.html

Fig. image of SuperDARN
http://vt.superdarn.org/tiki-index.php?galleryId=82&fast

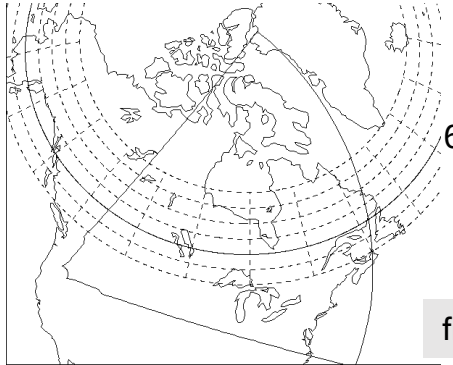
SuperDARN: Super Dual Auroral Radar Network [Greenwald et al. (1995)]

ground-based coherent-scatter radars that operate in the high-frequency (HF) band to observe ionospheric flow

- Coverage: 180 km - 3,500 km (line of sight)
- time resolution : 1 – 2 min
  spatial resolution : 30 km

Table. SuperDARN radar sites

sites	Geomagnetic lat. [deg]	Geomagnetic lon. [deg]
Christmas Valley East (CVE)	49.02	304.53



field of view of CVE radar

Calculation of isotropic pressure from omni differential flux $J_{omni}(E_i)$

Energy density [Nosè et al. (2000)]

$$\varepsilon = \iiint \frac{1}{2} m\, v^2 f(\boldsymbol{v})\, dv^3$$

Relation between $f(\boldsymbol{v})$ and J

$$f = \frac{m^2}{2E} J$$

m : mass
$\boldsymbol{v}$: velocity
E : energy
$f(\boldsymbol{v})$: distribution function
J : differential flux

Isotropic pressure $p = 2\varepsilon$ then

$$p = \iiint m v^2 f(\boldsymbol{v})\, dv^3$$

$$= \int_v \int_\alpha \int_{\phi=0}^{2\pi} m^2 v^2 J(E, \alpha, \phi)\, sin(\alpha)\, dv d\phi d\alpha$$

$$= 2\pi \int_E \int_{\alpha=0}^{\pi} \sqrt{2mE}\, J_{\phi\_ave}(E, \alpha)\, \sin(\alpha)\, dE d\alpha$$

$$= 4\pi \int_E \sqrt{2mE}\, J_{\alpha\phi\_ave}(E)\, dE$$

$$= 4\pi \sum_{E_i} \sqrt{2mE_i}\, J_{omni}(E_i)\, \Delta E_i$$

ϕ : perpendicular velocity phase angle
α : pitch angle

E_i : center energy of each channel
ΔE_i : energy band width of each channel
$J_{omni}(E_i)$: omni differential flux

Overview of ERG-SuperDARN conjunction event (July 9th, 2017)

7/8/2017 0:00 UT ~
IMF Bz changed southward
7/9/2017 2:00 UT ~
AE index increased suddenly (~1000 nT)

Event time (7/9/2017 2:30~3:00 UT)

→transition period between expansion phase and recovery phase of strong substorm

- ERG was on duskside (outbound)
- ERG's footprint was in SuperDARN CVE radar site

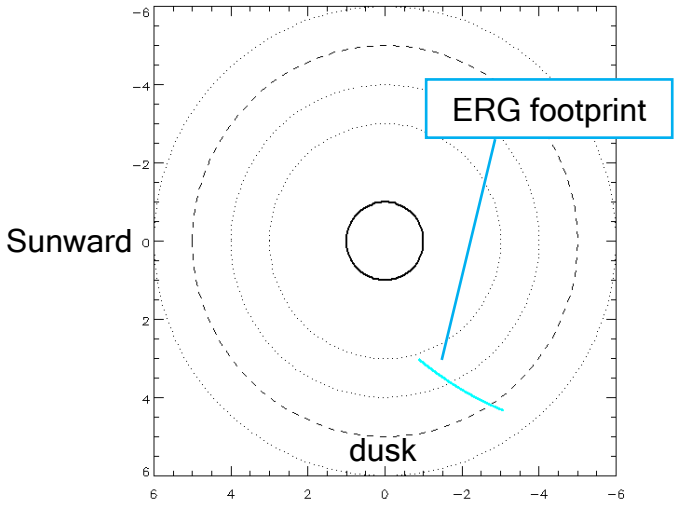


Fig. ERG FP @Magnetic equator

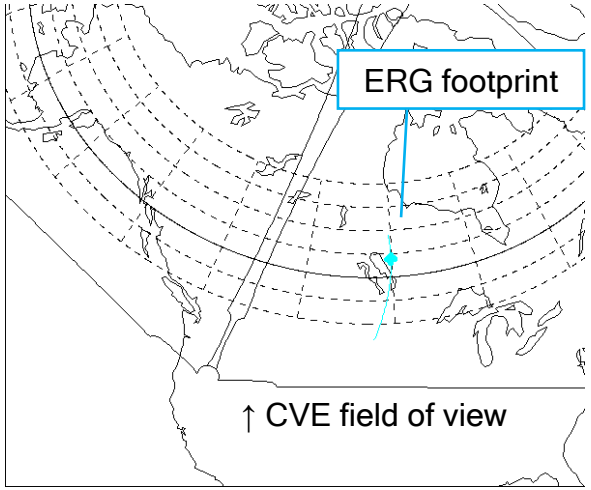


Fig. ERG FP @Ionosphere

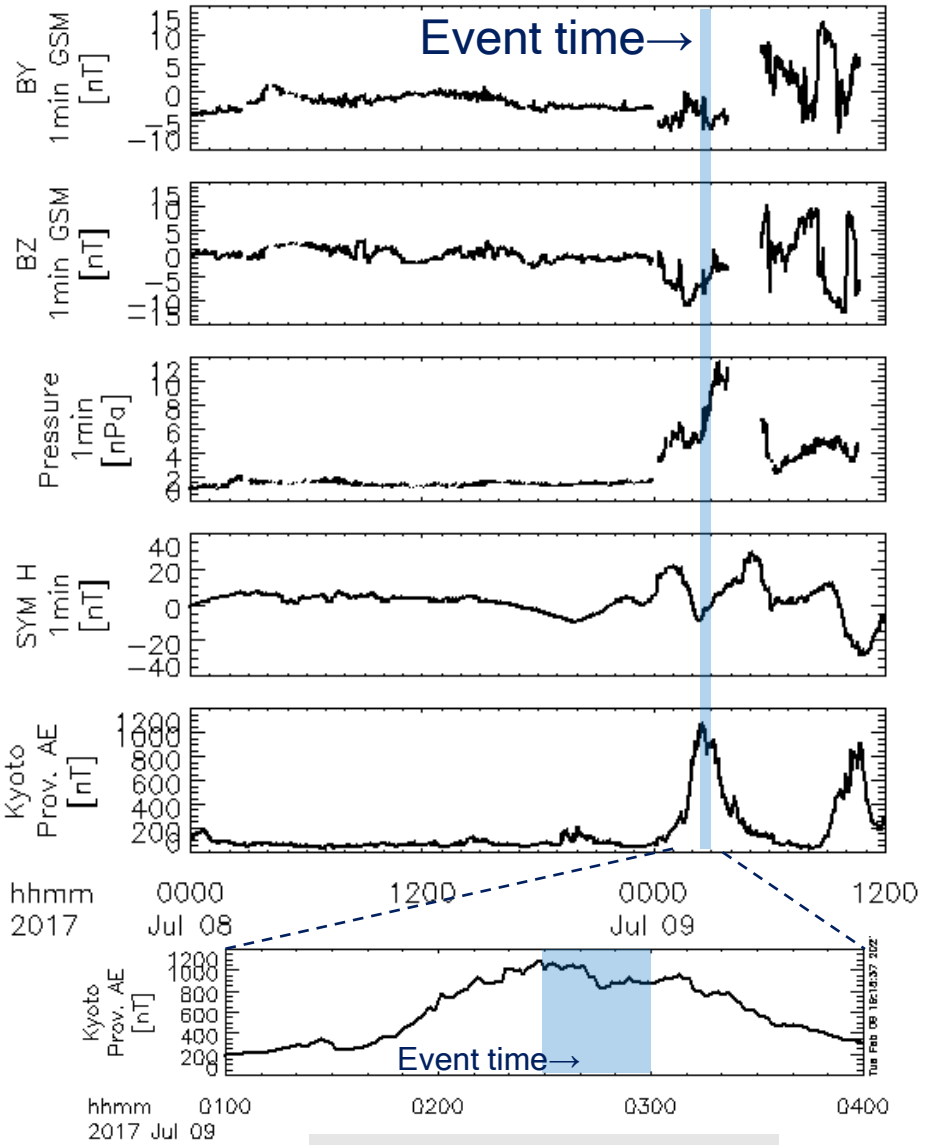


Fig. 7/9/2017 Event overview

3. Result
SuperDARN observation on July 9th, 2017

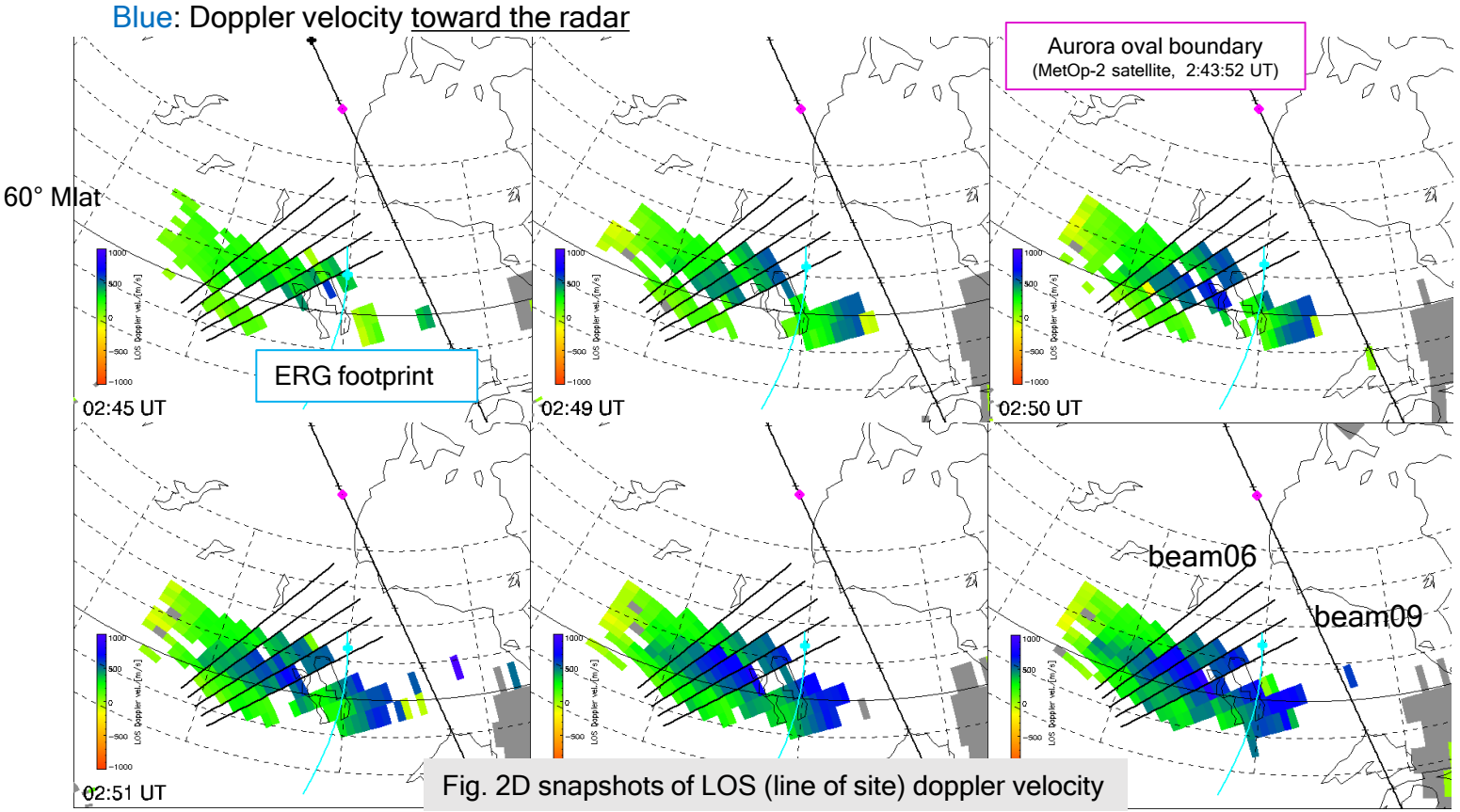


Fig. 2D snapshots of LOS (line of site) doppler velocity

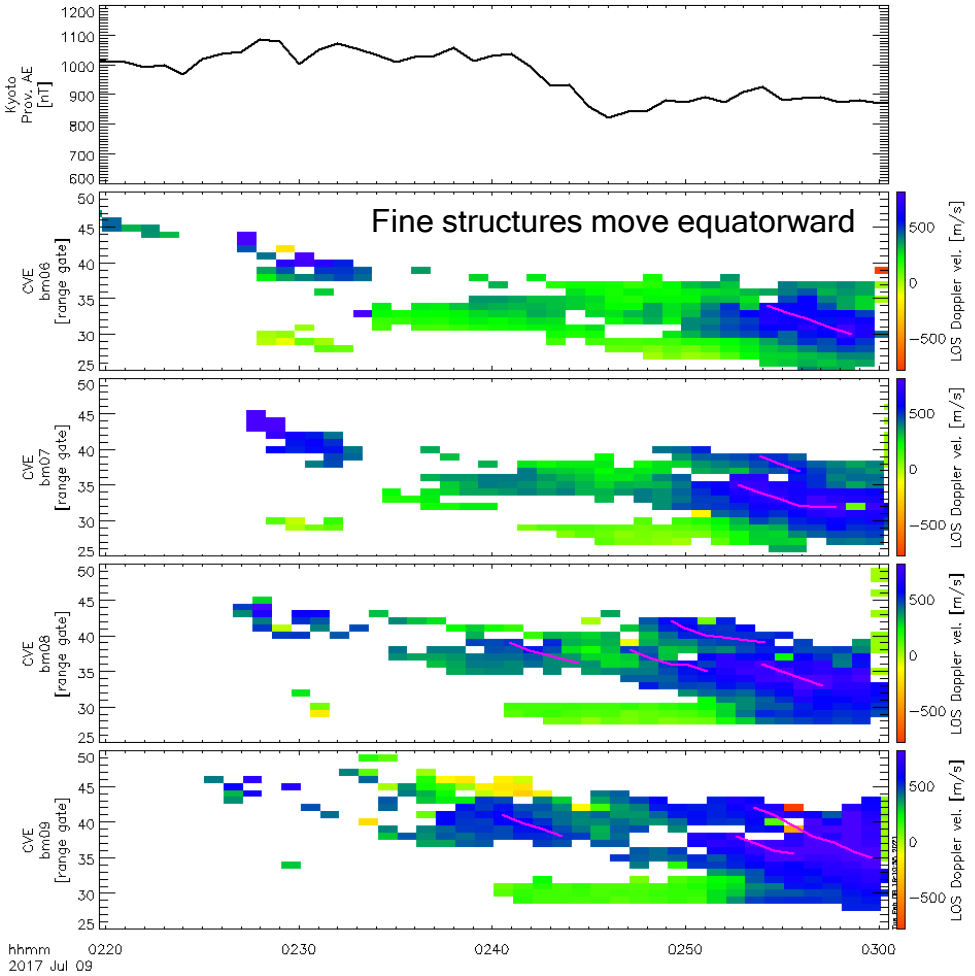


Fig. time variation of SAPS flows on each beam

Ionospheric westward flow fluctuations (SAPSWS) enhance near ERG's footprint.

- Fine structure: flow variation ~200 m/s, latitudinal wave length ~230 km
- Moving equatorward with 30 km/min

ERG observation on July 9th, 2017

02:27 – 02:42
Electric field variation appears.
Amplitude: ~2.5 mV/m
Period: ~5-6 min

02:27 Proton flux increases.
02:46 Electron flux increases.
→Ion nose structure
Ion's isotropic pressure: ~31 nPa

dE
: applying high-pass filter (10 minutes)

- **SAPSWS is observed with ion nose structure**
- **Ion's pressure is high and has variation**

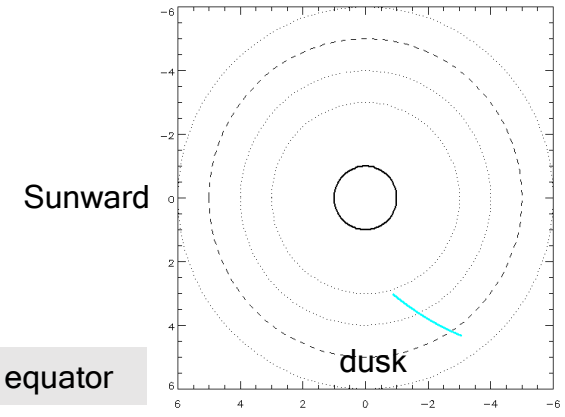


Fig. ERG FP @Magnetic equator

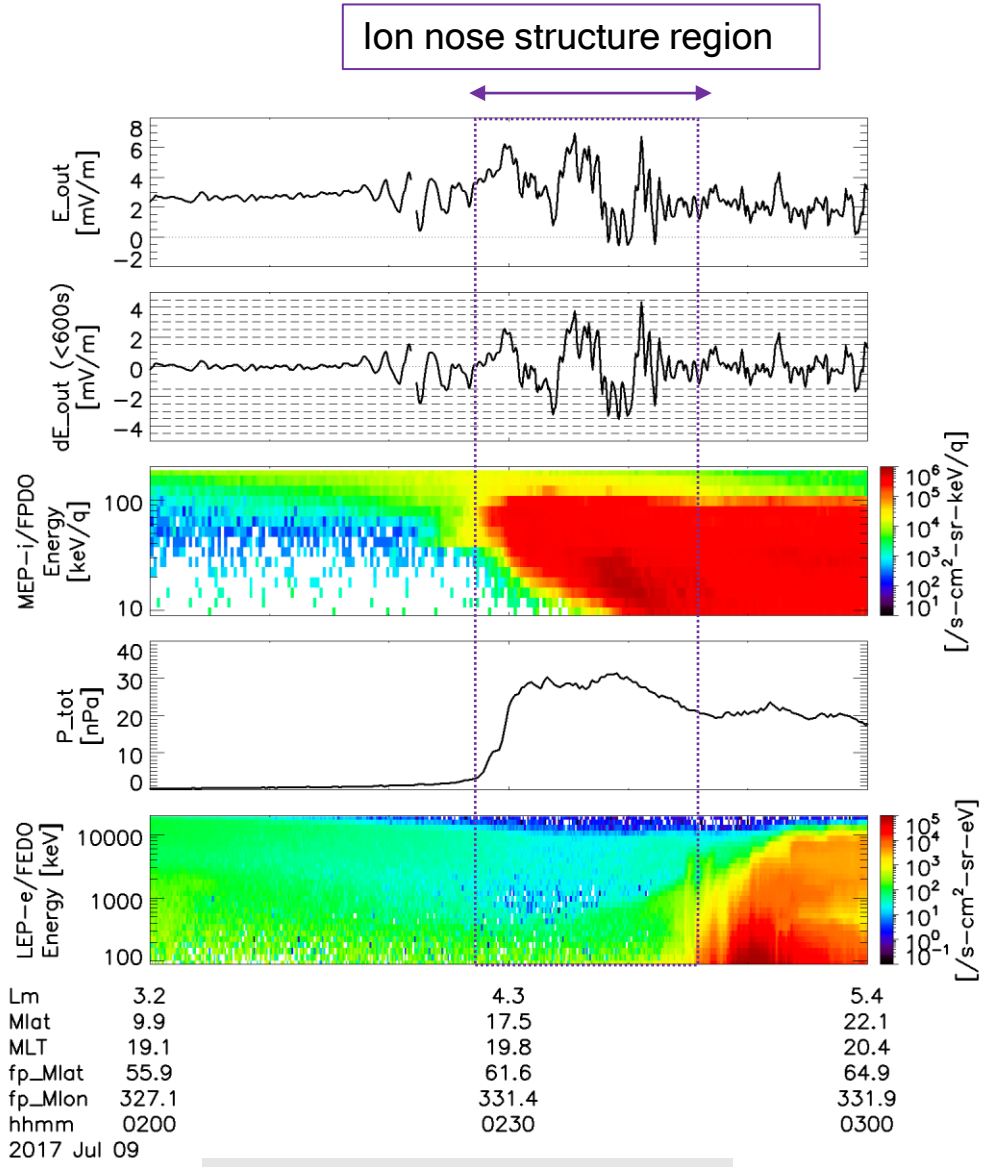
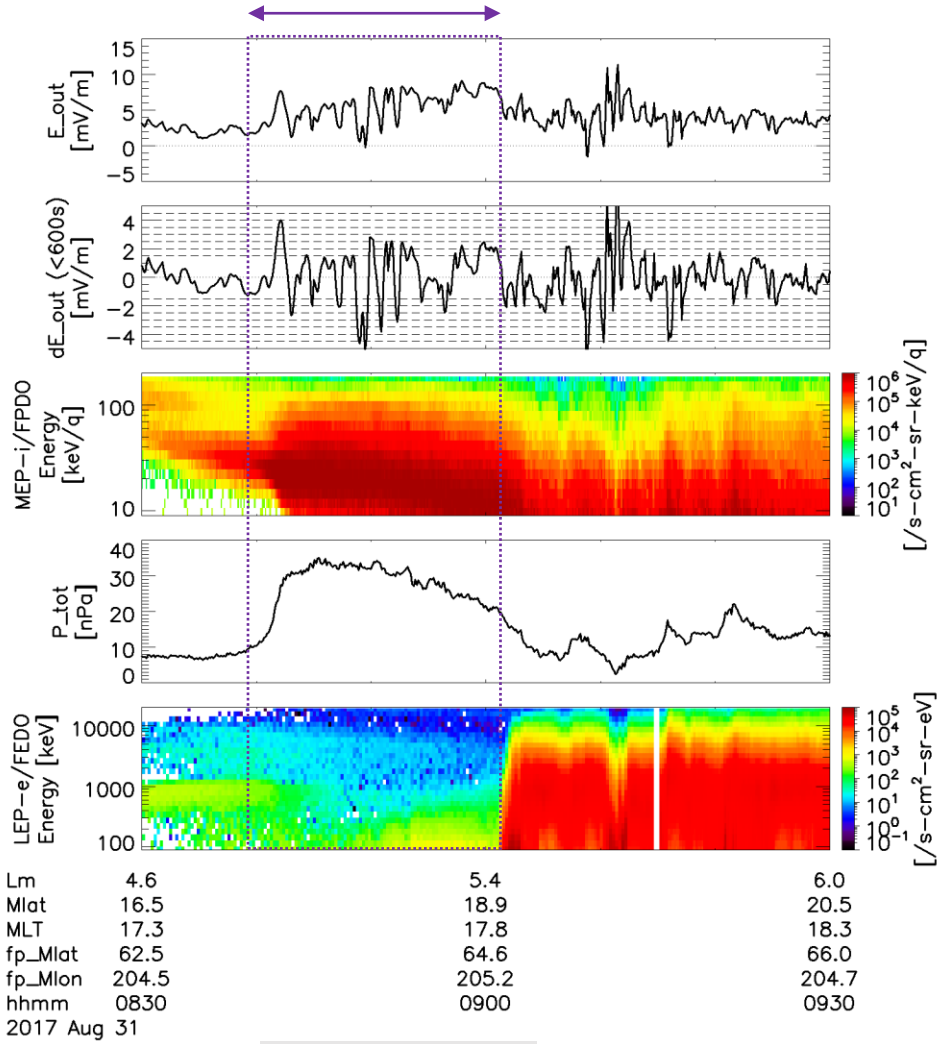
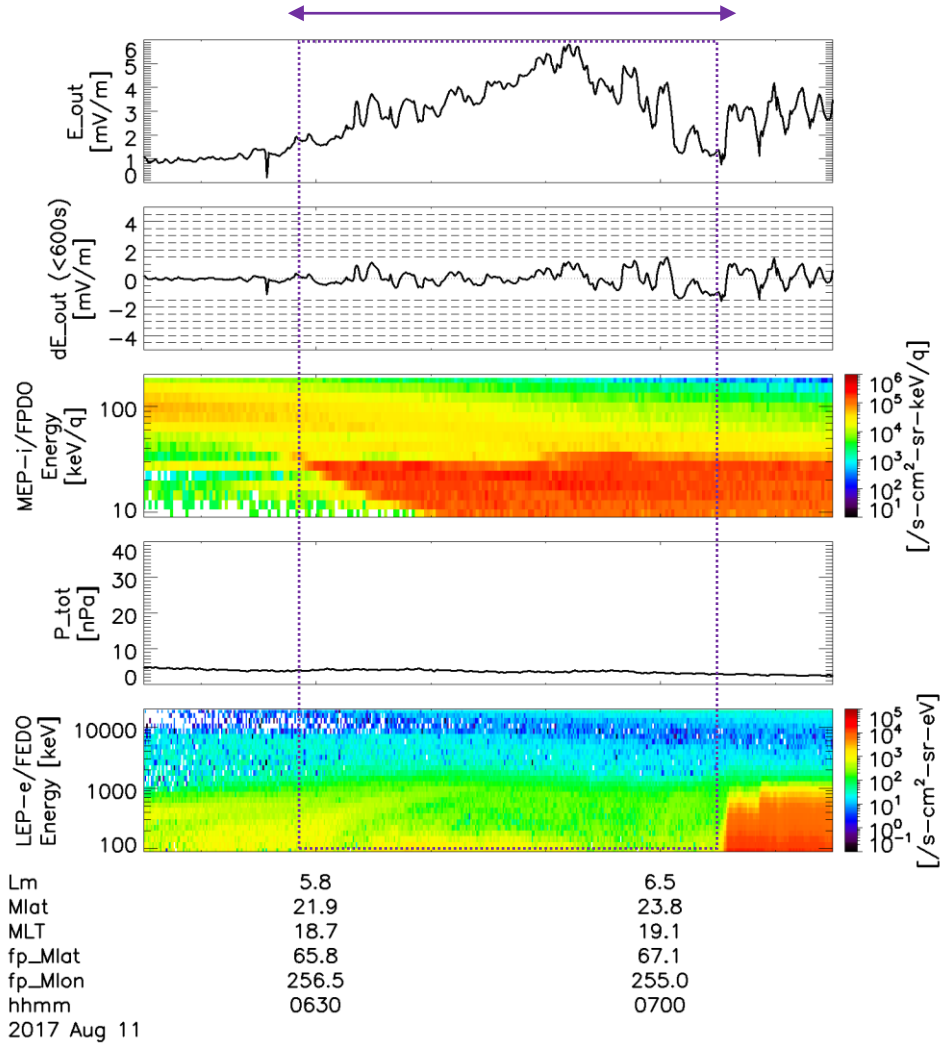


Fig. ERG observation on 7/9/2017

Comparison of strong and weak variation event



8/31/2017 event



8/11/2017 event

- Strong E variation
- Ion's pressure is high and has variation (similar to 2017-7-9)

- Weak E variation
- Ion's pressure is low

Features of ion nose structure events

We found 15 ion nose structure events observed by ERG.
Electric field variation seems to be enhanced with large variations of pressure (dP).

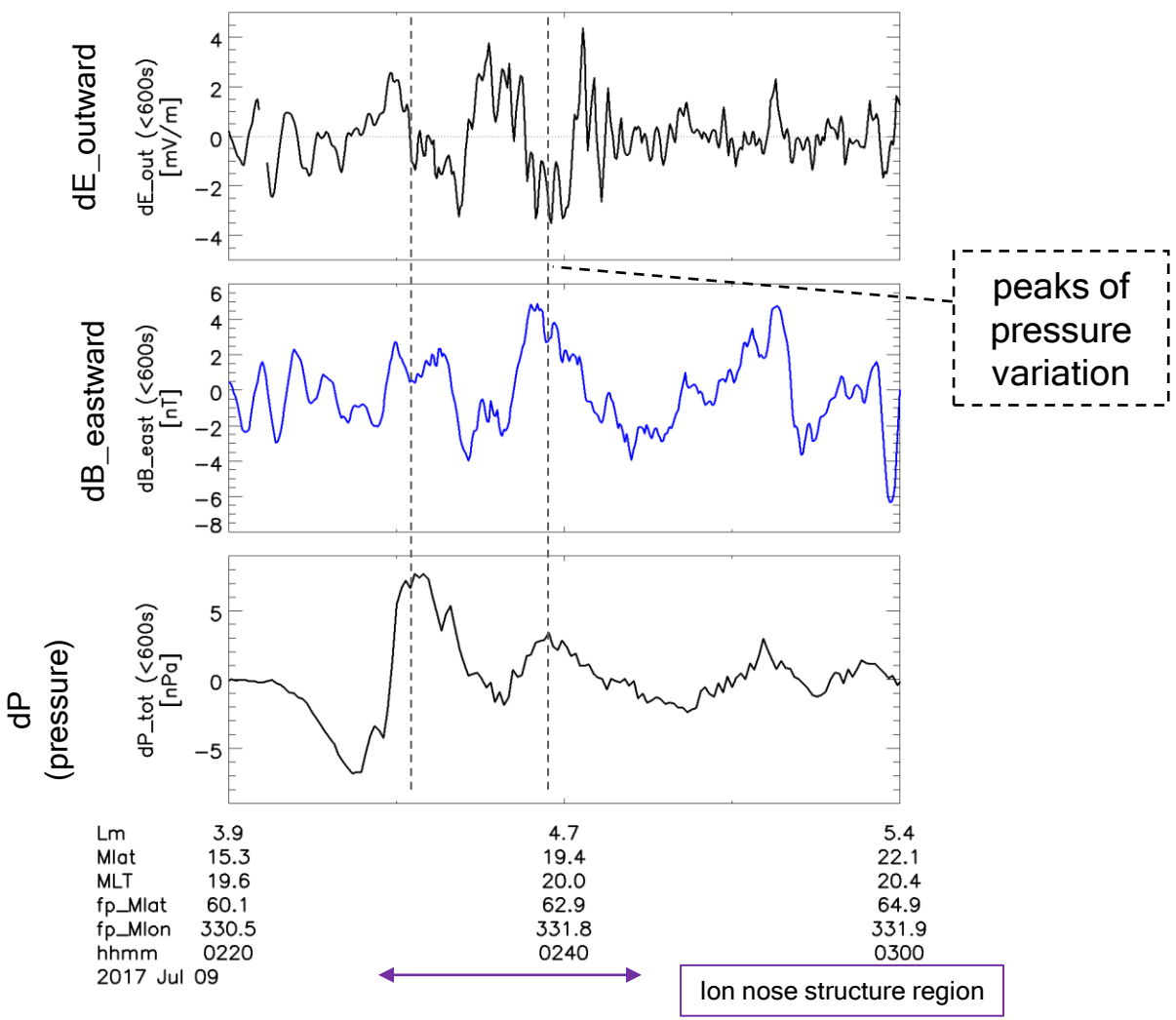
Table. Features of Ion nose structure events

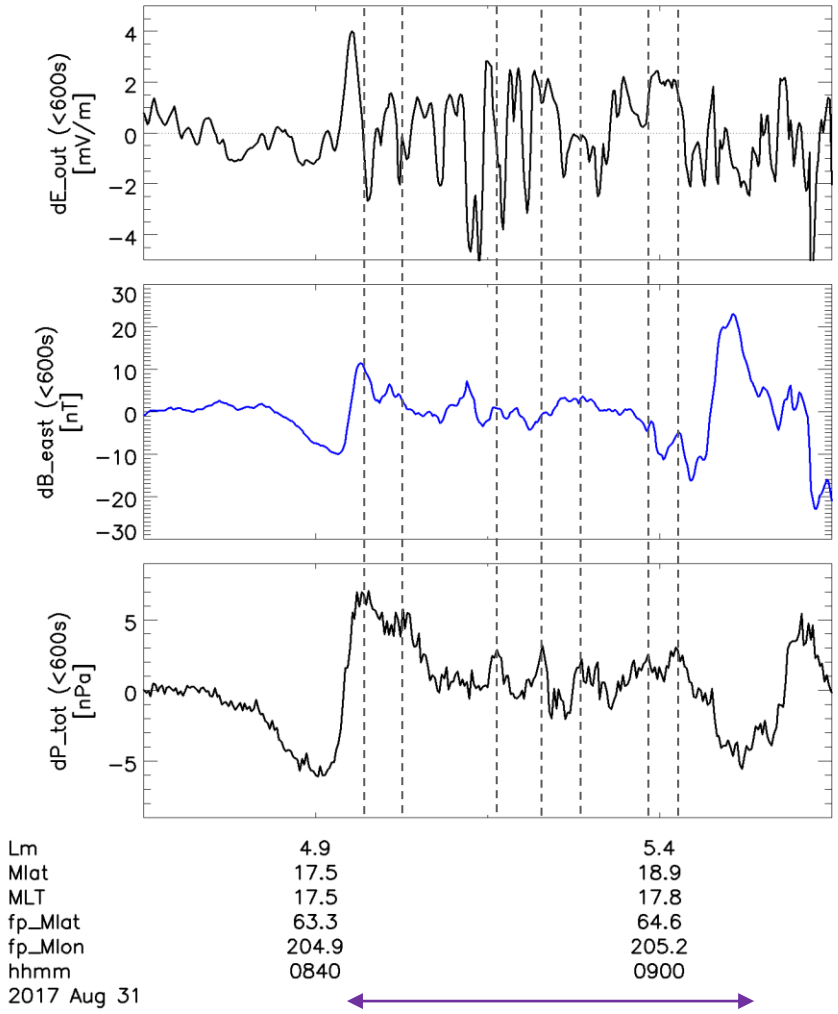
date	dE [mV/m]	P [nPa]	dP [nPa]
2017-7-23/07:30-08:30	17.5	27.0	9.5
2017-8-17/12:30-14:00	6.0	39.0	10.0
2017-7-9/02:00-03:00	5.0	31.0	14.0
2017-8-31/08:30-09:30	5.0	35.0	13.0
2017-9-13/08:00-10:00	5.0	38.0	6.0
2018-12-1/16:20-17:20	4.0	23.0	7.5
2017-7-1/05:20-06:20	3.5	15.0	4.0
2017-6-25/07:00-08:00	×	18.0	3.0
2017-8-3/17:30-19:00	×	9.0	3.0
2018-12-26/13:30-14:30	×	14.0	2.0
2018-10-21/15:00-16:00	×	10.0	1.0
2017-8-11/06:15-07:15	×	5.0	0.5
2019-1-4/15:10-16:10	×	5.0	0.5
2018-10-4/16:30-17:30	×	4.0	0.0
2017-8-1/11:20-12:20	×	3.0	0.0

×: weak (< 2 mV/m)

dE, dP
・difference from positive peak to negative peak
(applying high-pass filter (10 minutes))

Variations of Electric / Magnetic field and pressure

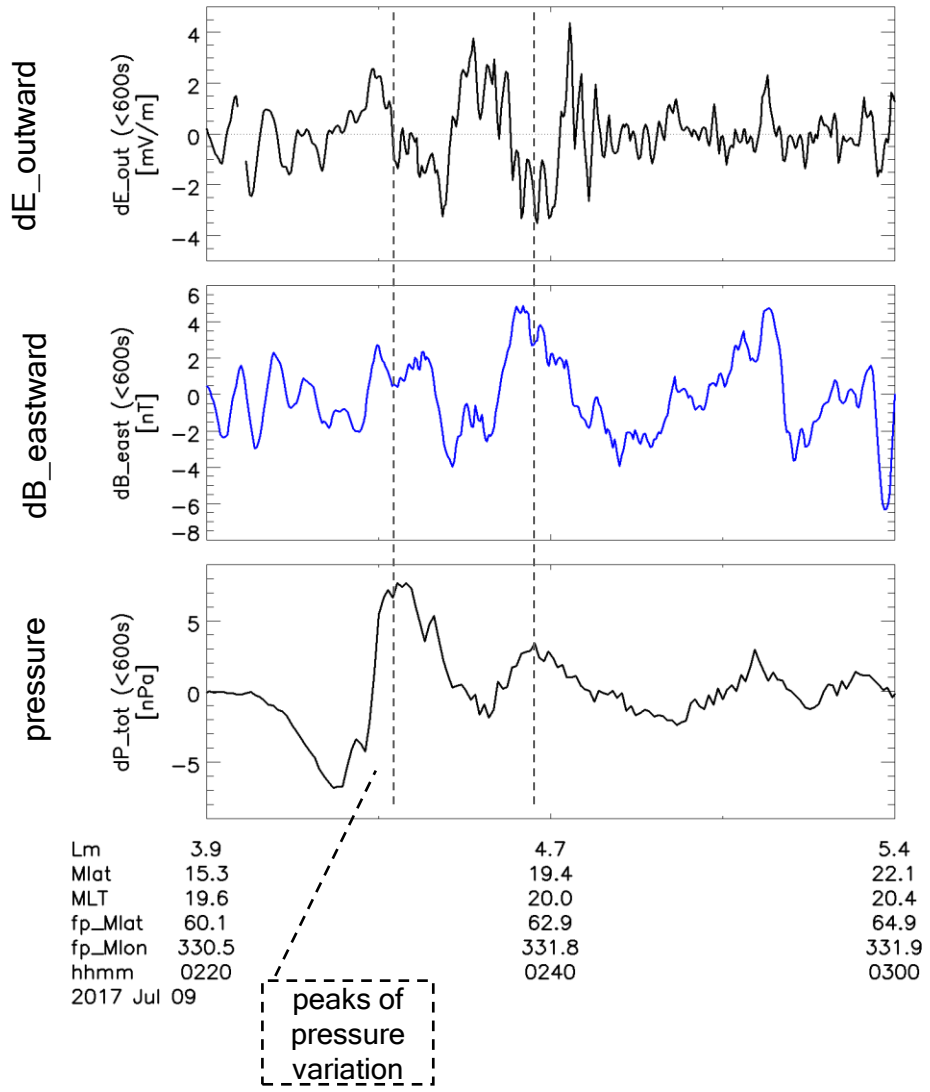




Focusing on variations shorter than 600s,

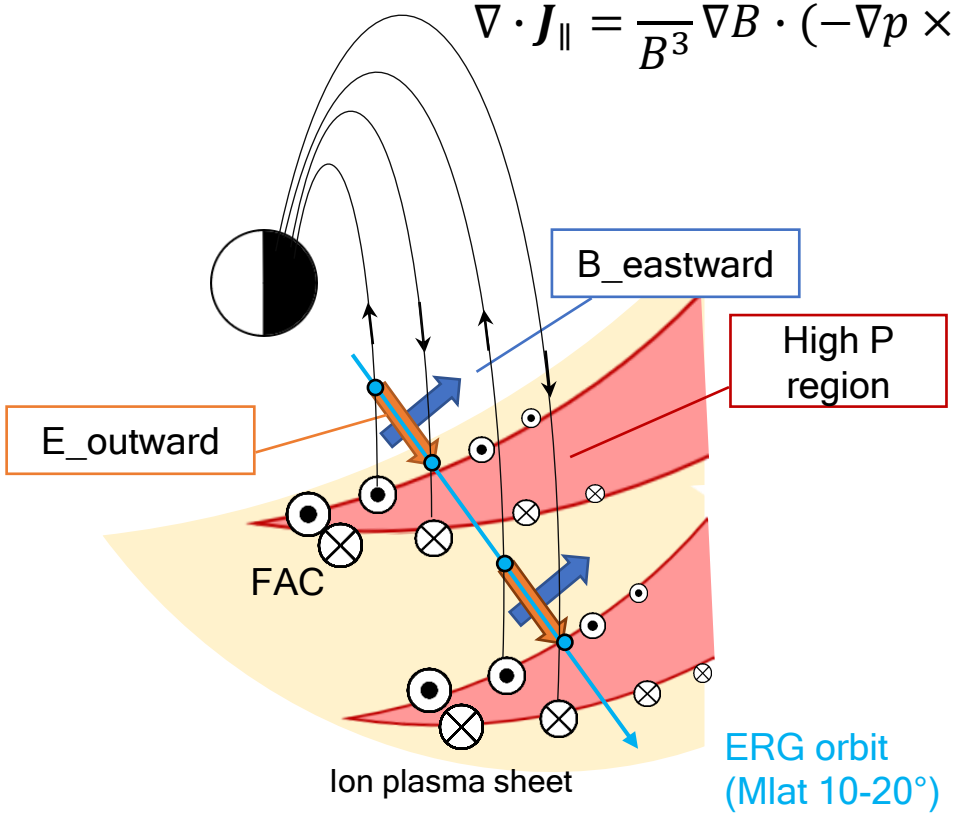
- dB_eastward peaks roughly coincide with pressure ones
- dE_outward appears in a close period

Variations of Electric / Magnetic field and pressure



FAC are enhanced around locally high-pressure points.

$$\nabla \cdot \boldsymbol{J}_{\parallel} = \frac{2}{B^3} \nabla B \cdot (-\nabla p \times \boldsymbol{B})$$

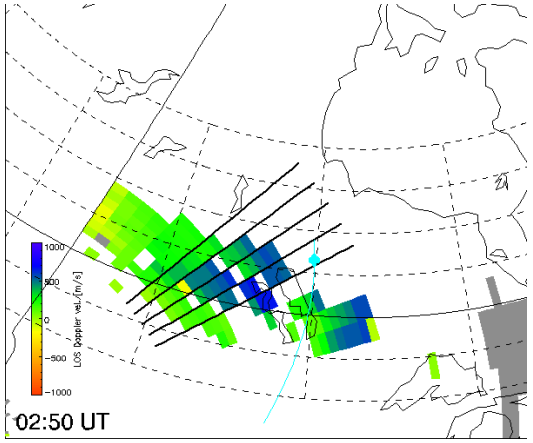


Because of FACs and Pedersen current, electric field enhanced at the point's ionospheric footprint.

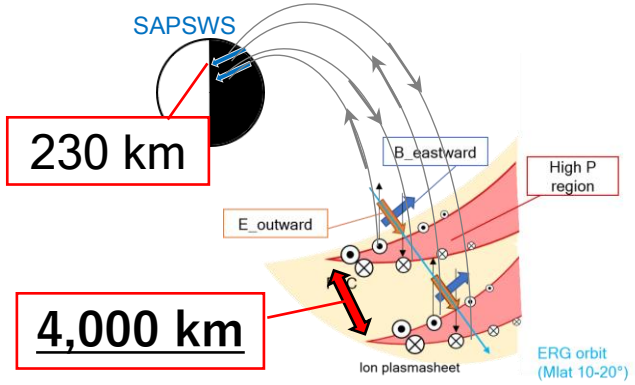
- These implies that current generator theory can be applied for small scall variation (SAPSWS).

comparison of the scale size in the ionosphere and the magnetosphere

■ latitudinal wave length
~ 230 km

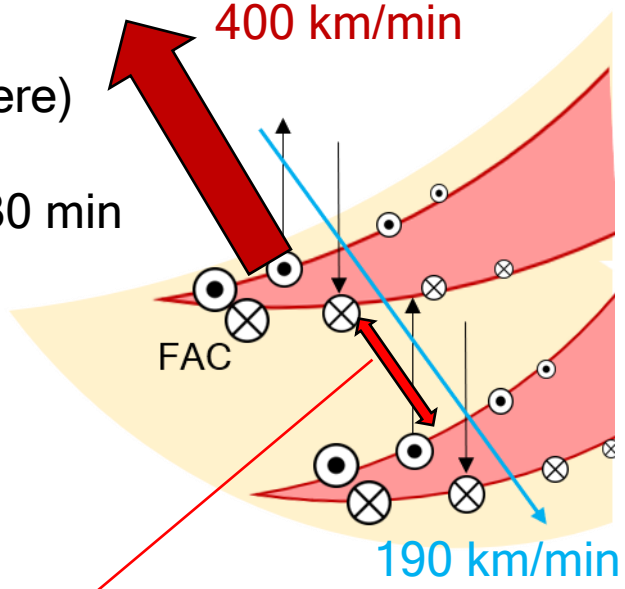


Assuming dipole
→ ~ 4,000 km
@magnetic equator



High P region
inward moving speed
~ 400 km/min
(↑30 km/min @Ionosphere)

(consistent to L=6.6→4.0/30 min
[Ebihara et al., 2009])



ERG
・outward moving speed
~190 km/min
・E peak period: ~5-6 min

Radial distance
=(190 + 400) km/min * 5-6 min
=<u>2,950 - 3,540 km</u>

It seems that
➢ Multiple fine high-pressure regions are distributed radially
➢ ERG and SuperDARN observed same structures

Summary and Future work

Summary

We analyzed 7 SAPSWS events and 8 weak/no wave structure events.

In 6 SAPSWS event,
an variation width of pressure variations is larger than 6 nPa.

Peaks of pressure and eastward magnetic field observed simultaneously.
Outward electric field is also observed near them.

It seems that SAPSWS can be explained with current generator theory.
:Multiple fine high-pressure regions extending in azimuthal direction are distributed radially, and there FAC is generated.

The quantitative evaluation is in progress.

Future work

- Compare electric field variations observed in the magnetosphere and the ionosphere
- Analyze observations by conjugated DMSP satellites (8/31/2017, 9/13/2017 event)

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