極域・中緯度SuperDARN研究集会
2015/9/14

内部磁気圏複数衛星を用いたPc5脈動の経度方向の広がり

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Drift-Bounce resonance

Resonance condition

$$\omega - m\omega_d = N\omega_b$$

ω :wave frequency

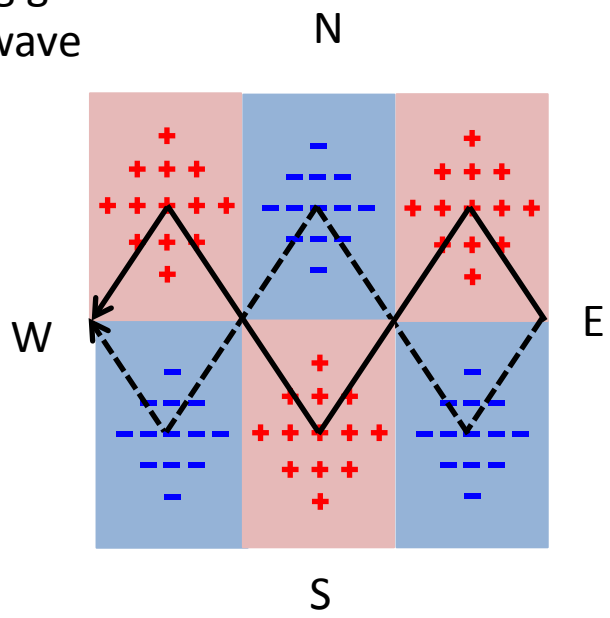
m :an azimuthal wave number

ω_d :azimuthal drift frequency

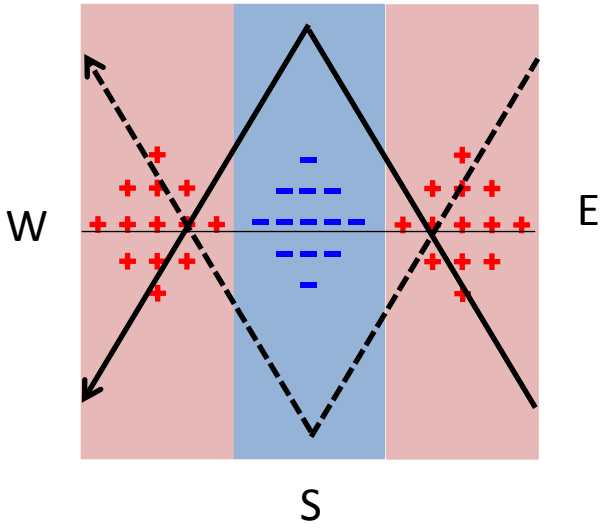
ω_b :bounce frequency

$N = 0, \pm 1, \pm 2, \pm 3 \cdots$

Standing guided Alfven wave



Second Harmonic N=1



Fundamental N=2

The charged particle will be accelerated in the regions marked as minus sings.
The charged particle will be decelerated in the regions marked as plus sings.

Duskward Electric field

Dawnward Electric field

Radial transport
inside the geosynchronous orbit by high m number Pc5

Storm recovery phaseでの放射線帯・内帯への電子の供給メカニズムとして
High m number Pc5 (poloidal mode) による動径拡散関与を示唆 （シュミレーション）

High m number Pc5脈動によって動径拡散が起きる為には
Pc5脈動が長時間(~30 h)継続している必要がある。

[Ukhorskiy et al., 2009]

m=50
E_ϕ＝2mV/m
Δψ＝2/π
で設定

10^3の電子をL=5に設定して電子の動きを追う

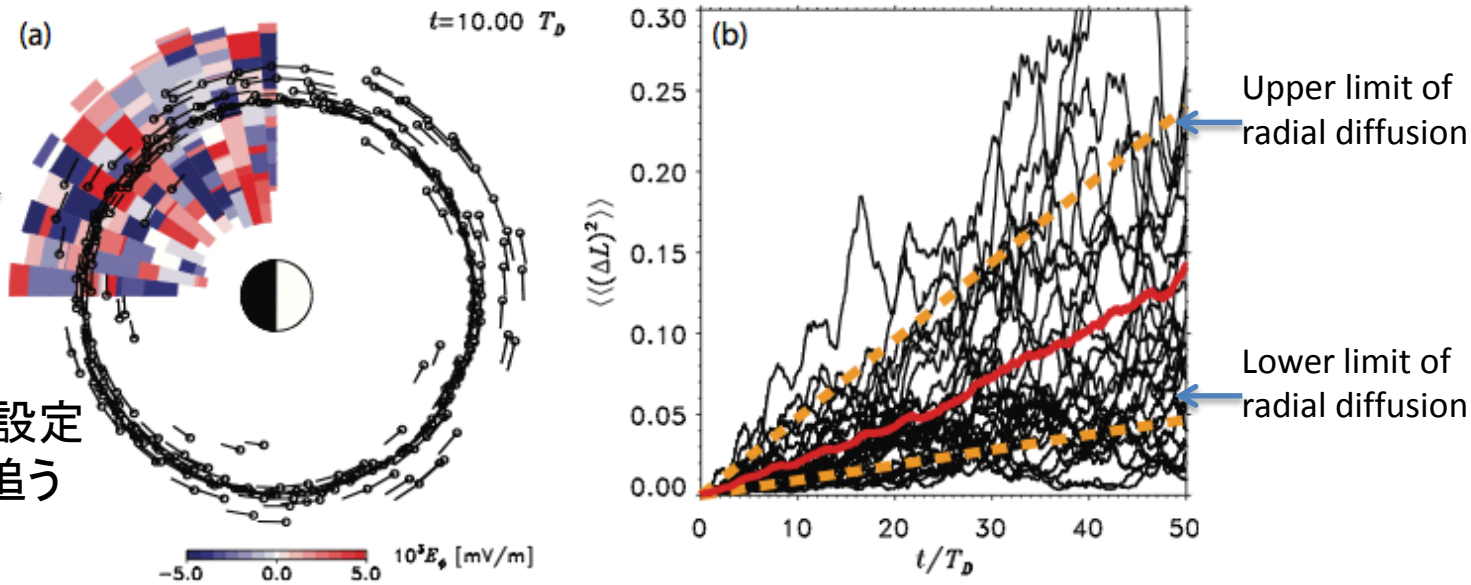


Fig. 5. Panel **(a)** A snapshot of electron motion in the presence of stormtime Pc5s: E_φ^{rms}=2 mV/m, m=50, and $\Delta\varphi=\pi/2$. Panel **(b)** Radial transport in 30 statistically similar realizations of electron motion (black lines), analytical estimates of the upper and lower limits of radial diffusion (yellow line). Radial transport averaged over all realizations (red line).

Drift resonance in a Compressed Dipole

Elkington et al [1999, 2003]

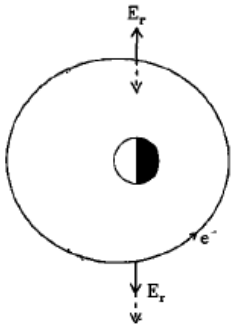


Figure 2. Sketch of an electron drift path in a compressed dipole, with electric fields indicated for an m=2 mode. Solid arrows indicate the electric field at t=0 for an electron starting at dusk, while the dashed arrows indicate the electric field direction half a drift period later.

Toroidal-mode wave can accelerate electrons via drift-resonance interaction in the compressed dipole.

The resonance condition

$$\omega - (m \pm 1)\omega_d = 0$$

ω :wave frequency
m :an azimuthal wave number
ω_d :azimuthal drift frequency

同周期のULFは本当に経度方向にGlobalに広がっているのか?

1/2しか広がっていなければ、波から得られるエネルギーは1/2倍
(図の例だと0.128 MeVが0.064MeVに)

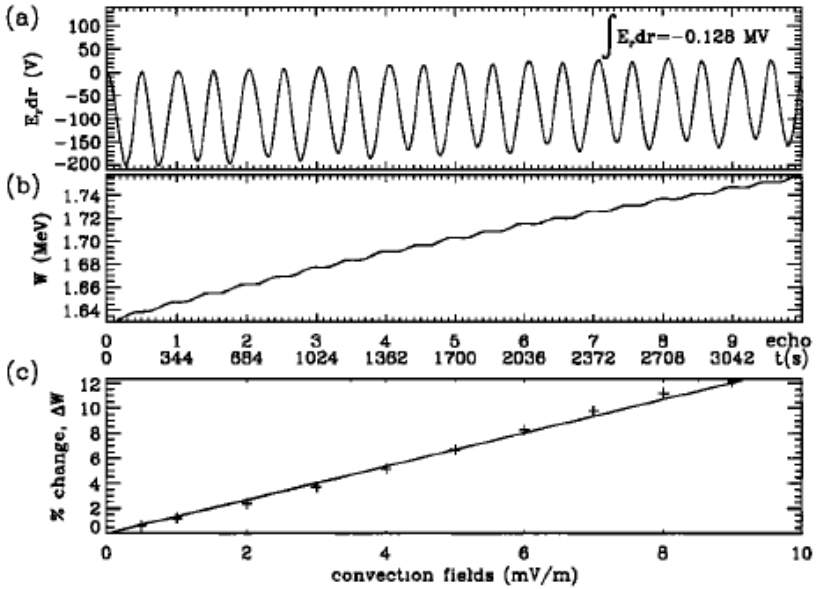


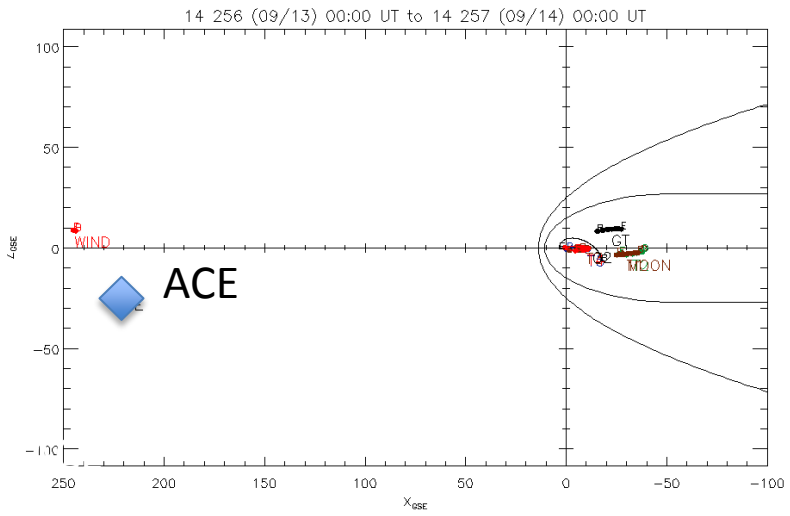
Figure 3. $E_r dr$ (a) and energy (b) as a function of time and drift echoes for an electron with initial energy of 1.63 MeV, moving in a 3 mHz, m=2 toroidal field of amplitude 3 mV/m. (c) Relative increase in energization for same particle, as a function of increasing dawn-dusk convection electric field.

Motivation

The extent of ULF waves is consider to be important for particle acceleration.

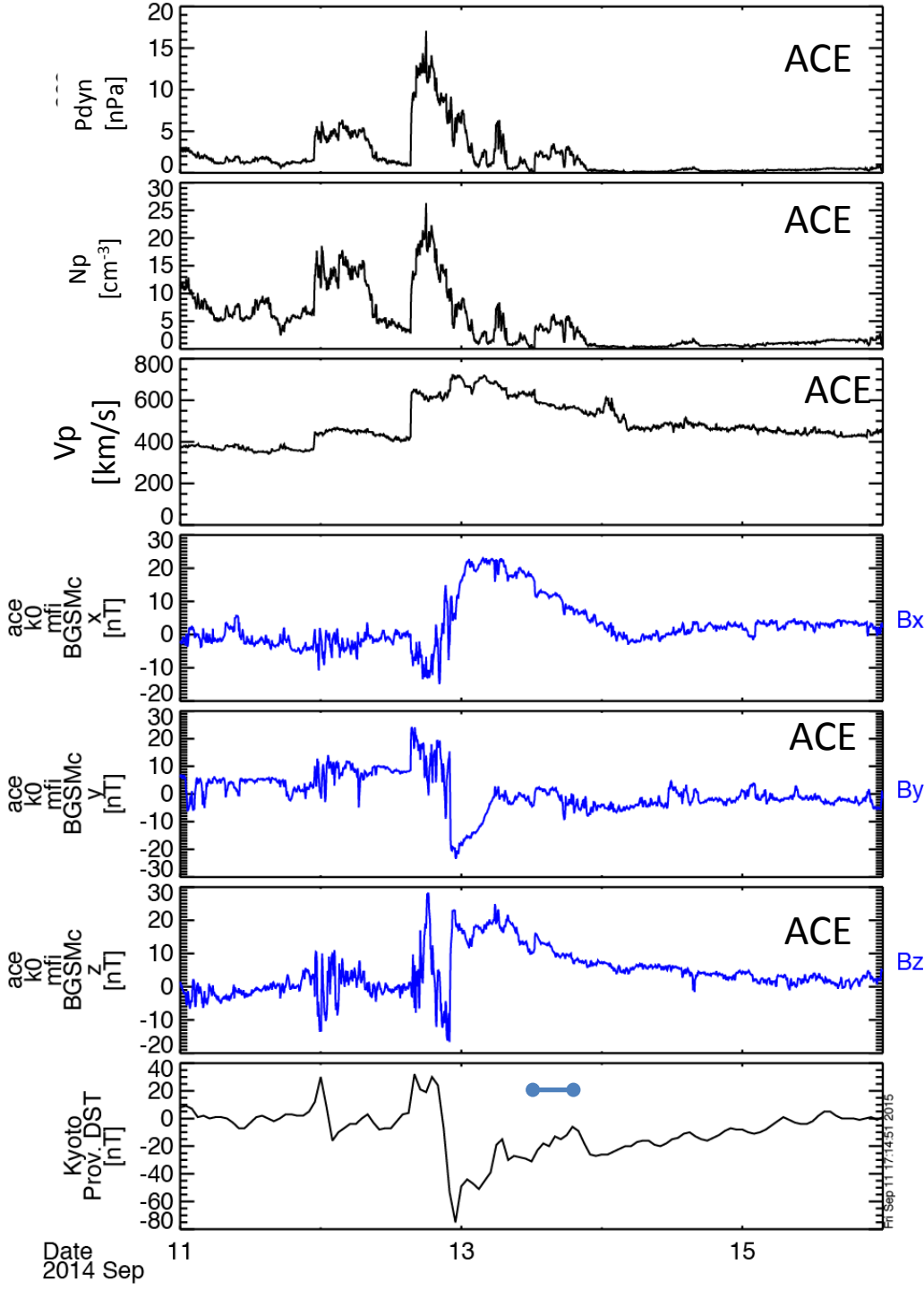
We investigate the extent of ULF waves, using multiple satellite in the inner magnetosphere.

Solar wind condition



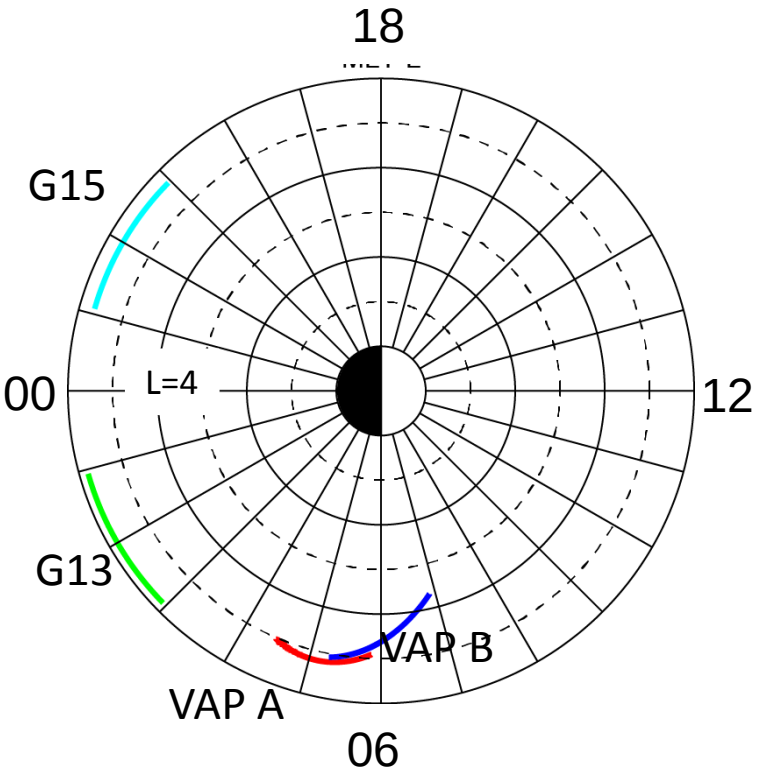
ACE observed two times when there were discontinuities in solar wind dynamic pressure, density, and solar wind speed through 11-16 September 2014.

Pc5 pulsations occurred at 0600-0800 UT on 13 September 2014 in the recovery phase of this storm.

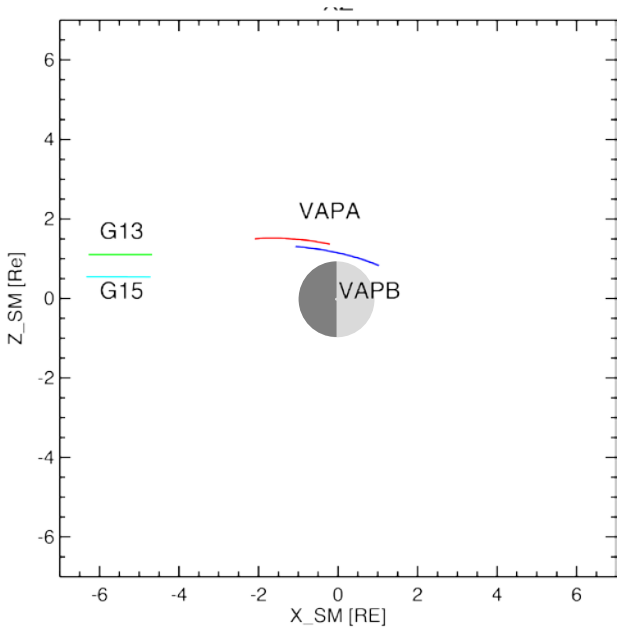


Satellite locations

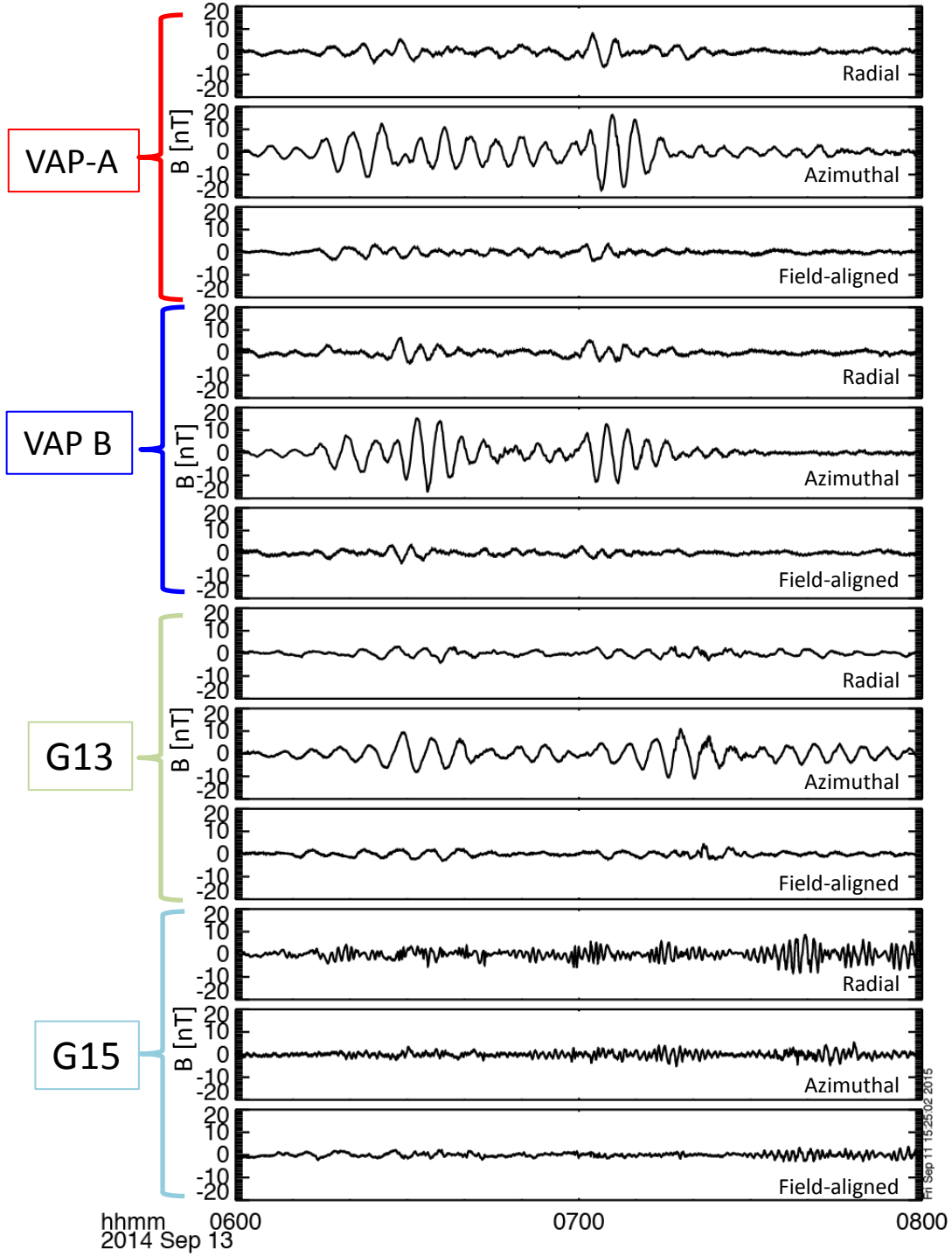
2014-09-13 06:00-08:00



2014-09-13 06:00-08:00



VAP-A and VAP-B were located on the dawntside off the eequatorial plane.
GOSE



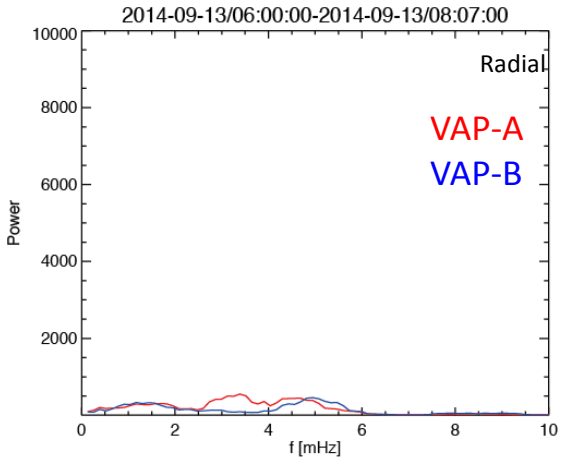
Magnetic field data observed by satellites

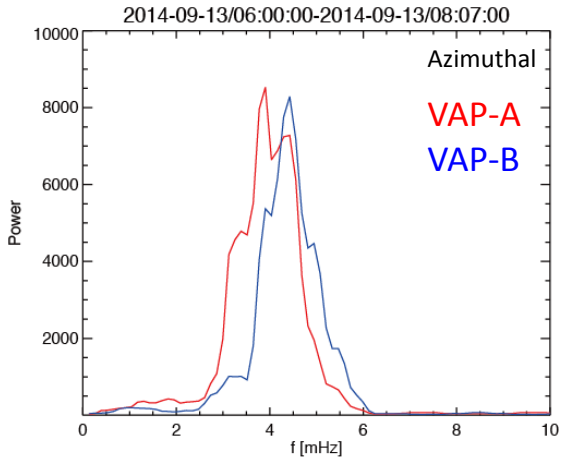
VAP-A, VAP-B (dawn)
GOES 13 (post midnight)

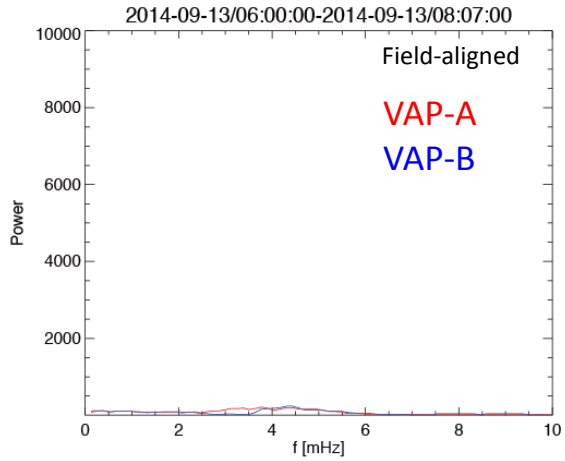
Toroidal ULF waves
With the amplitude of ~ 30 nT

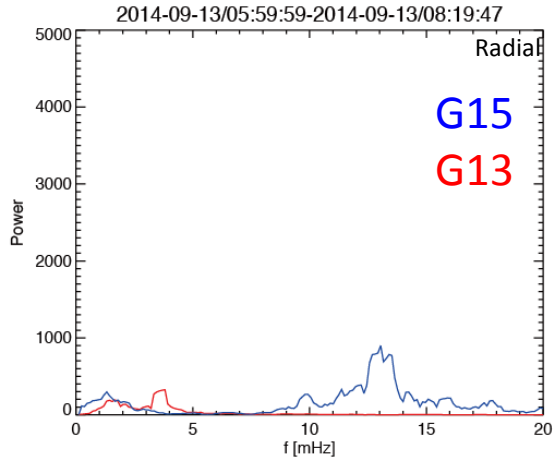
GOES 15 (pre mindnight)
Poloidal ULF waves
with the amplitude of ~ 20 nT

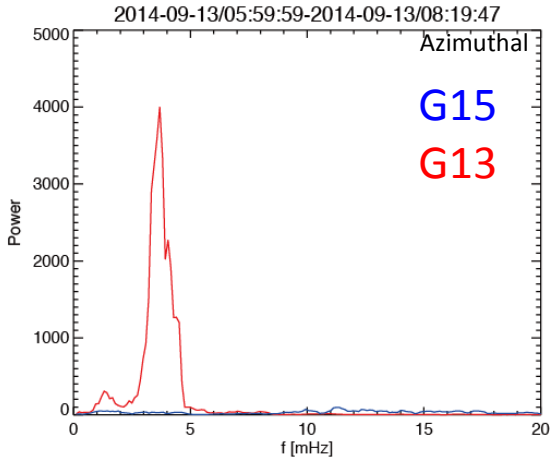
Spectral analysis

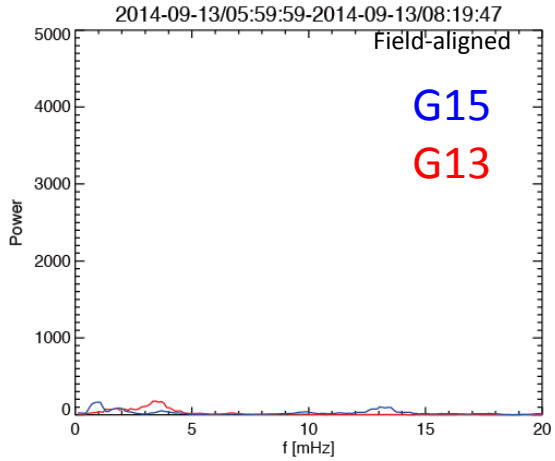






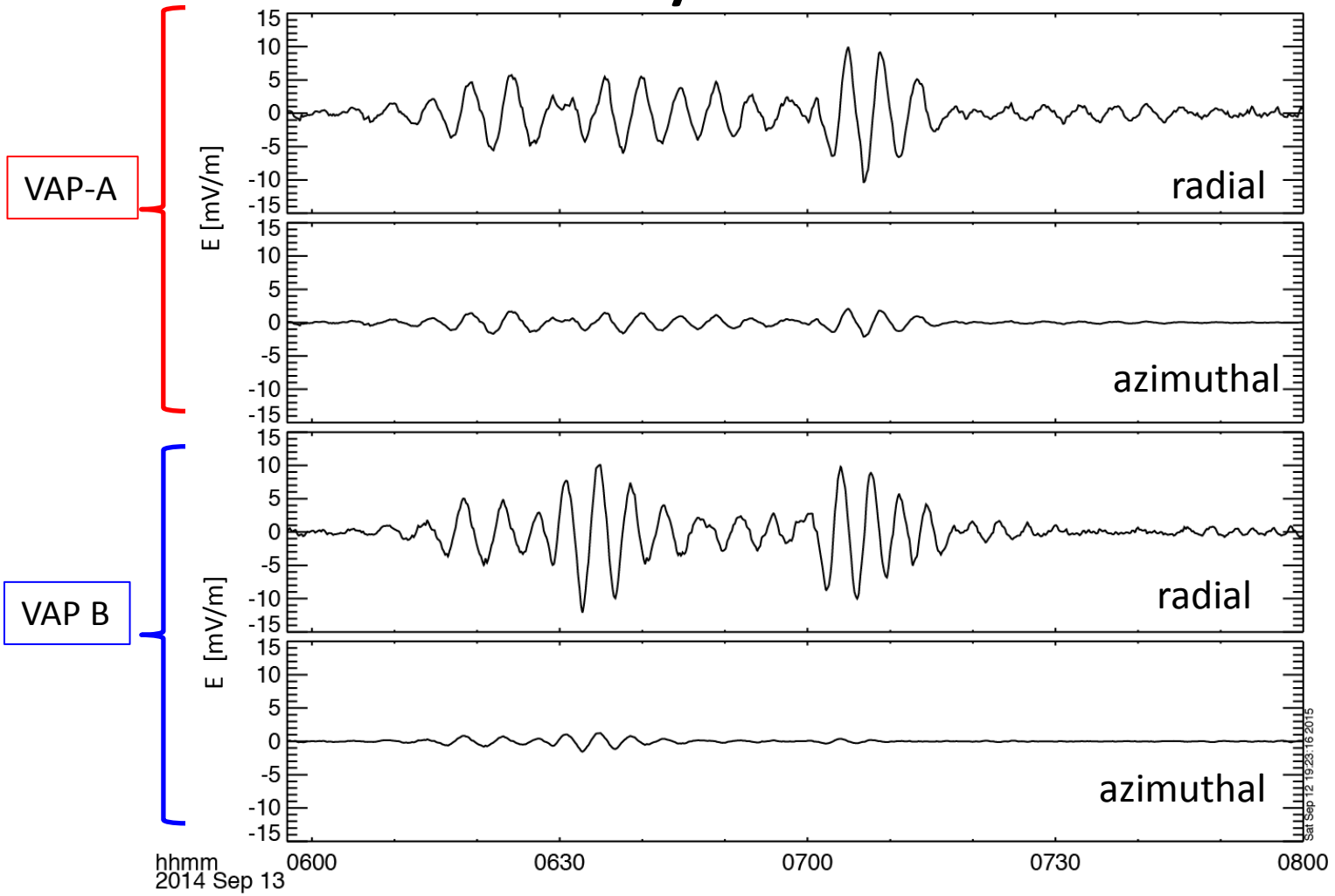






toroidal mode with 3.8 mHz (VAP-A and GOES 13)
toroidal mode with 4.5 mHz (VAP-B)
poloidal mode with 14 mHz (GOES 14)

THE Electric field observed by EFW on VAPs

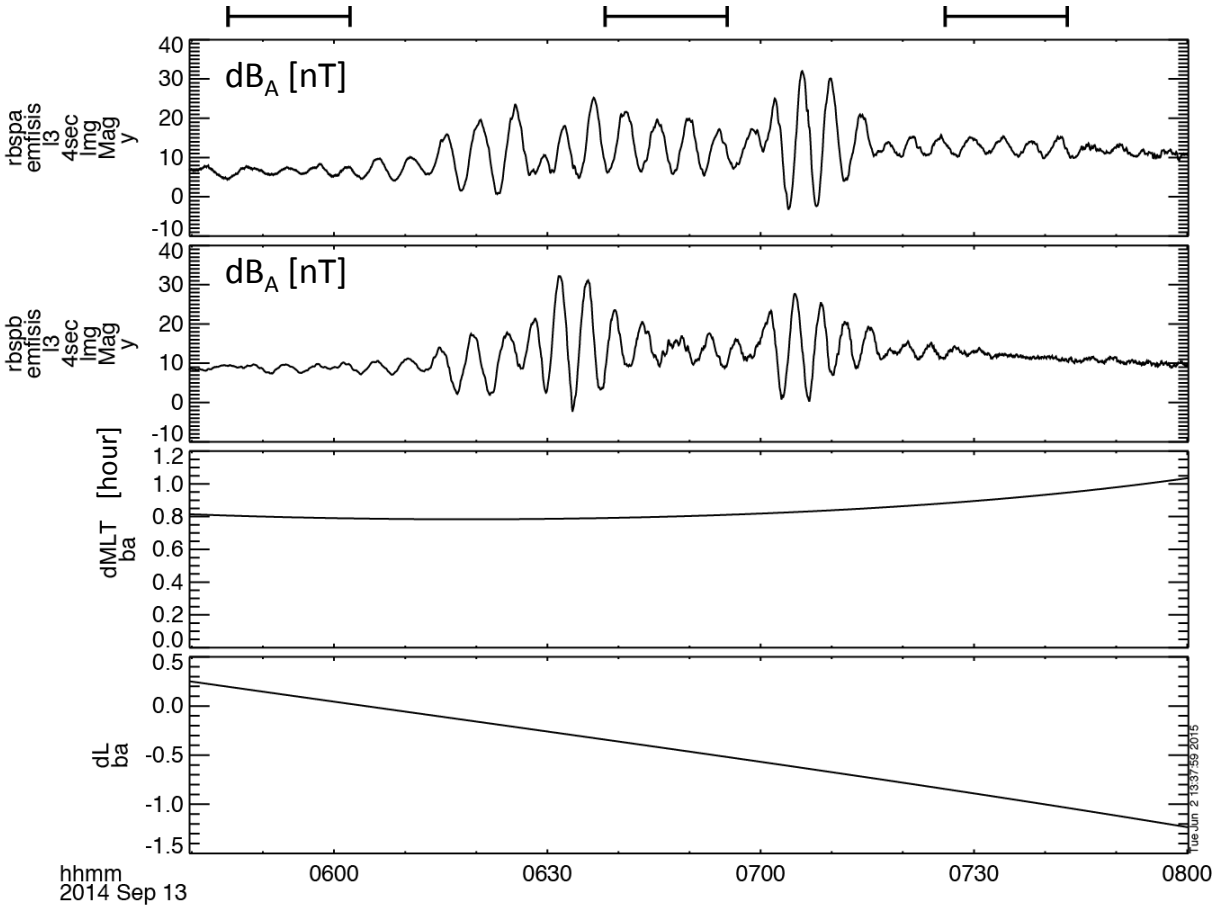


VAPs A and B observed Pc5 pulsations in the radial component with large amplitudes (20mV/m)

M numberの同定

VAPsは、イベント期間中、ΔLを変える。

30秒ずつずらしながら、Time window 256×4sでFFTをかけ、
Cross Phase、平均差分ΔL ,平均差分ΔMLTを求めて、m numberを計算する。



$$m = \frac{\Delta\phi}{360} \times \frac{24}{\Delta MLT}$$

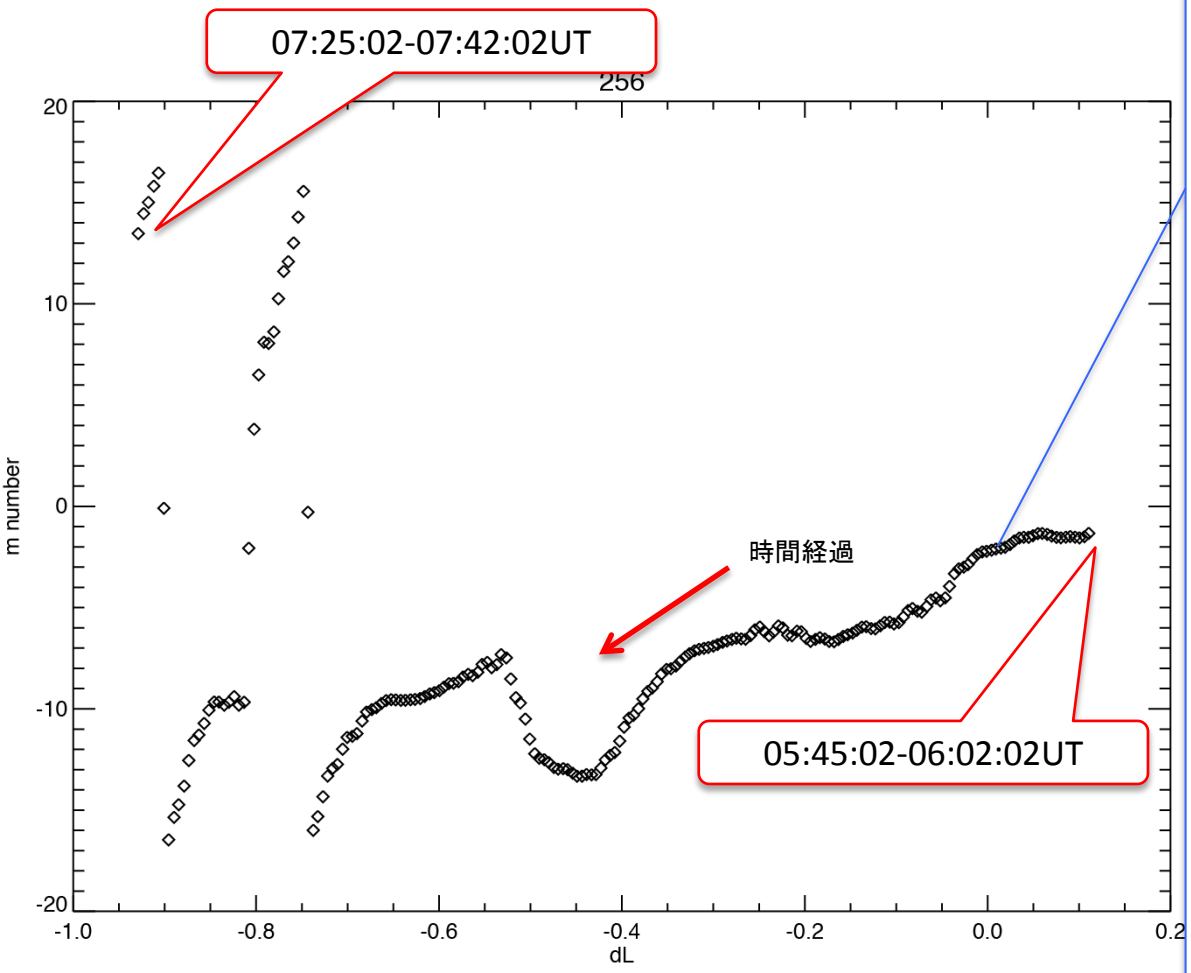
$\Delta\phi$ 位相差[deg]

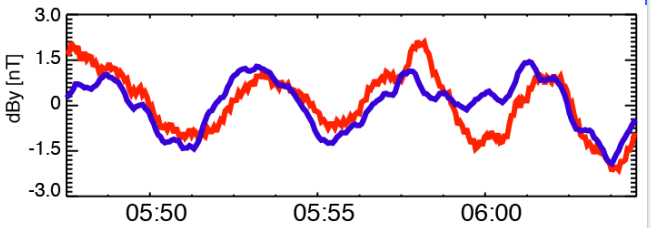
ΔMLT 同L値上の衛星同士の経度差 [hour]

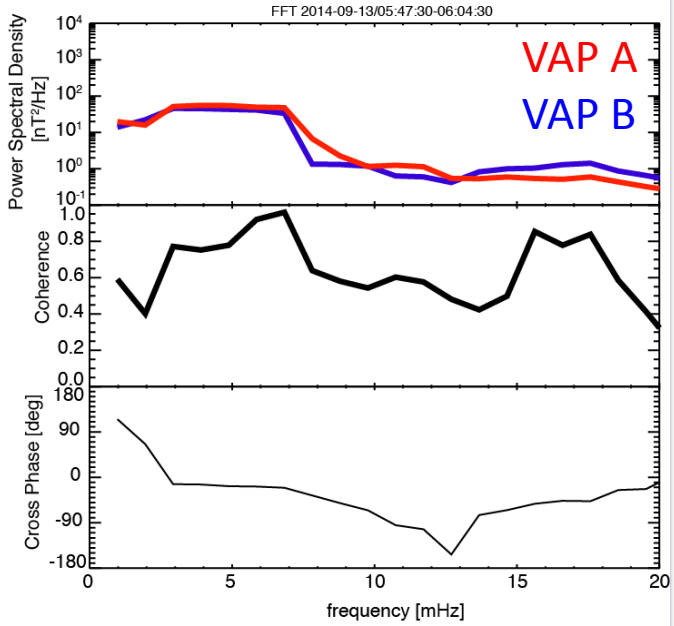
MLT_B-MLT_Aは、
ΔMlon~12°

イベント中、
L_B-L_Aは、一定ではない。

Window ~256*4でのm number



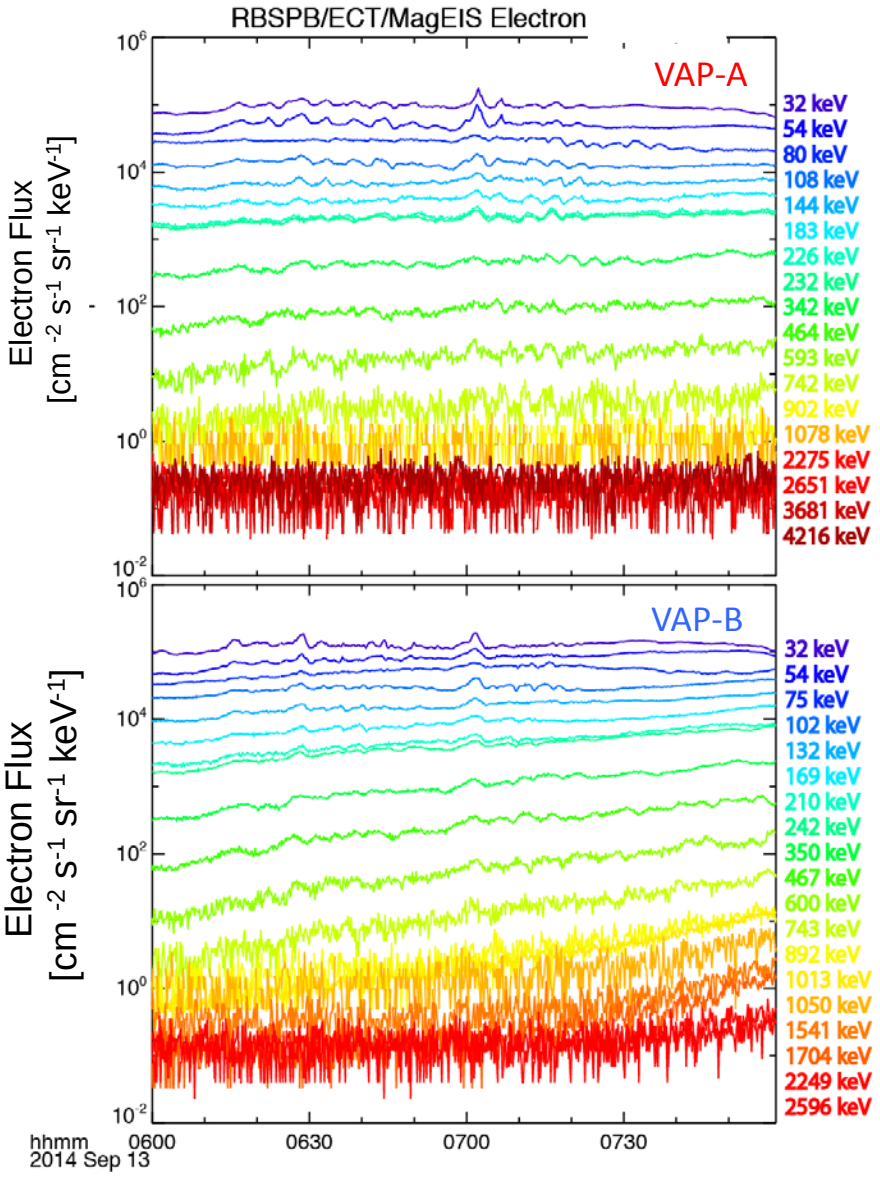


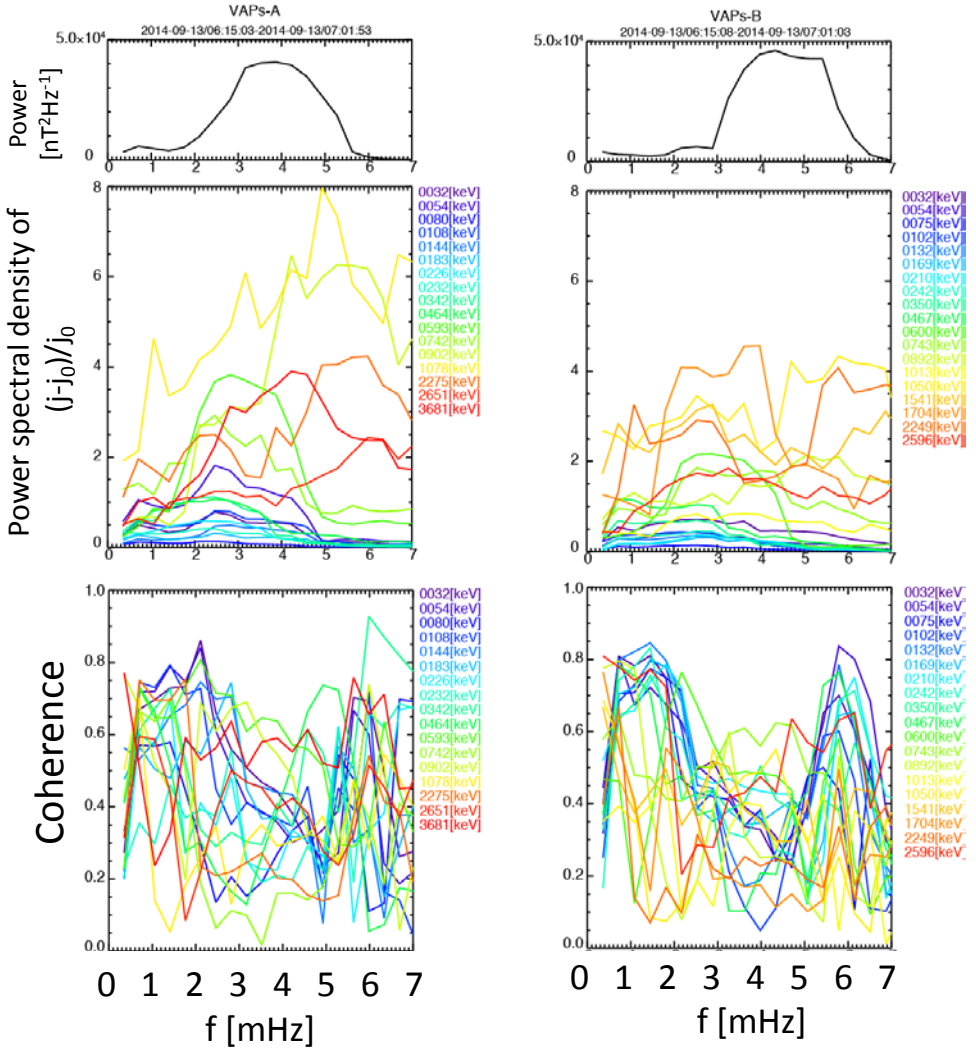


dL~ -0.0012　f ~ -4.394 mHz

m~ -2.2

MaGEIS Data





The electron with energies at 593 keV (743 keV) have high coherence, ~0.6, with Pc5 from VAP-A (VAP-B) at 3.5 mHz.

In a dipole magnetic filed, angular drift frequency ω_d of the ions with energy, W are given

$$\omega_d = -\frac{6WLP(\alpha)}{qB_E R_E^2} - \frac{2\Psi_0 L^3 \sin\phi}{B_E R_E^2} + \Omega_E$$

Gradient curvature drift

E × ***B*** drift effects

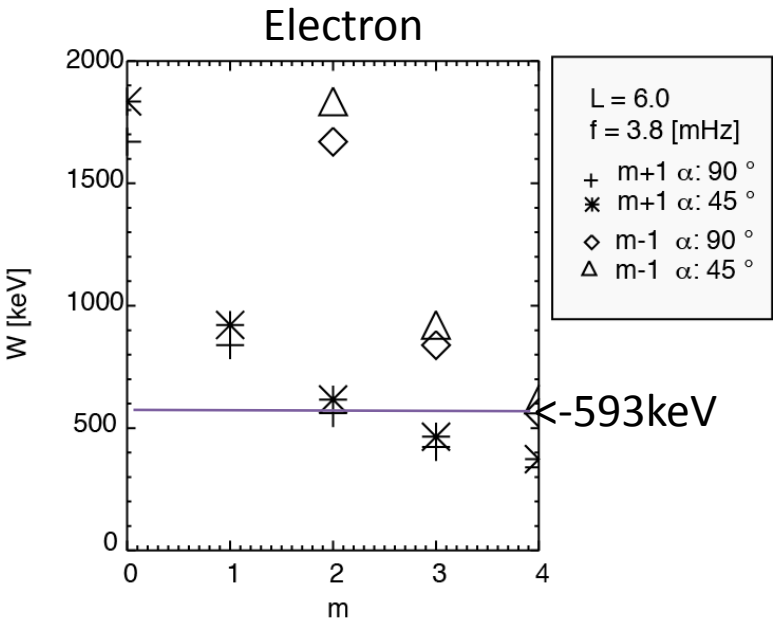
Convection electric field

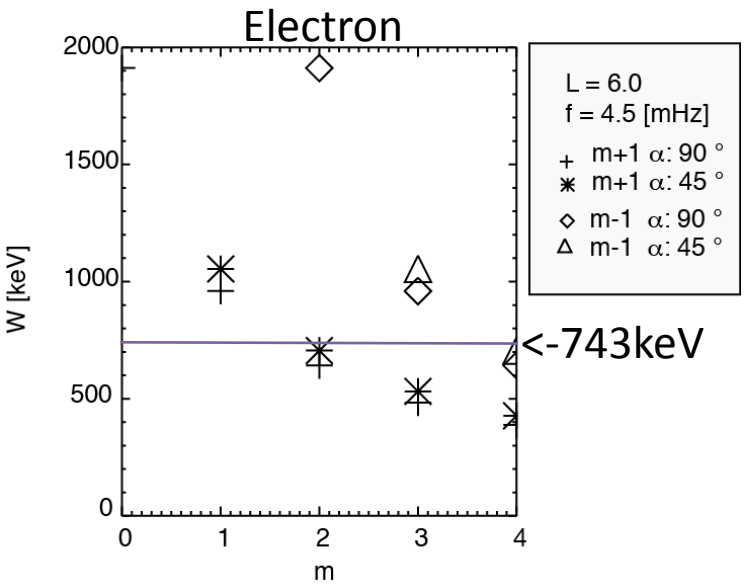
Corotation electric field

[Hamlin et al., 1961 ;Yang et al.,2011]

$P(\alpha) = 0.35 + 0.15 \sin\alpha$

α: ion's equatorial pitch angle
m_i: ion mass
L: L shell value
R_E: the Earth's radius
B_E: the equatorial magnetic field strength at surface of the earth
ϕ : the azimuthal angle (positive eastward with midnight at 0)
Ψ_0: electric potential indicating the dawn-dusk convection electric field
$\Psi_0 = 45\ (1 - 0.159Kp + 0.0093Kp^2)^{-3}$
Ω_E :the angular frequency of the Earth's rotation





The observations are consistent with theoretical estimate(?)

summary

2014年9月13日、中規模磁気嵐のrecovery phase中におきたULFに関して、GOES-13, GOES-15, VAP-A, VAP-Bを用いてm-numberを求め、広がりを調べた。

朝側 postmid nightにおいて、L~6-6.7の範囲で、3.8-4.5 mHzをもつ大振幅のtoroidal mode のPc5を観測した。

- 朝側Pc5の電場(radial成分)の振幅は非常に大きい(~10[mV/m])。
- m numberは2.2（westward）
- Drift-Resonance をおこす電子のエネルギーは、590-750keV。理論式による見積もりとも一致する。

pre-midnight においては、L~6.7で、toroidal mode のPc5が観測されず、Poroidal mode が卓越。（MLT~21-23まではtoroidal mode が観測されていない）

→ m-numberが小さくとも、経度方向にGlobalとはいえない？

3.8mHzのPc5の端はどこか？→アメリカ大陸・日本のSuperDARNを調べる必要がある。