St. Patrick's Day 2015 storm時に観測されたhigh-m ULF について
On the high-m ULFs observed during the St. Patrick's Day 2015 magnetic storm

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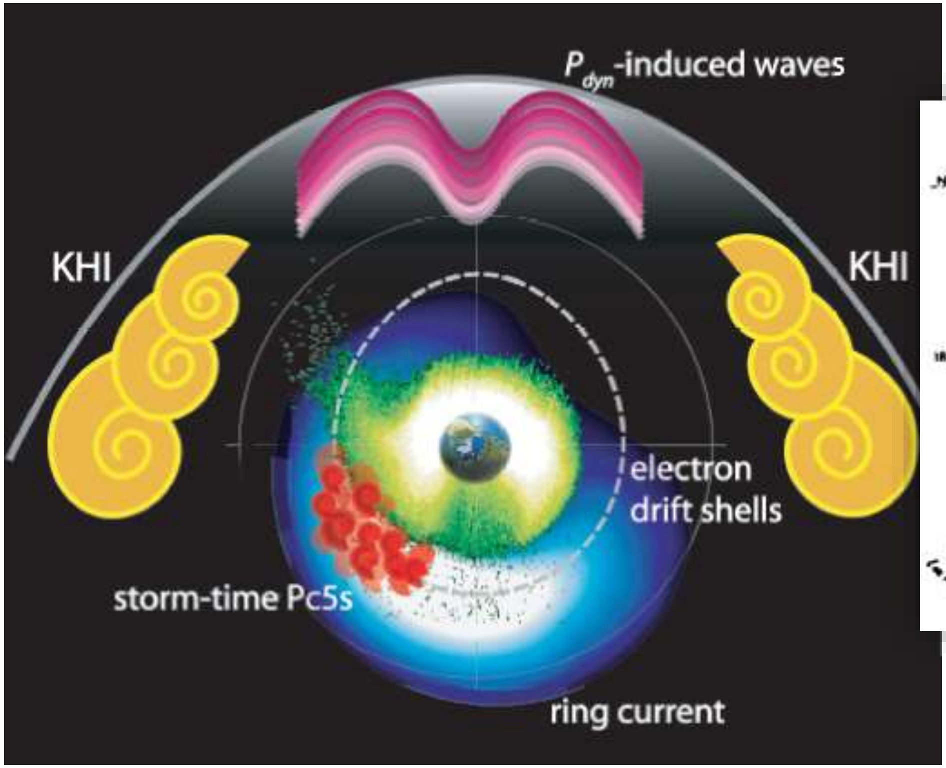
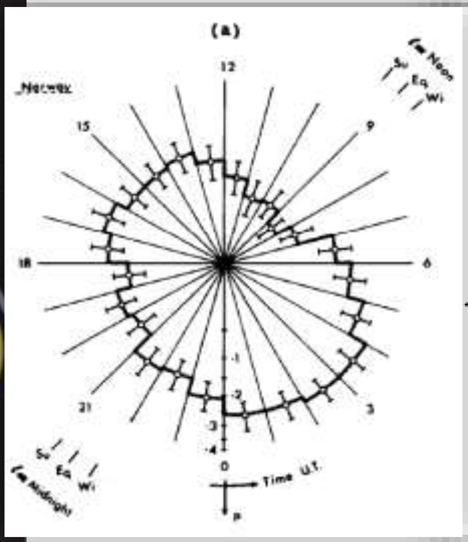
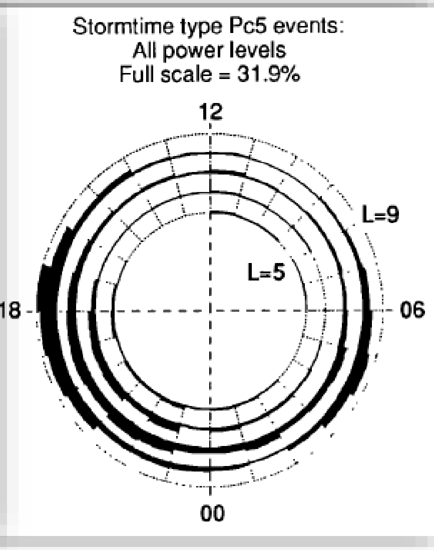
Introduction:
Storm-time Pc5, a category of Pc5 ULF waves



[Ukhorskiy+2009]



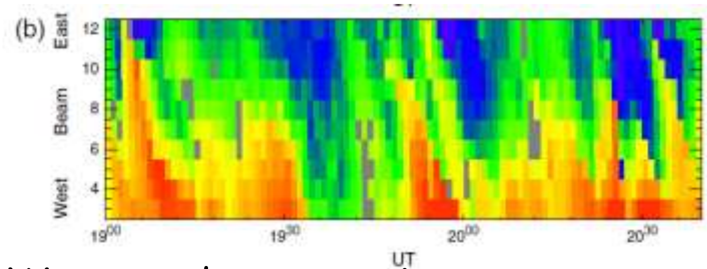
[Walker+1981]



[Anderson+1990]

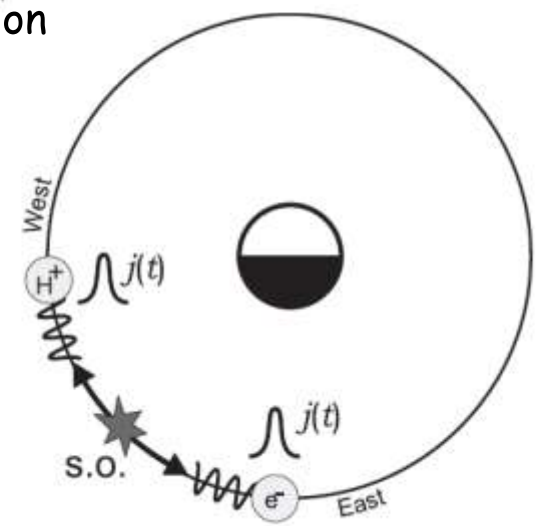
- Pc5 ULF waves can roughly be classified by their energy source into two categories:
  - Solar wind driven Pc5 ULFs →transverse, typically low-m, pumped externally
  - Storm-time Pc5 ULFs → compressional, often high-m, driven internally

Introduction:
Drivers of storm-time Pc5



Westward propagation
by SD observation

[James+2013]



Simulation of ULFs excited
by drifting ions

[Mager+2008]

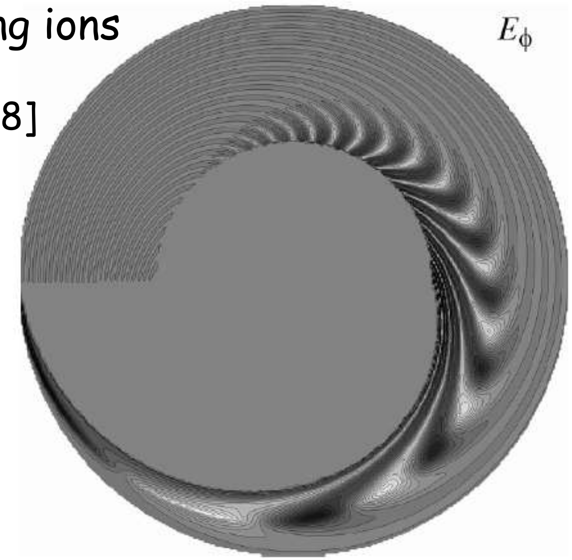


Fig. 6. The azimuthal component of the electric field.

- High-m, poloidal, more or less irregular fluctuations of Pc5 freq. range
- Interactions with the ring current and drifting particle populations in the inner magnetosphere are thought to be the driver of this type of high-m Pc5 ULF waves [e.g., Southwood, 1976, 1980; Yeoman+2000, Mager+2008].

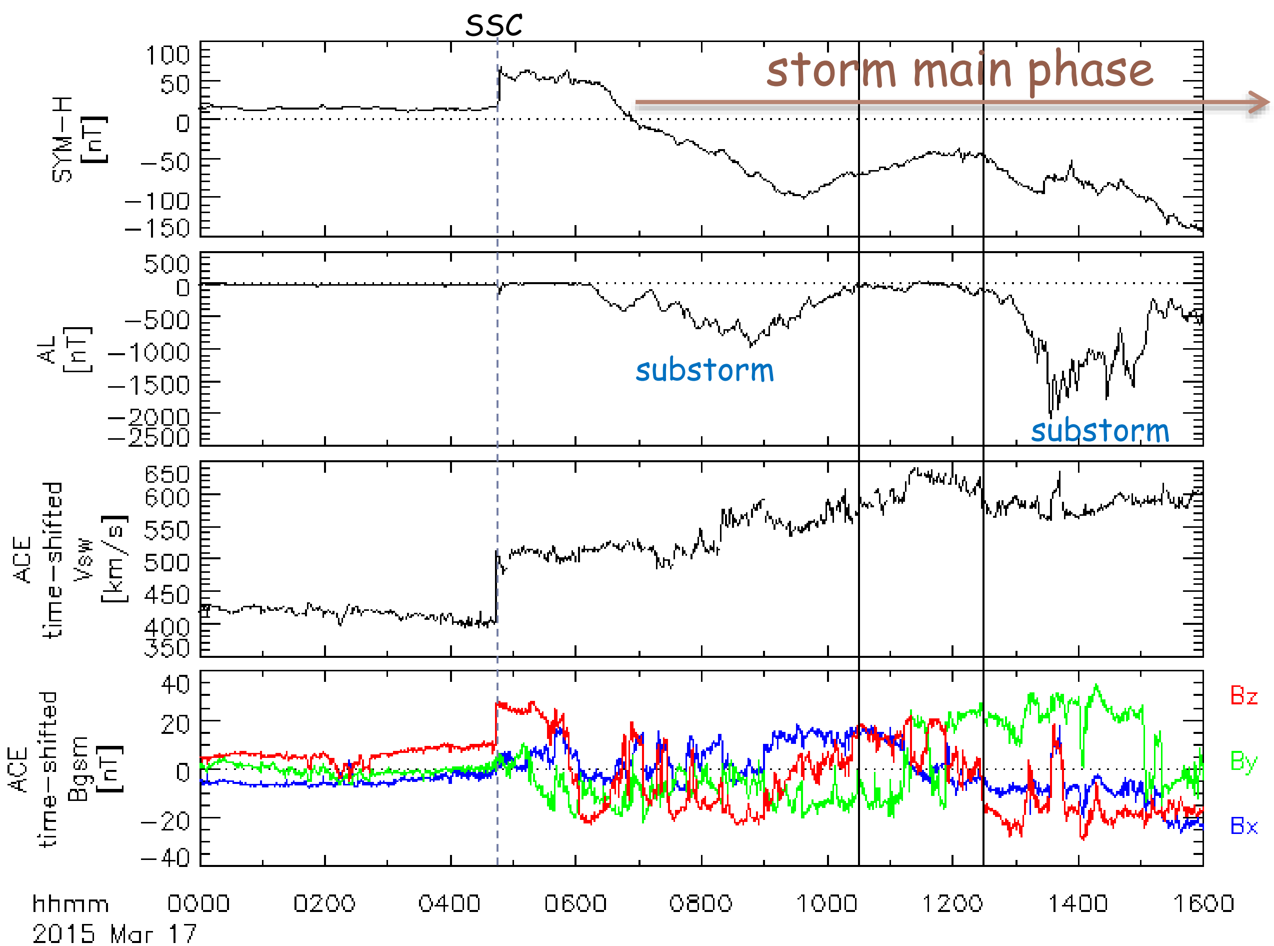
Motivations

- The extensive set of mid-latitude SuperDARN radars has observed a ULF activity during the March 2015 magnetic storm that shows interesting characteristics of large-scale evolution.
- By examining them with a help of multiple satellites recently available in the magnetosphere, we study how the storm-time ULF wave-like structures develop and evolve spatially.

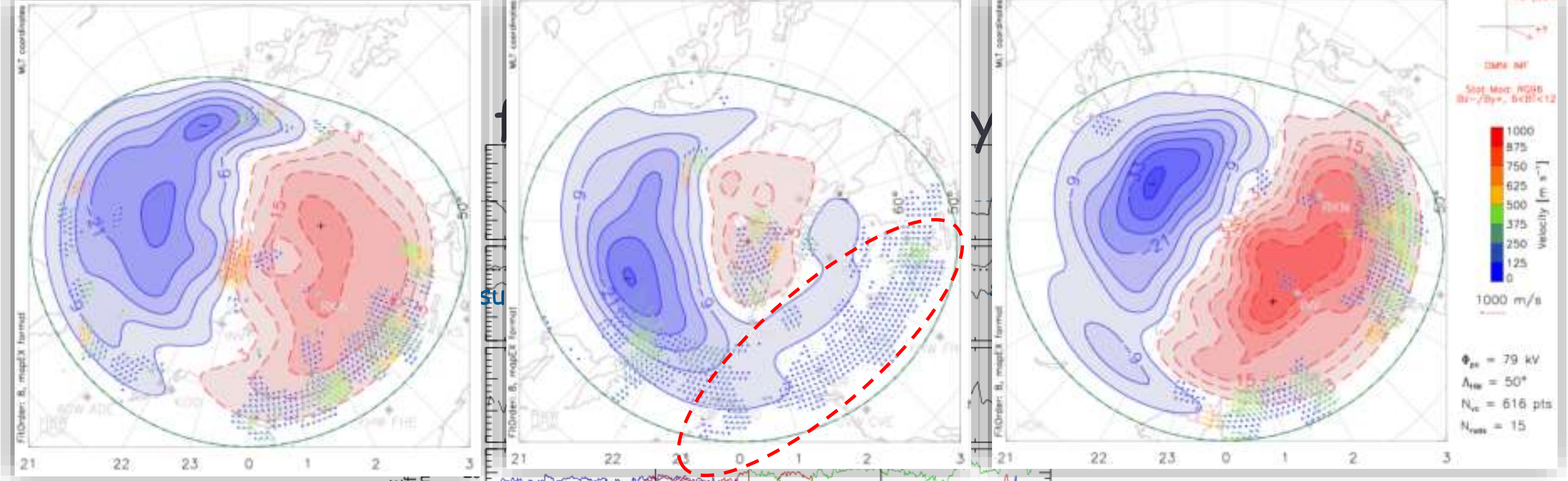
Goal of the present study

- On the basis of a case study with interesting ULF activities seen by the SuperDARN radars, we seek to address the following questions:
  - How farther do the ionospheric ULF waves evolve, particularly in the local time direction?
  - What wave characteristics do they have?
  - What is the cause of the ionospheric flow fluctuations?

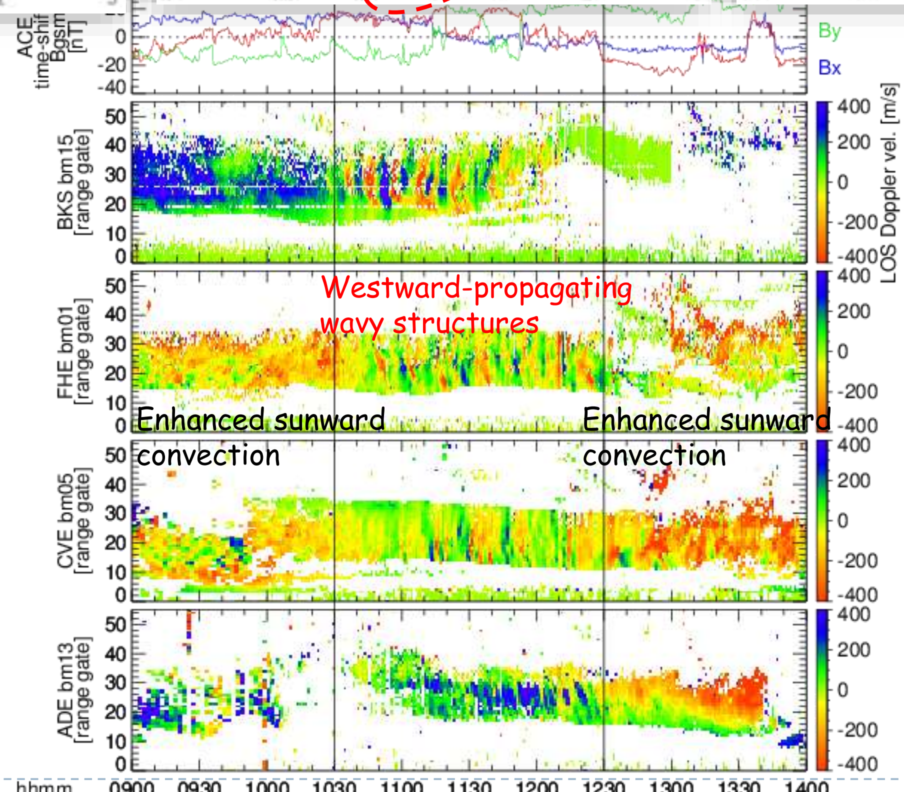
Data analysis: March 17, 2015 magnetic storm



- a.k.a. St. Patrick's day storm

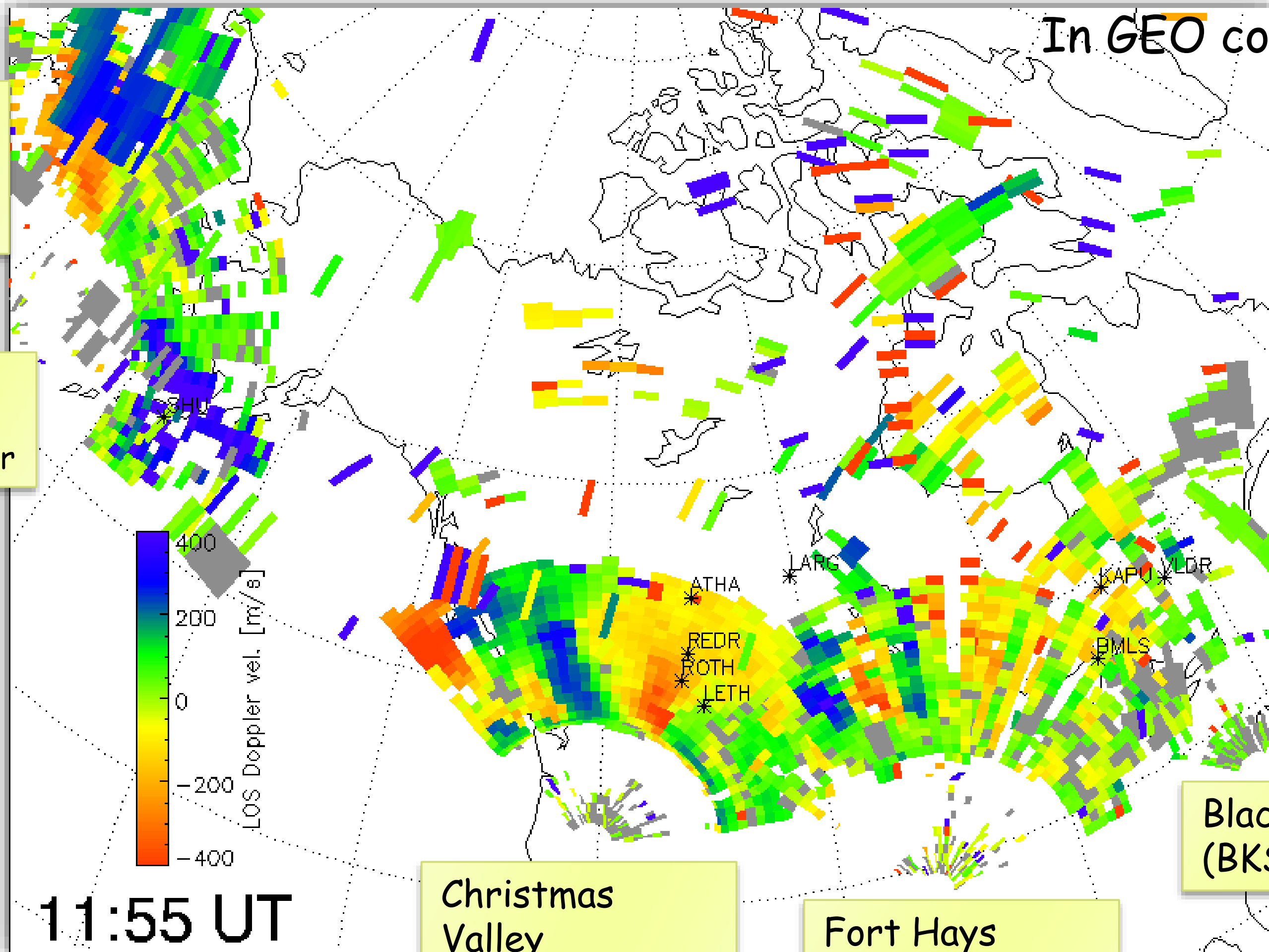


21 22 23 0 1 2 3
1000 m/s



ACE time-shift Bgsm [nT]
By
Bx
BKS bm15 [range gate]
FHE bm01 [range gate]
CVE bm05 [range gate]
ADE bm13 [range gate]
LOS Doppler vel. [m/s]
Westward-propagating wavy structures
Enhanced sunward convection
Enhanced sunward convection
hhmm
2015 Mar 17
0900 0930 1000 1030 1100 1130 1200 1230 1300 1330 1400

Data analysis:
2-D view of dynamical ionospheric flow fluctuations



Hokkaido East/West (HOK,HKW) radar

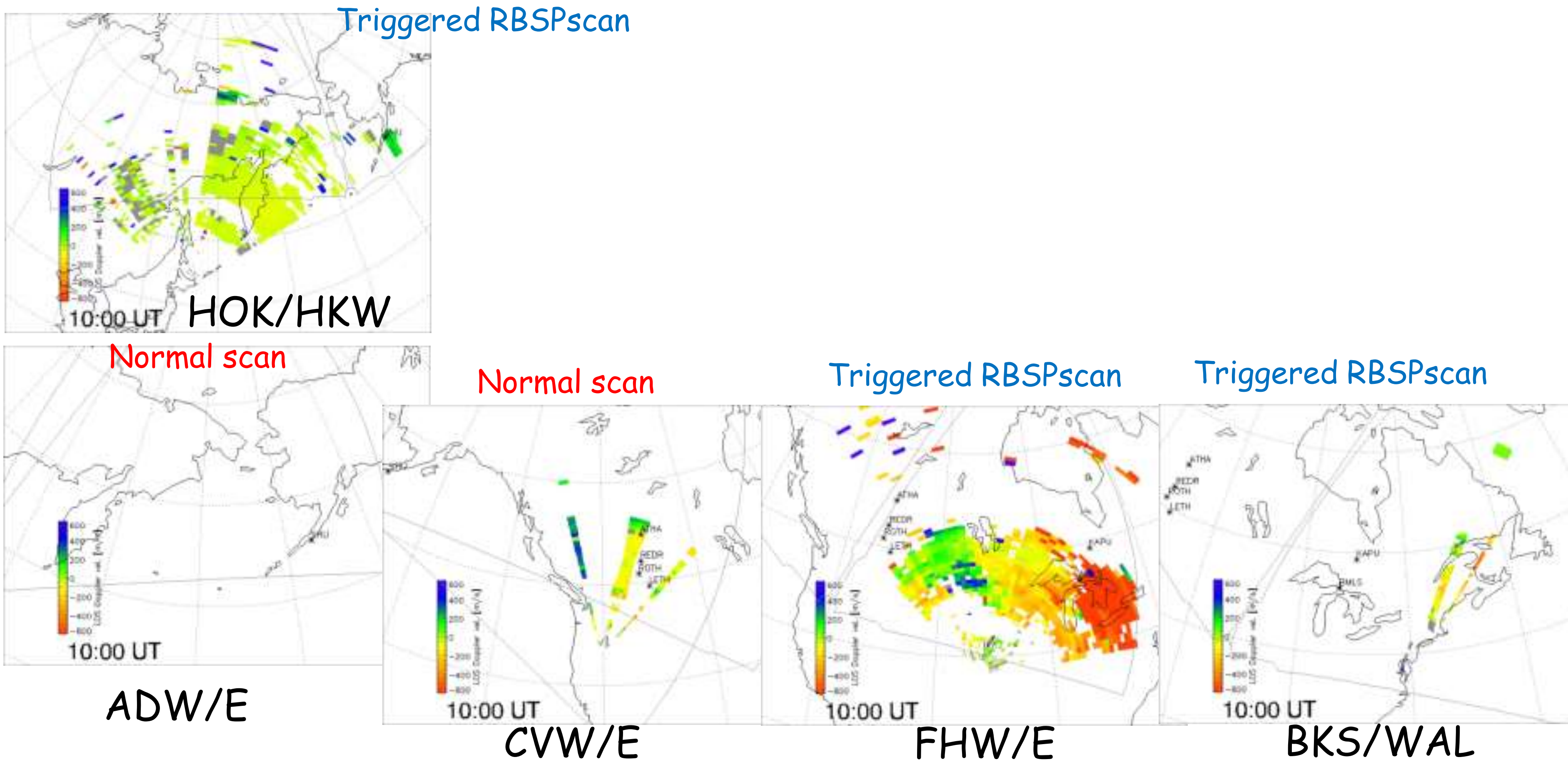
Adak East/West (ADE,W) radar

Christmas Valley East/West (CVE,W) radar

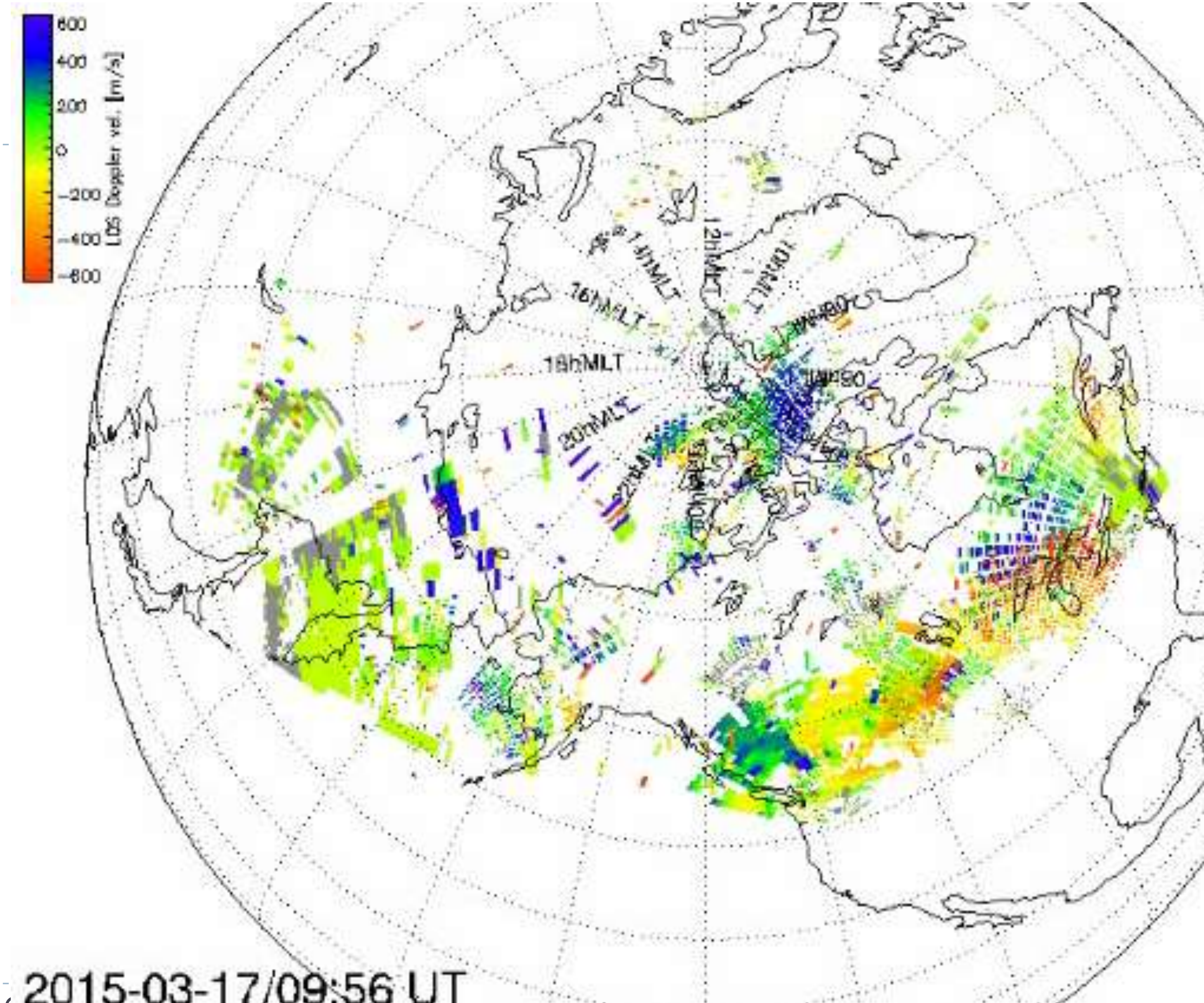
Fort Hays East/West (FHE,W) radar

Blackstone (BKS) radar

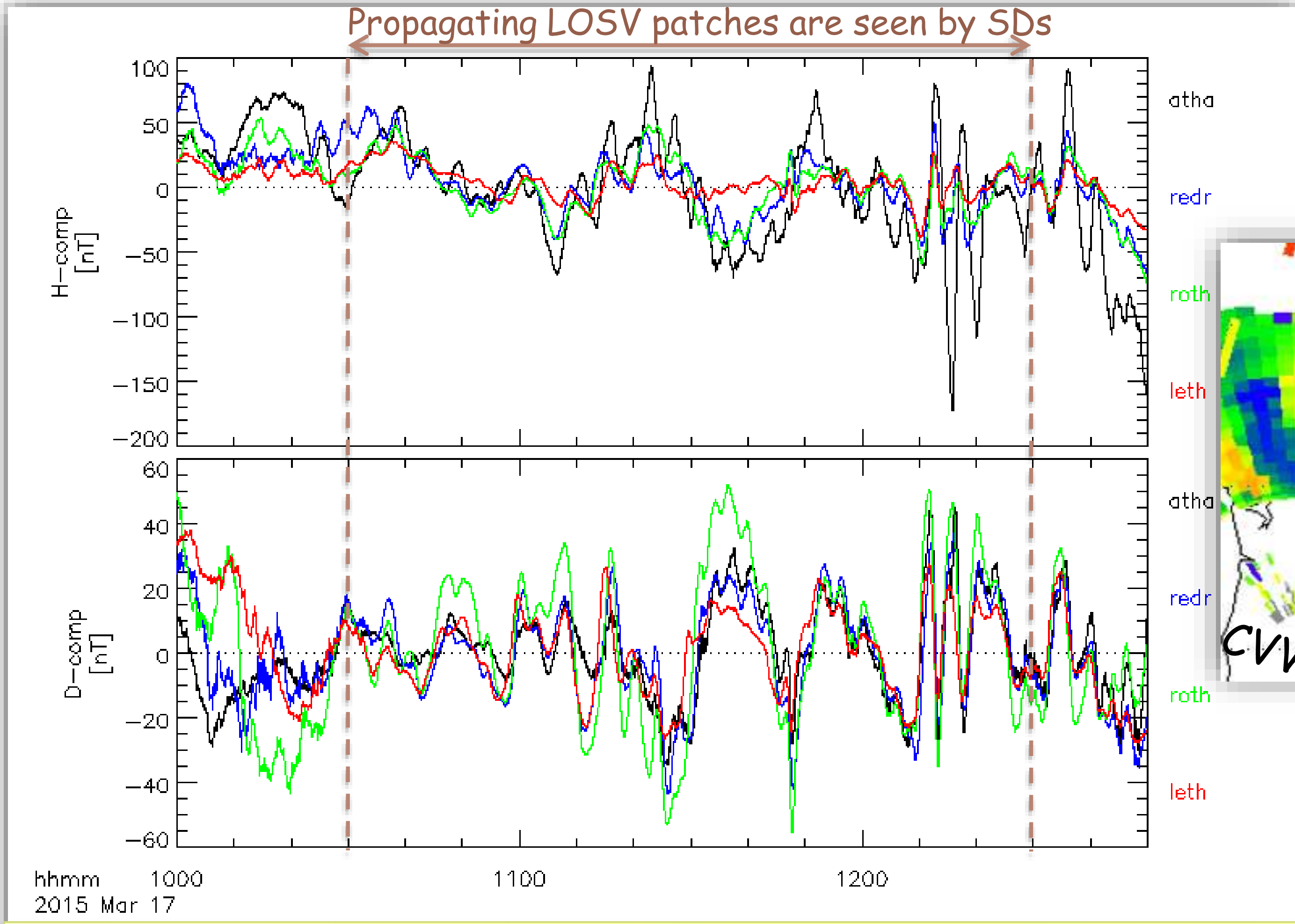
Data analysis:
2-D view of dynamical ionospheric flow fluctuations

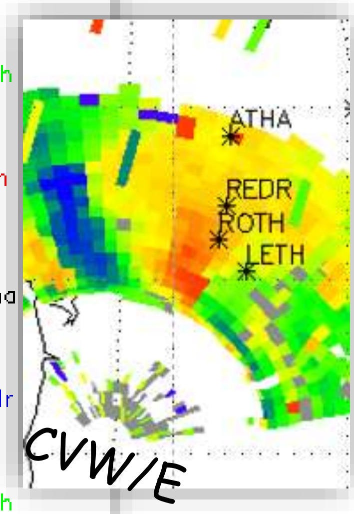


- Westward-propagating velocity structures are seen during ~10:30 to ~12:40


600
400
200
0
−200
−400
−600
LOS Doppler vel. [m/s]
12hMLT
14hMLT
16hMLT
18hMLT
20hMLT
10hMLT
2015-03-17/09:56 UT

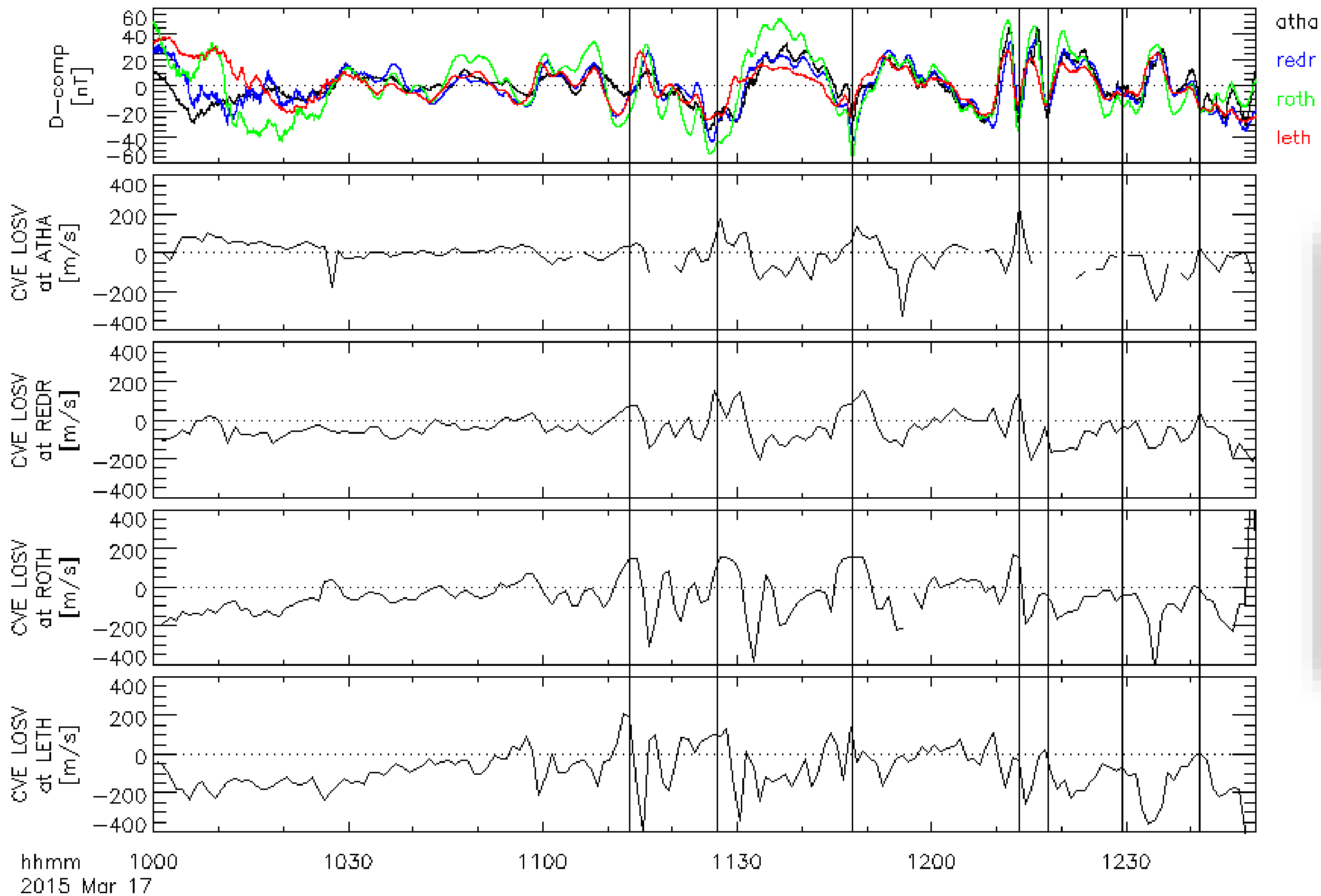
Data analysis: Geomag. observations underneath a radar f-o-v

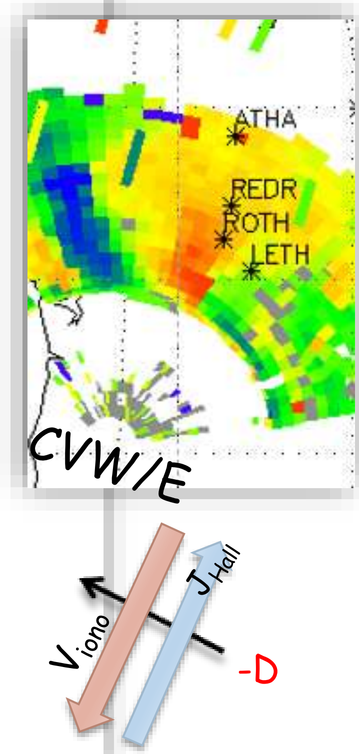




The D-components show good coherence over the latitude range, rather than the H-components.

Data analysis:
Qualitative comparison with geomag. observations

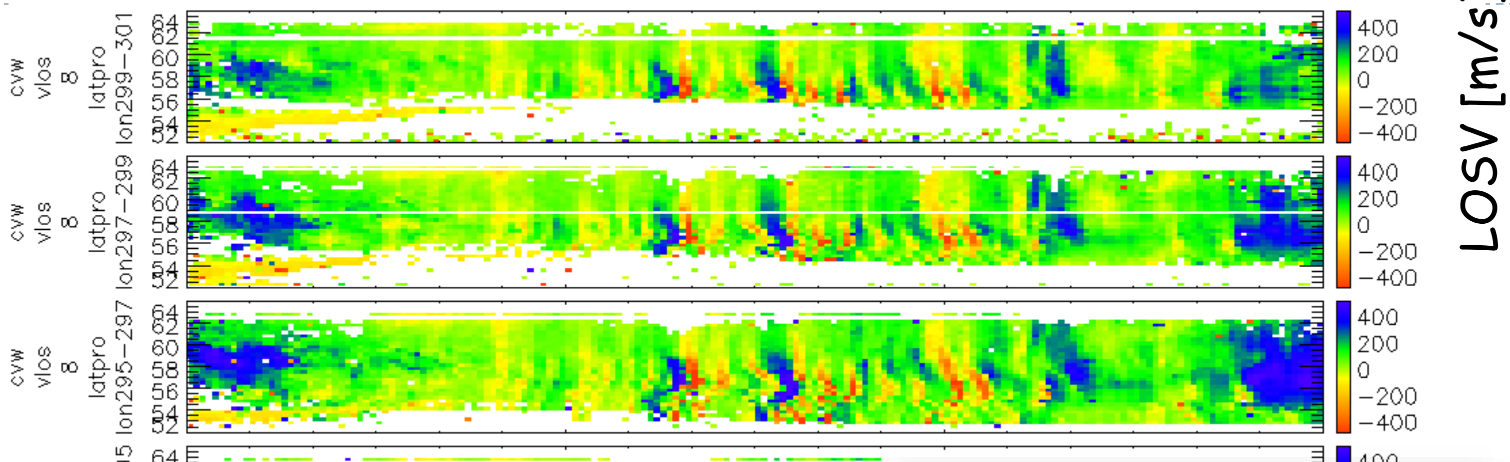




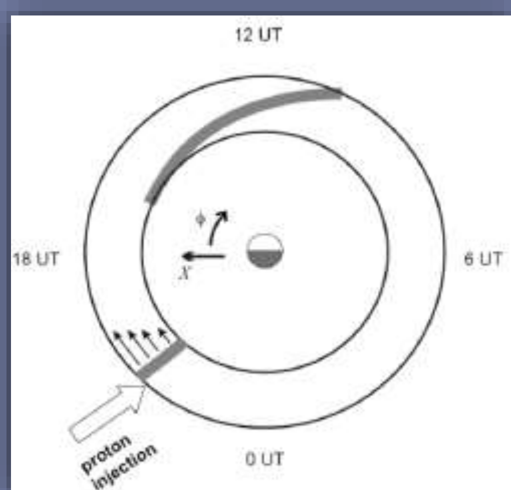
Ionospheric flow oscillations are basically in the north-south direction, indicating a significant poloidal component.

-D → southward V_{iono}
→ +LOSV

Data analysis:
Keograms of fluctuating flows seen by CVW



The higher-lat. branch propagating equatorward can be explained by this theory. But the lower-lat. part propagating poleward?



[Mager+2008]

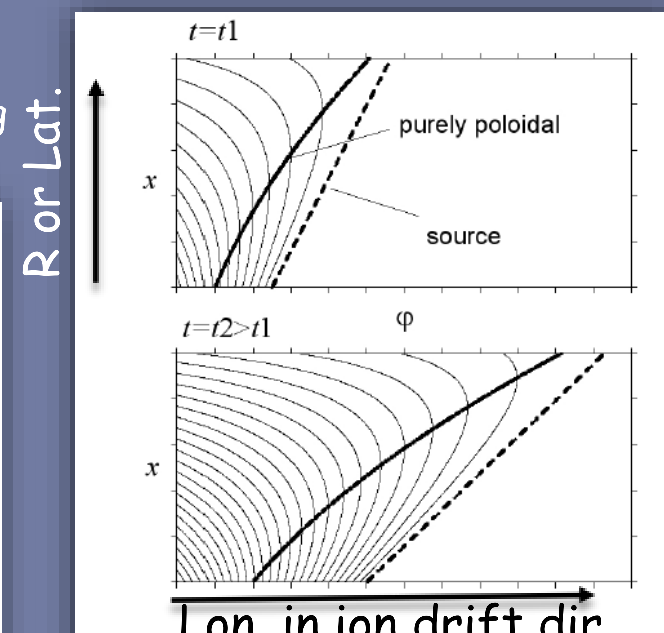
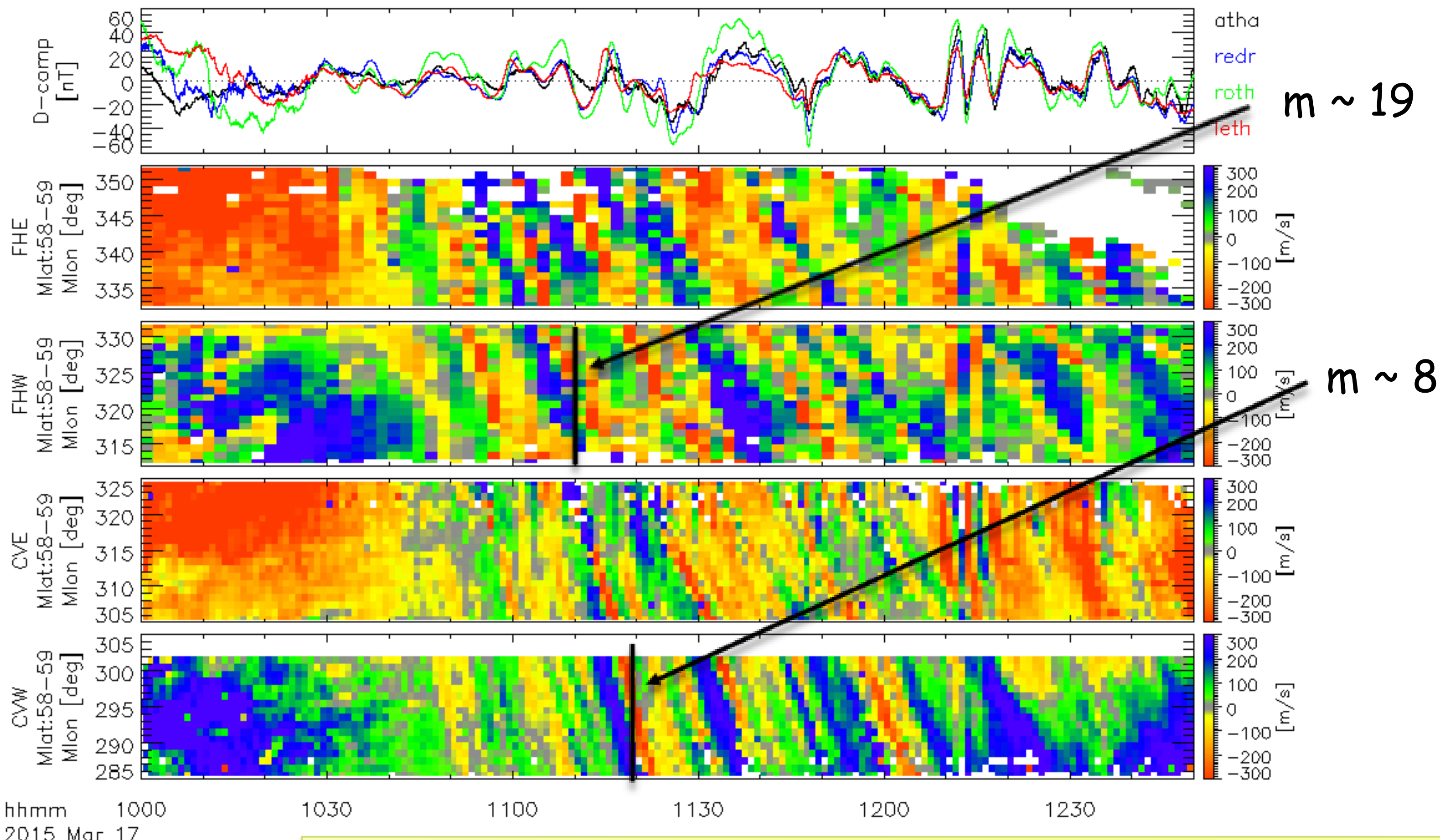


Fig. 3. The lines of the constant phase for different time instants.

Data analysis: Ewograms of fluctuating flows seen by FHE, FHW, CVE, and CVW

m-number ~ 2π/ (azimuthal scale)

Mlat: 58-59

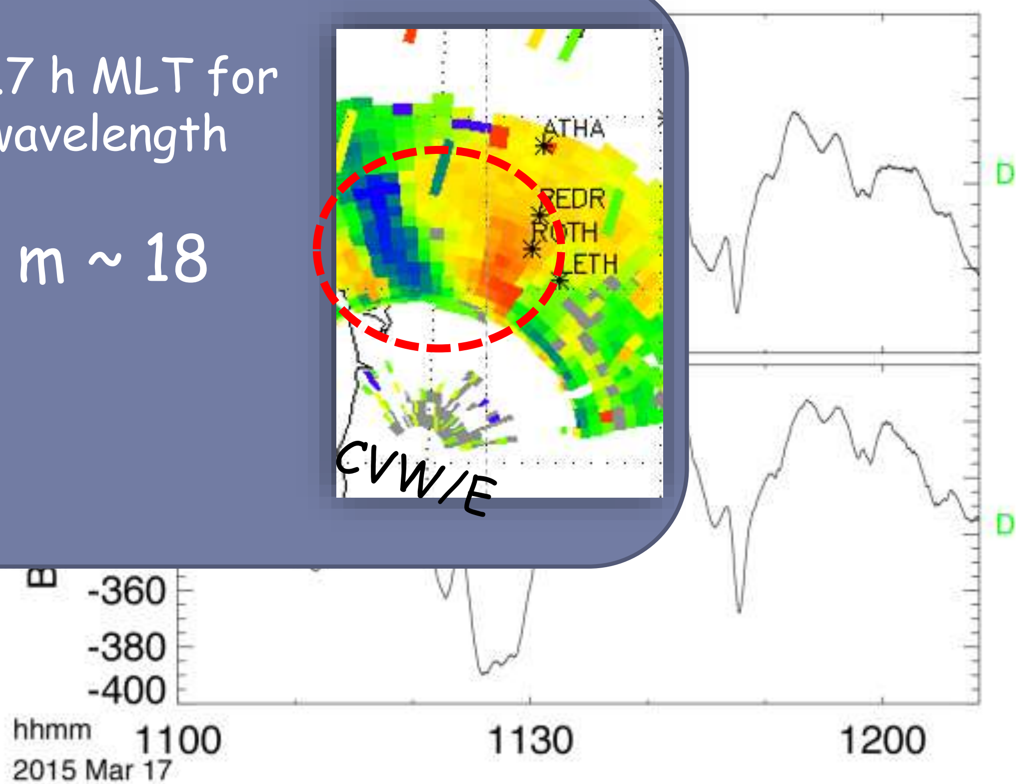


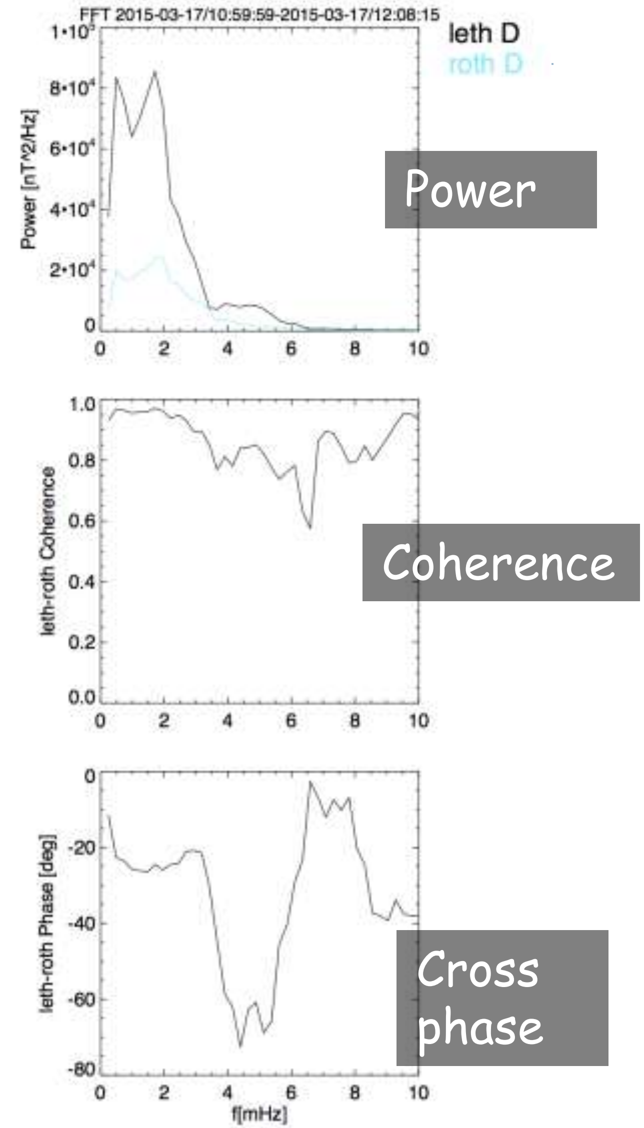
m-number ranges from ~7 to ~25

Data analysis: M-number estimate

~0.7 h MLT for ½ wavelength

→ m ~ 18

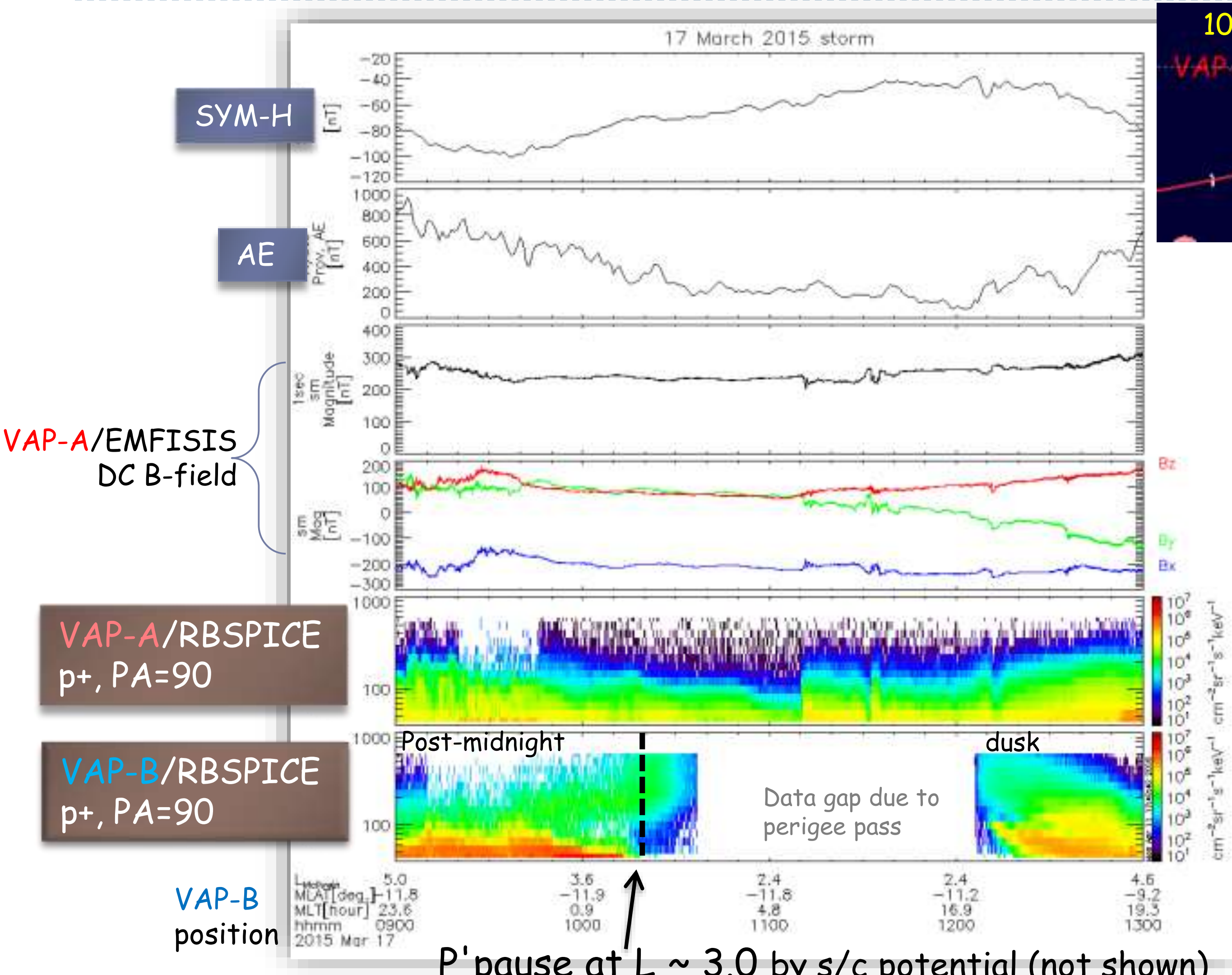


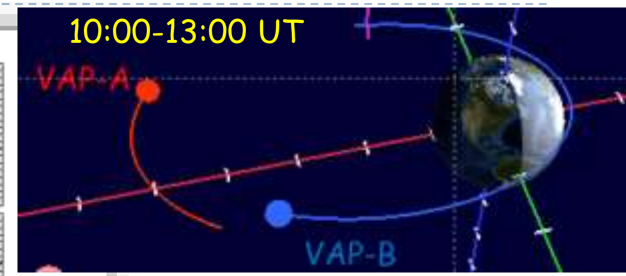


- Δlon for LETH-ROTH : 2.1 [deg]
- Δphase for LETH-ROTH : -25 [deg] @1.0-2.5mHz

→m-number~20 (westward)

10¹-10² keV proton flux by VAP-A, B





An approximate form of angular drift frequency (ω_d) for a particle with energy W [Yeoman+2001]

$$\omega_d = -\frac{6WL(0.35 + 0.15\sin\alpha)}{B_s R_E^2} + \frac{90\left(1 - 0.159K_p + 0.0093K_p^2\right)^{-3} L^3 \sin\varphi}{B_s R_E^2}$$

ω_d~ 5.8 x 10-4 rad/sec, alpha = 90 deg, and L = 4.0 gives a particle energy W ~ 57 keV.

Ions with the expected resonant energy are actually observed at L ~ 3-5 by VAP-B. Further fresh injections come in after ~11:10 UT, as seen by VAP-A.

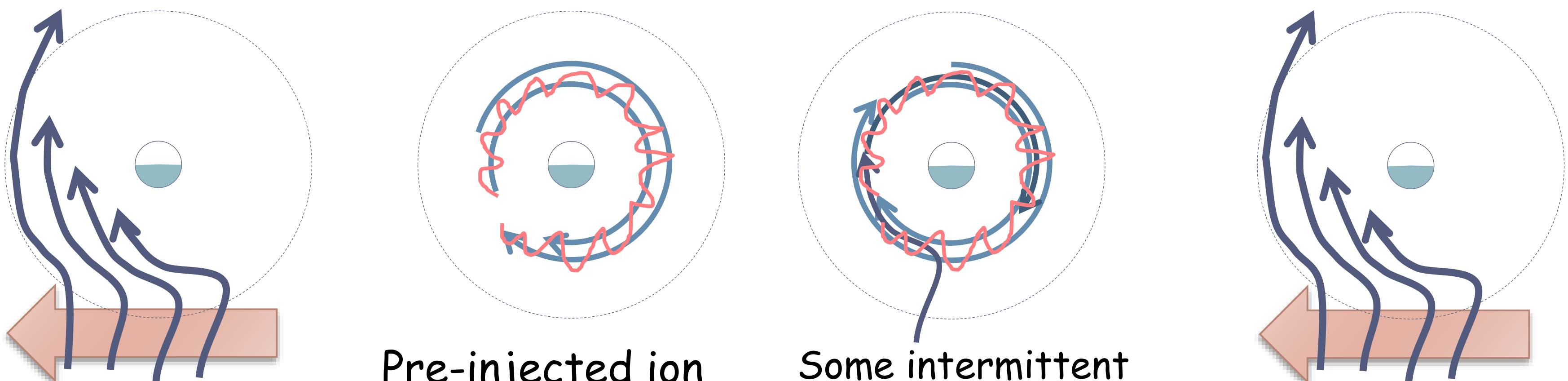
Discussion:
The interpretation of the present obs.

Before ~10:00 UT

~10:30— 11:10 UT

~11:10— 12:40 UT

After ~13:00 UT



Strong convection E

Pre-injected ion clouds are left as drift echoes accompanied by poloidal ULFs excited by them

Some intermittent injections come in, joining the older ones.

Strong convection E

- We speculate that the enhanced convection might keep out drift echoes and/or the strong SAPS/convection E-field might apparently mask the SD observation before ~10:00 and after ~13:00.

Summary and conclusions

- ULF signatures of ionospheric plasma flow during a stagnant period of the storm main phase on March 17, 2015 were examined using mid-latitude SuperDARN radars, with ground magnetometers, and several inner magnetospheric satellites.

- The ULFs seen around L ~ 3.0-4.5 (~55-62° in MLAT) show an extensive westward propagation over ~7-8h MLT, with a speed of ~2-3 km/s at the ionospheric height (roughly ~8-12 km/s in the equatorial magnetosphere at L =4).
- The ULFs passed azimuthally by the region at higher latitudes than (in m'sphere, outside of) the plasmapause.
- The observed protons with the expected resonant energy in the inner magnetosphere strongly suggest that the poloidal ULFs are driven by wave-particle interactions.

Acknowledgments

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