Observations of Pi2 Pulsations at Substorm Onset with the SuperDARN THEMIS mode

J.B.H. Baker[1], J.M. Ruohoniemi[1], R.A. Greenwald[1], I.J. Rae[2], L.Kepko[3], M. Lester[4], T.K. Yeoman[4]

[1] Department of Electrical and Computer Engineering, Virginia Tech

[2]Department of Physics, University of Alberta

[3]Space Science Center, University of New Hampshire

[4]Department of Physics and Astronomy, University of Leicester

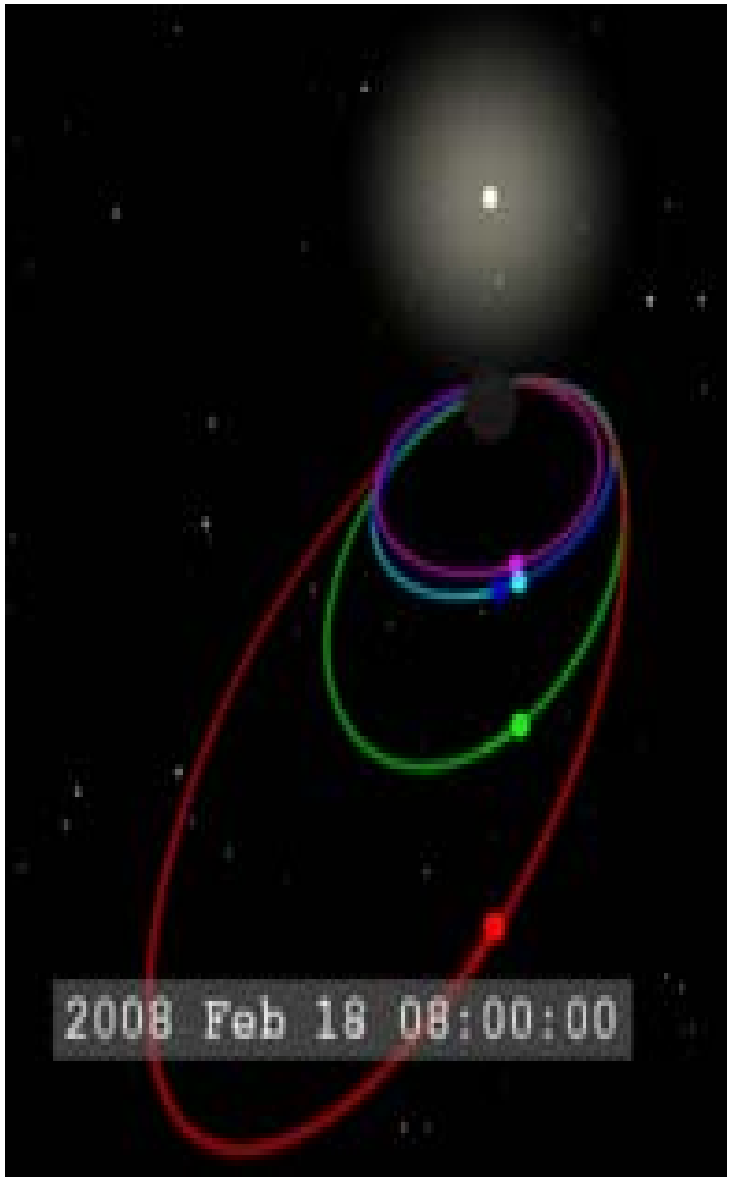
Outline

- Pi2 Pulsations
- NASA THEMIS
- SuperDARN THEMIS-mode
- Event Study: 22nd February 2008
  - THEMIS Observations
  - Ground Magnetometers
  - SuperDARN Radars
- Summary
- Future Work

Pi2 Pulsations

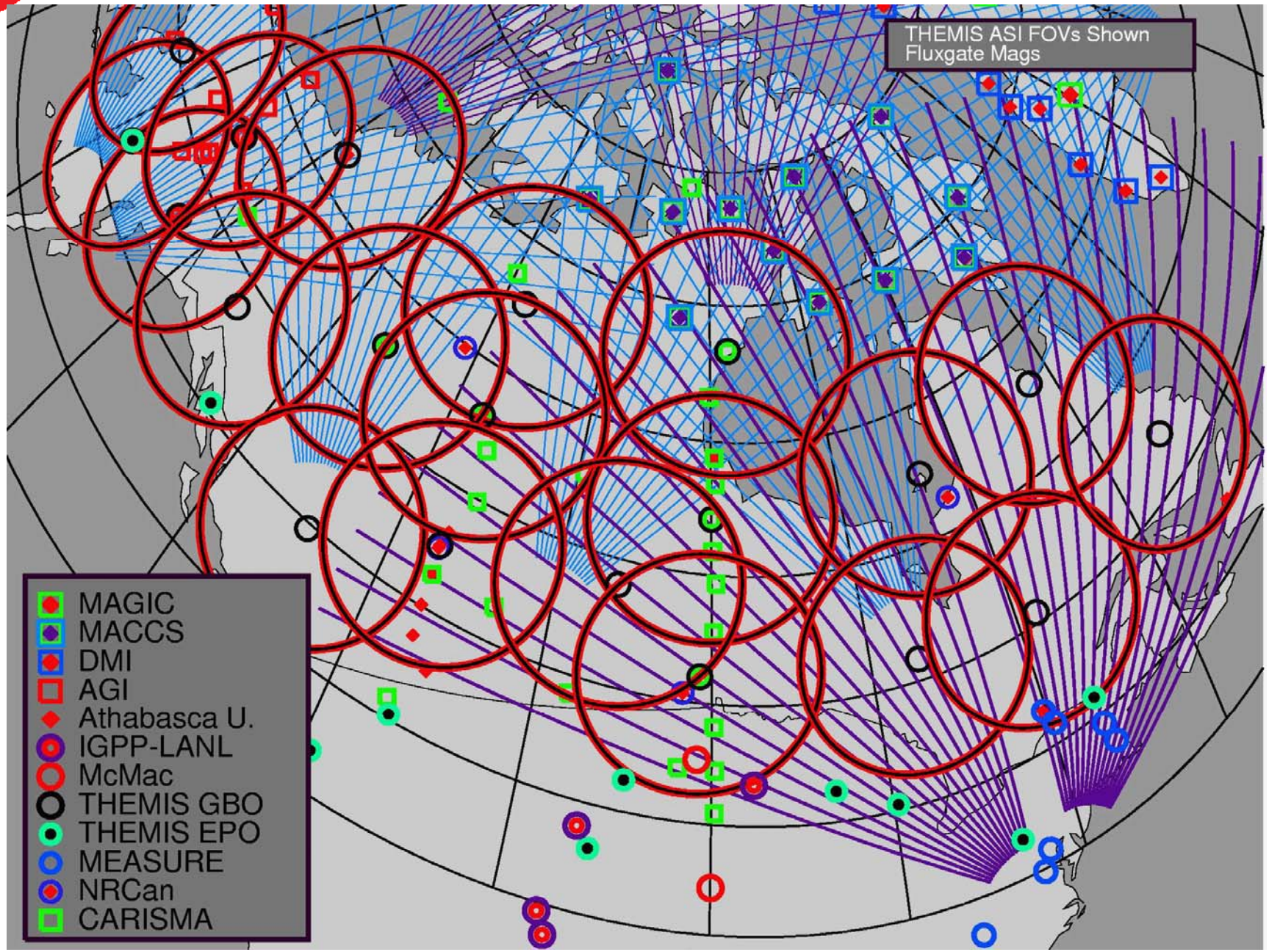
- Pi2s are irregular damped ULF pulsations (T=40-150s) .
- There are different types of Pi2s:
  - Cavity modes
  - Directly driven
  - Transient response
- Pi2s are useful for identifying substorm onsets.
- Pi2s have been observed with SuperDARN radars but they are more commonly observed with ground magnetometers .
- Simultaneous radar-magnetometer observations can be used to determine the characteristics of the waves generating the Pi2s [*Gjerloev et al.,* 2007]
- We present observations of Pi2 activity captured by the SuperDARN THEMIS mode during the onset of a substorm identified by the THEMIS spacecraft at ~0437 UT on February 22nd 2008.

The NASA THEMIS Mission

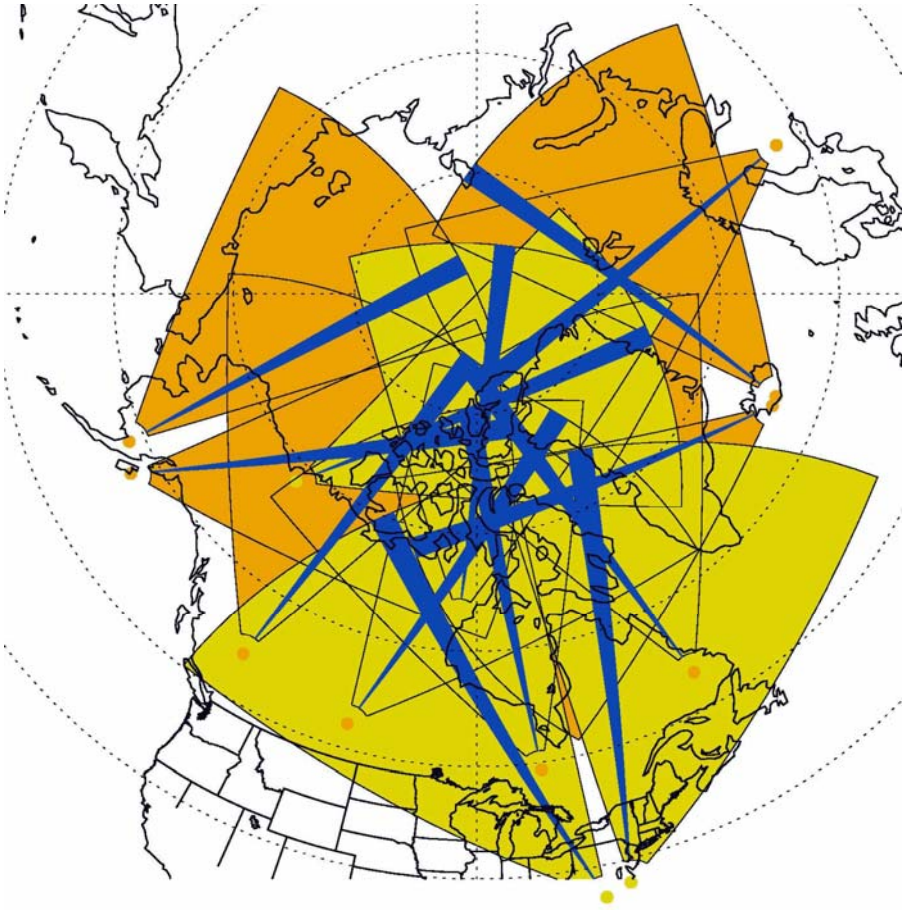


- THEMIS (Time History of Events and Macroscale Interactions during Sustorms) is a multi-spacecraft mission that was designed to “solve” the substorm problem.
- The primary objective is to determine where substorms are initiated: near-Earth or mid-tail.
- Periodically, the 5 spacecraft come into alignment along the Sun-Earth line so that the relative timing of mid- and near-Earth processes can be resolved.
- THEMIS also has a robust ground-based component -- which does not include SuperDARN (at least, not officially).

THEMIS Ground-Based Instruments



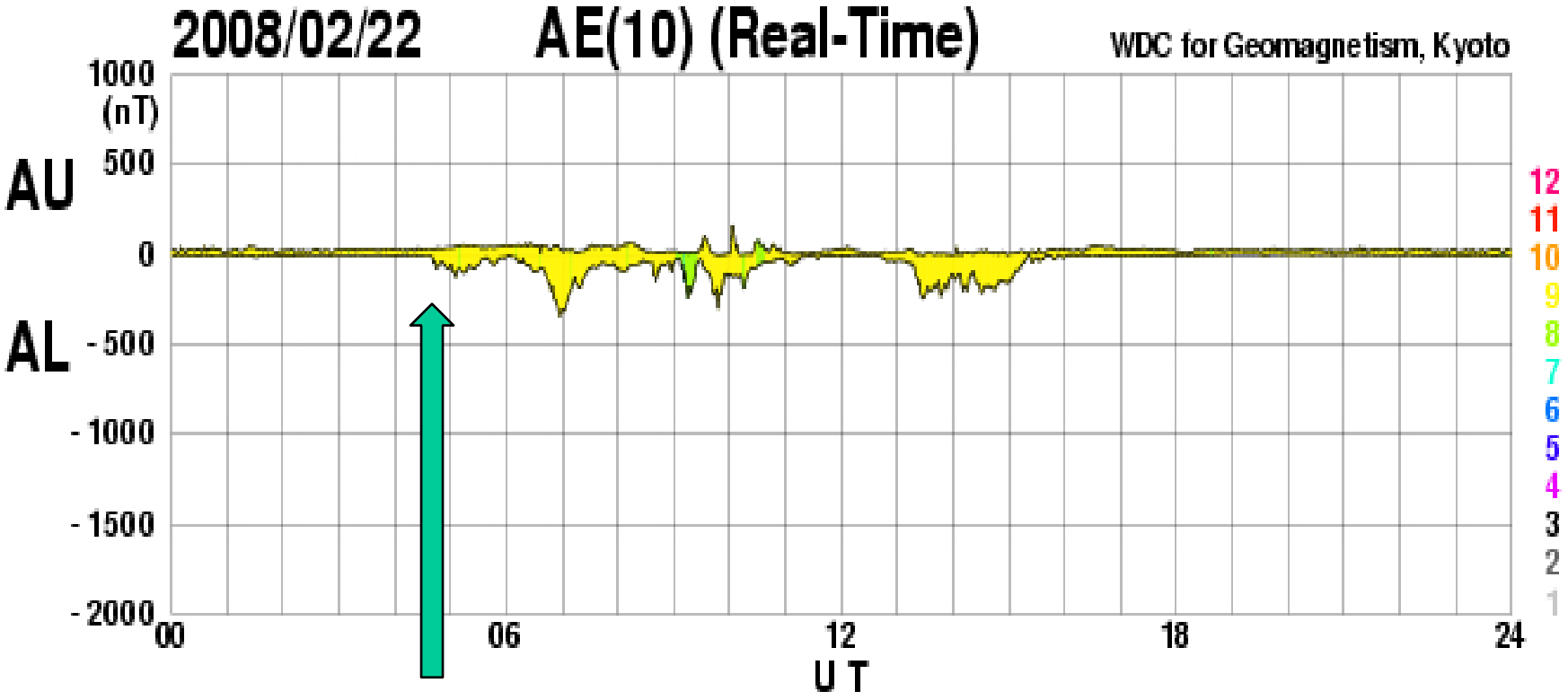
SuperDARN THEMIS Mode



- Dwell time on each beam is halved to 4 seconds.
- Interleaves measurements on a designated camping-beam between the beams of the normal scan.
- The THEMIS-mode simultaneously provides:
  - Hemispheric spatial coverage (i.e. 2 minute scans).
  - High temporal resolution on one beam per radar (7-8 seconds).

Space @ Virginia Tech
Center for Space Science and Engineering Research

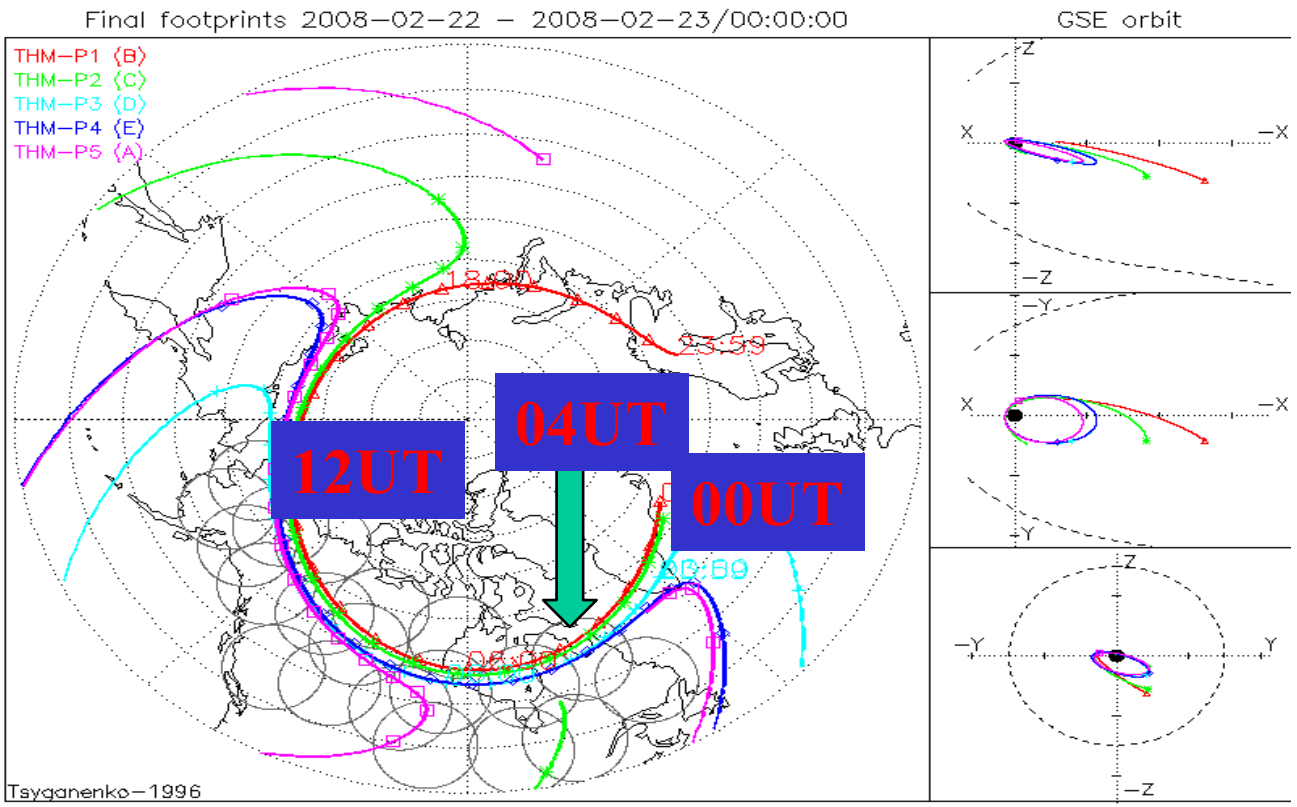
Substorm Event: February 22nd 2008



Small enhancement in AL index at approximately 0440-0450 UT is the first sign of geomagnetic activity on this particular day.

Space @ Virginia Tech
Center for Space Science and Engineering Research

Substorm Event: February 22nd 2008

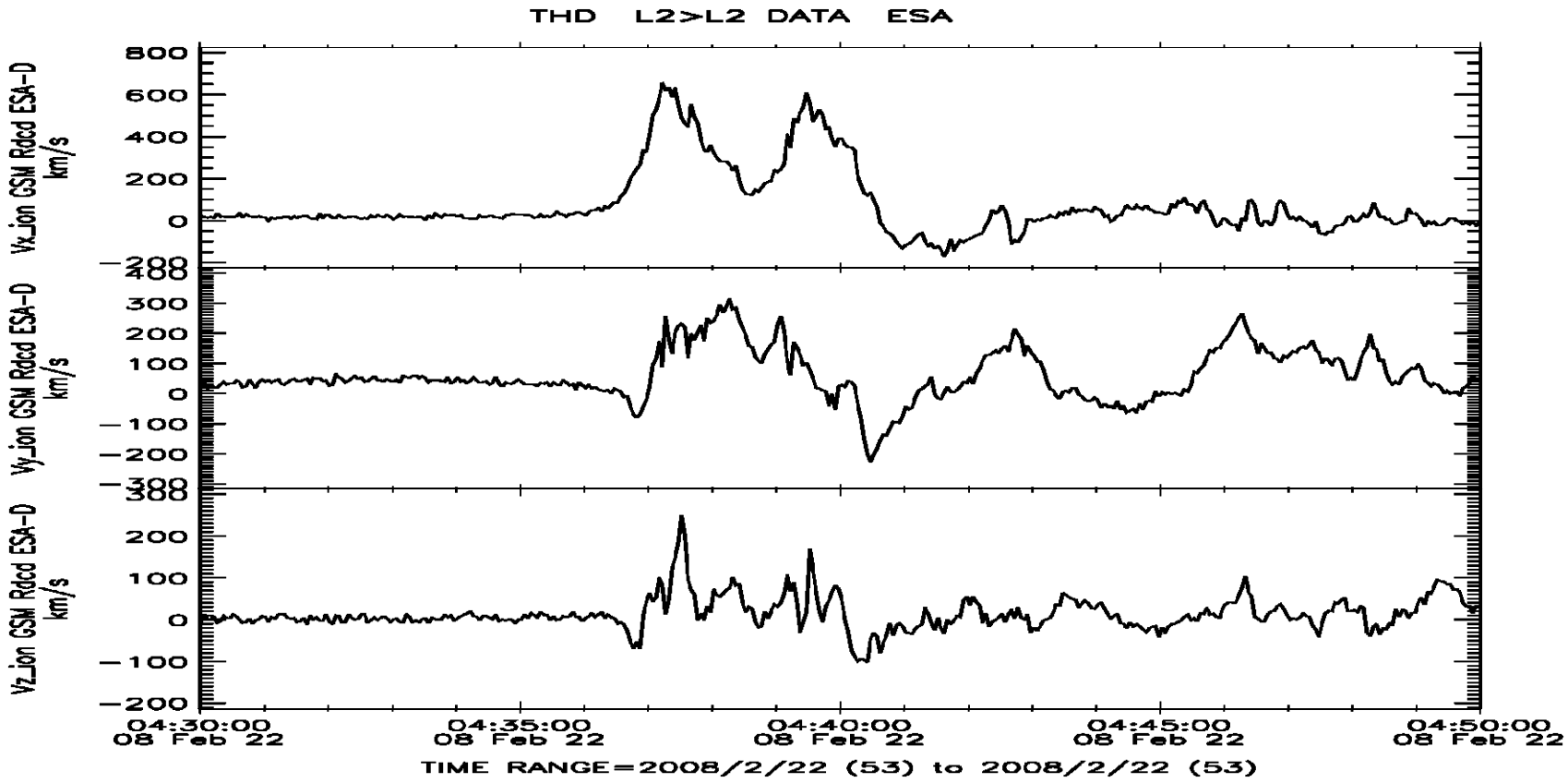


During this period the ground tracks of the THEMIS spacecraft were over eastern Canada.

THEMIS-E: (-10.1, 3.1, -3.5) Re
THEMIS-D: (-10.9, 2.3, -3.4) Re

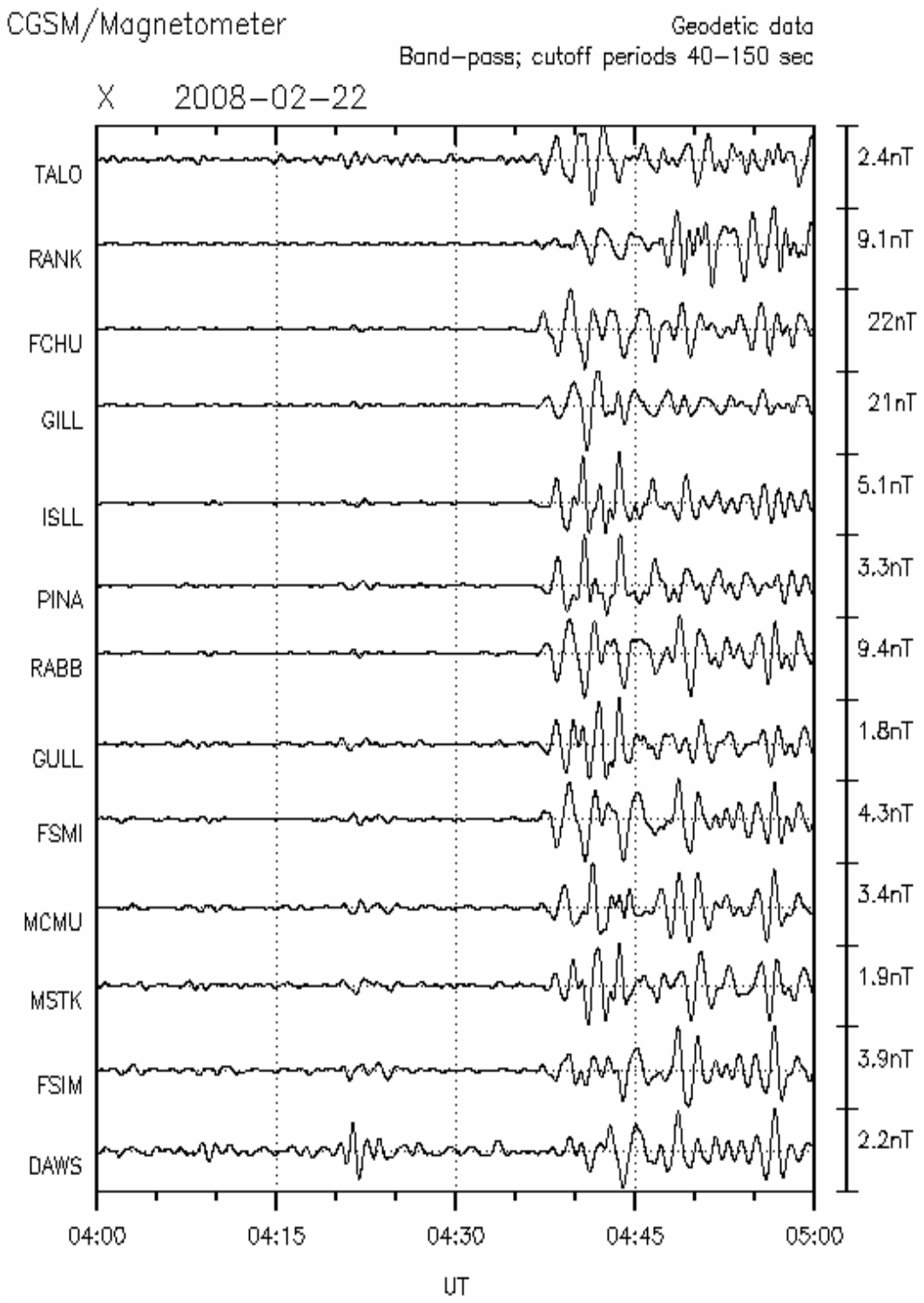
Space @ Virginia Tech
Center for Space Science and Engineering Research

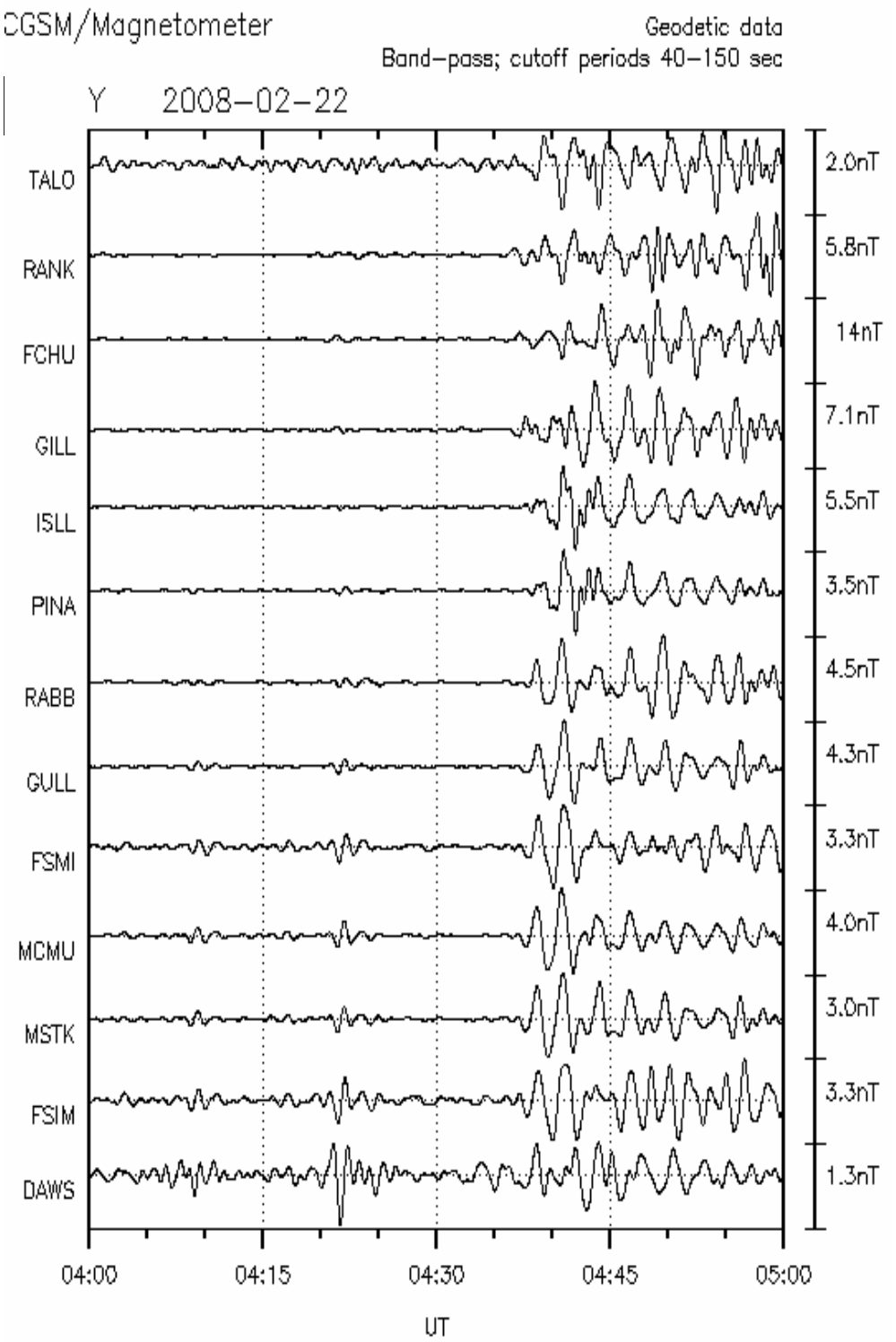
THEMIS-D measurements



At ~0437 UT the THEMIS-D spacecraft measured the first of two bursts of earthward convection. The other THEMIS spacecraft measured similar features.

Space @ Virginia Tech
Center for Space Science and Engineering Research


CGSM/Magnetometer
Geodetic data
Band-pass; cutoff periods 40-150 sec
X 2008-02-22
TALO
RANK
FCHU
GILL
ISLL
PINA
RABB
GULL
FSMI
MCMU
MSTK
FSIM
DAWS
2.4nT
9.1nT
22nT
21nT
5.1nT
3.3nT
9.4nT
1.8nT
4.3nT
3.4nT
1.9nT
3.9nT
2.2nT
04:00
04:15
04:30
04:45
05:00
UT


CGSM/Magnetometer
Geodetic data
Band-pass; cutoff periods 40-150 sec
Y 2008-02-22
TALO
RANK
FCHU
GILL
ISLL
PINA
RABB
GULL
FSMI
MCMU
MSTK
FSIM
DAWS
2.0nT
5.8nT
14nT
7.1nT
5.5nT
3.5nT
4.5nT
4.3nT
3.3nT
4.0nT
3.0nT
3.3nT
1.3nT
04:00
04:15
04:30
04:45
05:00
UT

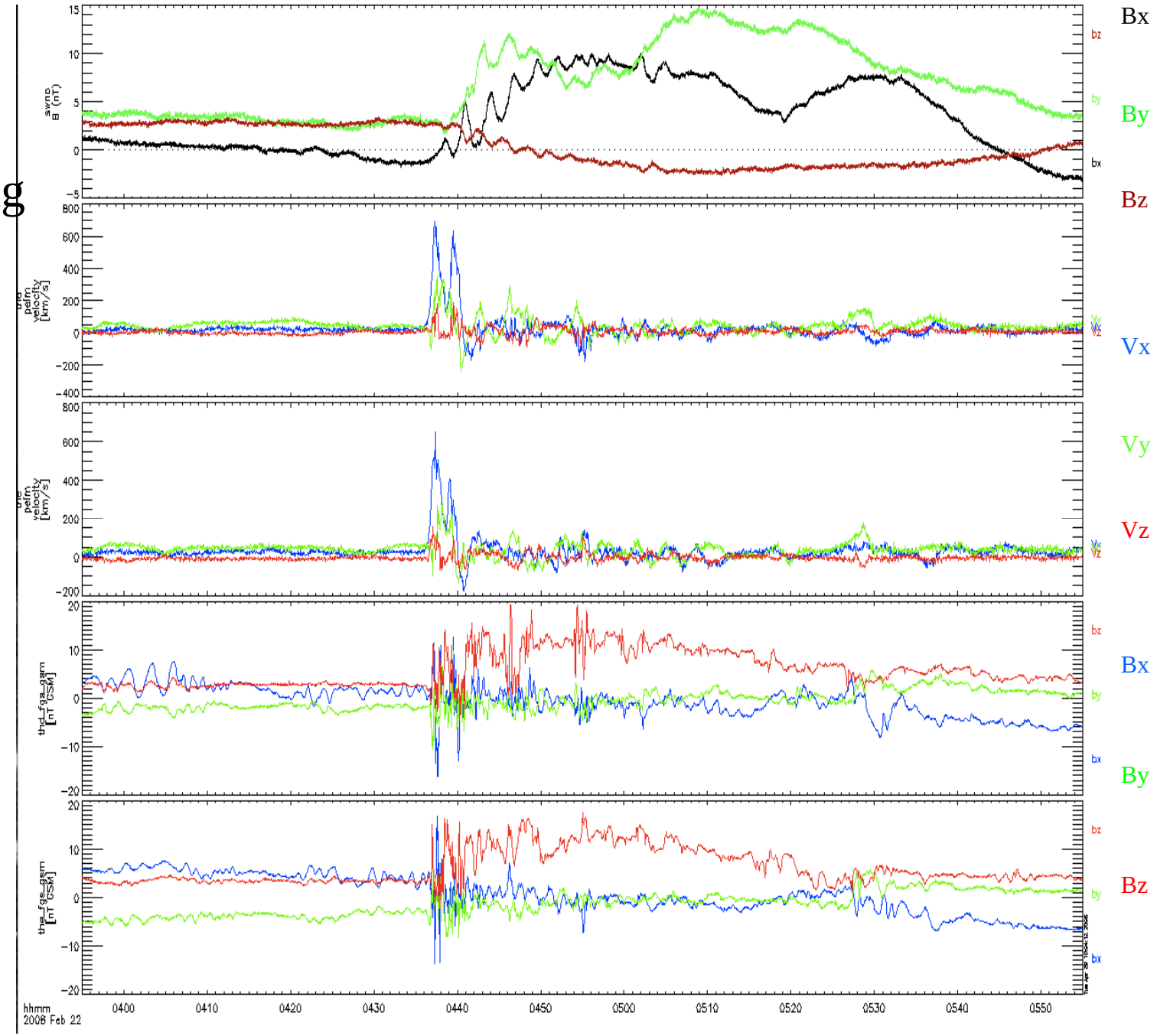
SWNO Ground Mag

THEMIS-D ESA
(-10.9,2.3,-3.4) Re

THEMIS-E ESA
(-10.1,3.1,-3.5) Re

THEMIS-D FGM

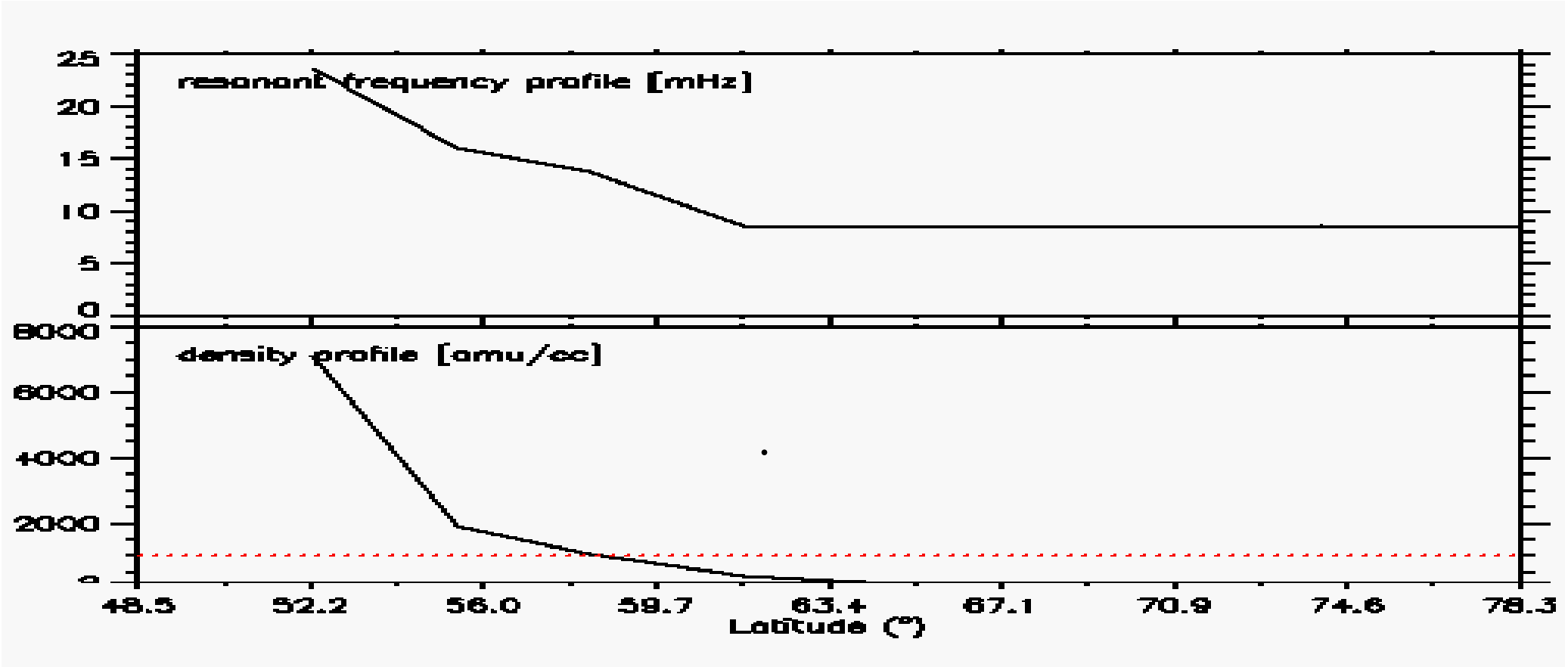
THEMIS-E FGM



0400UT

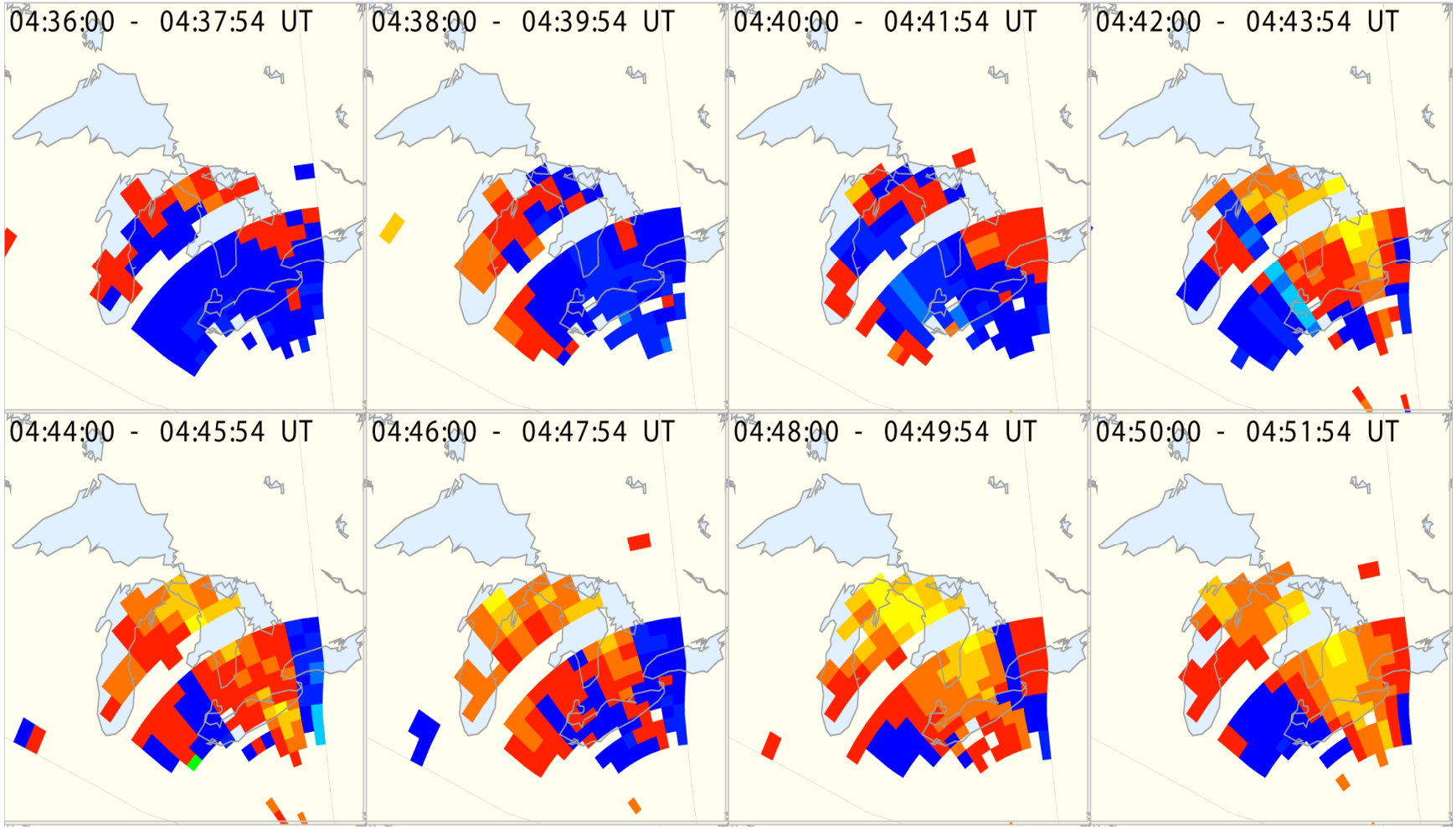
0600 UT

Cross-phase Calculations (Zoe Kale)



Plasmapause is located at L-shell ~ 3.0-3.71 (54-58Λ)

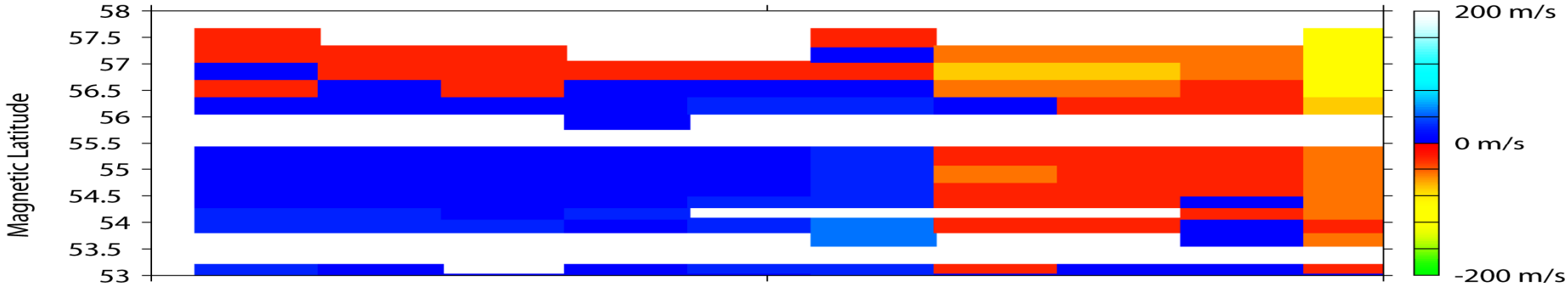
Blackstone: February 22nd 2008



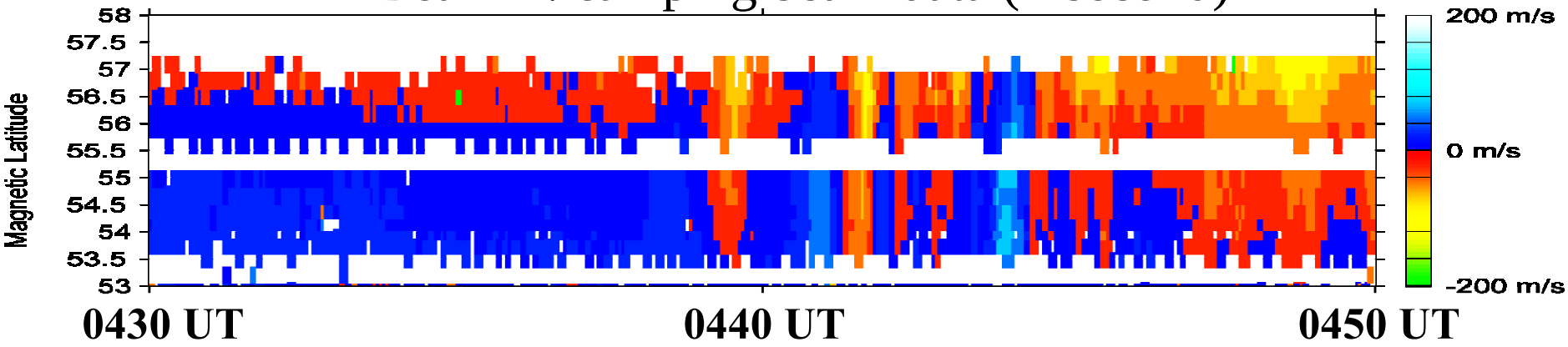
At ~0440 UT flows within the field-of-view of the Blackstone radar are enhanced.

Blackstone: February 22nd 2008

Beam-8: normal scan data (2-minutes)

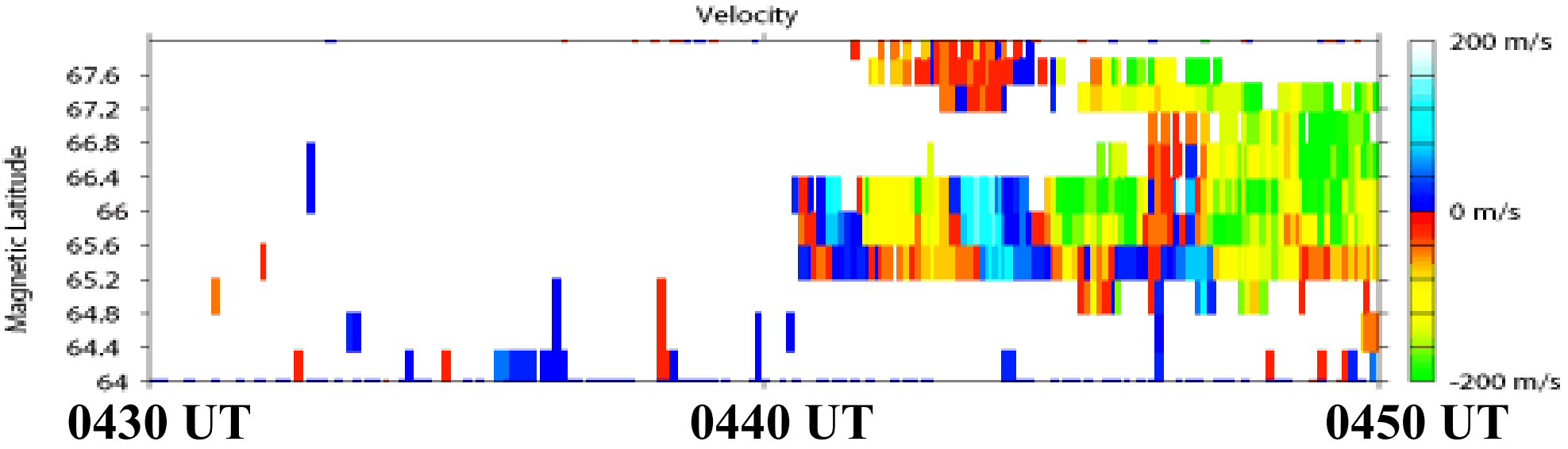


Beam-7: camping beam data (7-second)



- At 0438 UT Blackstone measures oscillations on camped beam-7.
- Neighbouring beam-8 sees no evidence of oscillations.
- These measurements are near the plasmapause.

Goose Bay: February 22nd 2008

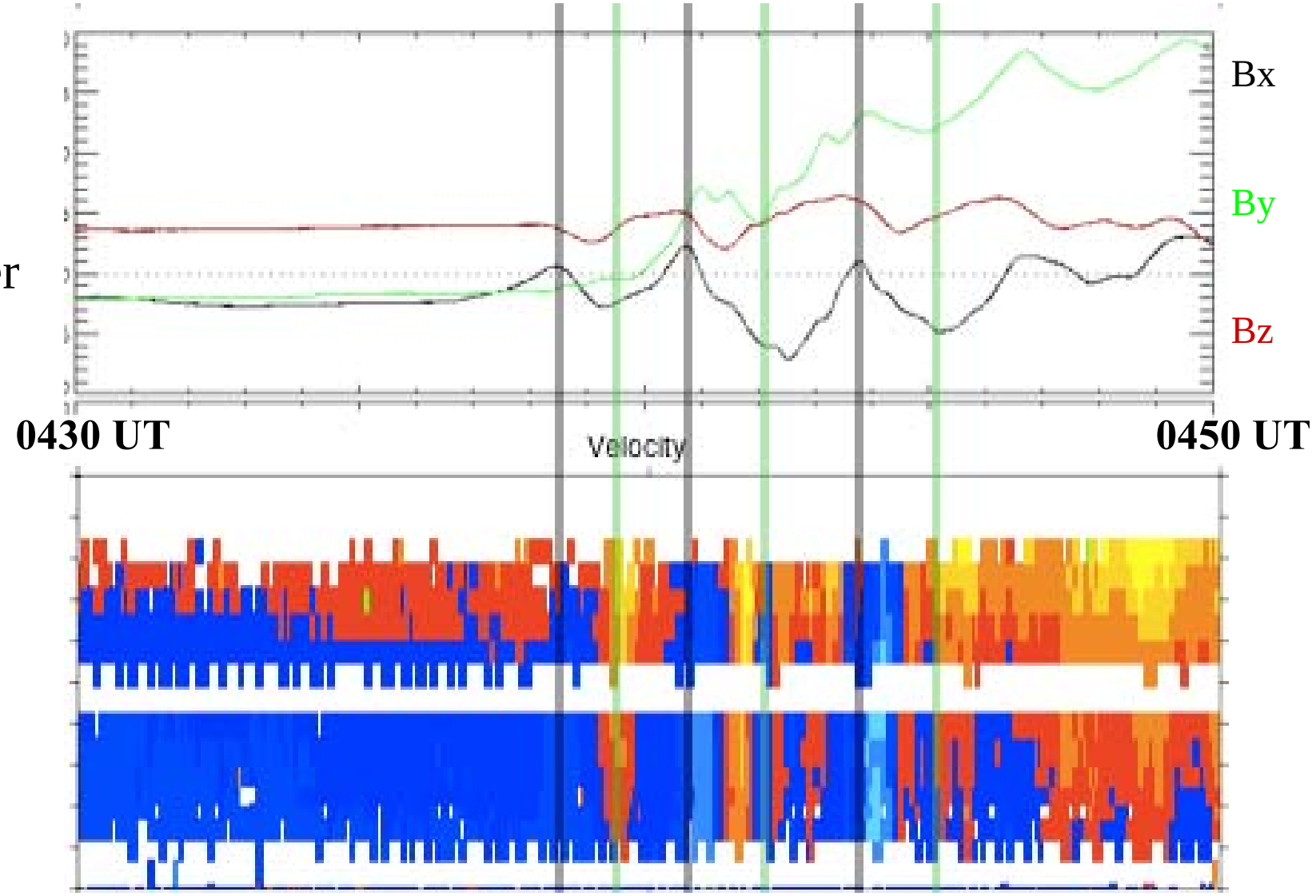


- At 0441 UT Goose Bay sees Pi2 pulsations followed by a general increase in the strength of poleward convection.
- Unlike Blackstone, the pulsations are moving equatorward.
- These measurements are poleward of the plasmapause.

Space @ Virginia Tech
Center for Space Science and Engineering Research

Shear Alfven Waves?

Pinawa
Magnetometer



Blackstone
Beam-7

Summary

- We have investigated Pi2 activity during the onset of a substorm observed by THEMIS spacecraft on February 22nd, 2008.
- Two flow bursts were measured by the THEMIS-D and THEMIS-E spacecraft starting at approximately 0437 UT.
- The plasmapause location from cross-phase technique is L=3.0-3.7
- Blackstone started measuring pulsations in the vicinity of the plasmapause at 0438 UT that were in phase with oscillations measured by the Pinawa magnetometer.
- Goose Bay started measuring pulsations at 0441 UT in a region poleward of the plasmapause. The pulsations moved equatorward.
- The Pi2 pulsations measured by both radars were only observed on the THEMIS mode camping beams.

Future Work

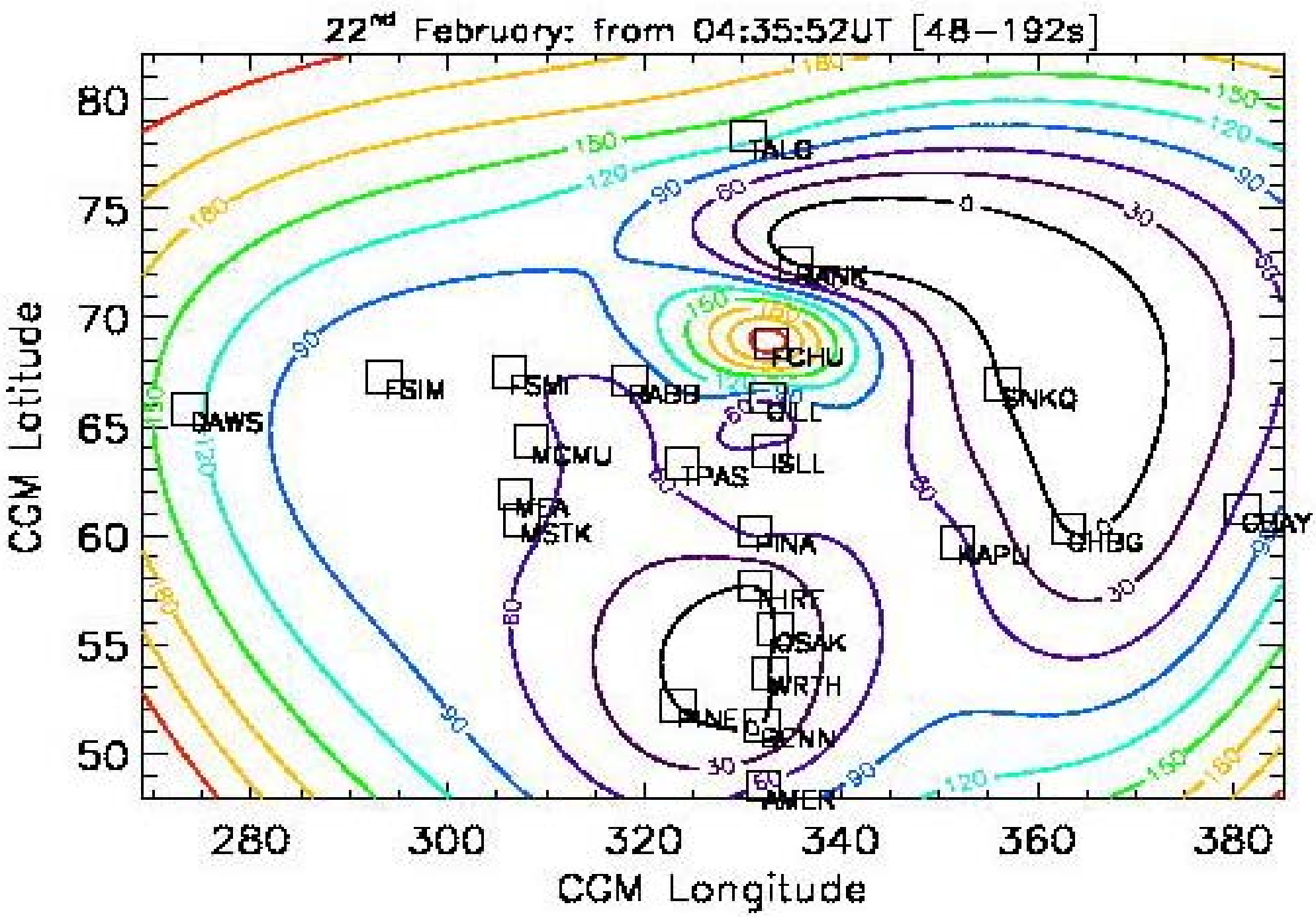
- So far the analysis has been rather qualitative.
- Future work will investigate the relative magnitude and phase of the oscillations in the radar and magnetometer data in an effort to better understand the nature of the waves.
- We have identified other similar events that can be studied.

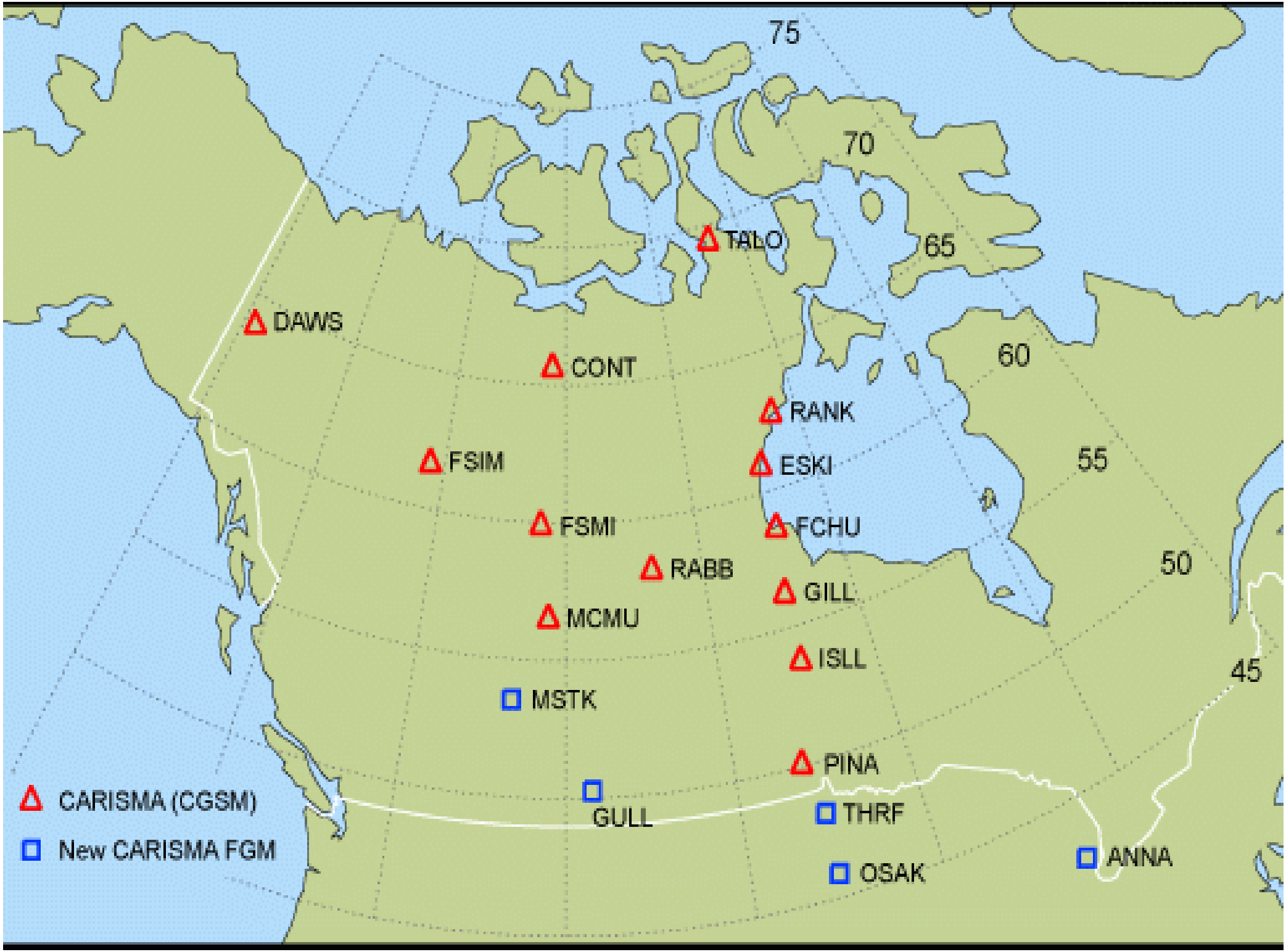
Notes on Cross-Phase

- ---
- Stn. pr. L-shell UT fr_min fr fr_max dens_max dens dens_min
- [mHz] [amu/cc]
- ---
- AMER-BENN 2.12 1350-1430 23.3 23.7 24.3 7356.38 7110.16 6763.37
- BENN-WRTH 2.70 1330-1430 15.8 16.1 16.4 2000.77 1926.90 1857.05
- WRTH-OSAK 3.01 1400-1430 13.2 13.8 14.4 1145.89 1048.41 962.87
- THRF-PINA 3.77 1330-1430 07.9 08.6 08.9 489.56 413.11 385.72
- PINA-ISLL 4.51 1330-1400 07.5 08.4 09.0 123.77 98.67 85.95
- GILL-FCHU 6.71 1330-1430 07.2 08.6 09.1 5.22 3.65 3.26
- FCHU-RANK 8.88 1400-1430 07.6 08.4 09.0 0.48 0.39 0.34

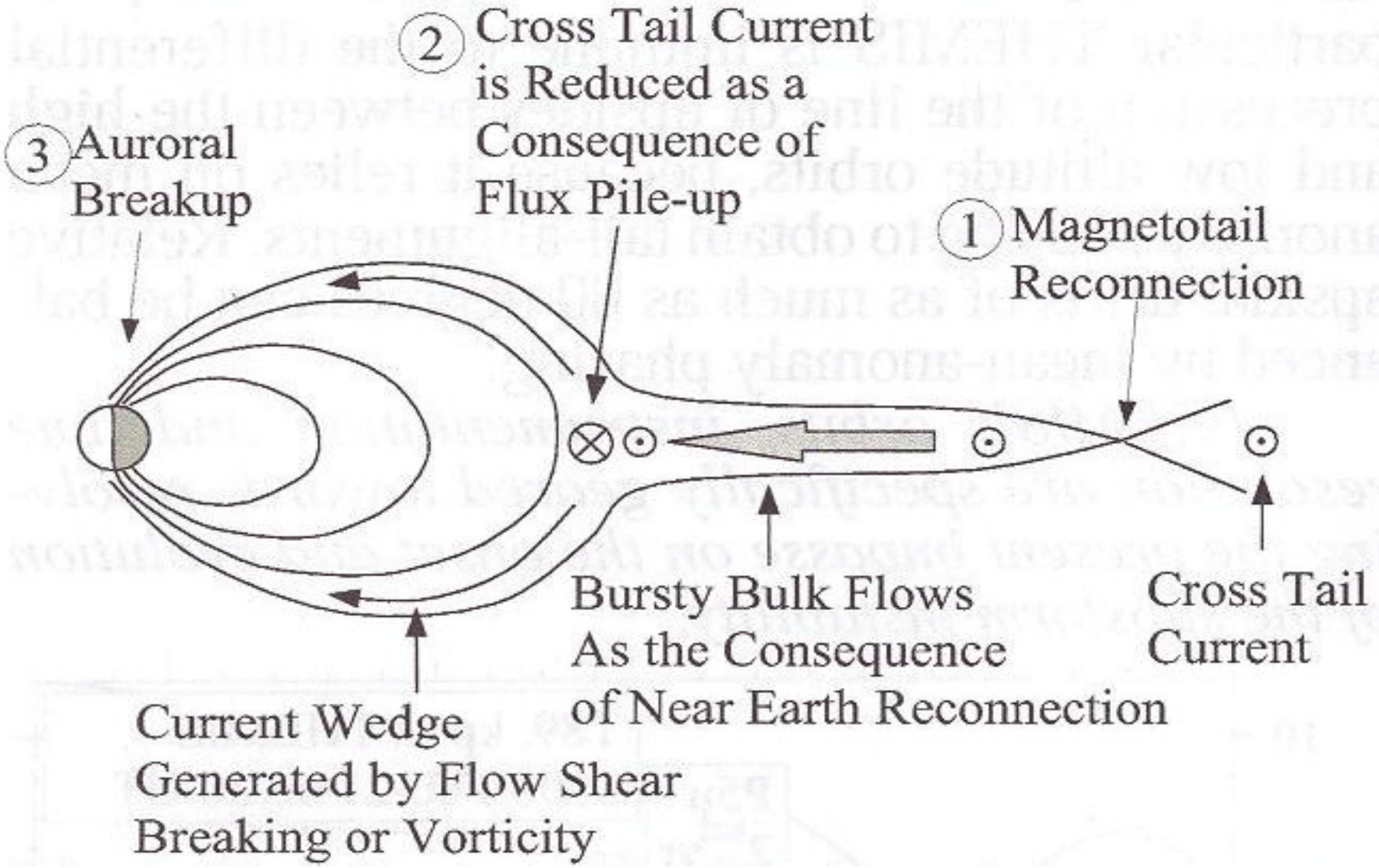
Notes on Cross-Phase

- Plasmapause is estimated at 3.0-3.7 L-shell
- Derivation assumes a dipolar geometry and r^-3 radial density distribution.)
- Plasmapause corresponds to 500amu/cc.
- No cross-phase peak was present in the dynamic xp spectra for OSAK-GLYN (L=3.26) and GLYN-THRF (L=3.77); and was very weak for ISLL-GILL (L=5.57). This in itself may be a signature of the steep density gradient.
- The GILL-FCHU (L=6.71) and FCHU-RANK (L=8.88) station pairs show some mixed polarity cross-phase peaks, again, these may suggest a steep density gradient.
- Beyond the plasmapause, the resonance frequency value doesn't change much with L-shell, and the peak is weak or suppressed at others. These steep density gradient signatures occurring over a large range of L-shells (which is hovering around density ~ L^-8, assuming a dipolar geometry is reasonable) is something I've not seen before, but is not unexpected or unusual per se. Looking at the Dst index for February, the days leading up to this event were geomagnetically quiet, so it is a little unusual to see such a steep profile. However, aziumuthal asymmetry is often present after an interval of quiet / refilling, so that could explain these observations.


22nd February: from 04:35:52UT [48–192s]
CGM Latitude
CGM Longitude
80
75
70
65
60
55
50
280
300
320
340
360
380
THL
FCHU
FSIM
FSMI
GILL
ISLL
TPAS
MCMU
NAIN
NSTK
HRNA
SNKQ
GHB
GDAY
NAPN
OSAK
WRTH
PINE
GBAY
PAWS
150
120
90
60
30
0


75
70
65
60
55
50
45
TALO
DAWS
CONT
RANK
FSIM
ESKI
FSMI
FCHU
RABB
GILL
MCMU
ISLL
MSTK
PINA
GULL
THRF
OSAK
ANNA
CARISMA (CGSM)
New CARISMA FGM

The Substorm Controversy: Near-Earth Neutral Line Model (NENL)



The Substorm Controversy: Current Disruption Model (CD)