SuperDARN Radars in Space Science Research

M. Maimaiti, Shibaji Chakraborty, Bharat Kunduri, Xueling Shi, Mike Ruohoniemi, Jo Baker

Center For Space Science and Engineering Research (Space@VT)
Bradley Department of Electrical and Computer Engineering

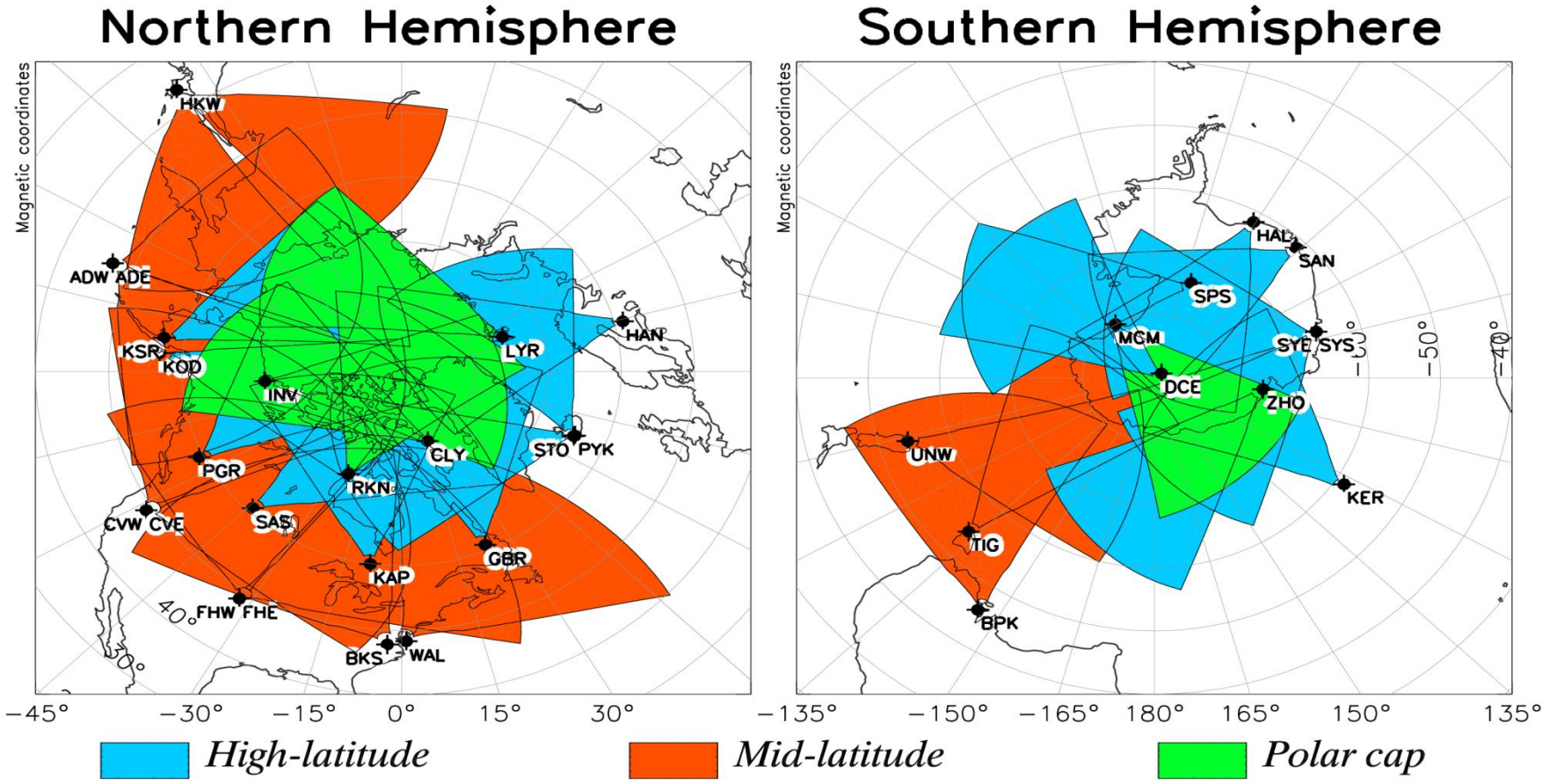
Virginia Tech

Outline

- Introduction to SuperDARN
- Accessing Data and Analysis Tools
- Studies on plasma dynamics & irregularities using SuperDARN radars
  - Shortwave Fadeout (SWF)
  - Polar Cap Dynamics
  - SAPS
  - SAIS
  - ULF Waves
- Conclusions

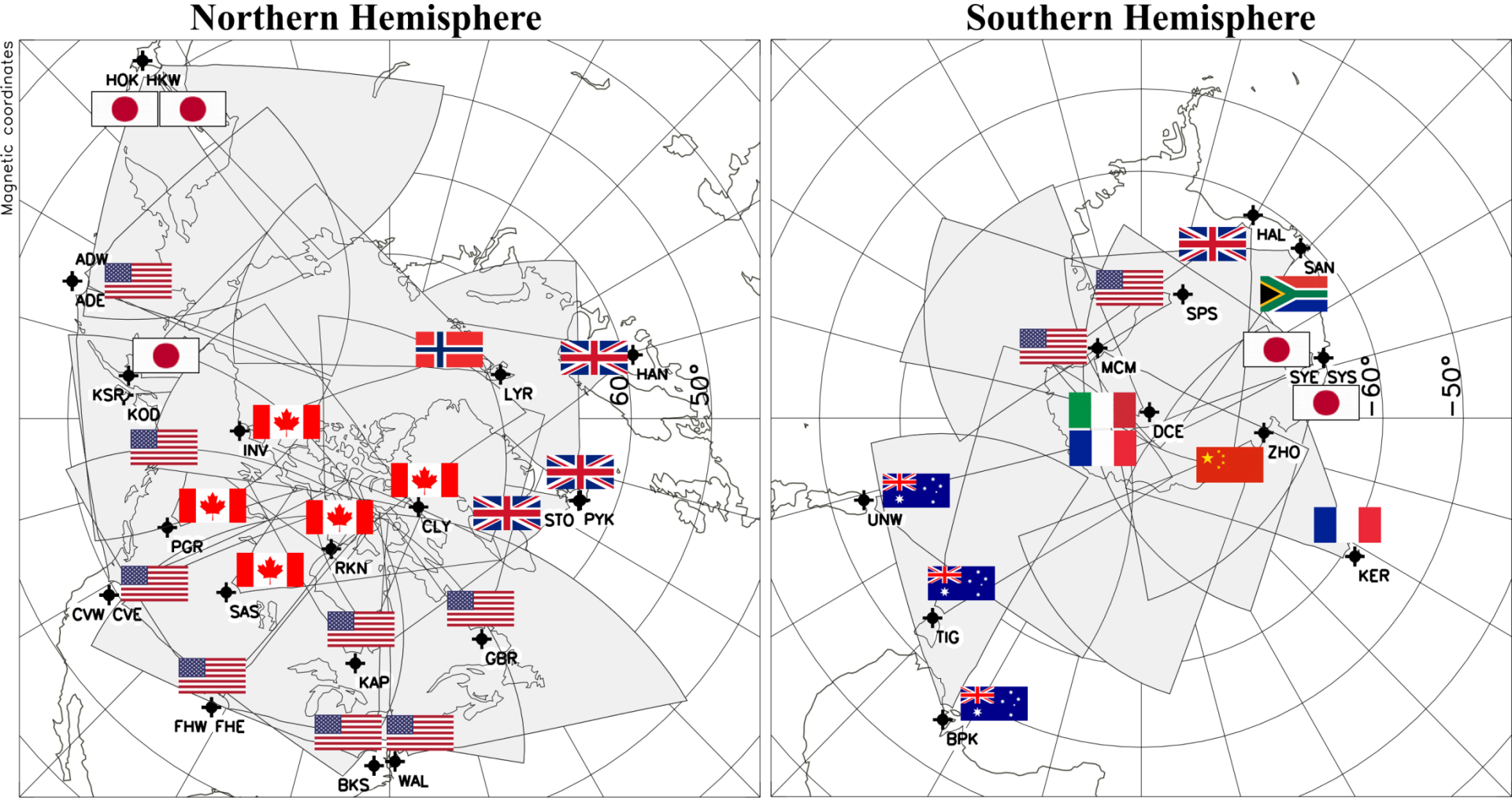
Overview of SuperDARN

SuperDARN Radar Fields of View Coverage

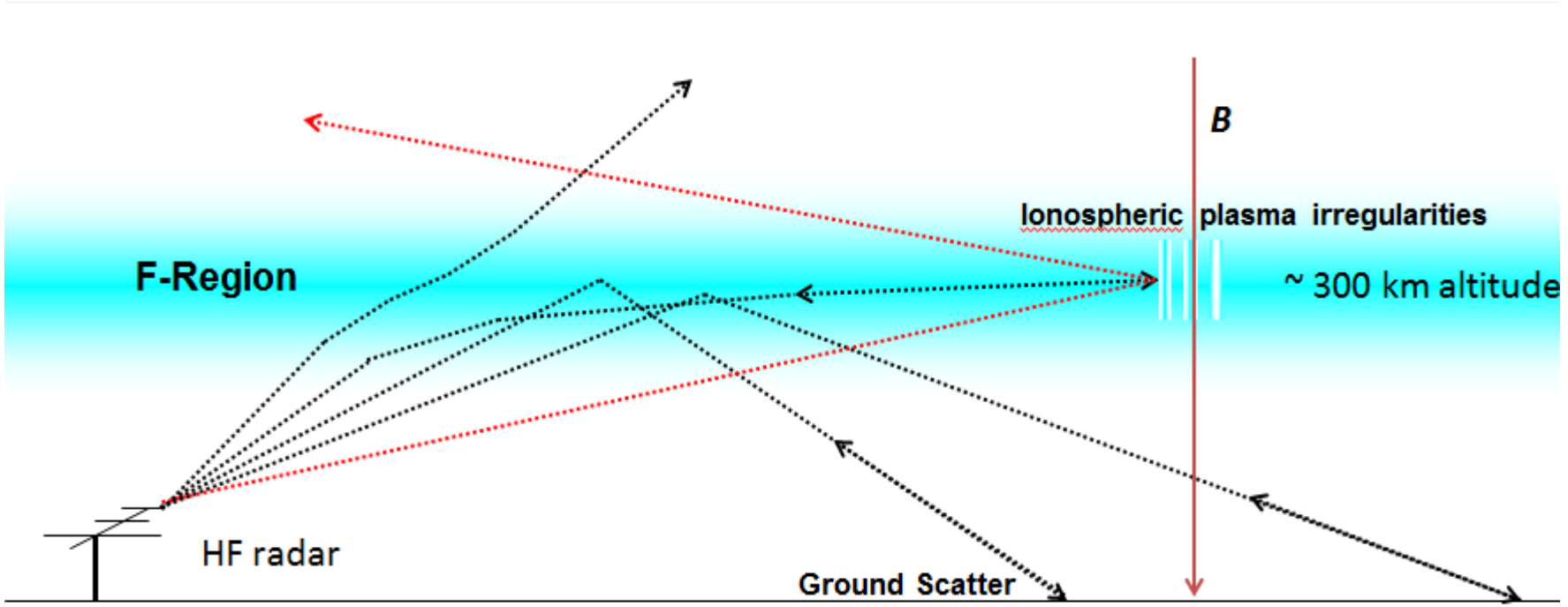


- Over the last ten years new chains of SuperDARN radars have been built to provide coverage over the polar cap and mid-latitude regions.

SuperDARN International Collaboration



Propagation and Reflection of HF Signal



- HF rays are refracted in the ionosphere as they encounter gradients in electron density
- Transmitted signals can be reflected back to the radar by:
  - Ionospheric plasma irregularities
  - Earth's surface
- Information about the reflectors is carried in the returned signal, e.g., Doppler velocity

Overview of SuperDARN Data Products and Analysis Tools

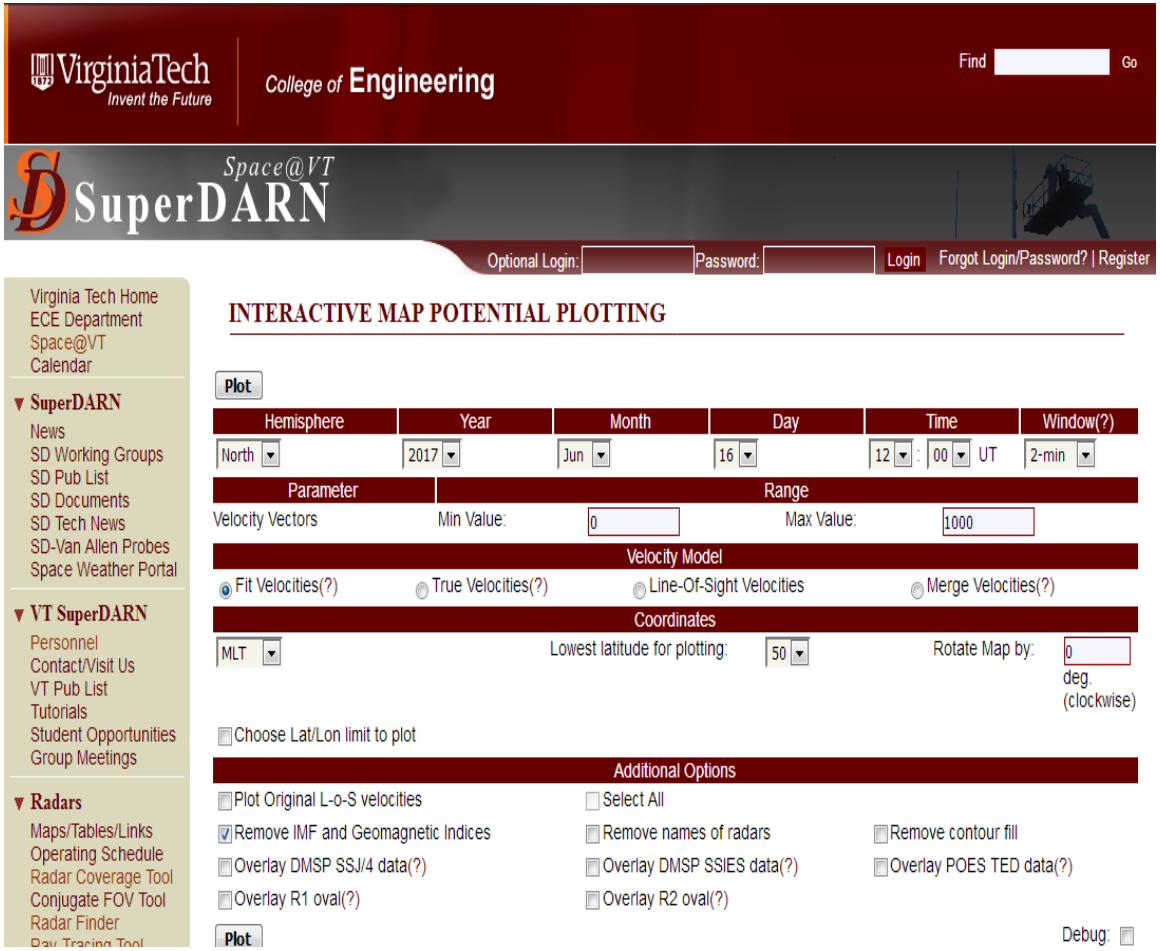
SuperDARN Data Products

❑ Levels of SuperDARN data

- Raw line-of-sight velocity measurements (resolution of 45 km)
- Gridded line-of-sight velocity (square cells, resolution of ~ 150 km)
- Global electrostatic potential data (resolution of several hundreds of km, depending on the order of the fitting)

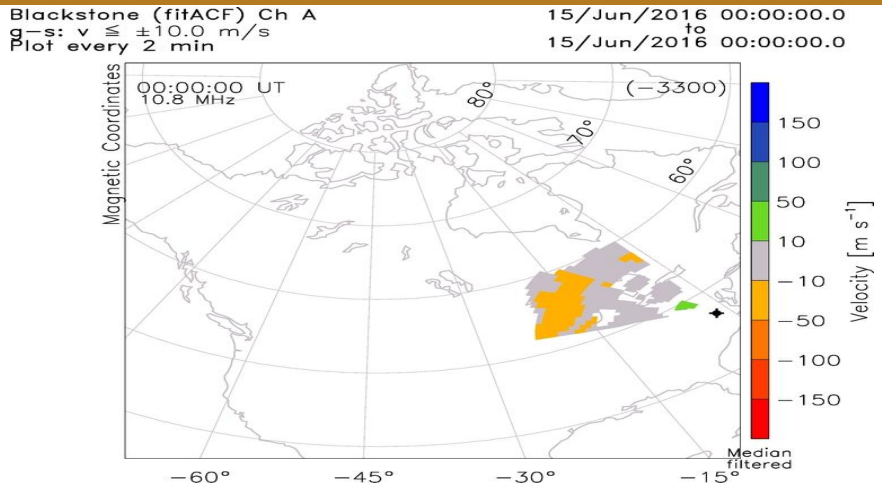
SuperDARN Interactive Web based Tools

- **Frequently used tools –**
  - Scan (f-o-v) Plot
  - Range-Time Plot
  - Map Velocity Plot
  - Map Potential Plot
  - GPS/TEC Plotting Tool
  - Real-time Monitoring
  - etc.



WEB URLS: http://vt.superdarn.org/tiki-index.php
http://superdarn.usask.ca/realtimedisplay.html

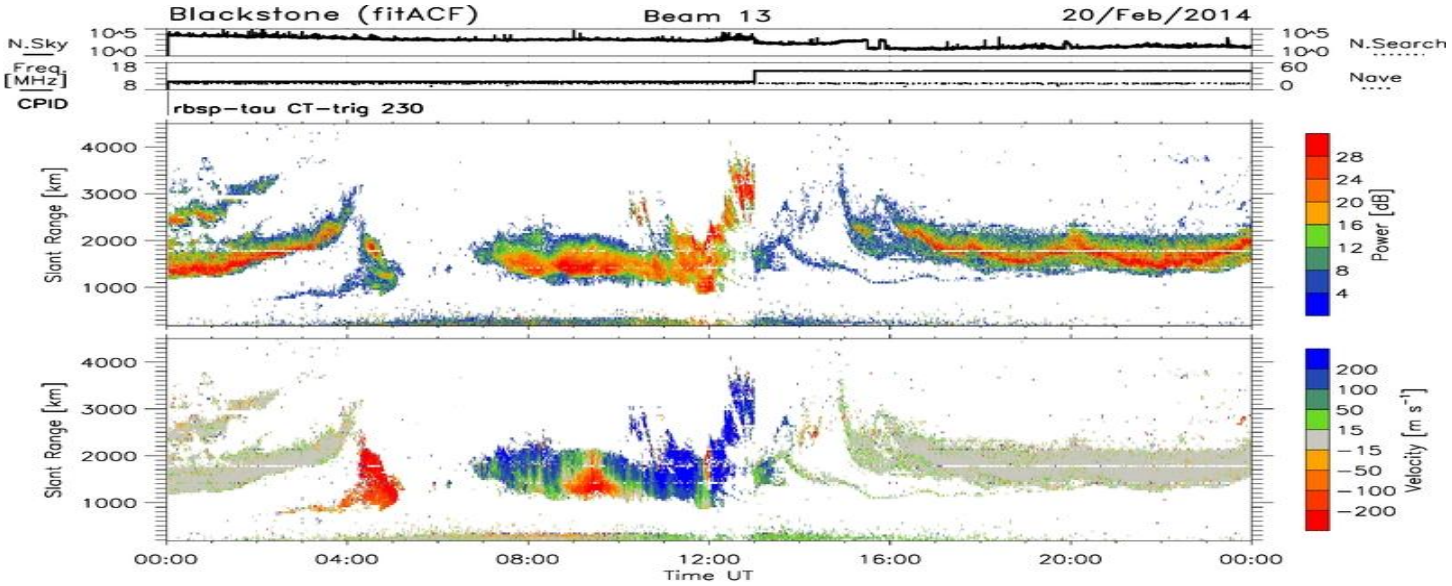
SuperDARN Interactive Web based Tools (Cont.)



FOV Plot

(Data Level : Lowest)

Shows spatial distribution of radar measurements at a particular time

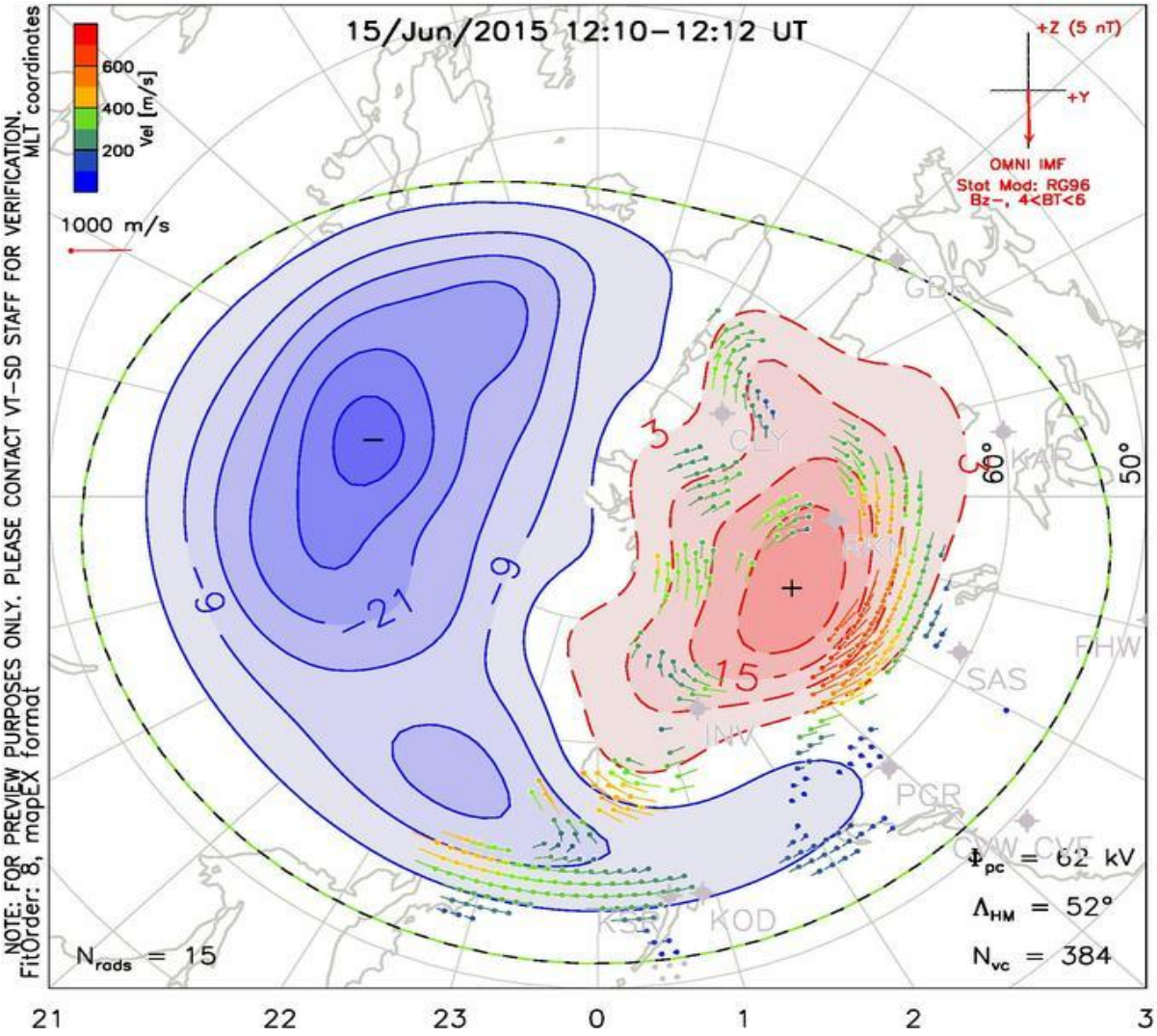


RTI Plot

(Data Level : Lowest)

Shows temporal distribution of radar measurements at a specific radar look direction

SuperDARN Interactive Web based Tools (Cont.)

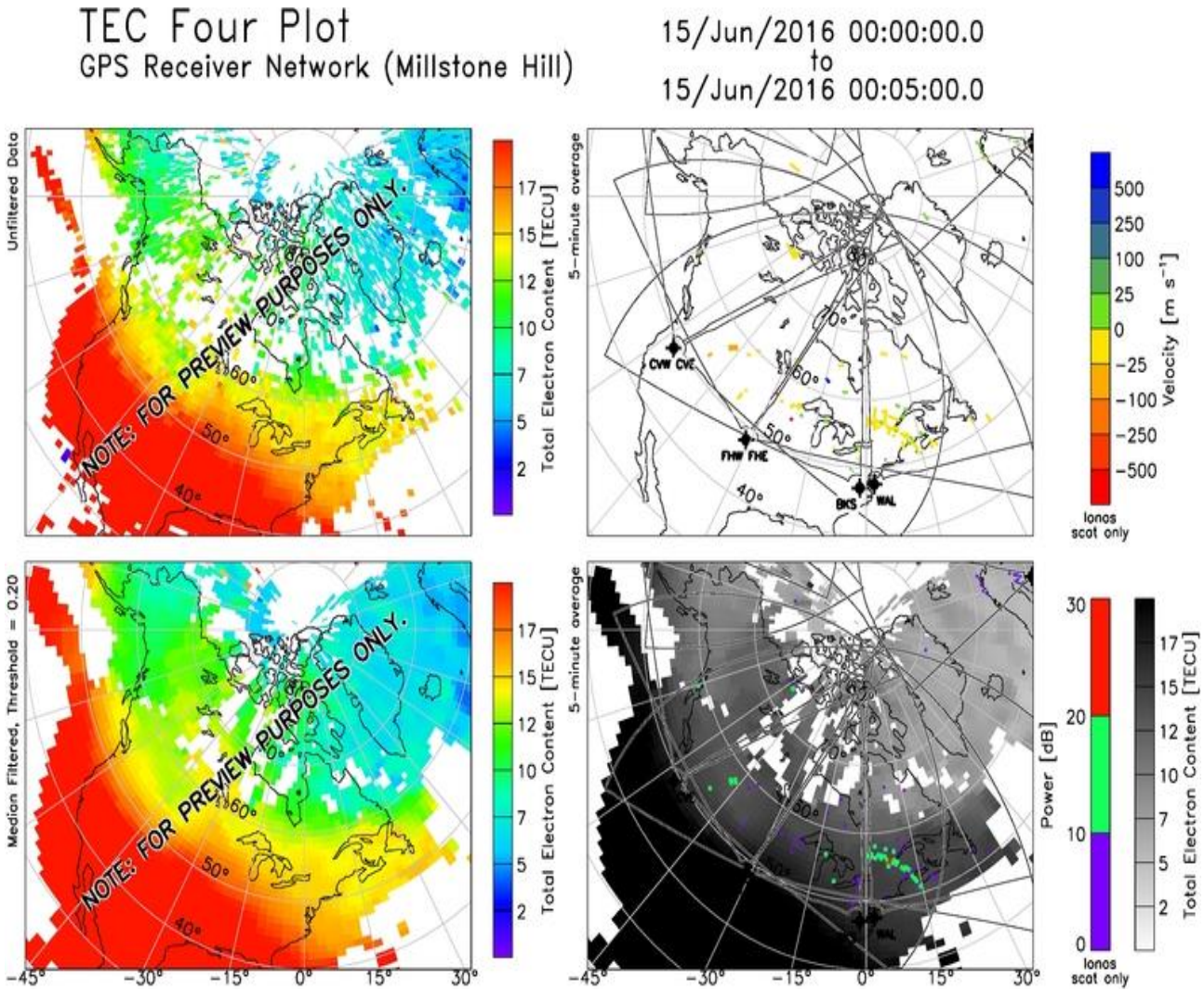


Map Potential Plot -

(Data Level : Highest)

Provides electric field measurements

SuperDARN Interactive Web based Tools (Cont.)



TEC Plotting Tool

Provides relation between TEC data and radar measurements

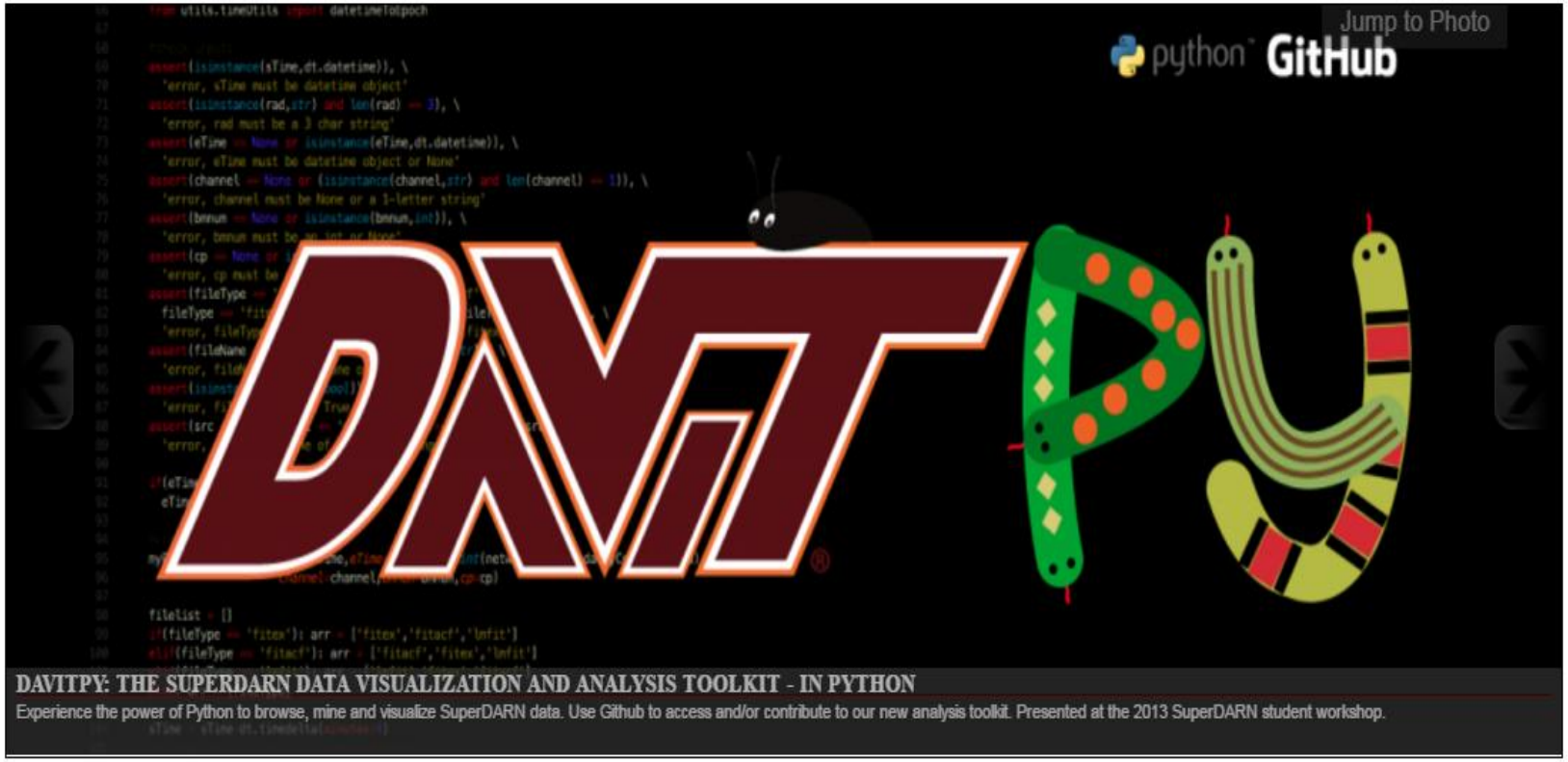
How to get SuperDARN data?

- Raw Data from website
  - Line-of-Sight data – ASCII format.
  - Electric Field Data – ASCII format.
- *Contact with us if you need large amount of data*.

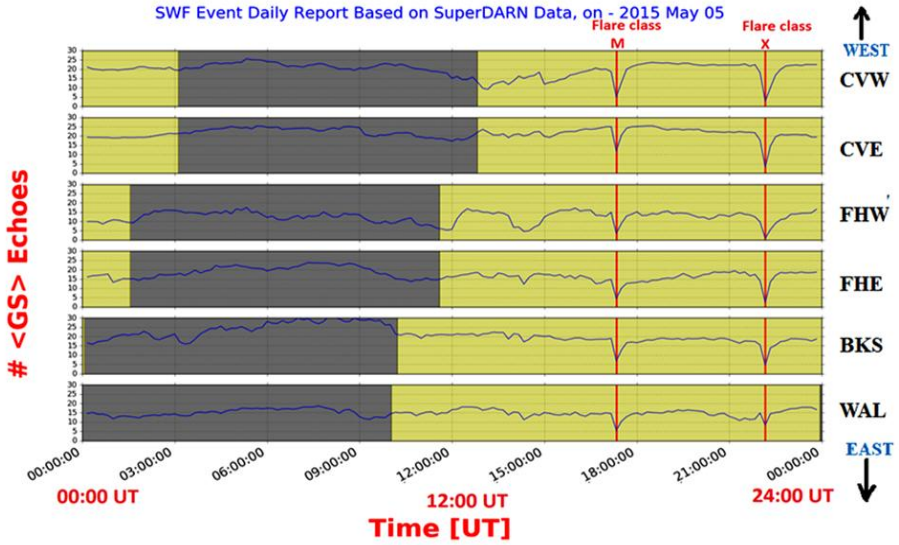
```
#SuperDARN Data file.
#For North Vectors, positive means North and negative means South.
#For East Vectors, positive means East and negative means West.
#
d 2015-06-16/12:00:00
> Number of Measured Vectors (VCNUM): 100
> IMF Model: RG96 By+, 4<BT<6, Fit Order: 8
> OMNI IMF:  Bx=-1 nT, By=4 nT, Bz=0 nT
> Potential: Drop=44 kV, Min=-28 kV, Max=15 kV
#
#Record  Indices mlat              mlon              EField_north      EField_east       Fitted_Vel_North  Fitted_Vel_East   Potential
TimeStamp
#                [deg]             [deg]             [V/m]             [V/m]             [m/s]             [m/s]             [V]
[UT]
 0       [1,1]         50.0000           0.00000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
 0       [1,2]         50.0000           2.00000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
 0       [1,3]         50.0000           4.00000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
 0       [1,4]         50.0000           6.00000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
 0       [1,5]         50.0000           8.00000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
 0       [1,6]         50.0000           10.0000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
 0       [1,7]         50.0000           12.0000           0.00000           0.00000           0.00000           -0.00000          0.0000000
2015-06-16/12:00:00
```

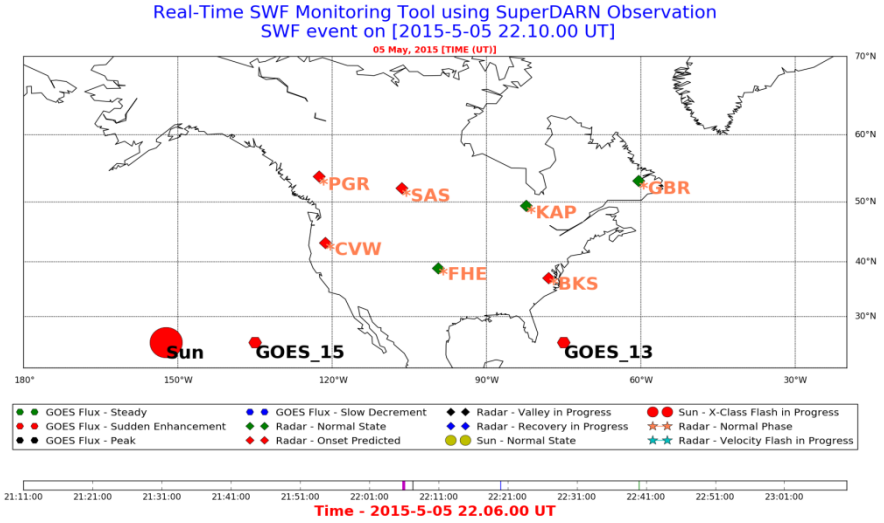
SuperDARN Software and Data

- Available Software to access SD Data –
  - Davitpy (python based, open source, available on our vtsuperdarn GitHub page - https://github.com/vtsuperdarn/davitpy)



Upcoming Tools





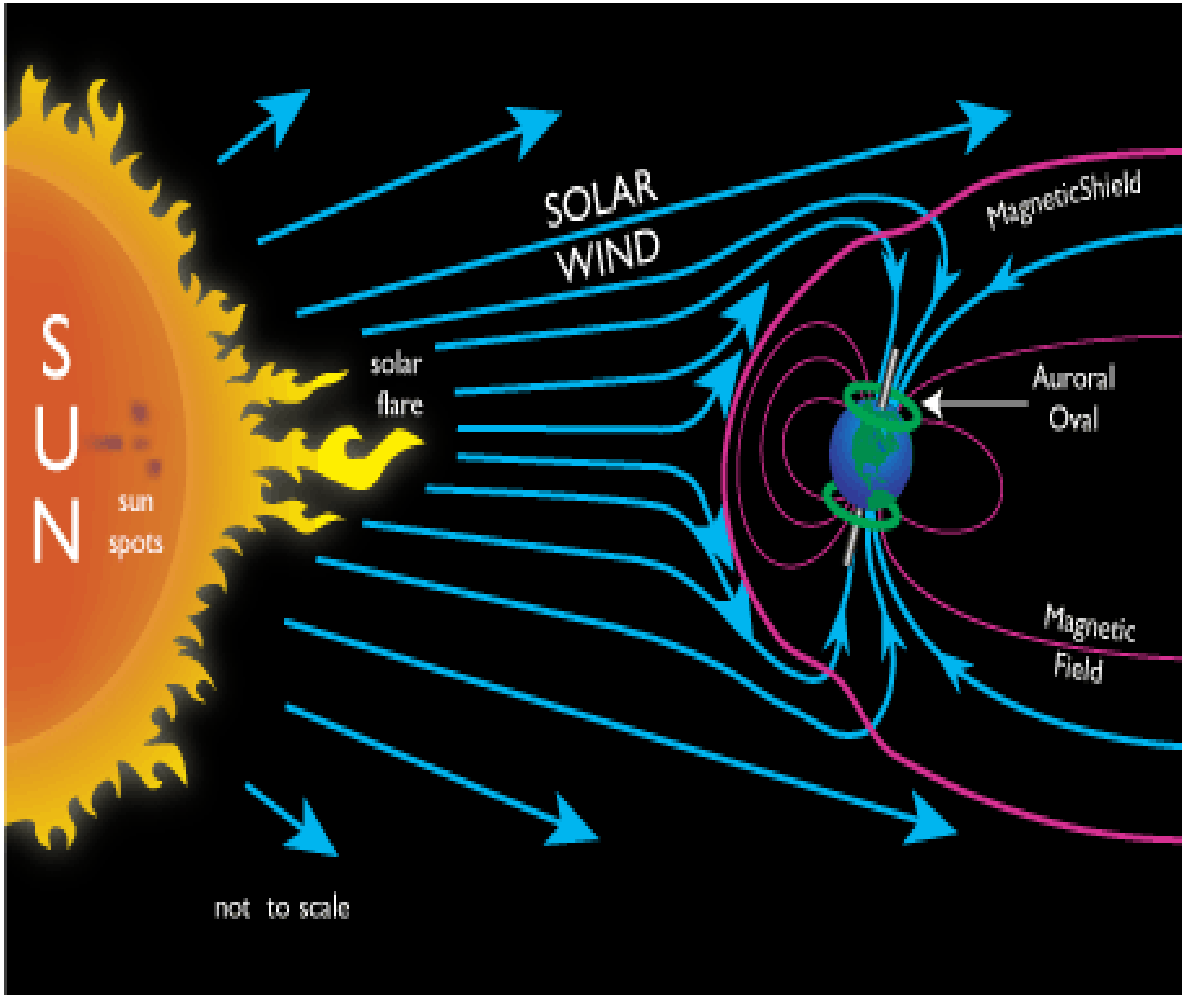
- Upcoming (WEB) Tools –
  - SAIS Identification
  - SWF Detection and Real-Time Monitoring of SWF
  - ULF Wave Detection

WEB URL : http://vt.superdarn.org/tiki-index.php *[Stay Tuned]*

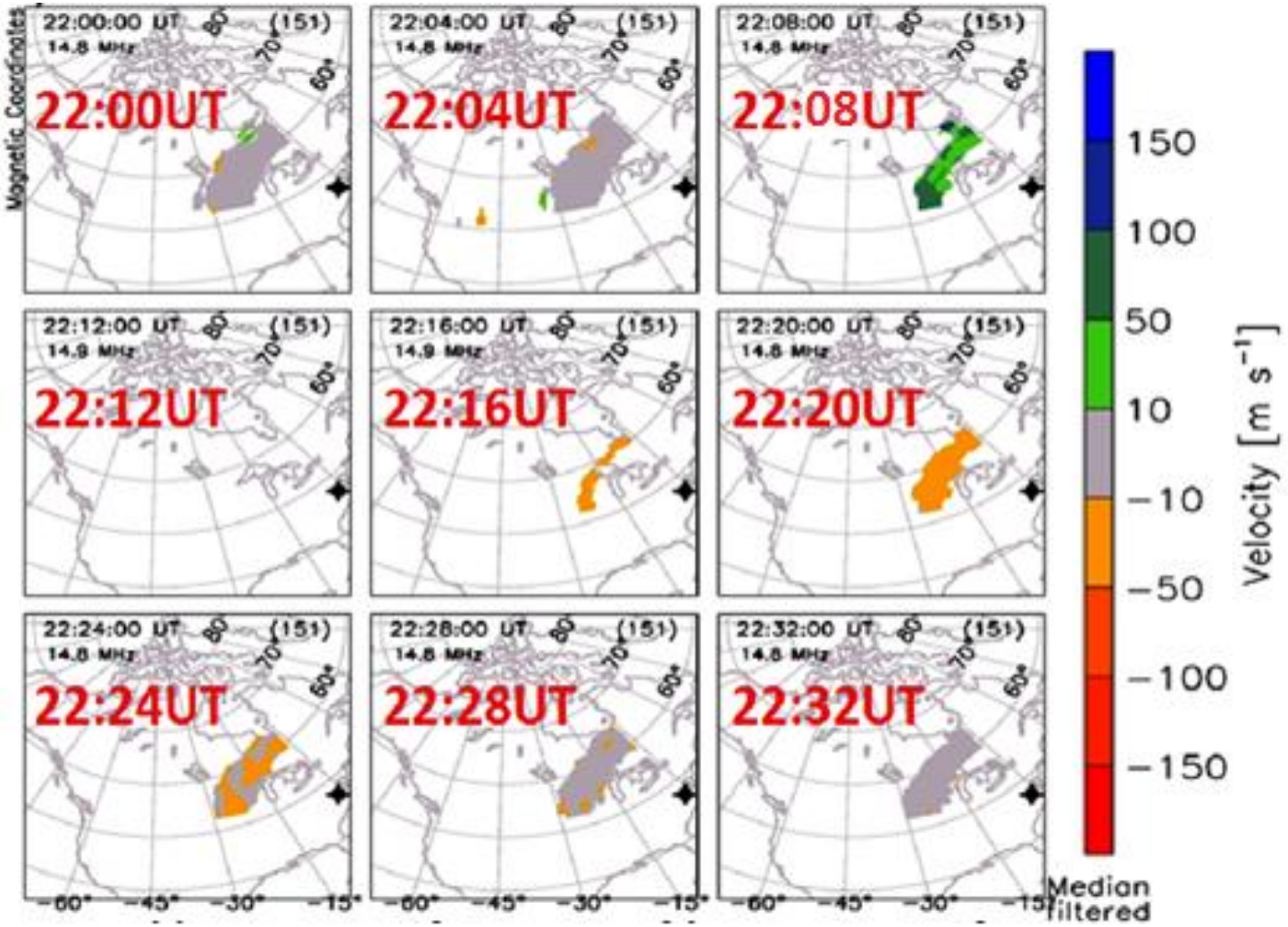
Addressing Research Topics using SuperDARN Radar Data

Prologue on Shortwave Fadeout (SWF)

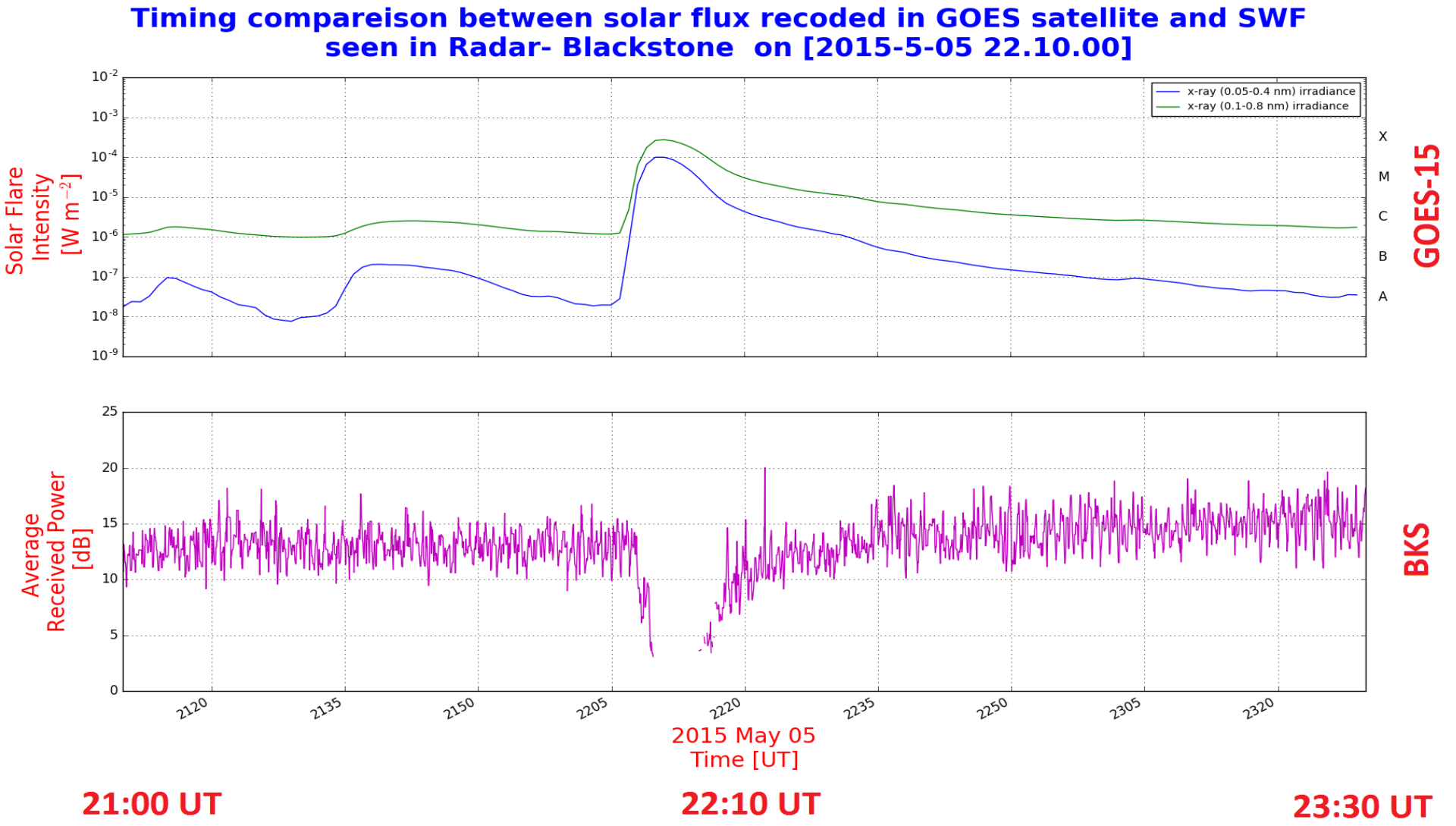
- Solar flare produces intense ultraviolet (EUV) & x-ray radiation.
- Strikes the dayside of the Earth, creating anomalies and absorption in the travelling radio waves through ionosphere, known as ShortWave Fadeout (SWF).
- Represents earliest space weather effects of a flare, with only an 8 min delay.



Effects of Shortwave Fadeout (SWF) on SuperDARN

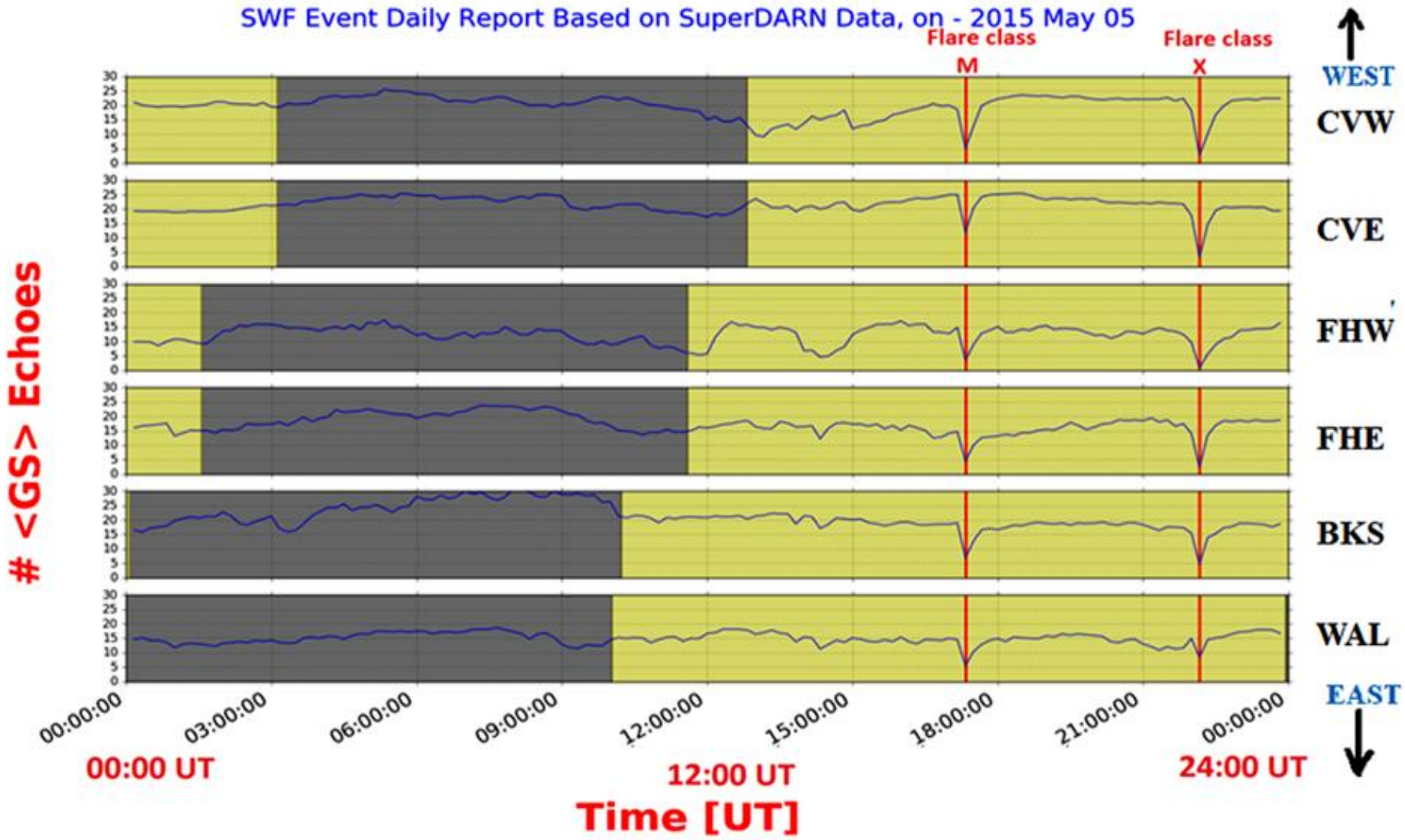


GOES X-Ray Imager Data versus SuperDARN Measurements



Automatic SWF Event detection tool – Daily Report

[For details visit Poster IRRI-01]



Summary of Shortwave Fadeout

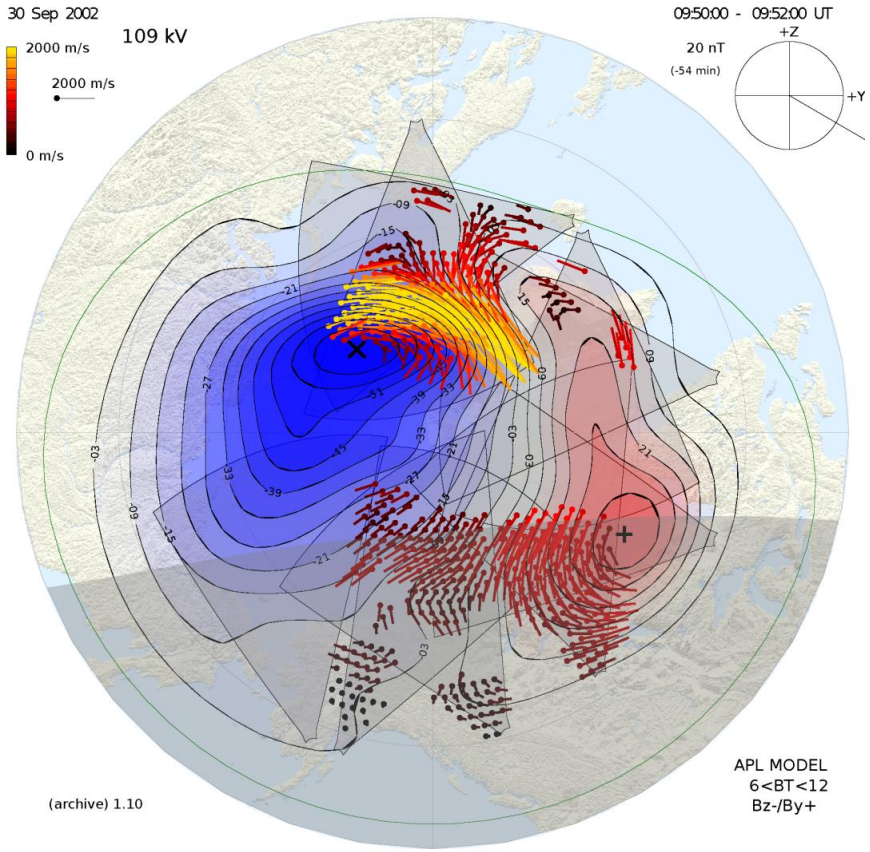
- Daytime SuperDARN ground-scatter echoes get suppressed by the SWF events. It is one of the most significant effects seen in any HF communication system during SWF.

- We can identify multiple phases of SWF in ground-scatter measurements from SuperDARN radars.

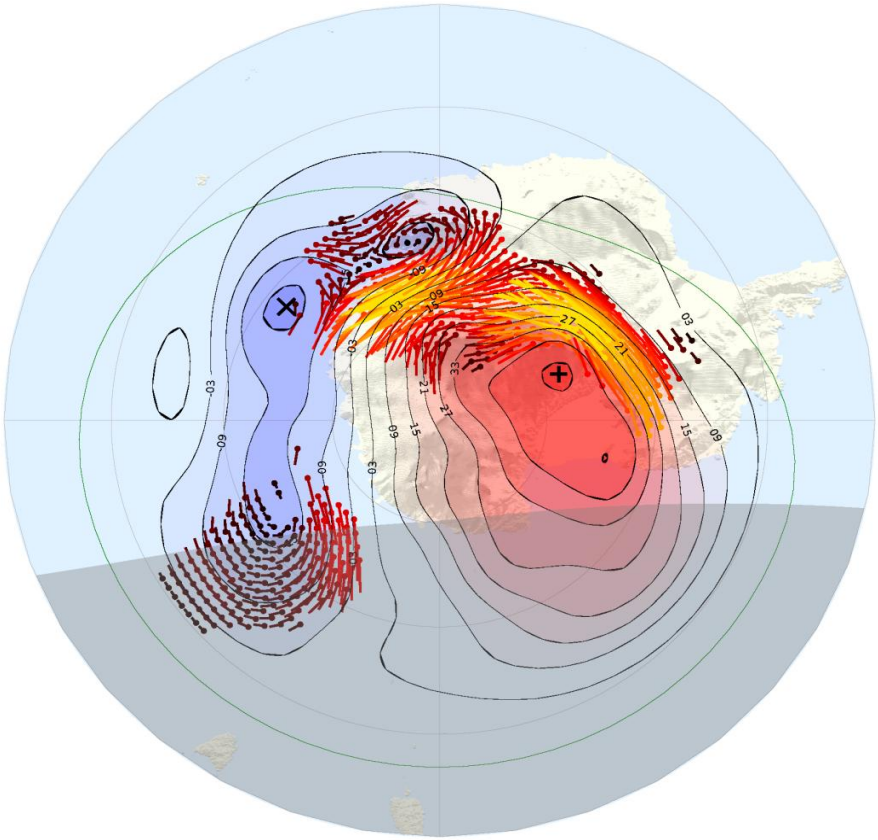
- We can use historical SuperDRAN data to detect SWF events, which will be very useful for statistical studies.

Large-Scale Mapping of Ionospheric Plasma Motion

September 30, 2002: 09:50 – 09:52 UT



Northern Hemisphere



Southern Hemisphere

Mid-Latitude Anomalies and Disturbances

- For the past 10 years, SuperDARN has been expanded to the mid-latitude regions to image the storm expansion

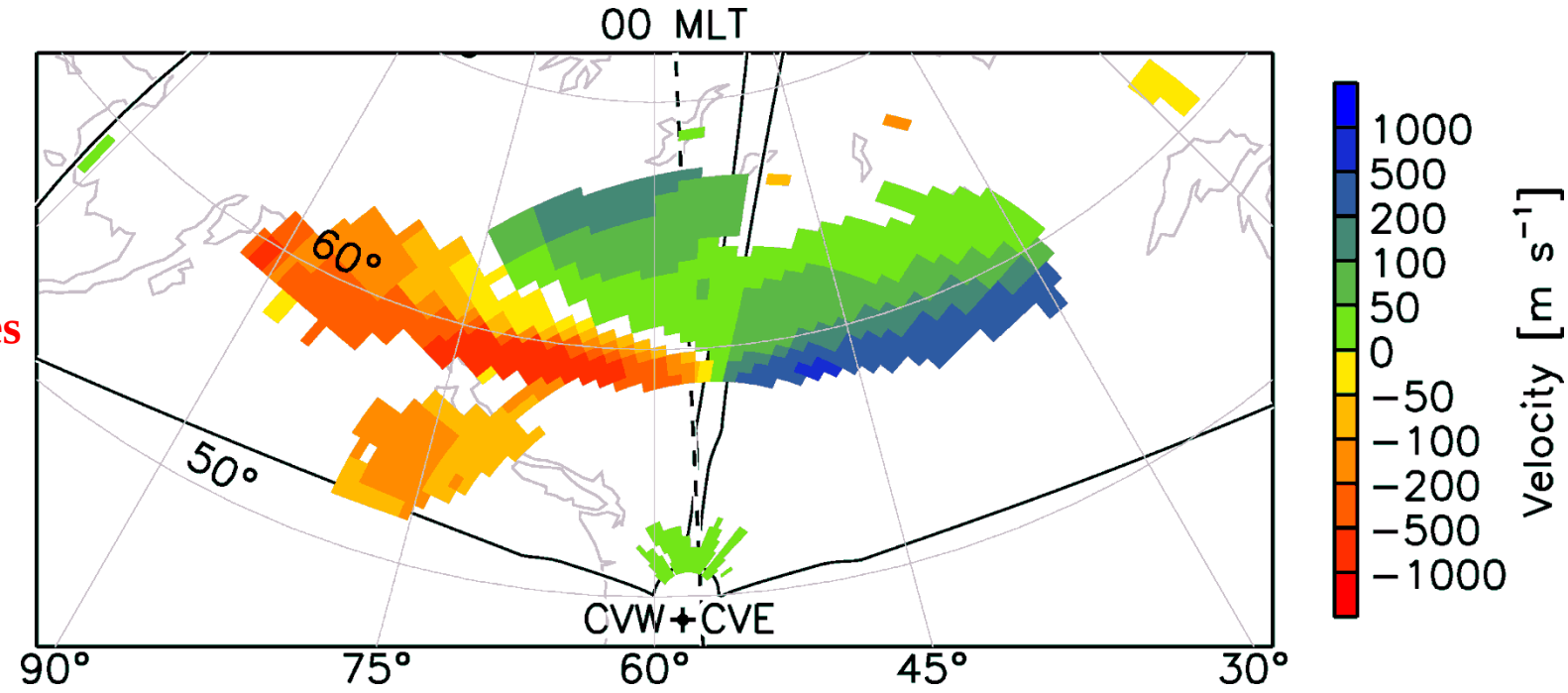
- Surprised to observe extensive subauroral ionosphere scatter (SAIS) on the night-side during quiet time, e.g., Ribeiro et al. [2012]

- With the mid-latitude chain, it has became possible to map the flows of the subauroral polarization stream (SAPS) instantaneously over many hours of MLT, e.g., Clausen et al. [2012]

SAPS Disturbance – April 9, 2011

Line-of-sight velocity measurements

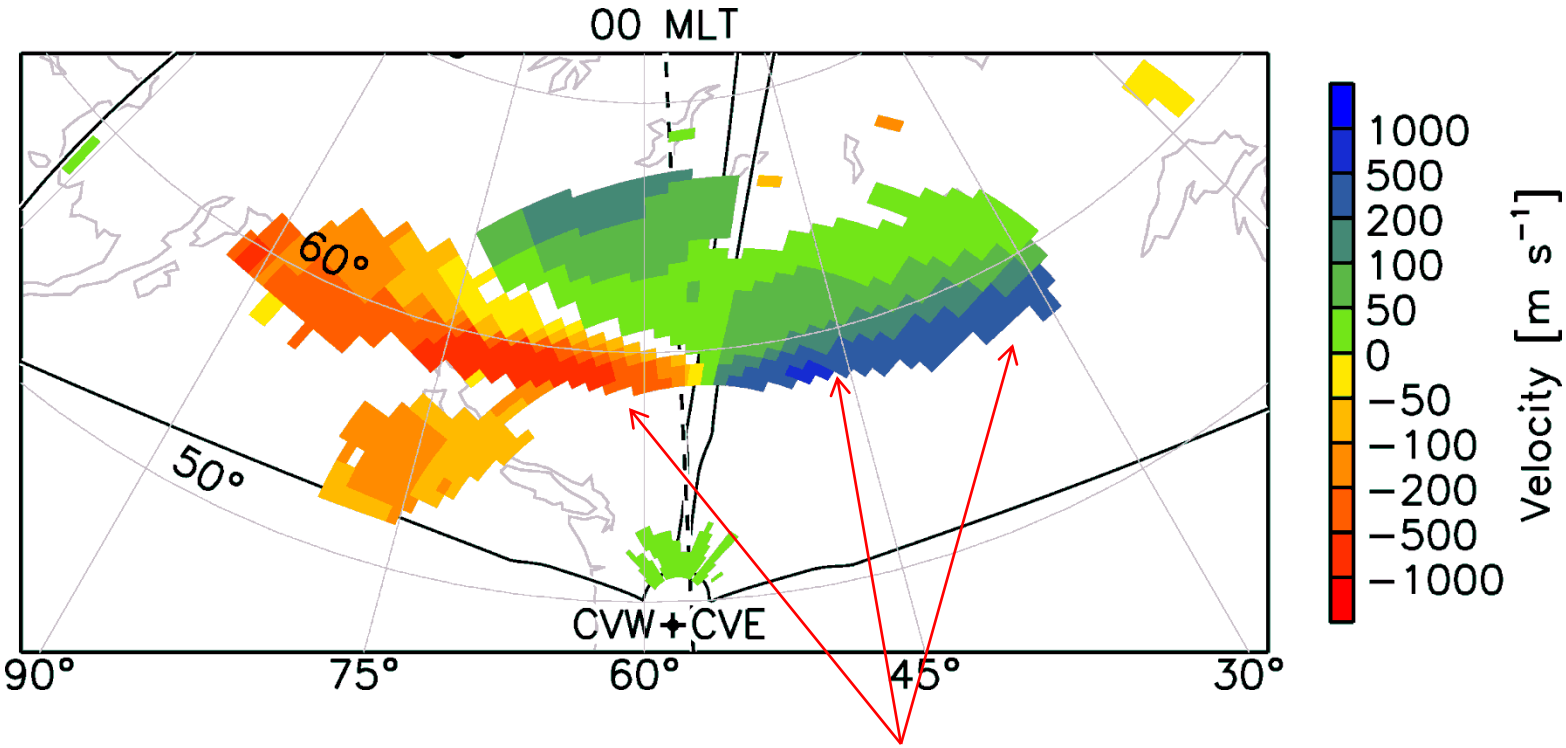
Magnetic coordinates



Fields of view of the Christmas Valley West and East radars (Oregon)

SAPS Disturbance – April 9, 2011

Line-of-sight velocity measurements
0840 UT



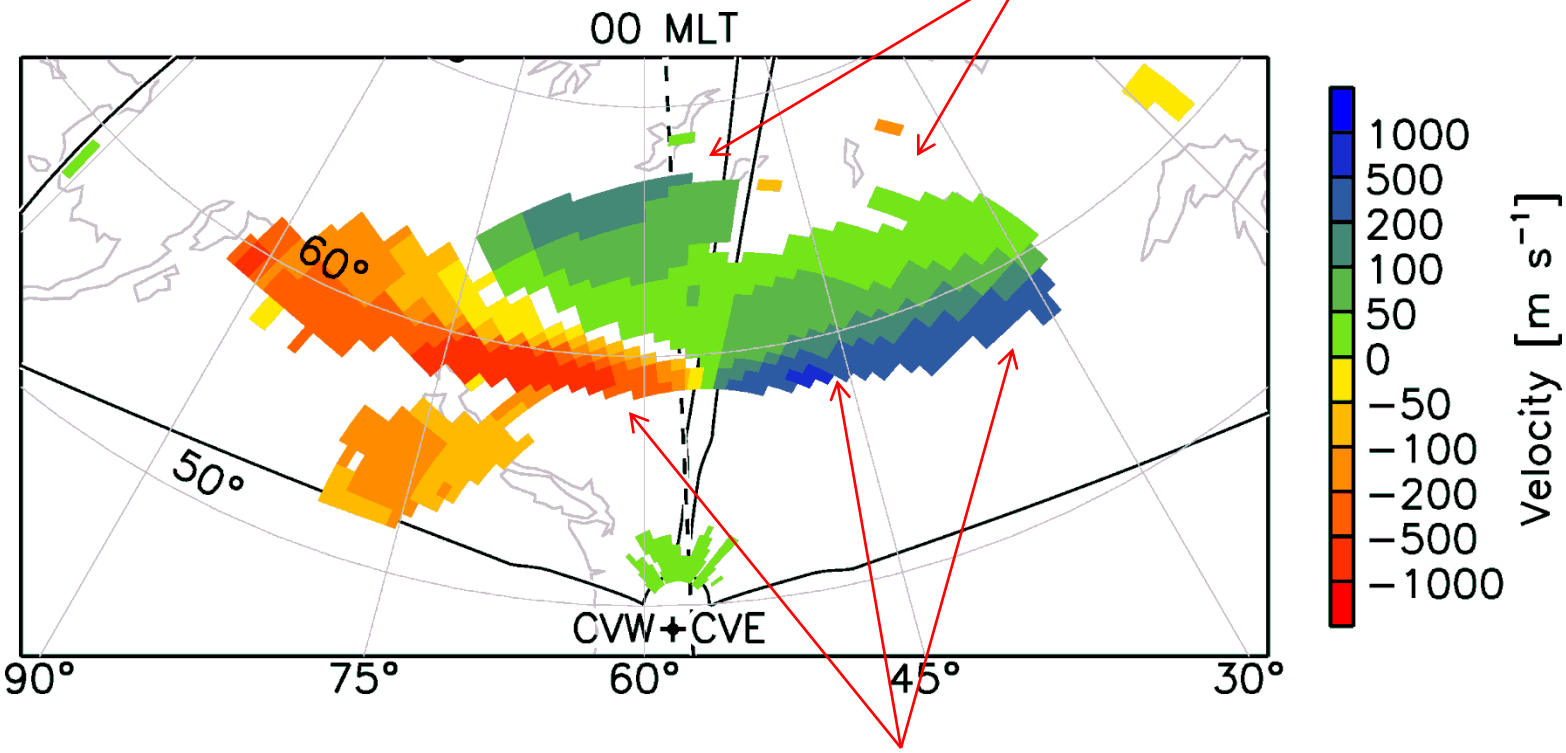
SAPS Channel (Oksavik et al. [2006])

SAPS Disturbance – April 9, 2011

Line-of-sight velocity measurements

0840 UT

Auroral Oval



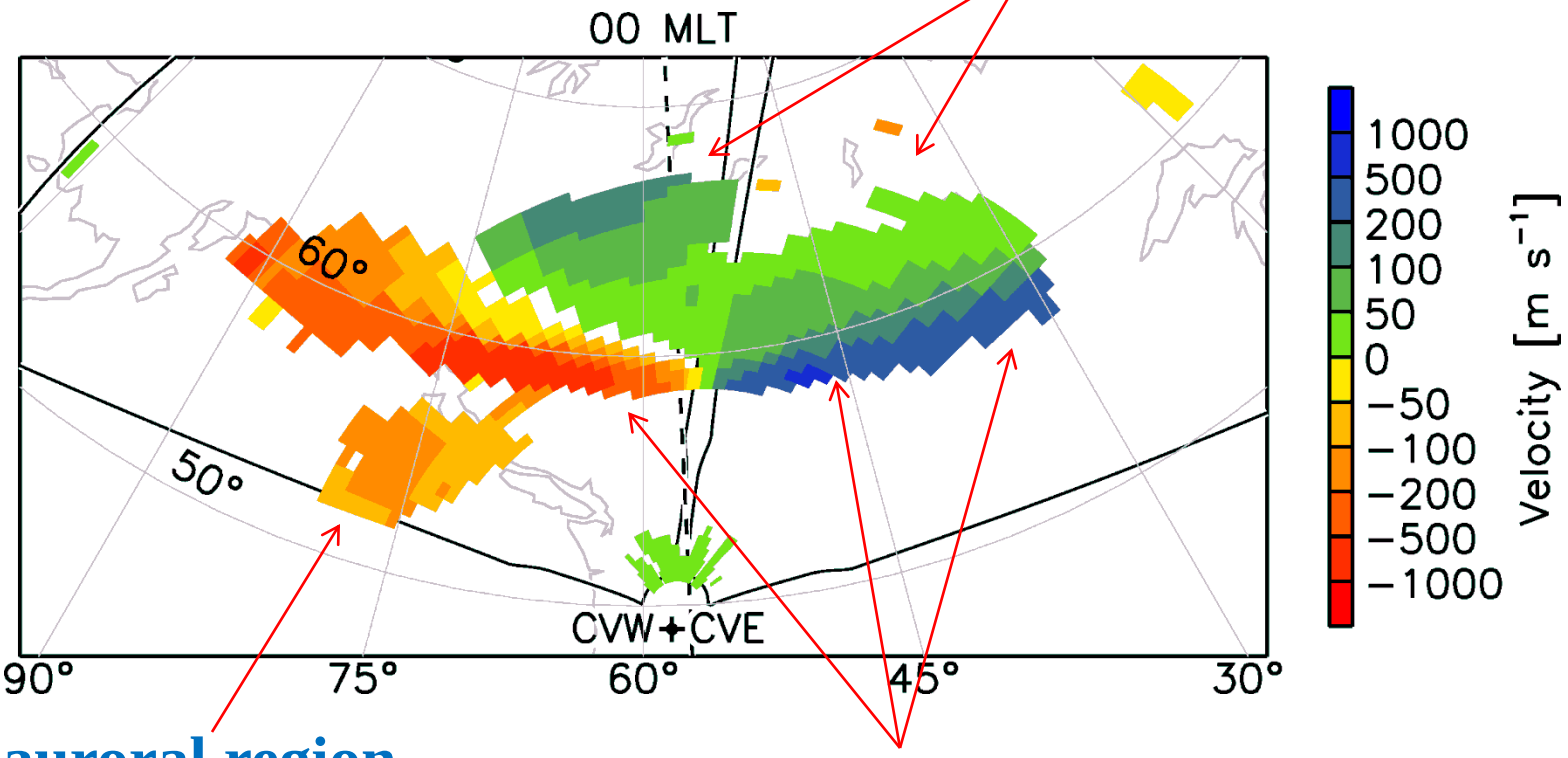
SAPS Channel (Oksavik et al. [2006])

SAPS Disturbance – April 9, 2011

Line-of-sight velocity measurements

0840 UT

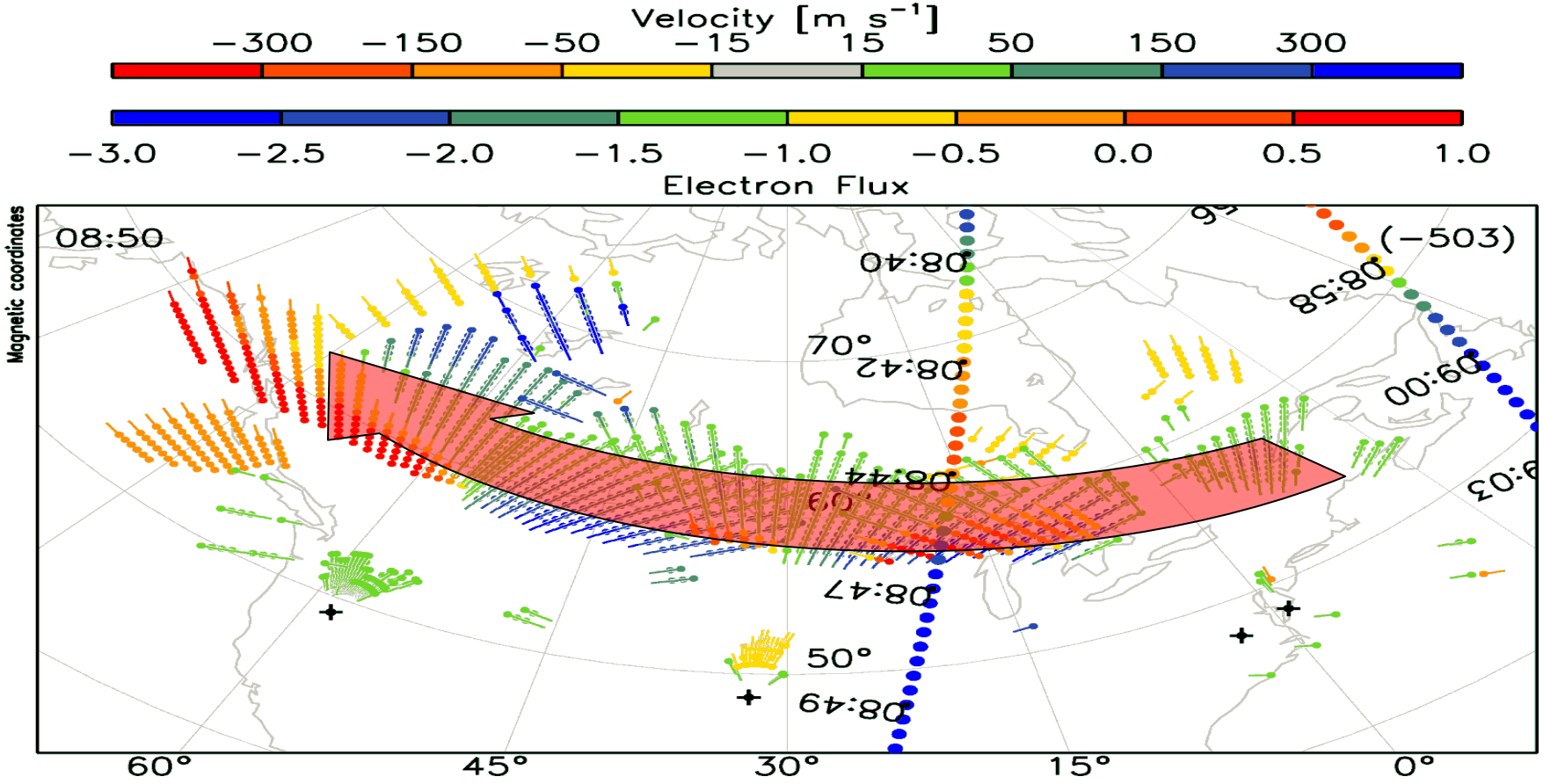
Auroral Oval



Subauroral region (Riberio et al. [2012])

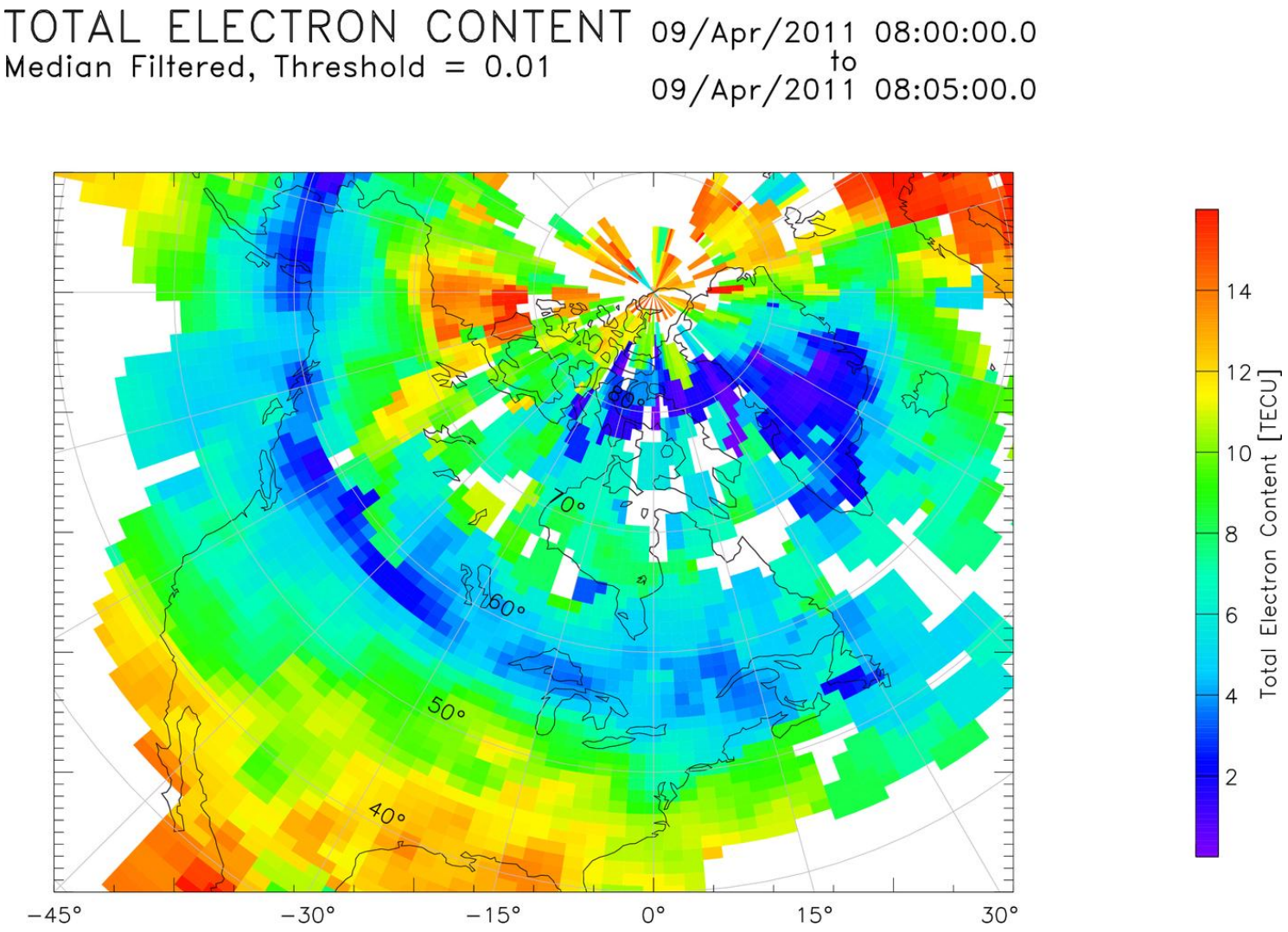
SAPS Channel (Oksavik et al. [2006])

An Example of SAPS

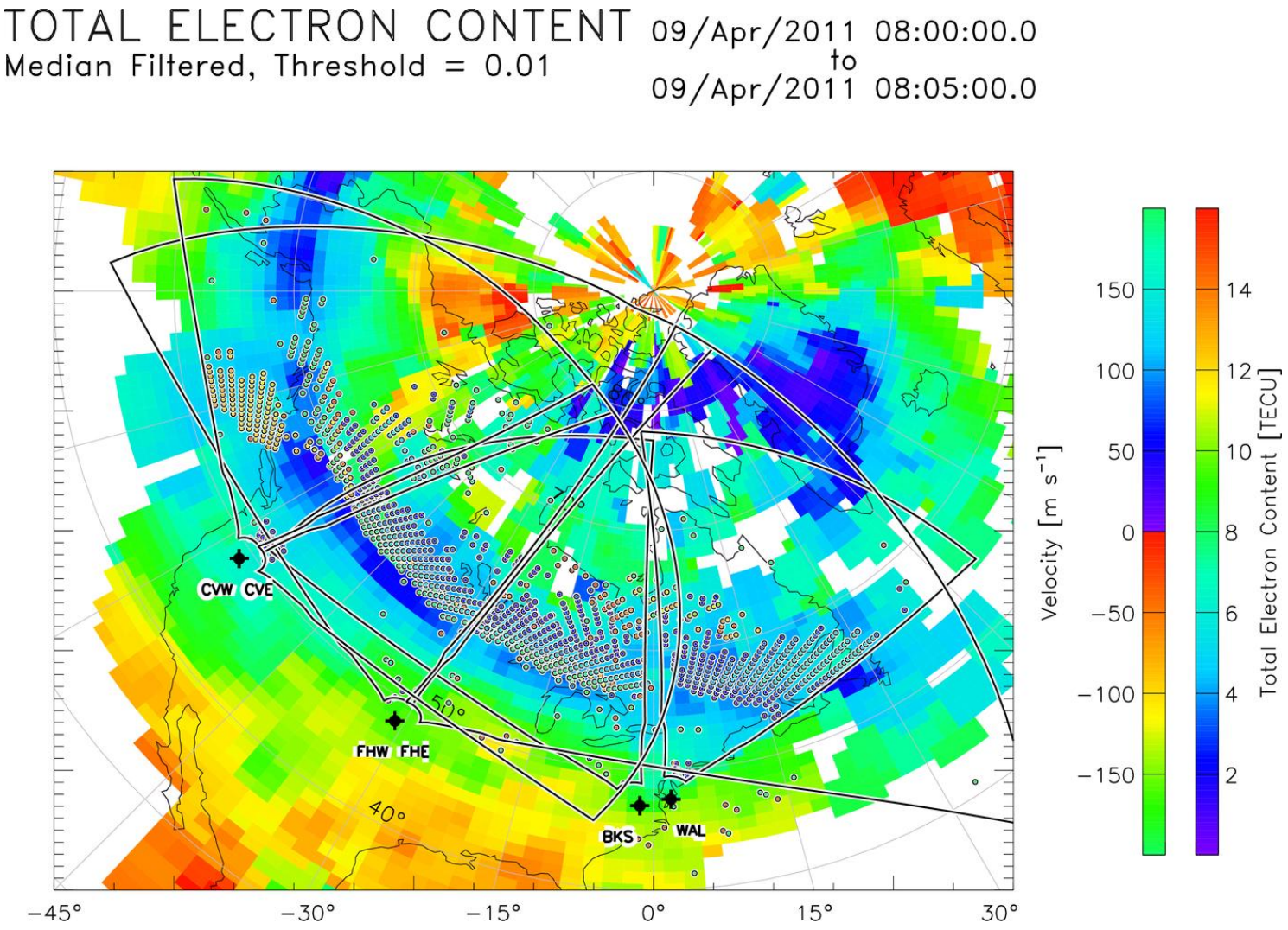


- The new mid-latitude array of SuperDARN radars images the large-scale evolution of storm-time features such as SAPS.

Mid-Latitude Disturbance: SAPS and TEC Trough

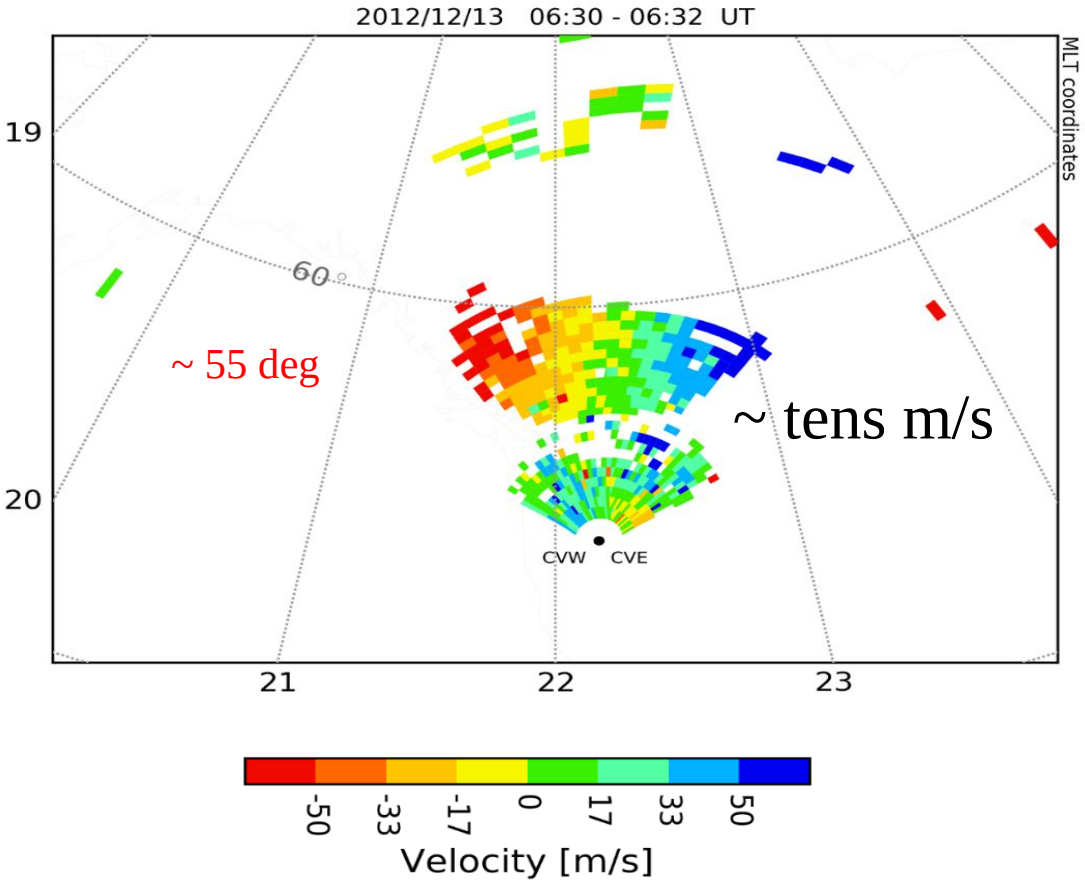


Mid-Latitude Disturbance: SAPS and TEC Trough



Example of SAIS (Blackstone) – February 5, 2012

2012/12/13 08:24 - 08:26 UT



Scan plot of SAIS showing azimuthal sense of velocity variation

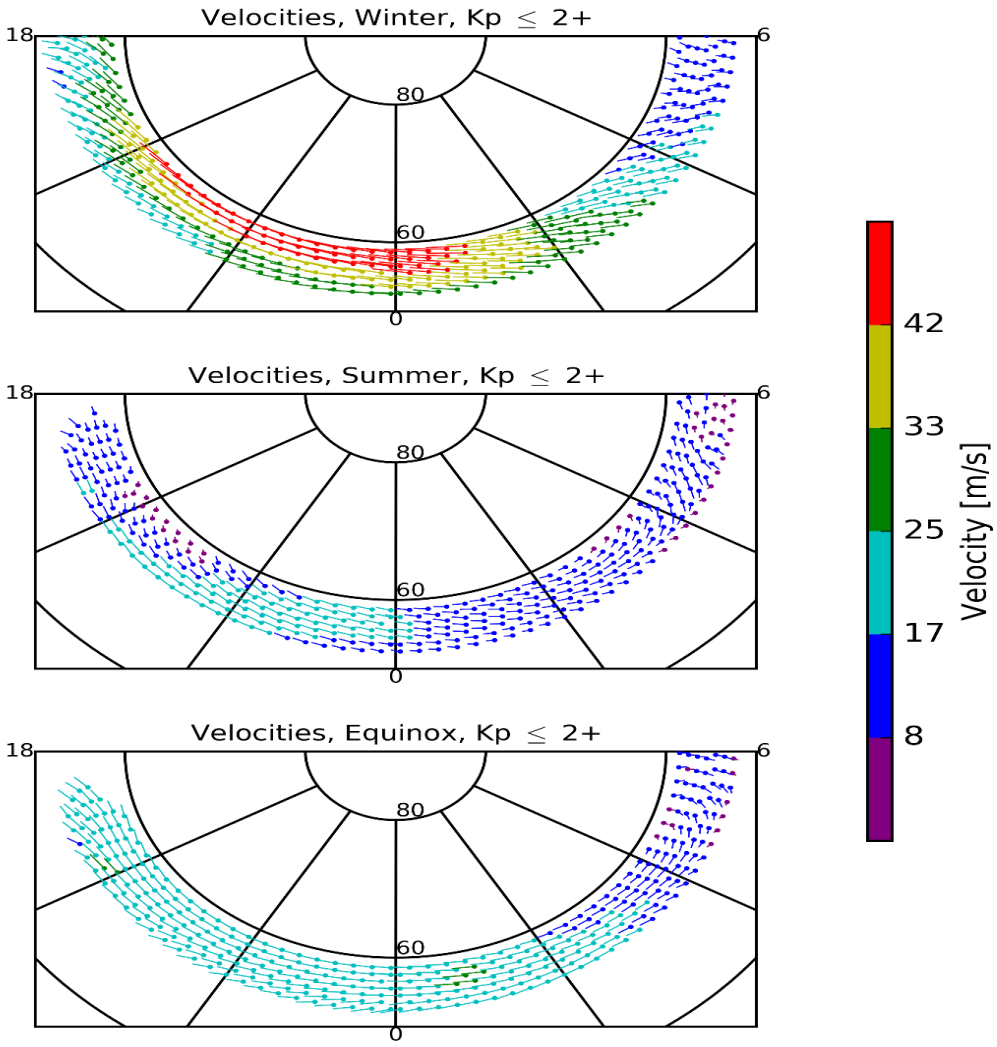
Subauroral Convection Patterns

[For details visit Poster MDIT-06]

Winter

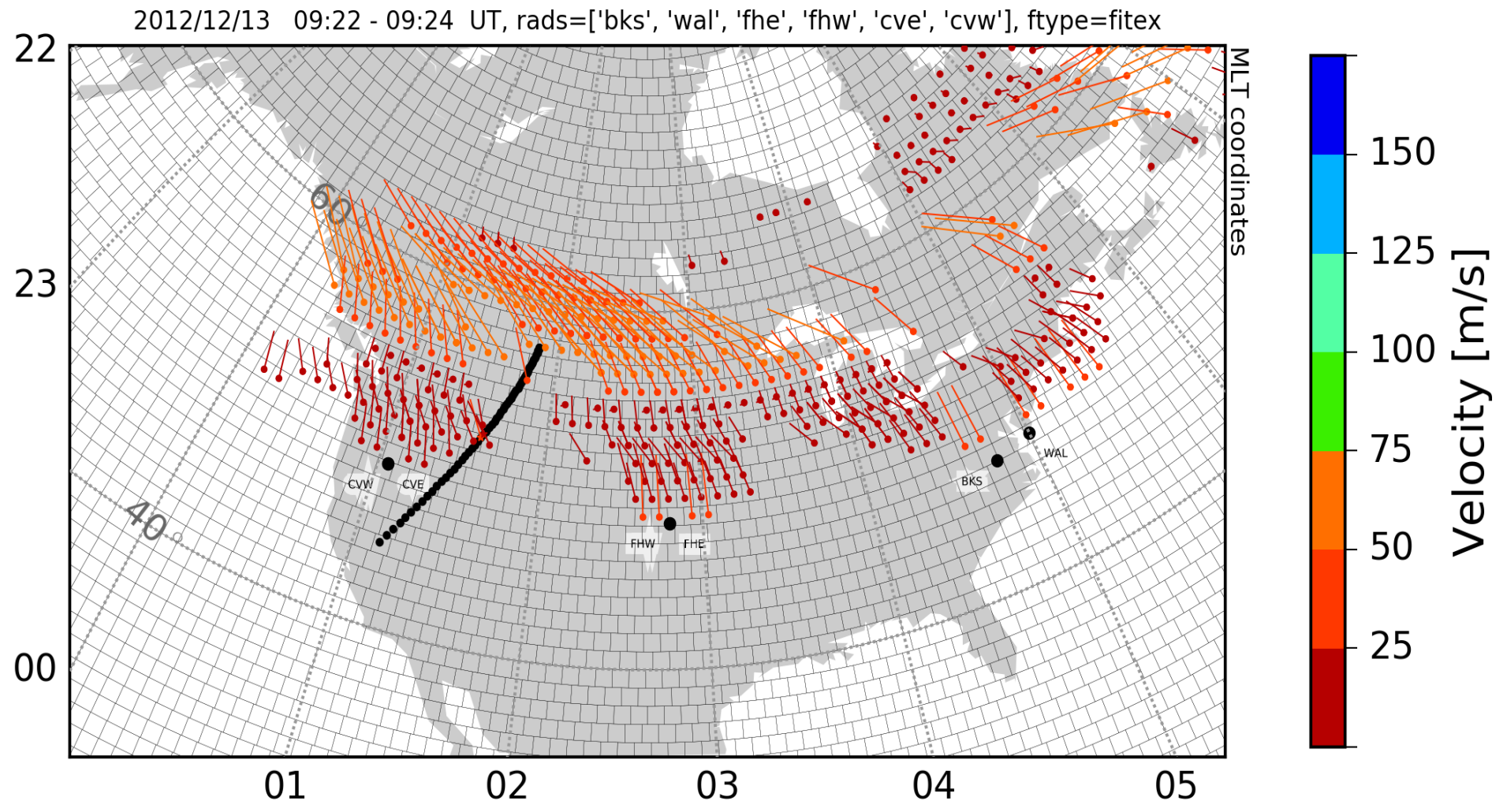
Summer

Equinox



- Data are split into three seasons; Winter (Nov-Feb, Summer (May-Aug) and Equinox (Mar-Apr, Sep-Oct)
- Flows are mainly westward across the night-side

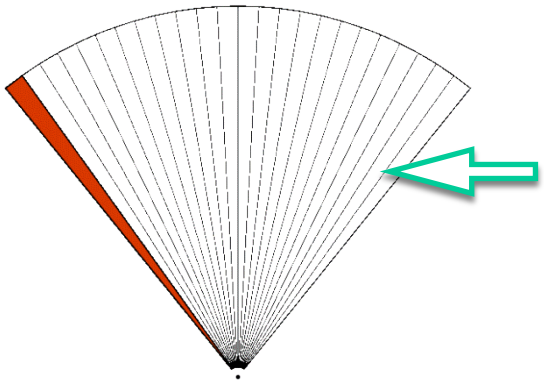
SAIS Observation in Conjunction with Van Allen Probe



Summary of Mid-Latitude Disturbances

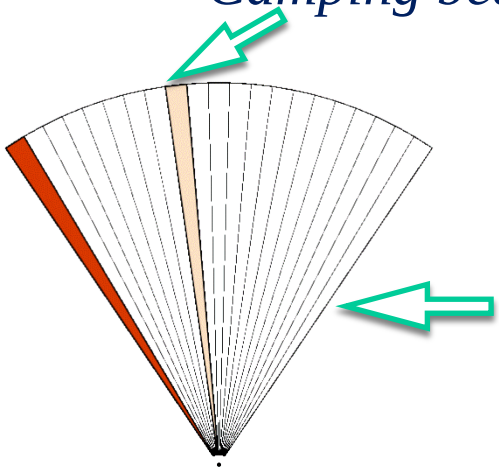
- Original concept of 'StormDARN' is realized with expanded mapping of storm time convection
- Subauroral ionospheric scatter (SAIS) gives views of plasma flows and electric fields conjugate to the inner magnetosphere
- Extensive observations of SAPS provides a testbed for modelling storm-time dynamics and coupling to the inner magnetosphere
- Strong correlations observed between SAPS and global distribution of TEC

SuperDARN THEMIS Mode for ULF Wave Study



Normal scan mode

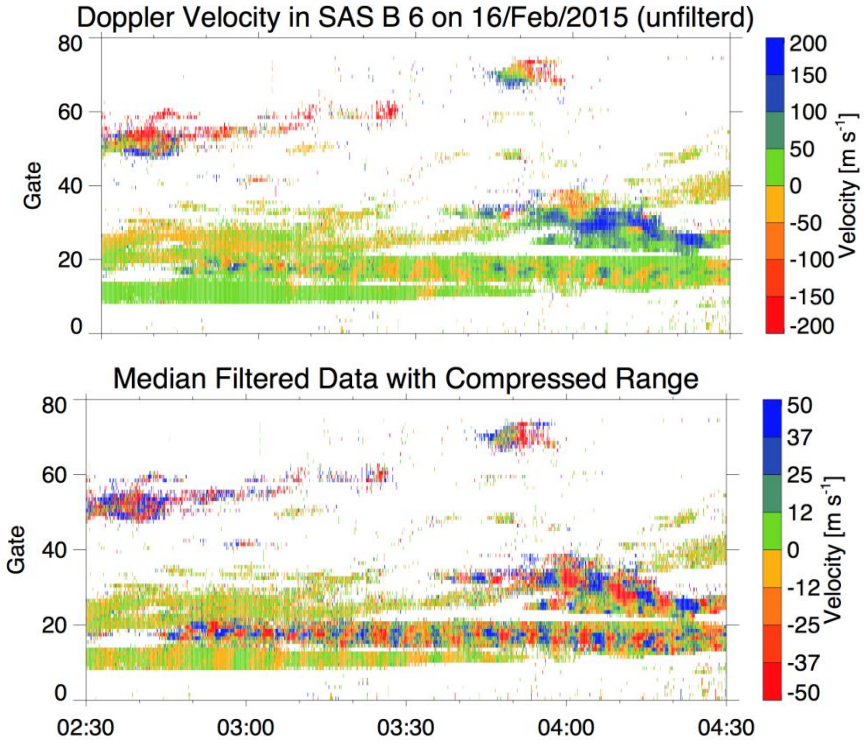
Camping beam ~6 s



THEMIS scan mode

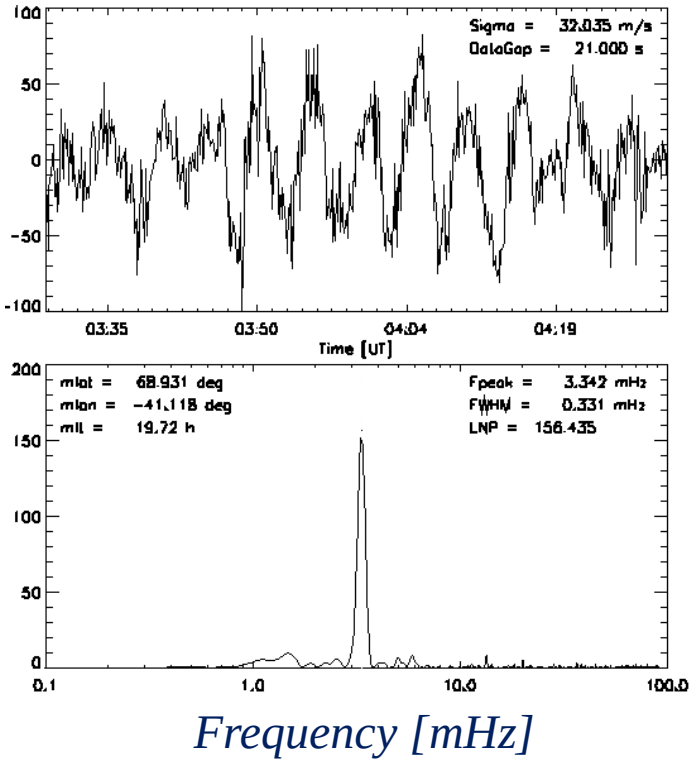
ULF Example Waveform Plot using THEMIS Mode Data

- Ultra-low frequency (ULF) Waves:
  - MHD plasma wave at 1mHz ~ a few Hz;
  - ULF wave electric field results in oscillations in drift velocities in the ionosphere.



Doppler Velocity in SAS Beam 6 Gate 16 on 16/Feb/2015

$\vec{E} \times \vec{B}$



Other Science Topics

- Magnetic Reconnection
- Storms and Substorms
- Ionospheric Plasma Irregularities
- MHD Waves and ULF Waves
- Gravity Waves and Traveling Ionospheric Disturbance
- The Neutral Atmosphere

QUESTIONS?

THANK YOU **!!!**