CEDAR 2023 Tutorial on SuperDARN

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Tutorial: SuperDARN

- Presented on behalf of the U.S. SuperDARN collaboration:

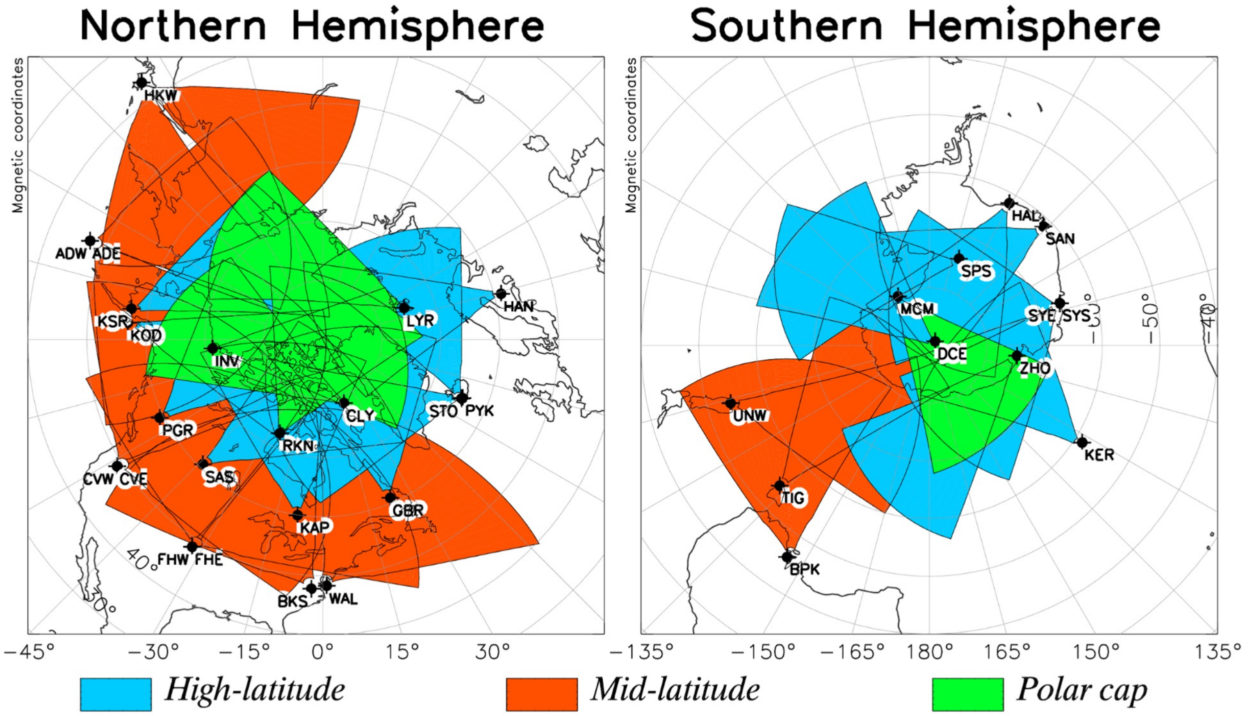
Virginia Tech [VT]	J. Michael Ruohoniemi, PI
Pennsylvania State [PS]	William Bristow, PI
Dartmouth College [DC]	Simon Shepherd, PI
JHU/APL	Alex Chartier, PI

- With contributions by Bharat Kunduri (VT), Xueling Shi (VT), Evan Thomas (DC), Kevin Sterne (VT), Jordan Wiker (JHU/APL)
- All four PIs are attending the Workshop this week!

Outline

- Introduction to the Super Dual Auroral Radar Network (SuperDARN) and the HF coherent scatter radar technique
- Applications to studies of plasma dynamics
- Applications to studies of the ionosphere and thermosphere
- Types of data available, e.g., fitacf files and convection maps
- Accessing and visualizing SuperDARN data via pyDARN: A *python-*based API

SuperDARN HF Radar Fields-of-View (FoV) Coverage



Chains of SuperDARN radars have been built to extend coverage from the auroral zone to the polar cap and mid-latitude regions.

SuperDARN International Collaboration

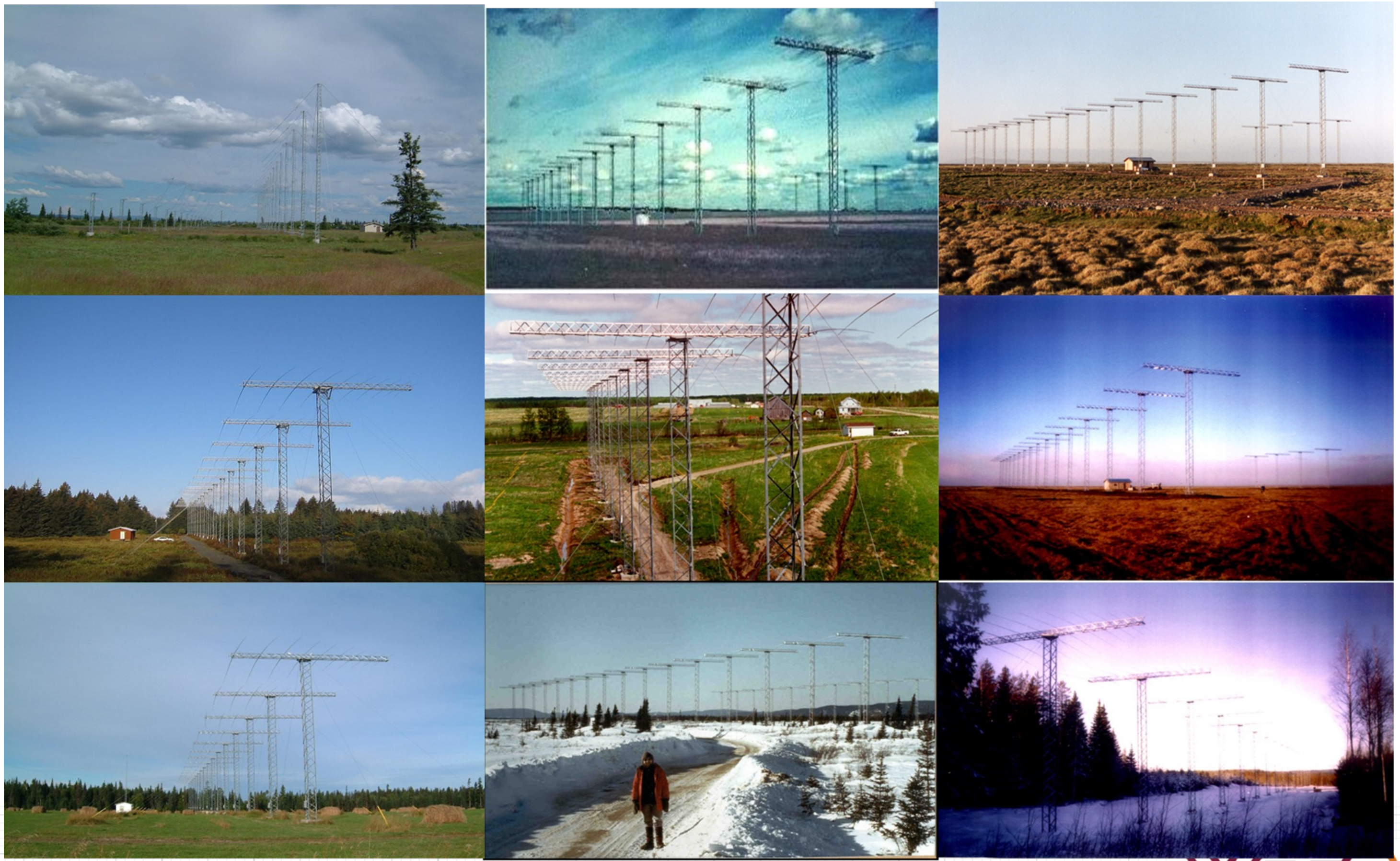
- Over 30 SuperDARN radars are supported by the funding agencies of ten countries
- The U.S. collaboration is supported under the Space Weather Research (SWR) program of NSF / AGS
- Major SuperDARN partner in North America:

  University of Saskatchewan (Kathryn McWilliams, PI)

SuperDARN International Collaboration

- Johns Hopkins University Applied Physics Laboratory, USA (1983)
- British Antarctic Survey, UK (1988)
- University of Saskatchewan, Canada (1993)
- Centre National de la Recherche Scientifique, France (1994)
- National Institute for Polar Research, Japan (1995)
- University of Leicester, UK (1995)
- University of KwaZulu-Natal, South Africa (1997)
- La Trobe University, Australia (1999)
- University of Alaska Fairbanks, USA (2000) / Penn State (2018)
- National Institute of Information and Communications Technology , Japan (2001)
- Nagoya University, Japan (2008)
- Virginia Tech, USA (2008)
- Polar Research Institute of China (2010)
- Dartmouth College, USA (2010)
- National Space Science Center, China (2020)

Radar Sites: Northern Hemisphere Radars (2004)



Antenna arrays of the newly built SuperDARN radars Iceland (2023)

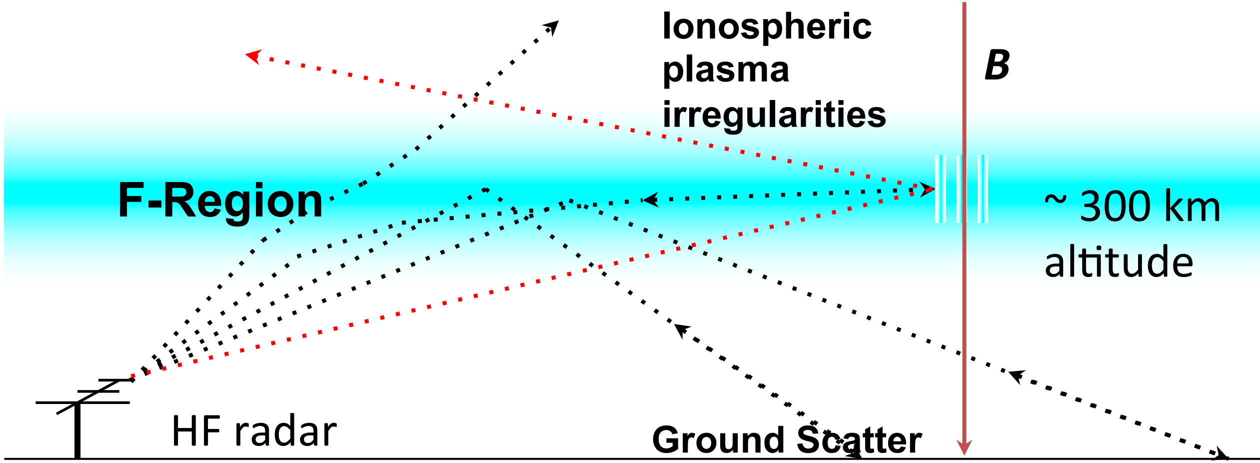
Dual radar site near Pykkvibae - Simon Shepherd, PI

SuperDARN HF Radar: Coherent Scatter Radar

- Operates continuously at low power on High Frequencies (HF), 8 - 20 MHz
- Reaches great distances (1000s of km) by virtue of refraction in the ionosphere
- Signal can be backscattered by irregularities in the ionization that in the F region are drifting with the background **E** x **B** plasma drift
- These irregularities have been amplified far beyond thermal levels by processes of plasma instability, resulting in Coherent Scatter (CS)
- This type of scatter requires (i) the presence of irregularities and (ii) propagation perpendicular to the magnetic field lines
- Signal can also be backscattered by the ground after reflection from the ionosphere

Propagation and reflection of HF Signal

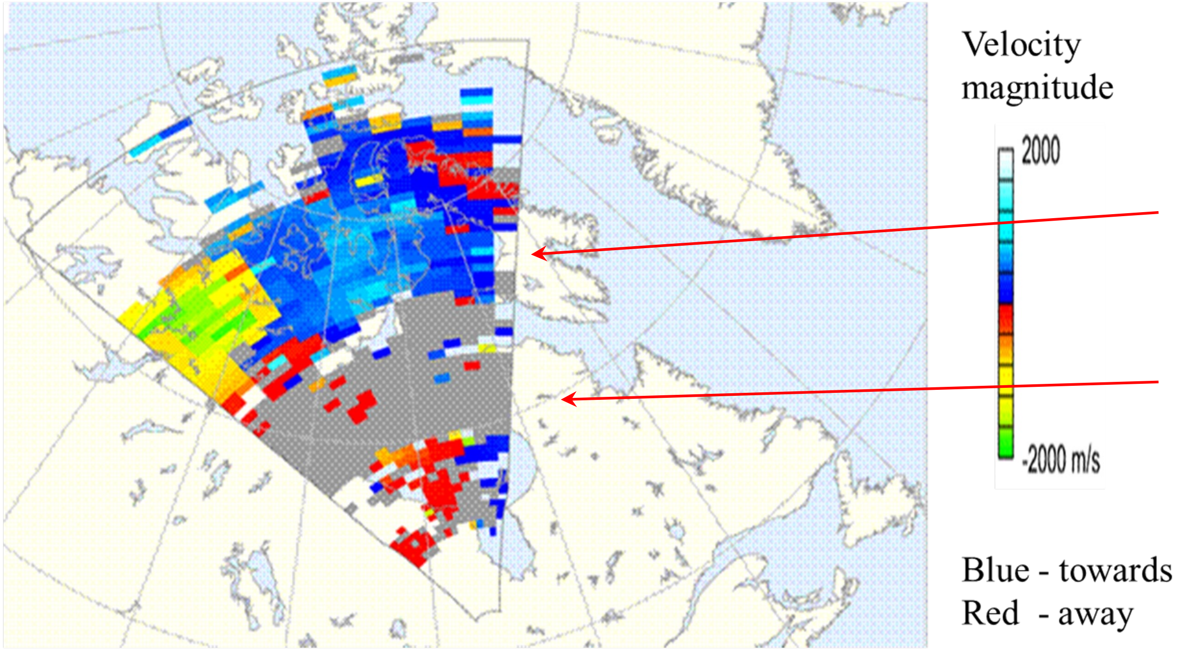
- HF rays are refracted in the ionosphere as they encounter gradients in electron density.
- Transmitted signals can be reflected back to the radar by
  - Ionospheric plasma irregularities.
  - Earth's surface



- Information about the reflectors is carried in the returned signal, e.g., in the Doppler-shifted frequency

HF Backscatter from the Auroral Ionosphere and Earth's surface

Map of Doppler velocity obtained from a single 2-min radar scan



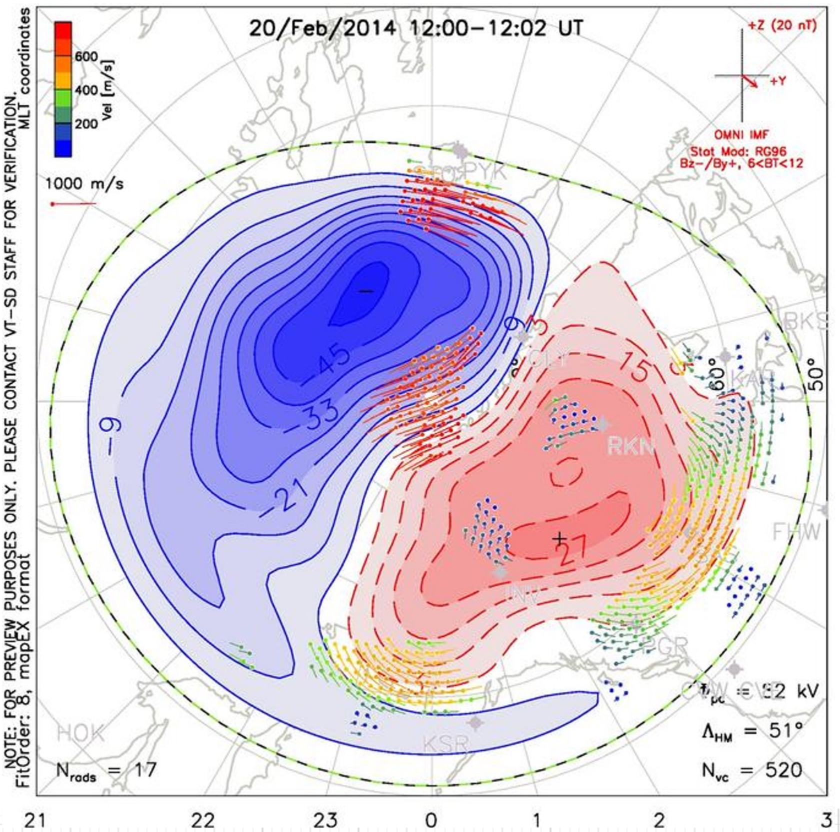
Ionospheric Scatter

Ground Scatter

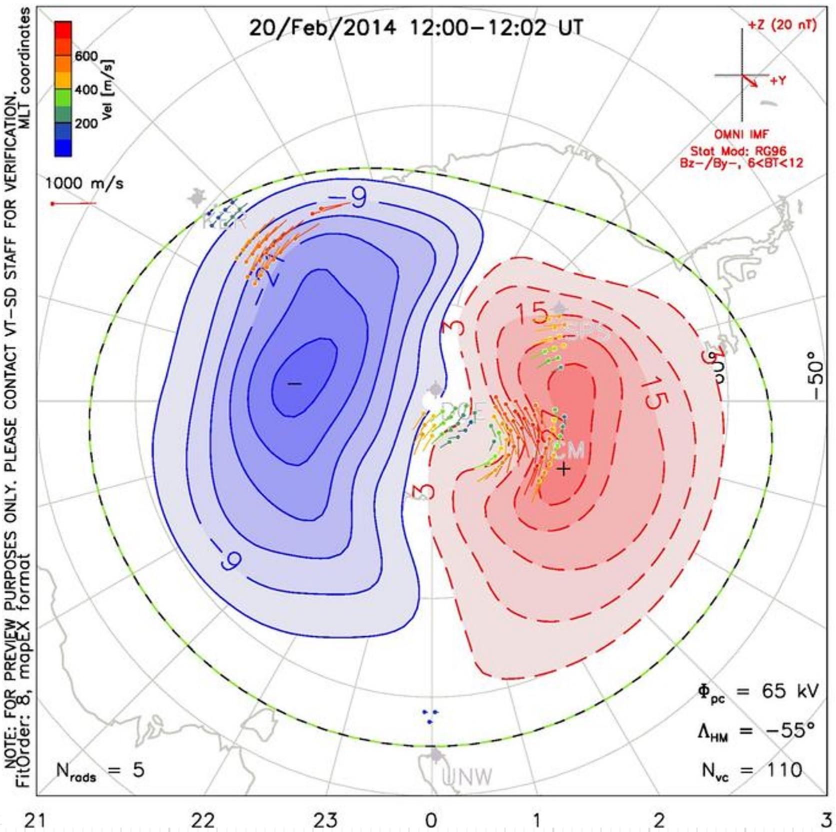
SuperDARN radar located at Kapuskasing, Ontario (Canada)

Primary Objective: Mapping large-scale plasma convection

Date: 20 Feb 2014, 12:00 UT



Hemisphere: North



Hemisphere: South

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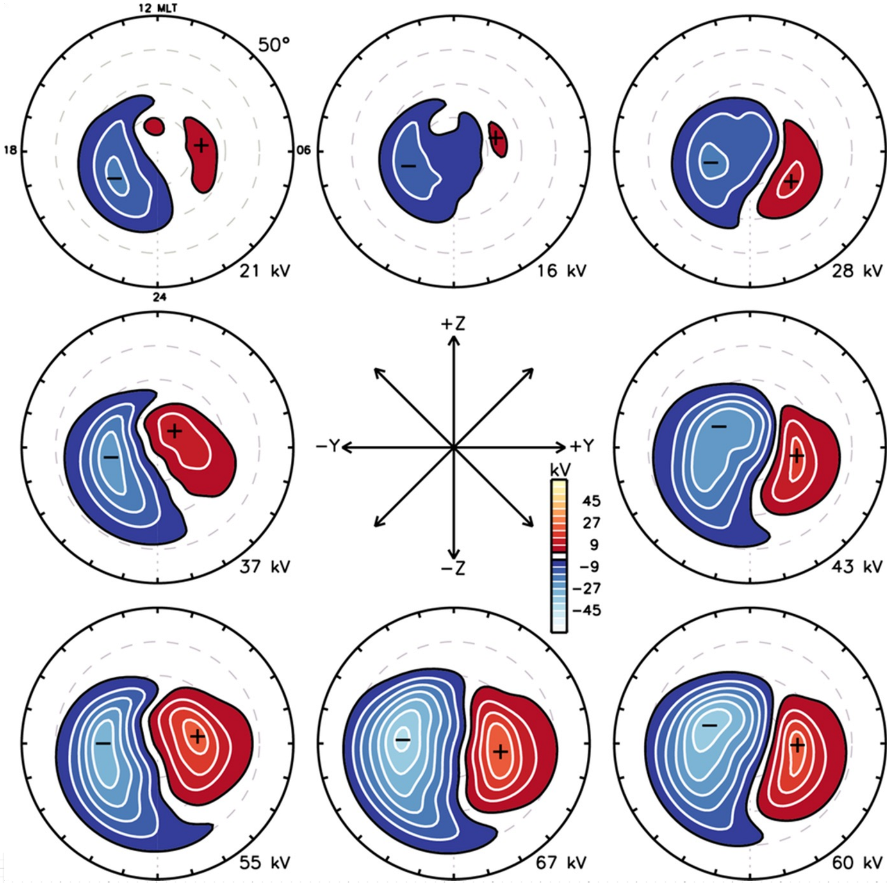
TS18 Climatological Convection Model

Thomas & Shepherd (2018)

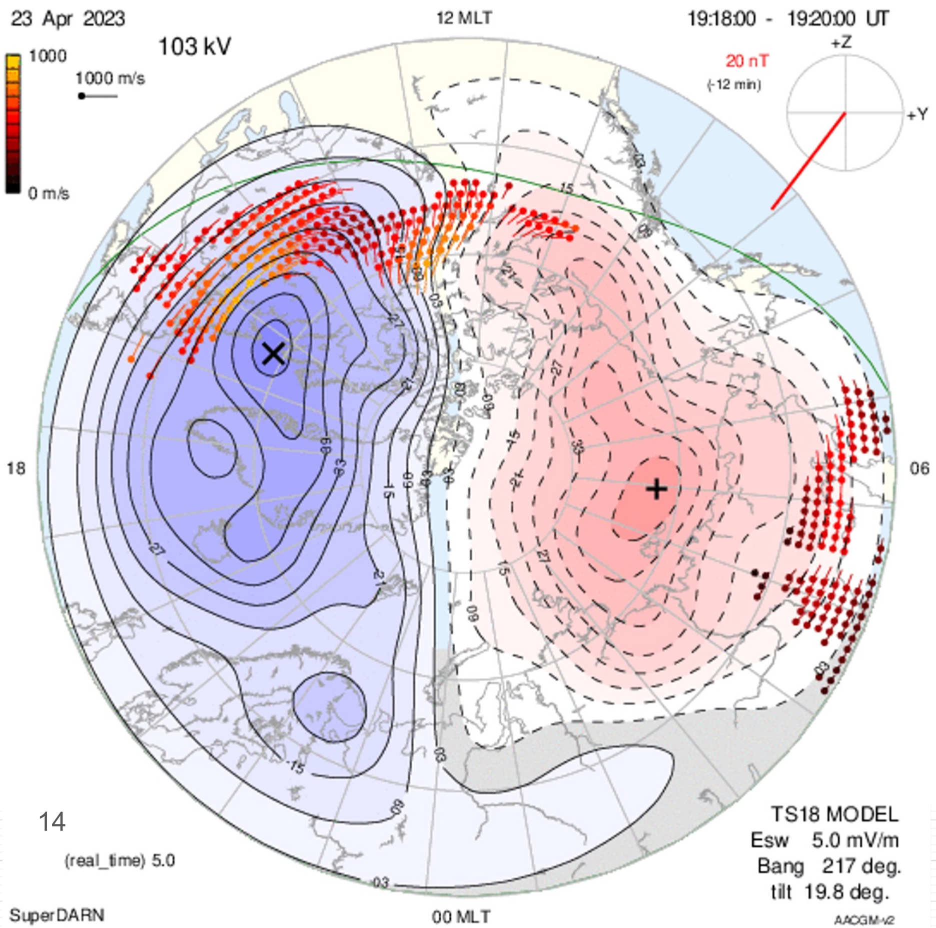
The figure shows the variation in plasma convection for different orientations of the IMF derived from statistical analysis of SuperDARN data.

https://superdarn.thayer.dartmouth.edu/convection.html

Thomas, E. G. and S. G. Shepherd (2018), Statistical patterns of ionospheric convection derived from mid-latitude, high-latitude and polar SuperDARN HF radar observations, *J. Geophys. Res. Space Physics, 123*, 3196-3216, doi:10.1002/2018JA025280.



Movie showing real-time mapping of the plasma convection pattern



Sequence of images:
April 23, 2023, 19:20 - 19:48 UT

A near real-time image of the global convection pattern is generated using data links to radars and posted to the Dartmouth College SuperDARN website.

https://superdarn.thayer.dartmouth.edu/convection.html

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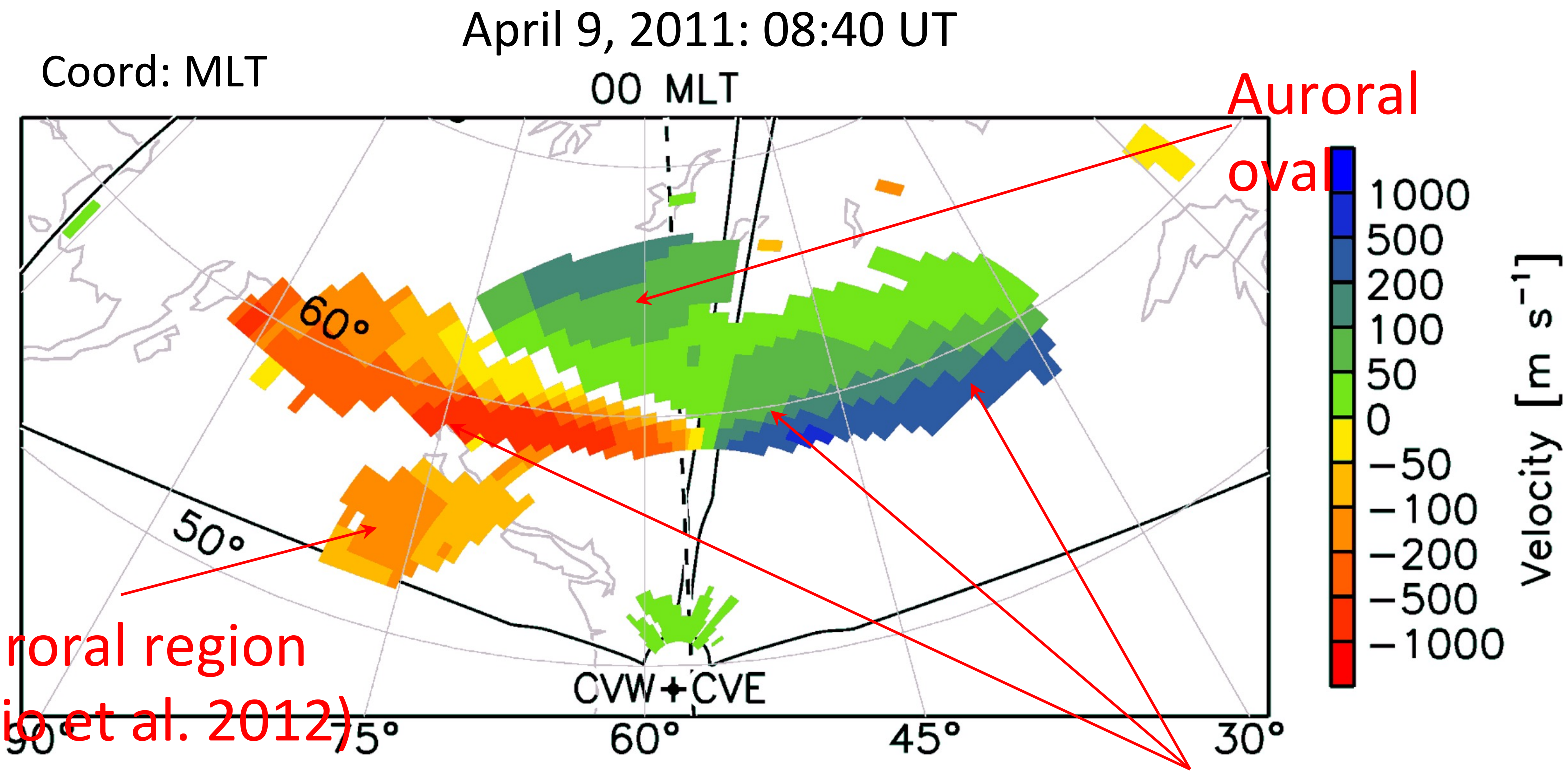
Science Highlights:

- Mapping high-latitude plasma convection (previous slides)
- Mapping subauroral plasma flows using the mid-latitude radar chain in North America
- Solar flare effects on the dayside ionosphere
- ULF waves, TIDs , mesospheric winds from meteor scatter, etc.

Plasma flows at the boundary of the auroral oval



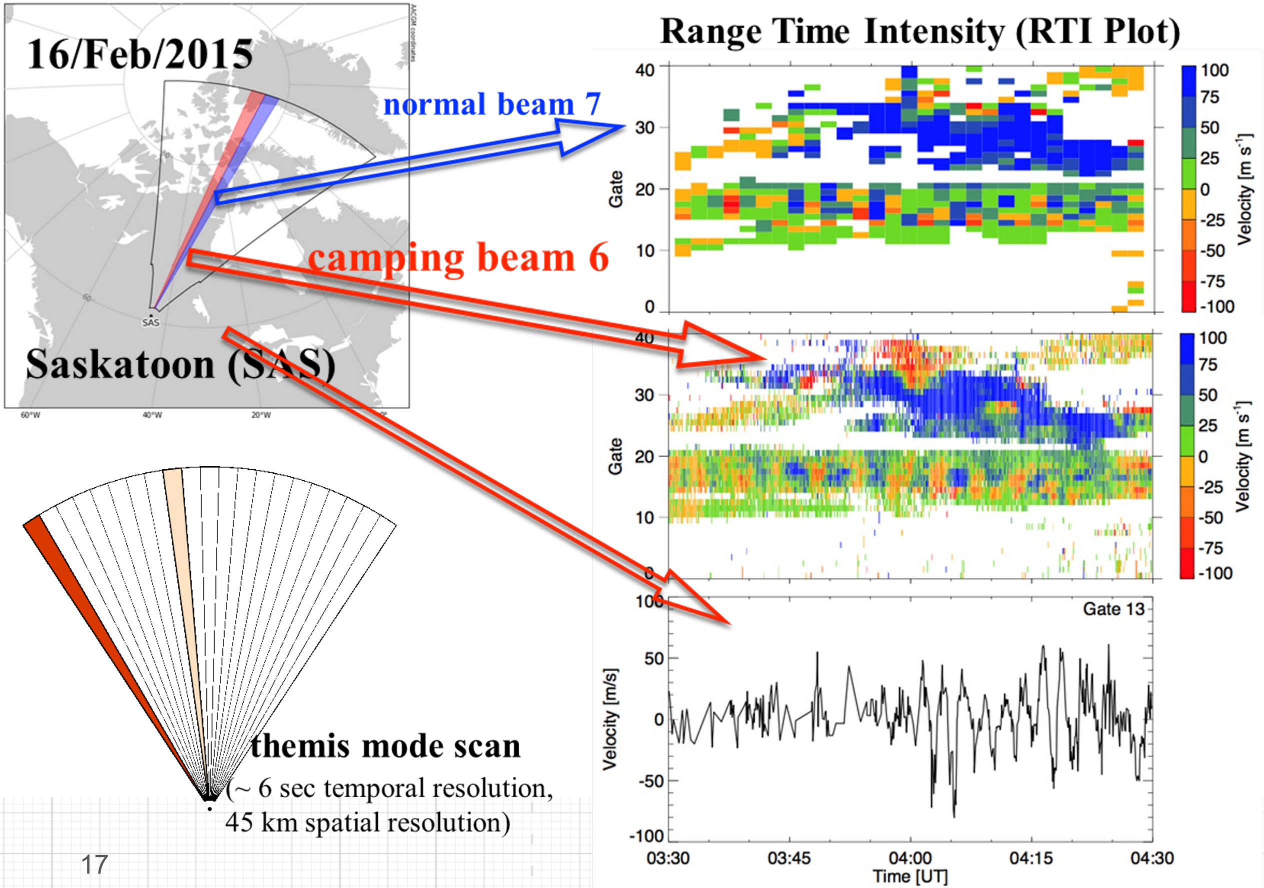
Auroral oval

Subauroral region (Riberio et al. 2012)

SAPS channel (Clausen et al., 2012)

FoV of the Christmas Valley West and East radars (Oregon)

ULF Wave Signatures in SuperDARN Data



- ULF wave electric field results in oscillations in plasma velocity
- Using higher temporal resolution radar modes ULF wave pulsations can be observed with periods of seconds
- Users can request that the radars be scheduled to operate in special modes

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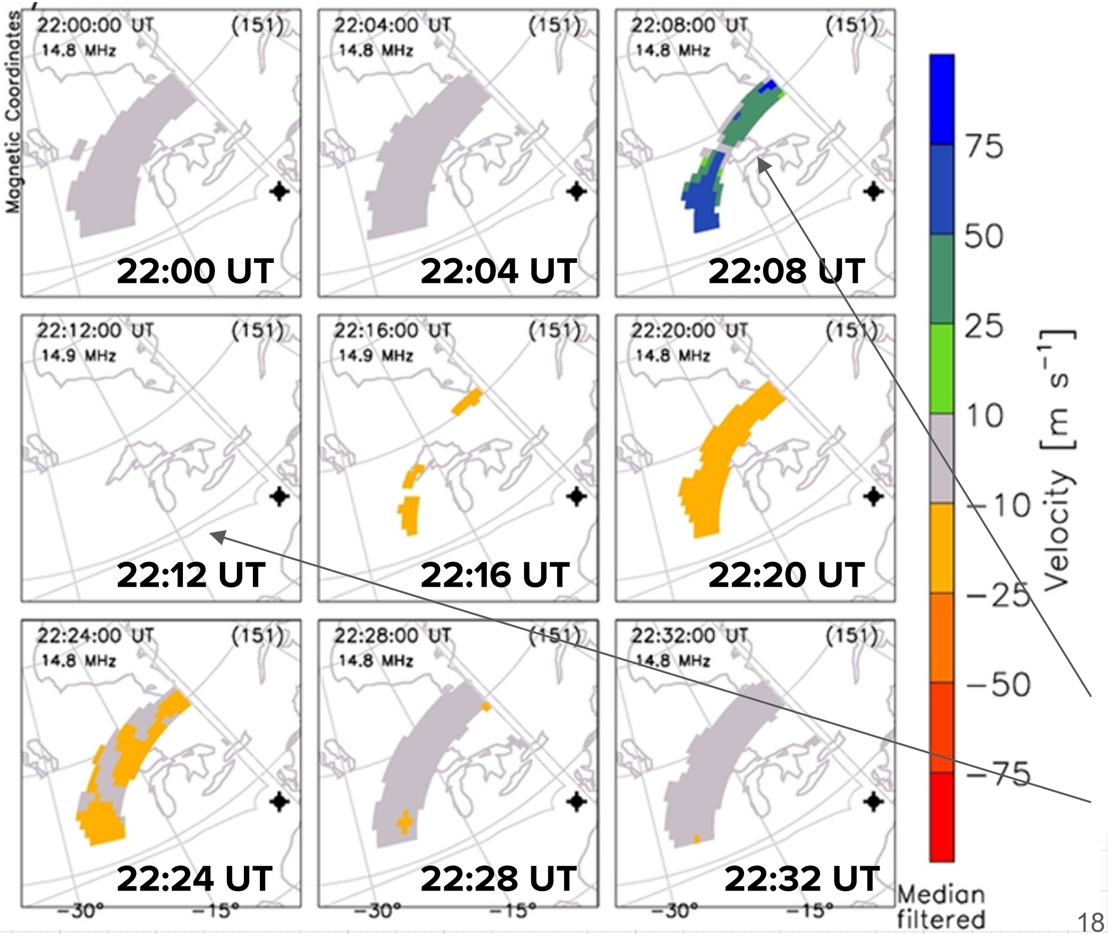
Impact of Solar Flare on the dayside ionosphere



Response of groundscatter to an X2.7 Class flare that occurred on 5 May 2015 at 22:10 UT

Enhancement in D region density leads to heavy absorption on HF

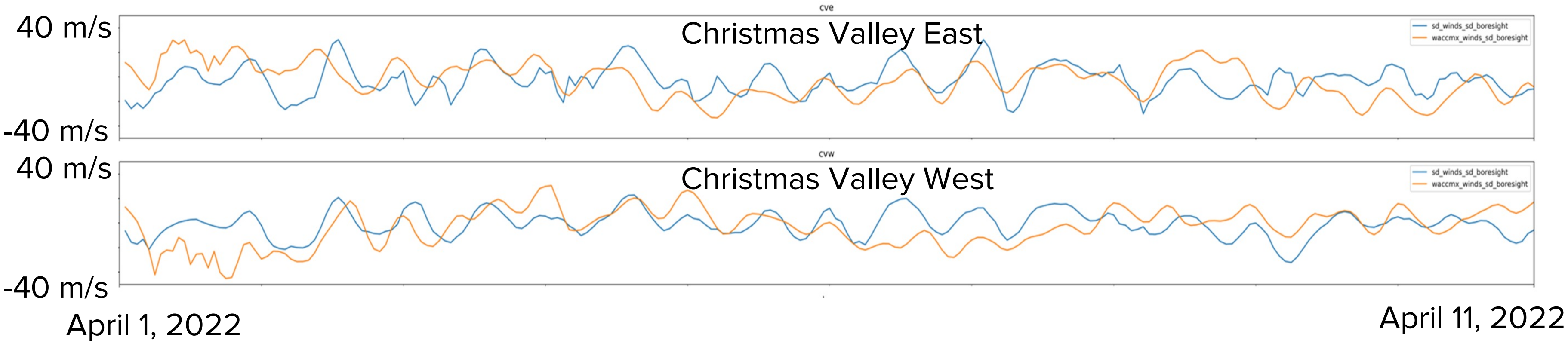
Fastest (~ 8 min) space weather effect of an earthward-directed solar flare

Doppler velocity enhancement

Peak of HF absorption event

Meteor wind data at mesospheric heights (JHU/APL)

- The radars detect backscatter from meteor trails
- The Doppler shift provides information on the neutral wind velocity
- A recent study shows remarkable agreement between radar observations and WACCM-X modeling



- The wind velocity components are routinely generated for the SuperDARN radars and distributed by the JHU/APL group, see https://doi.org/10.5281/zenodo.7984853

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SuperDARN Data Types: iq, raw, fit, grid, and map

IQDat

Voltage level data from I & Q channels

Correlation operation

RawACF

Autocorrelation functions

FitACF

Fitted parameters, e.g. LOS velocity

R1

FitACF

R2

FitACF

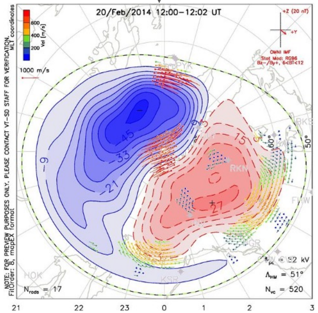
Rn

FitACF

Grid

Convection Model

Map



Credit: Kevin Sterne, VT

SuperDARN: How to view and access data, get help

- Contact for plotting tools, data access, and assistance:

Virginia Tech vt.superdarn.org
Dartmouth College superdarn.thayer.dartmouth.edu
Penn State superdarn.met.psu.edu

SuperDARN VT

- Fitacf file downloads available at:

JHU/APL - Geolocated netCDFs https:/superdarn.jhuapl.edu
University of Saskatchewan superdarn.ca

SuperDARN Canada

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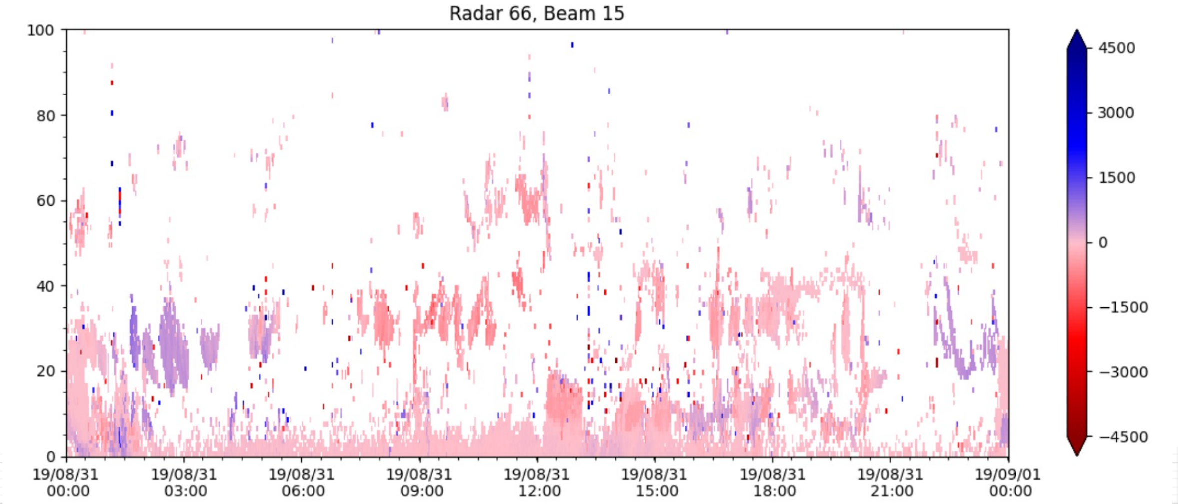
pyDARN: A python-based library for data visualization of SuperDARN data

- The library source code can be found on the pyDARN GitHub repository.
- Installation: ‘pip install pydarn’ OR ‘pip3 install pydarn’
- Needed: Ubuntu >= 20.4 / Python > 3.8.4
- Shi X et al. (2022) pyDARN: A Python software for visualizing SuperDARN radar data. Front. Astron. Space Sci. doi: 10.3389/fspas.2022.1022690

pyDARN: (Example code) plotting data (LoS Doppler velocity)

As an example, taking a look at some `v` data from the first record of Clyde River radar FITACF file:

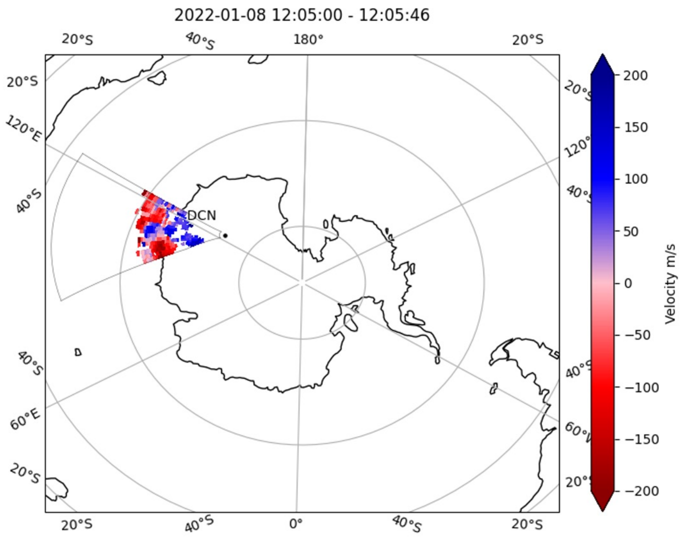
```
pydarn.RTP.plot_range_time(fitacf_data, beam_num=fitacf_data[0]['bmnum'], range_estimation=pydarn.RangeE
plt.title("Radar {:d}, Beam {:d}".format(fitacf_data[0]['stid'], fitacf_data[0]['bmnum']))

plt.show()
```



Range - Time - Intensity (RTI) plot showing variation of line-of-sight velocity with time and range from the radar

pyDARN: (Example code) plotting data (LoS Doppler velocity)

```
ax, _, _, _, _ = pydarn.Fan.plot_fan(data, scan_index=5, radar_label=True,
                                     groundscatter=True,
                                     coords=pydarn.Coords.GEOGRAPHIC,
                                     projs=pydarn.Projs.GEO,
                                     colorbar_label="Velocity m/s",
                                     coastline=True)
plt.show()
```



Scan plot showing the line-of-sight velocity measured during a single scan of the radar

pyDARN: Shi et al. (2022) Paper provides example codes

More on pyDARN: Snakes on a Spaceship Session, 30 June (Friday), 10:00 – 12:00 PDT

Thank You. Questions?

Funding Details: NSF SWR Awards

AGS-1935110 - Virginia Tech
AGS-2125323 - Penn State
AGS-1934997 - Dartmouth College
AGS-1934973 - JHU/APL

We acknowledge the use of SuperDARN data. SuperDARN is a collection of radars funded by various national scientific funding agencies across the globe.

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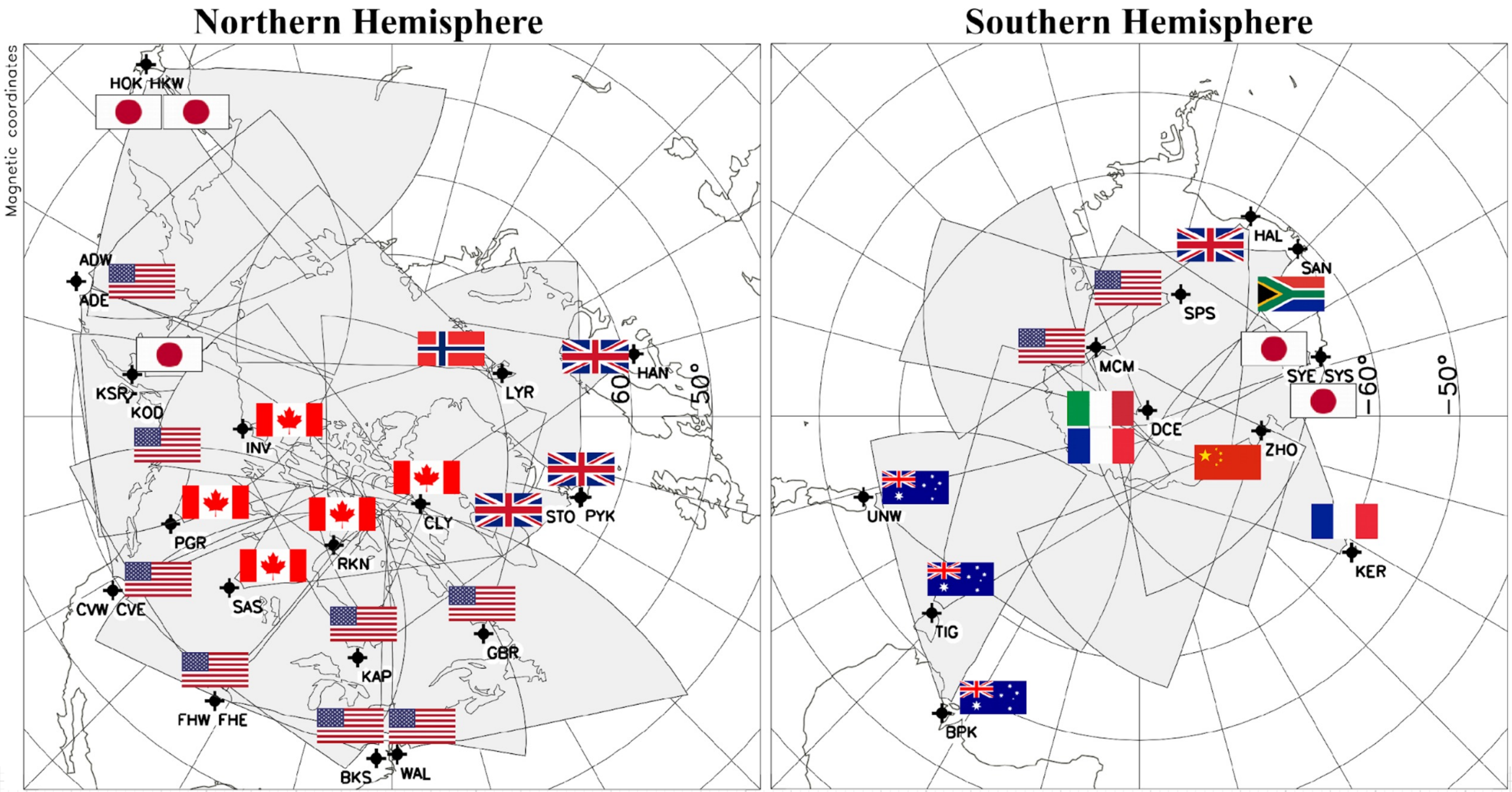
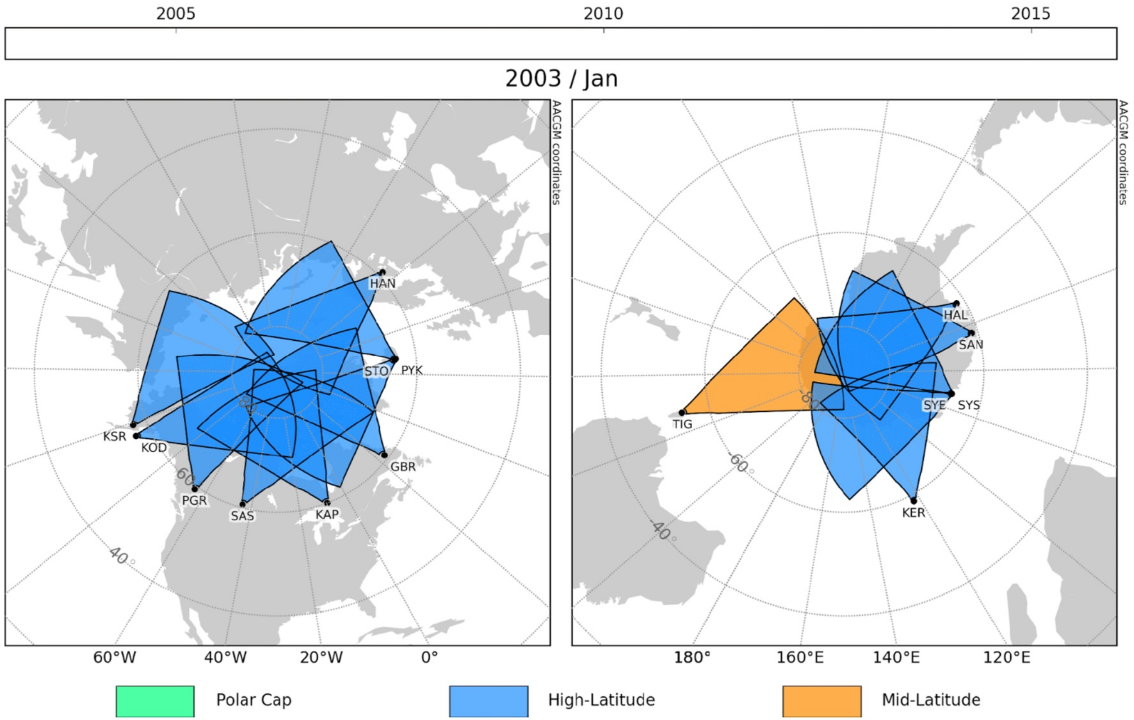
SuperDARN International Collaboration - Flags Map (2010)



SuperDARN International Collaboration

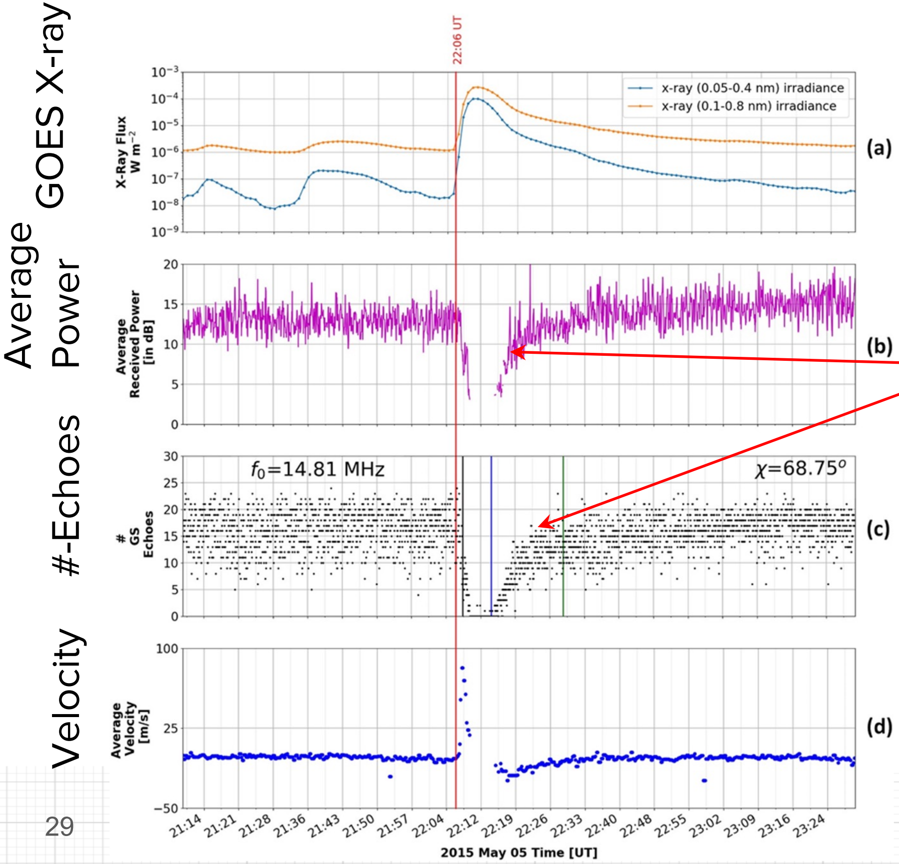
- The U.S. collaboration is supported
- Each university group maintains a website and provides community support

Expansion of SuperDARN mid-latitude radars [Drop]



Impact of Solar Flare on the Ionosphere and HF propagation

Solar flare on 5 May 2015 (22:10 UT), observed by Blackstone mid latitude SuperDARN radar



Solar Flare Signature

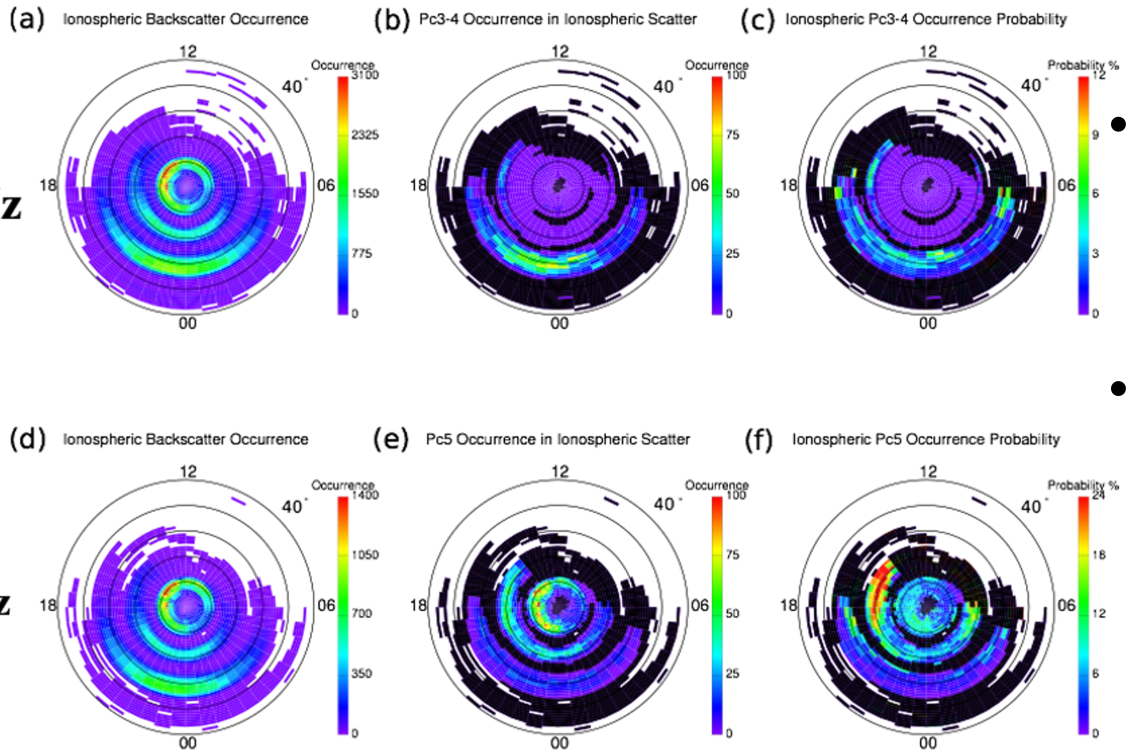
HF Absorption / Shortwave Fadeout effects (Chakraborty et al., 2018)

Doppler Flash (Chakraborty et al., 2018)

Occurrence Statistics of Ionospheric ULF Waves

Pc3-4:
6.7-40 mHz

Pc5:
1.7-6.7 mHz



- Pc3-4 events mainly occur at midlatitudes on the nightside and at high latitudes on the duskside.
- Pc5 events are detected mostly at high and polar latitudes with the occurrence rate peak at 70° on the duskside.

Shi et al. (2018)

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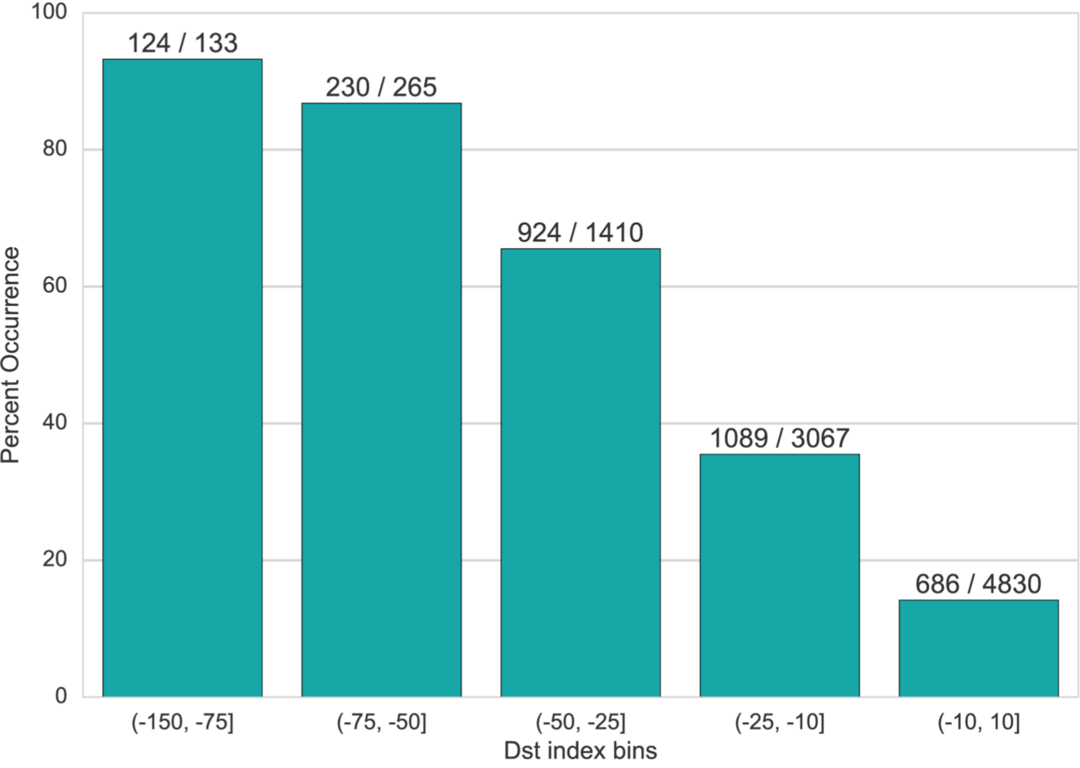
Statistical Study of SAPS using SuperDARN



- SAPS events observed between Ja
2011 and Dec-2014 in US midlatit
radars are analyzed.

- SAPS are observed during widely varying geomagnetic conditions.

- Probability of observing SAPS increased with geomagnetic activ

Kunduri et al. (2017)

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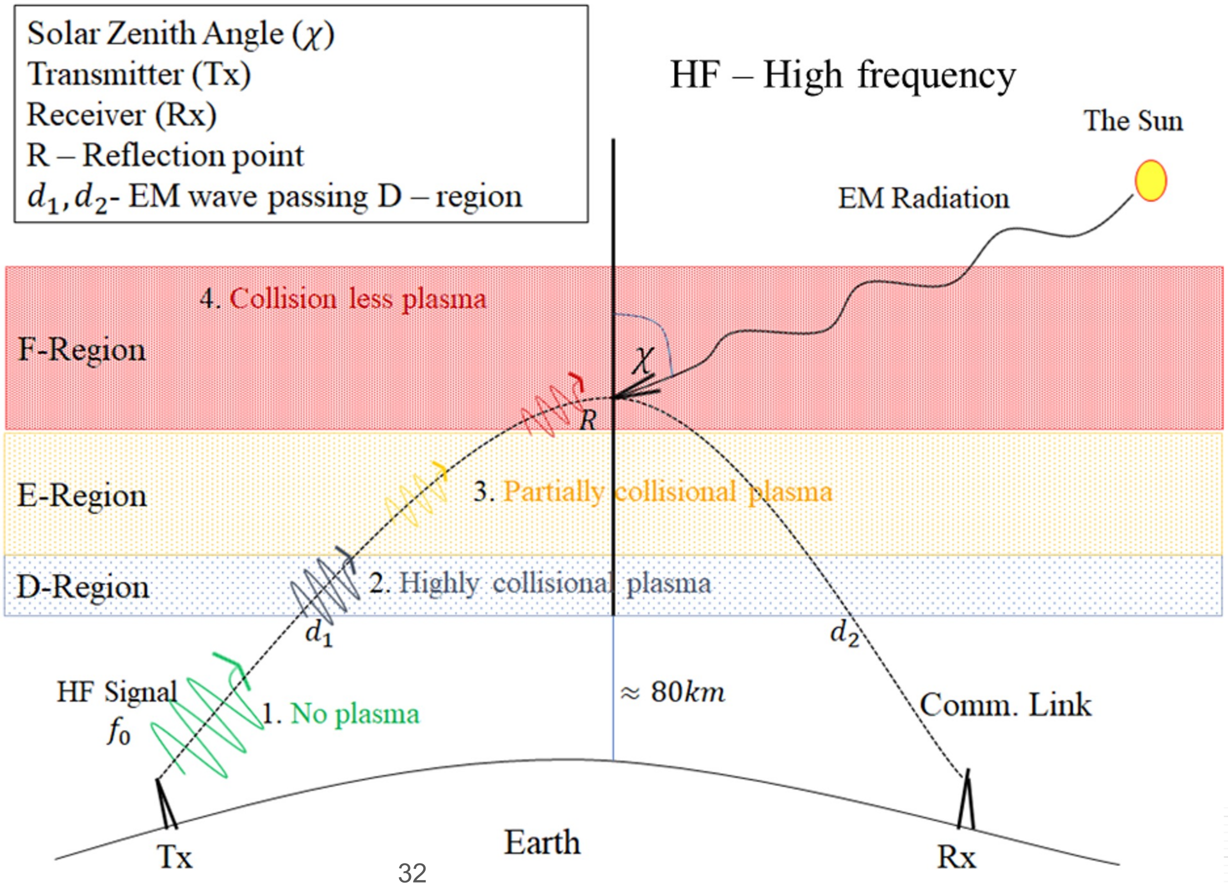
Impact of Solar Flare on the Ionosphere and HF propagation



The Sun shoots out the sudden localized intensification of EM radiation, commonly known as solar flare.

Increased solar radiation enhances dayside ionization, leading to sudden increase in radio-wave absorption in high frequency (HF) ranges (3-30 MHz) (Davies, 1990).

Additionally, this creates a sudden change radio-wave frequency in HF ranges.

pyDARN: (Example code) read Data Map binaries

Reading with SuperDARNRead

The basic code to read in a DMap structured file is as follows:

```
import pydarn

file = "path/to/file"
SDarn_read = pydarn.SuperDARNRead(file)
```