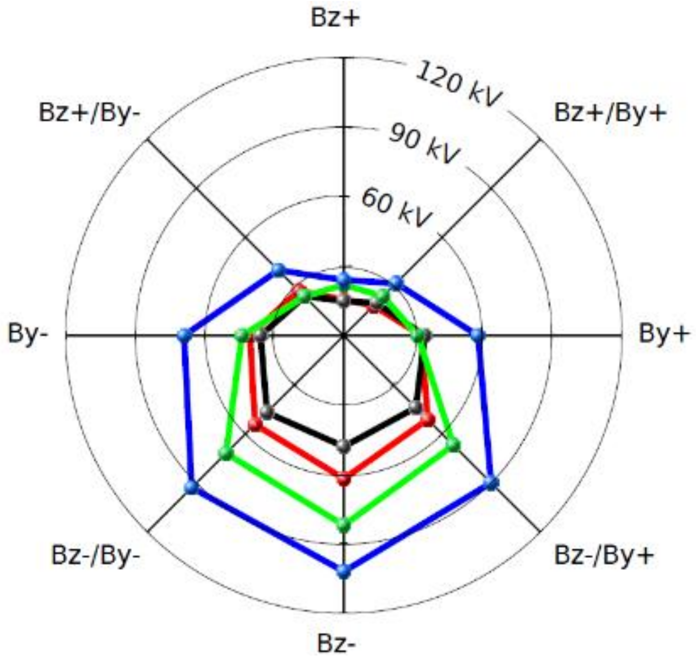
A proposal for a refractive index task force



Comparison of climatological CPCPs for different IMF directions, using plasma flow data from: DE2 satellite, DMSP satellites, Cluster satellites, SuperDARN.

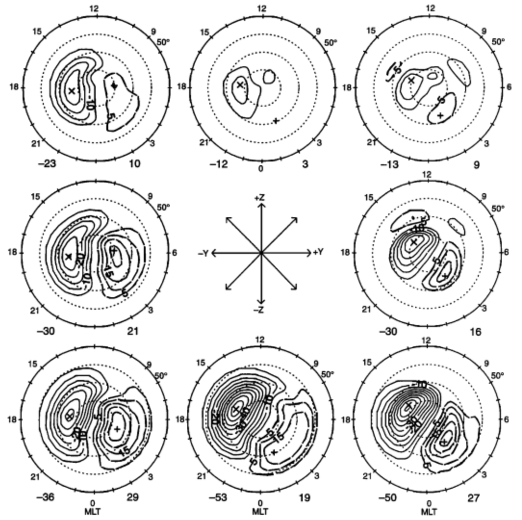
Gareth Chisham
Space Weather and Atmosphere Team
British Antarctic Survey

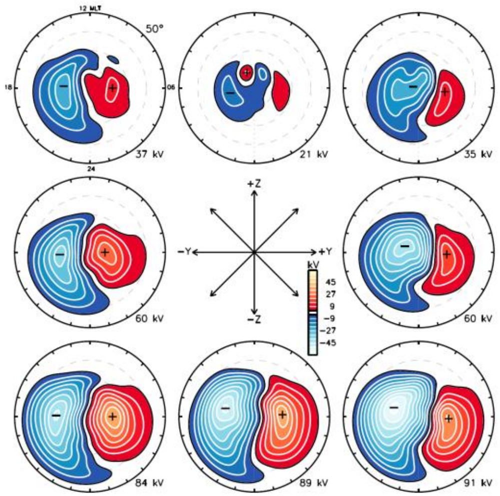
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

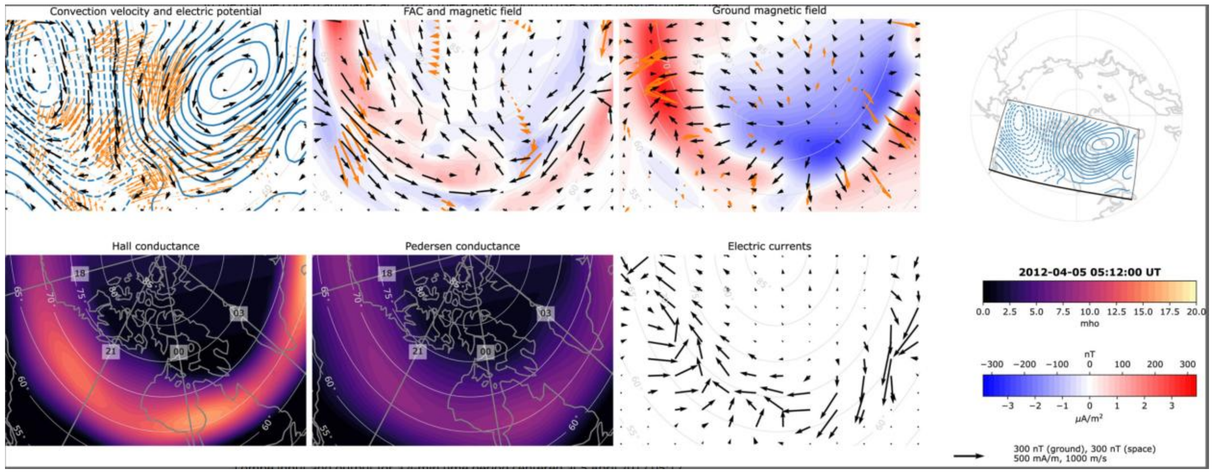
POLAR SCIENCE
FOR A SUSTAINABLE PLANET

Background

- SuperDARN is presently the only instrument capable of continuous and spatially-extensive measurements of ionospheric plasma flow.
- Important for the development of empirical models.
- Important for providing detailed and accurate estimates of the flow for data assimilation techniques.


Ruohoniemi and Greenwald (1996)

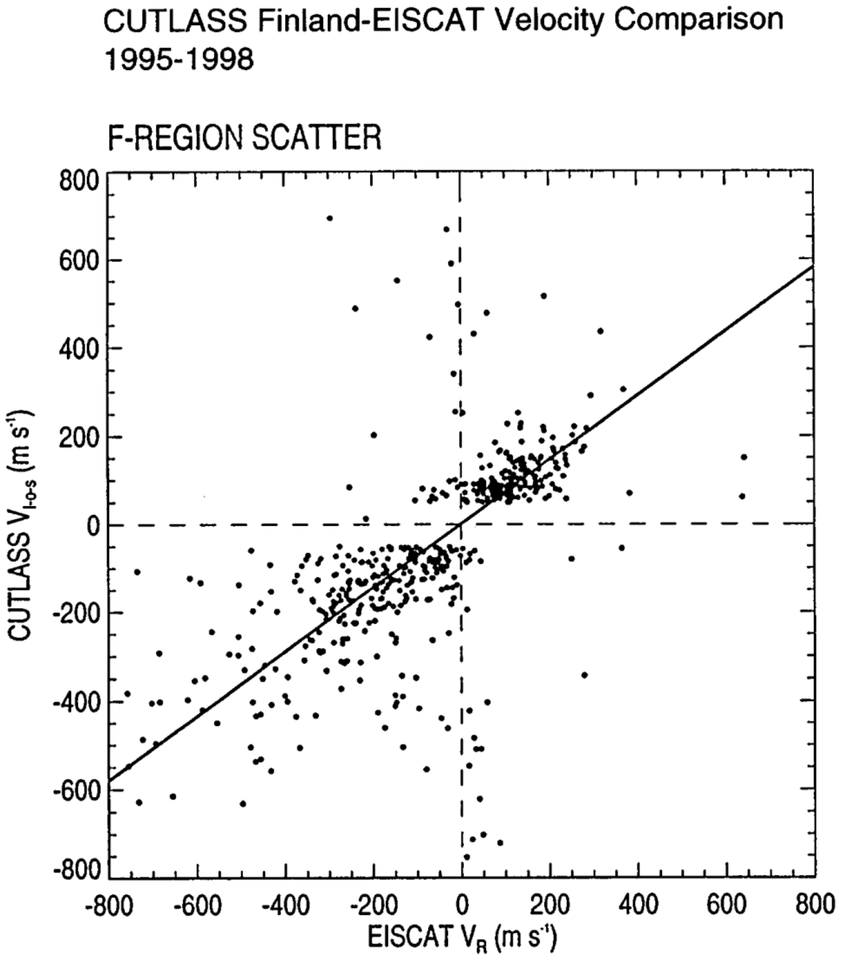

Thomas and Shepherd (2018)



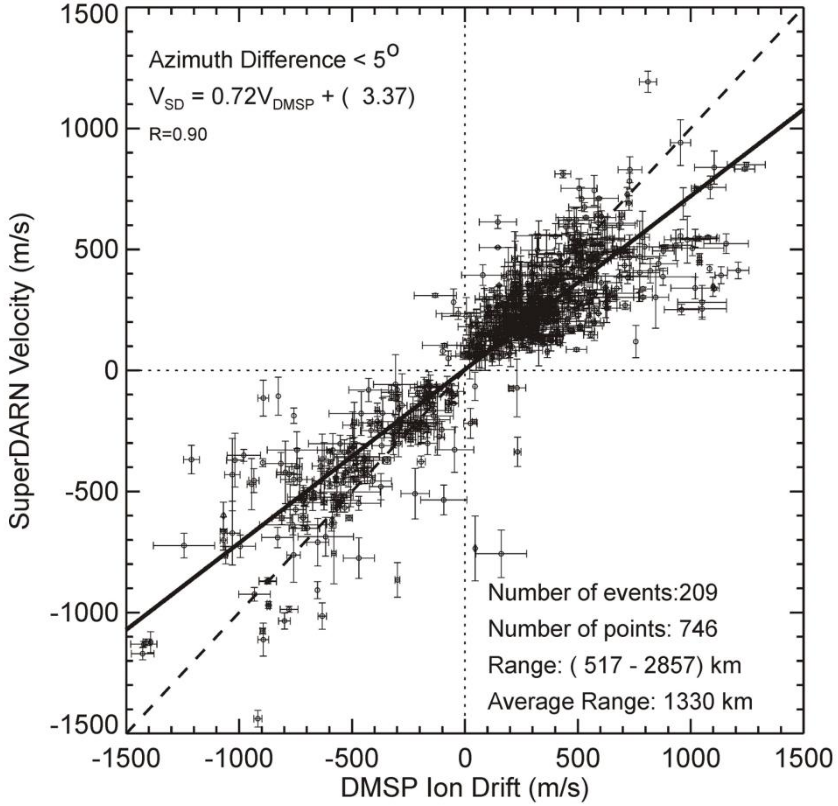
LOMPE – Laundal et al. (2022)

The Issue

- SuperDARN radars systematically underestimate the magnitude of the ionospheric plasma flow.



Davies et al. (1999)



Drayton et al. (2005)

The Issue

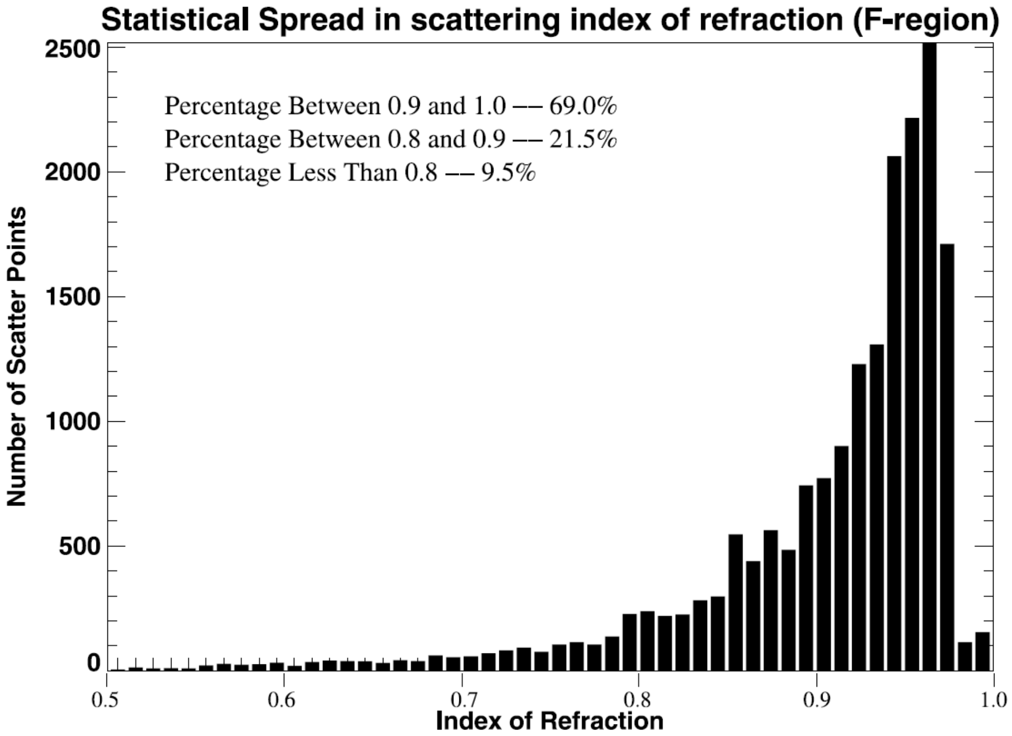
- This is due to ionospheric refractive index effects.

region has a refractive index of unity, the apparent line-of-sight velocity of the scatterer, $v_{s,a}$ is

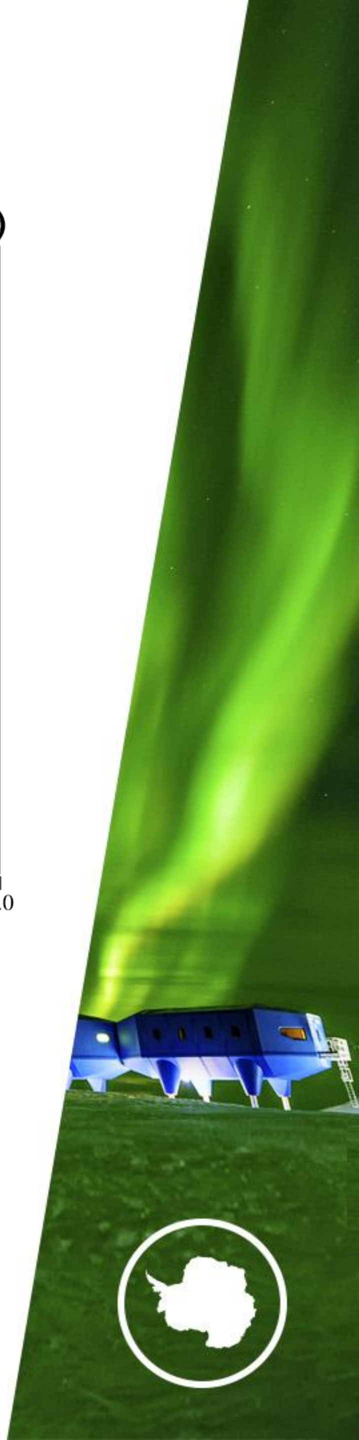
$$v_{s,a} = \frac{\Delta\omega_D c}{2\omega} \qquad (1)$$

where $\Delta\omega_D$ is the Doppler shift of the received wave, ω is the frequency of the radar wave, and c is the speed of light in a vacuum [*Baker et al.*, 1995]. However, the speed of the radar wave in a scattering region of refractive index n_s is c/n_s, so the scatterer velocity $v_{s,c}$ accounting for the refractive index is given as [*Ginzburg*, 1964]

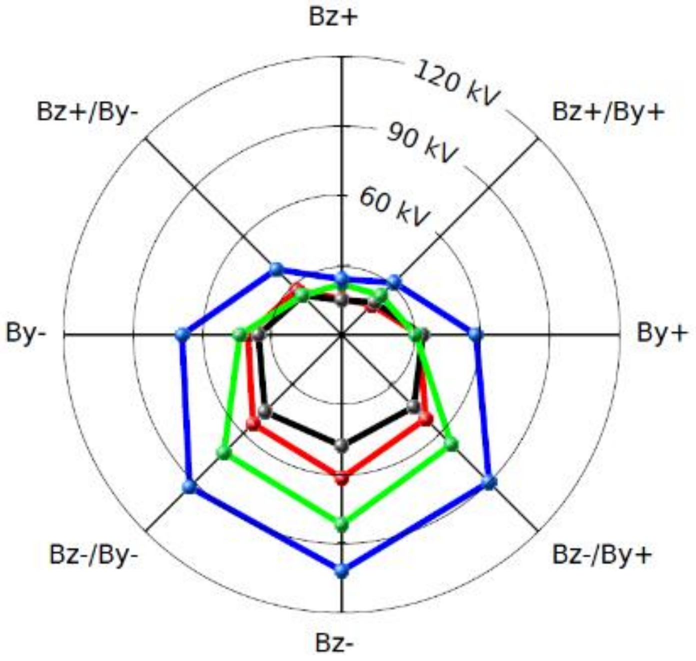
$$v_{s,c} = \frac{\Delta\omega_D c}{2\omega}\frac{1}{n_s} \qquad (2)$$



Gillies et al. (2009)

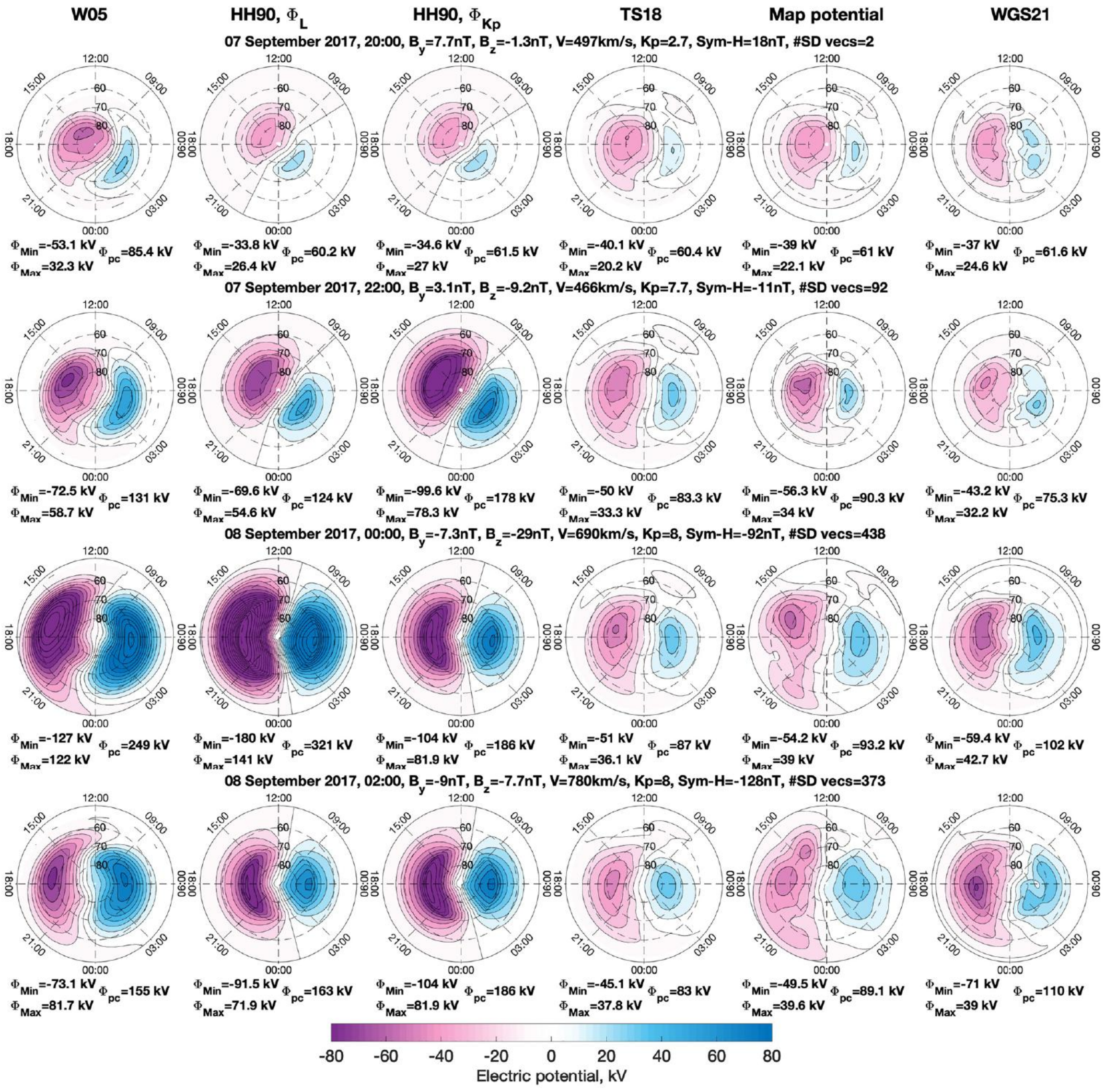


The Impact of the Issue



Comparison of climatological CPCPs for different IMF directions, using plasma flow data from: DE2 satellite, DMSP satellites, Cluster satellites, SuperDARN.

Haaland et al. (2007)



Orr et al. (2023)

The Need

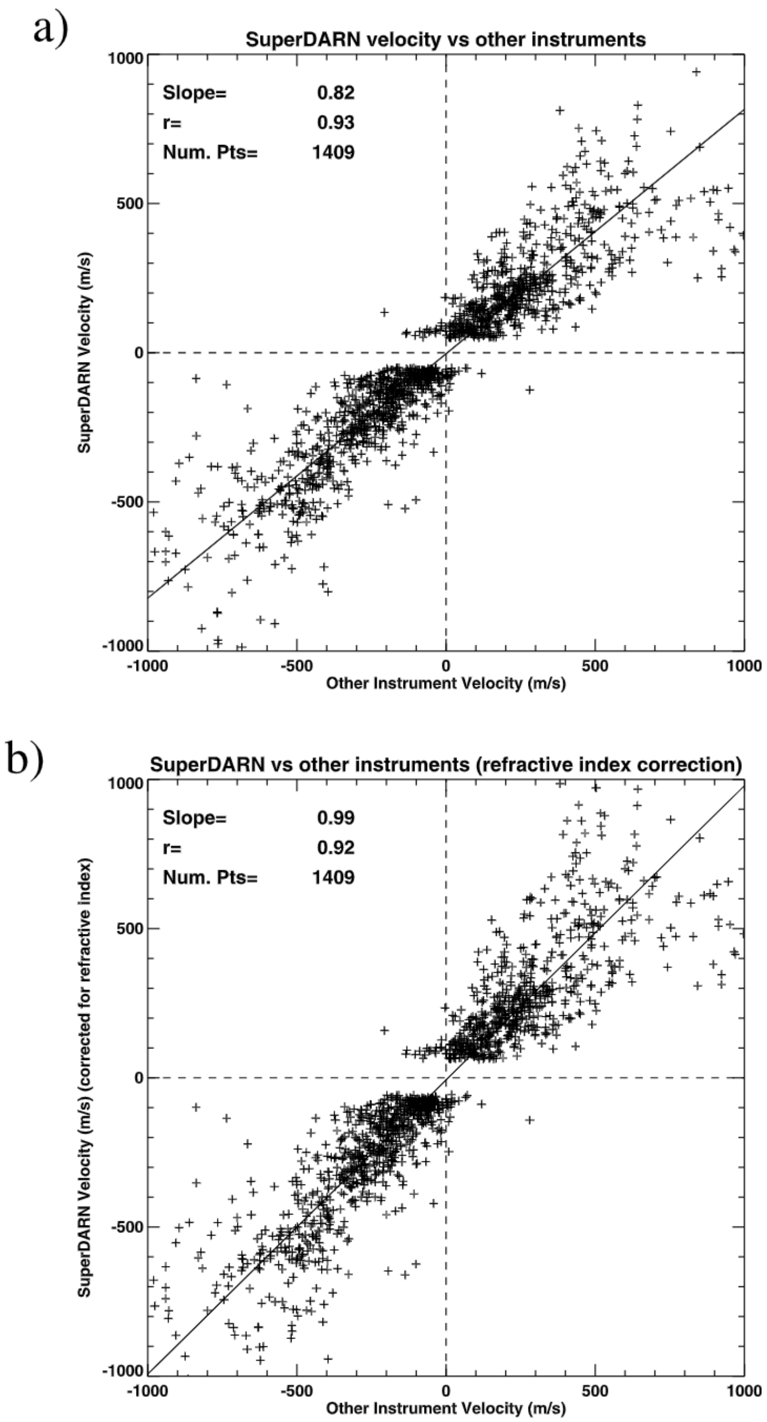
- A state-of-the-art capability for the calibration of line-of-sight velocity measurements.

Table 1. N_e in the Scattering Volume, the Required n_s Adjustment in Percent for SuperDARN Data at Two Representative Radar Frequencies and the Number of Frequency Shifts in Each Regime[a]

Latitude (°)	Solar Cycle	Local Time	Season	N_e ($\times 10^{11}$ m^{-3})	n_s Effect (10 MHz, %)	n_s Effect (15 MHz, %)	Number
Mid (<65°)	min	night	all	1.3	5.9	2.5	40926
Mid (<65°)	min	day	all	3.6	19	7.2	1883
Mid (<65°)	max	all	all	1.9	8.8	3.6	20147
Auroral (65°–78°)	min	night	summer	4.0	21	8.0	629332
Auroral (65°–78°)	min	night	winter	3.2	16	6.3	539554
Auroral (65°–78°)	min	day	summer	5.6	35	12	182413
Auroral (65°–78°)	min	day	winter	4.2	23	8.5	573514
Auroral (65°–78°)	max	night	summer	6.1	40	13	1785664
Auroral (65°–78°)	max	night	winter	6.2	41	13	2814188
Auroral (65°–78°)	max	day	summer	5.9	38	13	549376
Auroral (65°–78°)	max	day	winter	5.2	31	11	1170913
Polar (>78°)	min	night	summer	3.3	16	6.4	194954
Polar (>78°)	min	night	winter	2.3	11	4.4	177008
Polar (>78°)	min	day	summer	6.9	50	15	183722
Polar (>78°)	min	day	winter	3.1	15	6.0	246975
Polar (>78°)	max	night	summer	4.3	23	8.6	96095
Polar (>78°)	max	night	winter	2.2	10	4.3	2884168
Polar (>78°)	max	day	summer	8.4	76	20	55949
Polar (>78°)	max	day	winter	2.4	11	4.6	1958548

[a]Minimum solar cycle data is from 1993–1998 and 2004–2010, inclusive (maximum solar cycle data is from 1999–2003 and 2011–2012).

Gillies et al. (2012)



How to Address the Issue? Data-Derived Electron Density

refractive index at the point of scatter (equation (1)). Using this relationship and the dependence of refractive index n_s on radar wave frequency f and plasma frequency f_p:

$$n_s = \sqrt{1 - f_p^2/f^2}, \tag{2}$$

Gillies et al. [2011] developed the following formula to calculate f_p at the point of scatter given two velocities (v_1 and v_2) at two frequencies (f_1 and f_2):

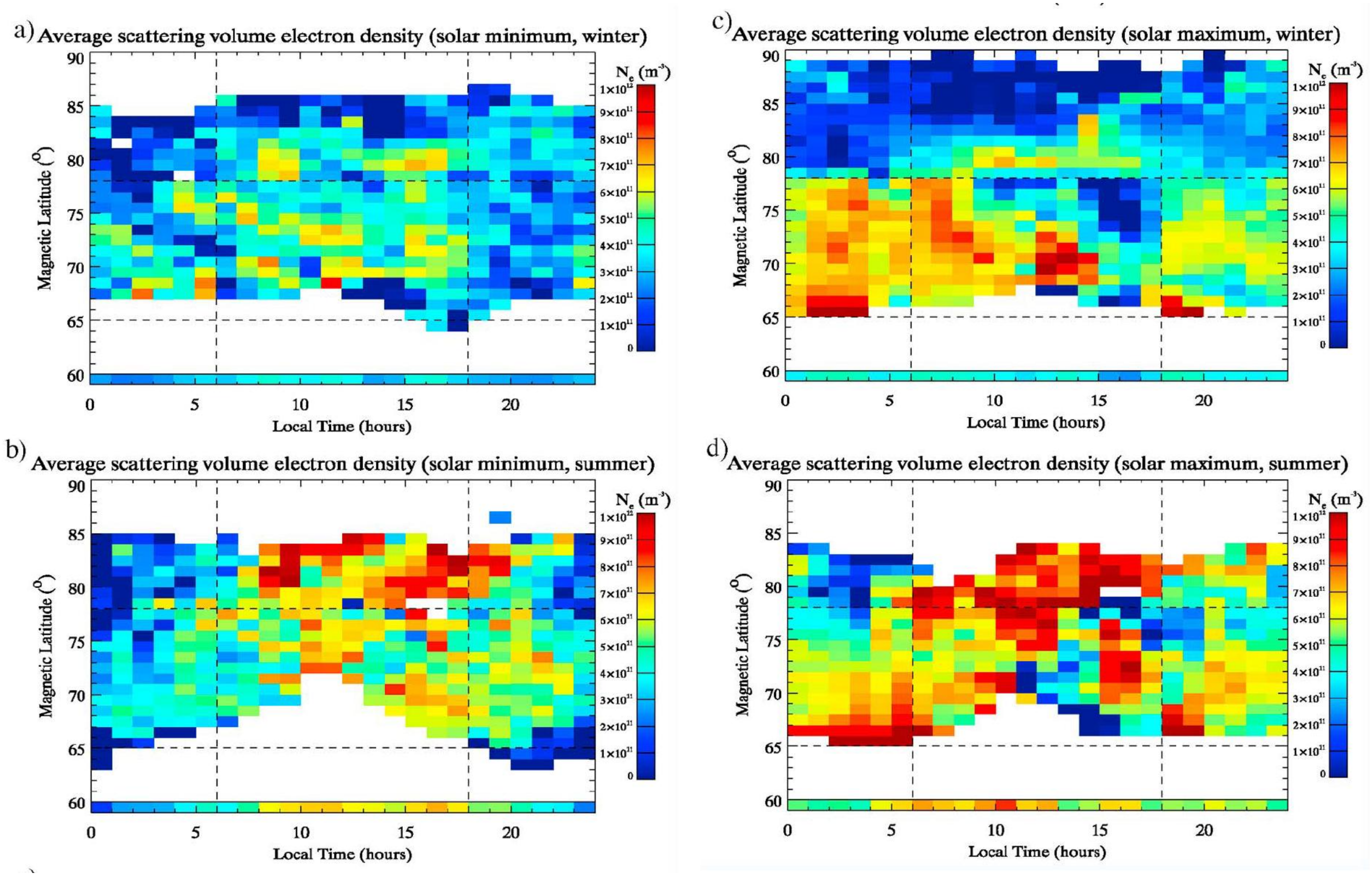
$$f_p^2 = \frac{f_1^2\left(1 - v_1^2/v_2^2\right)}{\left(1 - v_1^2 f_1^2/v_2^2 f_2^2\right)}. \tag{3}$$

Since f_p (in units of Hz) is related to N_e (in units of m^{-3}) by:

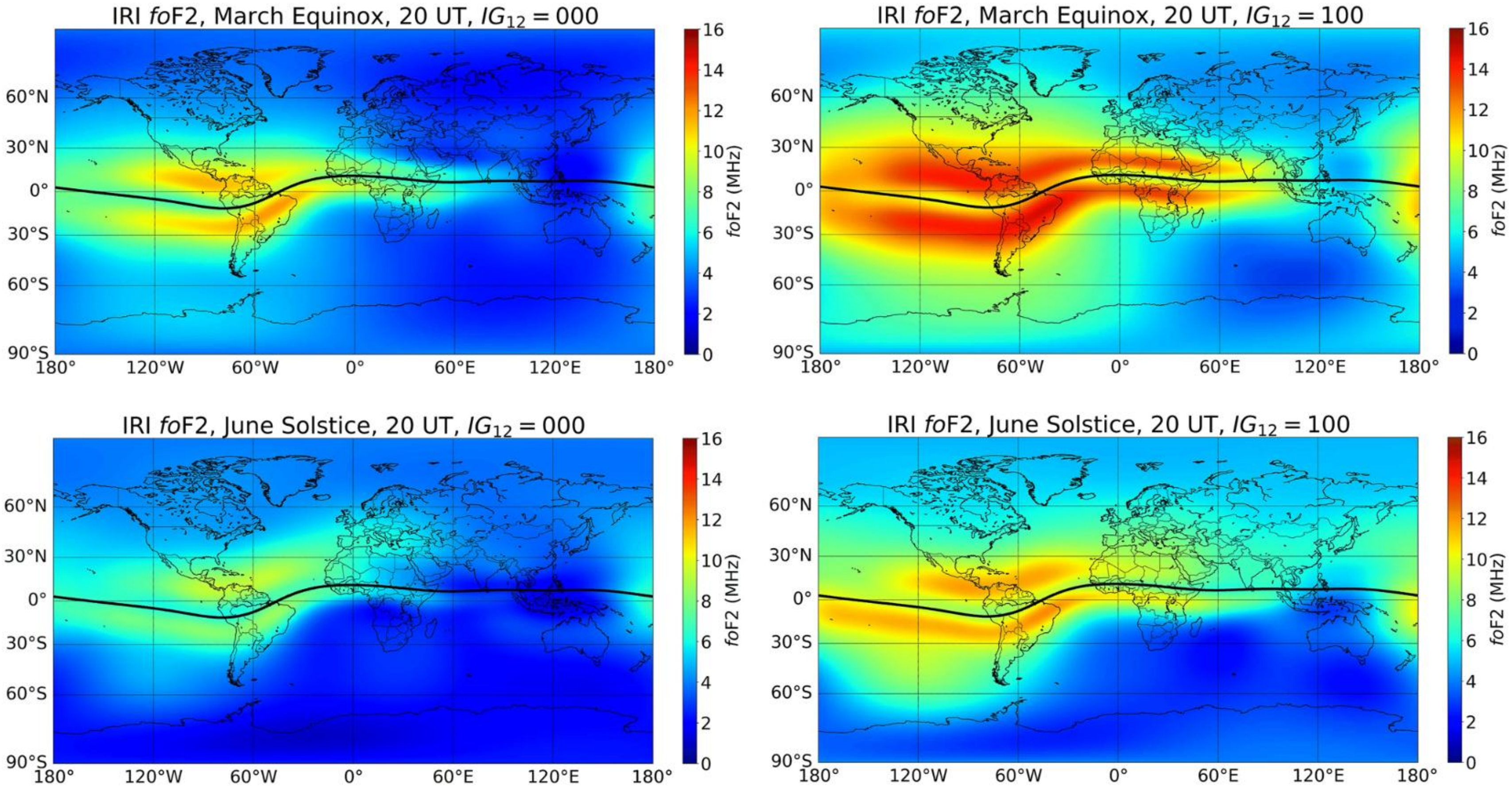
$$N_e = 0.0124 f_p^2, \tag{4}$$

an examination of velocities at two different frequencies will provide a measurement of the scattering volume electron density.

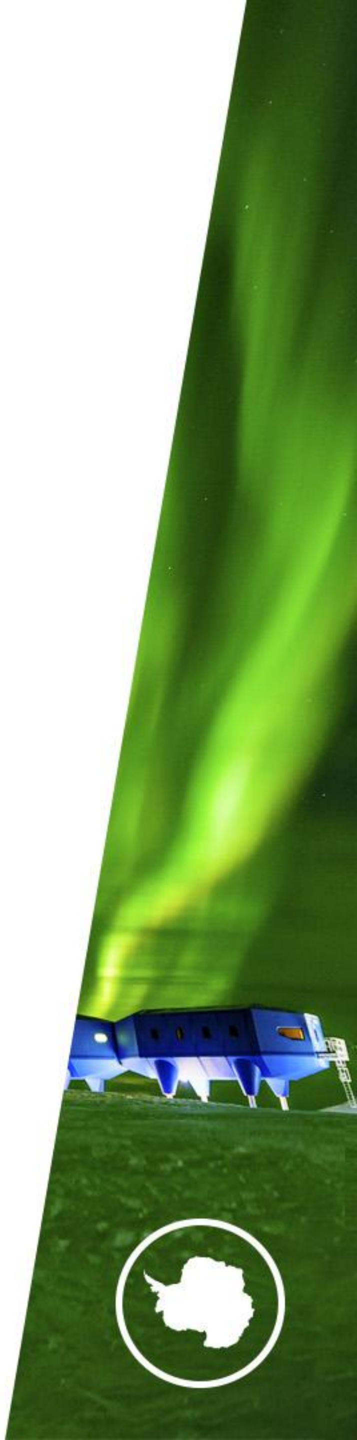
Gillies et al. (2012)



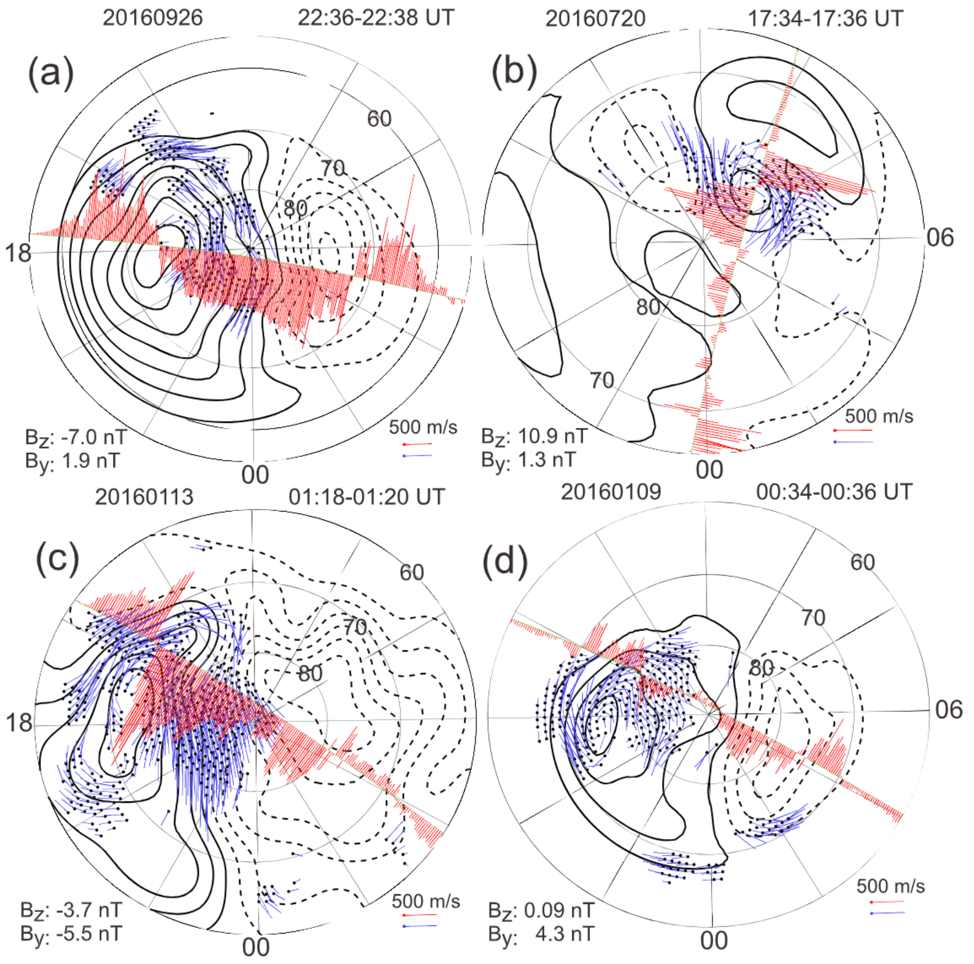
How to Address the Issue?
Ionospheric Models, e.g. IRI

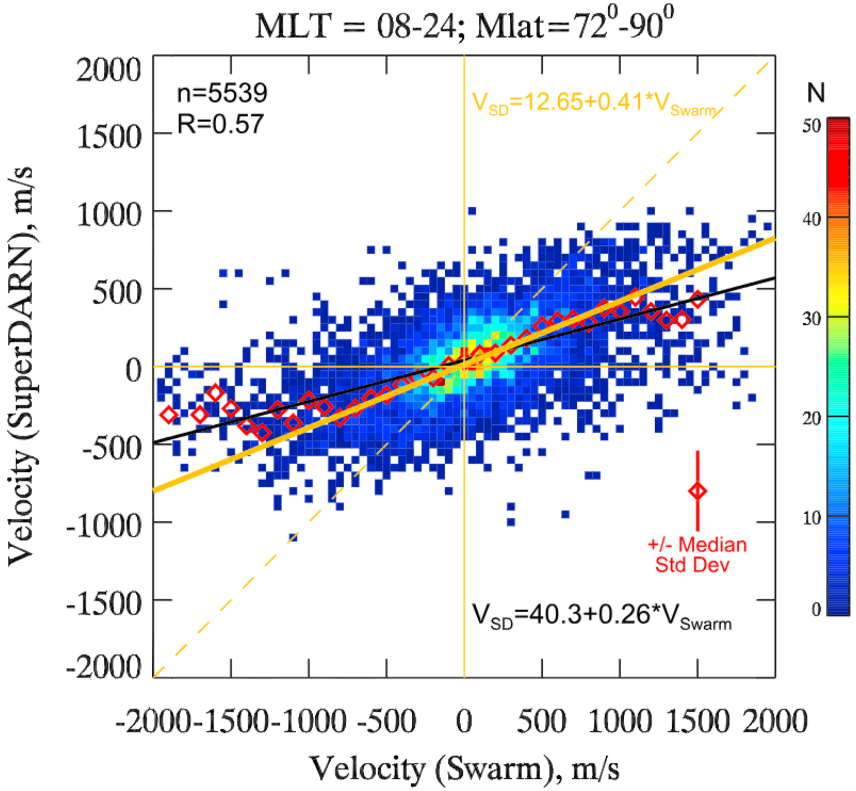


Bilitza et al. (2022) – International Reference Ionosphere (IRI)



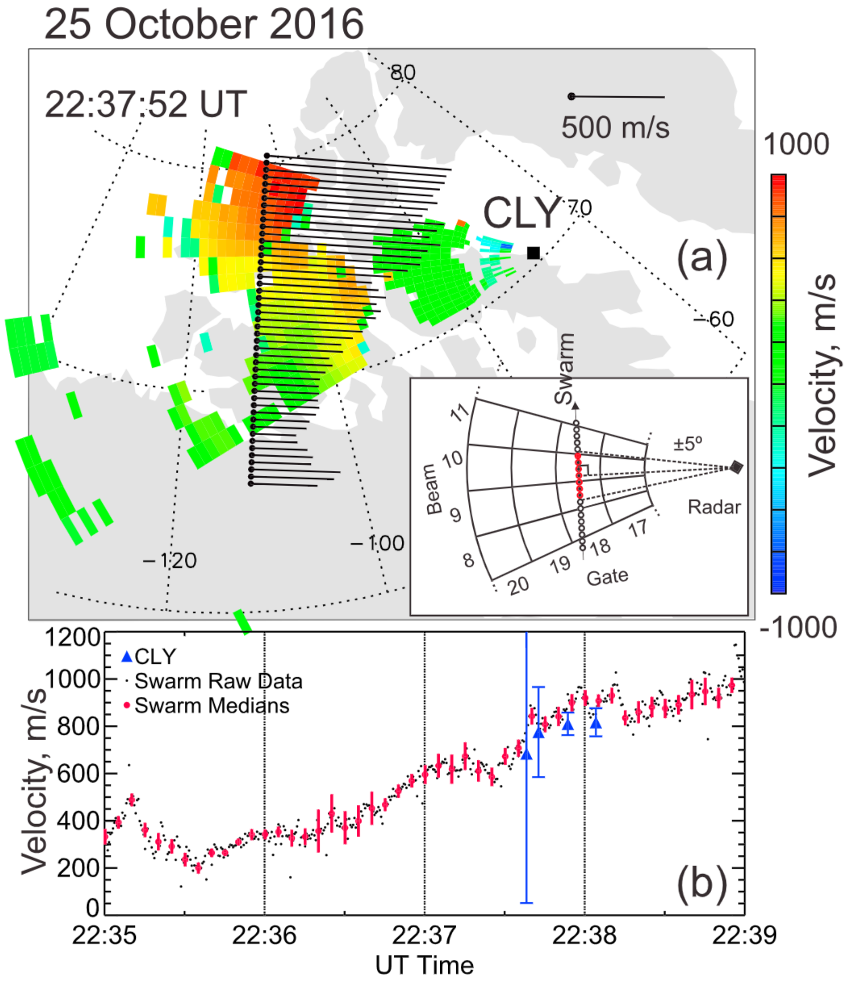
How to Address the Issue?
Velocity Comparison (Convection)

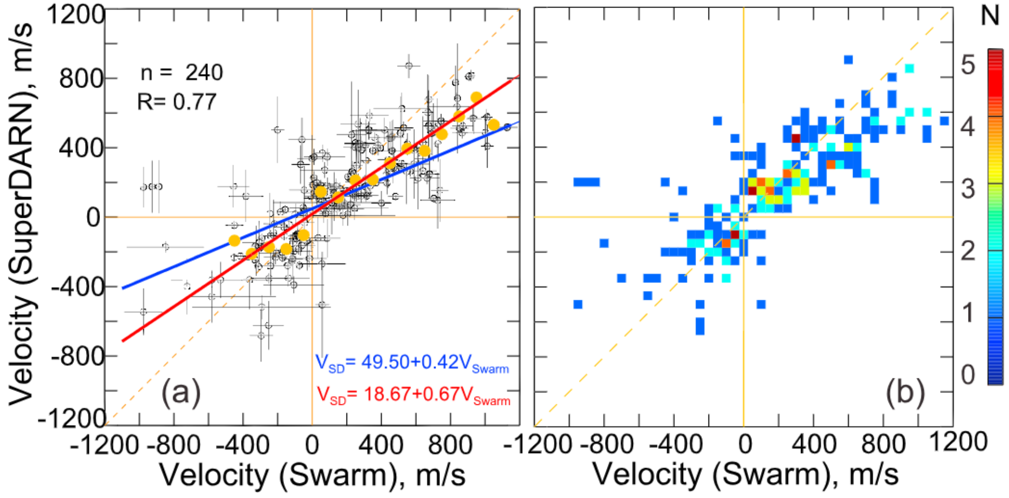




Koustov et al. (2019)

How to Address the Issue?
Velocity Comparison (LOS)



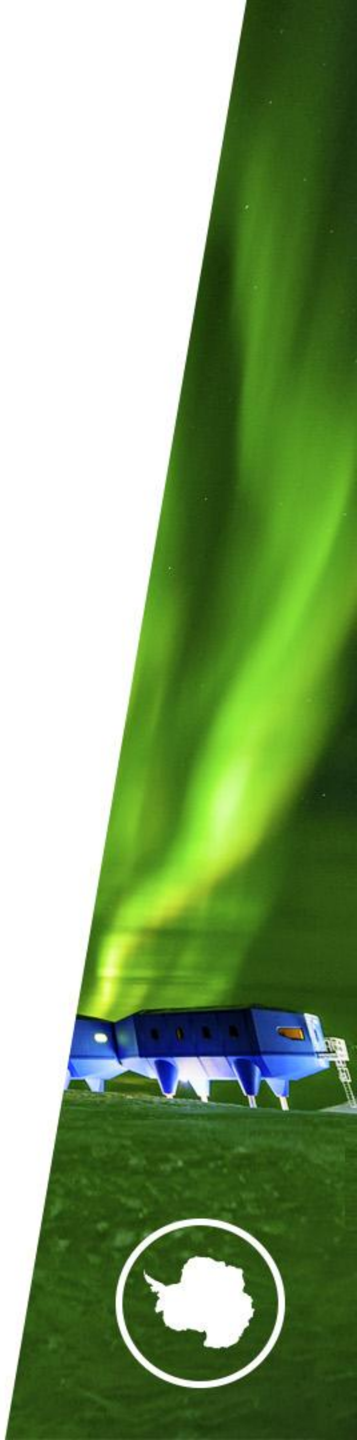


Koustov et al. (2019)

Proposition

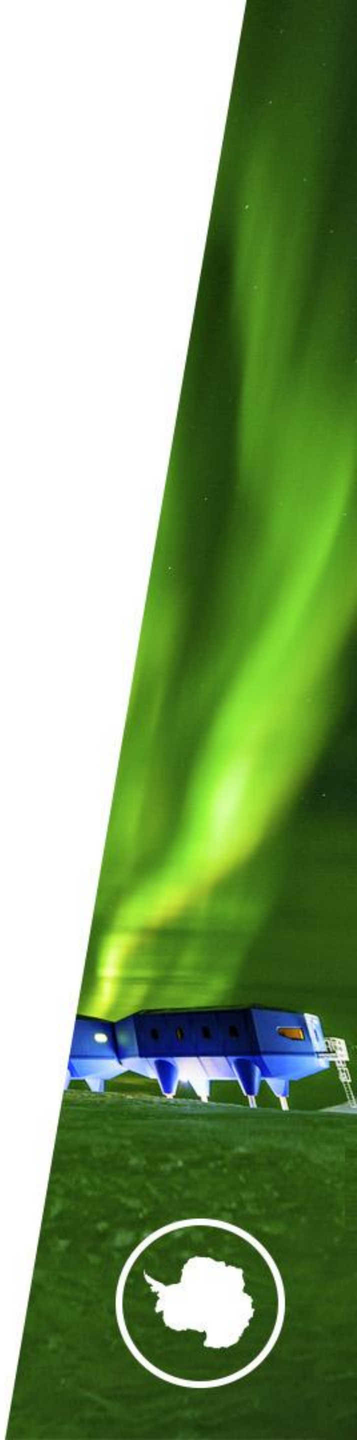
- Propose the creation of a new SuperDARN task force to assess different methods for velocity correction, through estimation of the refractive index:
    1. Directly from SuperDARN Data.
    2. Directly from electron density models.
    3. Indirectly through comparisons of SuperDARN data with in-situ spacecraft measurements of plasma flow.

- The task force will develop a new framework for systematic calibration of SuperDARN velocity measurements.



Questions to Answer

- How should this correction be implemented? As a line-of-sight velocity correction model (next slide)?
- Should this be an optional process to apply to the data? Yes! This correction is more important when quantitative analysis is needed.
- Where in the SuperDARN processing should this be applied?
  - As part of FITACF? But FITACF does not include geolocation.
  - As part of the production of secondary data products or during data visualisation? But that would mean changes to a wide range of software.

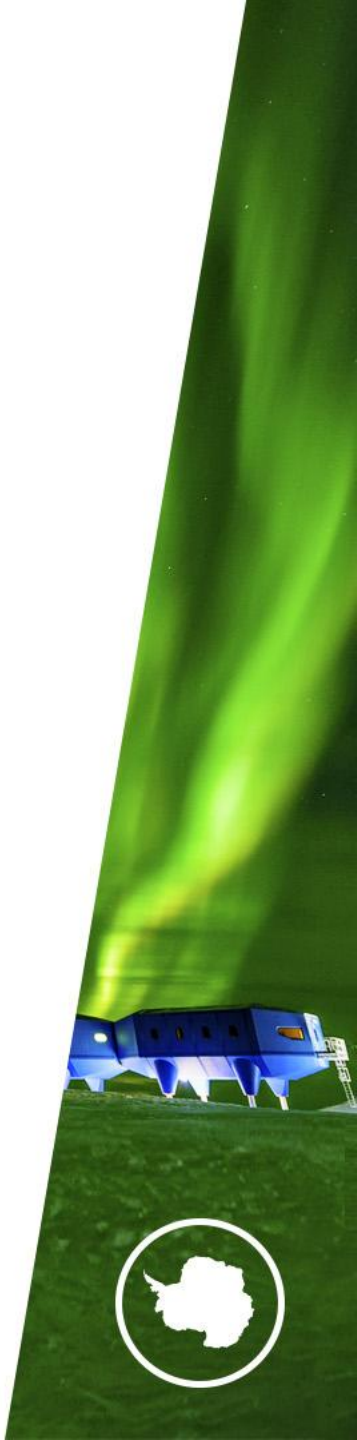


Implementation

- Develop a new framework for systematic calibration of SuperDARN velocity measurements.

- Need a line-of-sight velocity correction tool that the whole community can apply to data on a simple routine basis.

- Need a model correction that varies with:
  - Time of Day (MLT?)
  - Day of Year
  - Position in Solar Cycle (F10.7?)
  - Magnetic Latitude (AACGM?)
  - Geomagnetic Activity (Kp?)



Summary

- Without resolution of the refractive index problem, models and data assimilation schemes of ionospheric plasma flow will not be fit for the needs of future science and operational applications.

- The SuperDARN community needs to provide a state-of-the-art capability for the calibration of the line-of-sight velocity measurements that it makes.

- I don’t know the answers – a task force will provide the concerted effort required to develop a new framework for the systematic calibration of SuperDARN velocity data.