NeWT

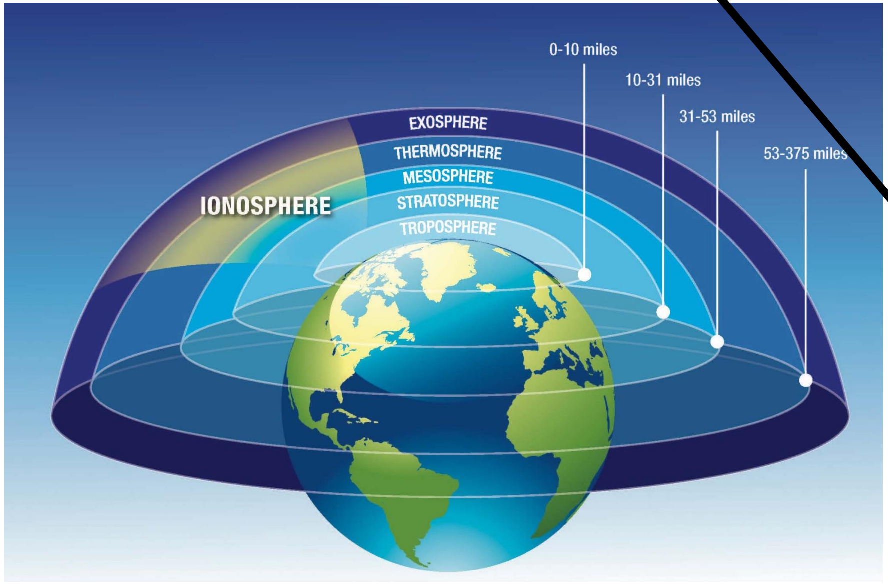
Neutral Winds in the Thermosphere

Charlie Acomb, Maya McKean, Sergei Kamaletdinov, Nina Servan-Schreiber, Xiaoyu Sun, Wout De Jonghe

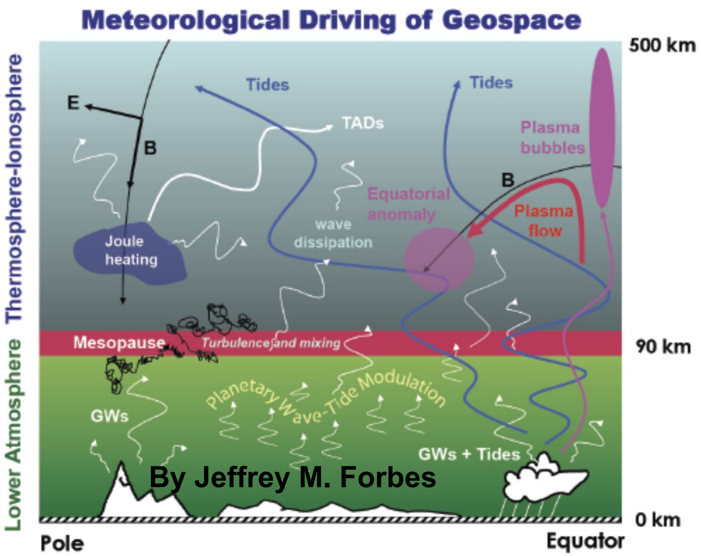
The **ionosphere** is a region of the ionized upper atmosphere whose dynamics are coupled to both:

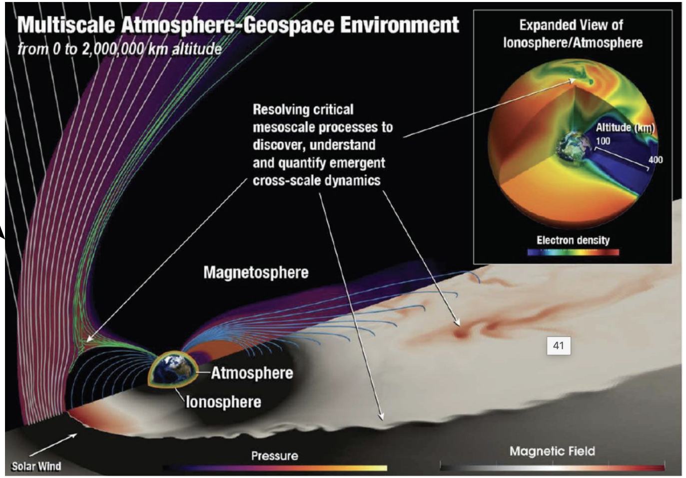
(a) **the neutral atmosphere below**

(b) **the magnetosphere above.**

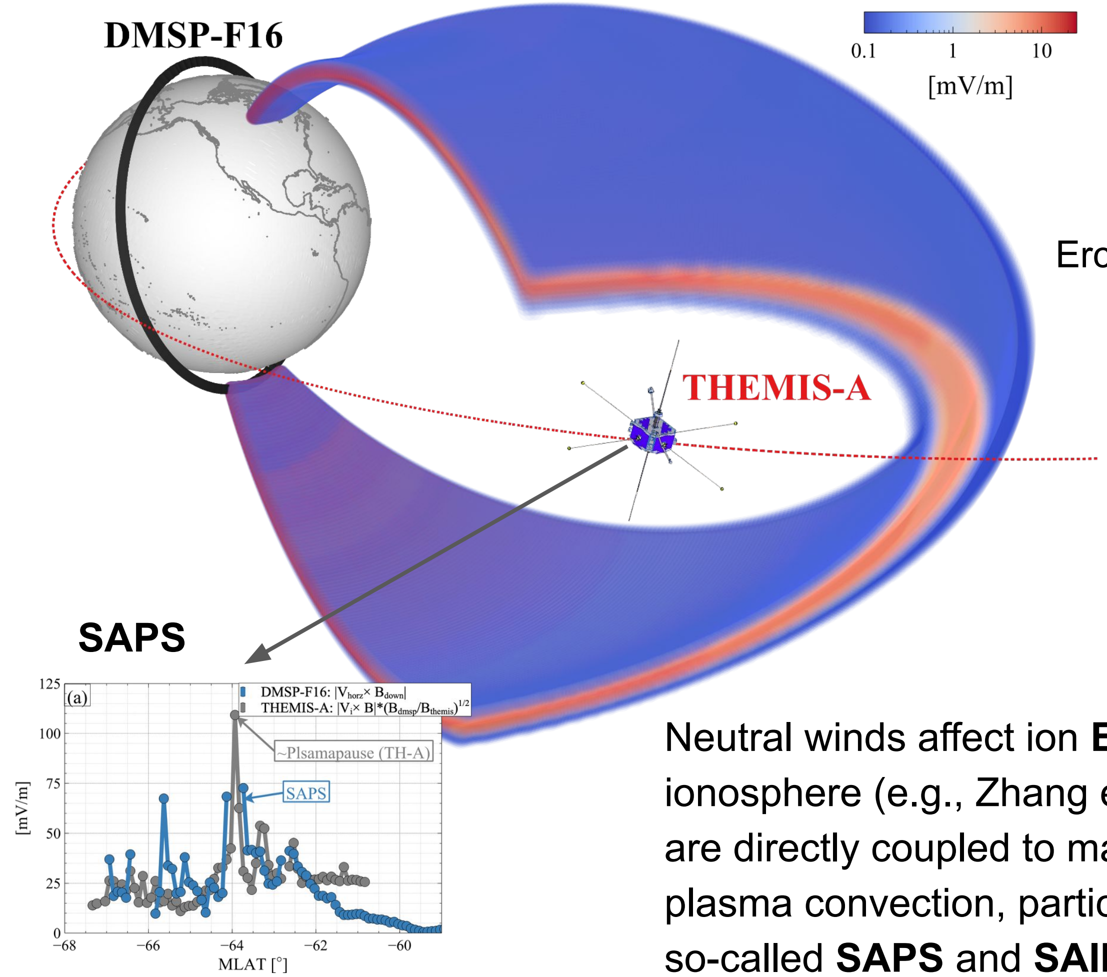


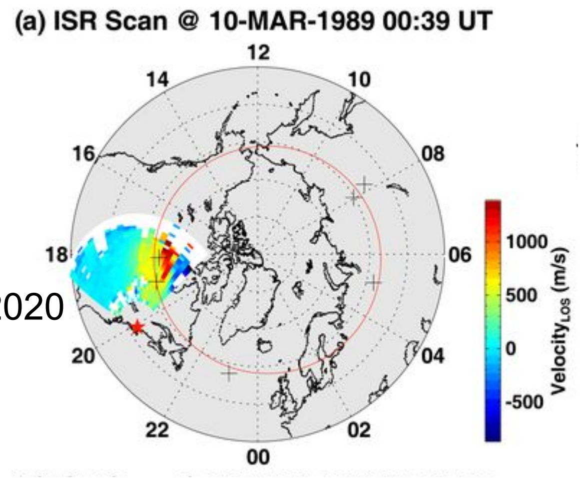
Credit: NASA's Goddard Space Flight Center/Mary Pat Hrybyk-Keith





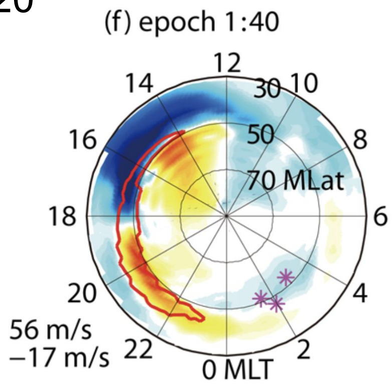
Neutral winds and ExB-drifts - integral parts of MI coupling





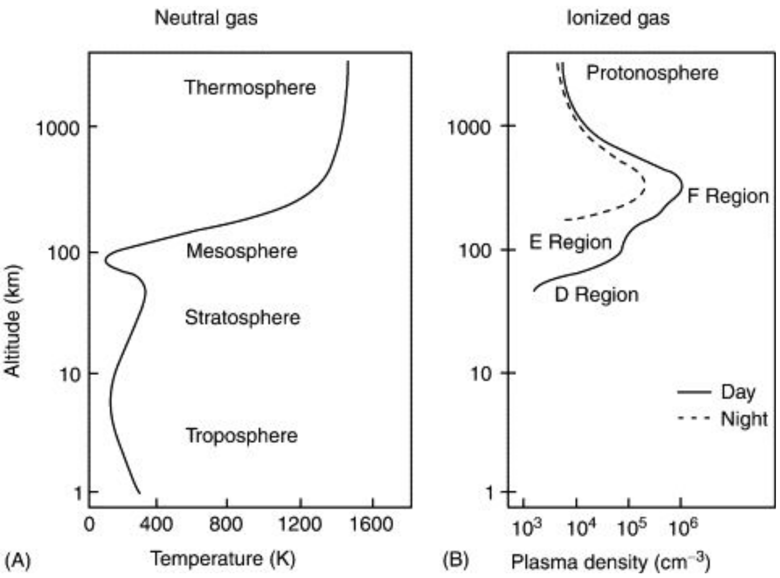
Ercha Aa et al 2020

SAPS - neutral winds interaction
Zhang et al, 2020

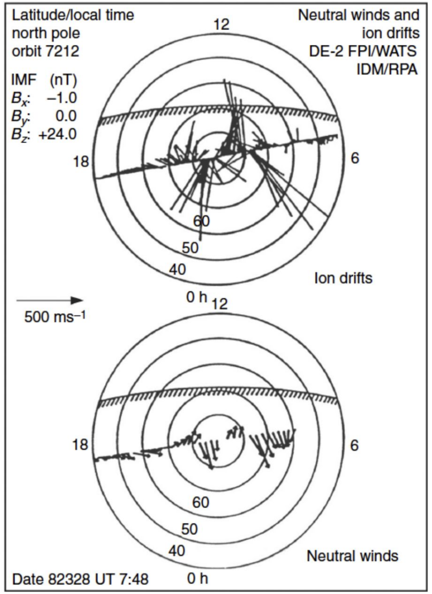


Neutral winds affect ion **E×B** drifts in the ionosphere (e.g., Zhang et al, 2020), which are directly coupled to magnetospheric plasma convection, particularly during so-called **SAPS** and **SAID** events.

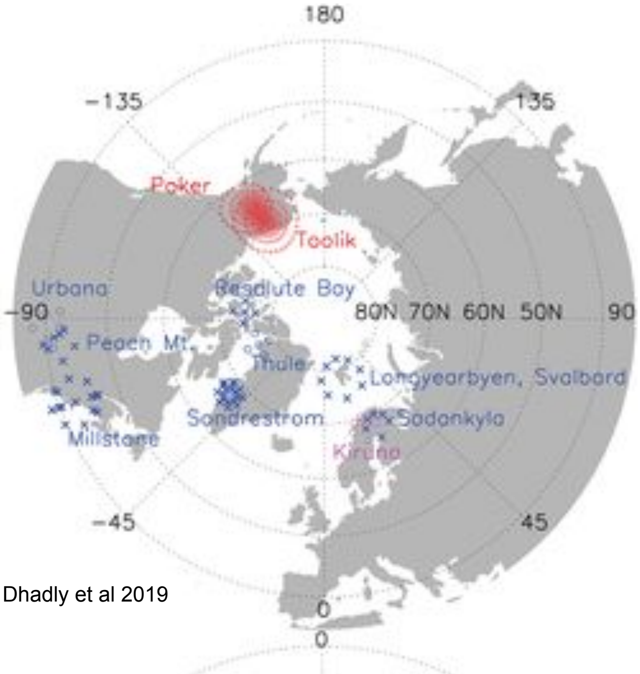
Ionosphere-Thermosphere Coupling



The Earth's Ionosphere - Kelley



Ionospheres - Schunk & Nagy

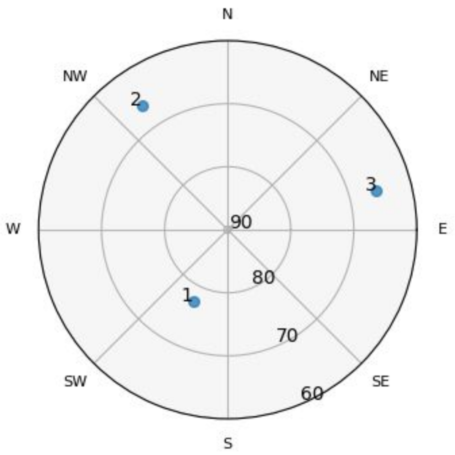


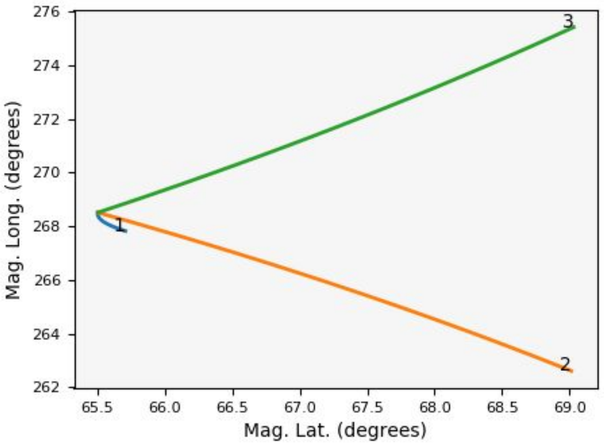
Dhadly et al 2019

- The Ionosphere overlaps with the Thermosphere and Mesosphere
- Ion neutral collisions act to modify ion flows, joule heating rates, current closure, etc.
- Few neutral wind measurements exist at high latitudes making it hard to fully model high-latitude electrodynamics

The experimental set-up

- Goal
  - We aim to derive E-region neutral wind profiles per Heinselman and Nicolls 2008
  - Measure a “quiet” ionosphere to utilize long integration
- Beams:
  - 3 beams used (similar to IPY mode, removing the up-looking beam).
  - Minimum required to measure vector velocities, optimizes SNR
- Codes:
  - Long Pulse (F-region)
  - Alternating Code (E-region)
  - Allows sampling of ion flows at a range of altitudes, required for neutral wind calculations





Comparison of PFISR Integration Times

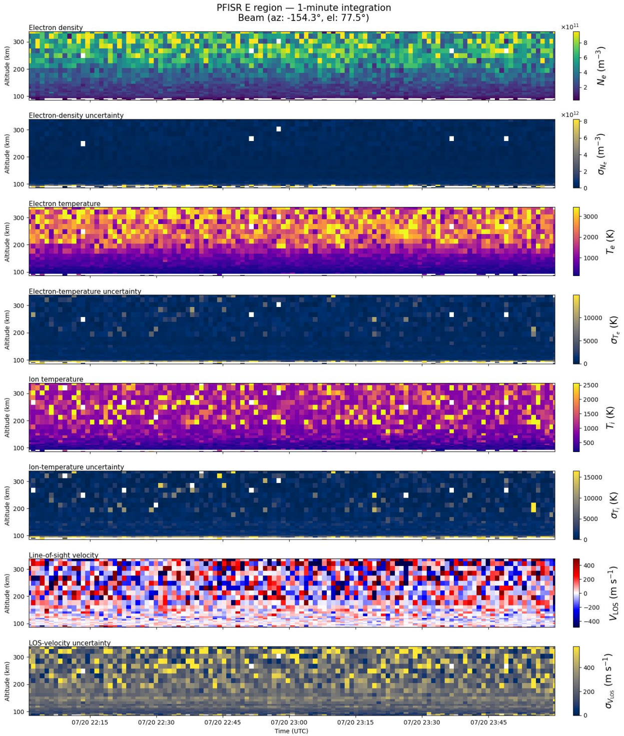
- Compared how electron density (N_e), electron temperature (T_e), ion temperature (T_i), and line-of-sight velocity (V_{LOS}) changed between integrations

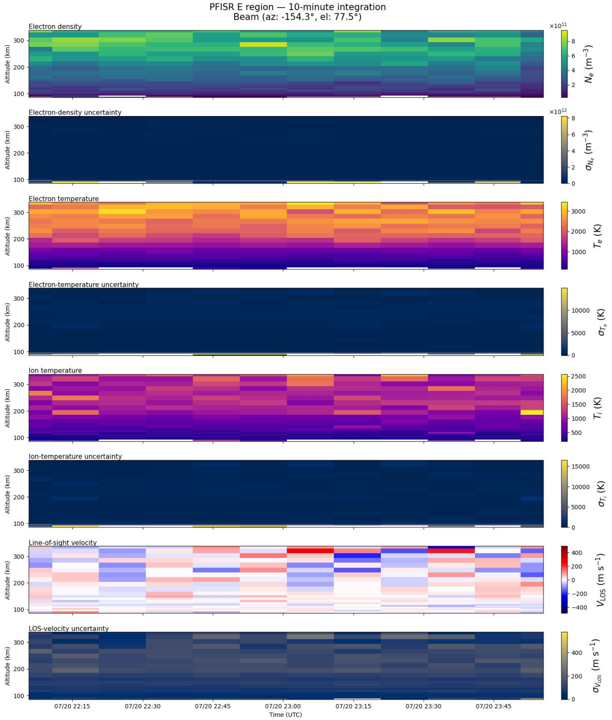
- Investigated typical integration times 1, 5, 10, 15, & 20 mins and extended integration times of 30, 60, 90, & 120 mins

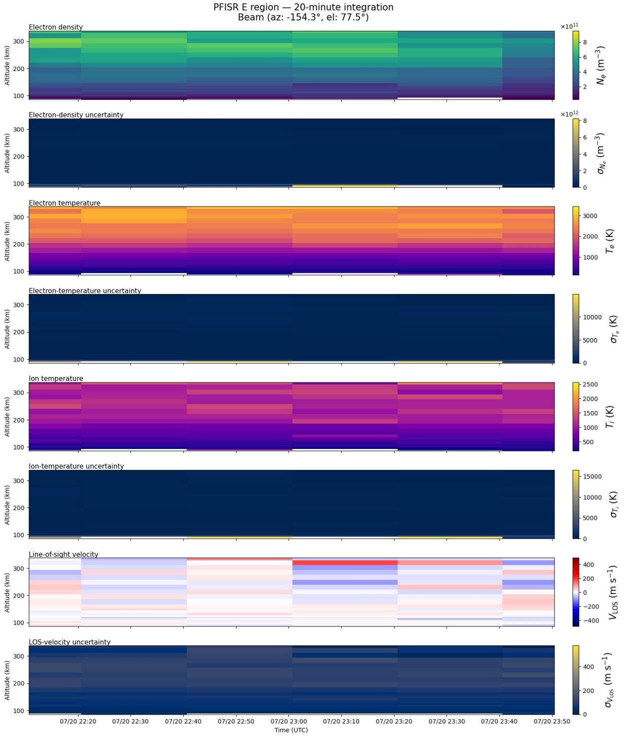
- Compared how error for each parameter changed between integration times and pulse modes (Alternating Code and Long Pulse)

Do these results confirm our idea of a quiet ionosphere on 07/20/26?

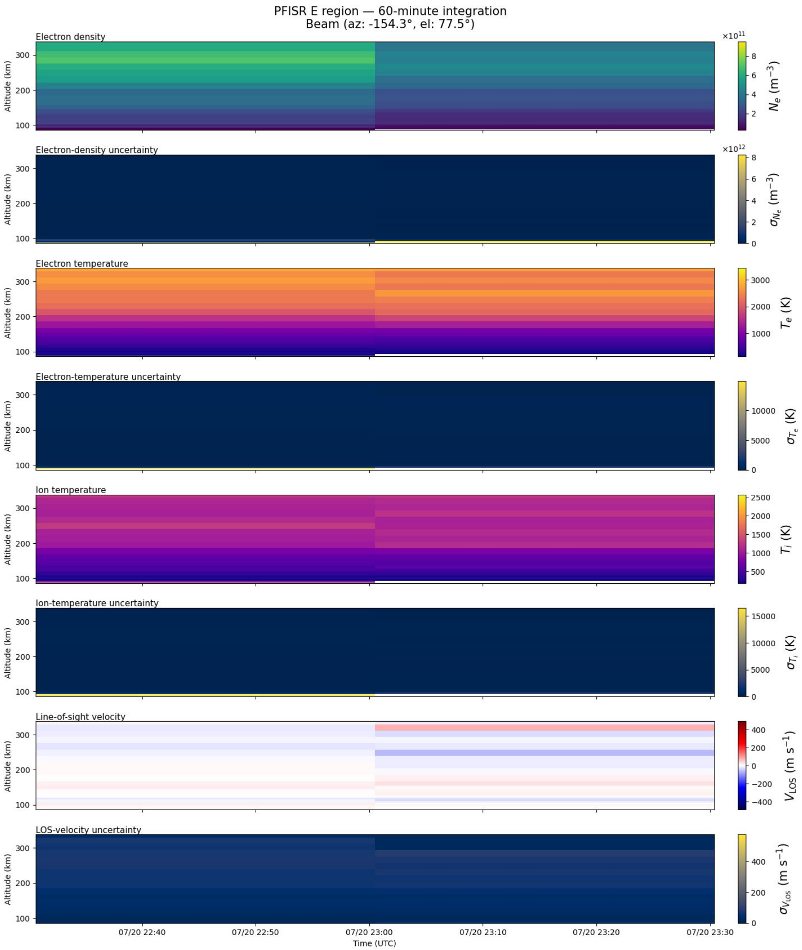
Alternating Codes (E-Region) Integration Times 1 min - 20 min

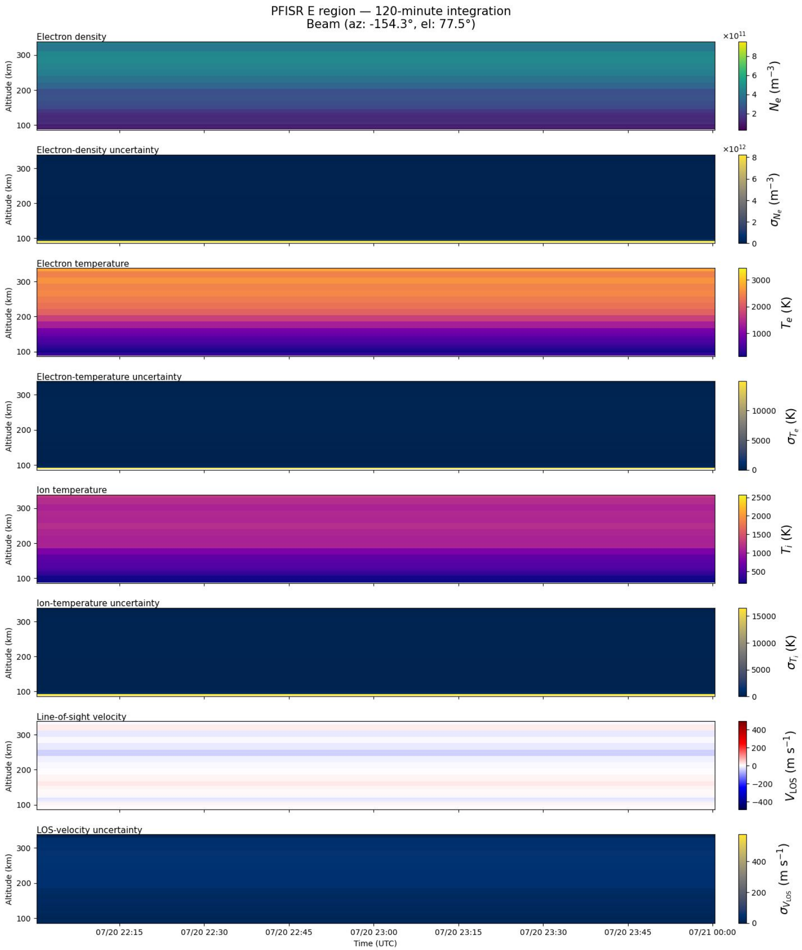




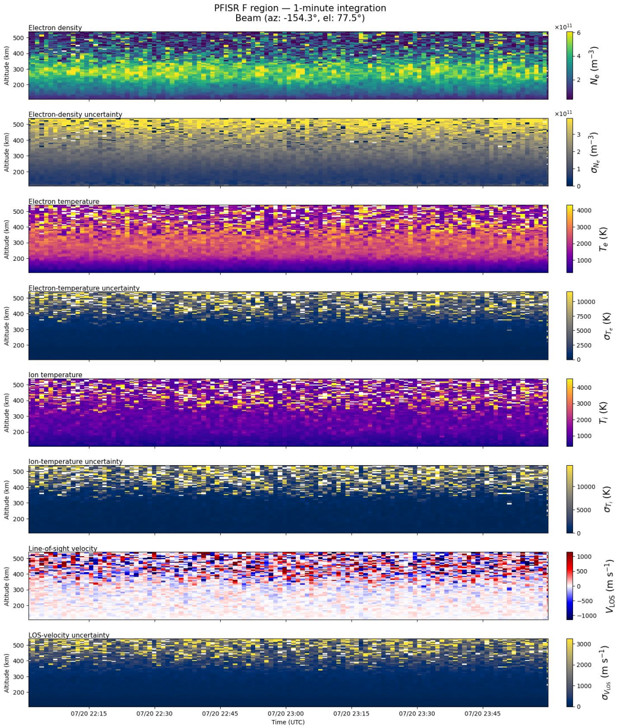


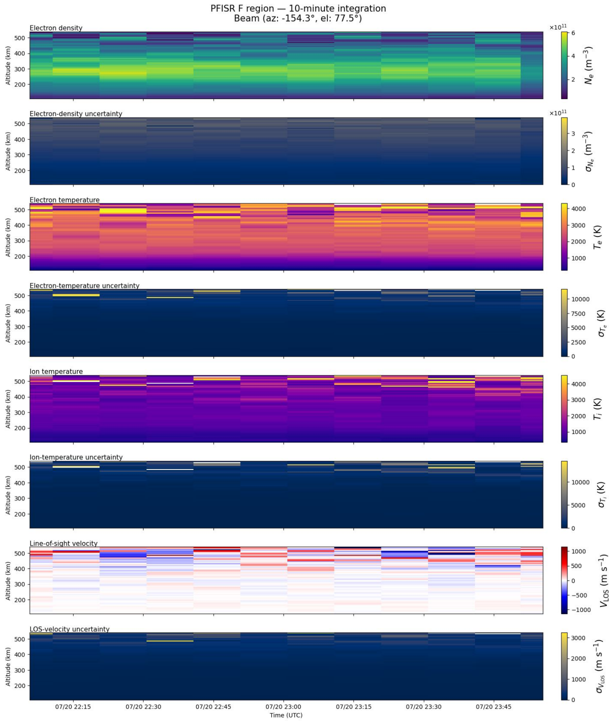
Alternating Codes (E-Region) Extended Integration 60 min, 120 min

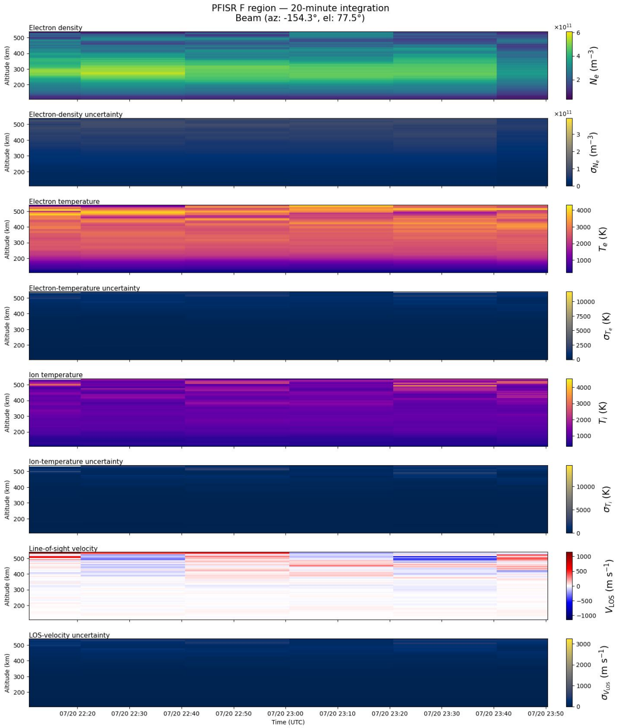




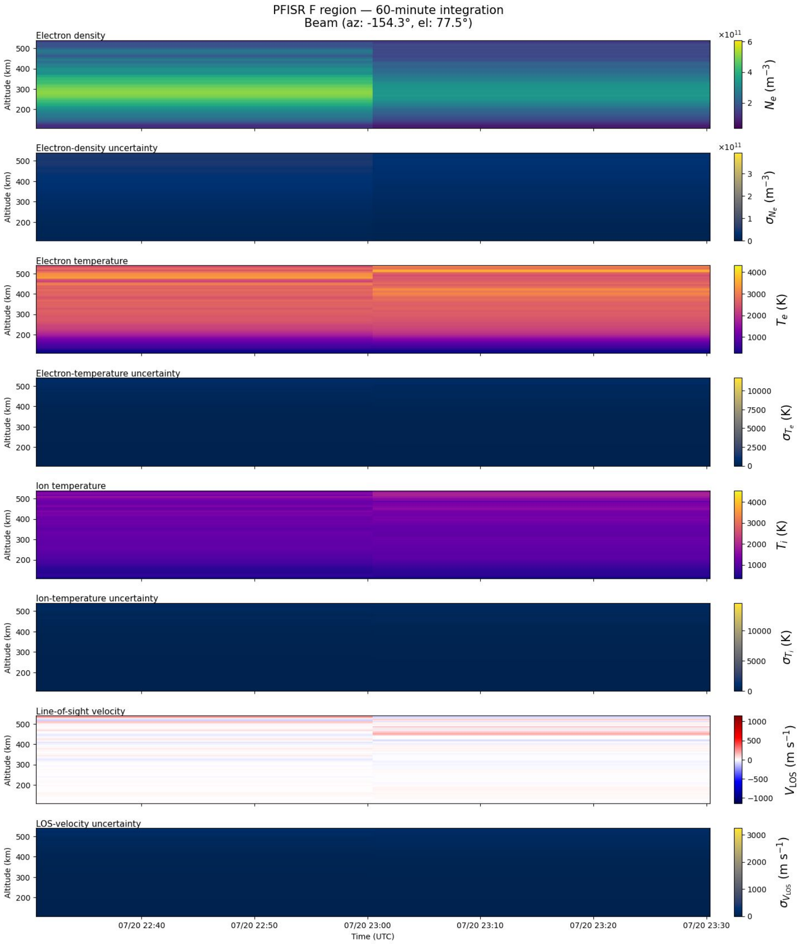
Long Pulse (F-Region) Integrations 1 min - 20 min

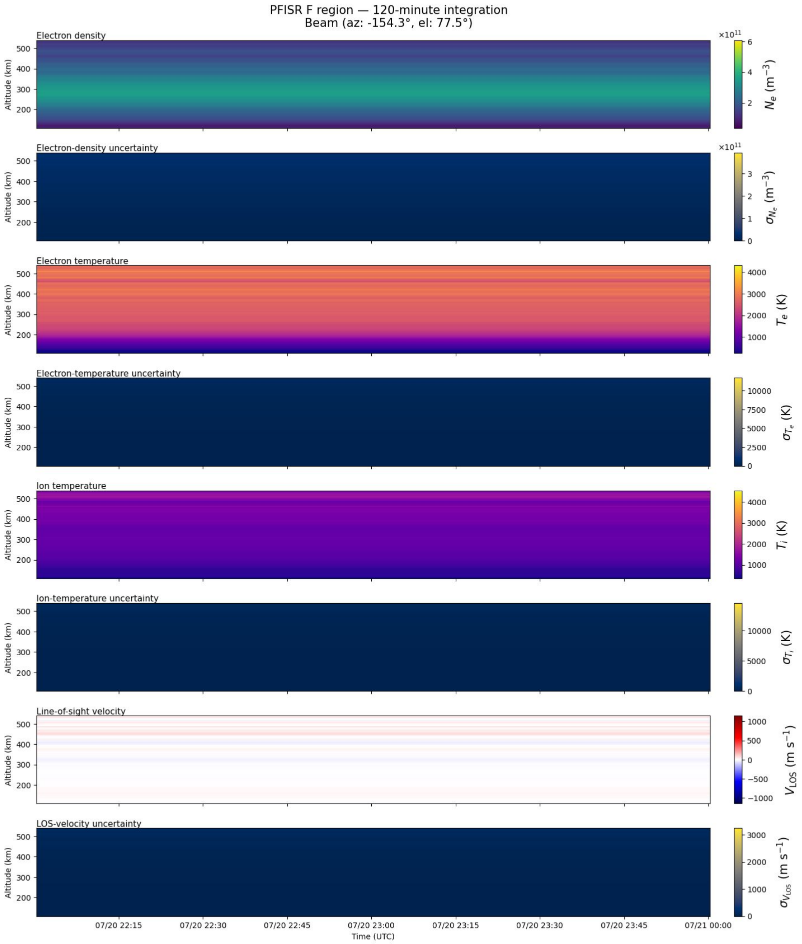






Long Pulse (F-Region) Extended Integrations 60 min, 120 min





Constructed Time Integration

Attempted to complete 60 min and 120 min integration independently by utilizing the 20 min integrated PFISR Madrigal data:

- 5 out of the 6 available 20 min integration windows were used, the corrupted data point near the end of the 2nd hour was removed to prevent skewing results

- The pulse mode (AC or LP), beam, and altitude were all averaged for each integration time

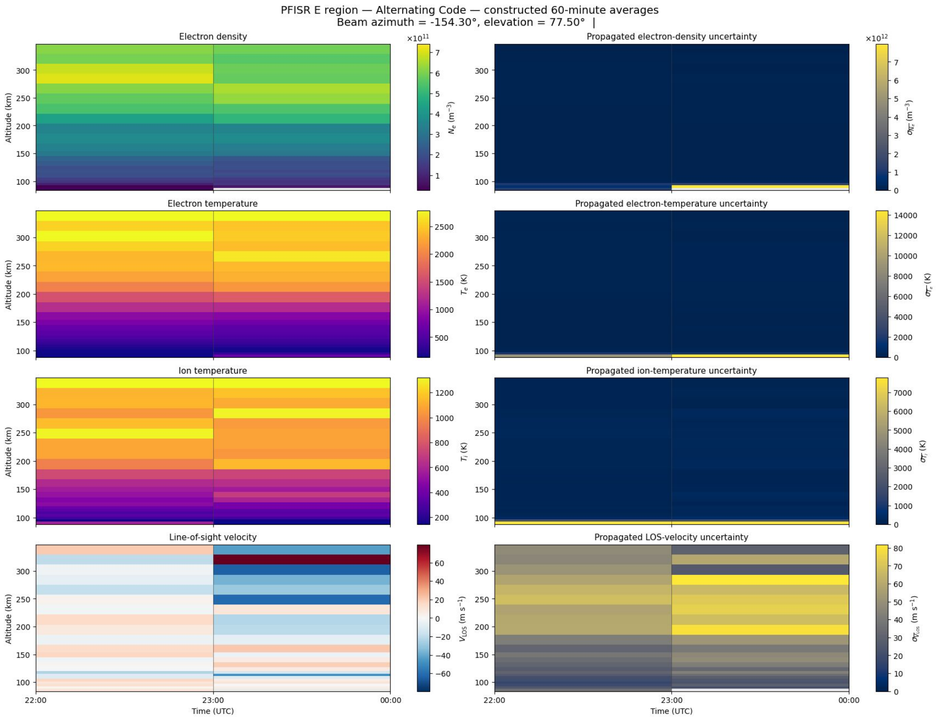
$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

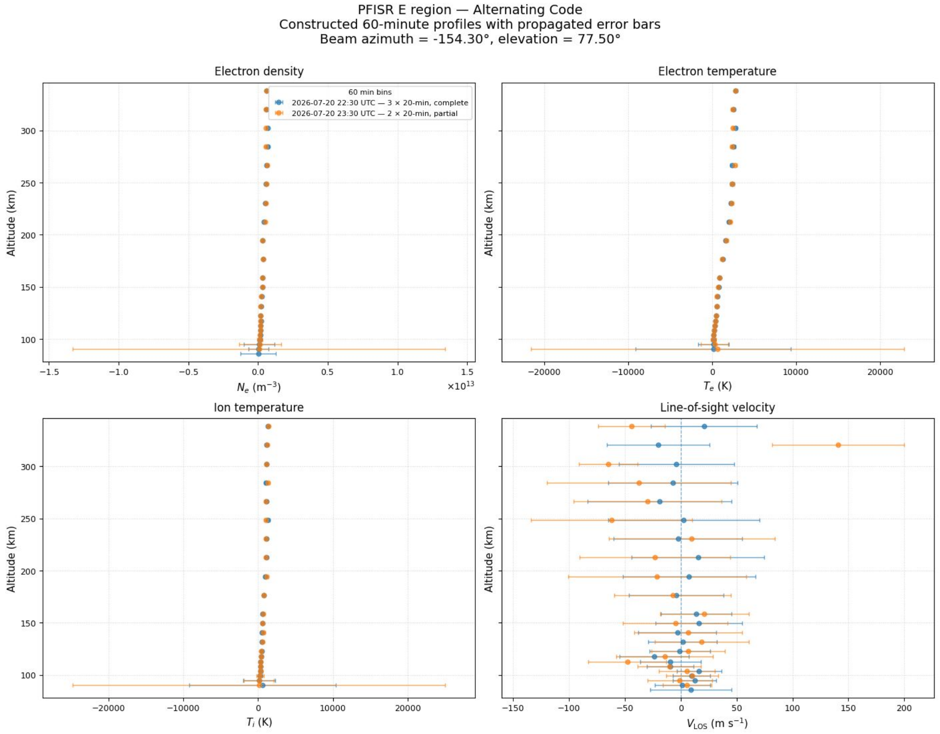
- Error for each averaged parameter was determined through uncertainty propagation

$$\sigma_{\bar{x}} = \frac{1}{N}\sqrt{\sum_{i=1}^{N} \sigma_i^2}$$

Averaged Integration for 60 mins

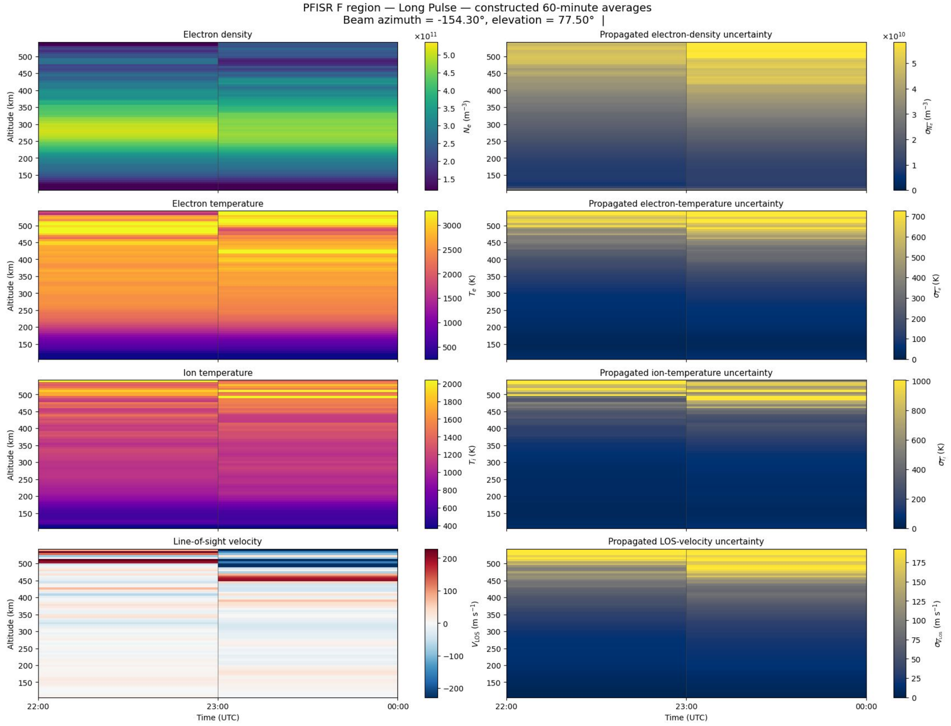
- Alternating Code (E-Region)

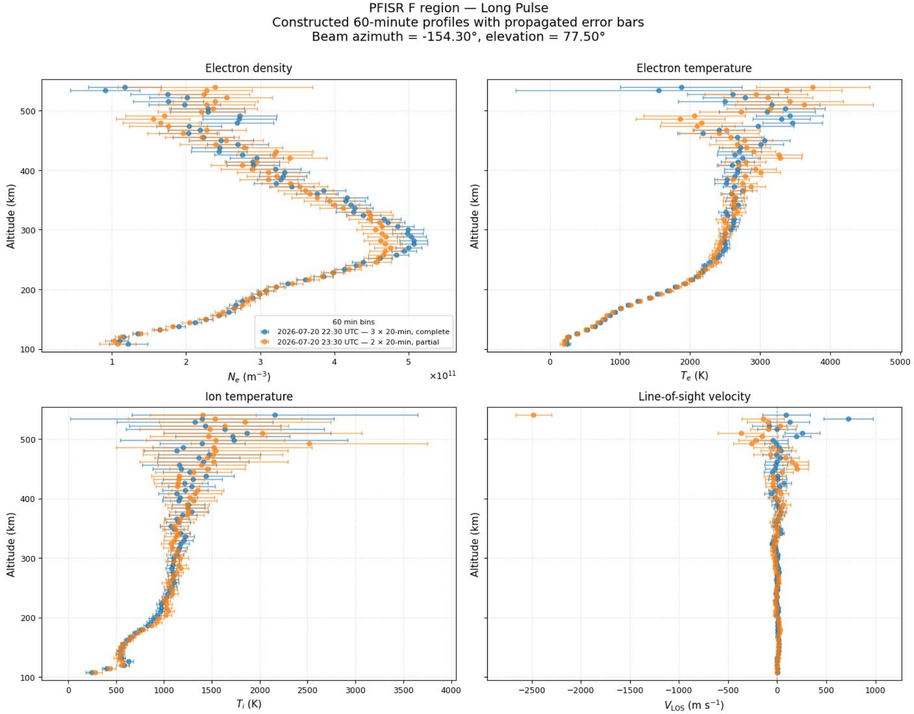




Averaged Integration for 60 mins

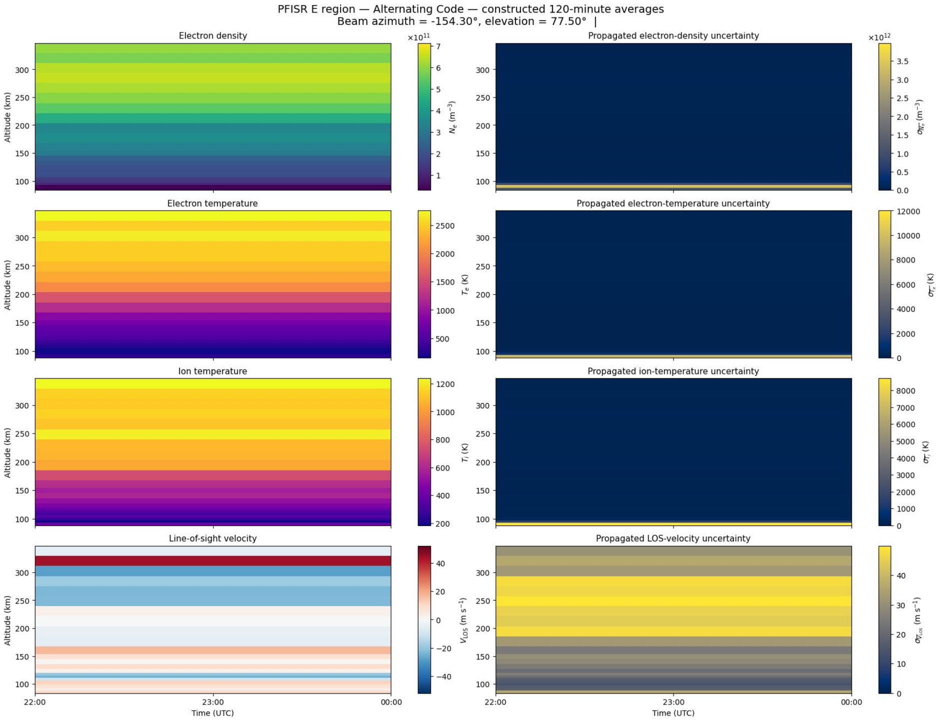
- Long Pulse (F-Region)

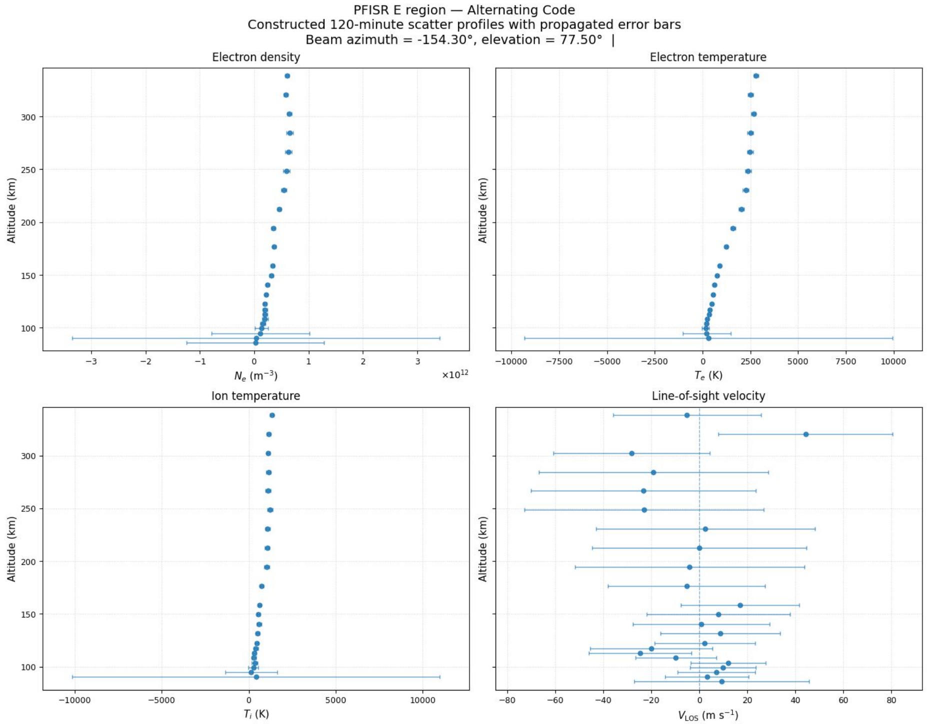




Averaged Integration for 120 mins

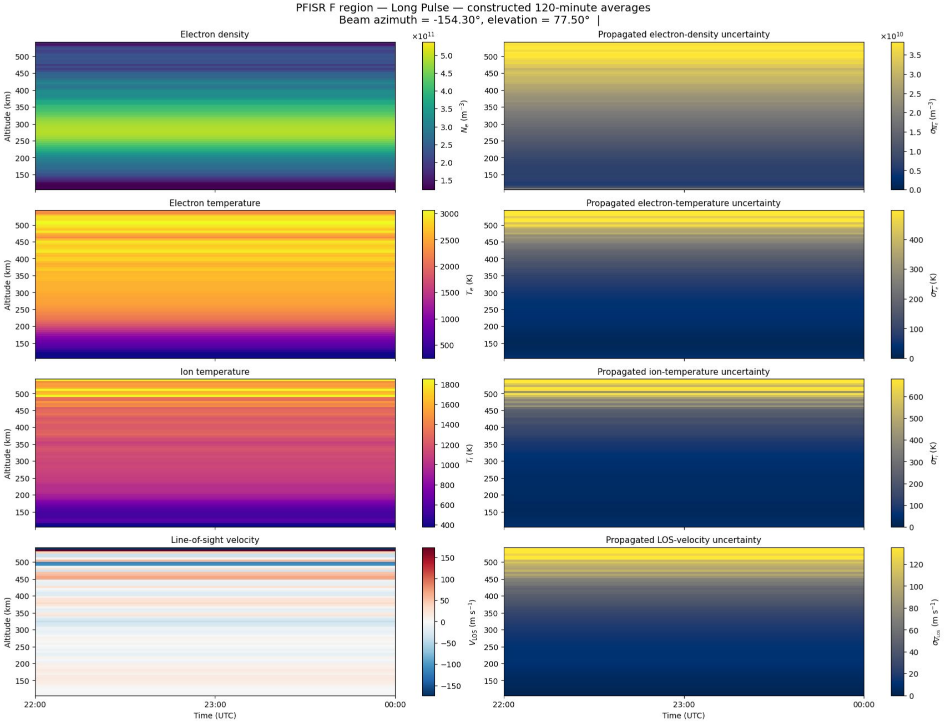
- Alternating Code (E-Region)

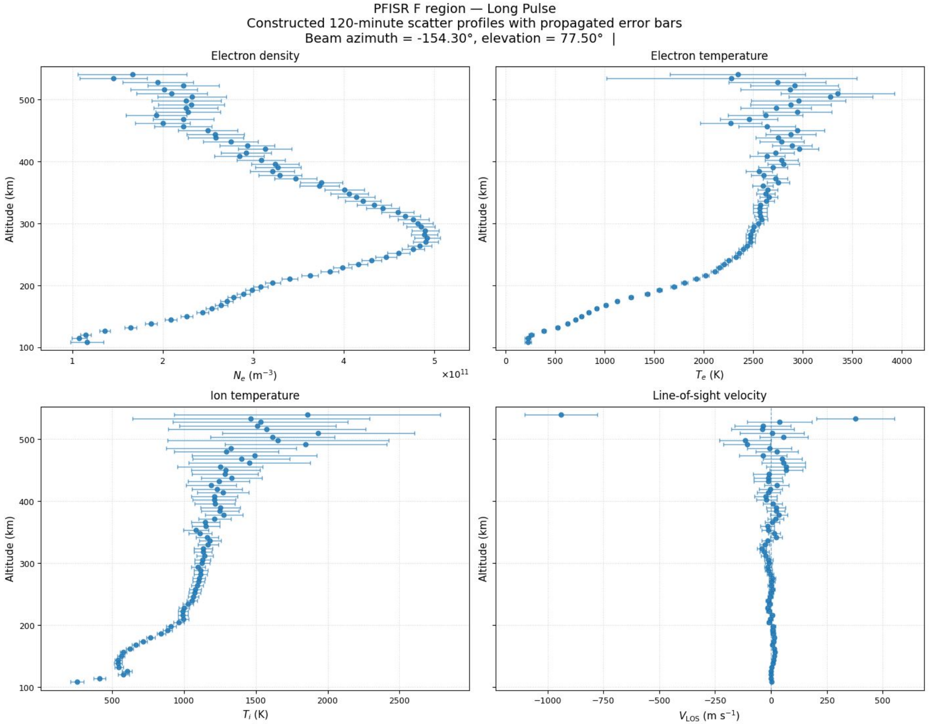




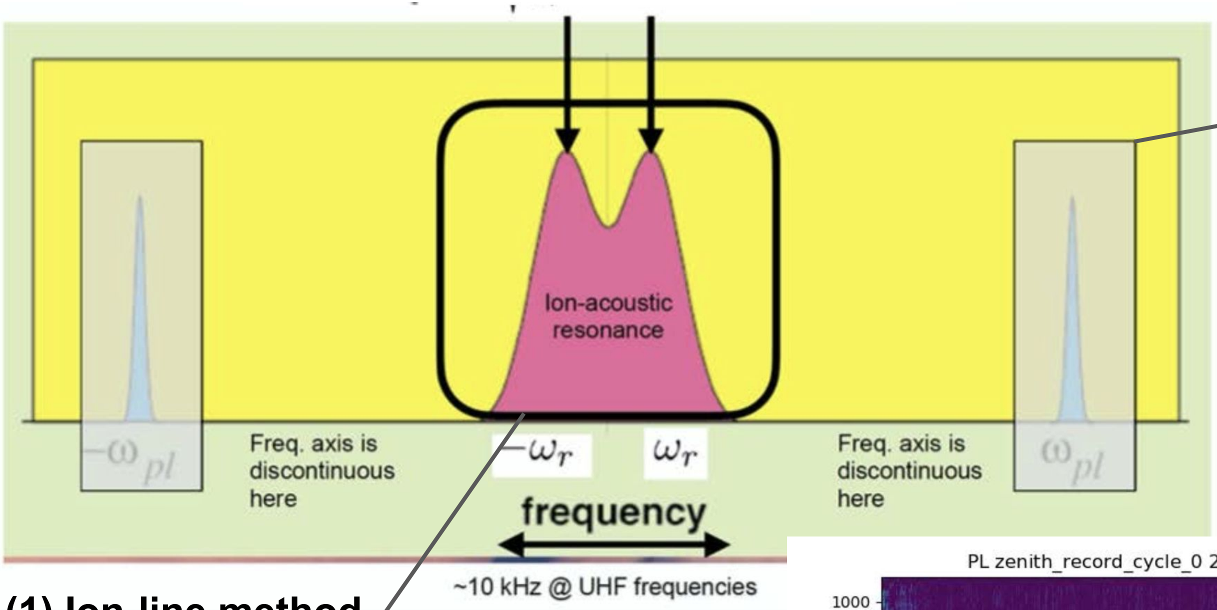
Averaged Integration for 120 mins

- Long Pulse (F-Region)



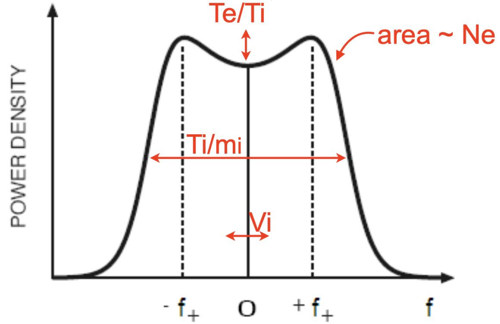


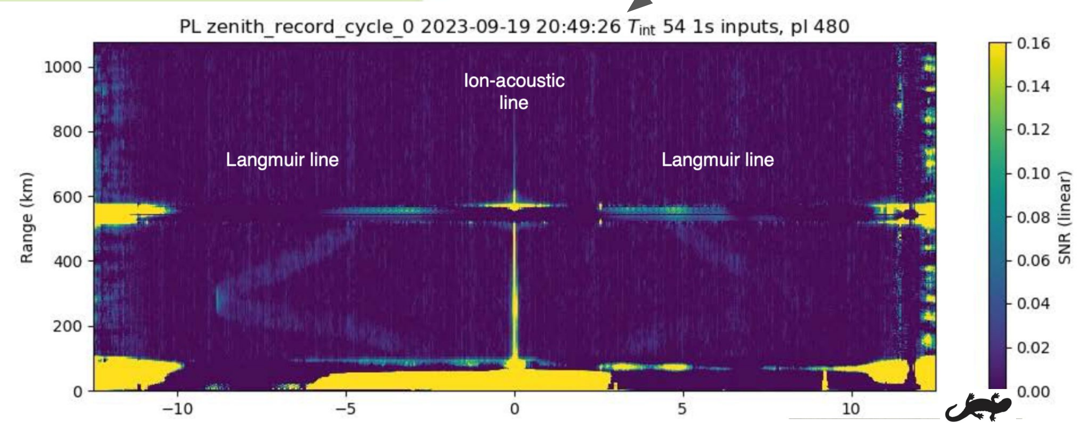
Comparing plasma density measurements with f_pe



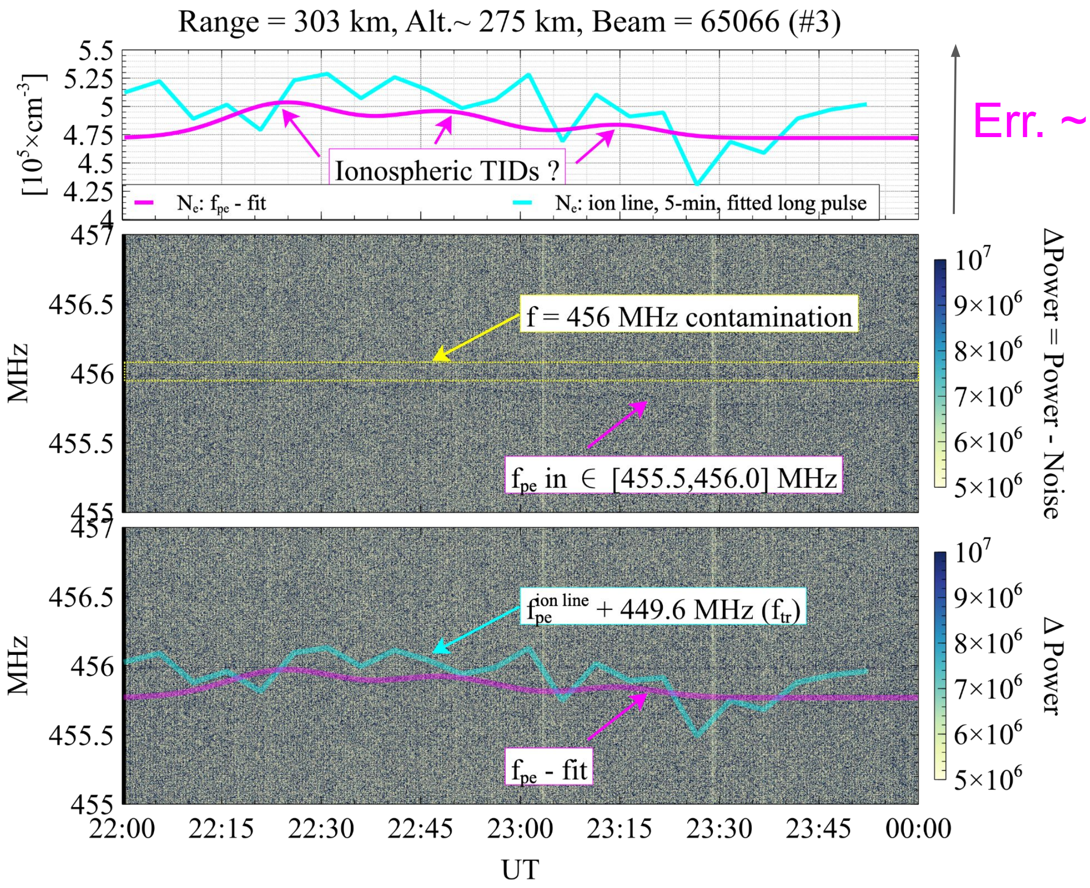
(2) A more direct approach to estimating the electron density is through measurements of the local plasma frequency, f_pe. However, this is often challenging because of the low signal-to-noise ratio of wave emissions in the vicinity of f_pe.

(1) Ion-line method

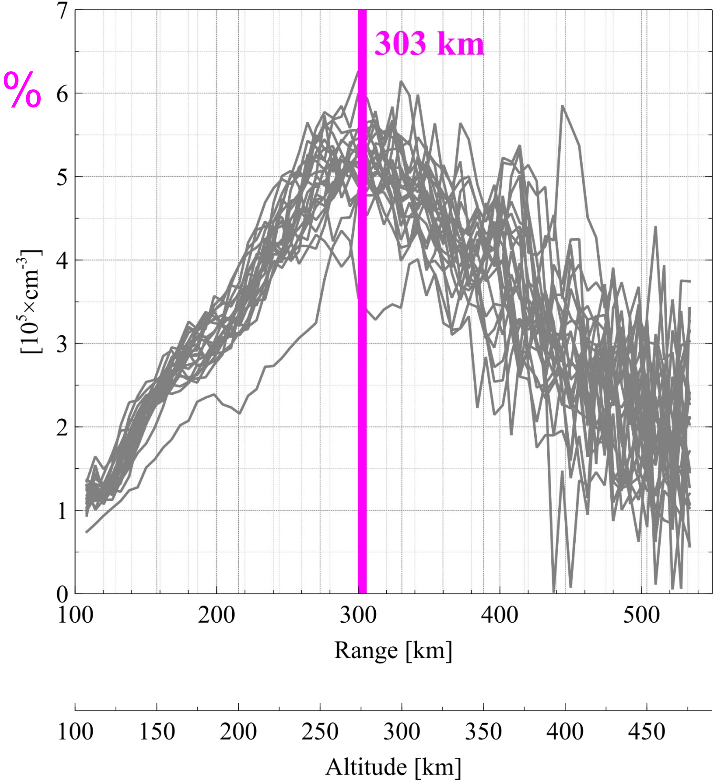




Comparing f_pe and ion line methods:

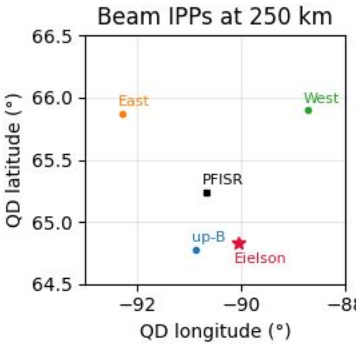


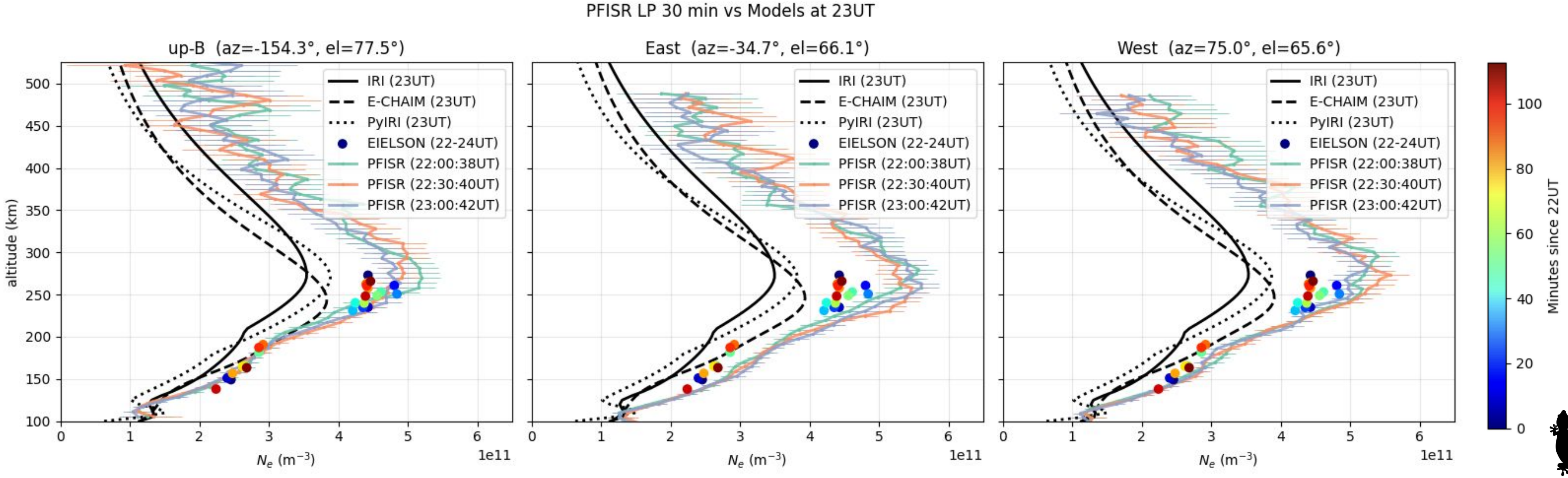
Err. ~ 5%



Comparing with models — F-region Ne

- **IRI** (International Reference Ionosphere)
- **E-CHAIM** (Empirical-Canadian High Arctic Ionospheric Model)
- **PyIRI** (Python IRI)
- **Ionosonde** (Eielson)

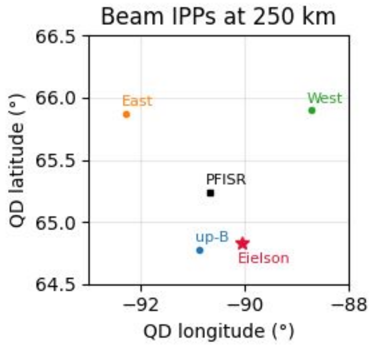


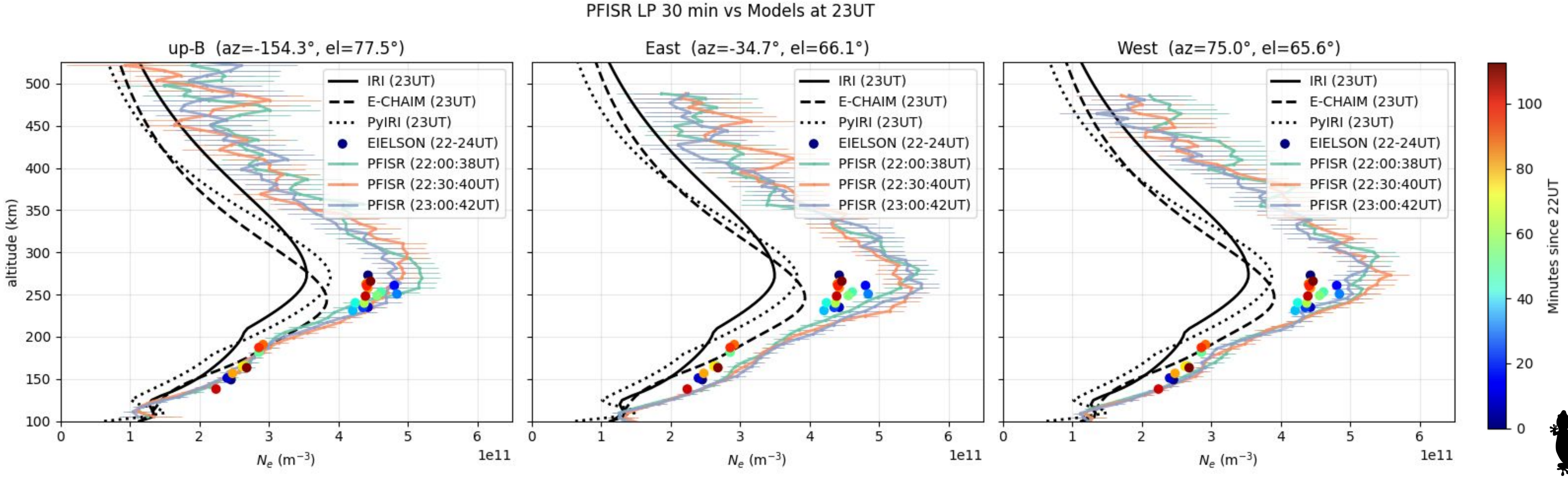


Comparing with models — F-region Ne

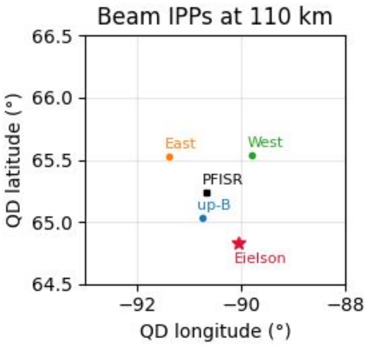
All models underestimate Ne

- **foF2**: E-CHAIM and PyIRI (daily F10.7) perform best
- **hmF2**: E-CHAIM matches the ionosonde, IRI/PyIRI match PFISR
- **F1 layer**: IRI matches PFISR best



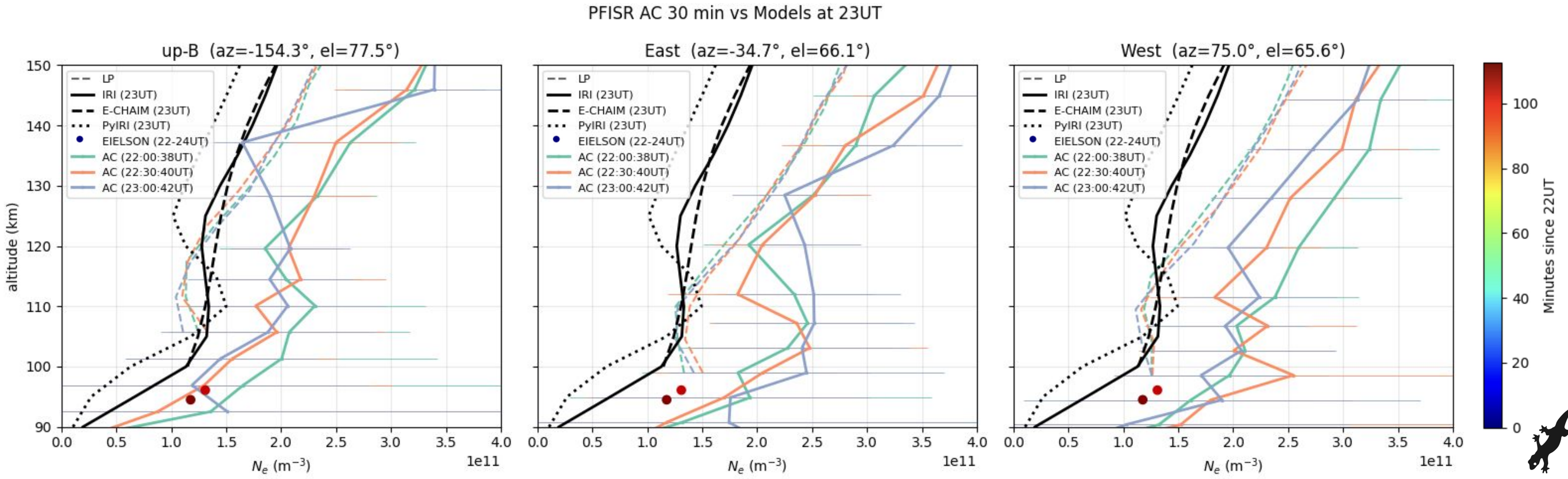


Comparing with models — E-region Ne



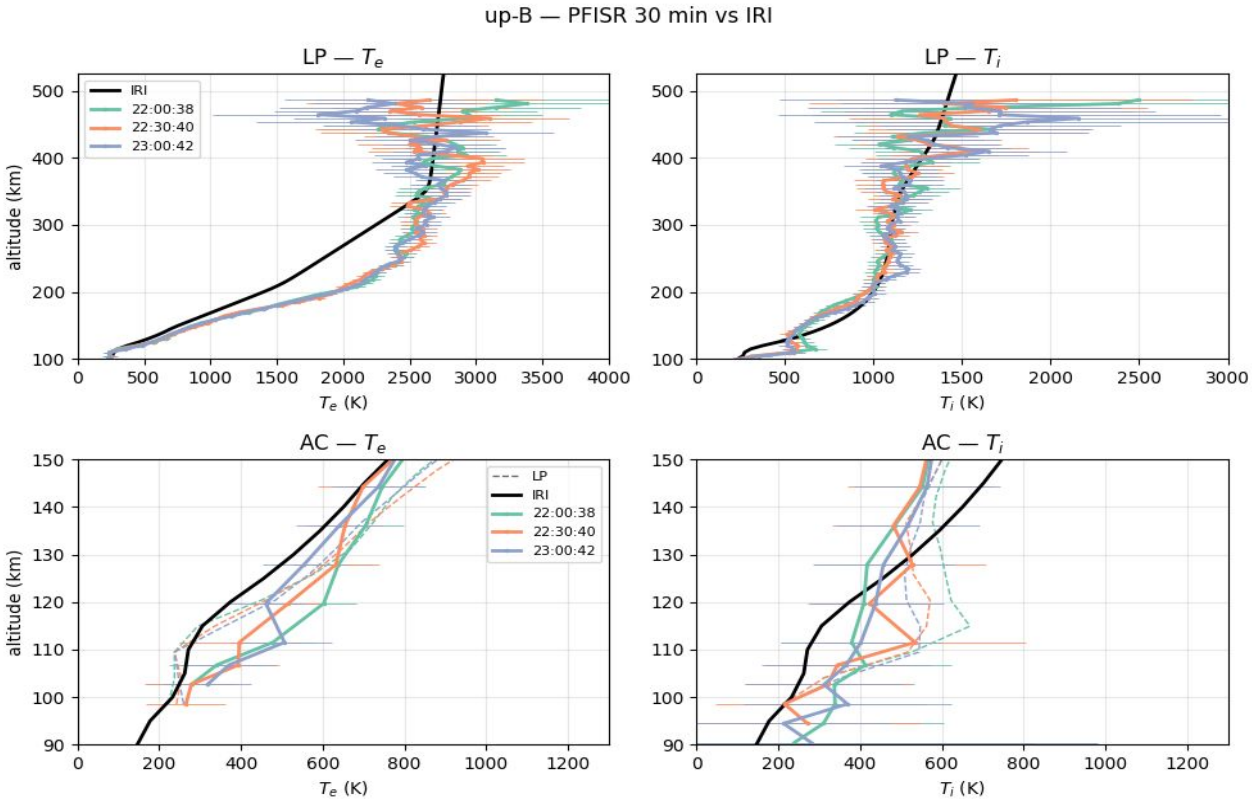
All models *still* underestimate Ne

- **E-layer**: IRI and PyIRI (daily F10.7) show an E-layer
- **hmE**: PyIRI hard-coded at 110km, IRI lower hmE



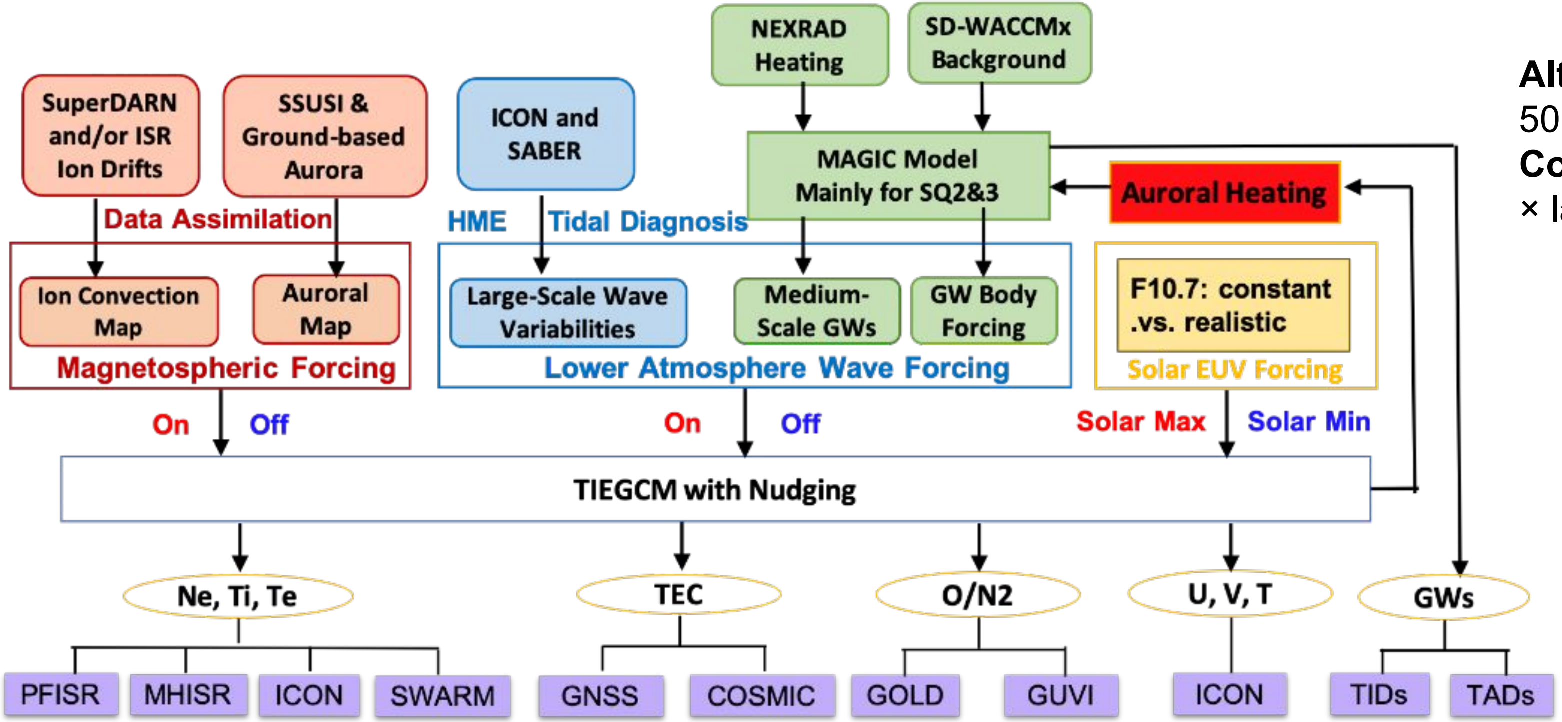
Comparing with models - Te and Ti

(PyIRI/E-CHAIM give **Ne only!)**



- IRI Te is **bad**
- IRI Ti is **okay > 200 km**

Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM)



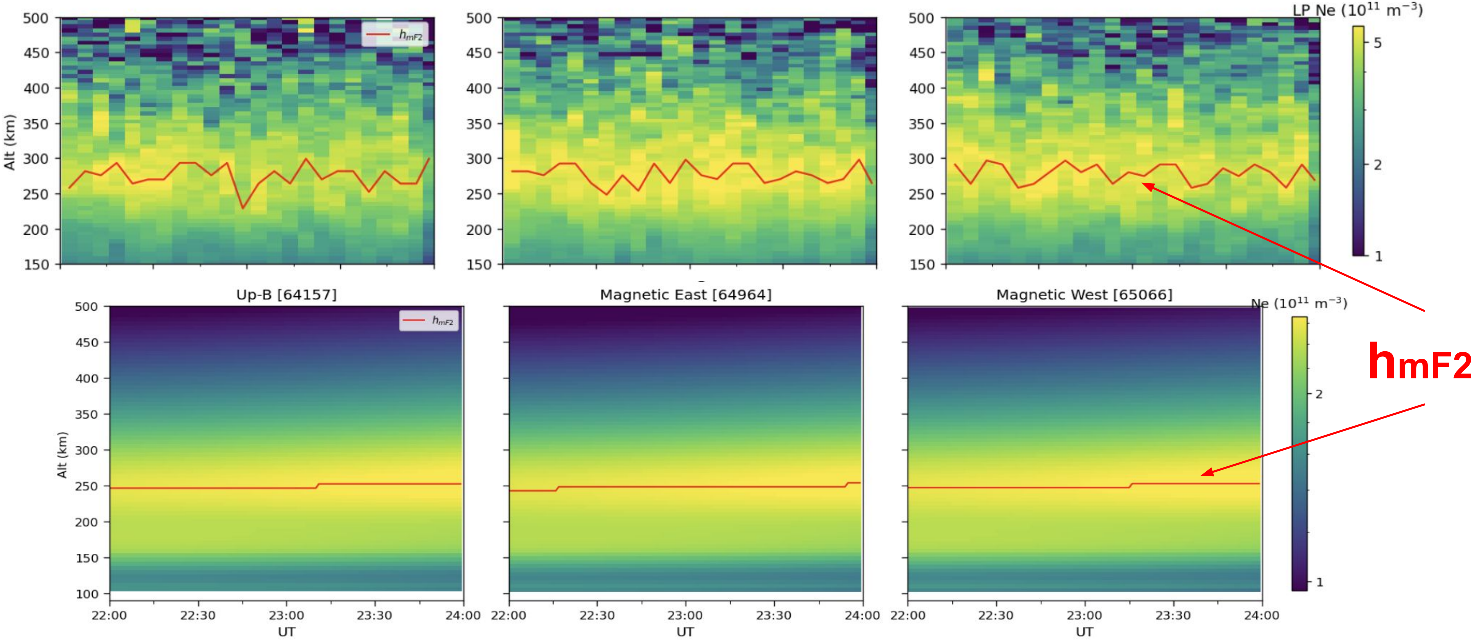
Alt range: ~97 km to 500-1000 km
Coordinates: longitude × latitude × level

Setup:
3h KP=1
F10.7=114.0
F10.7A=134.0

Ne

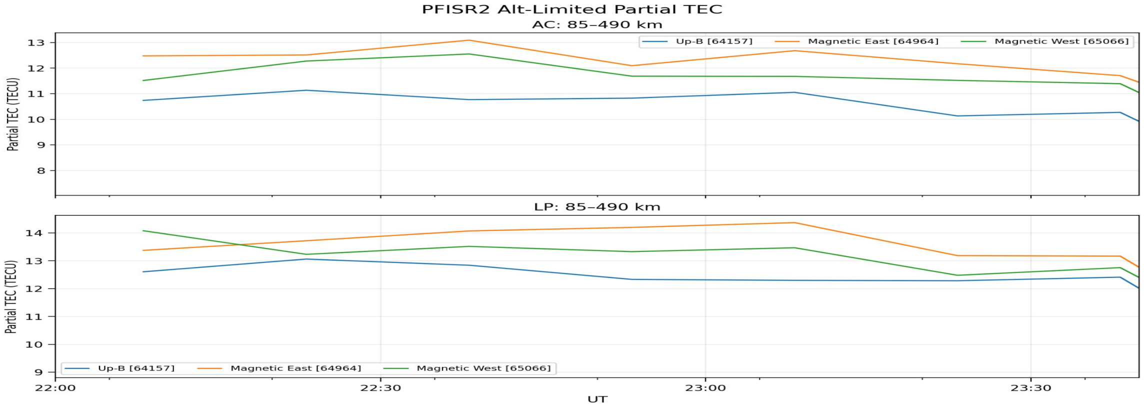
PFISR (5min)

TIEGCM

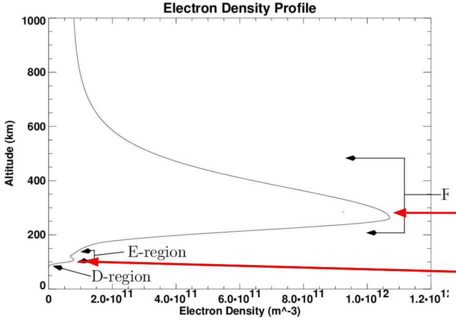


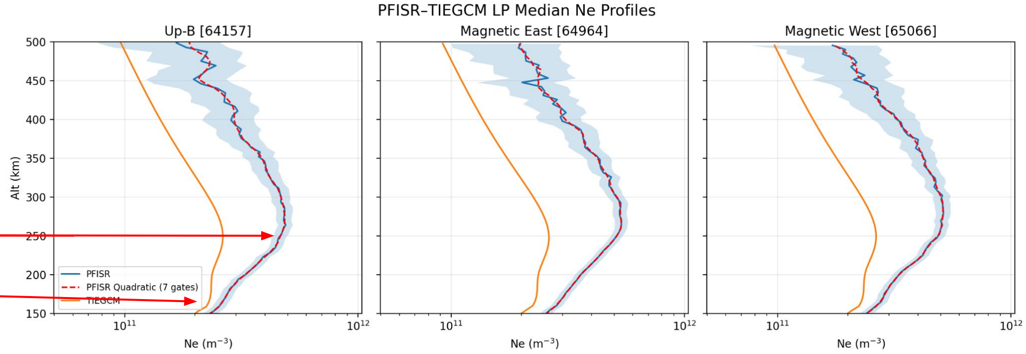
TEC

$$\mathrm{pTEC\,(TECU)} = \frac{1}{10^{16}} \int_{h_1}^{h_2} N_e(h)\, d$$

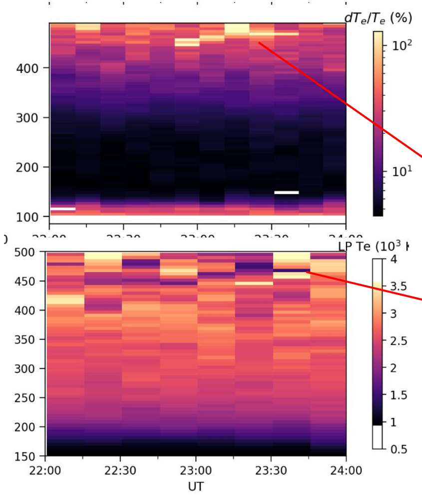


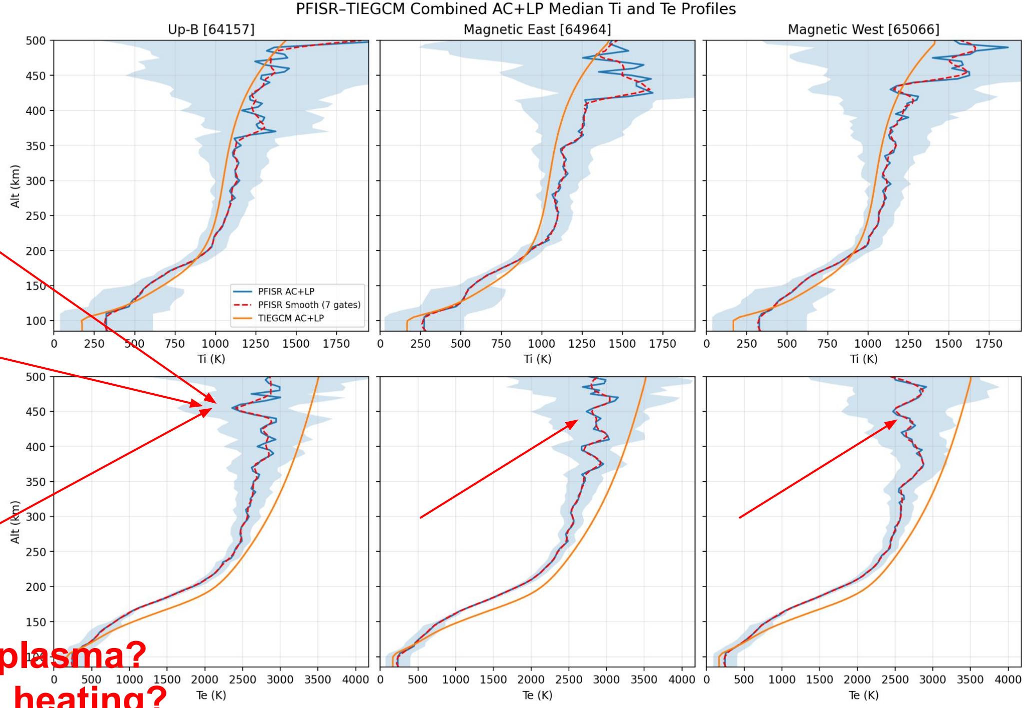
Ne profiles





Ti and Te profiles





- PFISR beam path
- Time average

SNR reliable？
Range-gate？
Transport of cooler plasma?
Changes in electron heating?

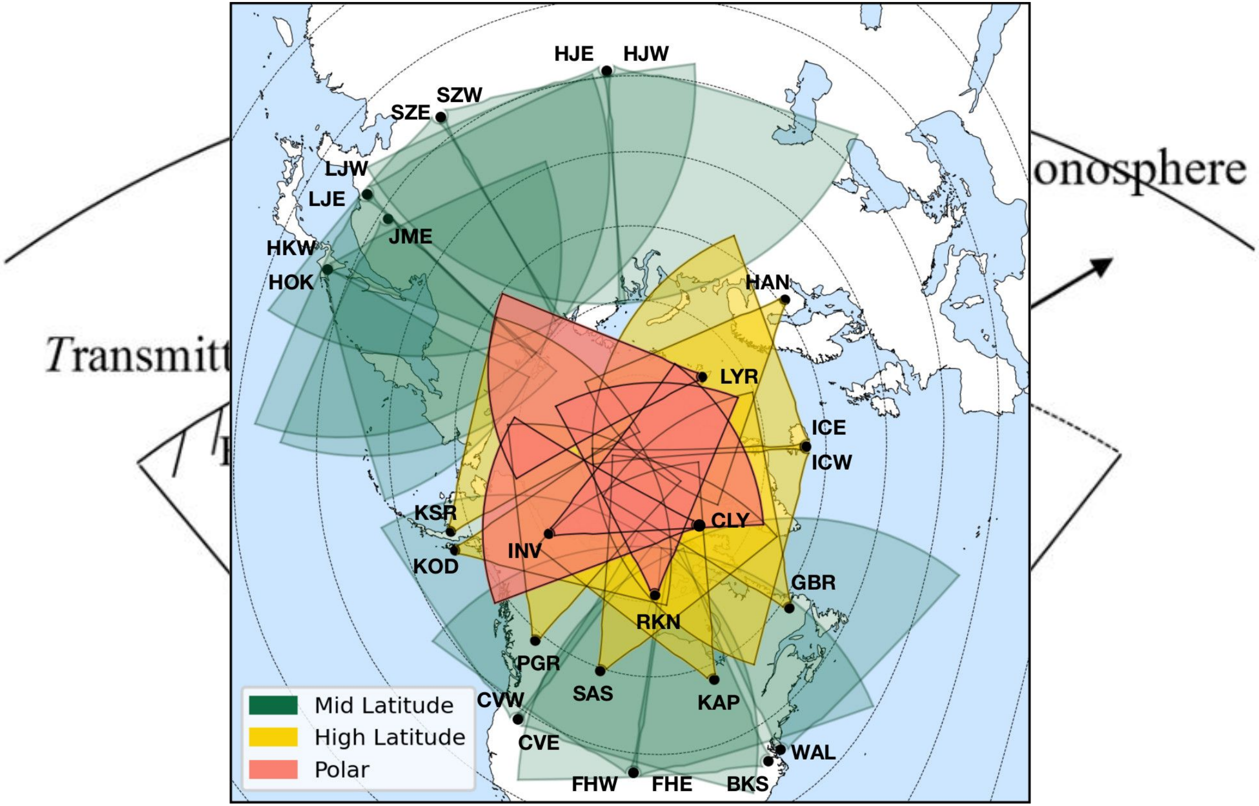
SuperDARN comparison and the electric field

Coherent
Scatter radar

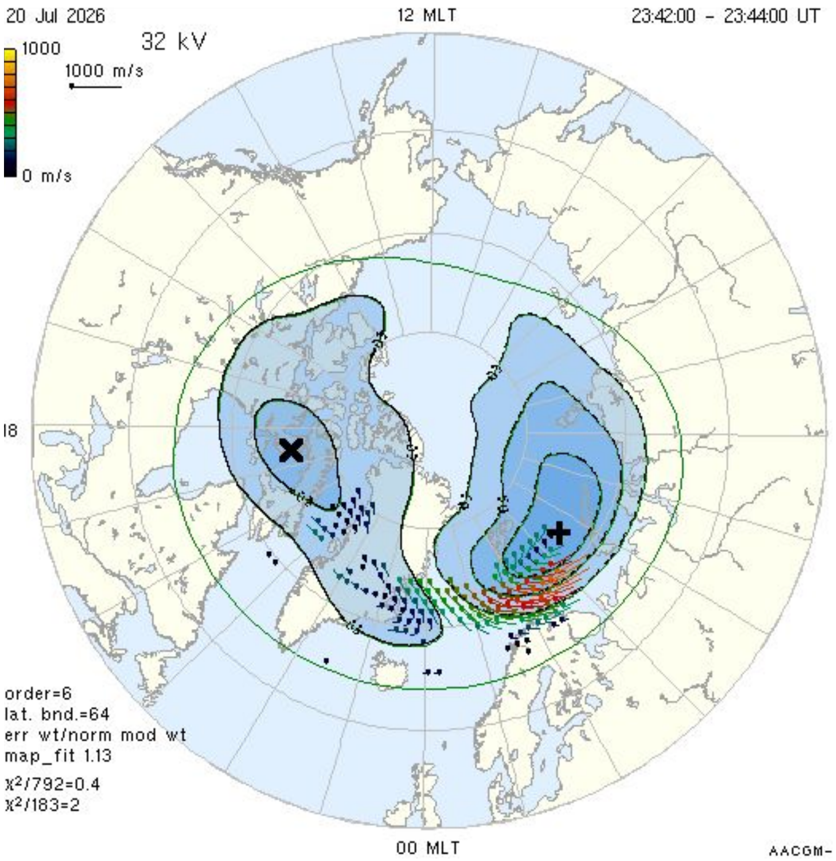
Enormous field
of view

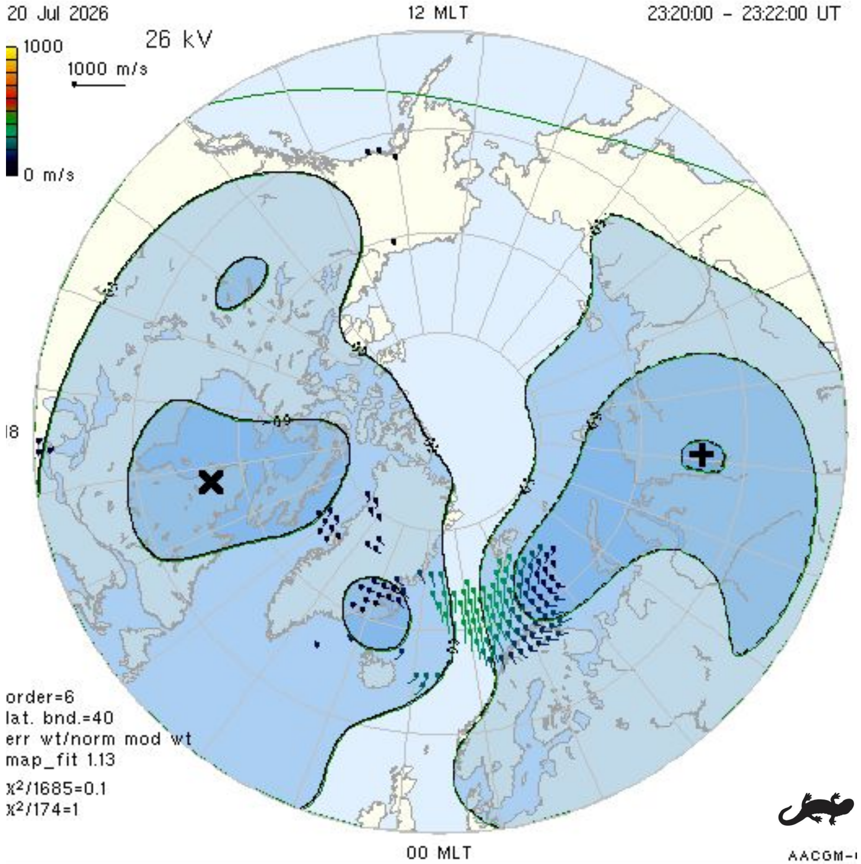
ExB drift

Data sparsity

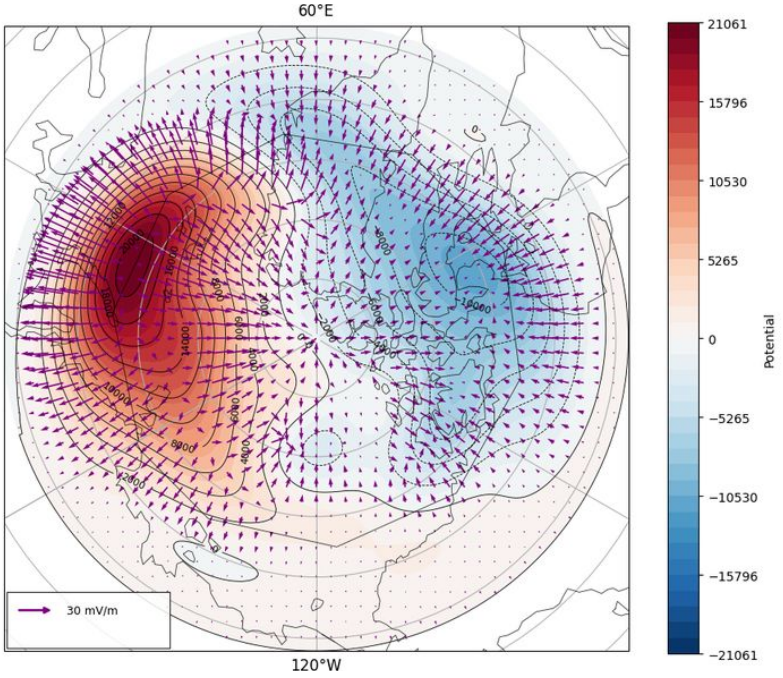


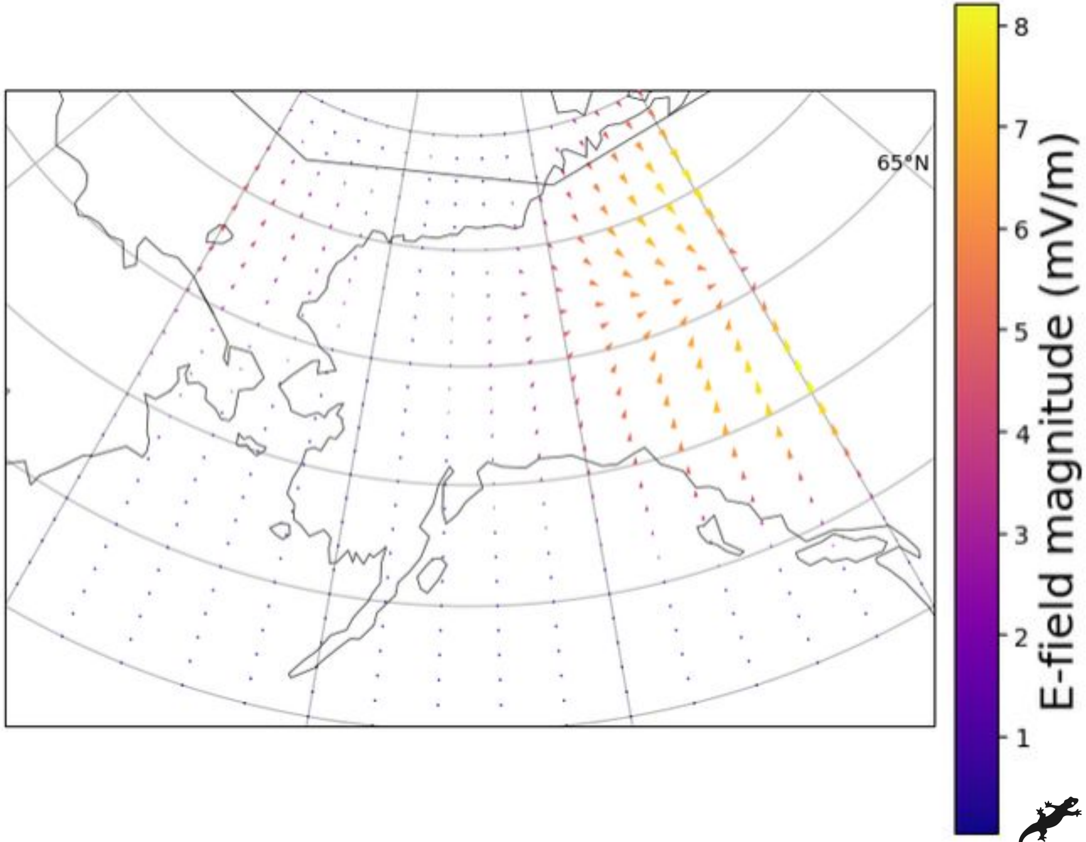
A quiet noon in Alaska

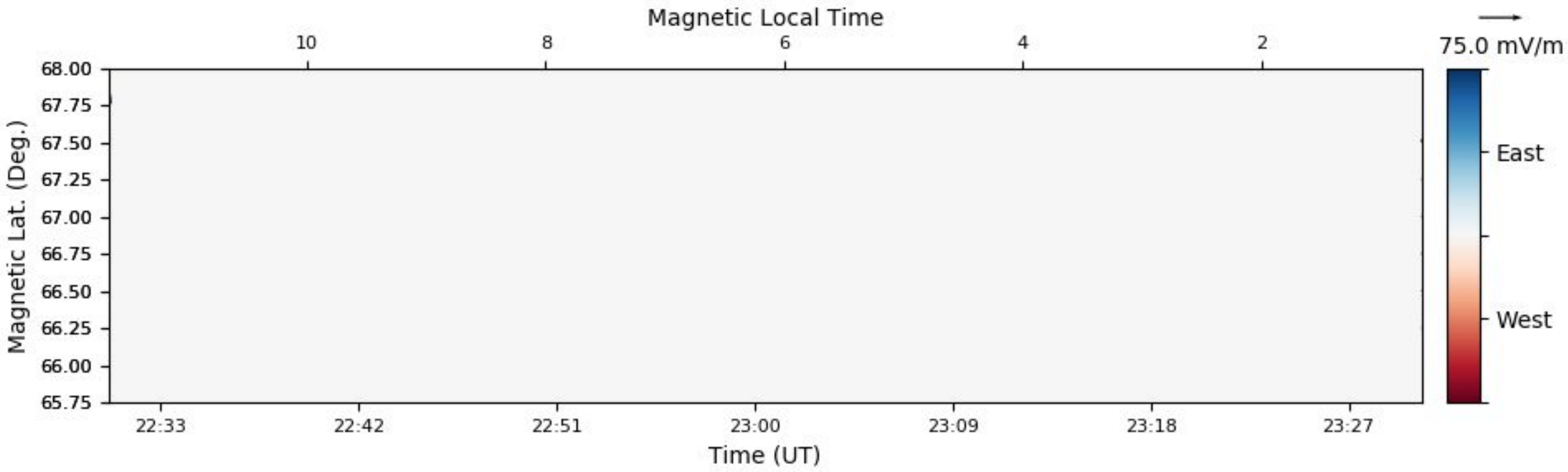




The electric field





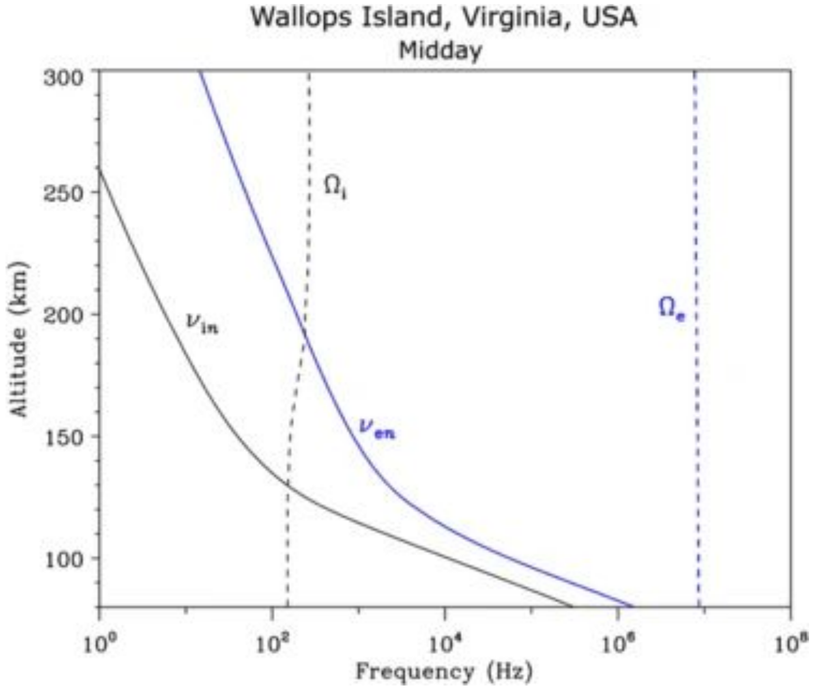


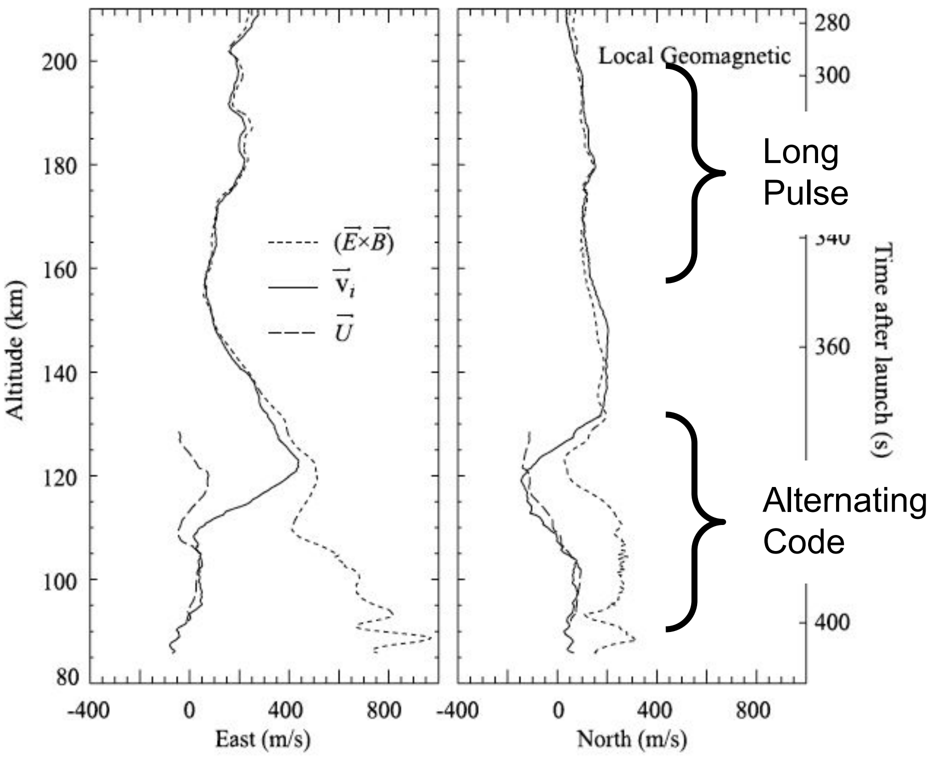
Relative deviation = (0 mV/m - 0 mV/m) / 0 mV/m = 0% (± ∞)

=> Perfect accuracy!!

Neutral Winds

$$0 = e(\mathbf{E} + \mathbf{v}_i \times \mathbf{B}) - m_i \nu_{in}(\mathbf{v}_i - \mathbf{u})$$

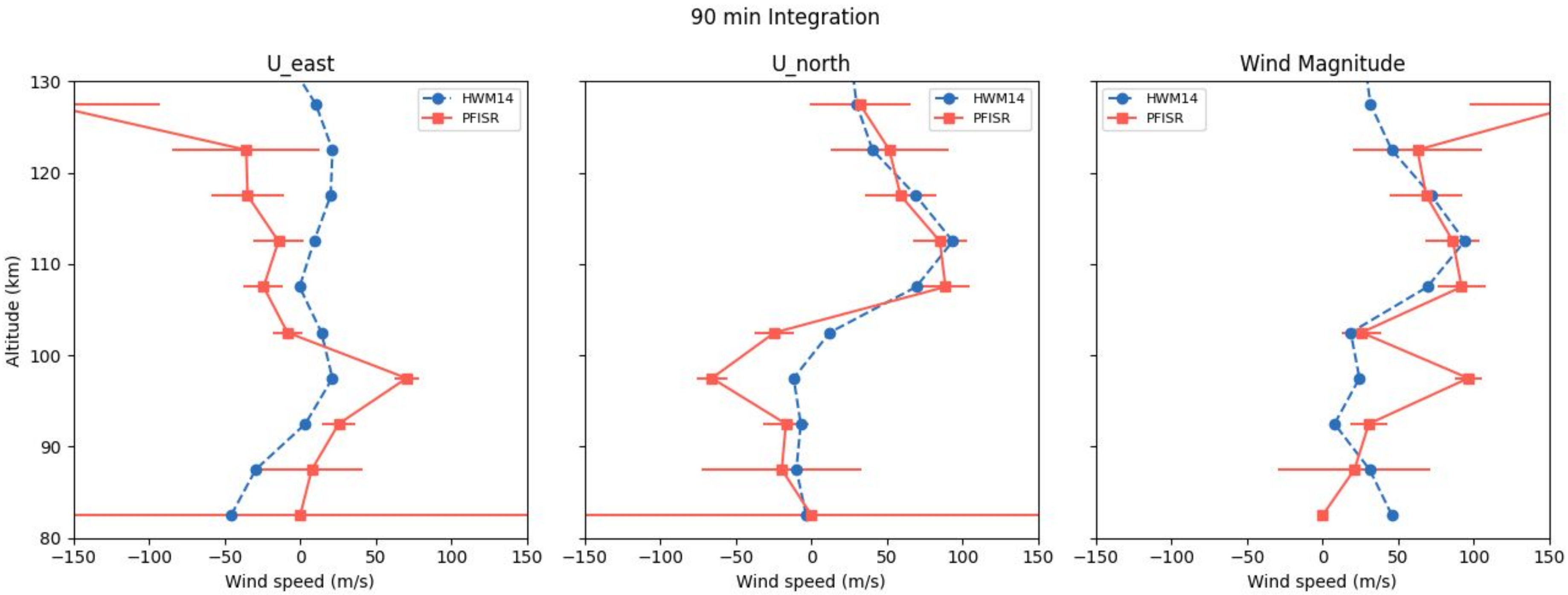




- Ion neutral collisions become significant below ~120km
- LP data gives measure of E.
- By ‘removing’ E from AC data, just left with neutral flows

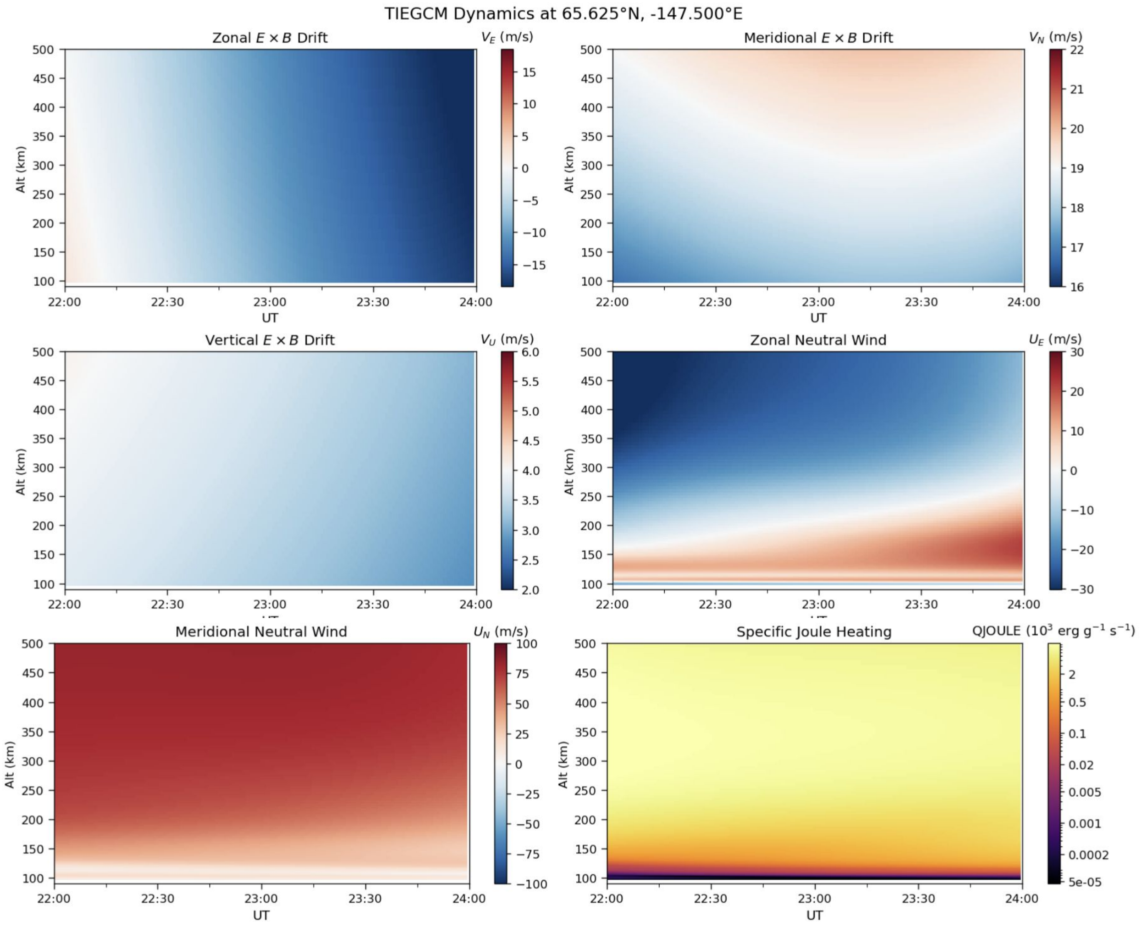
Pfaff et al 2012, Sangalli et al 2009

Deriving Neutral Winds



- This process is combining the LP and AC measurement errors, we need lots of integration to get good measurements
- If we integrate for the full 2 hours, our neutral wind profiles agree very strongly with HWM14 (Drob et al 2015)

Comparing with TIEGCM



- TIEGCM also gives output of neutral winds
- TIEGCM winds are typically weaker, and don’t always agree on direction
- Using PFISR to take more measurements of E region profiles can better constrain these models in the future

Fin

Deriving Neutral Wind Velocities (extra slide)

Ion Velocities

$$\mathbf{v}_{los} = A\mathbf{v}_i + \mathbf{e}_{los}.$$

$$\hat{\mathbf{v}}_i = \Sigma_v A^T \left(A\Sigma_v A^T + \Sigma_e\right)^{-1} \mathbf{v}_{los}.$$

$$\Sigma_{\hat{v}} = \left(A^T \Sigma_e^{-1} A + \Sigma_v^{-1}\right)^{-1}$$

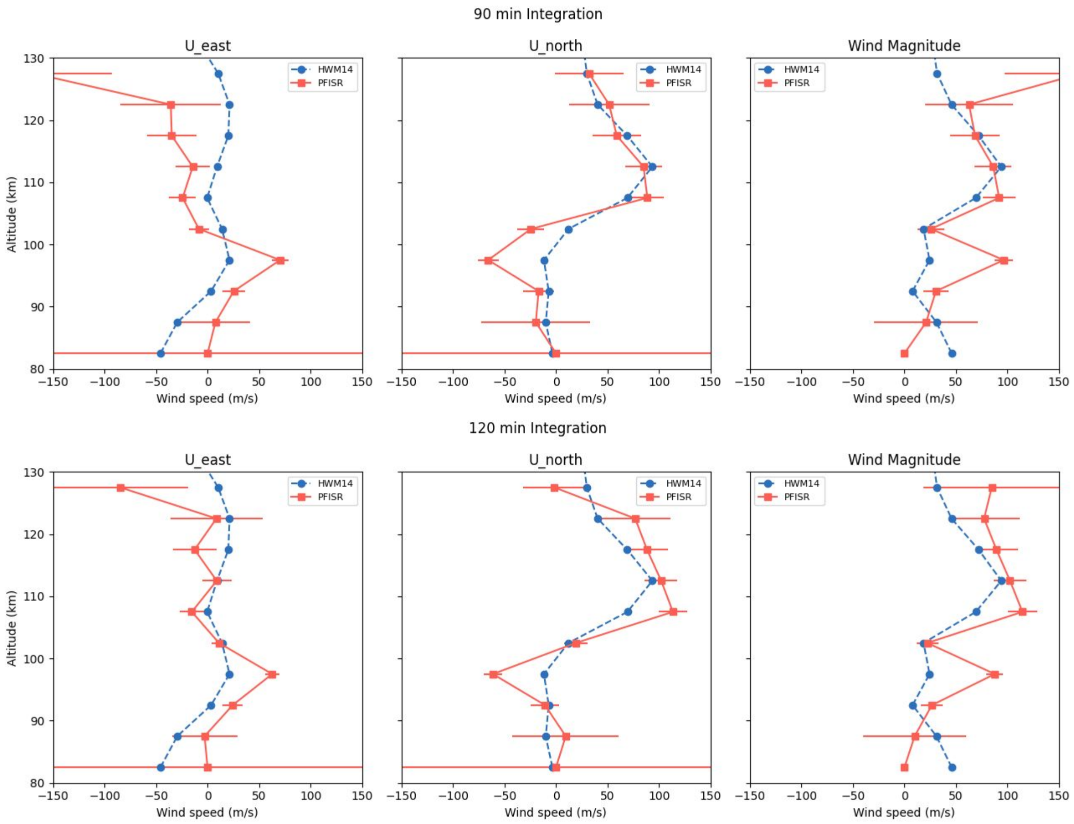
Neutral Velocities

$$\mathbf{v}_{los} = (A \cdot D)\mathbf{x} + \mathbf{e}_{los}$$

A: defines mapping from orthogonal velocity components to the beam's line of sight
D: contains ion mobility/ion-neutral collision information

$$\mathbf{x} = [E_{pe}\ E_{pn}\ E_{||}\ u_{pe}^1\ u_{pn}^1\ u_{||}^1\ u_{pe}^2\ u_{pn}^2\ u_{||}^2 \ldots\ u_{pe}^n\ u_{pn}^n\ u_{||}^n]^T.$$

Neutral wind bonus slide (90 min vs 120 min



- Long integration times require constant variables through the entire time
- 120 min integration includes final data points with drops in ion density etc.
- 90 min integration time therefore provides a closer fit to HWM, as it's constant through the whole integration