OPERATION nrawhal

NeutRAl Wind High-latitude observations over ALaska

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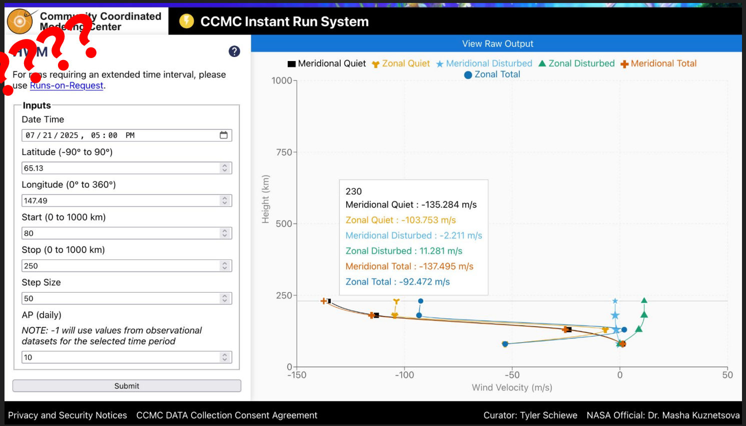
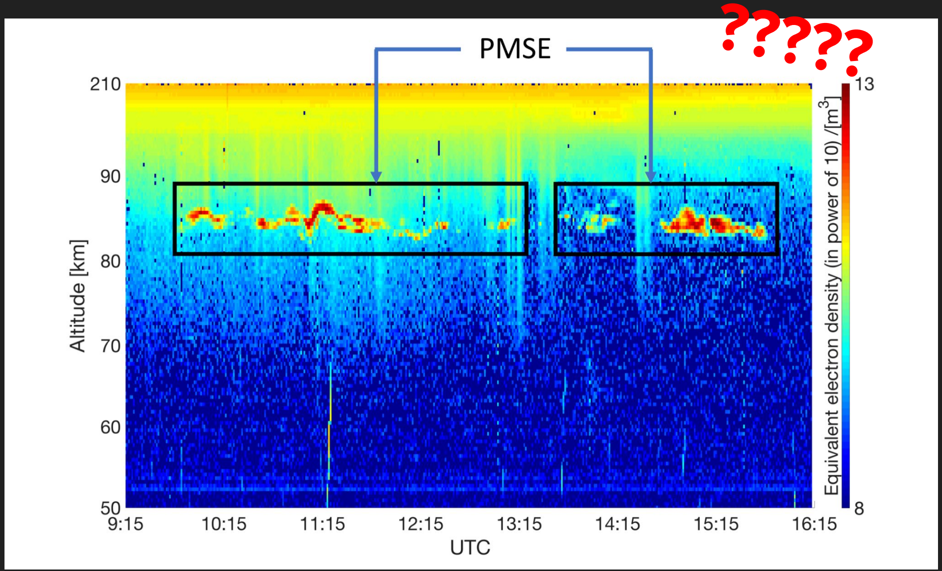
Group 3

Objectives:

- Gain a better understanding of ISR pulse types and integration times.
- Estimate neutral wind velocities in D region and lower E region.
    - Hoping to observe Sporadic E or PMSE to aid in calculations !!!





Background

PMSE: Polar Mesosphere Summer Echoes

PMSEs are strong radar echoes that occur in the polar mesosphere region during the summer

Observations PMSEs can be observed using ISR in the lower regions of the ionosphere (D/E region)

Noctilucent clouds (NLC) large, visual PMSEs

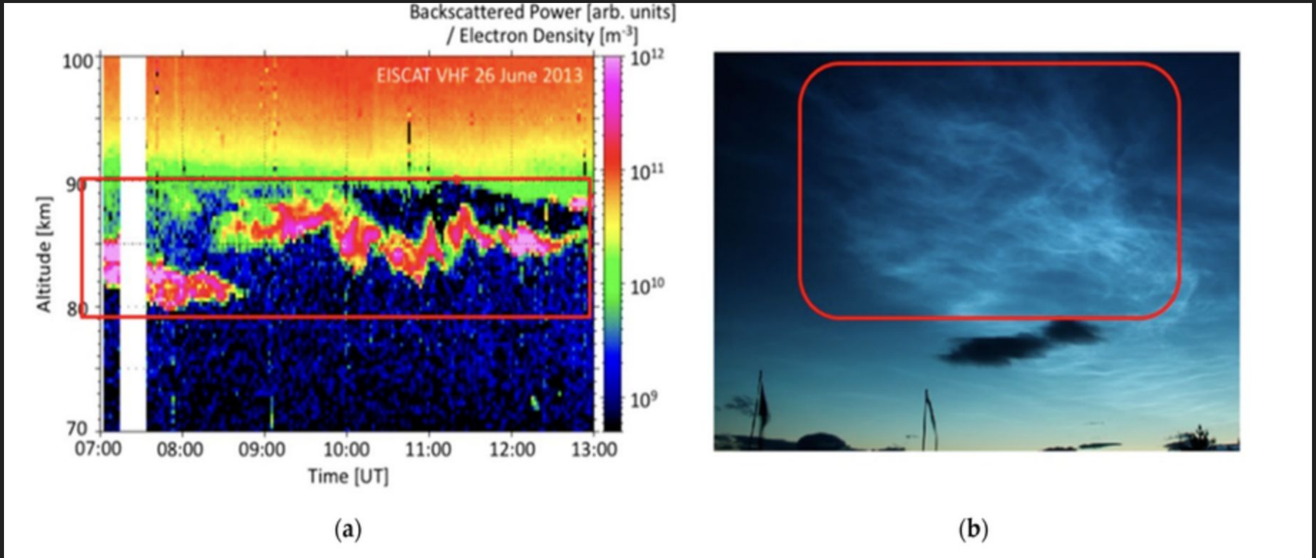
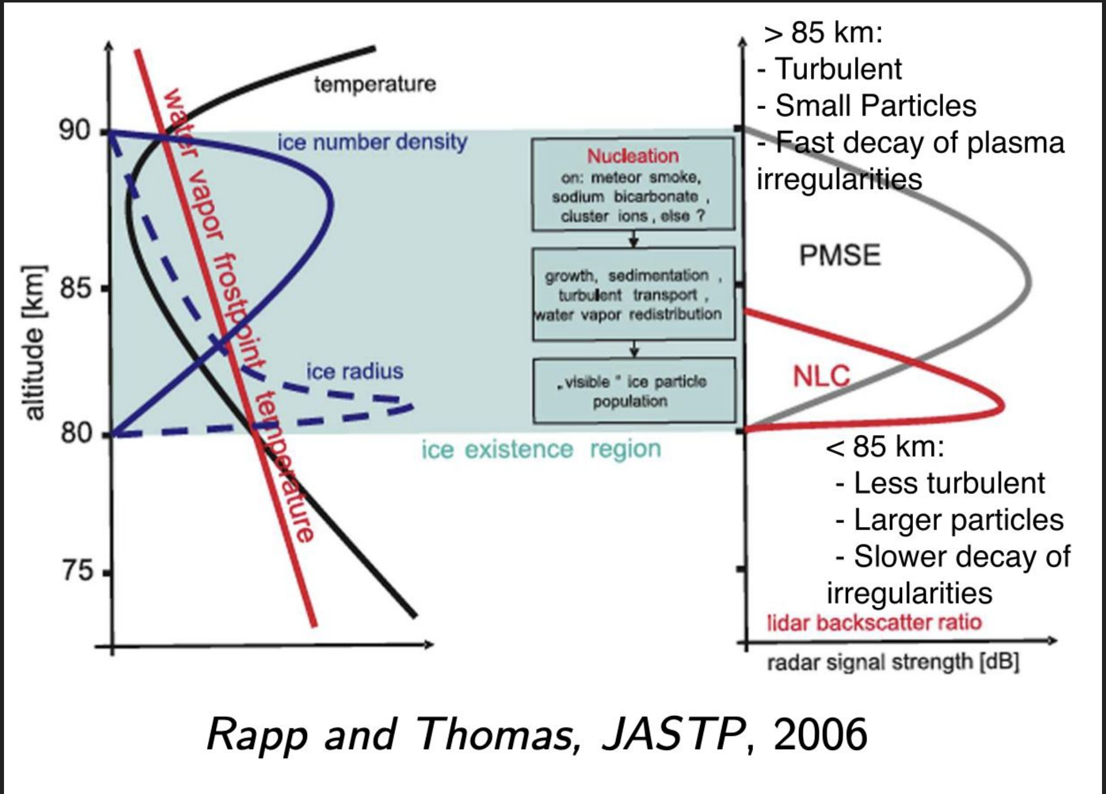


Figure 1. (**a**) The PMSE radar echoes associated with polar ice clouds and (**b**)optical image consisting of NLC

Sapkota et al.

How are PMSEs Formed?

PMSEs are structures of small ice particles that form in the mesosphere when the mesosphere temperature is below the freezing point of water vapor and the area experiences disturbances.



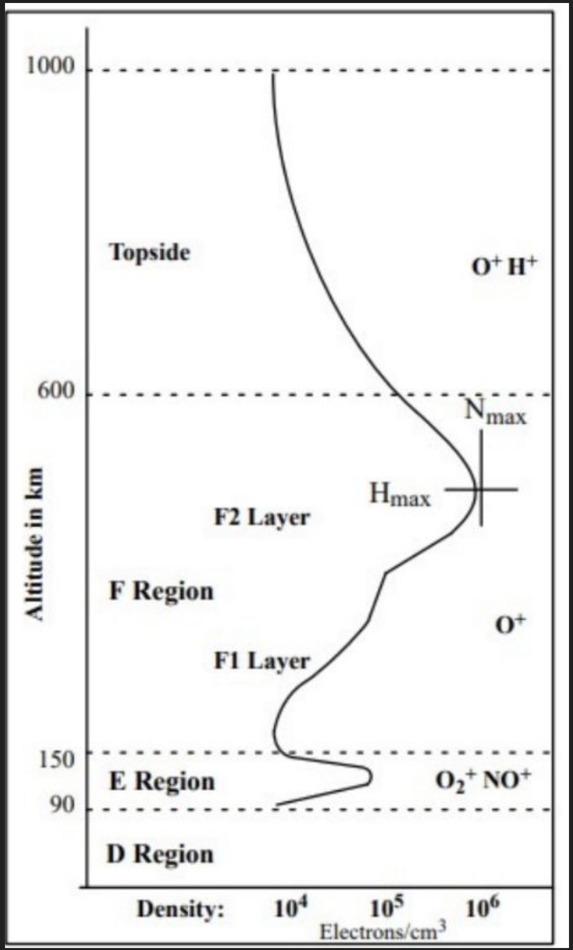
Nicolls et al.

Neutral Winds and Ion Velocities

Neutral Winds the movement of neutral particles, driven by collisions

Ion Velocities the movement of ionized particles, driven by ExB drift

Primary Driving Force at any altitude depends on the dominating species



T. F. Tascione et al.

Experiment Setup:

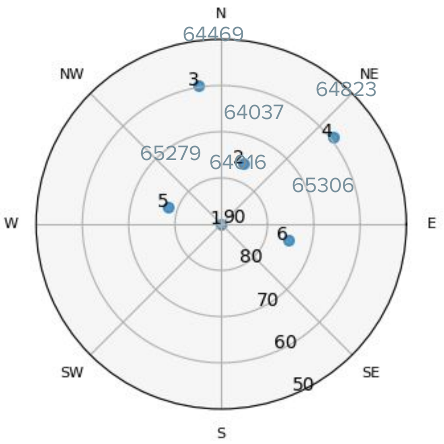
Beams

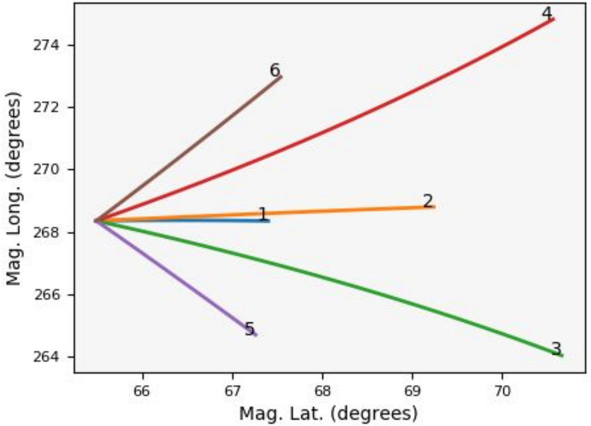
- Six beams chosen to maximize signal quality.
- Placement chosen to maximize the area measured.

Codes

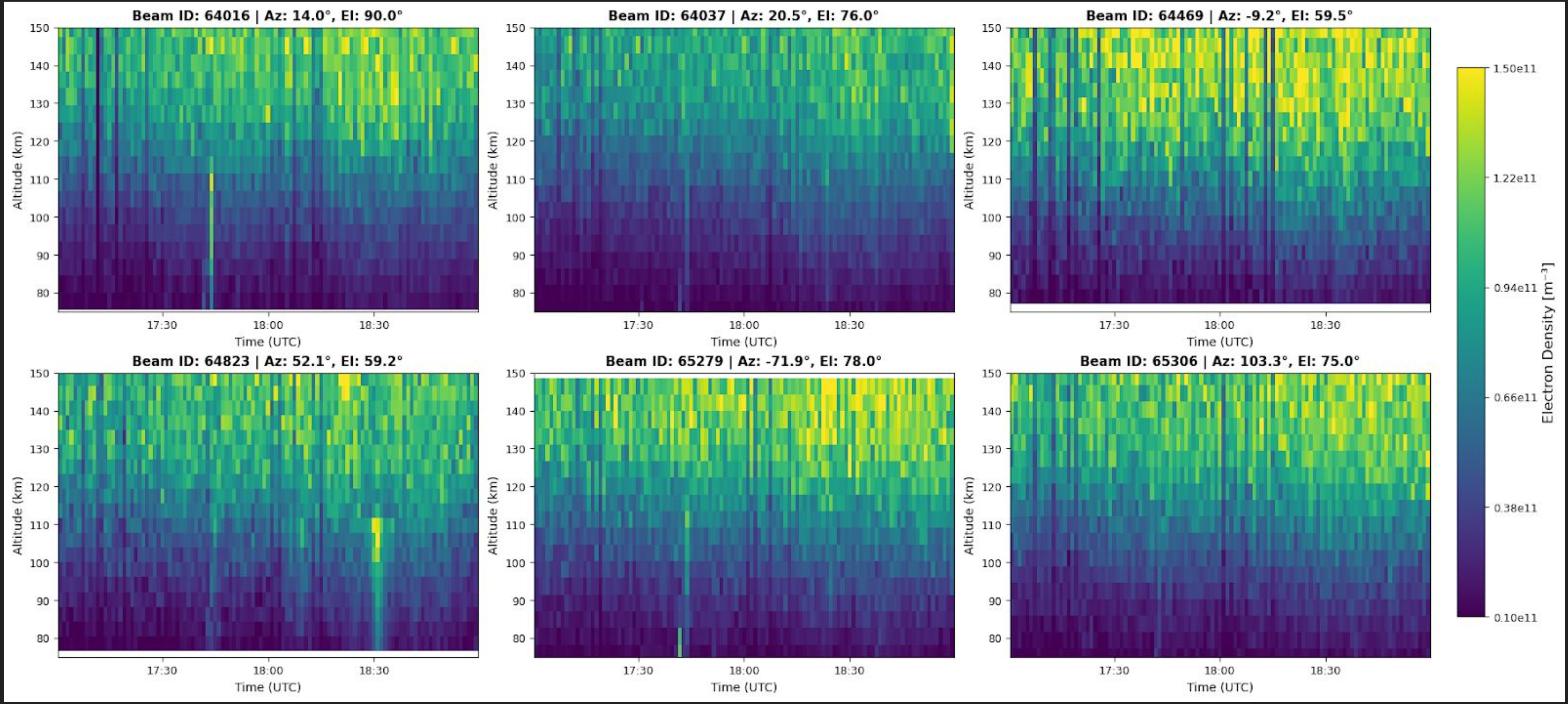
- Long pulse (F-Region)
- Alternating code (E-Region)
- Barker Code (D-Region)

used to support investigation of neutral winds.



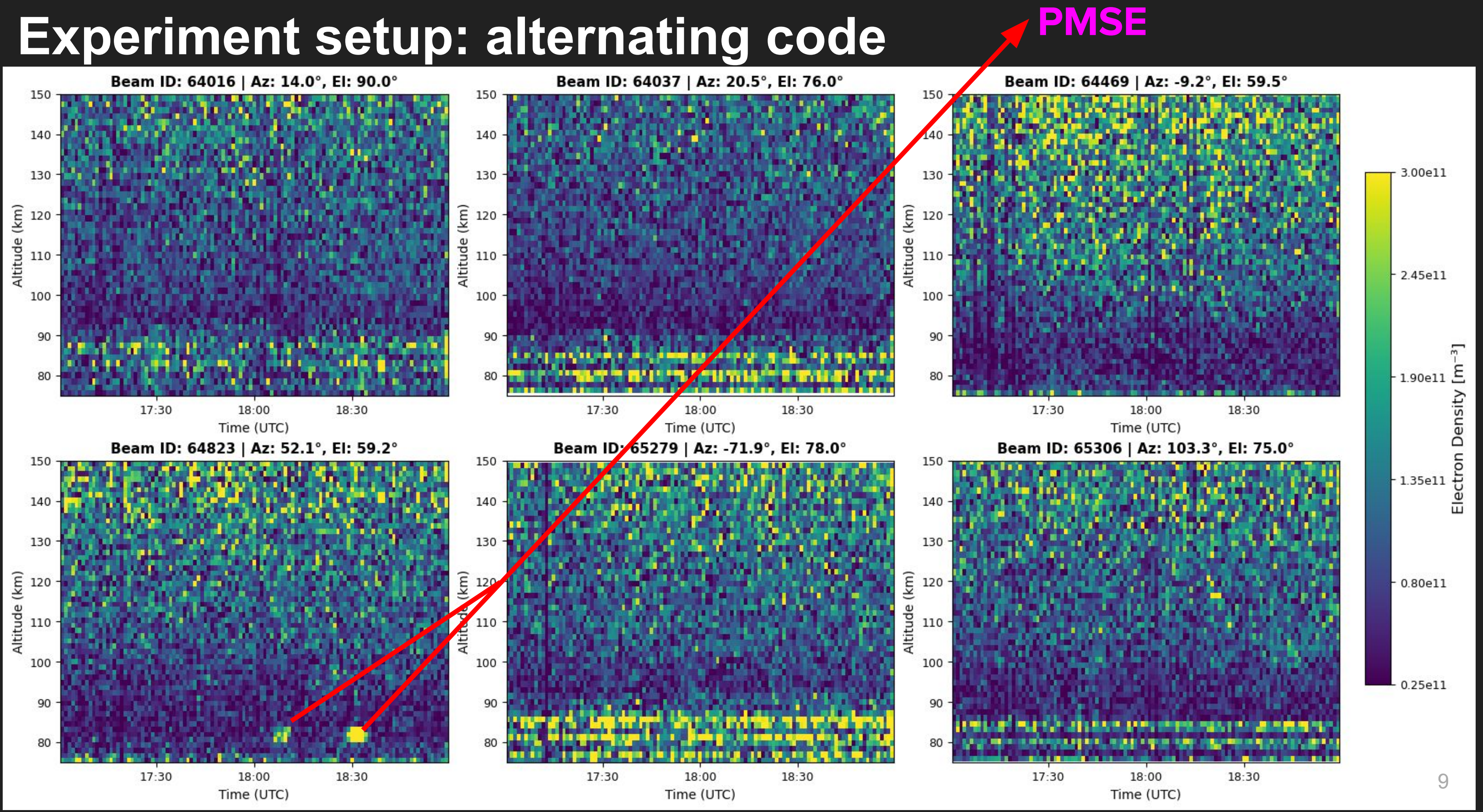


Experiment setup: long pulse electron density

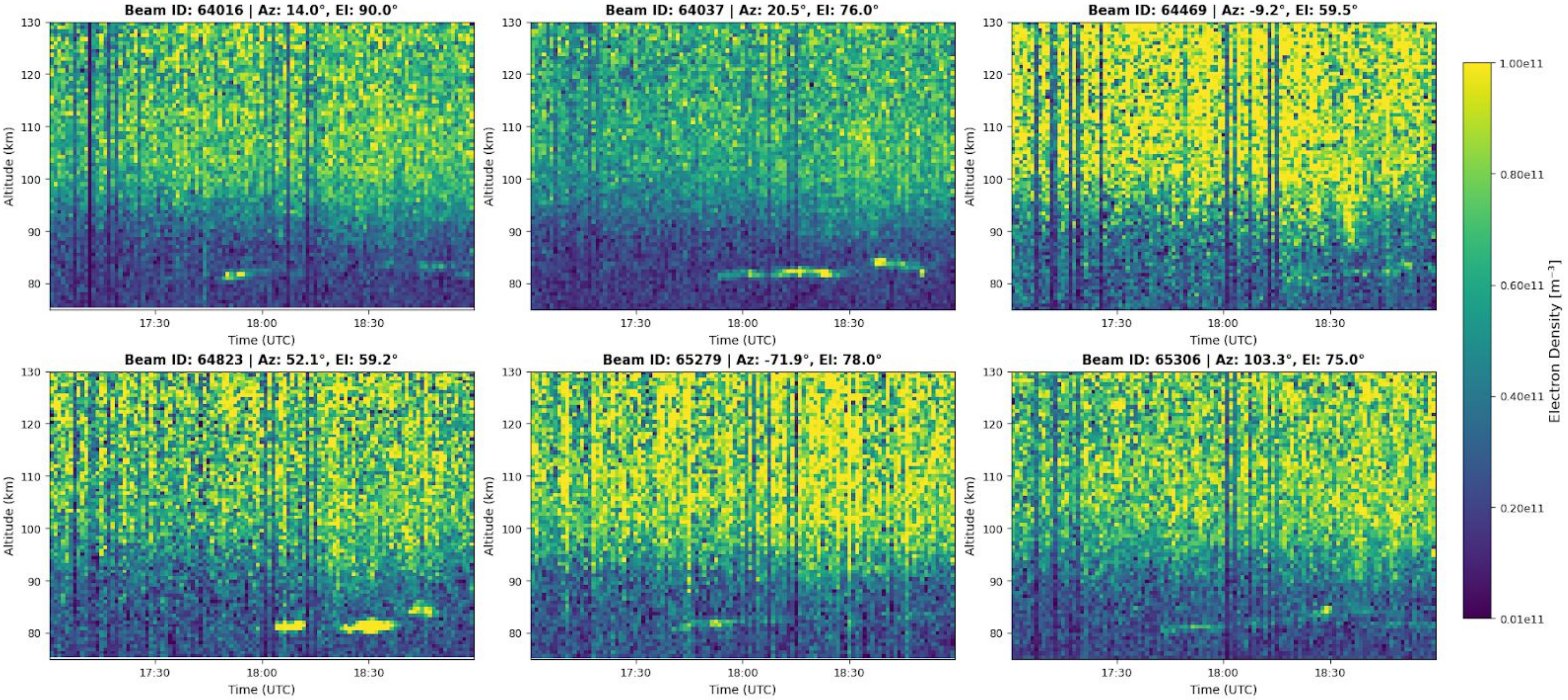


Electron density profile plotted from 80–150 km on July 22, 2025, 17–19 UT.

Experiment setup: alternating code

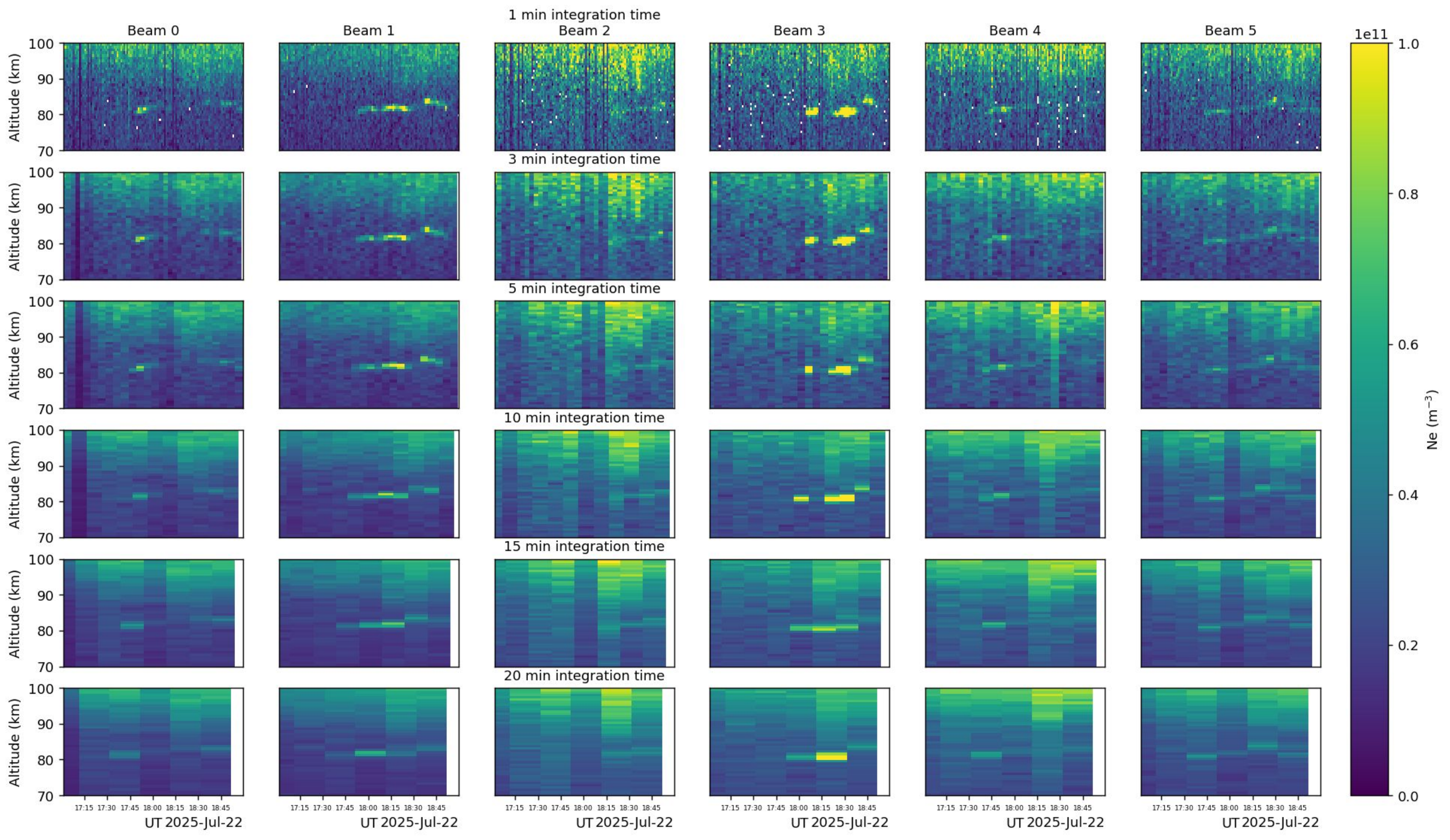


Experiment setup: barker code electron density

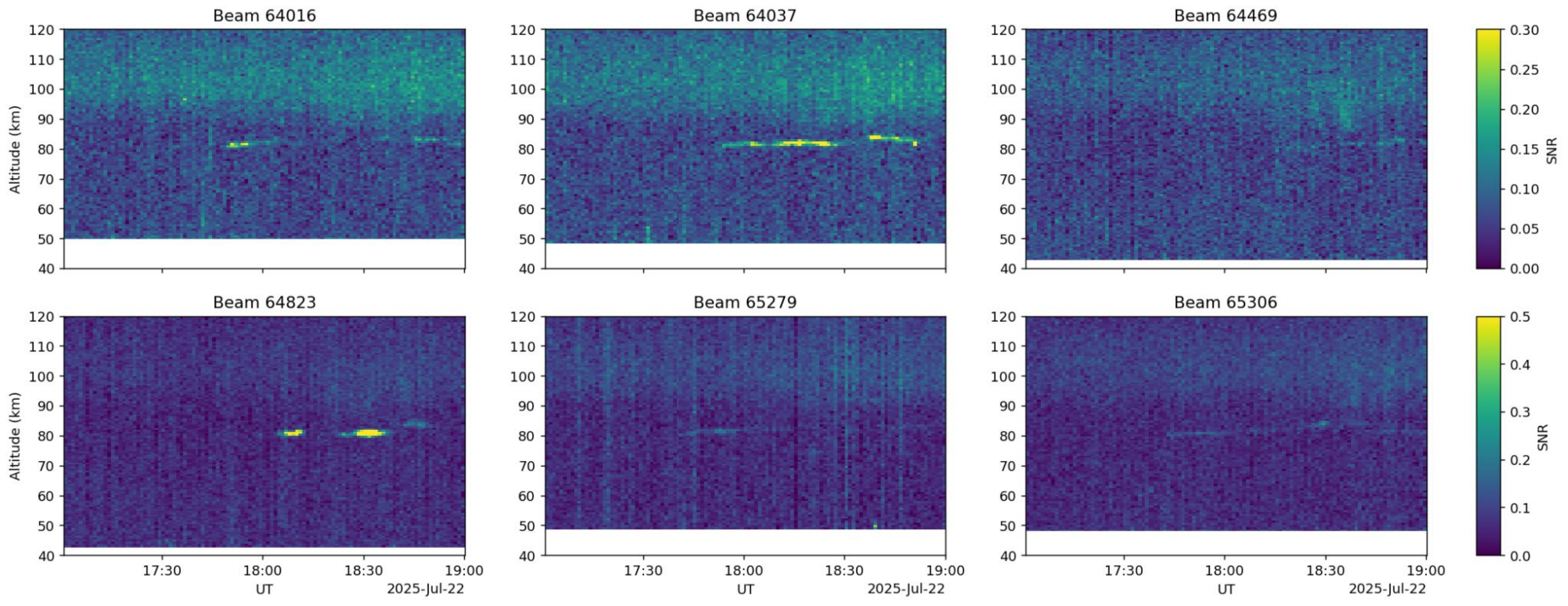


Bright localized enhancements below 90 km indicate the presence of Polar Mesospheric Summer Echoes (PMSE)

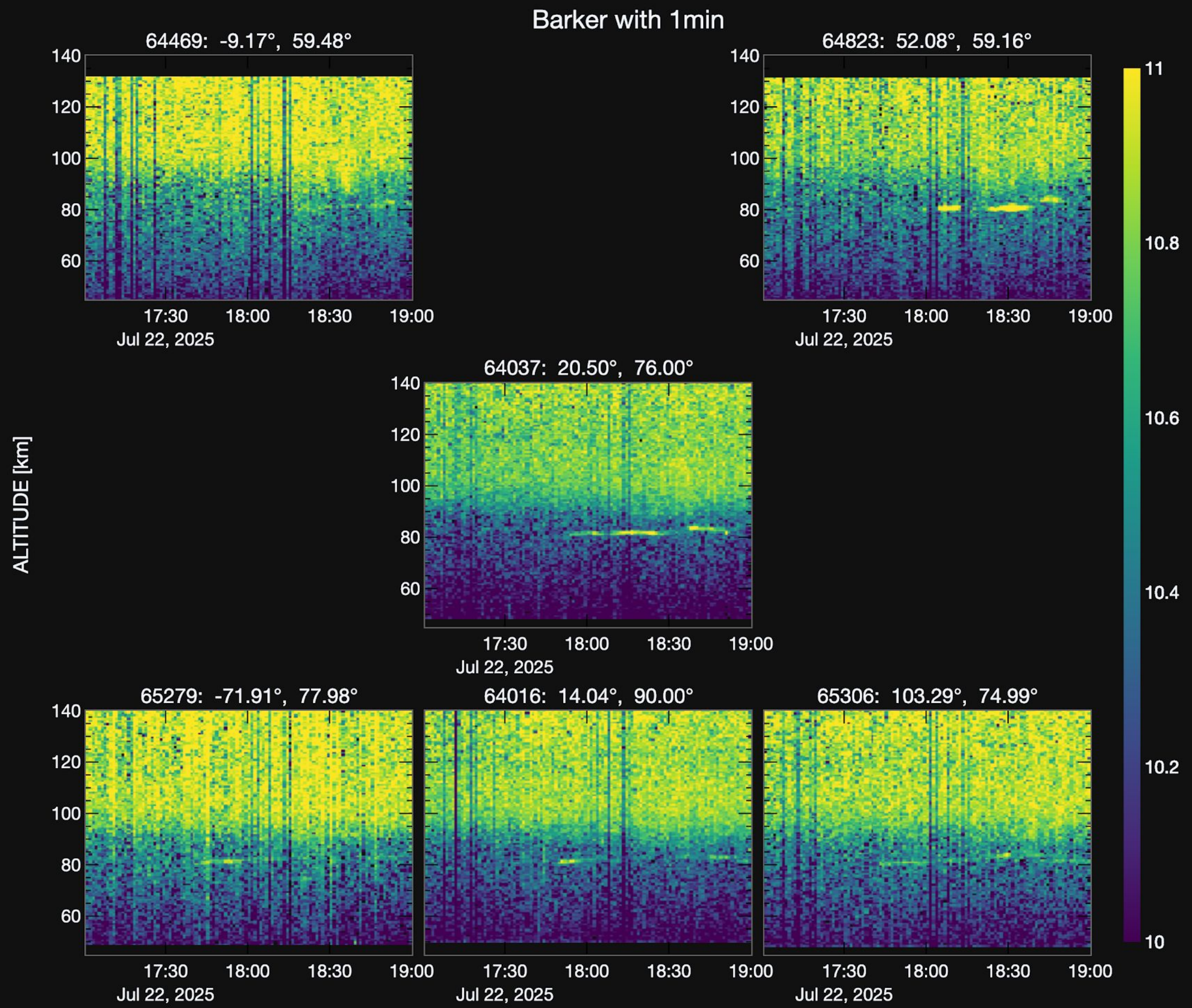
Experiment setup: integration time comparisons

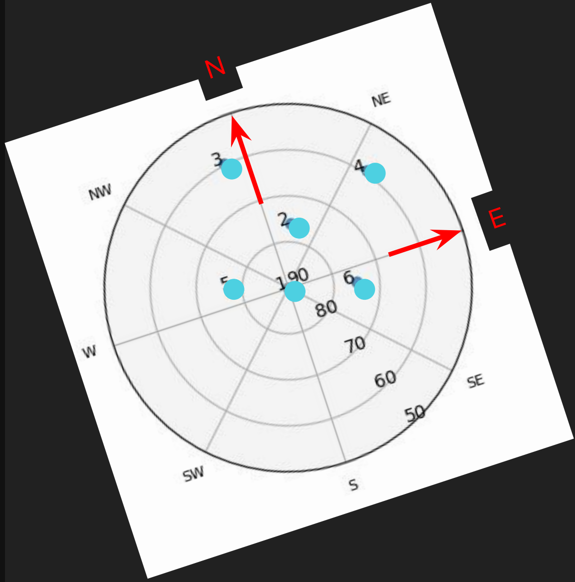


Barker Code Signal-to-Noise Ratio

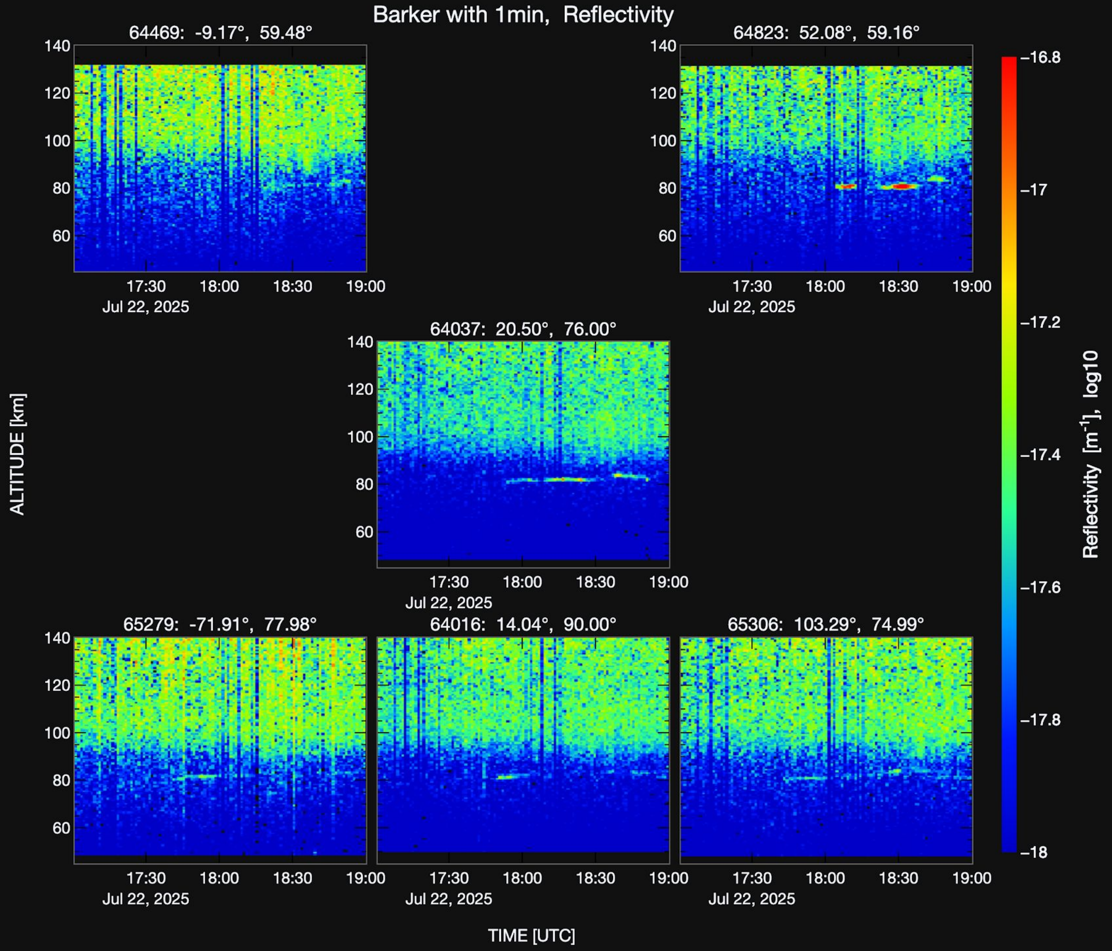


Observations:





Reflectivity



$$\eta = \frac{P_r}{P_t}\frac{\sigma_e}{\tau_p k_{sys}}$$

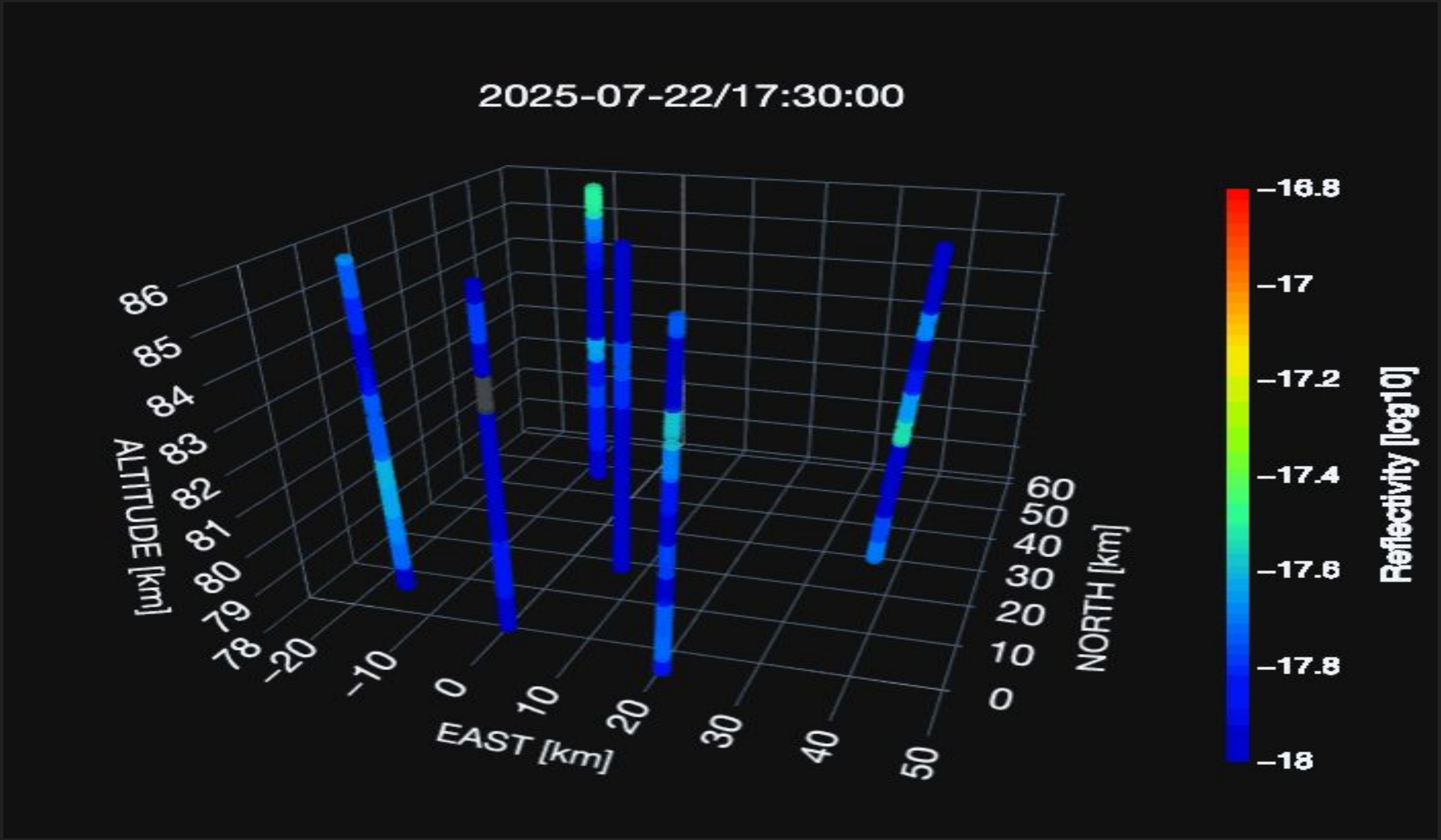
$$\eta \approx \frac{N_e \sigma_e}{1 + T_e/T_i}$$

$$\frac{T_e}{T_i} \approx 1$$

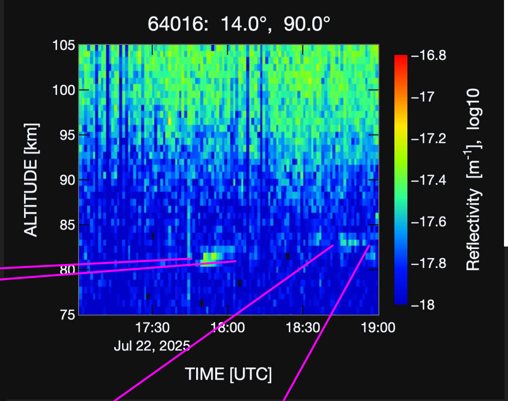
$$\eta \approx \frac{1}{2} N_e \sigma_e$$

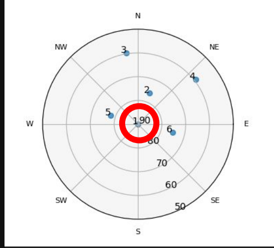
$$\eta \approx (0.5 \cdot 10^{-28}\mathrm{m}^2) \cdot N_e$$

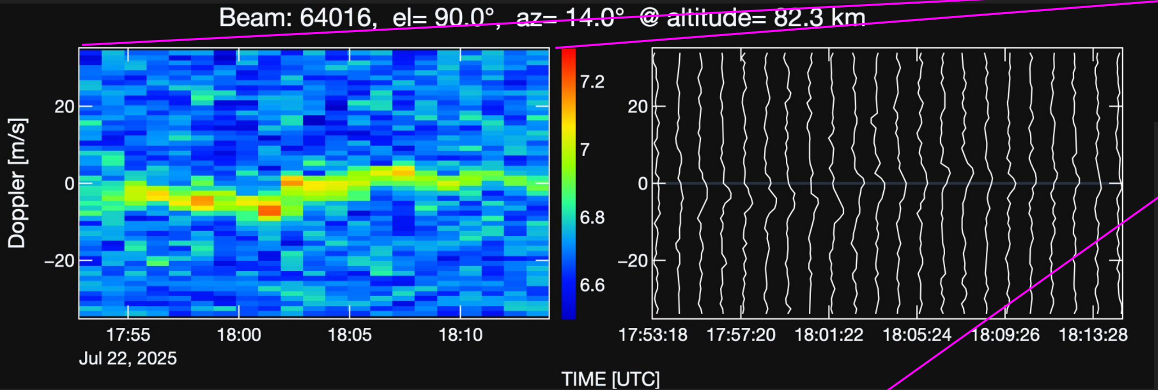
Nicolls et al.


2025-07-22/17:30:00
ALTITUDE [km]
86
85
84
83
82
81
80
79
78
EAST [km]
−20
−10
0
10
20
30
40
50
NORTH [km]
0
10
20
30
40
50
60
Reflectivity [log10]
−16.8
−17
−17.2
−17.4
−17.6
−17.8
−18

Doppler Spectra – Straight up (90°)

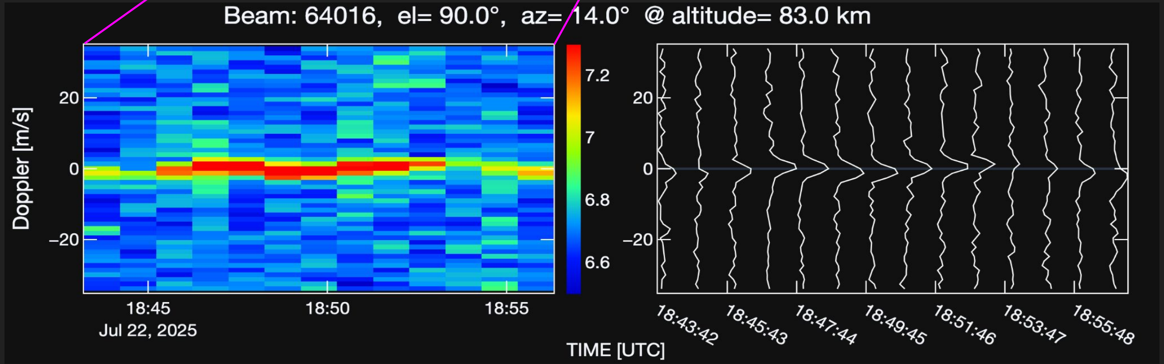






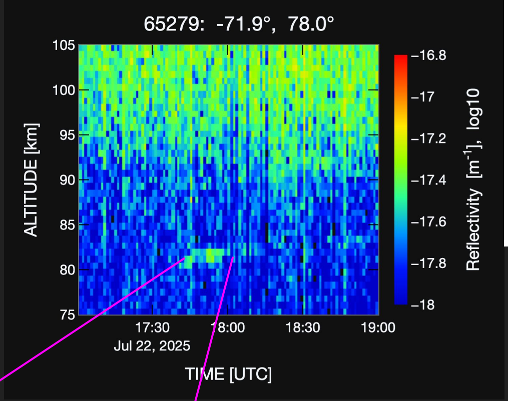
Pulse-to-pulse mode

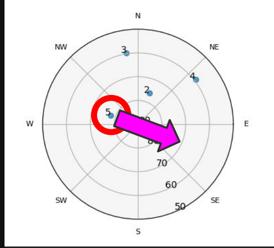
No apparent vertical motion!

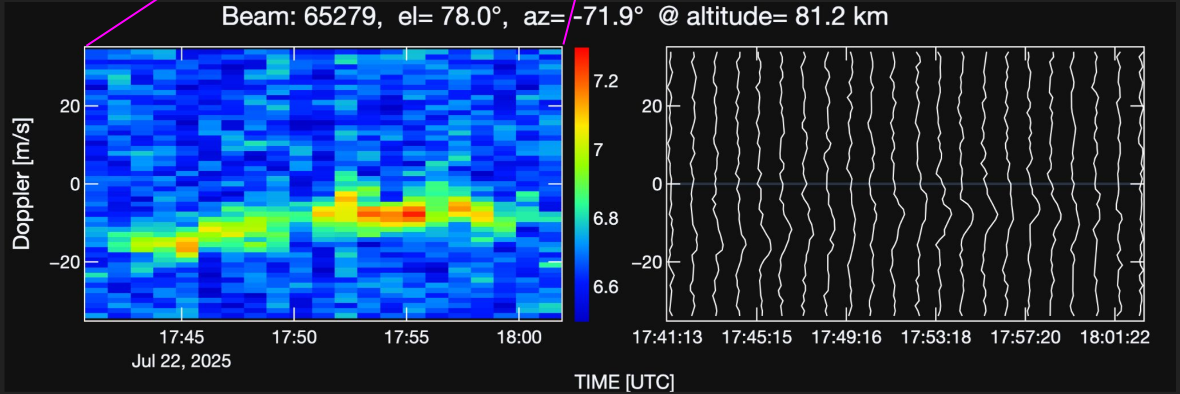


Doppler Spectra – North-West direction

~ 8 m/s towards from NW direction

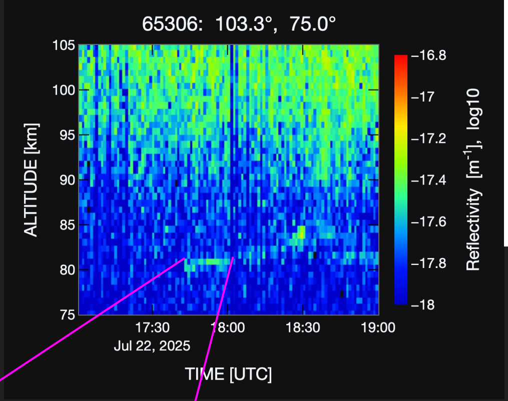


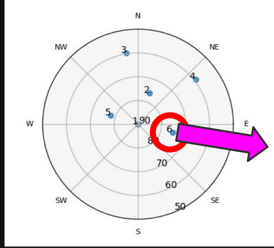


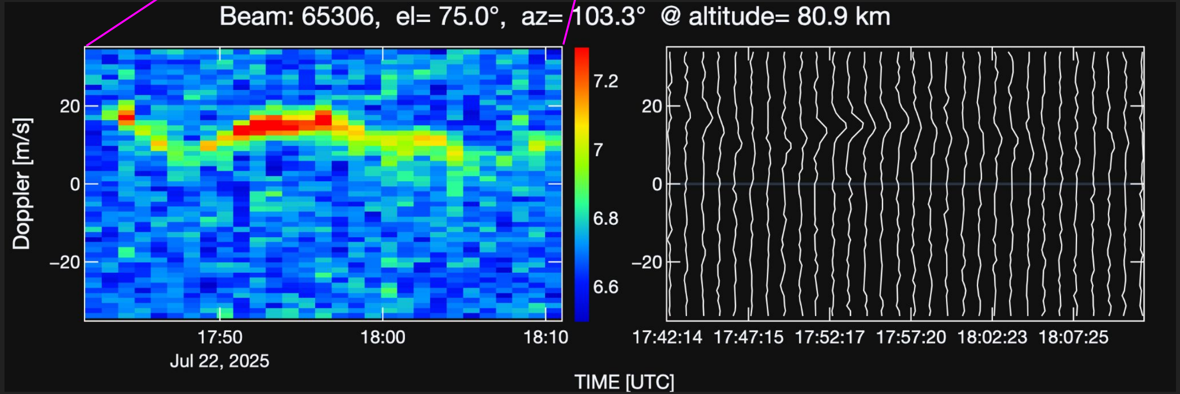


Doppler Spectra – East direction

~ 15 m/s away from East direction







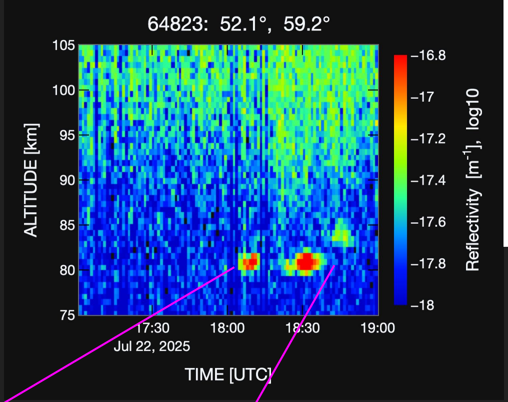
Doppler Spectra – North-East direction

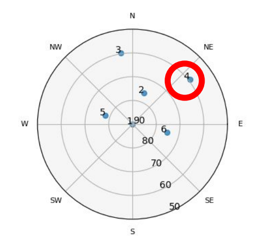
- Broad band of velocities
- Turbulence!
- Estimated energy dissipation rates,

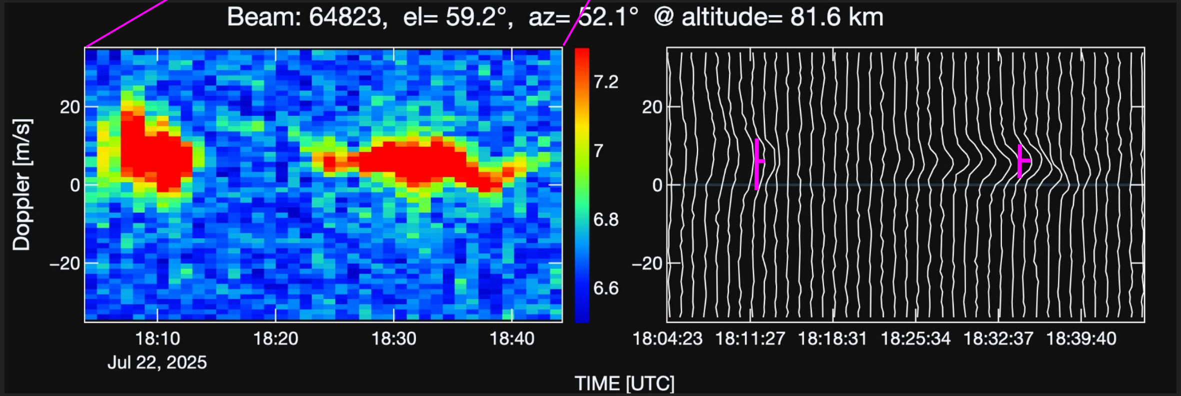
$$\epsilon \approx 9.8\,\sigma_v^2\,\mathrm{mW/kg}$$

Nicolls et al (2009)

ε = ~ 0.15 – 0.26 W/kg



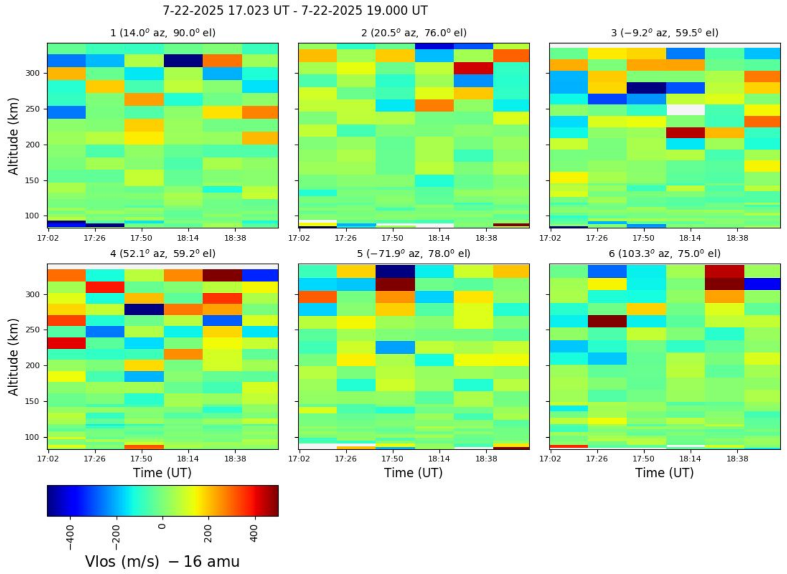




Fitting Vector Velocities

Beam Index

$$\underbrace{\begin{bmatrix} \hat{r_{1,x}} & \hat{r_{1,y}} & \hat{r_{1,z}} \\ \hat{r_{2x}} & \hat{r_{2,y}} & \hat{r_{2z}} \\ \hat{r_{3,x}} & \hat{r_{3,y}} & \hat{r_{3,z}} \\ \hat{r_{4,x}} & \hat{r_{4,y}} & \hat{r_{4,z}} \\ & \dots & \end{bmatrix}}_{\text{M}} \underbrace{\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix}}_{\mathbf{v}} = \underbrace{\begin{bmatrix} v_{los,1} \\ v_{los,2} \\ v_{los,3} \\ v_{los,4} \\ \dots \end{bmatrix}}_{\mathbf{p}}$$



M$\mathbf{v}$ **= p ?**

Least squares soln (M has >= 3 lin ind rows) – solve:
$M^T M\mathbf{v} = M^T\mathbf{p}$

Why? Note ($M^T(M\mathbf{v} - \mathbf{p}) = \mathbf{0}$)

$\mathbf{v}_{\mathbf{best}} = (M^T M)^{-1}\mathbf{p}$

Or with known covariance matrix R:
$M^T R^{-1} M\mathbf{v} = M^T R^{-1}\mathbf{p}$

Let $H = (M^T R^{-1} M)^{-1} M^T R^{-1}$

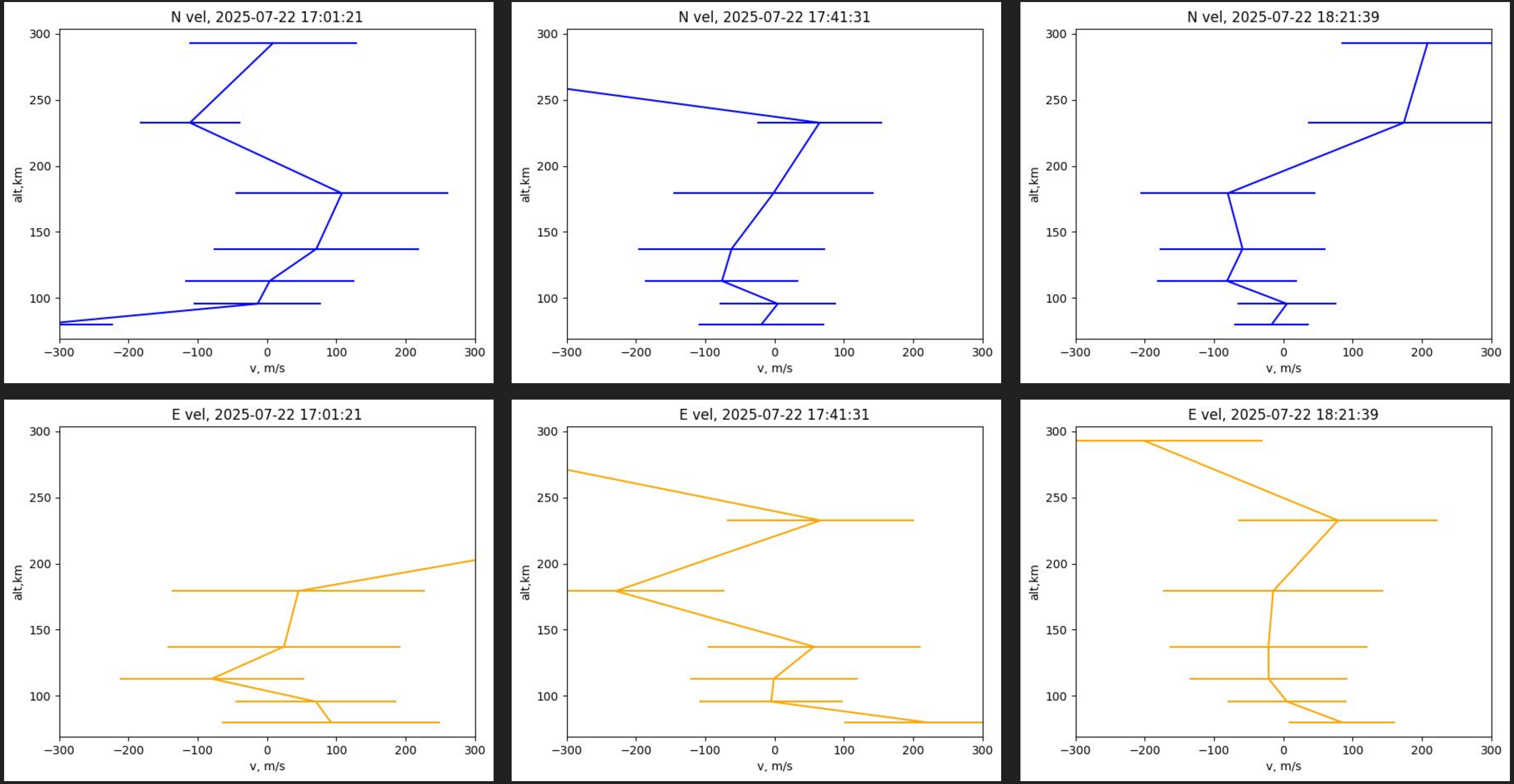
Then $\mathbf{v}_{best} = H\,\mathbf{p}$, also

$Var(\mathbf{v}_{best}) = H\,\mathbf{R}\,H^T$

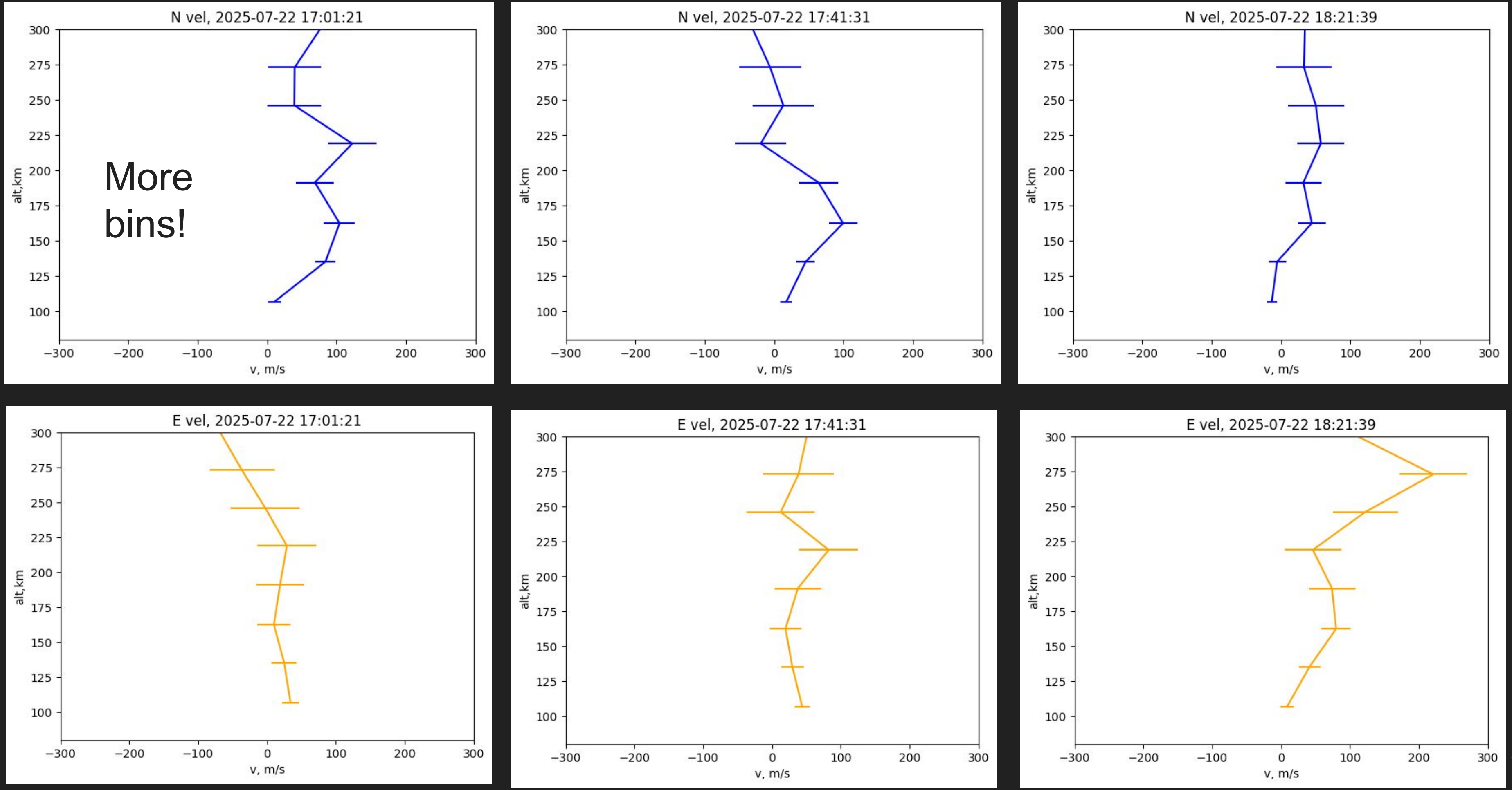
Fitting Vector Velocities

- Use longest integration time (20 min)
- Neglect variation in lat and lon, and vertical velocity
- Quantile bin by altitude
- Find least-squares solution to linear system

Observations: Vector Velocities (from alternating codes)

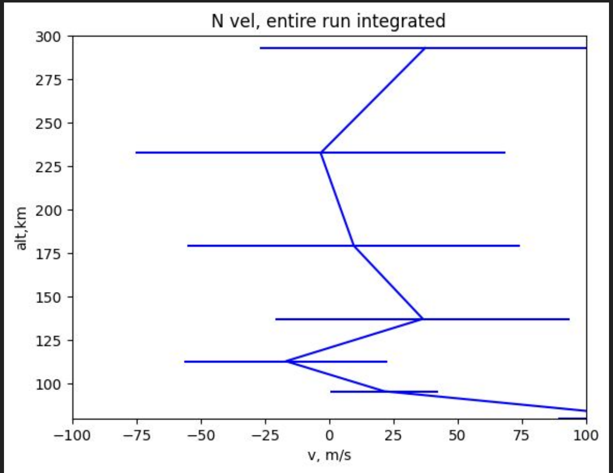


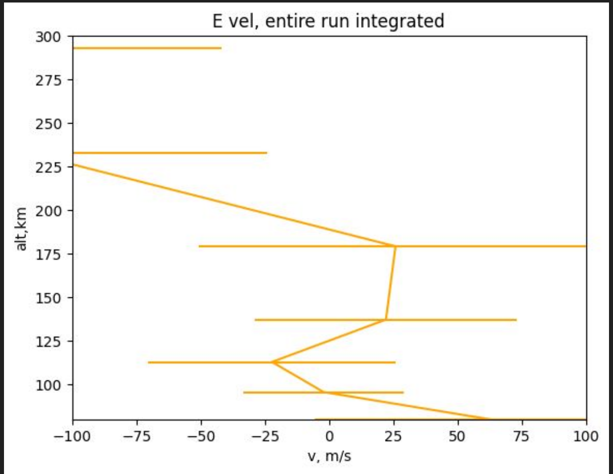
Observations: Vector Velocities (from Long Pulse)



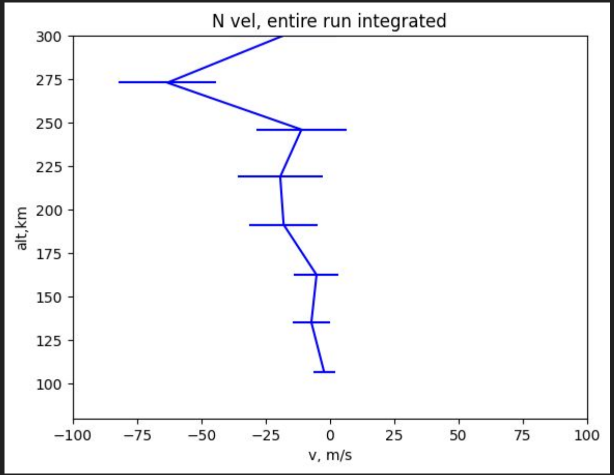
Time-integrated Velocity Estimates

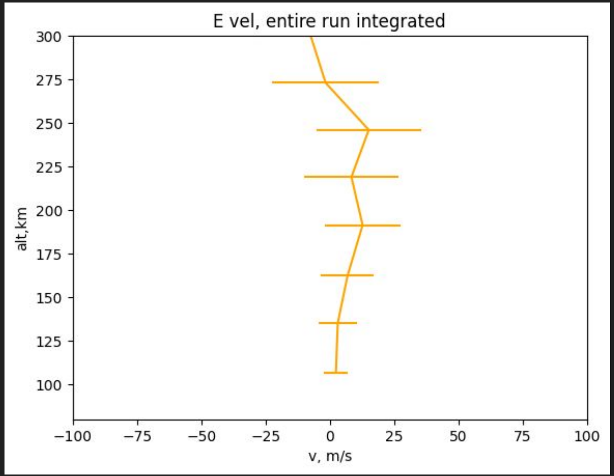
AC:





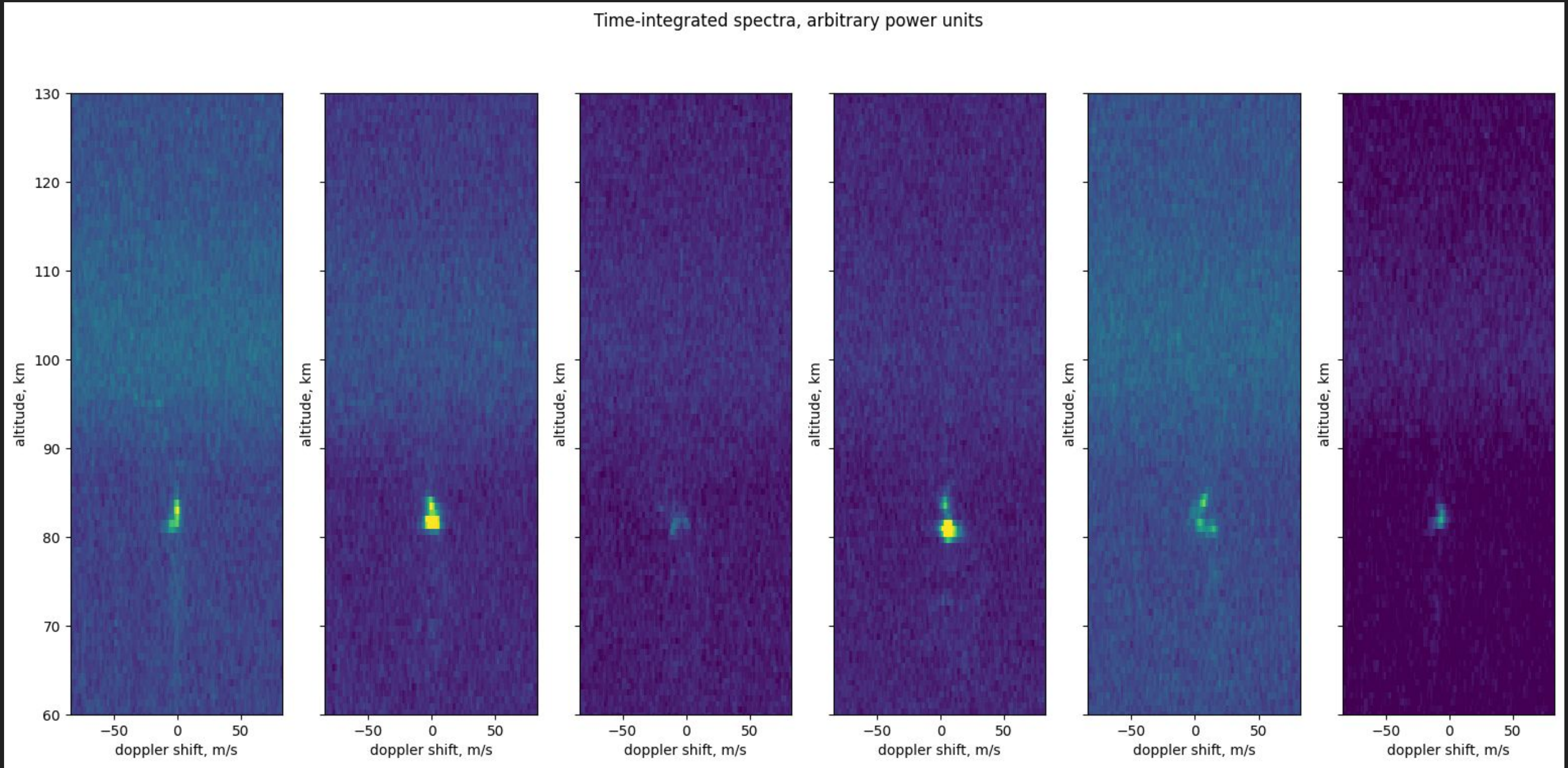
LP:





Estimating velocity from Barker Code Power Spectra

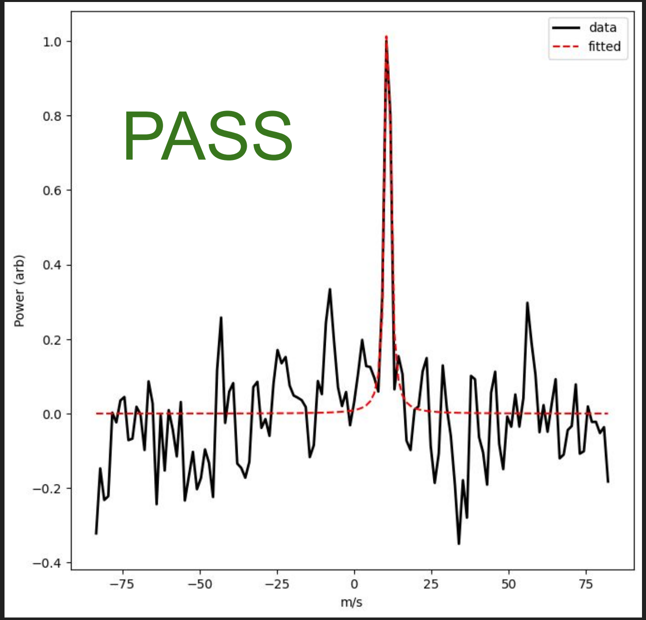
Easily detectable E-region, but far too hot!



Estimating velocity from Barker Code Power Spectra

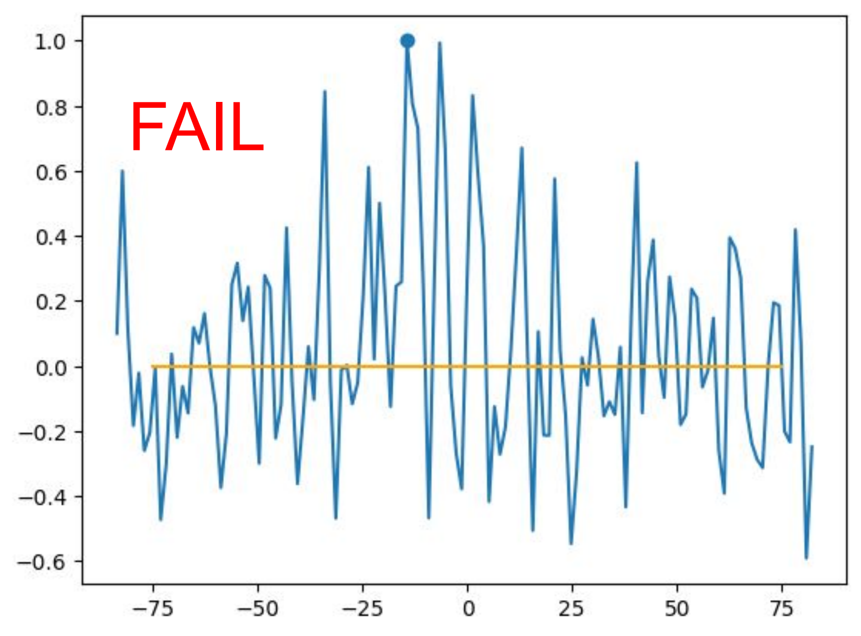
- “Chi by eye” - fitter sometimes showed high confidence for poor fits, so we filtered inputs by height of largest spike above noise floor

Power, arbitrary



Doppler velocity, m/s

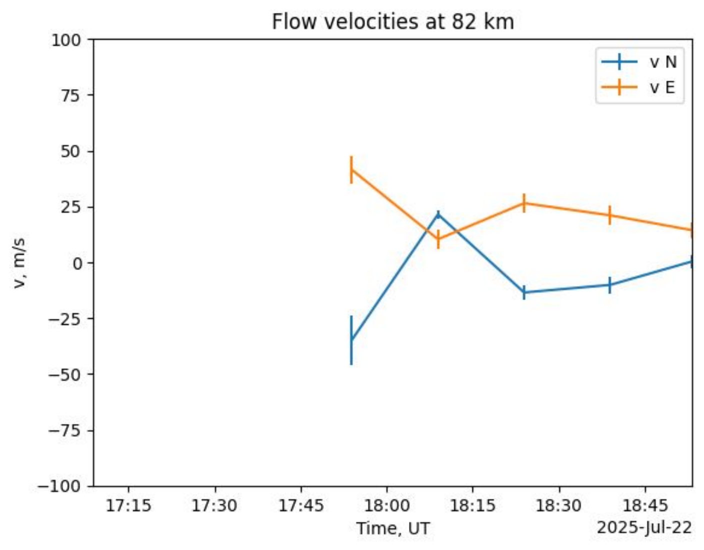
Power, arbitrary



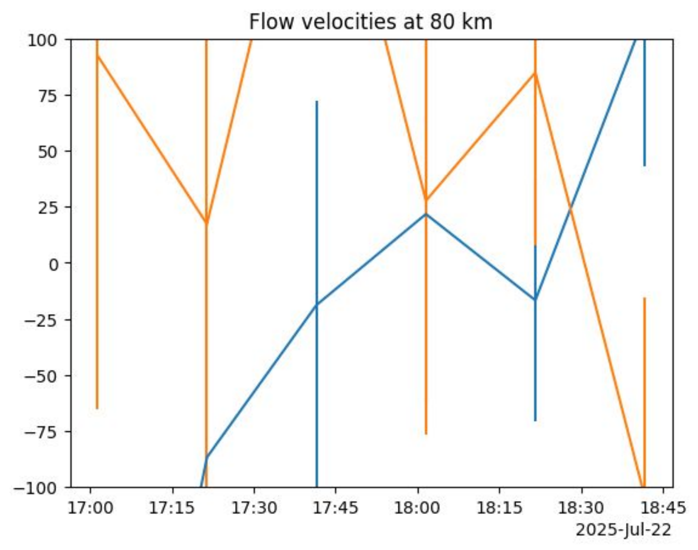
Doppler velocity, m/s

Velocities at ~80 km

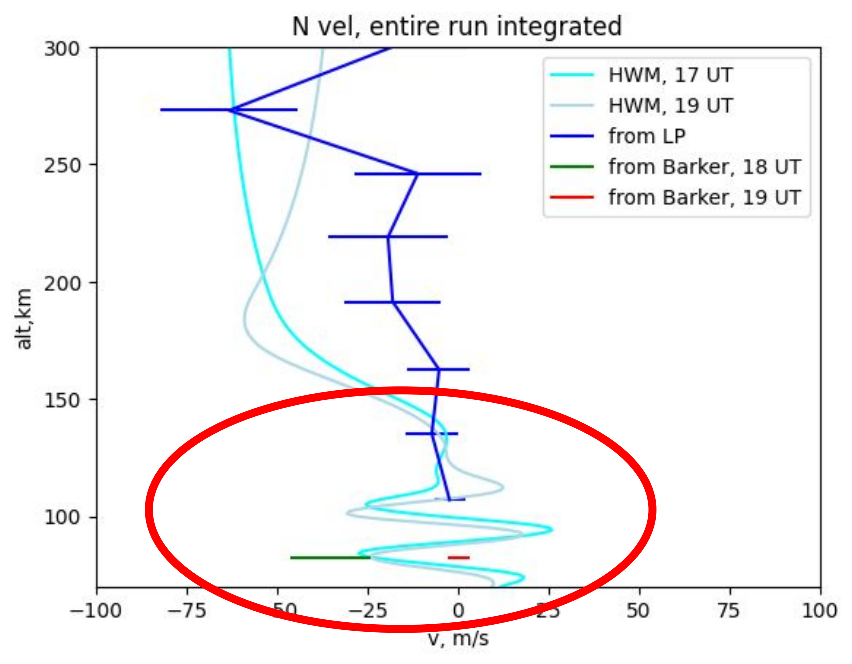
Barker Spectra:

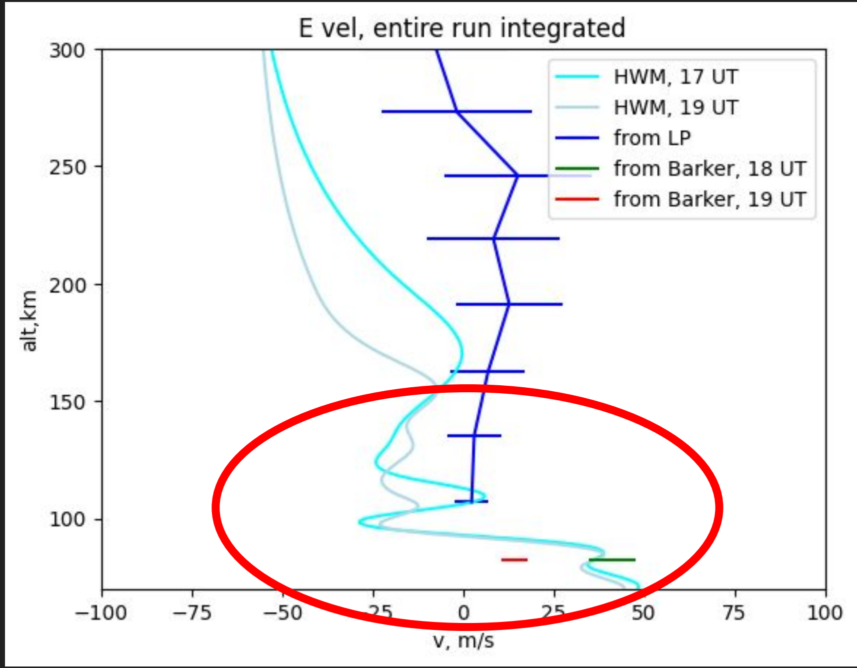


AC:



Comparison with HWM14





- Good agreement at low (neutral dominated) altitudes

Final Comparison of Velocities at ~80km

- Visual observation of the electron density plots: Eastward Velocity
- Doppler estimated velocity: Eastward
- Spectra estimated velocity: Eastward
- HWM14 estimated velocity: Eastward

Conclusion

1. **Detection of PMSE Signatures**
   - Using **Barker code** (D-region), **bright localized electron density enhancements below 90 km** were observed.
   - These enhancements are consistent with **PMSE (Polar Mesospheric Summer Echoes)**, which are known to appear in this altitude range during summer.
2. **Calculation of reflectivity of PMSEs**
   - Using the reflectivity equation derived in Nicholls et al. the reflectivity is calculated from the electron density measurements to give a true measure/view of the PMSEs
3. **Estimating neutral wind velocities**
   - AC-derived vector velocities were too noisy to be useful
   - LP-derived vector velocities were more reliable but have a higher minimum altitude
   - Barker spectra-derived vector velocities provided a reliable single-altitude data point
   - At low altitudes, flow data were consistent with HWM14 and qualitatively consistent with visible proper motion

Compared the neutral wind velocities estimated using; visual observation of electron density, doppler shift, spectra, HWM14. Found that all were consistent with eastward movement.

References

Nicolls, M. J., C. J. Heinselman, E. A. Hope, S. Ranjan, M. C. Kelley, and J. D. Kelly (2007), Imaging of Polar Mesosphere Summer Echoes with the 450 MHz Poker Flat Advanced Modular Incoherent Scatter Radar, *Geophys. Res. Lett.*, 34, L20102, doi:10.1029/2007GL031476.

Sakanoi, Kazuyo & Murayama, Yasuhiro & Collins, Richard & Mizutani, Kohei. (2007). Characteristics of aerosol in the polar mesosphere derived from Rayleigh lidar observations. Journal of the National Institute of Information and Communications Technology. 54. 47-55.

Sapkota, Rajendra & Sharma, Puneet & Mann, Ingrid. (2022). Comparison of Deep Learning Models for the Classification of Noctilucent Cloud Images. Remote Sensing. 14. 2306. 10.3390/rs14102306.

Nicolls, Kelley, Varney, Heinselman (2009), Spectral observations of polar mesospheric summer echoes at 33 cm (450 MHz) with the Poker Flat Incoherent Scatter Radar. 10.1016/j.jastp.2008.04.019

Thank you!