Group2BestGroup: Final Presentation

“Measurement of Neutral Wind Velocities in the E-region”

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Table of Contents

- Experiment Objectives
- Theory
- Radar Set-up and Operations
- Data Overview
- Results
    - Ion Velocity Vectors
    - Electric Fields
    - Neutral Winds
    - Ion-Neutral Collision Rate Discussion
- Conclusions and Outlook

Experiment Objectives

- Primary objective is *E* region neutral wind calculations
  - Employ technique articulated by Heinselman and Nicolls, *Radio Science*, 2008
  - Provides basis for comparison/validation of neutral wind calculations from other sources (such as UAF meteor radar)
- Secondary objective, manifest through measurement technique, is calculation of *F* region electric field
- Measurement of upper atmosphere dynamics (e.g. atmospheric tides, gravity waves) is important for aeronomy and climate research

Theory*

- Starting point is the steady-state ion momentum equation given by:

$$0 = \nu_i(z)\left[\mathbf{u}(z) - \mathbf{v}(z)\right] + \frac{\Omega}{B}\mathbf{v}(z) \times \mathbf{B} + \frac{\Omega}{B}\mathbf{E} \qquad (1)$$

where ν_i = ion-neutral collision frequency, $\mathbf{u}$ = neutral gas velocity, $\mathbf{v}$ = ion velocity and Ω = ion gyro frequency

- Dividing through by Ω:

$$\frac{\nu_i(z)}{\Omega}\left[\mathbf{u}(z) - \mathbf{v}(z)\right] + \mathbf{v}(z) \times \frac{\mathbf{B}}{B} + \frac{\mathbf{E}}{B} = 0 \qquad (2)$$

and making use of the fact that ${}^{\nu}/_{\Omega} \ll 1$ at high altitudes yields:

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0 \qquad (3)$$

- Eqn (3) allows for calculation of $\mathbf{E}$ field from measurement of ion velocity in the *F* region. Conductivity along (near) vertical *B* field lines enables *E* field to map down to *E* region.
- Solving Eqn (2) for $\mathbf{u}$(z) gives:

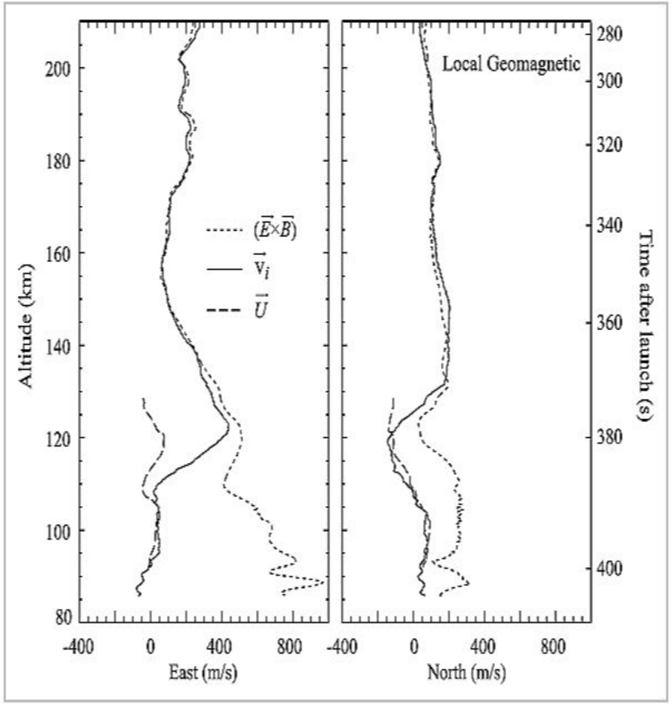
$$\mathbf{u}(z) = \mathbf{v}(z) - \frac{\Omega}{B\nu_i(z)}\left[\mathbf{v}(z) \times \mathbf{B} + \mathbf{E}\right] \qquad (4)$$

* Reference: "A Preliminary Study of the Neutral Wind in the Auroral *E* Region," by A. Brekke & J.R. Doupnik; *Journal of Geophysical Research*, Vol. 78, No. 24, pp 8235 – 8250, December 1, 1973

Theory (cont.)

- Method requires:
  - high electron density
  - high ion-neutral collision rate

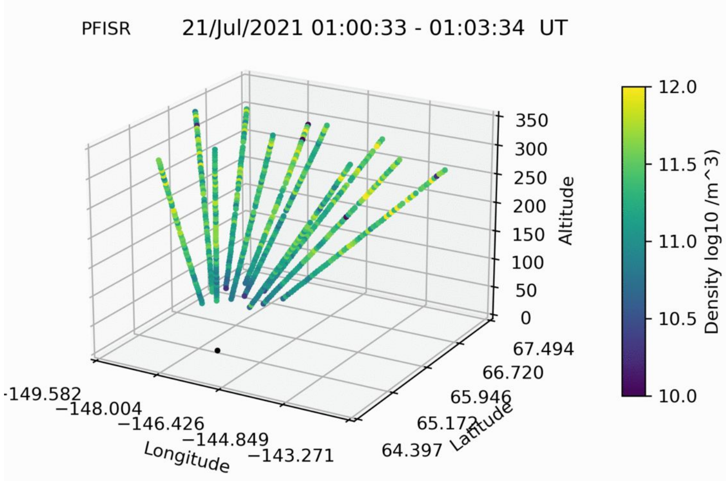
- Ratio of gyro frequency to collision frequency should be a maximum of order 1 (in the altitude range of approximately 120 - 130 km) for a more simplified calculation (detailed in previous slide)

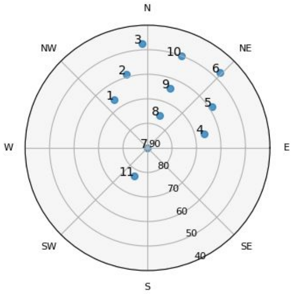


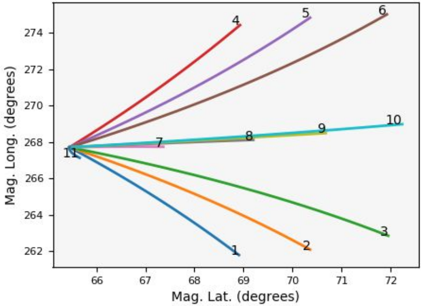
Plot from "Rocket-based measurements of ion velocity, neutral wind, and electric field in the collisional transition region of the auroral ionosphere," by L. Sangelli, et.al., JGR Vol. 114, Issue A4

Radar Set-up and Operations

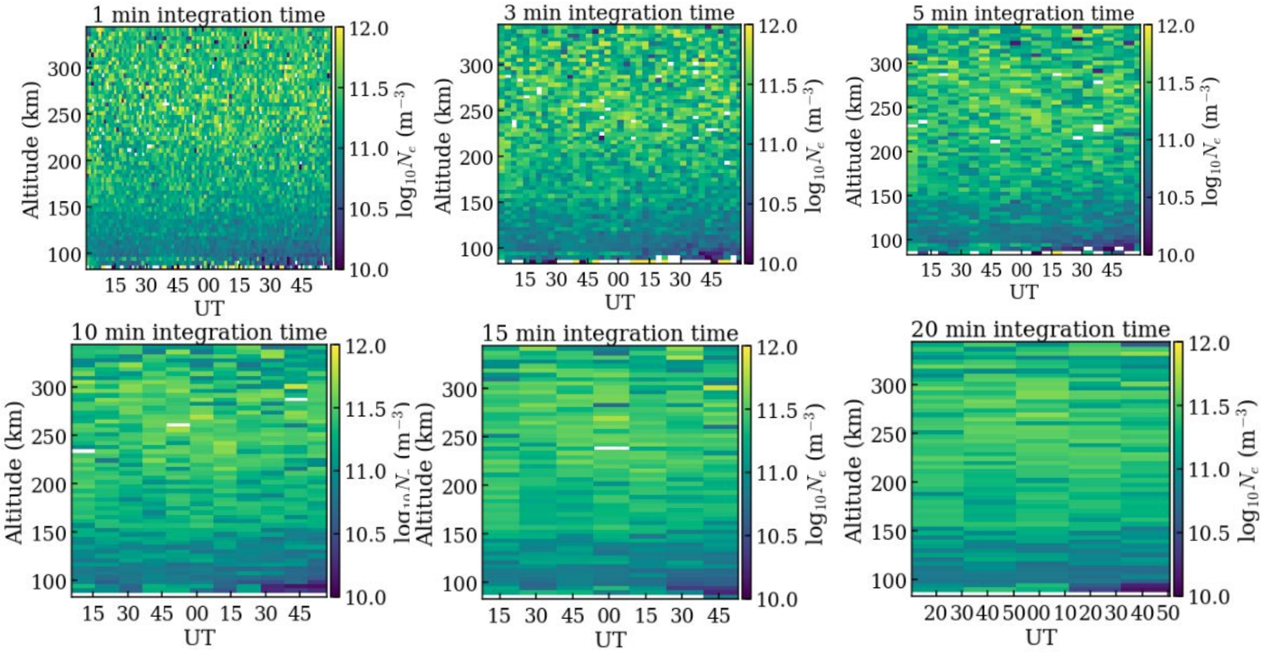
- 11 beams utilized
  - 63197, 63239, 63281, 63365, 63401, 63449, 64016 (vertical), 64037, 64055, 64079, 64157 (upB)
- EWinds4ac1lp.v01
- Cycle of 4 alternating codes and 1 long pulse code
  - AC - E region targeted for electron densities
  - LP - F region targeted for electric fields
- Focused on E and F regions
  - E region: neutral wind velocities can be compared to meteor data
  - F region: electric field demonstration to neglect ion neutral collisions





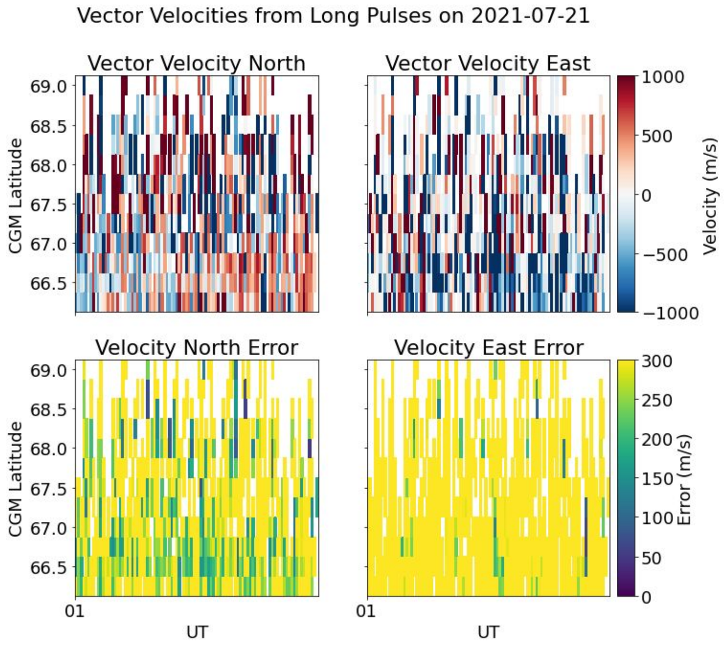


Data Overview - Electron density

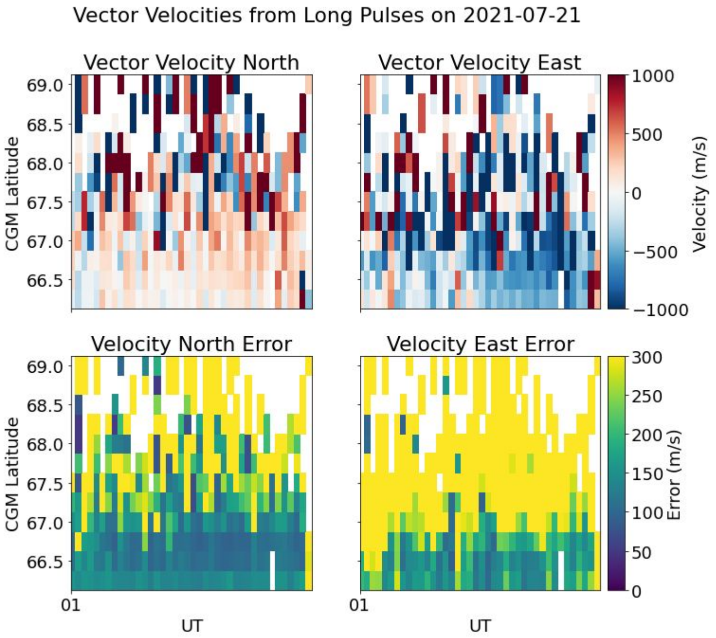


⇒ electron density in the E region may not be large enough to allow meaningful neutral wind calculations

Data Overview- Velocity Vectors



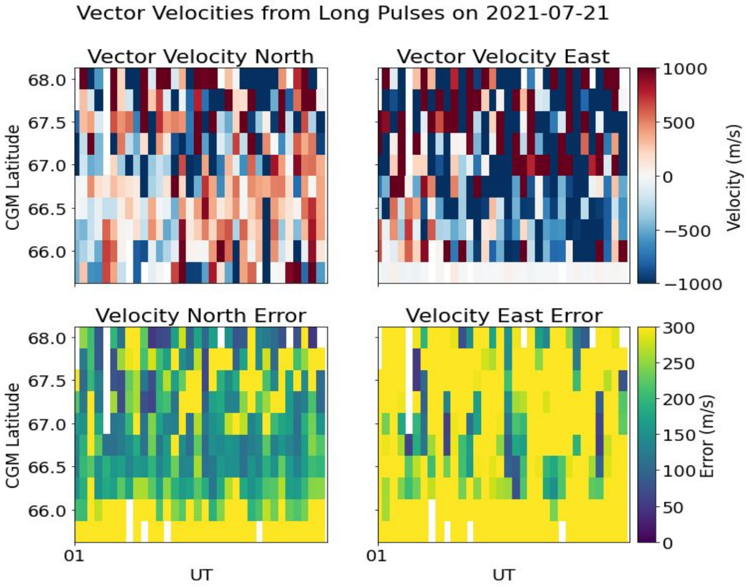
1 min integration time, data taken over 60 s



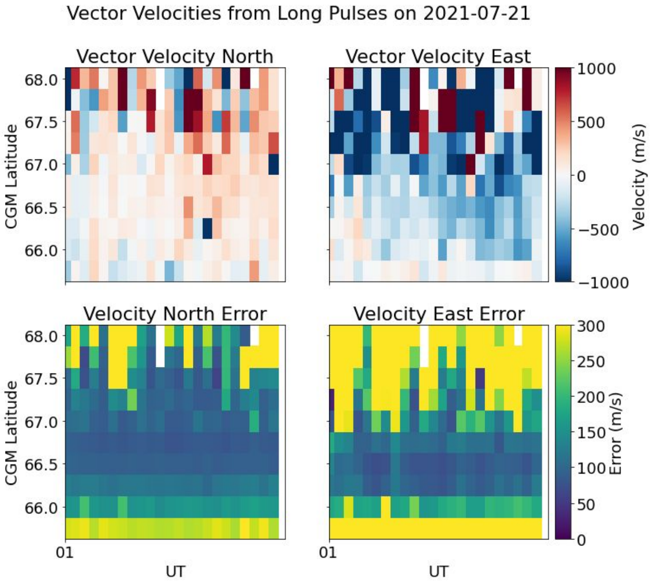
3 min integration time, data taken over 180 s

Over time, more westward velocities are observed, especially at lower latitudes

Data Overview- Velocity Vectors



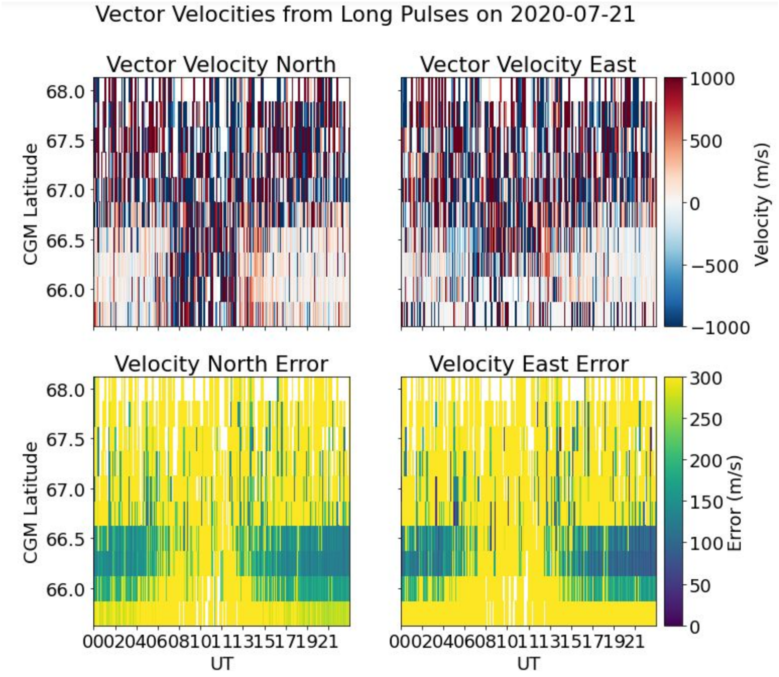
3 min integration time, data taken over 180 s

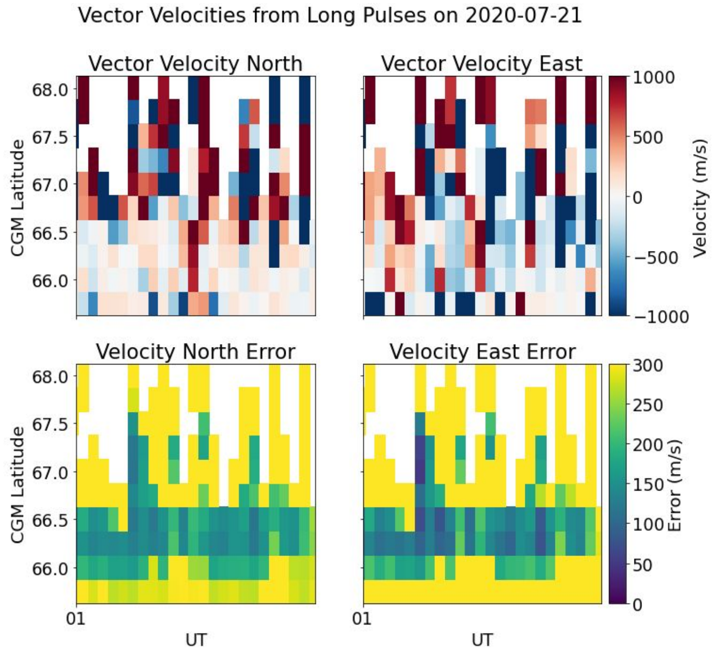


5 min integration time, data taken over 300 s

As integration time increases, data fineness decreases, but quality increases

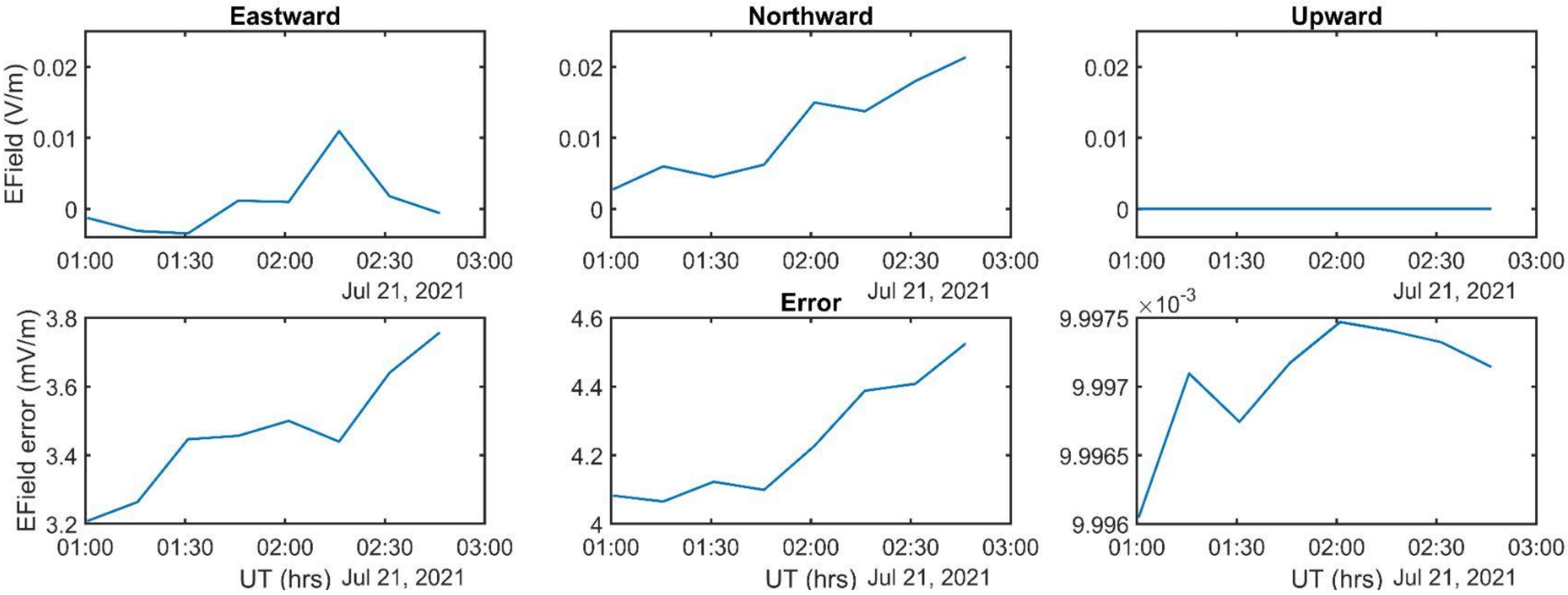
Comparison with Data from 2020





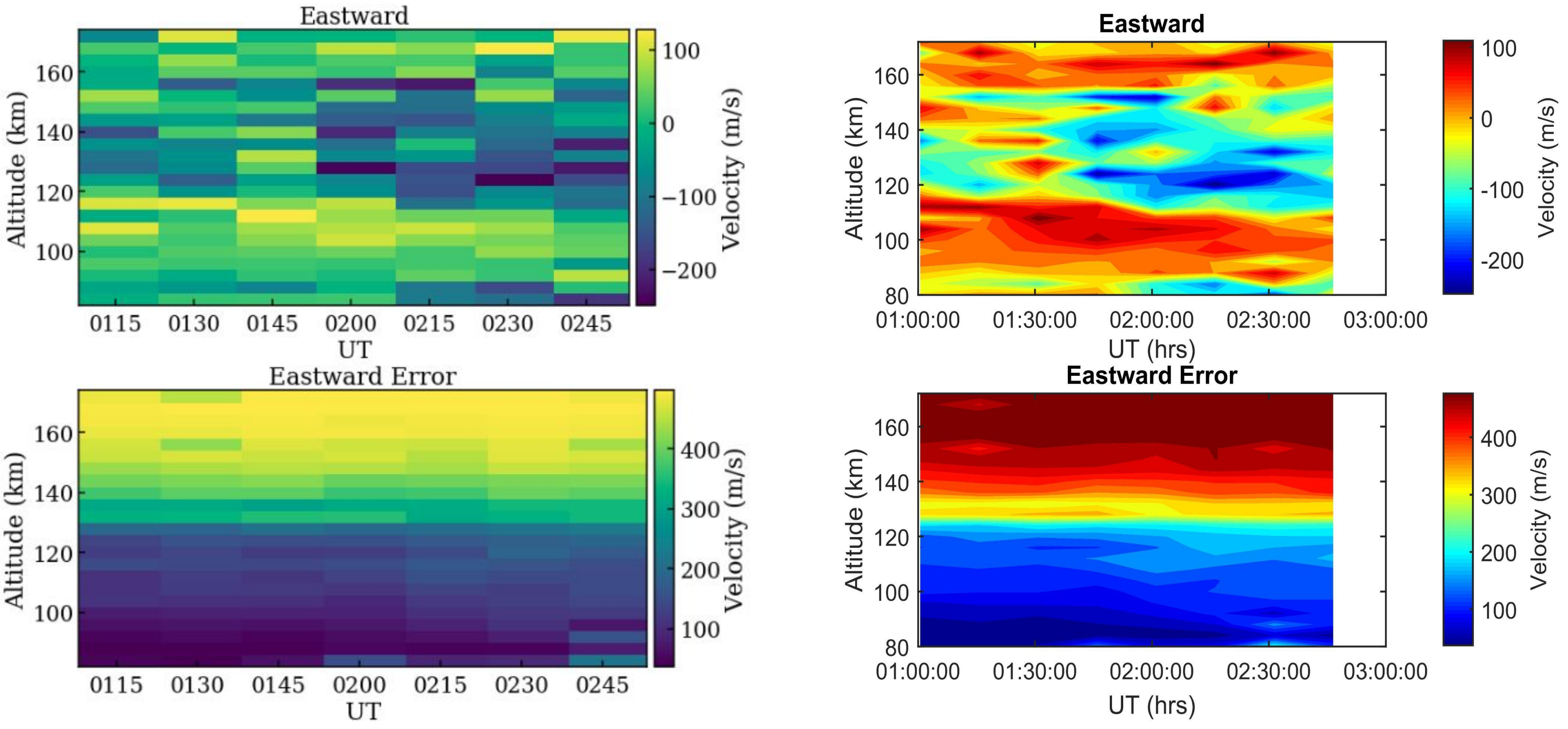
- Same integration time above (5 min, 300 s), figure on the right shows UT 01:00-03:00 section
- The westward tendency was at a slightly higher latitude, potentially due to Earth's latitude, different weather conditions, etc

E Fields

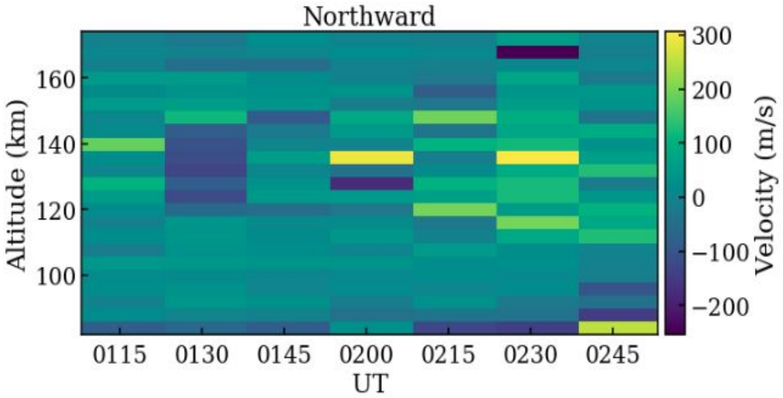


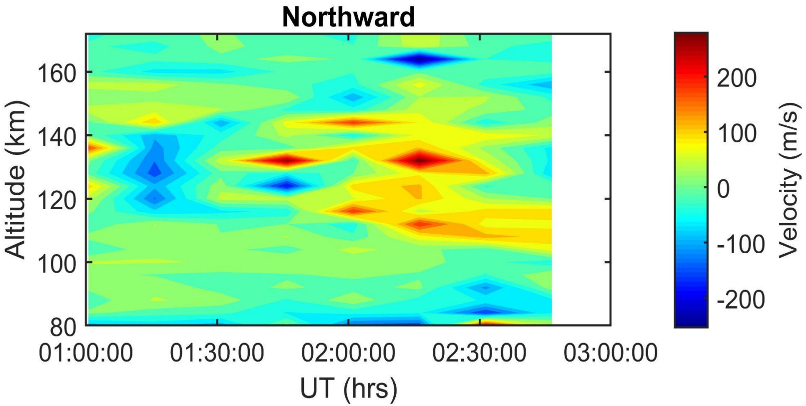
Eastward
Northward
Upward
EField (V/m)
0.02
0.01
0
01:00
01:30
02:00
02:30
03:00
Jul 21, 2021
Error
EField error (mV/m)
3.8
3.6
3.4
3.2
4.6
4.4
4.2
4
×10^-3
9.9975
9.997
9.9965
9.996
UT (hrs)

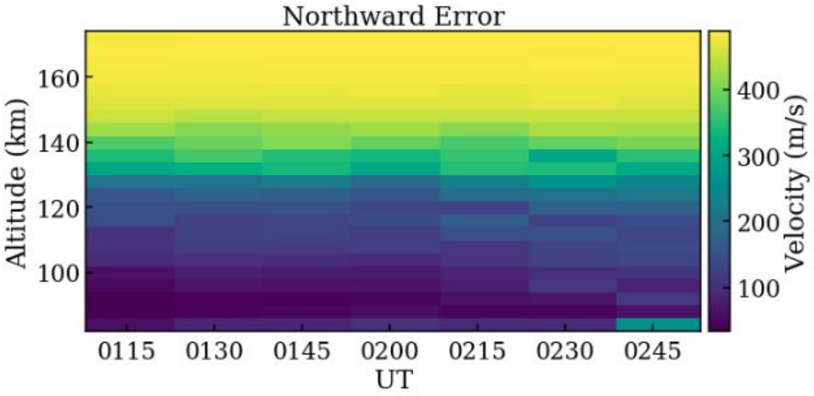
Neutral wind data (Eastward)

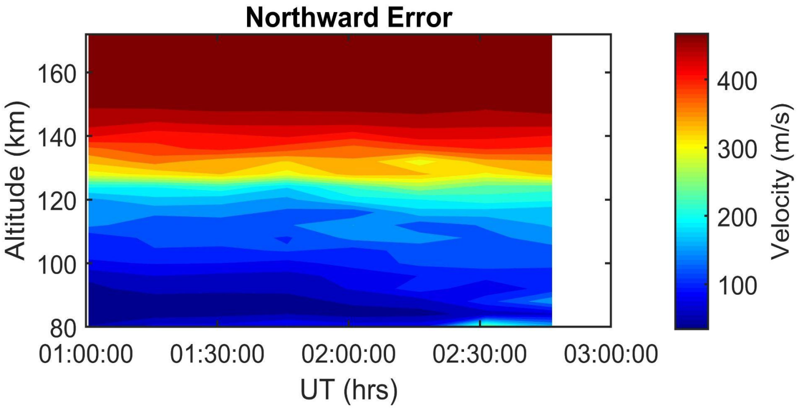


Neutral wind data (Northward)

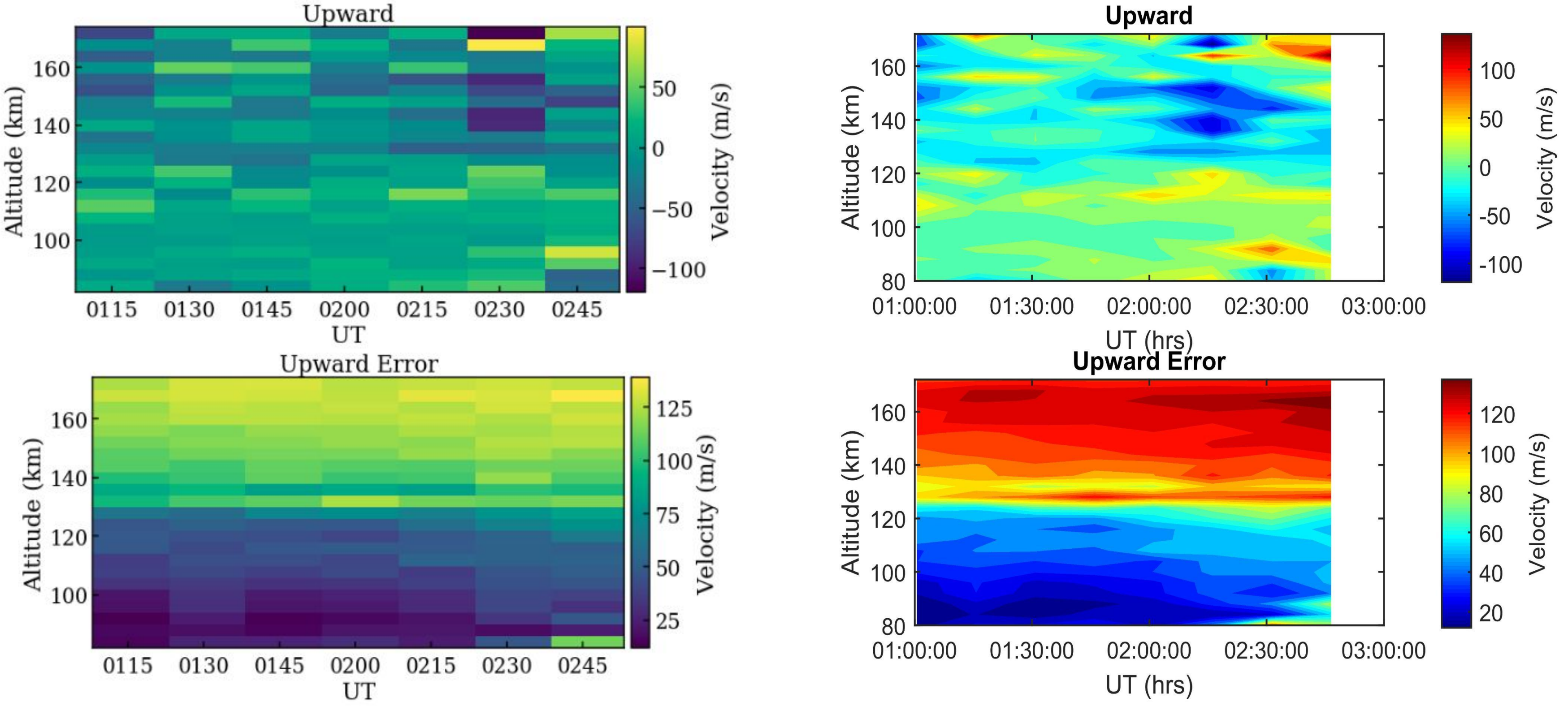






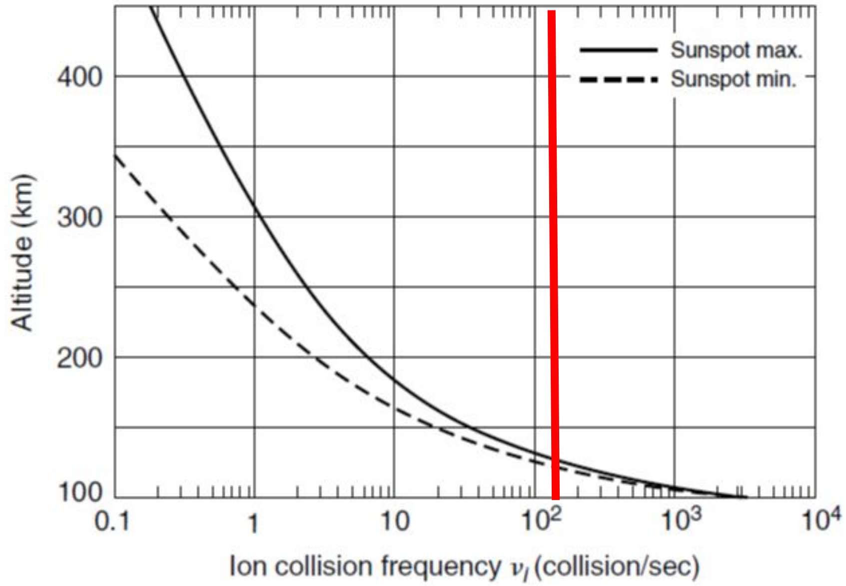


Neutral wind data (Upward)



Impact of ion-neutral collision frequency on neutral wind calculation

$$\frac{\nu_{in}}{\Omega_i}(\vec{u} - \vec{v}) + \vec{v} \times \frac{\vec{B}}{B} + \frac{\vec{E}}{B} = 0$$



[Michael C. Kelley, *The Earth's Ionosphere: Plasma Physics and Electrodynamics,* 2nd Edition, Cornell University, Academic Press, 2009]

Comparison of different collision models

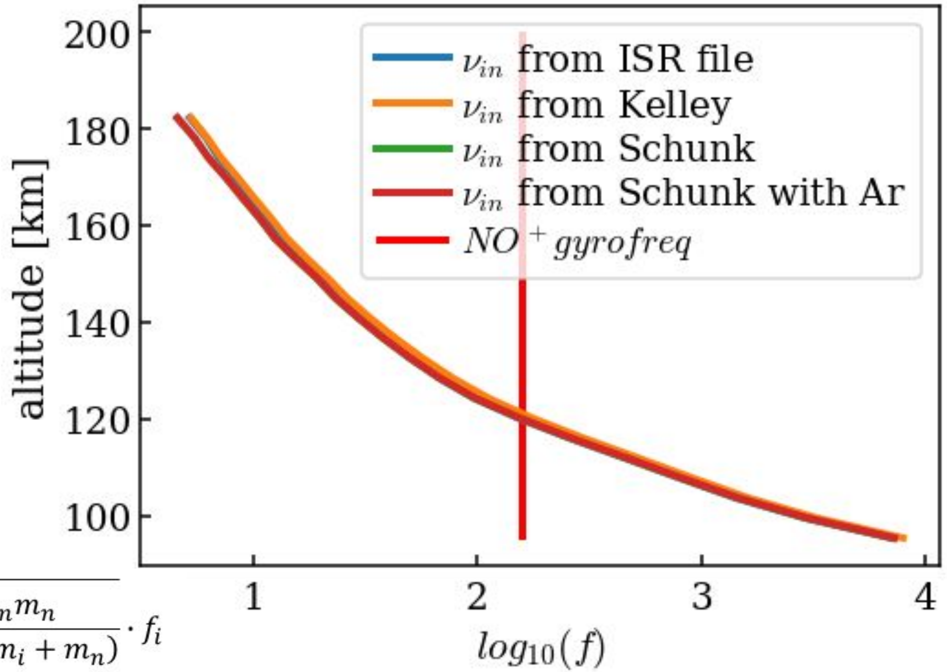
Coll. frequs can be calculated from ion and neutral compositions with different models leading to slight deviations:

- ISR files give coll. freq. data
- model given in Kelley's book (originally from Chapman):

$$\nu_{in_{tot}} = \sum_i 2.6 \cdot 10^{-9} \cdot n_{n_{tot}}[\mathrm{cm}^{-3}] \cdot m_i^{-1/2} \cdot f_i$$

- model given by Schunk and Nagy:

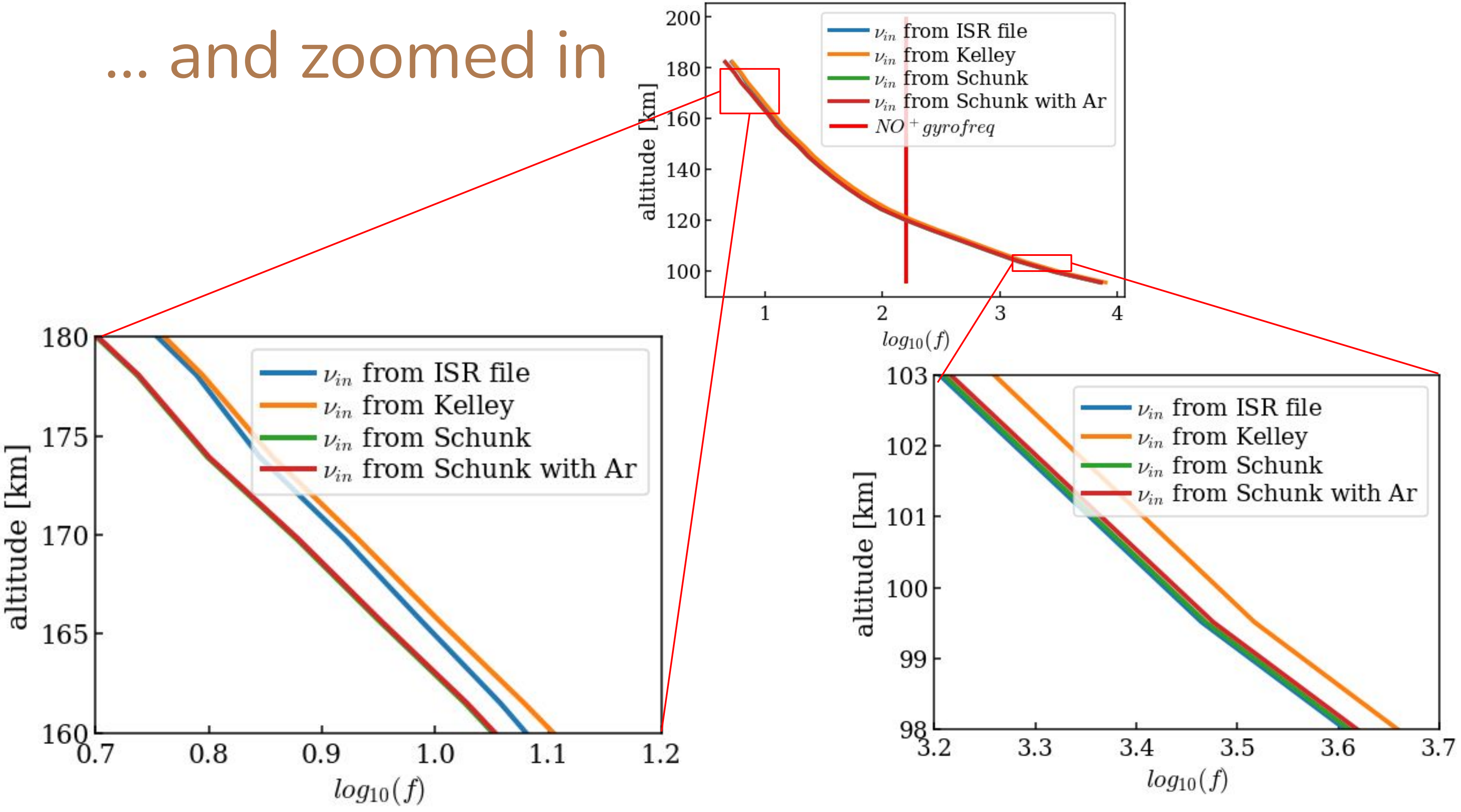
$$\nu_{in_{tot}} = \sum_n \sum_i \nu_{in} = \sum_n \sum_i 2.59 \cdot 10^{-3} n_n [\mathrm{m}^{-3}] \sqrt{\frac{\eta_n m_n}{m_i \cdot (m_i + m_n)}} \cdot f_i$$



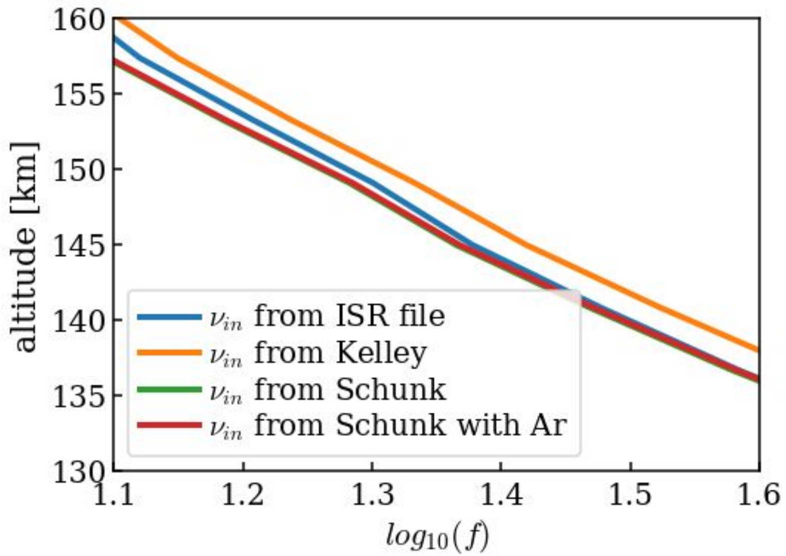
η_n: neutral gas polarizability in cm^3

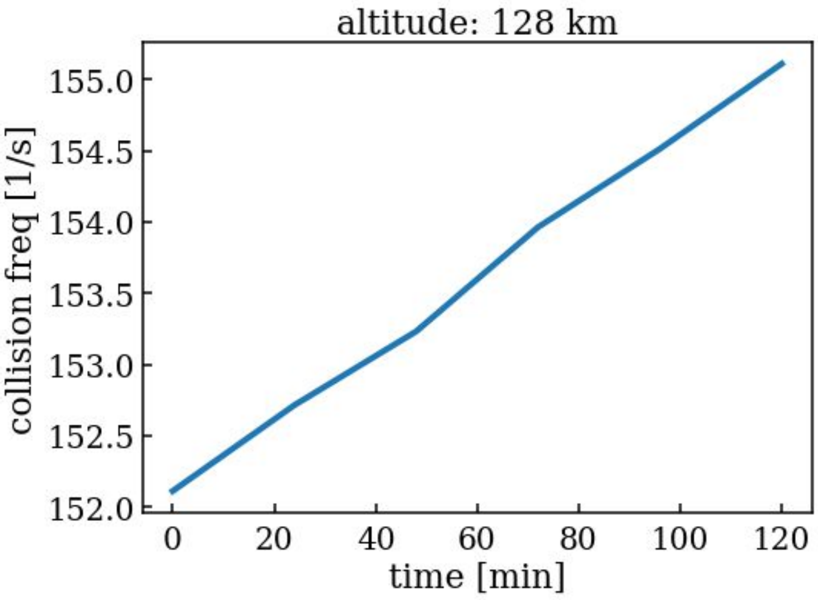
f_i, m_i, m_n: ion fraction, ion mass and neutral mass in amu

… and zoomed in



Influence of atomic resonant collisions and time evolution





- Kelley and Schunk model differ by a factor of about 1.12
- Above around 145 km, ISR freqs propagate from Schunk's to Kelley's model

⇒ time variation over 2 h window negligible

Conclusions and Outlook

- Principal take-away: ***ISR is an important resource for the calculation of neutral atmospheric winds***
- Calculation technique used is dependent upon electron density
  - Density profile during actual experiment was low, yielding poor neutral wind calculations even with sophisticated statistical methods
- Velocity vectors are not consistent spatially over time, but tend towards westward velocities at that time of day.
  - Integration time: if shorter, greater fineness, if longer, less errors
- Neutral wind data becomes increasingly invalid at higher altitudes
- Different ion-neutral collision models yield similar results
- Outlook: Good tool for comparison to different experiments, databases or models

Thank you! Questions?