IS Radar Data Examples: Basic and Derived Parameters

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Topics covered:

- Basic measured plasma parameters
- Derived plasma and neutral parameters
- Science examples using ISR data

Summary of IS Radar Remote Sensing Capabilities

IS Radar Remote Sensing Capabilities

Parameters sensed (Full altitude profiles):

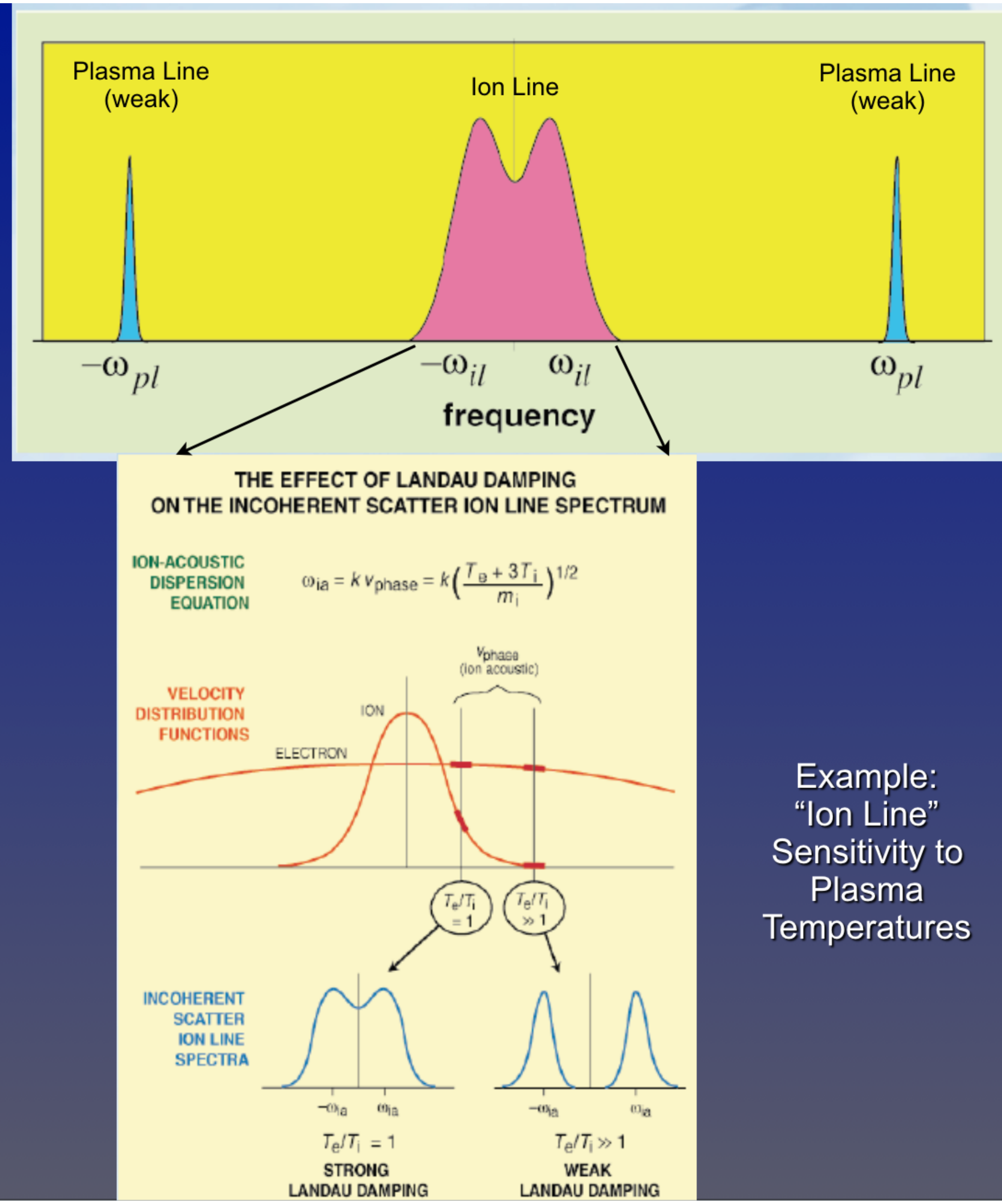
Basic

- Electron density
- Electron temperature
- Ion temperature
- Ion composition
- LOS Velocity

Derived

- Neutral winds
- Neutral temperature
- Vector velocity

More parameters possible

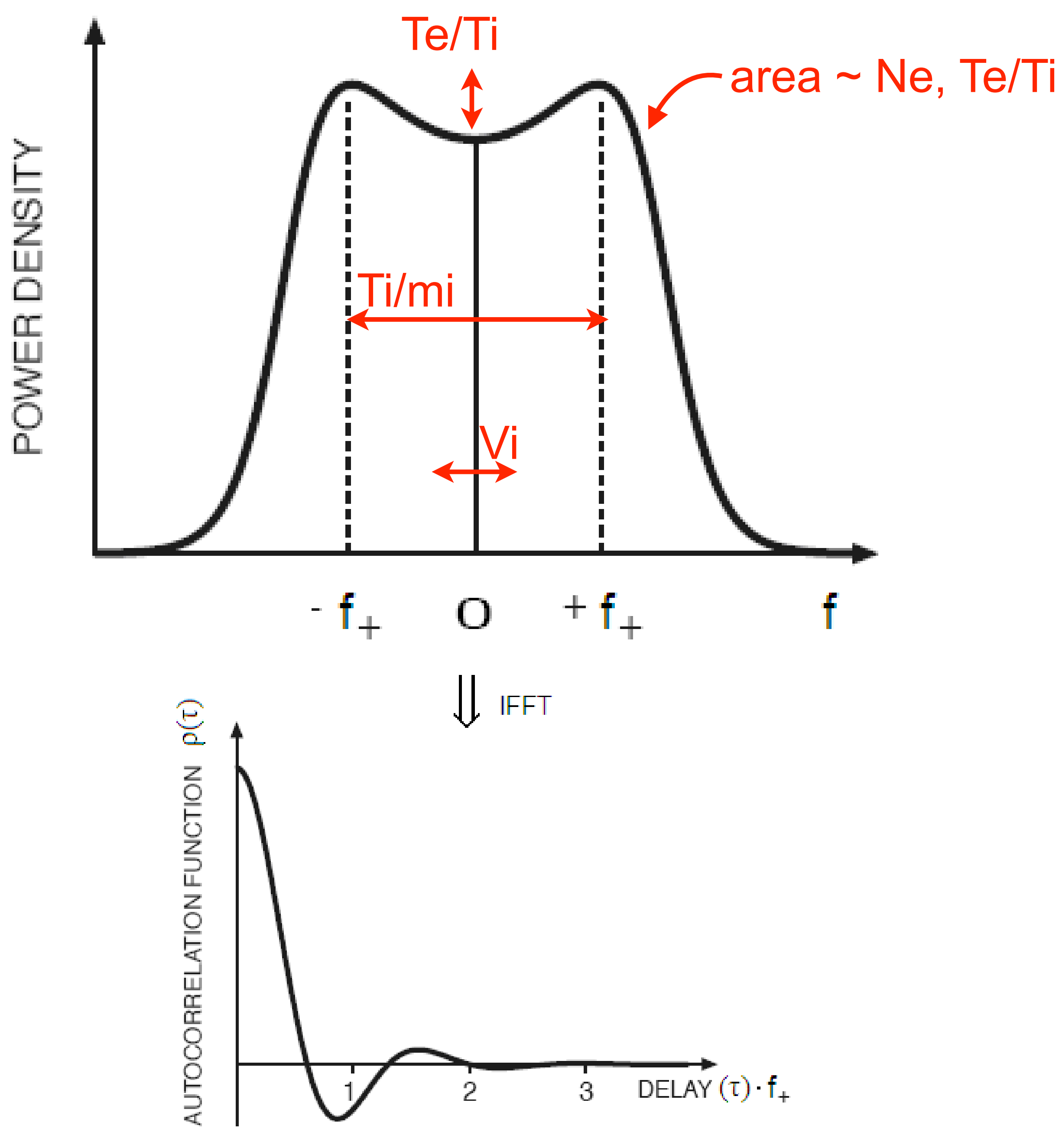


Example: "Ion Line" Sensitivity to Plasma Temperatures

Basic IS Radar Measured Parameters (Ion Line)

Ne, Te, Ti, Vi

(only one ion species here)



Rules of Thumb

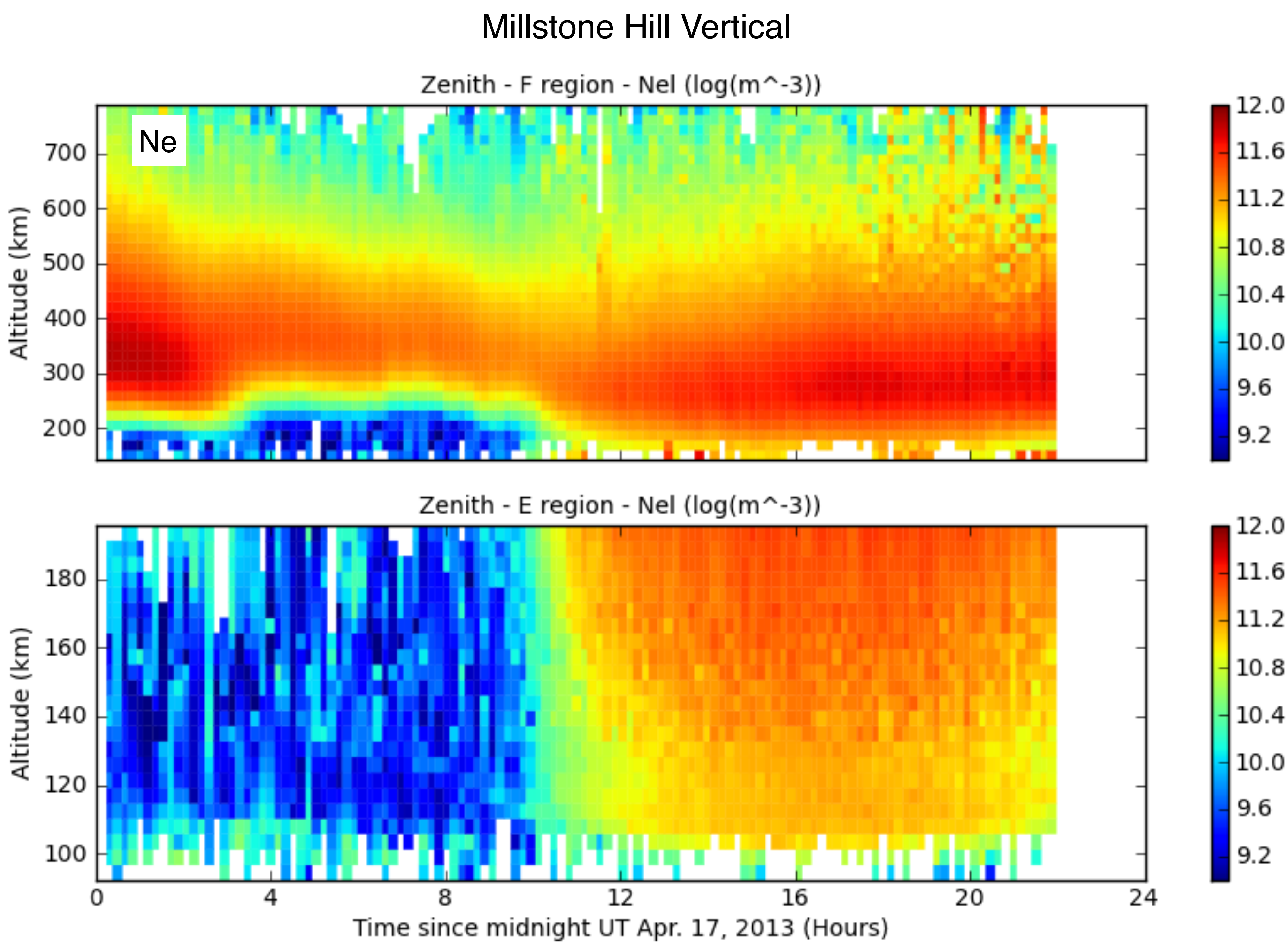
Ion temperature (Ti) to ion mass (mi) ratio from the width of the spectra

Electron to ion temperature ratio (Te/Ti) from "peak_to_valley" ratio

Electron (= total ion) density from total area (corrected for temperatures)

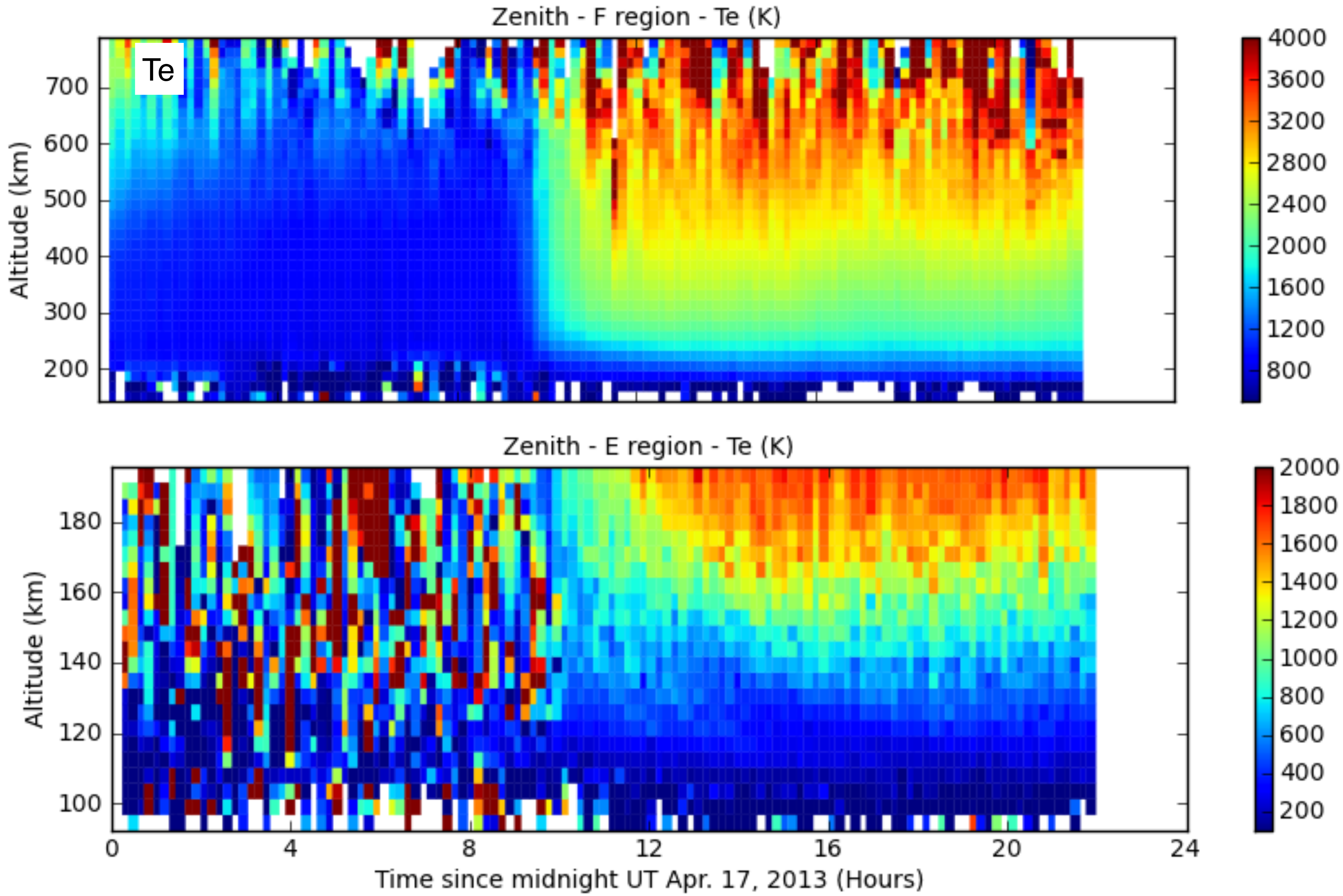
Line-of-sight ion velocity (Vi) from the Doppler shift

Basic IS Radar Measured Parameters (Ion Line)

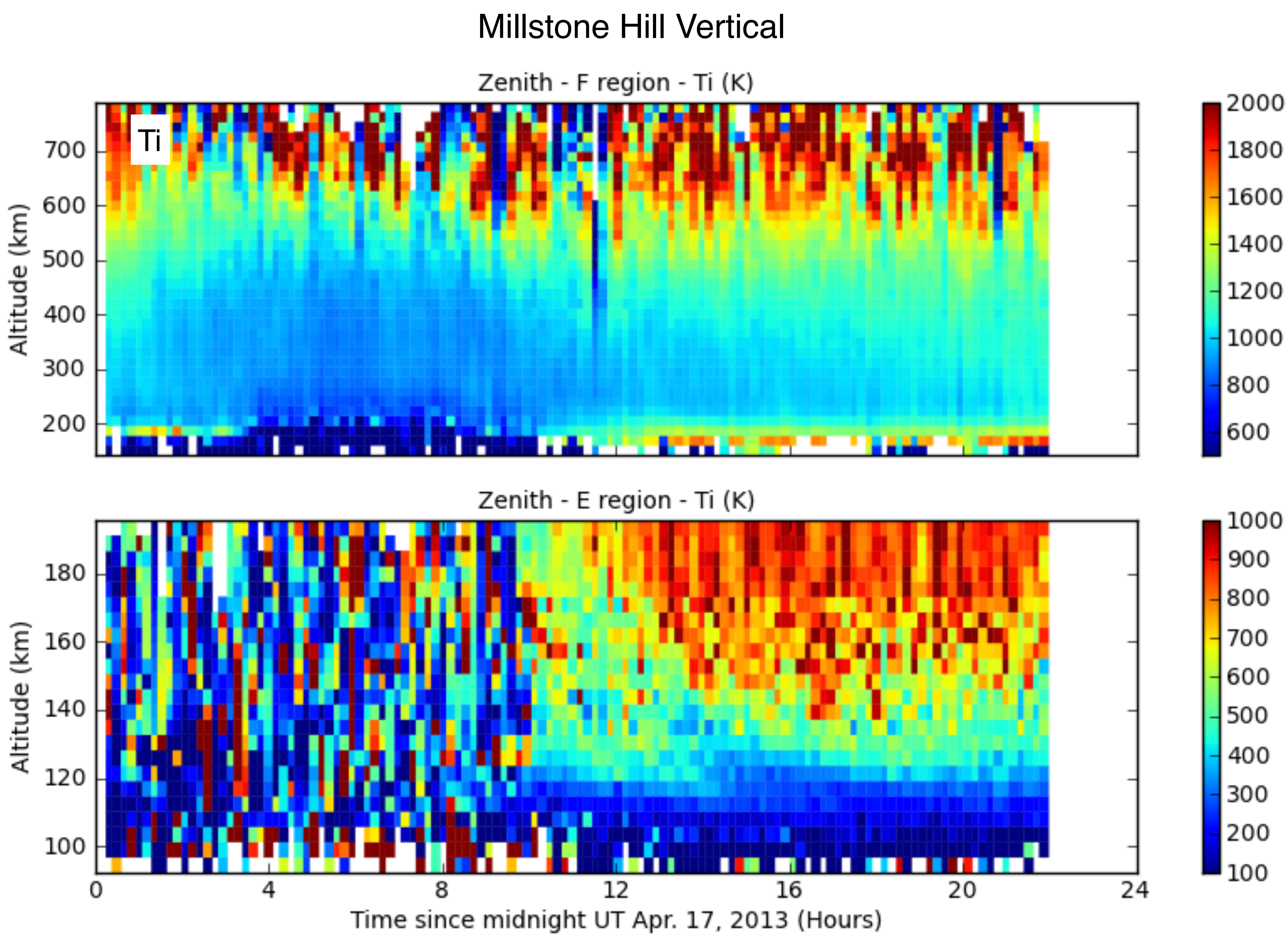


Basic IS Radar Measured Parameters (Ion Line)

Millstone Hill Vertical



Basic IS Radar Measured Parameters (Ion Line)



Basic IS Radar Measured Parameters (Ion Line)

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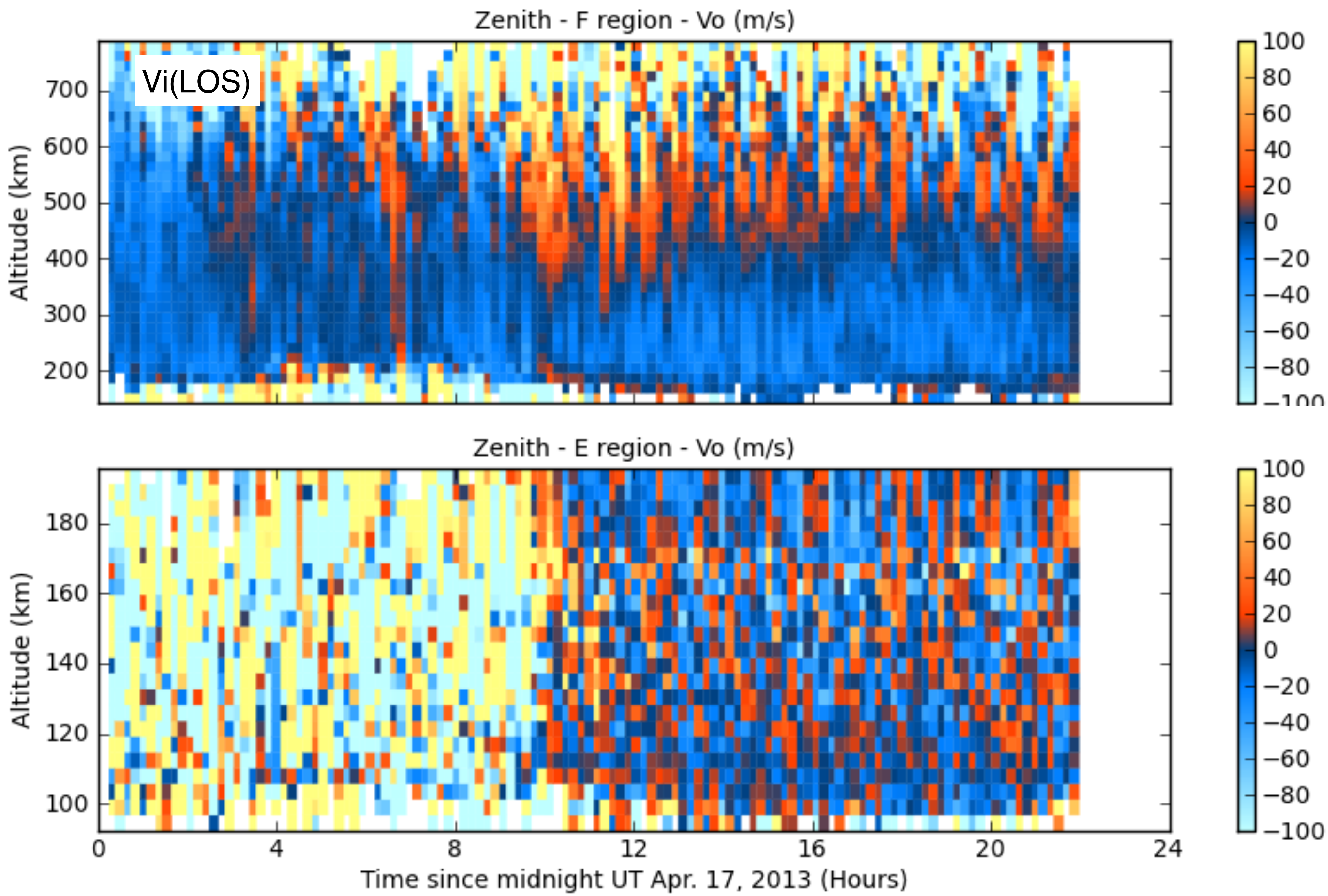
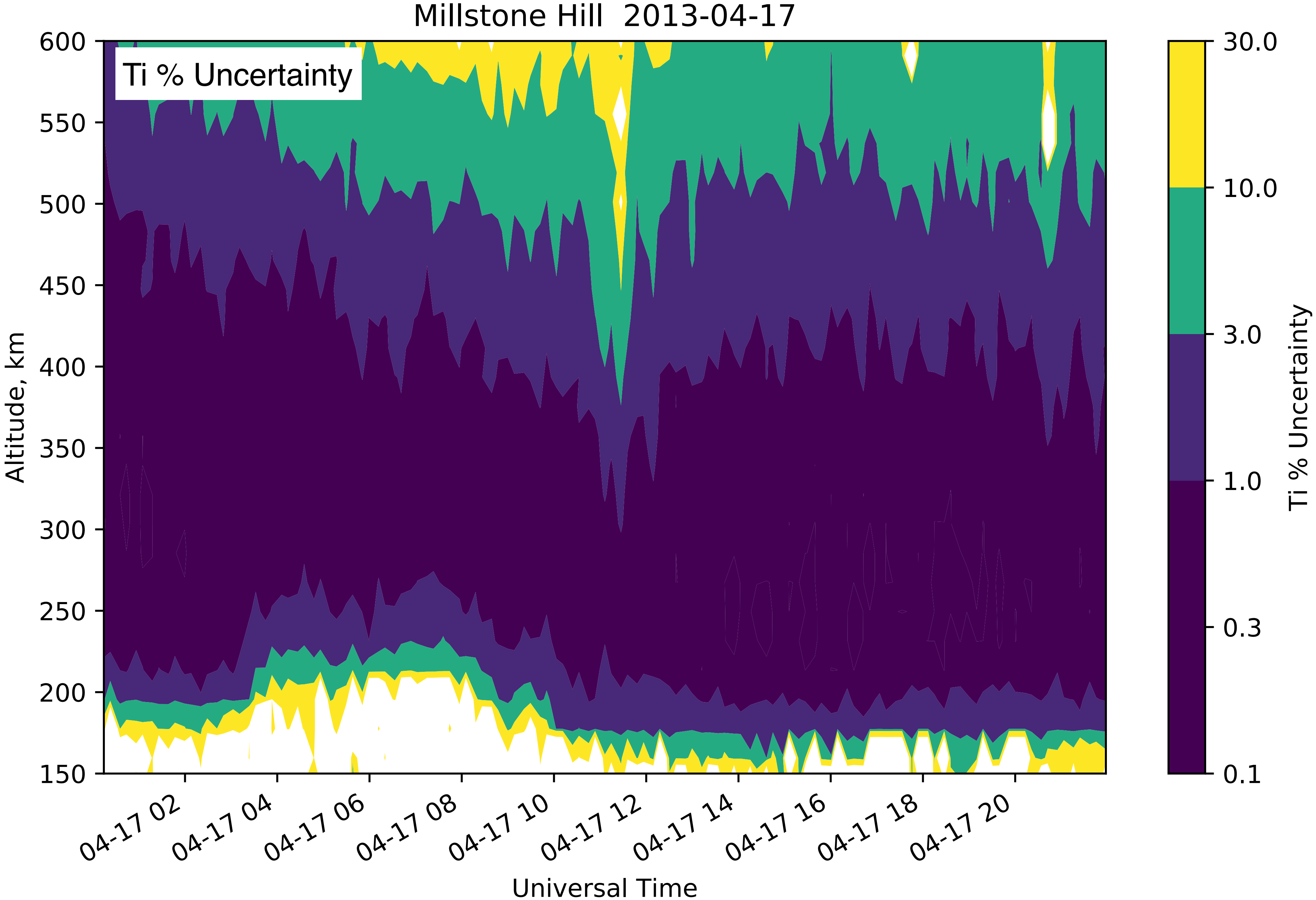


Basic IS Radar Measured Parameters (Ion Line)

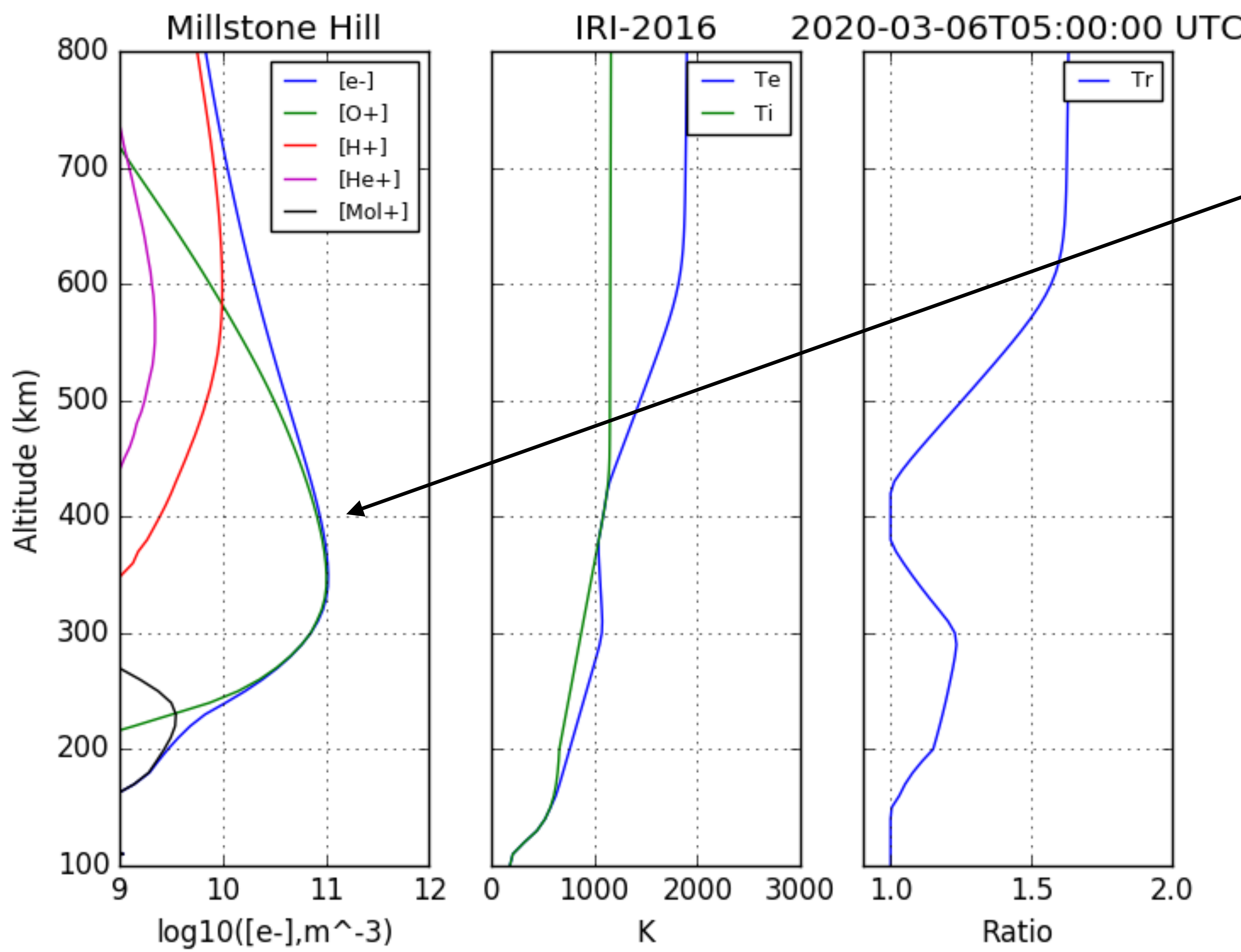
Millstone Hill Vertical



Uncertainties are available on each parameter

Ion Composition Fractions

Geophysical Location Dependent



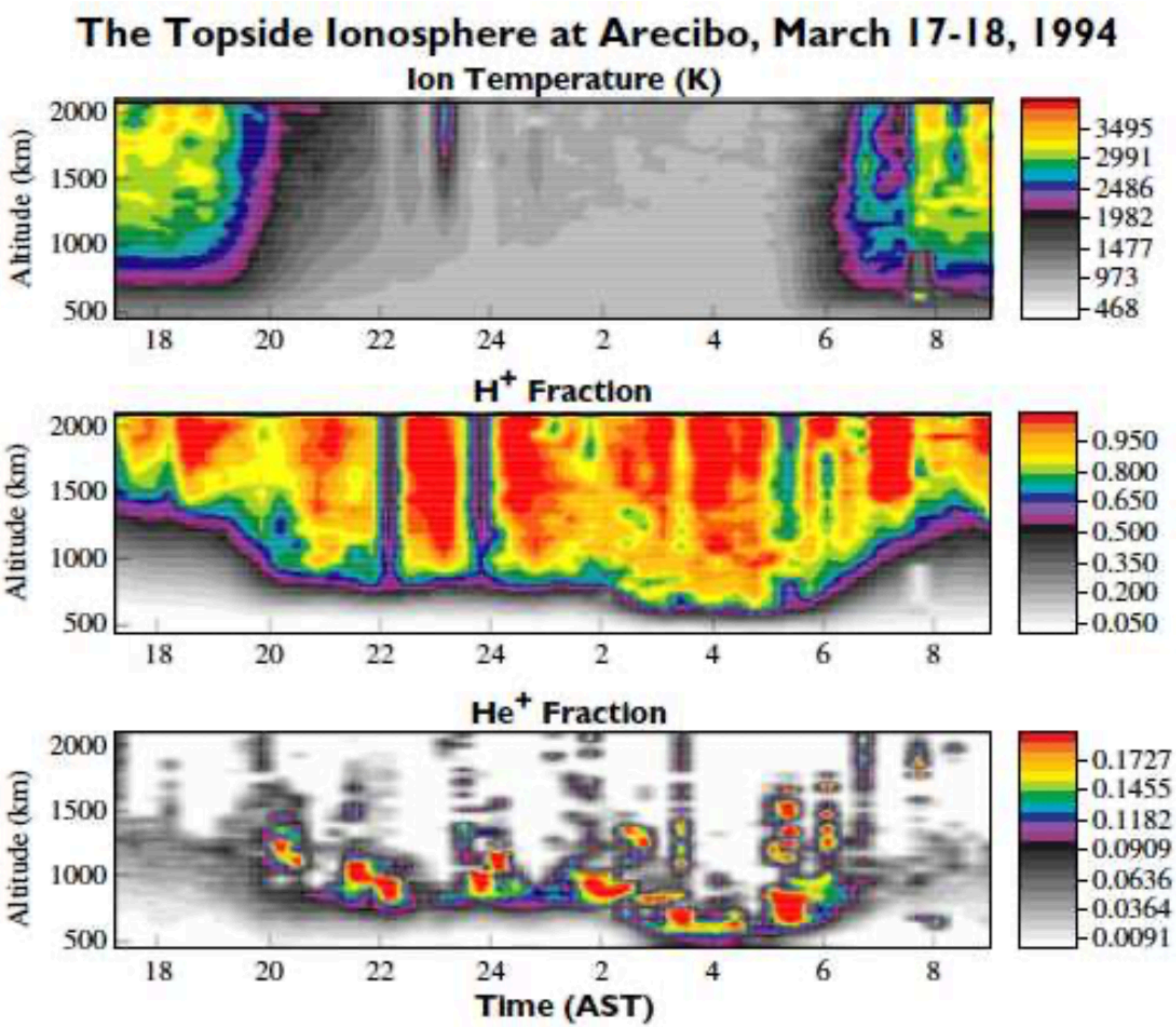
Ion composition (which ions allowed at what altitude) can be set by priors from e.g. modeling

Good assumptions can be also made - e.g. O+ is the only ion species near the F2 region

Allows Ti measurement through resolution of Ti/mi ratio ambiguity inherent in ion-acoustic resonance

Fraction of each ion can be fit in most 2-ion cases (occasionally 3-ions at Arecibo)

Ion Composition Fractions

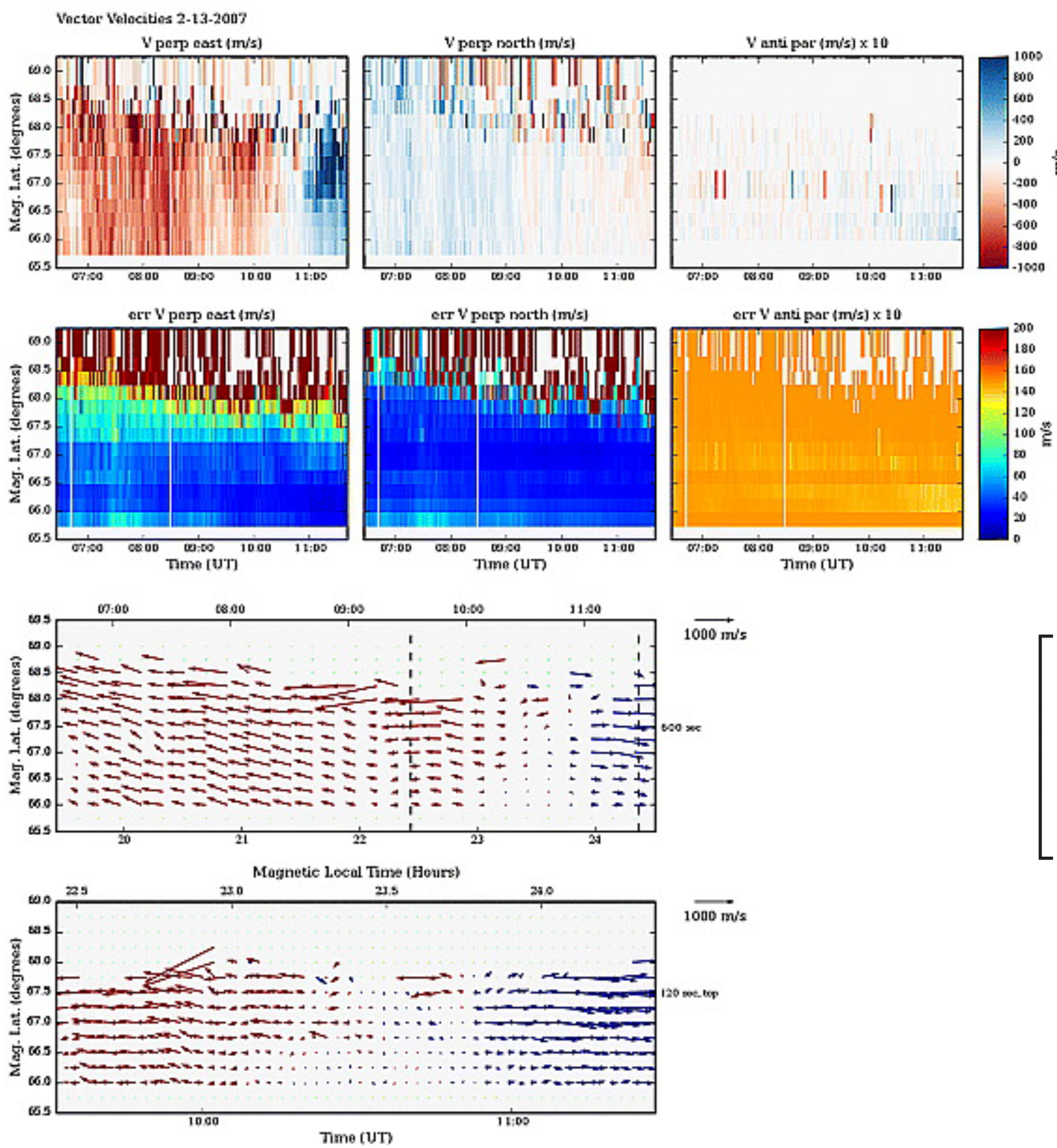


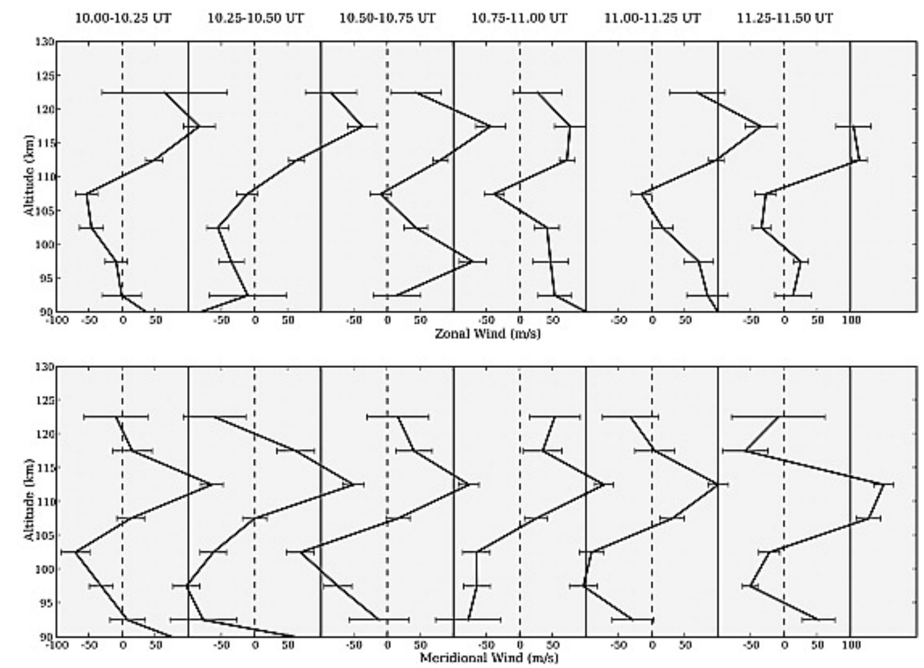
Arecibo:

Topside fractions of O+, He+, H+ can be measured: high enough SNR small enough measurement uncertainty in ACF / spectral measurement

Gonzalez and Sulzer 1996
doi:10.1029/96GL02212

Derived Parameters: Vector Ion Velocities, Neutral Winds





$$\begin{bmatrix} v_{los}^1 \\ v_{los}^2 \\ \vdots \\ v_{los}^n \end{bmatrix} = \begin{bmatrix} k_{pe}^1 & k_{pn}^1 & k_{ap}^1 \\ k_{pe}^2 & k_{pn}^2 & k_{ap}^2 \\ \vdots & \vdots & \vdots \\ k_{pe}^n & k_{pn}^n & k_{ap}^n \end{bmatrix} \begin{bmatrix} v_{pe} \\ v_{pn} \\ v_{ap} \end{bmatrix} + \begin{bmatrix} e_{los}^1 \\ e_{los}^2 \\ \vdots \\ e_{los}^n \end{bmatrix}$$

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

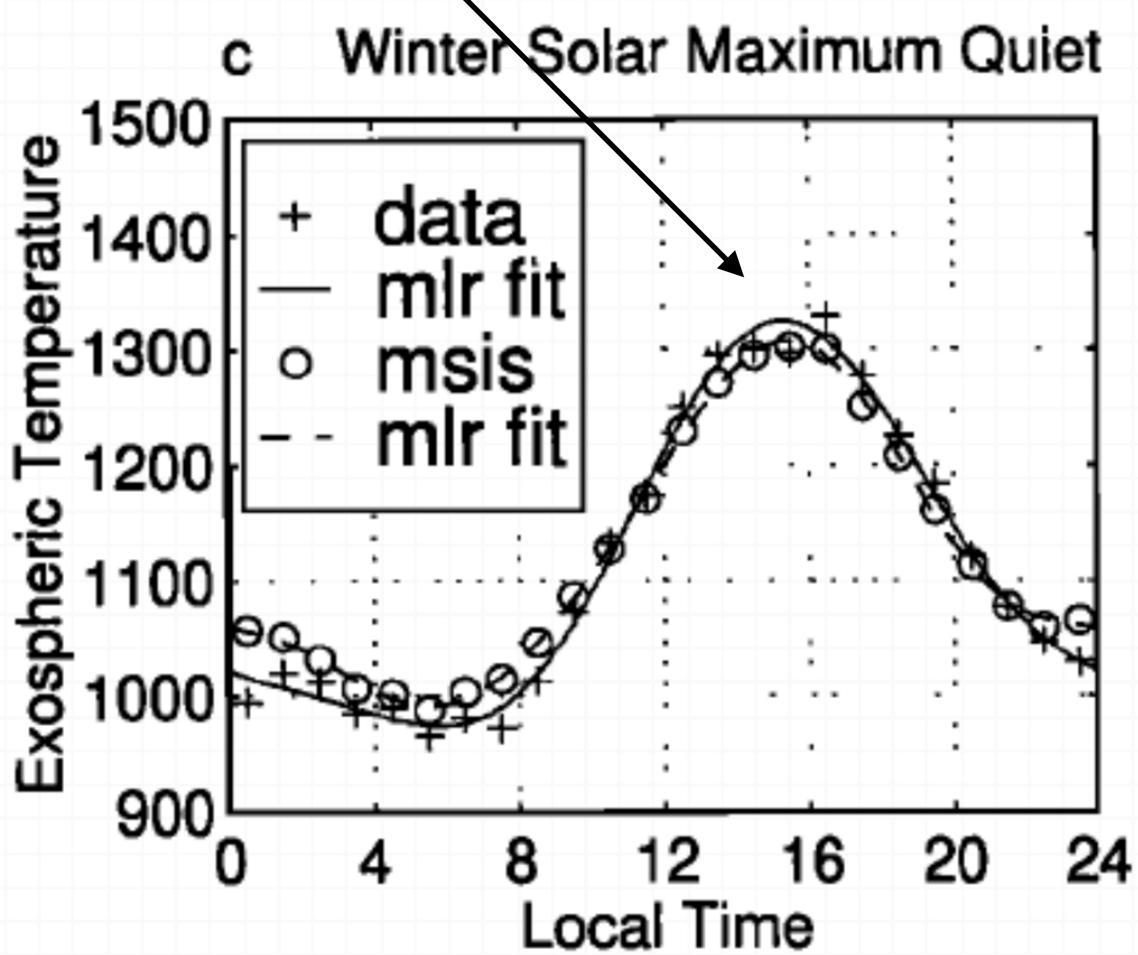
$$\mathbf{v}_i = b_i C\mathbf{E} + C\mathbf{u} \qquad C = \begin{bmatrix} (1+\kappa_i^2)^{-1} & -\kappa_i(1+\kappa_i^2)^{-1} & 0 \\ \kappa_i(1+\kappa_i^2)^{-1} & (1+\kappa_i^2)^{-1} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Heinselman, C. J., and Nicolls, M. J. (2008), *Radio Sci.*, doi:10.1029/2007RS003805.

Derived Parameters: Neutral Temperatures

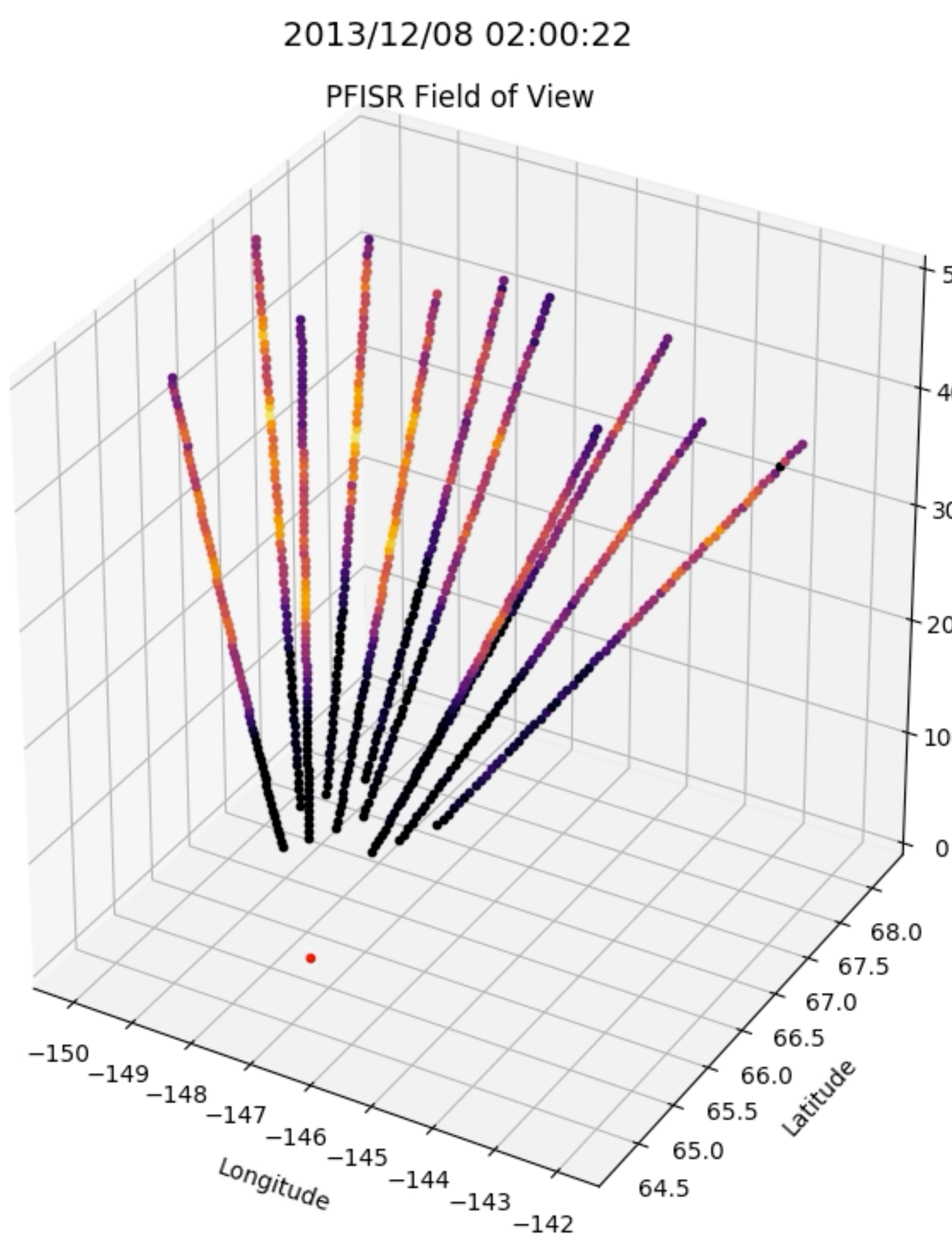
$$\sum_i L_{ei} = \sum_{i,n} L_{in} \qquad a(T_e - T_i) = b(T_i - T_n)$$

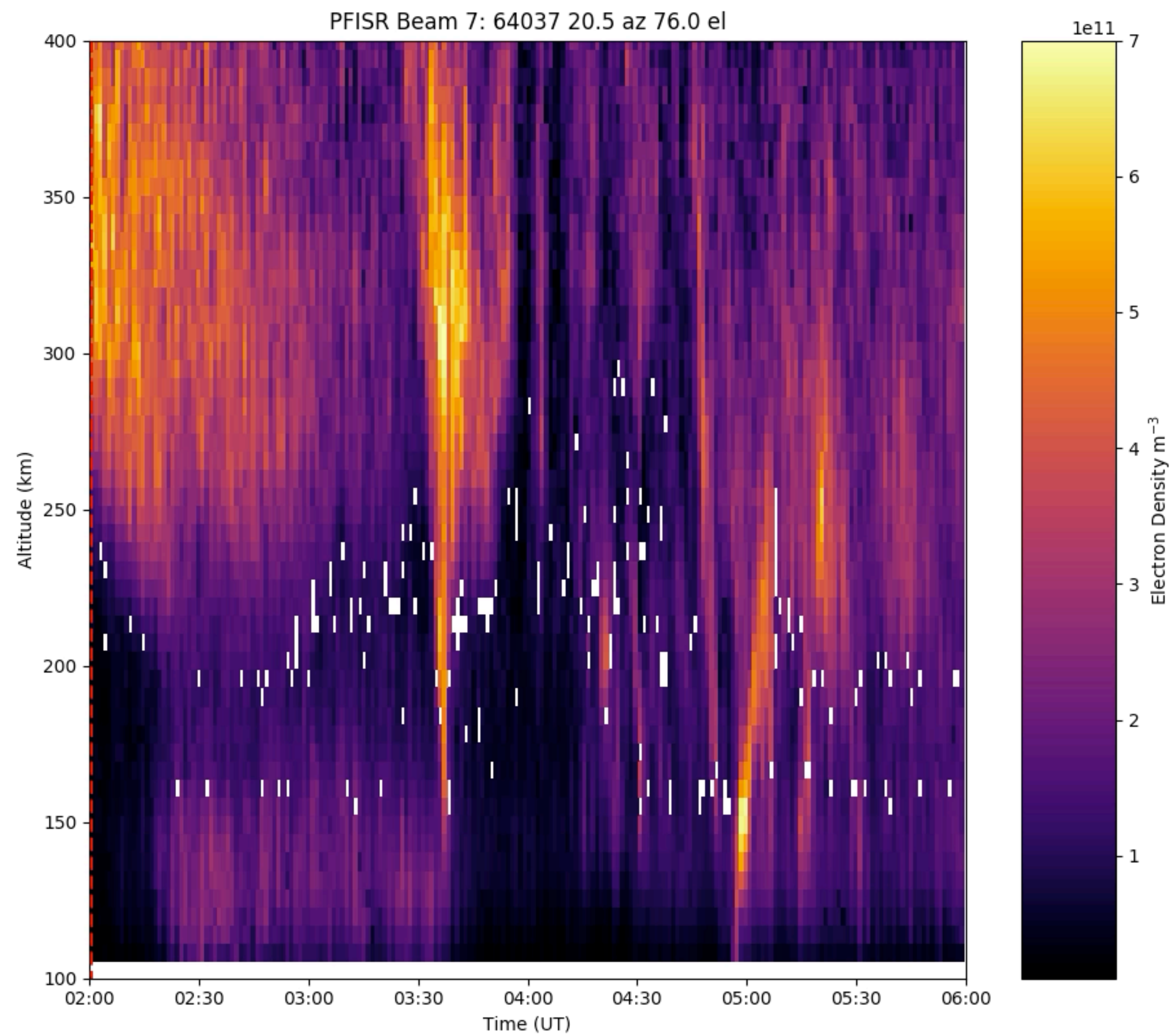
$$T_n(z) = \boxed{T_\infty} - (T_\infty - T_0)\exp[-s(z - z_0)(R_E + z_0)/(R_E + z)] \quad (3)$$



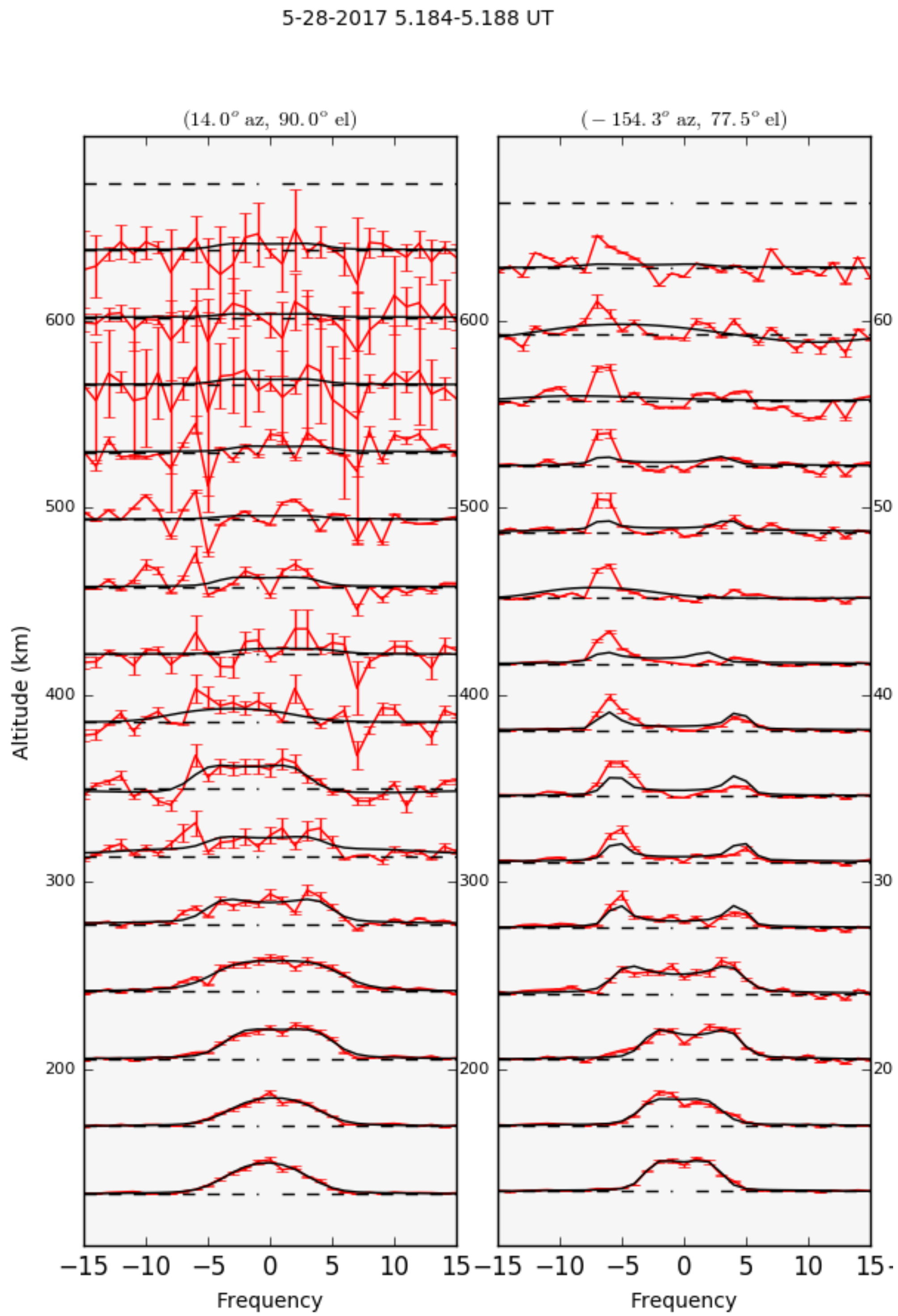
Buonsanto, M. J., and Pohlman, L. M. (1998), Climatology of neutral exospheric temperature above Millstone Hill, *J. Geophys. Res.*, 103(A10), 23381–23392, doi:10.1029/98JA01919.

PFISR Multi-beam Measurements of Auroral Ionization



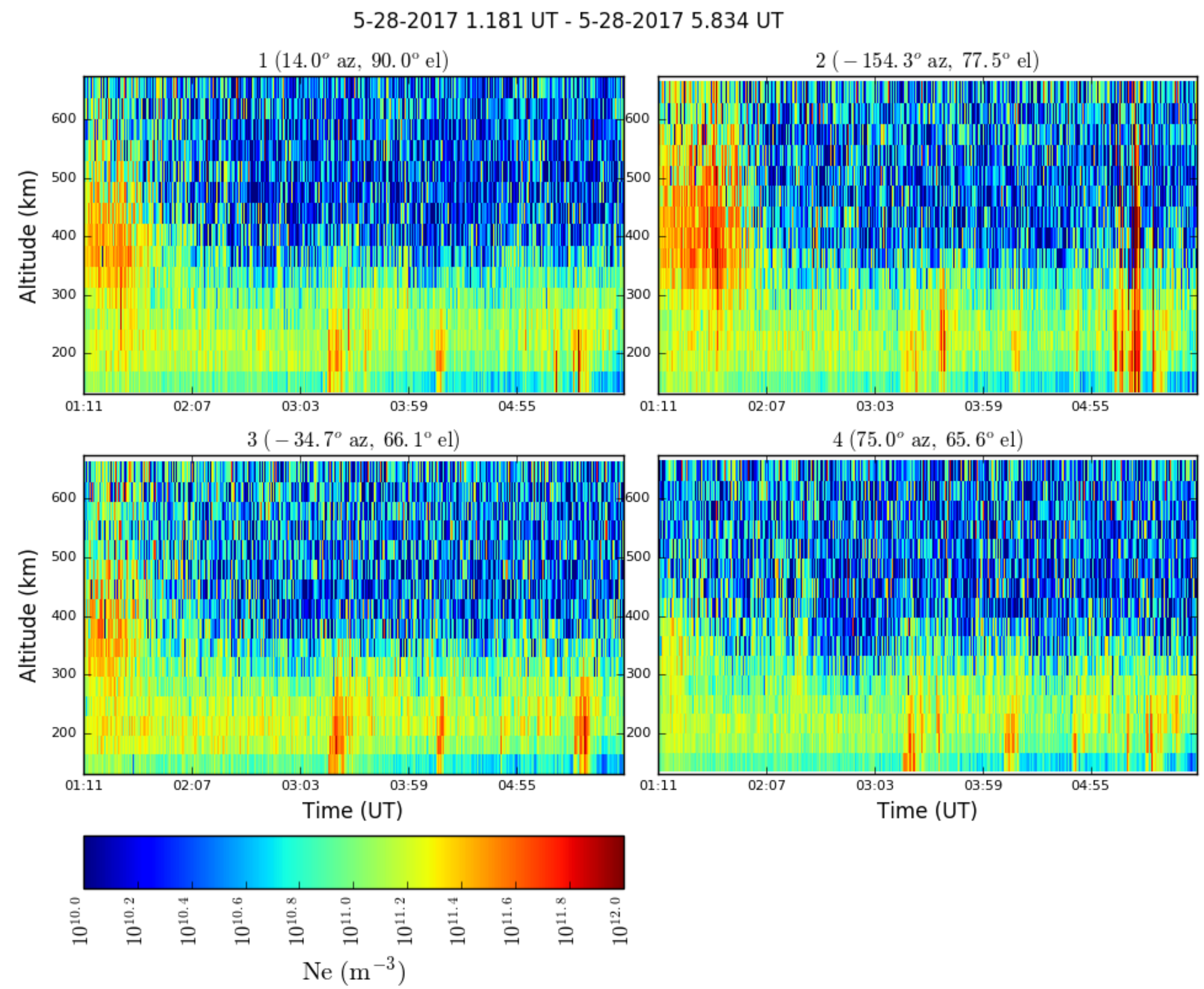


PFISR Naturally Enhanced Ion-Acoustic Lines

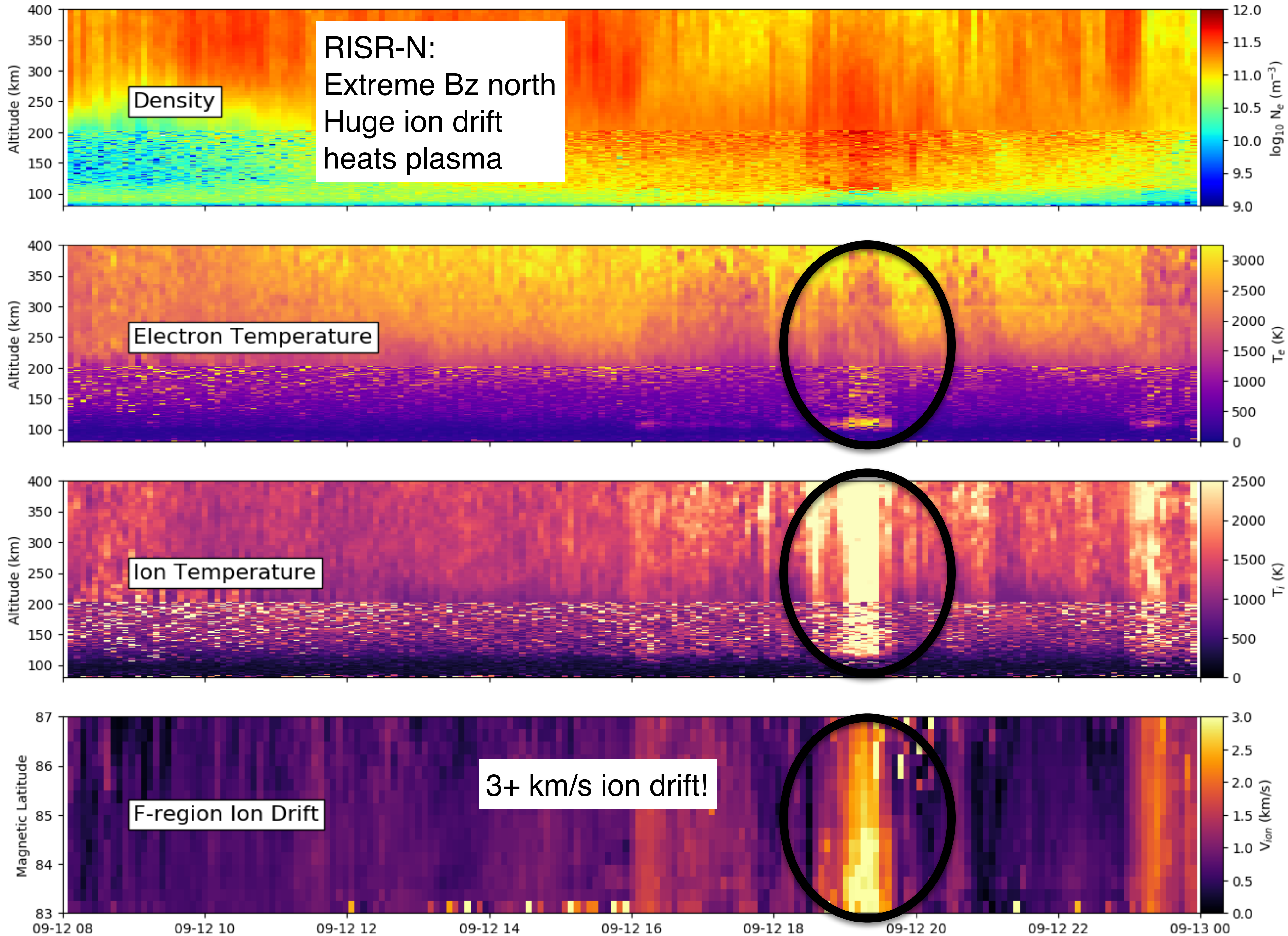


Plasma instability process [current driven F region instabilities, ion-ion 2 stream, Langmuir wave parametric decay]

Particle precipitation is directly or indirectly involved
E.g. Lunde et al, 2007, doi:10.5194/angeo-25-1323-2007

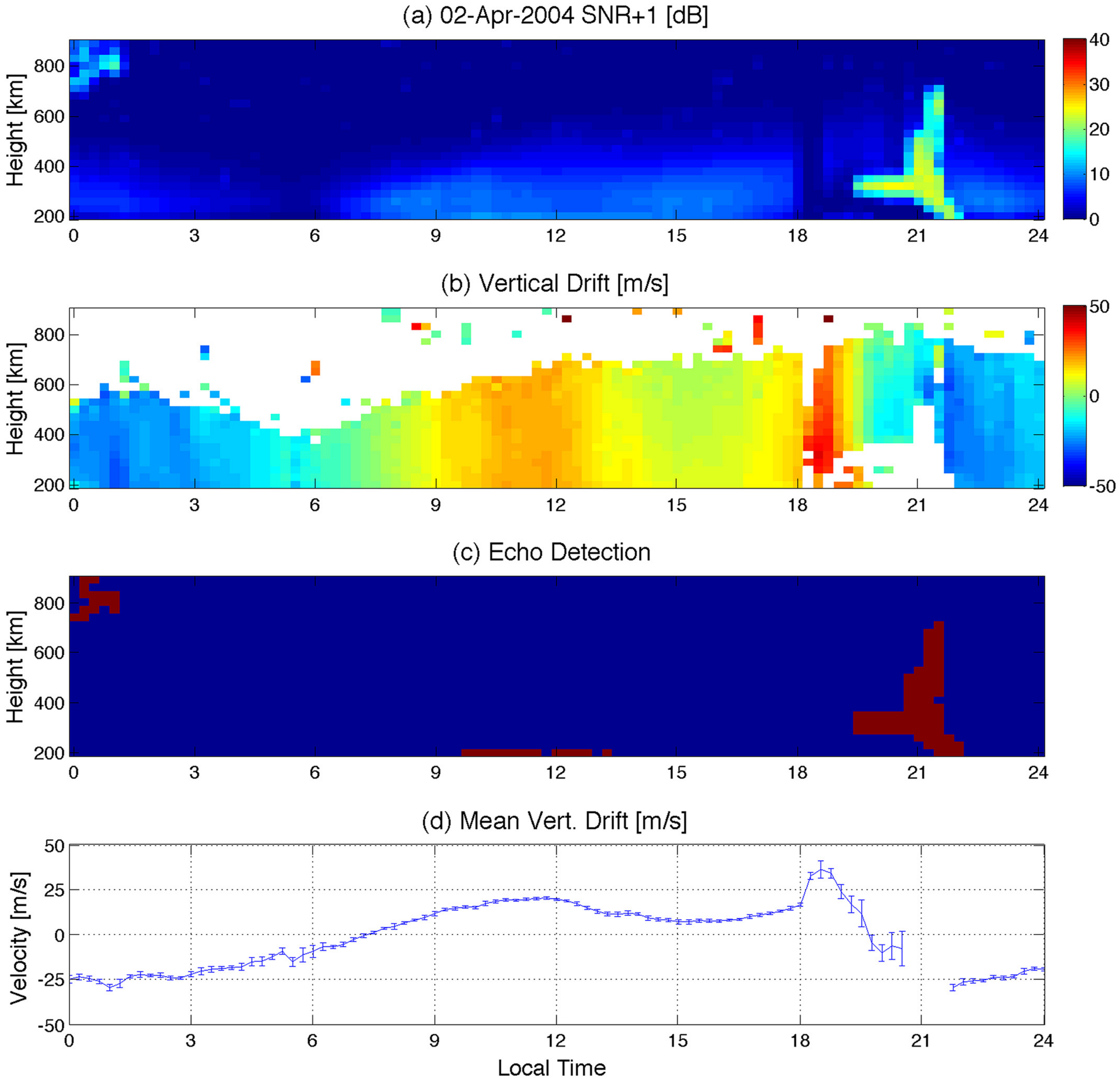


Polar Cap Response to Non-Saturated Potential Drop



cf.
Clauer et al. JGR 2016
doi:10.1002/2016JA022557

Equatorial spread F simultaneous with vertical drifts



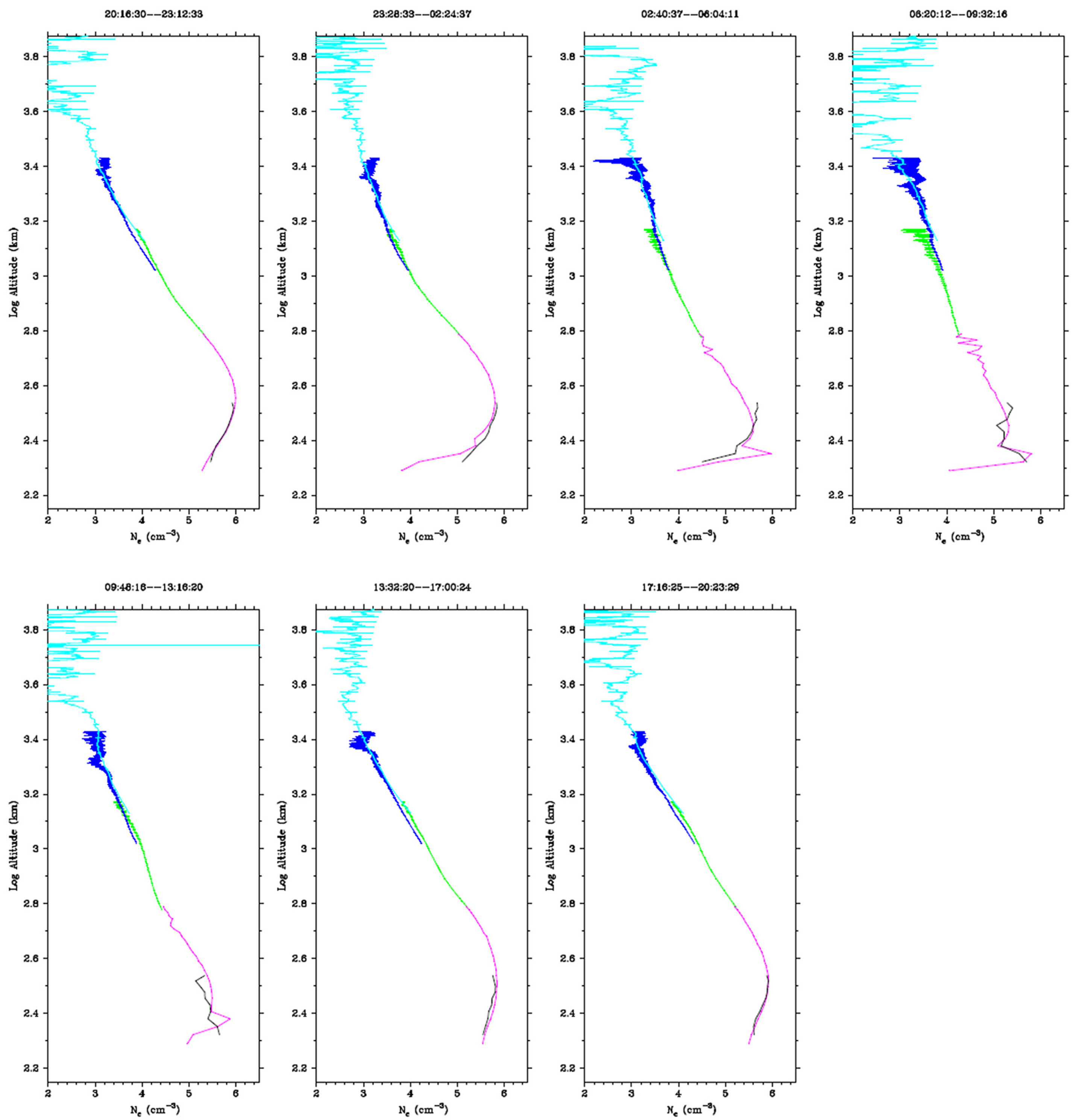
Jicamarca

Near-perpendicular to B = highly accurate vertical drifts

Dusk sector: spread-F coherent irregularities (very bright)

Smith, J. M., Rodrigues, F. S., Fejer, B. G., and Milla, M. A. (2016), Coherent and incoherent scatter radar study of the climatology and day-to-day variability of mean F region vertical drifts and equatorial spread F , J. Geophys. Res. Space Physics, 121, 1466– 1482, doi:10.1002/2015JA021934.

Extreme High-Altitude Equatorial Electron Density



Jicamarca
4 transmitters (6 MW peak) @ 50 MHz

Electron density to L=2!
(~6,000 km altitude)

Possible to 10,000 km in daytime

(2500 km threads through Arecibo field of view @ 400 km altitude)

Larger system would be able to perhaps see plasmapause from the ground (connections to SED plume)

Hysell, D. L., Milla, M. A., and Woodman, R. F. (2017), High-altitude incoherent-scatter measurements at Jicamarca, J. Geophys. Res. Space Physics, 122, 2292– 2299, doi:10.1002/2016JA023569.

Interpreting IS Radar Measurements with Common Sense (and Physics)

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Summary:

- Basic plasma parameters are readily observed with ISR
- Derived parameters (with assumptions) provide more information about the neutral and ionized atmosphere
- Rich geophysics discovery space