ISR Workshop 2013

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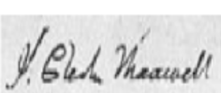
Question

What are plasma (Langmuir) Waves?

→ Electron plasma waves are high frequency electrostatic waves that can propagate in any direction in an unmagnetized plasma.

→ Maxwell's Equations

Gauss' Law (electric field around charges)	$\nabla \cdot D = \rho_f$	in free space: $\mathbf{D} = \varepsilon_0 \mathbf{E}$, $\mathbf{H} = \mathbf{B}/\mu_0$
Gauss' Law for magnetism (no magnetic monopoles)	$\nabla \cdot B = 0$	
Faraday's Law (electric field around a changing magnetic field)	$\nabla \times E = -\frac{\partial B}{\partial t}$	
Ampere's Law (magnetic field circulation around electric charges)	$\nabla \times H = J_f + \frac{\partial D}{\partial t}$	↑ Maxwell's correction (displacement current)



→ Maxwell's Equations in Static Case

$$\mathbf{K} \cdot \mathbf{E}_1 = 0$$

$$\mathbf{K} \times \mathbf{E}_1 = \omega \mathbf{B}_1$$

$$\mathbf{K} \cdot \mathbf{B}_1 = 0$$

$$\mathbf{K} \times \mathbf{B}_1 = -\frac{\omega}{c^2} \mathbf{E}_1 .$$

Question

What are plasma (Langmuir) Waves?

Fluid Reductions: Moment Equations, Approximations

Integrate Vlasov over all velocity space:

$$\frac{\partial}{\partial t} n + \nabla \cdot (n\mathbf{u}) = 0$$

Continuity equation

Combining Vlasov with Lorentz equation:

$$m \frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = q(\vec{E} + \vec{v} \times \vec{B})$$

yields

$$m \frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = q(\vec{E} + \vec{v} \times \vec{B}) \qquad \frac{\mathrm{d}}{\mathrm{d}t} = \frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla$$

Momentum equation

Loses information on distribution function momentum space.

Question

What are plasma (Langmuir) Waves?

- For analysis we often assume linearized plane waves and small perturbations.

Perturbation Equations

$$n_s(\mathbf{r}, t) = n_{s0} + n_{s1}(\mathbf{r}, t)$$

$$\mathbf{u}_s(\mathbf{r}, t) = \mathbf{u}_{s0} + \mathbf{u}_{s1}(\mathbf{r}, t)$$

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E}_0 + \mathbf{E}_1(\mathbf{r}, t)$$

$$\mathbf{B}(\mathbf{r}, t) = \mathbf{B}_0 + \mathbf{B}_1(\mathbf{r}, t)$$

Electric Field

$$\mathbf{E}_1(\mathbf{r}, t) = \mathbf{E}_{10} e^{i(\mathbf{K}\cdot\mathbf{r} - \omega t)}$$

Question

What are plasma (Langmuir) Waves?

The basic characteristic of a plasma wave can be elucidated by considering a two-component, fully ionized plasma that is electrically neutral, stationary, uniform and steady.

$$\frac{\partial n_s}{\partial t} + \nabla \cdot (n_s \mathbf{u}_s) = 0$$

$$n_s m_s \left[\frac{\partial \mathbf{u}_s}{\partial t} + (\mathbf{u}_s \cdot \nabla)\mathbf{u}_s \right] + \nabla p_s - n_s e_s (\mathbf{E} + \mathbf{u}_s \times \mathbf{B}) = 0$$

$$\frac{D_s p_s}{Dt} + \gamma p_s (\nabla \cdot \mathbf{u}_s) = 0$$

Simplified Continuity, Momentum and Energy Equations

$$\omega n_{e1} = n_{e0} \mathbf{K} \cdot \mathbf{u}_{e1}$$

$$i\omega \mathbf{u}_{e1} - i\mathbf{K} \frac{\gamma_e k T_e}{n_{e0} m_e} n_{e1} - \frac{e}{m_e} \mathbf{E}_1 = 0$$

$$i\mathbf{K} \cdot \mathbf{E}_1 = -e n_{e1}/\varepsilon_0$$

Question

What are plasma (Langmuir) Waves?

Plasma Resonance Mode: Langmuir Oscillations

Assume electrostatic equations and no thermal motions - also, 1D:

$$mn_e\left[\frac{\partial \vec{v_e}}{\partial t} + (\vec{v_e}\cdot\nabla)\vec{v_e}\right] = -en_e\vec{E}$$

$$\frac{\partial n_e}{\partial t} + \nabla\cdot(n_e\vec{v_e}) = 0$$

$$\epsilon_0\nabla\cdot\vec{E} = e(n_i - n_e)$$

Combine, linearize, keep 1st order terms, assume plane waves:

$$-im\omega\Delta v = -i\frac{n_0e^2}{\epsilon_0\omega}\Delta v$$

Question

What are plasma (Langmuir) Waves?

Plasma Resonance Mode: Langmuir Oscillations

Plasma oscillations (Langmuir oscillations):

$$\omega_p = \left(\frac{n_0 e^2}{\epsilon_0 m} \right)^{1/2}$$

NB: group velocity = 0 so no information exchange in plasma.

Add electron thermal effects (now information is transmitted) to motion equation through an electron pressure gradient $-\nabla p_e$:

$$-\nabla p_e = 3 k_B T_e \nabla (n_0 + \Delta n)$$

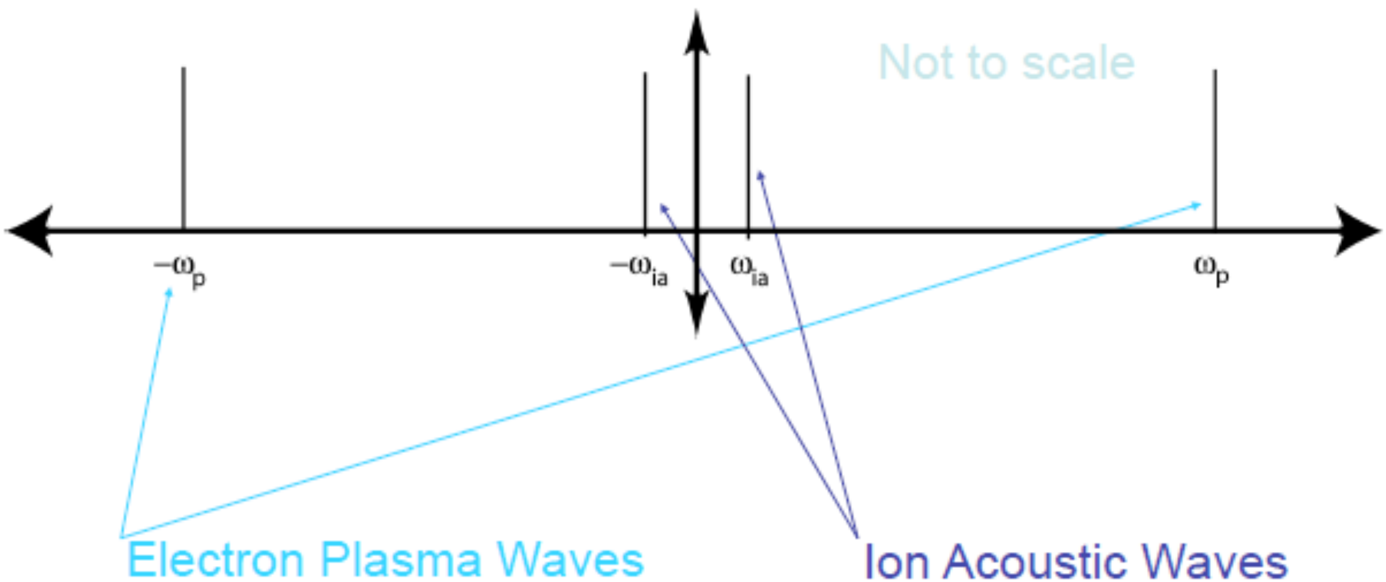
Linearize as before:

$$\omega^2 = \omega_p^2 + \frac{3}{2} k^2 v_{th}^2 \qquad v_{th}^2 = 2 k_B T_e / m_e$$

Question

How are they represented in the ISR Spectrum?

Wave Spectrum



Question

How they are observed?

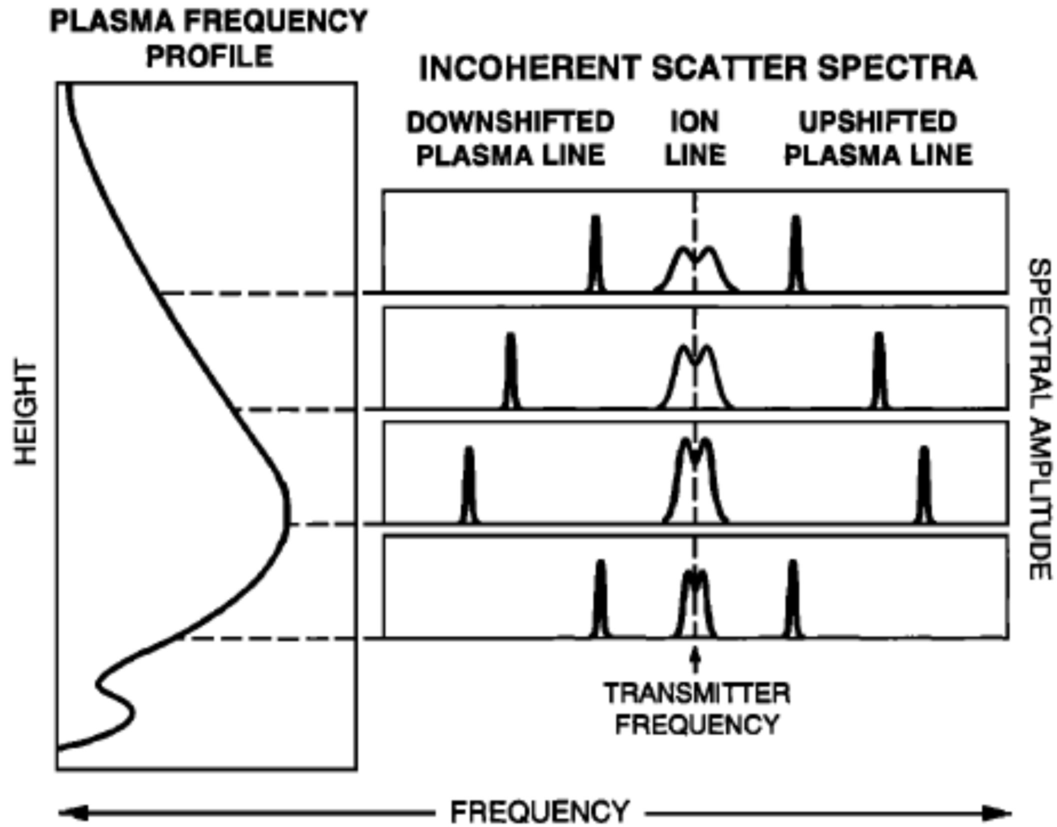


Figure 1. A schematic representation of the major features of the incoherent scatter radar spectrum and its relationship to the ionospheric plasma frequency profile. The ion and plasma lines arise from Bragg backscatter off thermal density fluctuations, the power of which is concentrated in the ion acoustic and electron Langmuir plasma wave modes, respectively.

ISR Experiment

Study of Large Scale Ionospheric Structures using PFISR

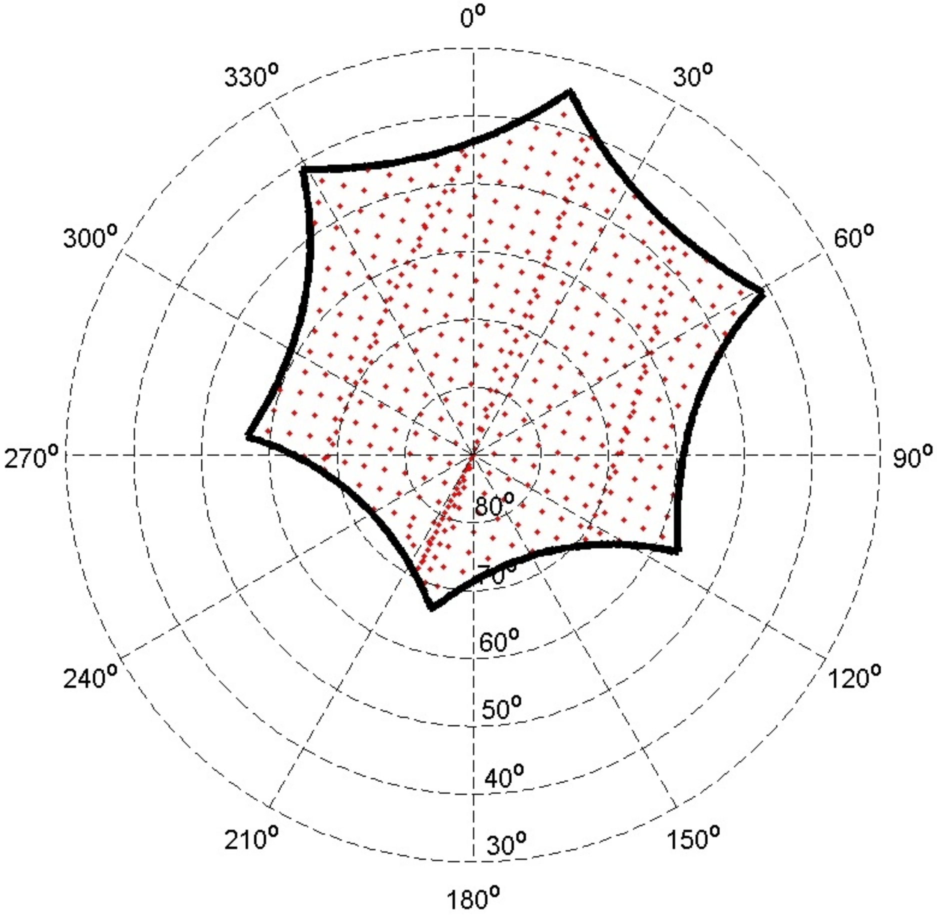
Introduction

- Experiment Planning
- Preliminary Results
- Processed Results
- Our Conjectures
- Other Evidences
- Summary and Questions

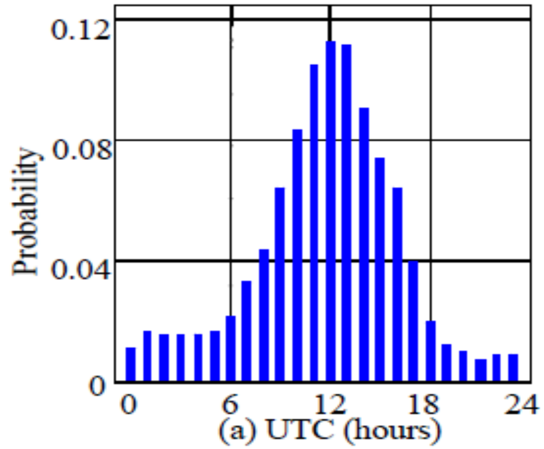
Experiment Planning

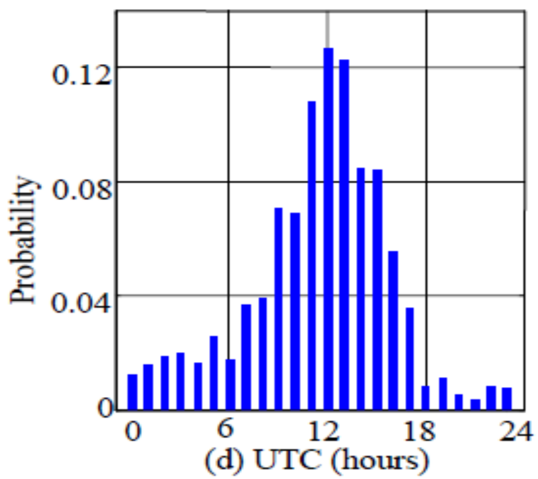
Timeslots Available from 2013/07/30 UT:

22:00 – 00:00
00:00 – 02:00
02:00 – 04:00
04:00 – 06:00
06:00 – 08:00
08:00 – 10:00



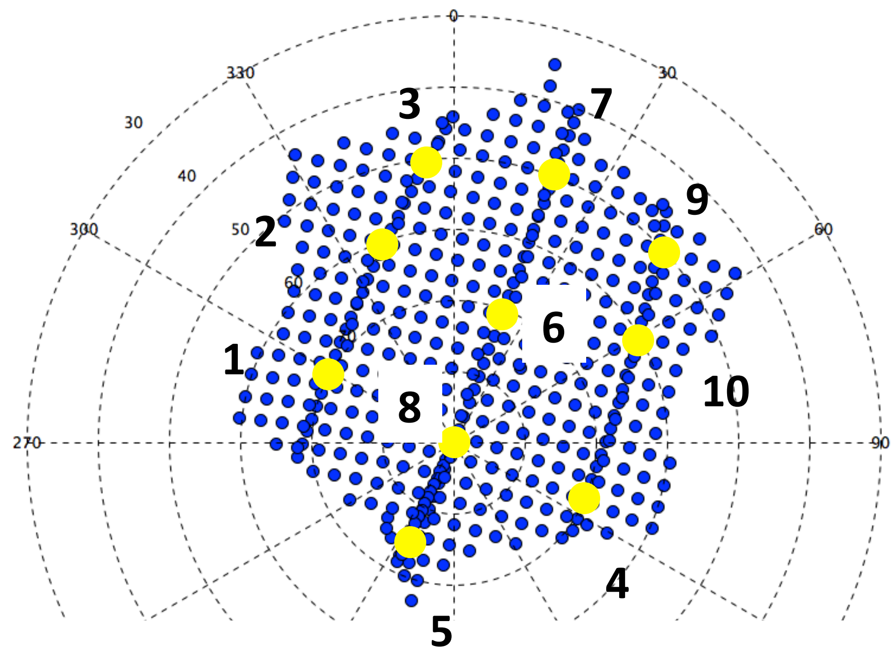
Experiment Planning





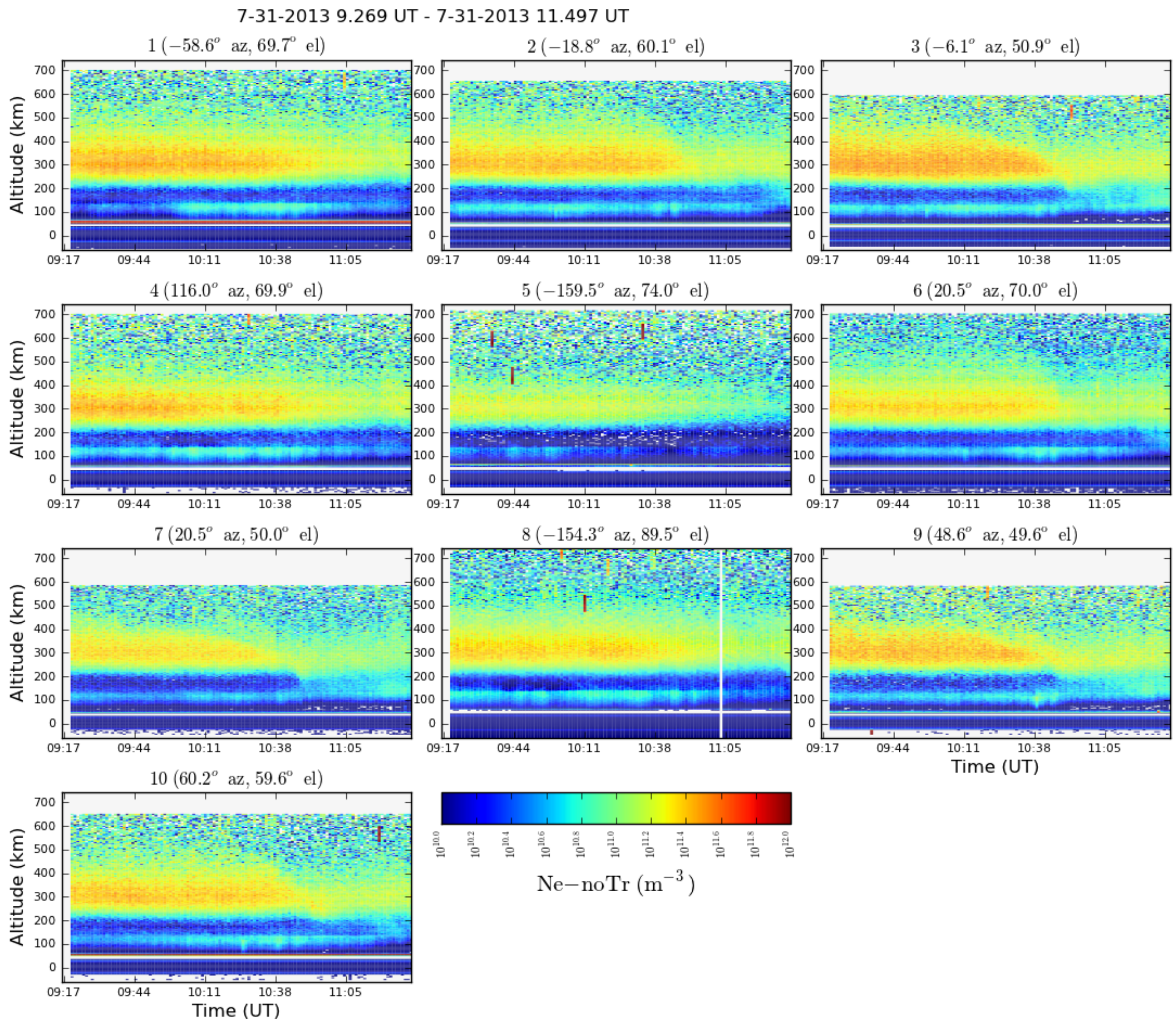
Y. Jiao, "High Latitude Ionospheric Scintillation Characterization", MS thesis

- ❑ 08:00 – 10:00 UT (9:20 – 11:30 UT)
- ❑ large scale ionospheric structures (traveling ionospheric disturbance (TID))

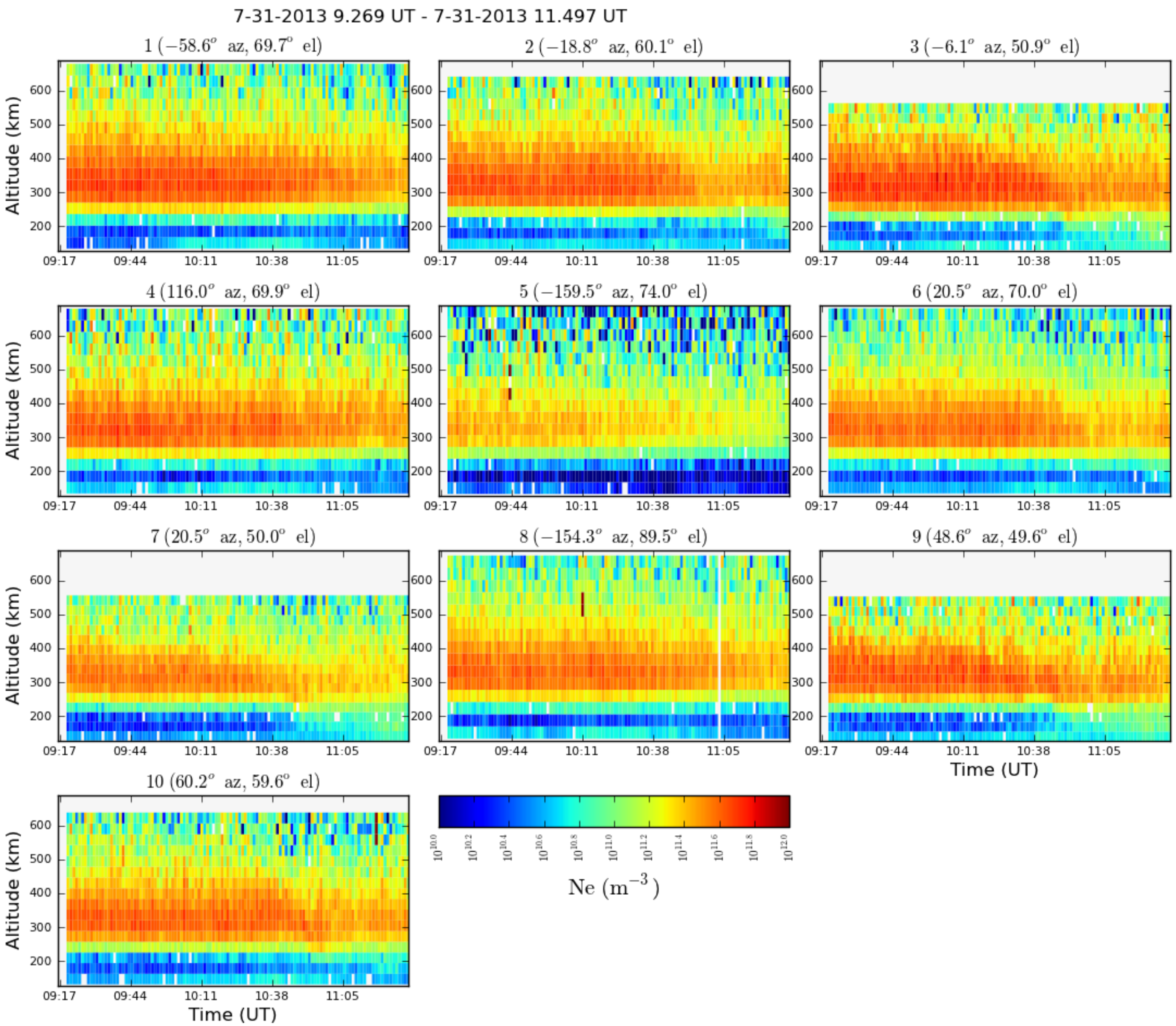


- ❑ Long Pulse + Alternating Code
- ❑ 1min + 3min integration

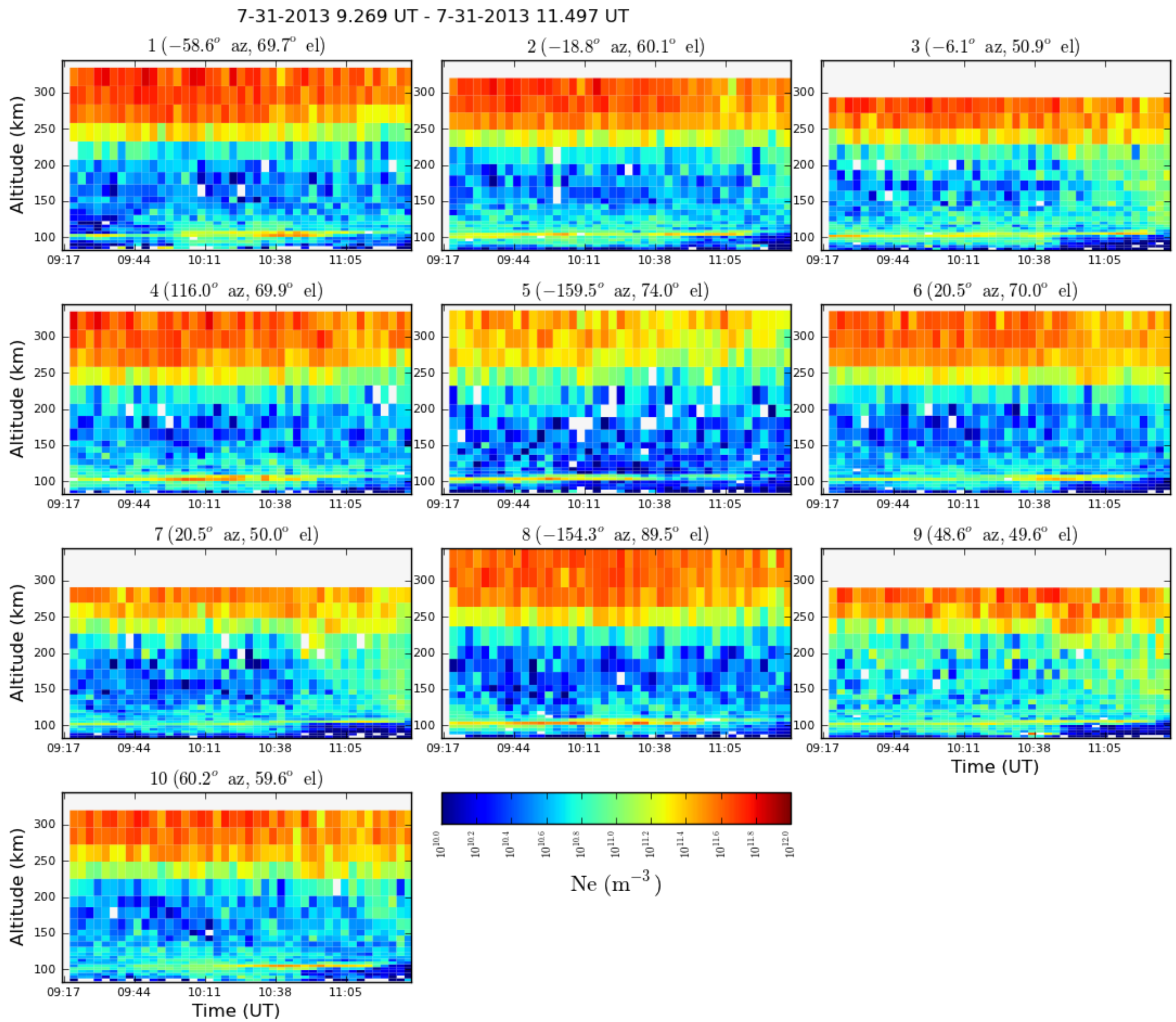
Electron Density w/o Te/Ti Correction (1min integration, Long Pulse)



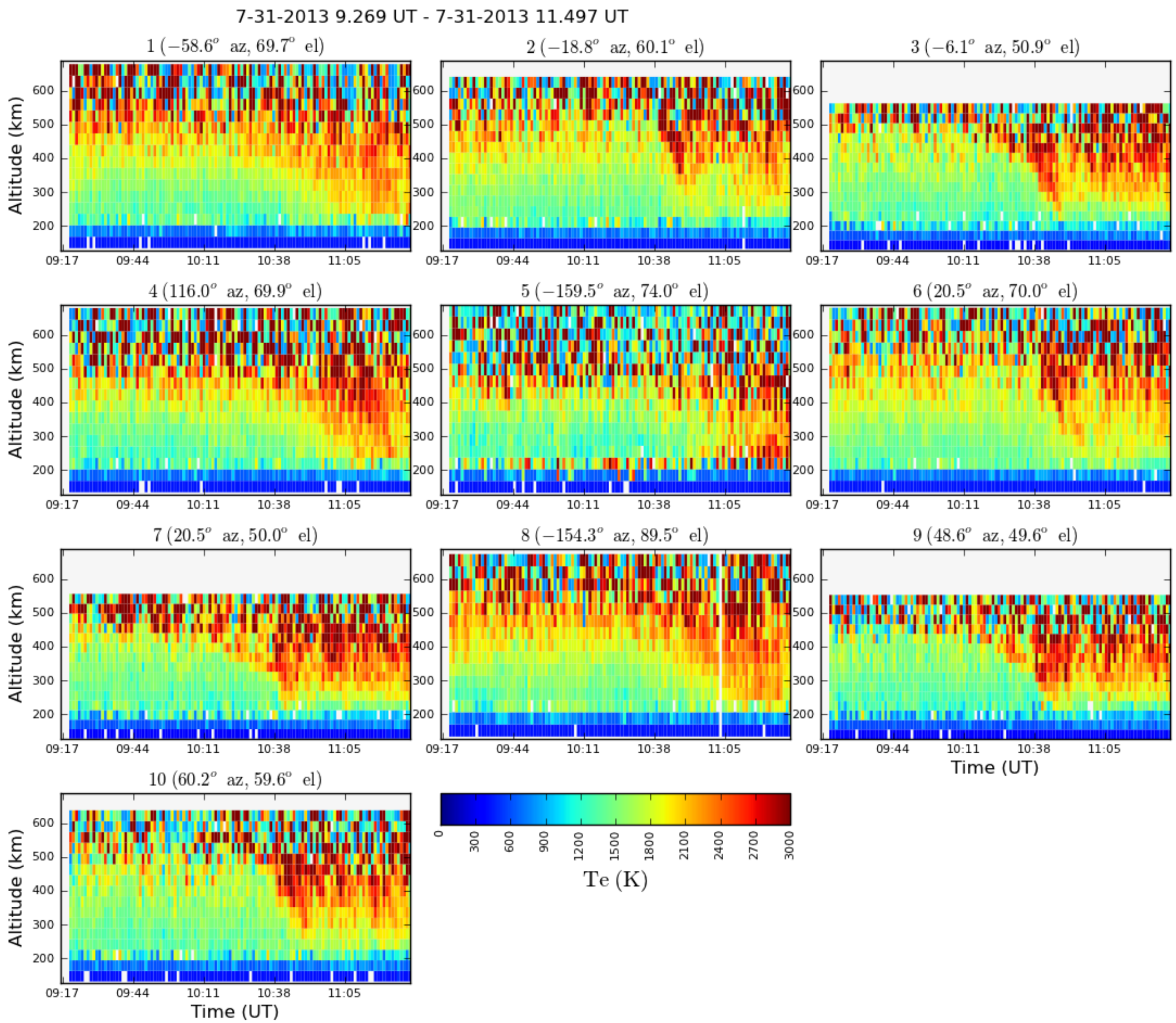
Electron Density with Te/Ti Correction (1min integration, Long Pulse)



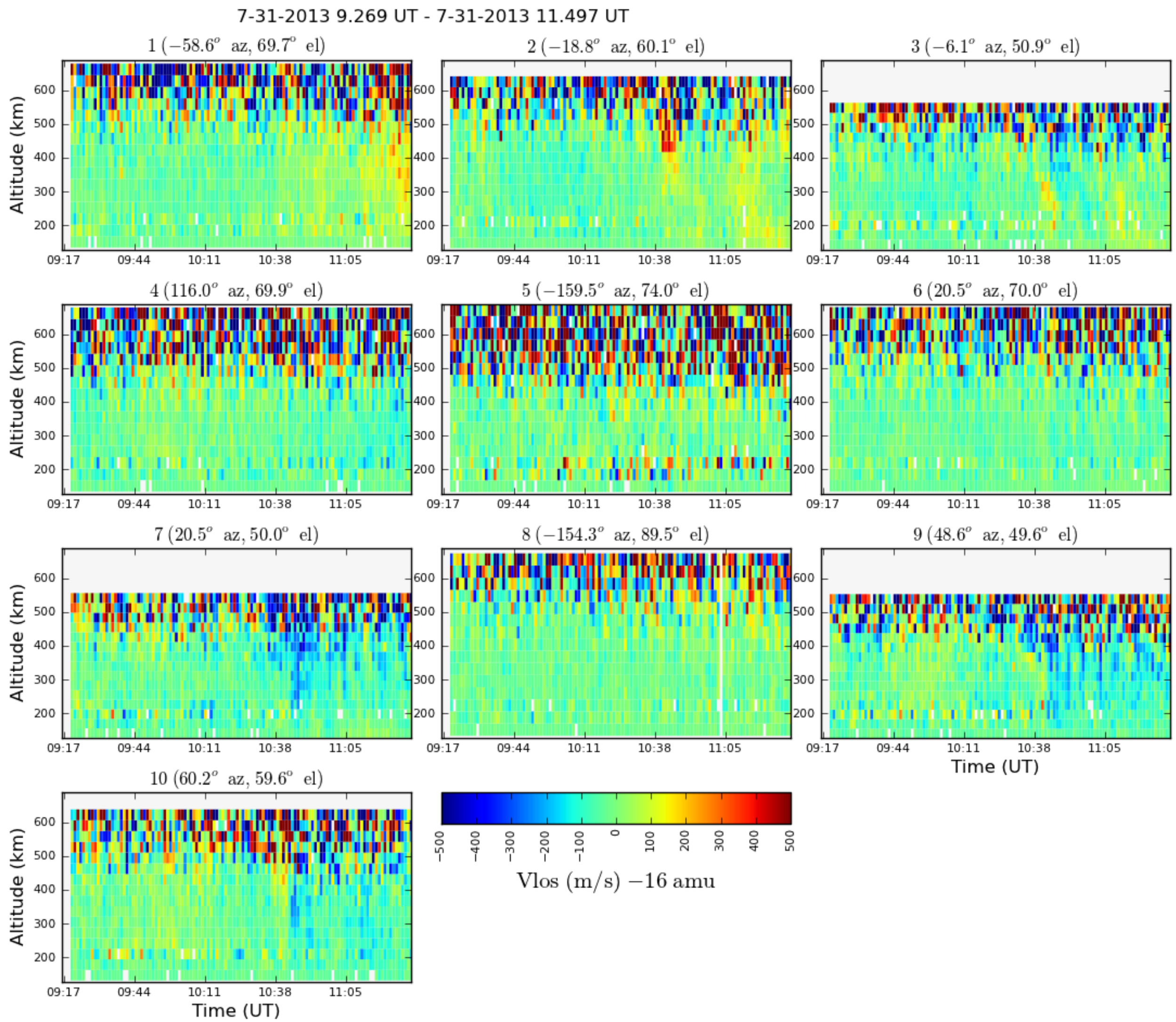
Electron Density with Te/Ti Correction (3min integration, Alternating Code)



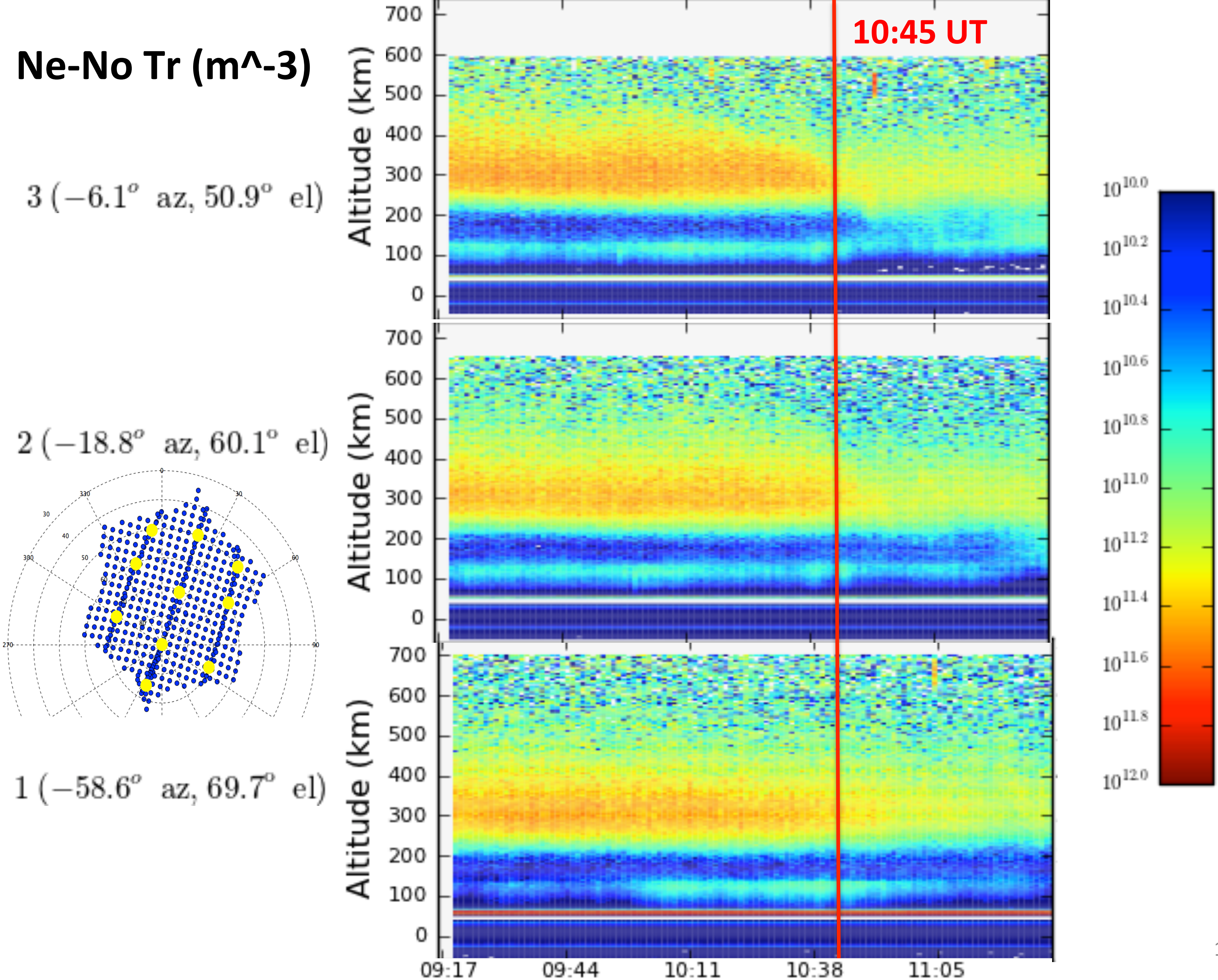
Electron Temperature (1min integration, Long Pulse)



LOS Velocity
(1min integration, Long Pulse)



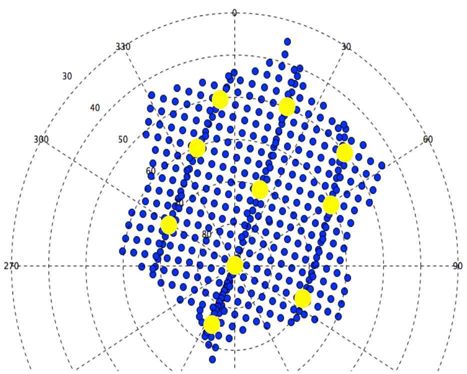
Ne-No Tr (m^-3)


3 (−6.1° az, 50.9° el)
2 (−18.8° az, 60.1° el)
1 (−58.6° az, 69.7° el)
10:45 UT
Altitude (km)
700
600
500
400
300
200
100
0
09:17
09:44
10:11
10:38
11:05
$10^{10.0}$
$10^{10.2}$
$10^{10.4}$
$10^{10.6}$
$10^{10.8}$
$10^{11.0}$
$10^{11.2}$
$10^{11.4}$
$10^{11.6}$
$10^{11.8}$
$10^{12.0}$

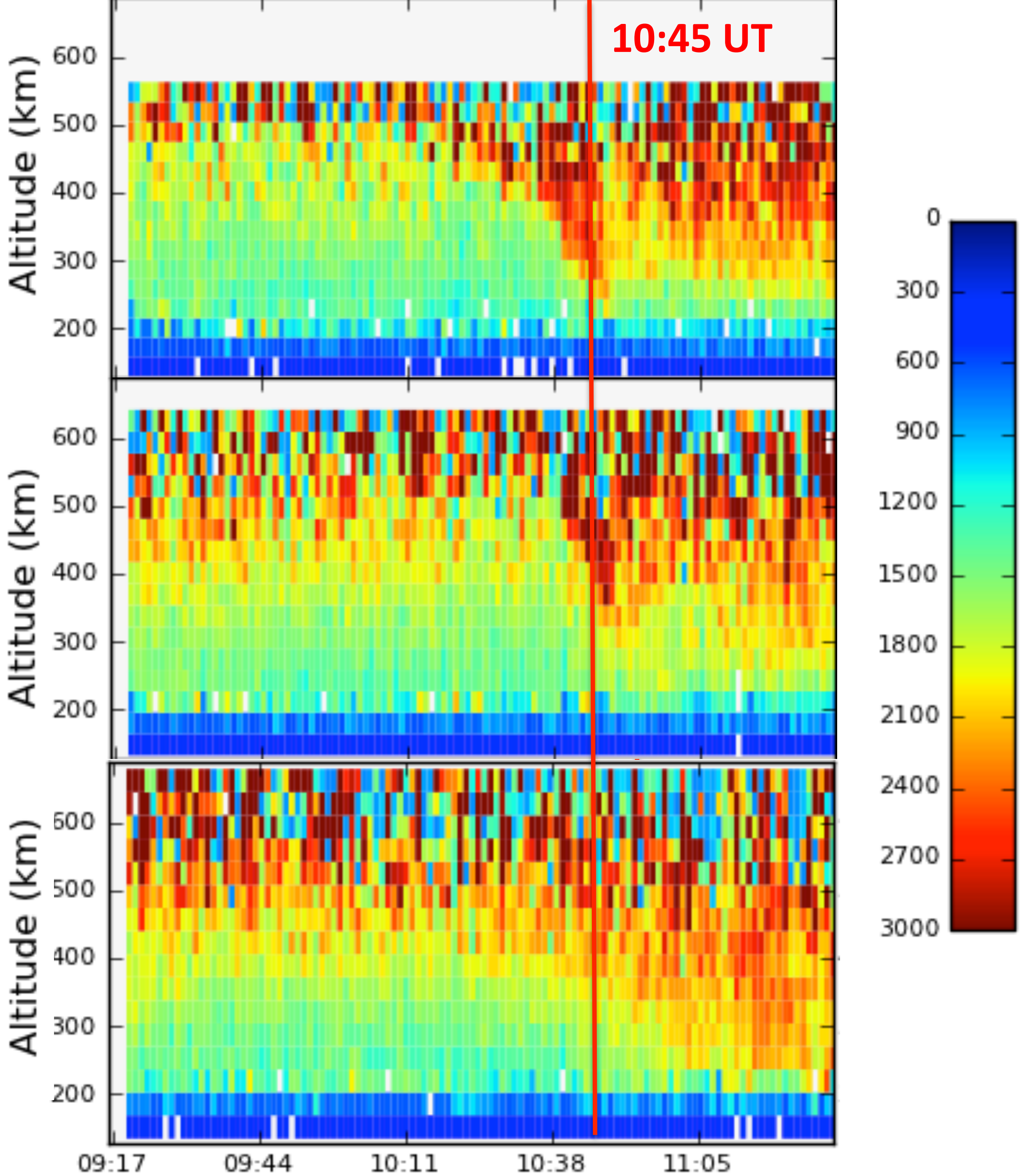
Te (K)

$3\ (-6.1^o\ \text{az},\ 50.9^o\ \text{el})$

$2\ (-18.8^o\ \text{az},\ 60.1^o\ \text{el})$



$1\ (-58.6^o\ \text{az},\ 69.7^o\ \text{el})$

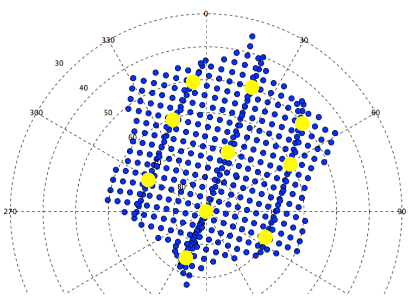


Te (K)

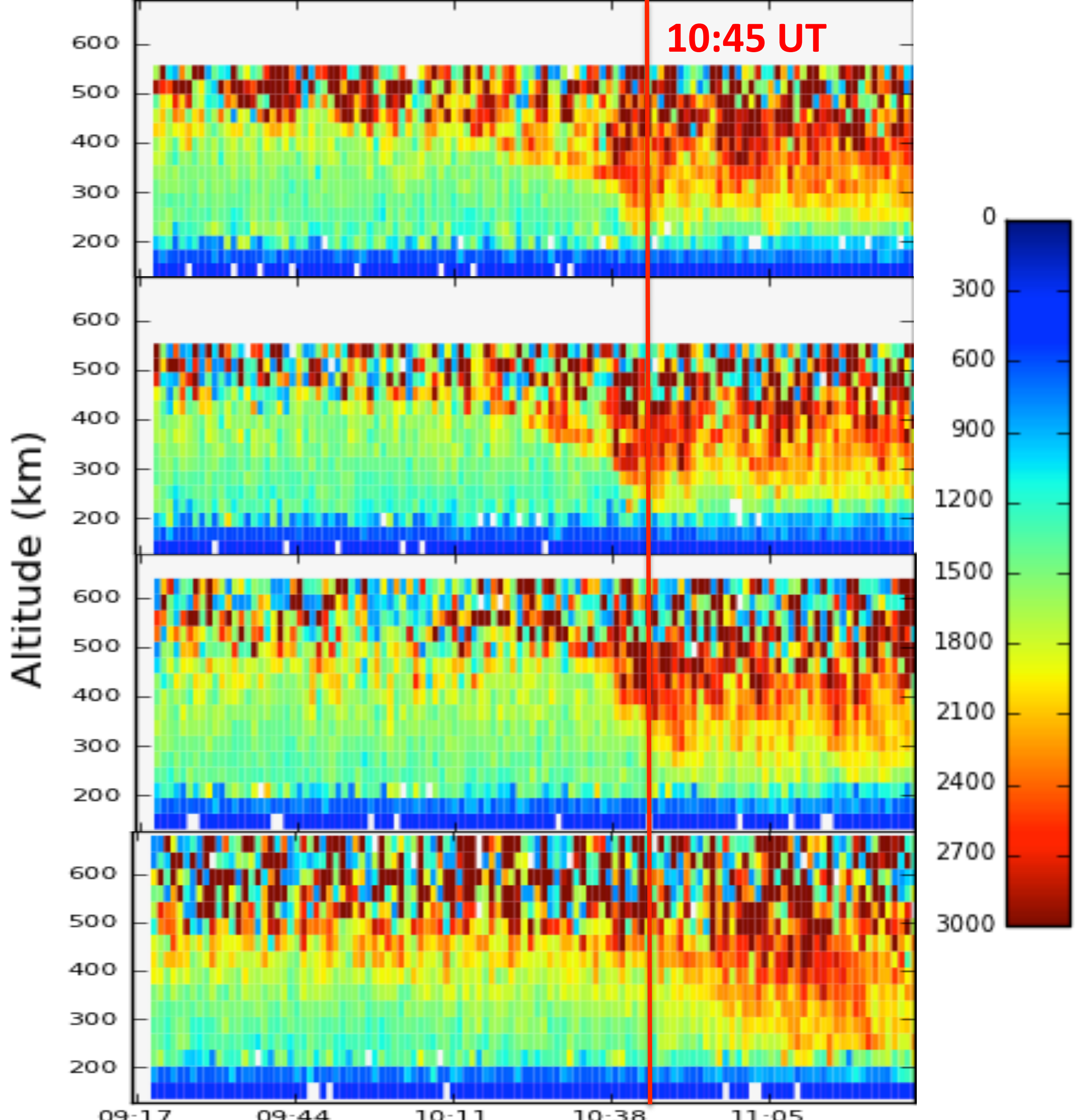
7 (20.5° az, 50.0° el)

9 (48.6° az, 49.6° el)

10 (60.2° az, 59.6° el)



4 (116.0° az, 69.9° el)

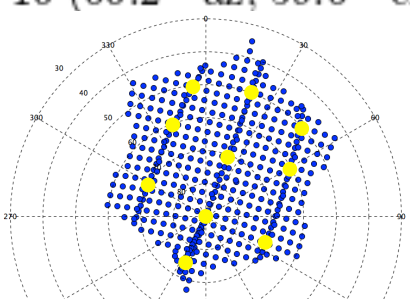


Los Vel (m/s)

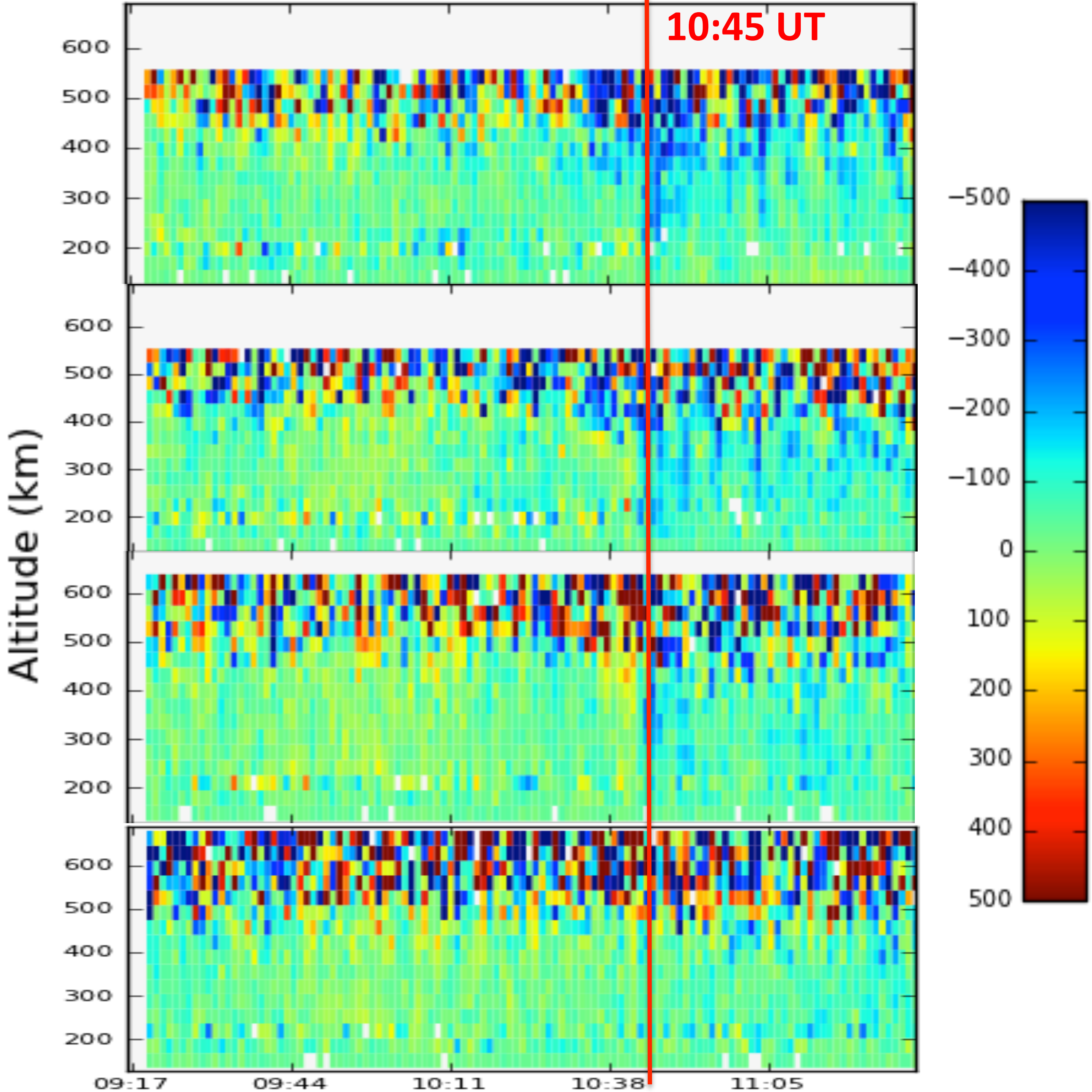
7 $(20.5^o\ \text{az}, 50.0^o\ \text{el})$

9 $(48.6^o\ \text{az}, 49.6^o\ \text{el})$

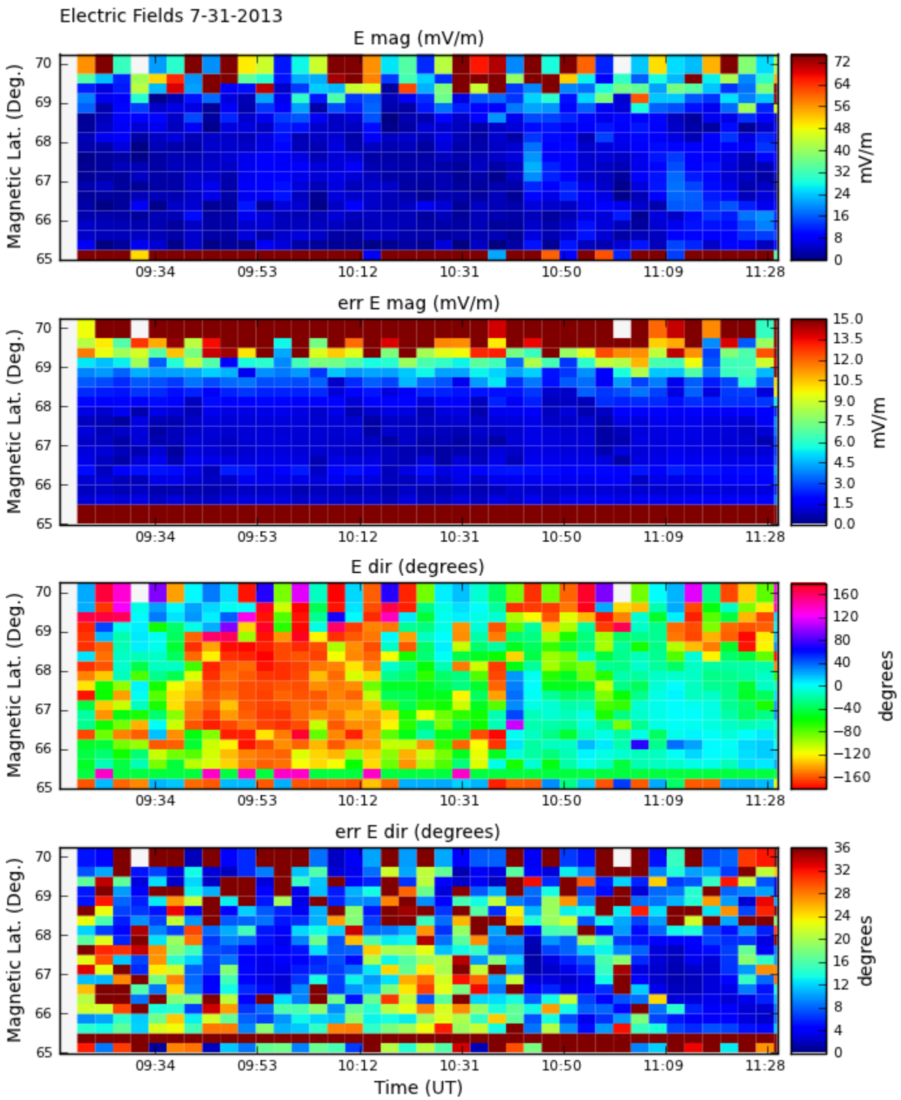
10 $(60.2^o\ \text{az}, 59.6^o\ \text{el})$



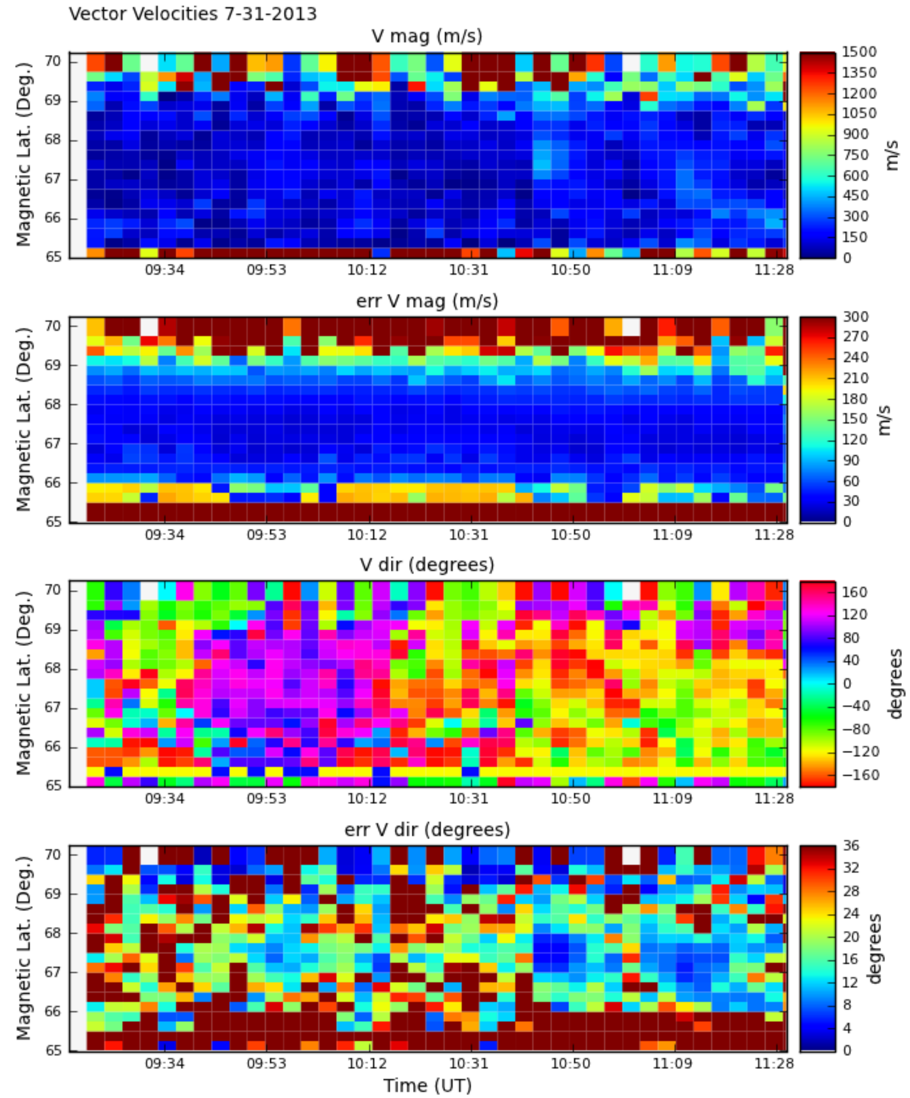
4 $(116.0^o\ \text{az}, 69.9^o\ \text{el})$



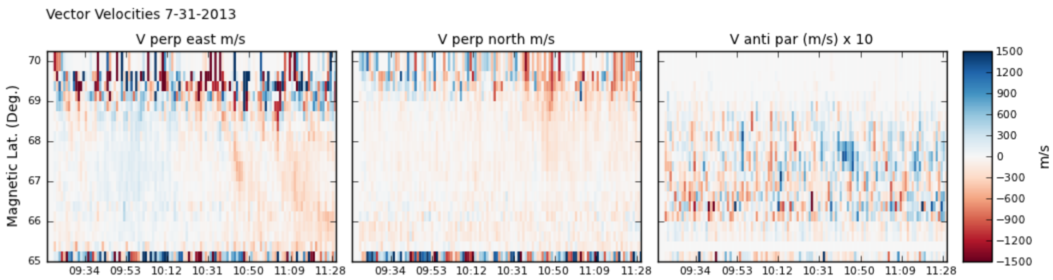
E-field

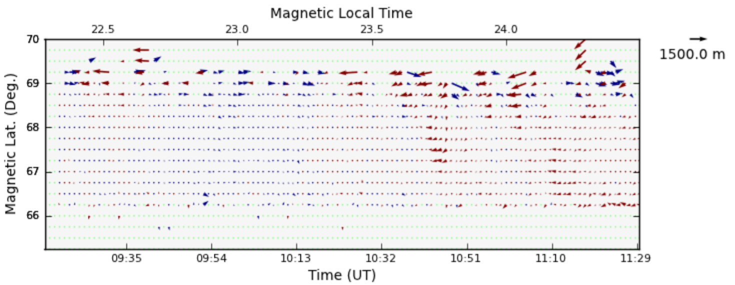


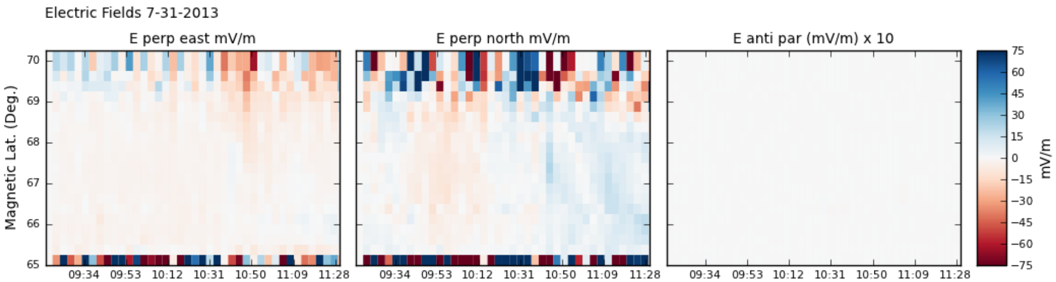
Velocity

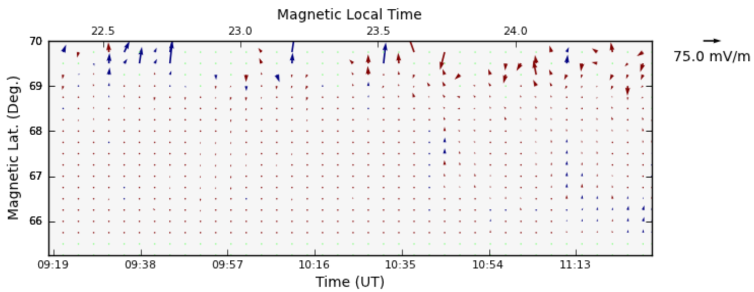


Vector Velocity and E-Field

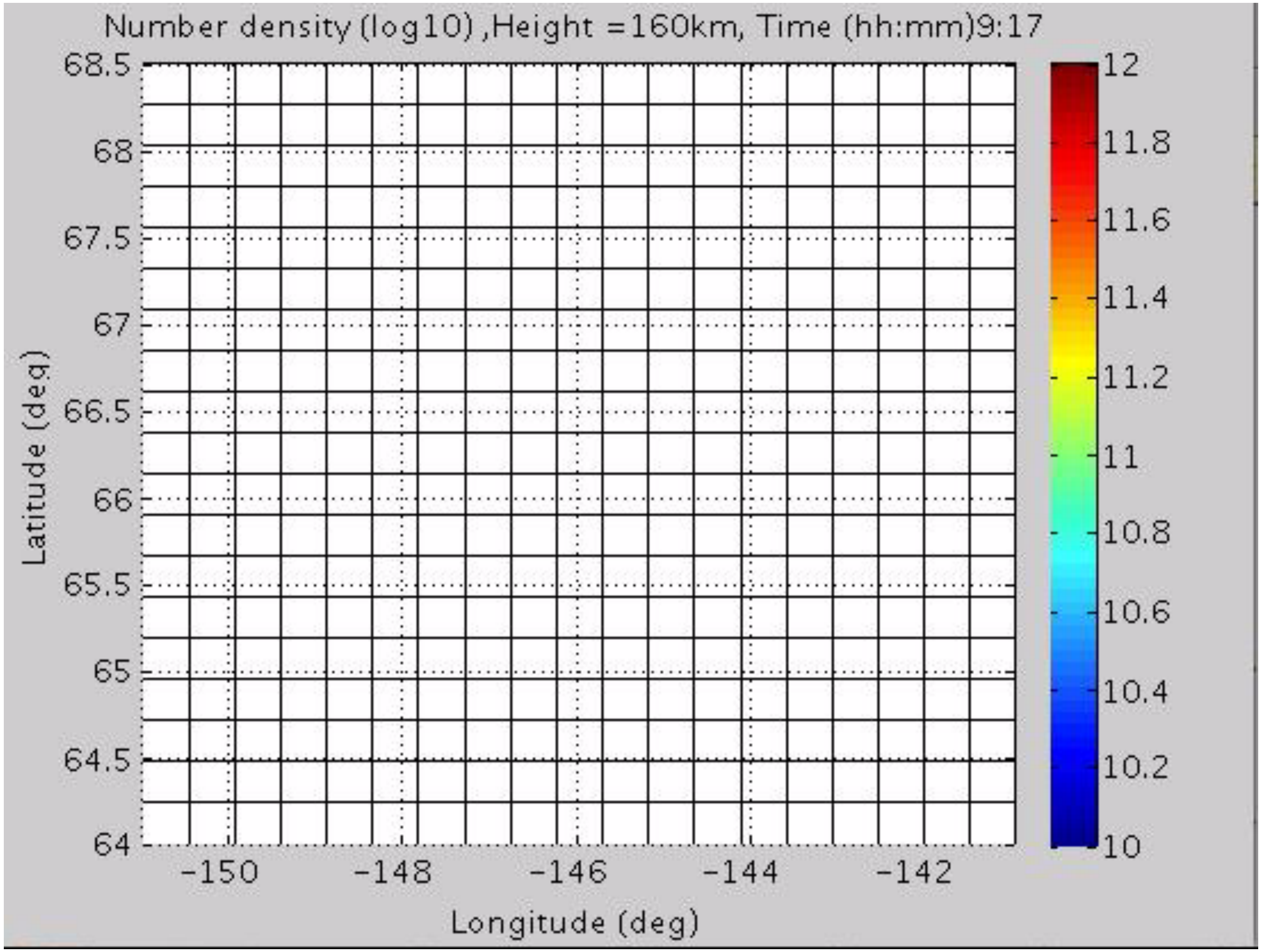




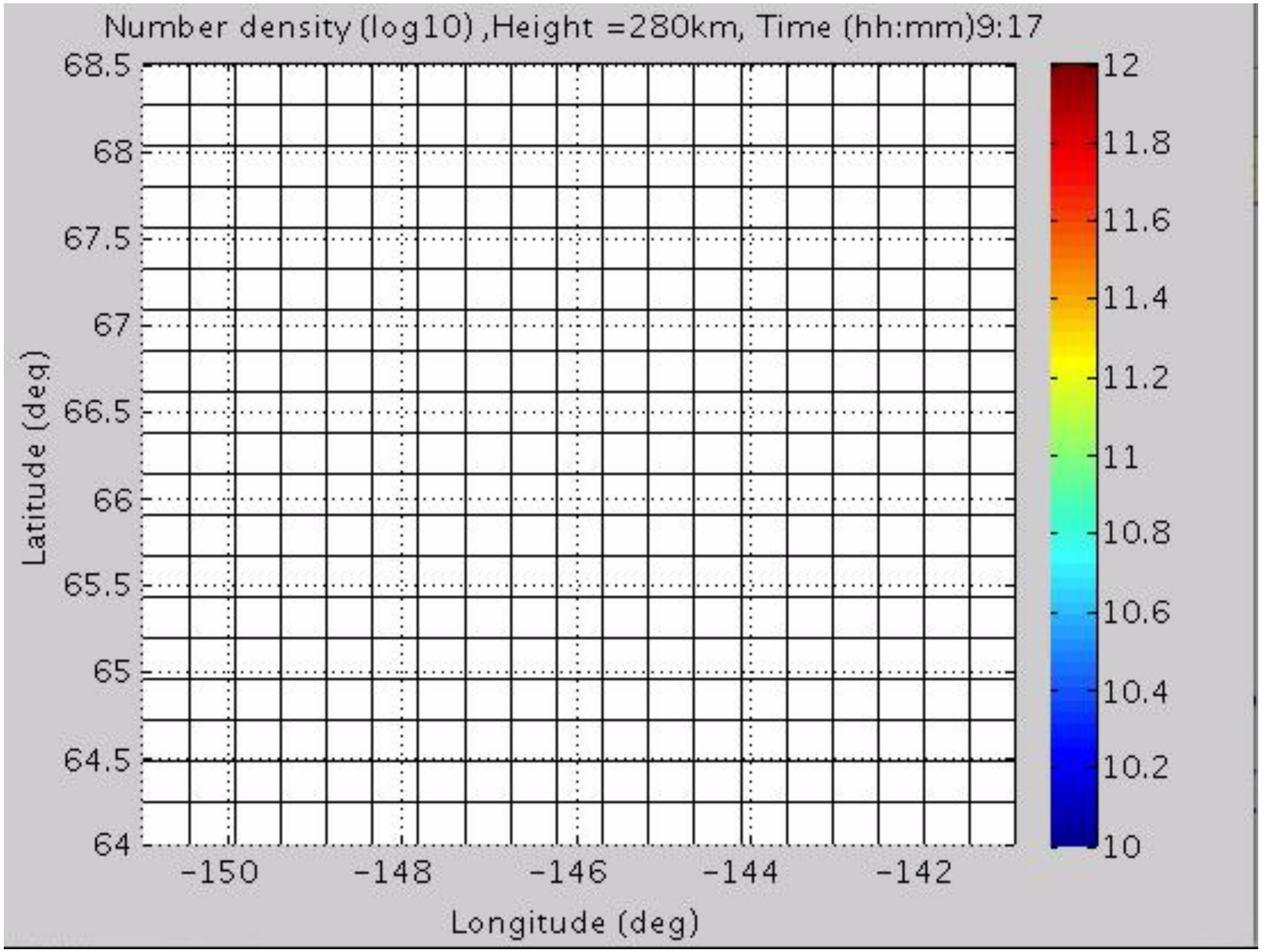




E region: Density low, but increases after 10:30 UT



F region: Density high, but slightly decreases after 10:30 UT



What we think is going on

- Sporadic E layer
  - Meteors
  - Descending Intermediate Layers
  - Auroral Precipitation

Meteor induced ionization and Sporadic E

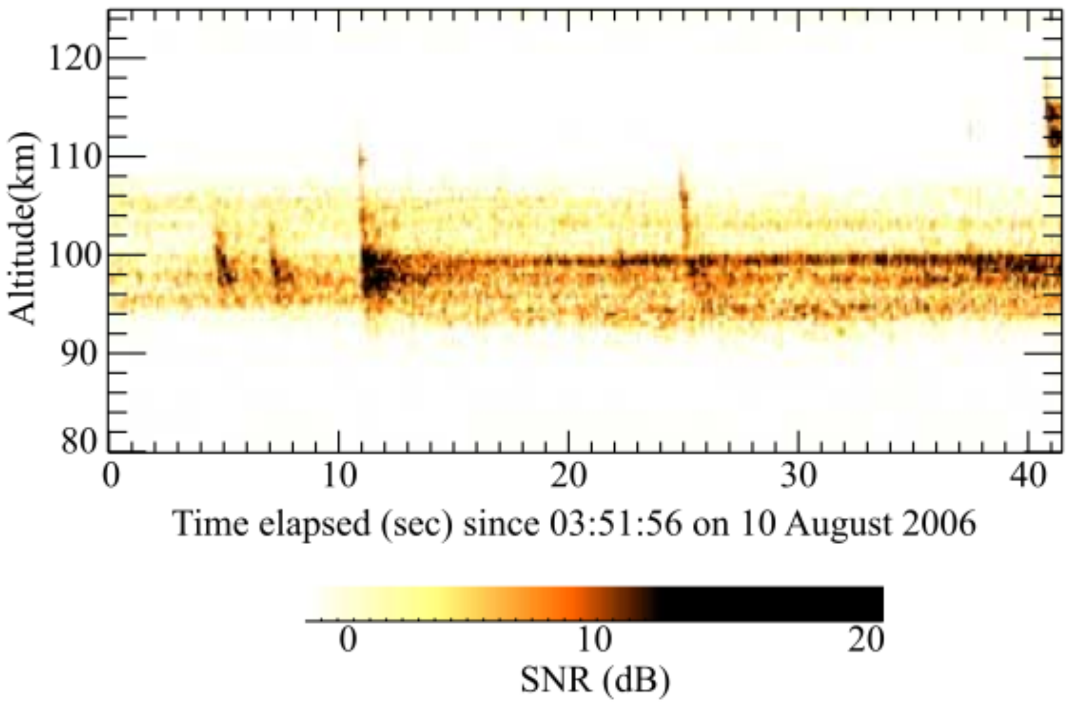


Figure 3. RTI plot showing a direct relationship between meteor induced ionization and Sporadic-E. The ionization produced by the meteor event occurring at ~10 seconds can be clearly seen strengthening the Sporadic-E return.

Effect of meteor ionization on sporadic-E observed at Jicamarca, GRL2008, A. Malhotra et.al

Descending Intermediate Layer

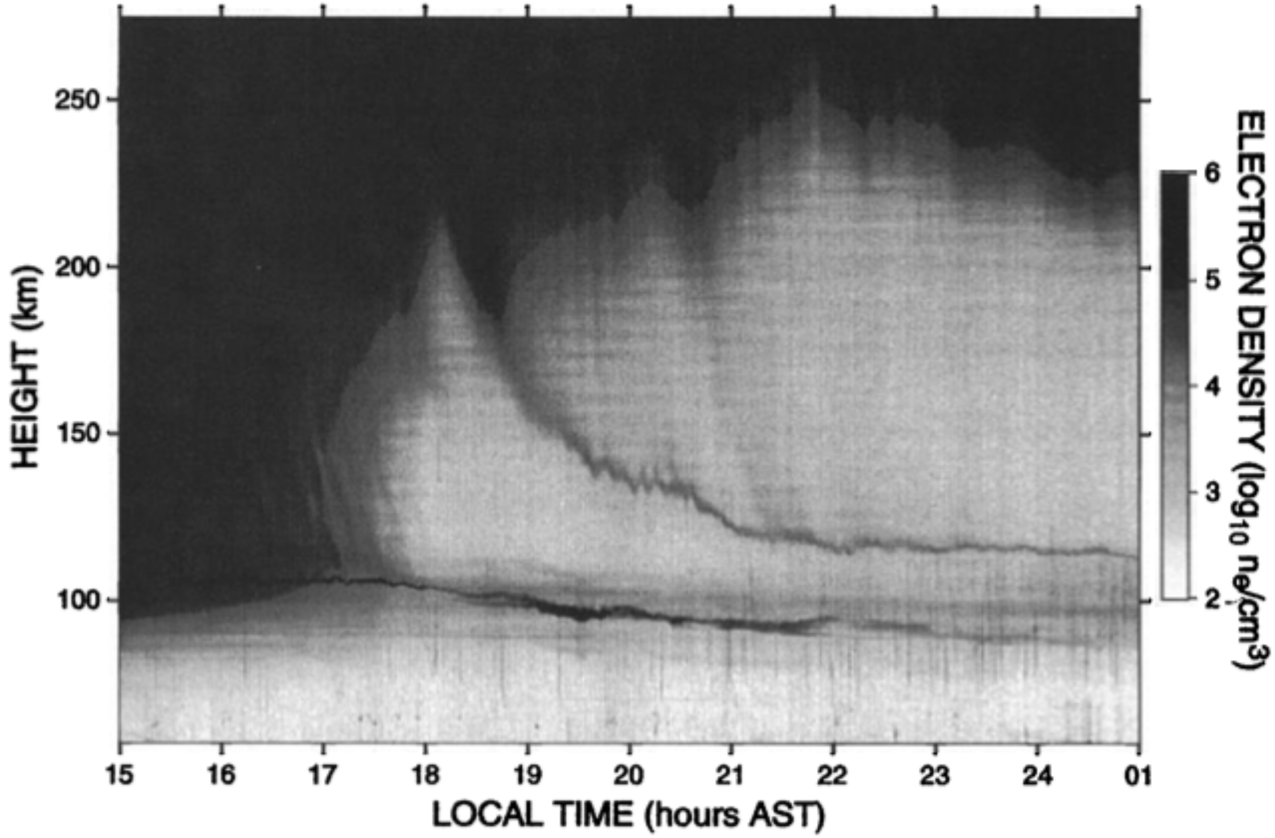


Figure 3. A height versus time plot showing the variation in the electron density between 60 and 270 km on September 2, 1994. An intermediate layer is seen descending from the base of the *F* region at 1830 LT, and ion rain is clearly visible between 1900 and 2200 LT merging with the downgoing oscillations of the intermediate layer. The layer descending from 110 to 85 km is sporadic *E*; the light vertical steaks occurring mainly between 80 and 110 km altitude are meteor echoes broadened by unsuccessful decoding to twice the length of the radar code. The structure and dynamics of the ion rain and of the layers varies greatly from day to day; the detailed explanation of the variability is another topic of current interest. The data were taken using an 88-baud code with 1-μs baud length and 10-ms pulse repetition period [*Mathews et al.*, 1997*b*].

Upper atmospheric observations at the Arecibo Observatory: Examples obtained using new capabilities, JGR2000, Isham et. al

Auroral Precipitation

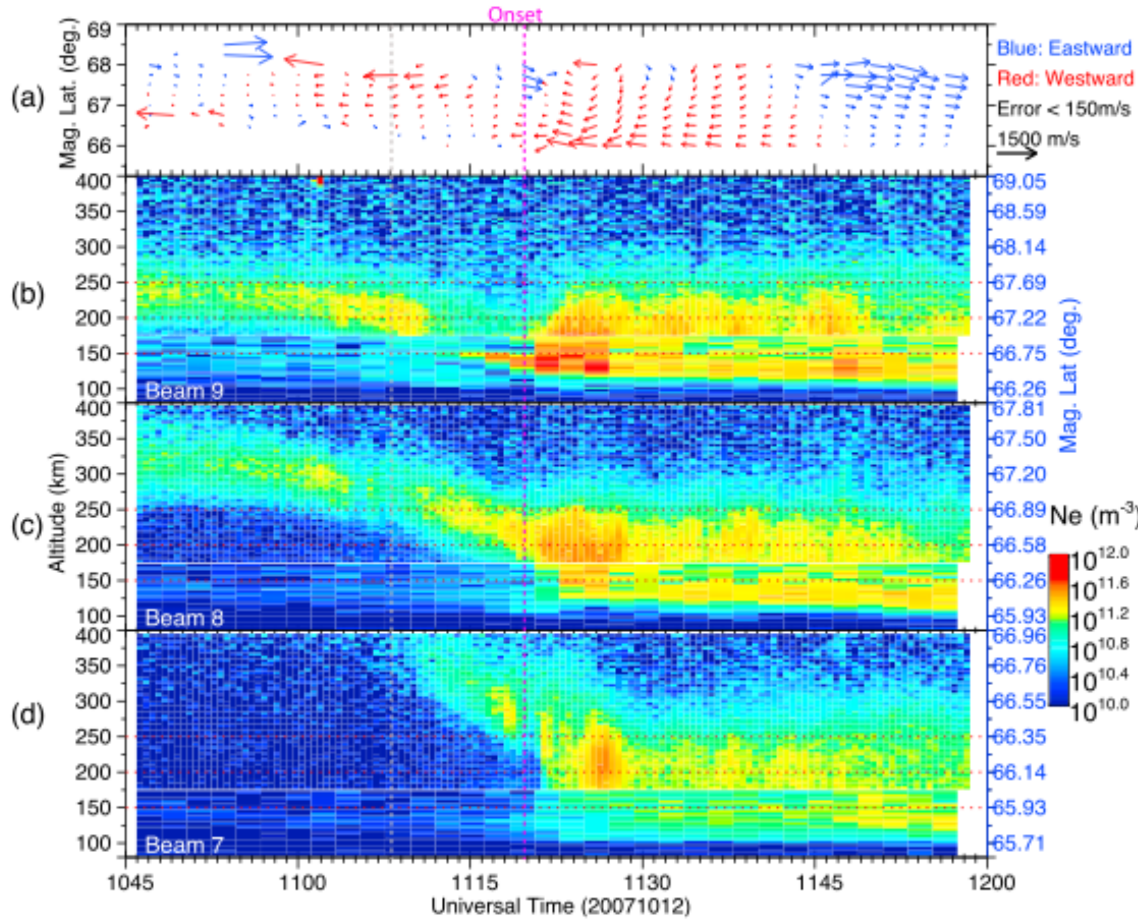
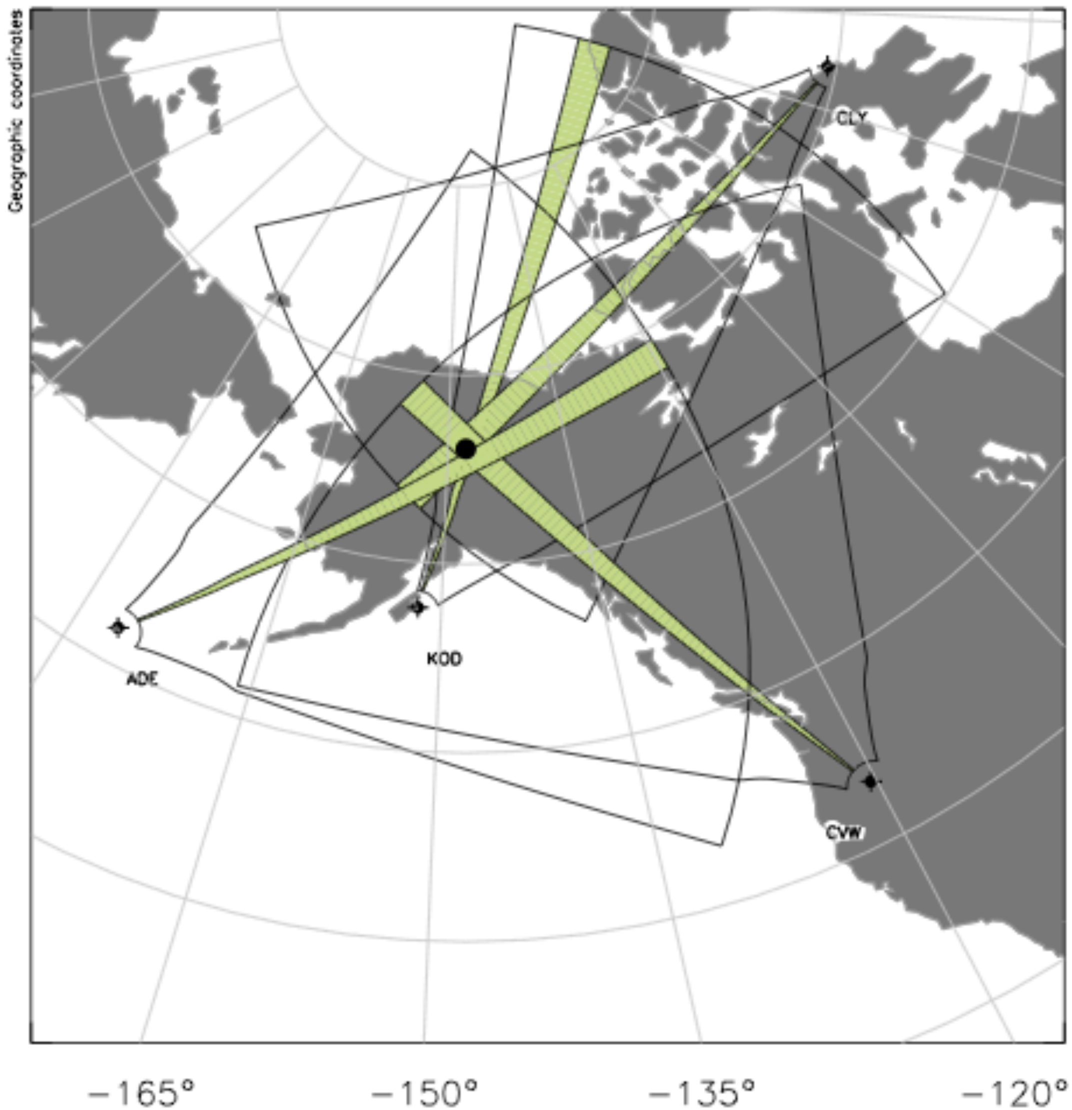


Figure 5. (a) Nightside convection flows measured by PFISR on 12 October 2007 are shown as a function of magnetic latitude and UT; data are plotted only if the measurement uncertainty is less than 150 m/s. Flows with eastward component are blue, and those with westward component are red. (b–d) Raw electron densities with no correction for T_e/T_i or Debye length effects measured by three central northward looking beams are shown as a function of UT. Altitude (magnetic latitude) is indicated on the left (right) Y ordinate. The electron density below 175 km is from the alternating code pulse measurement, while that above 175 km is from the long pulse measurement. The magenta and gray vertical lines indicate the substorm onset time determined by the THEMIS ASI observations at 1119:42 UT and the start time of a rapid equatorward motion of the auroral oval inferred from the electron density profiles at ~1108 UT, respectively.

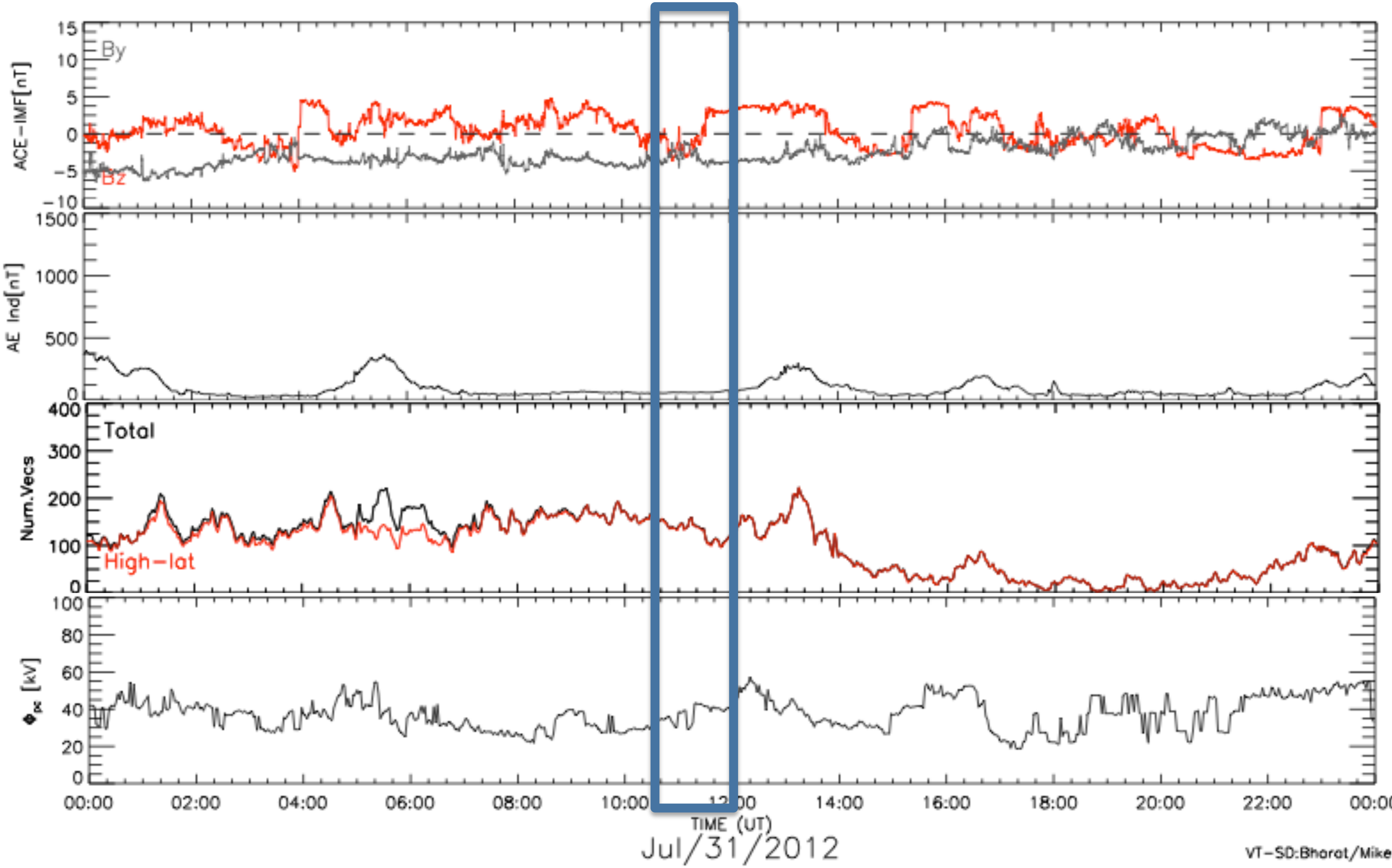
Identification of substorm onset location and preonset sequence using Reimei, THEMIS GBO, PFISR, and Geotail, JGR2010, S. Zou, et. Al.

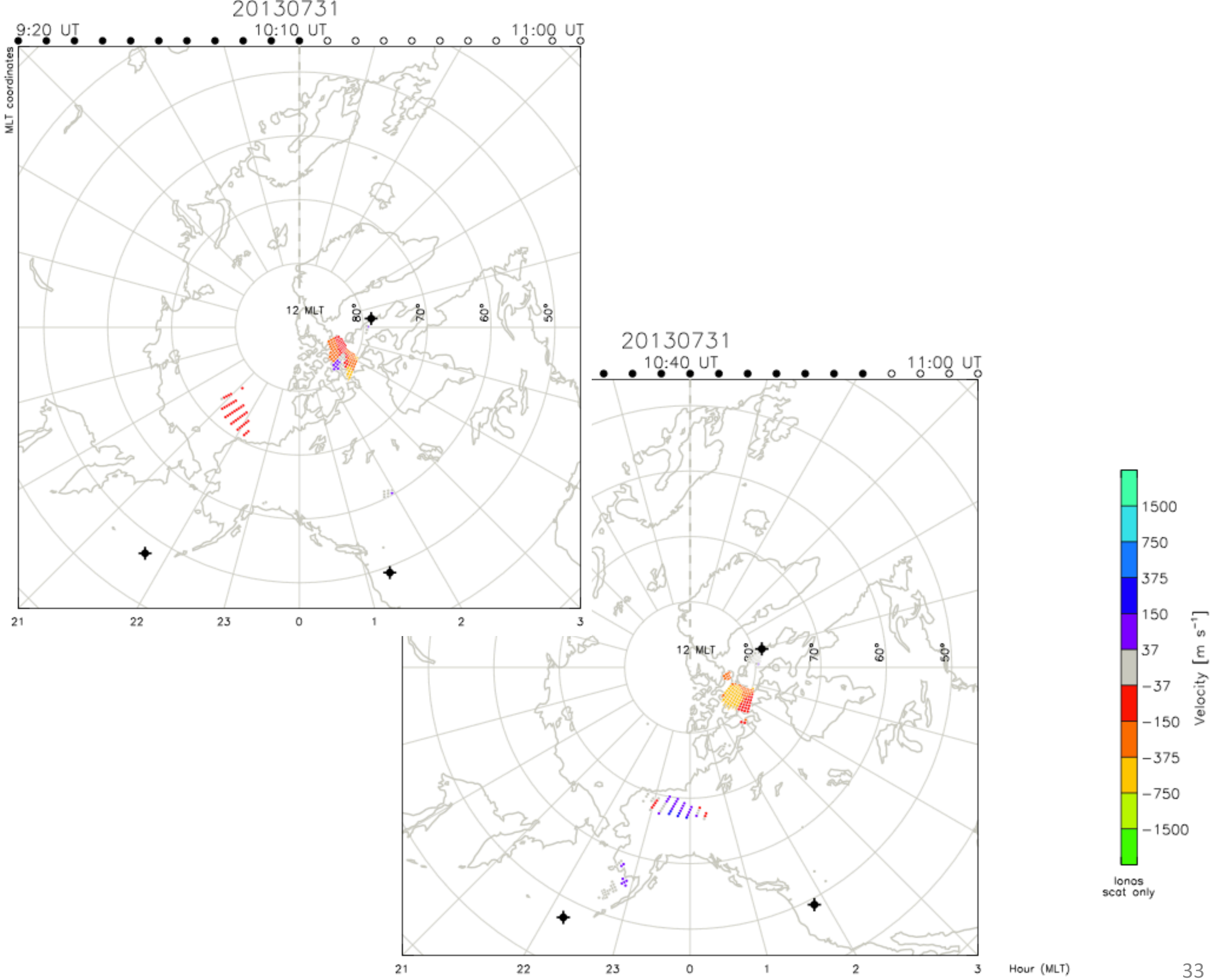
SuperDARN Coverage



Kodiak (kod)
Clyde River (cly)
Christmas Valley West (cvw)
Adak East (ade)

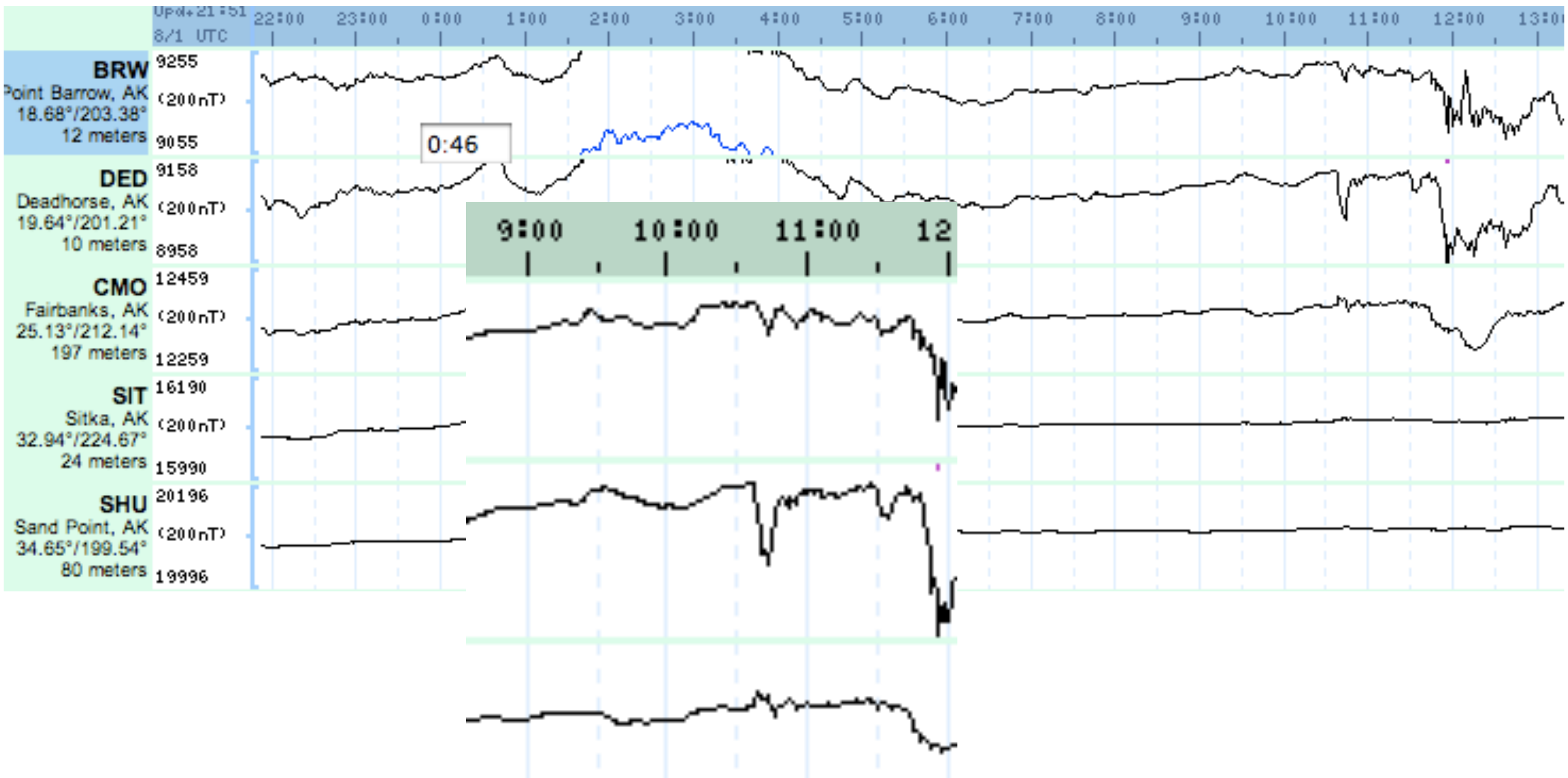
Summary Plot from SuperDARN website



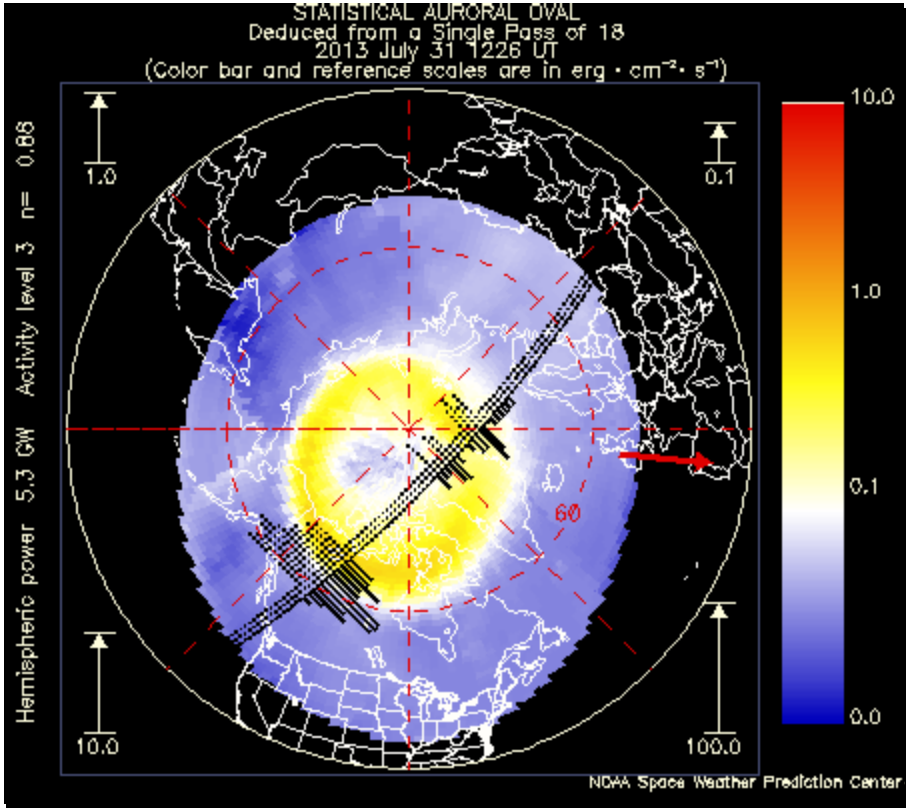


20130731
9:20 UT
10:10 UT
11:00 UT
MLT coordinates
12 MLT
80°
70°
60°
50°
21
22
23
0
1
2
3
20130731
10:40 UT
11:00 UT
12 MLT
70°
60°
50°
21
22
23
0
1
2
3
Hour (MLT)
1500
750
375
150
37
−37
−150
−375
−750
−1500
Velocity [m s⁻¹]
Ionos scat only

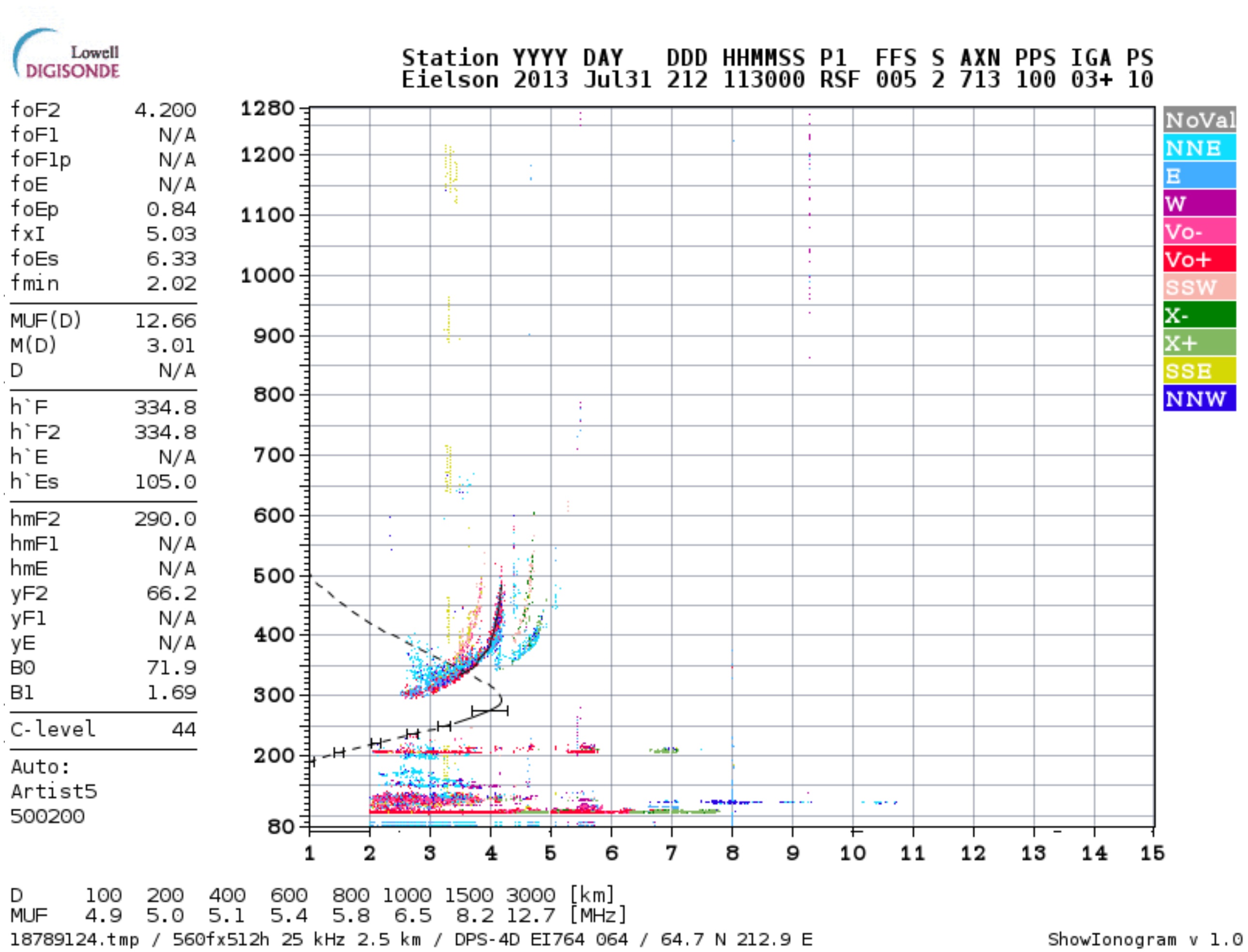
Magnetometer Measurements



Auroral Oval



Ionosonde Results



Summary

- Relatively quiet day, but we saw interesting features.
- Enhanced electron density in E region for almost the whole dataset.
- Depletion in ne after 10:45 UT in F region.
- Enhanced Te after 10:45 UT in F region.
- Direction reversal in E field and LOS velocities.

Questions

- Sporadic E-layer?
- Auroral precipitation?
- Convection or FACs causing high Te?