Perp-to-B incoherent scatter measurements of F-region drifts, density, and temperatures at JRO

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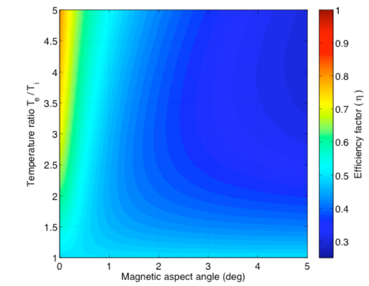
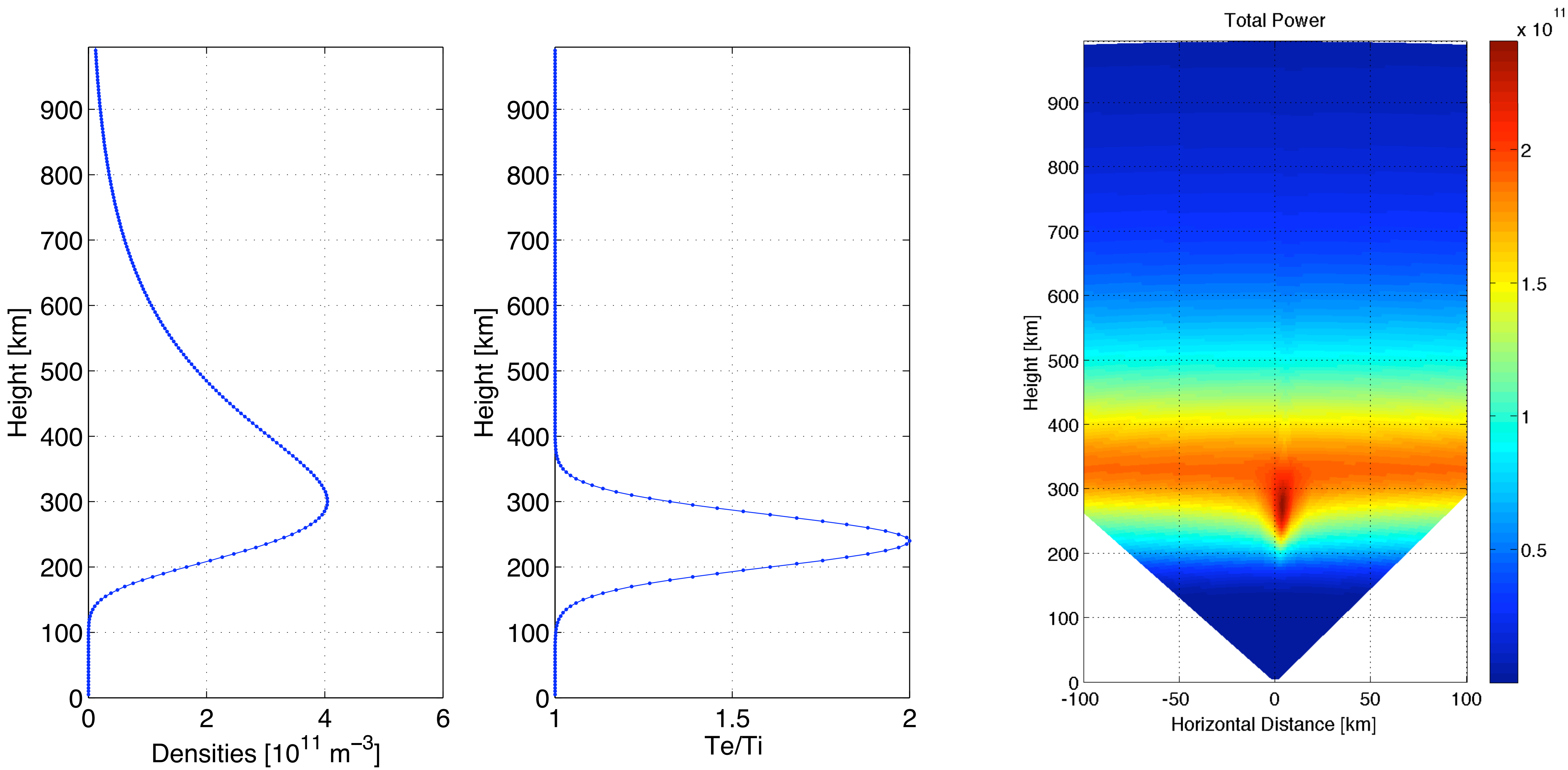
- During the past decade we have learned how to "forward-model" the altitude variations of F-region incoherent scatter signals (power, correlations, spectra) collected with multi-beam radar configurations including polarization and spatial diversity:
  - Experience gained in differential-phase (*Feng et al.*), MST-ISR (*A. Akgiray* M.S. Thesis) experiments, and also beam-scanned ALTAIR results...
  - Advances in ISR theory close to perp-to-B: *Sulzer and González* (1999), *Woodman* (2004), *Kudeki and Milla* (2005), *M. Milla* PhD Thesis work...
  - Faster computing, availability of clusters, reliable magnetic field model (IGRF)...
- As a consequence we are reaching the point of being able to conduct **difficult experiments** at JRO such as measuring **F-region densities and temperatures** simultaneous with **high-quality perp-to-B drifts**:
  - **We describe here one such experiment conducted in June 2008 and show preliminary results.**

Basic idea used in the experiment: In an ionosphere with **Ne and Te/Ti profiles** shown on the left, a north-south beam scan would produce a **total backscatter power map** shown on the right, with the sharp enhancement ("dagger") in the direction where the radar beam is perpendicular to B:

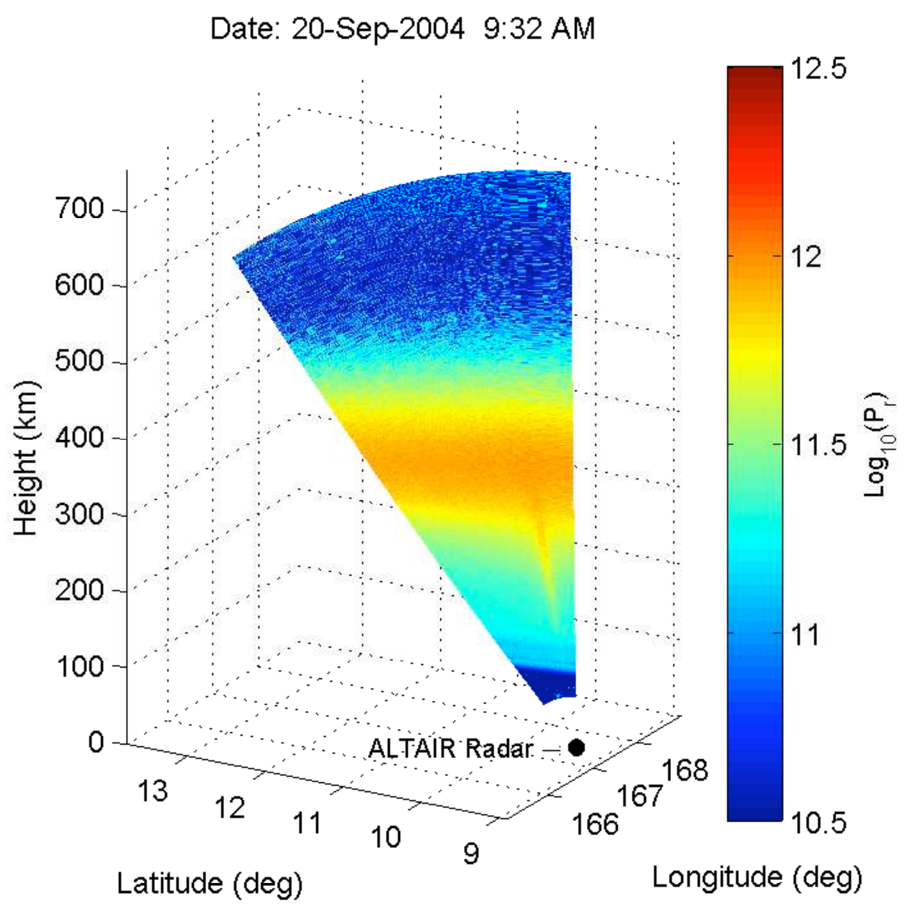
$$P_s \propto \frac{N_e}{1+T_e/T_i}$$ away from perp to B, otherwise $P_s \propto N_e \eta, \ \eta =$

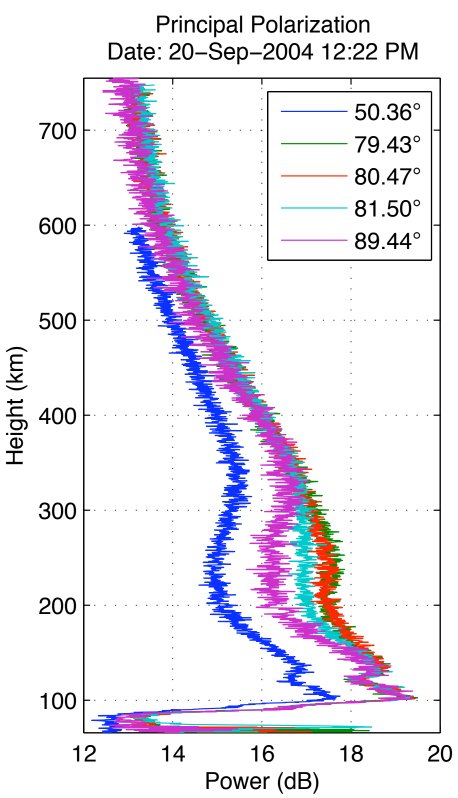


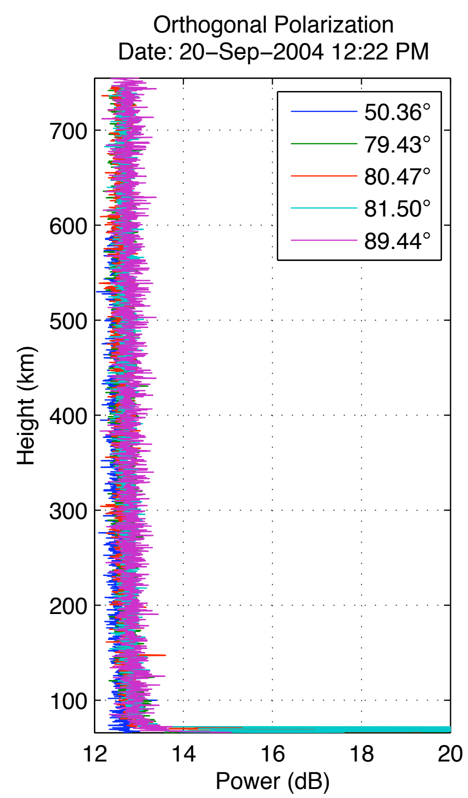
A scan like this cannot be done at JRO having fixed beams, but the effect has been observed and fully modeled at ALTAIR to estimate Ne and Te/Ti parameters from power scan data.



ALTAIR power scan:



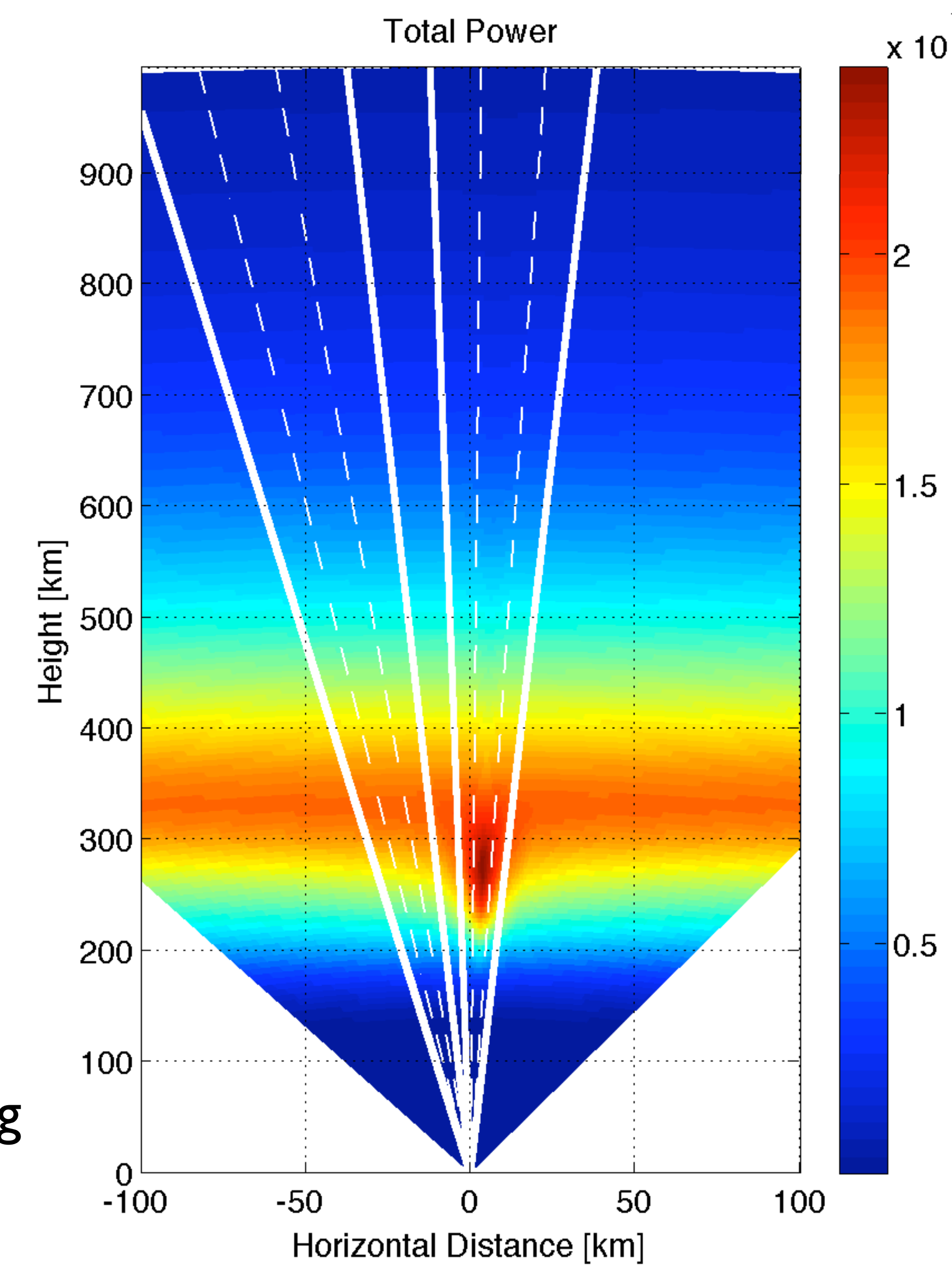




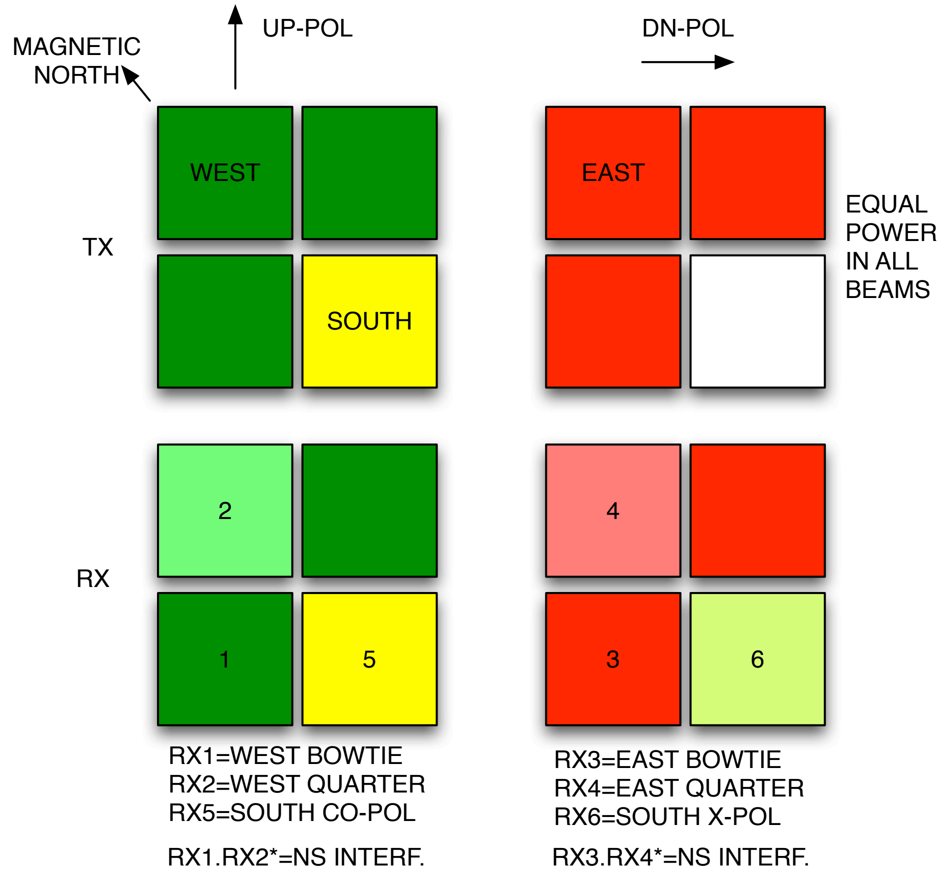
At ALTAIR, operating at 422 MHz, magneto-ionic effects are negligible, so that total power can be collected using a single polarization (circular).

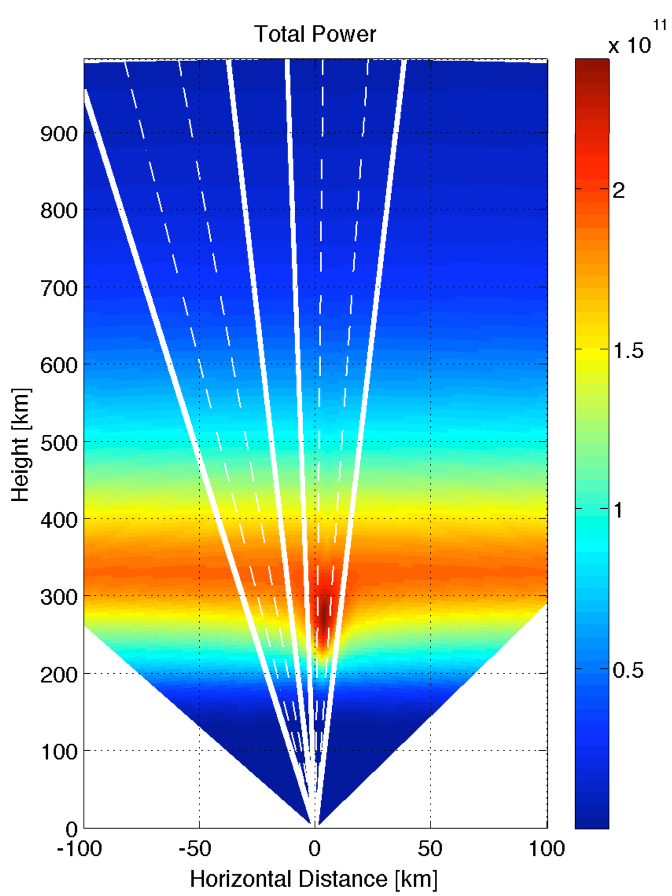
At JRO, operating at 50 MHz, MI-effects are important, and thus both “co-pol” and “x-pol” components of the scattered power need to be collected and processed to make Ne and Te/Ti estimation using a similar approach.

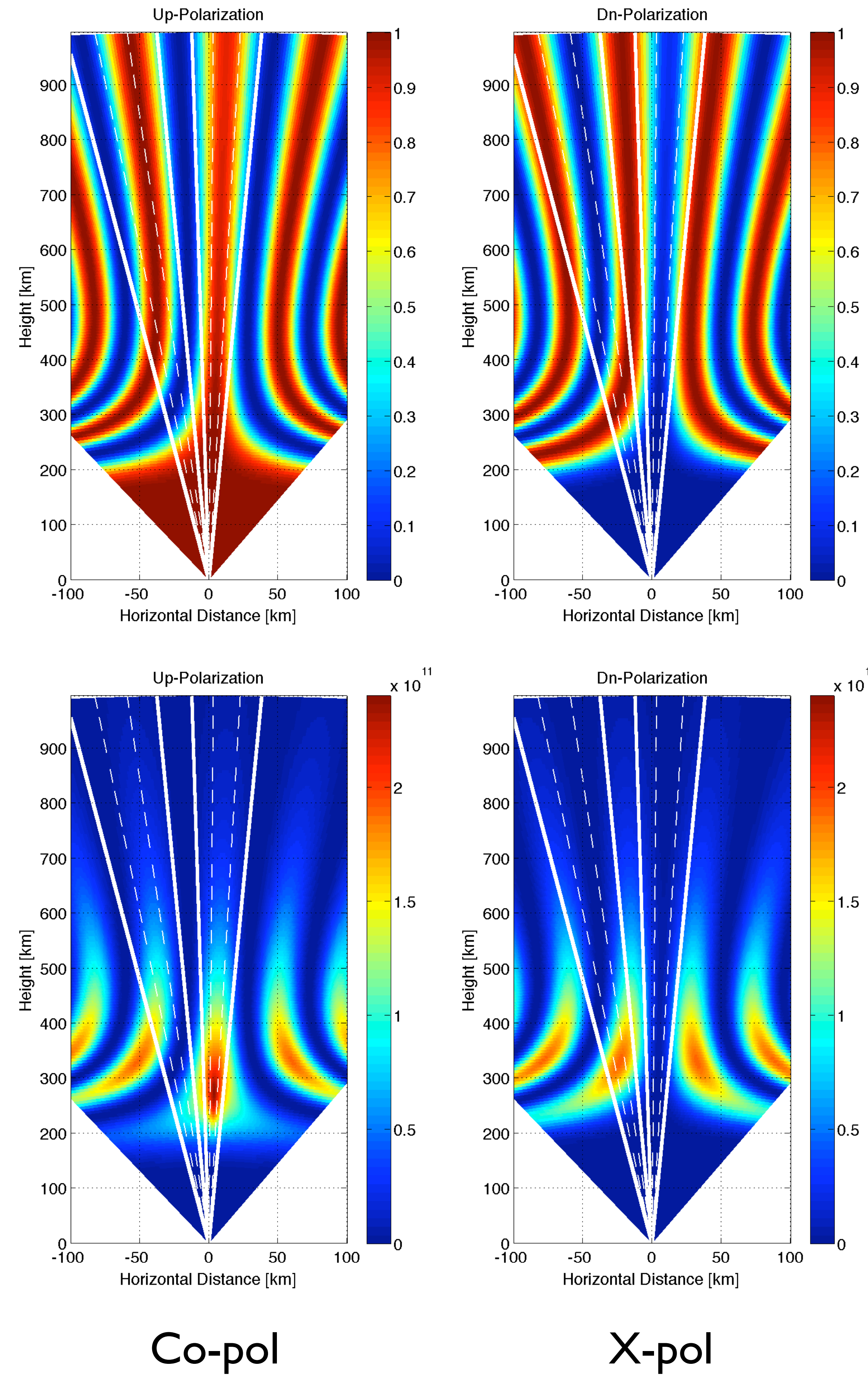
Simulated total power and JRO beams used in June 08 experiment:



June 08 experiment: A multi-beam and dual-polarization mode taking advantage of the modularity of the JRO antenna:



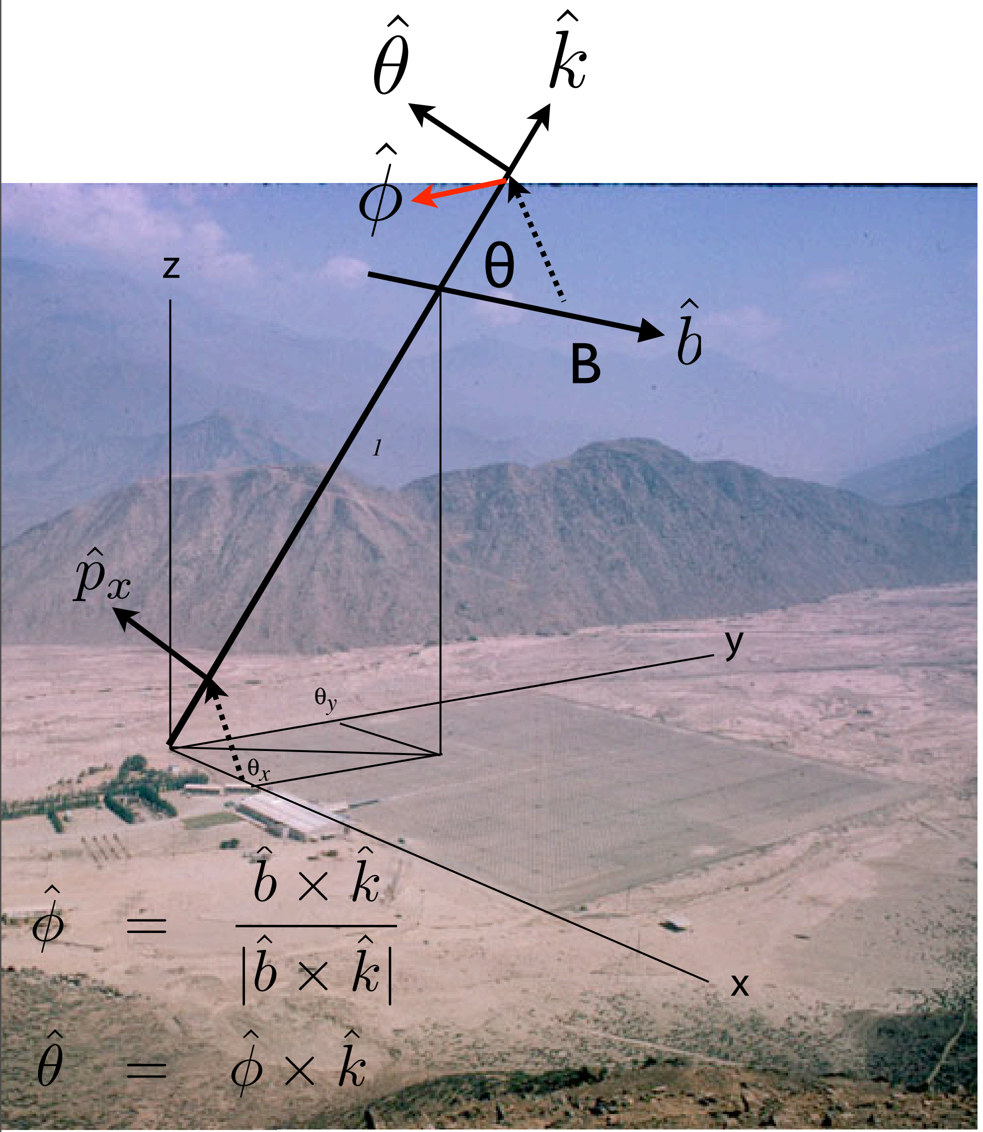




Forward model details

- A multi-slab magneto-ionic propagation model based on IGRF (*see next slide*):
  - "Rotates" the polarization vectors of tx'ed x-pol (dn) and y-pol (up) signals in proportion to electron density and magnetic aspect angles:
    - Faraday rotation at large aspect angles
    - Cotton-Mouton effect at small aspect angles
- Two-way antenna beam pattern (*see slide 7*) calculations based on FFT's of phasing distributions on antenna modules of both polarizations:
  - Includes complex valued two-way cross-beam patterns for "rotated" signal components --- e.g., east beam (dn) couples to west beam (up) via common sidelobes
- Receiver gains included as model unknowns in addition to Ne and Te/Ti
- Ionosonde virtual heights can be used as additional constraints
- Updated collisional IS theory (*see slide 14*) used to relate the backscatter RCS to ionospheric state parameters

A magneto-ionic propagation problem through a multi-slab ionosphere model:



Polarization unit vector: $\hat{p}_x = \frac{\hat{k}\times\hat{k}\times\hat{x}}{|\hat{k}\times\hat{k}\times\hat{x}|} \equiv E_{xo}\hat{x} + E_{yo}\hat{y} + E_{zo}\hat{z} \equiv E_{\theta o}\hat{\theta} + E_{\phi o}\hat{\phi}$

$$Y_L = Y\cos\theta, \quad Y_T = Y\sin\theta, \quad Y = \frac{\Omega}{\omega}, \quad X = \frac{\omega_p^2}{\omega^2}$$

$$F_O = F_1 - F_2, \quad F_X = F_1 + F_2, \quad F_1 = \frac{Y_T^2/2}{1-X}, \quad F_2^2 = F_1^2 + Y_L^2$$

$$n_{O,X}^2 = 1 - \frac{X}{1 - F_{O,X}}$$

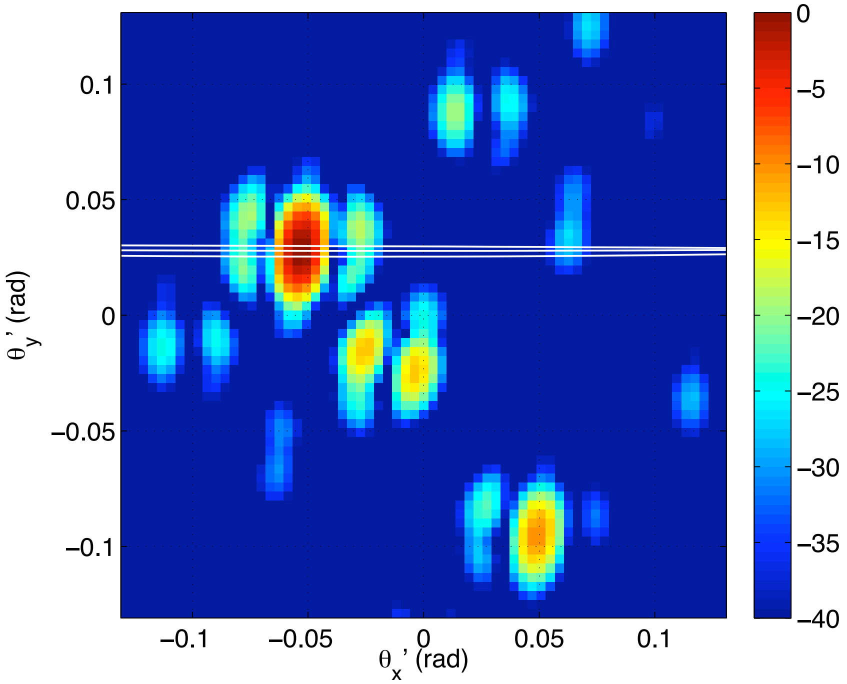
$$\Delta n = \frac{n_O - n_X}{2} \qquad \bar{n} = \frac{n_O + n_X}{2} \qquad a = \frac{F_O}{Y_L}$$

$$\mathbf{E}(\delta r) = \begin{bmatrix} E_\theta \\ E_\phi \end{bmatrix} = \underbrace{\frac{e^{-jk\bar{n}\delta r}}{1+a^2}\begin{bmatrix} a^2 e^{jk\Delta n\delta r} + e^{-jk\Delta n\delta r} & 2a\sin(k\Delta n\delta r) \\ -2a\sin(k\Delta n\delta r) & a^2 e^{-jk\Delta n\delta r} + e^{jk\Delta n\delta r} \end{bmatrix}}_{\bar{\bar{M}}} \begin{bmatrix} E_{\theta_o} \\ E_{\phi_o} \end{bmatrix}$$

Iterate after modifying $\Delta n, \bar{n}, a, \hat{\theta}, \hat{\phi}$ due to slow varing density and $\vec{B}$

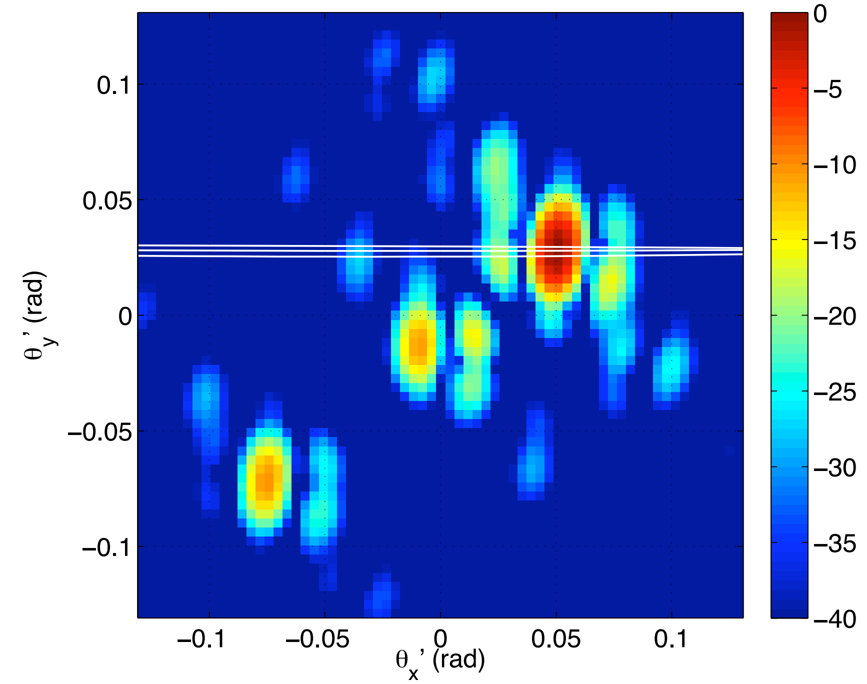
$$v_x \propto \hat{p}_x \cdot (E_\theta\hat{\theta} + E_\phi\hat{\phi}) \qquad\qquad v_y \propto \hat{p}_y \cdot (E_\theta\hat{\theta} + E_\phi\hat{\phi})$$

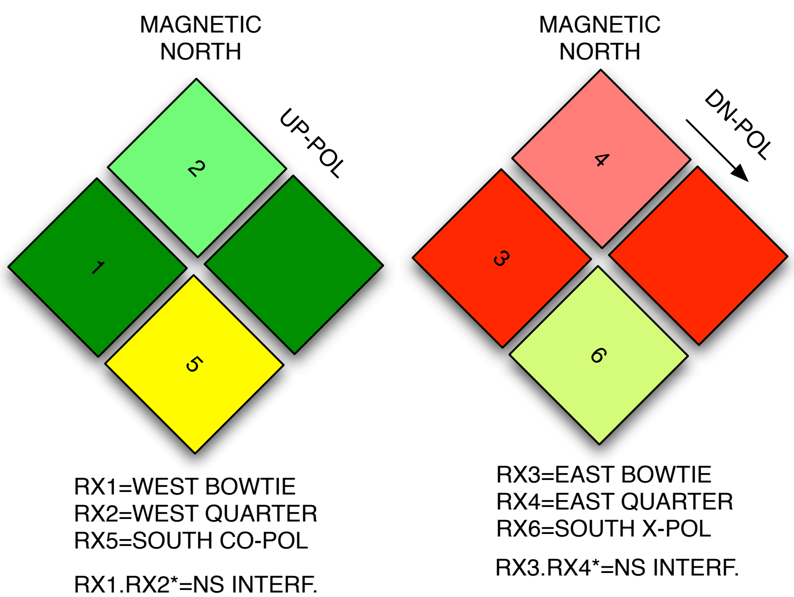
West beam (Bow–tie)
D2W = 78.30 dB
ABS = 4716.19



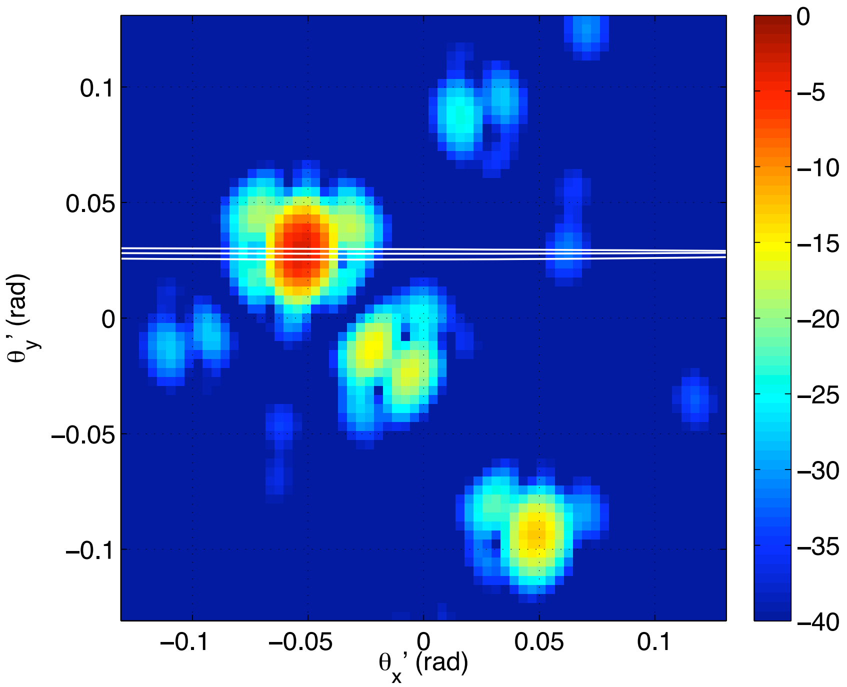
3-Tx, 6-Rx
3-Beam directions
1 polarization diversity (south)
2 spatial diversities (west and east)

East beam (Bow–tie)
D2W = 78.04 dB
ABS = 4363.89

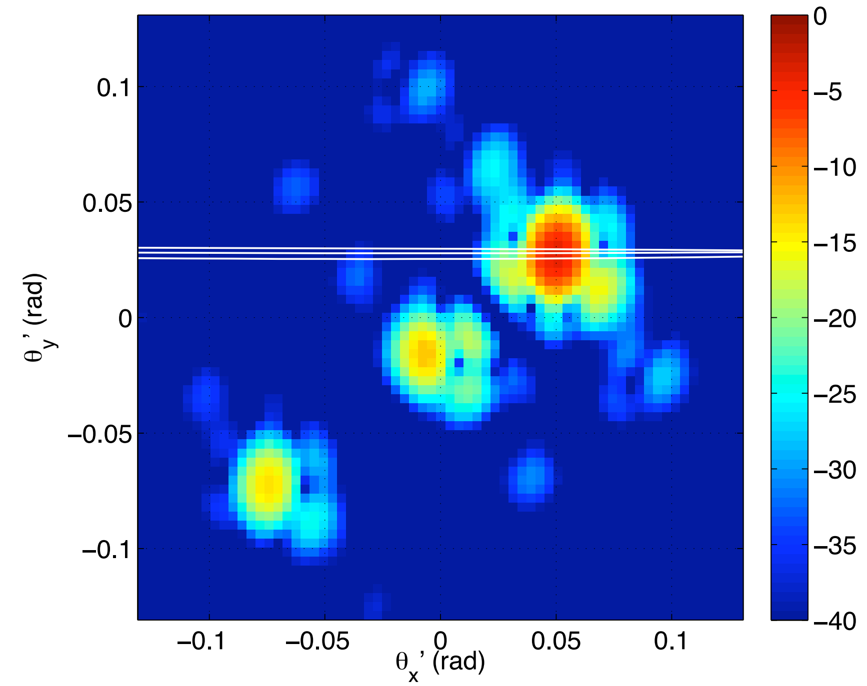




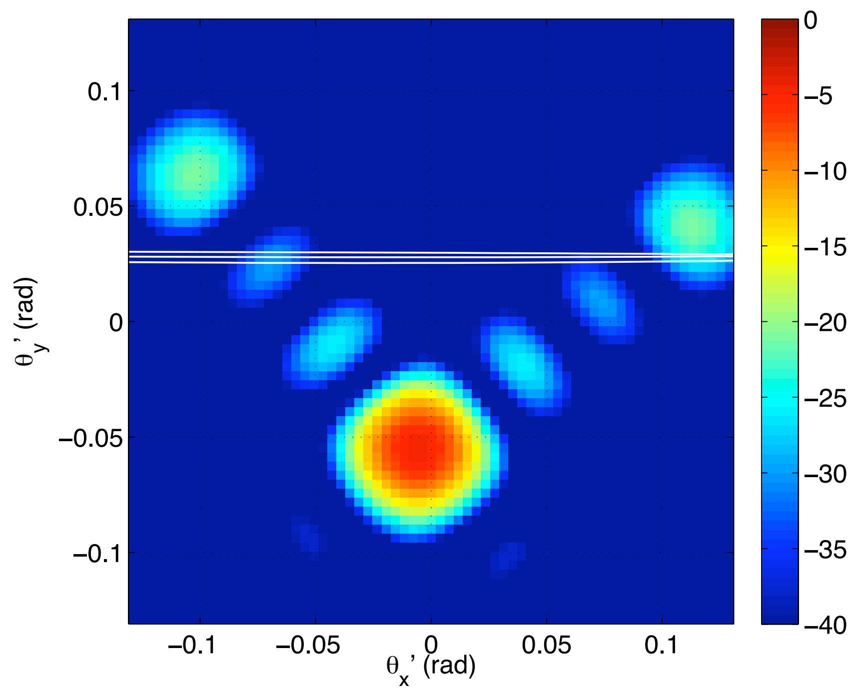
West beam (One quarter)
D2W = 74.88 dB
ABS = 3111.32

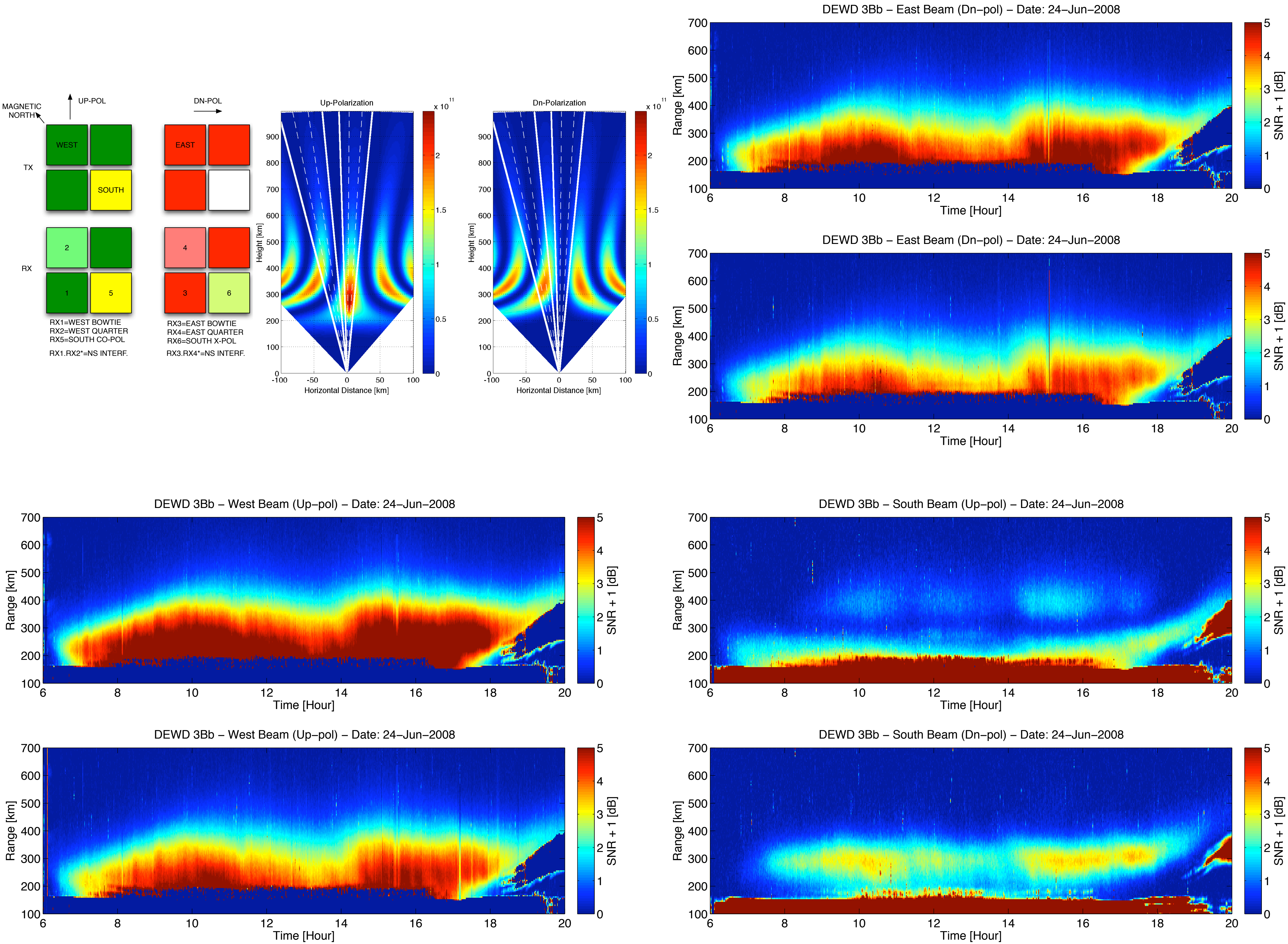


East beam (One quarter)
D2W = 74.54 dB
ABS = 2888.92

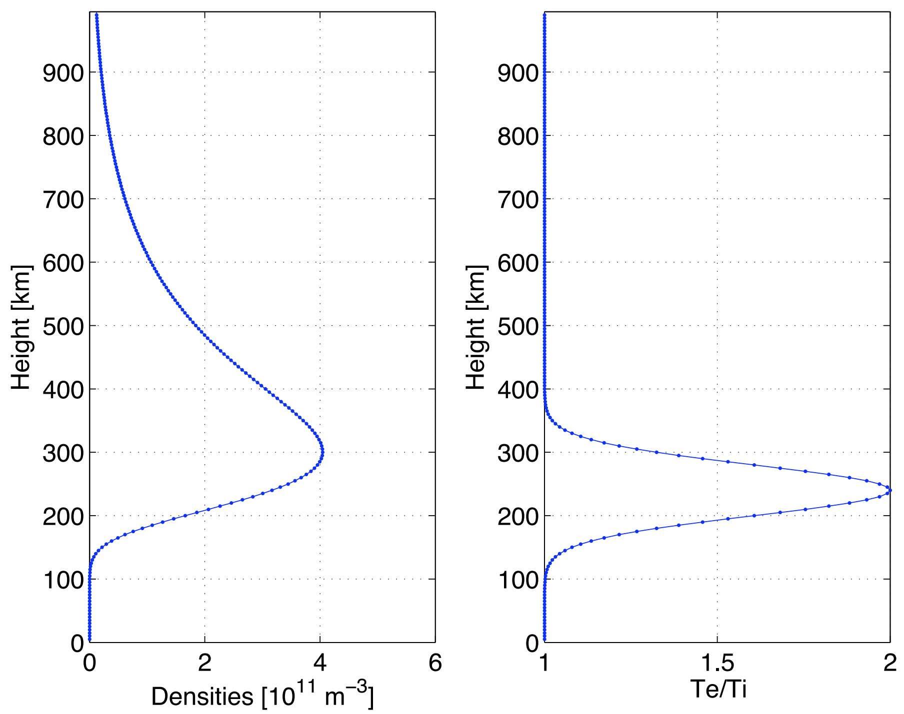


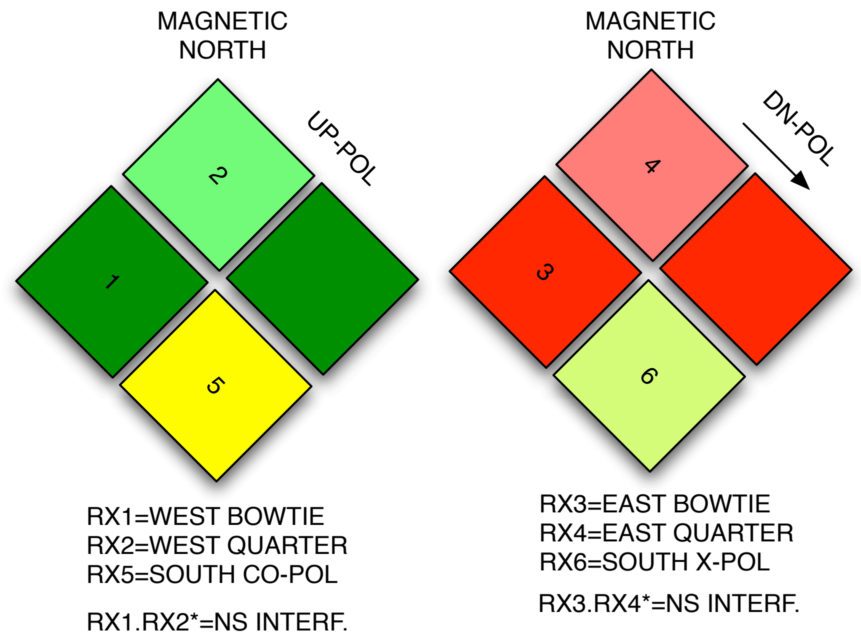
South beam (One quarter)
D2W = 73.73 dB
ABS = 4375.94



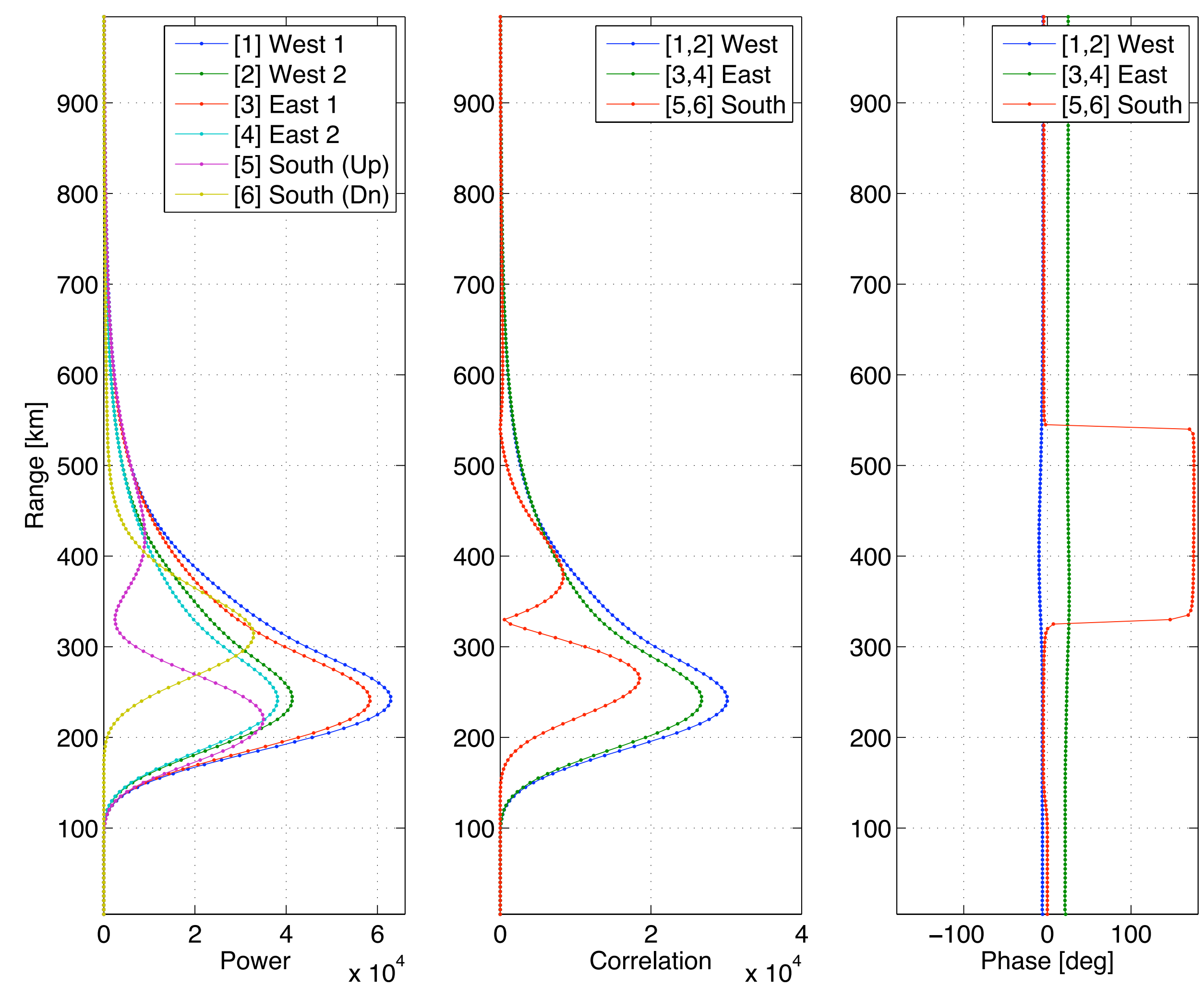

MAGNETIC NORTH
UP-POL
DN-POL
TX
WEST
SOUTH
EAST
RX
2
1
5
4
3
6
RX1=WEST BOWTIE
RX2=WEST QUARTER
RX5=SOUTH CO-POL
RX1.RX2*=NS INTERF.
RX3=EAST BOWTIE
RX4=EAST QUARTER
RX6=SOUTH X-POL
RX3.RX4*=NS INTERF.
Up-Polarization
Dn-Polarization
Height [km]
Horizontal Distance [km]
x 10^11
DEWD 3Bb – East Beam (Dn–pol) – Date: 24–Jun–2008
DEWD 3Bb – East Beam (Dn–pol) – Date: 24–Jun–2008
DEWD 3Bb – West Beam (Up–pol) – Date: 24–Jun–2008
DEWD 3Bb – West Beam (Up–pol) – Date: 24–Jun–2008
DEWD 3Bb – South Beam (Up–pol) – Date: 24–Jun–2008
DEWD 3Bb – South Beam (Dn–pol) – Date: 24–Jun–2008
Range [km]
Time [Hour]
SNR + 1 [dB]

Hypothetical ionosphere:

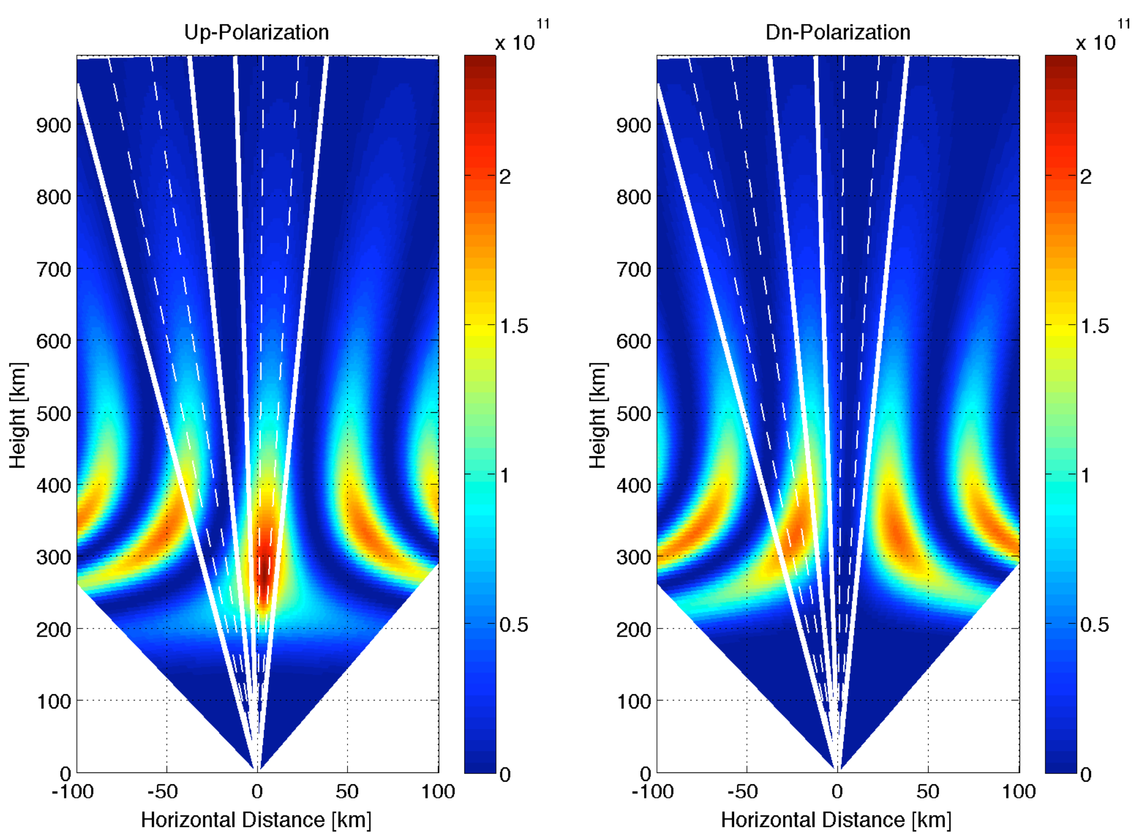




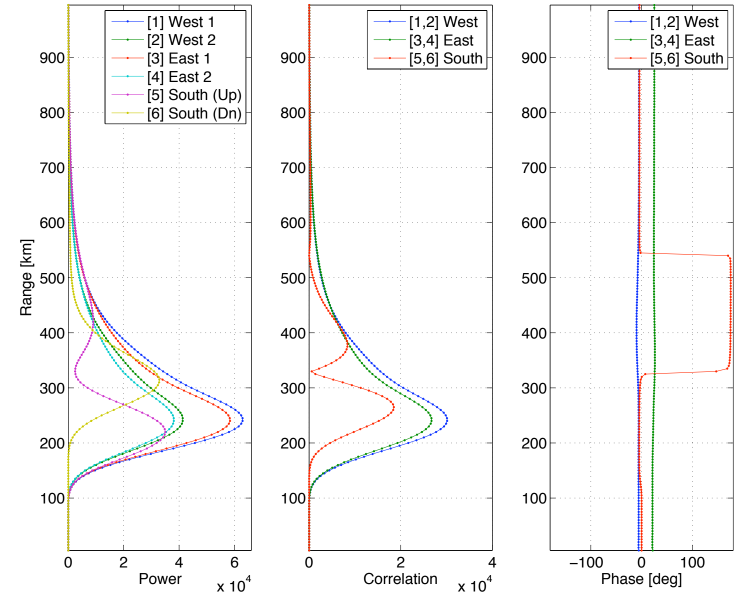
"Beam weighted" simulations of power and cross-correlation profiles for the six receivers:

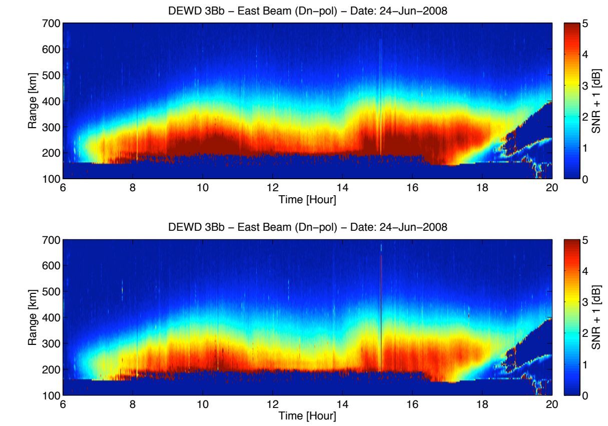


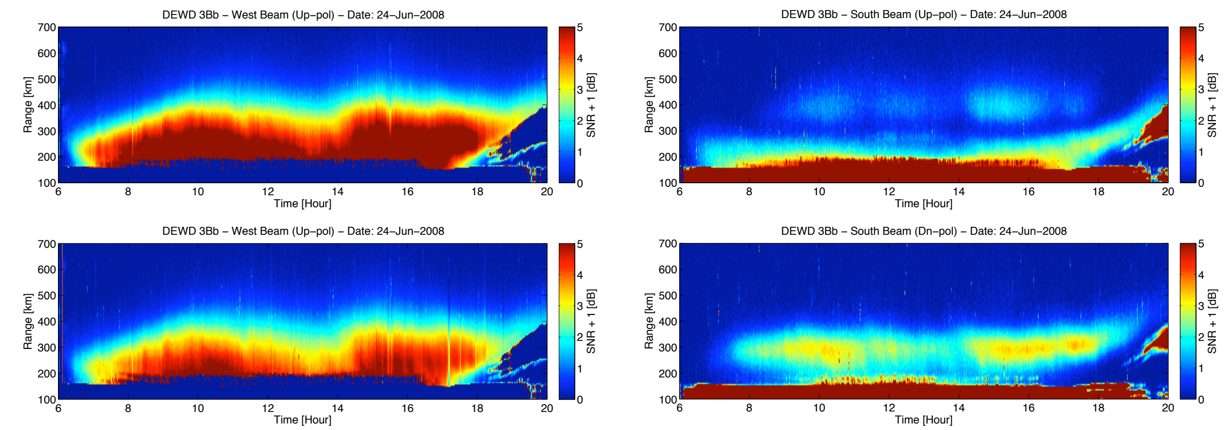
Simulated co-pol and x-pol power distributions:

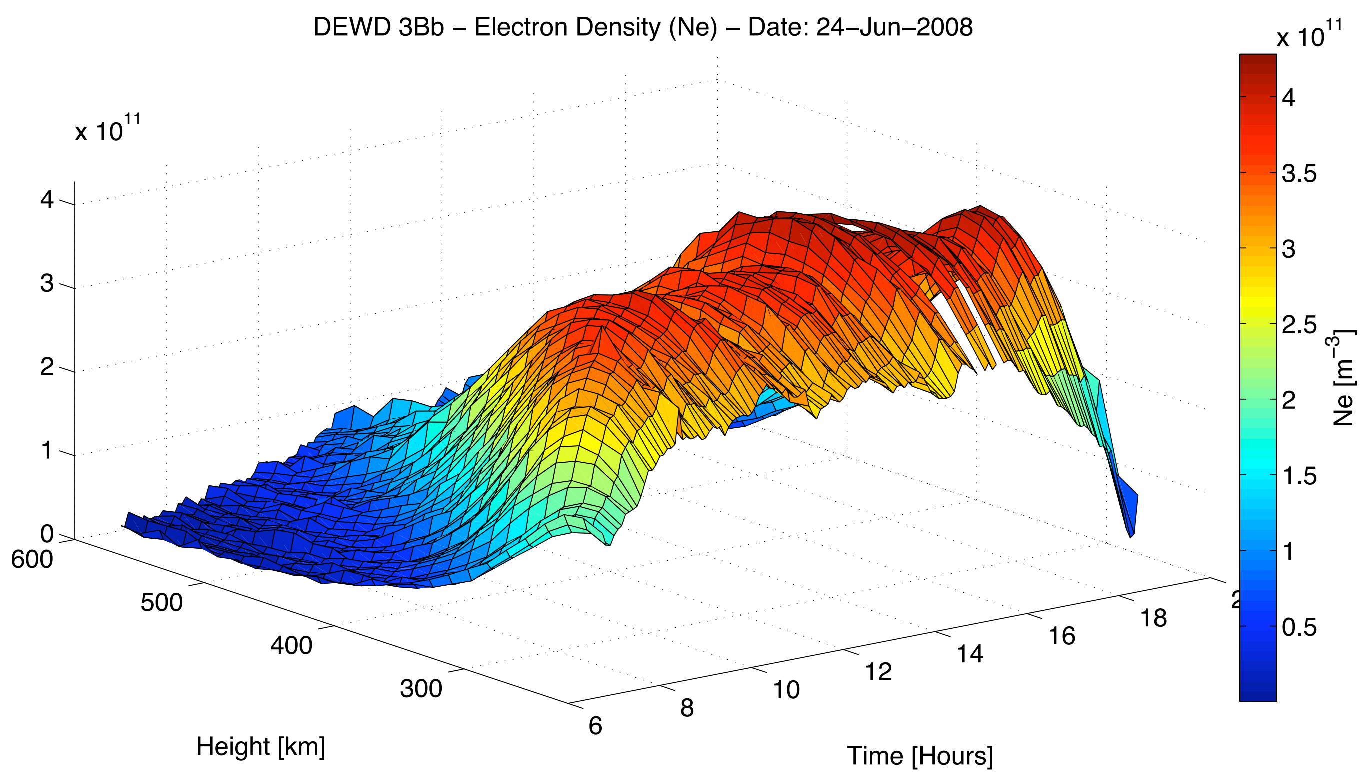


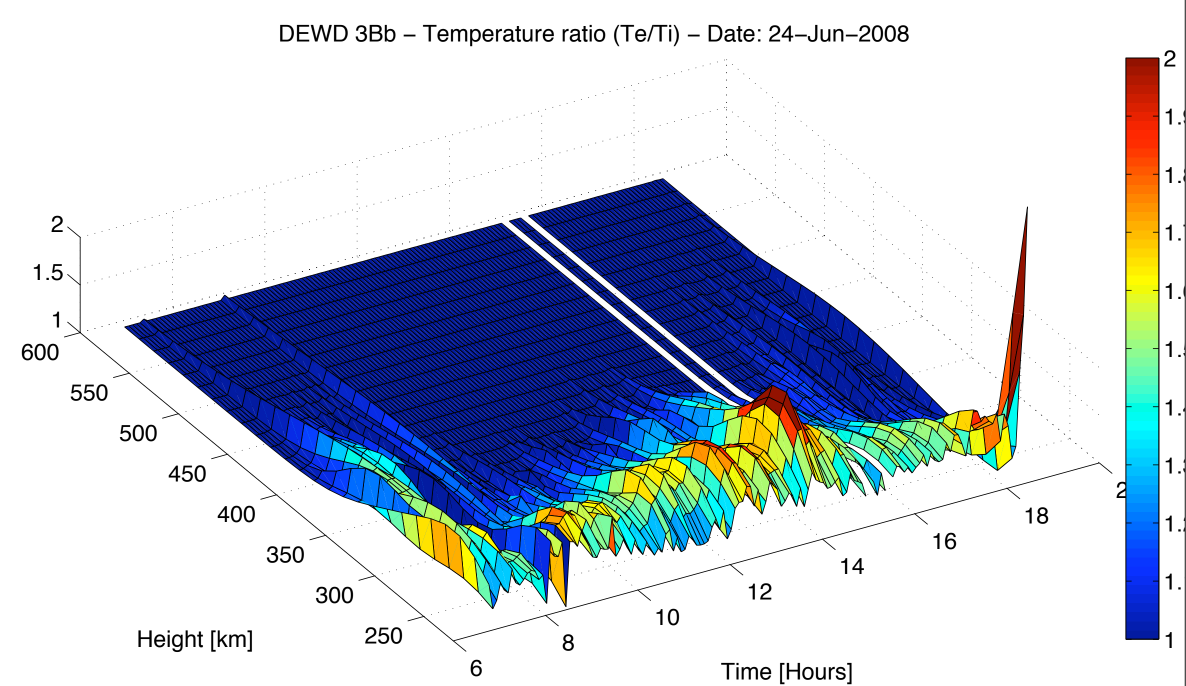
Least-squares fit beam-weighted power and cross-correlation profiles obtained from the six receivers to estimate the Ne and Te/Ti profiles at 5 min integration intervals:



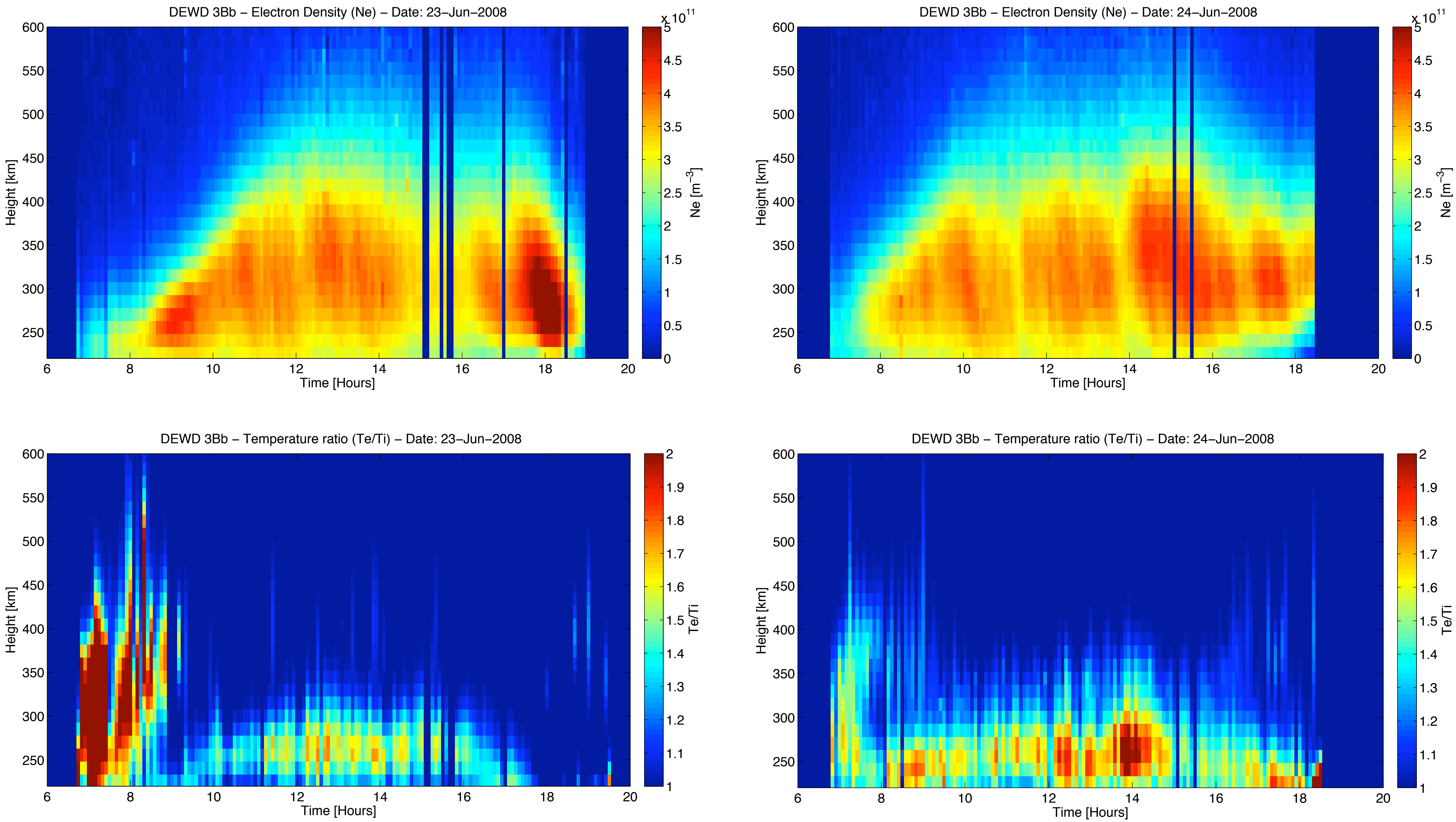


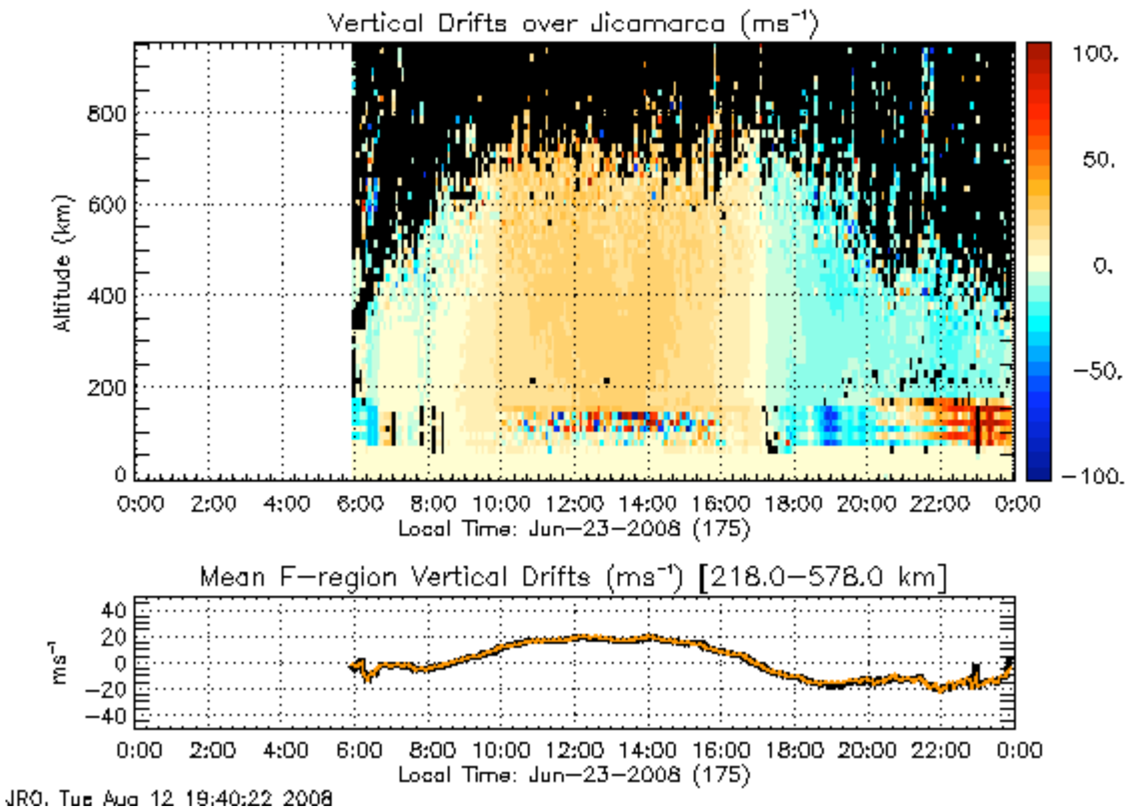


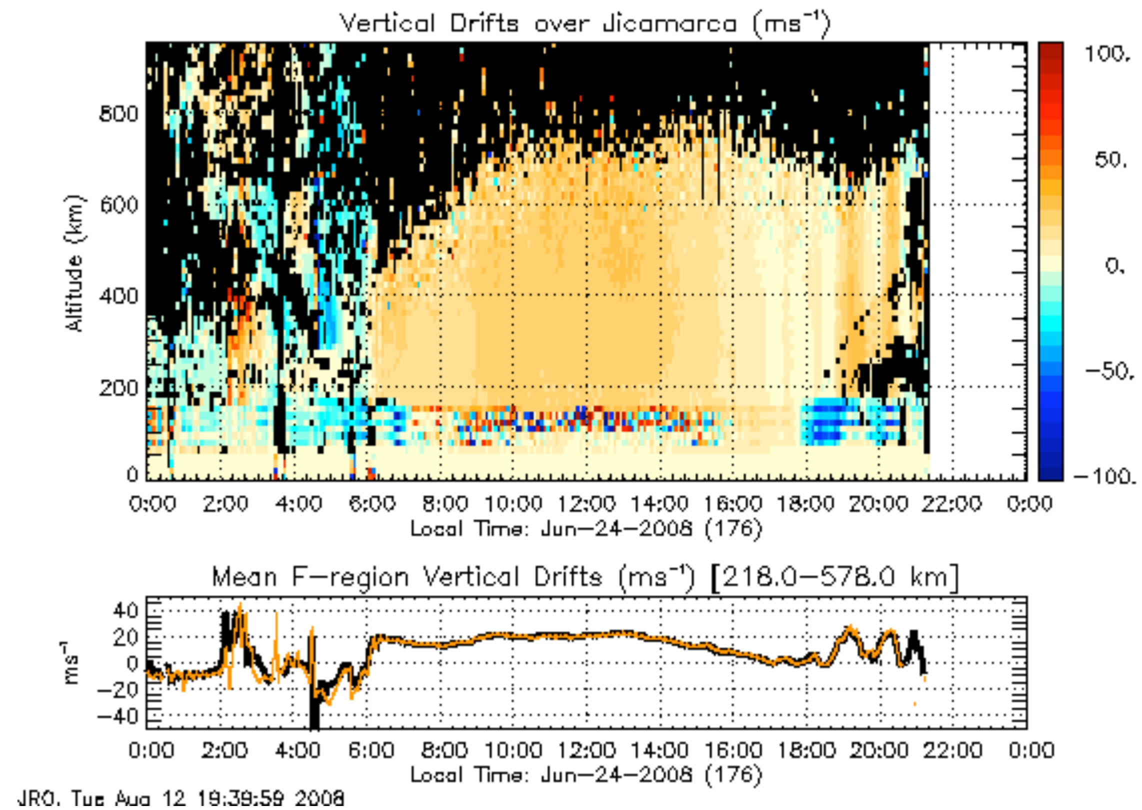


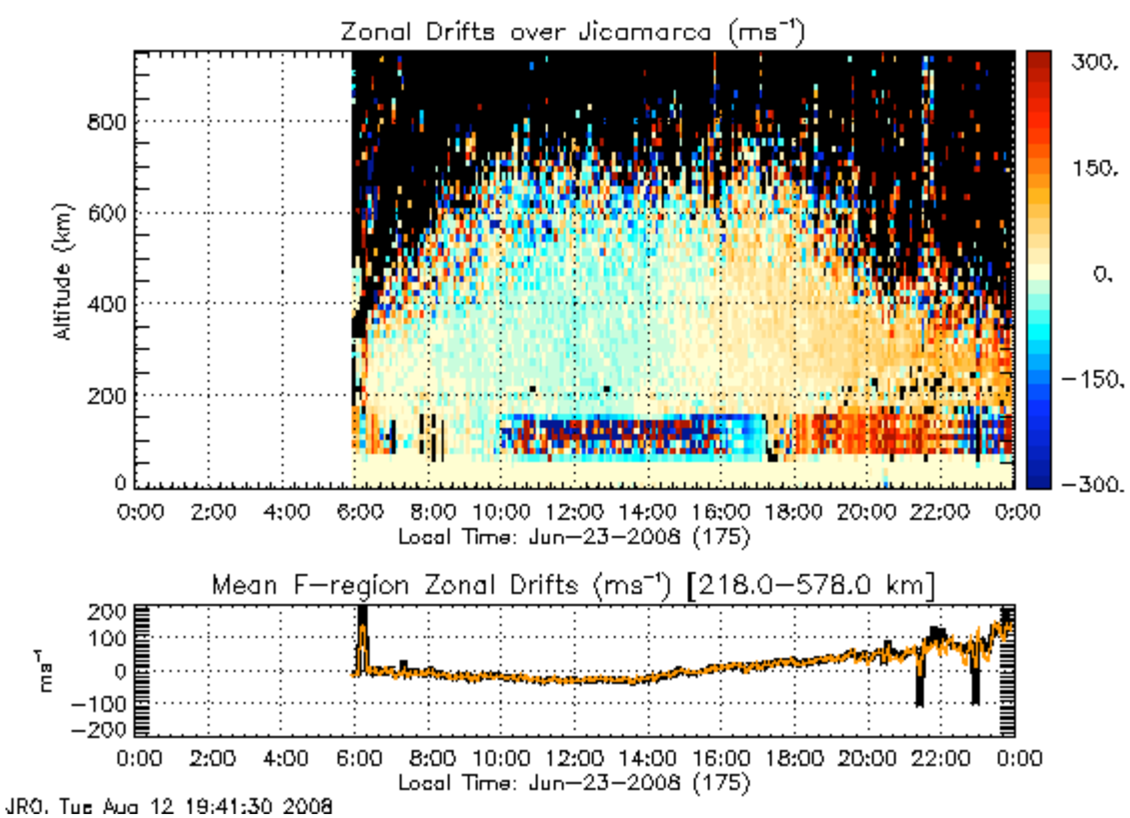


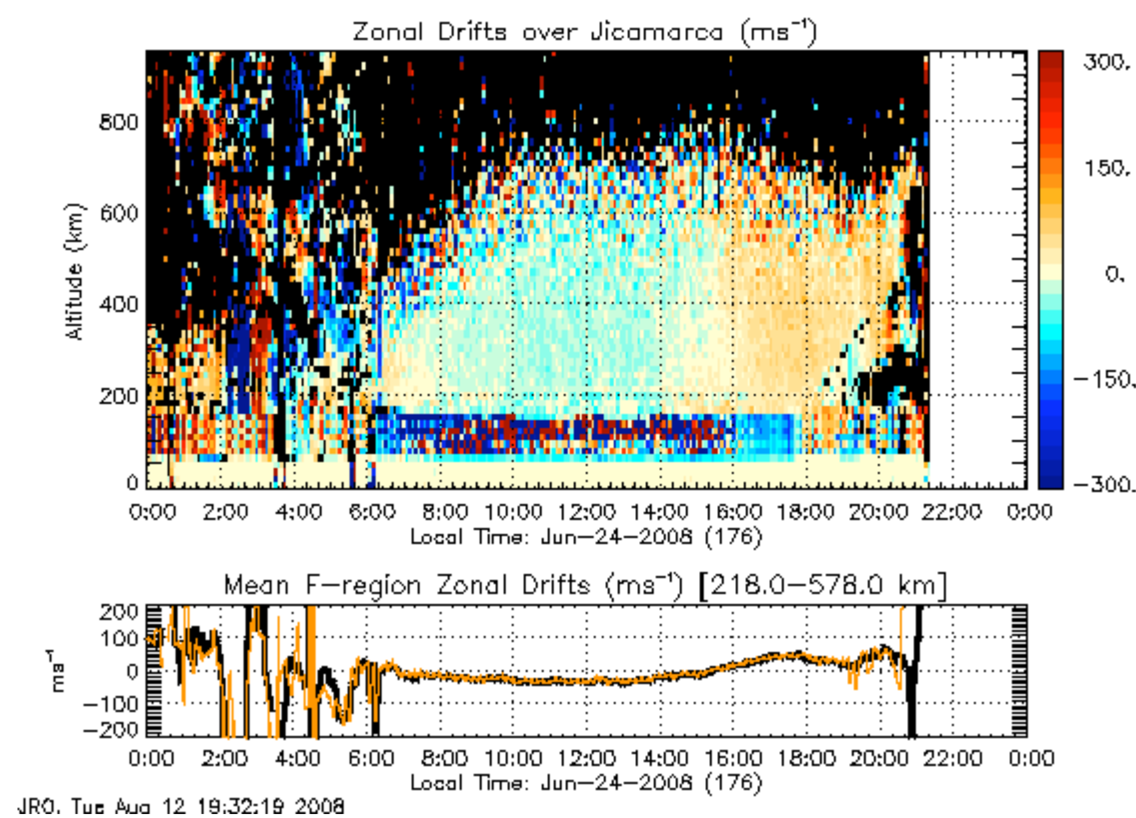
June 23-24, 2008 Experiments: Ne and Te/Ti estimates:




Vertical Drifts over Jicamarca (ms⁻¹)
Altitude (km)
Local Time: Jun-23-2008 (175)
Mean F-region Vertical Drifts (ms⁻¹) [218.0-578.0 km]
ms⁻¹
JRO. Tue Aug 12 19:40:22 2008

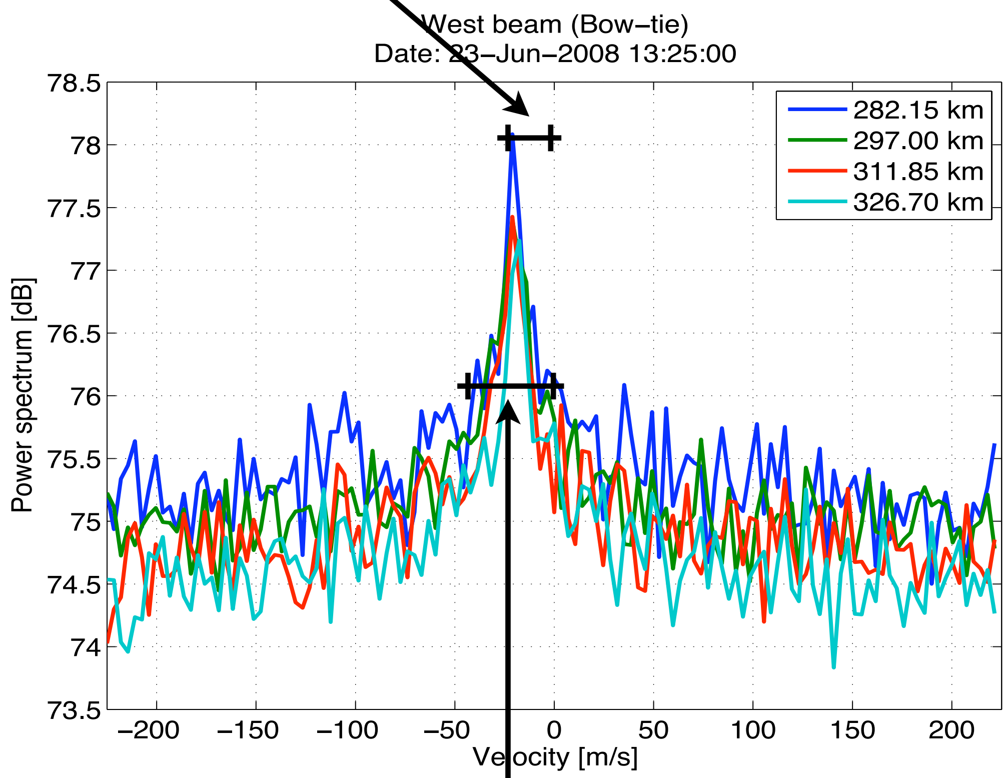

Vertical Drifts over Jicamarca (ms⁻¹)
Altitude (km)
Local Time: Jun-24-2008 (176)
Mean F-region Vertical Drifts (ms⁻¹) [218.0-578.0 km]
ms⁻¹
JRO. Tue Aug 12 19:39:59 2008


Zonal Drifts over Jicamarca (ms⁻¹)
Altitude (km)
Local Time: Jun-23-2008 (175)
Mean F-region Zonal Drifts (ms⁻¹) [218.0-578.0 km]
ms⁻¹
JRO. Tue Aug 12 19:41:30 2008

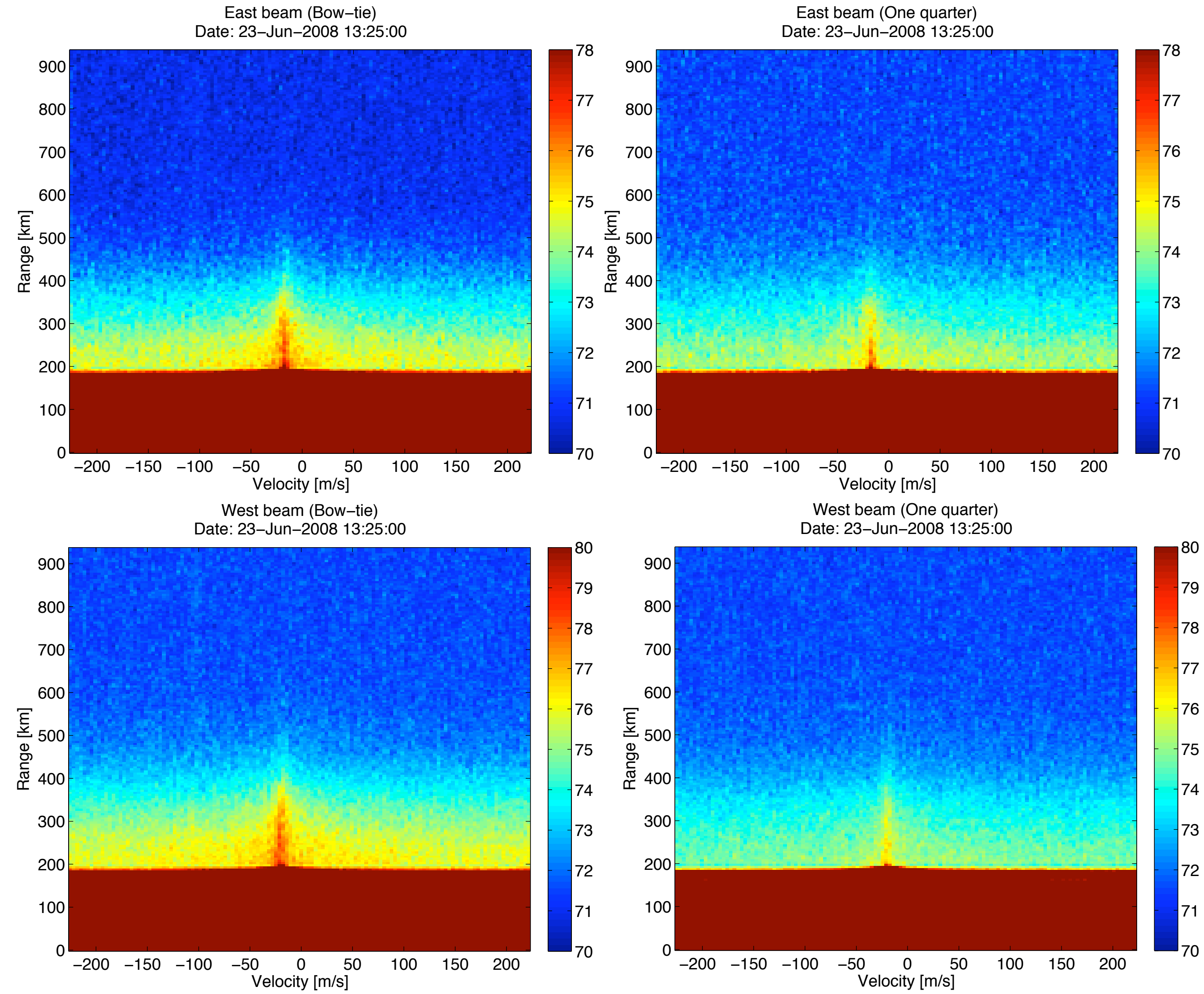

Zonal Drifts over Jicamarca (ms⁻¹)
Altitude (km)
Local Time: Jun-24-2008 (176)
Mean F-region Zonal Drifts (ms⁻¹) [218.0-578.0 km]
ms⁻¹
JRO. Tue Aug 12 19:32:19 2008

Spectral fitting and Te plans

The spectrum Doppler shift is a direct measurement of the drift.



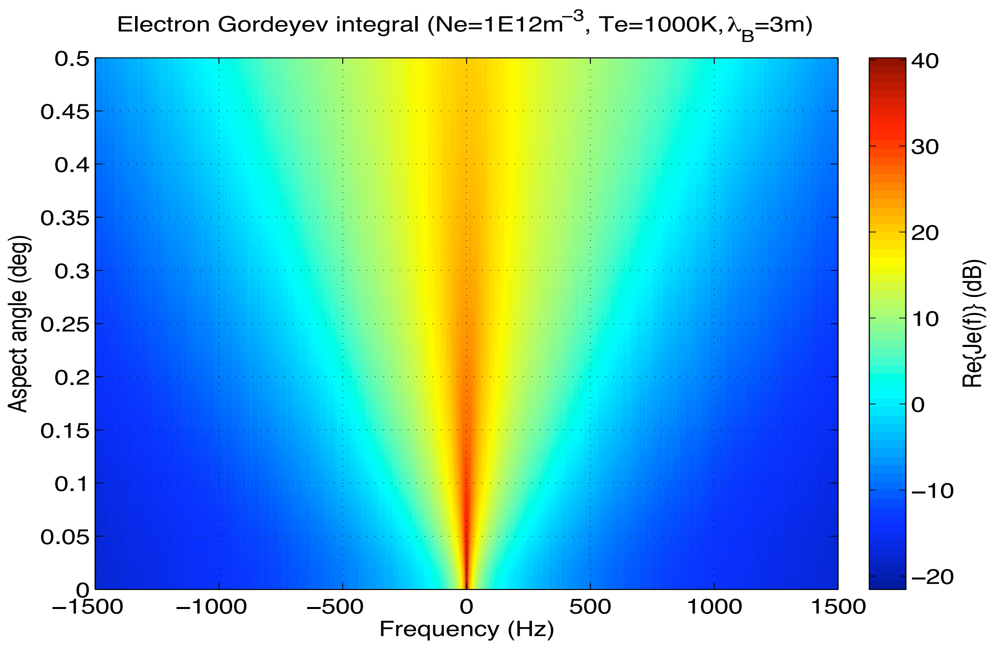
The spectrum width will tell us what the temperatures are.

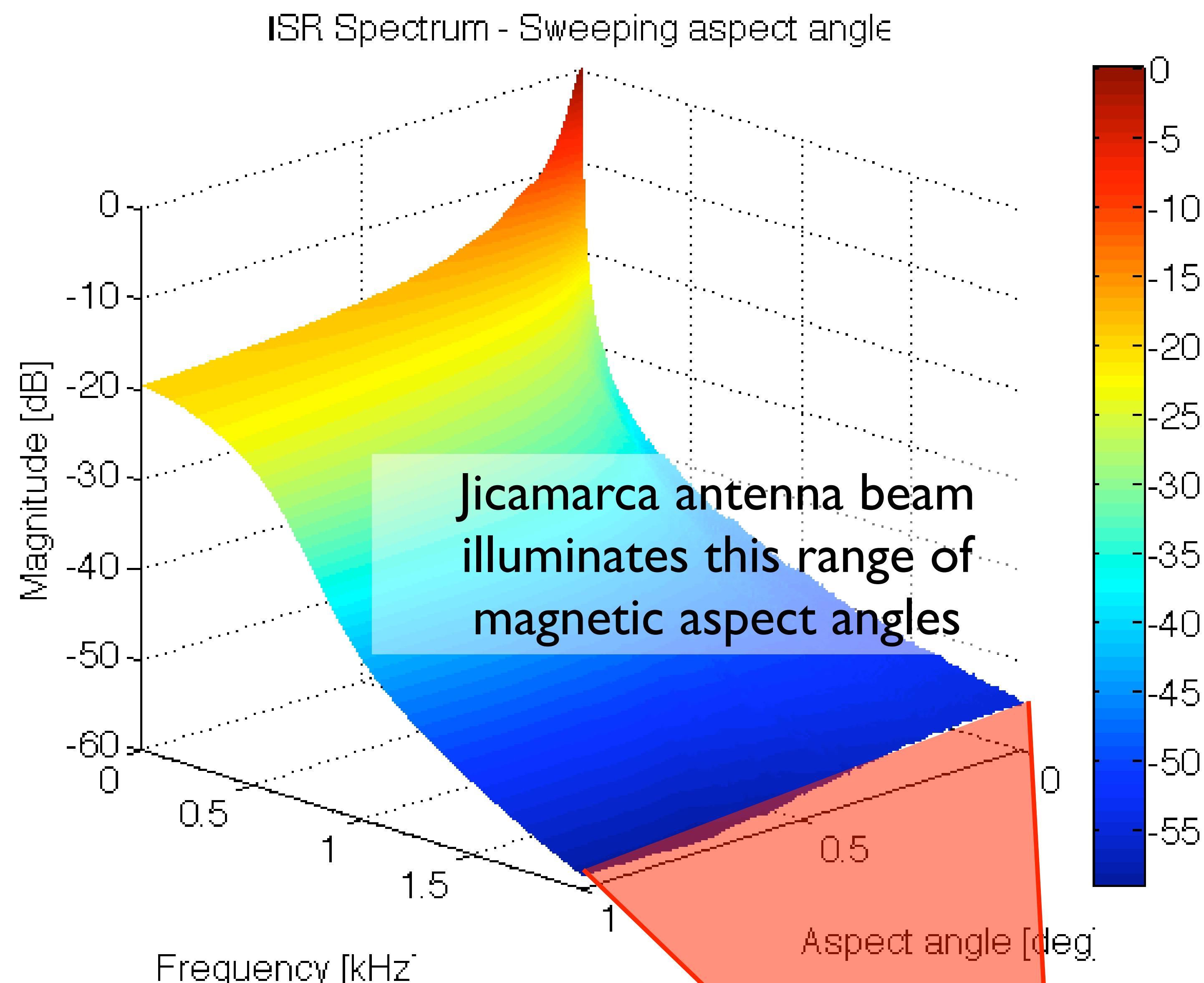


Once the densities and Te/Ti are known, we can analyze our spectrum measurements and estimate the remaining parameter (Te) from the width of the spectrum. For this purpose an Incoherent Scatter theory valid for all magnetic aspect angles is needed.

Collisional IS spectrum model

Based on the Fokker-Planck collision model, we have developed a Monte-Carlo procedure to compute the electron Gordeyev integral for all magnetic aspect angles (including the perpendicular to B direction).





Using this collisional IS spectrum theory and including magnetoioinic propagation effects we can model the beam-weighted spectrum measured at Jicamarca. Using this model, we can fit the data and obtain Te. Of course, we can use these estimates to improve our estimates of Ne and Te/Ti.

Conclusions, Future Work

- We have learned how to model and fit multi-beam/multi-polarization power and correlation data to estimate **electron density** and **Te/Ti** profiles in addition to F-region **vertical and EW drifts** under quiet (non-turbulent) ionospheric conditions.
  - We still need to streamline the process for routine operational use.

- Spectral fitting for **Te estimation** should now be possible given the Te/Ti profiles and the development of collisional ISR spectral model.
  - This is the fulfillment of objectives set about a decade ago, when spectral Te estimations were first tried (*Bhattacharyya*, 1998) and the inadequacy of ISR theory close to perp-to-B was first realized.
  - June 08 data set will be used in our renewed attempt to estimate Te.

- The forward models developed should also be useful in model verification/assimilation: e.g., in LISN project, we can examine to what extent the LISN model ionosphere (Ne, Te, Ti) fits the Jicamarca multi-beam/multi-polarization correlation and spectrum profiles --- a first step towards assimilation of JRO data in LISN.