Report on perpendicular-to-B incoherent scatter measurements at Jicamarca: 3Beam radar experiments

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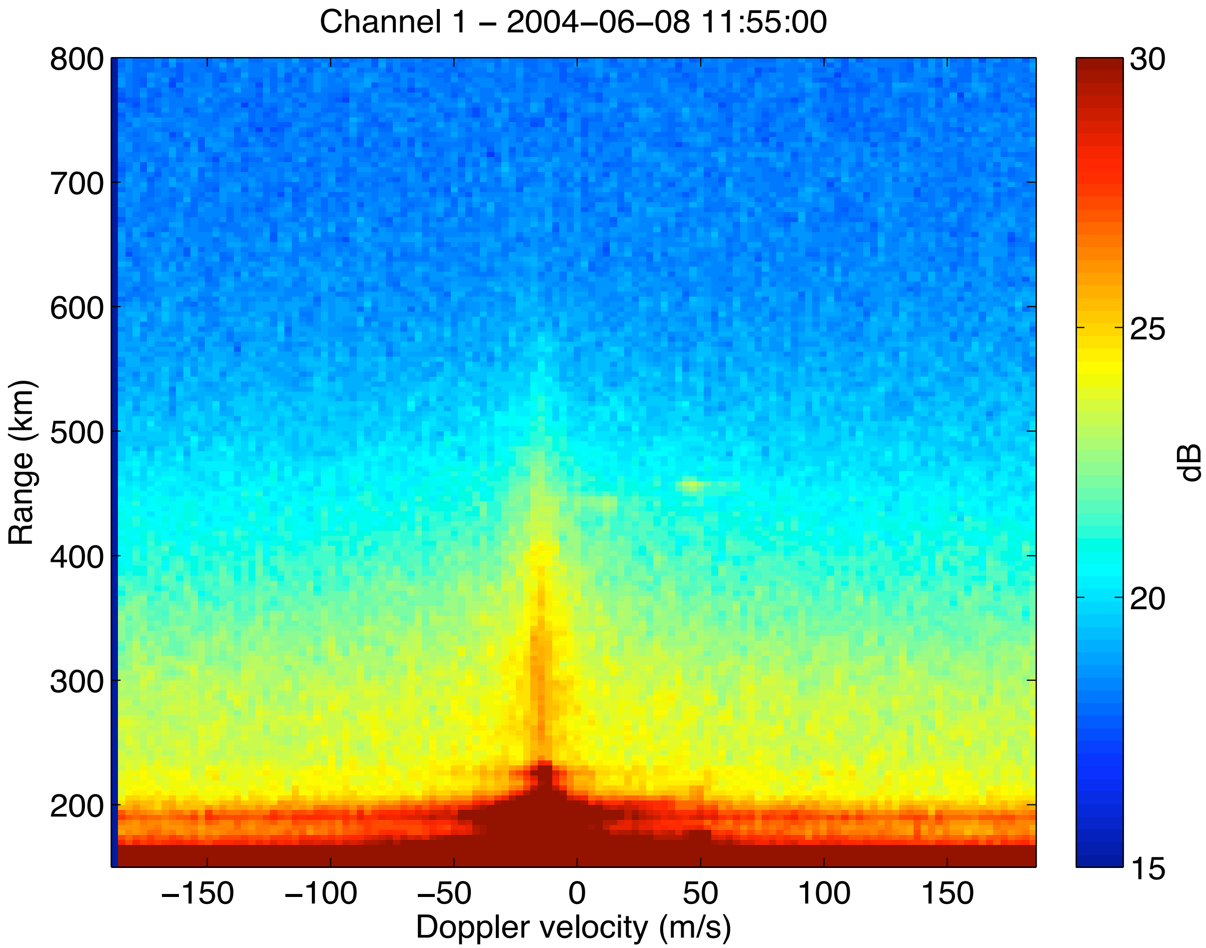
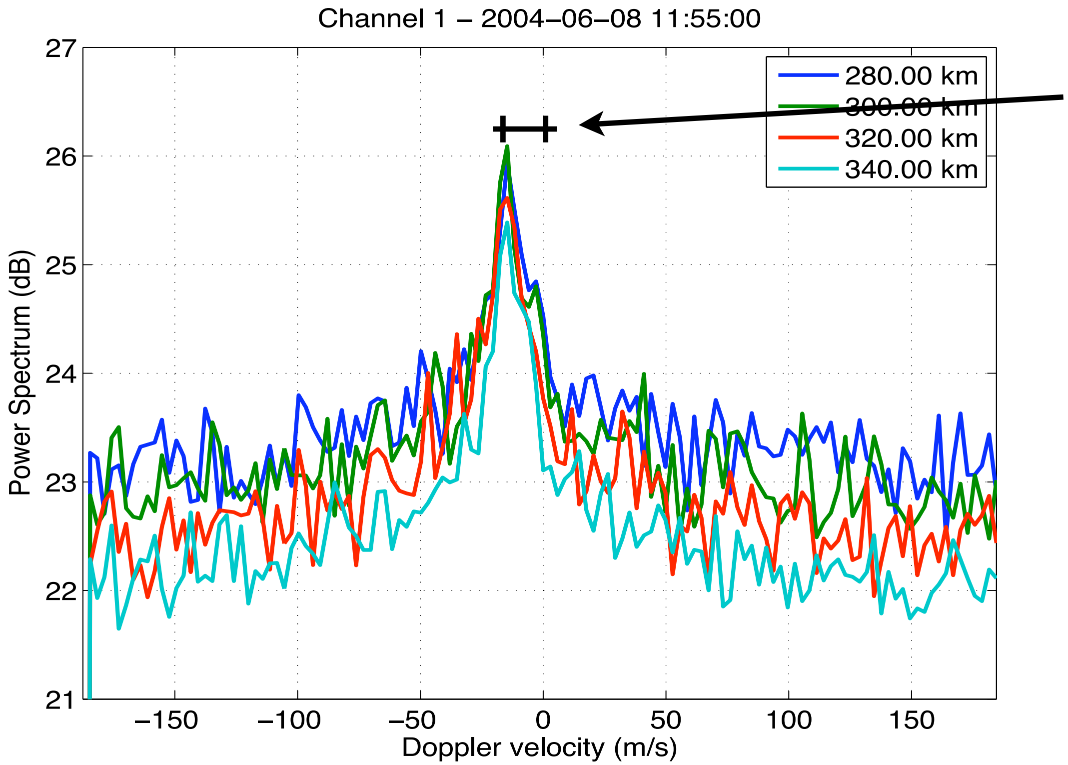
June 21, 2010

Perp-to-B ISR spectra and plasma drifts

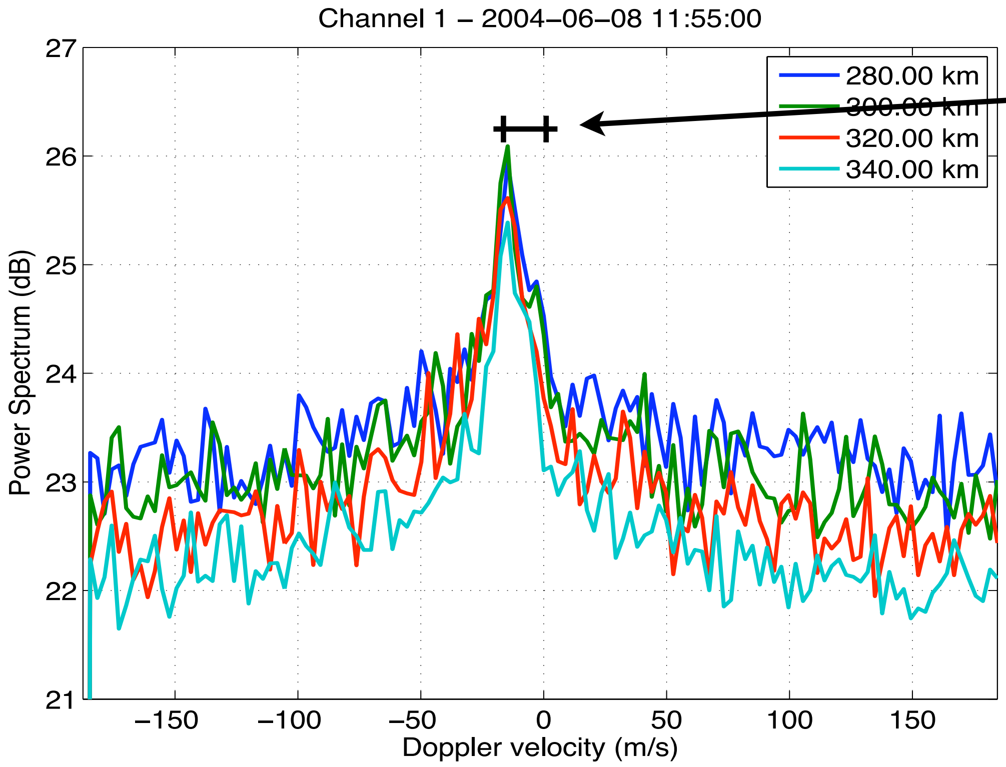


Perp-to-B ISR spectra and plasma drifts



Doppler shift of the spectrum is directly proportional to the drift.

Perp-to-B ISR spectra and plasma drifts



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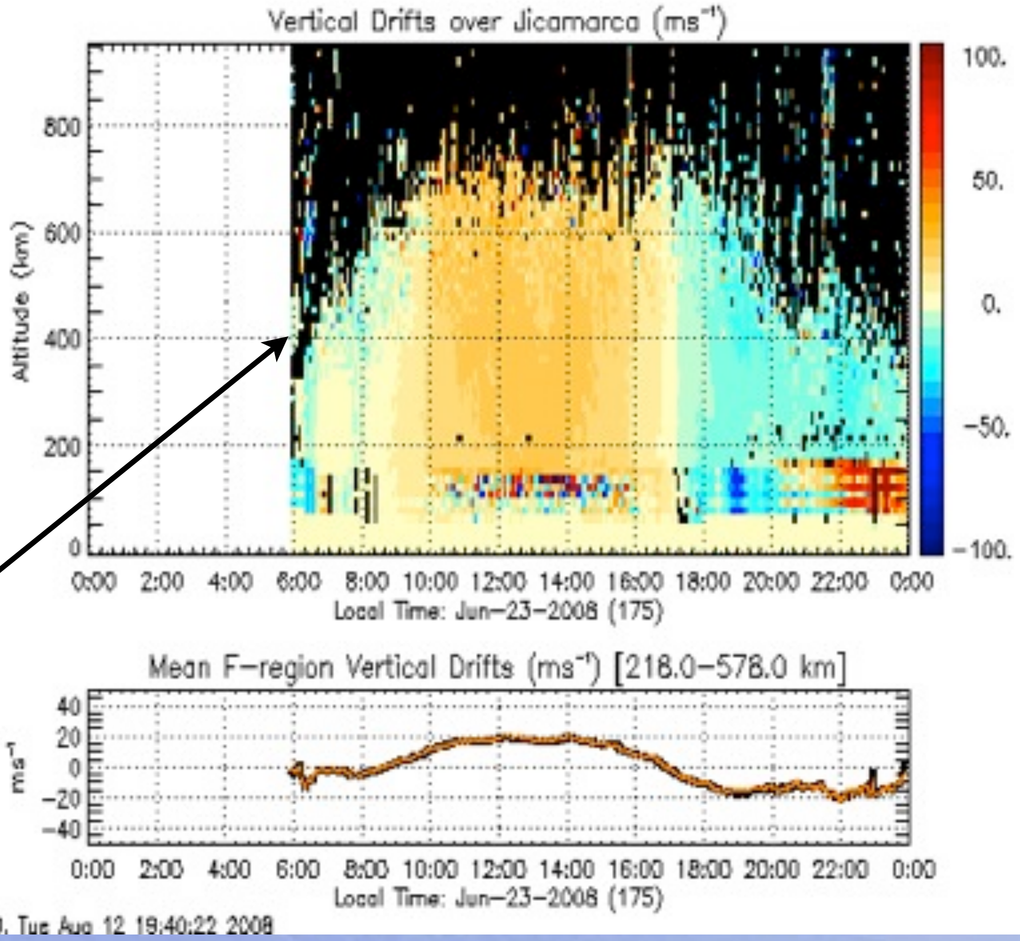
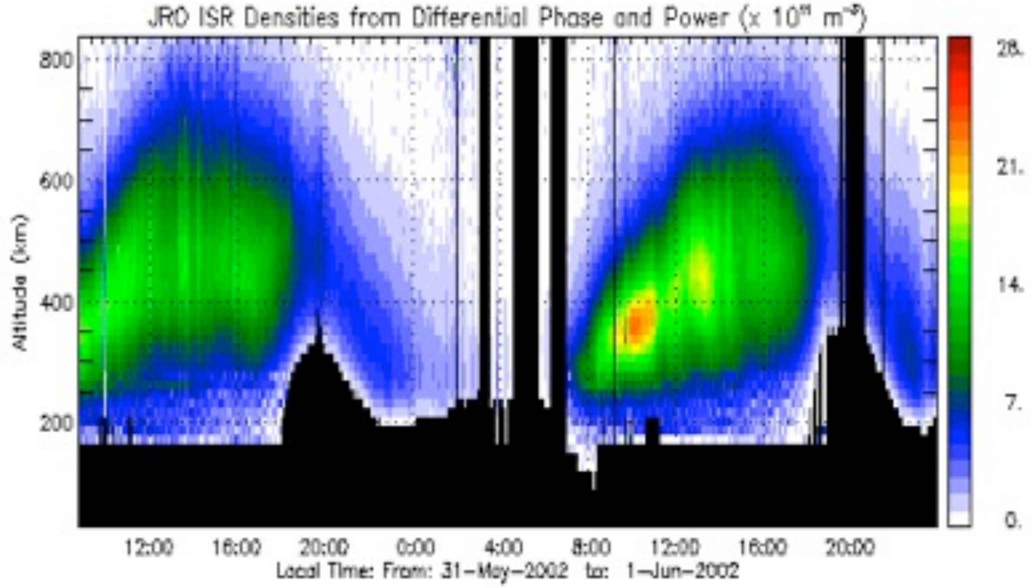
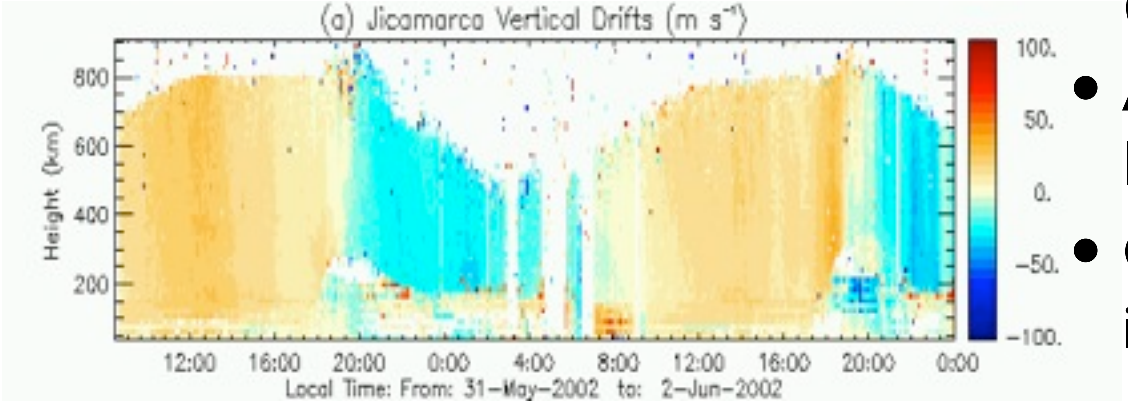


Very accurate drift measurements as function of height and time.

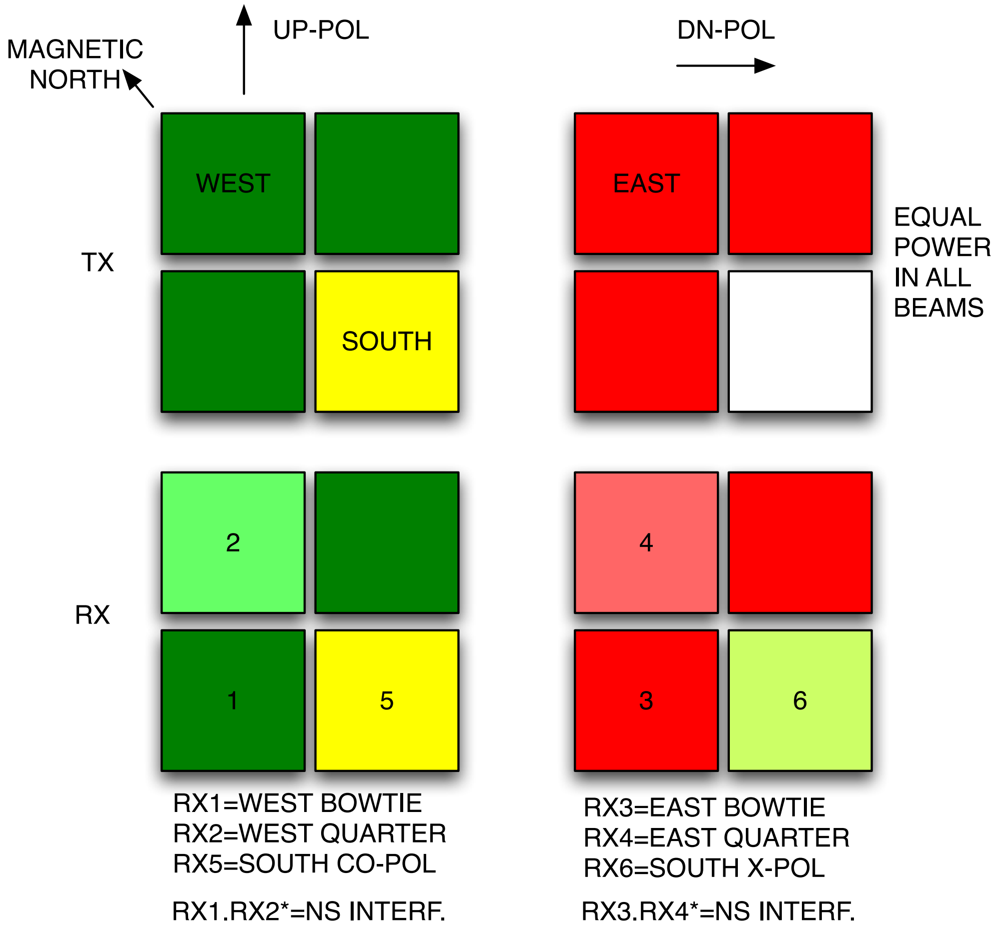
The differential-phase radar experiment





- A single pointing direction.
- First results were published by Feng et al. [2003, 2004].
- Electron density measurements in relatively good agreement with ionosonde estimates.
- High quality of the vertical drifts (Kudeki et al. [1999]).
- Aspect angle dependence of the IS-RCS was not fully modeled.
- Computational requirements impose a time resolution of 5 min.

The new 3Beam experiments



MAGNETIC NORTH

UP-POL

DN-POL

TX

WEST

SOUTH

EAST

EQUAL POWER IN ALL BEAMS

RX

2

1

5

4

3

6

RX1=WEST BOWTIE
RX2=WEST QUARTER
RX5=SOUTH CO-POL

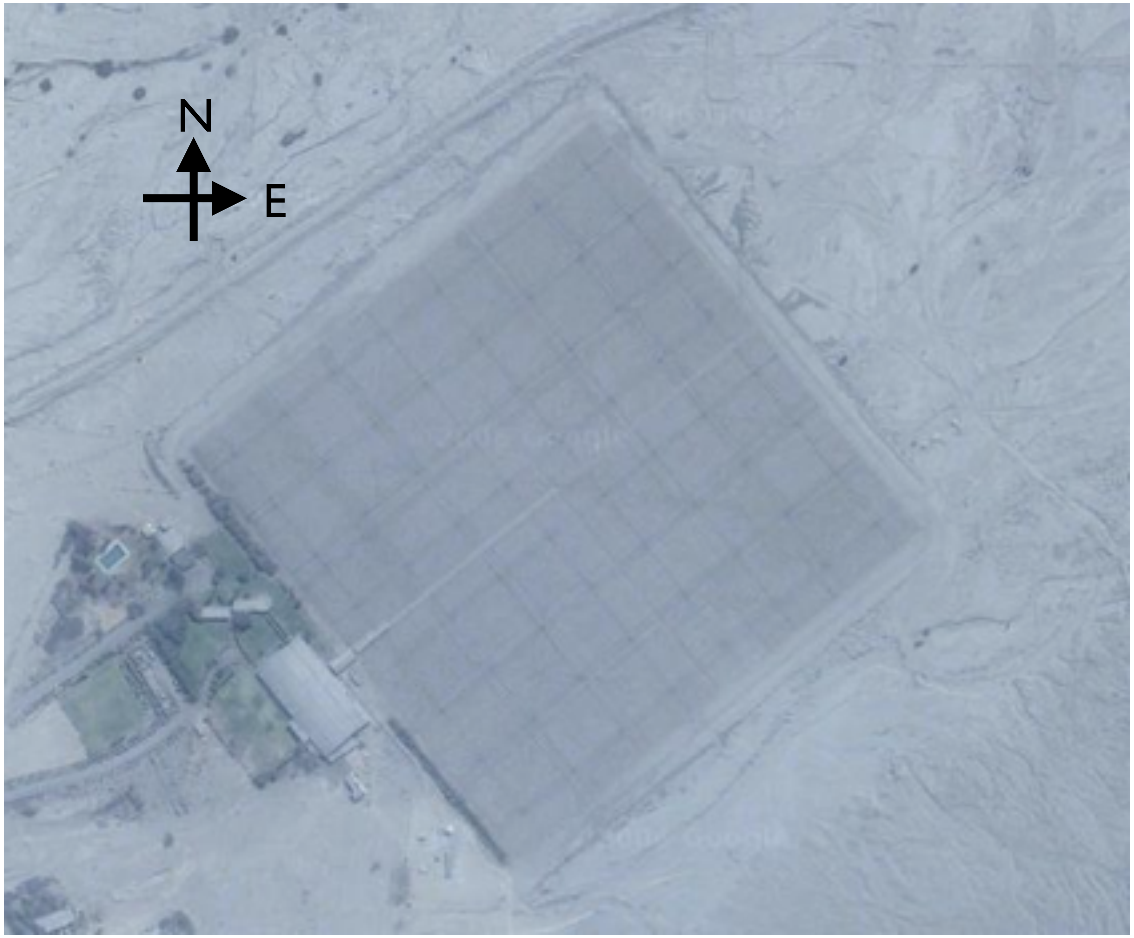
RX1.RX2*=NS INTERF.

RX3=EAST BOWTIE
RX4=EAST QUARTER
RX6=SOUTH X-POL

RX3.RX4*=NS INTERF.

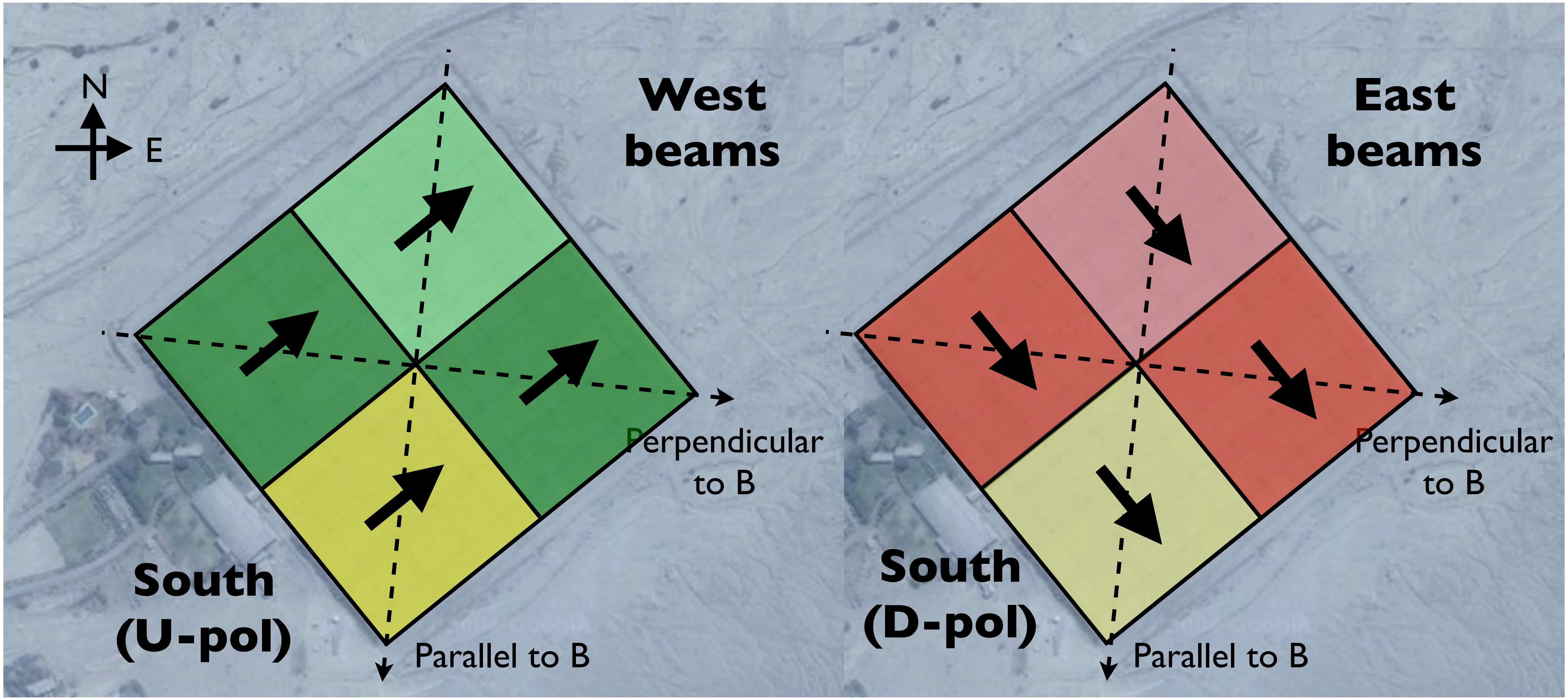
- Three beam pointing directions:
  - West and East (perp-to-B)
  - South (off perp-to-B)
- Six antenna channels, two per each pointing direction.
- 1 polarization diversity (south)
- 2 spatial diversities (west and east)
- We can measure:
  - Vertical and zonal drifts
  - Electron densities
  - Te/Ti ratios

Jicamarca antenna array has 2 polarizations, each polarization is divided in quarters:



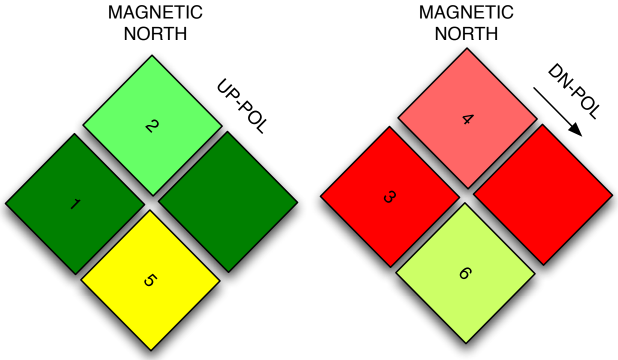
Jicamarca antenna array has 2 polarizations, each polarization is divided in quarters:

U-pol excites and detects the West beams



D-pol is used for East beams

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



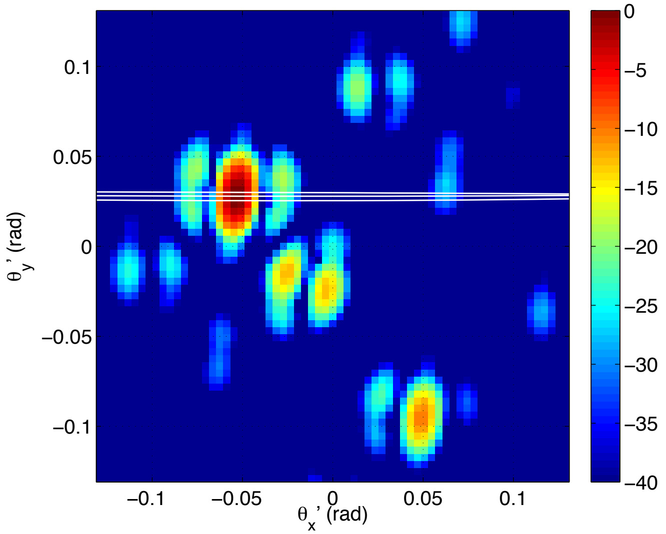
RX1=WEST BOWTIE
RX2=WEST QUARTER
RX5=SOUTH CO-POL

RX1.RX2*=NS INTERF.

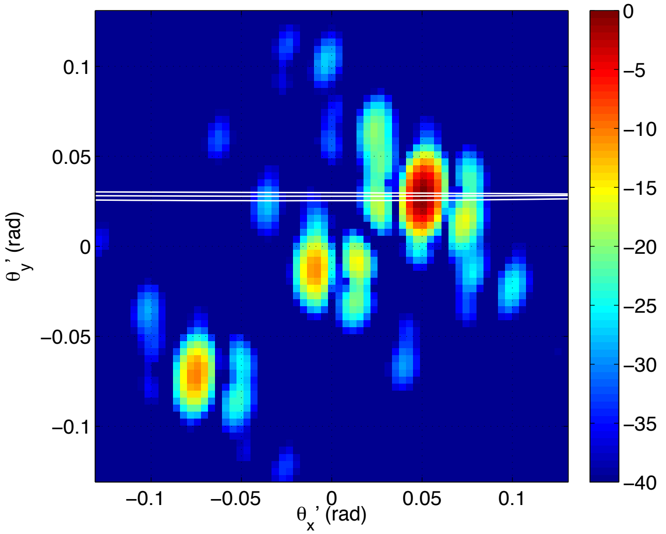
RX3=EAST BOWTIE
RX4=EAST QUARTER
RX6=SOUTH X-POL

RX3.RX4*=NS INTERF.

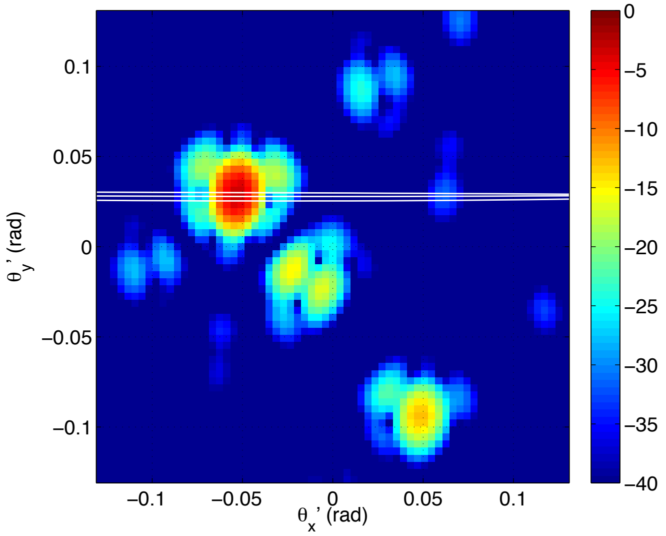
West beam (Bow–tie)
D2W = 78.30 dB
ABS = 4716.19



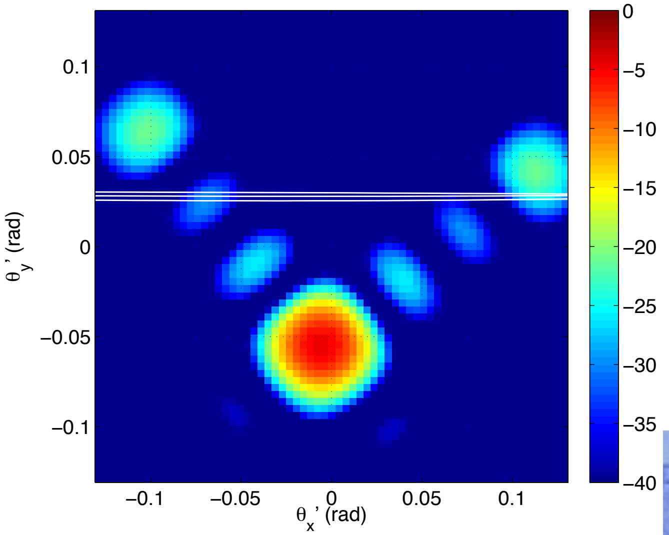
East beam (Bow–tie)
D2W = 78.04 dB
ABS = 4363.89



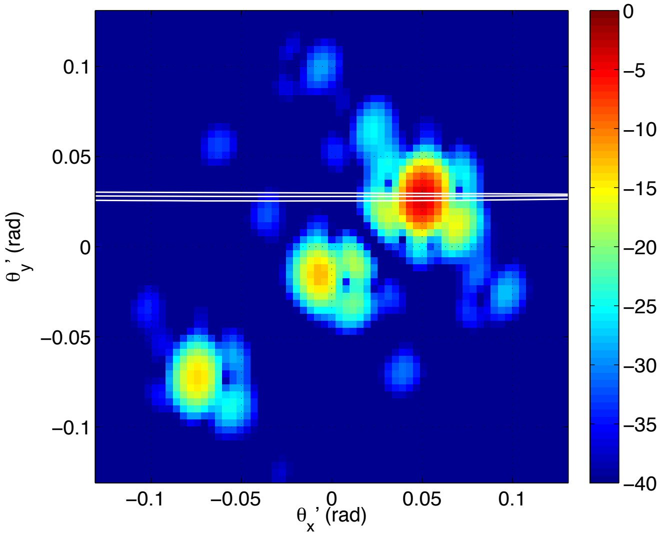
West beam (One quarter)
D2W = 74.88 dB
ABS = 3111.32



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

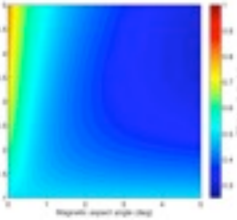


East beam (One quarter)
D2W = 74.54 dB
ABS = 2888.92

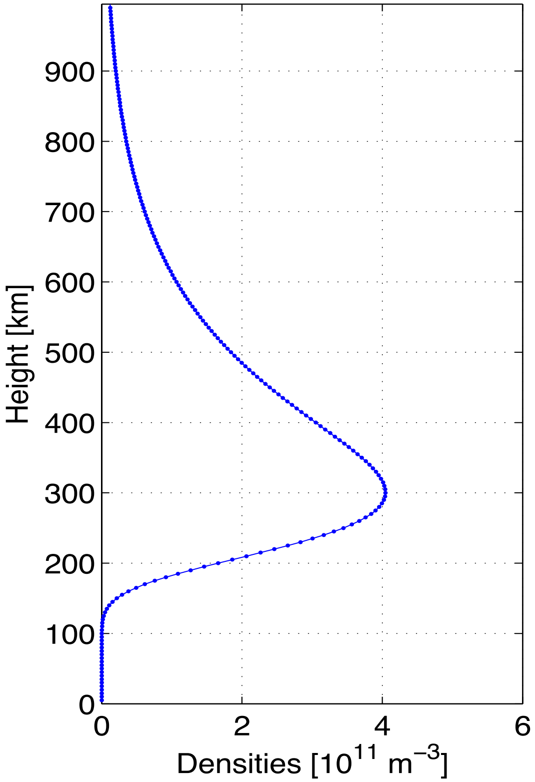


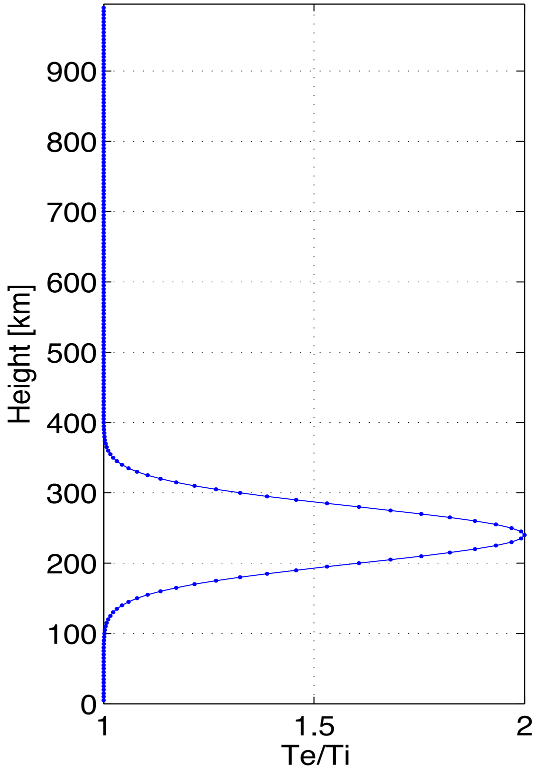
Basic idea used in the experiment: In an ionosphere with **Ne and Te/Ti profiles** shown on the left, a north-south beam scan would produce a **total backscatter power map** shown on the right, with the sharp enhancement ("dagger") in the direction where the radar beam is perpendicular to B:

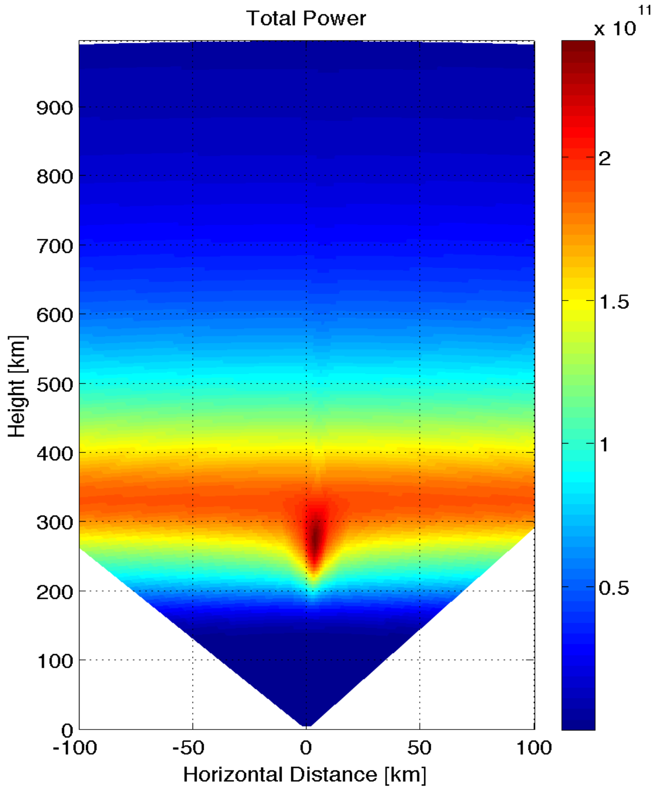
$P_s \propto \dfrac{N_e}{1+T_e/T_i}$ away from perp to B, otherwise $P_s \propto N_e \eta \quad \eta =$



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.

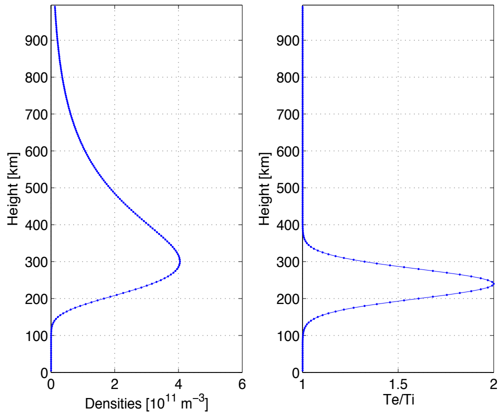


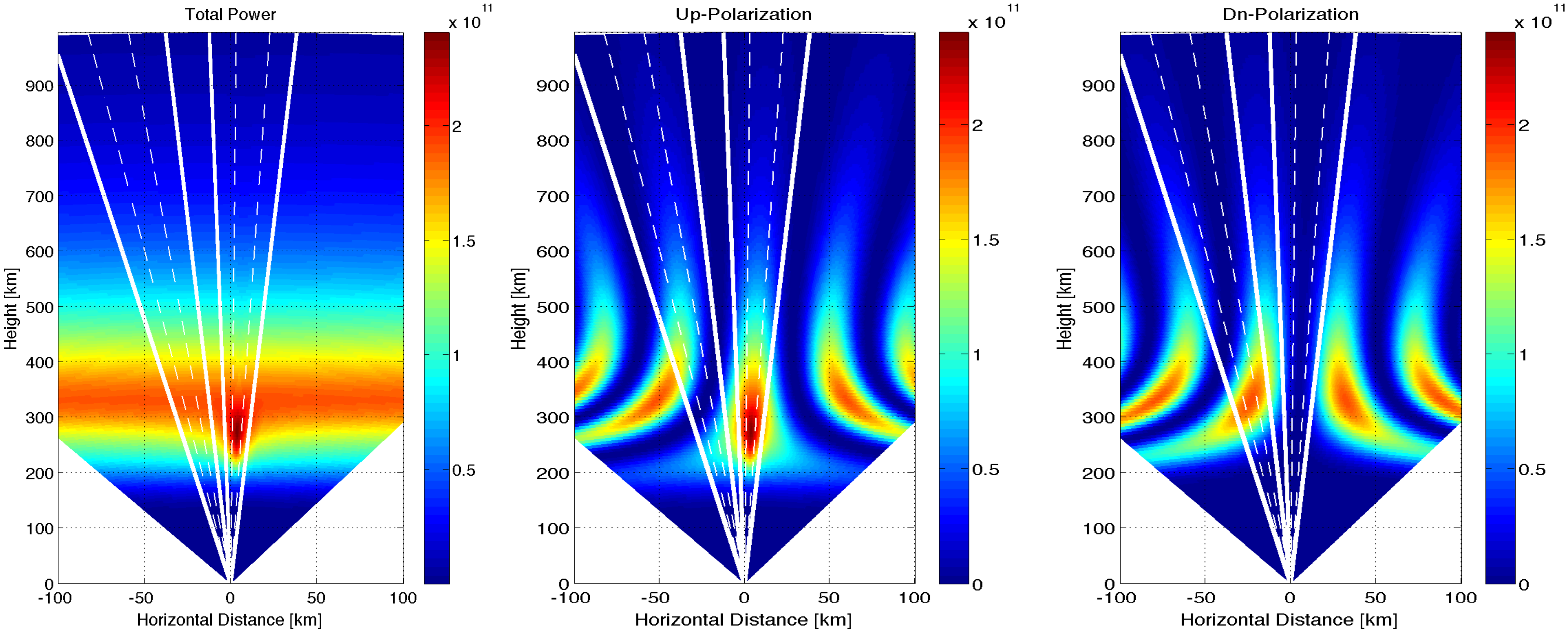




Simulated total power and JRO beams used in the 3B experiment:

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 modeled and processed to be able to estimate Ne and Te/Ti profiles.

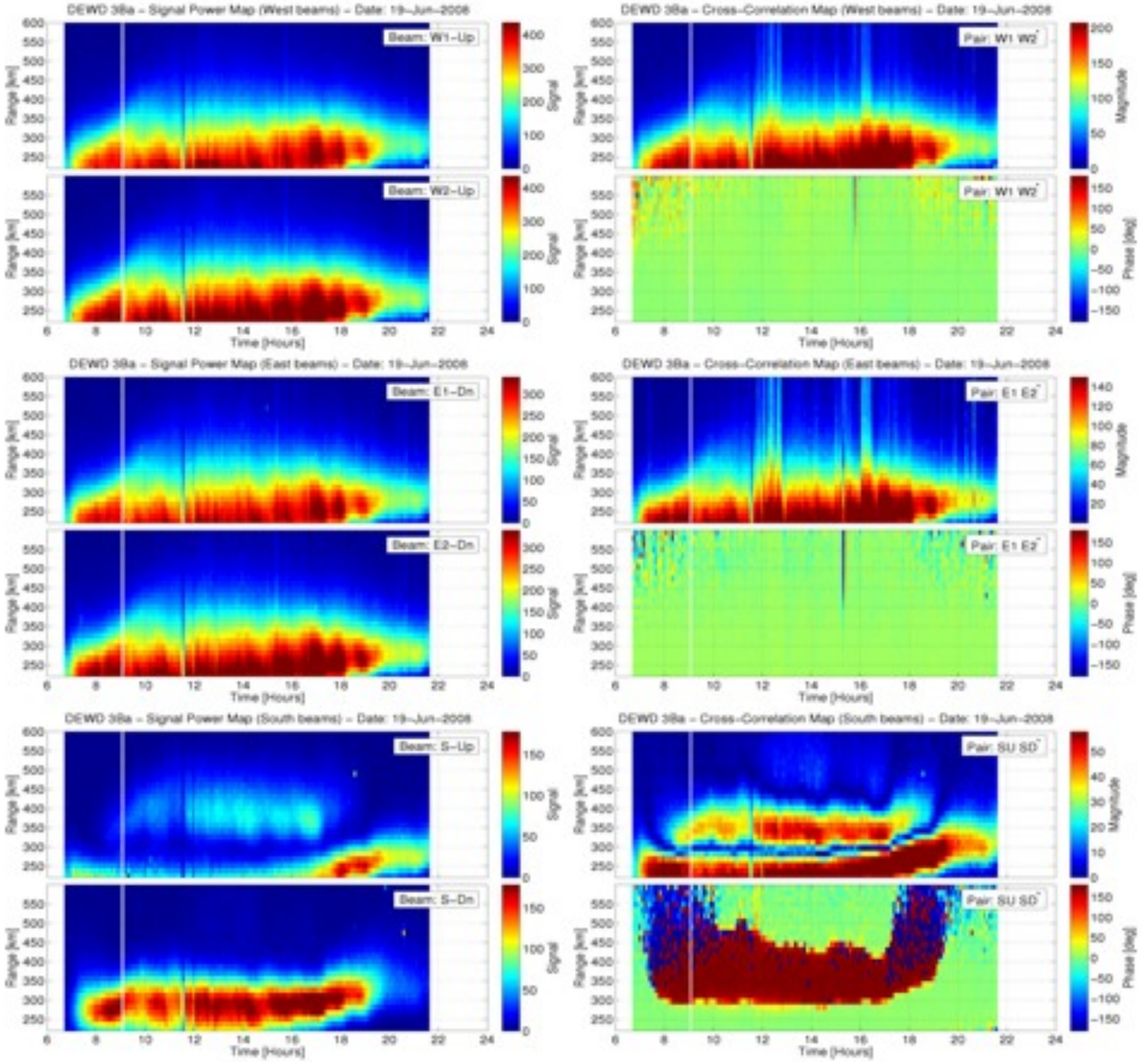




Co-pol

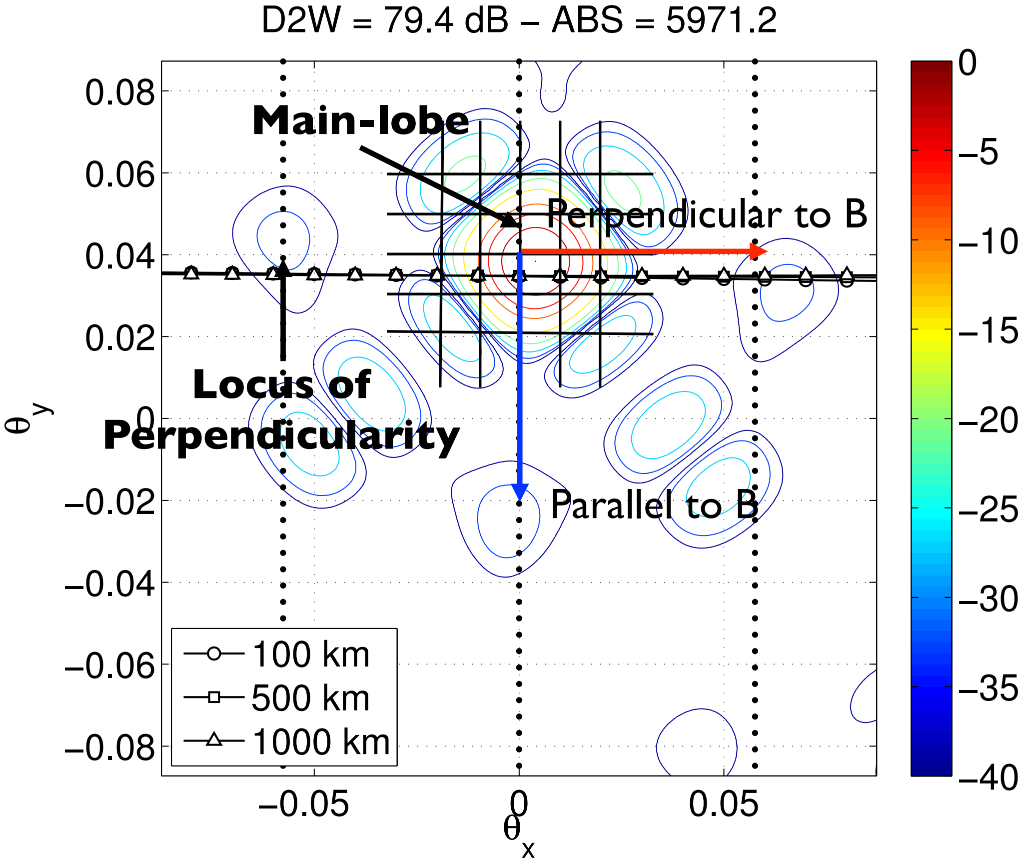
X-pol

Power and cross-correlation radar data



- Range vs. time plots of the signal power and cross-correlation data measured in the 3Beam experiment of June 19, 2008.
- On the left, the power data collected by each of the radar beams are displayed in linear scale.
- On the right, the magnitudes of the cross-correlation data are also plotted in linear scale, while the phase data are plotted in degrees.

Forward modeling the beam-weighted data



Magnetic field is obtained from the IGRF 2010 model.

- Antenna beam-widths: ~1 deg).
- The measured data is the sum of contributions coming from different magnetic aspect angles.

Radar equation:

$$\frac{P_r}{E_t K} = \frac{\delta R}{R^2} \int d\Omega \, W(\hat{\mathbf{r}}) \int d\omega \, \sigma(\vec{k},\omega)$$

IS-RCS

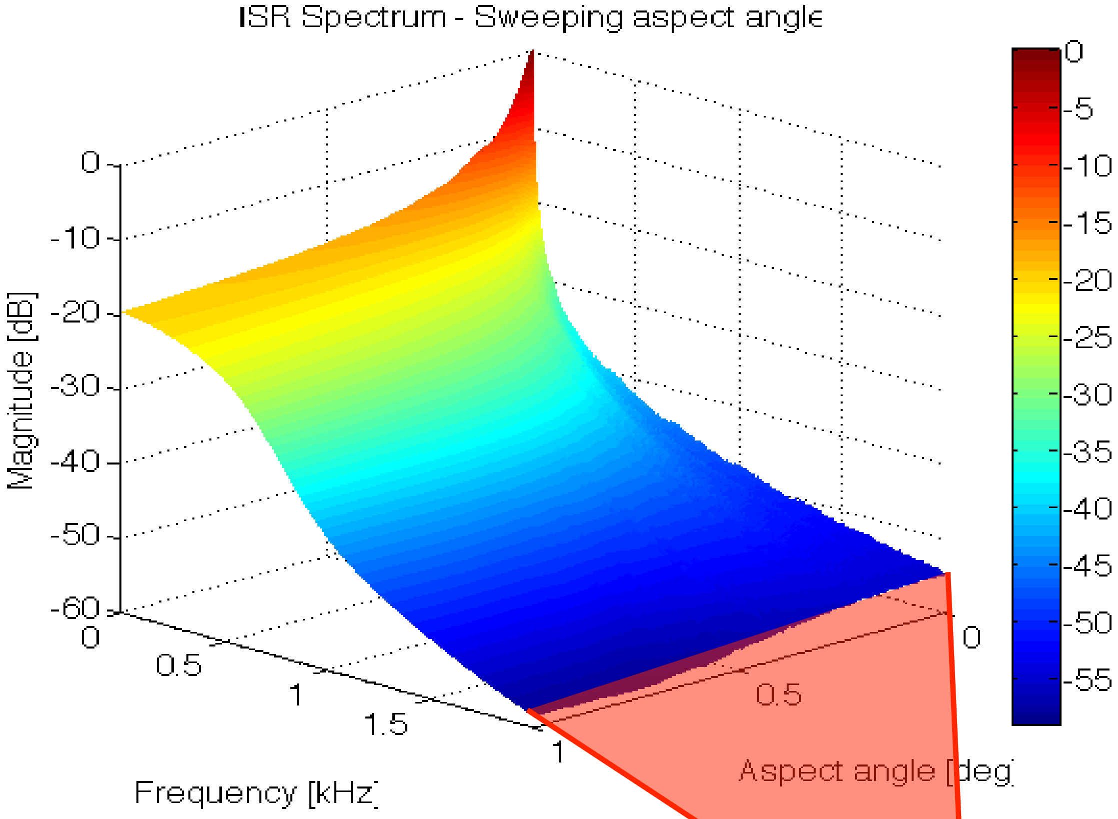
$$\sigma(\vec{k},\omega) = 4\pi r_e^2 \left\langle |n_e(\vec{k},\omega)|^2 \right\rangle$$

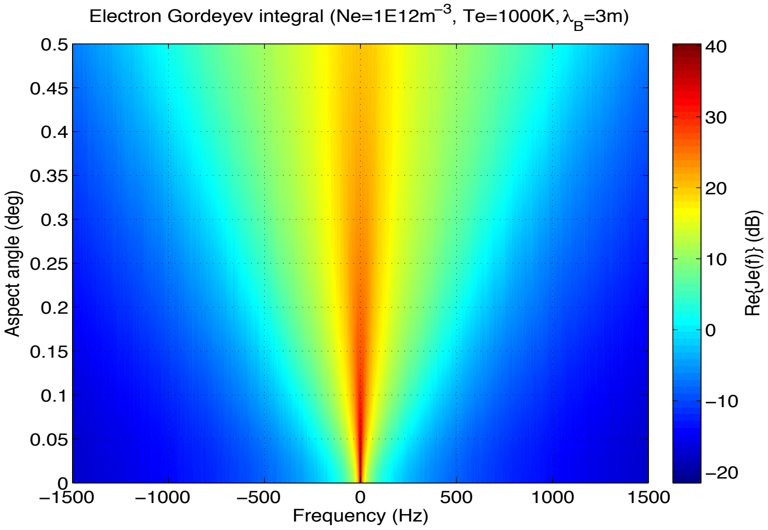
Unknowns: Densities Ne and Te/Ti

Radar Calibration parameters per channel

Collisional IS spectrum model

Based on the Fokker-Planck collision model, we have developed a Monte-Carlo procedure to compute the IS spectrum for all magnetic aspect angles.

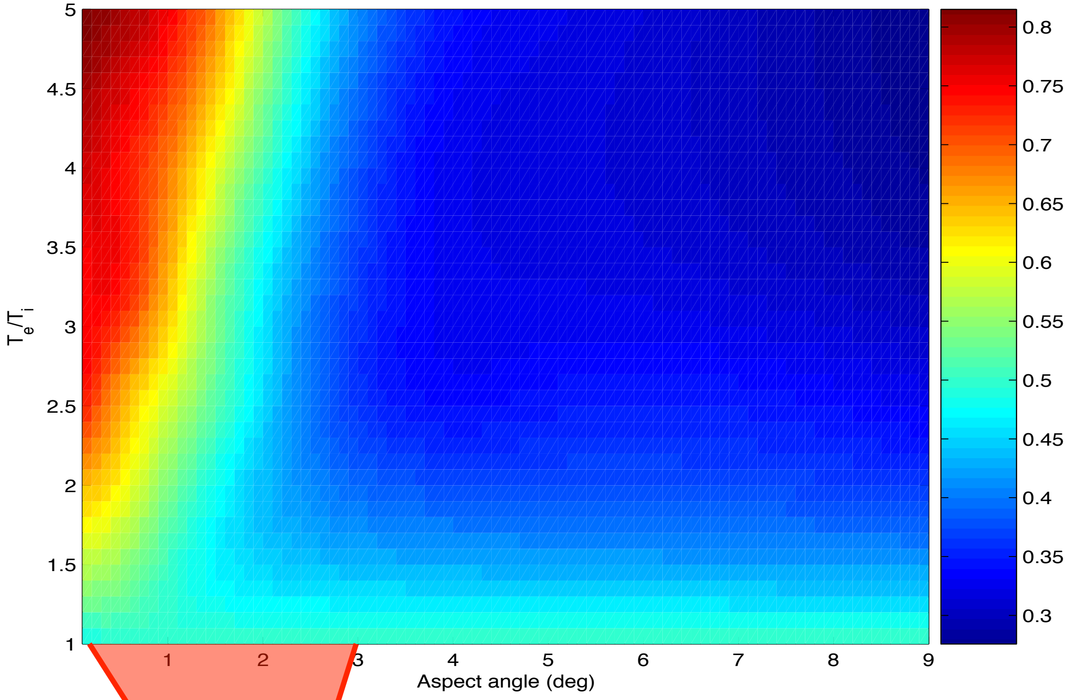




This model is an extension of the Sulzer & Gonzalez [1999] procedure.

Collisional IS RCS model

Dependence of RCS on Te/Ti and magnetic aspect angle:



Jicamarca antenna beams illuminate a finite range of magnetic aspect angles

Using the collisional IS spectra we compute IS-RCS as function of magnetic aspect angle and Te/Ti.

$$\tilde{\sigma} = 4\pi r_e^2 N_e f(\frac{T_e}{T_i})$$

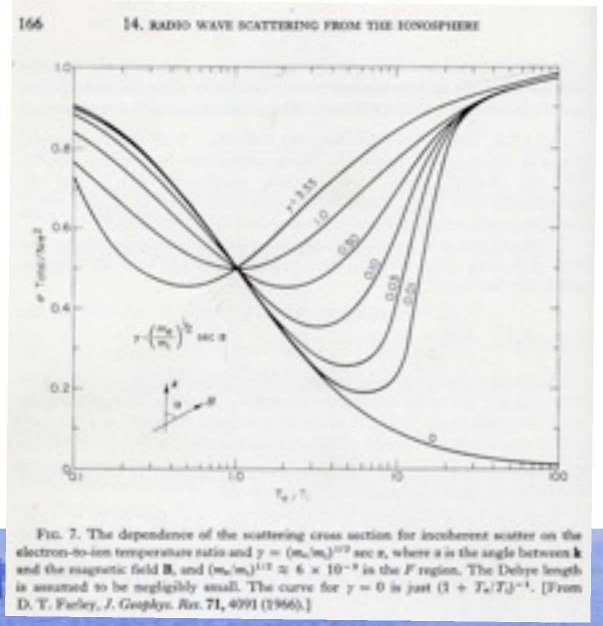


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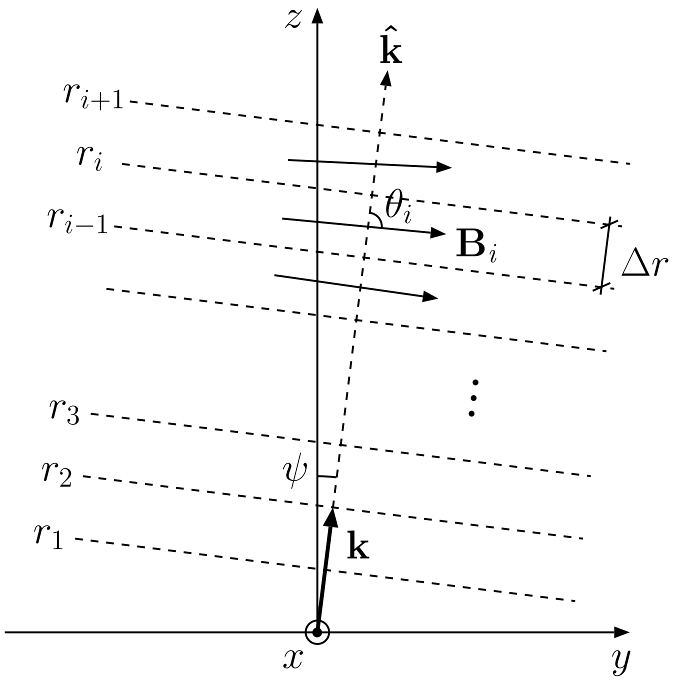
FIG. 7. The dependence of the scattering cross section for incoherent scatter on the electron-to-ion temperature ratio and $\gamma = (m_e/m_i)^{1/2} \sec \alpha$, where α is the angle between **k** and the magnetic field **B**, and $(m_e/m_i)^{1/2} \approx 6 \times 10^{-3}$ in the *F* region. The Debye length is assumed to be negligibly small. The curve for $\gamma = 0$ is just $(1 + T_e/T_i)^{-1}$. [From D. T. Farley, *J. Geophys. Res.* **71**, 4091 (1966).]

Magneto-ionic propagation model (I)



Geometry of wave propagation in an inhomogeneous magnetized ionosphere.

Appleton-Hartree Solution

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

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

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

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

$$\begin{bmatrix} E_\theta^i \\ E_\phi^i \end{bmatrix} = \underbrace{\frac{e^{-jk_o\bar{n}r}}{1+a^2}\begin{bmatrix} e^{-jk_o\Delta nr} + a^2 e^{jk_o\Delta nr} & 2a\sin(k_o\Delta nr) \\ -2a\sin(k_o\Delta nr) & a^2 e^{-jk_o\Delta nr} + e^{jk_o\Delta nr} \end{bmatrix}}_{\bar{\mathbf{T}}_i} \begin{bmatrix} E_\theta^{i-1} \\ E_\phi^{i-1} \end{bmatrix}$$

Backscattered electric field for every propagation direction →

$$\vec{E}_o^r \propto \kappa_i \underbrace{\bar{\mathbf{T}}_1\bar{\mathbf{T}}_2\cdots\bar{\mathbf{T}}_i\bar{\mathbf{T}}_i\cdots\bar{\mathbf{T}}_2\bar{\mathbf{T}}_1}_{\bar{\bar{\mathbf{\Pi}}}_i} \vec{E}_o^t$$

Two-way propagator matrix →

Magneto-ionic propagation model (2)

Soft-Target Radar equation:

$$\frac{P_r}{E_t K} = \frac{\delta R}{R^2} \int d\Omega\, W(\hat{\mathbf{r}}) \int d\omega\, \sigma(\vec{k},\omega) \qquad \sigma(\vec{k},\omega) = 4\pi r_e^2 \left\langle |n_e(\vec{k},\omega)|^2 \right\rangle$$

But now, $W(\vec{r})$ is an effective two-way radiation pattern

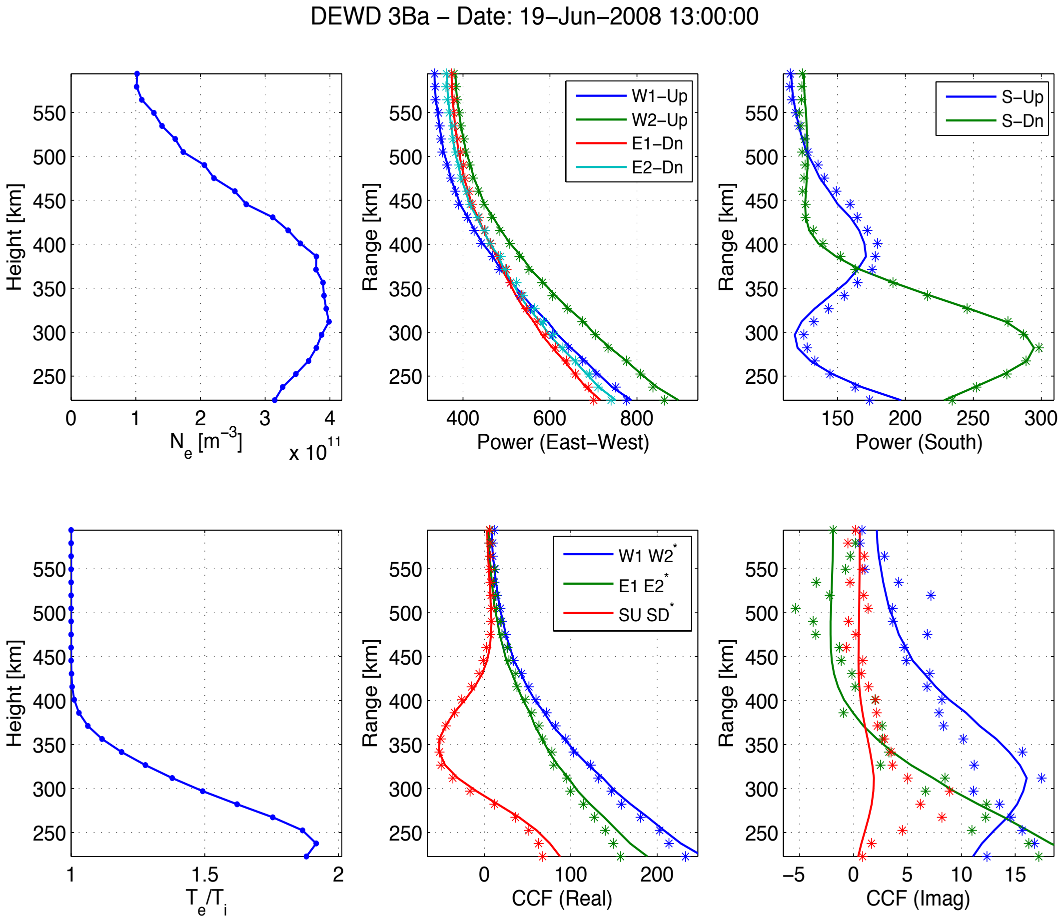
$$W(\vec{r}) = \frac{1}{k^2} G_t(\hat{\mathbf{r}})\, G_r(\hat{\mathbf{r}})\, \Gamma(\vec{r})$$

where $\Gamma(\vec{r})$ is a polarization coefficient

$$\Gamma(\vec{r}) = \left| \hat{\mathbf{p}}_r^{\mathsf{T}}\, \bar{\mathbf{\Pi}}(\vec{r})\, \hat{\mathbf{p}}_t \right|^2$$

polarization unit vectors

Fitting power and cross-correlation data


DEWD 3Ba – Date: 19–Jun–2008 13:00:00

Two step minimization algorithm

1. Fit for Ne. Fix Te=Ti.
2. Fit for Ne and Te/Ti.

Minimizing the following cost function:

$$\mathcal{E}^2_{i,j} = \sum_n \delta\vec{m}^{\mathsf{T}}_{i,j}[n]\,\bar{\mathbf{M}}^{-1}_{i,j}[n]\,\delta\vec{m}_{i,j}[n]$$

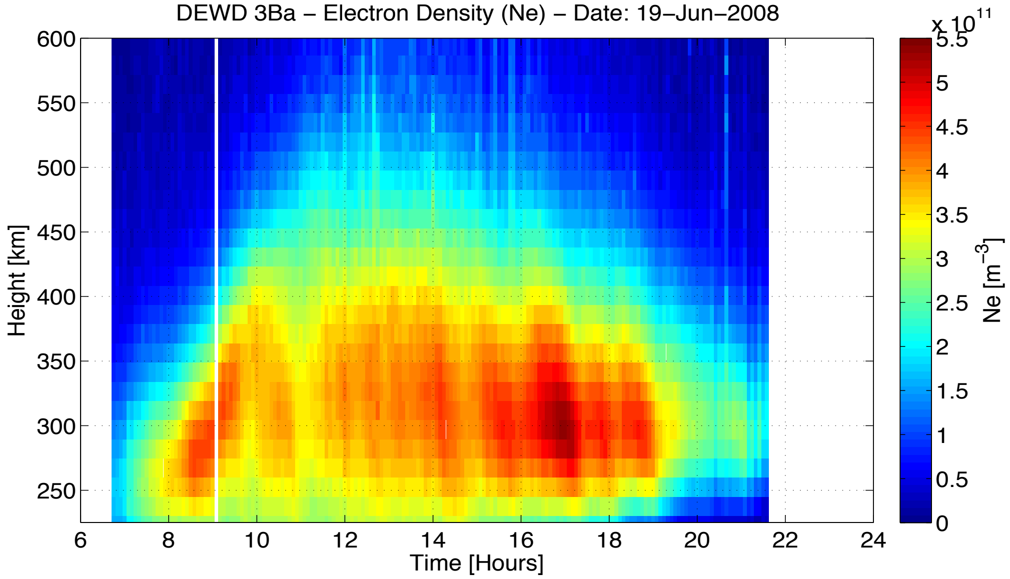
Vector of measurement errors:

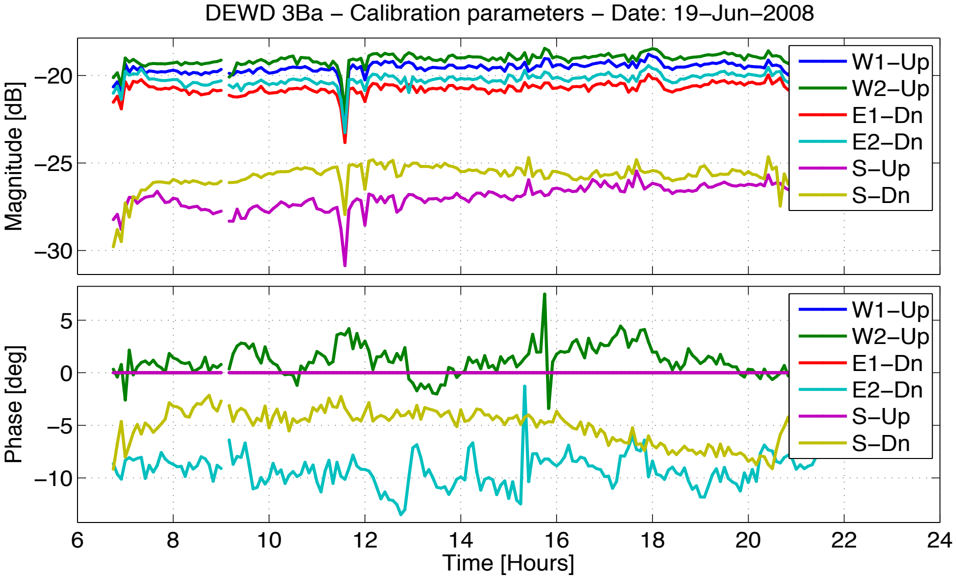
$$\delta\vec{m}_{i,j}[n] = \begin{bmatrix} \delta P_i[n] \\ \delta P_j[n] \\ \delta R_{i,j}[n] \\ \delta Q_{i,j}[n] \end{bmatrix} = \begin{bmatrix} p_i[n] - P_i[n] \\ p_j[n] - P_j[n] \\ r_{i,j}[n] - R_{i,j}[n] \\ q_{i,j}[n] - Q_{i,j}[n] \end{bmatrix}$$

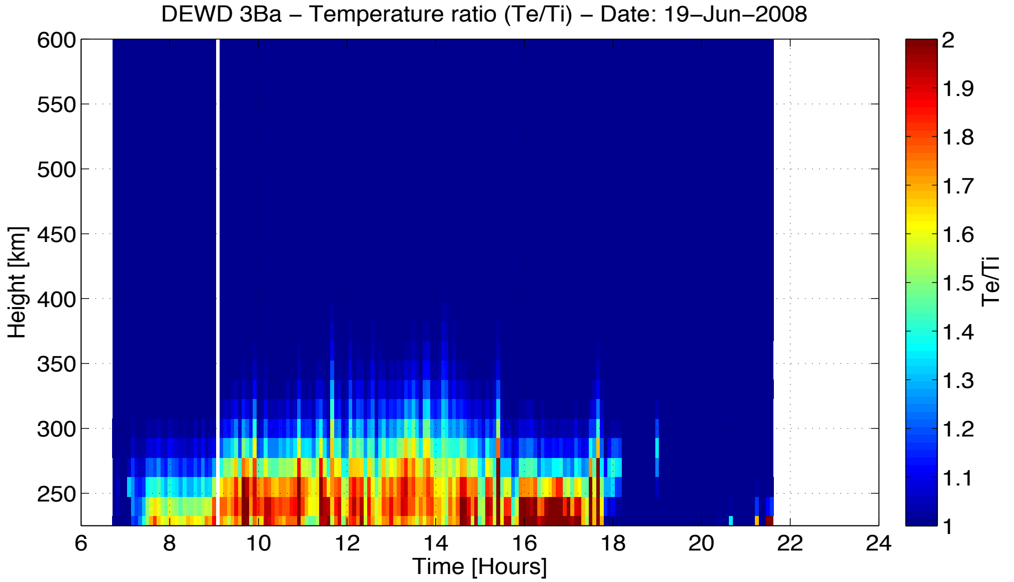
Covariance matrix

$$\bar{\mathbf{M}}_{i,j} = \frac{1}{I}\begin{bmatrix} P_i^2 & R_{i,j}^2 + Q_{i,j}^2 & P_i R_{i,j} & P_i Q_{i,j} \\ R_{i,j}^2 + Q_{i,j}^2 & P_j^2 & P_j R_{i,j} & P_j Q_{i,j} \\ P_i R_{i,j} & P_j R_{i,j} & \frac{1}{2}\left(R_{i,j}^2 - Q_{i,j}^2 + P_i P_j\right) & R_{i,j} Q_{i,j} \\ P_i Q_{i,j} & P_j Q_{i,j} & R_{i,j} Q_{i,j} & \frac{1}{2}\left(Q_{i,j}^2 - R_{i,j}^2 + P_i P_j\right) \end{bmatrix}$$

Data inversion results

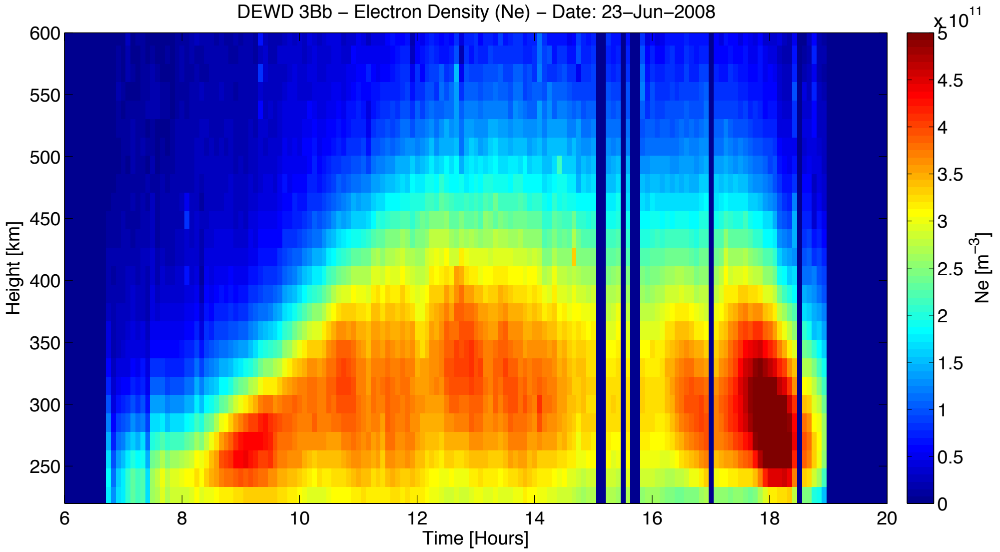


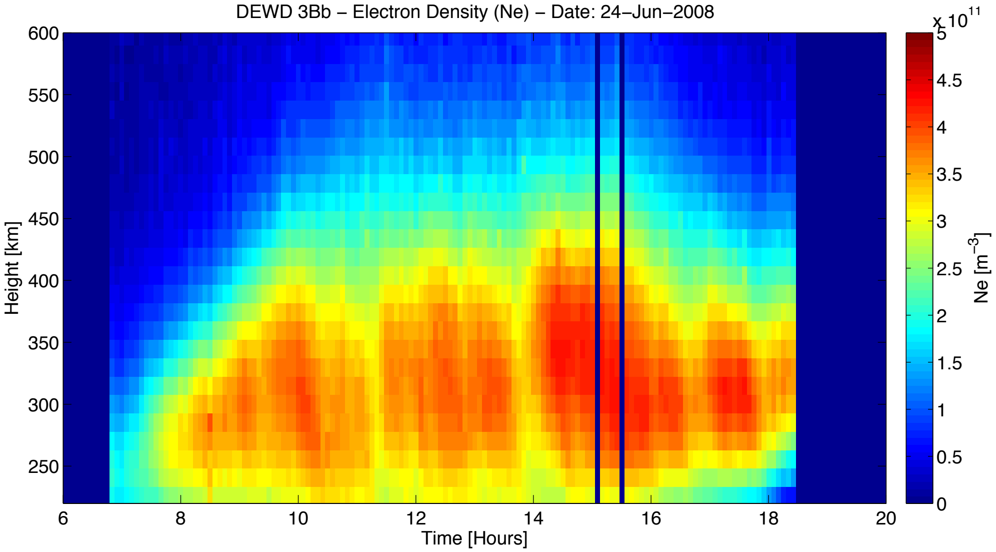


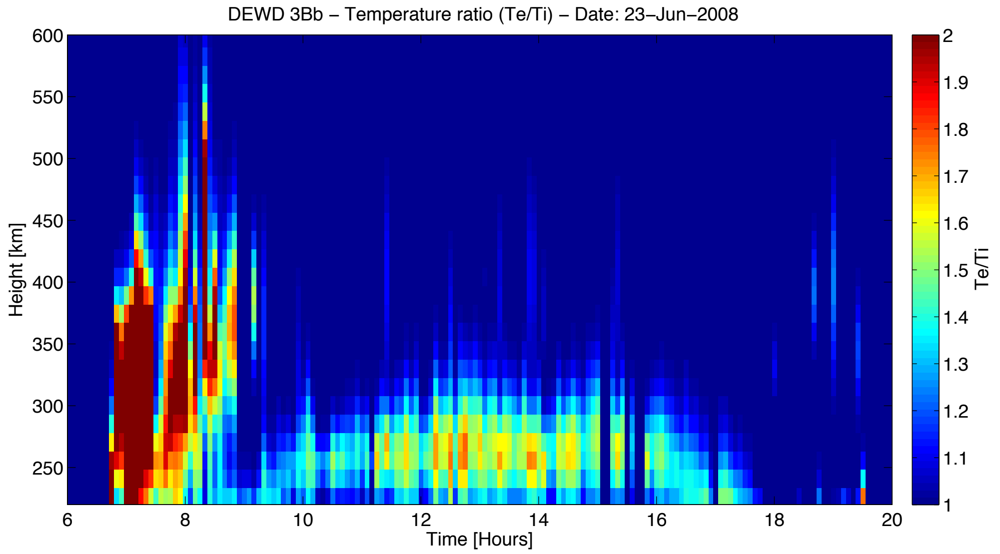


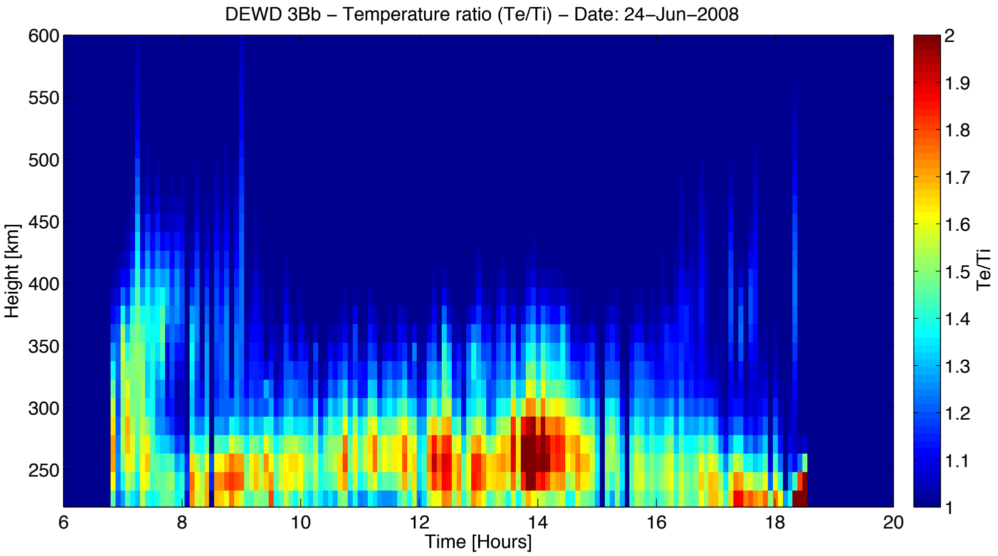
Estimated parameters
- Electron densities
- Te/Ti profiles
- Calibration parameters

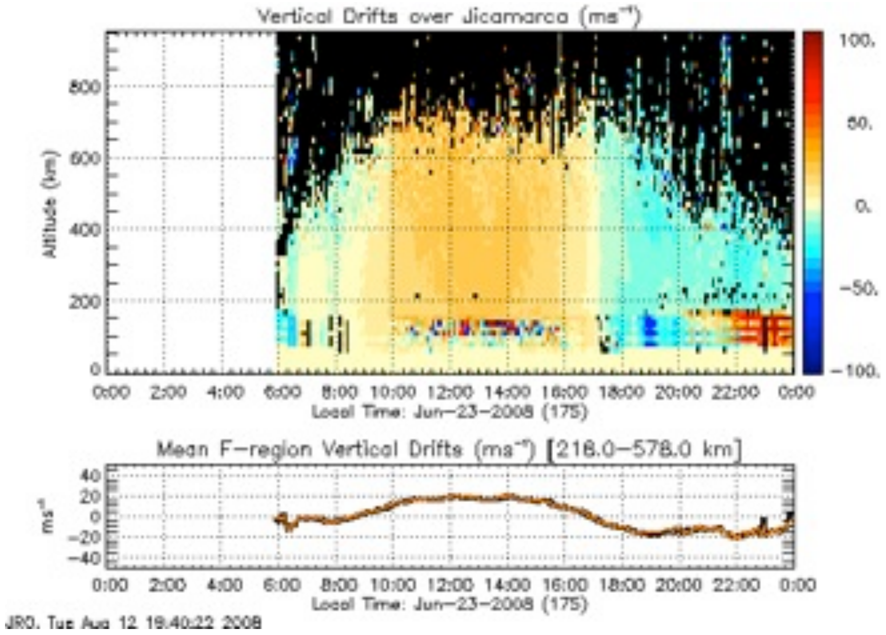
June 23-24, 2008 Experiments: Ne and Te/Ti estimates:


DEWD 3Bb – Electron Density (Ne) – Date: 23–Jun–2008

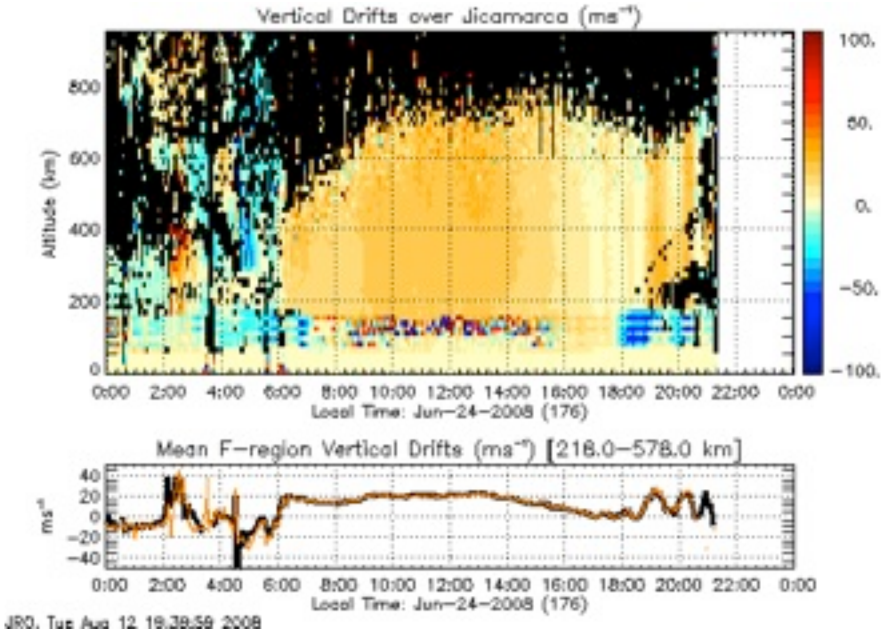

DEWD 3Bb – Electron Density (Ne) – Date: 24–Jun–2008


DEWD 3Bb – Temperature ratio (Te/Ti) – Date: 23–Jun–2008

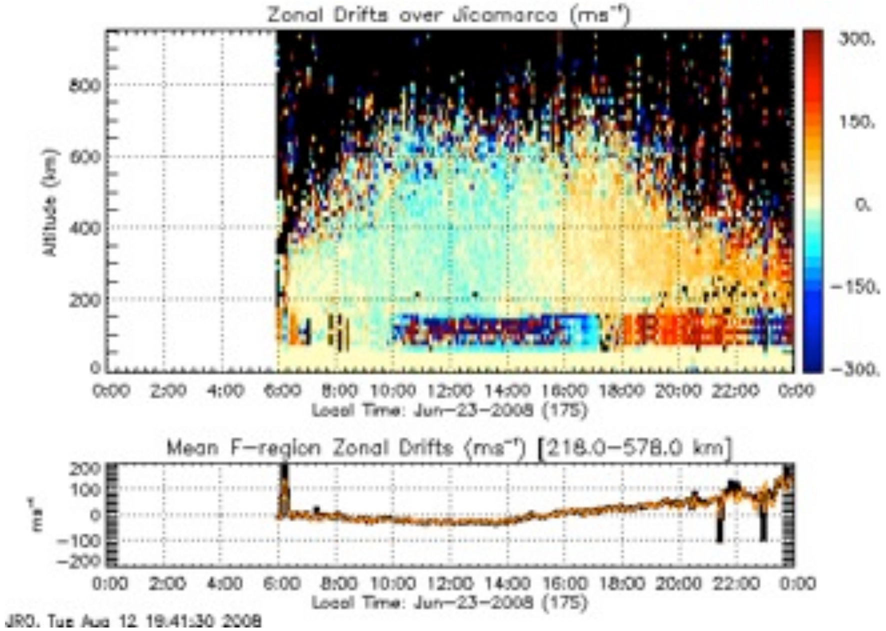

DEWD 3Bb – Temperature ratio (Te/Ti) – Date: 24–Jun–2008



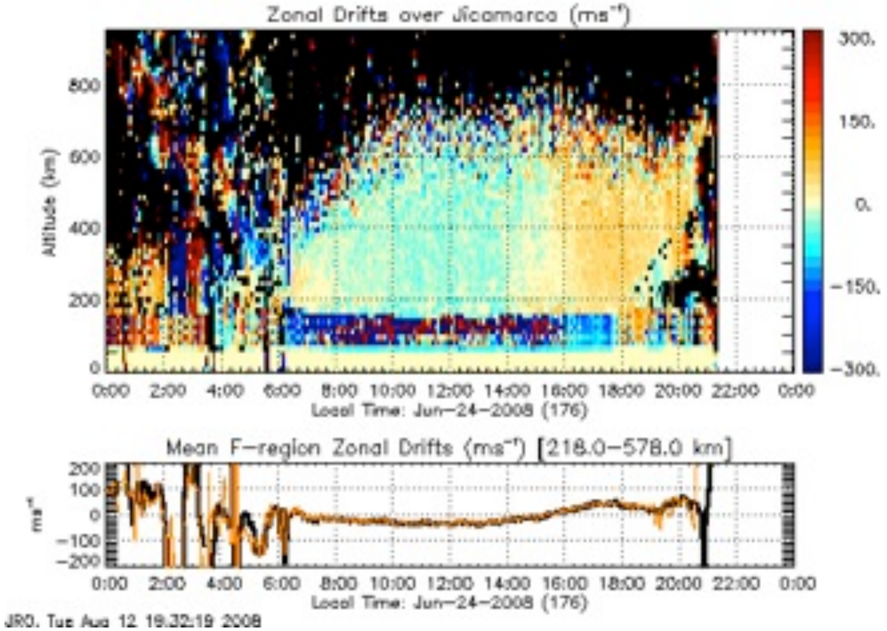
JRO. Tue Aug 12 19:40:22 2008



JRO. Tue Aug 12 19:38:59 2008



JRO. Tue Aug 12 19:41:30 2008



JRO. Tue Aug 12 19:32:19 2008

Conclusions and Future work

- The modeling of the IS radar data measured by the Jicamarca radar needs to consider:
  - Electron and ion Coulomb collisions effects
  - Magneto-ionic propagation effects
  - Beam-weighting effects
- We have developed the tools to model these effects, but still need to optimize our procedure for routine operational use.
- We also need to study in more detail the sensitivity of our model to plasma temperatures and densities.
- Our model was developed for an O+ plasma, we need to extend our model to H+ and He+ plasmas for radar observations of the topside.
- Spectral fitting for Te estimation should now be possible given the Te/Ti profiles and the development of our collisional ISR model.