Characteristics of the incoherent scatter radar observations at Jicamarca

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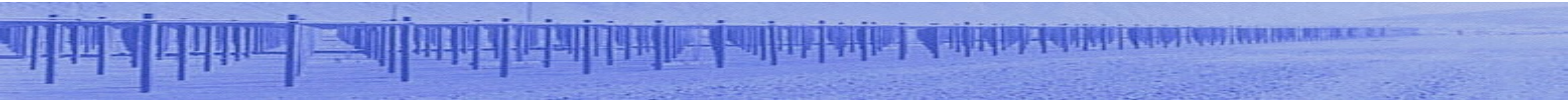


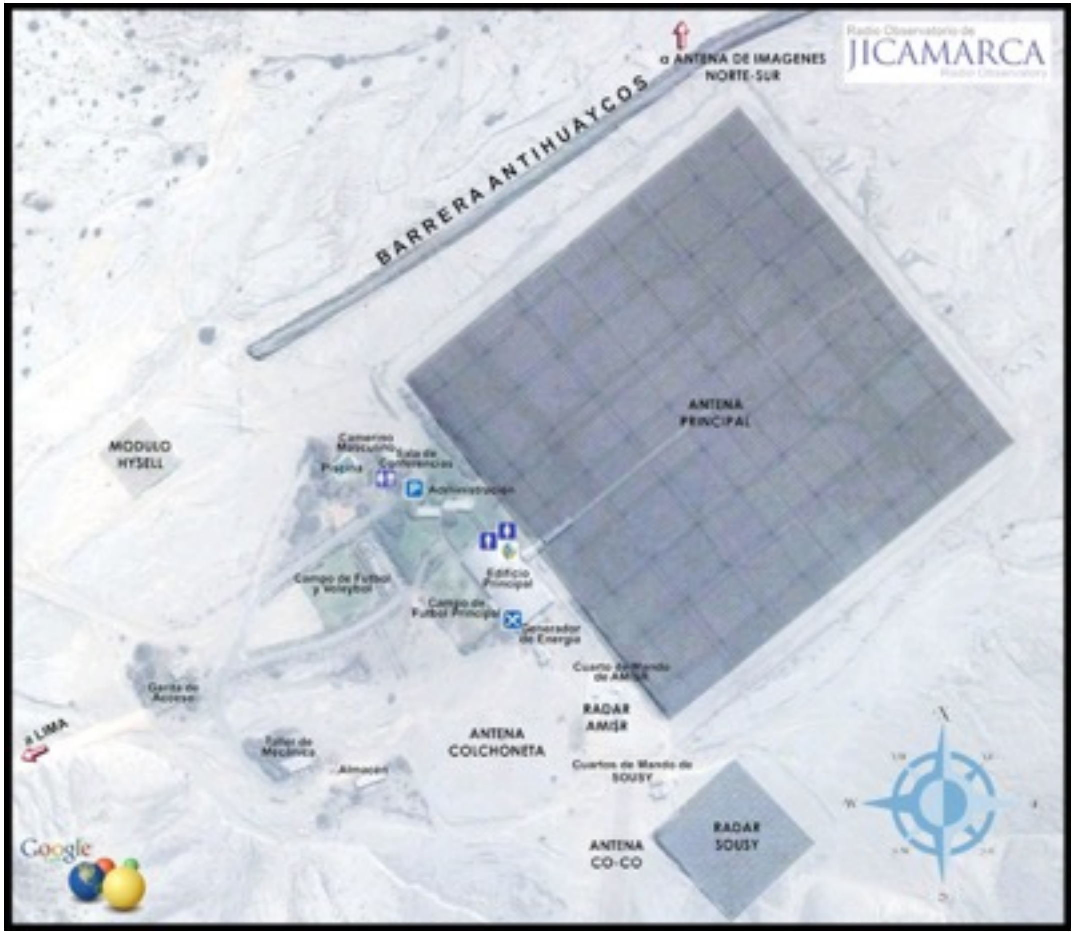
Jicamarca Radio Observatory

Our main instrument is one of the largest incoherent scatter radars in the World.

- It is a research center to study the ionosphere and upper atmosphere.
- Located at ~20 km east of Lima, Peru. (11.95°S, 76.87°W).
- It is part of a chain of observatories supported by NSF in America.
- Operates a variety of instruments: IS an CS radars, ionosondes, magnetometers, GPS receivers, Fabry Perot interferometers, etc.

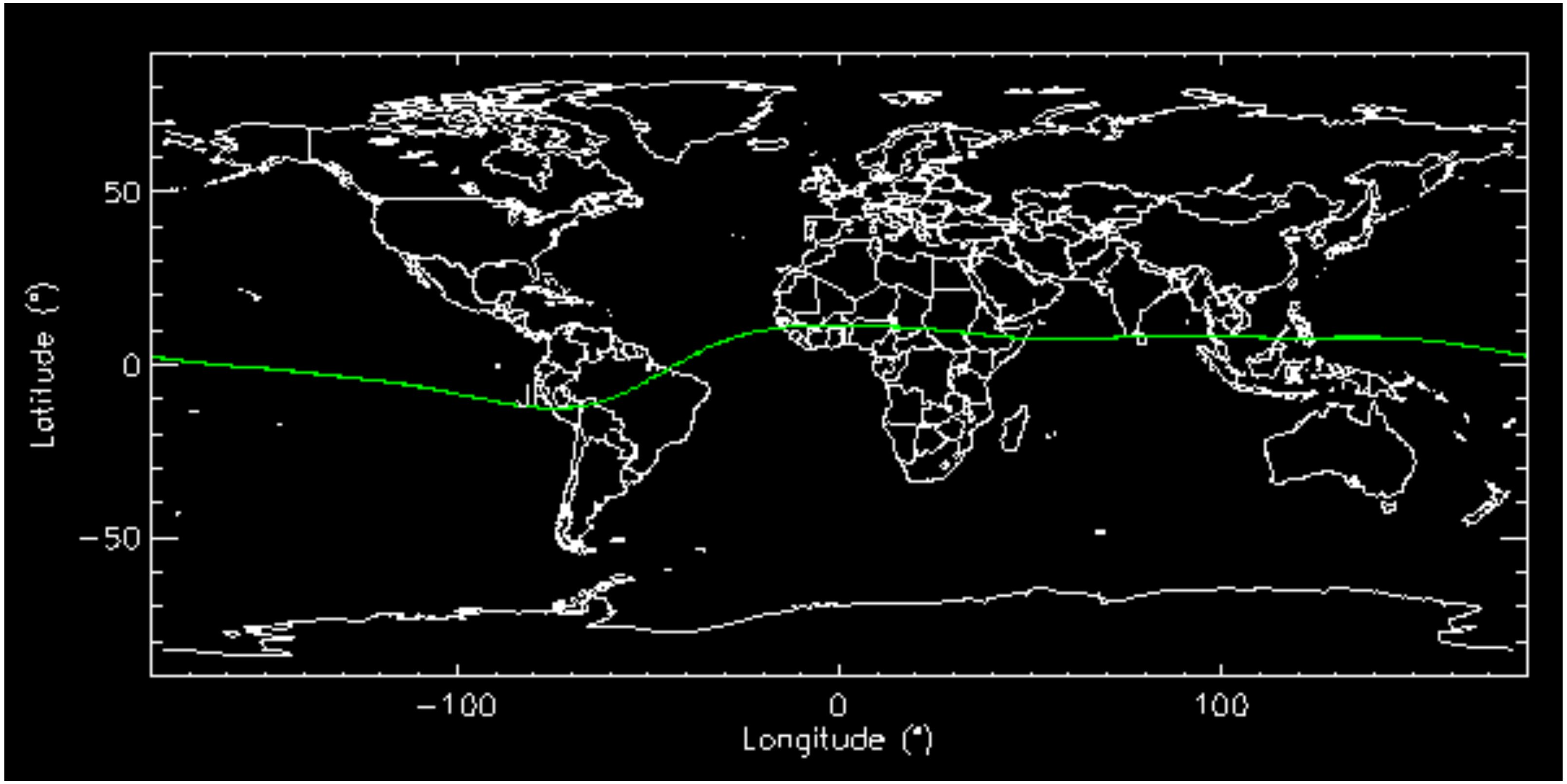
Characteristics of the Jicamarca Radar

- Operating frequency: 50 MHz
- Antenna: array of 18,432 half-wave dipoles covering an area of 300 x 300 m^2.
- The antenna is composed of 8x8 cross-polarized modules that can be combined in multiple ways.
- Pointing directions: within 3 degrees from on-axis.
- Transmitters: 3 x 1.5 MW peak-power with 5% duty cycle. Fourth TX under repair.
- We also have a set of low-power TXs (10 - 20 kW).

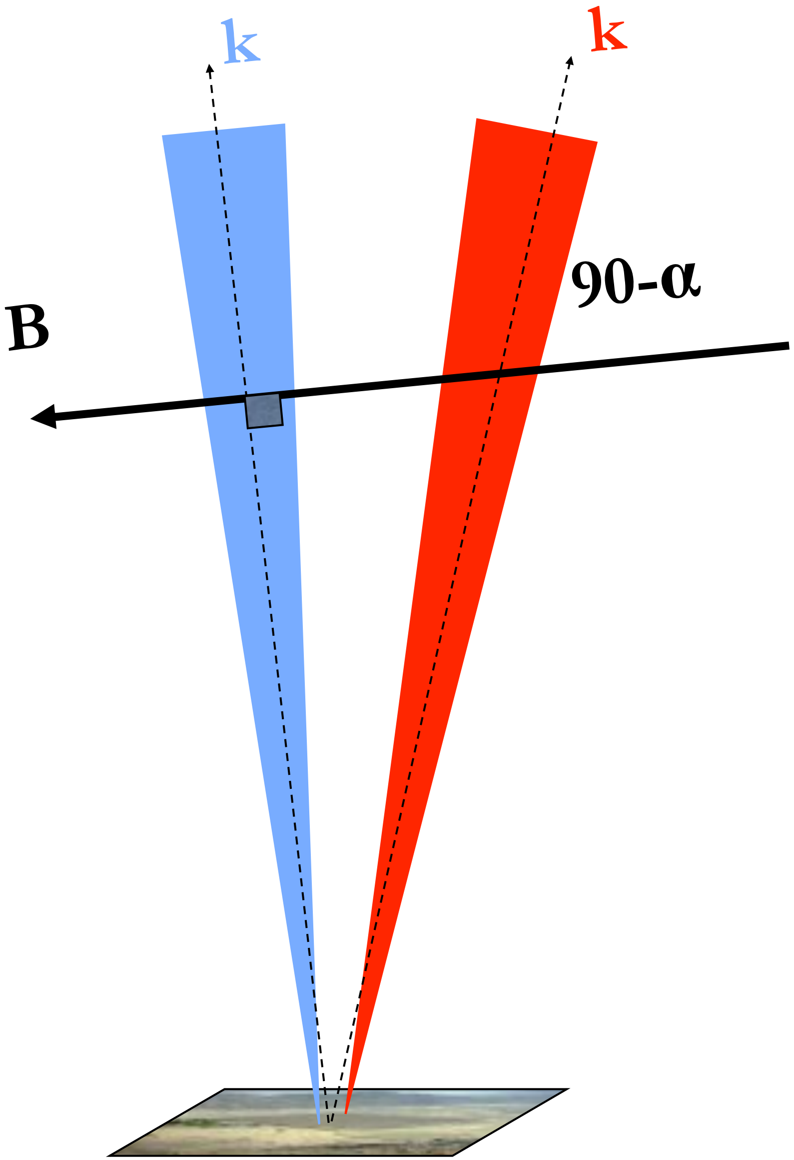


Why at Jicamarca?

- It is under de magnetic Equator (use of large horizontal antenna).
- It was built between 1960-1962. Dr. Ken Bowles, the founder of Jicamarca, worked in Peru (with IGP people) during the IGY 1958.
- It is free of electromagnetic interference (surrounded by mountains).

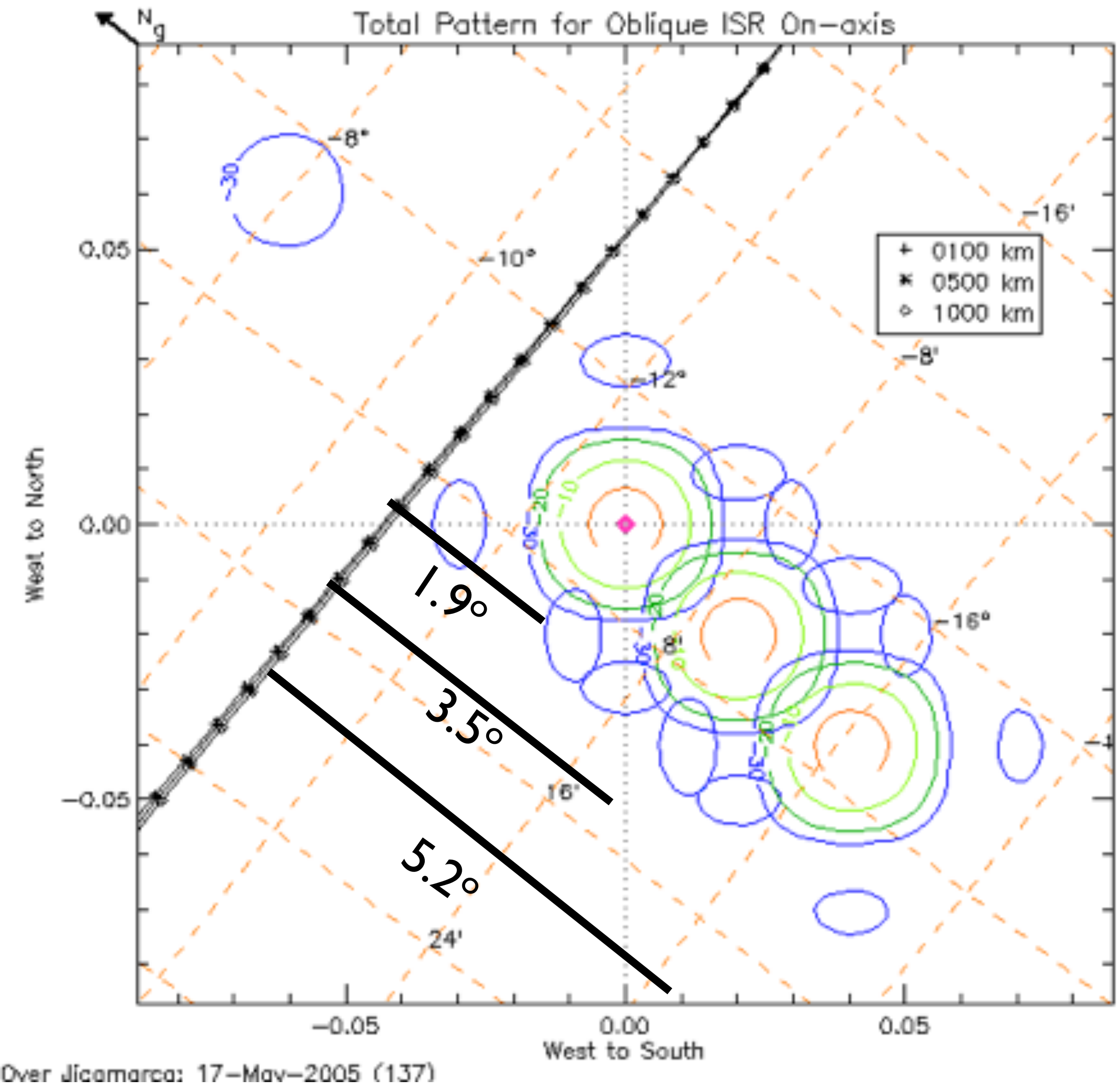


Oblique vs. Perpendicular ISR: Geometry

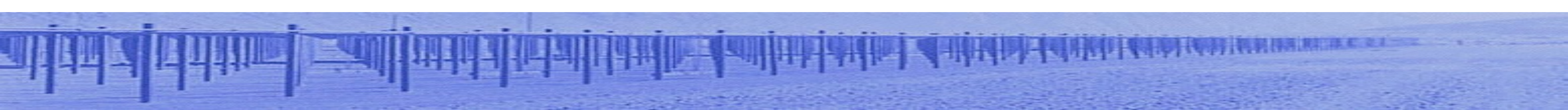


- Depending on α:
  - Oblique: α > 0
  - Perpendicular: α = 0
- What is the α boundary between modes?
- What are the antenna patterns used?
- What are the differences on ACFs and spectra between modes?
- How is the polarization of returned signals?
- How are the modes affected by coherent scatter echoes?
- What can be measured?

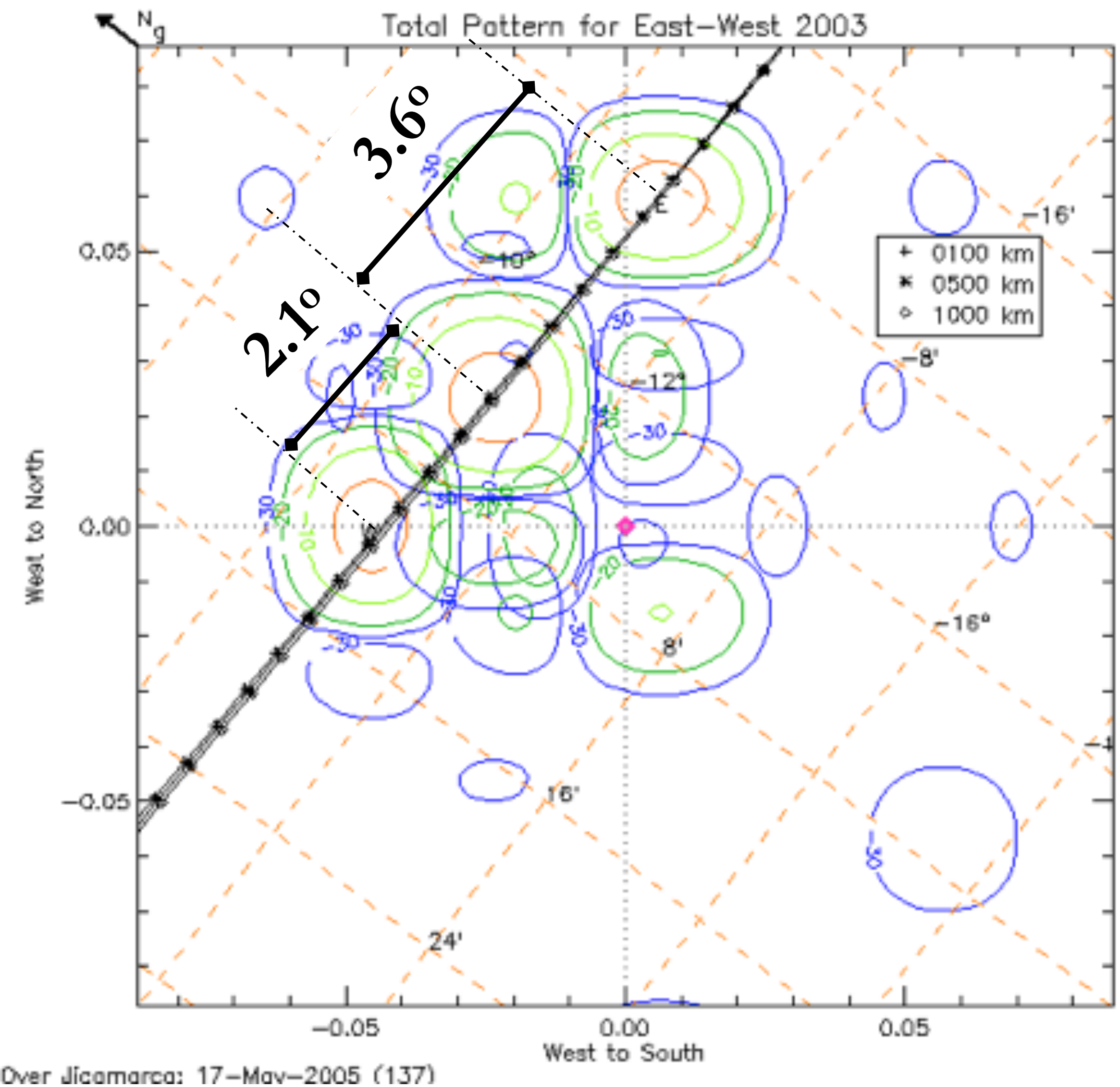
Oblique ISR: Antenna Patterns



- Three standard beam positions are used:
  - On-axis (α = 1.9º)
  - "4.5" (α = 3.5º)
  - "6.0" (α = 5.2º)
- Maximum antenna gain is obtained with "On-axis" and less with "6.0".
- Be careful of possible sidelobes pointing perpendicular to B, since locus of perpendicularity changes from year to year.
- Scattered signals will be weighted by the antenna pattern.



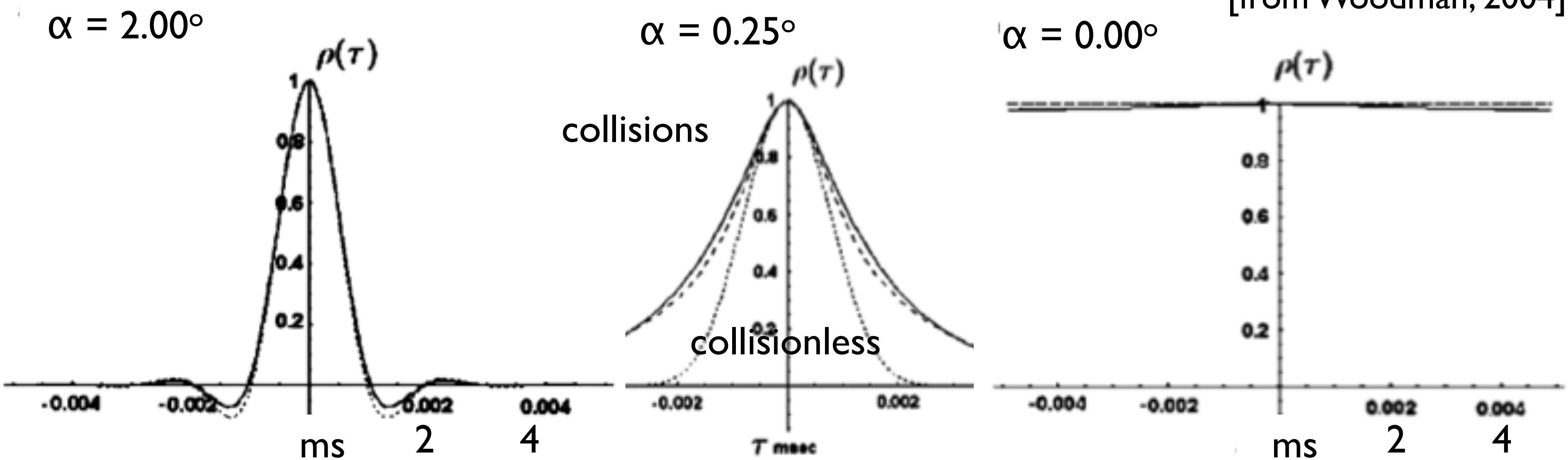
Perpendicular ISR: Antenna Patterns



- Three standard beam positions are used:
  - Vertical (both polarizations)
  - “East” (3.6° with respect to vertical). One linear polarization.
  - “West” (~2.1°). The other linear polarization
- Maximum antenna gain is obtained with “Vertical” and less with “East” or “West”.
- Either Vertical or East-West modes are run at the time, unless wider beams are used (i.e., smaller antennas).
- Recall that the scattered signals will be weighted by the antenna pattern.

Oblique vs. Perp: ACFs

[from Woodman, 2004]



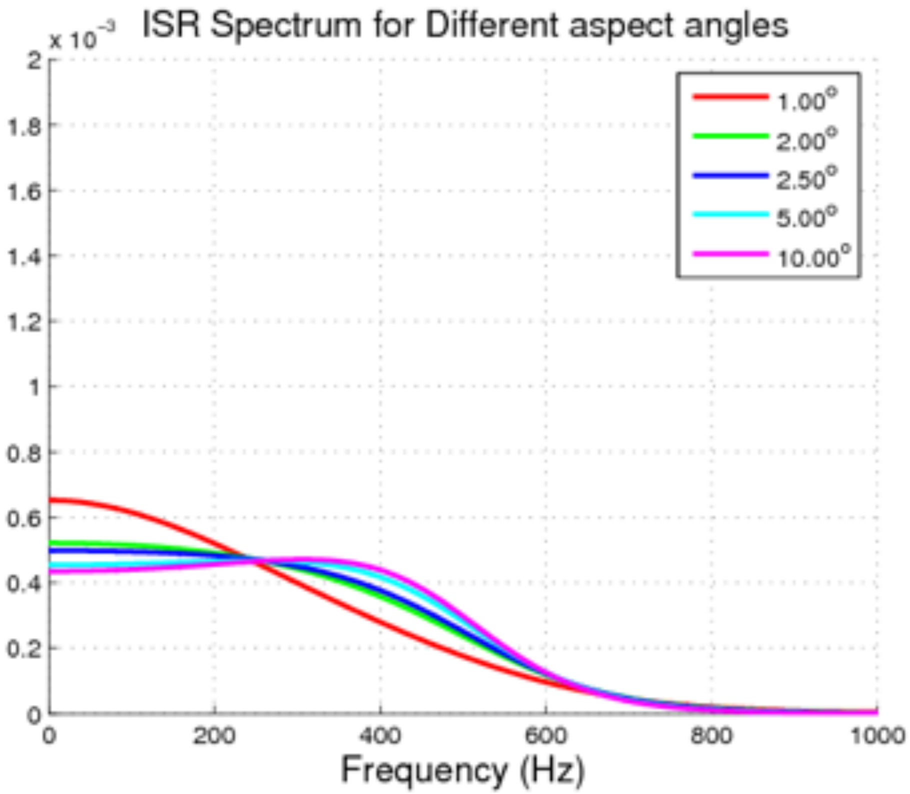
Oblique

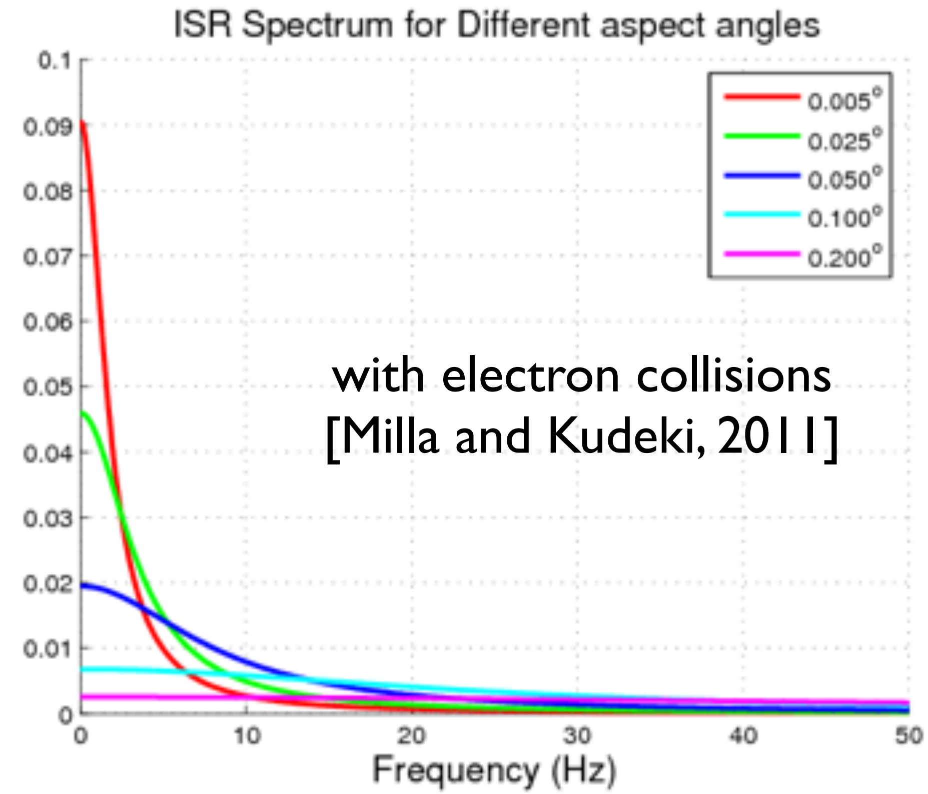
- ACFs are narrow
- 1 ms = 150 km (for monostatic measurements)
- ACFs are very similar to the non-collisional, unmagnetized case.
- ACFs are dominated by the ion dynamics
- Within the pulse (or IPP) estimation is needed to avoid range ambiguity
- Critical angle: α = 0.334° (where ions and electrons behave as they had equal "mass").

Perpendicular

- ACFs are very wide. Coulomb collisions and magnetic field effects need to be considered.
- ACFs dominated by the dynamics of the electrons (electrons behave "heavier" than ions).
- Very quickly gets wider (small α values).
- Due to long correlation times, pulse-to-pulse estimation can be performed, and very accurate vertical and zonal drifts are estimated.

Oblique vs. Perp: Spectra





Oblique

- Spectra are wide (>1000 m/s or 300 Hz at 50 MHz) and independent of α within typical antenna beam widths.

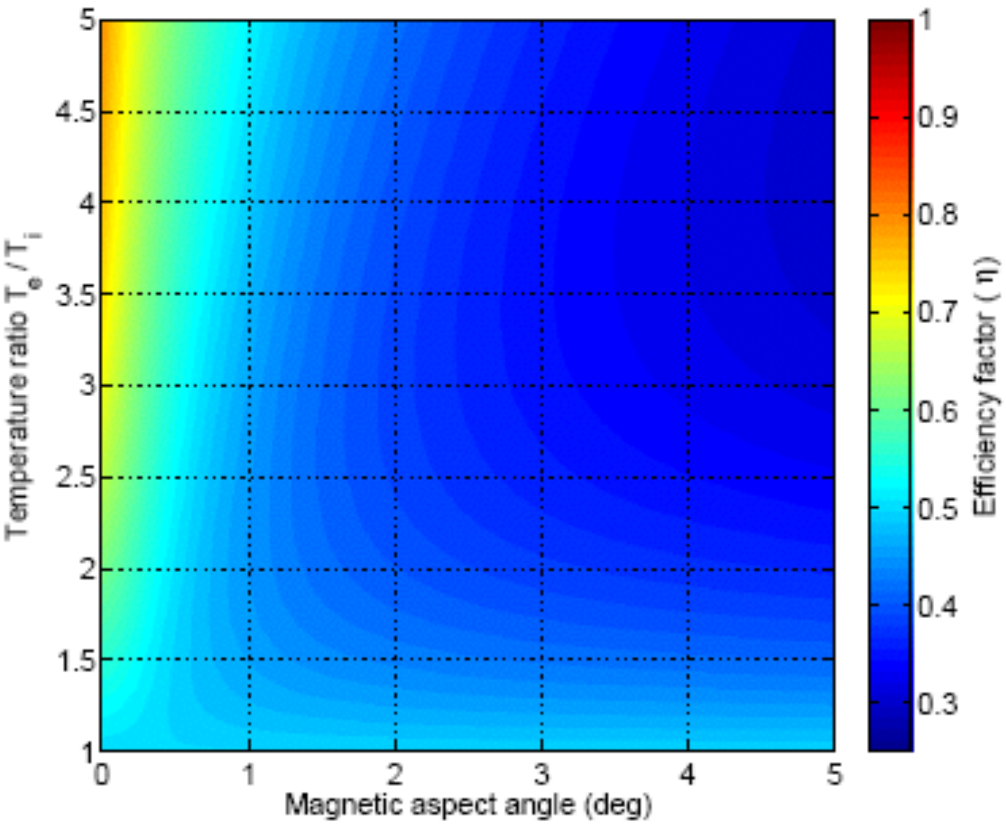
Perpendicular

- Spectra get narrower (less than 150 m/s) for smaller α and change very quickly.
- Measured spectra results from the sum of spectra of different widths due to finite antenna beam width.

Oblique vs. Perp: Power measurements

- Electron density measurements can also be obtained from absolute ISR power measurements.
- However, the absolute ISR power is also highly dependent on the pointing angle with respect to B. In addition, it is dependent on electron to ion temperature ratio (Te/Ti).

$$P_s(h) = K_s N_e(h) \sigma_{ne}(h) / h^2$$

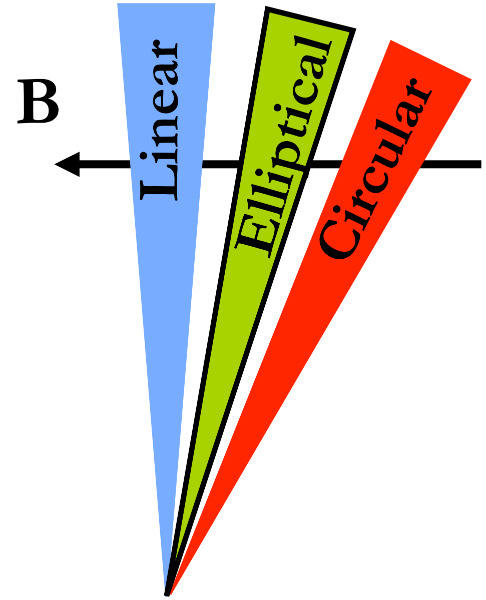


(a)

[from Milla and Kudeki, 2006]

Oblique vs. Perp: Magneto-ionic Propagation

- Faraday "rotation" arises from the difference between the refractive indices of the two characteristic modes of propagation in a magneto-ionic medium.
- At 50 MHz (Jicamarca's frequency, the lowest of all ISRs), significant "rotation" from ionospheric signals is observed.
- Phase difference between these modes of propagation is proportional to the integrated electron density.



$$N_e(h) = K_f d\phi/dh$$

Oblique

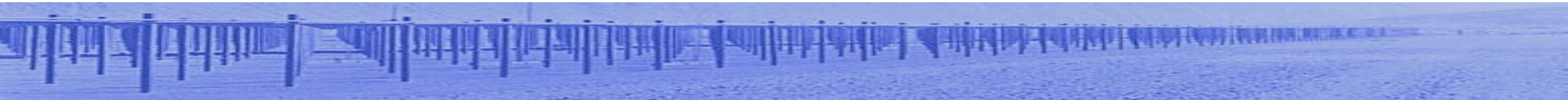
- Quasi-longitudinal approximation is valid for $\alpha > 0.5°$.
- Two-circular polarizations are transmitted and received.
- Small "cross-talk" due to elliptical modes need to be corrected for $\alpha < 2.0°$. We correct for this by flipping every other pulse.

[from Farley, 1969]

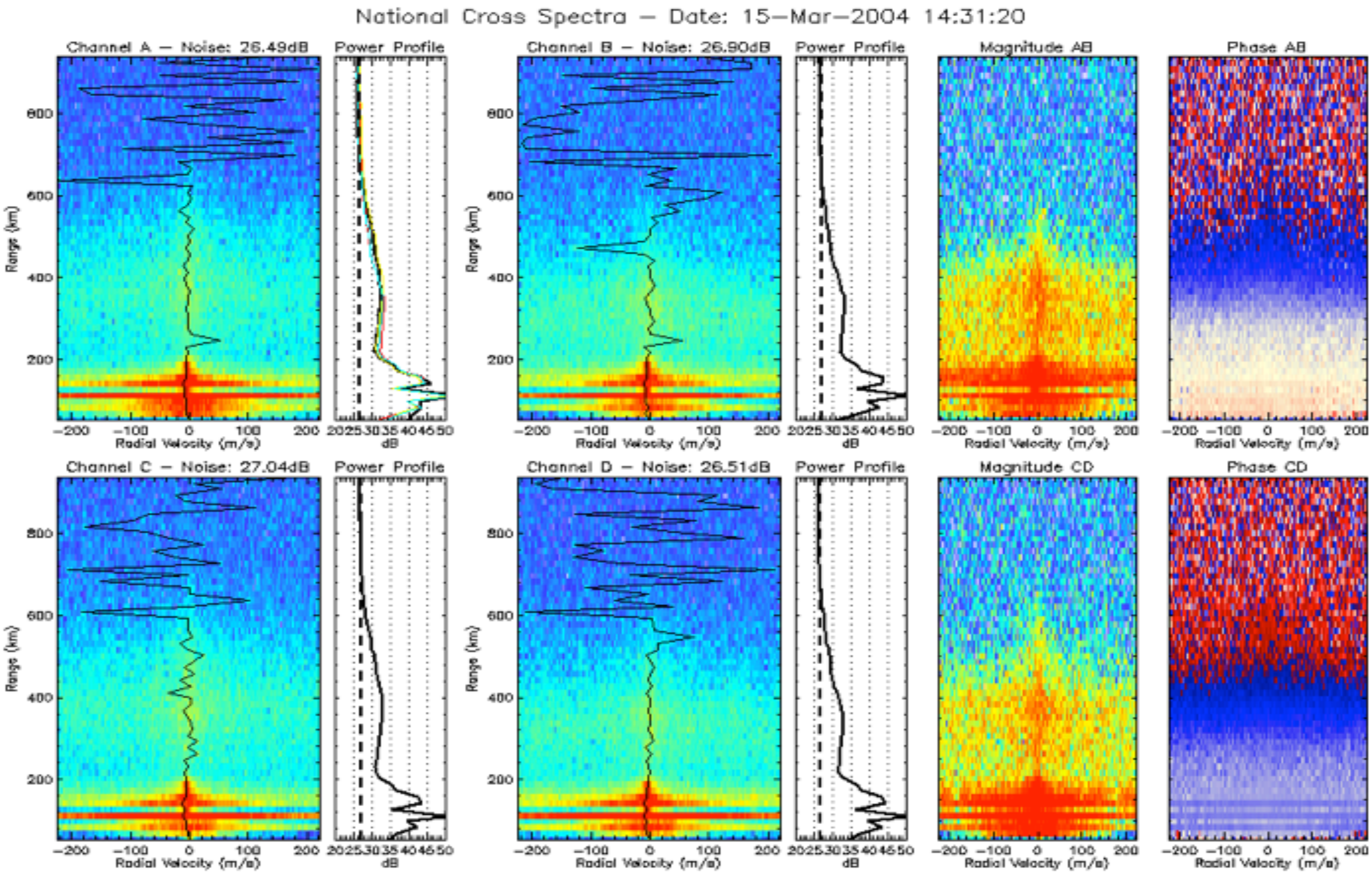
Perpendicular

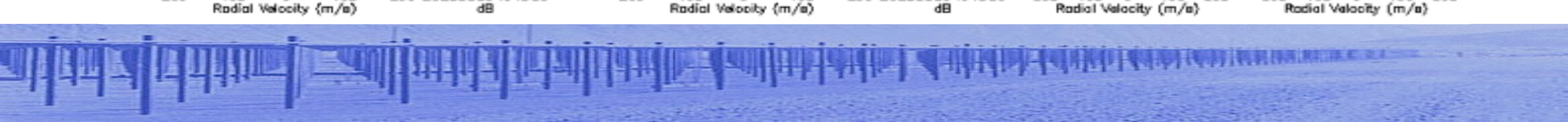
- Quasi-transverse approximation.
- A linear polarization is transmitted to excite both quasi-transverse modes (parallel and perp to B).
- On reception two linear polarizations are received.
- Each linear polarization is an integration of linear and highly elliptical modes due to the finite beam width.

[from Kudeki et al., 2003]

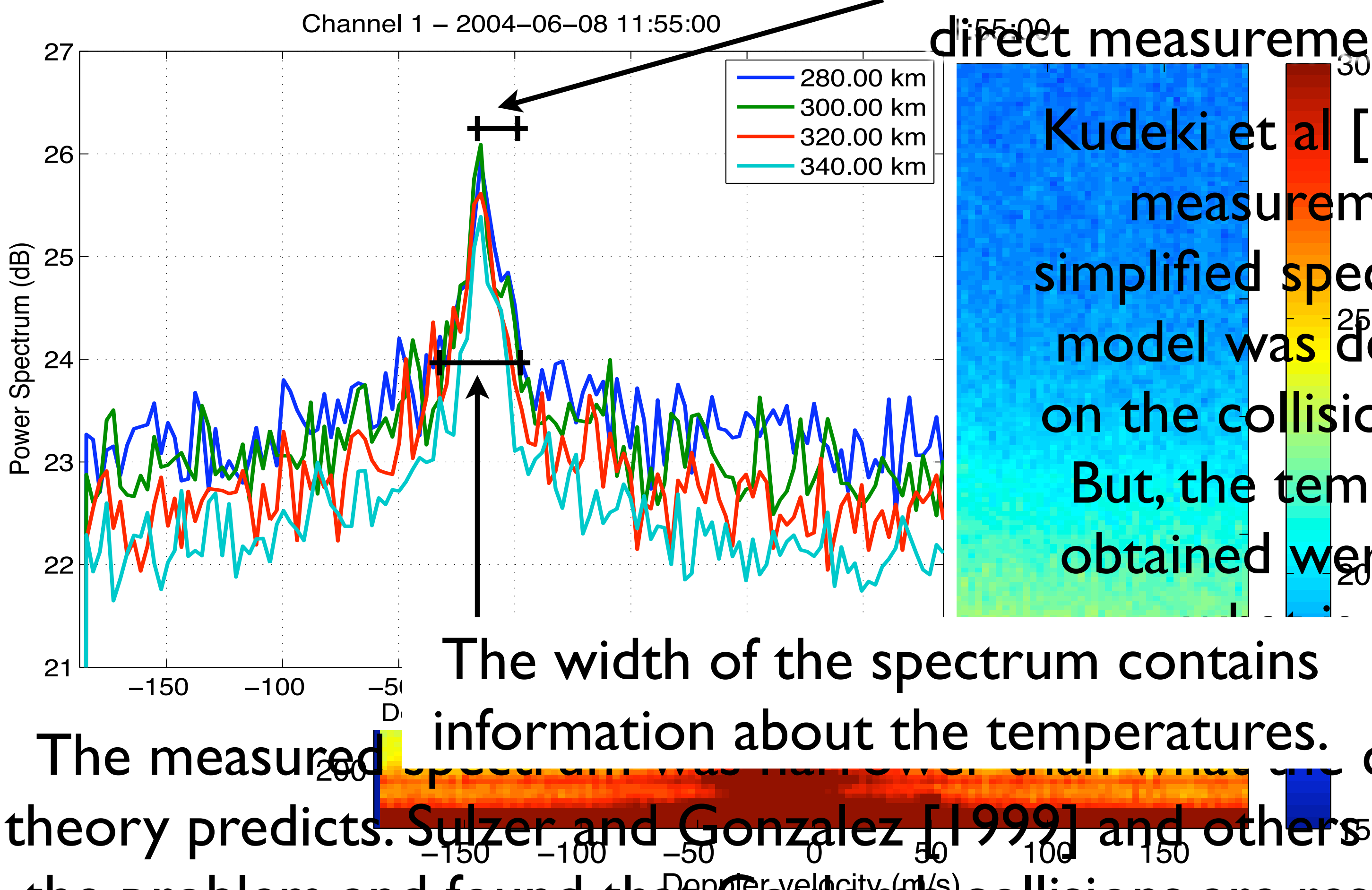


P2B Examples: Pulse-to-Pulse Spectra





Jicamarca ISR spectrum perp. to B



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

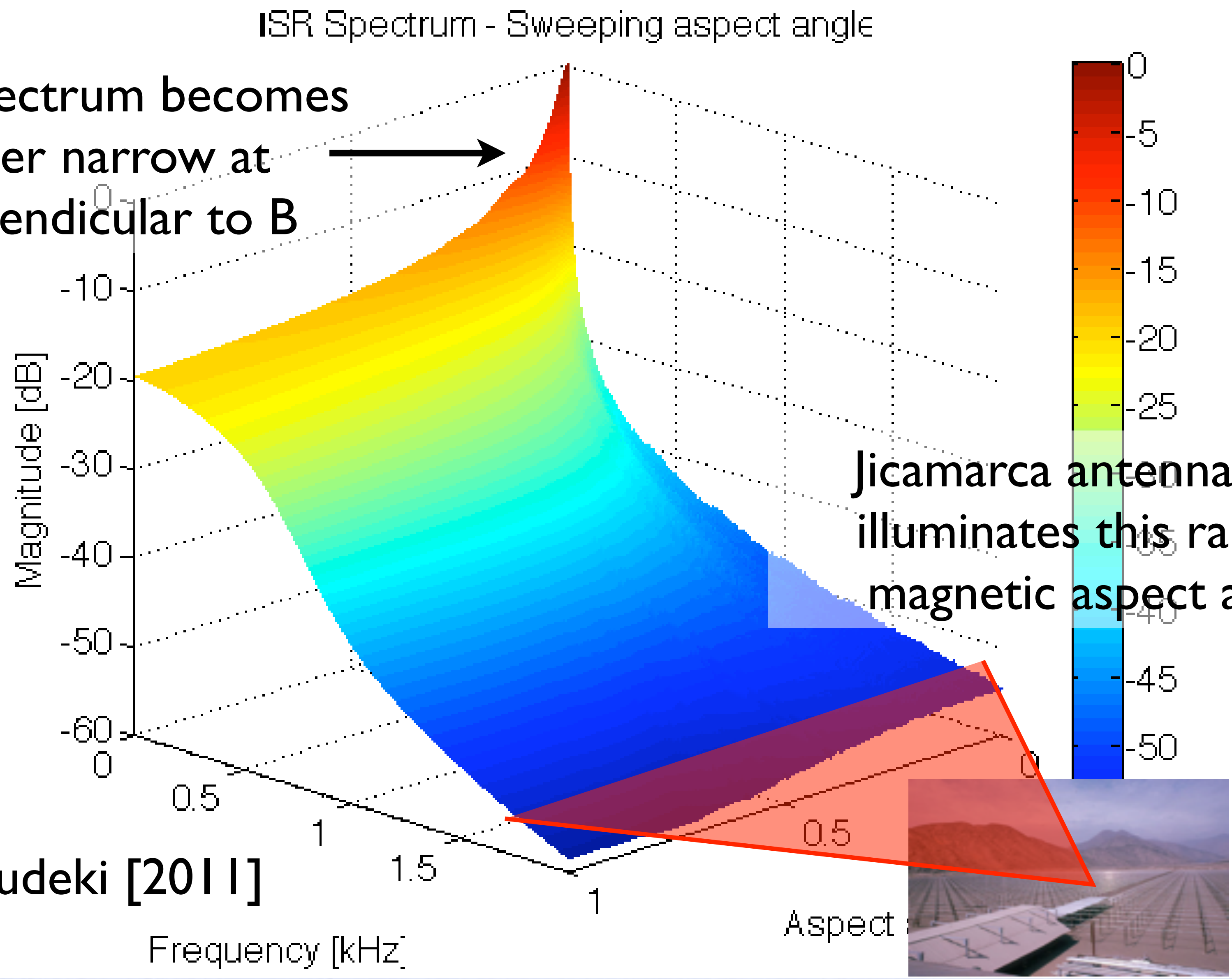
Kudeki et al [1999] fitted the measurements using a simplified spectral model. This model was developed based on the collisionless IS theory. But, the temperatures they obtained were about half of what is expected.

The width of the spectrum contains information about the temperatures.

The measured spectrum was narrower than what the collisionless theory predicts. Sulzer and Gonzalez [1999] and others have studied the problem and found that Coulomb collisions are responsible for having spectrum measurements narrower than expected.

Collisional IS Spectrum

The spectrum becomes super narrow at perpendicular to B



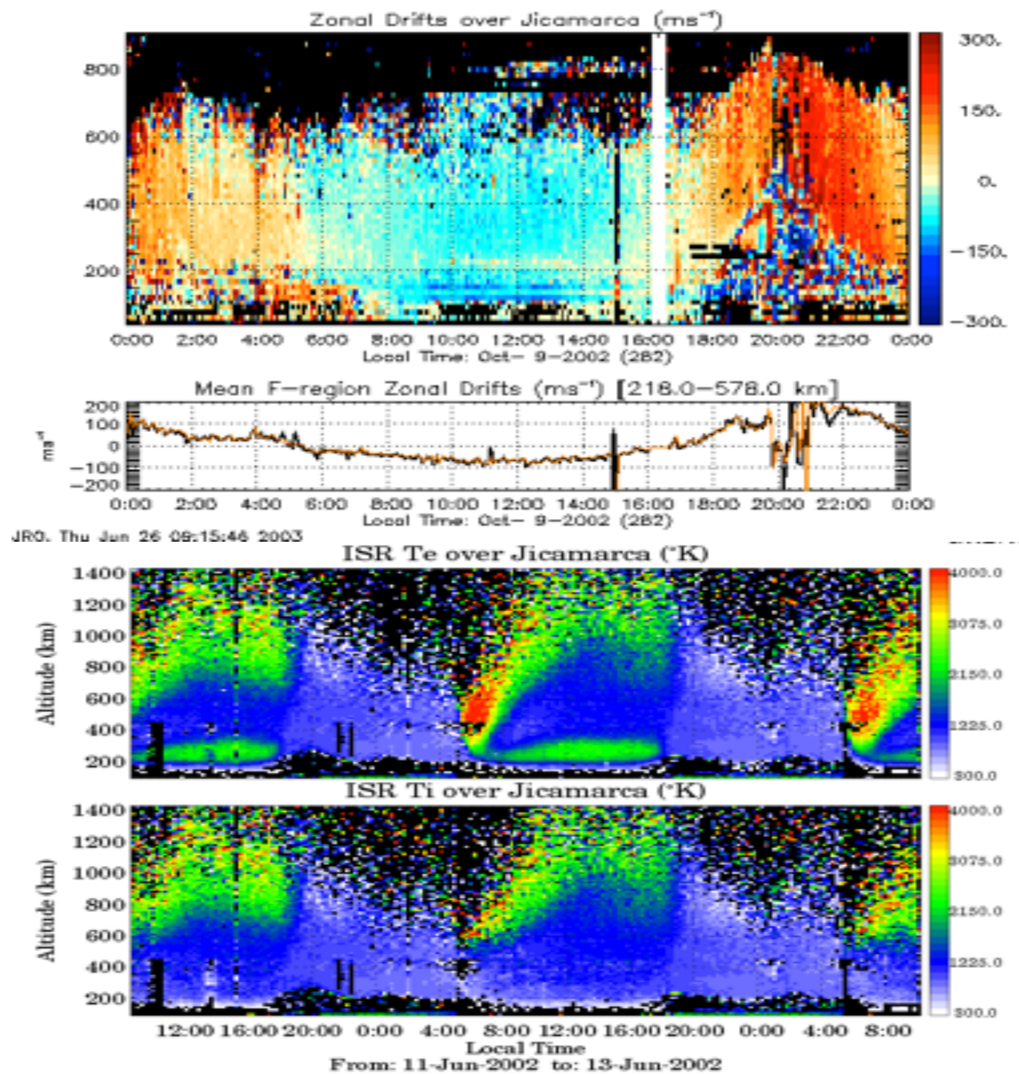
Jicamarca antenna beam illuminates this range of magnetic aspect angles

Milla & Kudeki [2011]

Incoherent Scatter radar modes at JRO

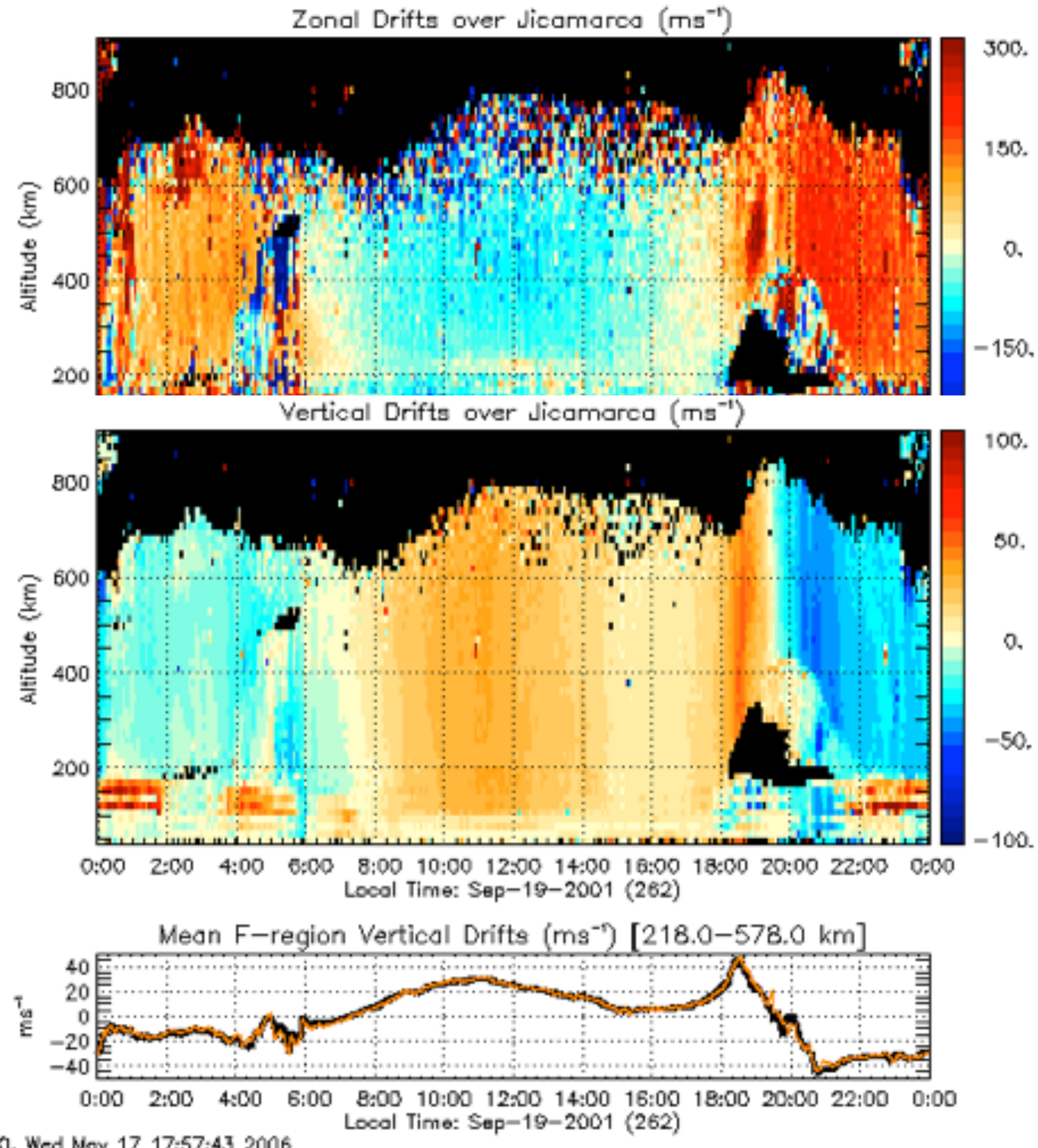
- Perpendicular to the magnetic field.
  - EW Drifts
  - Differential Phase

- Oblique to the magnetic field
  - Faraday / Double Pulse
  - Hybrid AC-Faraday



P2B Examples: Vertical and Zonal drifts

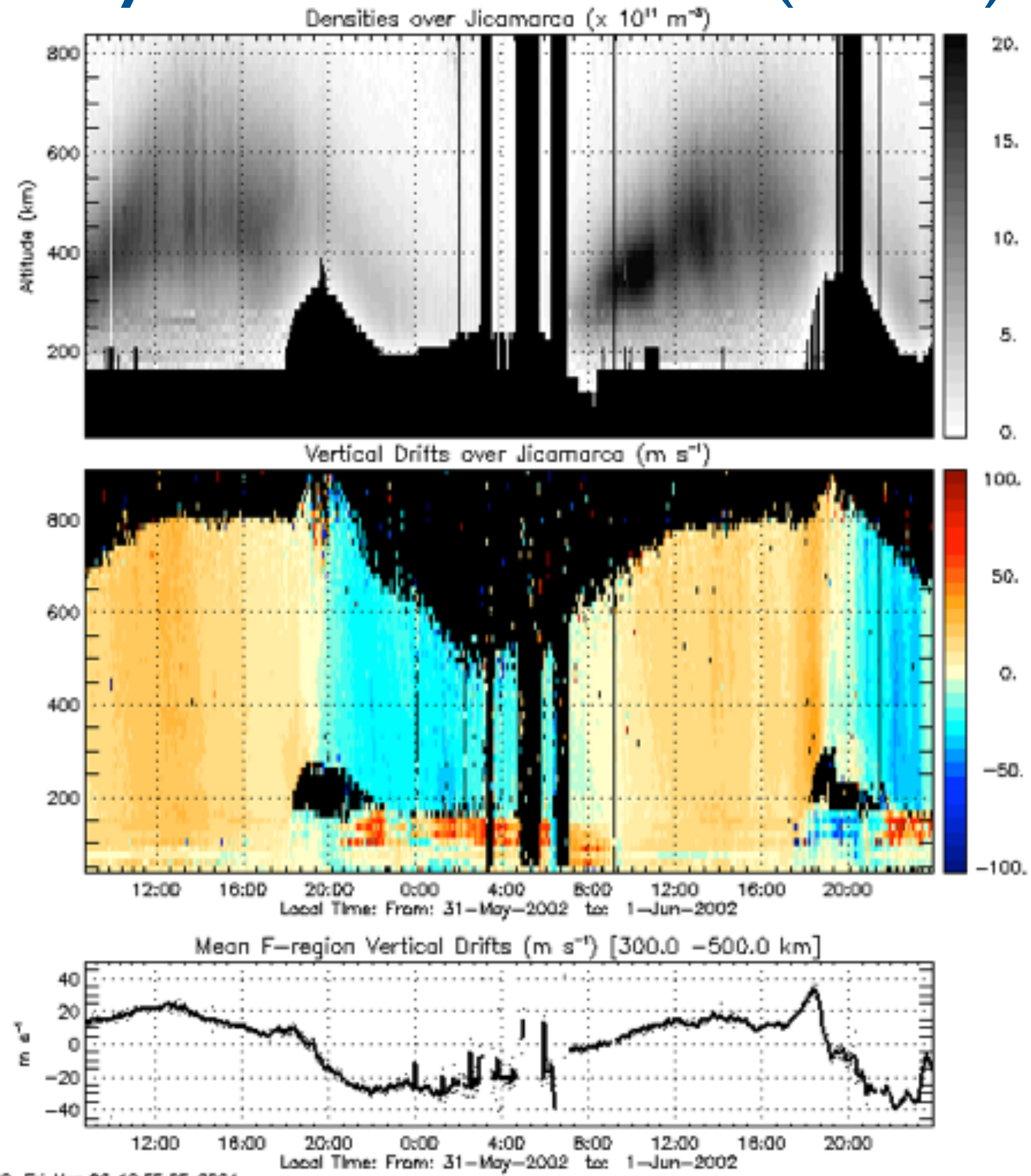
- Simultaneous measurements of vertical and zonal drifts, with 15 km and 5 min resolutions.
- JRO provides the most precise electric field measurements of the ionosphere.



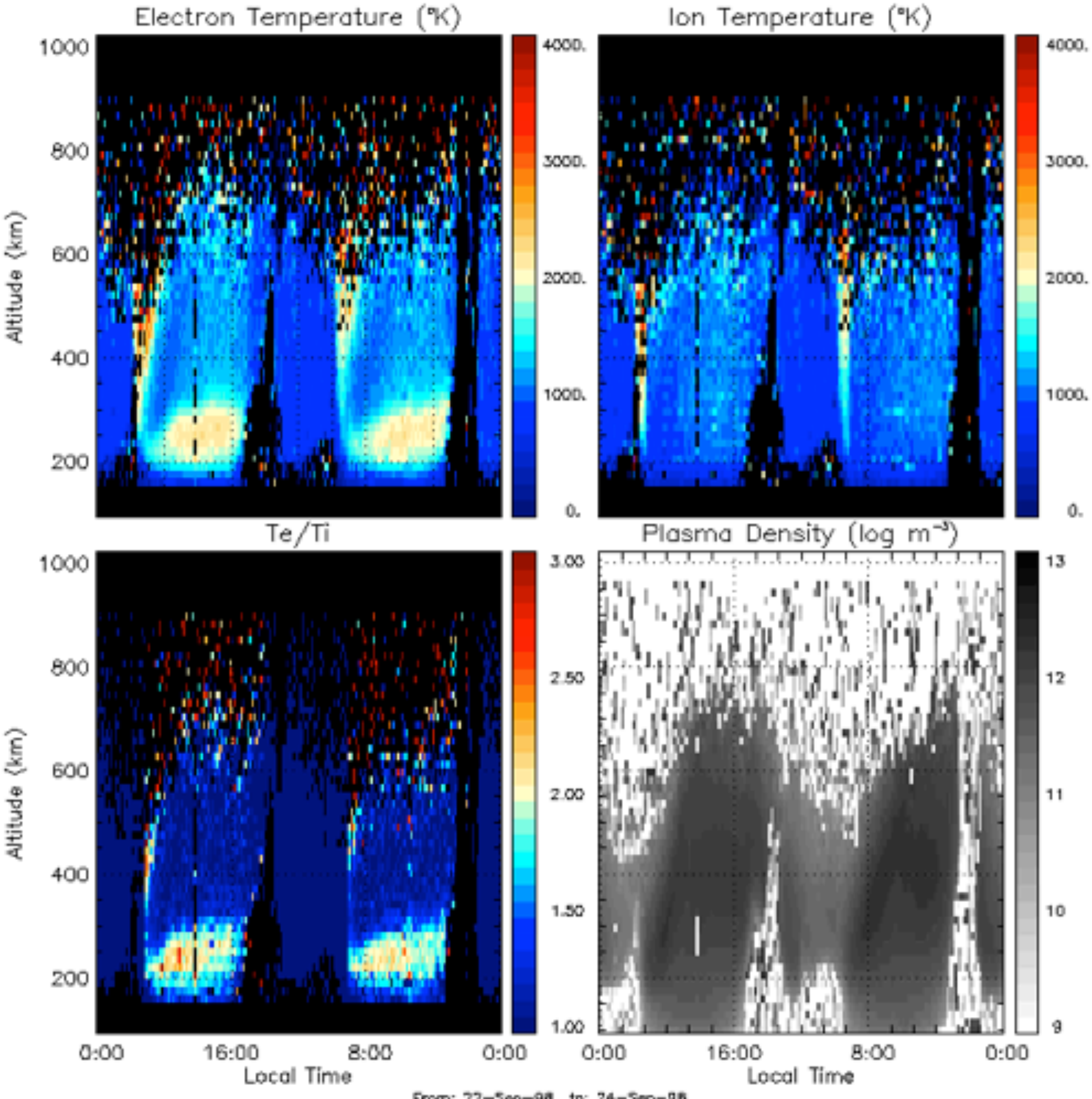
P2B Examples: Density & Vertical Drift (DVD)

- Simultaneous measurements of vertical drifts and densities.
- Densities are obtained from the differential phase of the normal modes of propagation.
- A new mode have been tested, combining East-West beams with differential phase measurements (3Beam).

[Kudeki et al.,2003]
[Feng et al., 2004]



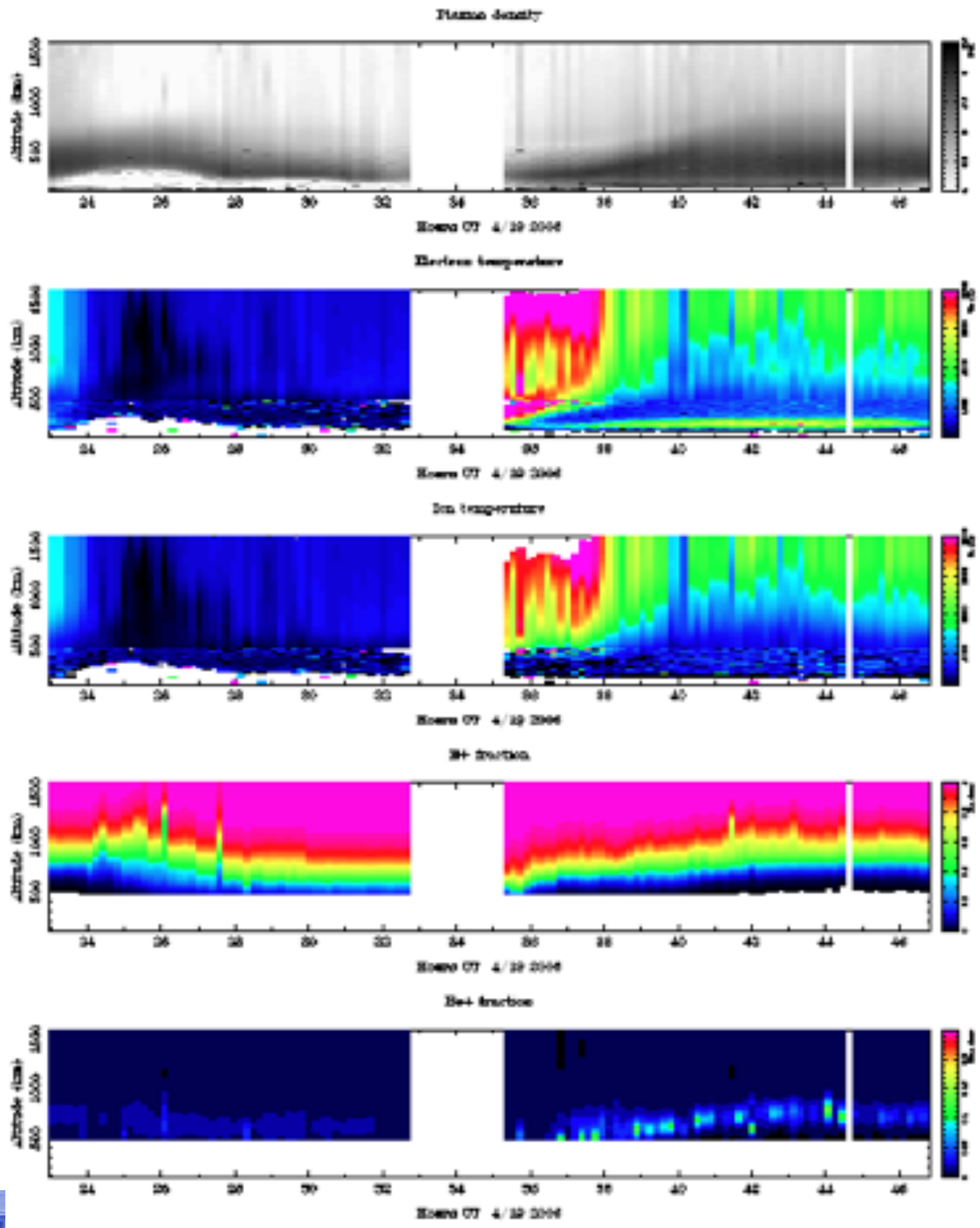
Oblique Examples: Faraday Double Pulse



- This is the traditional mode (since 1960's) to get:
  - Densities from Faraday rotation and power.
  - Temperatures and Composition from ACFs obtained with Double Pulse sequences.
- This mode doesn't use the available duty cycle.
- Composition is hardly obtained.
- After Sulzer & Gonzalez [1999] work, temperatures estimates have been improved and the data reanalyzed since 1996.
- e.g., This mode is ideal for studying the Midnight temperature maximum (MTM).

[Farley, 1969]

Oblique Examples: Hybrid Faraday DP+Long Pulse



- This mode combines the Faraday DP mode with a long pulse mode, maximizing the use of available duty cycle.
- The altitudinal coverage is better than the previous mode at the expense of less altitudinal resolution in the topside.
- Similarly, it provides:
  - Density and temperatures below 500 km
  - Density, temperatures and composition above 500 km.

[Hysell et al., 2008]

Can we combine oblique and perpendicular radar modes and get the best of each of them?

Sure, but wait for the presentations in the afternoon.