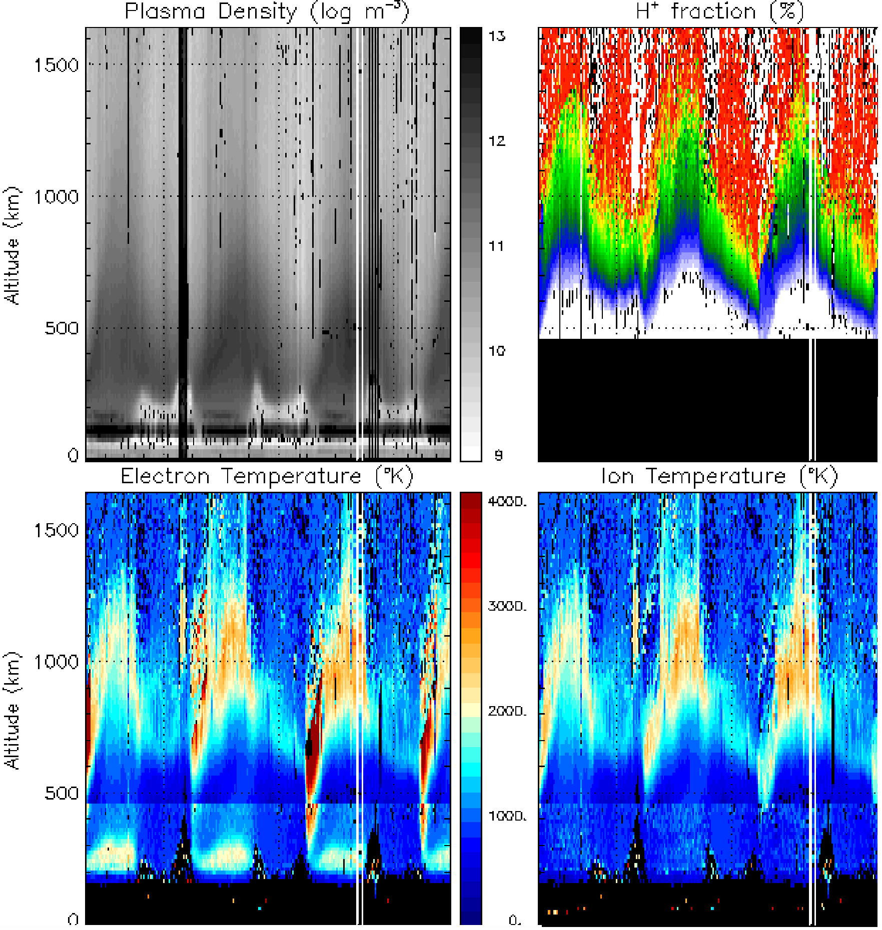

ISR Coordinated Science at Equatorial Latitudes

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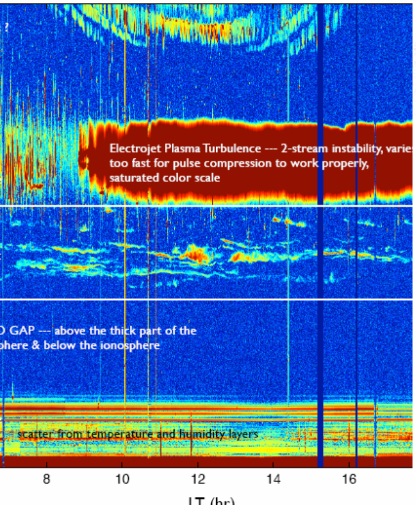
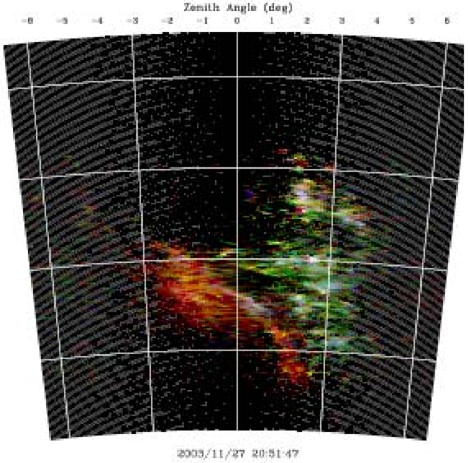
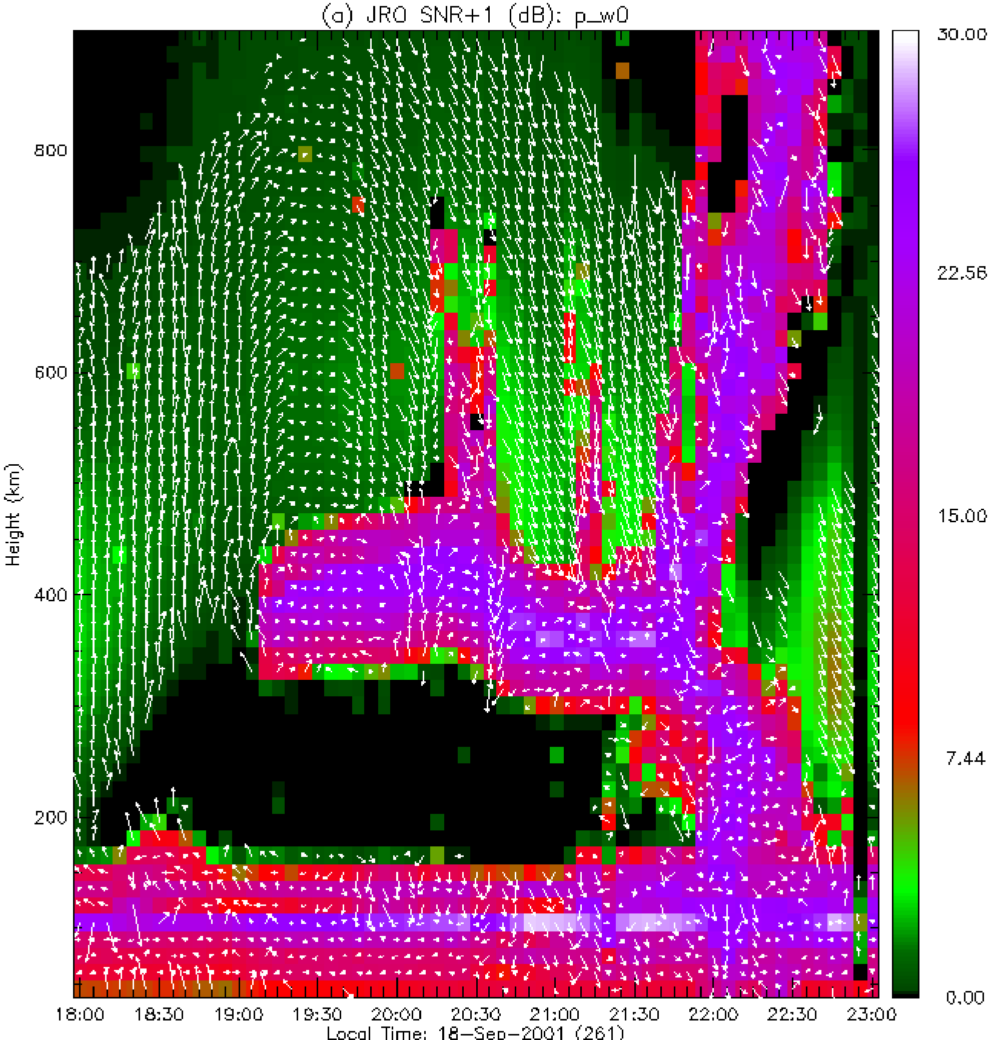




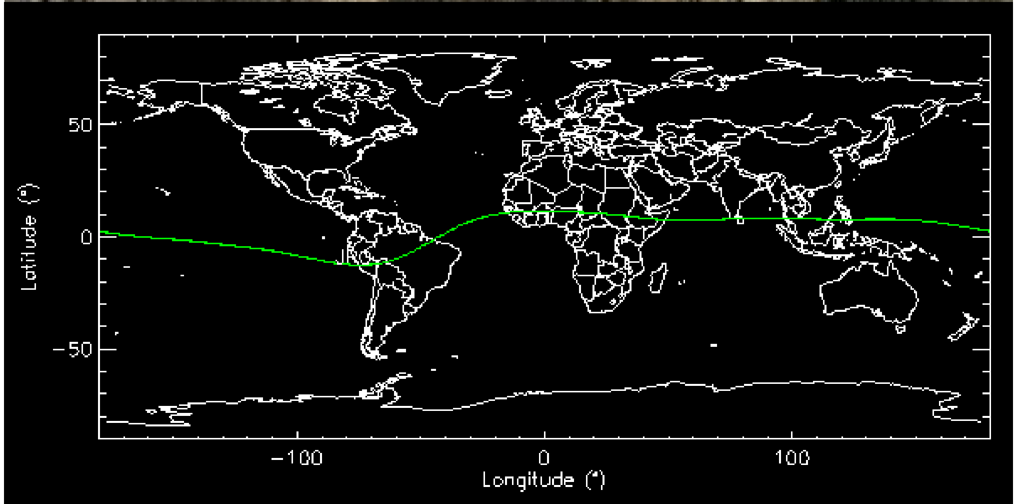


Outline

- Introduction
- JRO Research Themes and Mission
- ISR Modes at Jicamarca: Oblique vs. Perpendicular
- Coherent Scatter Echoes and Their Implications for ISR Modes
- ISR Examples
- Limitations of Jicamarca ISR Modes
- Examples of Coordinated Science at Jicamarca

The Jicamarca Radio Observatory

- Operating frequency: 50 MHz
- Antenna type: array of 18,432 dipoles, organized in 8x8 cross-polarized modules.
- Pointing directions: within 3 degrees from on-axis. Phase changes are currently done manually.
- Transmitters: 3 x 1.5 MW pea-power with 5% duty cycle.
- Located "under" the magnetic equator (dip 1^{o}).



JRO Themes 2004-2009 (1)

- **Understanding the stable ionosphere**
  - Topside: What controls the light ion distribution? Why are the equatorial profiles so different from those at Arecibo? What is the storm time response of the topside?
  - *F* region: Do current theories fully explain electron and ion thermal balance? Do we understand the electron collision effects on ISR theory now? What is the effect of *F*-region dynamics near sunset on the generation of ESF plumes? What are the effects of N-S winds on inter-hemispheric transport?
  - *E* region: What are the basic background parameters in the equatorial *E* region? What is the morphology of the density profiles in this difficult to probe region? How does this morphology affect the *E*-region dynamo?
  - *D* region: What effects do meteor ablation and mesospheric mixing have on the composition in this region?

JRO Themes 2004-2009 (2)

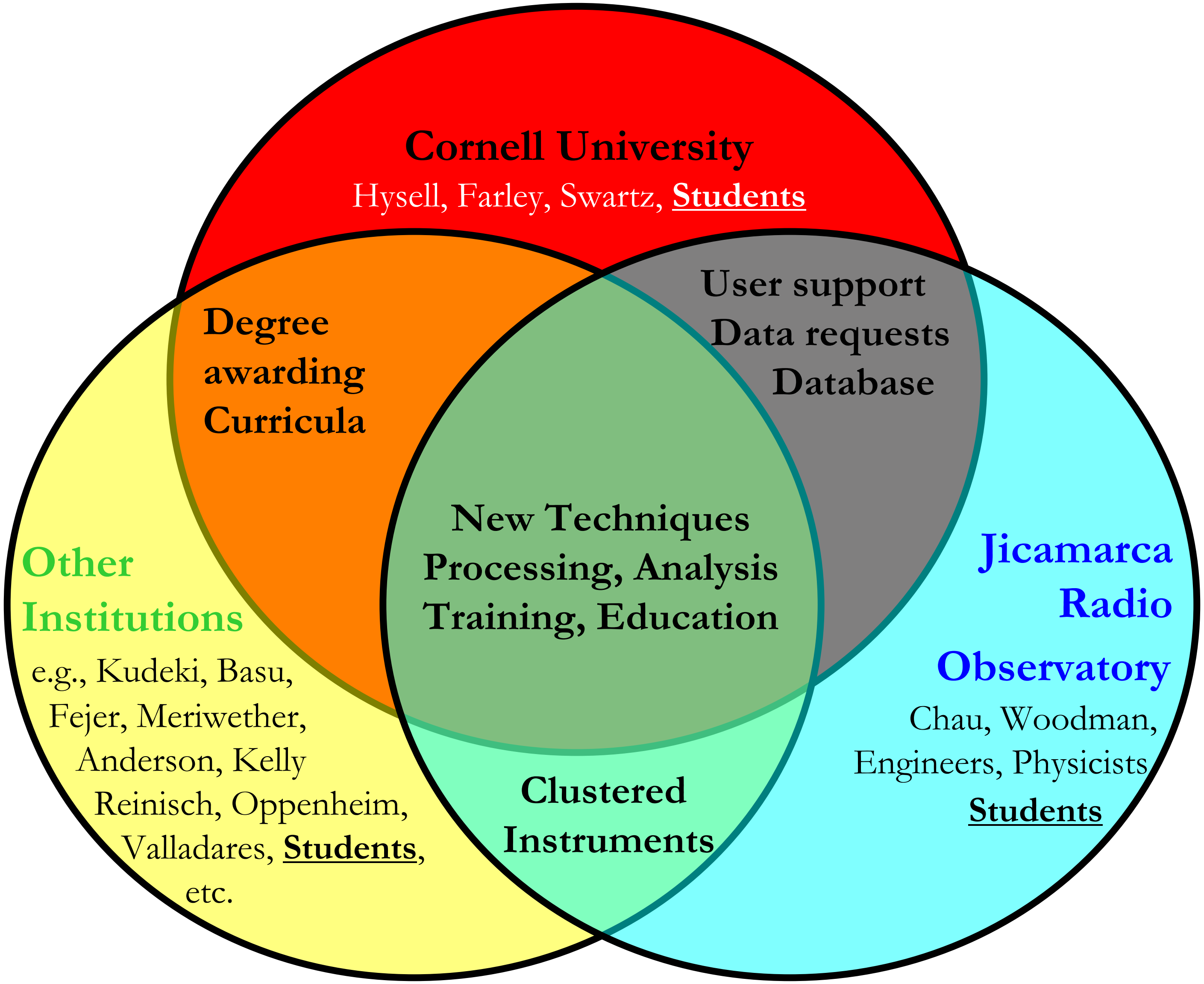
- **Understanding equatorial instabilities**
  - *F* region: What are the fundamental plasma processes, including nonlinear processes, that govern the generation of plasma plumes? What are the precursor phenomena in the late afternoon *F* region that control whether or not an *F*-region plume will be generated after sunset?
  - Daytime Valley echoes (or so-called 150-km echoes). What are the physical mechanisms causing them? (still a puzzle after more than 40 years!).
  - *E* region: What are the nonlinear plasma physics processes that control the final state of the electrojet instabilities? To what extent do these instabilities affect the conductivity of the *E* region, and by extension, the conductivity of the auroral zone *E* region, where similar, but stronger and more complicated, instabilities exist?

JRO Mission

The Jicamarca Radio Observatory exists today with the goals of:

- deepening our understanding of the equatorial and low-latitude atmosphere and ionosphere and the systems to which they are coupled
- fostering the creation of avant-garde radar and radio remote sensing techniques
- training and educating new generations of space physicists and radio scientists and technicians
- expanding its own capabilities through upgrade and invention
- increasing its influence internationally

Student Participation at JRO



Cornell University
Hysell, Farley, Swartz, **Students**

Degree awarding Curricula

User support
Data requests
Database

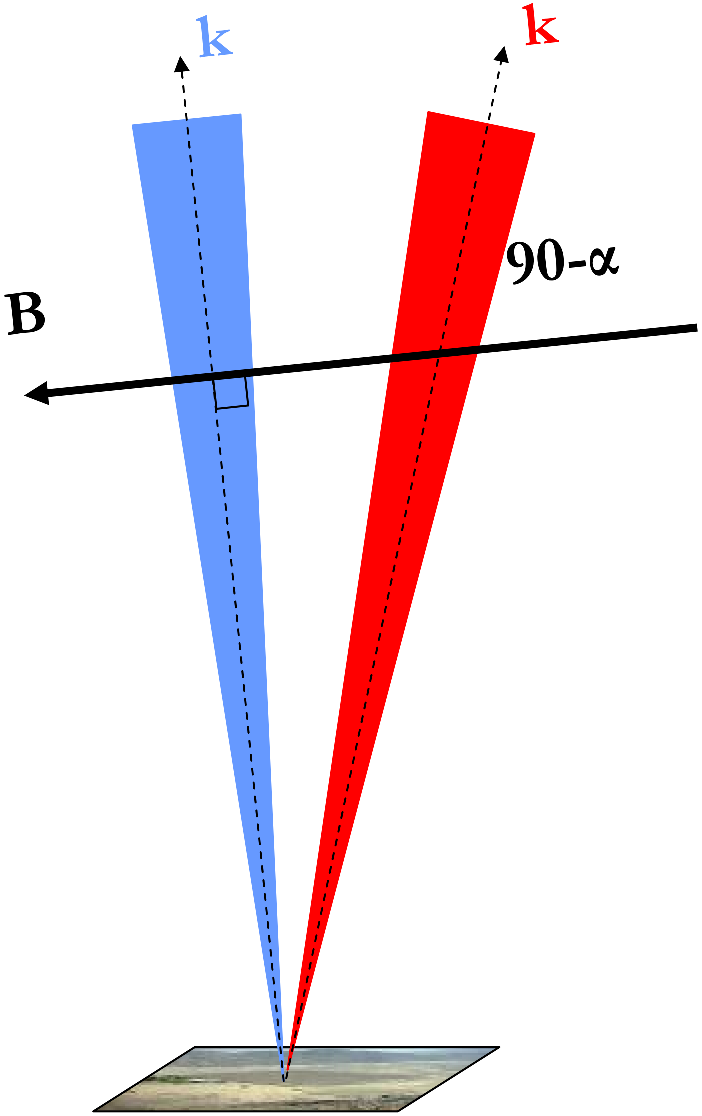
New Techniques
Processing, Analysis
Training, Education

Other Institutions
e.g., Kudeki, Basu, Fejer, Meriwether, Anderson, Kelly Reinisch, Oppenheim, Valladares, **Students**, etc.

Clustered Instruments

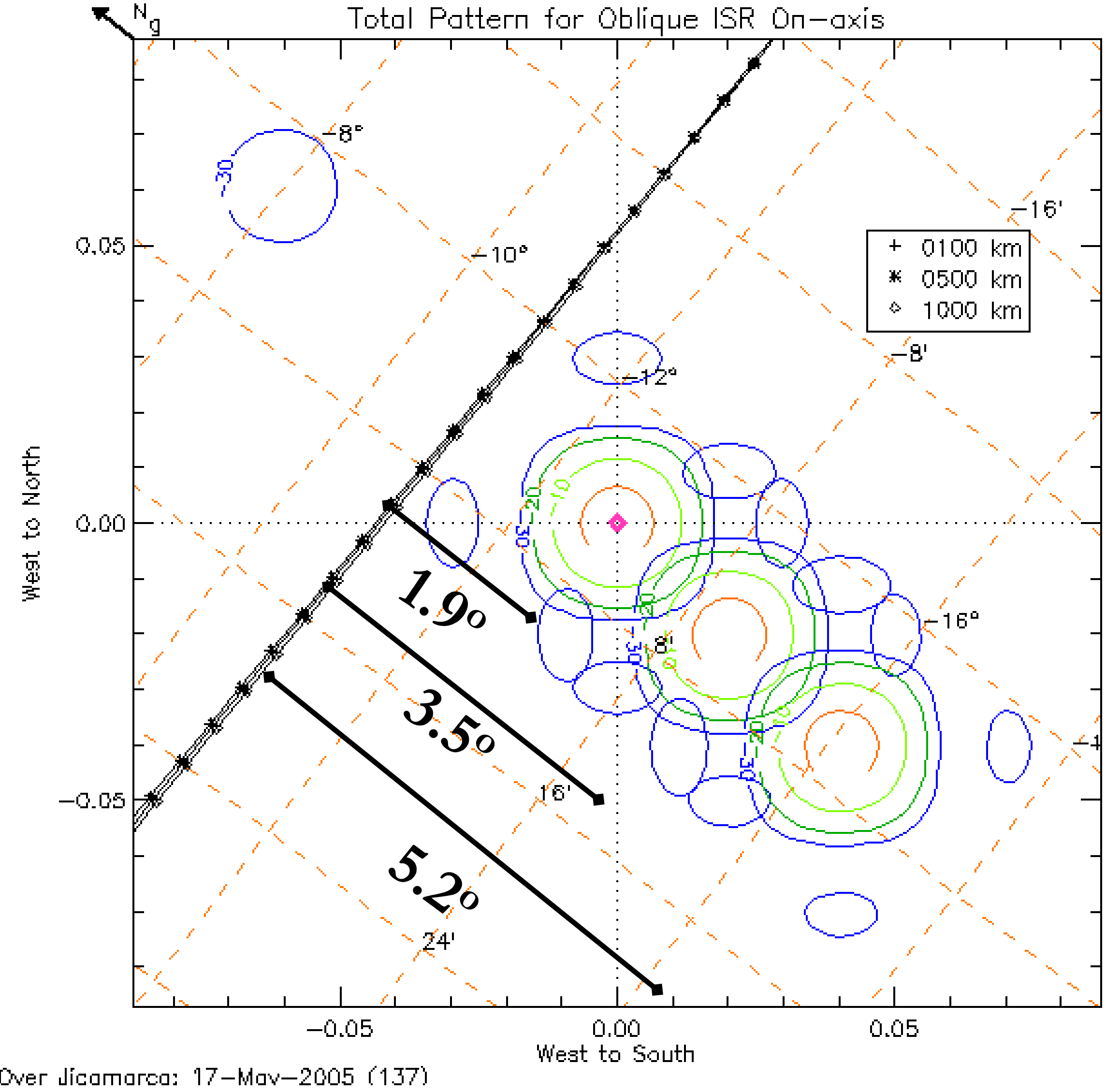
Jicamarca Radio Observatory
Chau, Woodman, Engineers, Physicists
Students

Oblique vs. Perpendicular ISR: Geometry



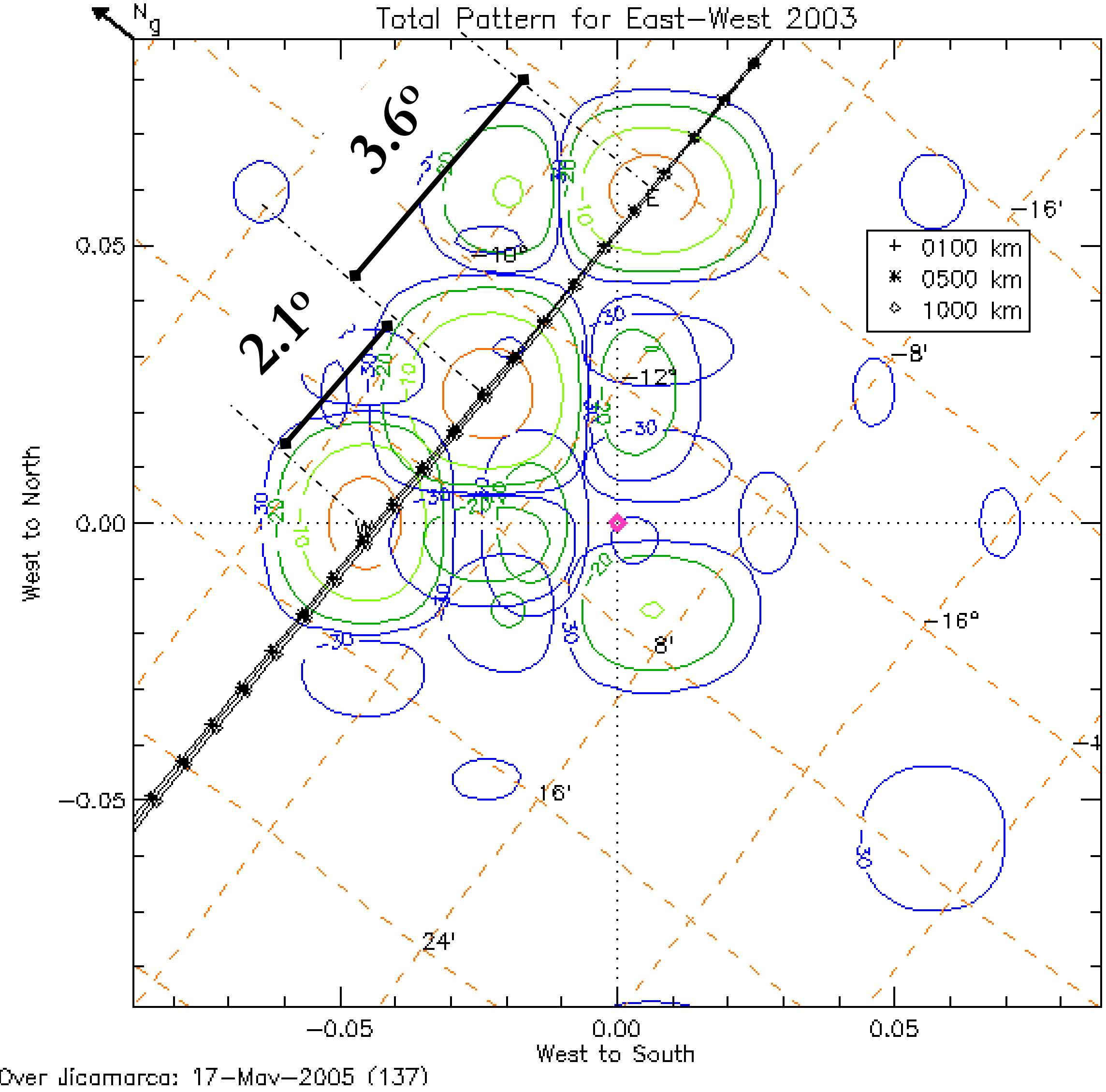
- Depending on α:
  - Oblique: $\alpha > 0$
  - Perpendicular: $\alpha = 0$
- What is the α boundary between modes?
- What are the antenna patterns used?
- What are the differences on ACFs and spectra between modes?
- How is the polarization of returned signals?
- How are the modes affected by coherent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

Oblique ISR: Antenna Patterns



- Three standard beam positions are used:
  - On-axis (α = 1.9°)
  - "4.5" (α = 3.5°)
  - "6.0" (α = 5.2°)
- 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 convolved with the antenna pattern.

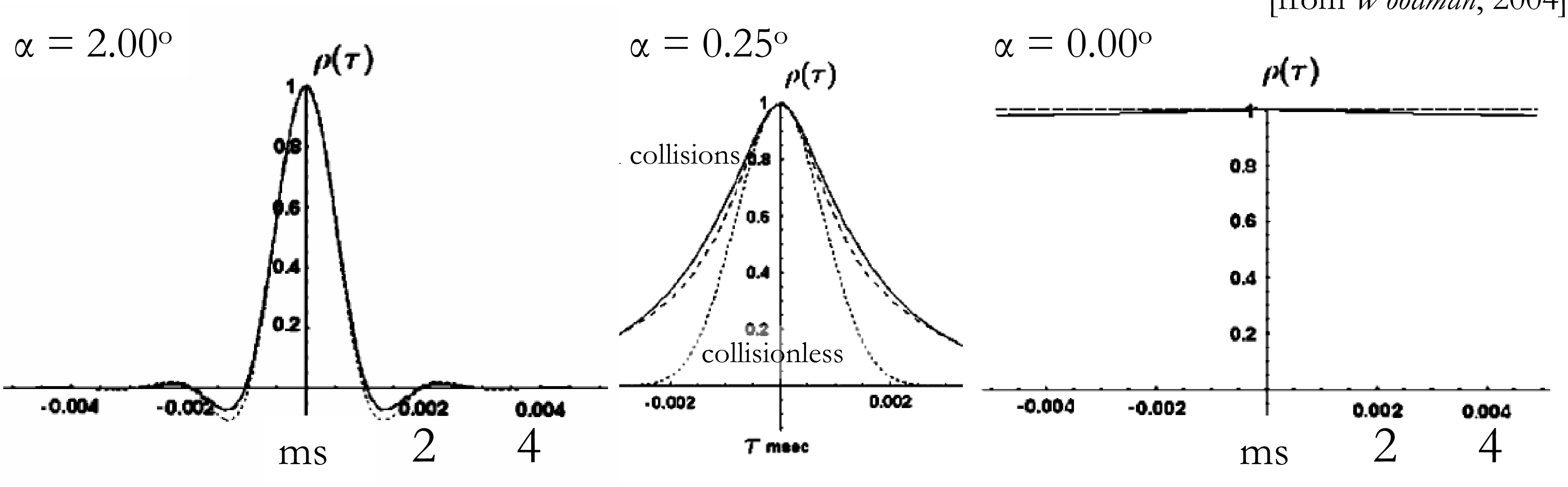
Perpendicular ISR: Antenna Patterns



- 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".
- 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 convolved with the antenna pattern.

Oblique vs. Perpendicular: ACFs

[from *Woodman*, 2004]



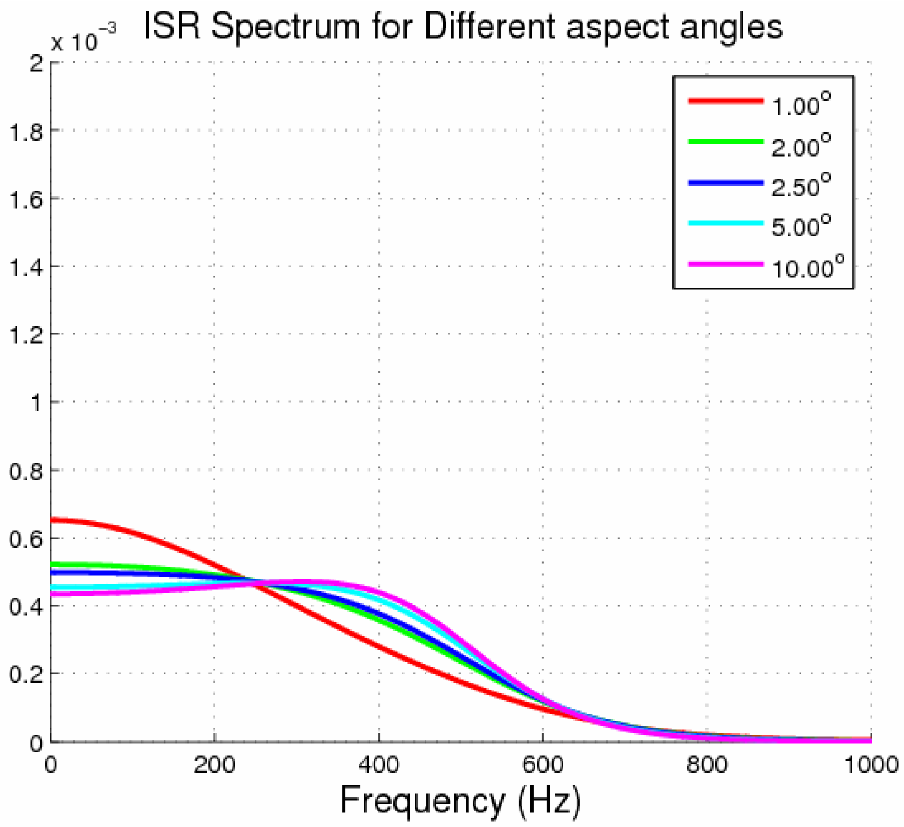
<u>Oblique</u>

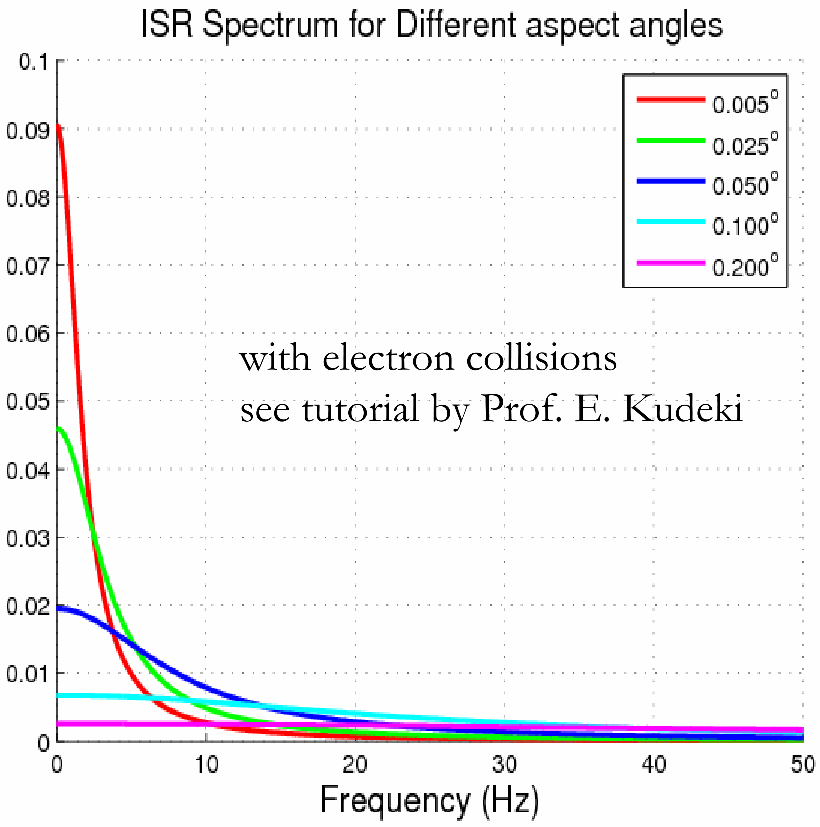
- ACFs are narrow
- 1 ms = 150 km (for monostatic measurements)
- ACFs are very similar to the non-collisional, unmagnetized case seen in previous talks.
- ACFs are dominated by the dynamics of the ions
- Within the pulse (or IPP) estimation is needed to avoid range ambiguity
- Critical angle: α = 0.334°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

<u>Perpendicular</u>

- 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. Perpendicular: Spectra





with electron collisions
see tutorial by Prof. E. Kudeki

Oblique

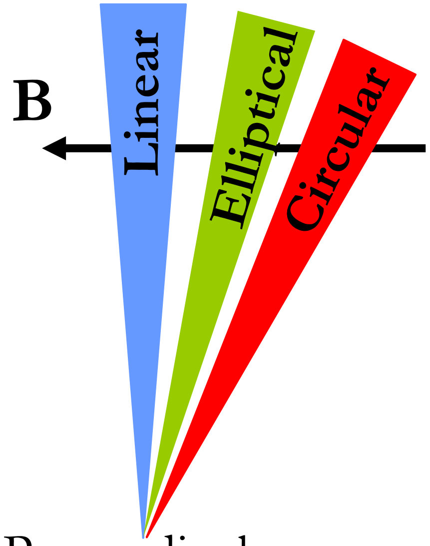
- Spectra are wide (>1000 m/s or 300 Hz at 50 MHz) and independent of α within typical antenna beam widths.

Perpendicular

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

Oblique vs. Perpendicular: Faraday Rotation

- Faraday "rotation" arises from the difference between the indices of refraction corresponding to the two characteristic modes of a magnetoionic medium.
- Phase difference between these modes of propagation is proportional to the integrated electron density.
- Given Jicamarca's 50 MHz frequency (the lowest of all ISRs), significant "rotation" from ionospheric signals is observed and from this absolute electron densities are obtained.



Oblique

- Quasi-longitudinal approximation is valid for $\alpha > 0.4^o$.
- Two-circular polarizations are transmitted and received.
- Small "cross-talk" due to elliptical modes need to be corrected for $\alpha < 2.0^o$ We do this correction by flipping every other pulse.

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

[from *Farley*, 1969]

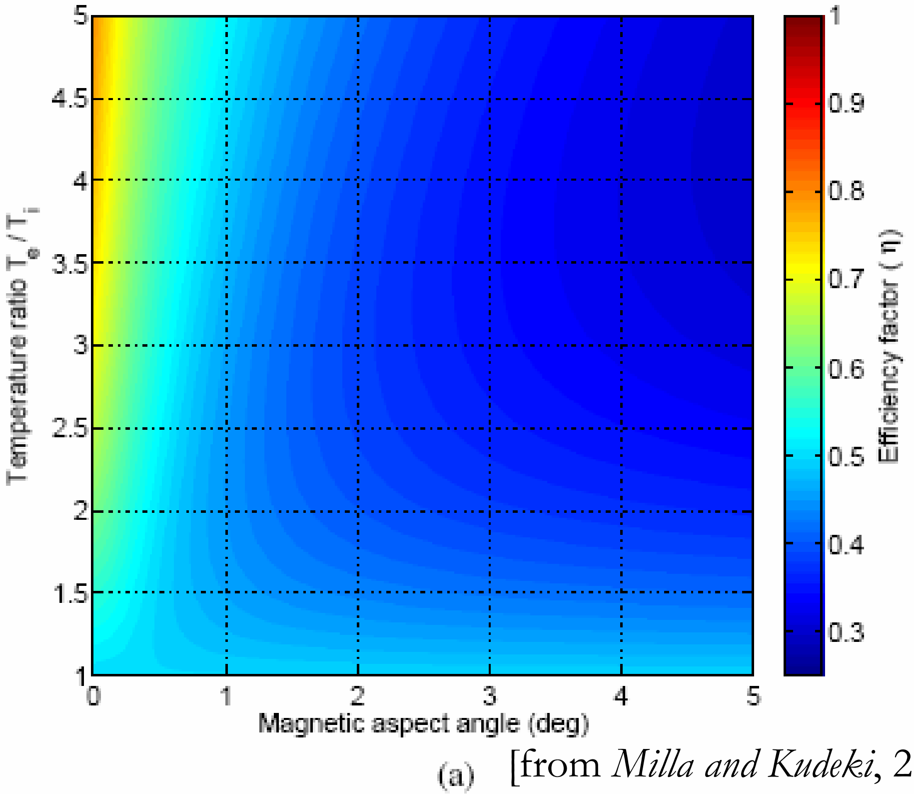
Perpendicular

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

[from *Kudeki et al.*, 2003]

Oblique vs. Perpendicular: 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). See specific details in the talk by Prof. Erhan Kudeki later this week.

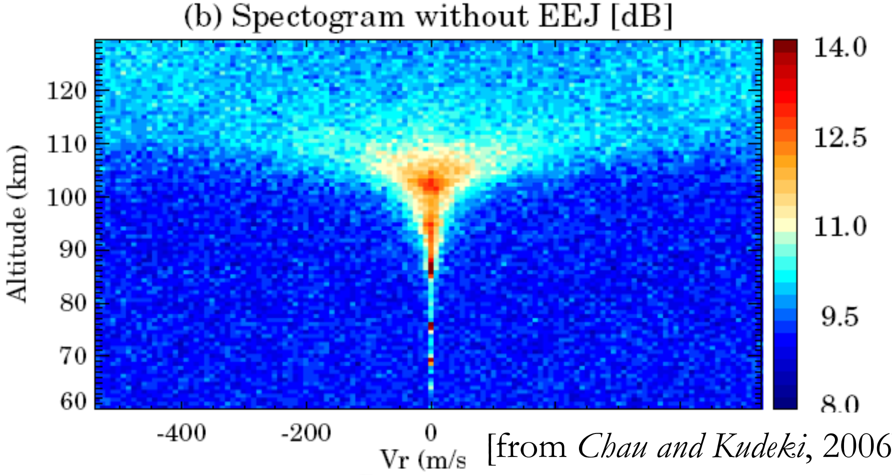


[from *Milla and Kudeki*, 2006]

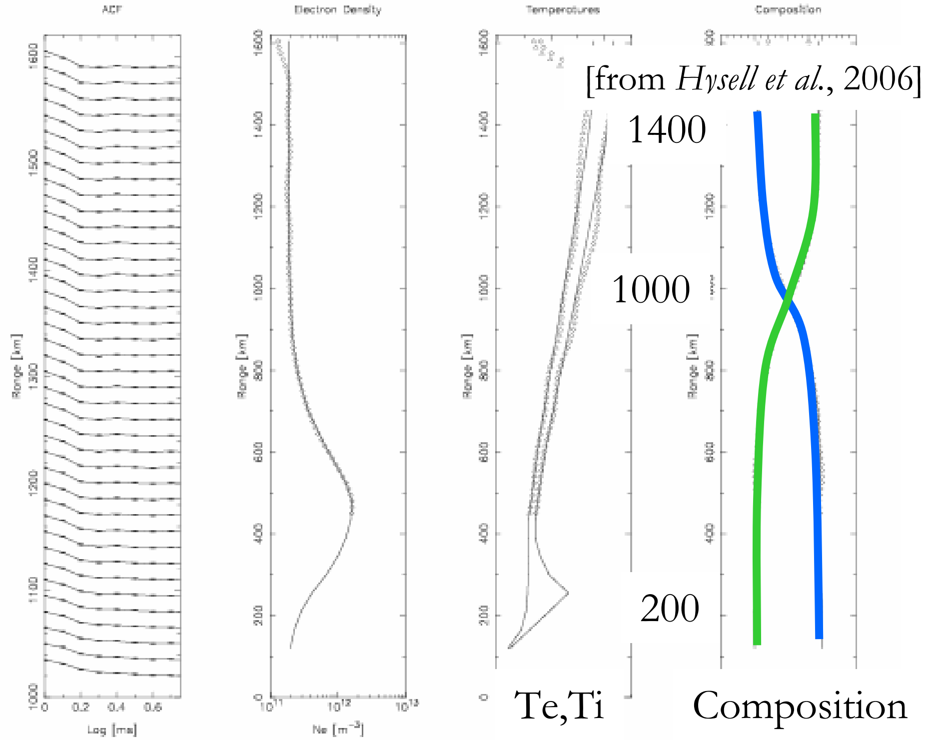
$$P_s(h) = K_s N_e(h) \sigma_{ne}(h) / h^2$$

Oblique vs. Perpendicular: Altitude issues

- Depending on the altitude of interest, collisions, temperatures and different ion composition, are the main parameters that changed the ISR spectrum shape. This is particularly true for Oblique measurements.
- Perpendicular spectra show very little, or none, dependence on these parameters.
- For example:
  - at *E* and *D* region altitudes, collisions with neutrals are important, the spectrum gets narrower as the altitude decreases.
  - At valley altitudes, in addition to typical [O^+], [NO^+] and [O_2^+] need to be considered [see *Nicolls et al.*]
  - At topside altitudes, more ion species are present [O^+],[H^+] and [He^+] [see *Rodrigues et al.*]



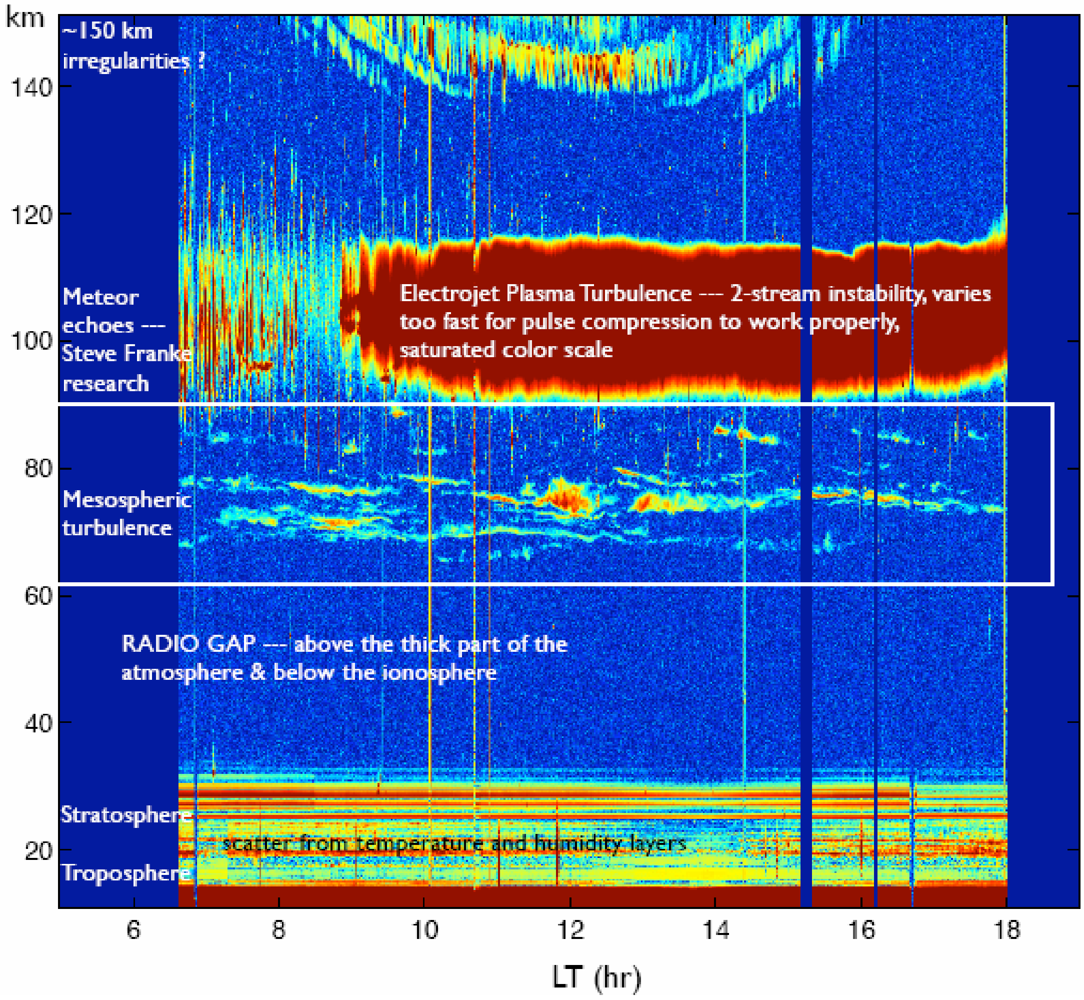
[from *Chau and Kudeki*, 2006]



[from *Hysell et al.*, 2006]

Coherent scatter echoes over Jicamarca (1)

- Field-aligned irregularities
  - EEJ
  - Non-specular meteor trails (short-lived EEJs)
  - Valley echoes
  - ESF
- Meteor head echoes
- Atmospheric echoes
- Mountains
- Satellites
- Moon



~150 km irregularities ?

Meteor echoes --- Steve Franke research

Electrojet Plasma Turbulence --- 2-stream instability, varies too fast for pulse compression to work properly, saturated color scale

Mesospheric turbulence

RADIO GAP --- above the thick part of the atmosphere & below the ionosphere

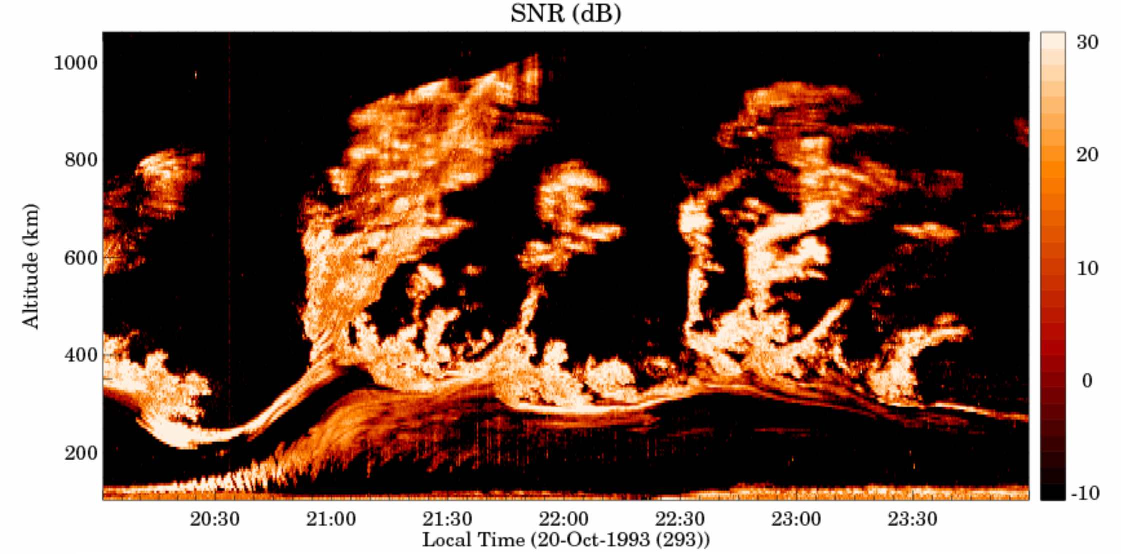
Stratosphere

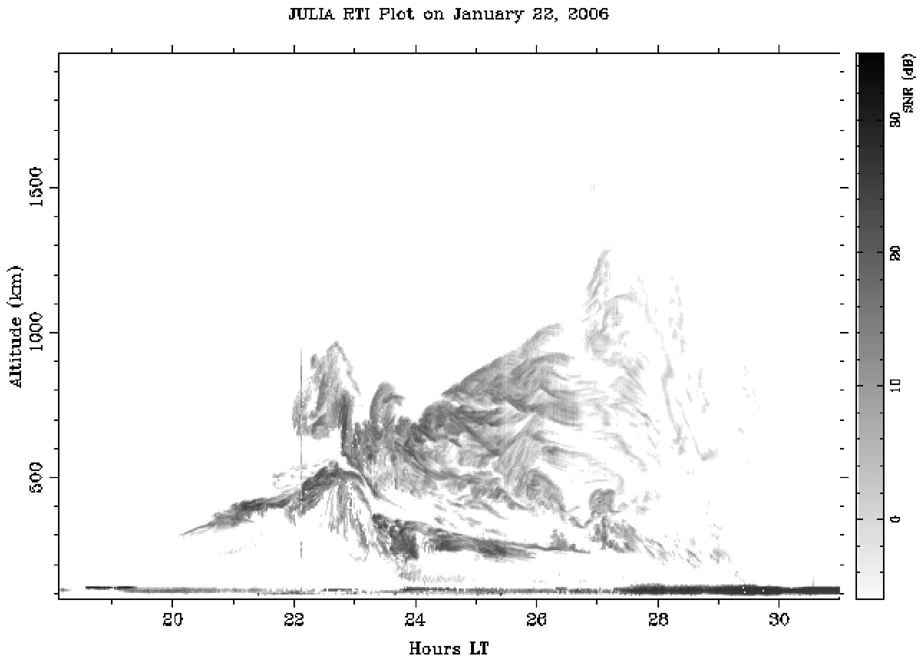
scatter from temperature and humidity layers

Troposphere

Coherent scatter echoes over Jicamarca (2)

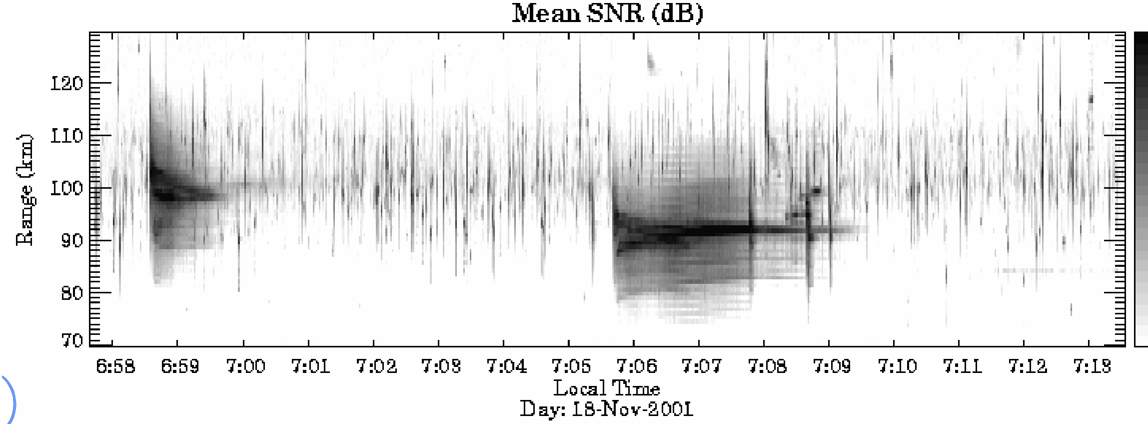
- Field-aligned irregularities
  - EEJ
  - Non-specular meteor trails (short-lived EEJs)
  - Valley echoes
  - ESF
- Meteor head echoes
- Atmospheric echoes
- Mountains
- Satellites
- Moon



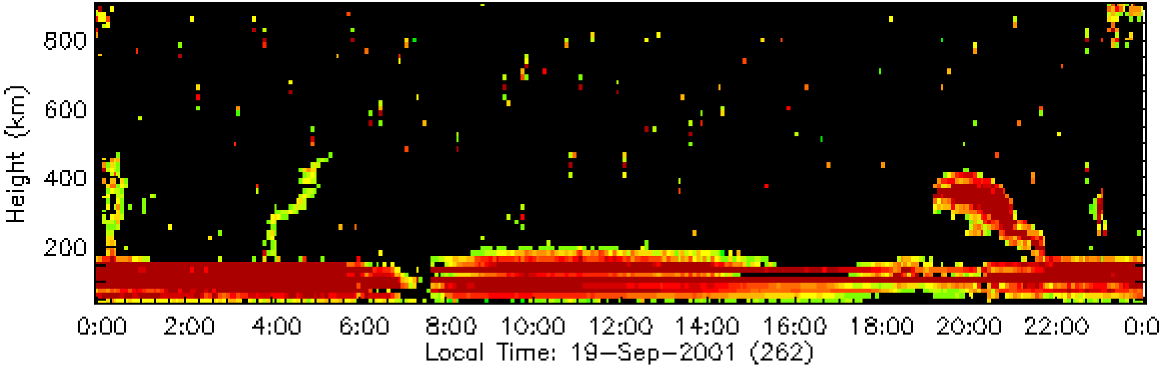


Coherent scatter echoes over Jicamarca (3)

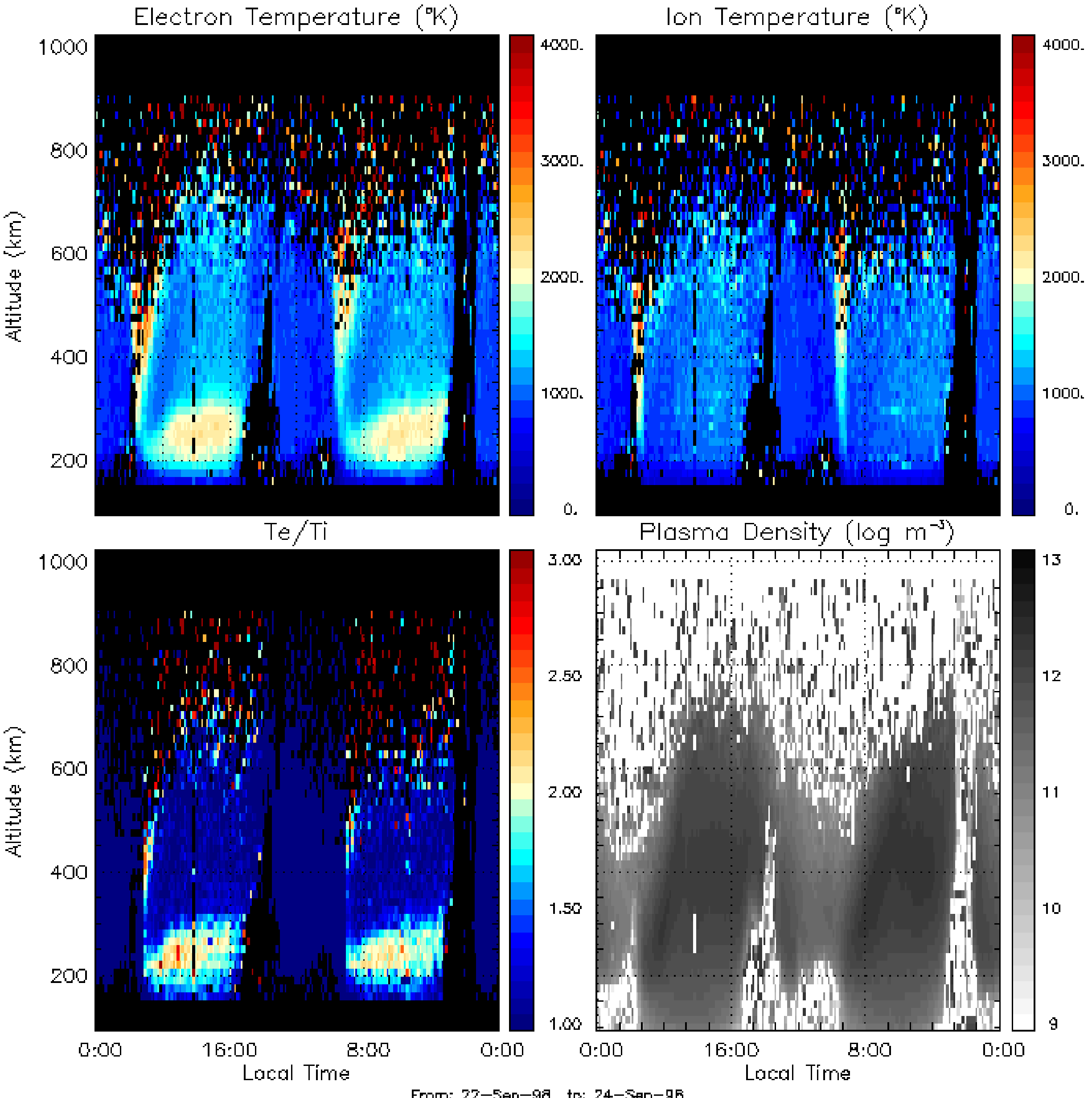
- Field-aligned irregularities
  - EEJ
  - Non-specular meteor trails (short-lived EEJs)
  - Valley echoes
  - ESF
- Meteor head echoes
- Atmospheric echoes
- Mountains
- Satellites
- Moon



(a) Jicamarca Power p_w0C (dB)



Oblique ISR Examples (1): 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.

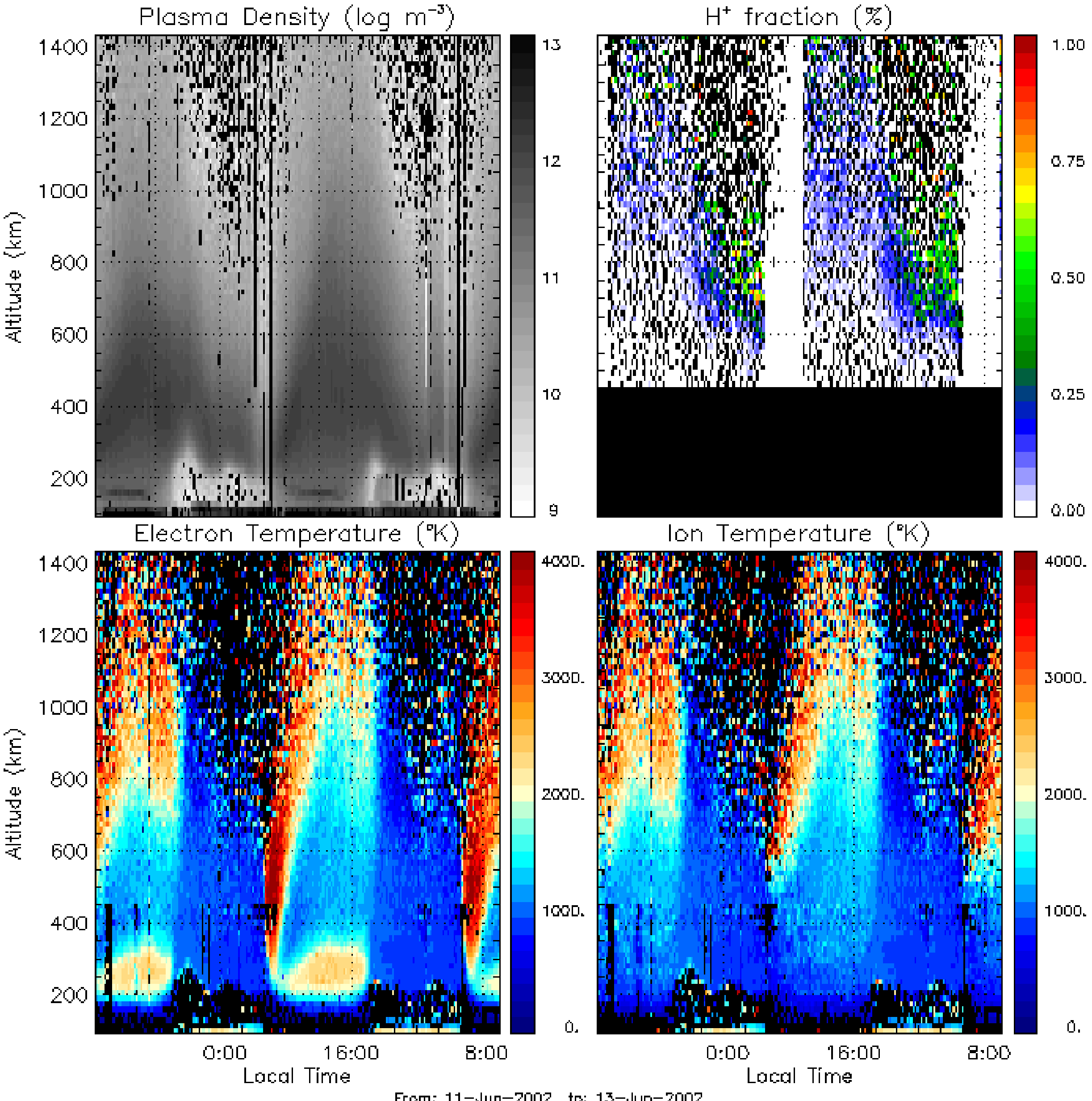
•Composition is hardly obtained.

•After *Sulzer and 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 ISR Examples (2): Hybrid 1 Faraday DP – Alternating codes

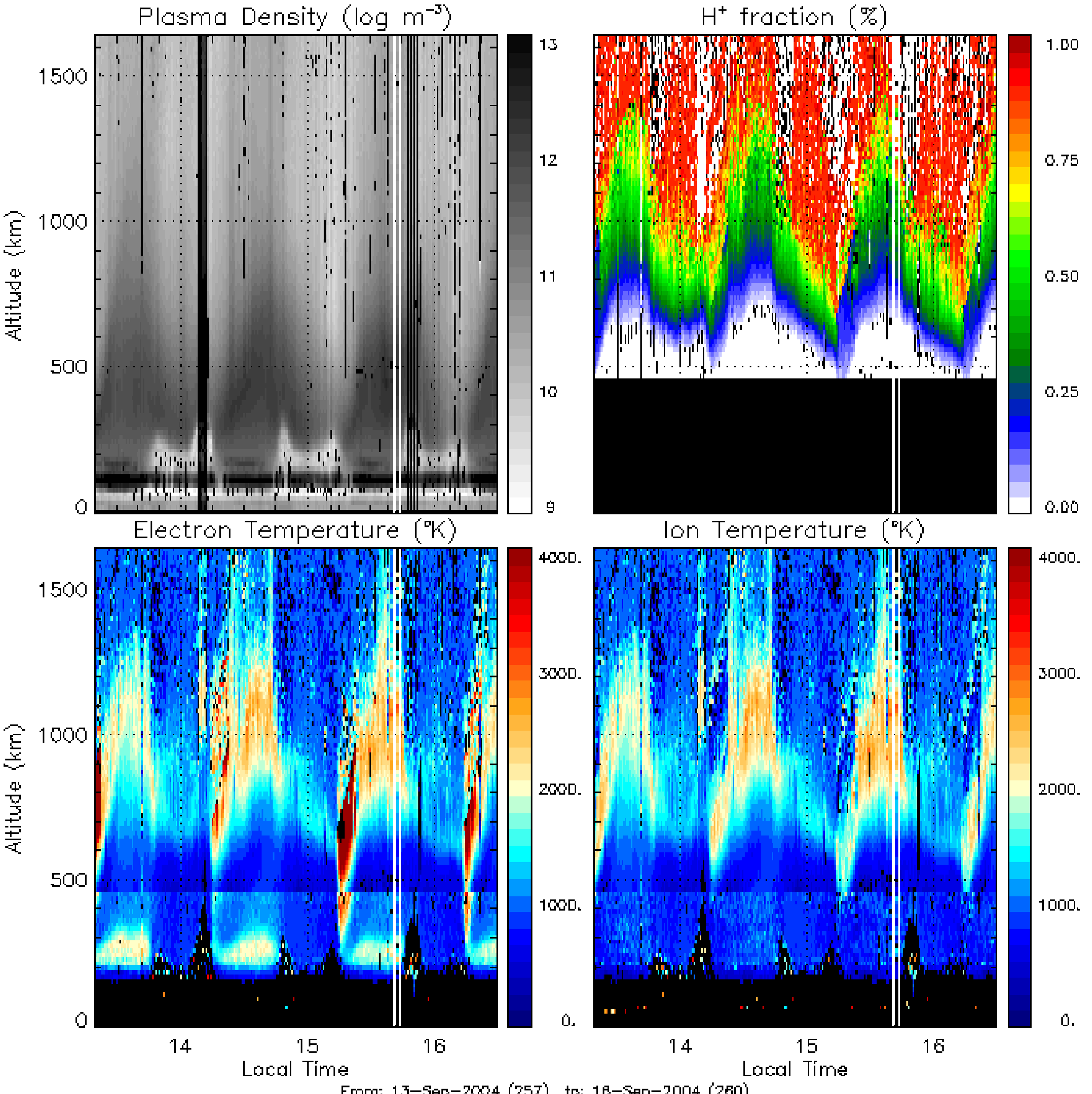


- •This modes combines the Faraday DP mode with an alternating code mode [e.g., *Hysell*, 2000]. Allowing us to use the available duty cycle. It provides:
- -Density and temperatures below 500 km from Faraday Double Pulse
- -Density, temperatures and composition above 500 km.
- •Altitudinal coverage it is better at the expense of bottom side temperature estimates with slightly less accuracy.
- •Very good for removing satellite clutter from raw voltages.

Oblique ISR Examples (3): Hybrid 2 Faraday DP – Long Pulse

Radio Observatorio de JICAMARCA Radio Observatory

CEDAR June 19, 2006



- This modes combines the Faraday DP mode with a long pulse mode, again allowing use of the available duty cycle.
- Altitudinal coverage it is better than previous two modes at the expense of less altitudinal resolution.
- Similarly it provides:

-Density and temperatures below 500 km

-Density, temperatures and composition above 500 km.

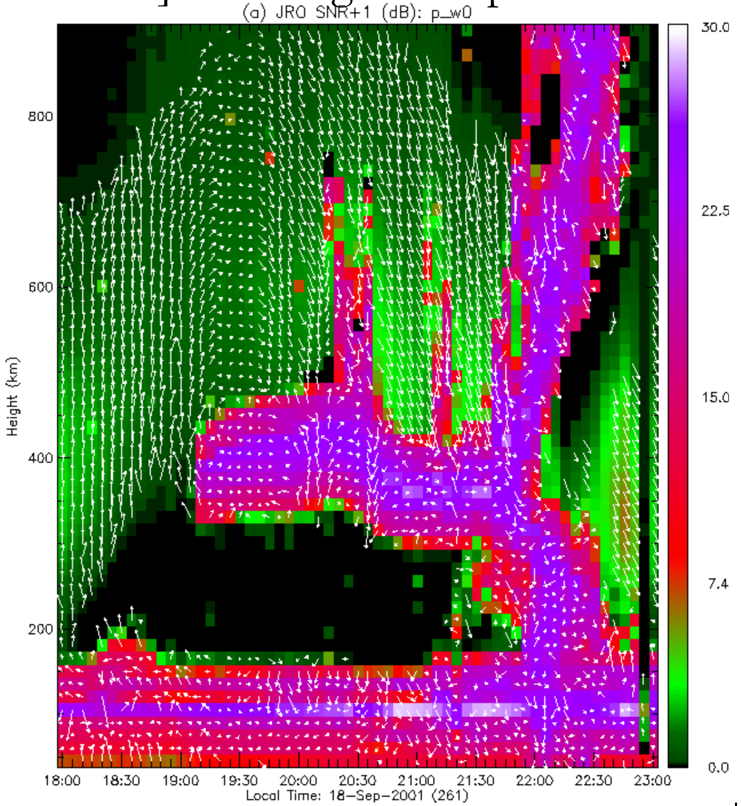
- Preliminary results (*Hysell and Rodrigues*, work in progress)

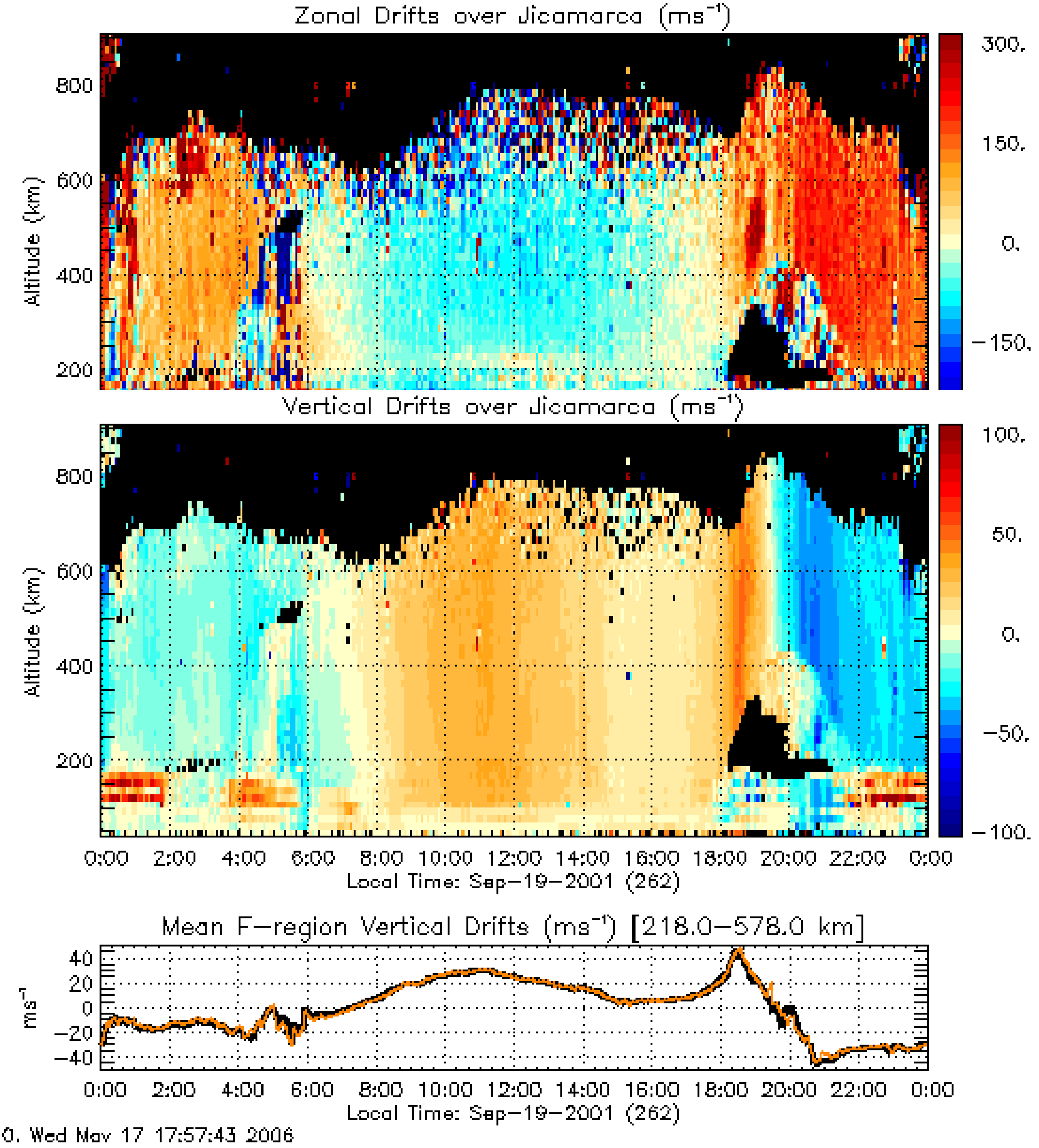
-Good for Topside work and sunrise observations.

-Hard to deal with satellite clutter.

Perpendicular ISR Examples (1): East-West Drifts

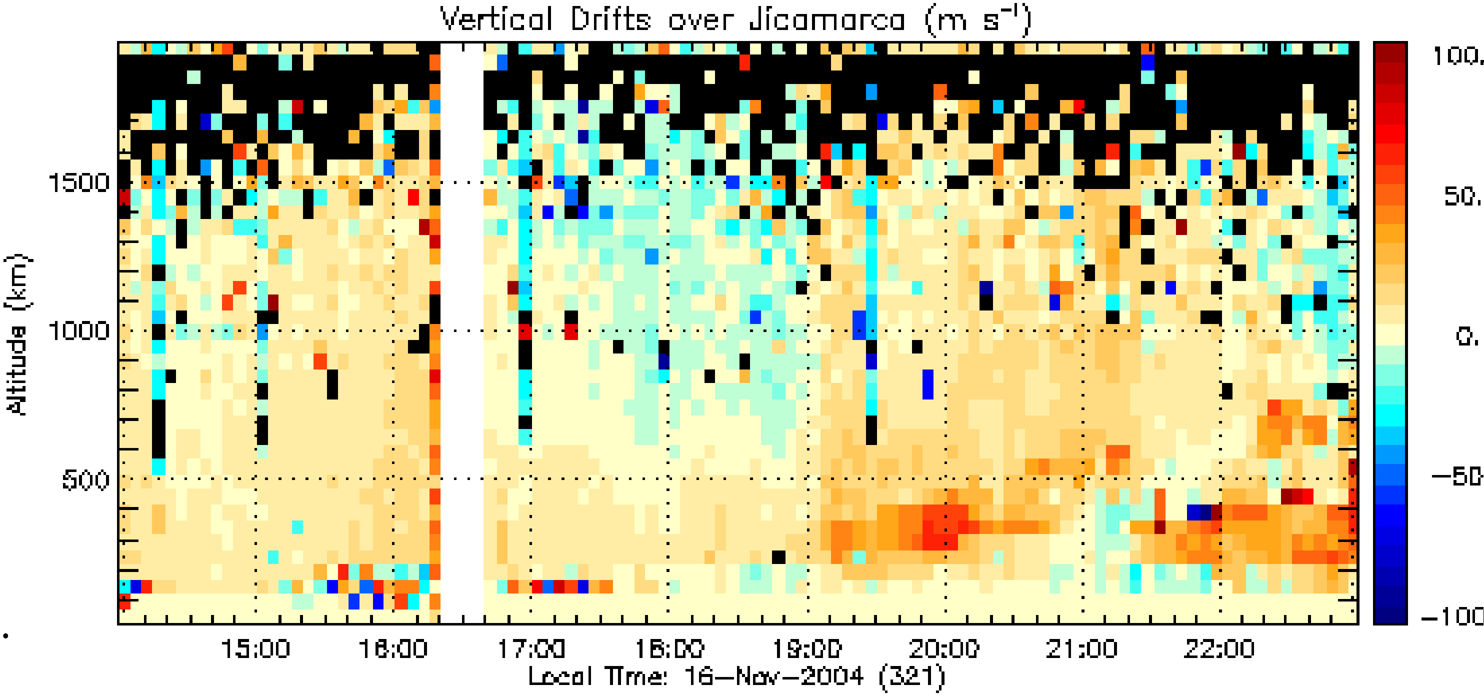
- Simultaneous measurements of vertical and zonal drifts, with 15 km and 5 min resolutions.
- Modes to get electron density measurements from phase [*Kudeki at al.* 2003, *Feng et al.* 2003] and absolute power [*Chau et al.*] are being developed.

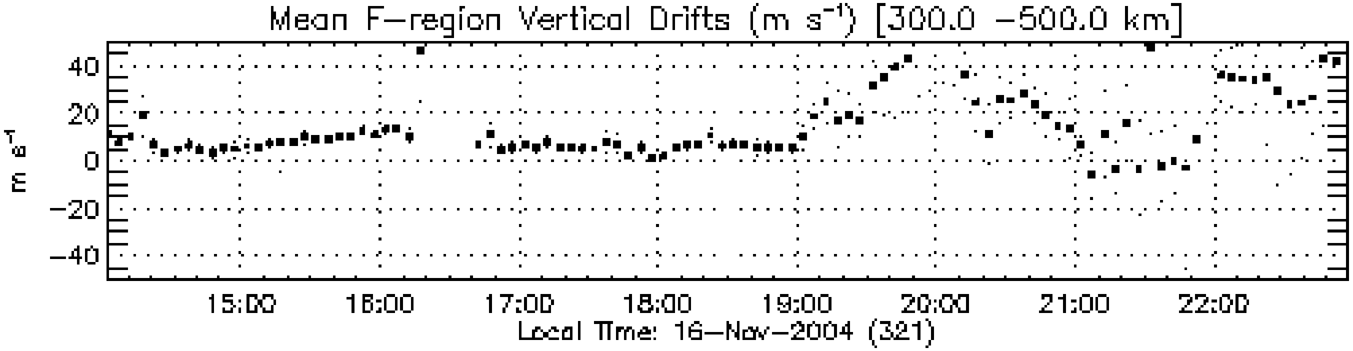




Perpendicular ISR Examples (2): High Altitude Drifts

- This mode uses antenna pointing perpendicular to **B** and long pulses.
- Drifts are obtained from pulse-to-pulse analysis.
- Altitudinal coverage is increase at the expense of resolution.
- It is currently being evaluated to see if usefulness in drift studies as function of altitude and/or latitude [*Fejer and Chau*]





Oblique vs. Perpendicular: Limitations

Oblique

- Reliable measurements above 200 km.
- Below 200 km, echoes from field-aligned irregularities are a problem. Not as much though, as the perpendicular modes, since these echoes come via antenna sidelobes. Ways of reducing the field-aligned clutter are being evaluated [*Chau et al.*].
- Drift measurements so far have not been possible, due to transmitter chirp and what appears to be more important, external FM radio interferences [*Hysell et al.*]
- “Overhead” measurements, no scanning capabilities.

Perpendicular

- Reliable measurements above 200 km due to field-aligned irregularities below.
- Temperature and composition measurements so far have not been possible. Spectra show very weak dependence on these parameters. *Kudeki et al.* are working on that [see talk later this week].
- Density measurements from phase differences are not straight forward as in the Oblique modes, a fitting procedure is needed.
- “Overhead” measurements.

What can be measured at JRO?

Radar Modes	**Region**	**η**	**V_z**	**V_x**	**V_y**	**T_e**	**T_i**	**%**	**u**
ISR-perpendicular	*F*, Top	✓	✓	✓		?	?		
ISR-oblique	***E***, *F*, Top	✓	?		?[1]	✓	✓	✓	
CSR-MST	4-90 kms								
CSR-JULIA "Vertical" EEJ,150-km, ESF	*E*, 150km, *F*, Top		✓[2]	✓[2]					
CSR-JULIA Oblique and/or Bistatic (EEJ)	*E*	✓	✓						✓
CSR-Imaging	*E*, 150 km, *F*, Top		✓	✓					?

[1] Maybe with SOUSY
[2] From irregularities (e.g., EEJ, ESF, 150-km echoes)
On-going improvements

Examples of coordinated science at JRO

- JRO provides the most precise ionospheric electric fields of all ISRs. See talks later this week on the use of this electric fields [e.g., Penetration electric fields and ionospheric storms workshop].
- Calibration campaigns for satellite measurements overhead JRO, mainly for electric fields and densities [e.g., C/NOFS, COSMIC], but also for topside densities, compositions and temperatures [e.g., DMSP].
- Validation campaigns for global ionospheric models [e.g., Equatorial Ionosphere and Scintillation Workshop]
- Comparison campaigns with the Arequipa ground-based Fabry Perot measurements of temperatures and zonal velocities [e.g. Recent Progress in Fabry-Perot Applications to CEDAR Science Workshop].
- Support of multi-instrument (GPS, ionosondes, scintillation receivers, optical instruments, …) campaigns/projects [e.g., CADRE, MISETA, LISN]
- Support of rocket campaigns [e.g., EQUION, CONDOR]
- Coordinated studies with other ISRS, e.g., penetration electric fields with Arecibo, Millstone Hill, and Sondy; topside composition studies with Arecibo; meteor-head studies with Arecibo, Millstone Hill, and Sondy, …
- More on equatorial aeronomy and Jicamarca will be covered at the “opportunities for Equatorial Aeronomy” and “Jicamarca Friends” workshops.

Coherent Scatter Imaging