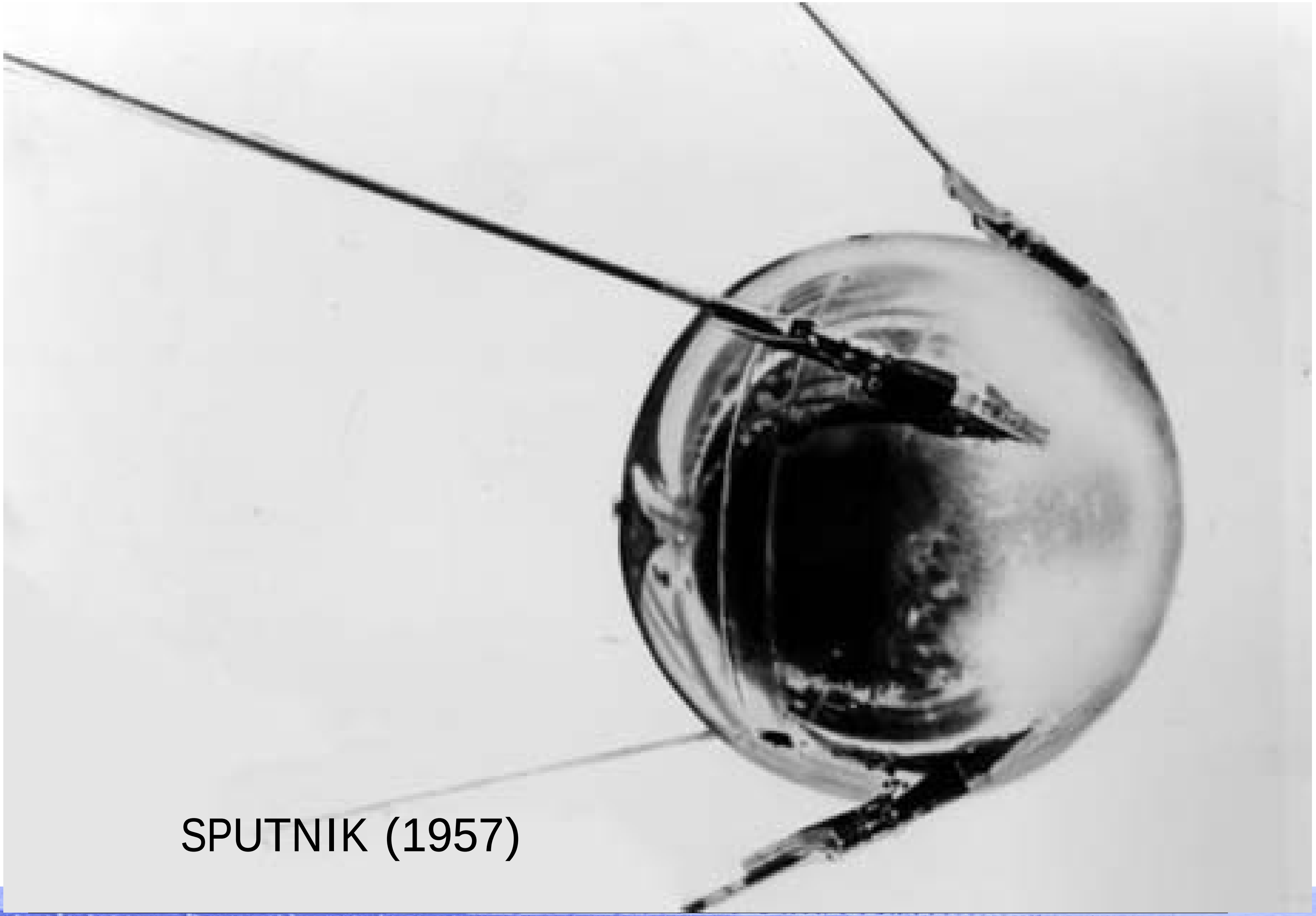
Incoherent and Coherent Scatter Radars: Jicamarca examples

R. F Woodman
Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima

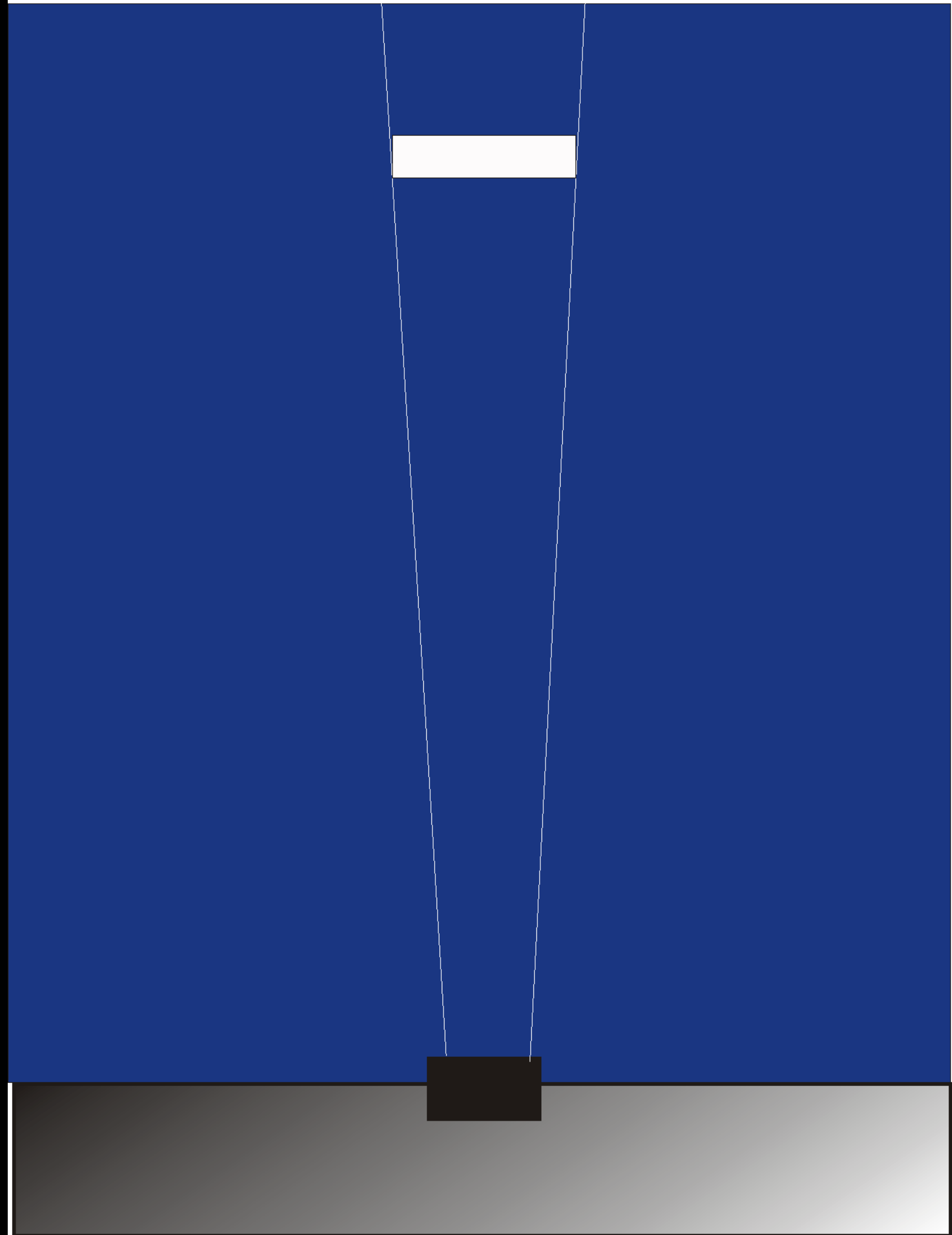
Early History



SPUTNIK (1957)

Incoherent Scatter History

- Gordon (1958) Proposes the technique



Incoherent Scatter History

- Gordon (1958) proposes the technique
- Bowles (1958) carries first succesfull experiment. Electrons do not control the spectrum. The ions do.

Incoherent Scatter History

- Gordon (1958) proposes the technique
- Bowles (1958) carries first succesfull experiment. Electrons do not control the spectrum. It is the ions.
- Fejer (1960), Dougherty and Farley (1960,1963), Salpeter(1960), Hagfors (1961), Rosenbluth and Rostoker (1962), Farley (1966), Woodman (1967), develop the theory . (See Hagfors, EISCAT Summer School 2003, for a comprehensive introduction).

Let

$$C_h(\tau) = \left\langle S_h(t) S_h^*(t+\tau) \right\rangle$$

$$\rho_h(\mathbf{r}, \tau) = \langle n(\mathbf{x}, t) n(\mathbf{x} + \mathbf{r}, t + \tau) \rangle$$

and

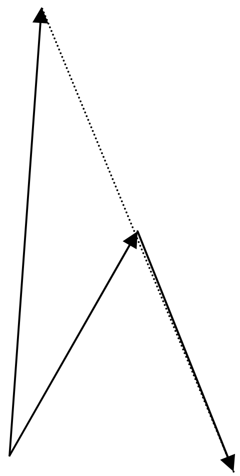
$$\hat{\rho}_h(\mathbf{k}_B, \tau) = \int \mathrm{d}\, V \rho_h(\mathbf{r}, \tau) e^{-i\mathbf{k}.\mathbf{r}}$$

then

$$\boxed{C_h(\tau) \propto \hat{\rho}_h(\mathbf{k}_B, \tau)}$$

where

$$\mathbf{k}_B = \mathbf{k}_i - \mathbf{k}_s$$



$$\boxed{C_h(\tau) \propto \hat{\rho}_h(\mathbf{k}_B, \tau)}$$

- Discussion
  - The statistics of the radar signal received is a (instrumental) functional of the fluctuation statistics of the medium.
  - Of all the spatial Fourier components of the fluctuations, only one component, that corresponding to $\mathbf{k}_B$, contributes to the radar signal.
  - For IS, plasma fluctuation theory provides us with an analytical expression for

$$\hat{\rho}_h(\mathbf{k}_B, \tau) \equiv \hat{\rho}_h(\mathbf{k}_B, \tau; n_e, [n_i], T_e, T_i, \mathbf{v}_\perp, v_\parallel, \mathbf{B})$$

Physical processes responsible for the fluctuations

- Discrete nature of electrons
- Discrete nature of ions
- Particles, electrons and ions, interact with the background plasma.

↓

Dressed particle approach

Measurable parameters

(For all ionospheric altitudes and time)

$$\hat{\rho}_h(\mathbf{k}_B, \tau) \equiv \hat{\rho}_h(\mathbf{k}_B, \tau; n_e, [n_i], T_e, T_i, \mathbf{v}_\perp, v_\parallel, \mathbf{B})$$

- Electron density,
- Ionic composition
- Electron temperature
- Ion temperature
- Drift velocities= Electric field
- Drag velocity (parallel to **B**) (not at Jicamarca)
- **B**

ISR Theory ( )

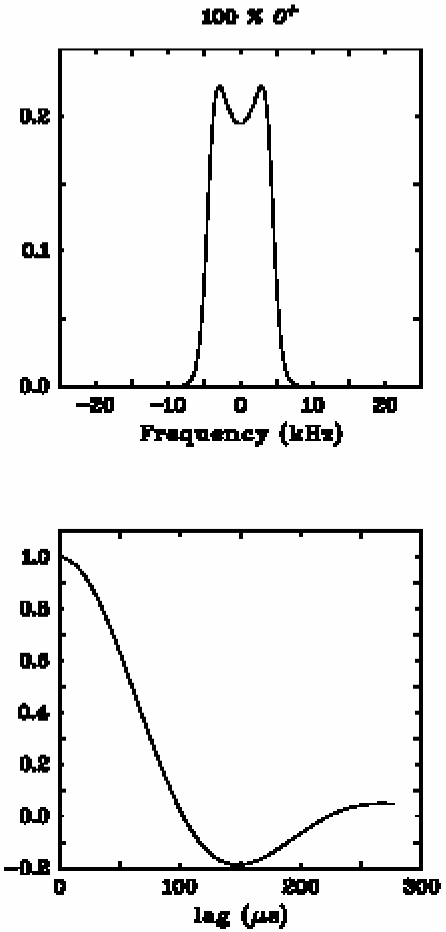


Figure 7: Sketches of equilibrium spectra and associated autocorrelation functions for hydrogen and oxygen ions with parameters as indicated.

ISR Theory ( )

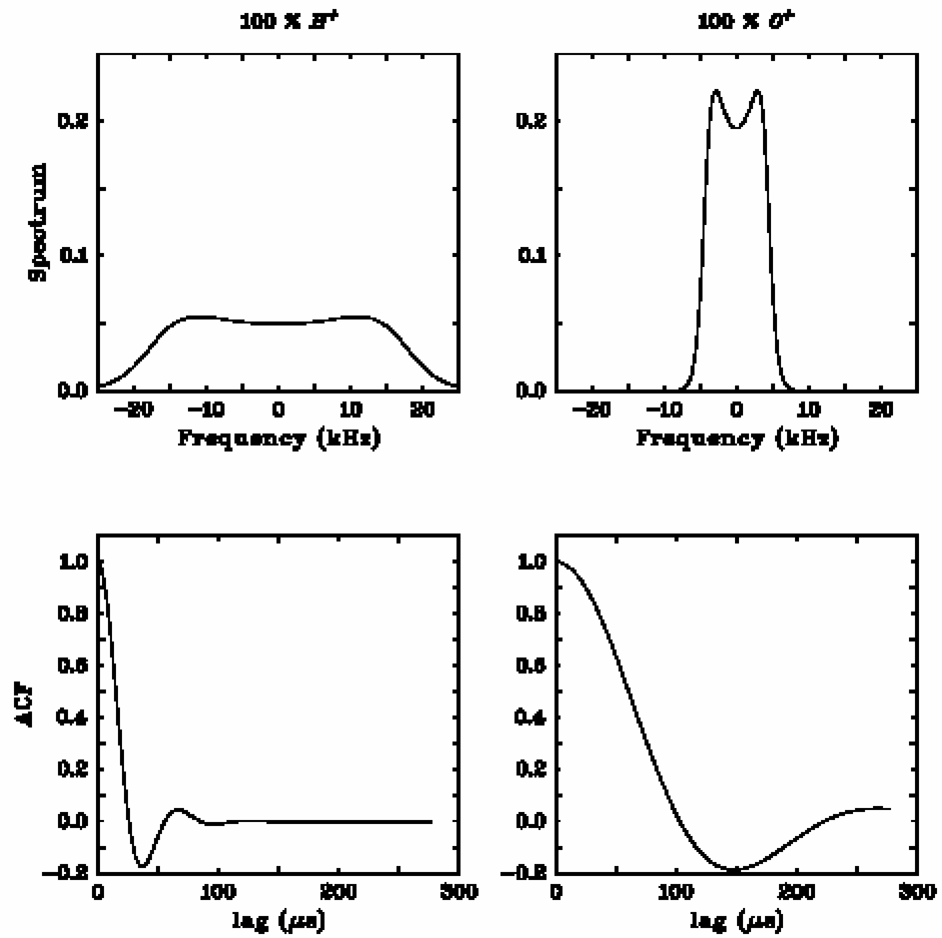


Figure 7: Sketches of equilibrium spectra and associated autocorrelation functions for hydrogen and oxygen ions with parameters as indicated.

ISR Theory ( )

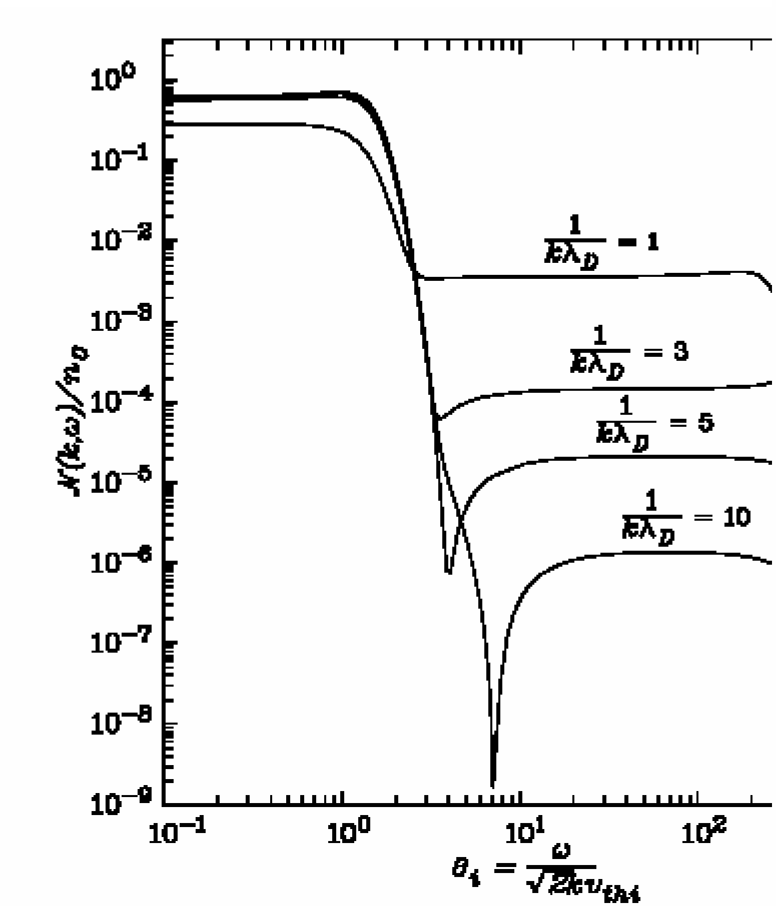


Figure 6: Early theoretical equilibrium spectra showing the line, [Hagfors, 1961].

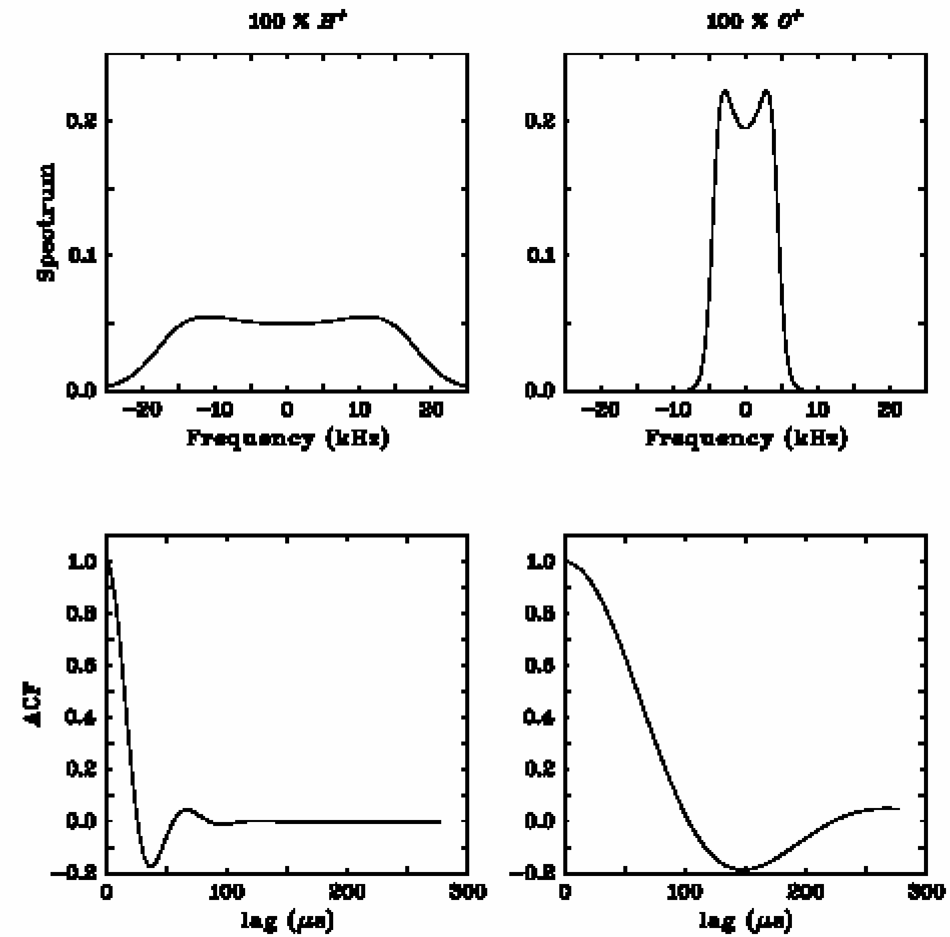
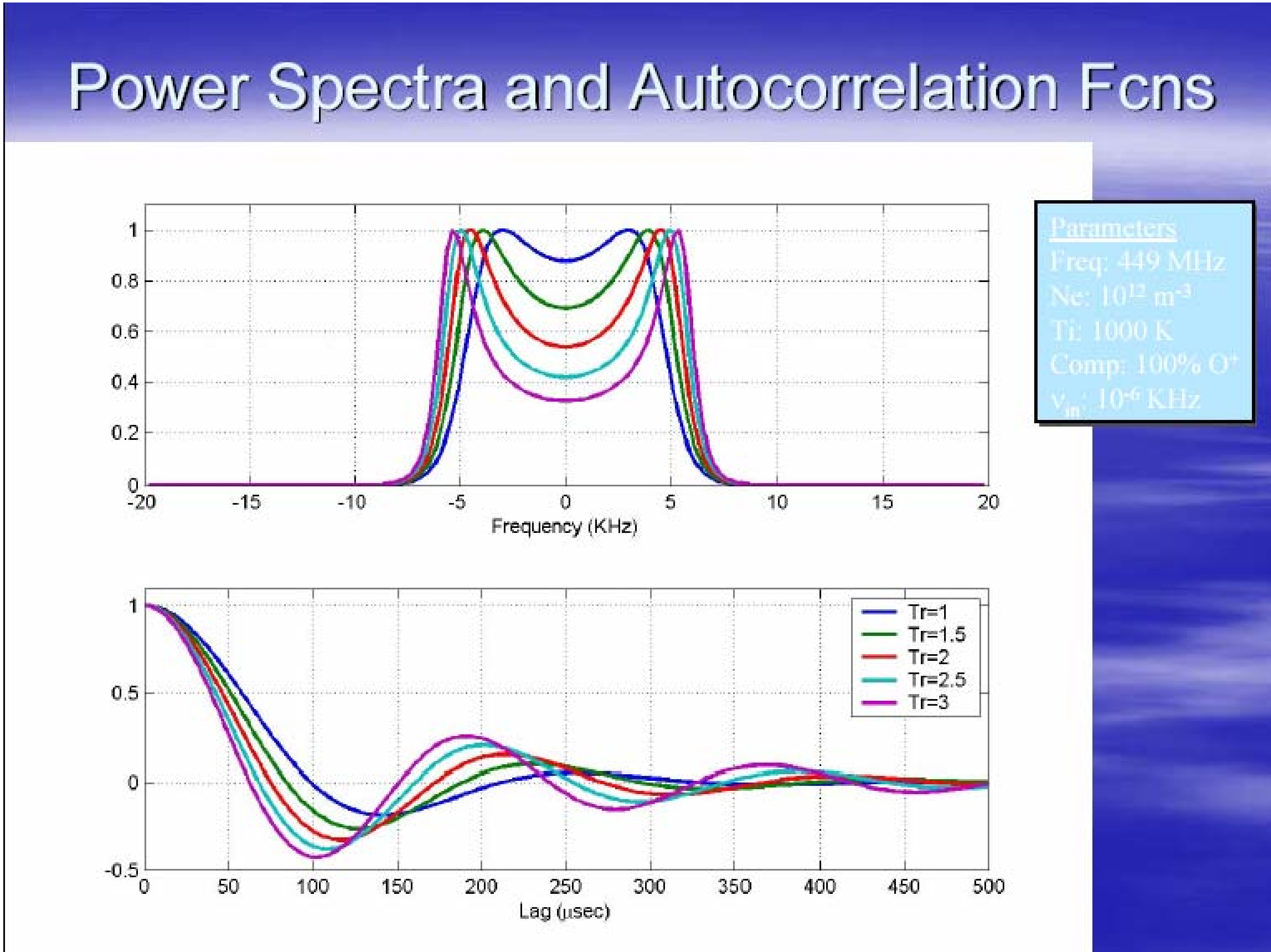


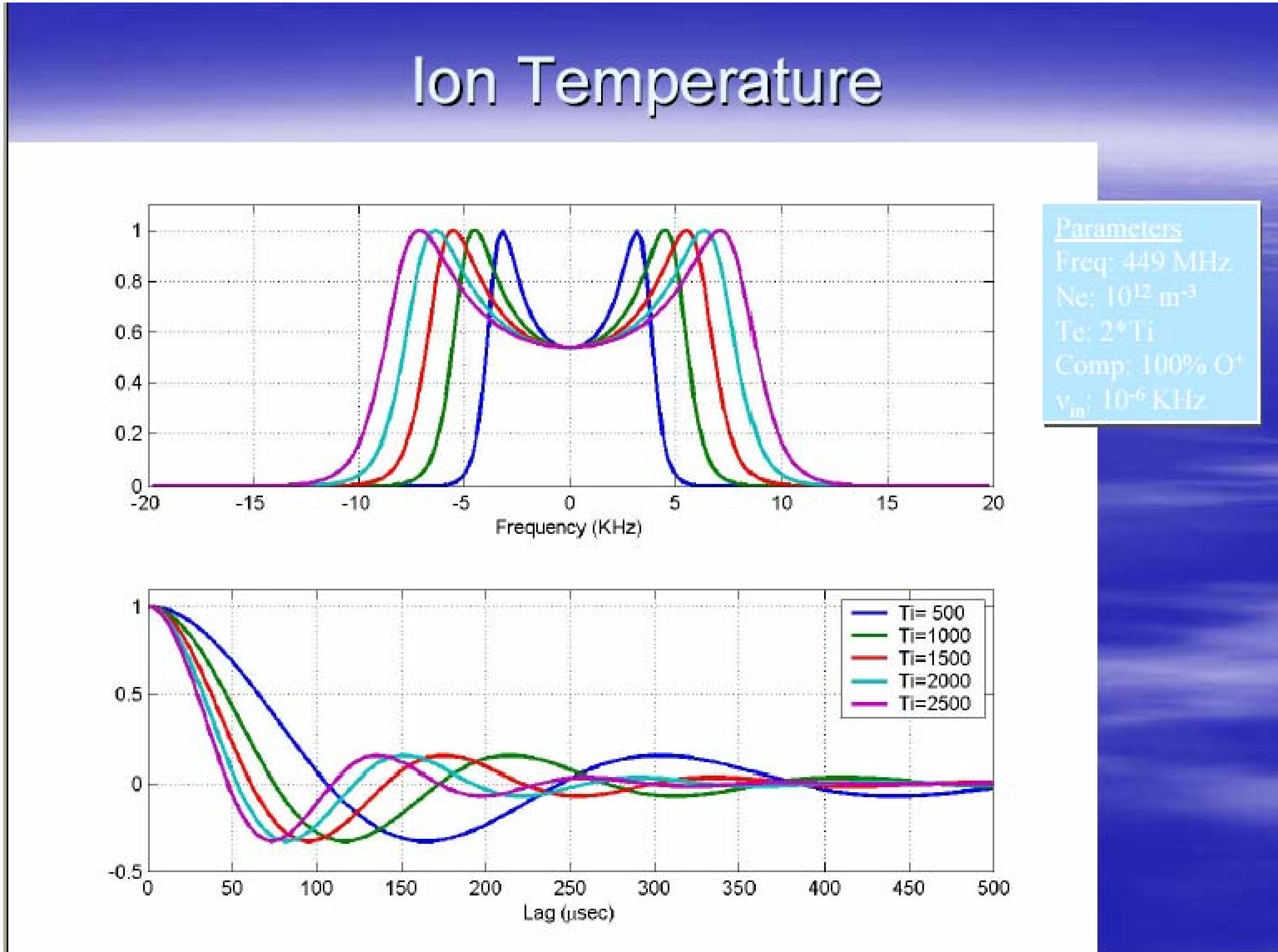
Figure 7: Sketches of equilibrium spectra and associated autocorrelation functions for hydrogen and oxygen ions with parameters as indicated.

ISR Theory ( )

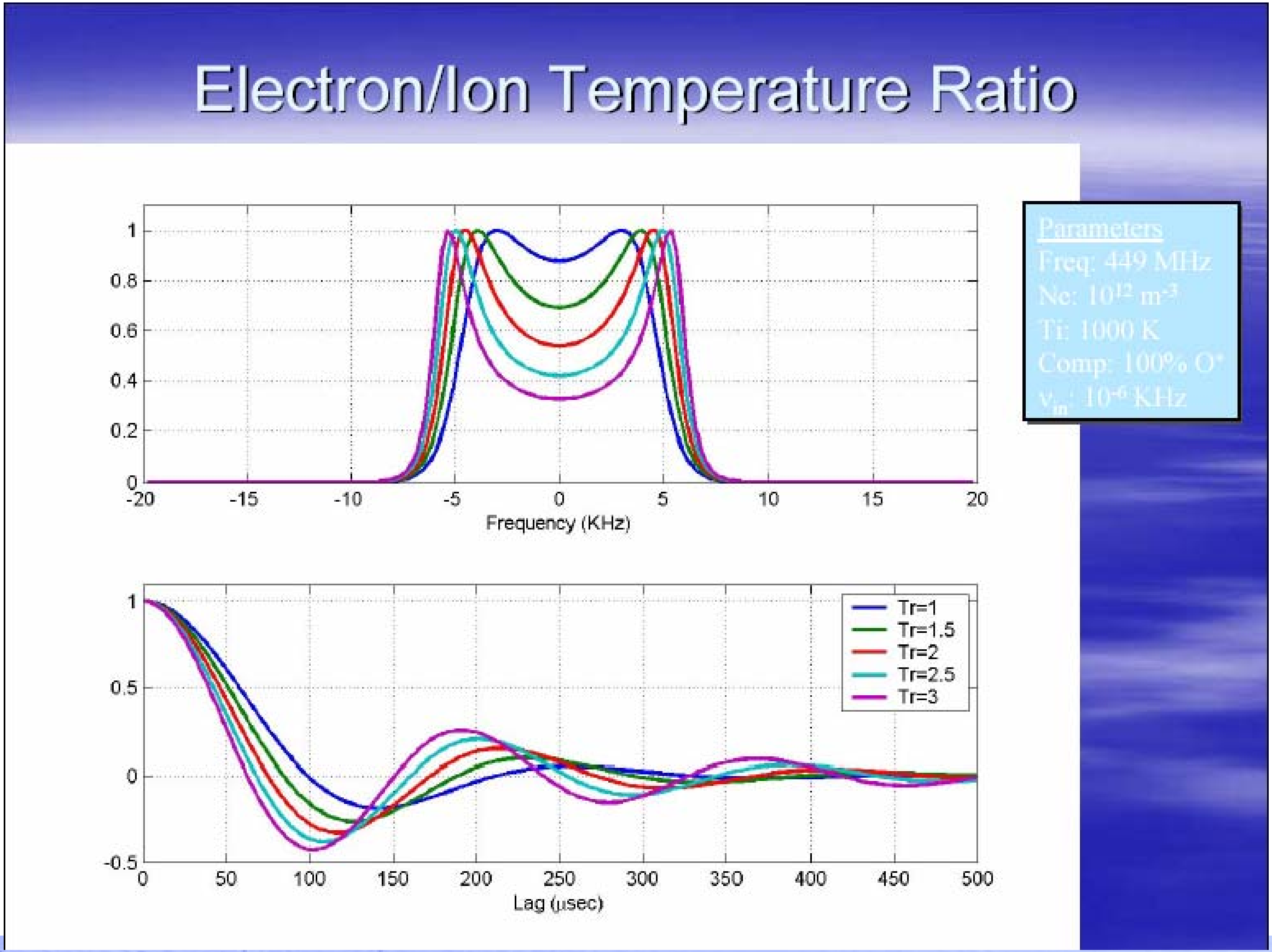


Power Spectra and Autocorrelation Fcns
Parameters
Freq: 449 MHz
Ne: 10¹² m⁻³
Ti: 1000 K
Comp: 100% O⁺
ν_in: 10⁻⁶ KHz
Frequency (KHz)
Lag (μsec)
Tr=1
Tr=1.5
Tr=2
Tr=2.5
Tr=3

ISR Theory ( )


Ion Temperature
Parameters
Freq: 449 MHz
Ne: 10^12 m^-3
Te: 2*Ti
Comp: 100% O+
v_in: 10^-6 KHz
Frequency (KHz)
Lag (μsec)
Ti= 500
Ti=1000
Ti=1500
Ti=2000
Ti=2500

ISR Theory ( )



Electron/Ion Temperature Ratio
Parameters
Freq: 449 MHz
Ne: 10^{12} m^{-3}
Ti: 1000 K
Comp: 100% O^+
ν_{in}: 10^{-6} KHz
Frequency (KHz)
Lag (μsec)
Tr=1
Tr=1.5
Tr=2
Tr=2.5
Tr=3

ISR Theory ( )

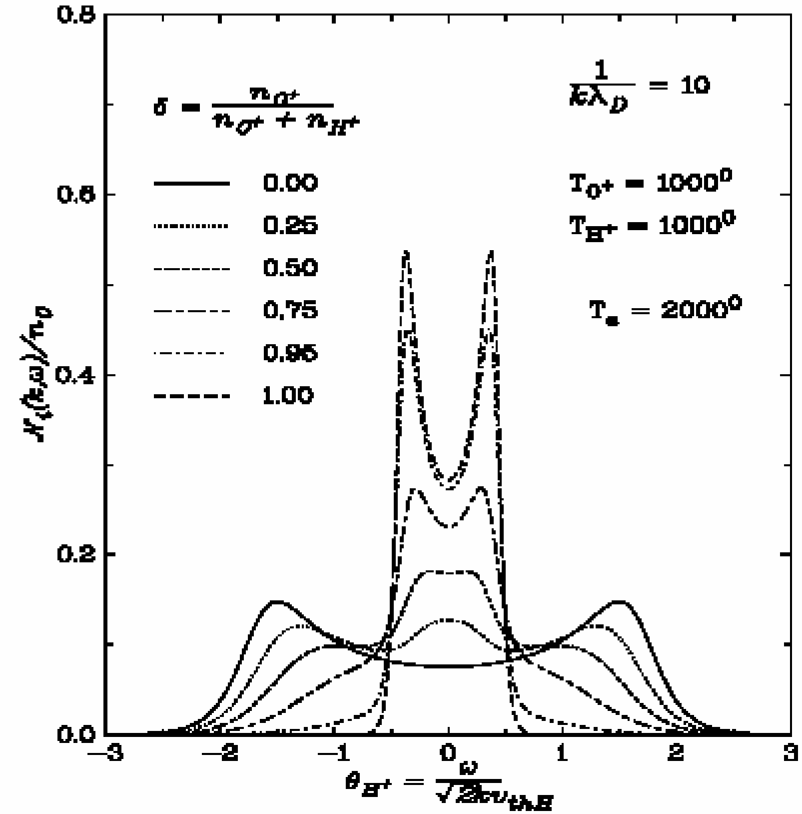


Figure 10: Spectra for mixtures of O^+ and H^+ ions in various mixing ratios. Note that $\delta = 0.0$ corresponds to all O^+ and that $k\lambda_D = 0.1$

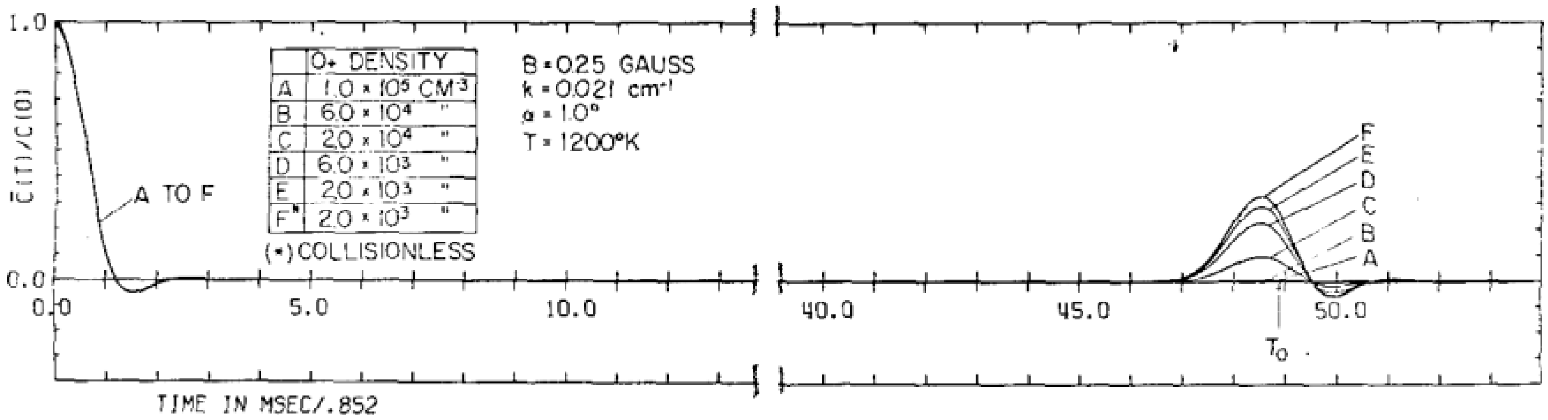


FIG. 8c. Same as Fig. 8a but for $[O]^+$

Introduction

- Built in 1961
- Antenna of 300m x 300 m
- 3 txs of 1.5 MW each
- Multiple rx capability

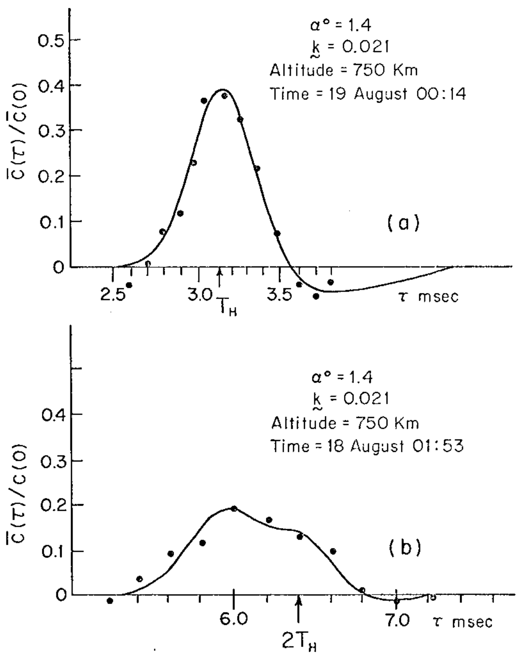
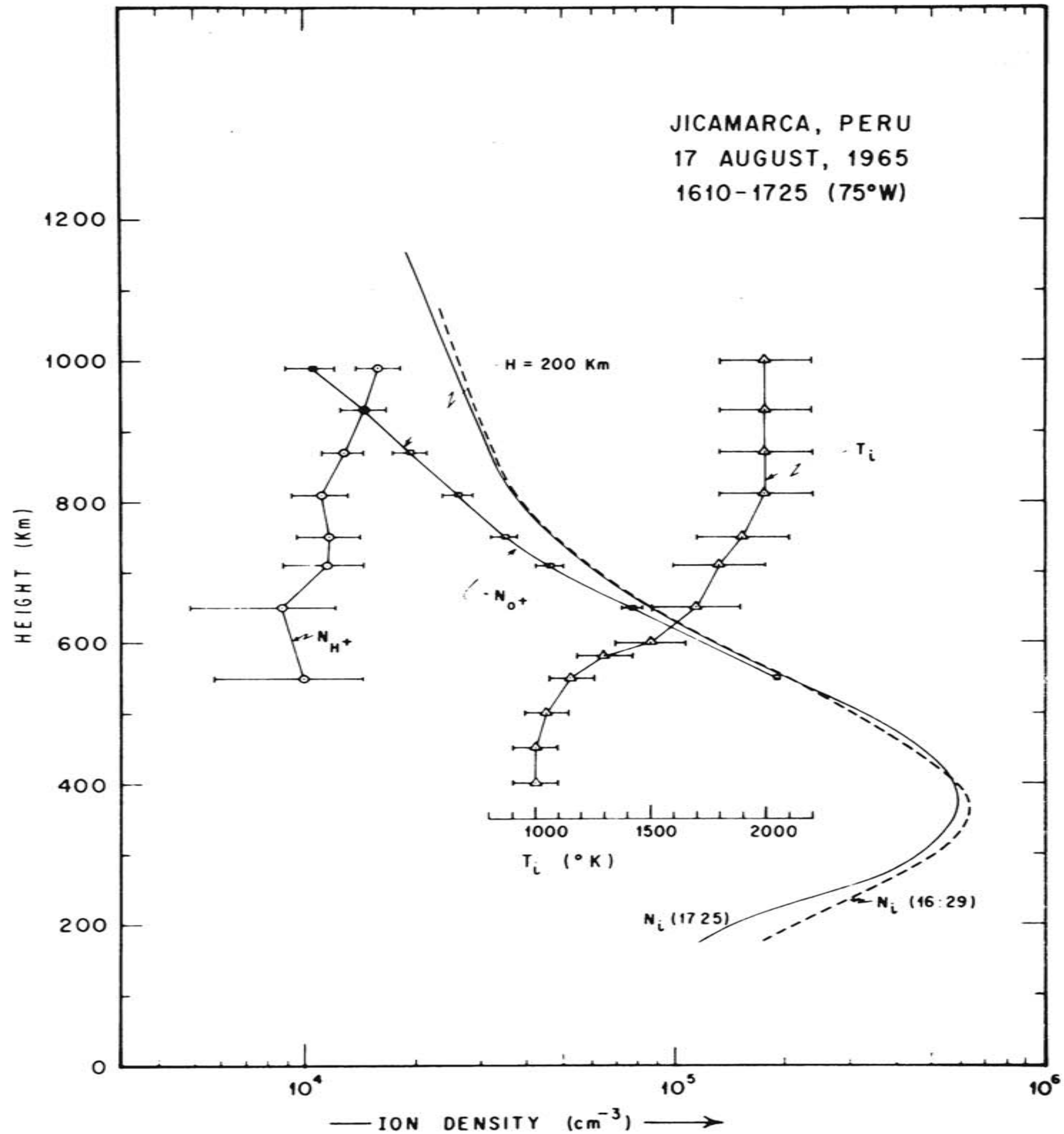


FIG. 14. Experimental points from Fig. 13 and theoretical curves with unknown parameters (temperature and composition) adjusted for best fit. Magnetic field has also been connected slightly (~2%) from theoretical models for best fit. Composition used is 60% $[H]^+$ and 40% $[O]^+$ for



JICAMARCA, PERU
17 AUGUST, 1965
1610-1725 (75°W)
H = 200 Km
T_i
N_{O^+}
N_{H^+}
N_i (17 25)
N_i (16:29)
1000
1500
2000
T_i (°K)
HEIGHT (Km)
0
200
400
600
800
1000
1200
10^4
10^5
10^6
ION DENSITY (cm^{-3})

Woodman and Hafgfors, 1971

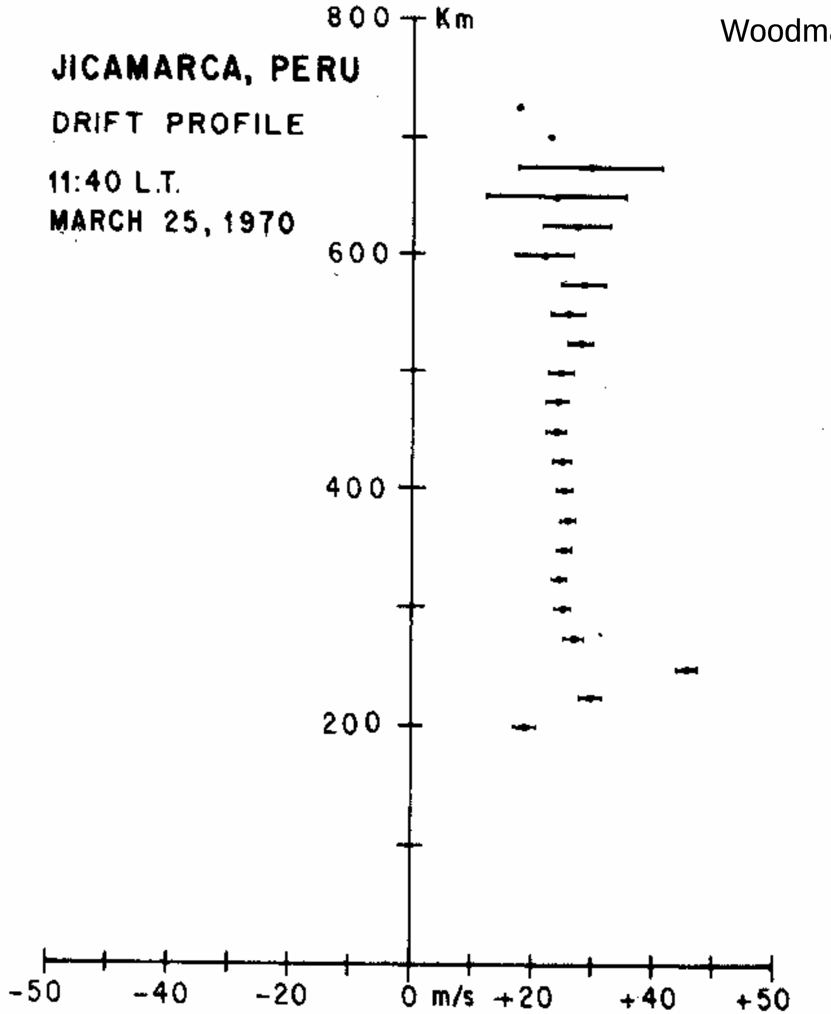


Fig. 1. Typical vertical velocity profile record obtained 'on line' at Jicamarca with 10 min of integration. The three lowest points are contaminated by strong electrojet echoes received through a side lobe of the antenna.

Woodman, 1971

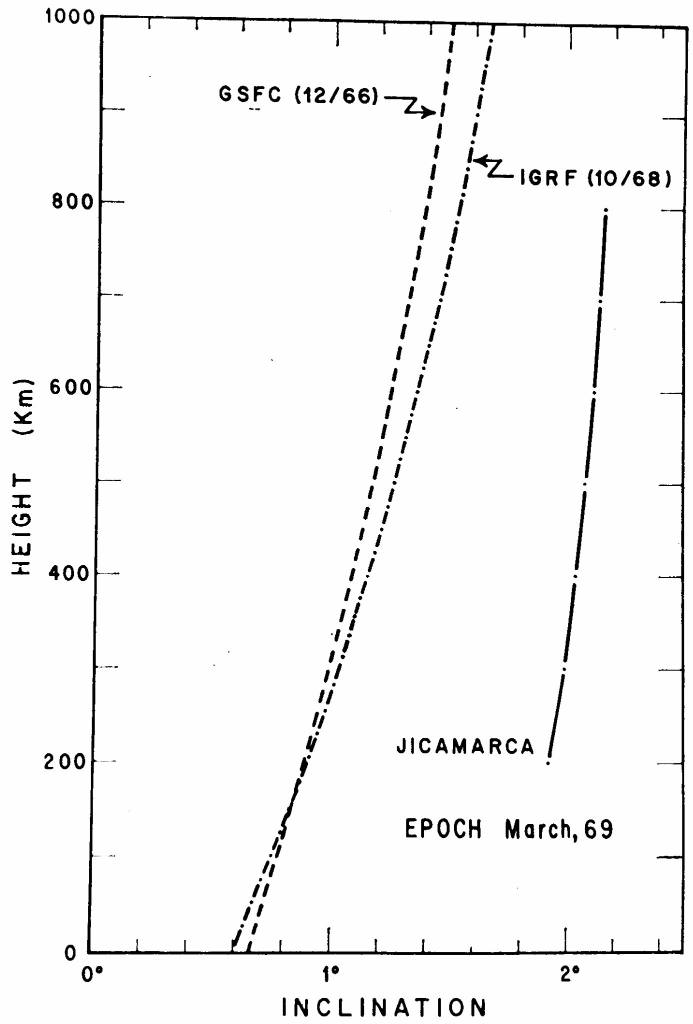
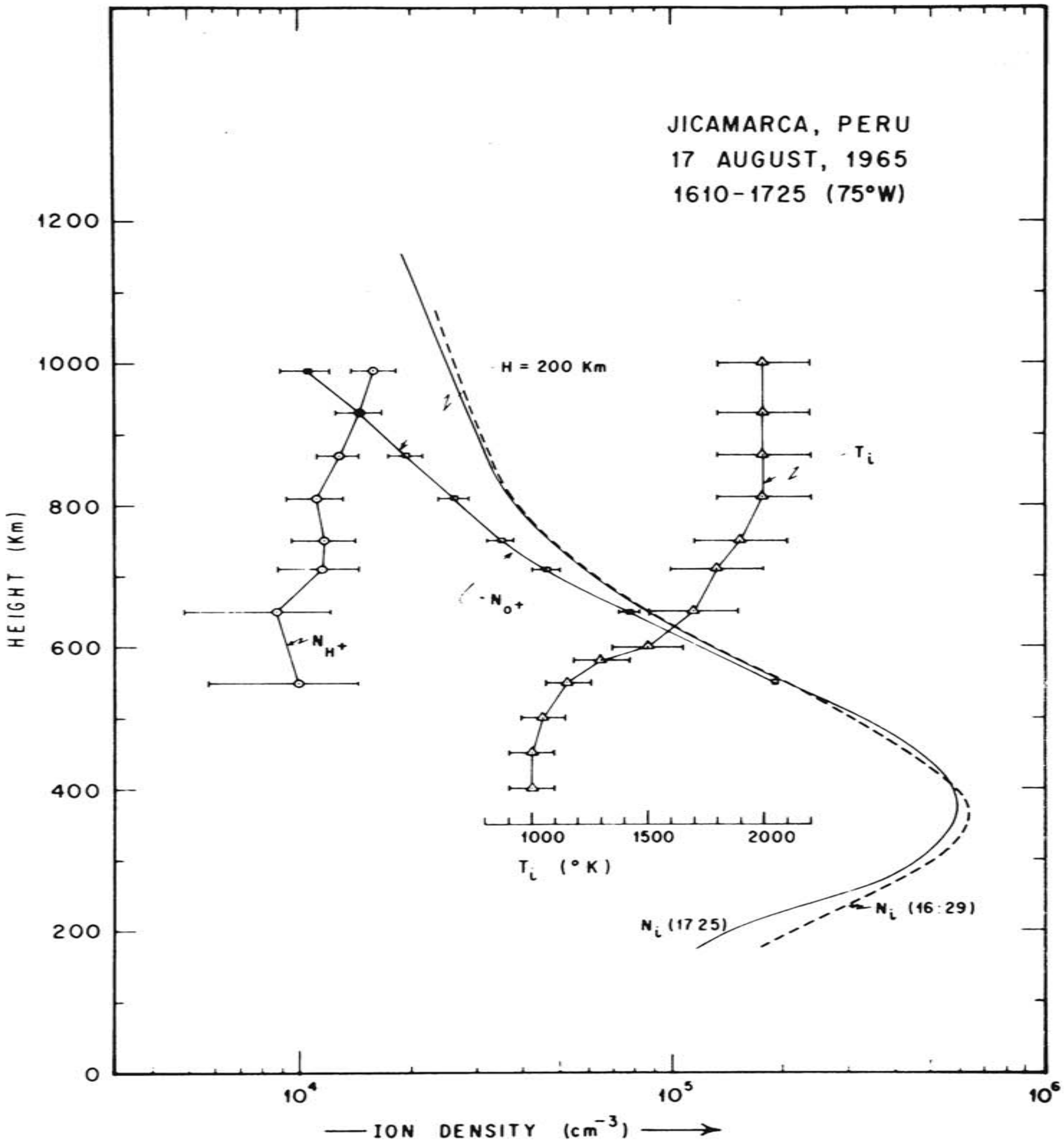


Fig. 6. Inclination of the magnetic field along Jicamarca vertical (−11.95° latitude 76°52′20″ longitude). The interrupted solid line corresponds to values determined experimentally at Jicamarca; the other two correspond to two of the latest earth magnetic field models, GSFC 12/66 and IGRF 10/68.


JICAMARCA, PERU
17 AUGUST, 1965
1610-1725 (75°W)
HEIGHT (Km)
H = 200 Km
T_i
N_{O^+}
N_{H^+}
T_i (°K)
N_i (17 25)
N_i (16:29)
ION DENSITY (cm^{-3})

Woodman and Hafgfors, 1971

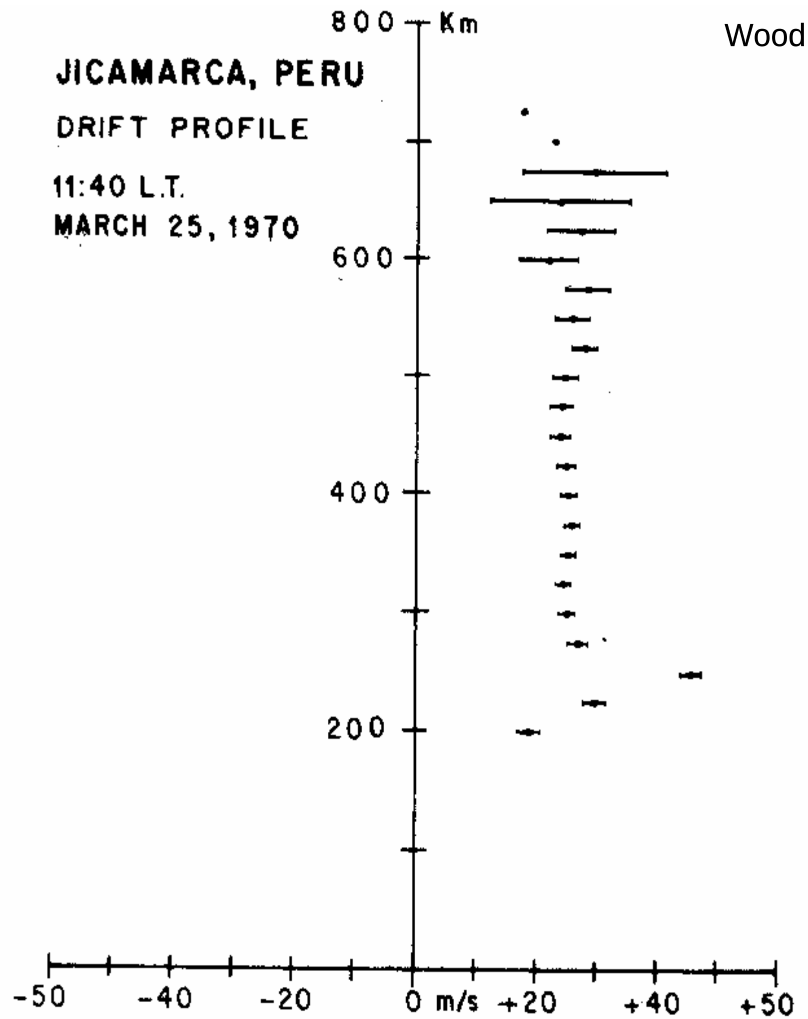


Fig. 1. Typical vertical velocity profile record obtained 'on line' at Jicamarca with 10 min of integration. The three lowest points are contaminated by strong electrojet echoes received through a side lobe of the antenna.

Woodman, 1971

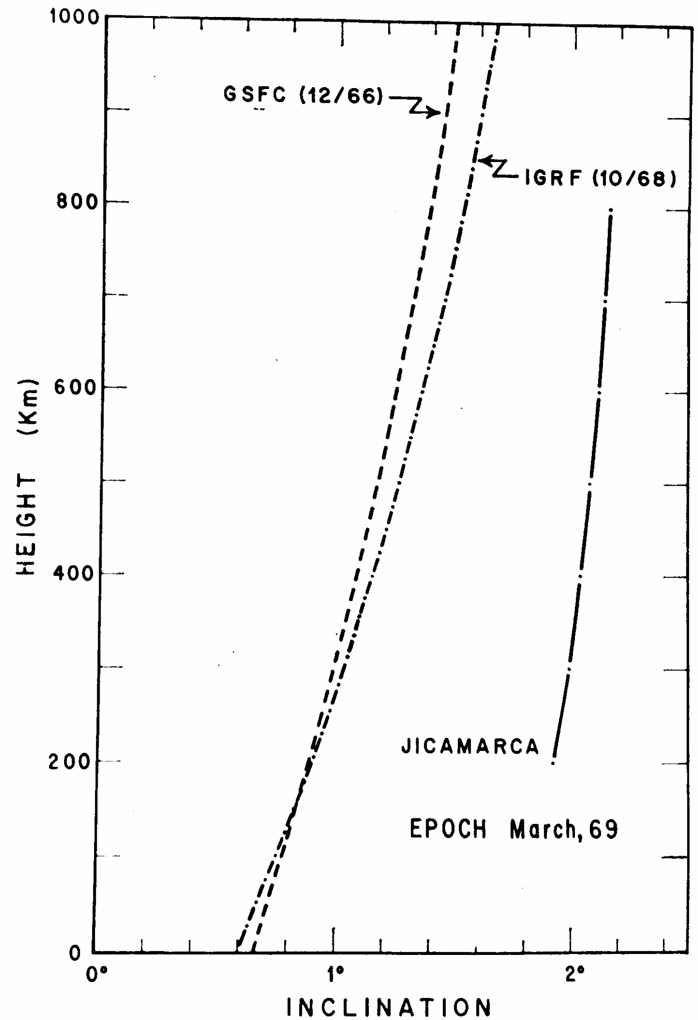
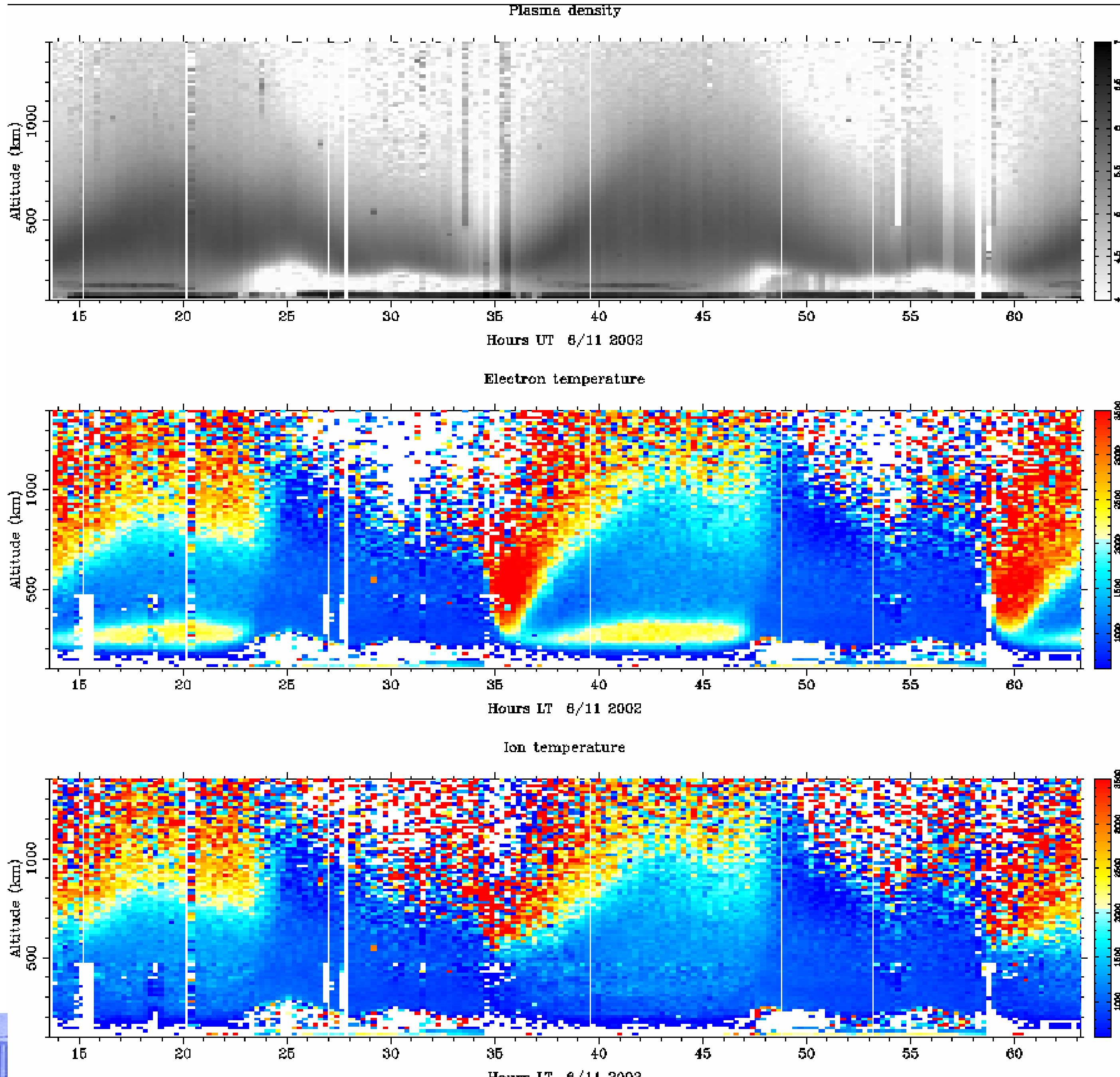


Fig. 6. Inclination of the magnetic field along Jicamarca vertical (—11.95° latitude 76°52′20″ longitude). The interrupted solid line corresponds to values determined experimentally at Jicamarca; the other two correspond to two of the latest earth magnetic field models, GSFC 12/66 and IGRF 10/68.

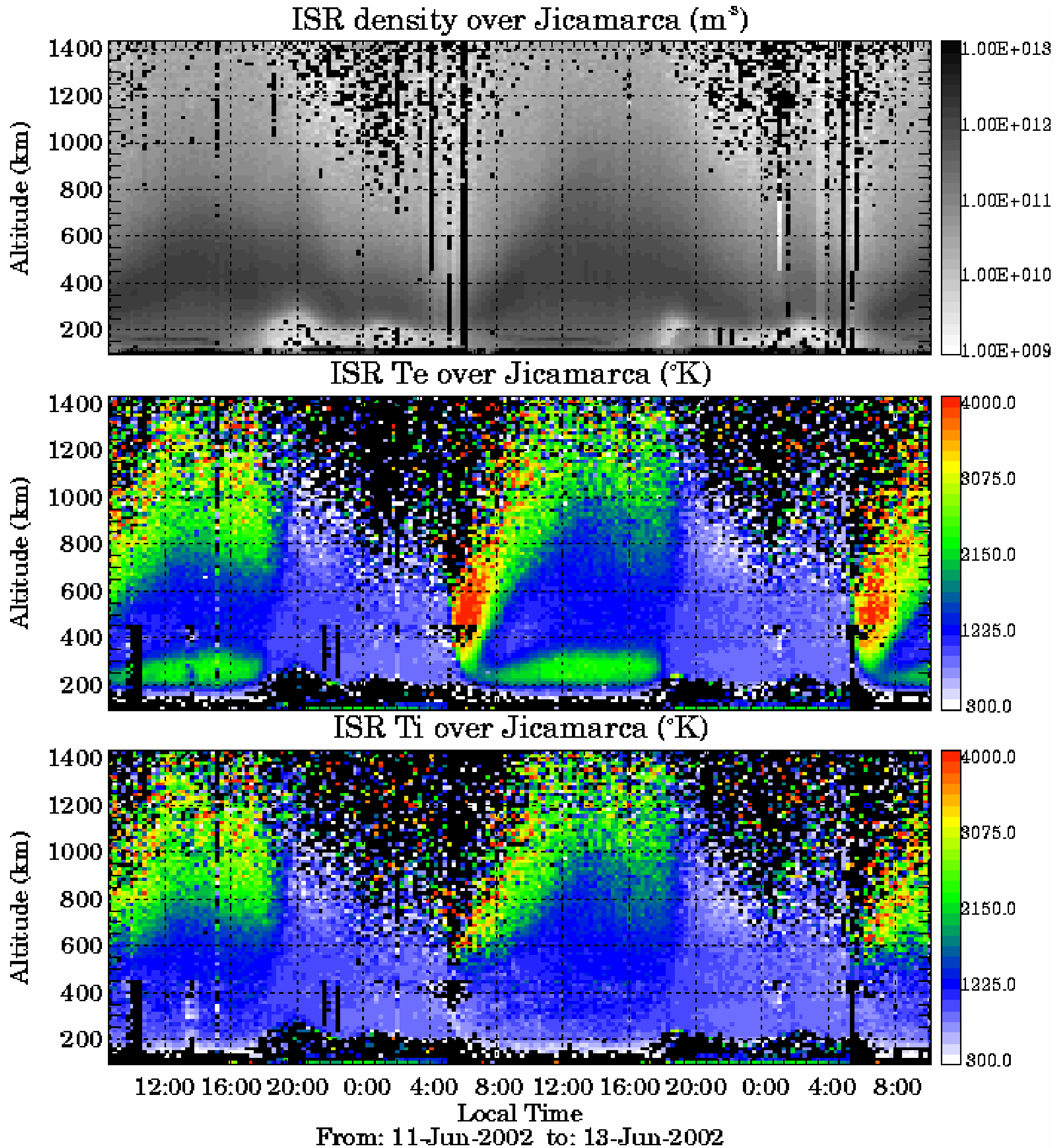
Ne
Te
Ti


Plasma density
Altitude (km)
1000
500
15 20 25 30 35 40 45 50 55 60
Hours UT 6/11 2002
Electron temperature
Altitude (km)
1000
500
15 20 25 30 35 40 45 50 55 60
Hours LT 6/11 2002
Ion temperature
Altitude (km)
1000
500
15 20 25 30 35 40 45 50 55 60
Hours LT 6/11 2002

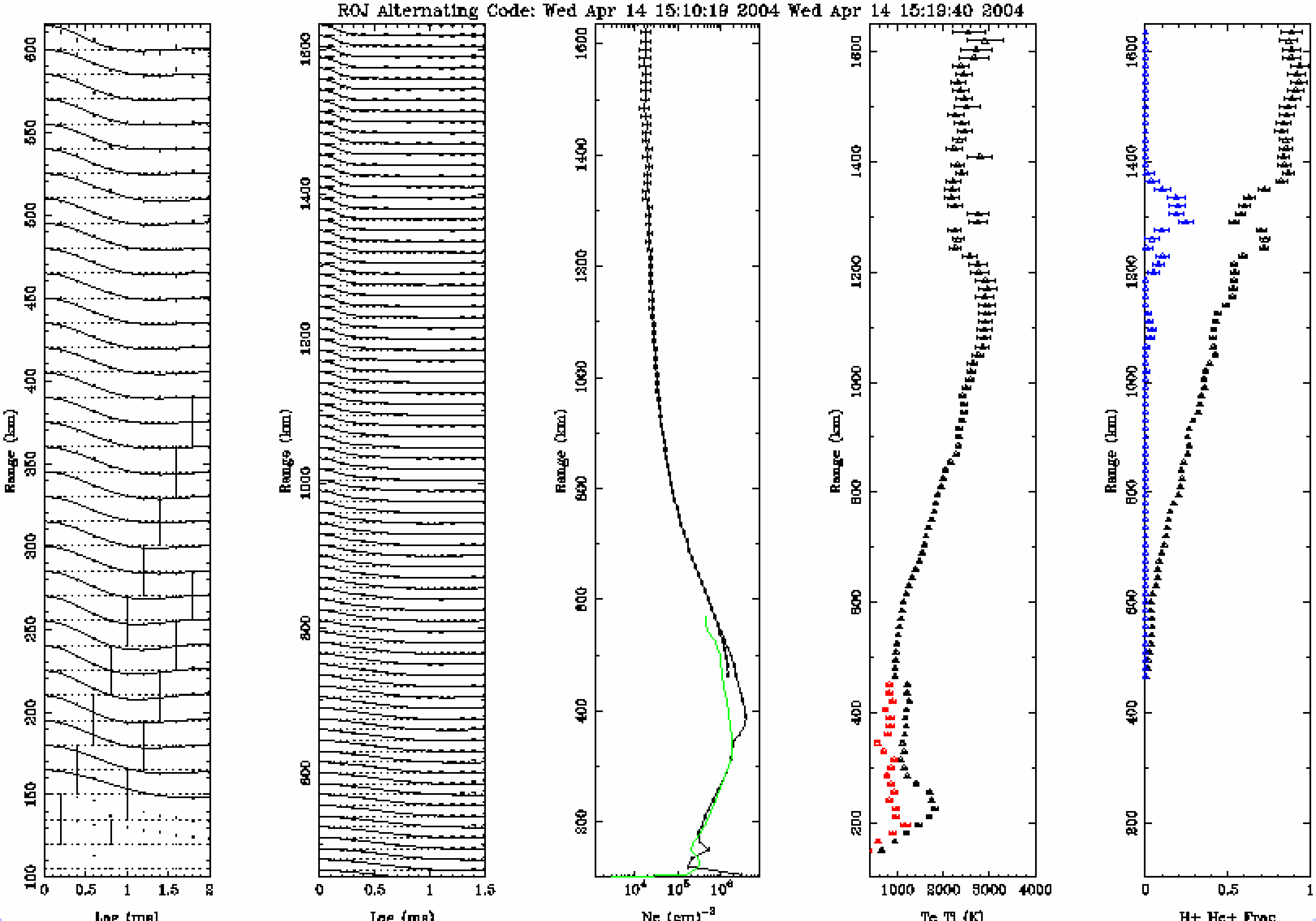
ISR example (1)
Oblique mode
Hybrid 1

It combines the traditional Faraday Double Pulse mode with alternating code mode. Allowing use of the available duty cycle and therefore better measurements and higher altitudinal coverage than before!

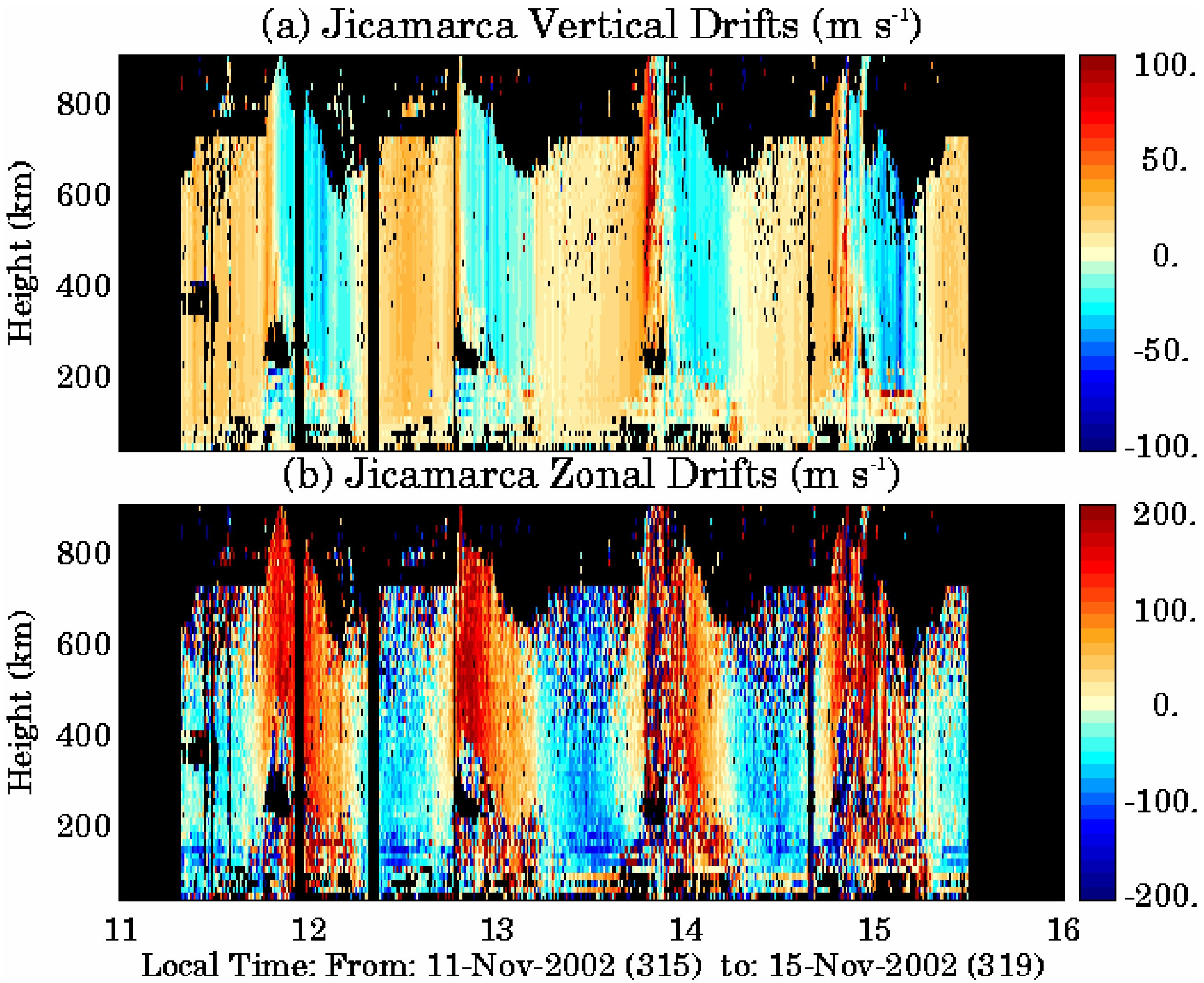
Note: There are no *E* region measurements!



ISR example (2)
Oblique mode Hybrid 2: Long Pulse + Faraday



ISR example (3)
Perpendicular Mode
East-West Drift



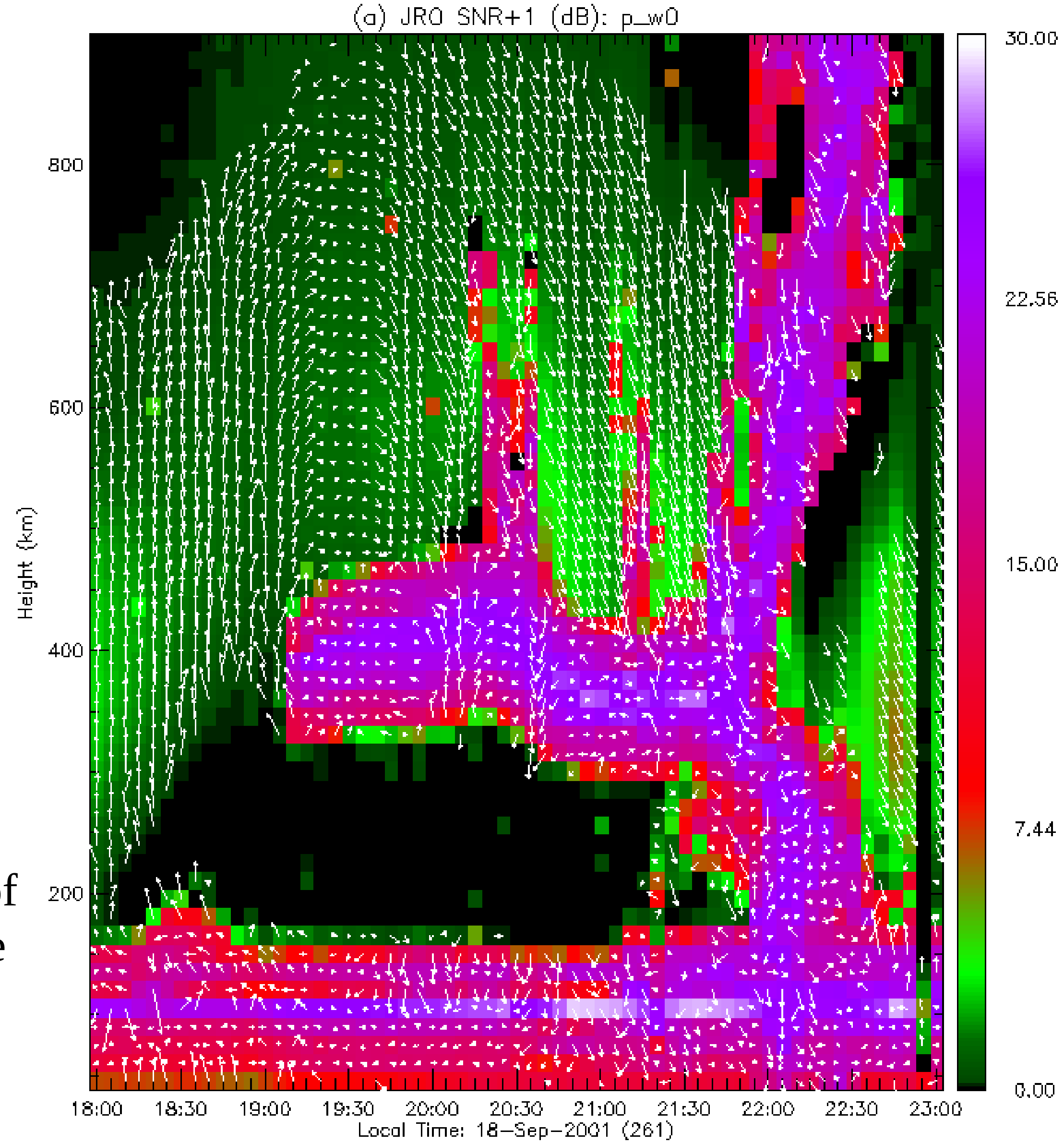
ISR example (4)
Perpendicular Mode
East-West Drift

(*Kudeki et al.* [1999])

•Combined measurements of Incoherent and coherent scatter measurements.

•Precise measurements allow the observation of *F* region vortex.

• We expect to improve those measurements with the addition of digital rxs at Jicamarca with more dynamic range.



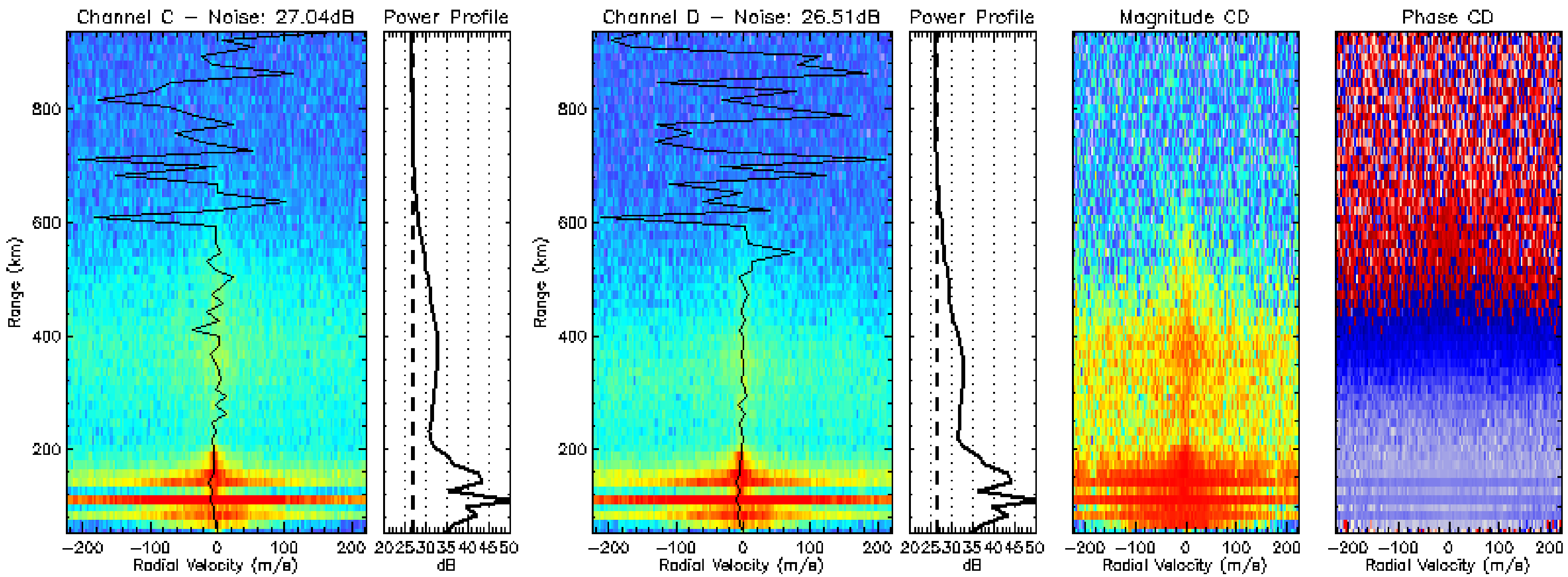
ISR example (5)
Perpendicular Mode -Differential Phase

(*Kudeki et al.* [2003], *Feng et al.* [2003], *Feng et al.* [2004])

•This new mode allows the simultaneous measurements of ionospheric drifts and densities.

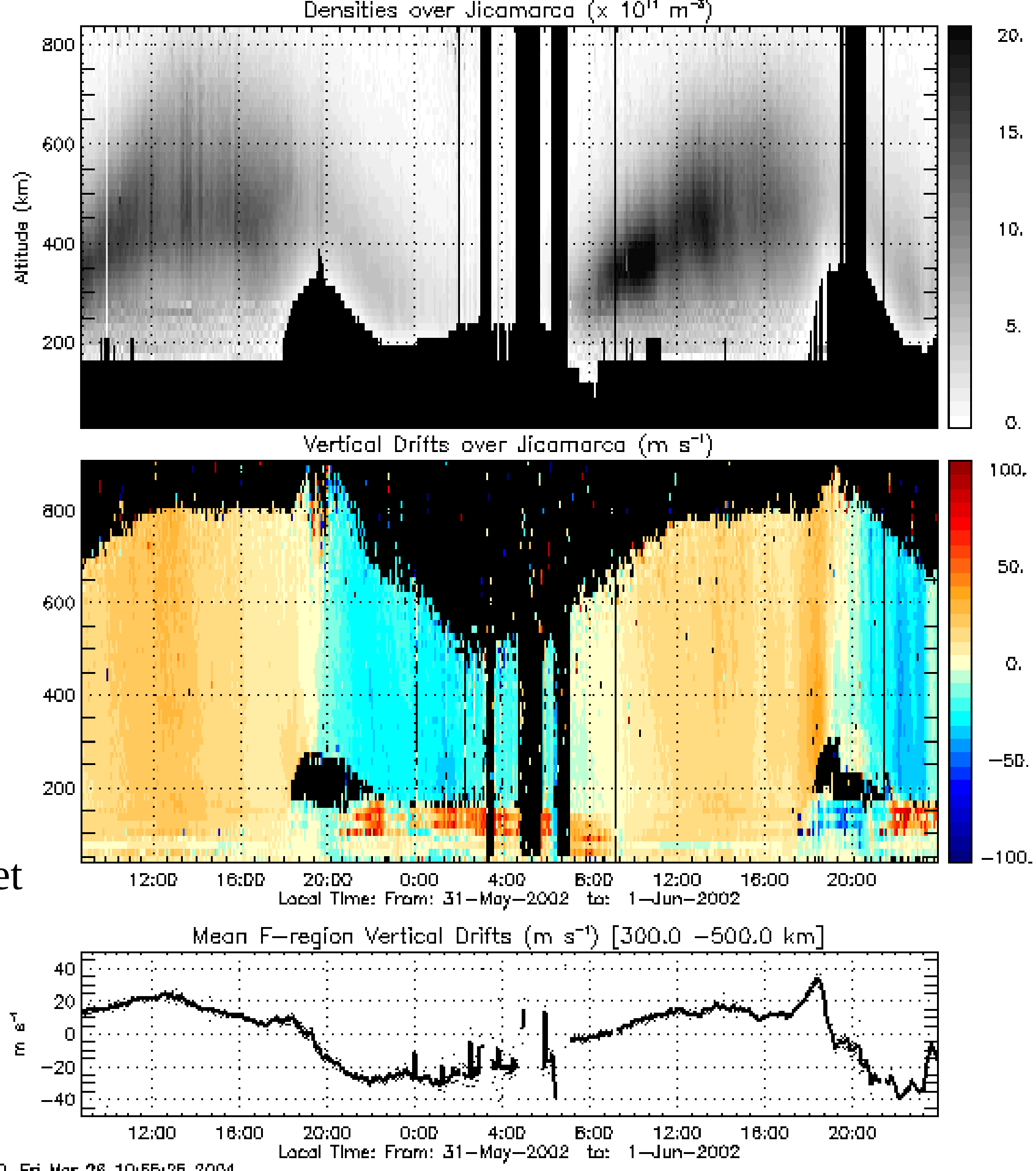
•Relative densities are obtained from total power measurements

•Absolute measurements are obtained from the differential phase measurements (self calibration) or from the ionosonde measurements.



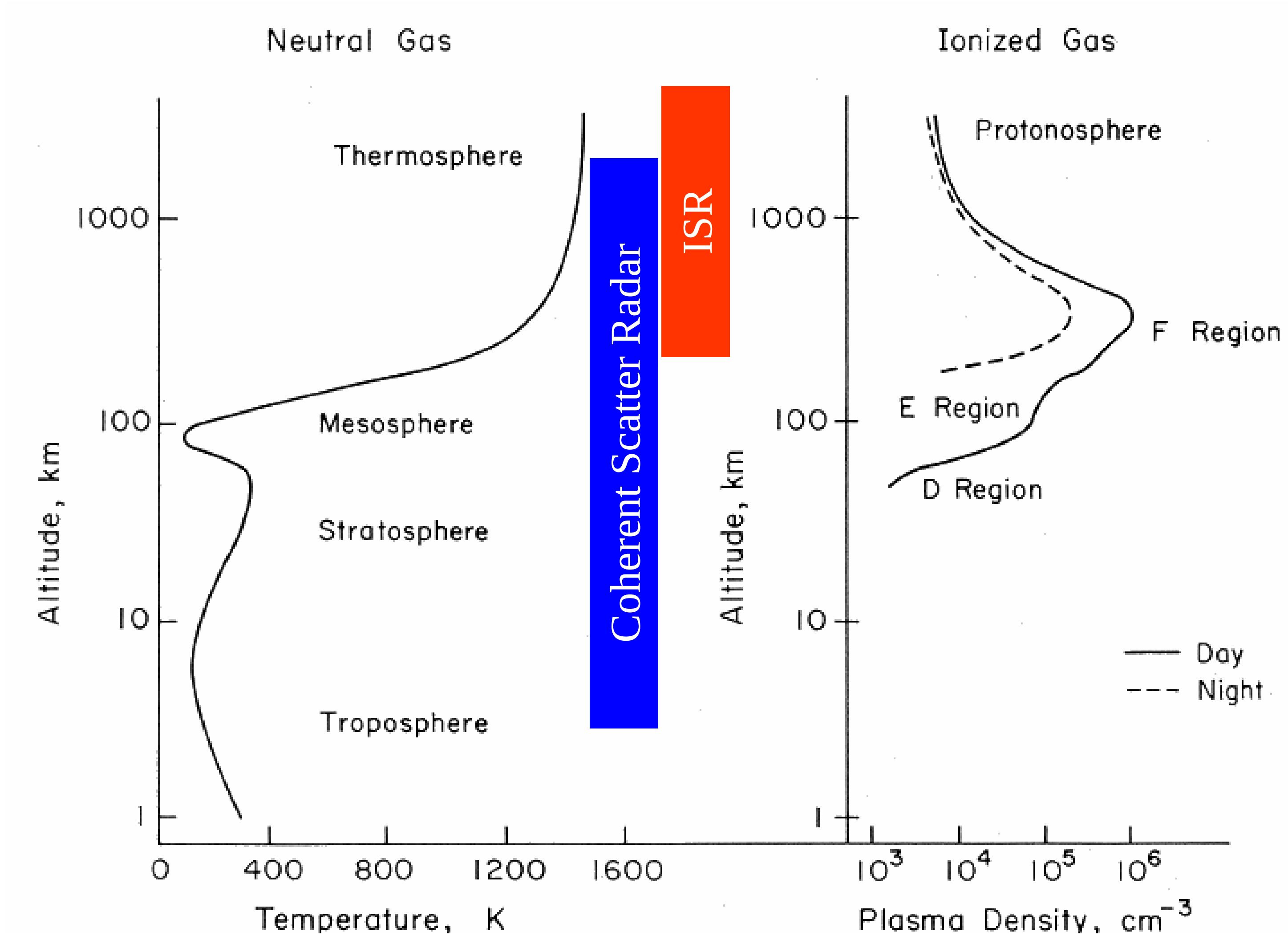
ISR example (6) Perpendicular Mode Differential Phase

(*Kudeki et al.* [2003]
Feng et al. [2003]
Feng et al. [2004])



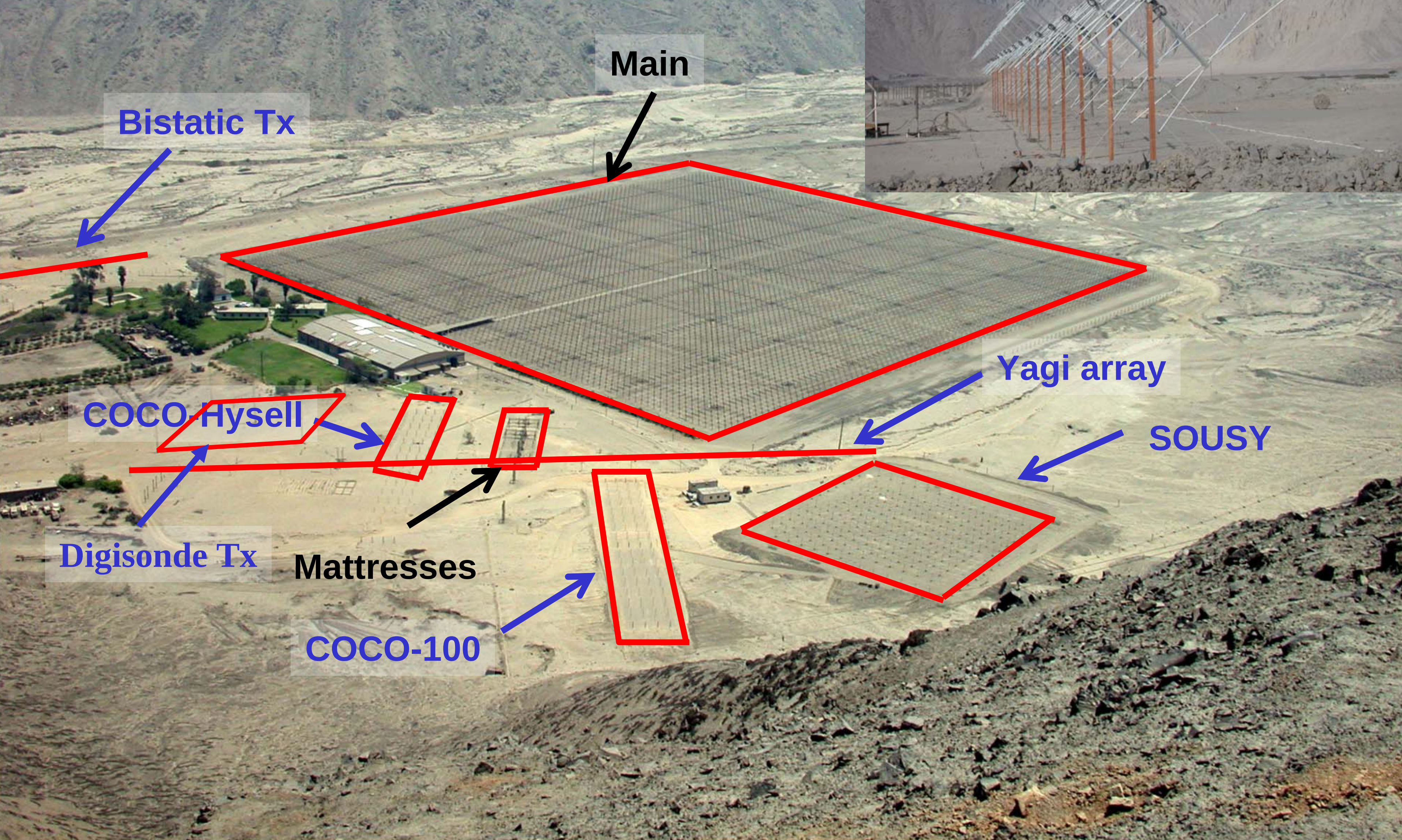
- Simultaneous measurements of <u>vertical</u> drifts and densities.
- Future efforts will be devoted to get simultaneously:
  - zonal drifts
  - temperatures

JRO Modes



Neutral Gas
Ionized Gas
Thermosphere
Mesosphere
Stratosphere
Troposphere
Coherent Scatter Radar
ISR
Protonosphere
F Region
E Region
D Region
Day
Night
Altitude, km
1000
100
10
1
0
400
800
1200
1600
Temperature, K
10^3
10^4
10^5
10^6
Plasma Density, cm^-3

Additional antennas and systems



MST Spectra

(from *Woodman* [2002])

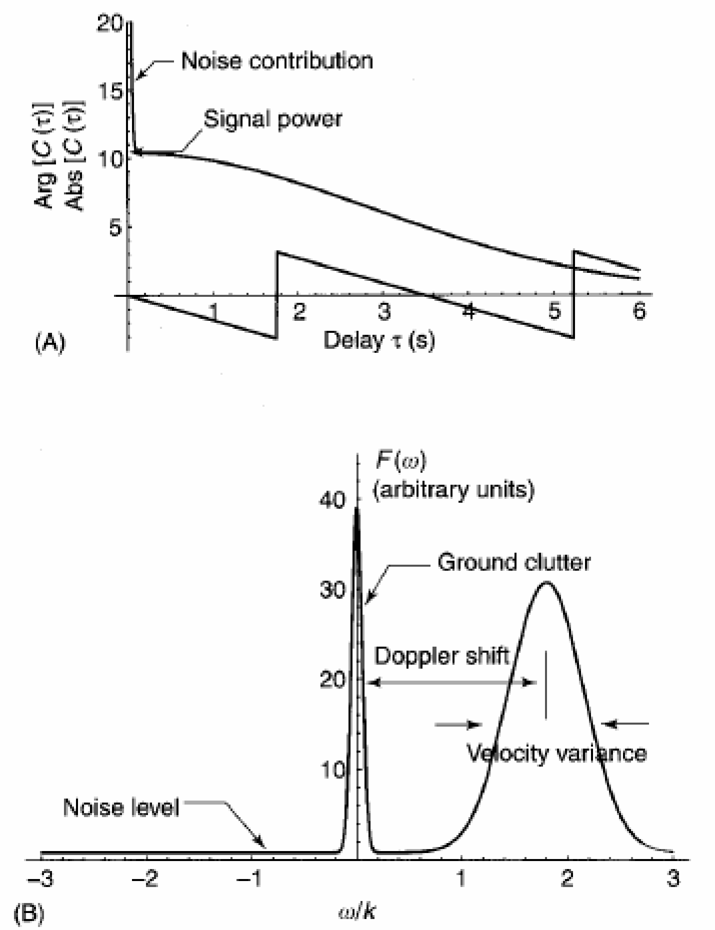
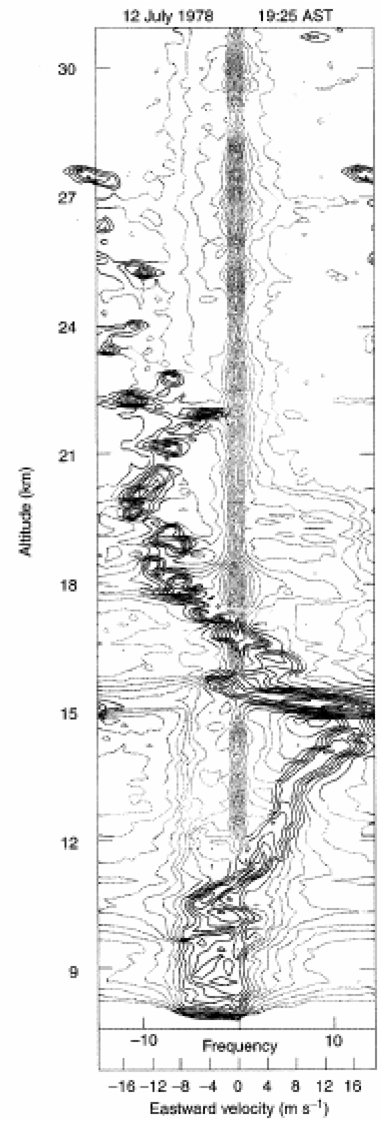
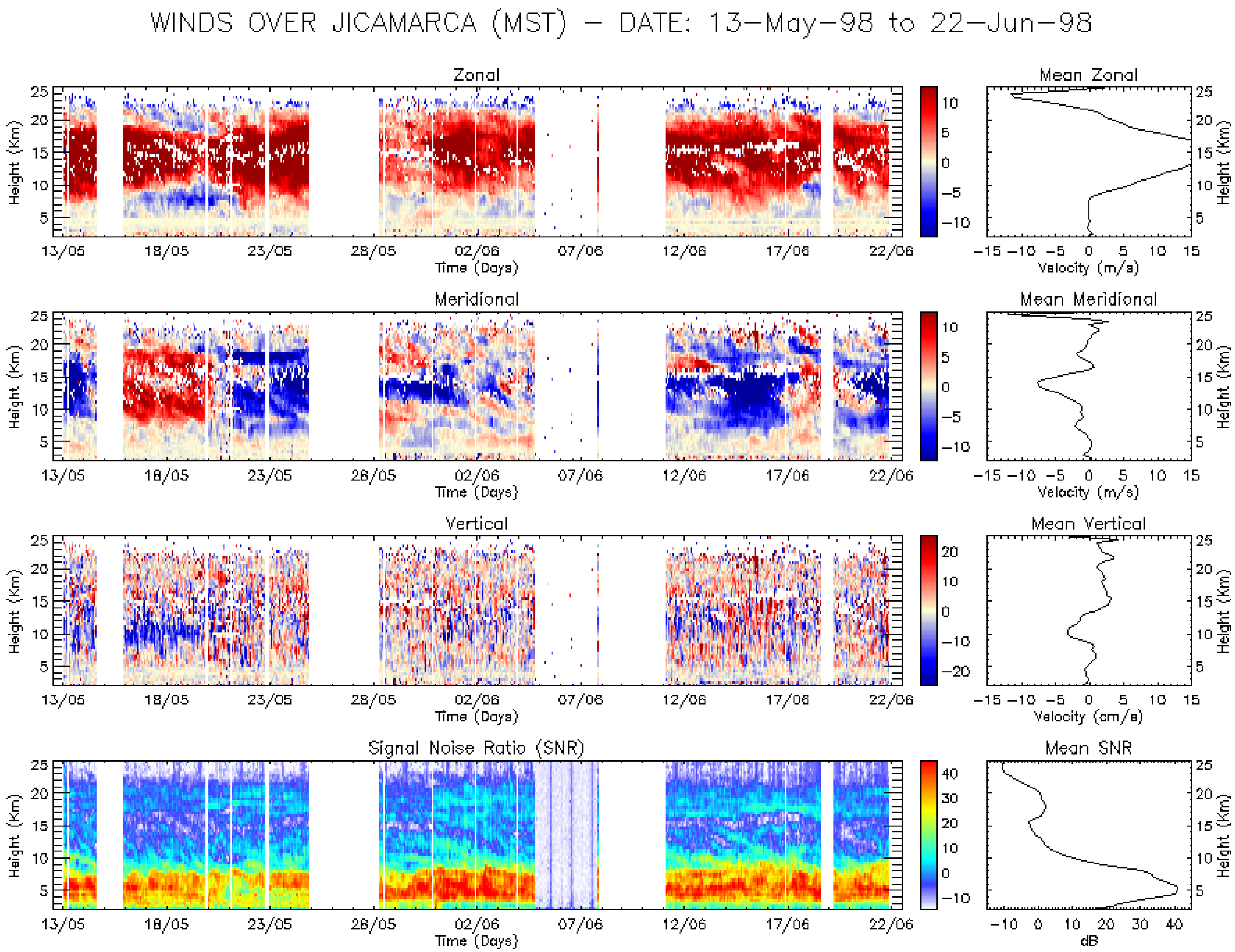


Figure 3 Statistical properties of the time series at a given altitude, h: (A) its complex, amplitude and phase, temporal autocorrelation function $C_h(\tau)$; (B) its corresponding frequency spectrum, $F_h(\omega)$.



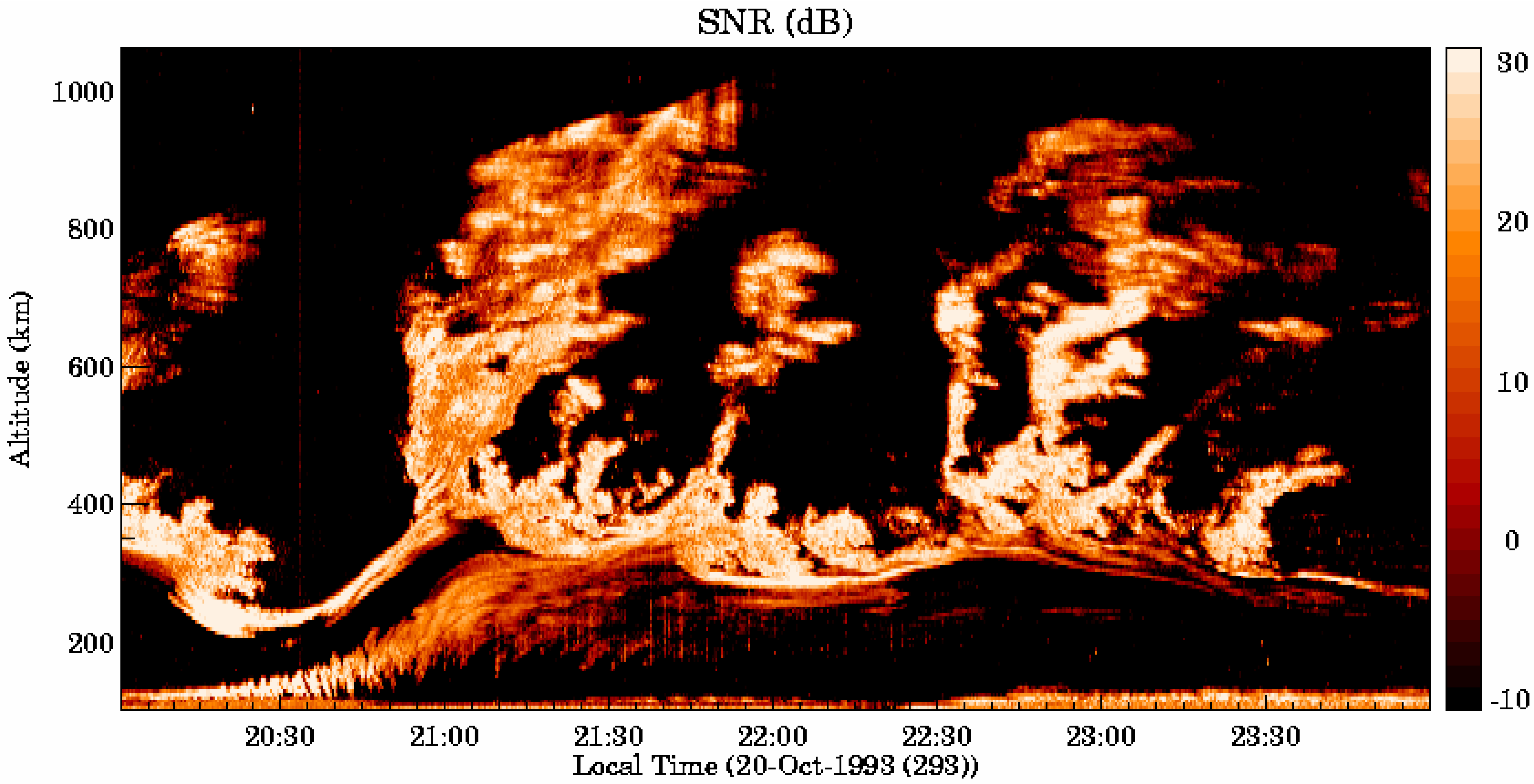
MST Winds



WINDS OVER JICAMARCA (MST) – DATE: 13–May–98 to 22–Jun–98
Zonal
Mean Zonal
Meridional
Mean Meridional
Vertical
Mean Vertical
Signal Noise Ratio (SNR)
Mean SNR
Height (Km)
Time (Days)
Velocity (m/s)
Velocity (cm/s)
dB
13/05
18/05
23/05
28/05
02/06
07/06
12/06
17/06
22/06

ESF echoes

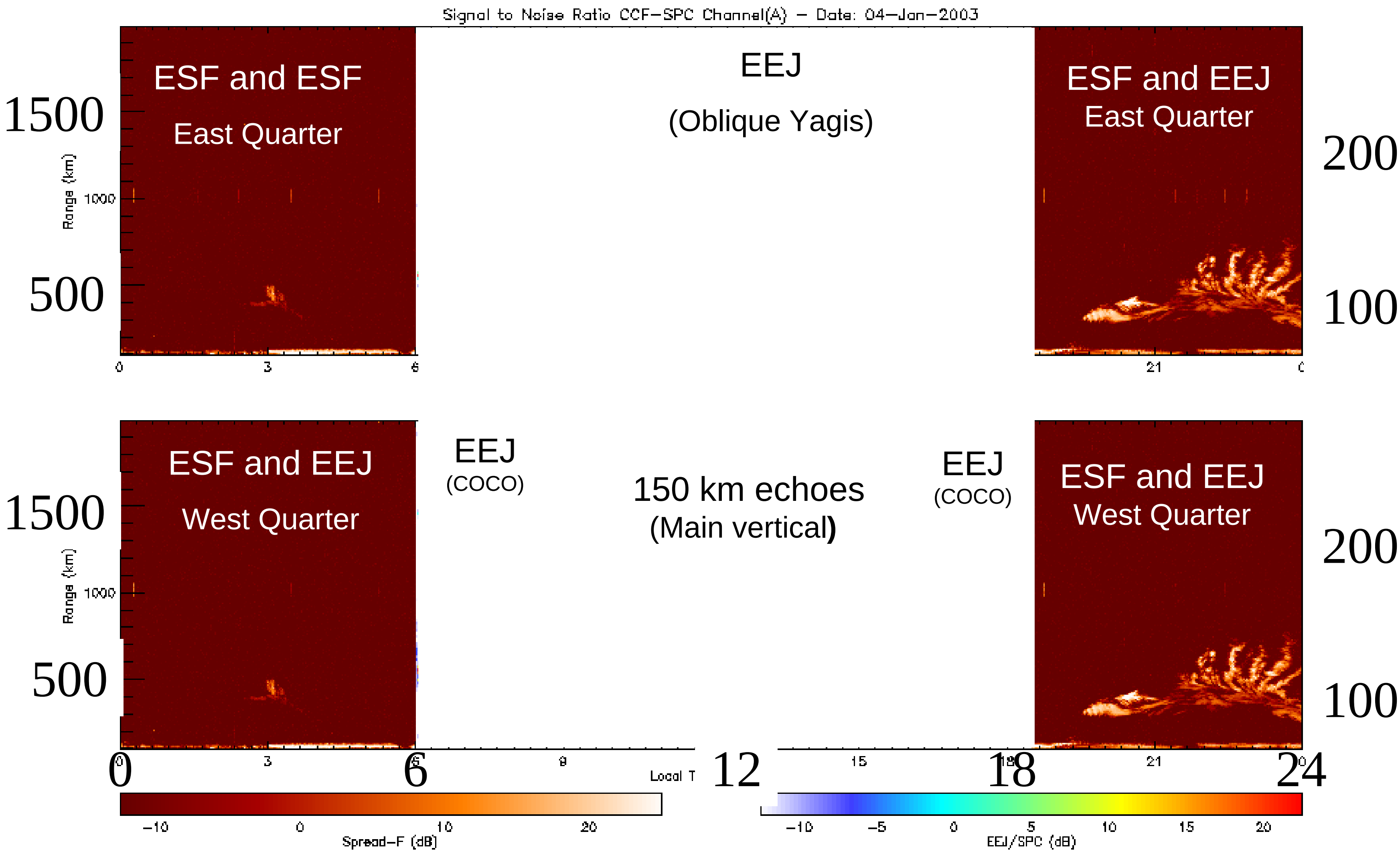
(from *Woodman and Chau* [2001])



CSR-JULIA: Multimode Ionospheric Observations

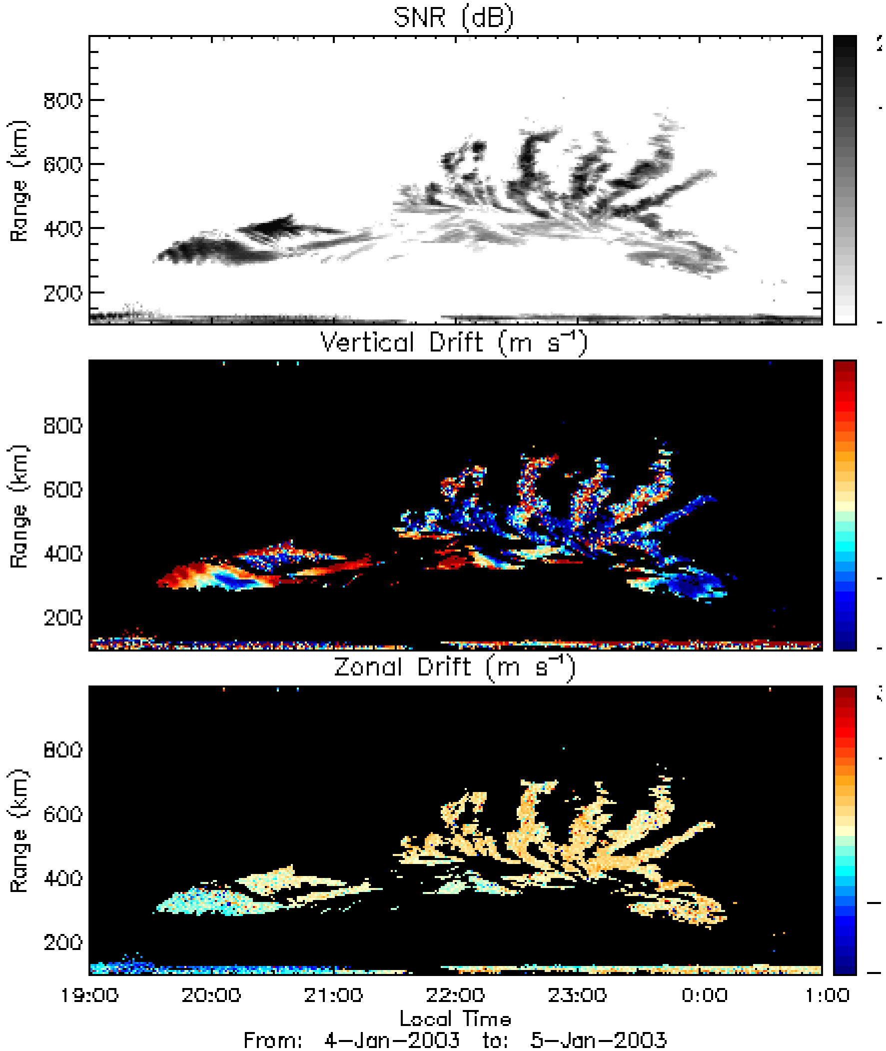
"Jicamarca Unattended Long term Investigations of the Atmosphere" (*Balsley*, 1993)

JULIA concept: "Low-power and long-term measurements at Jicamarca"

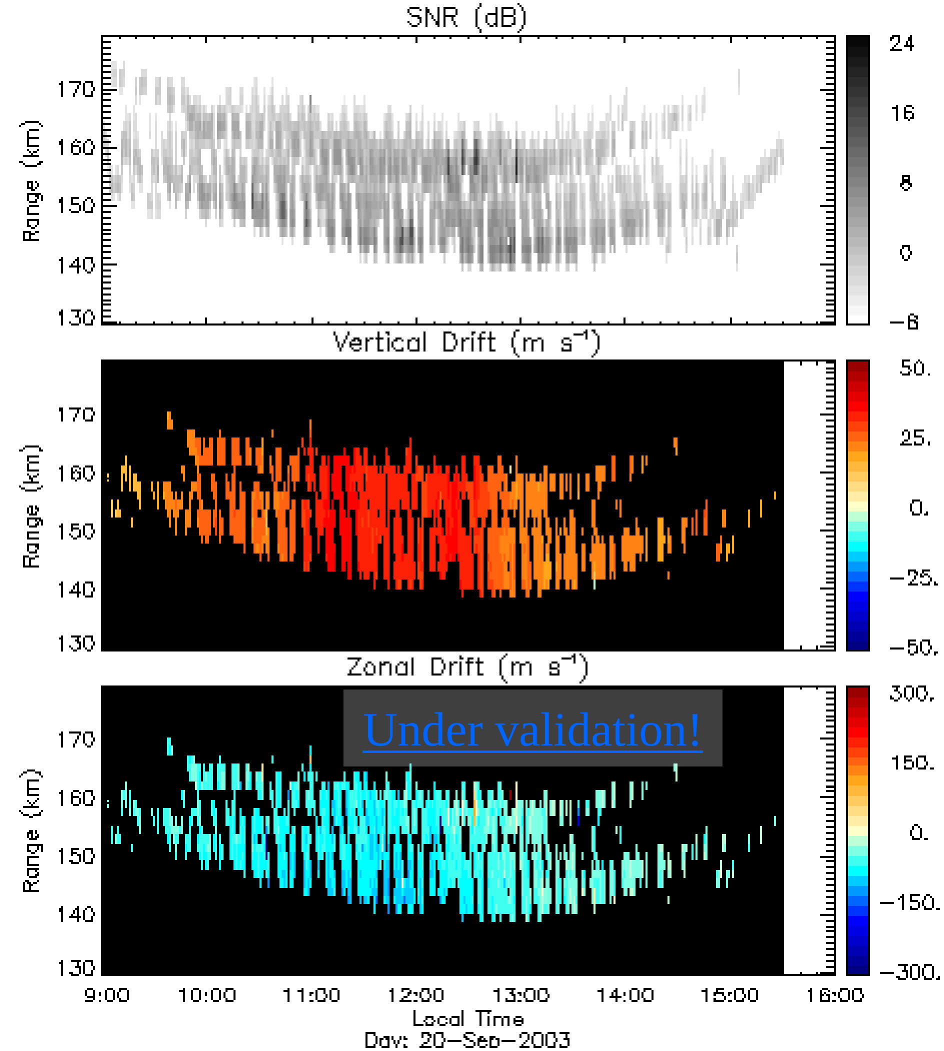


CSR- JULIA: Parameters from ESF and 150-km echoes

ESF: Interferometry

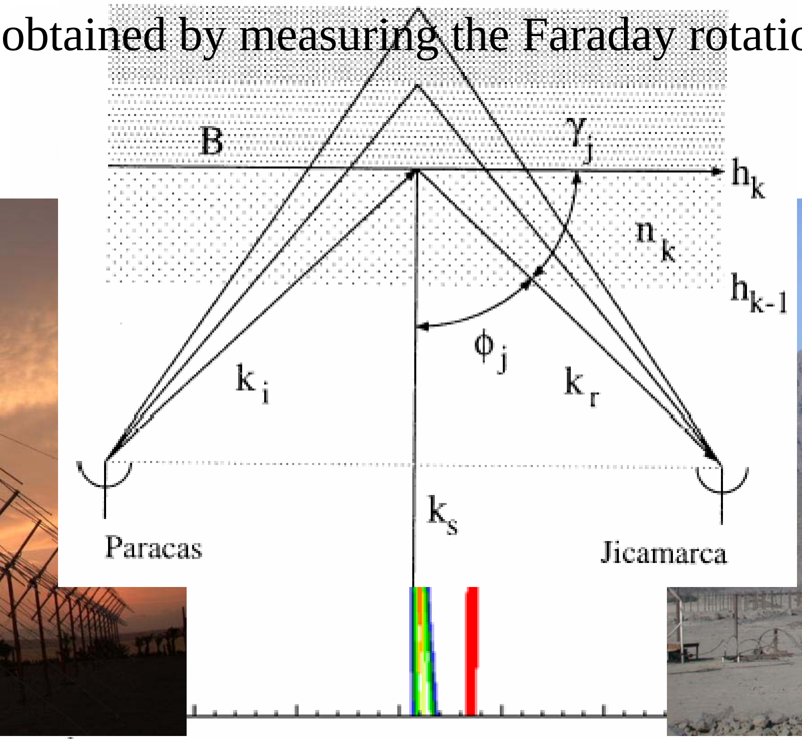


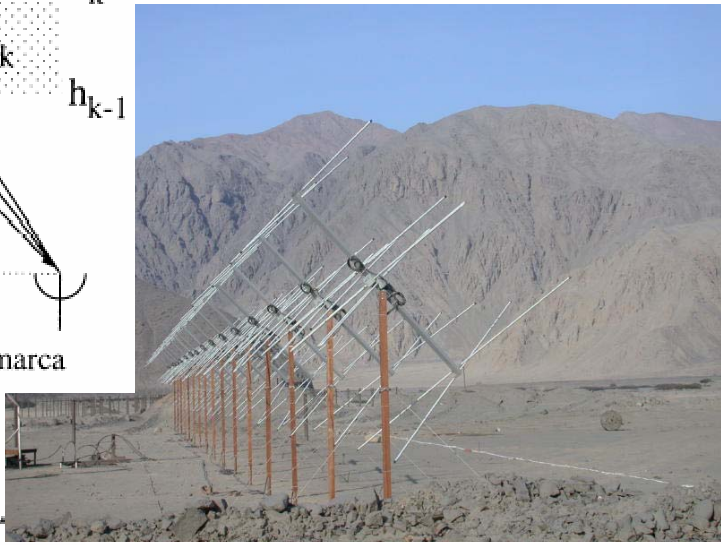
150-km:Dual beam



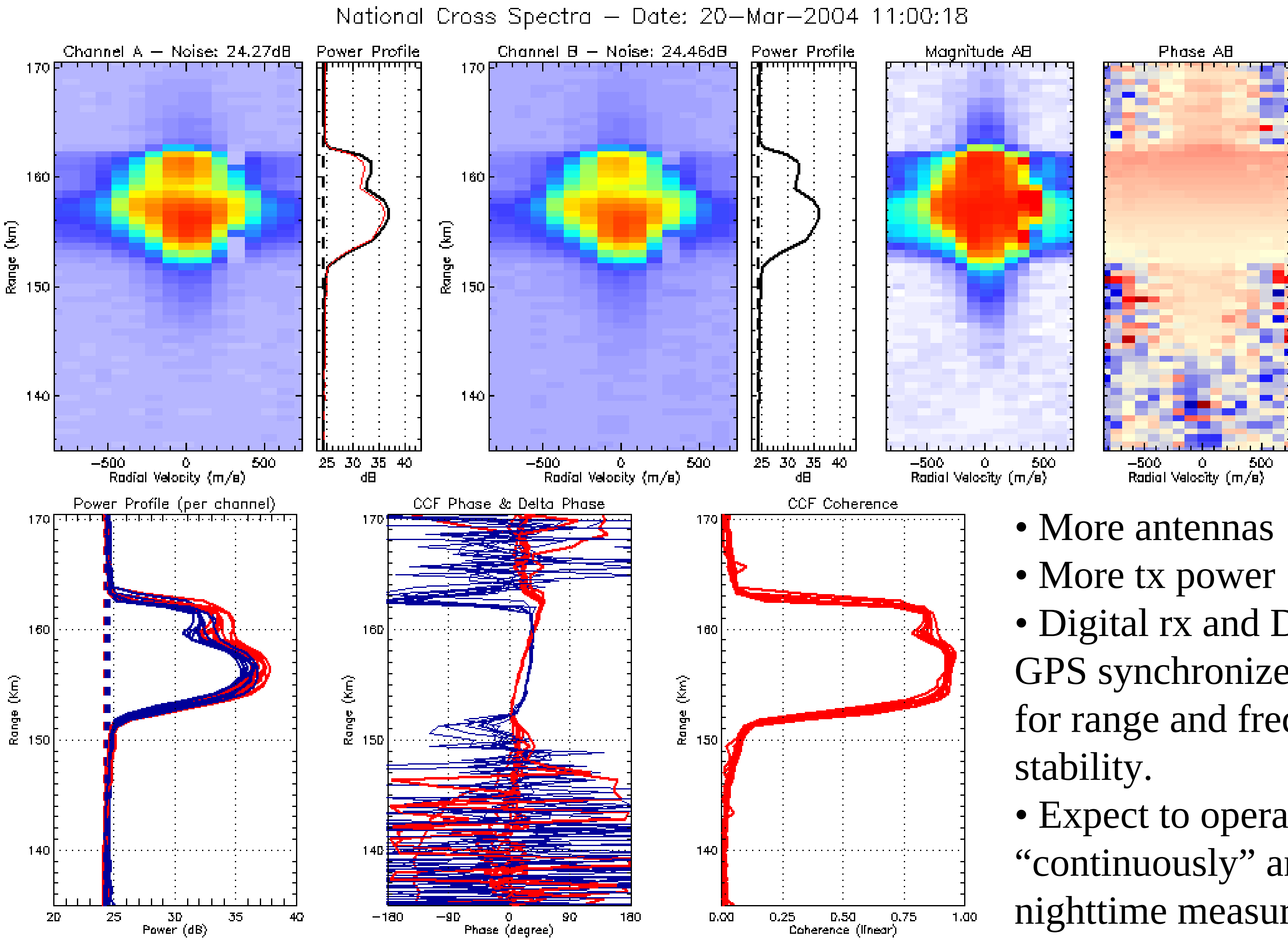
CSR- Bistatic Mode (1)

- This bistatic mode complements Jicamarca capabilities.
- *E* region measurements using ISR are not possible at JRO due to the presence of strong EEJ “clutter”.
- Technique was introduced by *Hysell and Chau* [2001] using very small systems. Only daytime observations were made at the time.
- The technique takes advantage of the strong EEJ echoes to scatter part of the signal transmitted.
- Density profiles are obtained by measuring the Faraday rotation of the scatter signal as a function of range.



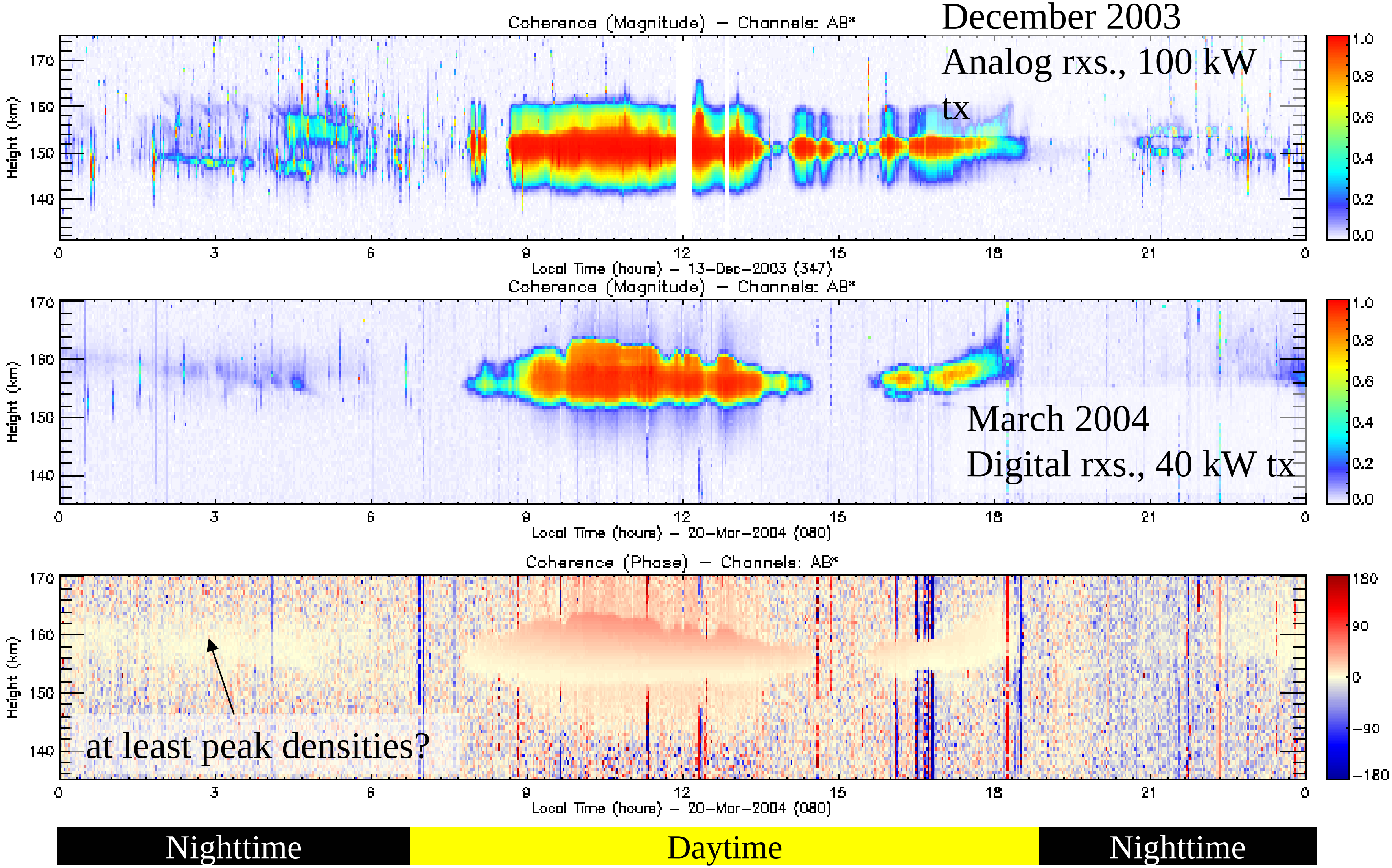


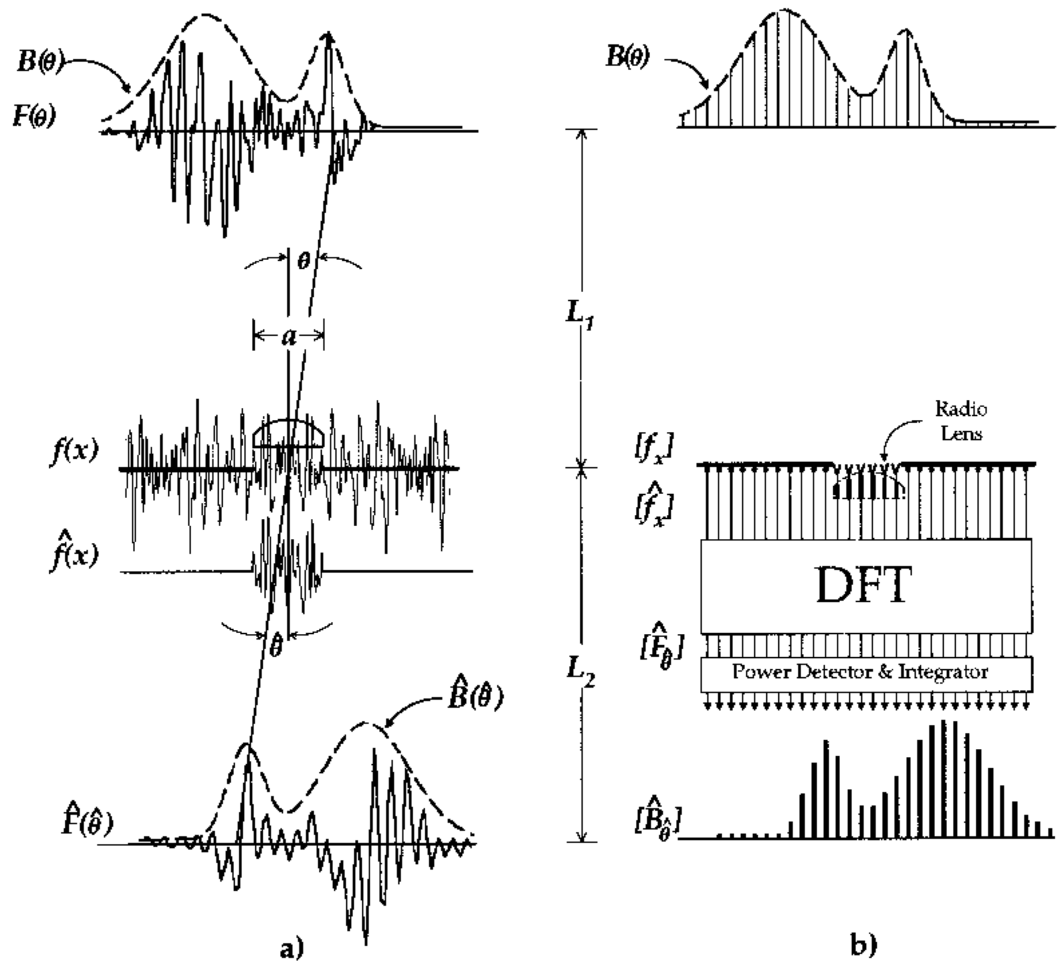
CSR- Bistatic Mode (3) - New “permanent” system



- More antennas
- More tx power
- Digital rx and DDS, using GPS synchronized clocks for range and frequency stability.
- Expect to operate “continuously” and get nighttime measurements

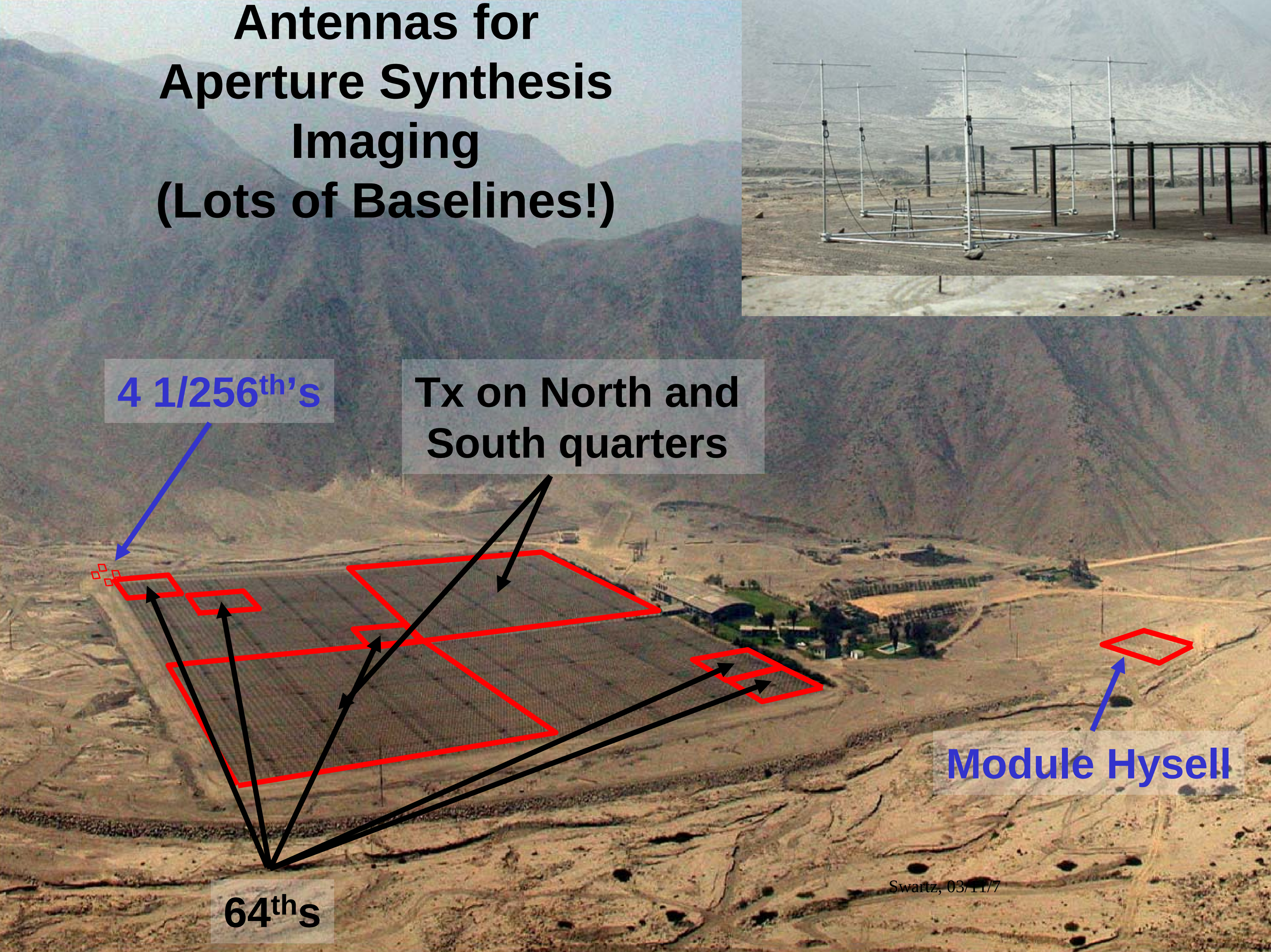
CSR- Bistatic Mode (4) – Nighttime capability (?)





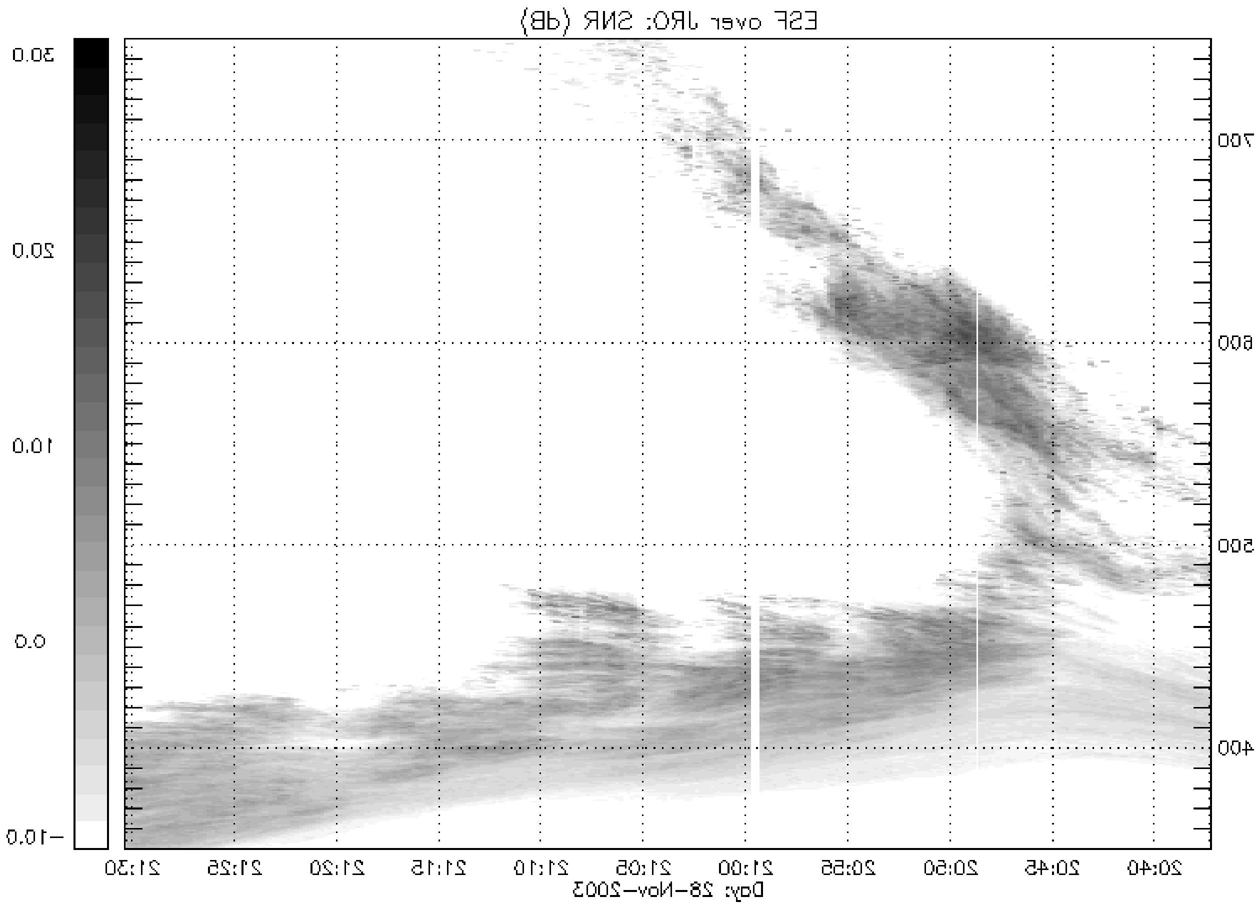
(from *Woodman* [1997])

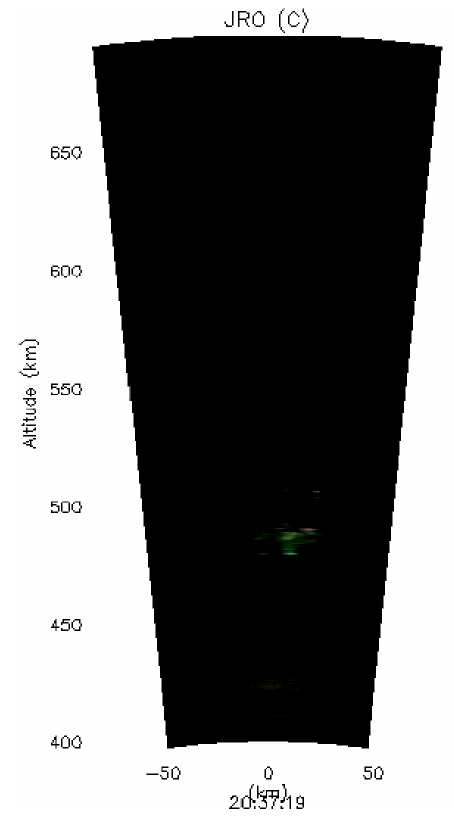
Antennas for Aperture Synthesis Imaging (Lots of Baselines!)



Radar Imaging (1) – ESF

(from *Hysell et al.* [2004])





Radar Imaging (2) – EEJ

(from *Chau and Hysell* [2004])