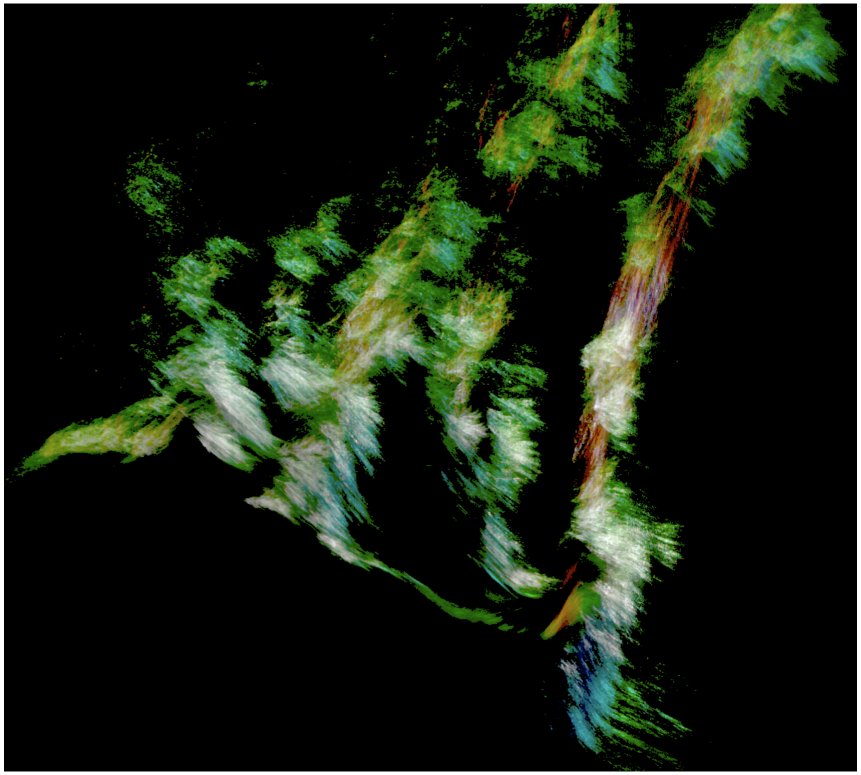
The Equatorial Ionosphere and the Jicamarca Radio Observatory



J. L. Chau et al.

Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima

Ackowledgements:

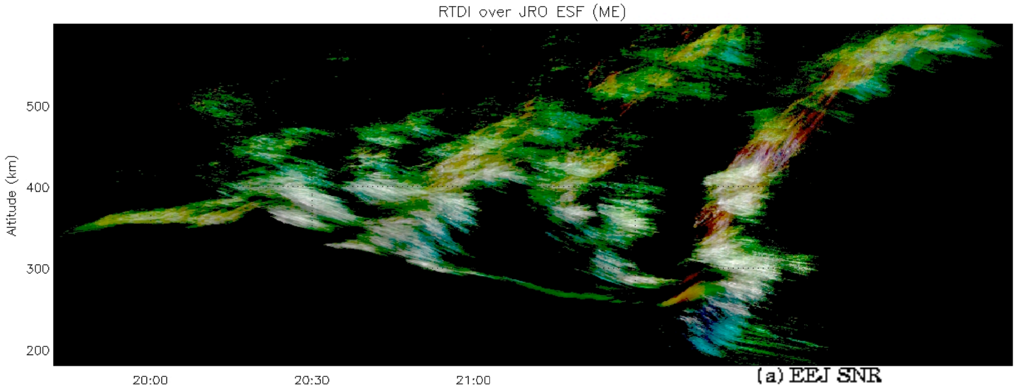
G. Lehmacher, Clemson University

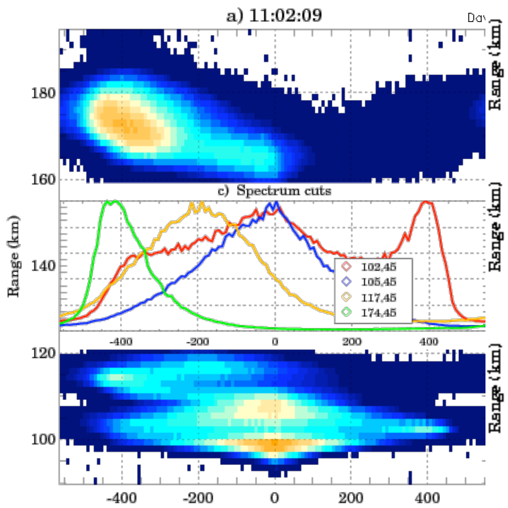
IAP, Kühlungsborn, Mar-25, 2009

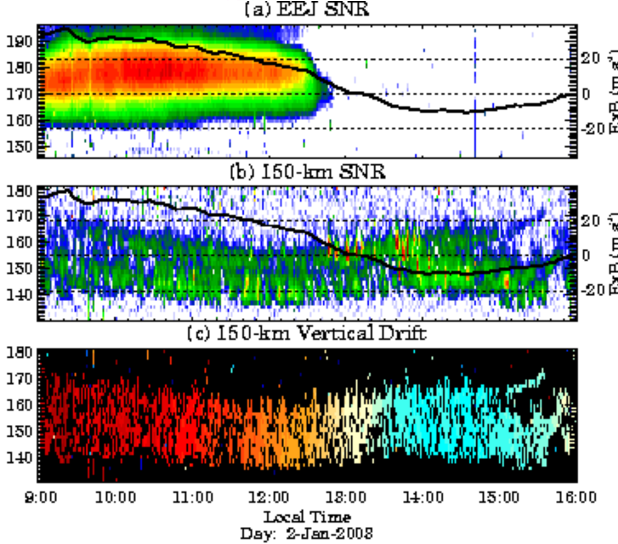
Outline

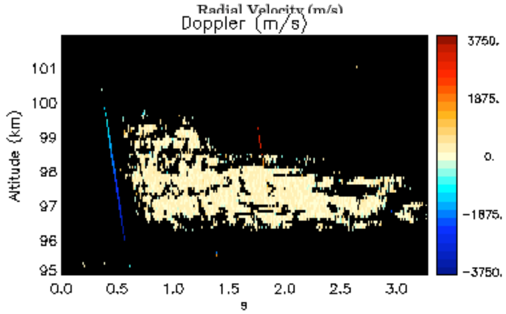
Radio Observatorio de
JICAMARCA
Radio Observatory

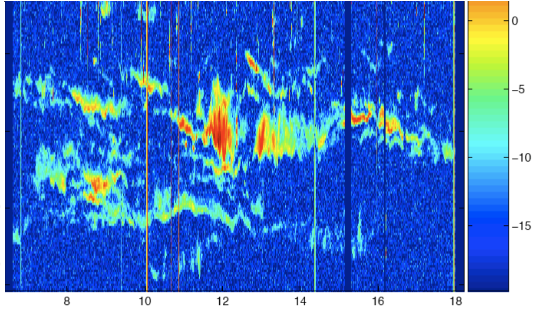
- The Equatorial ionosphere
- The Jicamarca Radio Observatory
  - Incoherent Scatter Radar Modes
  - Coherent scatter studies
- Selected Research Topics
  - Sudden Stratospheric Warming events.
  - Mesospheric Echoes (PEME)
  - Tropospheric KHI



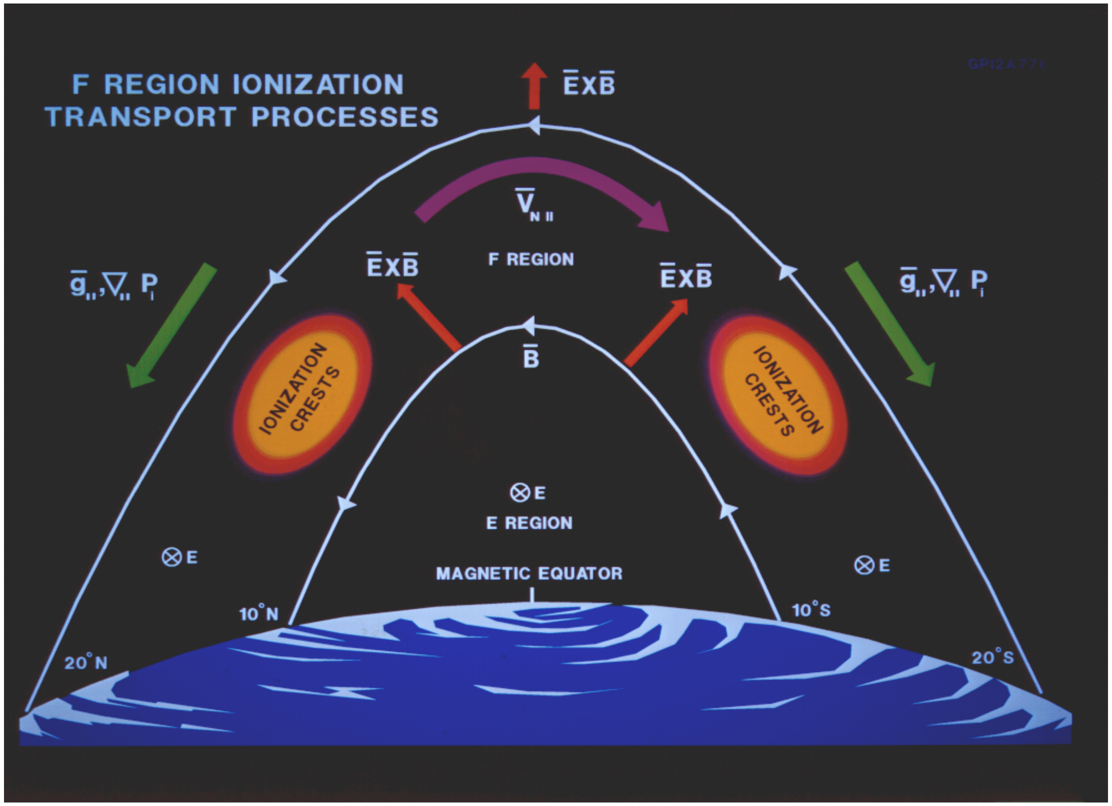


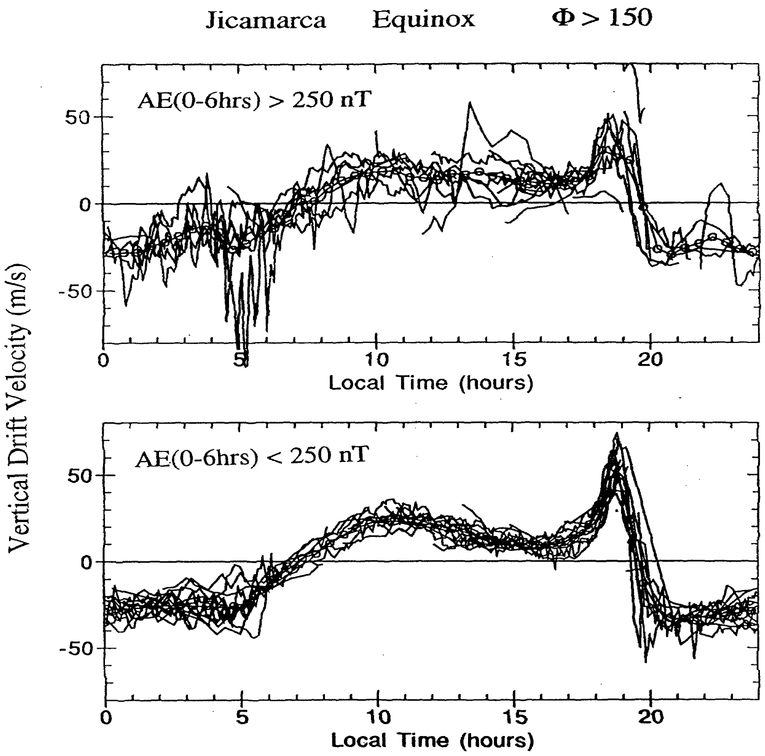






Equatorial Ionosphere

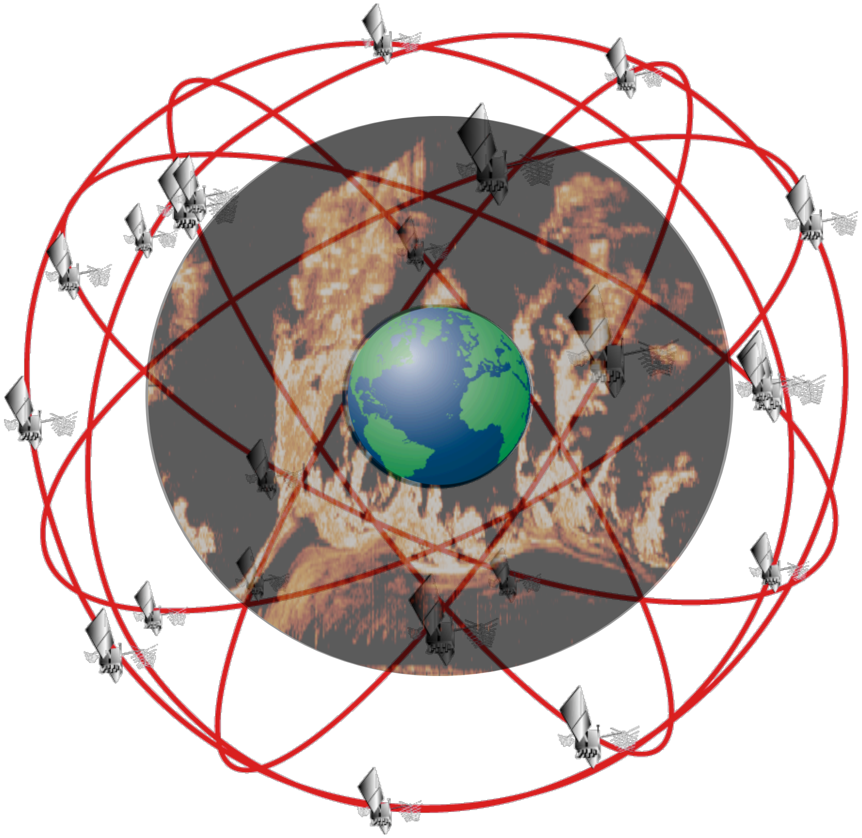




[from *Fejer et al*, 1999]

- **B** field is nearly horizontal
- Daytime:
  - *E*-region E is eastward
  - Off-equatorial E maps to F above mag. Equator -> Upward ExB
  - Formation of Appleton Anomaly
- Around sunset, *F* region dynamo develops and competes with *E*, generates PRE and ExB goes downward (E westward)
- At night upward density gradient is opposite in direction to g, Rayleigh-Taylor unstable, allowing plasma density irregularities to form.

GPS System



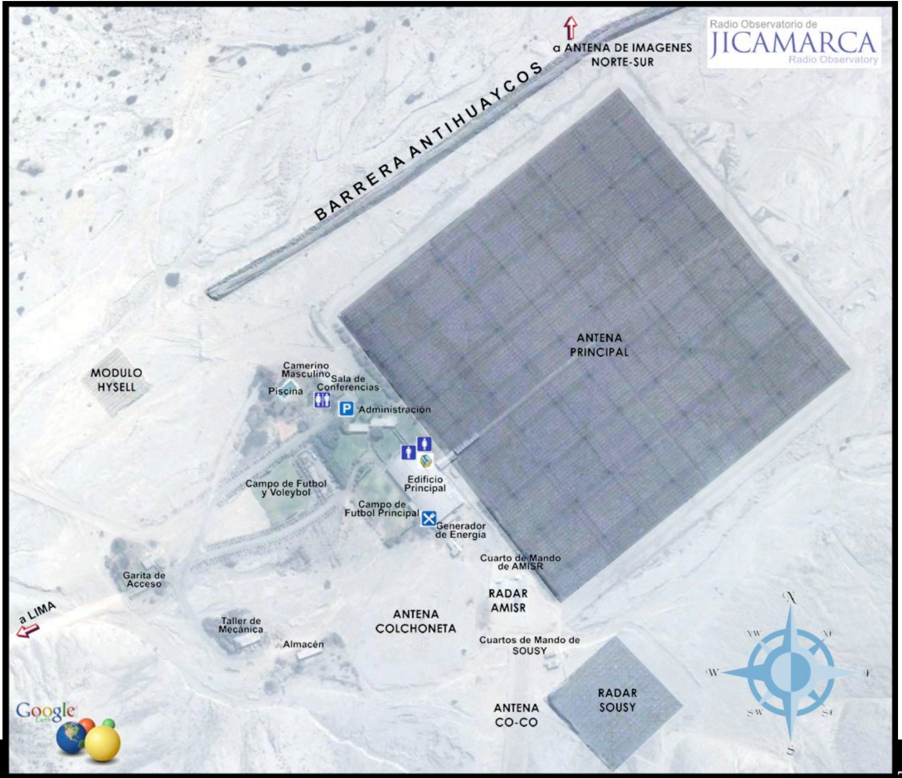
- 24 GPS satellites
- Orbits at 20,000 kms altitude and 6 orbital planes
- Each satellite completes an orbit every 12 hours

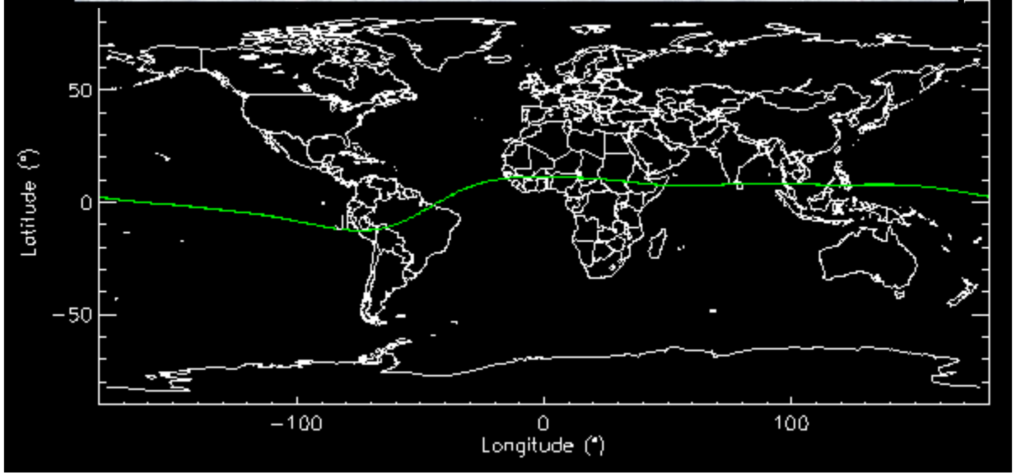
<u>Applications</u>

- Civil, military
- Scientific: Geodesy, Meteorology, Aeronomy

The Jicamarca Radio Observatory

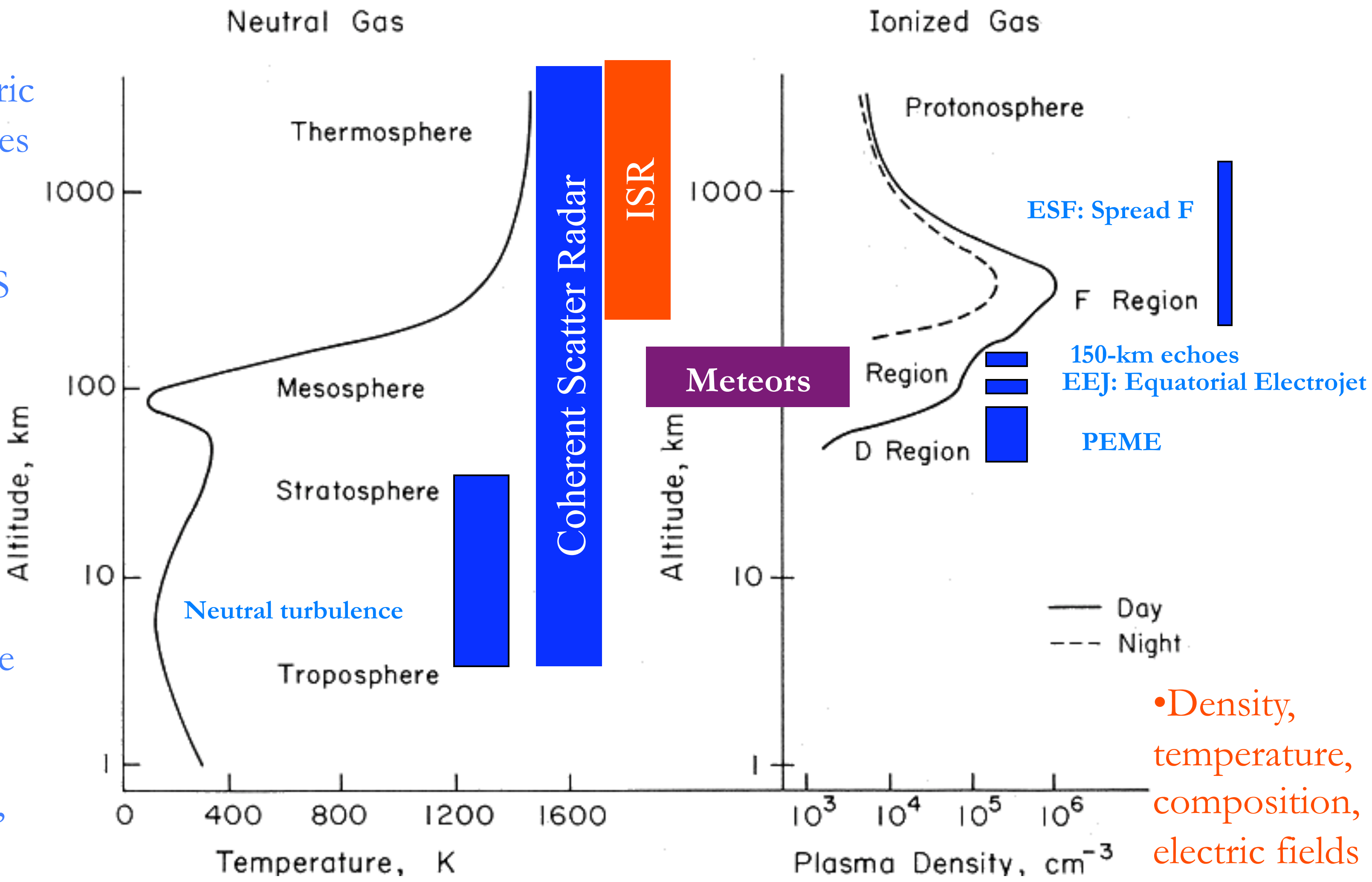
- Built in 1961 by the US NBS and then donated to IGP in 1969.
- Operating frequency: 50 MHz
- Antenna type: array of 18,432 dipoles, organized in 8x8 cross-polarized modules.
- Pointing directions: within 3 degrees from on-axis. Phase changes are currently done manually.
- Transmitters: 3 x 1.5 MW peak-power with 5% duty cycle.
- Located "under" the magnetic equator (dip 1º).





¿What do we study at Jicamarca?

- Ionospheric Irregularities (EEJ, 150-km, ESF).
- SAR, GPS



- Neutral atmosphere dynamics (winds, turbulence, vertical velocities)
- Meteorology, aviation.

- Density, temperature, composition, electric fields
- Modeling, space weather

Jicamarca Themes (Stable Ionosphere)

- **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?

Oblique ISR Examples

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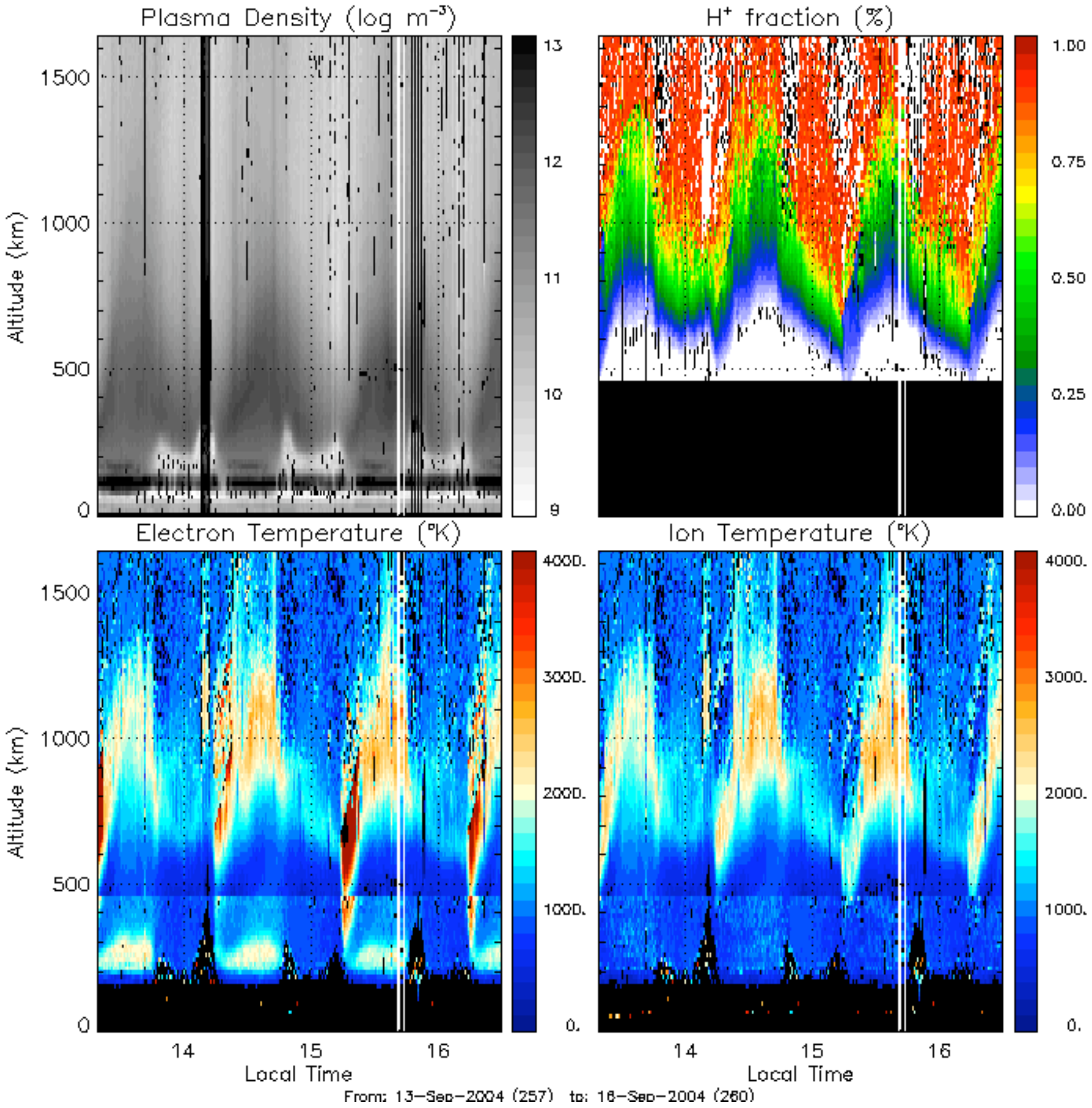

•This modes combines the Faraday Double Pulse mode with a long pulse mode, allowing the use of the available duty cycle.

•It provides:

-Absolute electron density (from Faraday rotation) and temperatures below 500 km.

-Density, temperatures and composition above 500 km.

•Preliminary results [*Hysell et al.* 2008].

-Good for Topside work and sunrise observations.

Perpendicular ISR Examples

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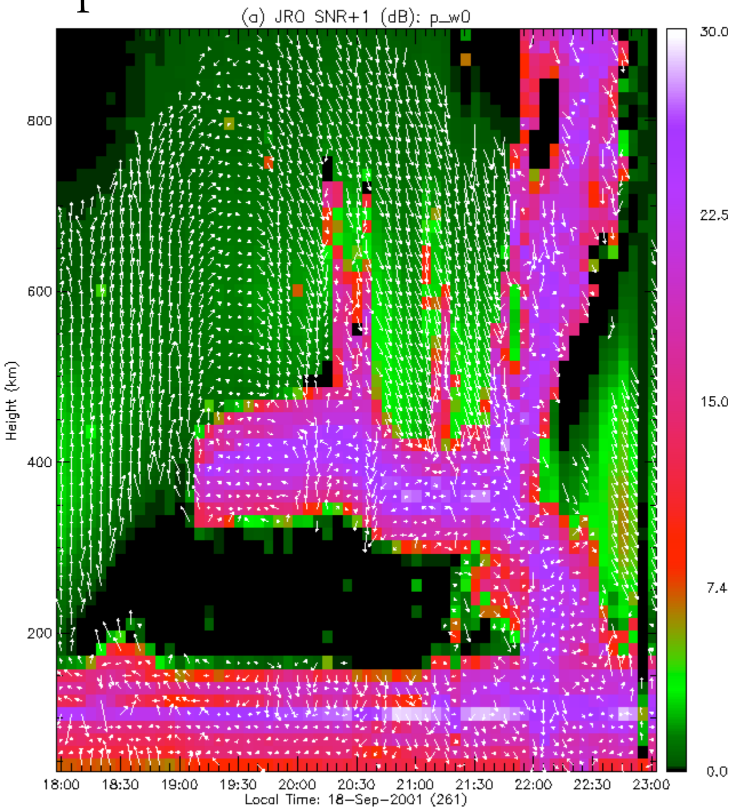
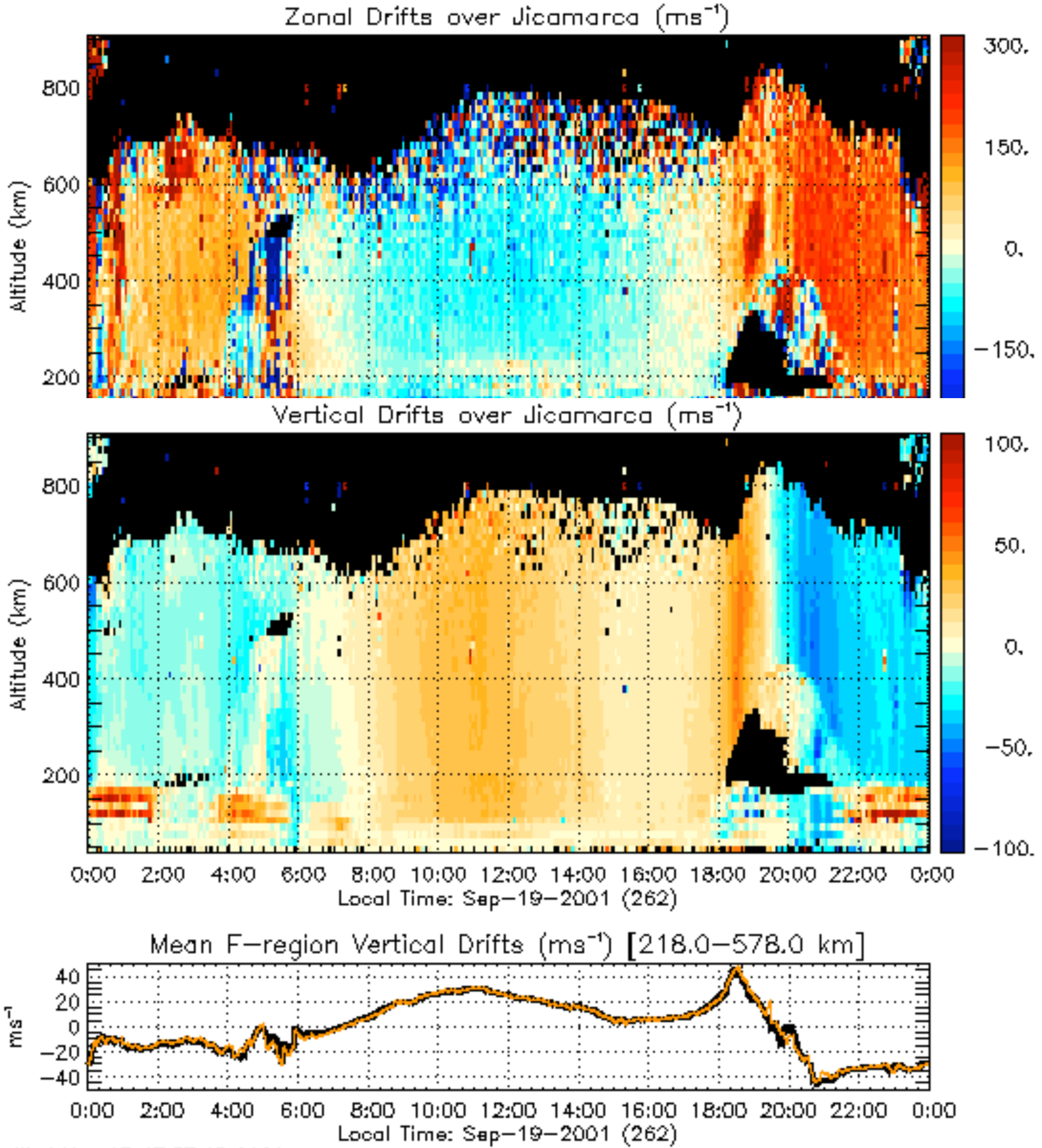
- Simultaneous measurements of vertical and zonal drifts, with 15 km and 5 min resolutions.
- JRO provides the most precise electric field measurements in the ionosphere.



[from *Kudeki and Batthacharyya*, 1999]



JRO. Wed May 17 17:57:43 2006

Plasma irregularities: What do we know from traditional radar studies?

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- Coherent echoes are typically 2-6 orders of magnitude stronger than ISR echoes.
- Range-time distributions (Intensity=RTI, Velocities)
  - Day-to-day and seasonal variability
  - Time periodicities (Gravity waves, tides)
- Spectral characteristics
  - Spectral shape (Gaussian, Lorentzian, more than one Gaussian)
  - Mean Doppler and Spectral width
- Multi-beam observations
  - Spatial Characteristics
  - 3D velocity vector
- Interferometry
  - Zonal velocity
  - Aspect Sensitivity (scale lengths)
- Imaging
  - Resolve space-time ambiguities

Coherent echoes over Jicamarca (1)
RTIs above 100 km

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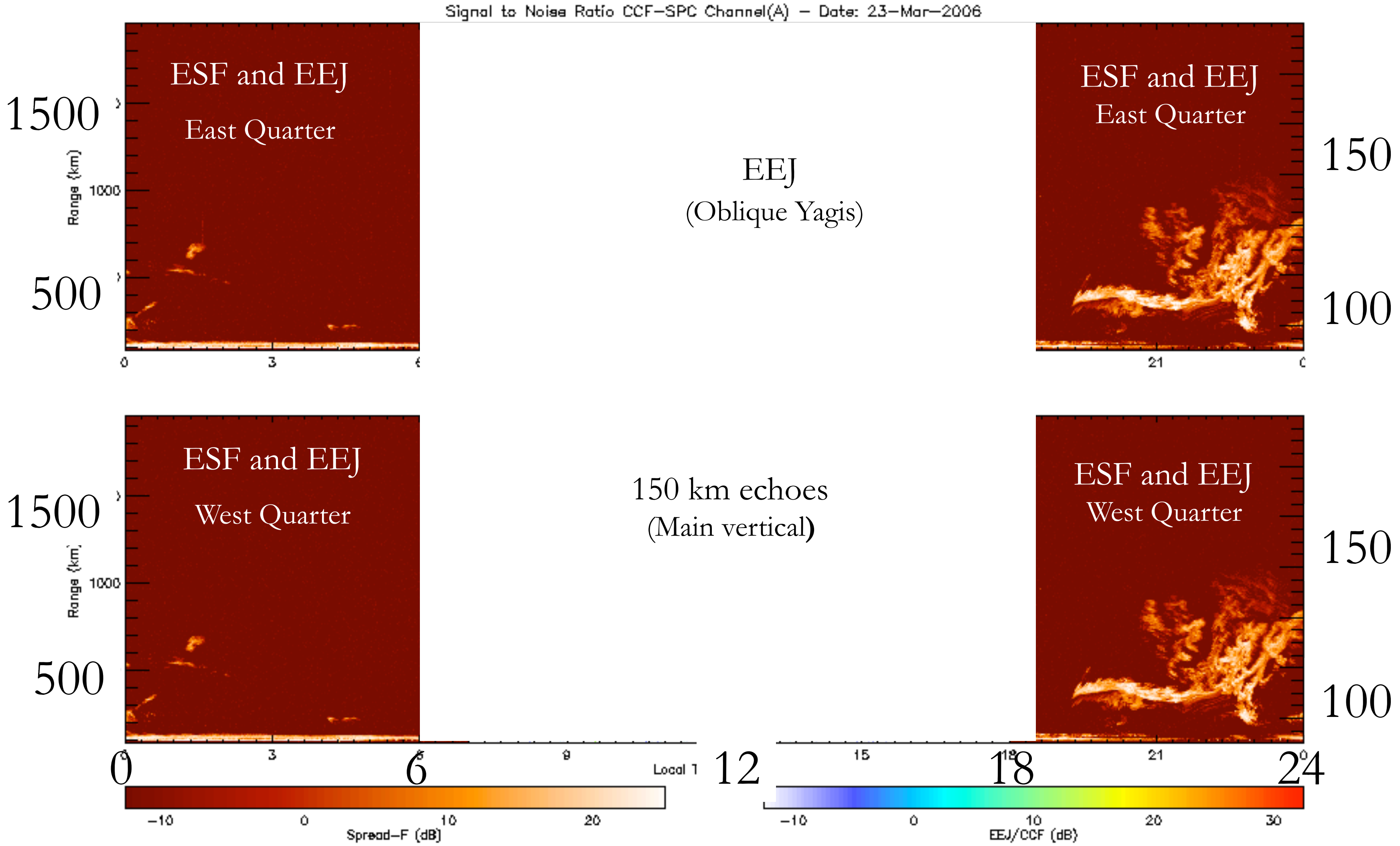
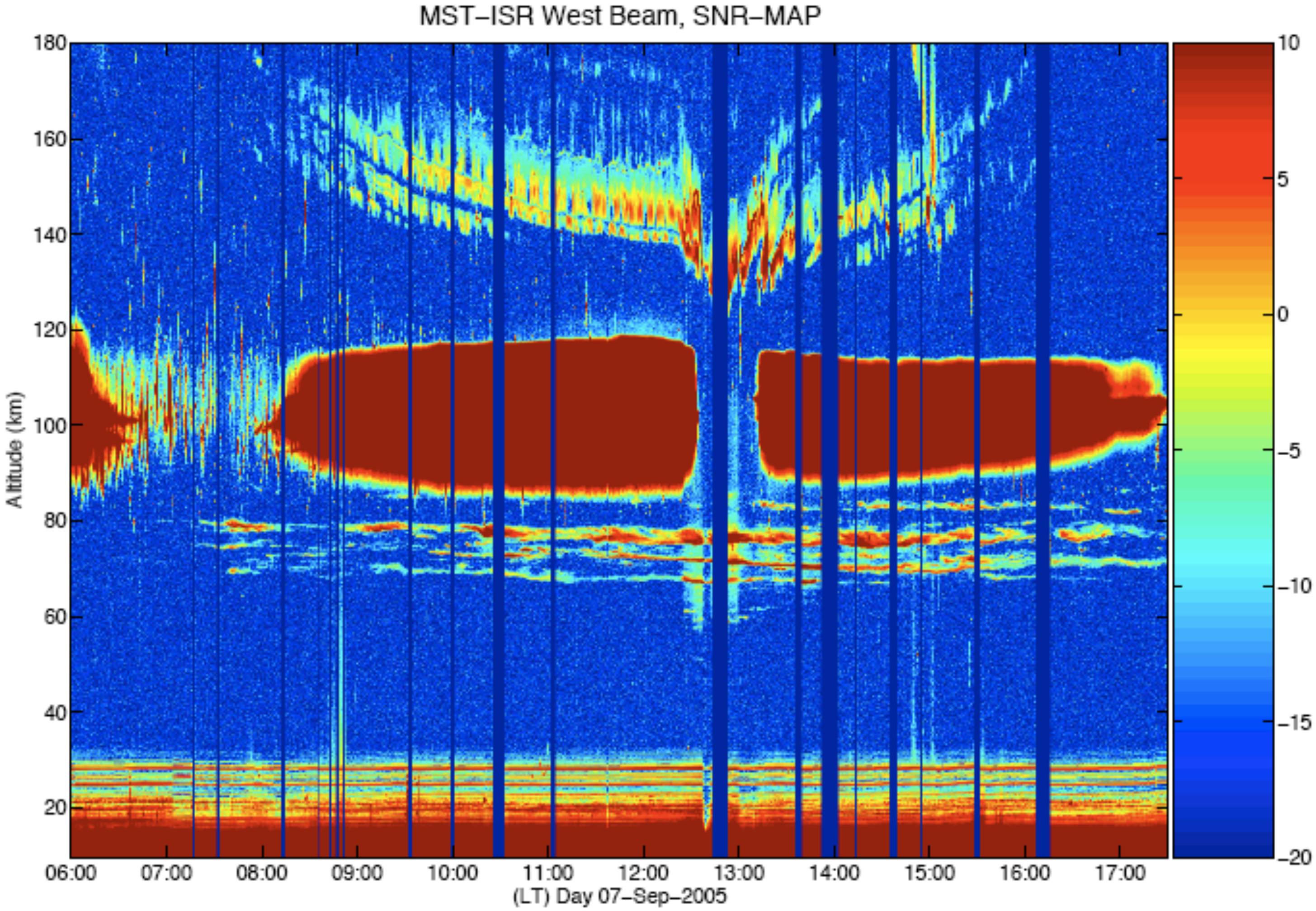


ESF: Equatorial Spread F (nighttime)

150-km echoes: Daytime

EEJ: Equatorial Electrojet (all day)

Coherent echoes over Jicamarca (2)
RTI below 200 km



150-km echoes
Daytime

EEJ echoes
All Day
(Daytime stronger)

Meteor echoes
All Day
(head, non-specular and specular trails)

Mesospheric echoes
Daytime

Stratospheric and Tropospheric echoes
All Day

ESF: RTI maps

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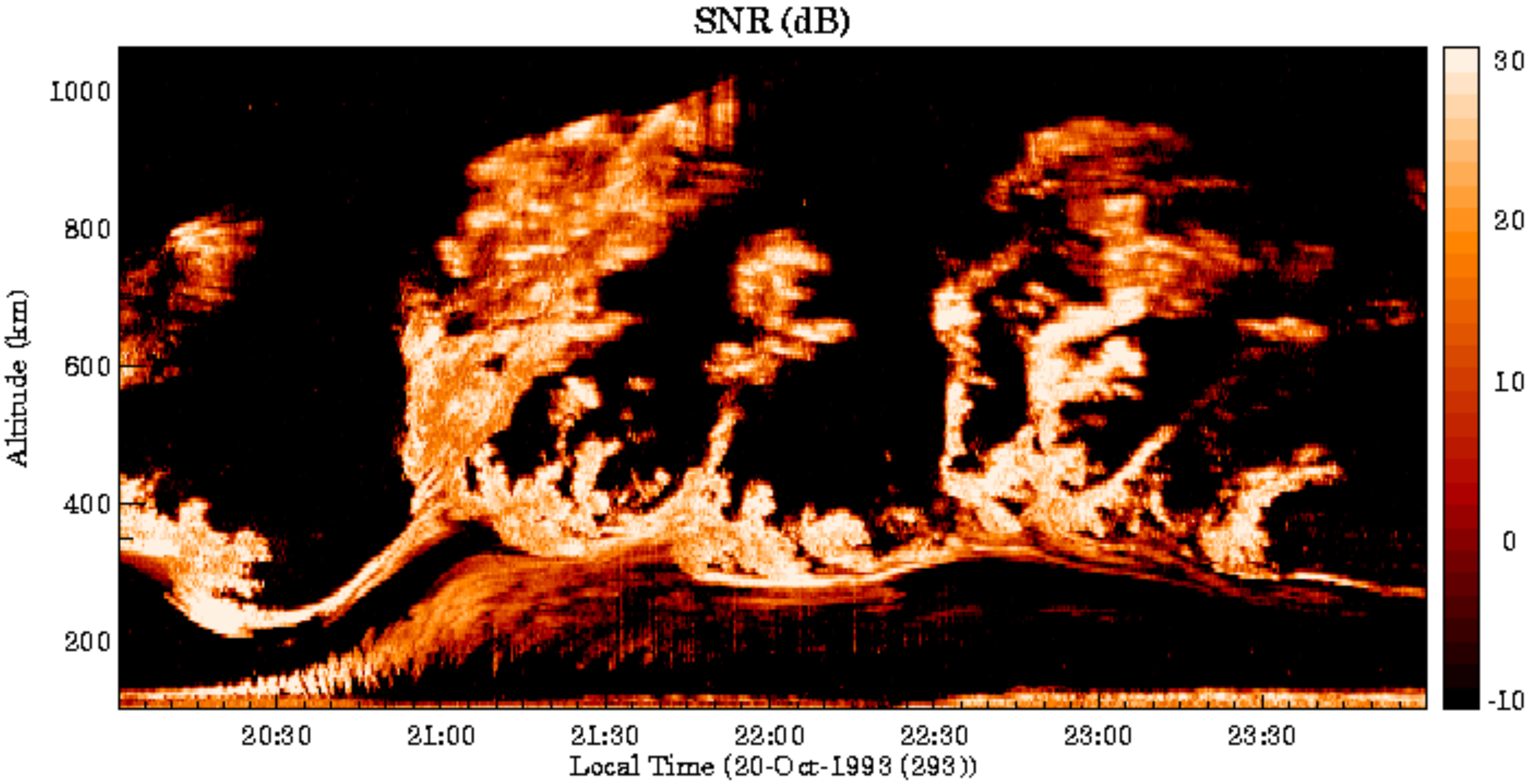
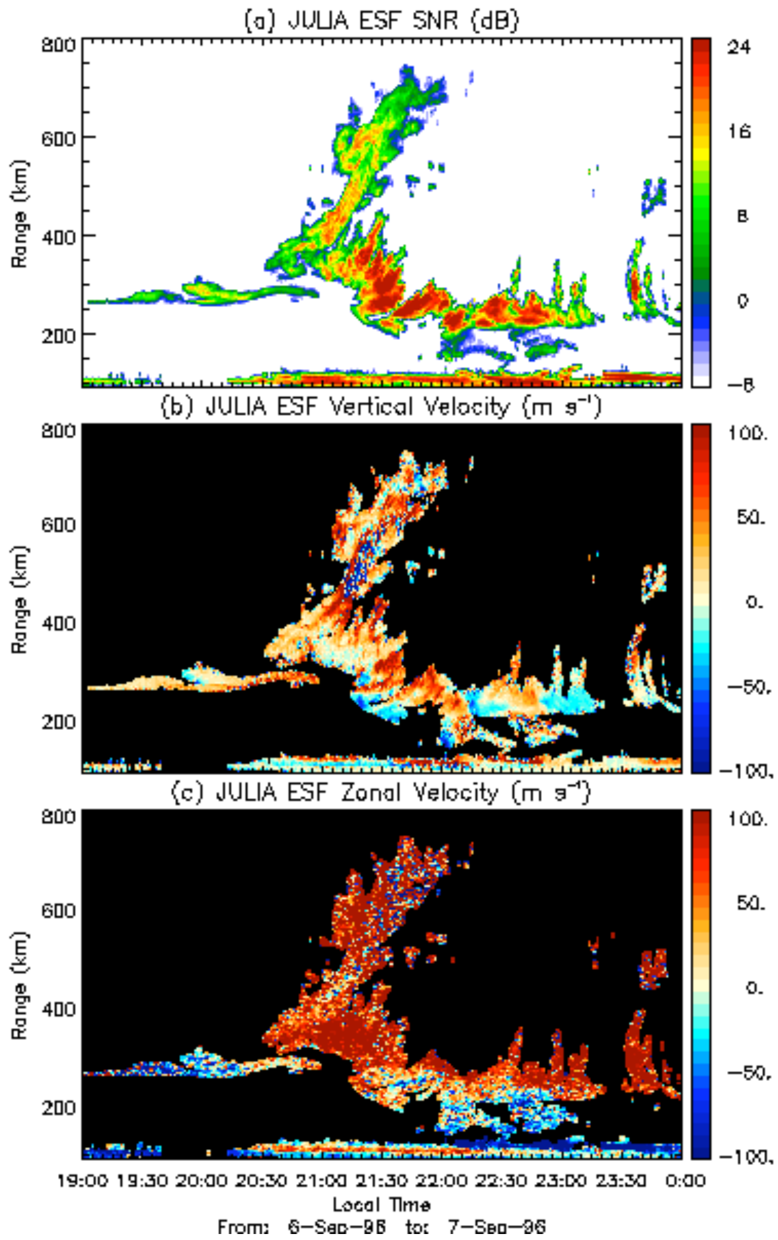


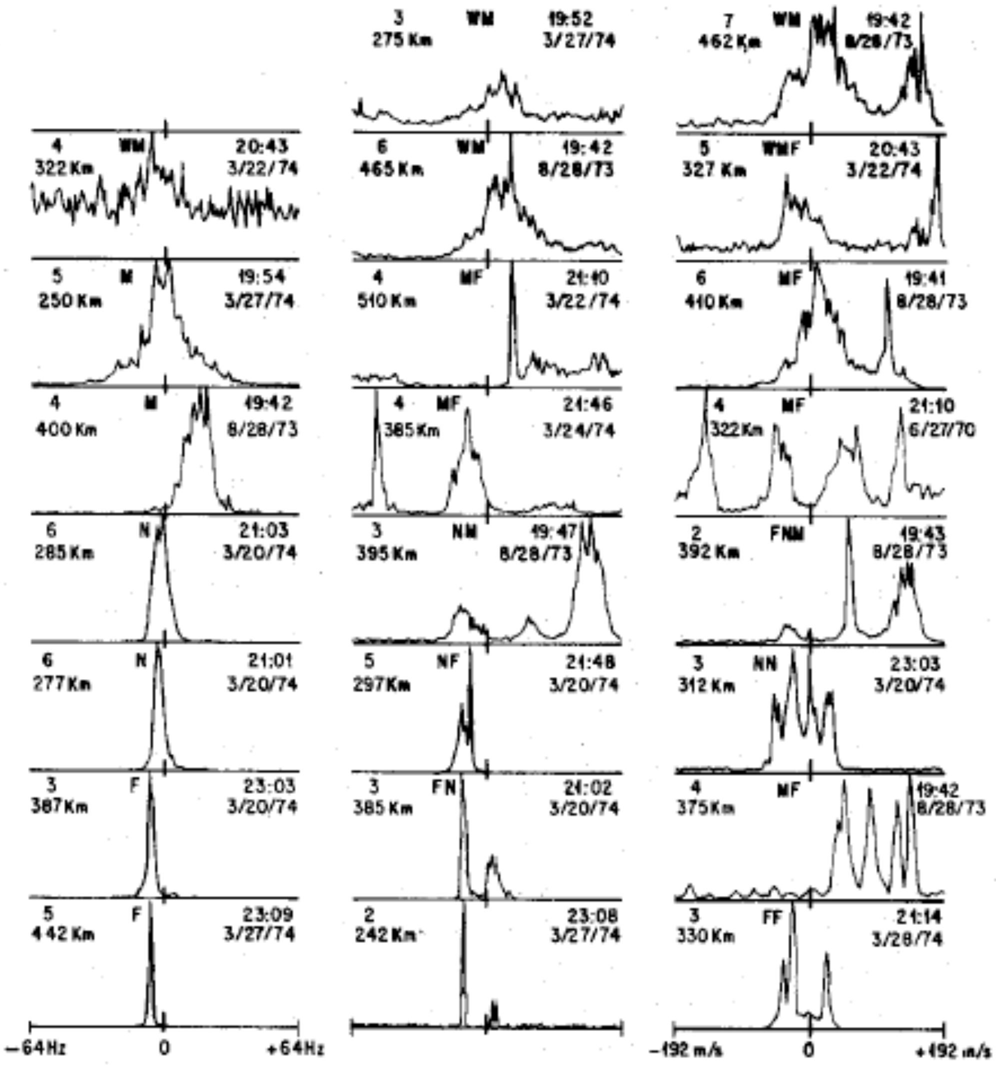
ESF: Type of echoes



- Nighttime
- Main type (interchange or generalized Rayleigh-Taylor instabilities)
  - Bottomtype layers
    - Composed of kilometer scale waves
    - Drift westward
  - Bottomside
    - Drift eastward
    - Greater vertical displacement
  - Topside (Plumes)
    - Drift eastward and upward
    - A variety of spectra shapes
  - Valley-type

[from *Hysell and Burcham,* 1998 and *Hysell* 2000]

ESF spectra: Do we understand all of them?



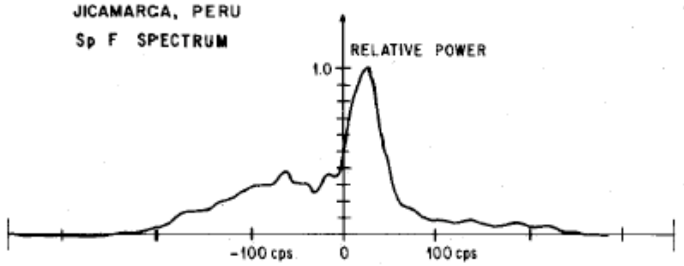
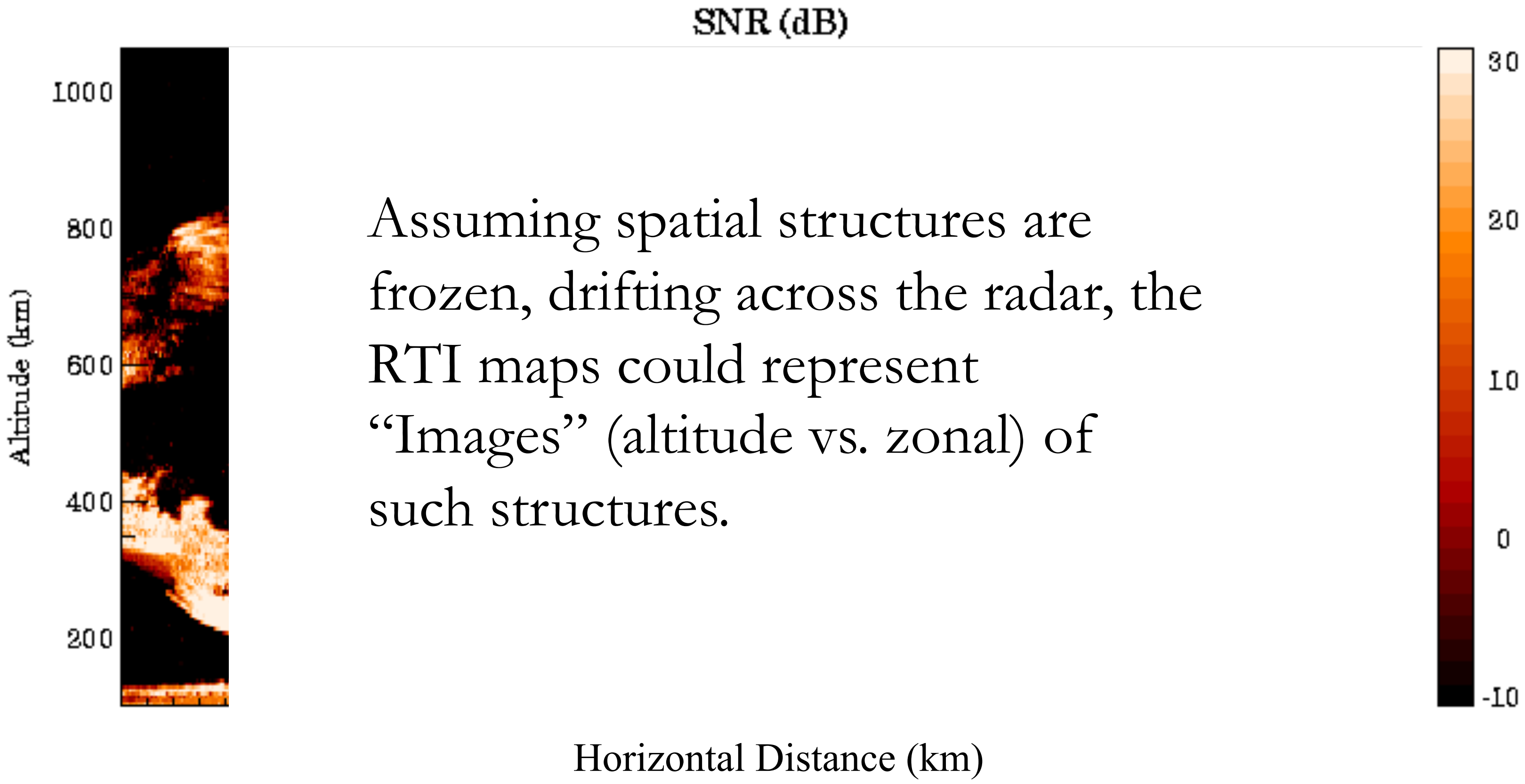


Fig. 5. Sampling record showing the WM type spectrum without frequency aliasing.

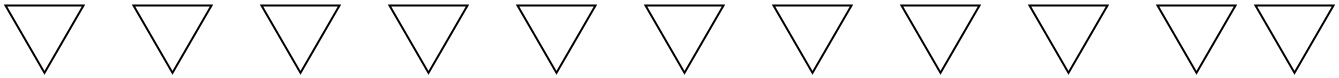
- Bottomtype: Very narrow single-peak spectra.
- Bottomside and Topside: Narrow, wide, multi-peak spectra.

[from *Woodman and La Hoz*, 1976]

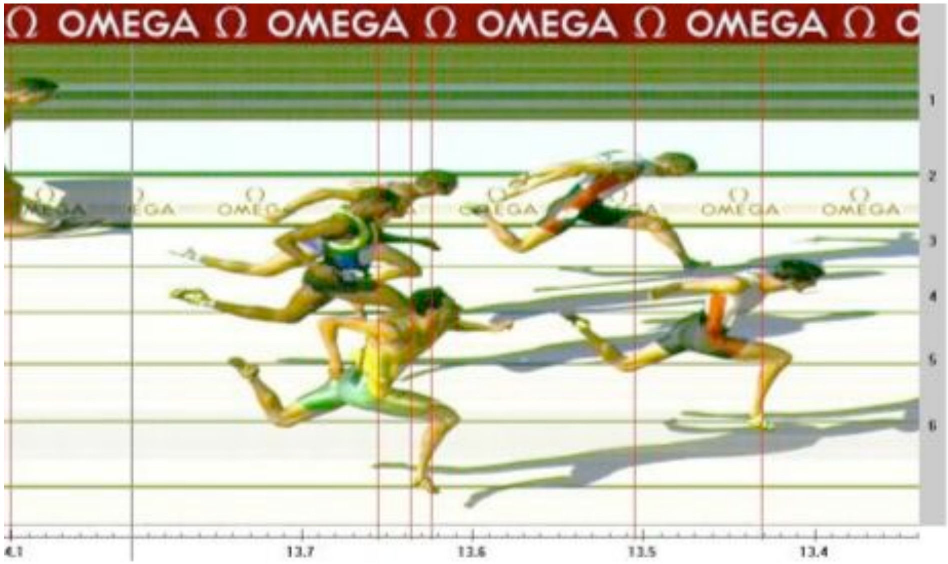
RTI maps as “images”: Slit camera interpretation



Assuming spatial structures are frozen, drifting across the radar, the RTI maps could represent “Images” (altitude vs. zonal) of such structures.



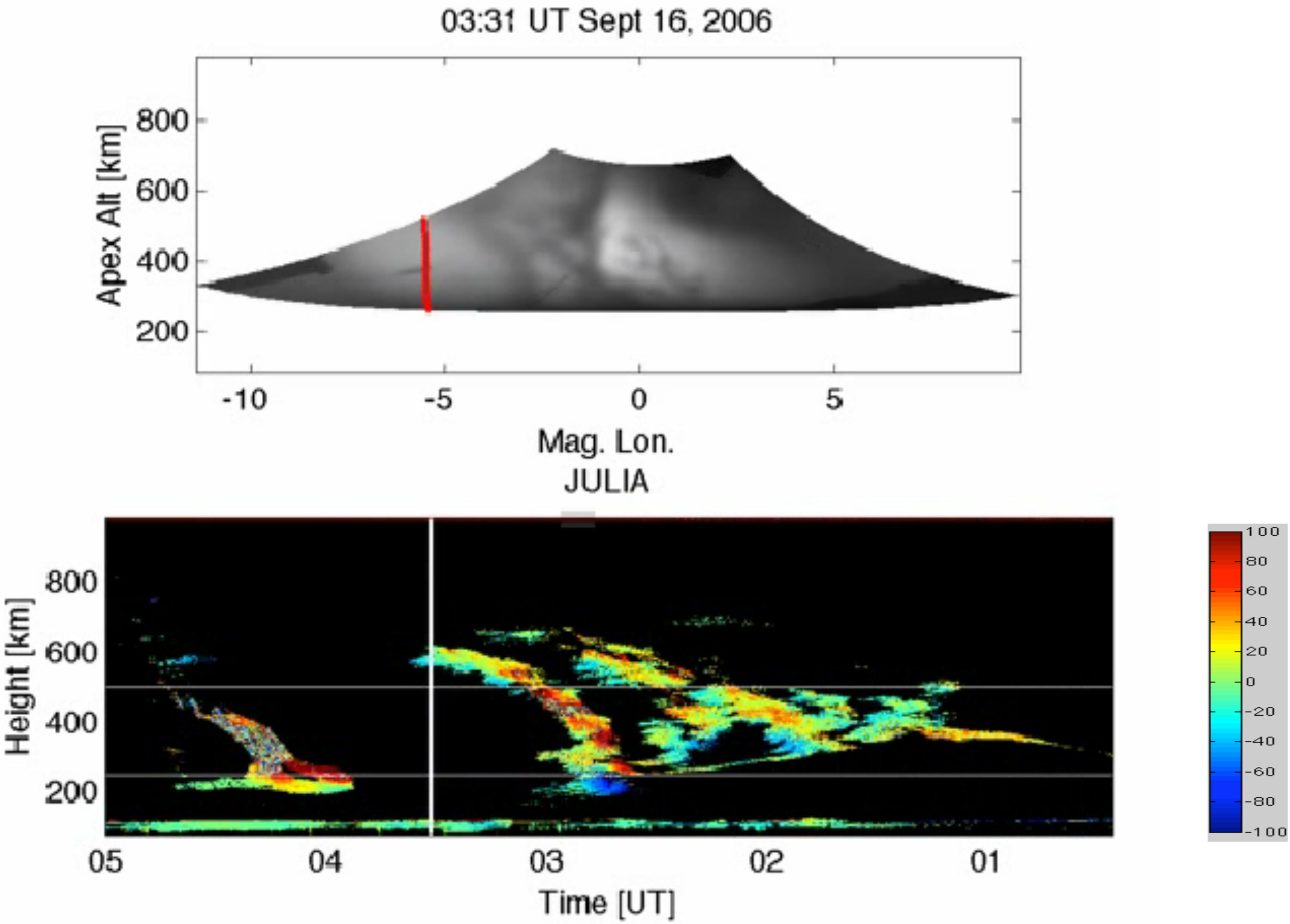
Slit-camera analogy and problems



- In some applications like races it is useful
- In many other applications it provides misleading results:
  - Slow structures are stretch out
  - Fast-moving structures are compressed.
  - In general, it is difficult to discriminate space-time features.

used with permission ©Tom Dahlin

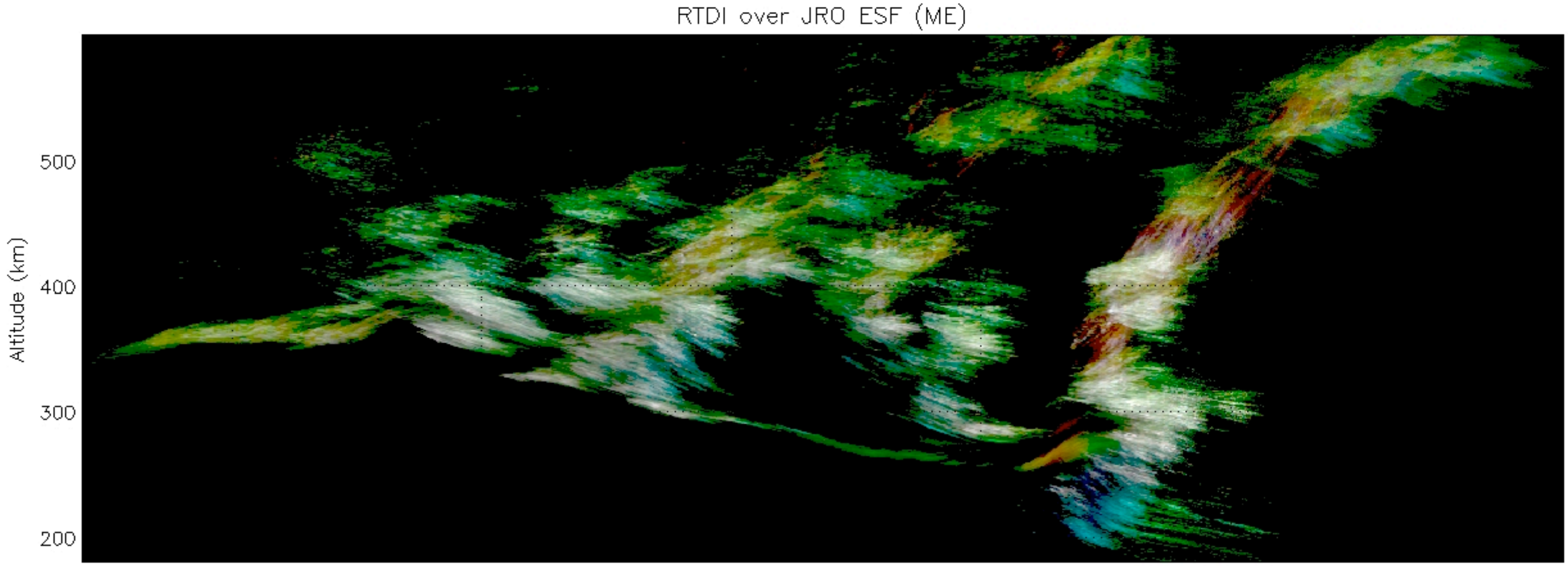
Radar “Slit” Camera vs. Optical “Airglow” Camera



[*Courtesy of J. Makela*]

JRO as Video RF Camera

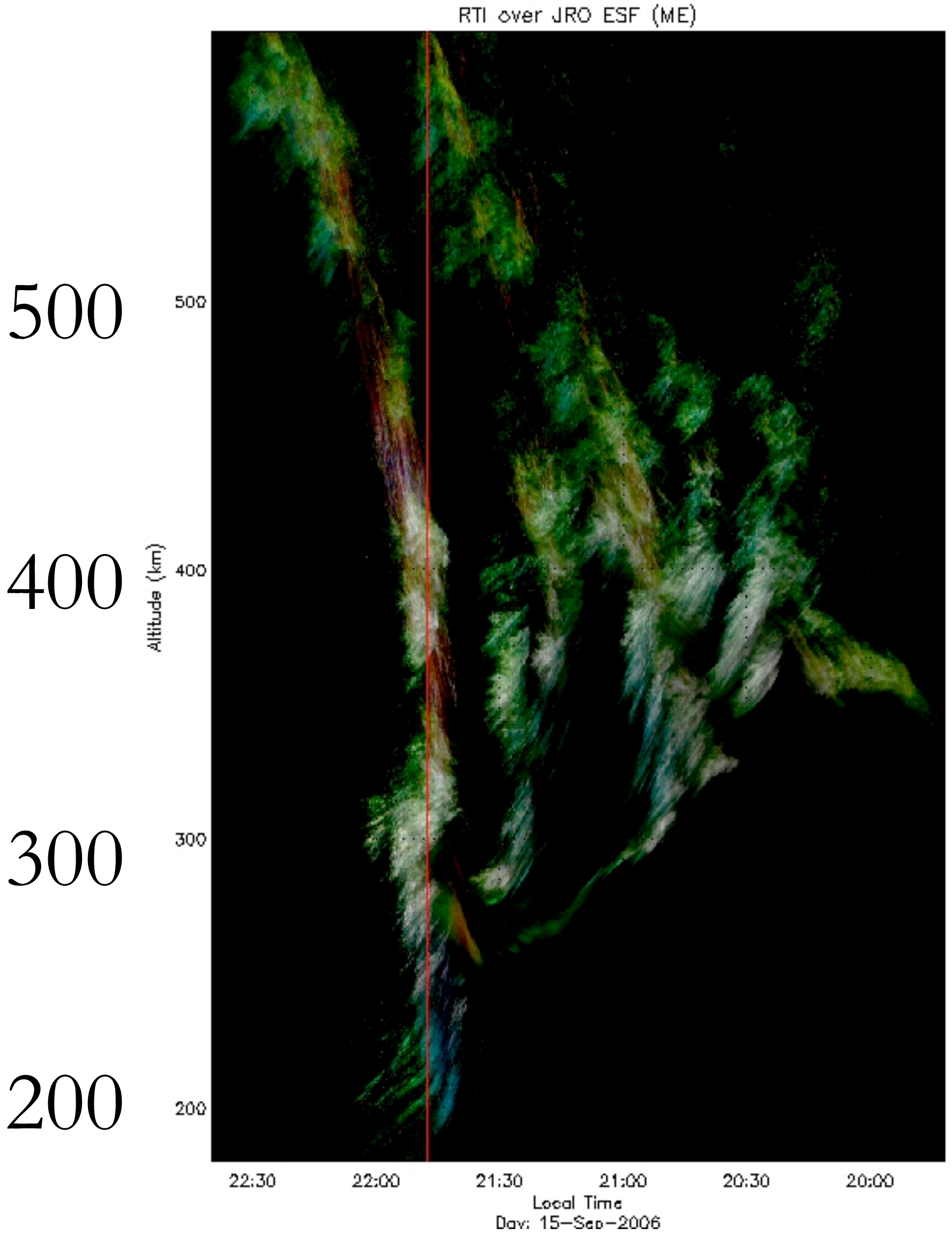
ESF RTDI: Slit camera interpretation

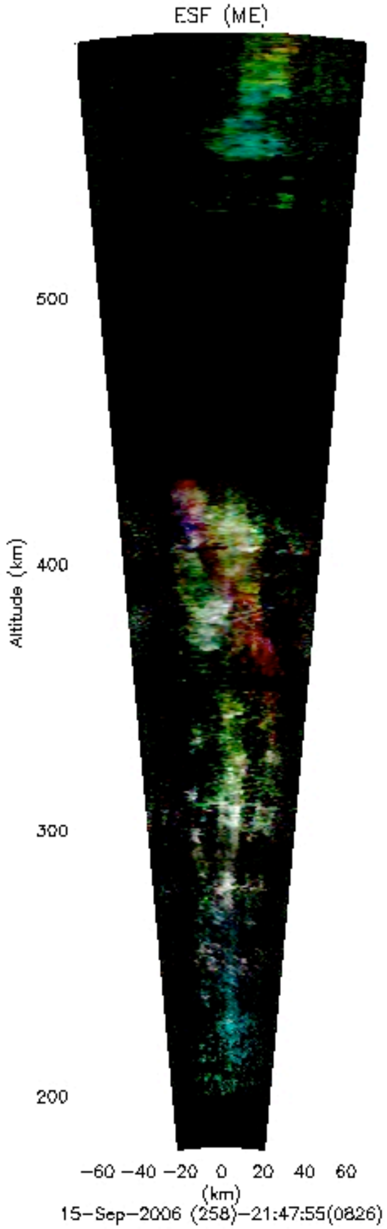


East (km) West

- Typical RTI maps are shown with "false" colors (colors from a pre-defined color table are associated to the signal intensity).
- Here we use Doppler for color. True 24-bit color range time intensity (RTI) plot using Doppler information (RTDI). RTI map is obtained for three Doppler regions centered around: -ve (Red), zero (Green), and +ve (Blue) Doppler velocities.
- It allows, for example, identification of regions and times where there is a depletion channel pinching off, Doppler aliasing, Doppler widening, etc.

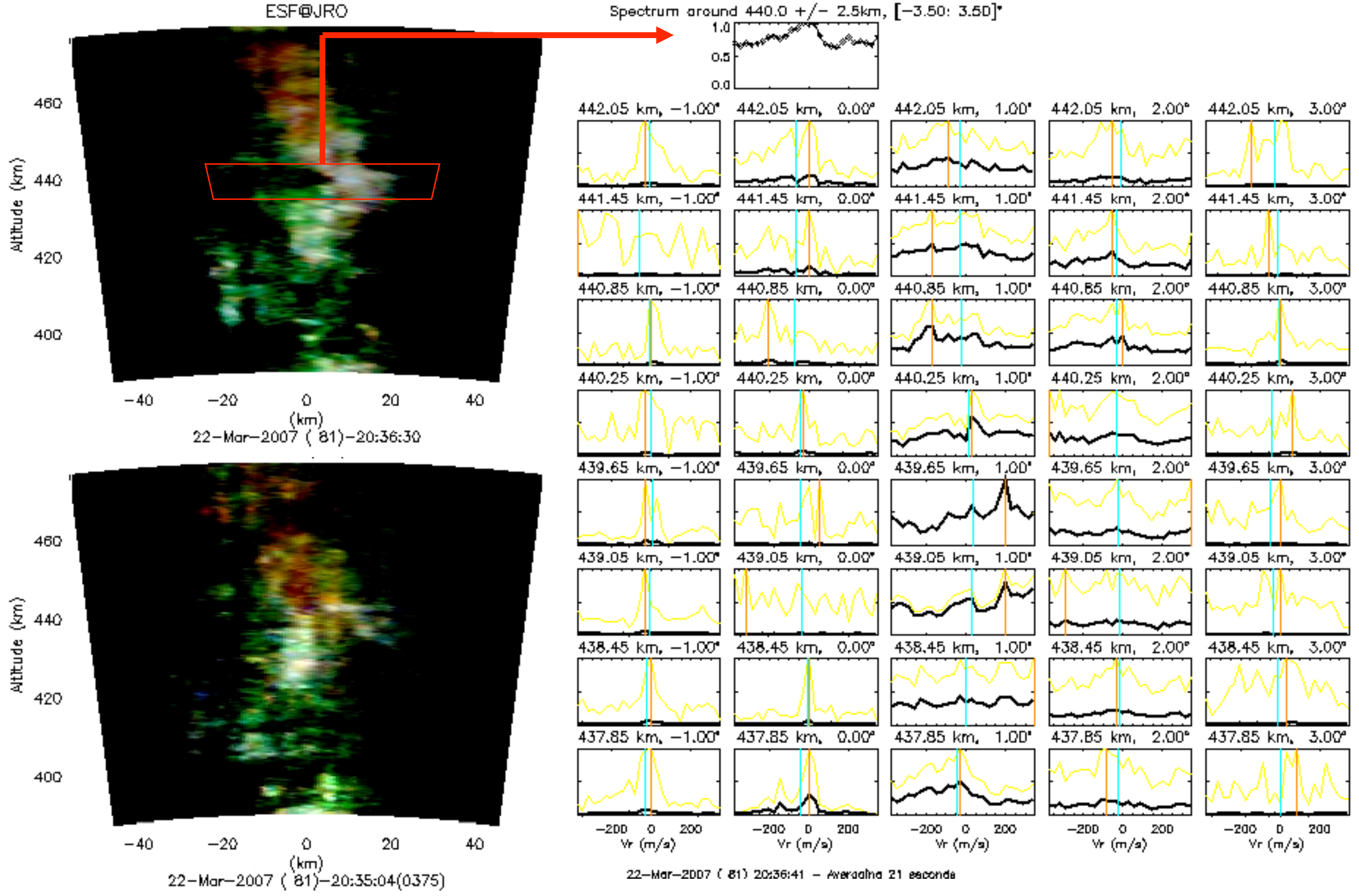
ESF RTDI + Imaging (1)





- Space and time ambiguities are avoided.
- New structures are identified and characterized, e.g.,
  - Bifurcations
  - Pinch-off of bottom irregularities
  - Vortices in the narrow bottomtype layers

ESF Imaging experiment with IPP=600: Frequency aliased spectra



ESF Imaging experiment with IPP=300: Range aliased, but without frequency aliasing

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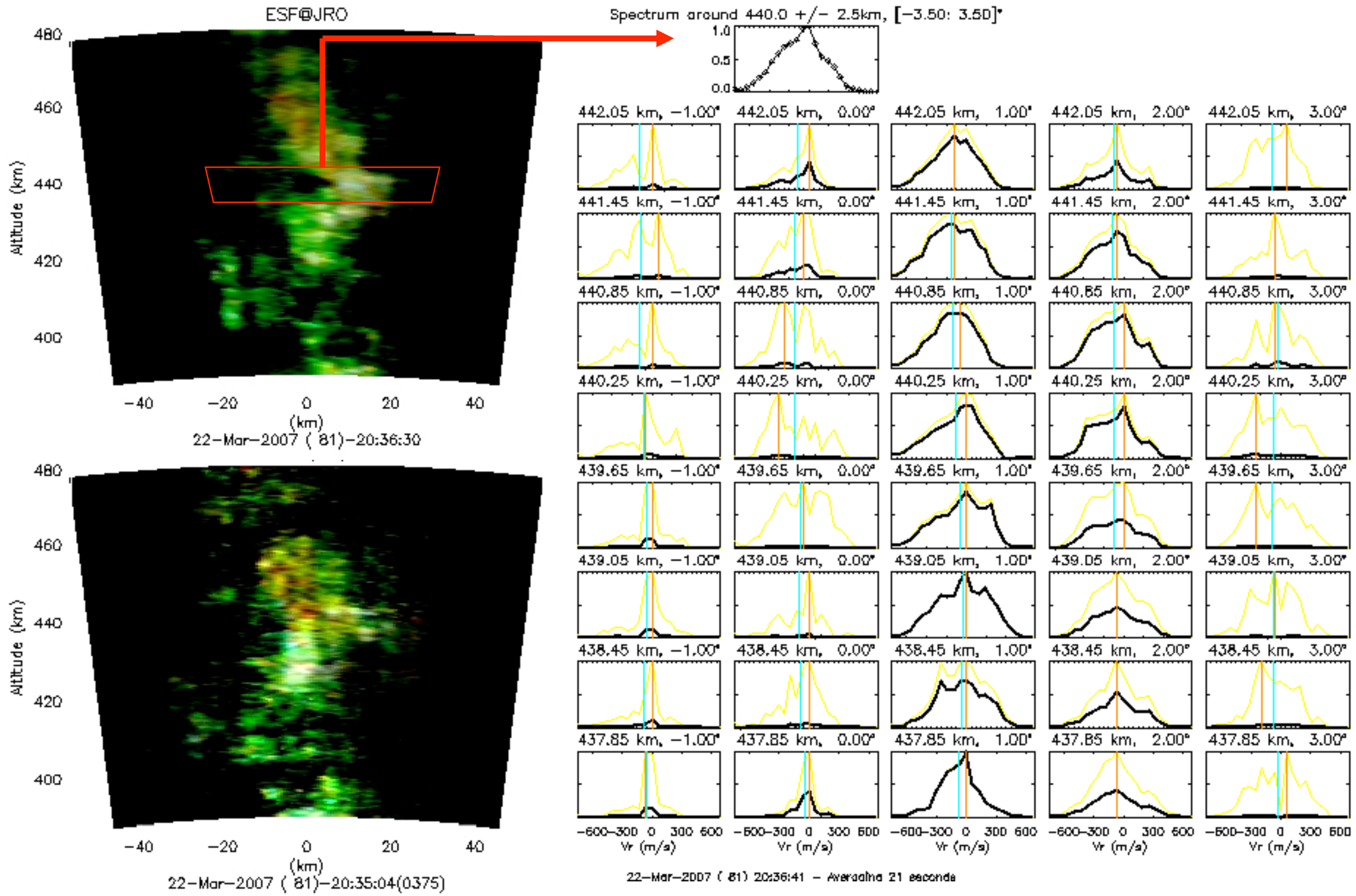
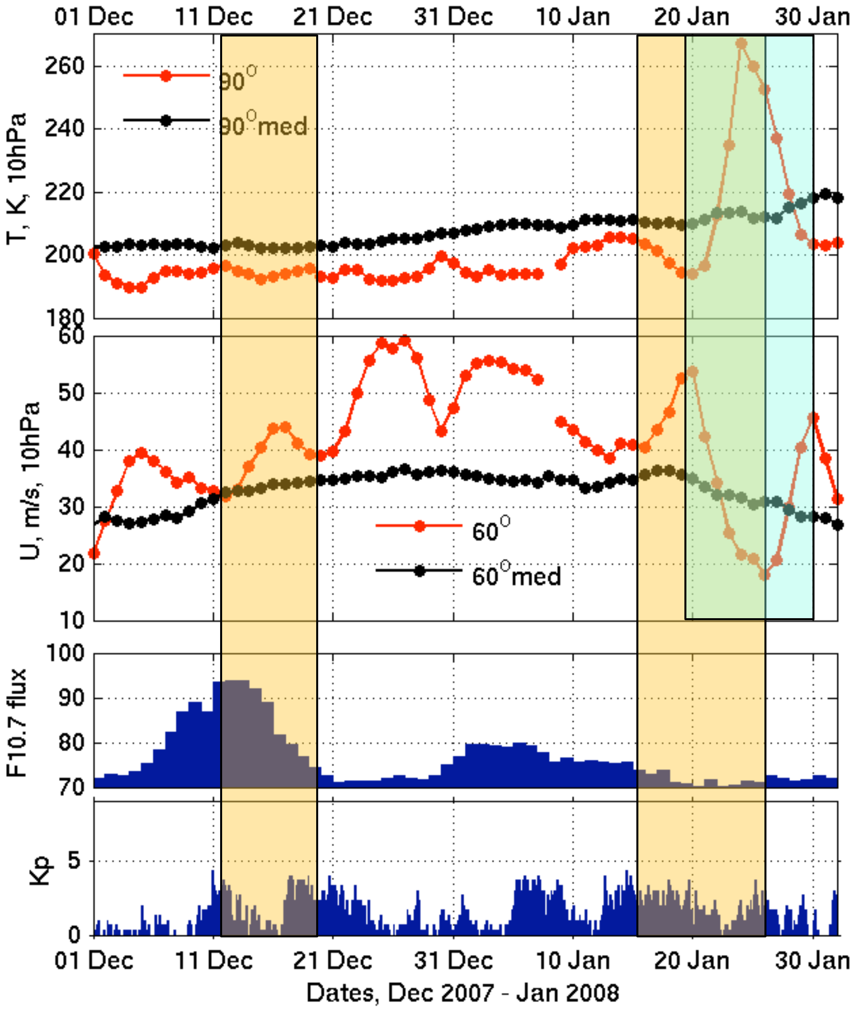


Sudden Stratospheric Warming and the Equatorial Ionosphere

SSW Jan 2008: SSW Main parameters



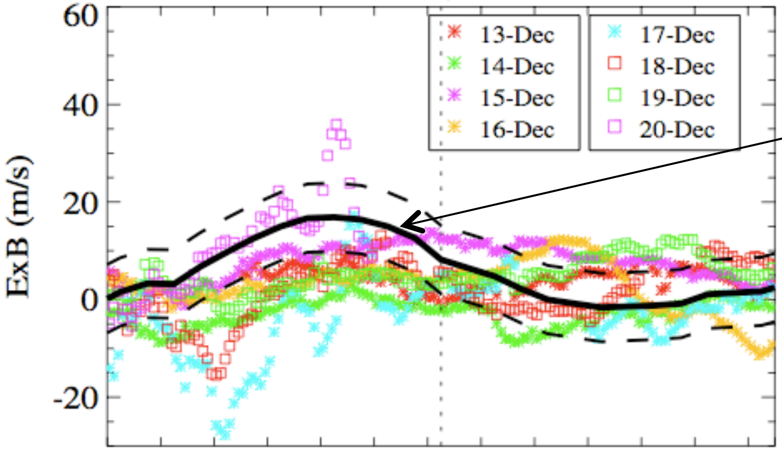
- Minor SSW event. Westerly winds slowed down
- One of the largest temperature increases in the last 30 years.
- Low solar flux (close to 70)
- Magnetically quiet conditions
- Many ground-based instruments operated 8-10 days in December 2007 and 10-14 days in January 2008.

[from *Chau et al.* 2009]

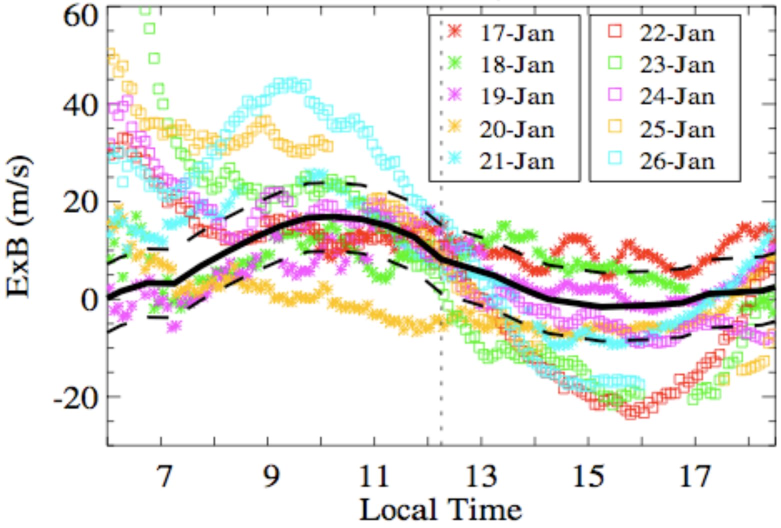
SSW Jan 2008: ExB Daytime Drifts

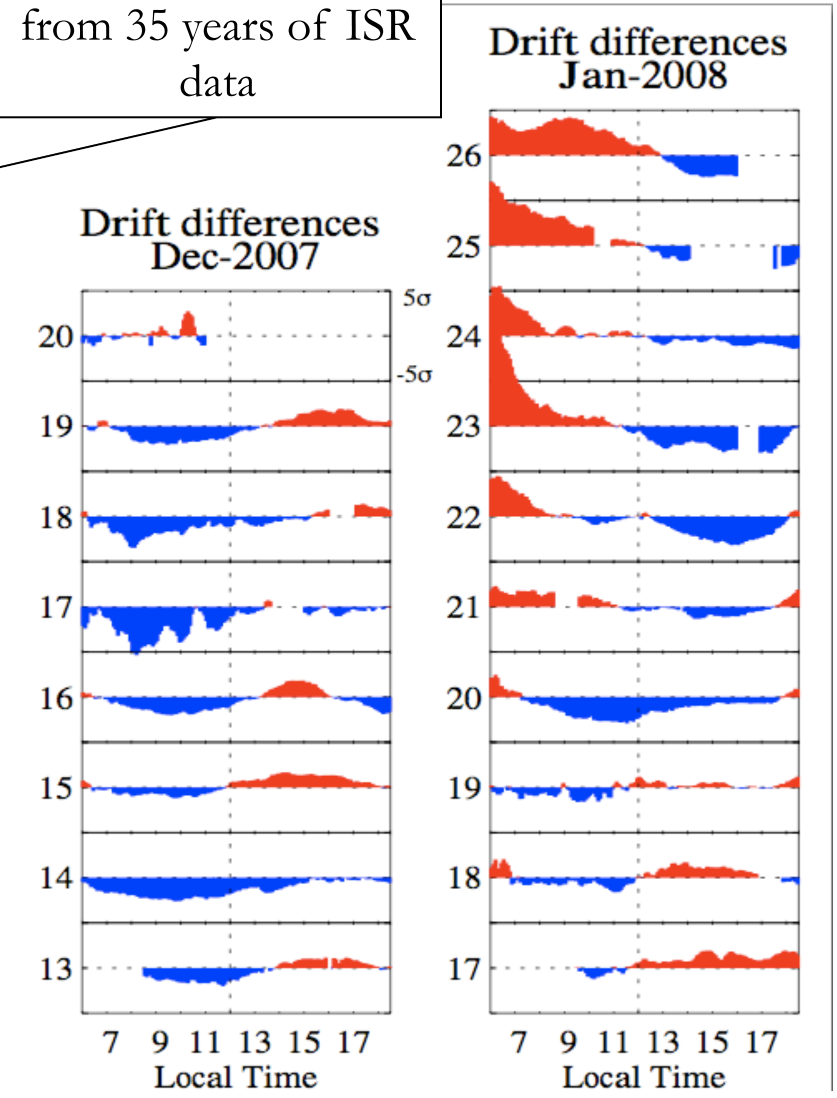
Average + variability from 35 years of ISR data

(a) Control days (Dec-2007)



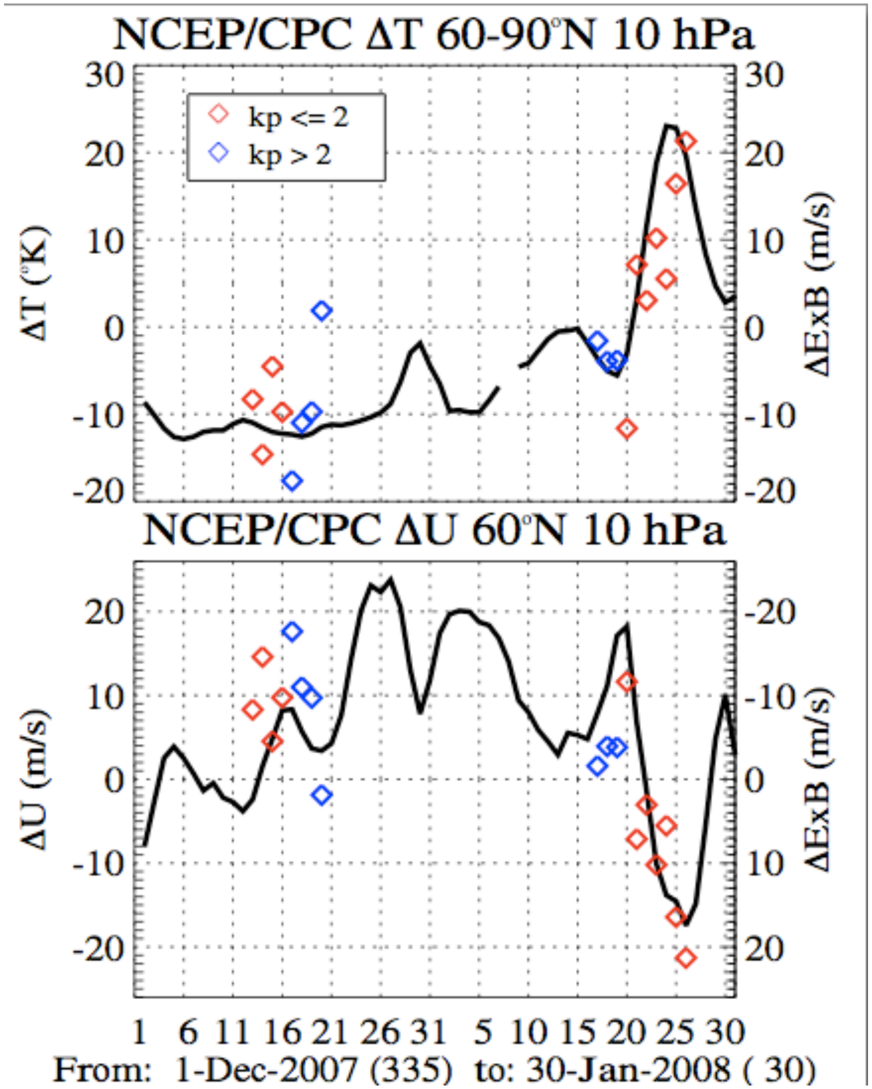
(b) Around SSW days (Jan-2008)





[from *Chau et al.* 2009]

SSW Jan 2008: ΔSSW vs ΔExB



- ΔExB: average morning ExB difference with respect to expected averages, after fitting a semidiurnal wave.
- ΔSSW: differences with respect to 30-year median values.
- High correlation/anticorrelation: ΔExB vs. ΔT/ΔU during SSW.
- Note the “persistence” of the ExB drift pattern during SSW period.

[from *Chau et al.* 2009]

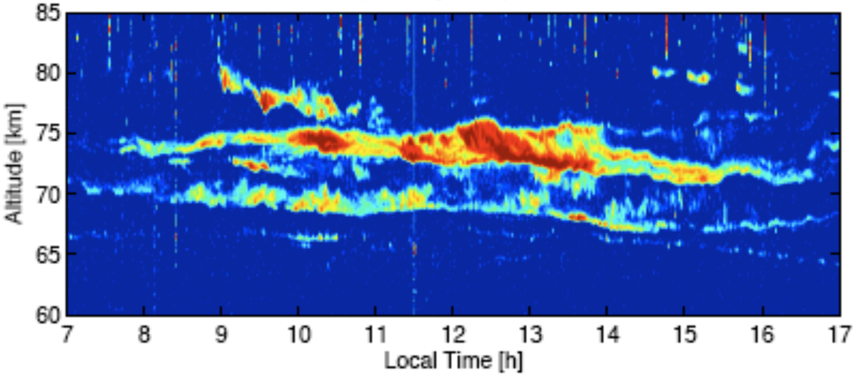
Perennial Equatorial Mesospheric Echoes (PEME)

PEME: Main Characteristics

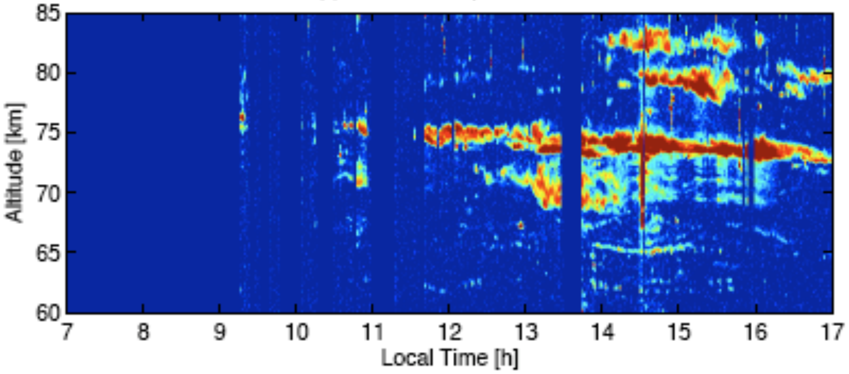
- Daytime occurrence, between 60-85 km, with preferred occurrence around 70-75 km.
- Mesospheric dynamics and turbulence are obtained from these echoes.
- RCS much weaker than PMSE and PMWE
- Rich temporal and altitudinal structure obtained from 3-m irregularities.
- Dependence on solar flux and X flares, indicate that high electron densities and strong density gradients enhance the strength of the echoes.

PEME: Fine structure

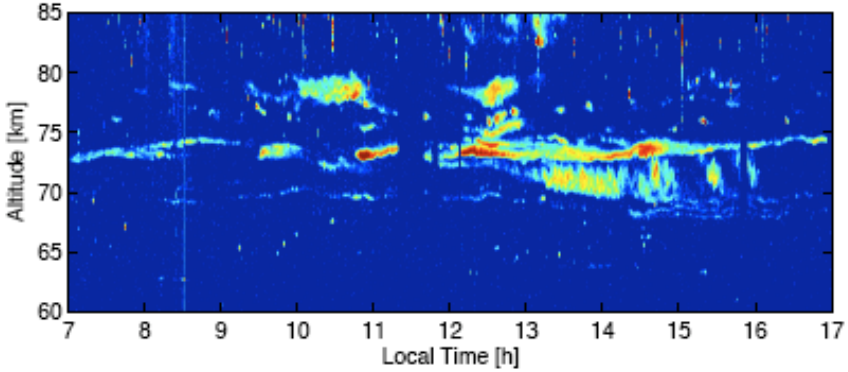
SNR Map, 27 May 2003, South Beam



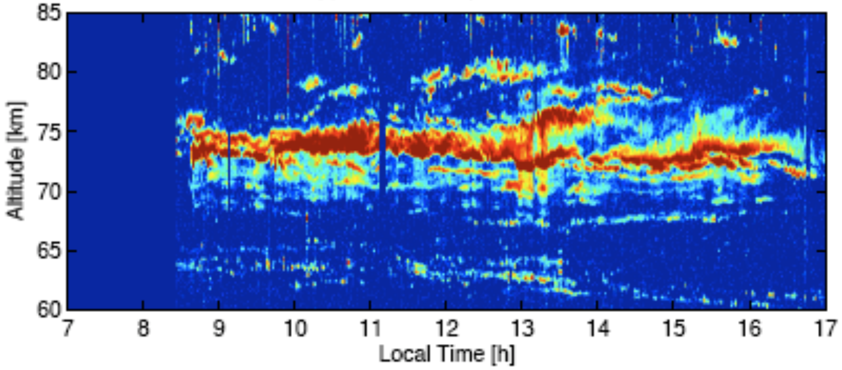
SNR Map, 13–Jul–2004, Off–vertical Beam



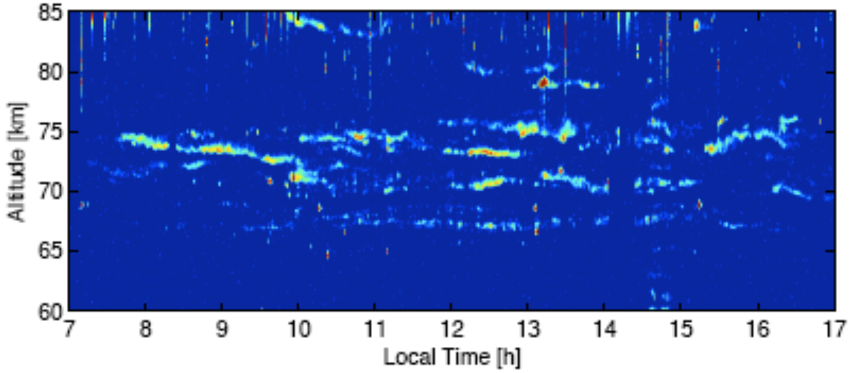
SNR Map, 28 May 2003, South Beam



SNR Map, 14–Jul–2004, Off–vertical Beam



SNR Map, 29 May 2003, South Beam



[from *Sheth et al*. 2006]

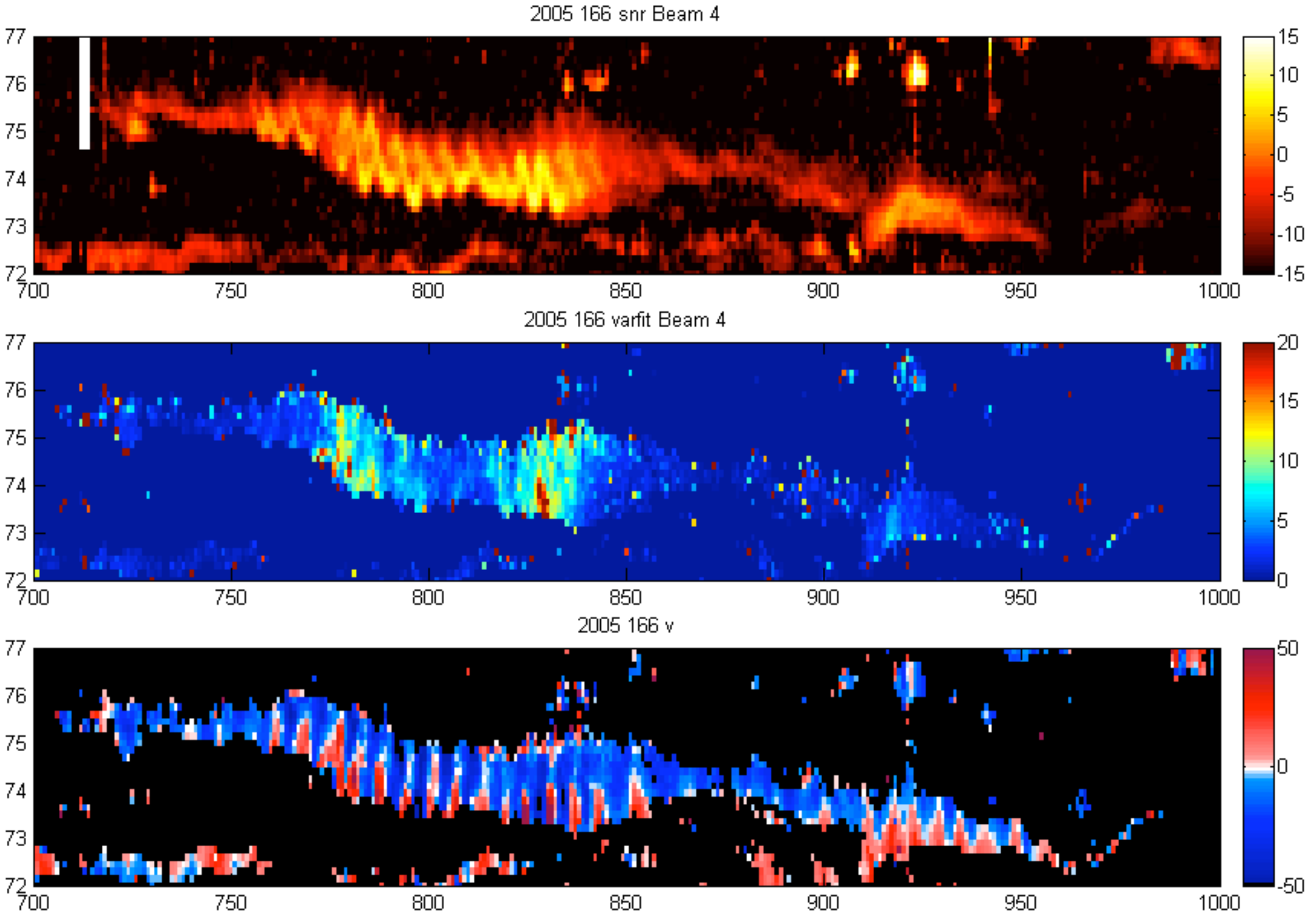
PEME: KHI (1)

[from *Lehmacher et al.* 2007]

SNR (dB) vs. altitude(km), time (min)

Spectral Width, Variance (m^2/s^2)

Meridional wind (m/s)



High resolution mesospheric echoes show evidence for KHI, braided structures with enhanced edges (top); turbulent fluctuations are intermittent (middle); layers are often strongly sheared (bottom). Observations: 8x3 days in 2005 and 2006.

PEME: KHI (2)

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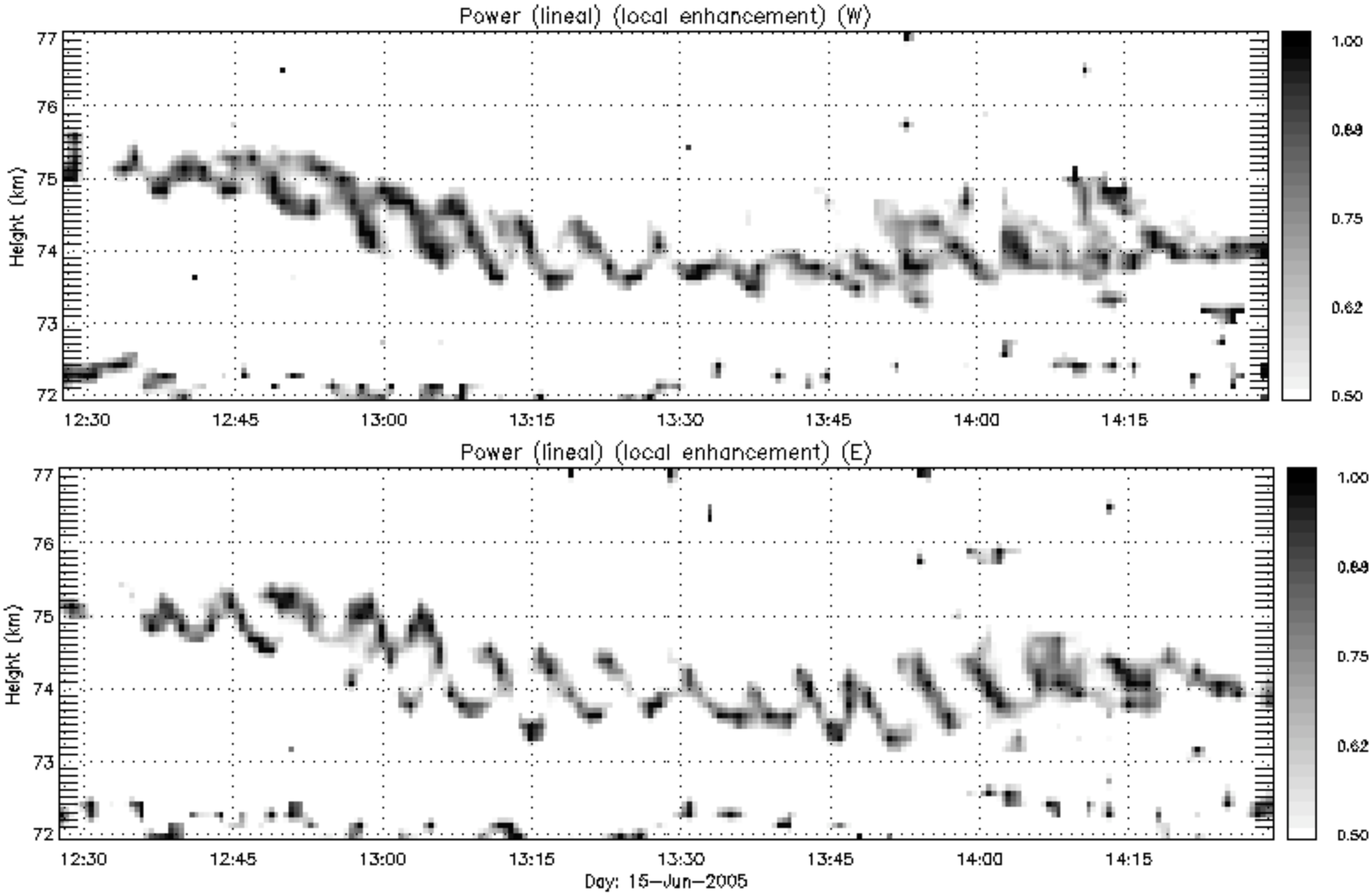


PEME: Turbulence

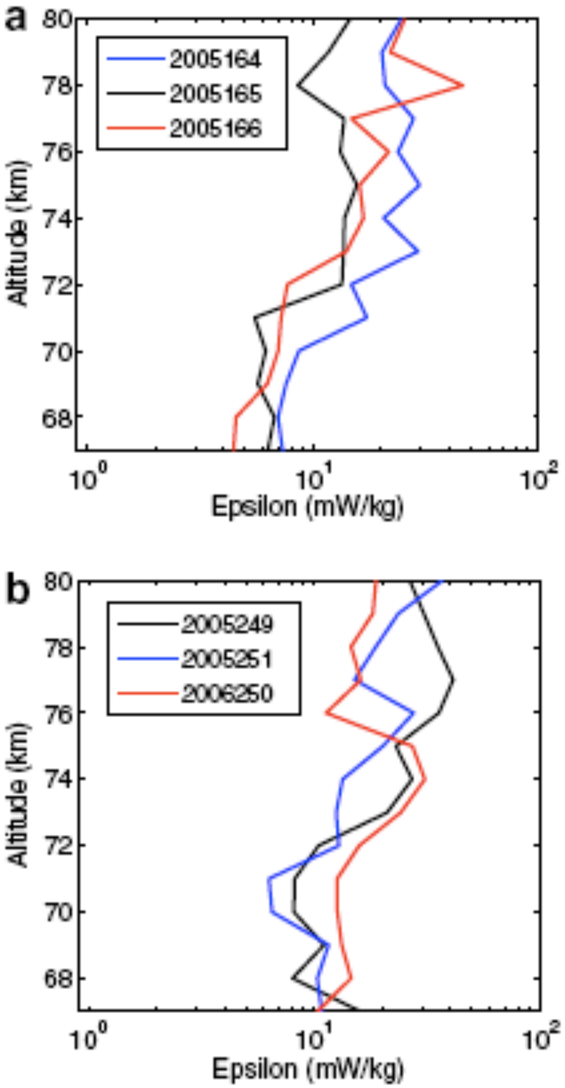
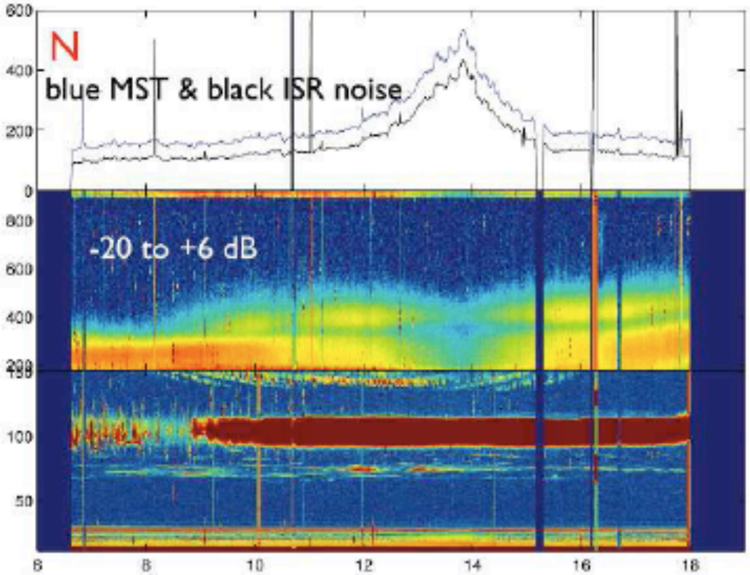


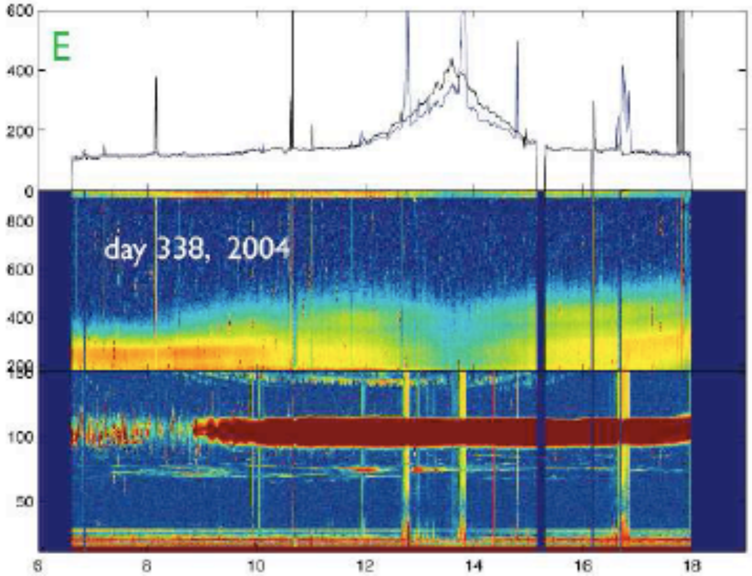
Fig. 5. Energy dissipation rates ε medians. (a) Energy dissipation rates ε daily medians for June 2005. (b) Energy dissipation rates ε daily medians for September 2005 and 2006.

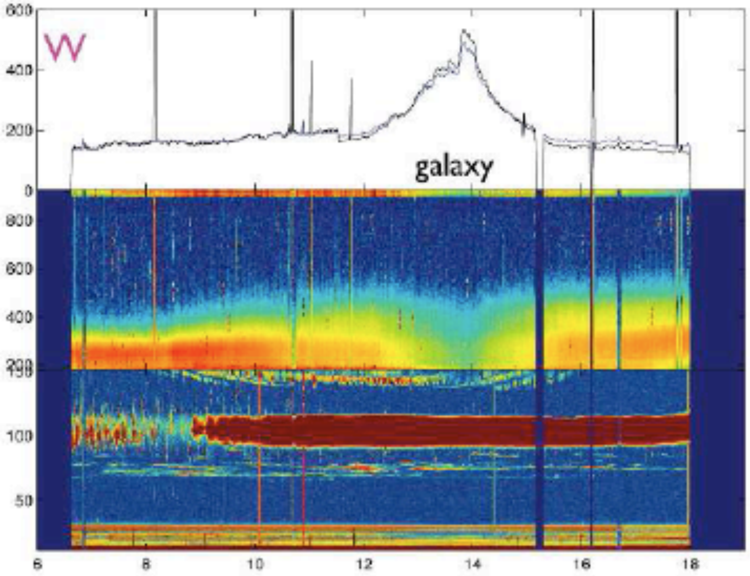
- ε from spectral widths. A small beam broadening effect has been removed from the observed spectral widths.
- The daily median energy dissipation rates ε increase from 5 to 30 mW/kg between 67 and 80 km, and the eddy diffusivities increase from 3 to 20 m2/s result at Japan and India.
- The energy dissipation rates are about the same magnitude as the ε estimates for low-latitudes from a global model and are larger than the averages from rocket observations at high-latitudes.

[from *Guo et al.* 2007]

PEME: RCS (1)

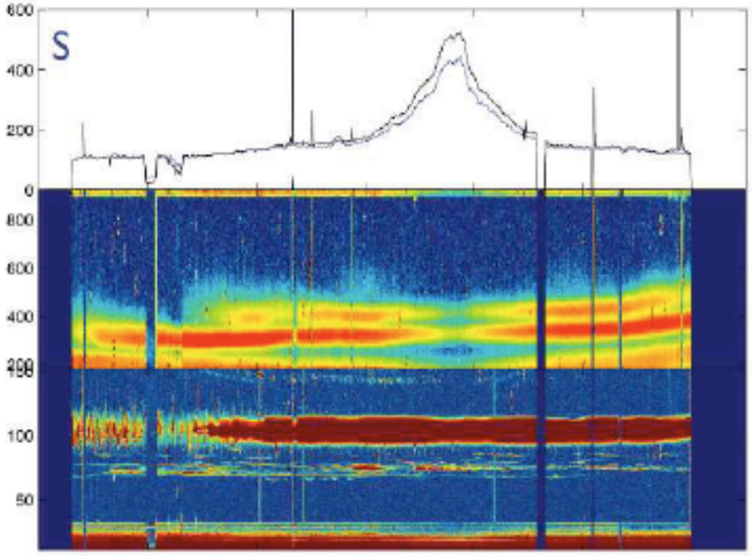






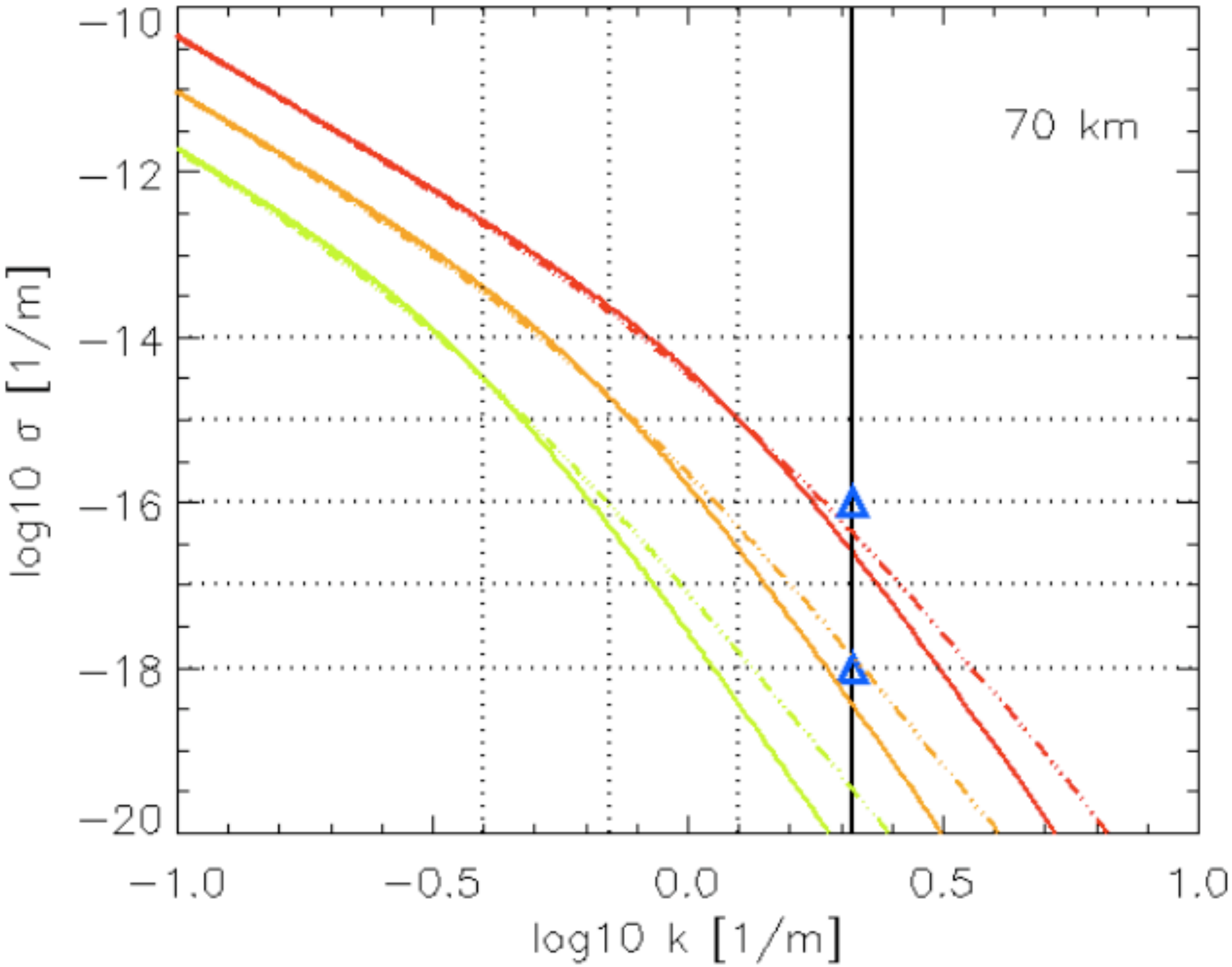
ISR

MST



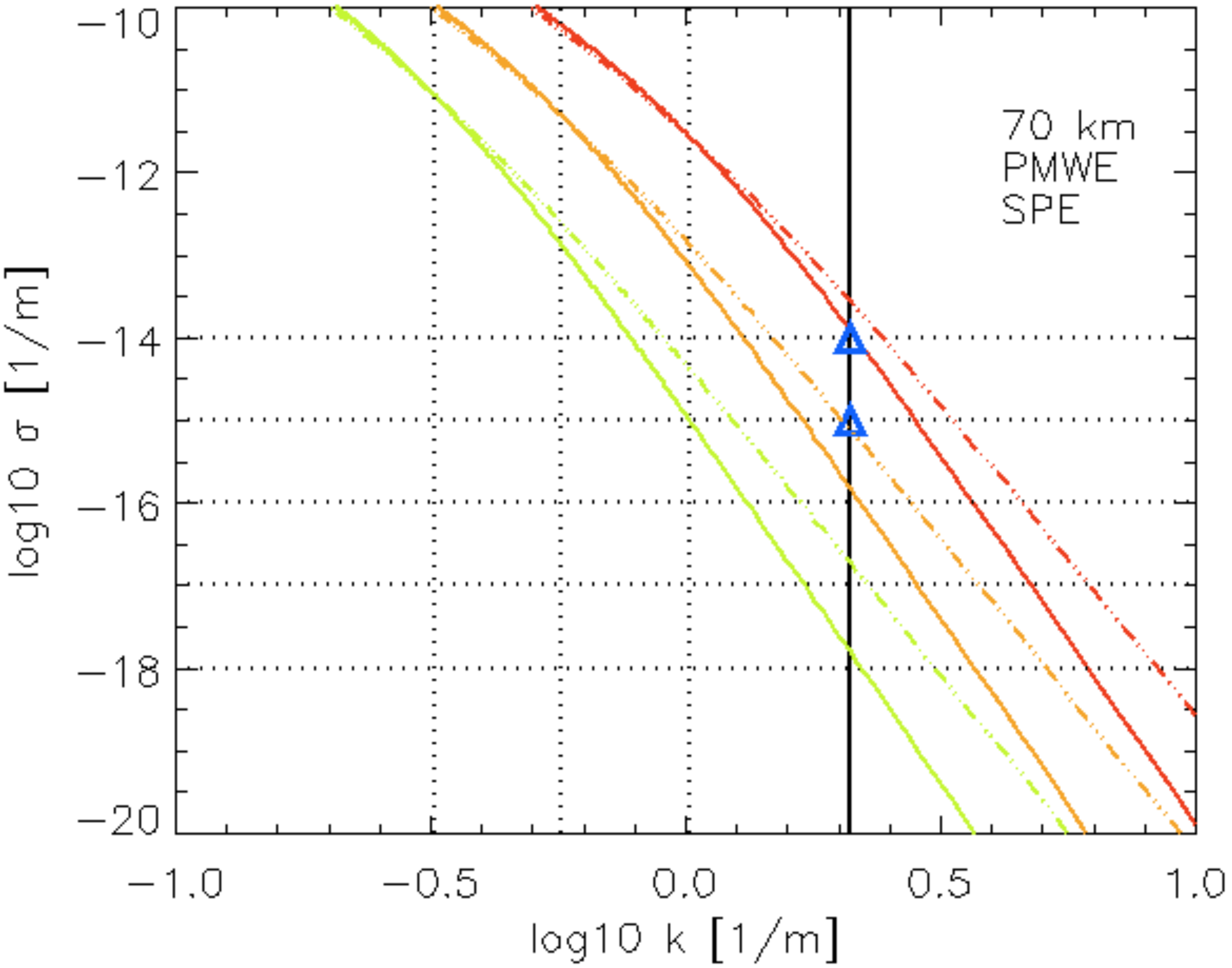
[from *Akgiray* 2007]

PEME: RCS (2)



[from *Lehmacher et al.* 2009]

PEME: RCS (3)



[from *Lehmacher et al.* 2009]

PEME: RCS (4)

- PEME RCS range from 10^{-18} to 10^{-16} m^{-1}, 3 orders of magnitudes smaller than RCS reported for PMWE during solar proton events and 6 orders of magnitude smaller than PMSE.
- For typical conditions, volume scattering coefficients for stationary, homogeneous, isotropic turbulence at 3 m are also in the range 10^{-18} to 10^{-16} m^{-1}.
- Theoretical values are still a matter of order-of-magnitude estimation, since the Bragg scale of 3 meters is near or inside the viscous subrange (turbulence spectrum is not well known).
- Steep electron density gradients can increase RCS significantly.
- For thin layers with large RCS and narrow spectra, isotropic turbulence theory fails and scattering or reflection from anisotropic irregularities maybe the cause, as suggested by numerical simulations.

[from *Lehmacher et al.* 2009]

PEME: Some open questions

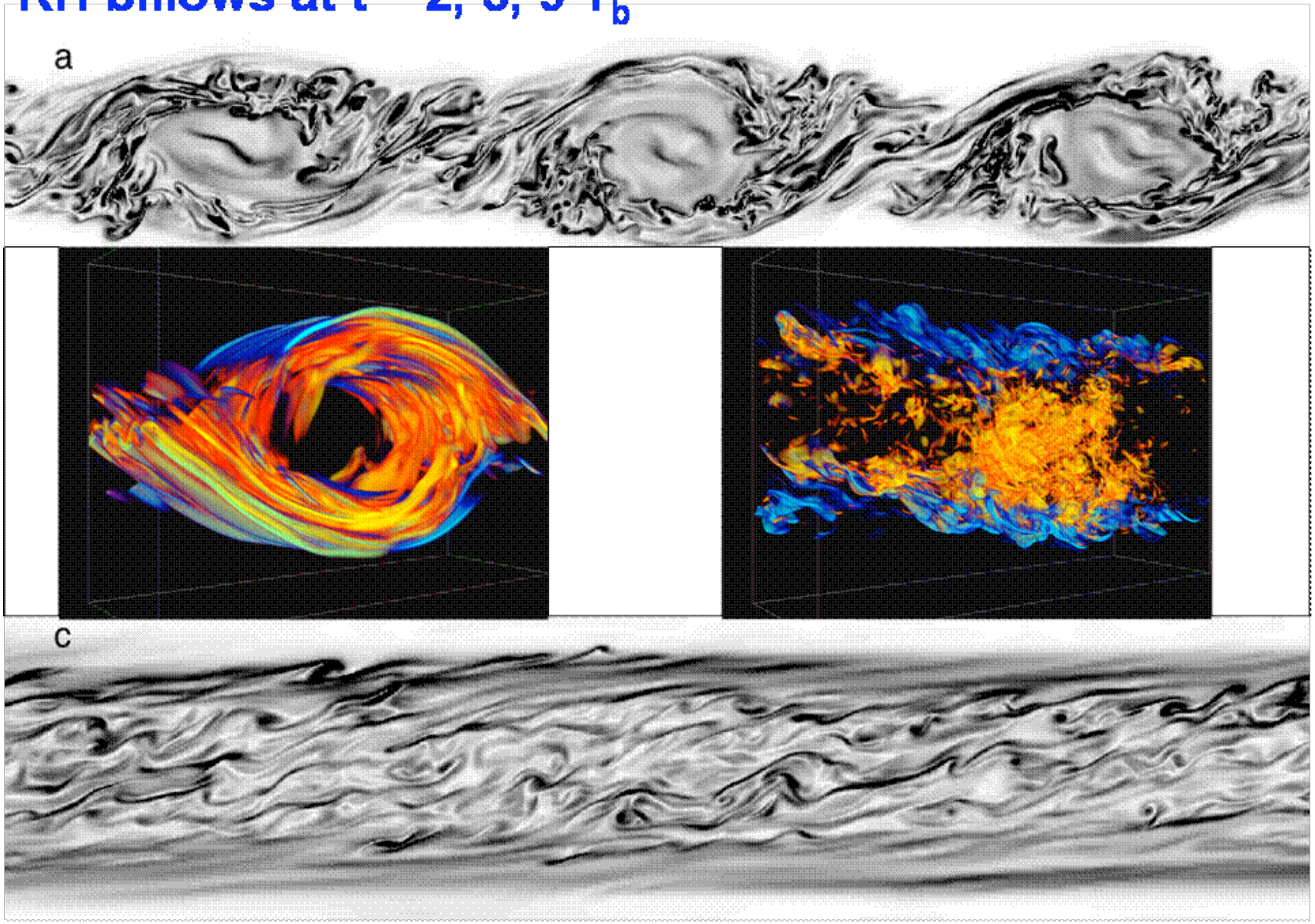
- What are the scattering mechanisms in aspect-sensitive layers and near the edges of layers?
  - As far as we know only one rocket experiment has reported sharp gradients density gradients in the 70-75 km region [*Smith and Klaus*, 1975].
- Is there "enhanced" electron diffusion in this region?
  - A heater experiment may be helpful with that. There is certainly a lot of water in the equatorial mesosphere and therefore also large water cluster ions.
- Are there mesospheric aerosol layers?
  - Rocket experiments with sensitive particle detectors

Lower Atmospheric Kelvin Helmholtz Instabilities

KHI Billows and turbulence

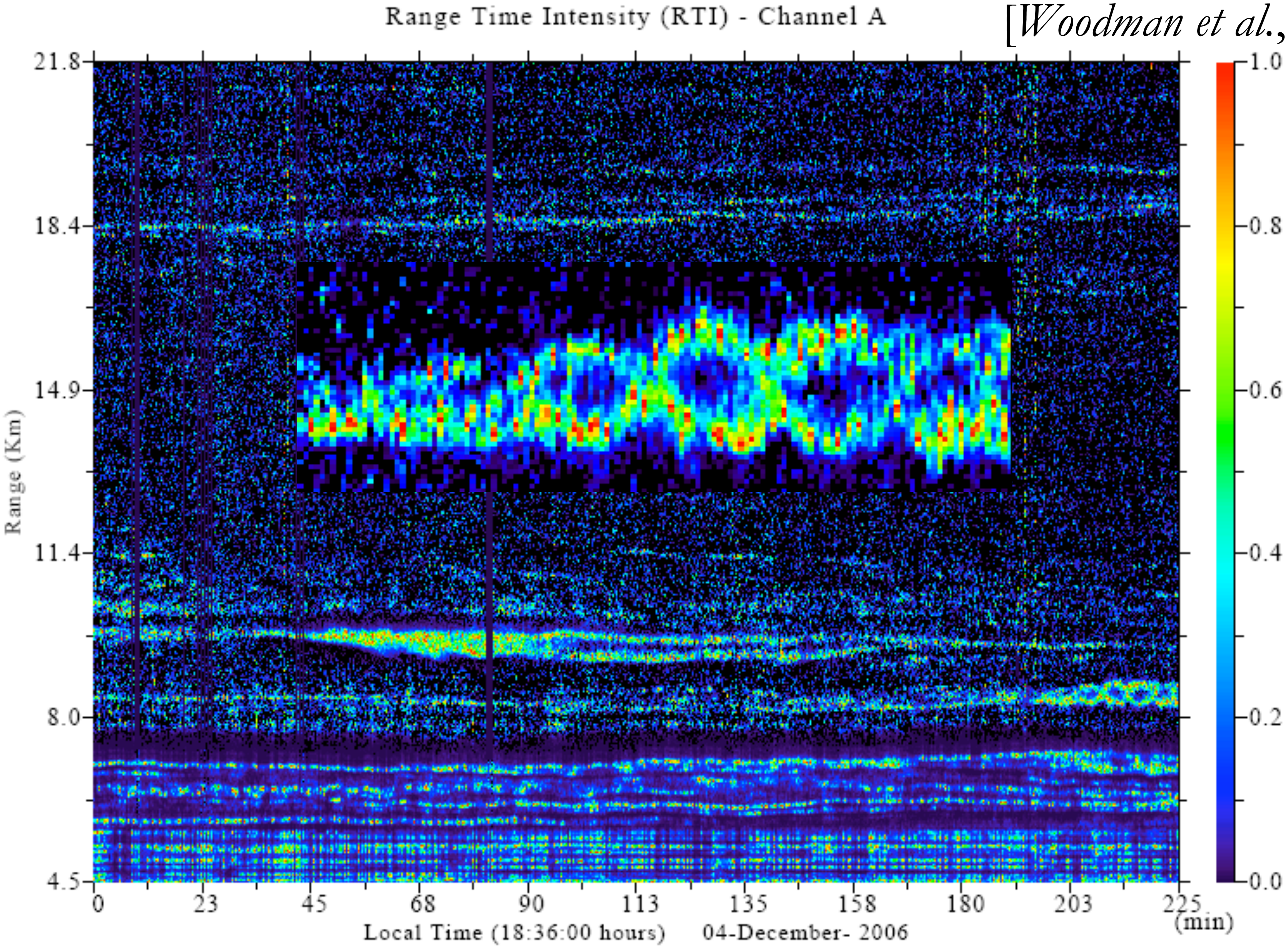
Fritts et al., 2007

KH billows at t ~ 2, 5, 9 T_b



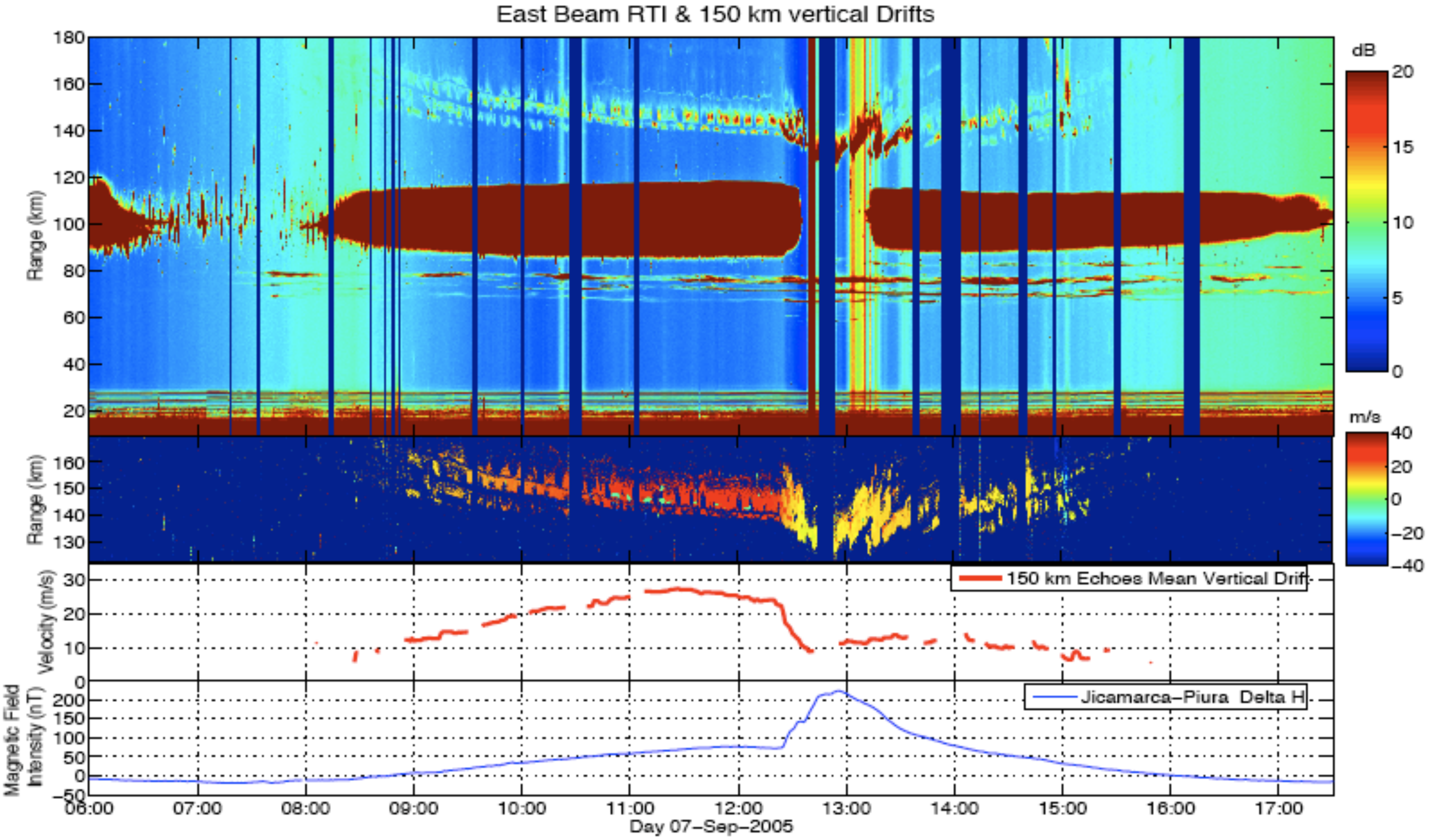
SOUSY: High resolution ST measurements

[*Woodman et al.*, 2007]



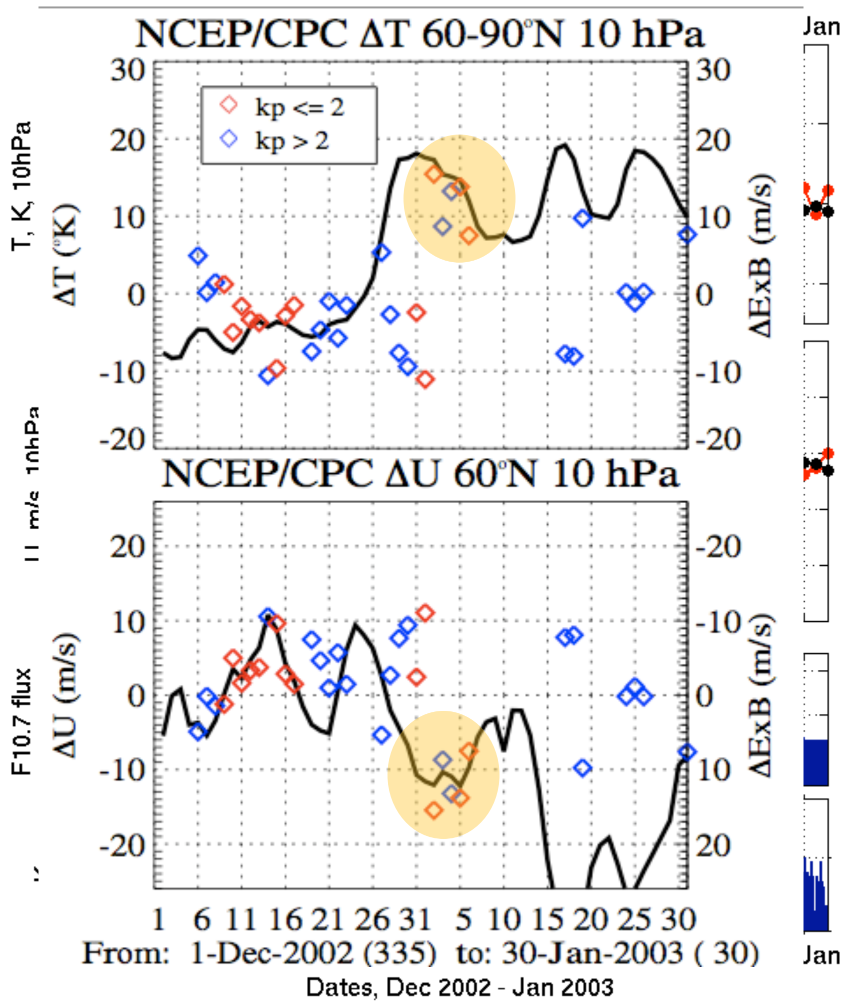
Solar flare 07-Sep-2005

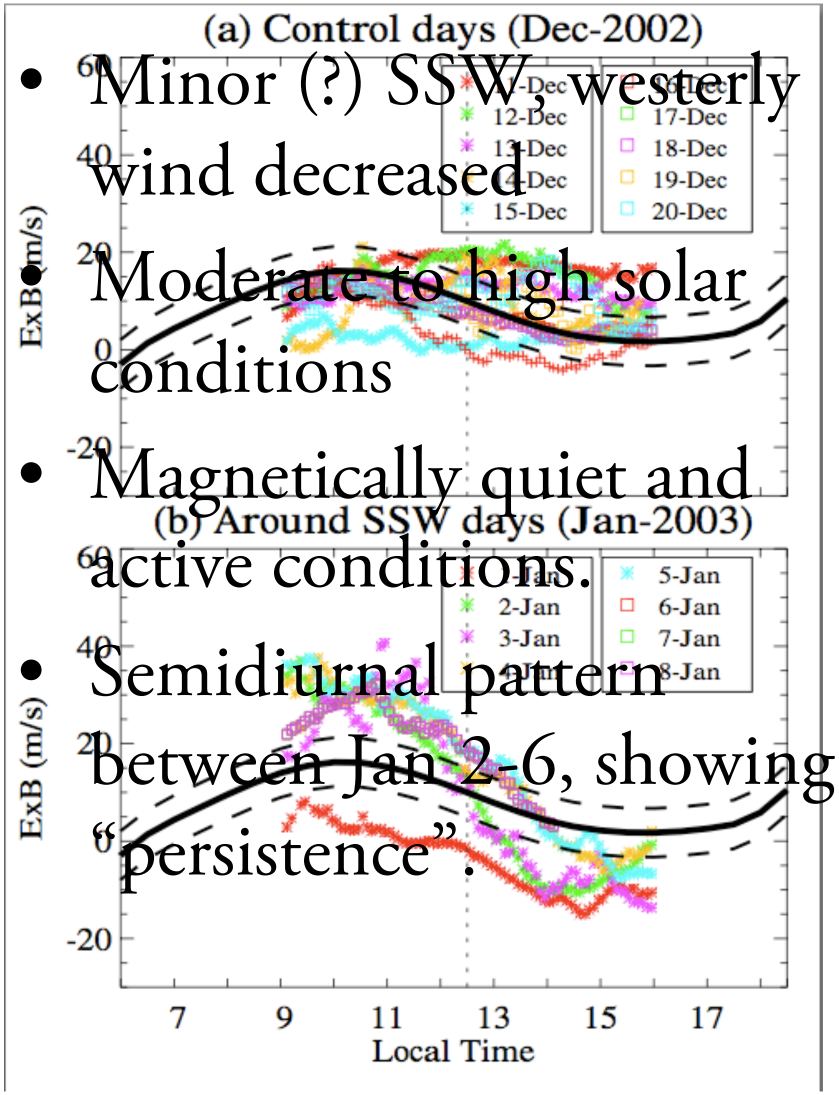
Radio Observatorio de JICAMARCA Radio Observatory



Other SSW events: Jan 2003 (ExB from 150-km echoes)

Radio Observatorio de JICAMARCA Radio Observatory





- Minor (?) SSW, westerly wind decreased
- Moderate to high solar conditions
- Magnetically quiet and active conditions.
- Semidiurnal pattern between Jan 2-6, showing "persistence".

PEME Variability

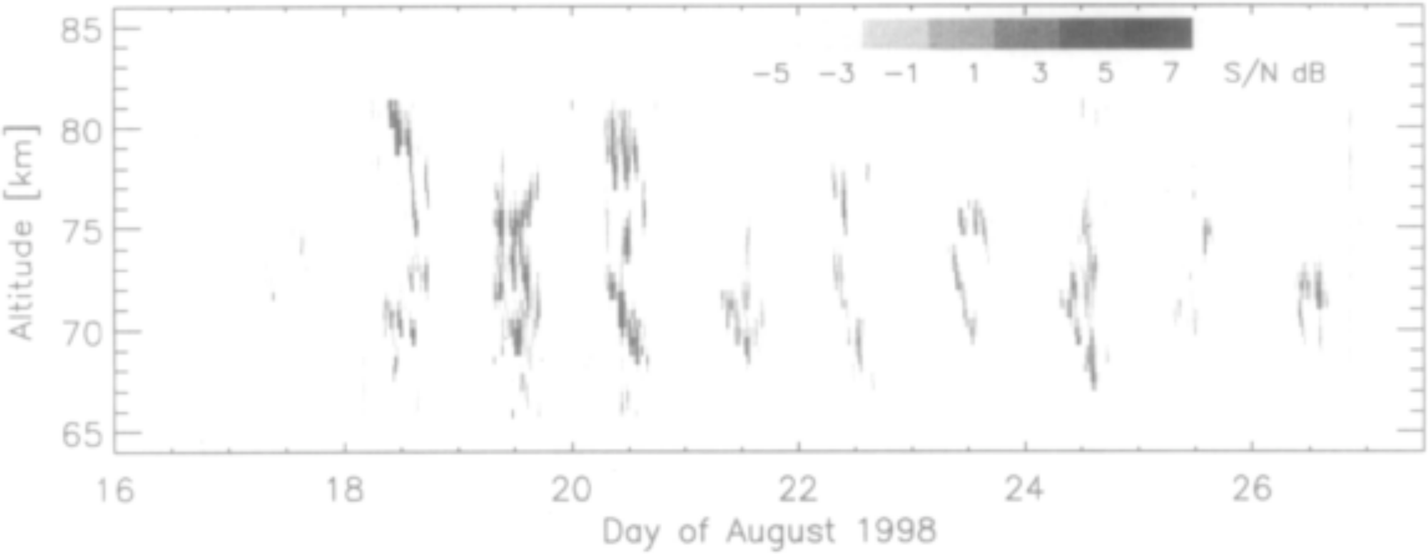
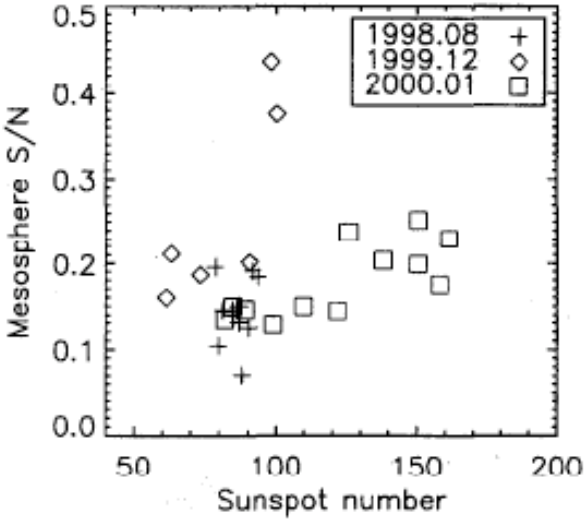
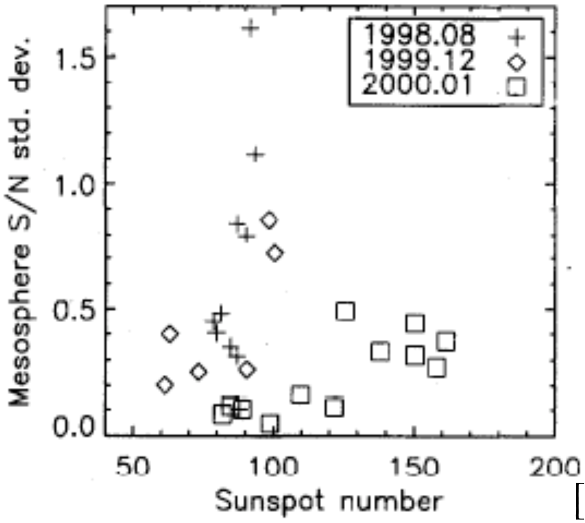


Fig. 4. Diurnal variation of vertical echo distribution. Each vertical pattern represents the daytime hours when echoes are present. Around 70 km, the echoes apparently descend at a rate of 12 km/day. The stronger S/N values near the beginning of the period are due to greater transmitted power.





[from *Lehmacher and Kudeki*. 2003]