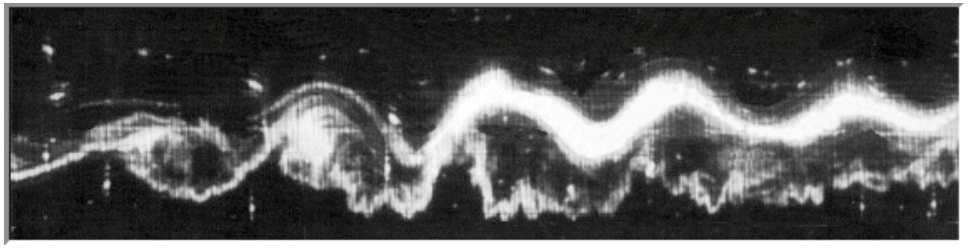
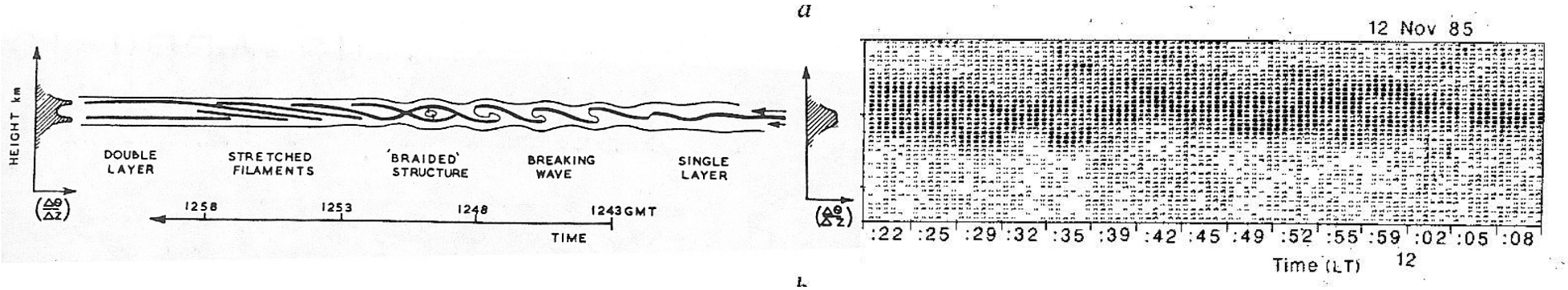


KHI* @ JRO

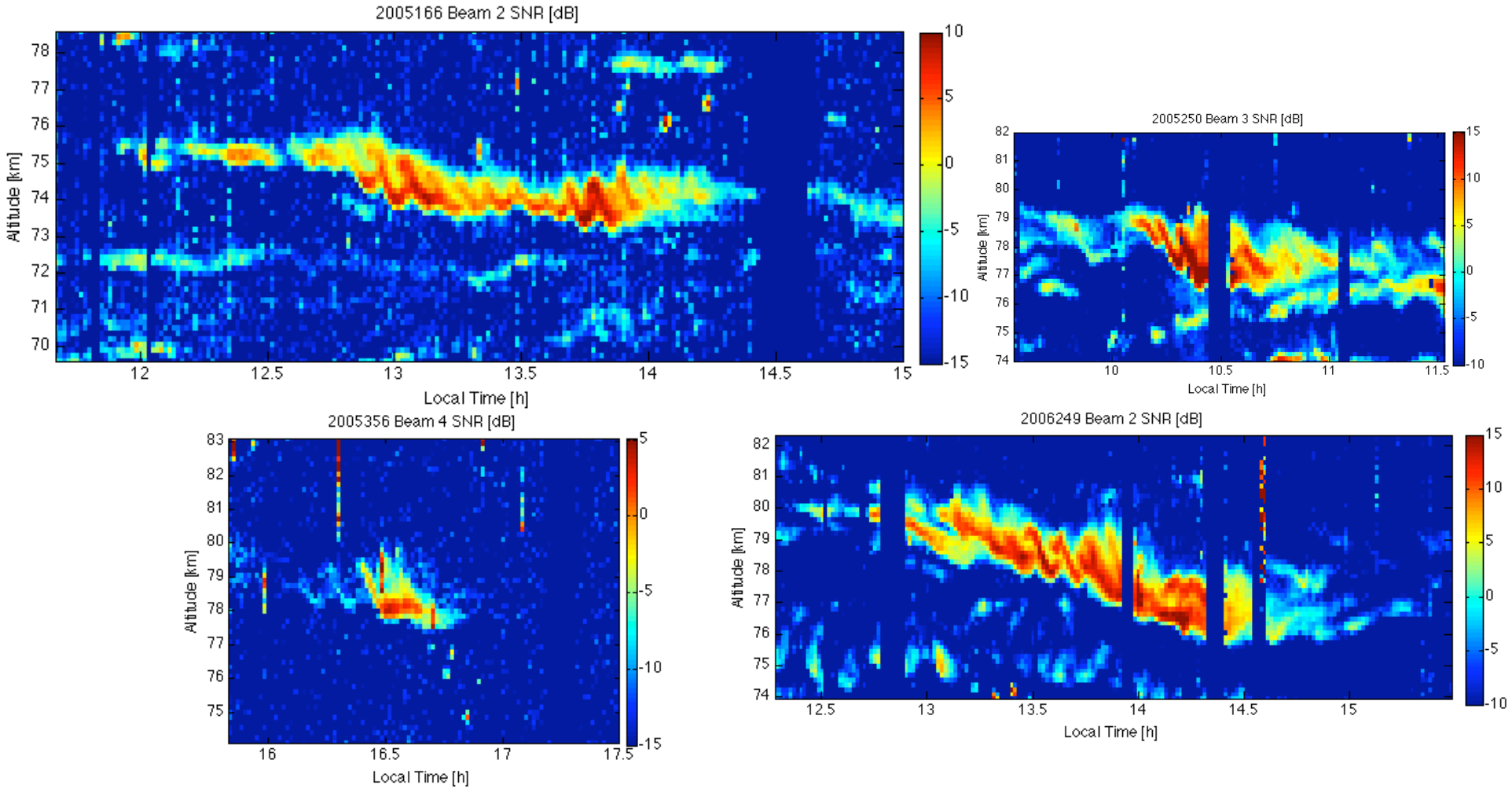


Gerald Lehmacher, Clemson University
Erhan Kudeki, University of Illinois
Jorge Chau, Jicamarca Radio Observatory

MST12, London, ON, May 2009

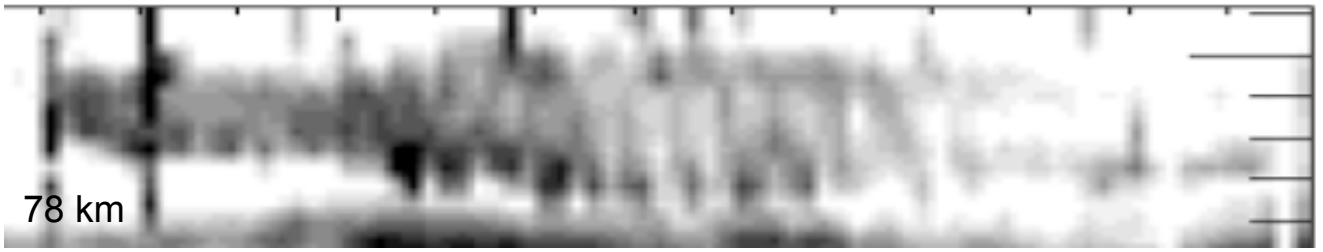
*in the mesosphere

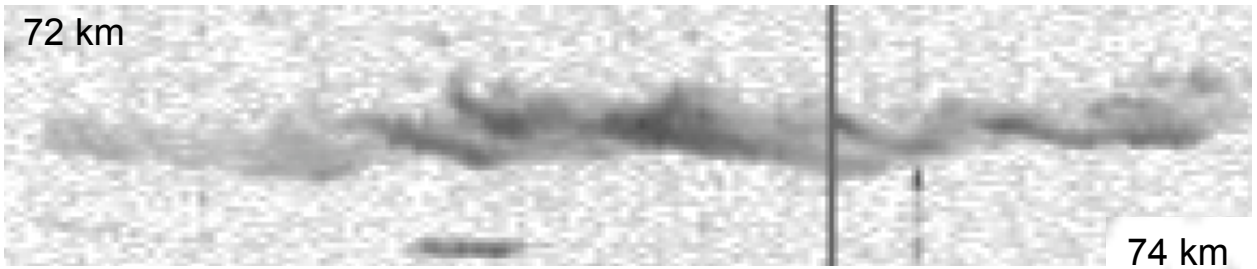
Examples from Jicamarca 1

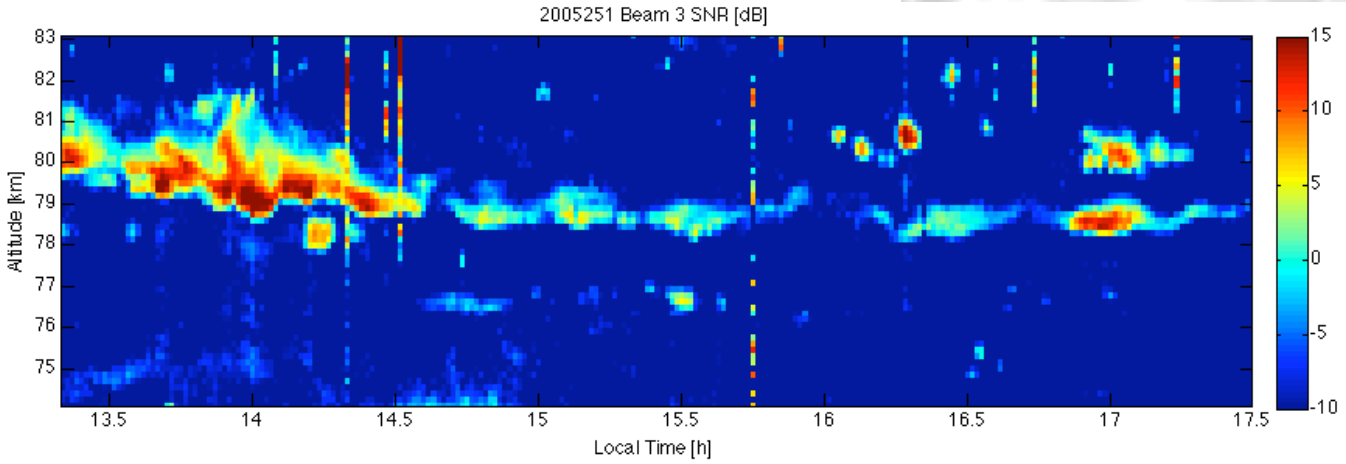


Lehmacher and Kudeki, 2002; Sheth et al., 2006; Lehmacher et al., 2007; Guo et al., 2007; KHI vortices made plausible by Rørvik, 1983.

Examples from Jicarmarca 2





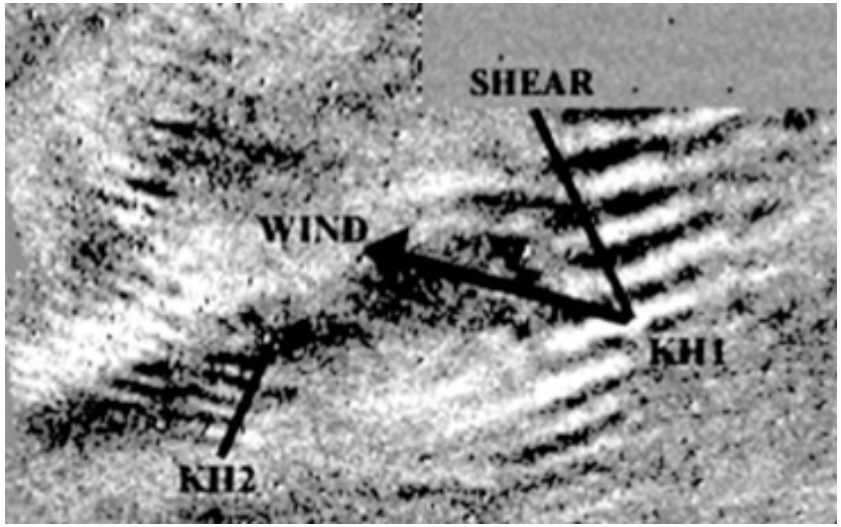


Examples: OH, NLC

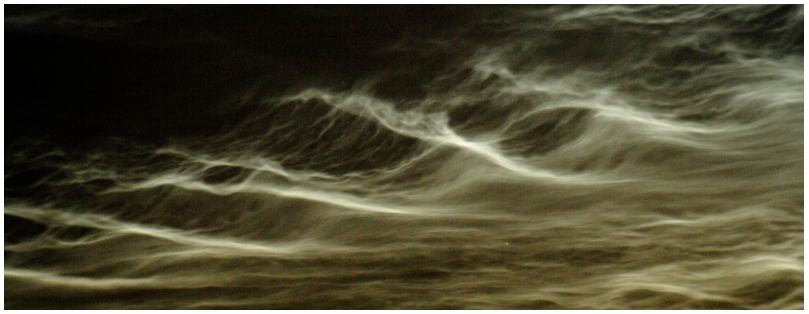
~ 85-90 km

82-83 km

e.g., Andreassen et al., 1994; images: 3sky.de, IAP

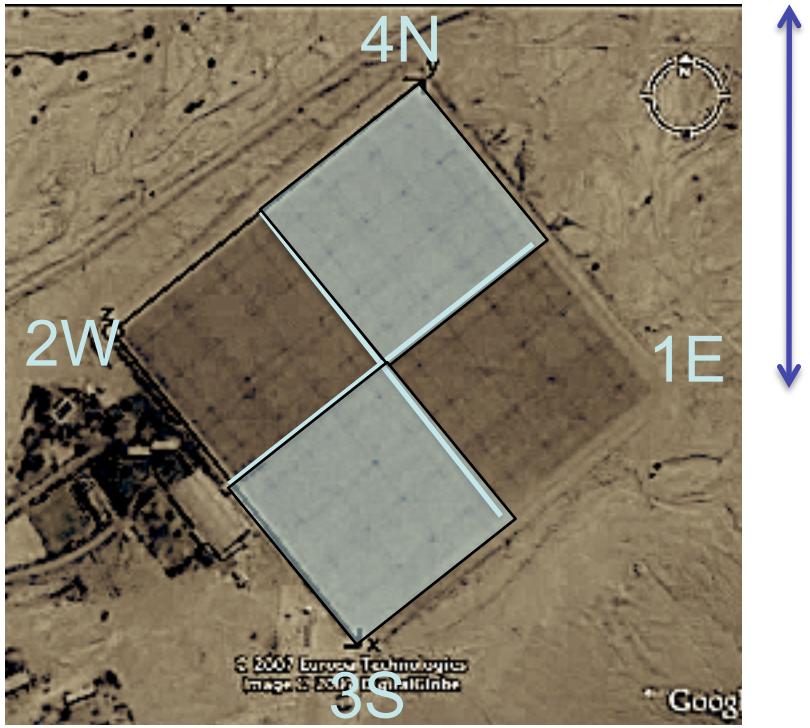


Hecht et al., 2005; 2007, and many more on bores and ducted waves



JRO MST geometry (simplified)

MST-ISR



49.92 MHz, 9216 crossed dipoles, 1.5 MW peak power, 1 μs, 64 -baud CC, 20 ci, 23 ii,
Four beams, half-power one-way beamwidth 0.7°, beams 2.5° off -zenith, Fritts et al., 1992; Hitchman et al., 1992.

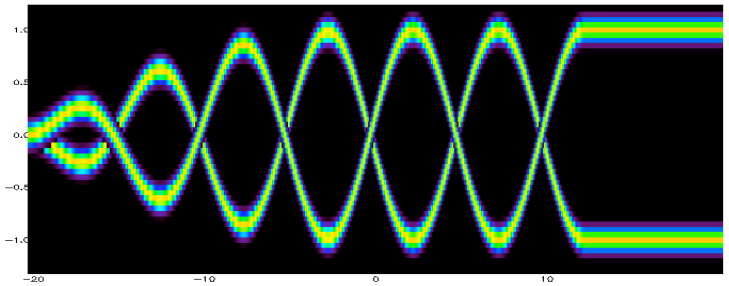
~3.2 km @75 km

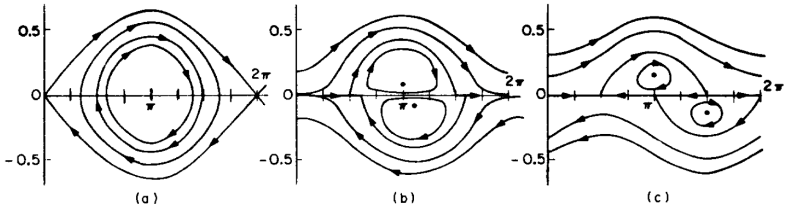
***U*~40 m/s~2.4 km/min**

$Ri \sim N^2/(dU/dz)^2 \sim 0.0004$ $s^{-2}/(40\ m/s/km)^2 = ¼$

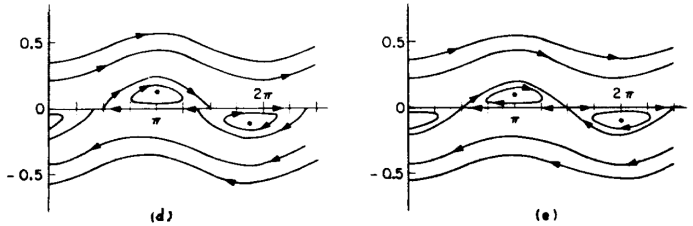
Basic shapes

Cat's eyes (Kelvin, 1871, Helmholtz, 1868)

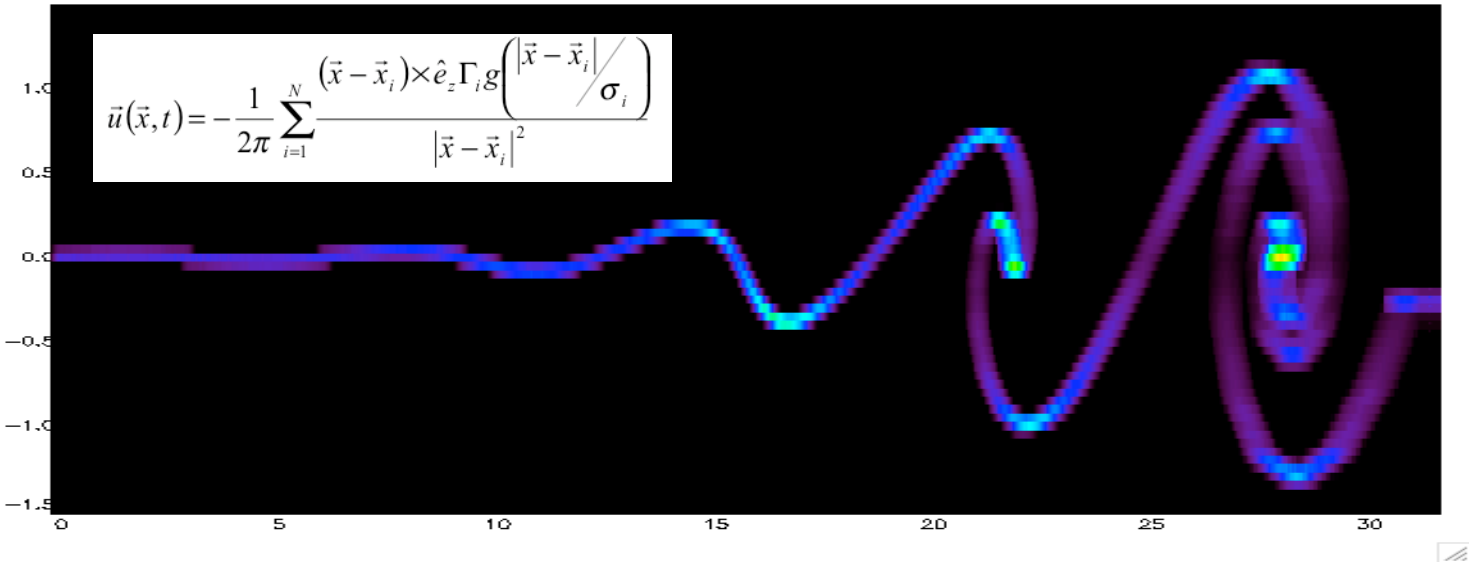




Cockeyed cat's eyes (G. I. Taylor, 1931, from Gossard and Frisch, 1975)



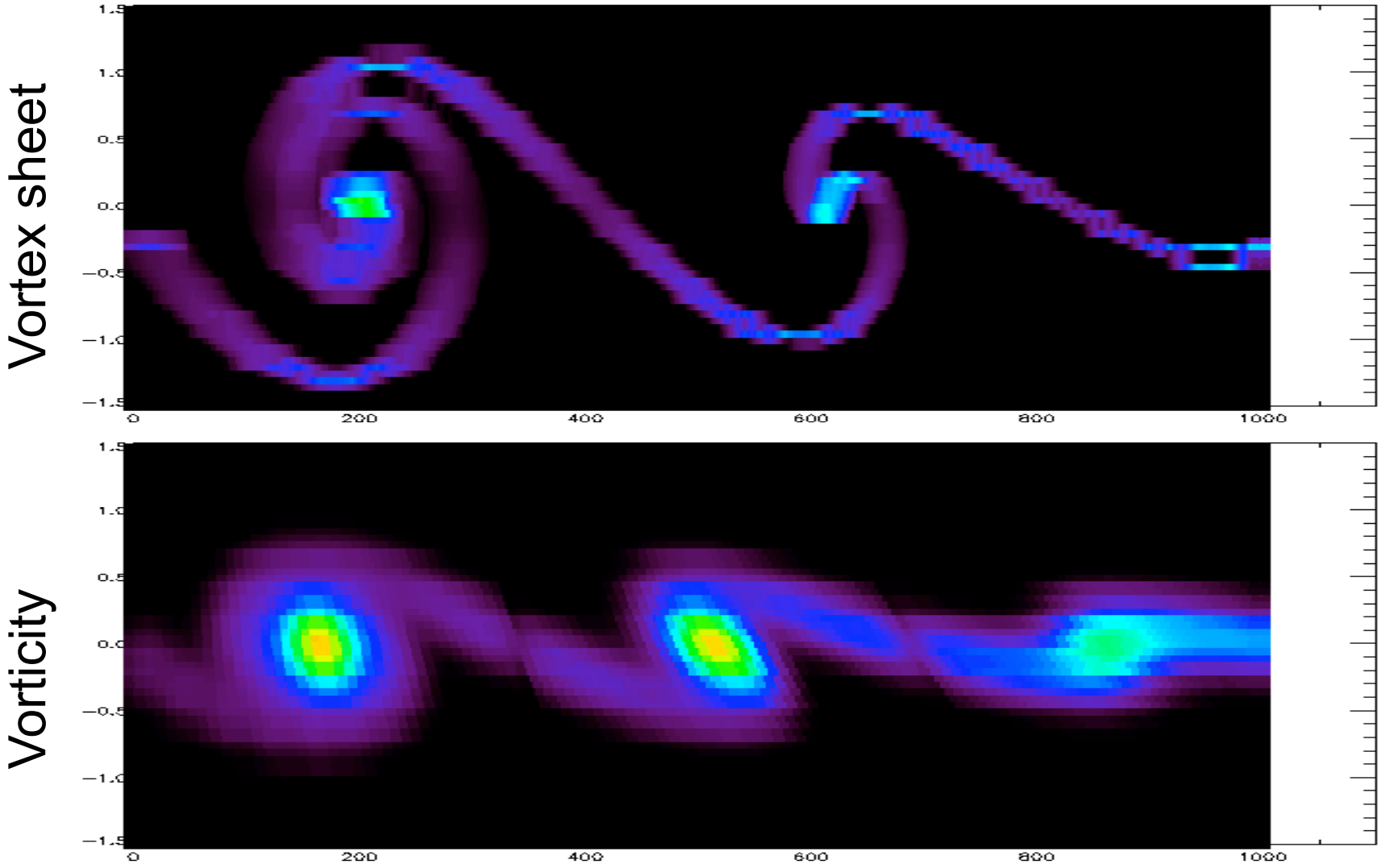
$$\vec{u}(\vec{x},t) = -\frac{1}{2\pi}\sum_{i=1}^{N}\frac{(\vec{x}-\vec{x}_i)\times\hat{e}_z\Gamma_i g\left(|\vec{x}-\vec{x}_i|/\sigma_i\right)}{|\vec{x}-\vec{x}_i|^2}$$



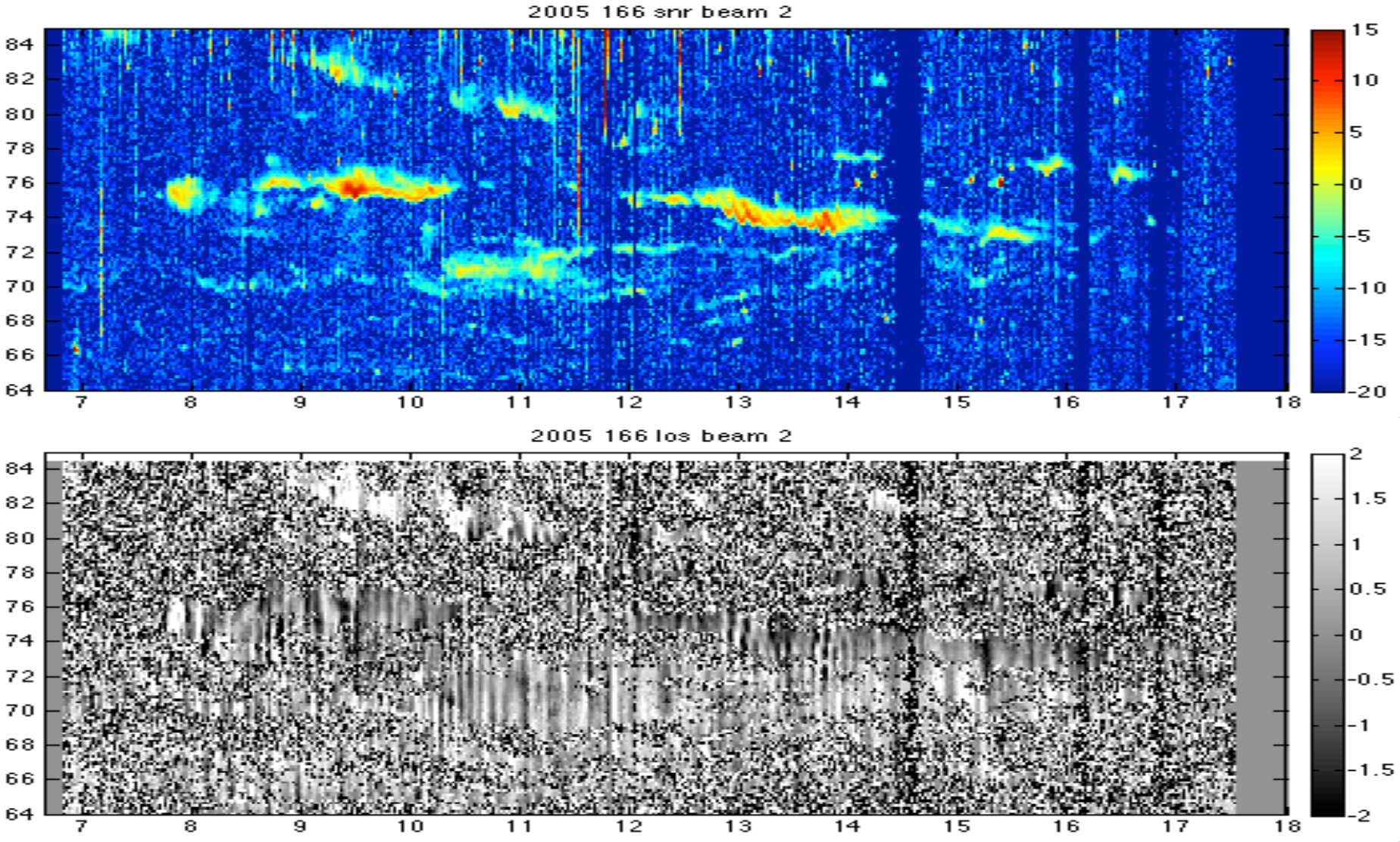
Vortex sheet rolling up (Rosenbaum, 1935?)

“Simulations”

advecting pattern across radar beam



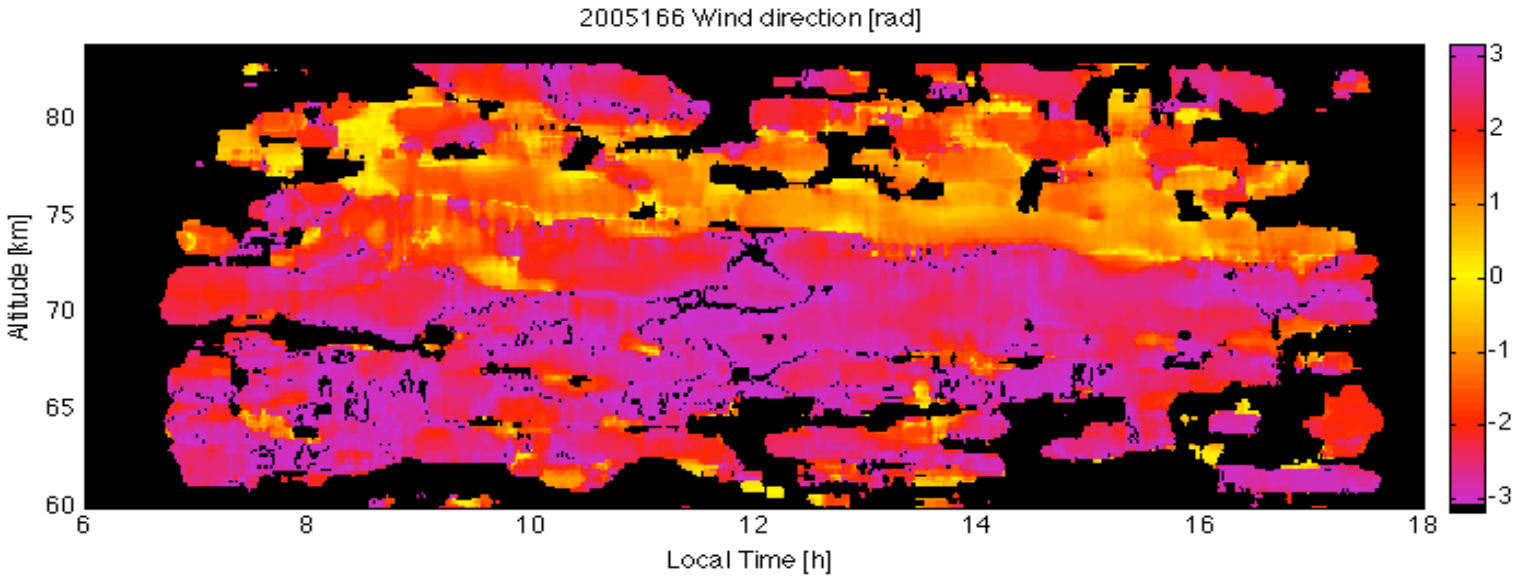
Overview: 2005 166



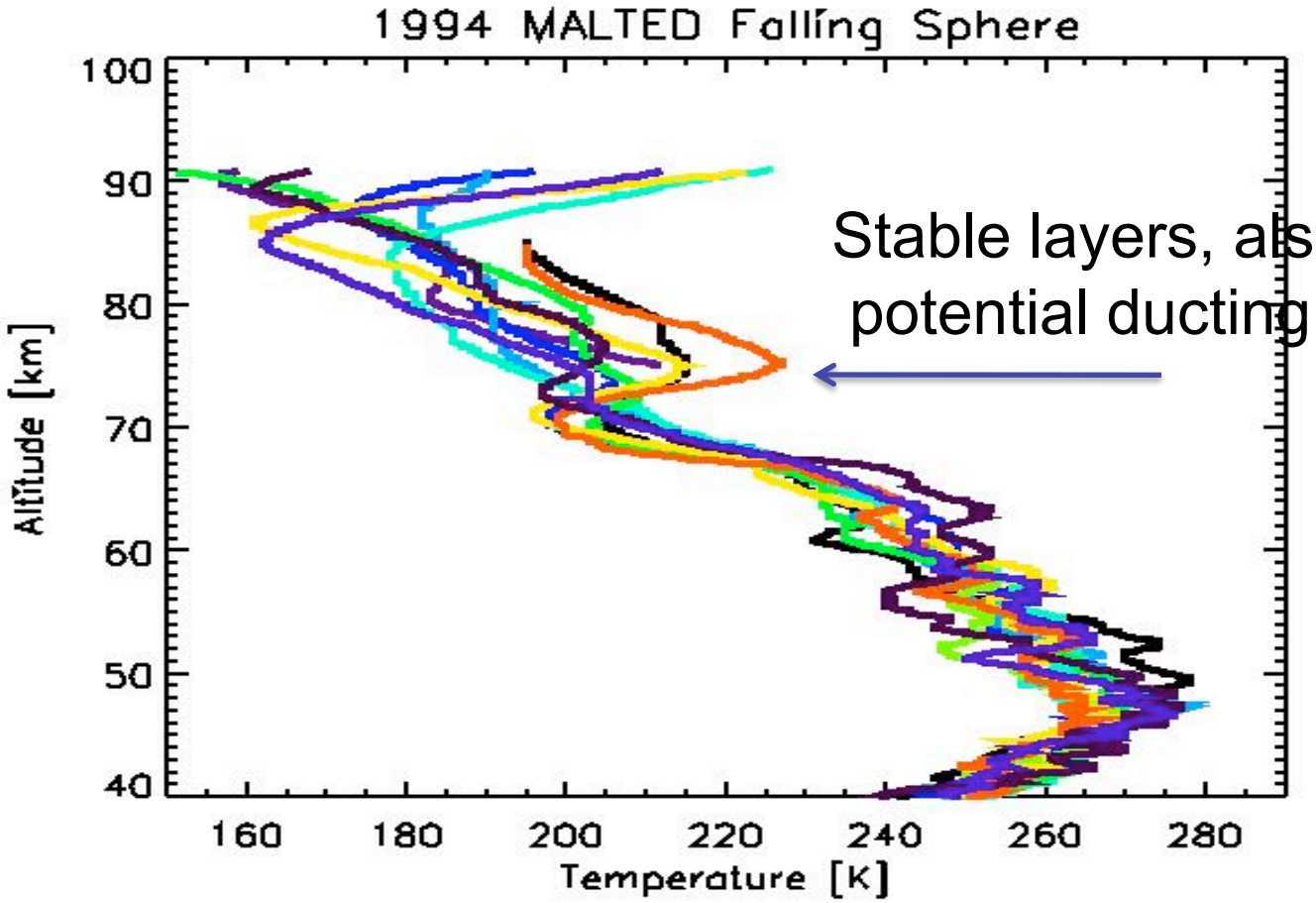
Lehmacher et al., 2007; average day in June, more echoes in equinox and winter, stronger echoes for higher solar flux

Horizontal winds

- Permanent horizontal wind shears, Richardson number $Ri = \omega_B^2/(du/dz)^2$
- Diurnal tide 24 h, $d\varphi/dz$ ~ 1 km/h
- Inertia-gravity waves, inertial freq. at 12° latitude $2\pi/f$ ~ 56 h
- Additional mean wind structure provided by MSAO



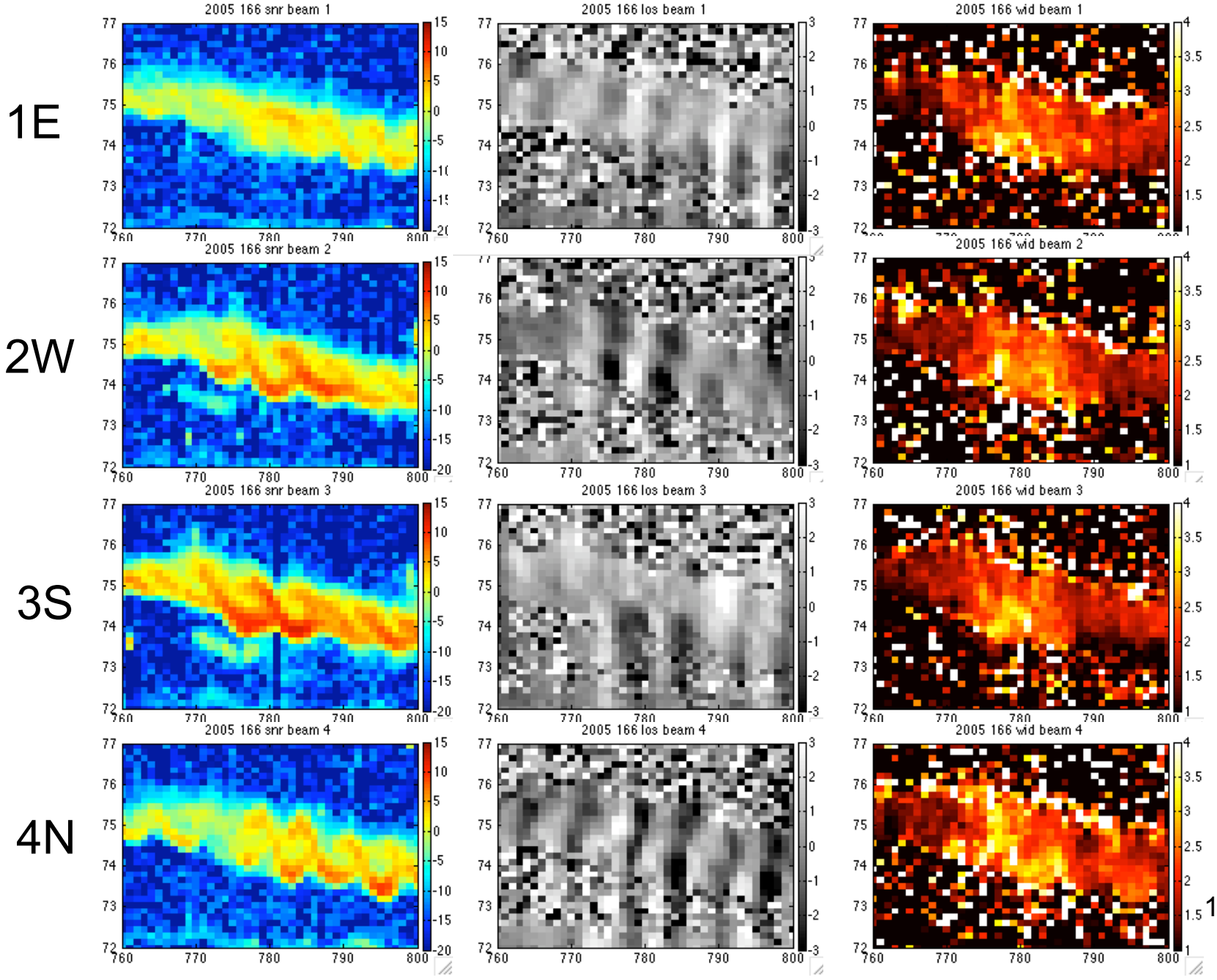
Temperature profiles (2.3° S)



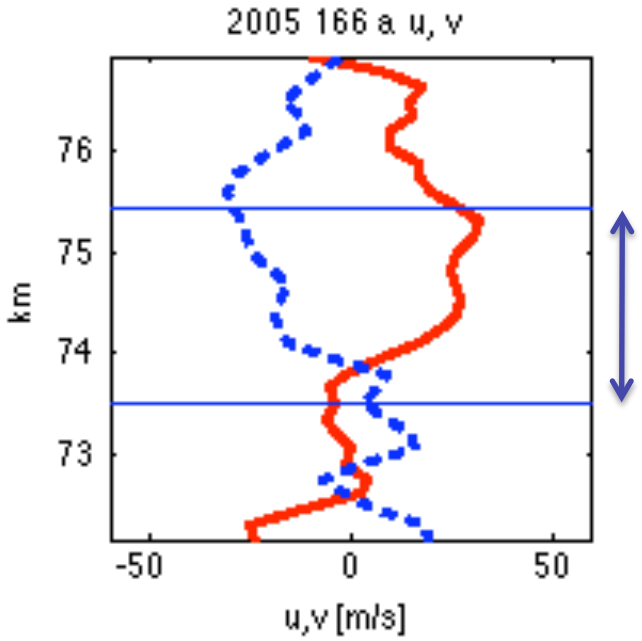
Stable layers, also potential ducting regions

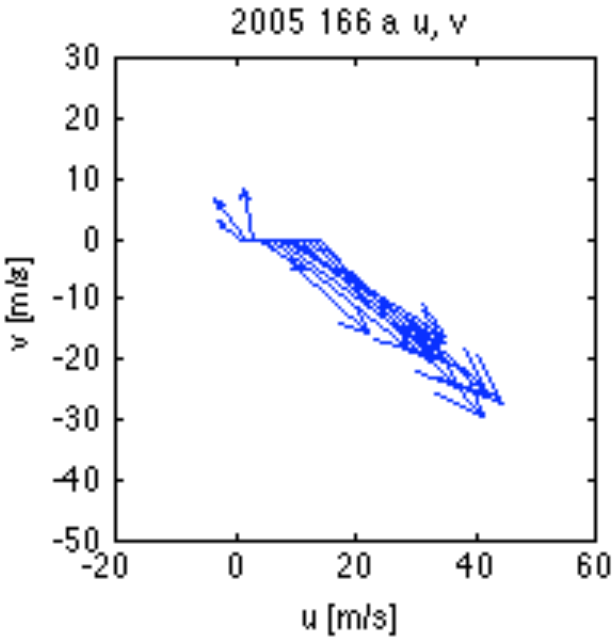
Goldberg et al., 1997

2005166 a


1E
2W
3S
4N
2005 166 snr beam 1
2005 166 los beam 1
2005 166 wid beam 1
2005 166 snr beam 2
2005 166 wid beam 2
2005 166 snr beam 3
2005 166 los beam 3
2005 166 wid beam 3
2005 166 snr beam 4
2005 166 los beam 4
2005 166 wid beam 4

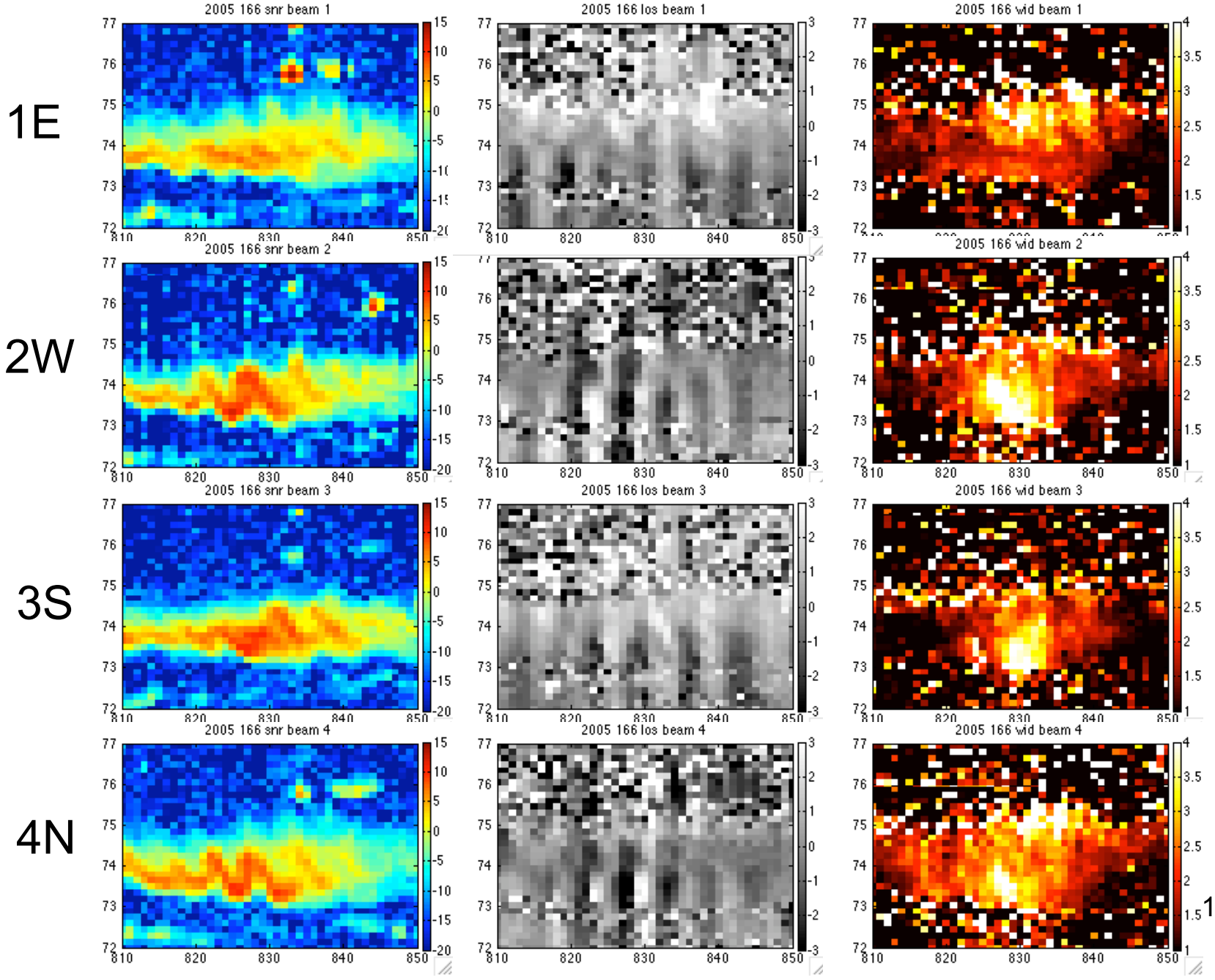
Horizontal winds: a



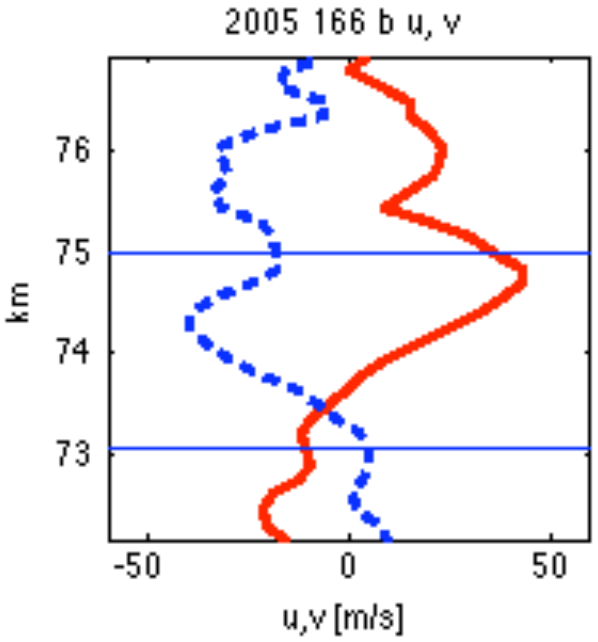


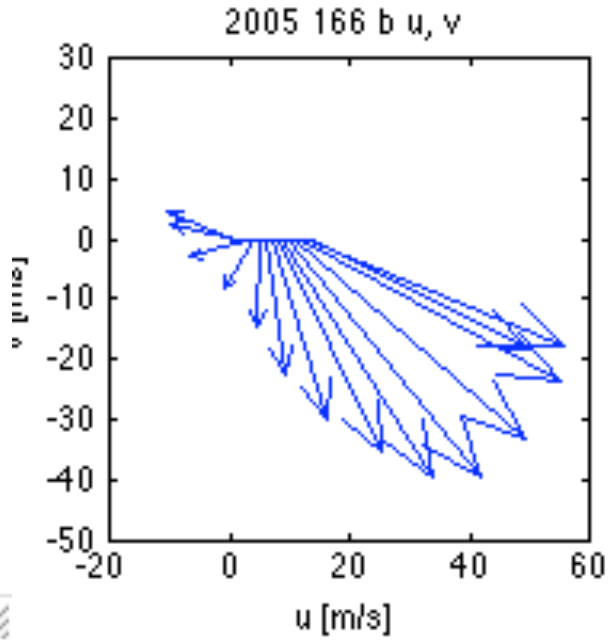
wind shear ~30 m/s km^{-1}
wind and wind shear southwestward

2005166 b


1E
2W
3S
4N
2005 166 snr beam 1
2005 166 los beam 1
2005 166 wid beam 1
2005 166 snr beam 2
2005 166 wid beam 2
2005 166 snr beam 3
2005 166 los beam 3
2005 166 wid beam 3
2005 166 snr beam 4
2005 166 los beam 4
2005 166 wid beam 4

Horizontal winds b





wind shear ~40 m/s km^{-1}
wind and wind shear southwestward with
rotation indicating IGW or tidal motion

Radial (vertical) velocities 1

- All observations show short-period, quasi-monochromatic vertical velocity fluctuations throughout the mesosphere, in phase, 10 or more kilometer (~2*H*) deep.
- What are they?
- Where do they come from?

Radial (vertical) velocities 2

- Doppler-shifted gravity waves peaking near *N*, (nearly) evanescent (Rastogi and Bowhill, 1976; Scheffler and Liu, 1985, Röttger, 1986; Fritts et al., 1992)

$$m^2 = \frac{N^2}{(\bar{u}-c)^2} - \frac{\bar{u}_{zz}}{(\bar{u}-c)} - k_h^2$$

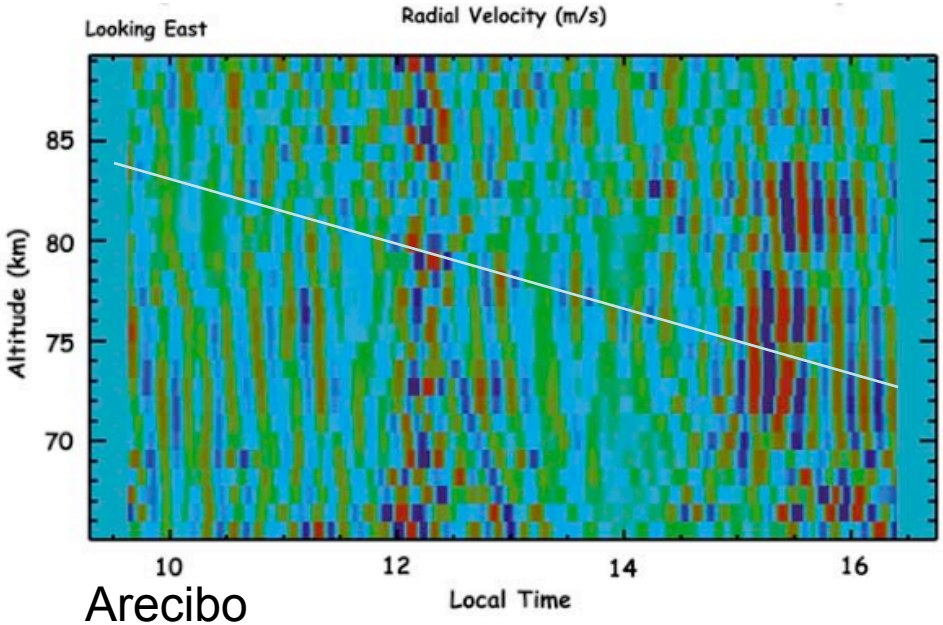
Dispersion relation (-1/4H^2 neglect?)

$$E(k,m) = \frac{2\,f\,N\,E\,m/m^*}{\pi\left(1+\frac{m}{m^*}\right)^{5/2}\left(N^2k^2+f^2m^2\right)}.$$

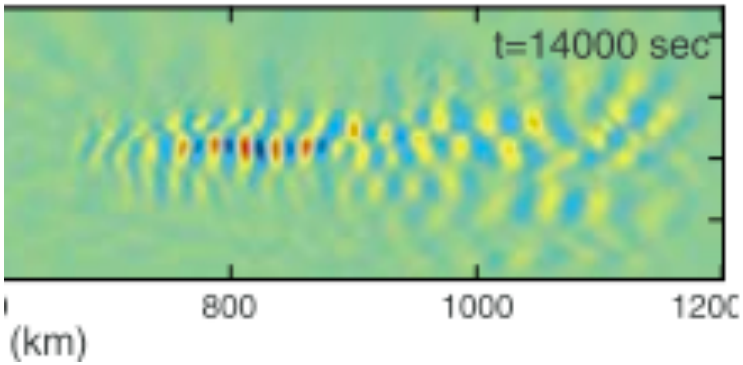
Garrett-Munk spectrum

Radial (vertical) velocities 3

- Thermally and Doppler ducted waves, quasi-monochromatic, (bores?), tunneling, providing initial disturbance of vorticity sheets, corrugation (e.g.,Chimonas and Hines, 1986; Fritts et al., 1992; Snively and Pasko, 2003; 2008; Fritts and Janches, 2008; Laughman et al., 2009)



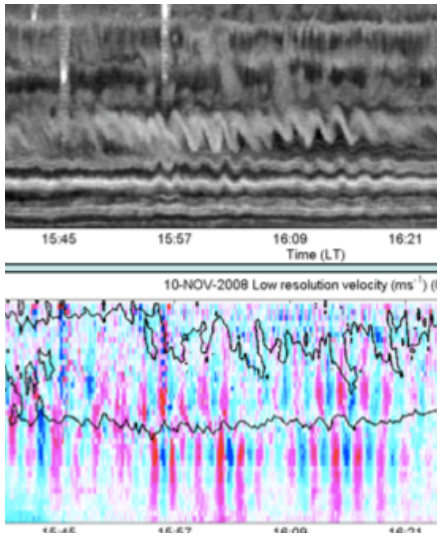
Arecibo



Ducting

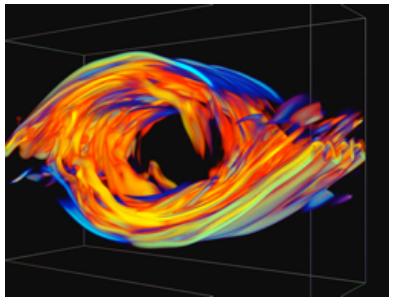
Radial (vertical) velocities 4

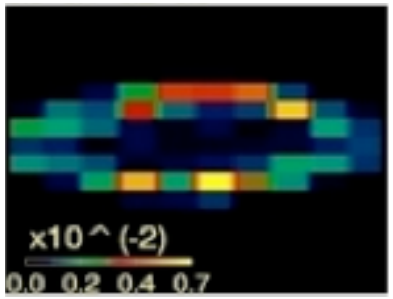
- Evanescent waves extending from or excited by KHI
  - including cockeyed cat's eyes (see poster by Luce et al.),
  - phase shift during maximum billow height
  - excitation and modulation of layers below and above



Radial (vertical) velocities 5

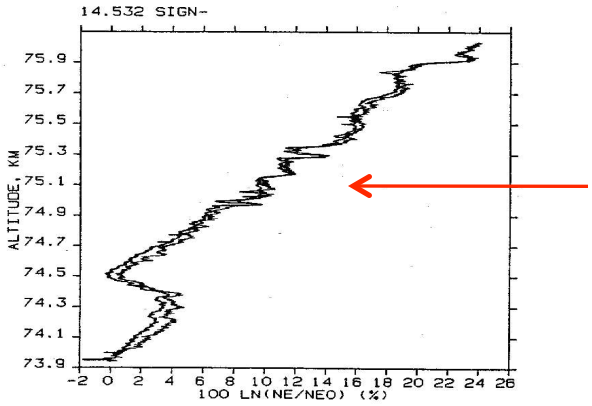
- Comparison with modeling results
  - Bias of radial velocities by tilted structures (Muschinski, 1996; Fritts, P. Franke, et al., 2009)
  - Top edge more reflective
  - Edge echoes are (very) aspect sensitive (Röttger et al., 1978; Fukao et al., 1980; Kudeki et al.,1990; Sheth et al., 2006)

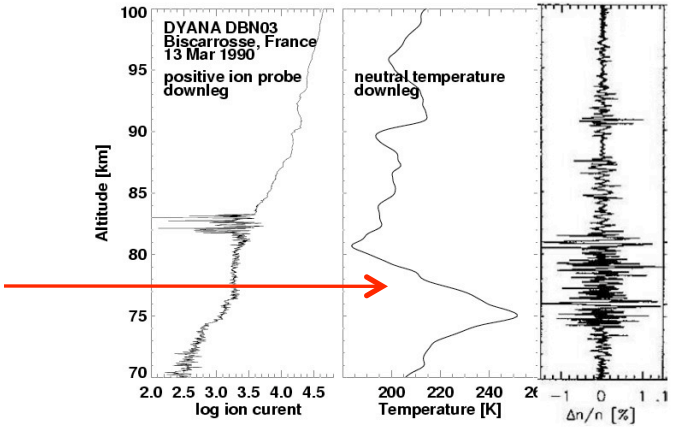




Summary

- Jicamarca mesospheric echoes show/confirm that
  - reflectivity patterns from KHI are modified or distorted by wind field
  - presence of large wind shears (inertia-gravity waves, tides), $Ri < 0.25$ (very) common
  - turbulent tracer (Δn @ 3 m) is best visible on density gradients ($\sim M_n^2$), but could also be fossil (Smith and Klaus, 1976, Parker and Bowhill, 1991; Lehmacher and Lübken, 1995)





Future: ideas

- filtering data for more robust horizontal winds
- dynamic spectra, (Fresnel echoes?)
- 3-D reconstruction of KH billows, aspect sensitivity
- comparison with SABER for (medium resolution) altitude profiles (temperature, water vapor…)