Radar Thermodynamic And Wind Profiling

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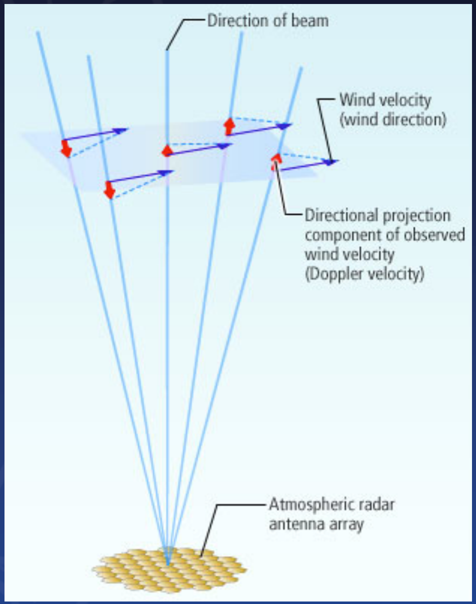
What should you expect to hear during this presentation?

- A discussion of wind and thermodynamic profiling methodologies with a focus on radar and wind profilers in particular
- What wind profilers provide in the way of dynamic and thermodynamic information
- Which parameters they not not so good at providing
- Which measurements are well suited to complement wind profiler observations

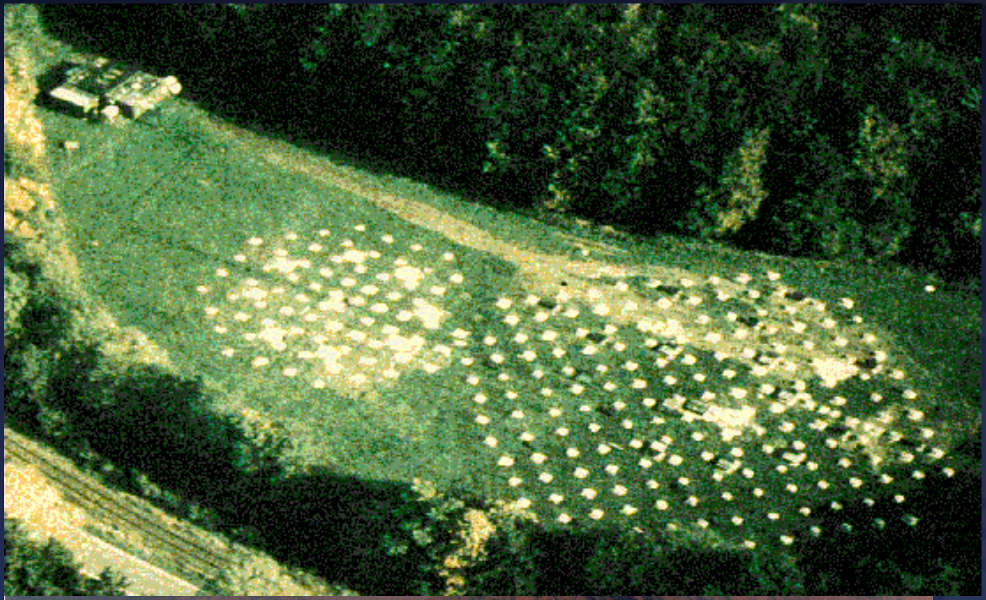
Strengths of Wind Profiling Radars

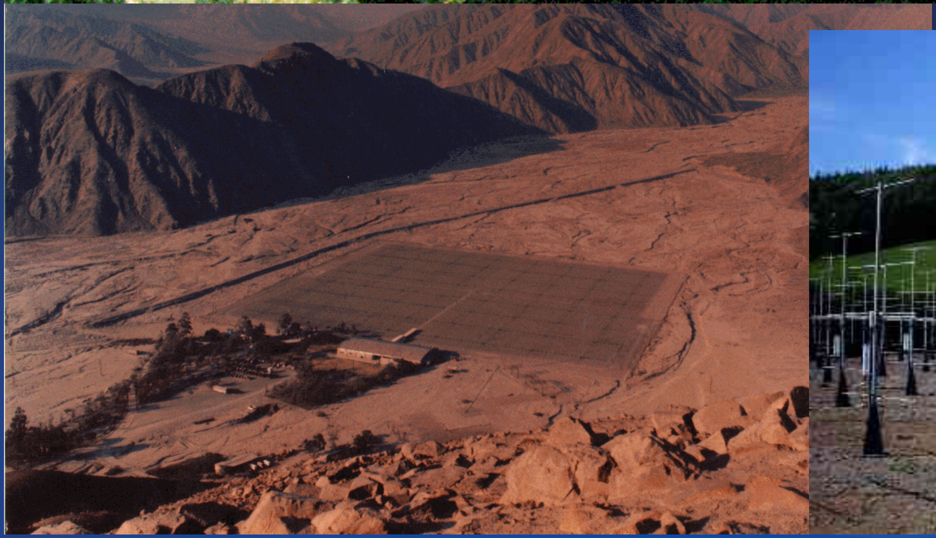
1. Provide continuous measurements of the atmosphere in all weather conditions over a large range of heights
2. Provide 'gated' observations (not just linearly integrated observations) with relatively good spatial and temporal resolution.
3. Capable of supporting atmospheric research in a wide range of topic areas
4. Have been in operation for many years at a variety of geographic locations, so plenty of opportunities for data mining.



Wind Profilers

Wind Profilers





Coherent Clear-Air Scatter

For the case of Bragg scatter from clear-air turbulence,
It is customary to assume that

$$P = C\frac{\eta}{r^2}$$

$$\eta = 0.379\frac{C_n^2}{\lambda^{1/3}}$$

Here it has been assumed that the turbulence is:

- Homogeneous,
- Isotropic.
- Volume-filling, and
- Within the inertial subrange

Structure Function Parameters

The structure function parameter is give by

$$C_n^2 = \frac{\left\langle |n(r) - n(r+\Delta)|^2 \right\rangle}{\Delta^{2/3}}$$

$$n - 1 = 77.6 \times 10^{-6} \frac{p}{T} + 0.3733 \frac{e}{T^2}$$

where
p is pressure in hPa
T is temperature in K
e is water vapor pressure in hPa

Neutral
Atmosphere

Coherent Clear-Air Scatter

For the case of Bragg scatter from clear-air turbulence, one can also write

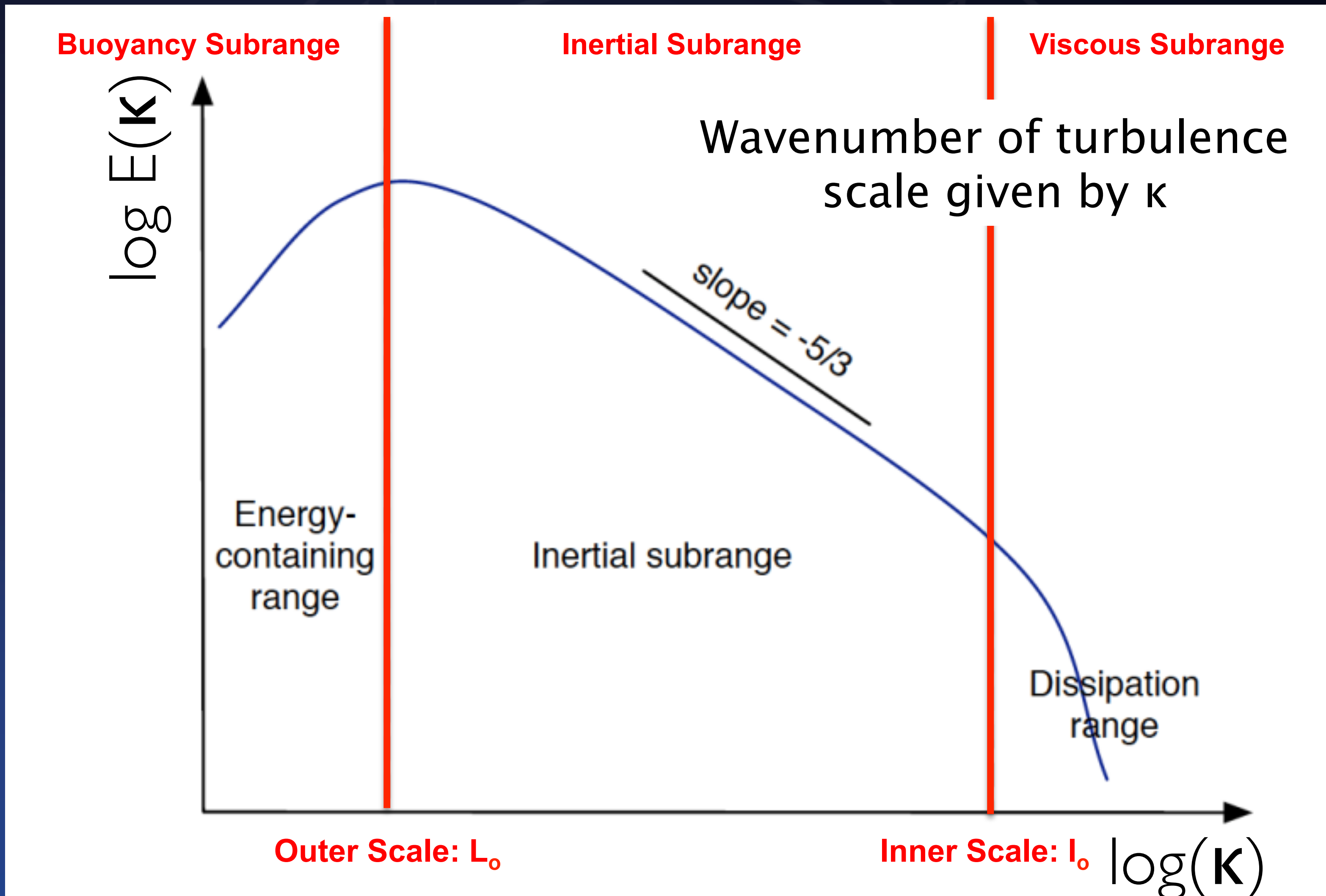
$$\eta = aL_o^{4/3}\frac{M^2}{\lambda^{1/3}}$$

$$M = \frac{dn}{dz} = \frac{\partial n}{\partial \Theta}\frac{d\Theta}{dz} + \frac{\partial n}{\partial q}\frac{dq}{dz}$$

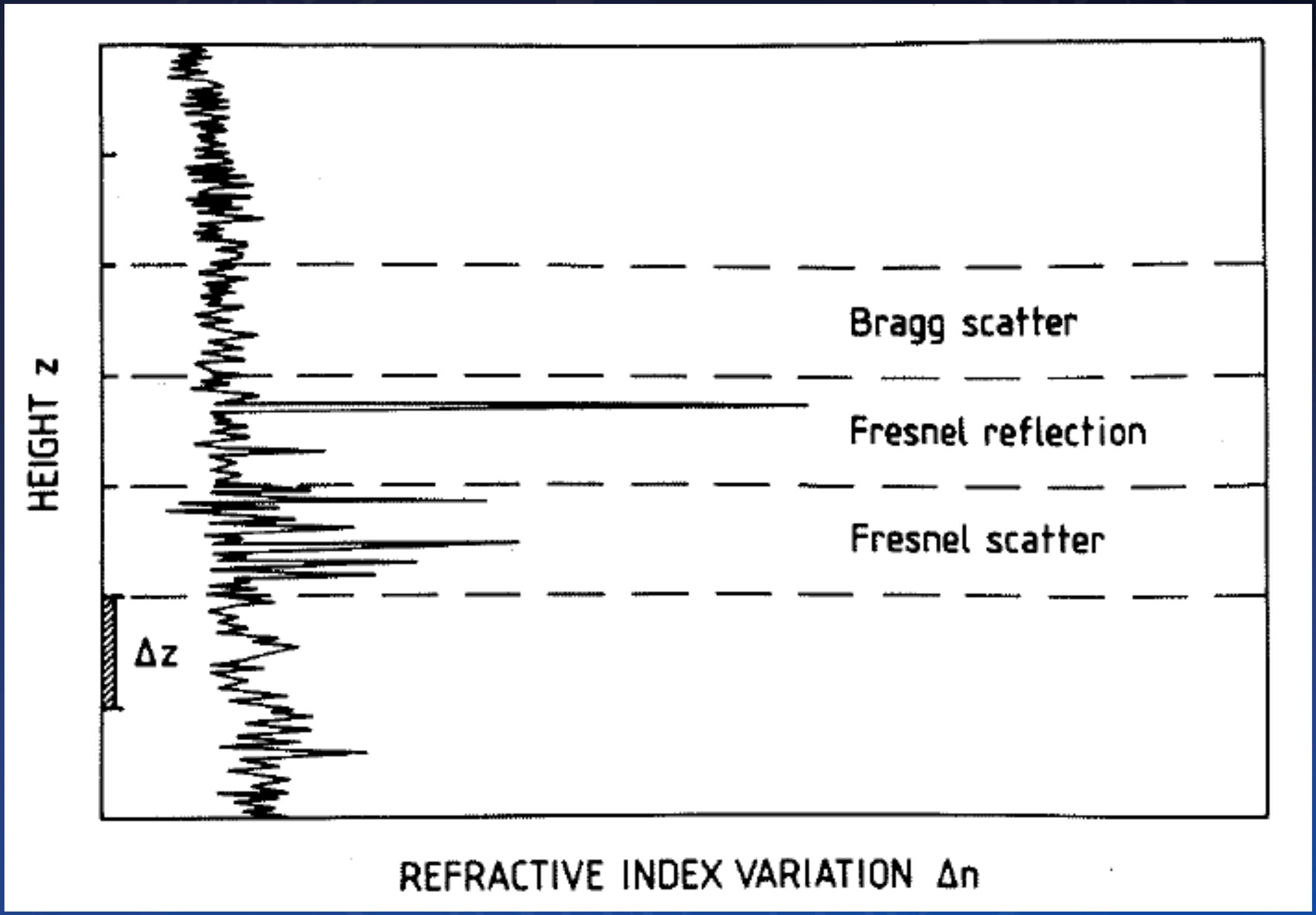
Where

- *M* is the mean gradient of potential refractive index
- *a* is close to unity for our application
- L_o is the outer scale of turbulence

Kolmogorov Energy Cascade

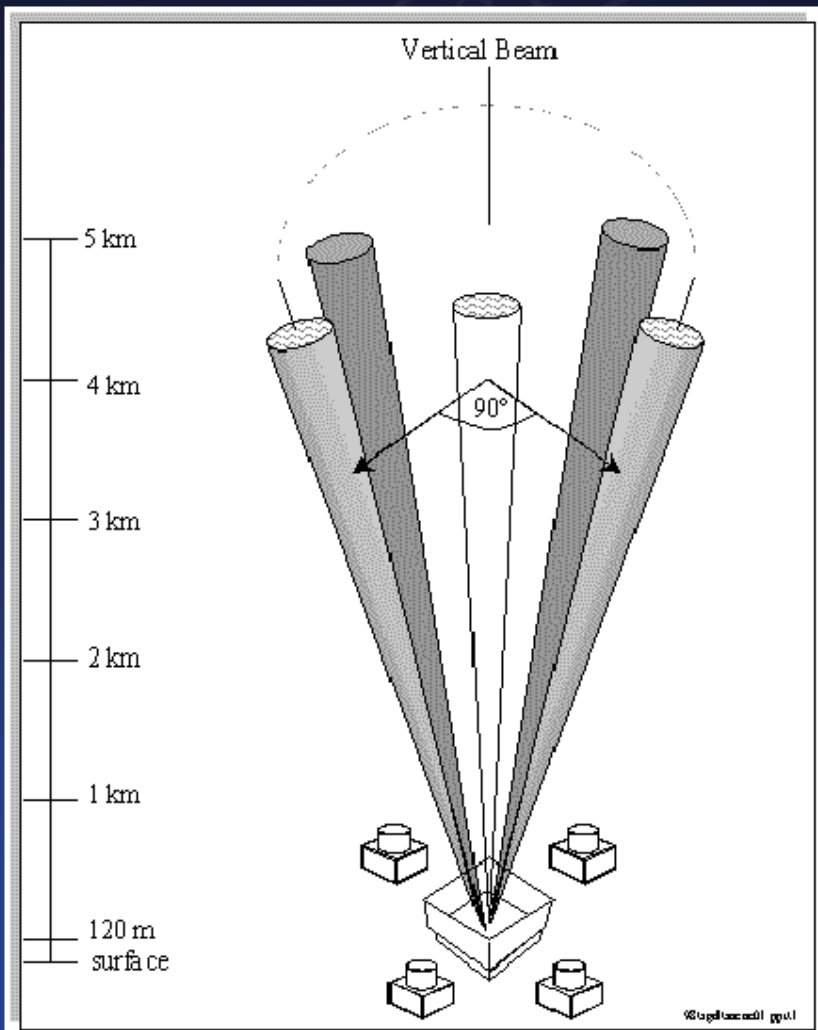


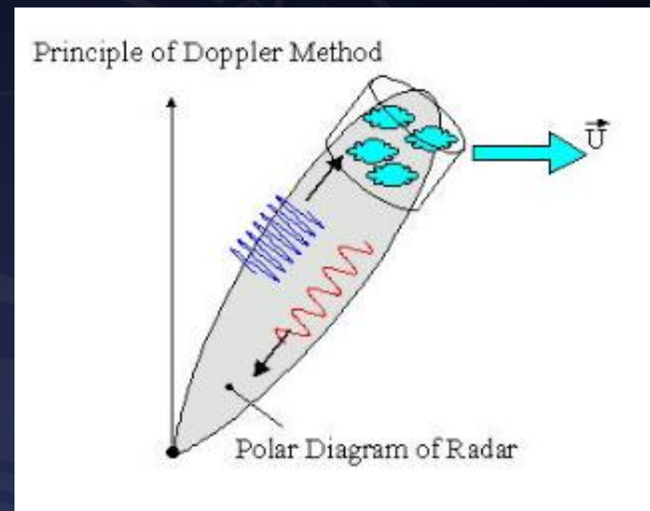
Fresnel Scatter and Reflection



Röttger & Larsen, 1990

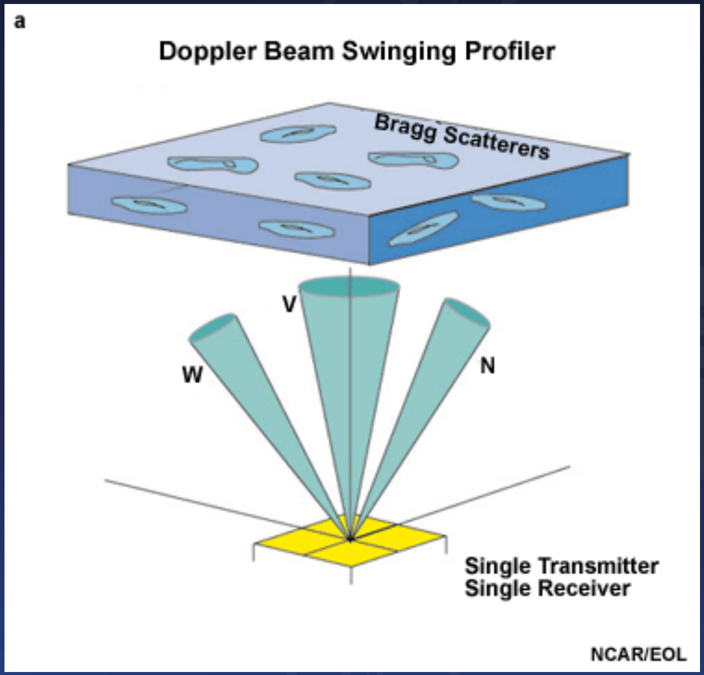
Doppler Beam Swinging

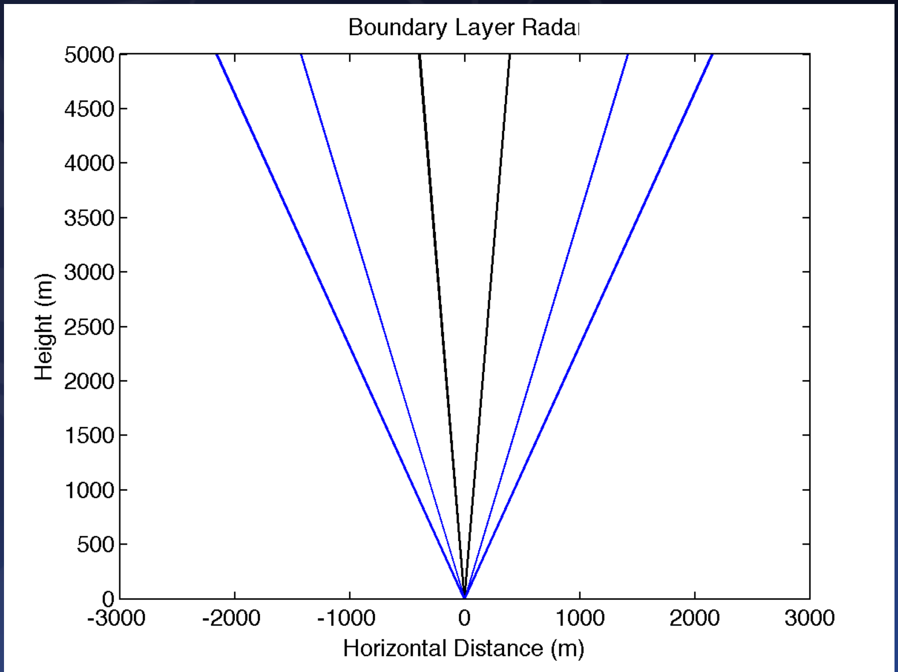




- Beam is rapidly steered to three or more directions (phased array antenna)
- Radial velocity measured for each beam
- Wind field reconstructed from the radial velocities
- Wind field assumed uniform over the sampling volume

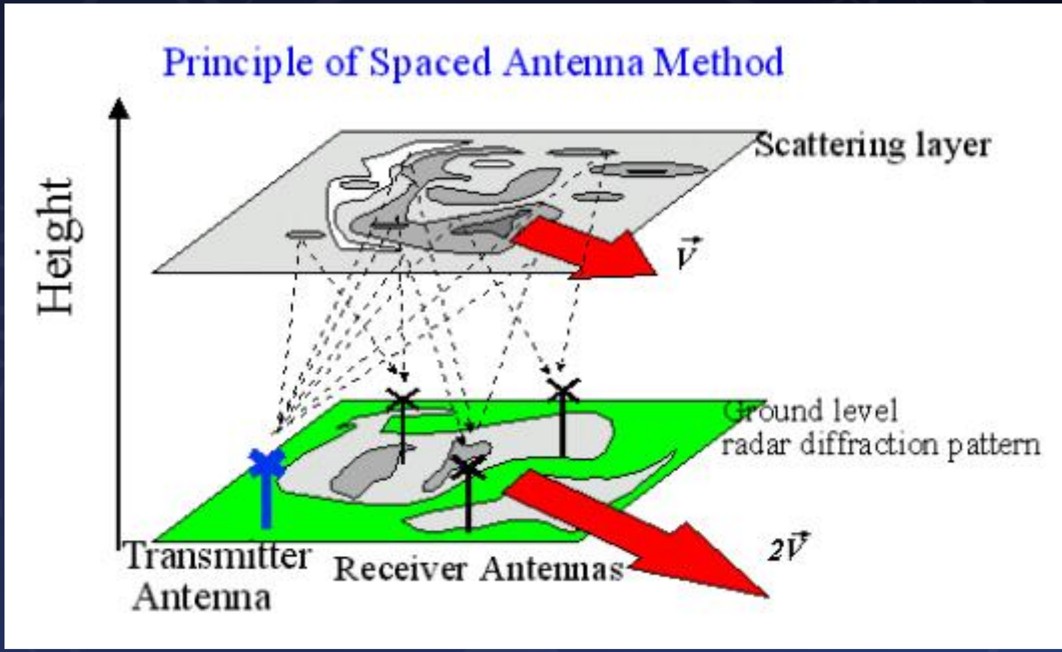
Doppler Beam Swinging





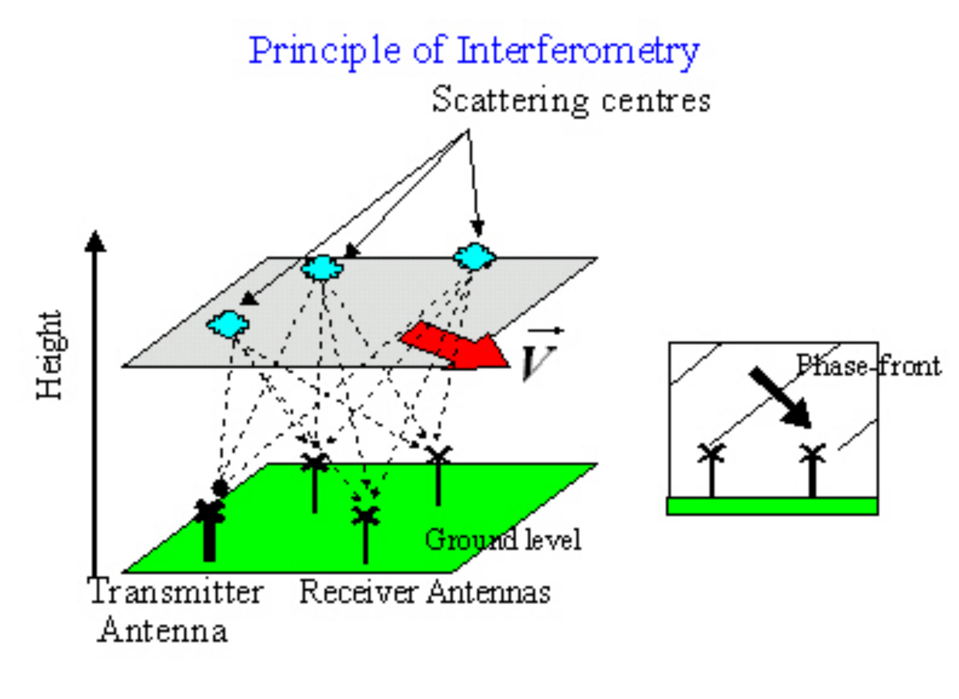
It is assumed that the wind field is uniform in space and time across the sampling volume

Spaced Antenna



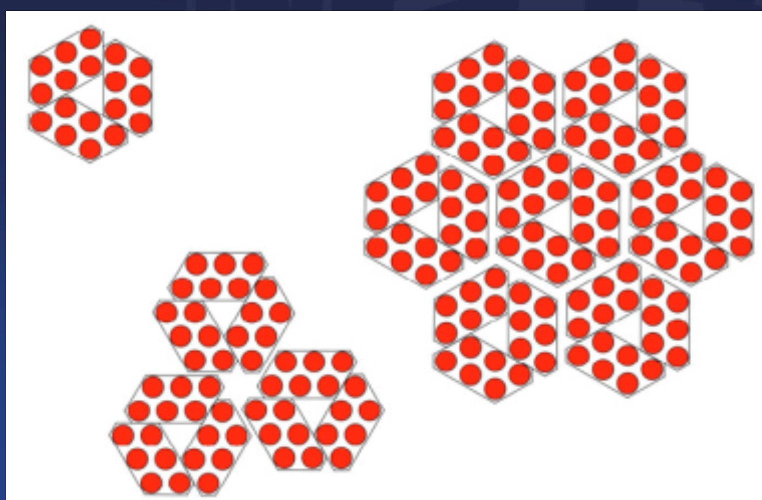
- Radio waves transmitted and the backscattered signals recorded on three or more spatially separated antennas (or groups of antennas)
- The backscattered signals form a diffraction pattern that moves across the ground
- The speed of the diffraction pattern is measured and related to the wind speed

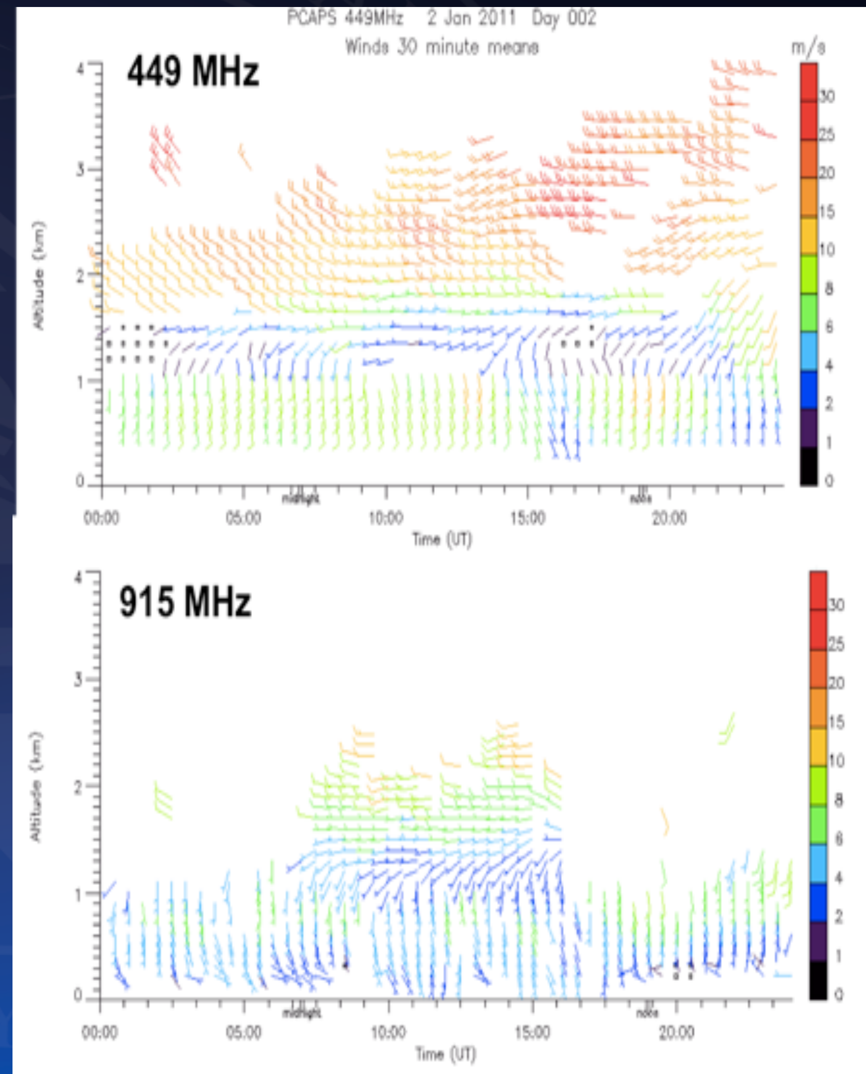
Interferometry



- Radio waves transmitted and the backscattered signals recorded on three or more spatially separated antennas (or groups of antennas)
- Assume that the backscatter primarily comes from a few scattering centers
- Use the time evolution of the phase differences between the echo power at the various receiver locations to measure the wind

Modular 449-MHz Profiler

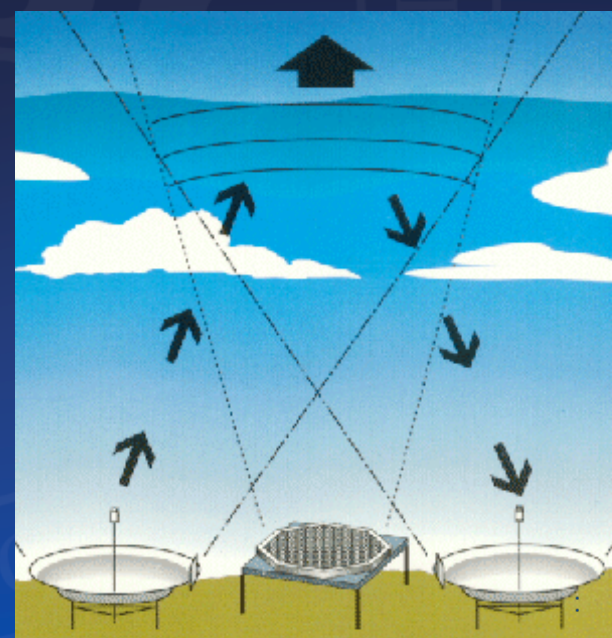




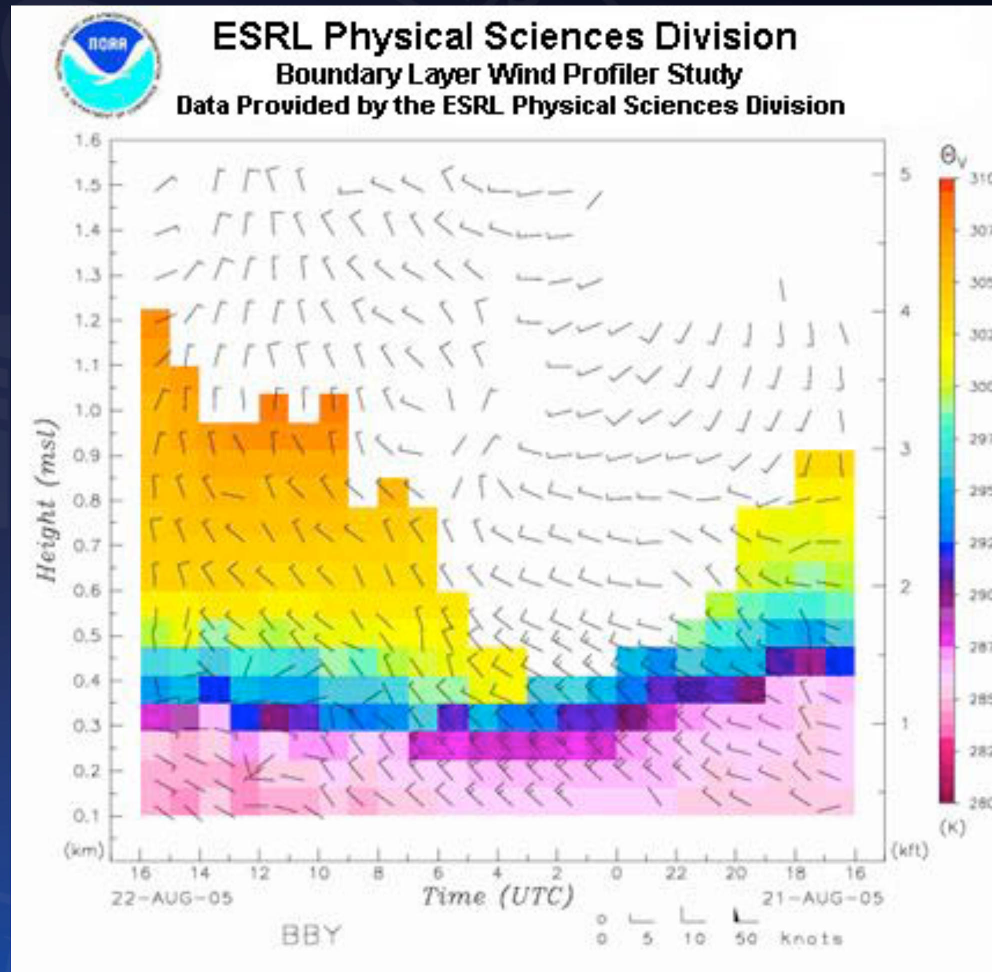
UHF Wind Profiler being developed
By NCAR EOL

Radio Acoustic Sounding System (RASS)

- Use radar to measure the propagation speed of sound
- Use an acoustic carrier frequency that produces structures that are Bragg matched with the radar
- Provides profiles of the virtual temperature



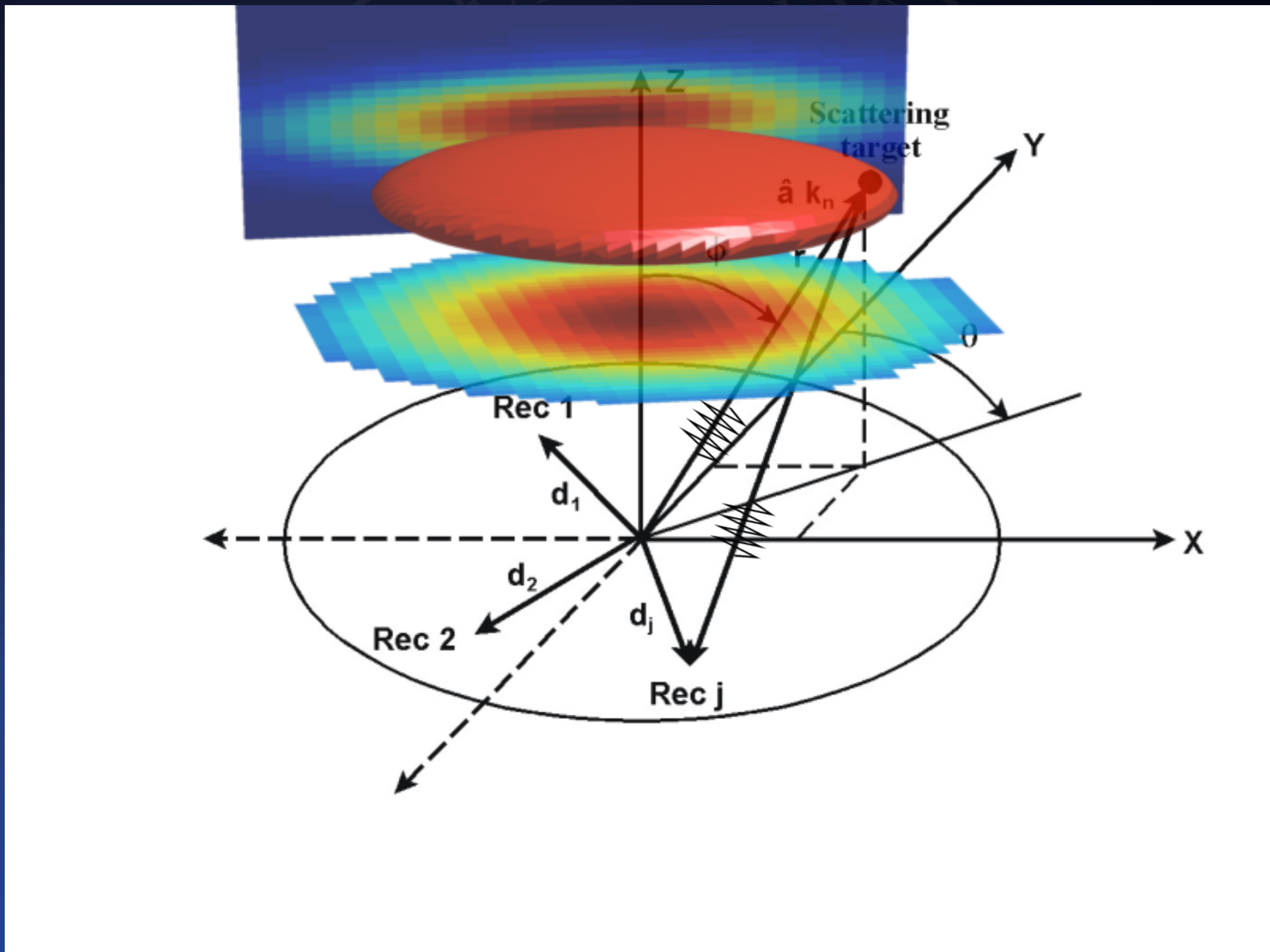
Radio Acoustic Sounding System (RASS)



Wind and temperature data collected by NOAA ESRL of the California coast

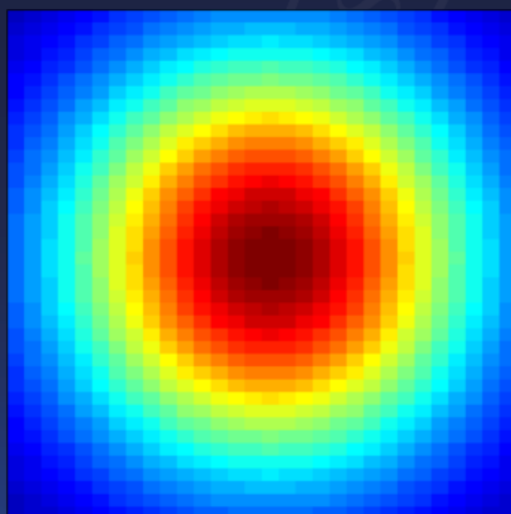
Multiple Receiver and Frequency Techniques

Atmospheric Radar Imaging



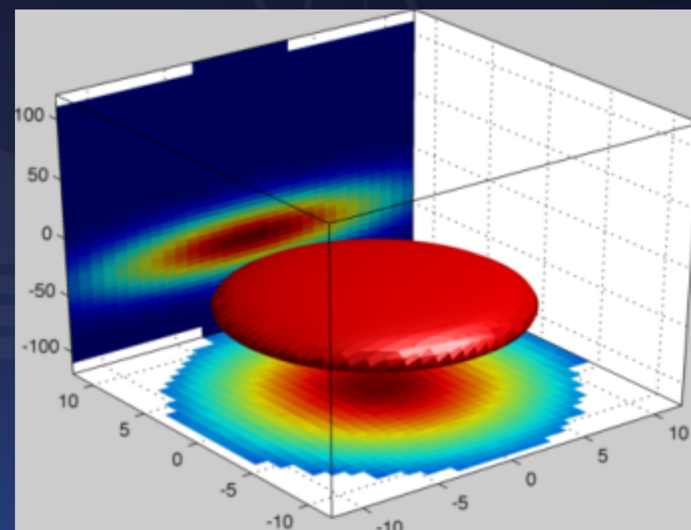
Atmospheric Radar Imaging

CRI (2D in angles)

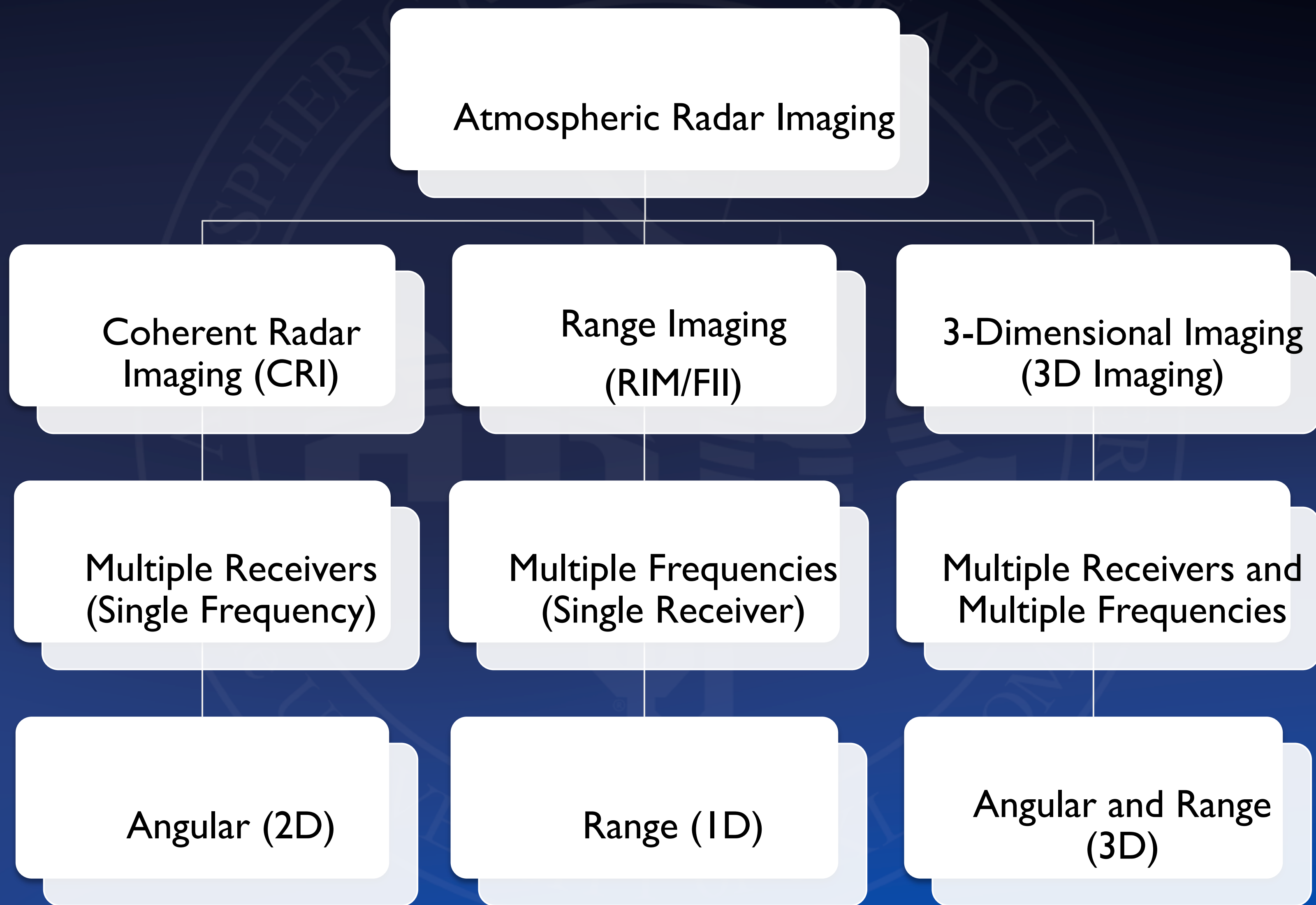


RIM (1D in range)

3D Imaging

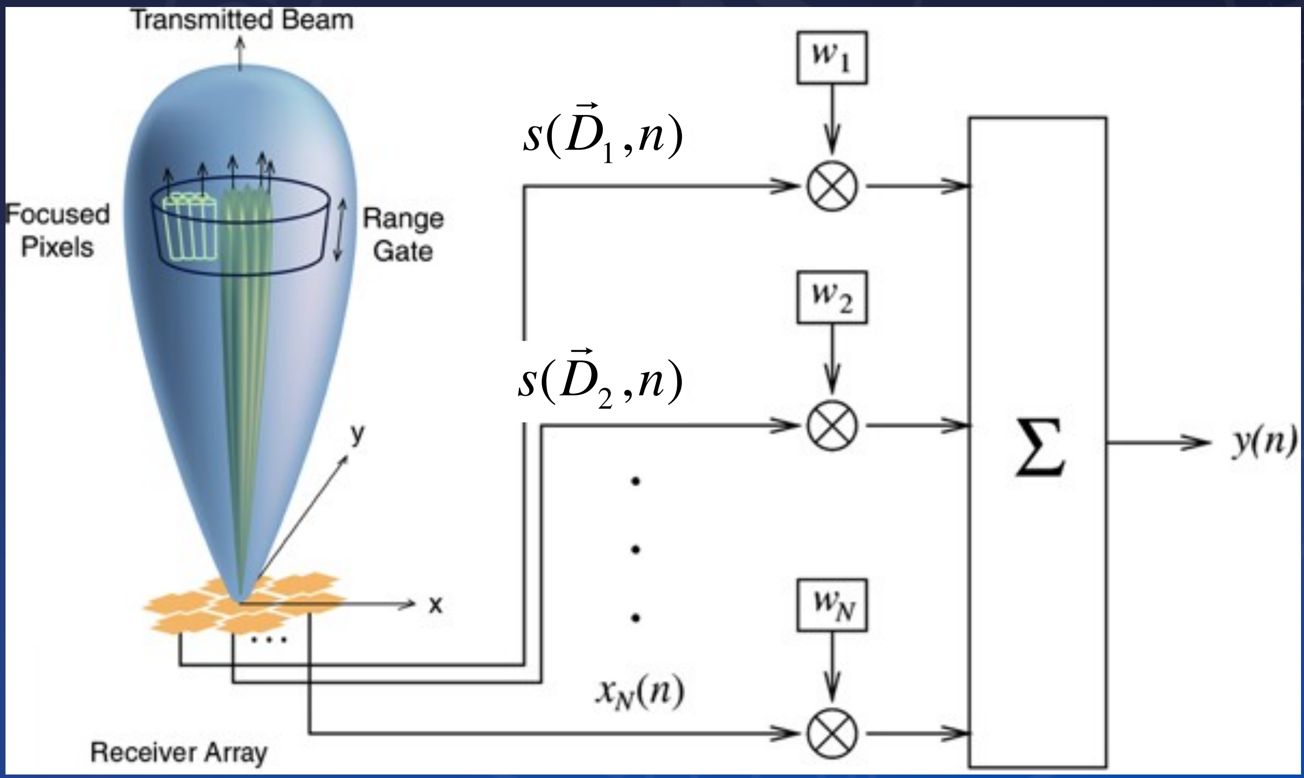


Atmospheric Radar Imaging



Coherent Radar Imaging

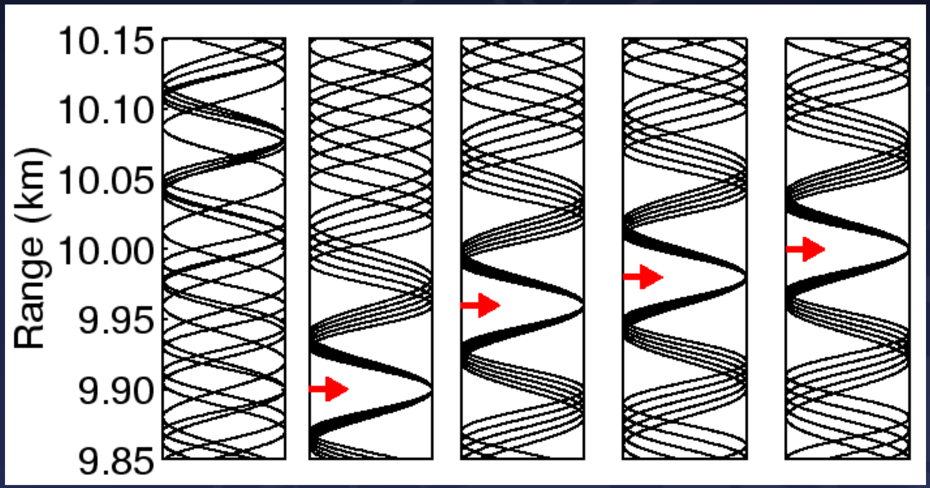
The formation of *multiple receive beams* by digitizing the output of the receiving array elements and forming beams by means of a digital processor



$$y(n) = \mathbf{w}^H \mathbf{s}(n)$$

$$\mathbf{s}(n) = [\; s(\vec{D}_1, n) \quad s(\vec{D}_2, n) \quad \cdots \quad s(\vec{D}_N, n) \;]$$

Range Imaging (RIM)



Sum signals from multiple frequencies coherently

RIM input signals

$$\mathbf{s}(n) = [\ s(k_1, n)\quad s(k_2, n)\quad \cdots\quad s(k_M, n)\ ]$$

RIM output signals

$$y(n) = \mathbf{w}^H \mathbf{s}(n)$$

Weighted sum !!

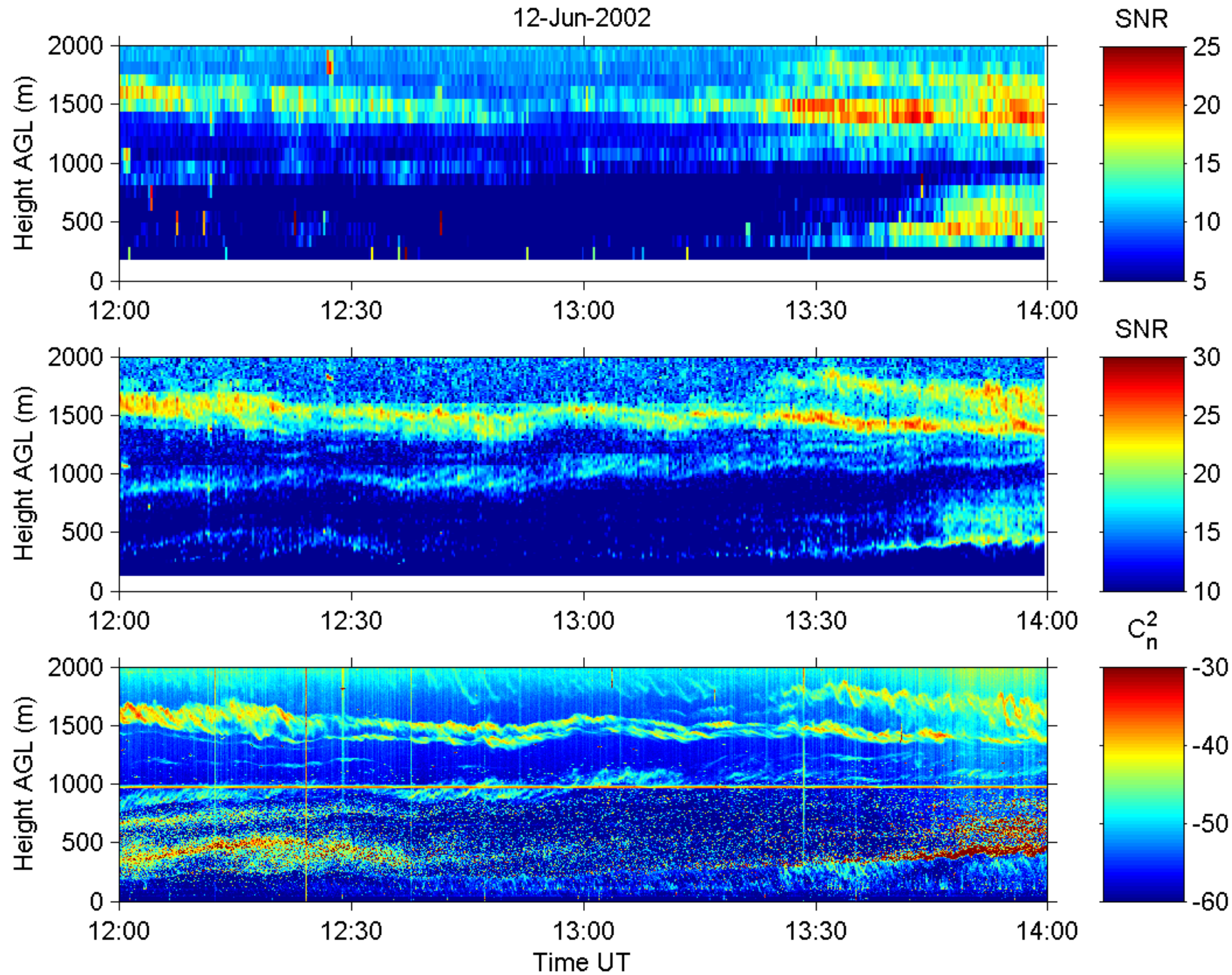
1. Fourier RIM: $\mathbf{w} = \left[\ e^{j2k_1 r_I}\quad e^{j2k_2 r_I}\quad \ldots\quad e^{j2k_M r_I}\ \right]^T$

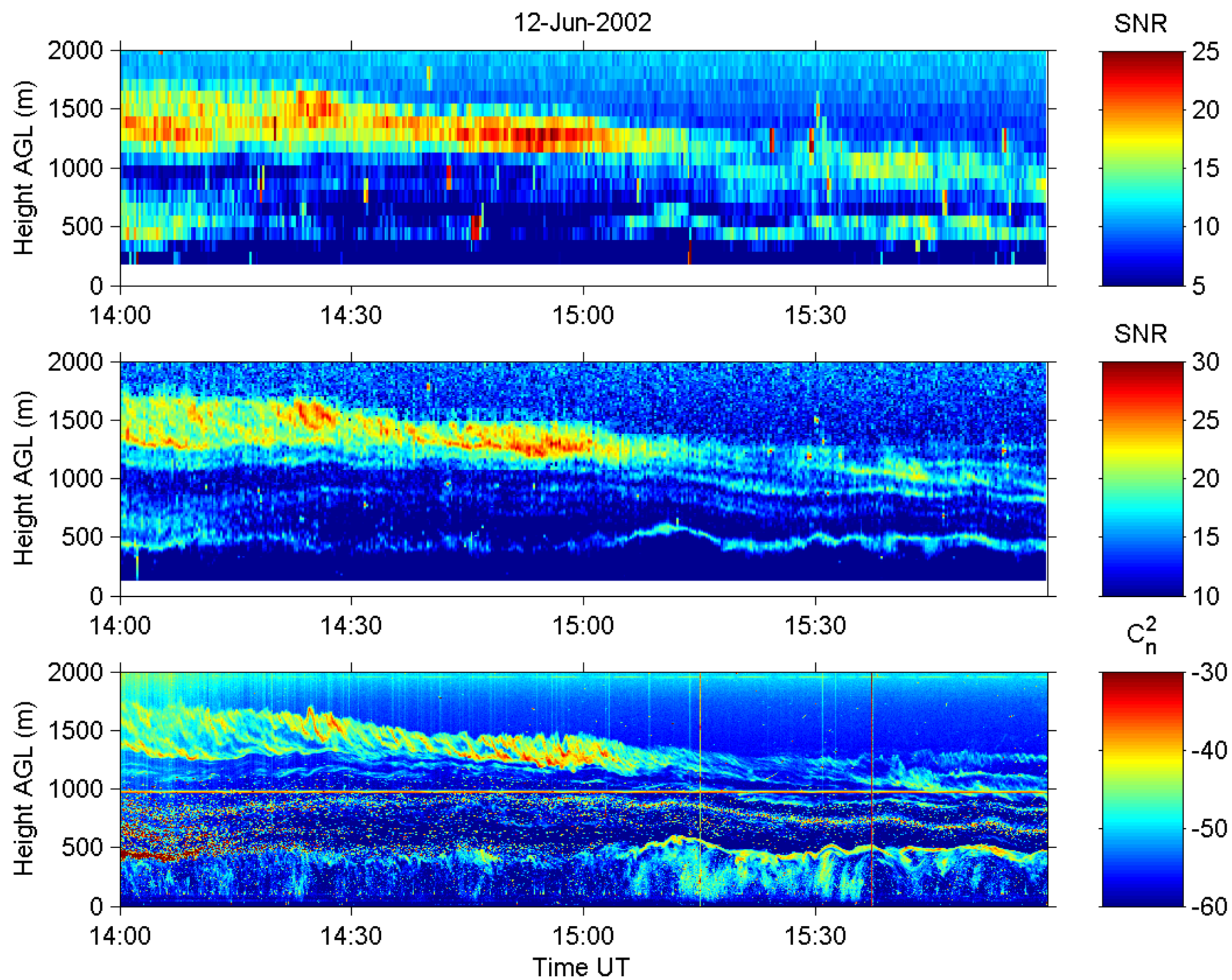
2. Capon adaptive RIM:

$$\mathbf{w} = \frac{\hat{V}^{-1}\mathbf{e}}{\mathbf{e}^H \hat{V}^{-1}\mathbf{e}}$$

$$\hat{P}_r(r_I) = \mathbf{w}^H \hat{V} \mathbf{w}$$

$$\hat{V}_{ij} = \hat{R}(\vec{D}_0, k_m, \vec{D}_0, k_n, \tau = 0) = \hat{R}(\Delta k)$$


12-Jun-2002
Height AGL (m)
2000
1500
1000
500
0
12:00
12:30
13:00
13:30
14:00
SNR
25
20
15
10
5
SNR
30
25
20
15
10
C_n^2
-30
-40
-50
-60
Time UT


12-Jun-2002
SNR
Height AGL (m)
2000
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1000
500
0
14:00
14:30
15:00
15:30
25
20
15
10
5
SNR
30
25
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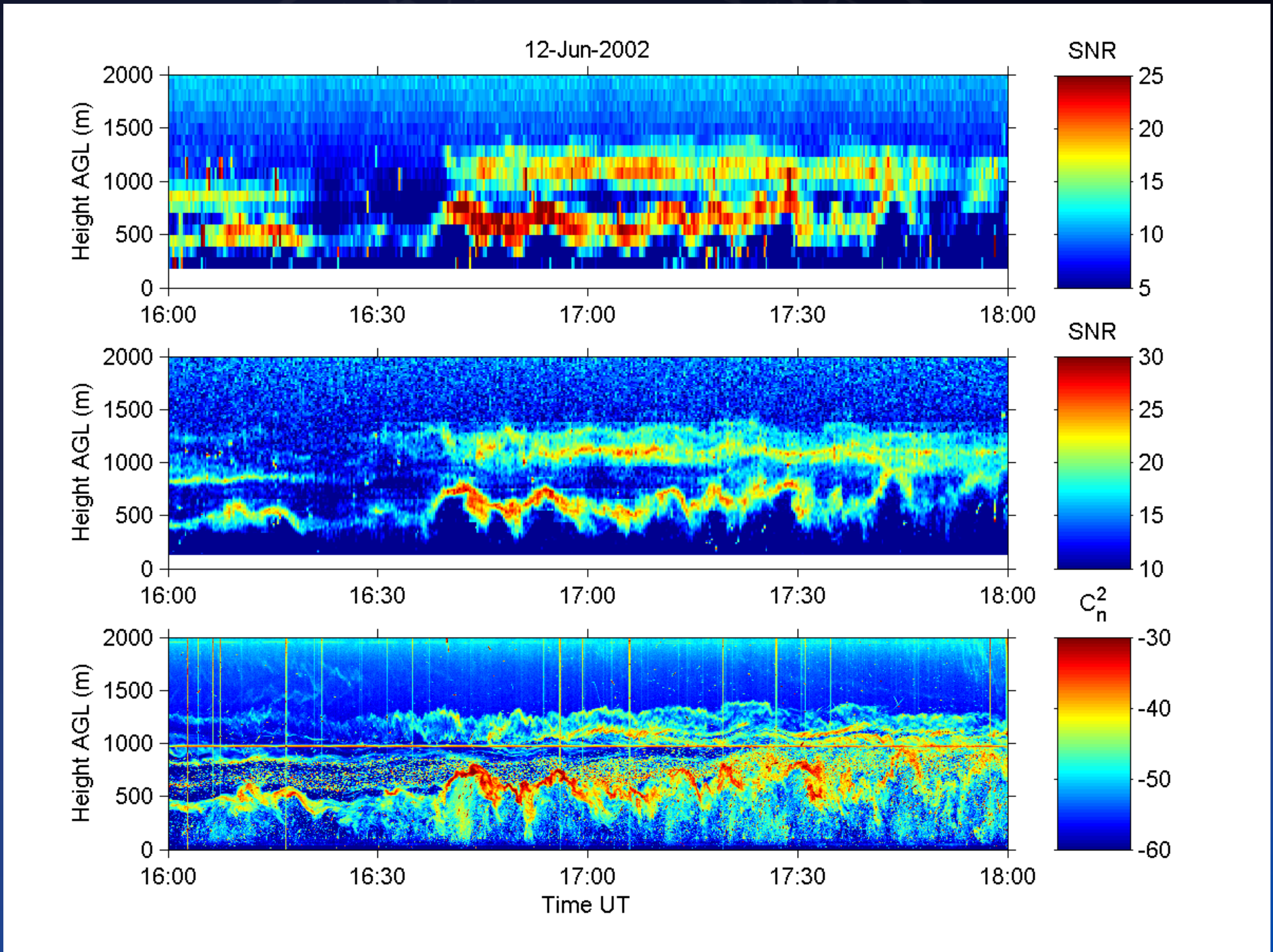
15
10
C_n^2
-30
-40
-50
-60
Time UT



12-Jun-2002
SNR
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SNR
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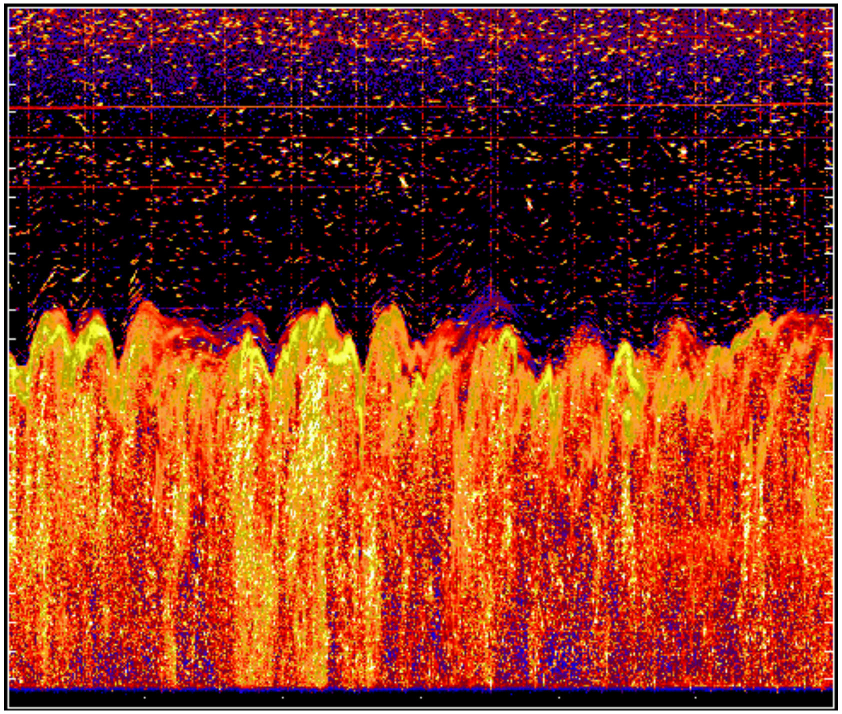
10
C_n^2
-30
-40
-50
-60
Height AGL (m)
2000
1500
1000
500
0
16:00
16:30
17:00
17:30
18:00
Time UT

S-Band FMCW Radar

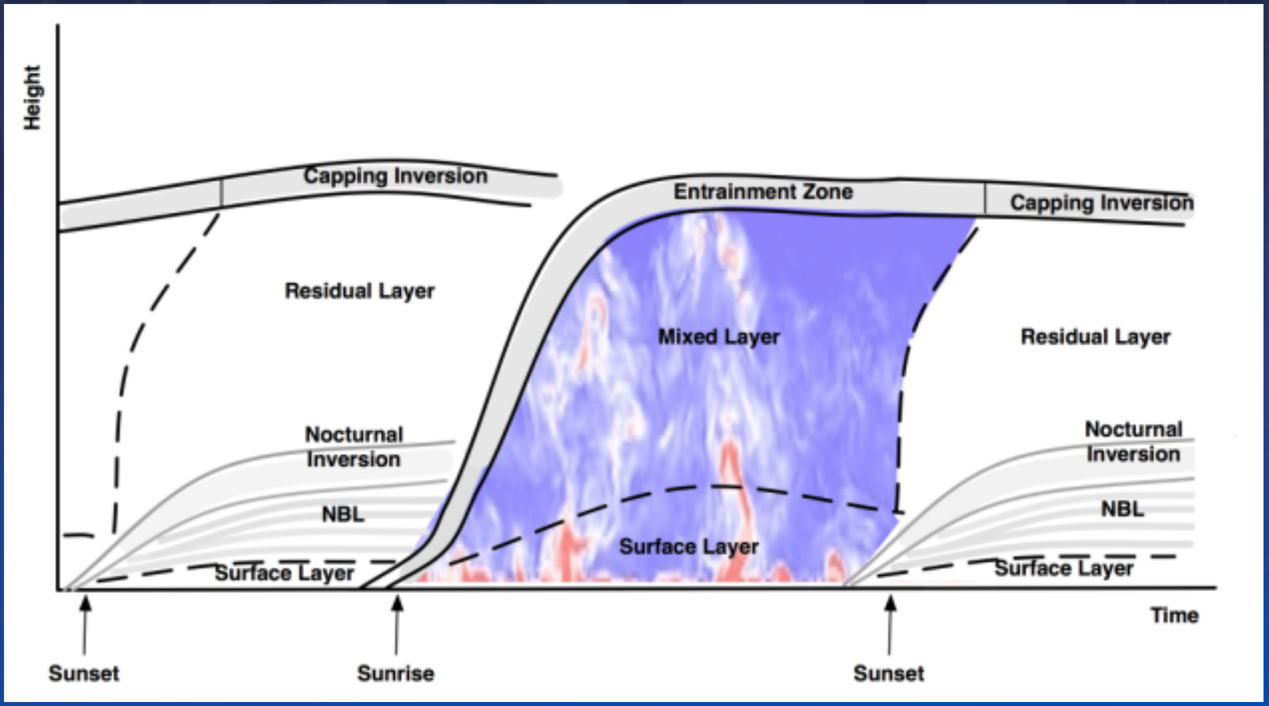
FMCW



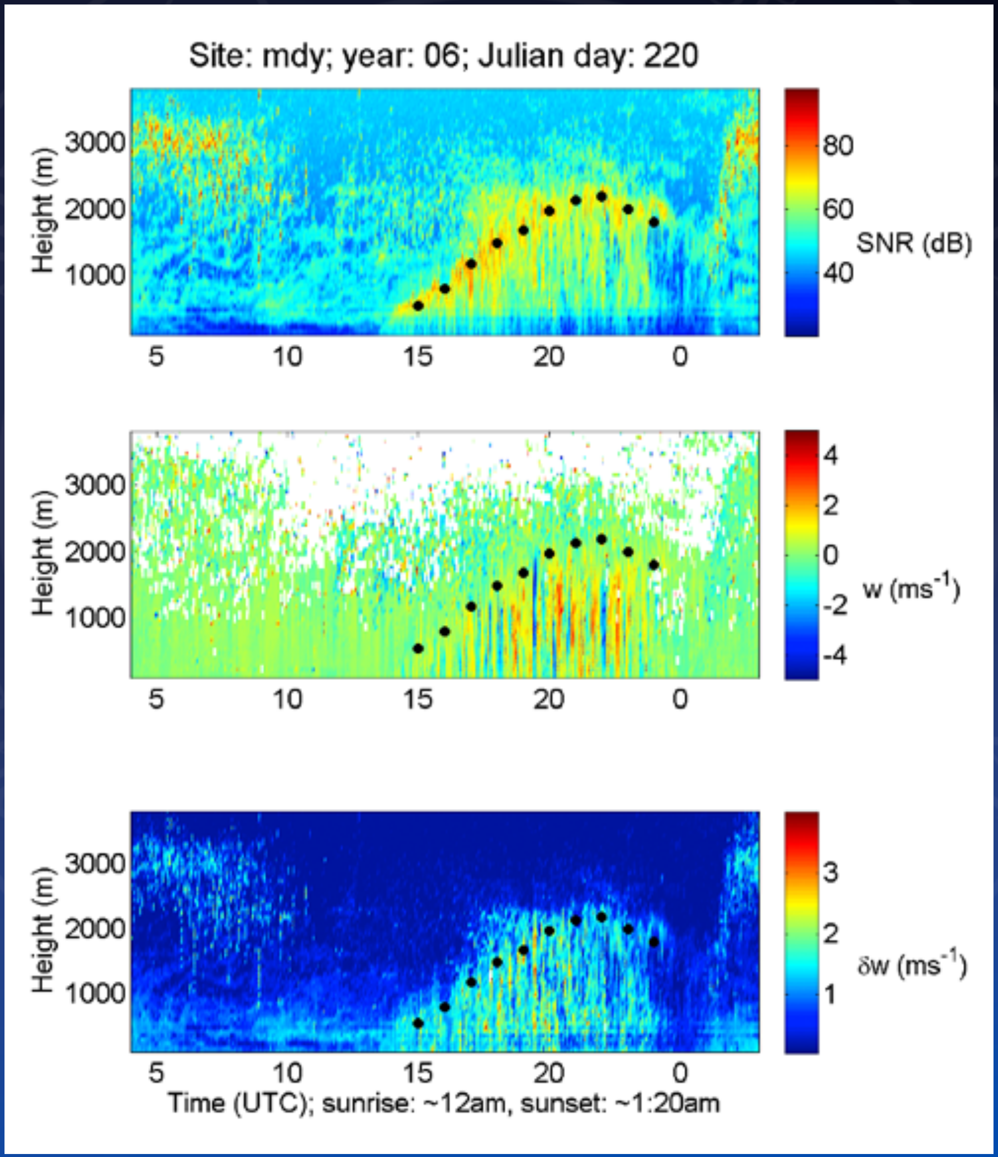
- 2.94 GHz single pol.
- 2.4 m parabolic antennas
- 250 W peak/average TWTA
- 60 MHz bandwidth
- >2.5 m range resolution
- Primary targets: insects and refractive index turbulence
- Tradeoff between range resolution, velocity range, and max range

Planetary Boundary Layer

- Can exhibit extremely complex flow on account of interactions with the Earth's surface
- Despite its relative proximity to the Earth, still difficult to monitor



Planetary Boundary Layer



In-Situ Instrumentation for PBL Research

SMARTSonde

Small

Multifunction

Autonomous

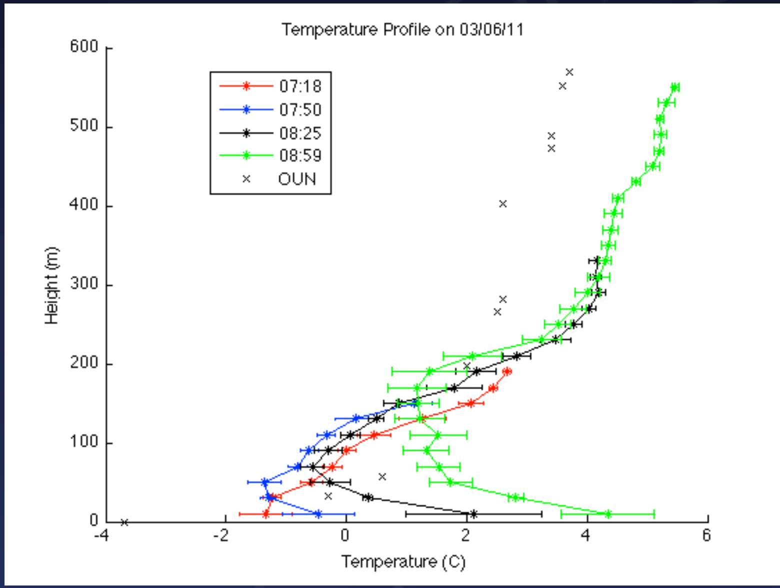
Research &

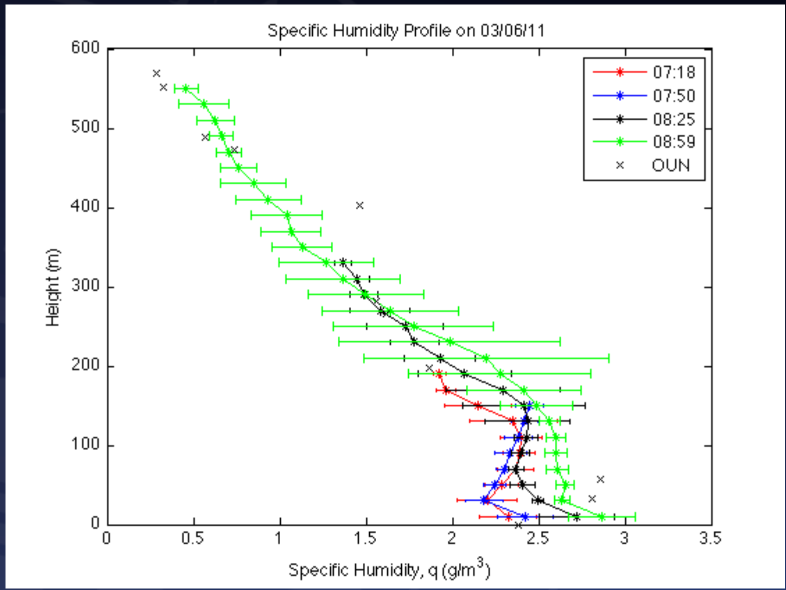
Teaching

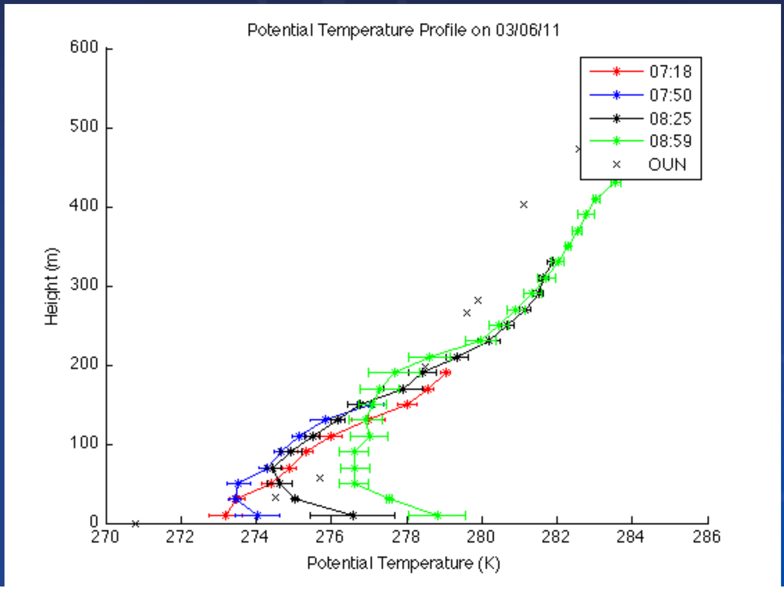
Sonde

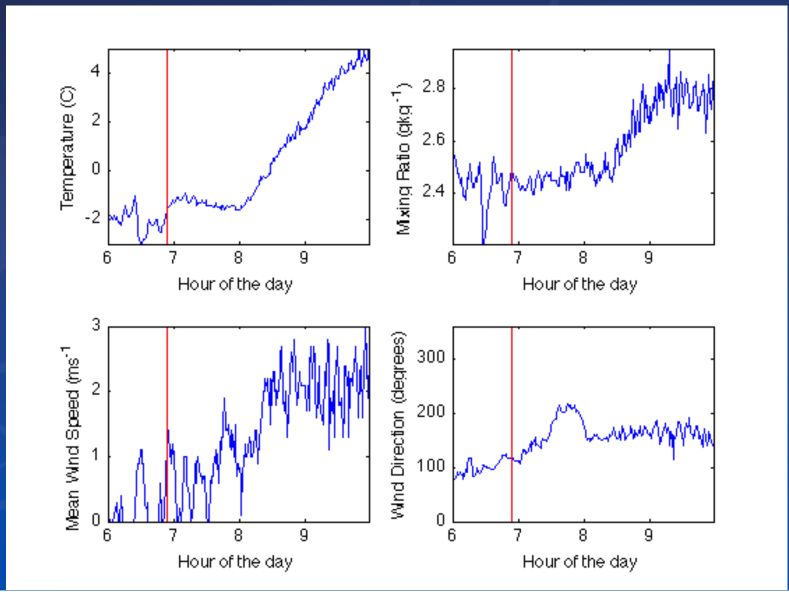
SMARTSonde's maiden flight on March 15, 2009

March 6th Morning Transition Observations
Sunrise: 6:53

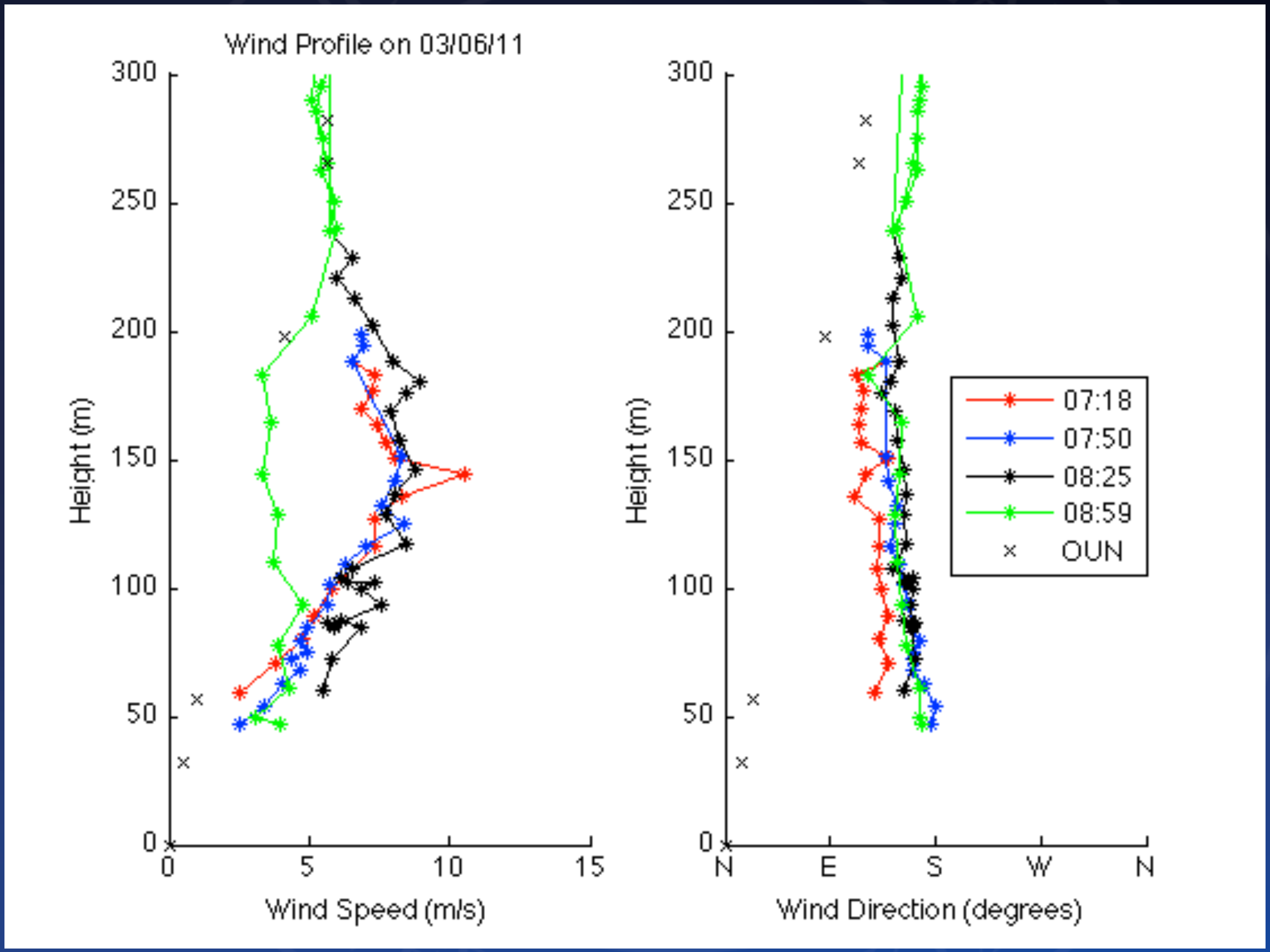




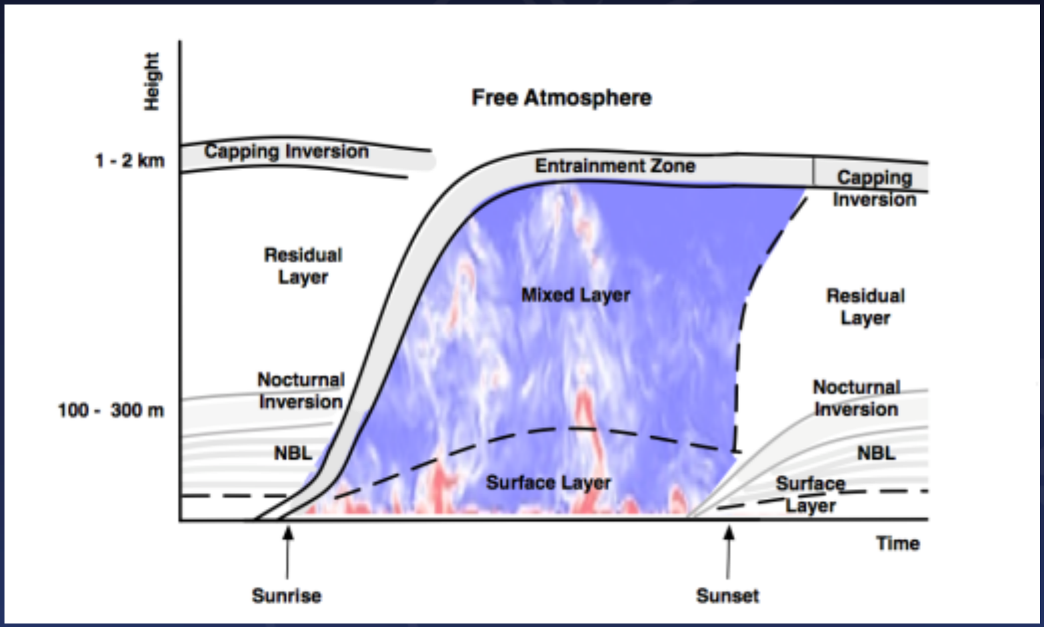


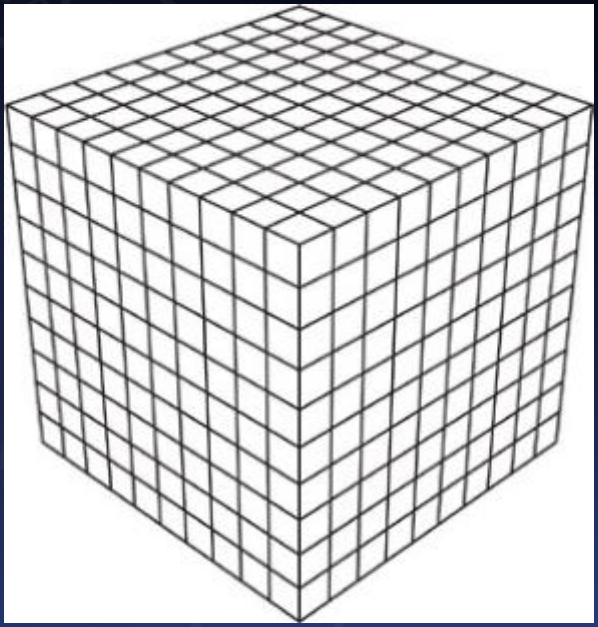


March 6th Morning Transition Observations
Sunrise: 6:53



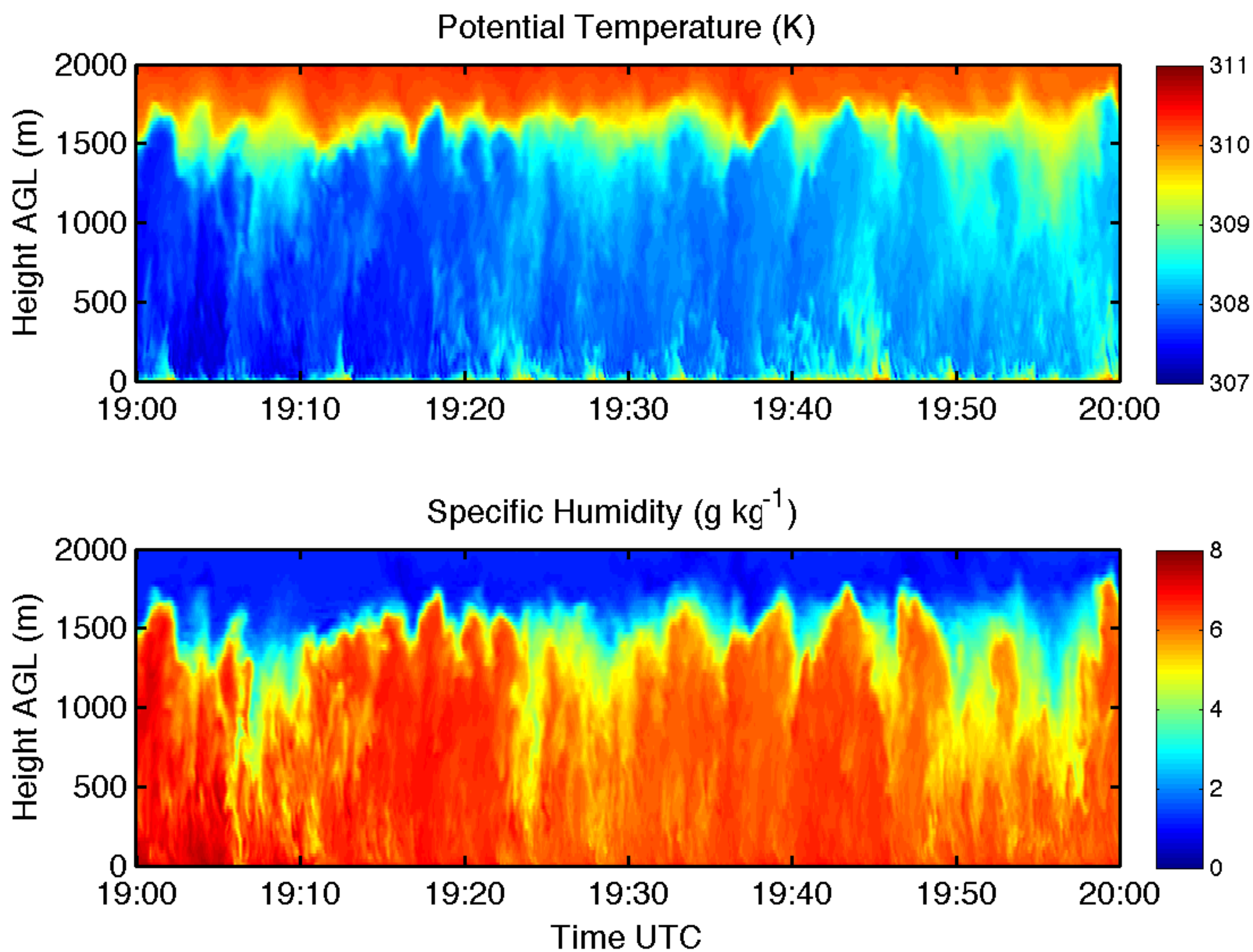
Large Eddy Simulation



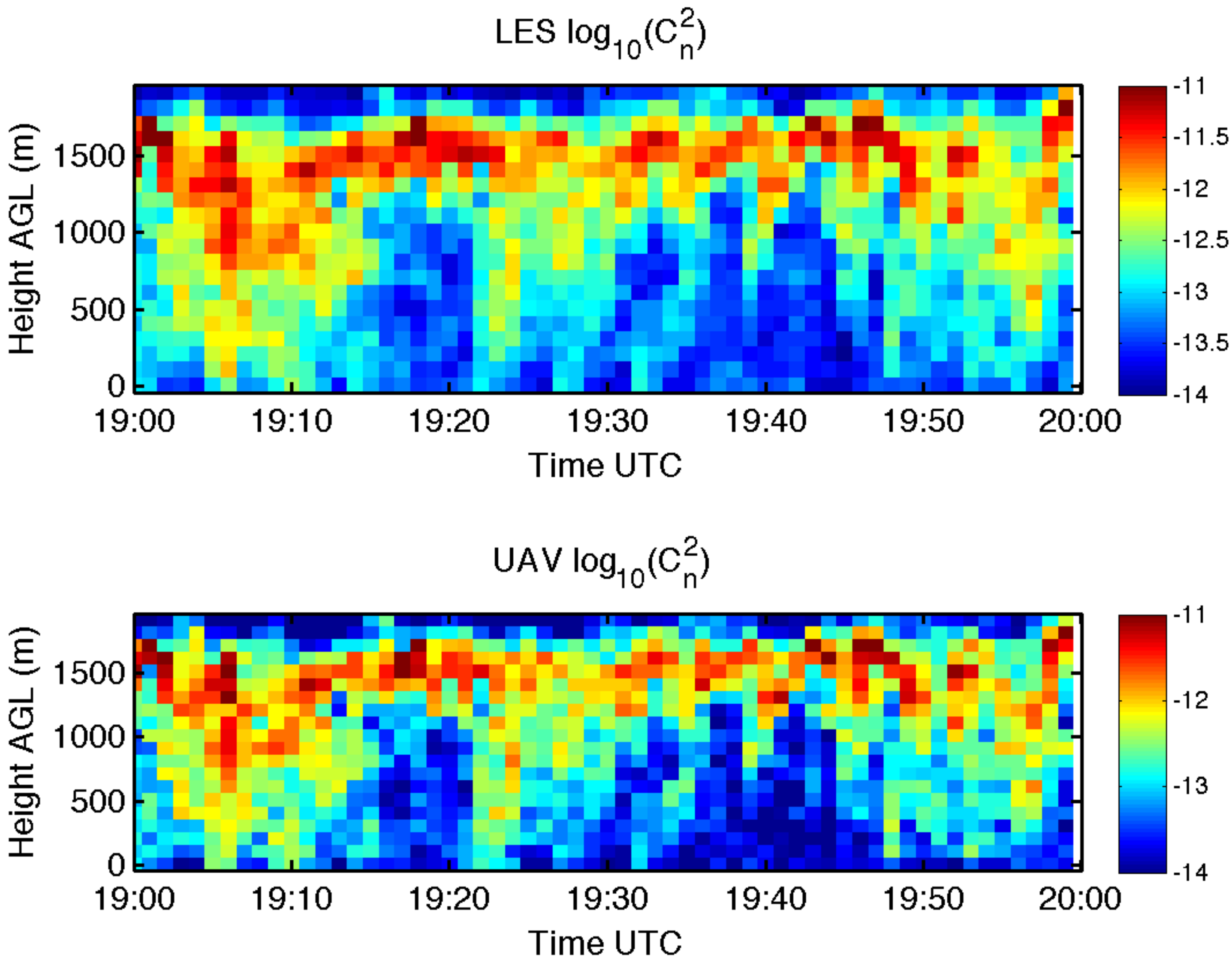


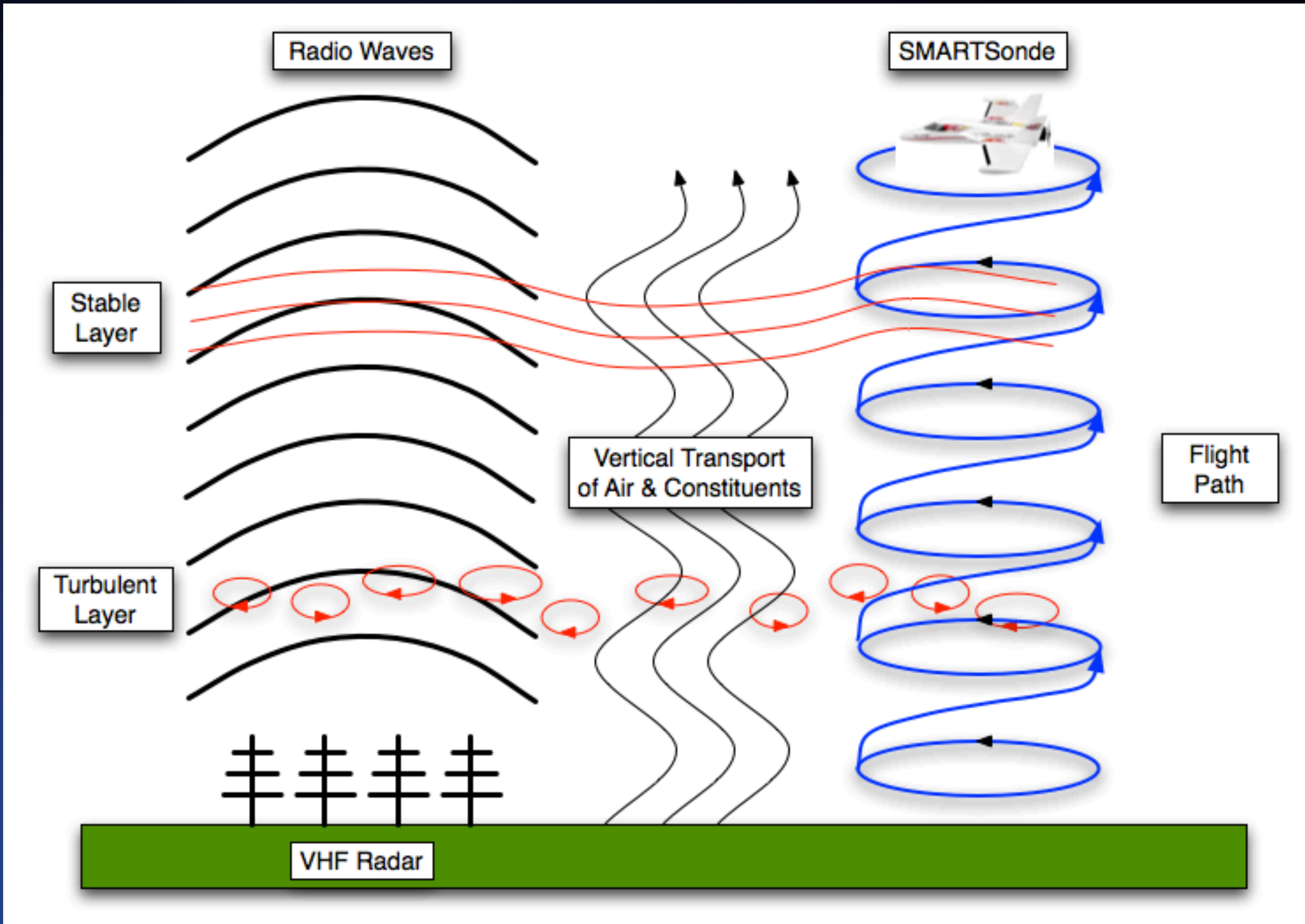
- Assign dynamic and thermodynamic variables to each grid cell
- Parameterize the turbulence within each grid cell
- Use prognostic equations to describe dynamics and thermodynamics at larger scales
- Initialize the LES based on measured values
- "Nudge" the LES based on measured values

LES Thermodynamic Fields

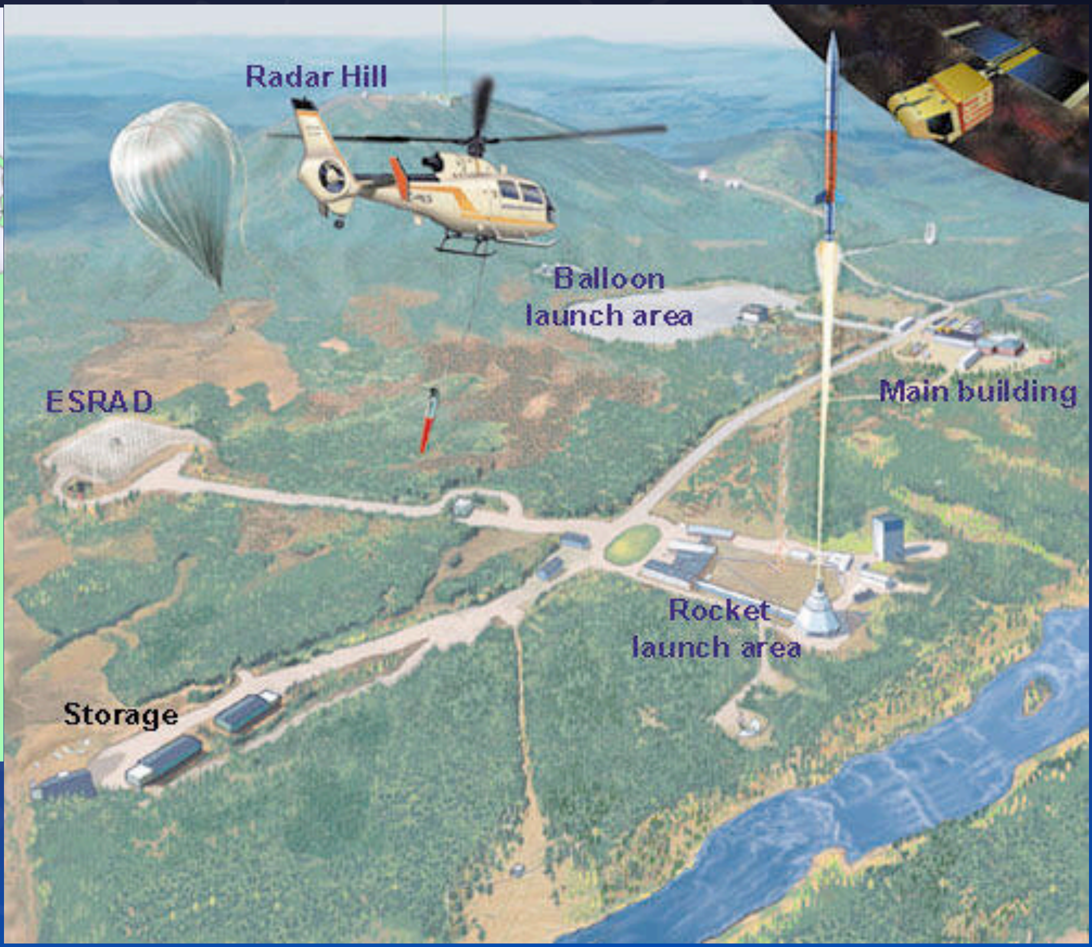


LES – UAS Comparison

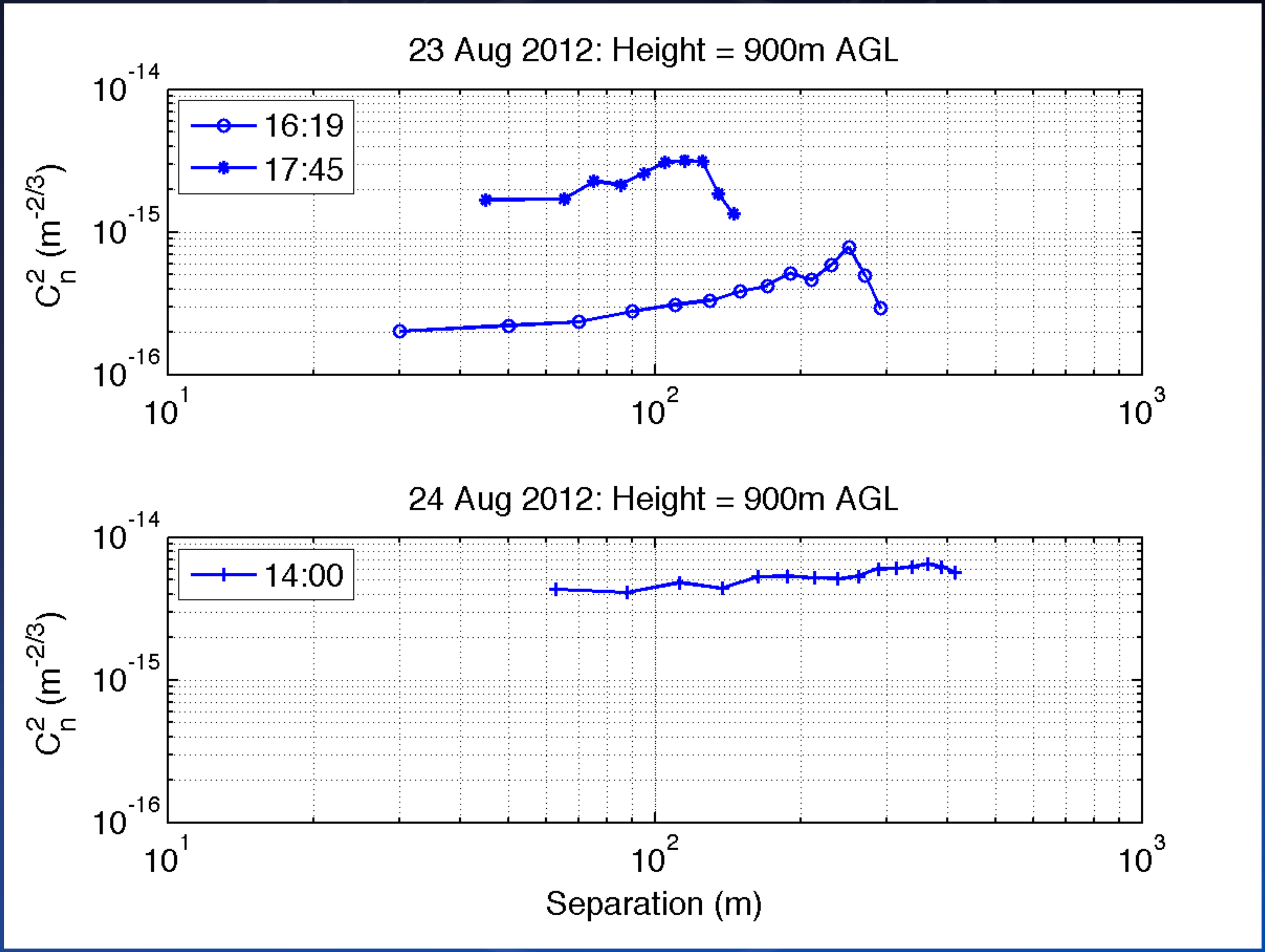



Radio Waves
SMARTSonde
Stable Layer
Vertical Transport of Air & Constituents
Flight Path
Turbulent Layer
VHF Radar

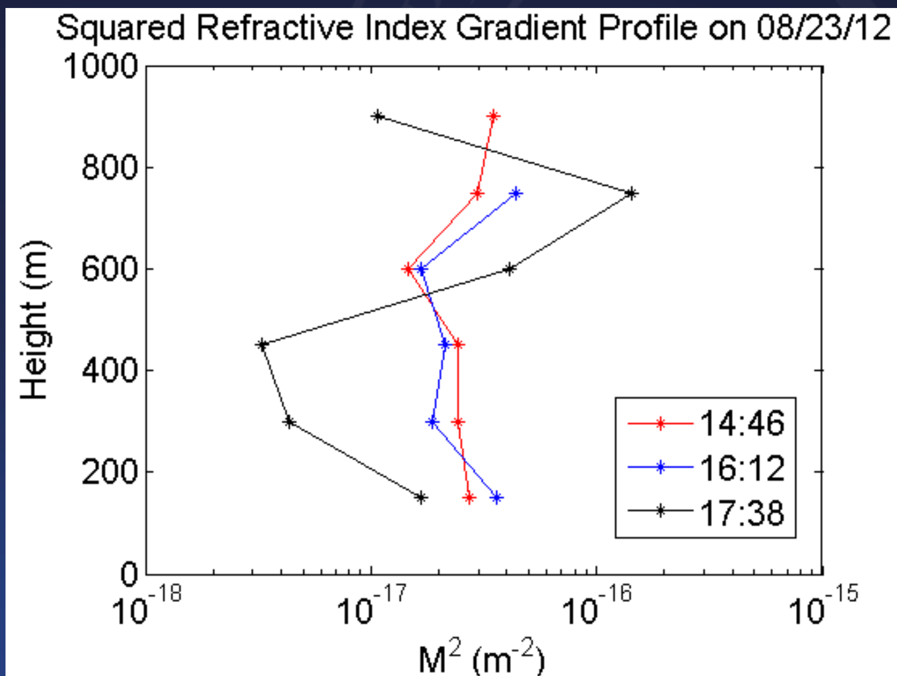
Observations at Esrange, Sweden
Swedish Space Corporation

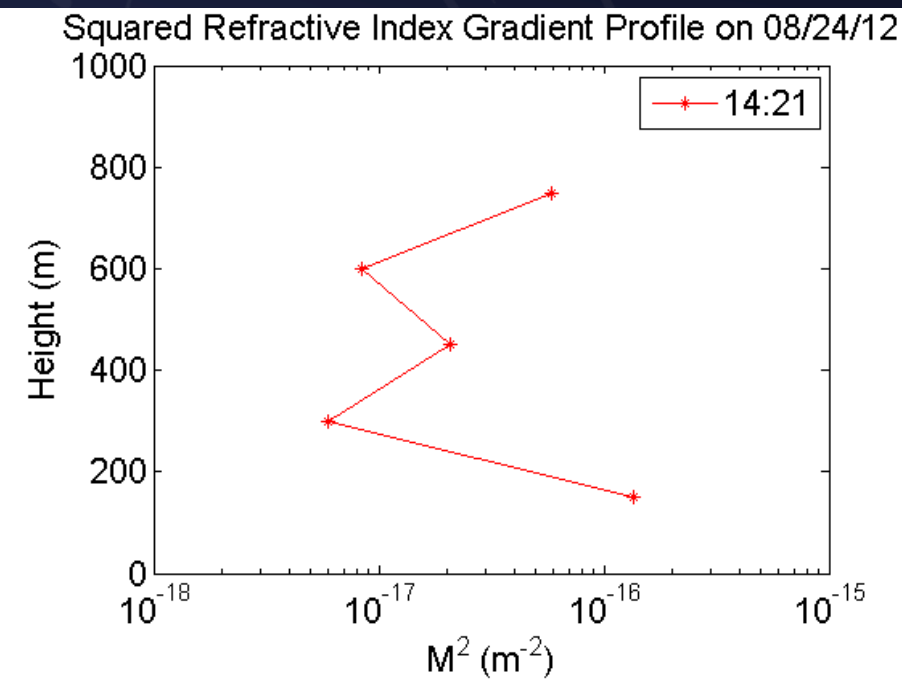


Measurements of C_n^2



Measurements of M^2





Additional Complementary Methods

- Microwave Radiometry
- Infrared Radiometry
- Lidar
- Dual-wavelength radar
- Global Navigation Satellite Systems
- Refractivity Methods
- Others …

Summary

- Wind profilers are well suited for wind retrievals and to some extent can be used for direct and indirect estimation of thermodynamic parameters
- The prospects of thermodynamic retrieval is enhanced when complementary observations from other sources are used.
- Thermodynamic Profiling Technologies Workshop held in Boulder, CO (April 2011)
  NCAR/TN-488+STR NCAR Technical Note
  "Thermodynamic Profiling Technologies Workshop Report to the National Science Foundation and the National Weather Service"
  http://opensky.library.ucar.edu/collections/TECH-NOTE-000-000-000-853