Acoustic Remote Sensing using SoDAR Technology

Presented by
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What is the field of Acoustics?

- Broadly, the field of acoustics is the study of the generation, transmission and reception of energy in the form of vibrational waves in matter.
  - The molecules or atoms of a fluid (or solid) are displaced from their equilibrium orientation causing an internal elastic restoring force.
  - Action of this restoring force and the inertia of the system enables matter to sustain oscillatory vibrations which generate and transmit acoustic waves.
- Acoustic frequencies are subdivided into three (3) ranges:
  - infrasonic 20 Hz or less
  - audible 20 Hz to 15,000 Hz
  - ultrasonic greater than 15,000 Hz

Acoustics (continued)

- Restricting our discussion to the atmosphere we observe that:
  - the background acoustic energy spectrum (atmospheric acoustic noise) is heavily weighted toward the lower frequencies as a consequence of the frequency dependence of the attenuation of this acoustic energy.
    - Infrasound will propagate much farther than ultrasound.
    - For many reasons (some we will discuss) neither infrasound or ultrasound are of much interest for the remainder of this discussion.
- Our interest for is in the audible acoustic frequency range (normally termed sound).

What is a SoDAR?

- SoDAR is derived from the acronym <u>So</u>und <u>D</u>etection <u>a</u>nd <u>R</u>anging.
- A SoDAR operates on a principle similar to an active SoNAR:
  - Emits pulsed acoustic energy;
  - Records the acoustic signature produced by the interaction of the pulsed energy with an object or refractive index changes along the propagation path

What is a SoDAR? (continued)

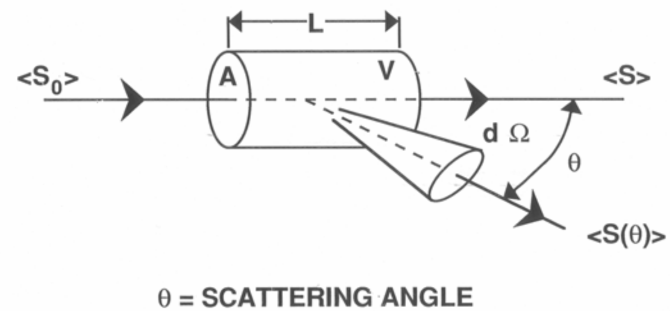
- Acoustic signature (or received signal) contains information about the sound energy from an object or a volume of air. The information is:
  - Intensity of the received signal;
  - Frequency of the received signal.
- Because theory relates propagating sound waves to atmospheric turbulence we are able deduce from the acoustic signature the following:
  - General atmospheric stability and elevated structures;
  - 3D wind profiles.

Atmospheric Sound Propagation Properties

- Refraction
- Reflection
- Transmission
- Absorption
- Scattering

Atmospheric Sound Scattering

- Pulse length
- Sampling Volume
- Solid Angle
- Scattering Angle



Interaction of Sound Waves and Atmospheric Turbulence

$$\eta(\theta) = \tfrac{1}{8} k^4 Cos^2(\theta) \left[\frac{\Phi(\kappa)}{T_0^2} + \frac{Cos^2(\theta / 2) E(\kappa)}{\pi C^2 \kappa} \right]$$

Acoustic Scattering Cross-section

Temperature Fluctuations

Velocity Fluctuations

Angular Dependence of Acoustic Scattering Cross-section

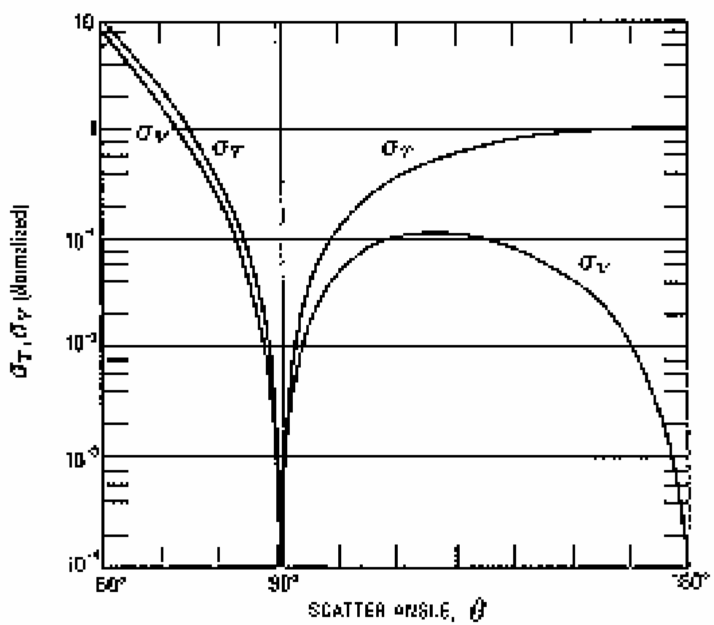
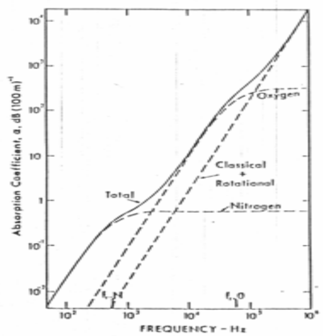


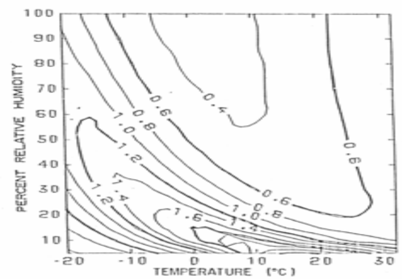
Fig. 1 Contributions to scattering cross section of separate effects of temperature σ_T and velocity fluctuations σ_V as a function of scatter angle.

SoDAR Geometries

- Monostatic
- Bistatic
  - active source
  - common volume

Atmospheric Attenuation of Sound





The attenuation of propagating acoustic energy increases as a function of:

- Increasing frequency
- Decreasing Temperature
- Decreasing Humidity

Basic monostatic SoDAR Equation

System Function

$P_0 A L_v$

$$P(R) = P_0 \frac{A}{R^2} L_v \, \mathrm{EXP}(-2\bar{\alpha}R) \quad \sigma(R)E$$

Received Acoustic Power

Range to the Scattering Volume

Atmospheric Attenuation

Scattering Cross-section

Back scattering Cross-section

Volume averaged inertial sub-range virtual temperature structure constant at range R.

$$\sigma(R) = 0.0072\,\lambda^{-1/3}\,\frac{C_{T_V}^{2}(R)}{T_V^{2}}$$

Volume averaged acoustic back scattering cross-section.

Average virtual temperature of the scattering volume.

Atmospheric Turbulence Profiles

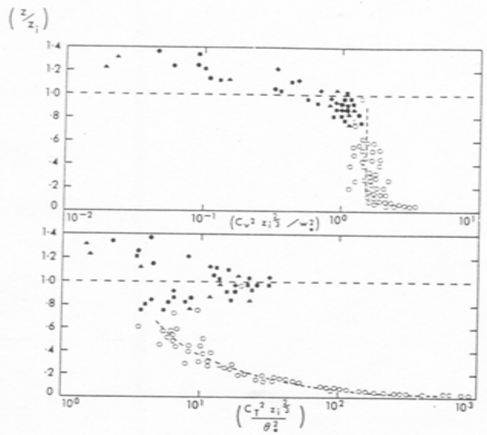


Figure 2. Variation of the normalized structure parameters for velocity and temperature with z/z_i. The dashed lines represent the free convection predictions (after Caughey and Palmer, 1979).

- Mixed layer scaling
- Temperature and Velocity structure constants

Monostatic SoDAR Equation Dynamic Range

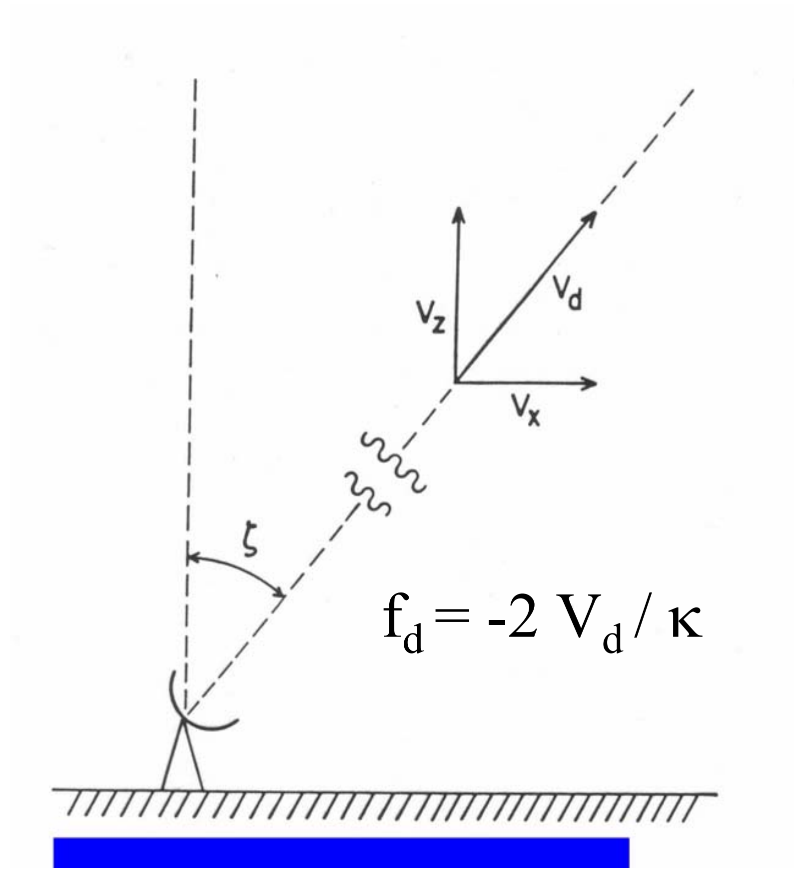
- Decibel formulation of SoDAR equation
- Assume of atmospheric and background noise conditions.
- System Function.
- Range estimate.

Acoustic Intensity Data Products

- Surface based and elevated scattering layers (mixing heights, wind shears, etc.)
- Atmospheric stability (facsimile displays)
- Temperature Structure Constant, C_T^2
- Derived quantities - surface heat flux, inversion height

Frequency of the Received Signal (monostatic)

- Assume that the movement of the scattering volume is <u>radial</u> relative to the antenna
- Doppler shift means that you must know the frequency of the transmitted signal.



$$f_d = -2\, V_d / \kappa$$

How is Frequency determined?

- Difficulty of determining the frequency of truncated signals.
- Mean frequency estimators and their robustness in the presence of noise.

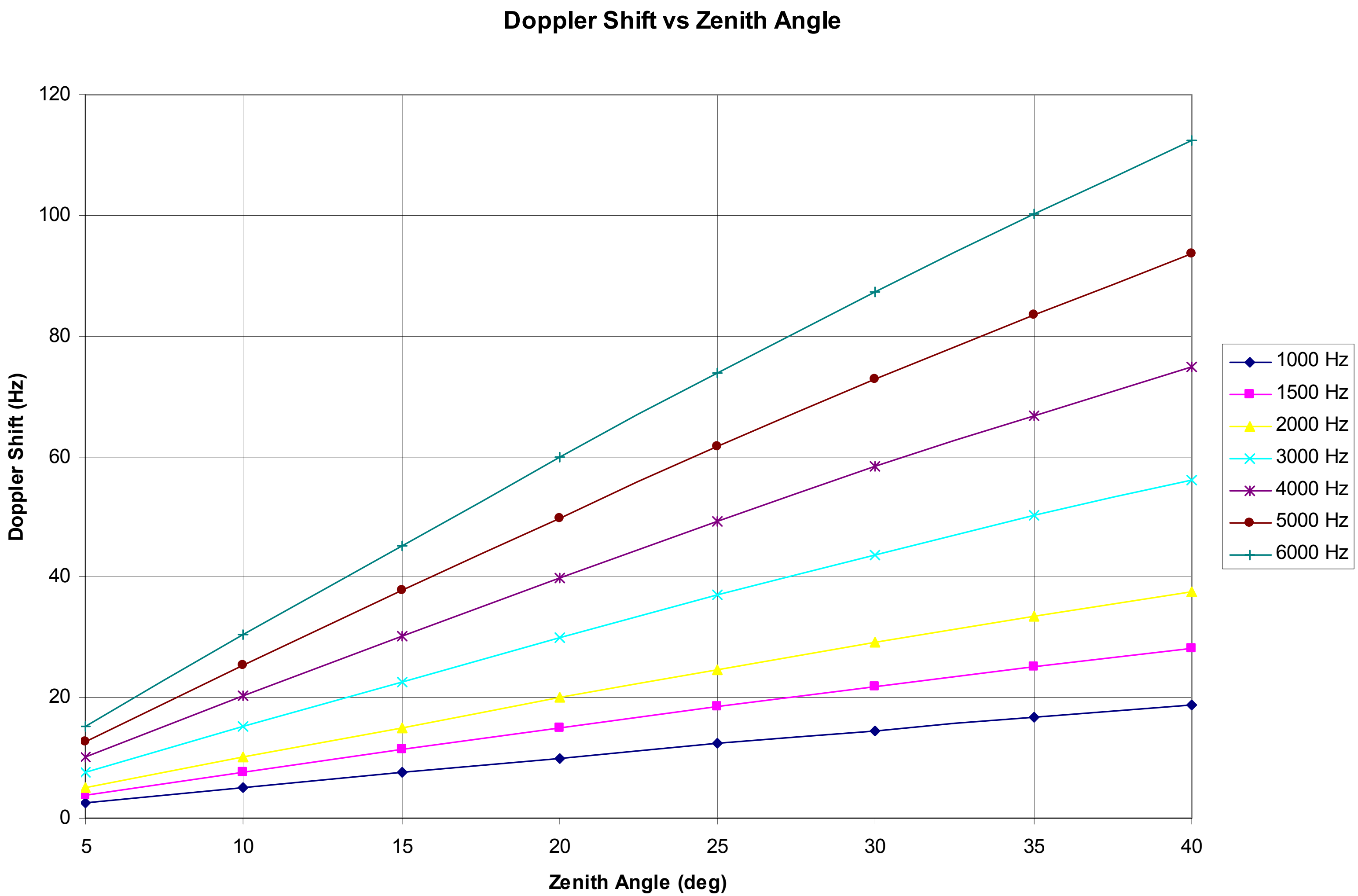
Relate Radial motions to Horizontal and Vertical motion (monostatic)

Zenith angle

$$f_d = -\frac{2V_x}{\lambda}\sin\zeta - \frac{2V_z}{\lambda}\cos\zeta$$

- Key equation that relates Horizontal and Vertical wind velocities to the frequency of the received signal.
- Includes Zenith angle and operating frequency dependence.

Doppler Shift Dependence on Zenith Angle and Operating Frequency (monostatic)



Doppler Data Products

- Spectra
- Mean component velocities
- Horizontal wind speed and direction.
- Vertical velocities
- Variances and co-variances of the components
- Derived variances

Summary

- SoDAR systems consist of simple technologies that are used to measure a complex atmosphere.
- SoDAR data are uniquely applicable for observing the processes within the lower atmospheric boundary layer.