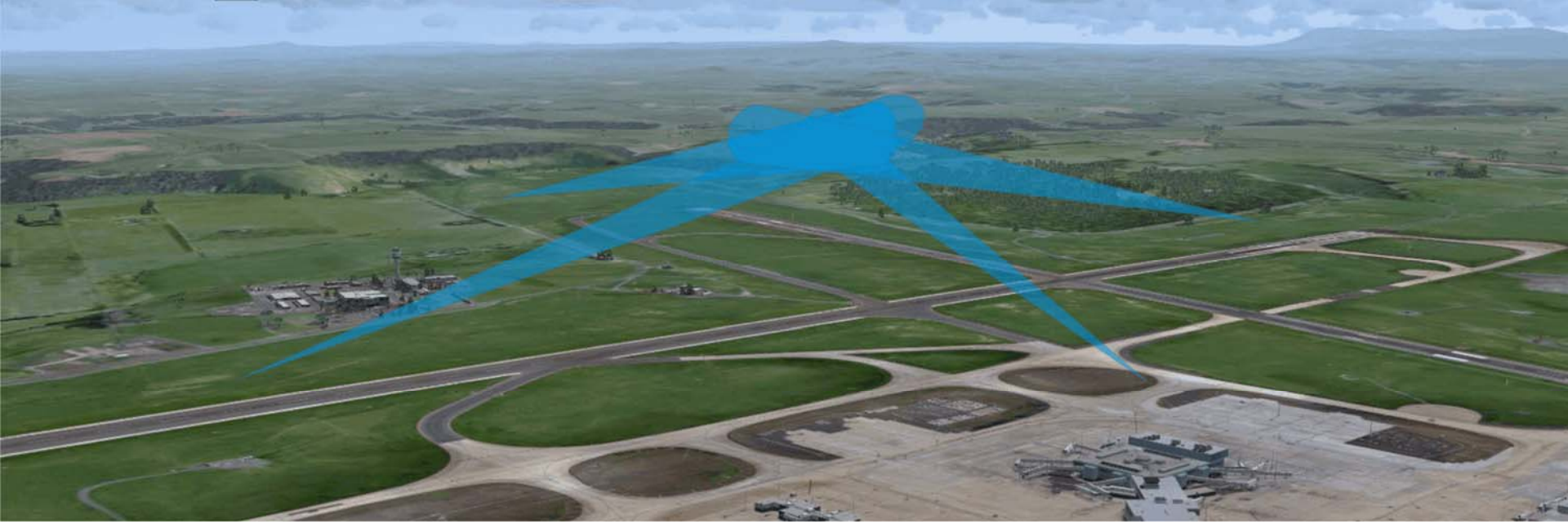


Multi-Static X Band Radar

Jone Saebboe
Triad
Paris, March 29, 2010

Talk Overview

- Triad and Wind, Vortex and Turbulence technology
- Multi-Static Wind Radar Concept
- Clear Air Turbulence
- Radar Equation for Volume Scattering
- Signal processing
- Experimental Results
- Summary
- Commercial system

Triad and Wind Measurements

About Triad

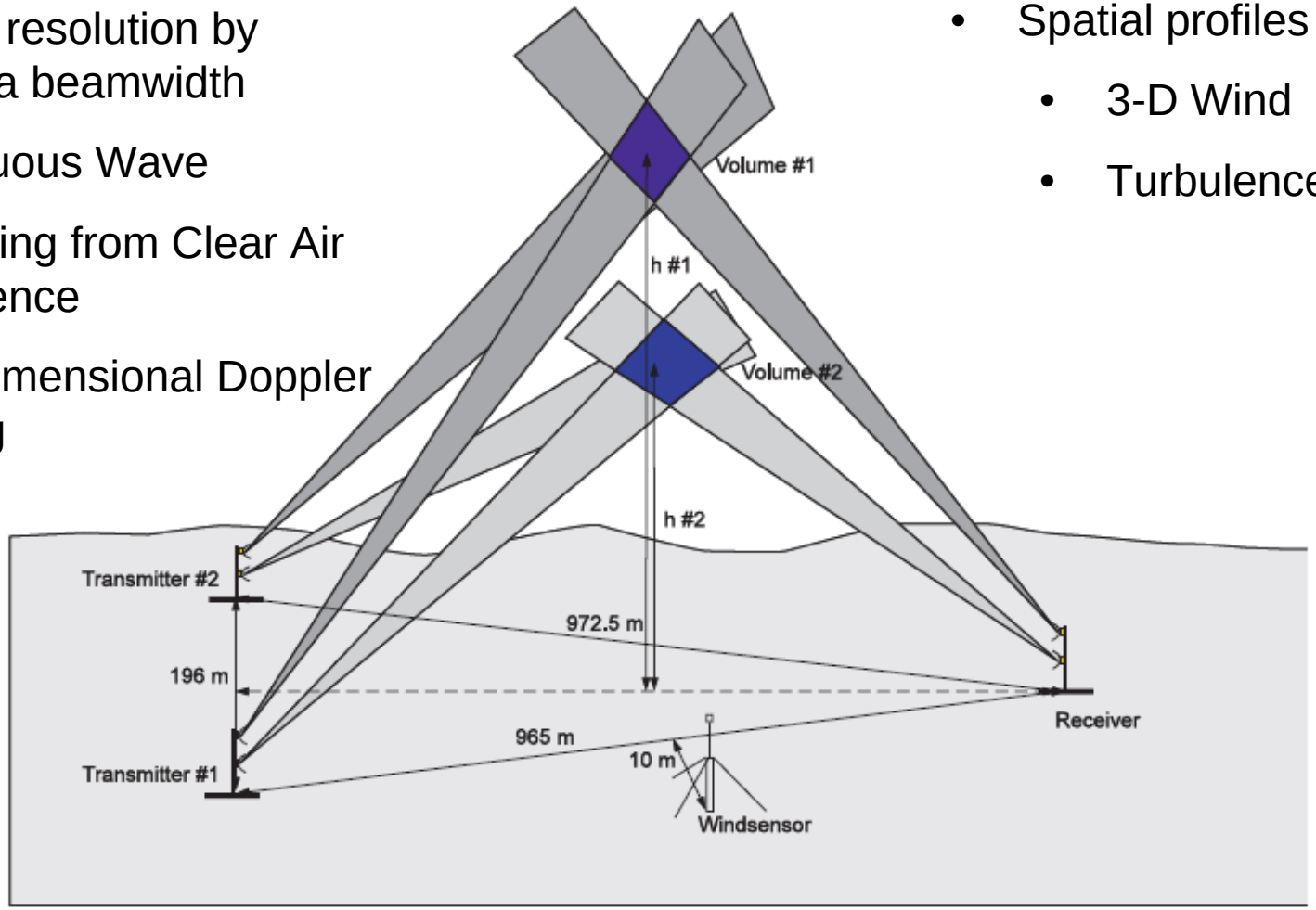
- Established in 1986 as a spin-off from the Norwegian Program for Environmental Remote Sensing (**PFM**)
- Intention: Create, develop and improve remote sensing technology
- Main focus on Radar technology
- Large efforts used on characterization and classification of targets and geophysical phenomena
- Some focus on Sonar, Optical and Seismic technology

Work on Wind and Vortex by PFM, TRIAD and SUSAR.

- **1980's Initial work**
  - Theoretical work with radar and radio acoustic methods
  - Initial experimental work
  - Initiated work at **APL** (89 - 95)
- **1990s Prototyping and testing**
  - Multi-Static Wind Radar
  - Radio-Acoustic technology
  - Several Trials
  - Software development
  - Patenting
  - Civil Aviation Authorities (UK).
  - Norwegian Aviation Authorities
- **2000s Hibernation**
  - Upgrade of the radio acoustic hardware
- **2010s Commercialization**
  - Commercialization targeting Airport, Meteorology and Wind Energy

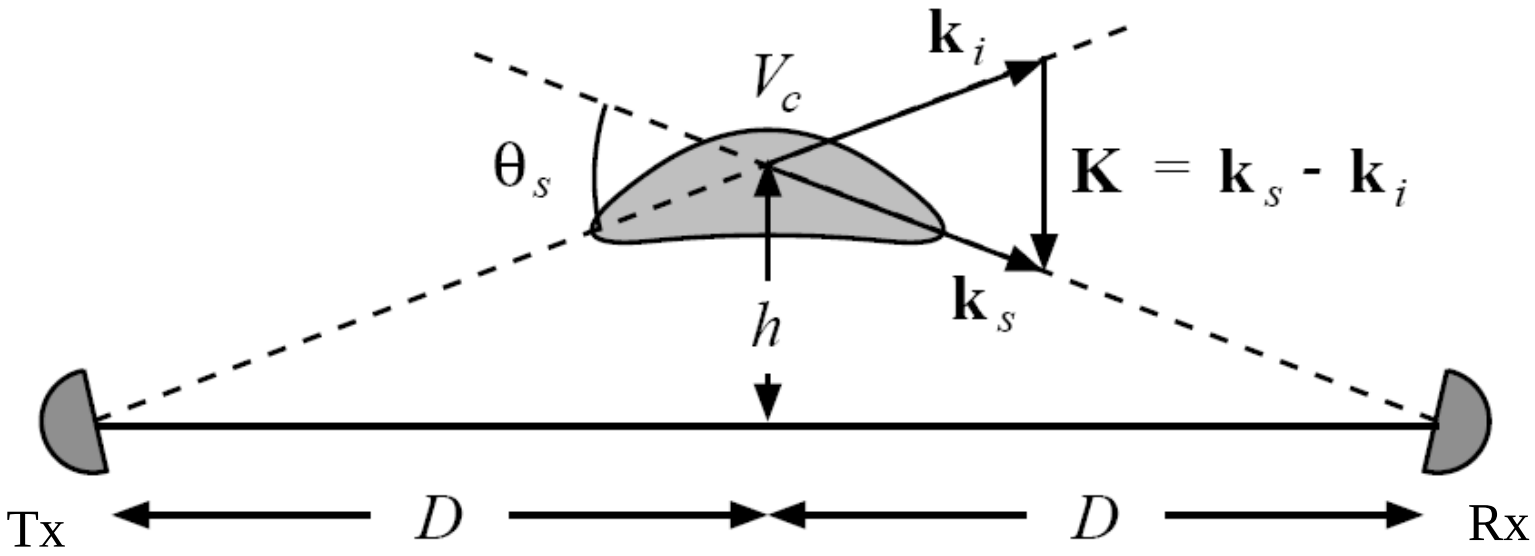
Multistatic Wind Radar Concept

- Several bi-static channels
- Spatial resolution by antenna beamwidth
- Continuous Wave
- Scattering from Clear Air Turbulence
- Multi-dimensional Doppler Tracing



- Vortex
- Spatial profiles of
  - 3-D Wind
  - Turbulence intencity

The Bi-Static Channel



- Scattering wavenumber depends on frequency and geometry
- Scattering wavenumber can be tuned both in direction and magnitude

$$K = 2k\sin(\theta_s/2)$$

$$k = \frac{\omega}{c} = \frac{2\pi f}{c} = \frac{2\pi}{\lambda}$$

Turbulence

Boundary layer turbulence

- Refractive index turbulence
- Mechanical turbulence

Turbulent Energy input

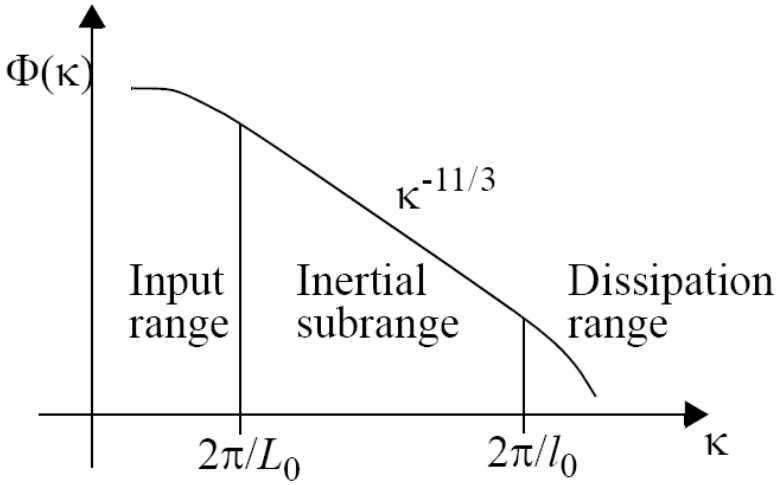
- buoyancy effects
- wind shears
- transport phenomena
- heating
- drag/friction

Turbulent Energy output/loss

- buoyancy effects
- wind shears
- transport phenomena
- viscous dissipation

ASSUMPTIONS

1. Komolgorov spectrum



2. Taylor ”Frozen Flow”

The turbulent eddy does not change dramatically when moving a distance comparable with it scale

Bi-Static Radar Equation

Volume Scattering:

$$\frac{P_r}{P_t} = \frac{\lambda^2 G_t G_r}{(4\pi)^2 R_1^2 R_2^2} \sigma_V(K) V_c$$

Volume Approximation:

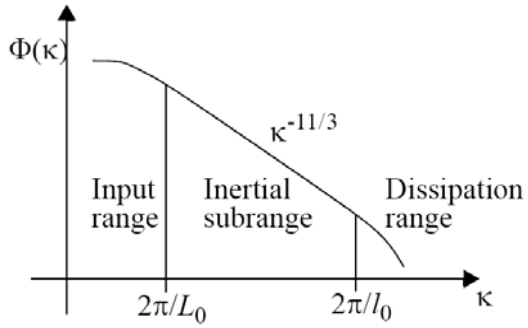
$$V_c = 0{,}853 \frac{R^3 \beta^3}{\sin\theta_s}$$

Bragg Scattering:

$$\sigma_V(K) = 2\pi k^4 \sin^2\chi \Phi_n(K)$$

Turbulence Spectrum:

$$\Phi(K) = 0{,}033 C^2 K^{-11/3}$$



The Bi-Static Radar Equation

Bragg Scattering:

$$\sigma_V(K) = 2\pi k^4 \sin^2\chi \Phi_n(K)$$

- Directional
- Strong in the forward direction
- 40 dB Gain vs Backscatter

Gain vs Height:

Influenced by

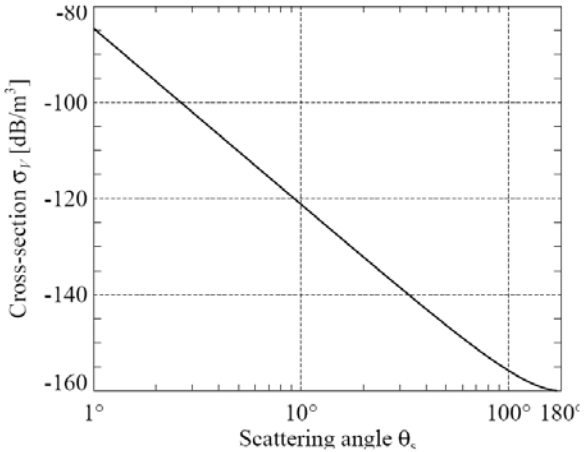
1. Geometry
2. Wavenumber
3. Antennas

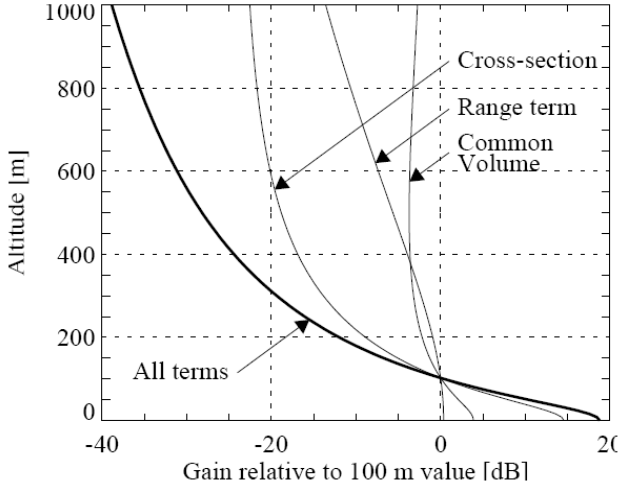
Structure Constant

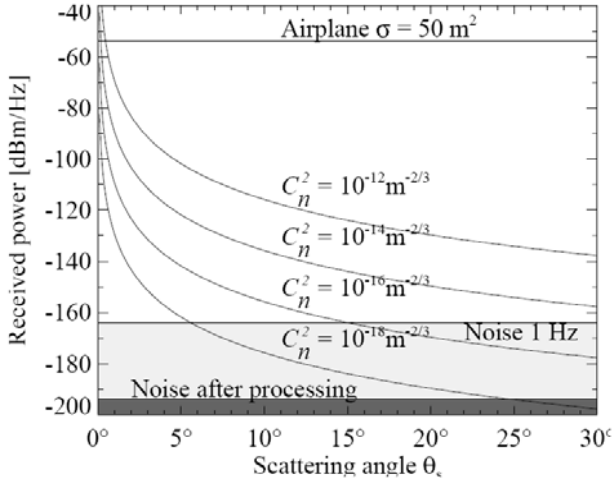
$$\Phi(K) = 0{,}033\, C^2 K^{-11/3}$$

Related to the variance

Determins the strenght of the scattering



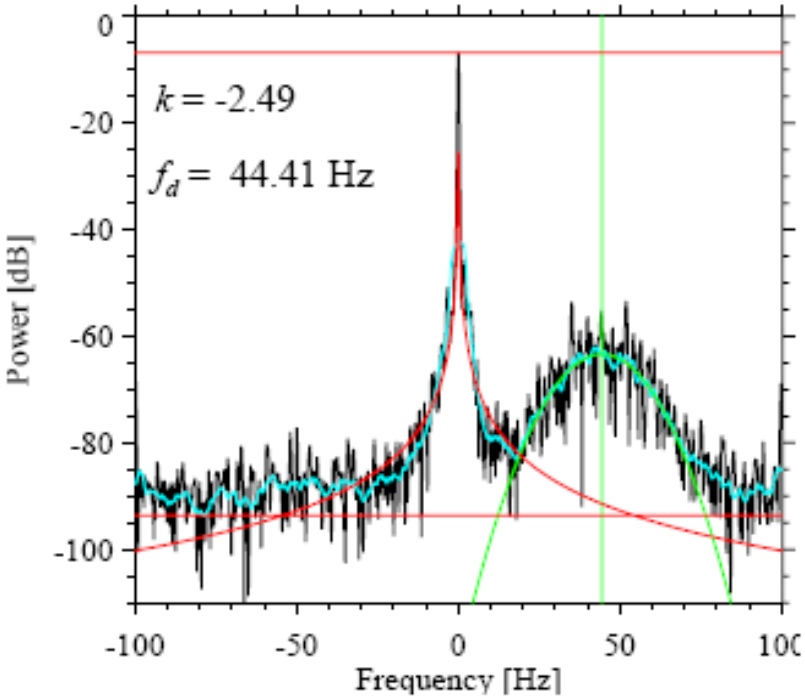




Doppler Extraction

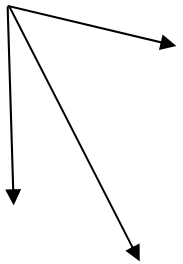
Parmetric estimation

- Black: Spectrum
- Cyan: Smoothed spectrum
- Green: Gausian parameter fitting routing
- Red: Fitted to DC Shape, DC level and Noise
- Dopplershift extracted
- Doppler widening extracted
- Converted to 1-D velocity uisng the using the scattering wavenumber



$$u = \frac{2\pi}{K} f_d = \frac{2\pi \cdot 44\ \text{Hz}}{137\ \text{m}^{-1}} = 2{,}0\ \text{m/s}$$

3-D Wind



Necessety:

Three bistatic channels with linearly independent scattering wavenumber vectors (ex 1 Transmitter and 3 receivers)

Doppler shifts are defined as : $b_i \equiv \mathbf{K}_i \cdot \mathbf{v} \quad i = \{1, 2, 3\}$

A 3-D Doppler shifts vector : $\mathbf{b} = (b_1, b_2, b_3)$

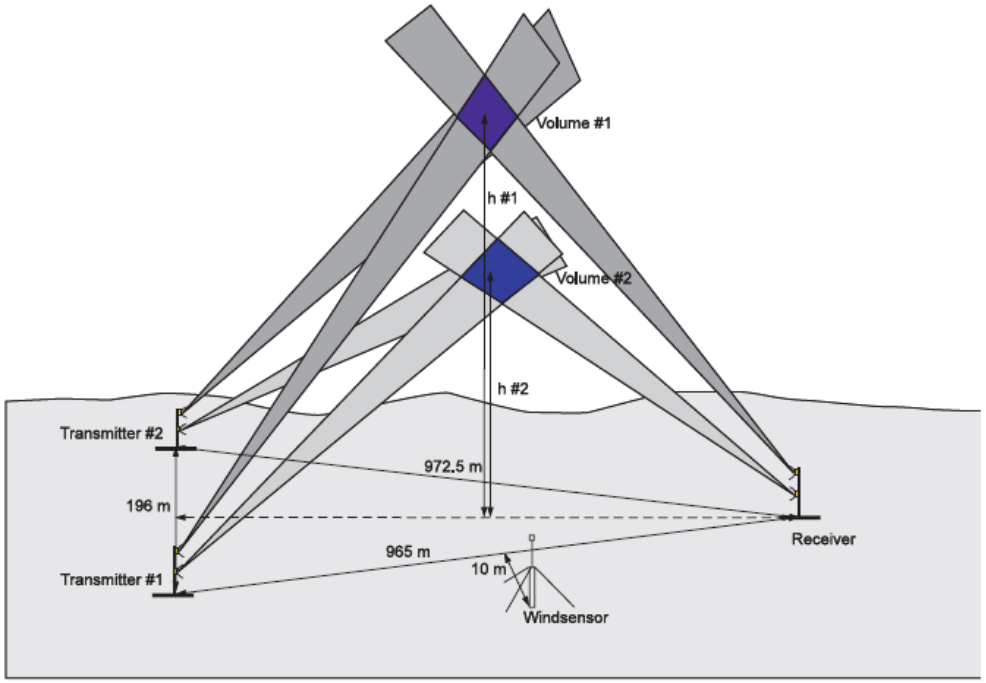
$$\mathbf{b} = T\mathbf{v}$$

$T = \left[\mathbf{K}_1, \mathbf{K}_2, \mathbf{K}_3\right]^T$ Wavenumber vectors

$\mathbf{v} = (v_x, v_y, v_z)$ Cartesian Wind coordinates

The Vector v is then found as: $\mathbf{v} = T^{-1}\mathbf{b}$

Measurements outside of Oslo



2 Transmitters

CW Power 1-10 Watts

4 receivers

10.5 GHz Carrier Frequency

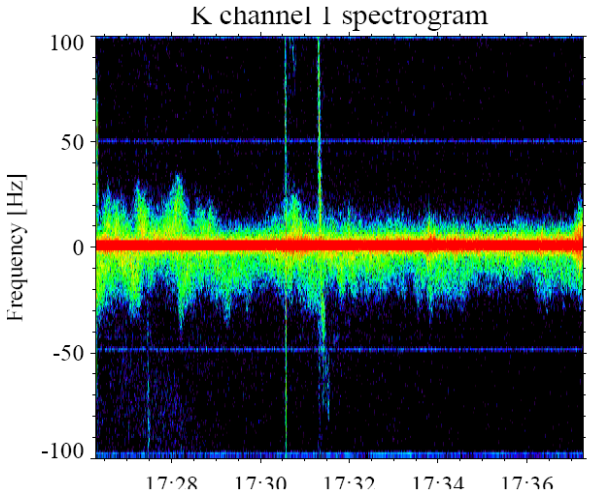
90 cm Parabolic Antenna

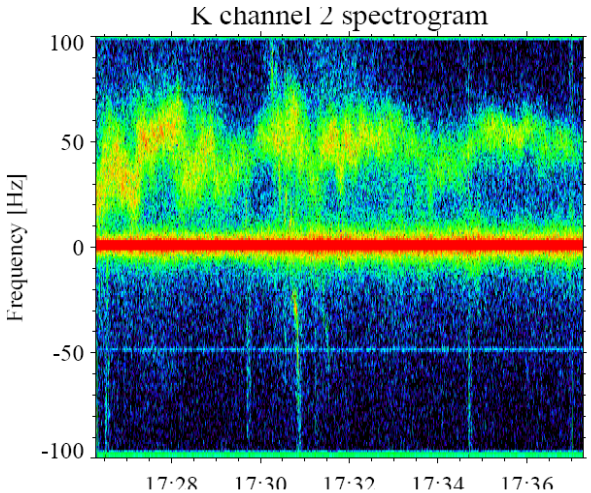
2.1 degrees beamwith

Mode	Common volumes	Purpose
1	50 m and 150 m	2D wind at two altitudes
2	50 m and 1000 m	2D wind at 50 m, test of high altitude
3	50 m and 400 m	2D wind at 50 m, test of high altitude
4	Variable	Altitude dependencies
5	None	Direct transmission test

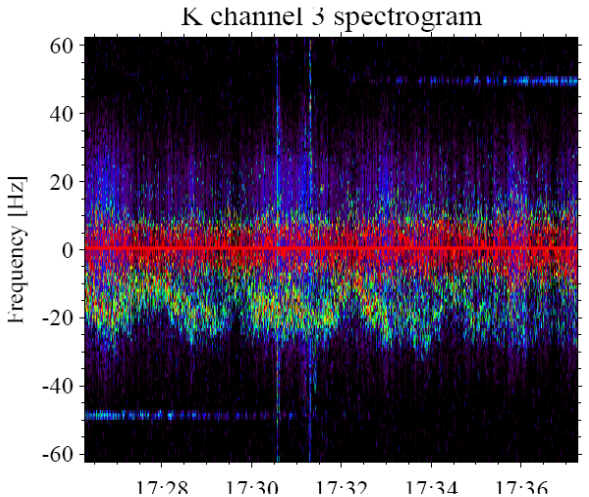
2-D Wind Raw Data

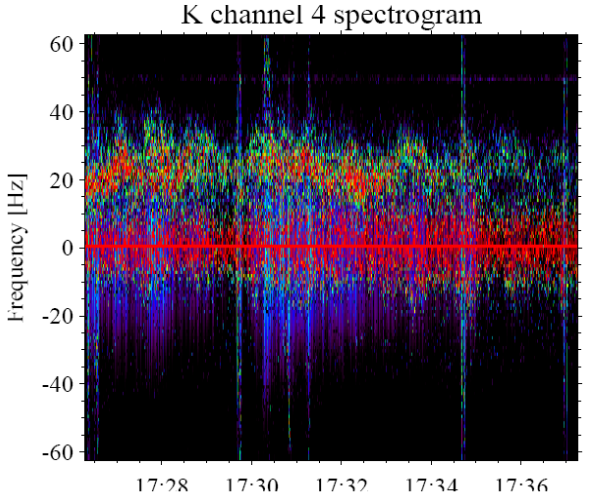
150 M



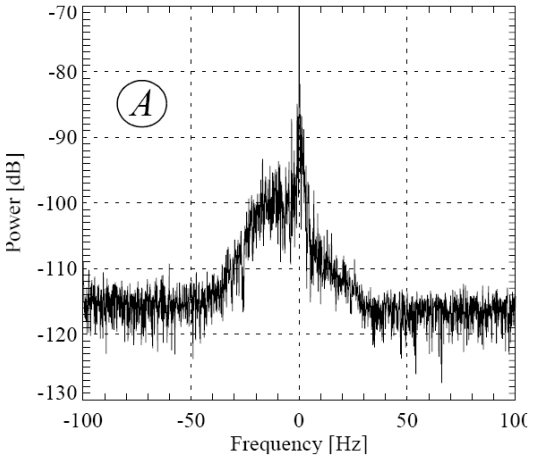


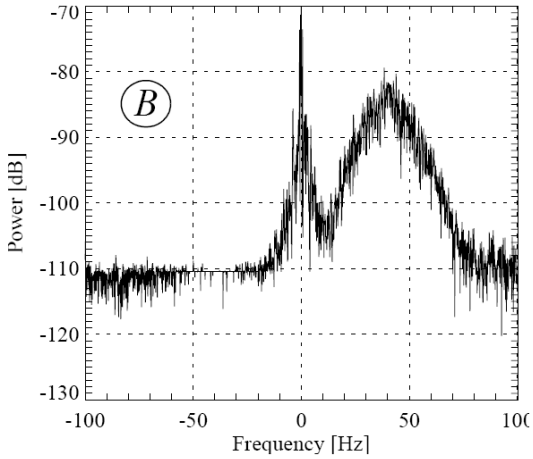
50 M





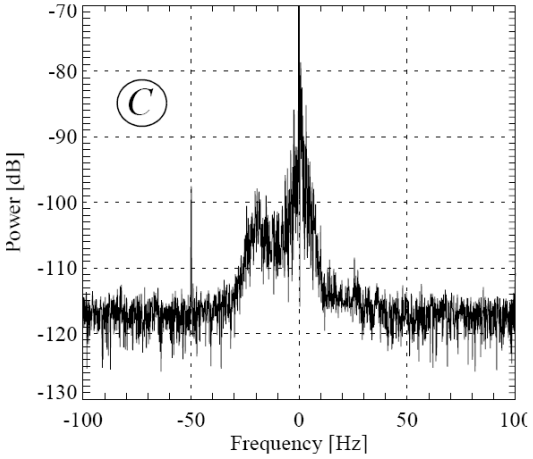
2-D Wind Spectrums

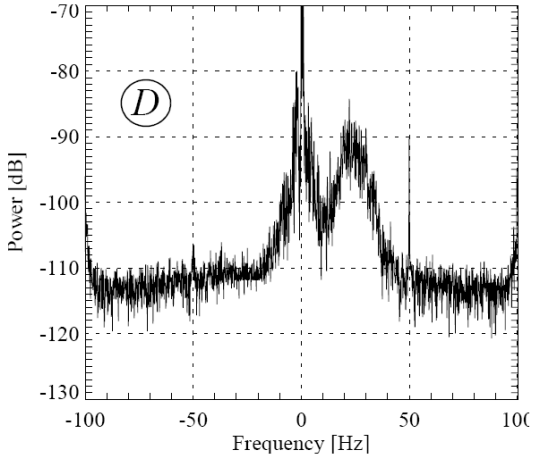




A: 150 m, Ch1, Tx1

B: 150 m, Ch2, Tx2



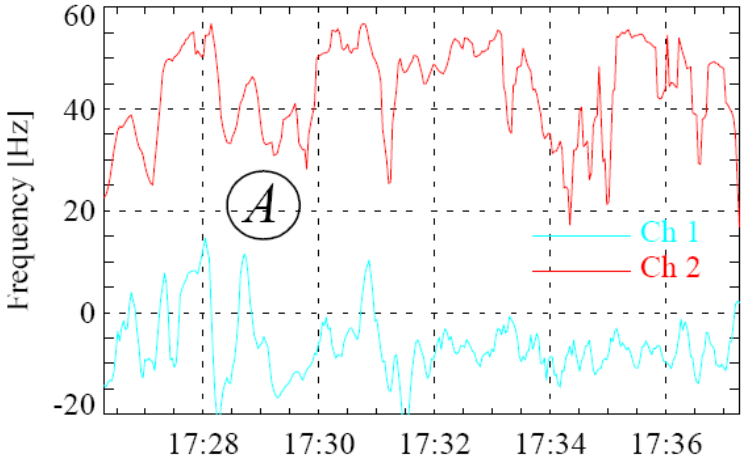


C: 50 m, Ch3. Tx1

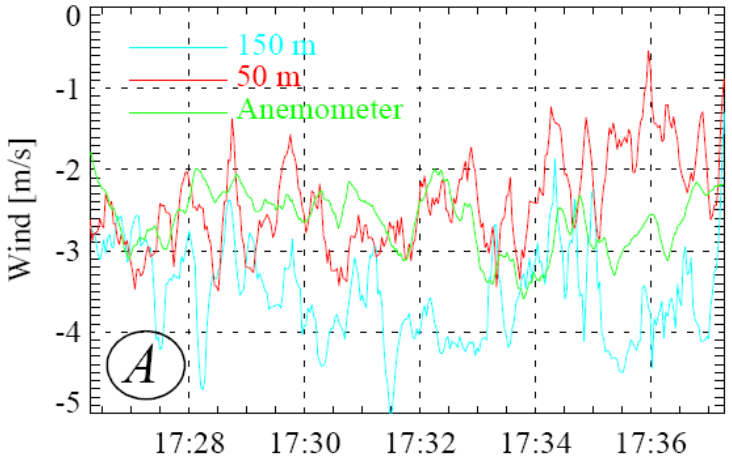
D: 50 m, Ch4, Tx2

2-D wind processed data

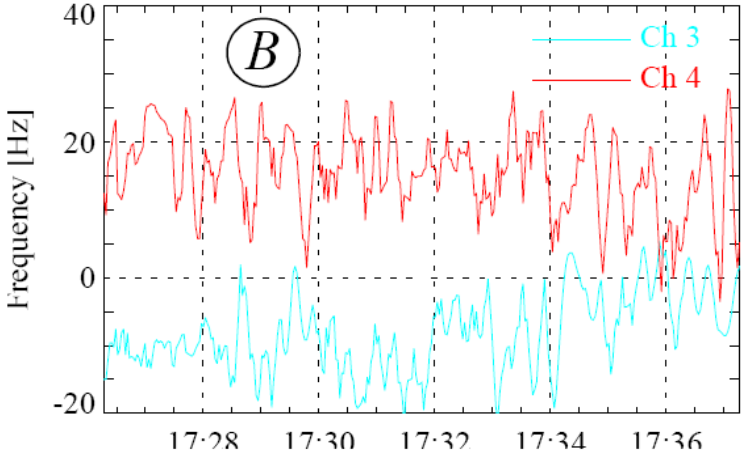
Doppler 150 m



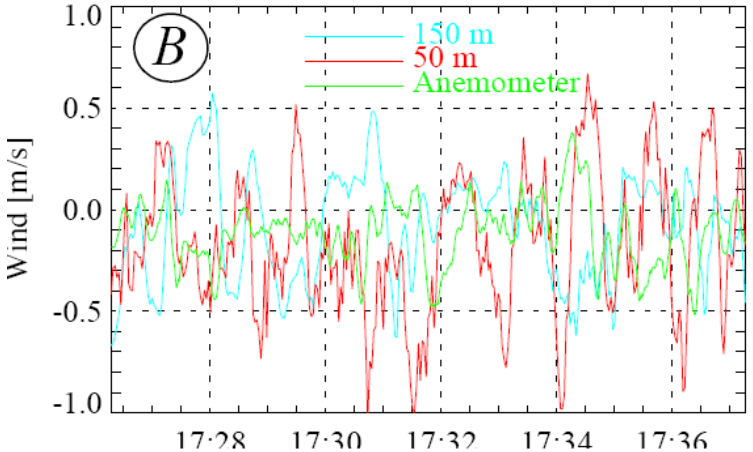
Horizontal Wind - X



Doppler 50 m

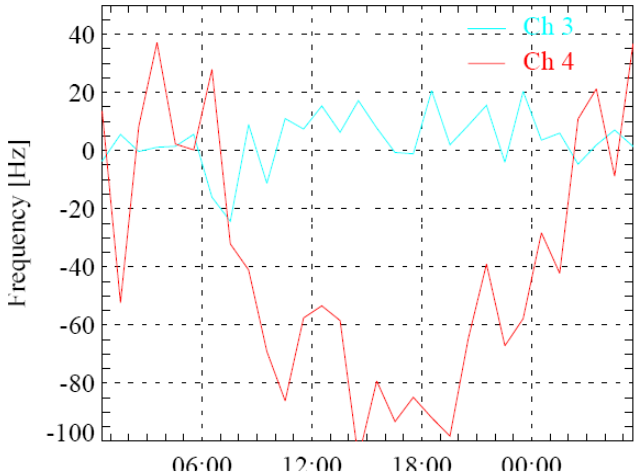


Vertical wind - Z

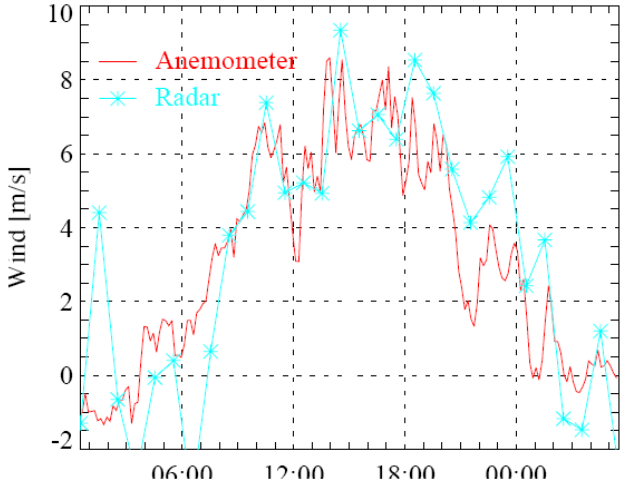


Horizontal wind During 1 Day

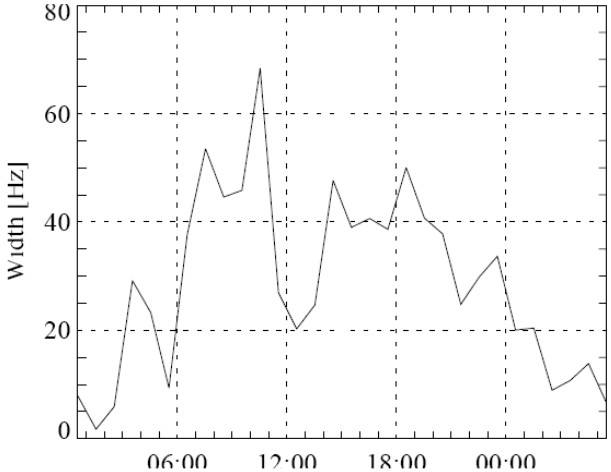
Doppler Shifts 50 m



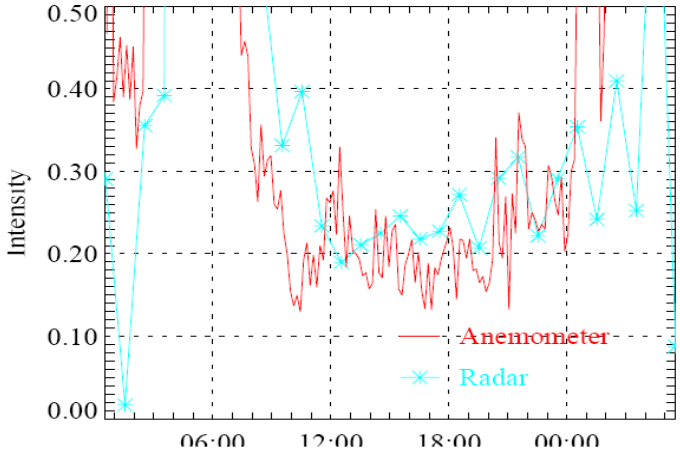
Wind Speed 50 m



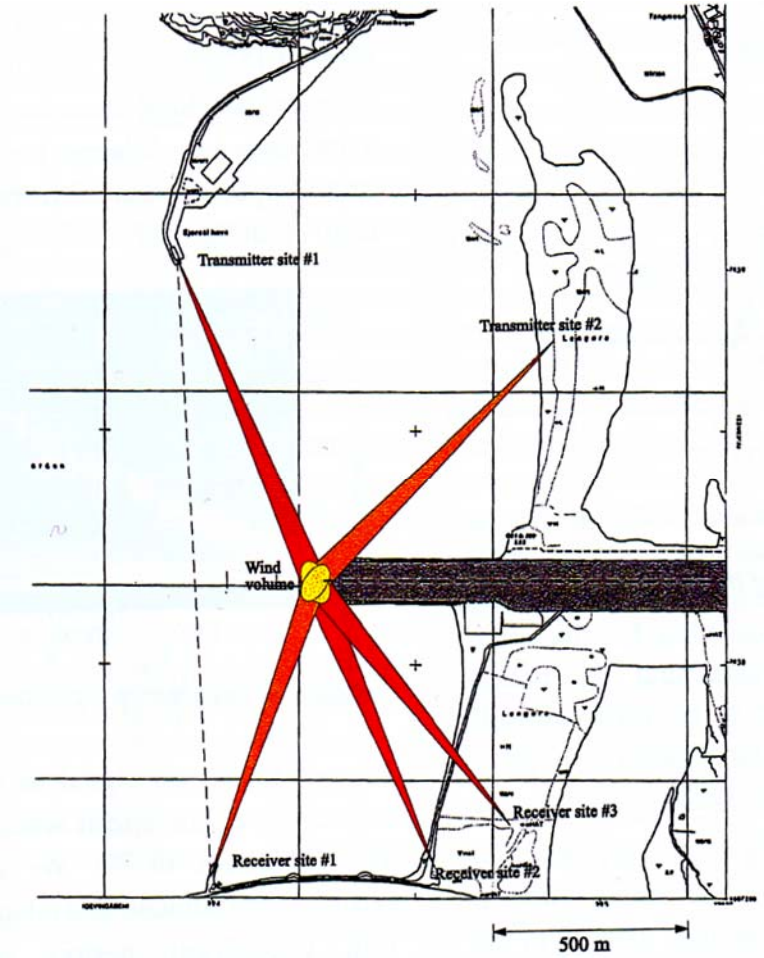
Doppler Widening 50 m

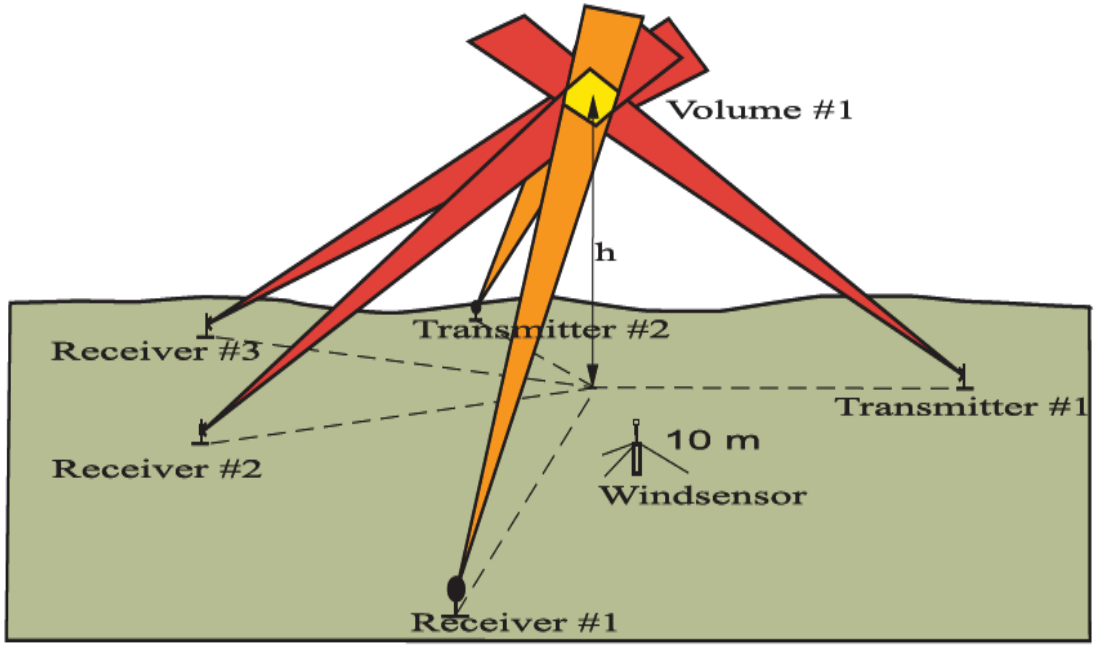


Turbulence Intensity 50m

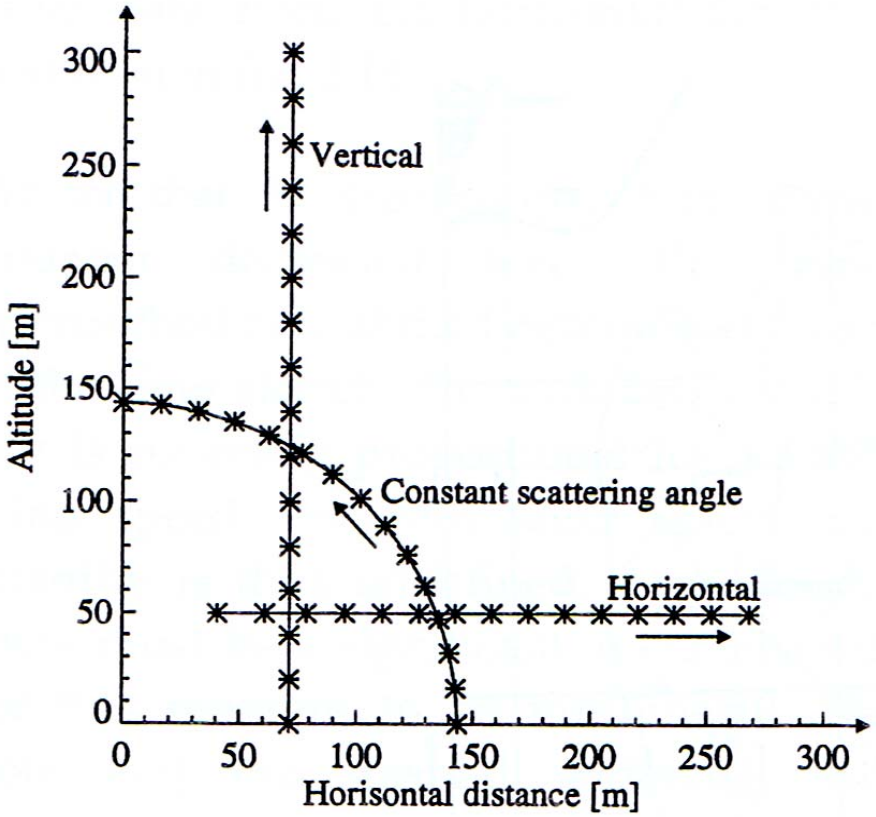


Trondheim Airport





Beam swinging experiment



Vertical scan:

Altitude profiles of Doppler velocity and structure parameter

Horizontal scan:

For Homogeneous conditions to test scattering angle dependency

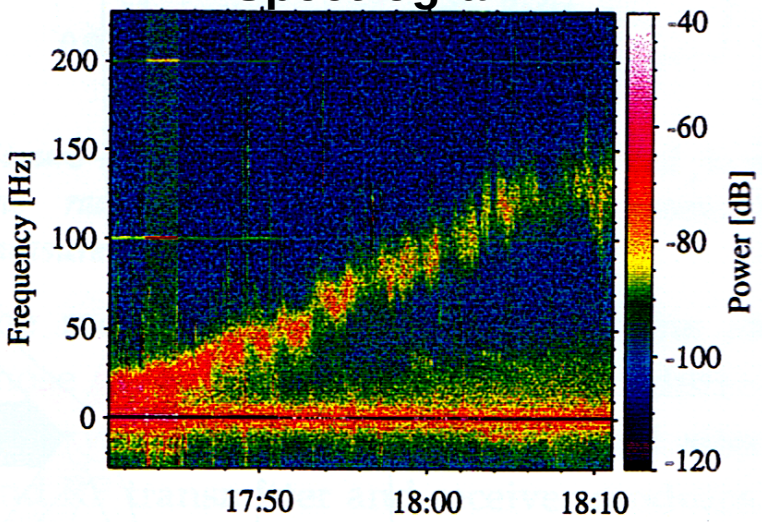
Constant scattering-angle scan:

Remove influence of Geometrical factors

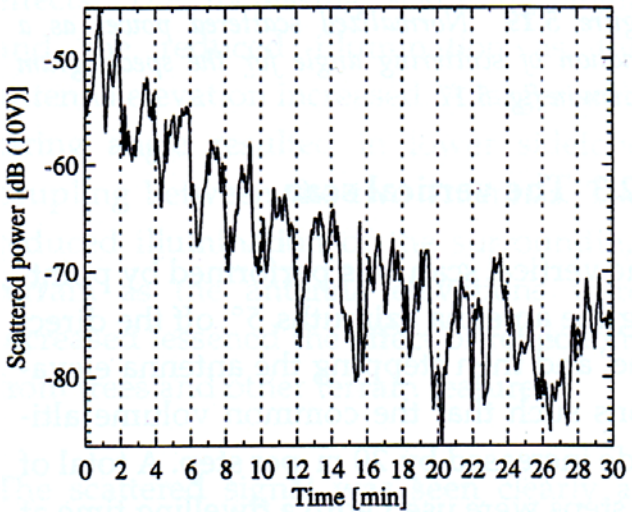
Demonstate Coverage

Horizontal Scan

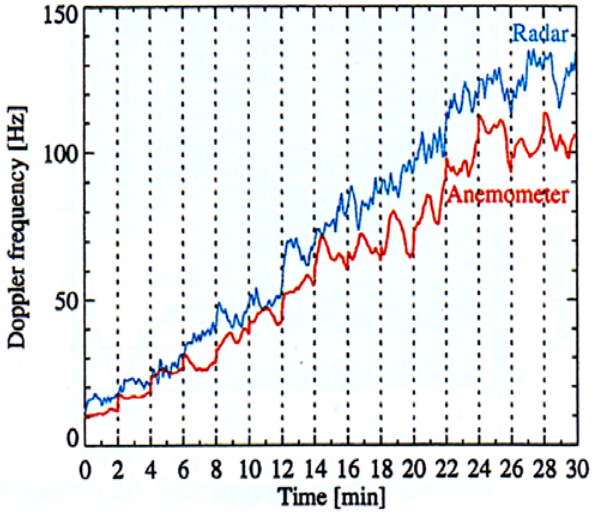
Spectrogram



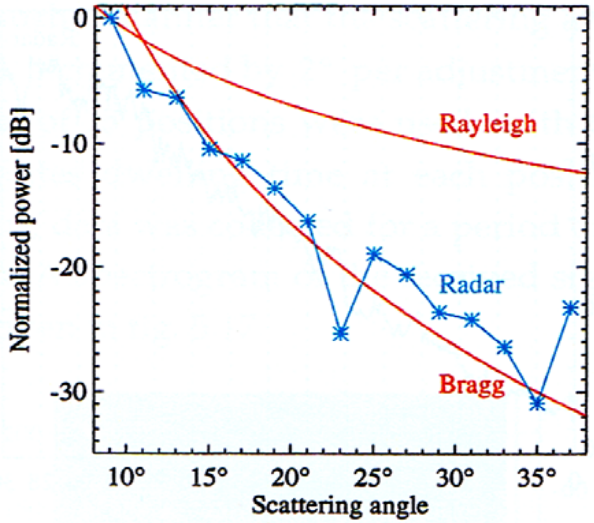
Scattered Power



Doppler Frequency

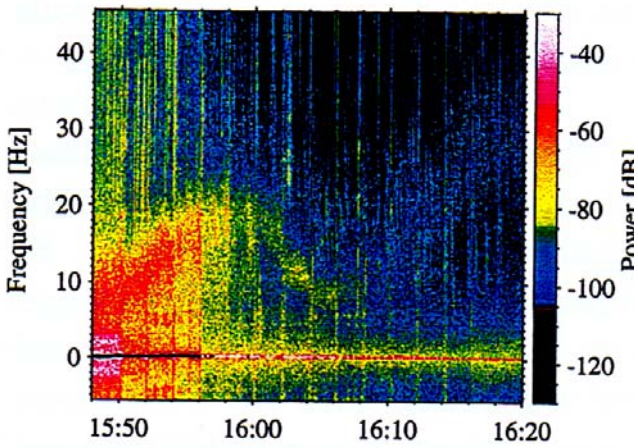


Scattering-angle dependancy

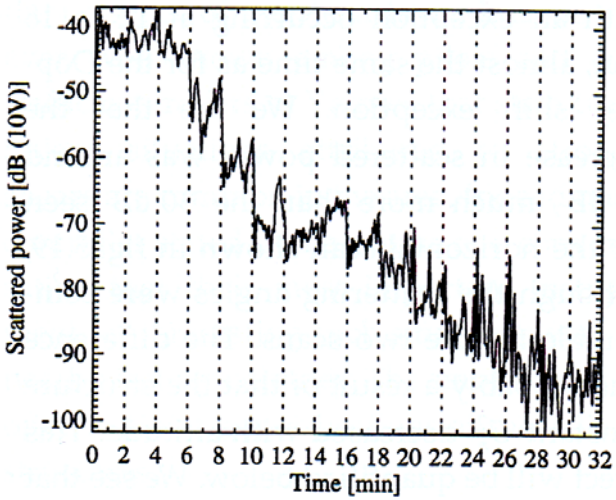


Vertical Scan

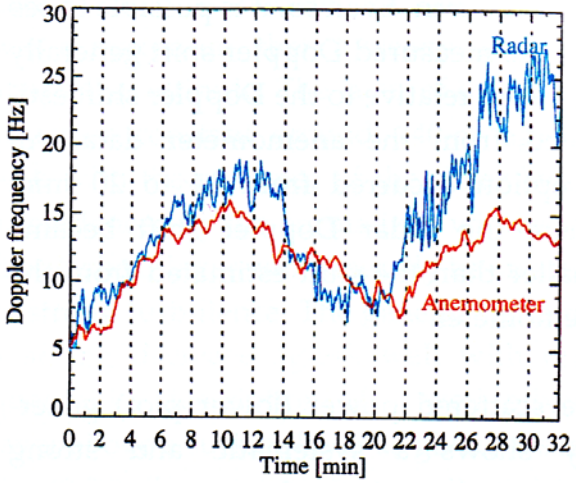
Spectrogram



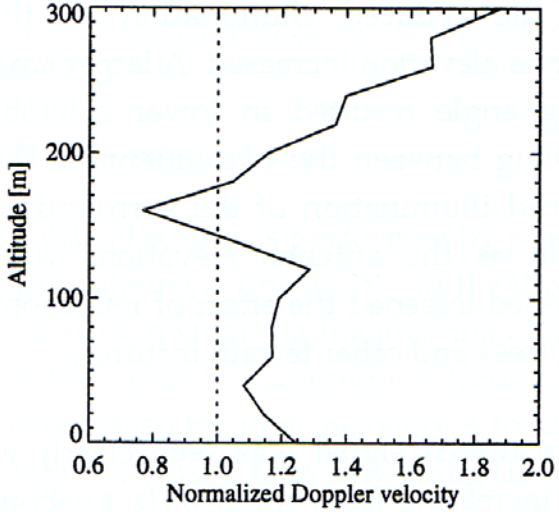
Scattered Power



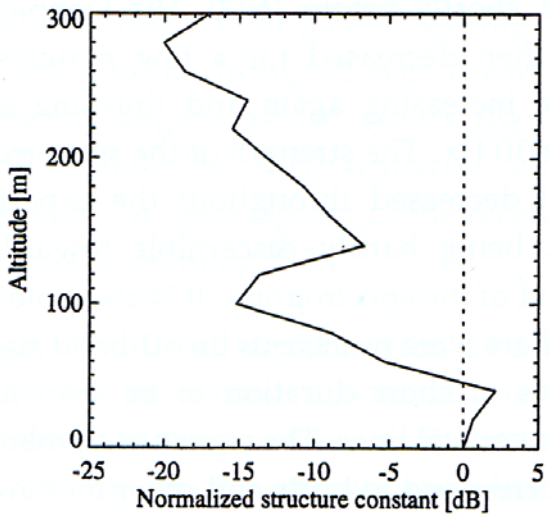
Doppler Frequency



Doppler - Altitude



Structure Constant

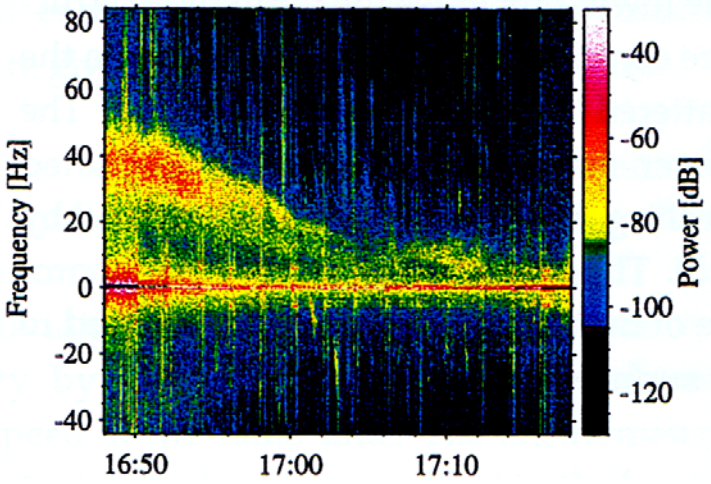


Shear layer (140 m)

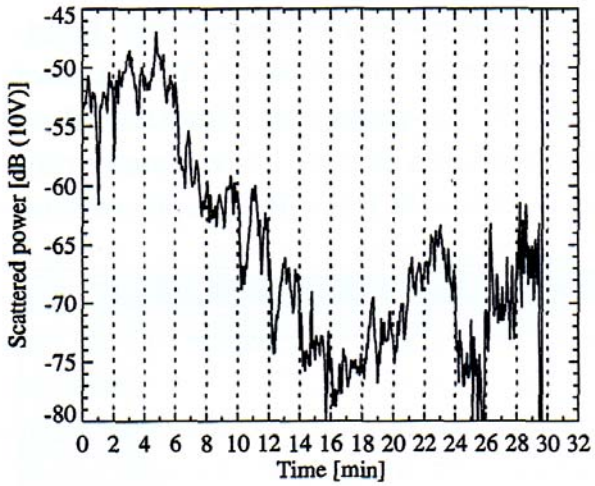
Surface layer (0-50m)

Constant Scattering-angle Scan

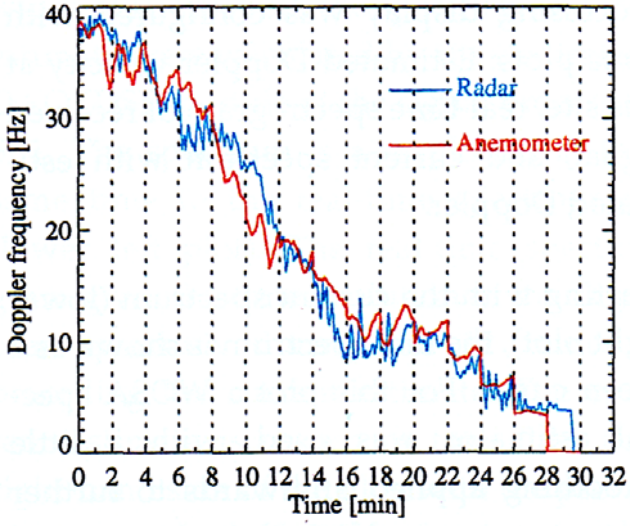
Spectrogram



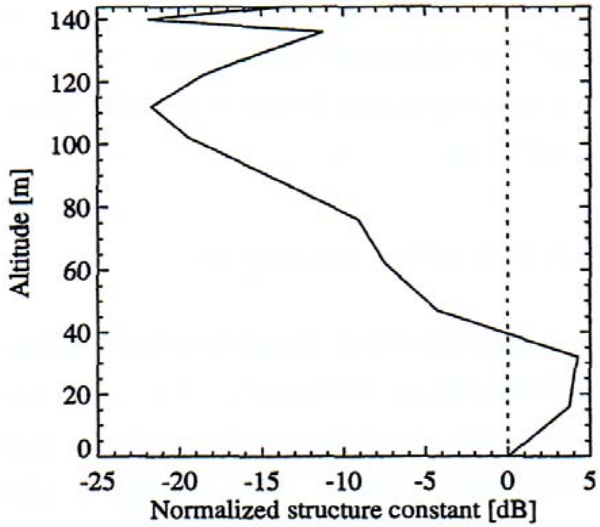
Scattered Power



Doppler Frequency



Structure Constant



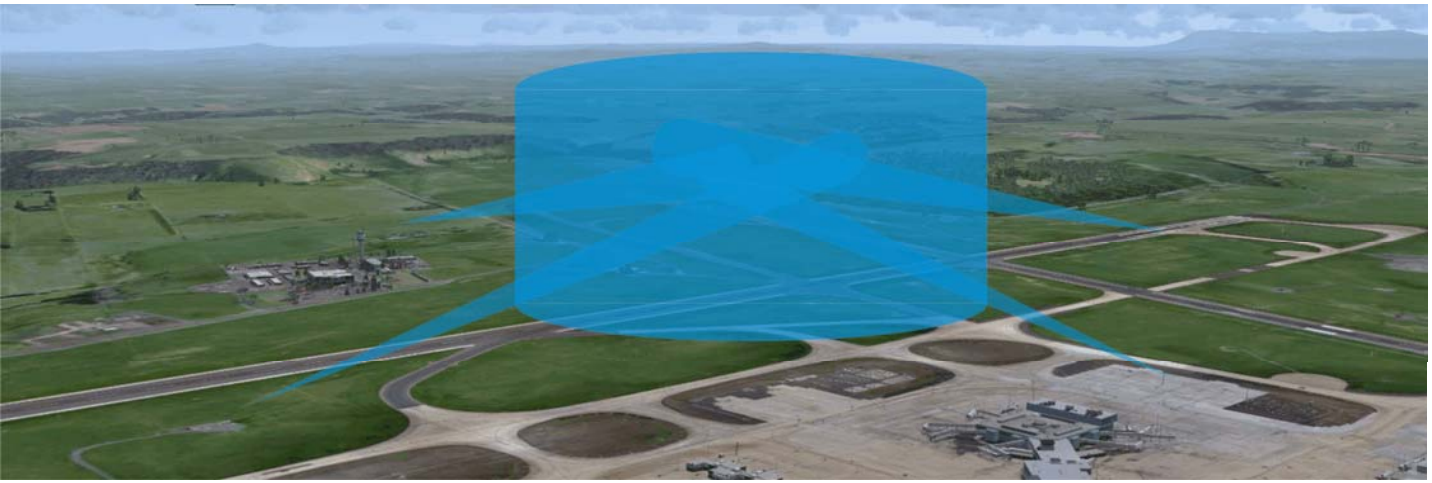
Shear layer (140 m)

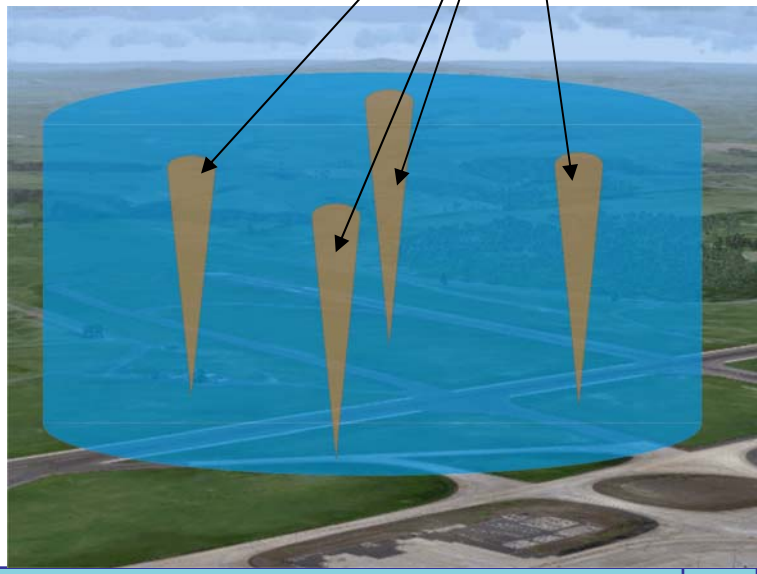
Surface layer (0-40m)

Multistatic summary

- Measurement of Wind, Vortex and Meterological parameters
- Strong directivity of scattering from turbulence (Bragg)
- Forward Scattering is 40 dB Stronger at 10 degrees compared to backscatterering
- Higher SNR - Higher Confidence – Lower Power
- Low altitue and high spatial resolution are possible
- Coupling to larger scales using higher frequencies (with narrow beamwidth)
- Time resoultion in the order of seconds or better
- Simultaneous wind measuremnt in the same volume
- Scattering angle and scattering wavenumber can be varied

Commercial system





Surveillance in a volume that is 300x300 meter

X-Band

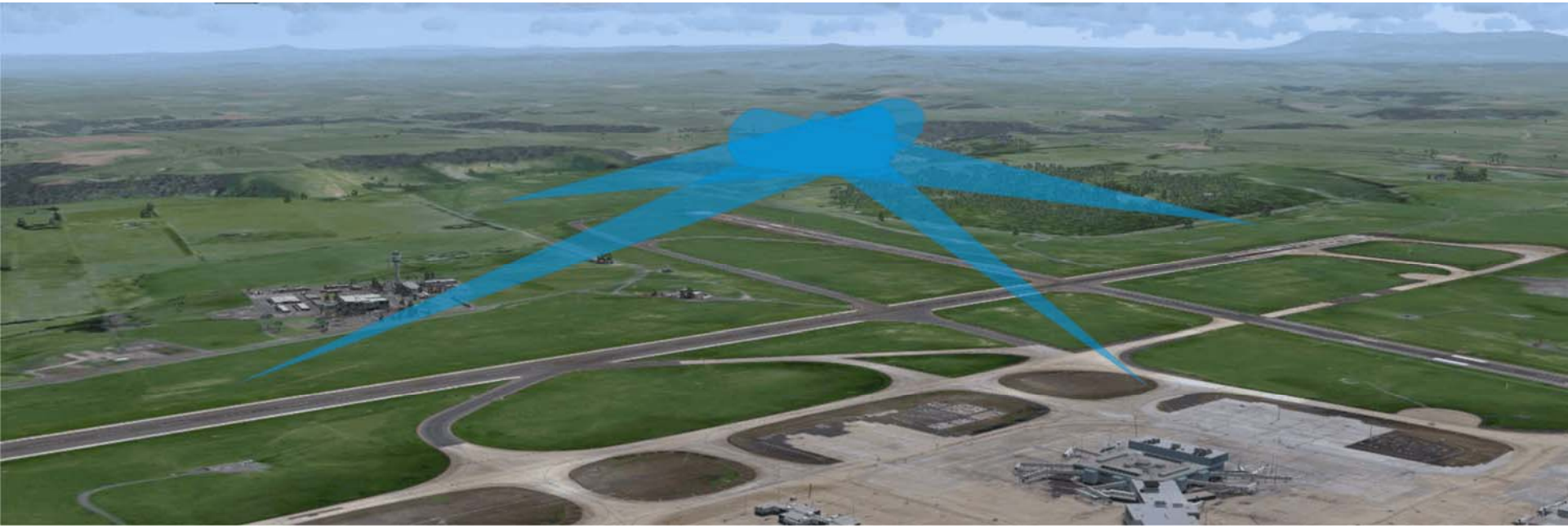
Phased array antennas

Can utilize both forward and backscatter

3-D wind and Wake Vortex

Airport and Wind Energy

The End



www.triad.no