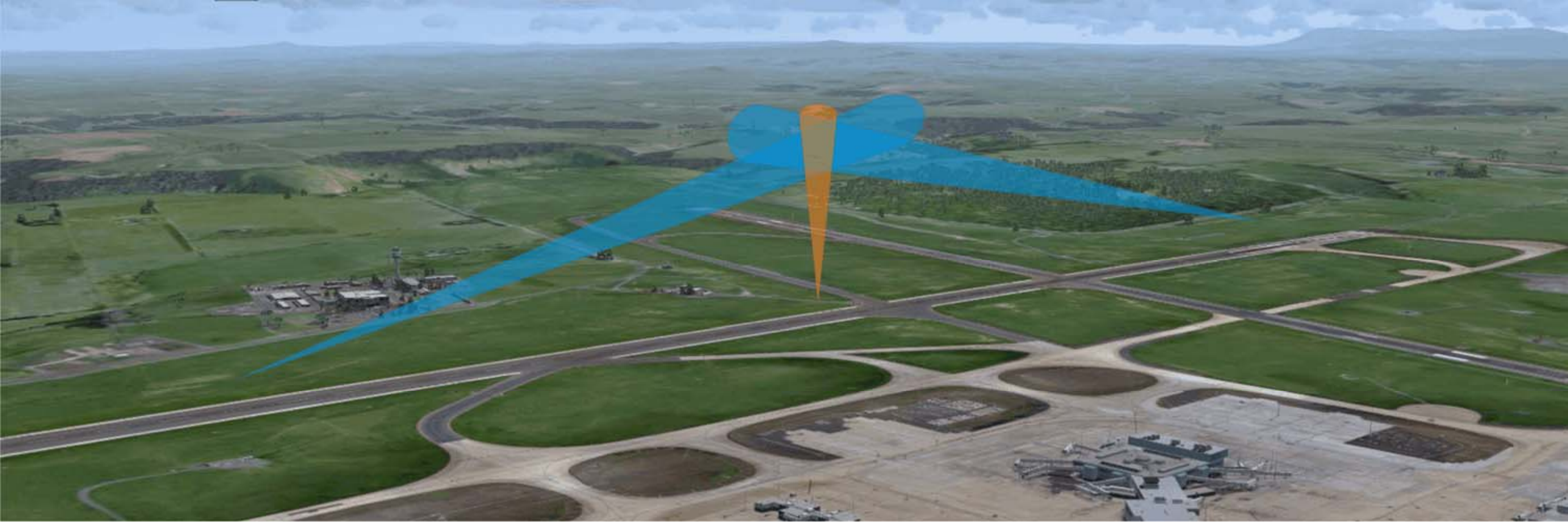


Bi-Static Radio-Acoustic System for Wake-Vortex monitoring

Jone Saebboe, Triad AS

Paris, March 30, 2010

Talk Overview

- Triad and Wind, Vortex and Turbulence technology
- Radio-Acoustic concept
- Forward scattering by acoustics
- Scattering volume limitations
- Signal power
- Wind sensitivity
- Turbulence
- Temperature/Vertical wind
- Wake Vortex
- 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

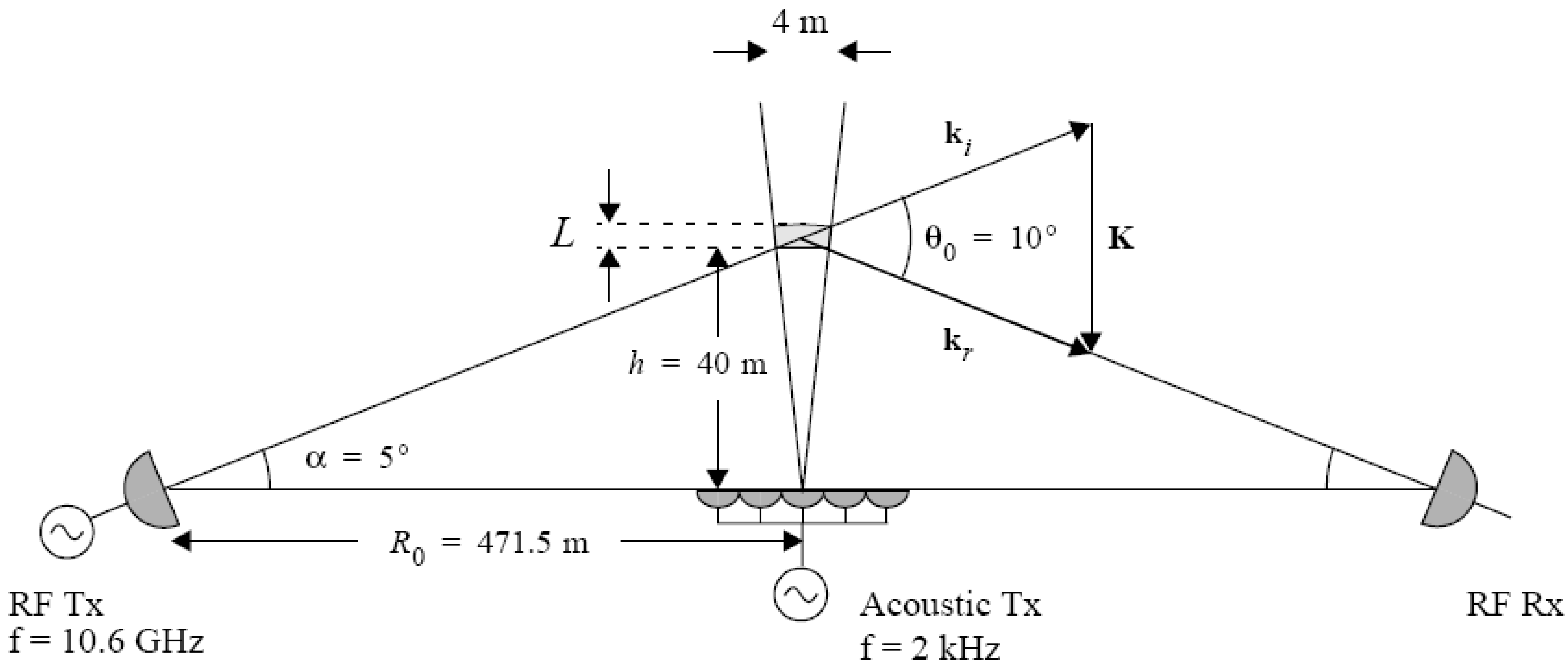
Work on Wind and Vortex by PFM, TRIAD and SUSAR.

- **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

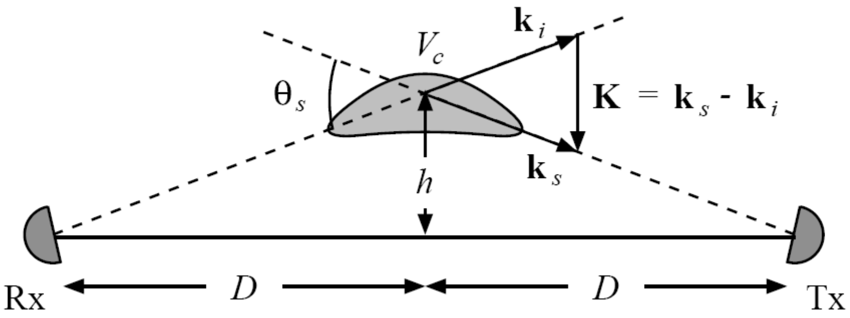
Bistatic Radio Acoustic Concept

- Bi- or Multistatic EM
- Angle of arrival detection EM
- Multifrequency EM and Acoustics

- 3-D Vind
- Vortex
- Temperature



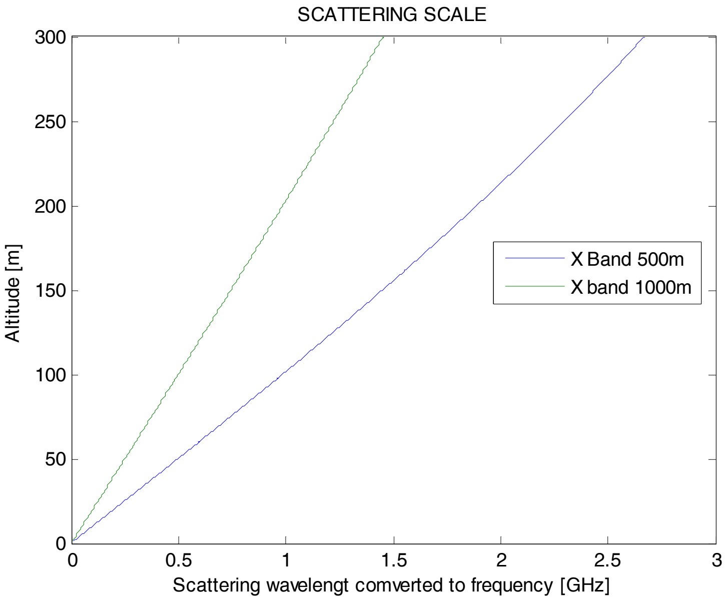
X-Band and Bragg Scatter



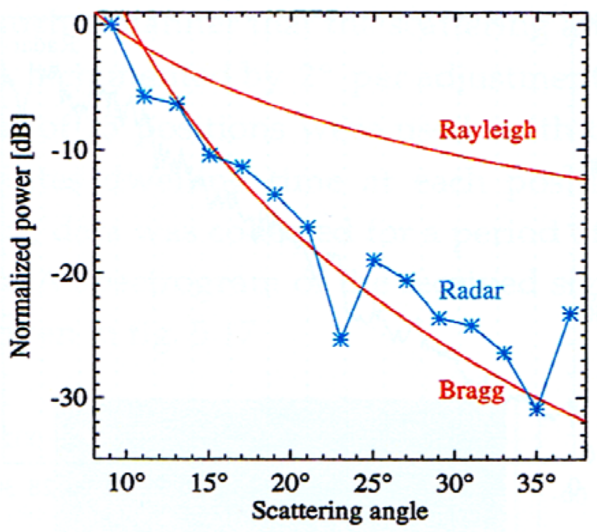
Scattering wavenumber: $K = 2k\sin(\theta_s/2)$

Scattering wavelength: $\Lambda = 2\pi/K$

"Scattering frequency": $f_S = c/\Lambda$



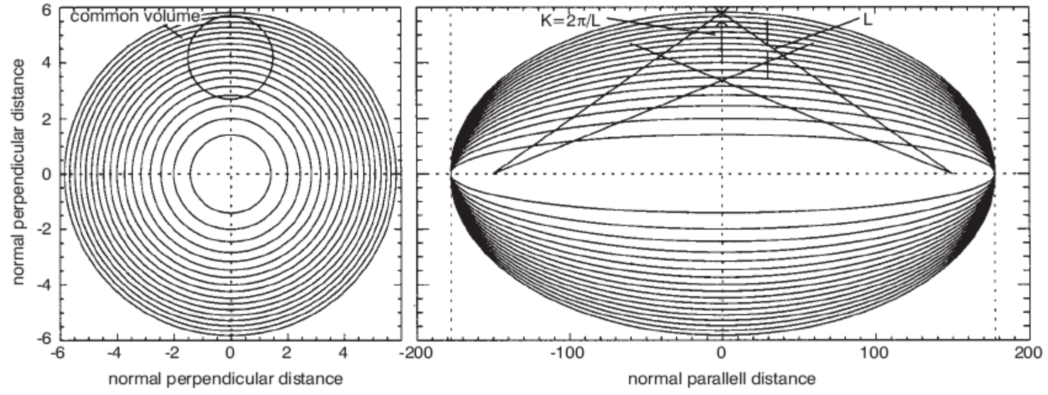
Experimental results

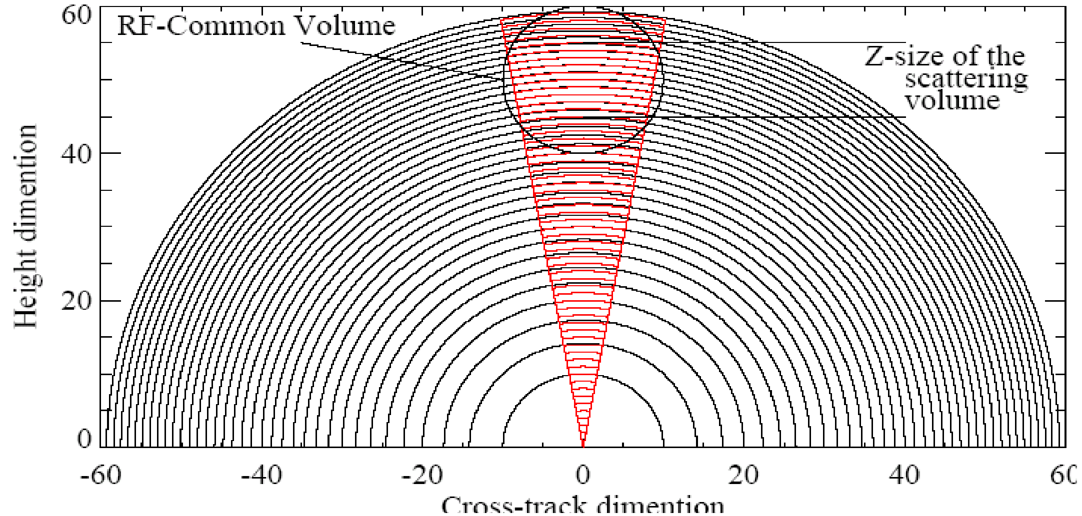


Radio acoustic forward scattering

- Bragg wave matching criterion
- Strong in the forward direction
- Acoustic frequency determins the height
- Frequency shift on receive

$$f_{aco} = \frac{2c_{aco}}{\lambda_{rf}} \sin\left(\frac{\theta_S}{2}\right)$$





$$H_1 = \frac{0.665}{\cos\theta_0/2}\sqrt{\lambda_{rf}R}$$

$$|\mathbf{K}_{em}| = |\mathbf{k}_s - \mathbf{k}_i| = 2k\sin\theta_0/2 = k_{ac}$$

Radio acoustic forward scattering

Modulation by the acoustic wave: $\delta n = \delta n_0 \exp(-j(\boldsymbol{k}_a \cdot \boldsymbol{r}' - \omega_a t))$.

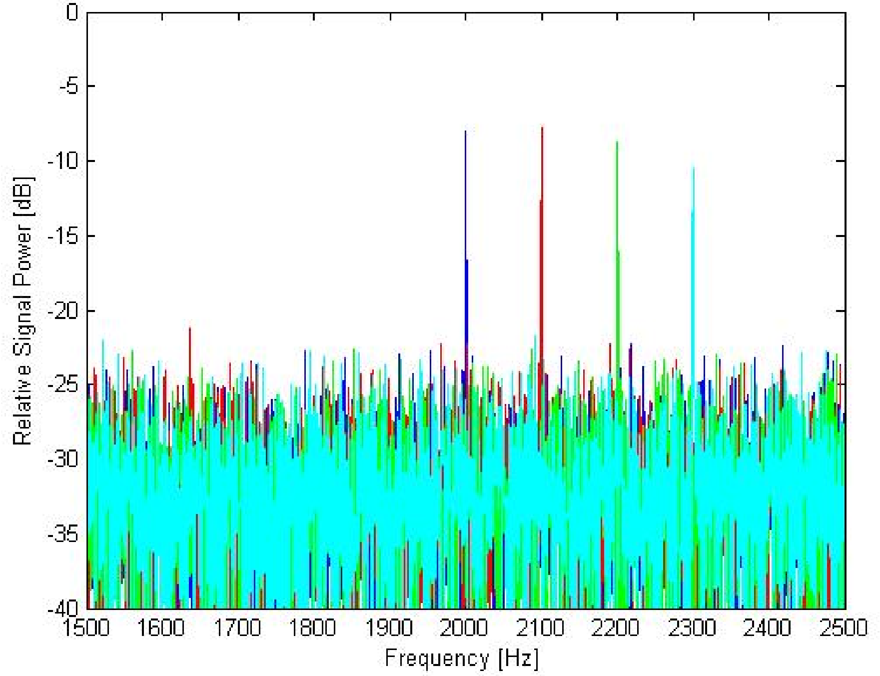
$$\boldsymbol{E}_s(\boldsymbol{r}, t) \approx \frac{\alpha}{2}\delta n_0 \frac{\exp(-jk_s r)}{4\pi\epsilon_0 r}\boldsymbol{k}_s \times (\boldsymbol{k}_s \times \boldsymbol{E}_0)$$

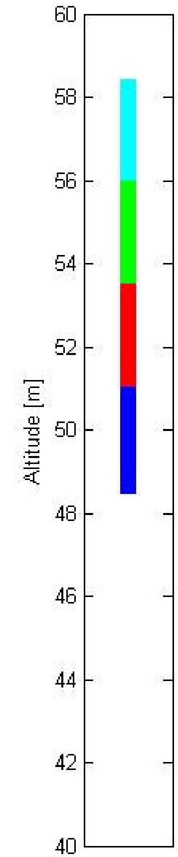
Acoustic frequency

$$\int d^3 r'([\exp(-j((\boldsymbol{k}_i + \boldsymbol{k}_a)\cdot \boldsymbol{r}' - (\omega_i + \omega_a)t)) + \exp(-j((\boldsymbol{k}_i - \boldsymbol{k}_a)\cdot \boldsymbol{r}' - (\omega_i - \omega_a)t))]).$$

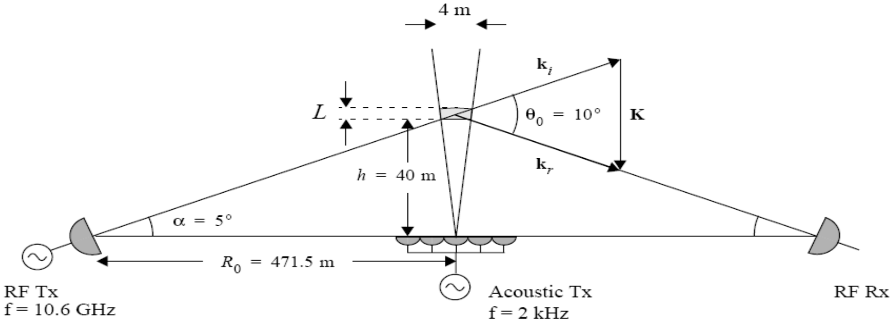
Acoustic frequency is proportional to height

The acoustic frequency is onmodulated on the received signal





Acoustic frequency vs altitude



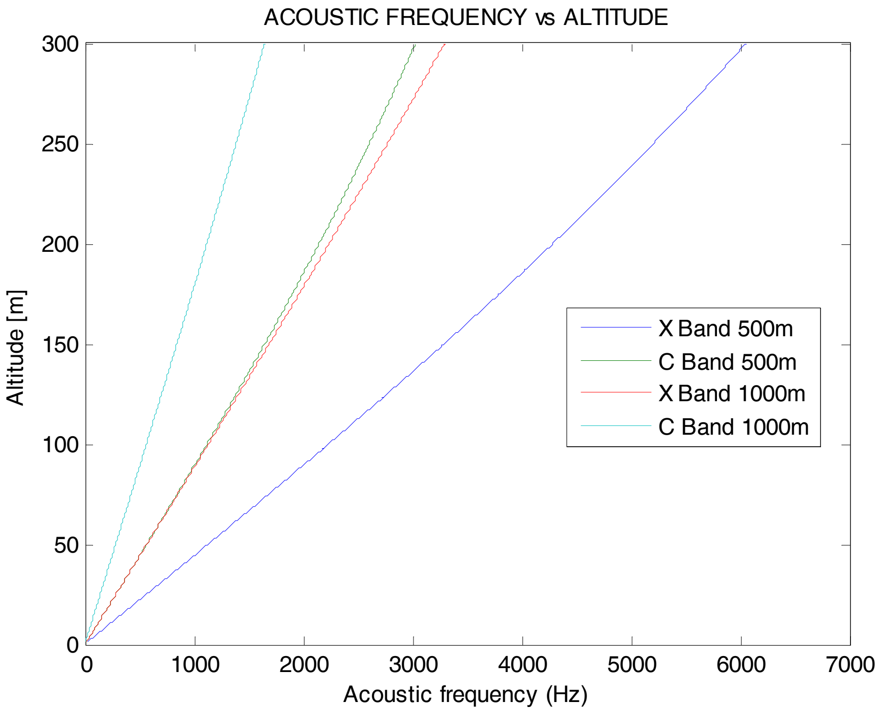
At 300 m altitude

1600 Hz for large C band system

3200 Hz for large X band system

3000 Hz for small C band system

6000 Hz for small X band system



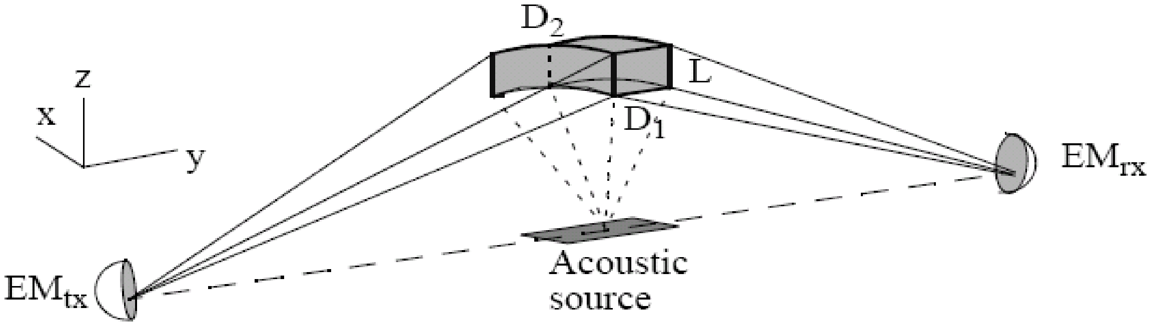
Dimension of the scattering volume

Cross track:

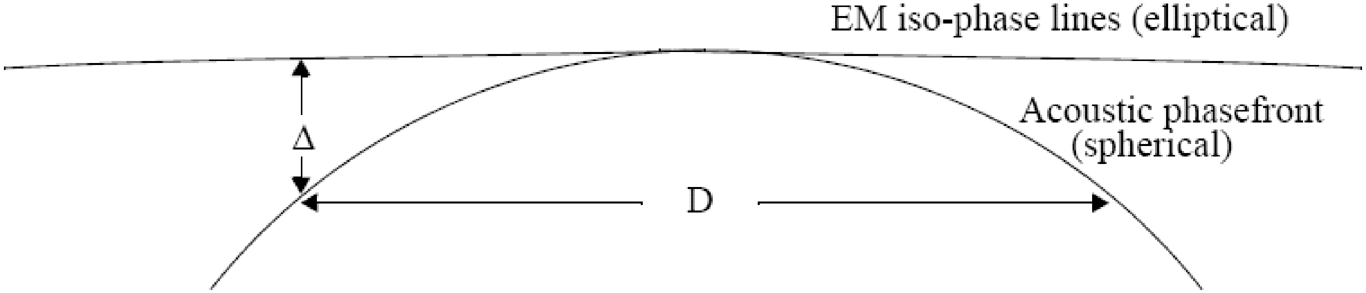
Acoustic or

EM beamwidht:

$$D_2 = \frac{\lambda}{d} R$$

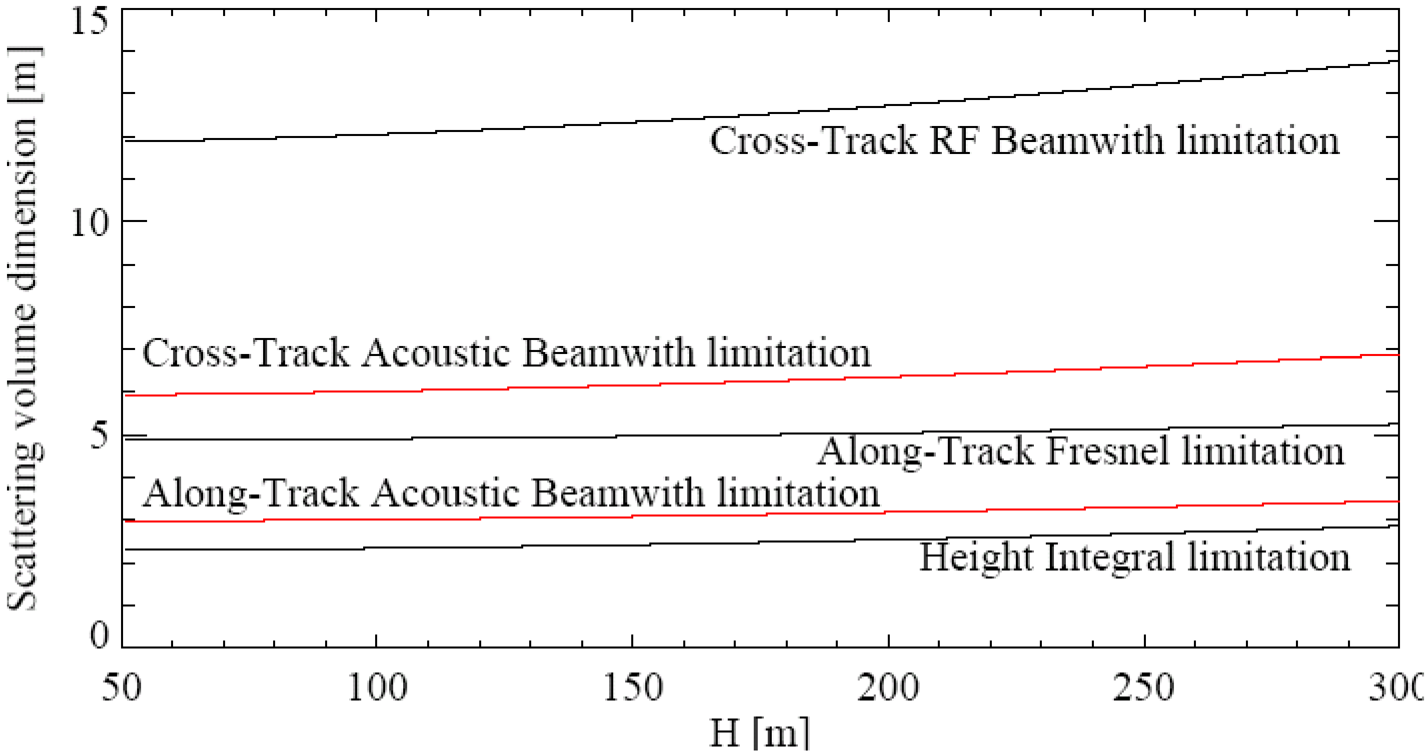


Along Track :



Acoustic beamwidth or Bragg 'Miss-Match'

Scattering volume X-Band



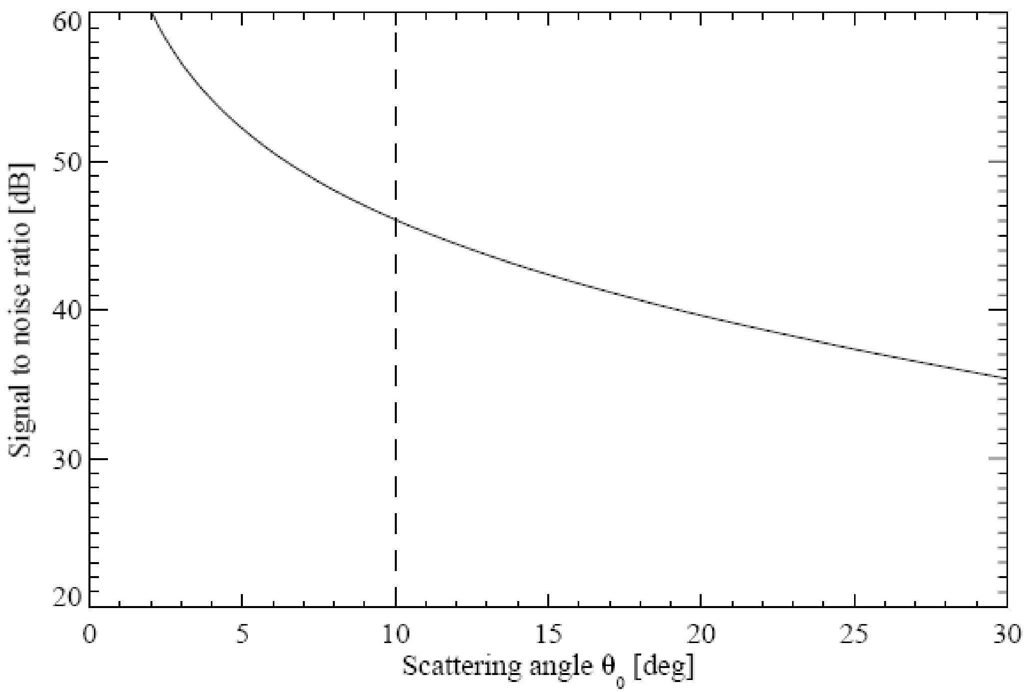
<u>Vertical direction</u>: 2-3 meters limited by Bragg Matching

<u>Cross track</u>: 6-7 meters limited by the acoustic beam

<u>Along track</u>: 4-5 meters limited by the acoustic beam

Signal Power

$$P_r = \frac{1}{128\pi} \frac{\chi^2}{c_a^3 \rho} \frac{\cos^2\theta_0}{1-\cos\theta_0} \left(\frac{L}{R^2}\right)^2 P_t G_t G_r \; G_a P_a$$

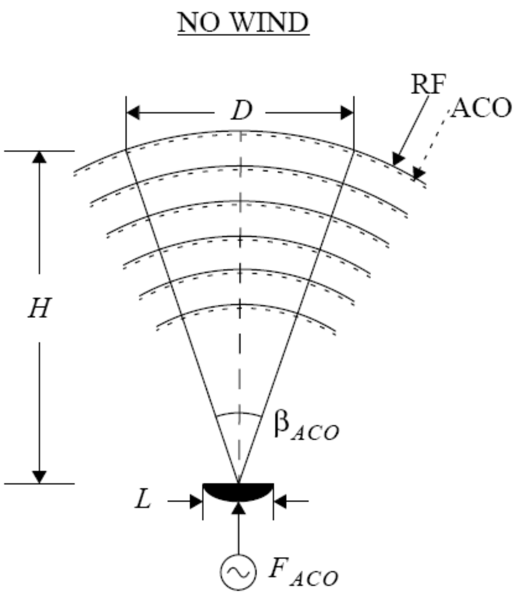


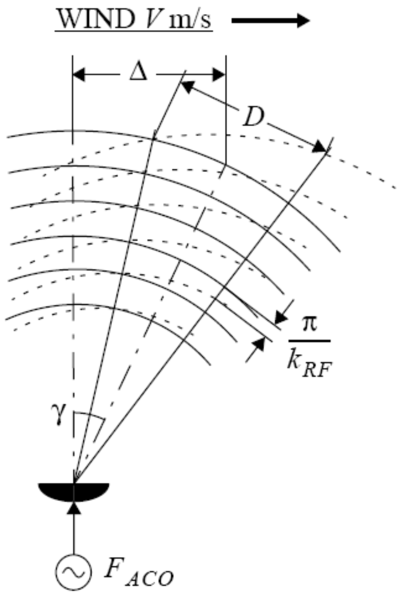
$$G_a = 20 \text{ dB}$$

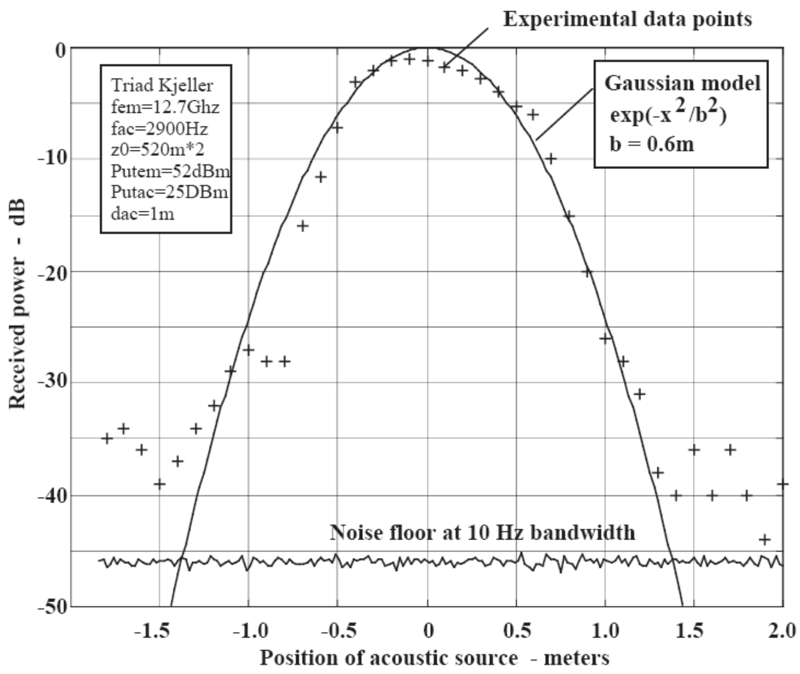
$$P_t = 1 \text{ W}$$

$$G_t = G_r = 37 \text{ dB}$$

Signal Power



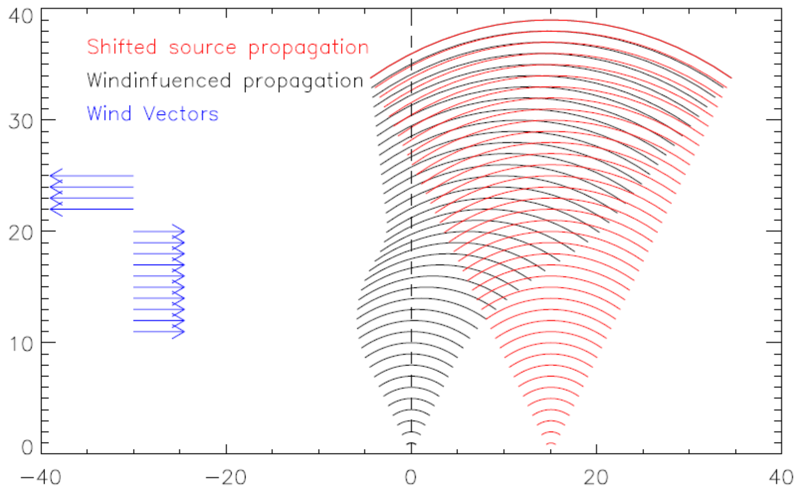




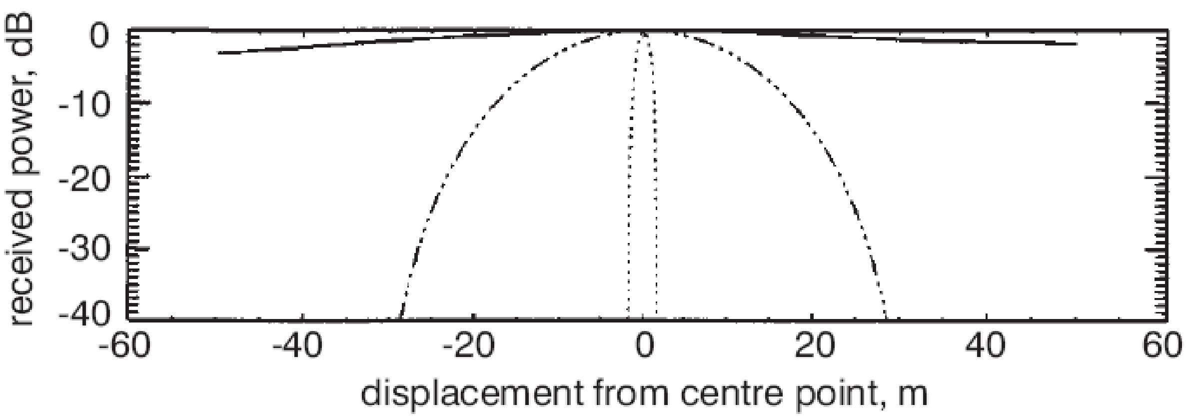
GAUSIAN MODEL FOR SIGNAL POWER

vs DISPLACEMENT/WIND

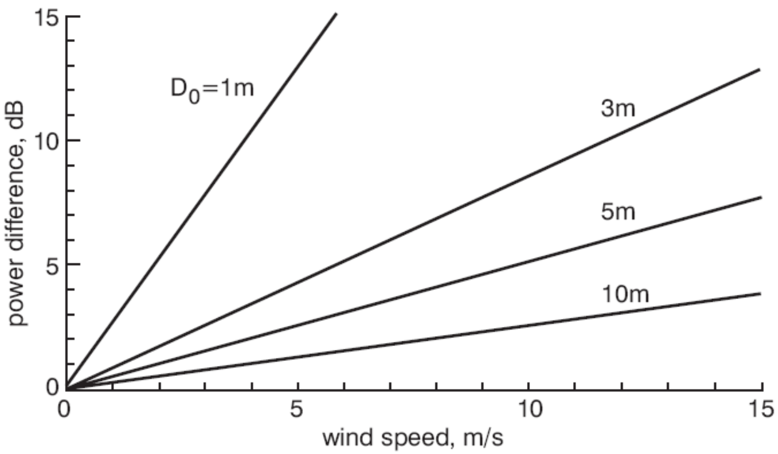
Wind Sensitivity

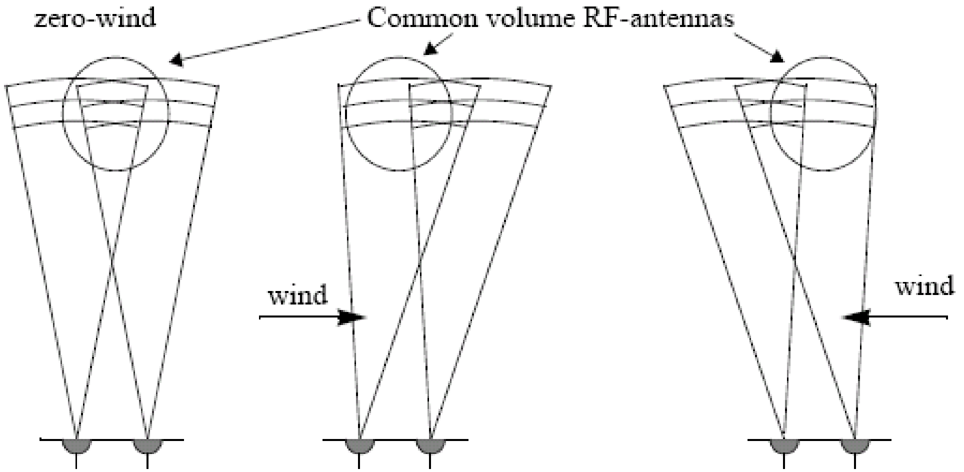


$$\Delta = V_{wind} \times t = \frac{H \times V_{wind}}{V_{acoustic}}$$

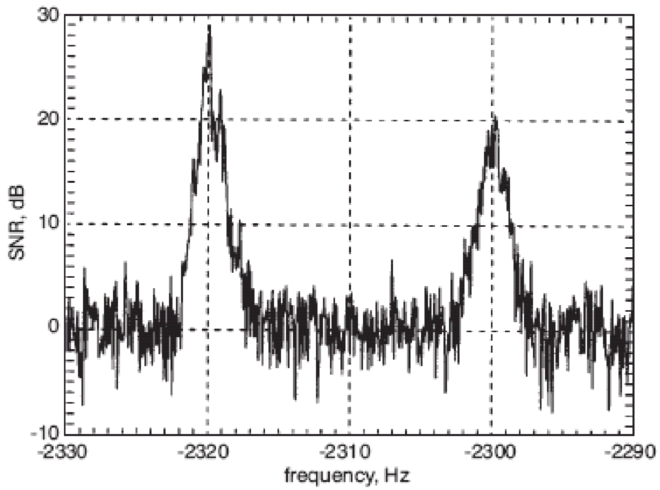


Cross Path wind

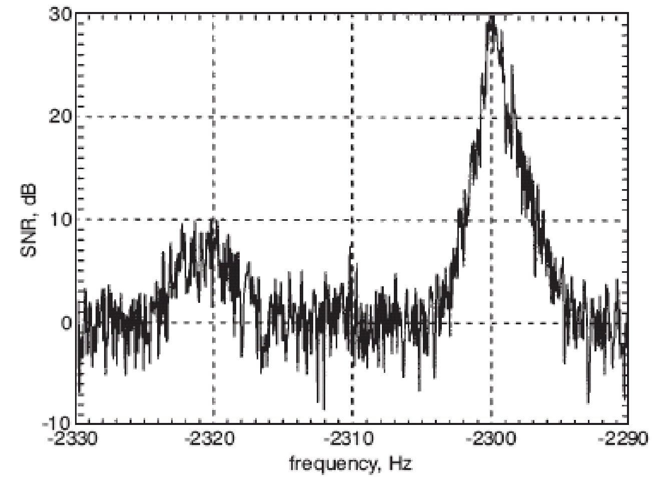




Wind →



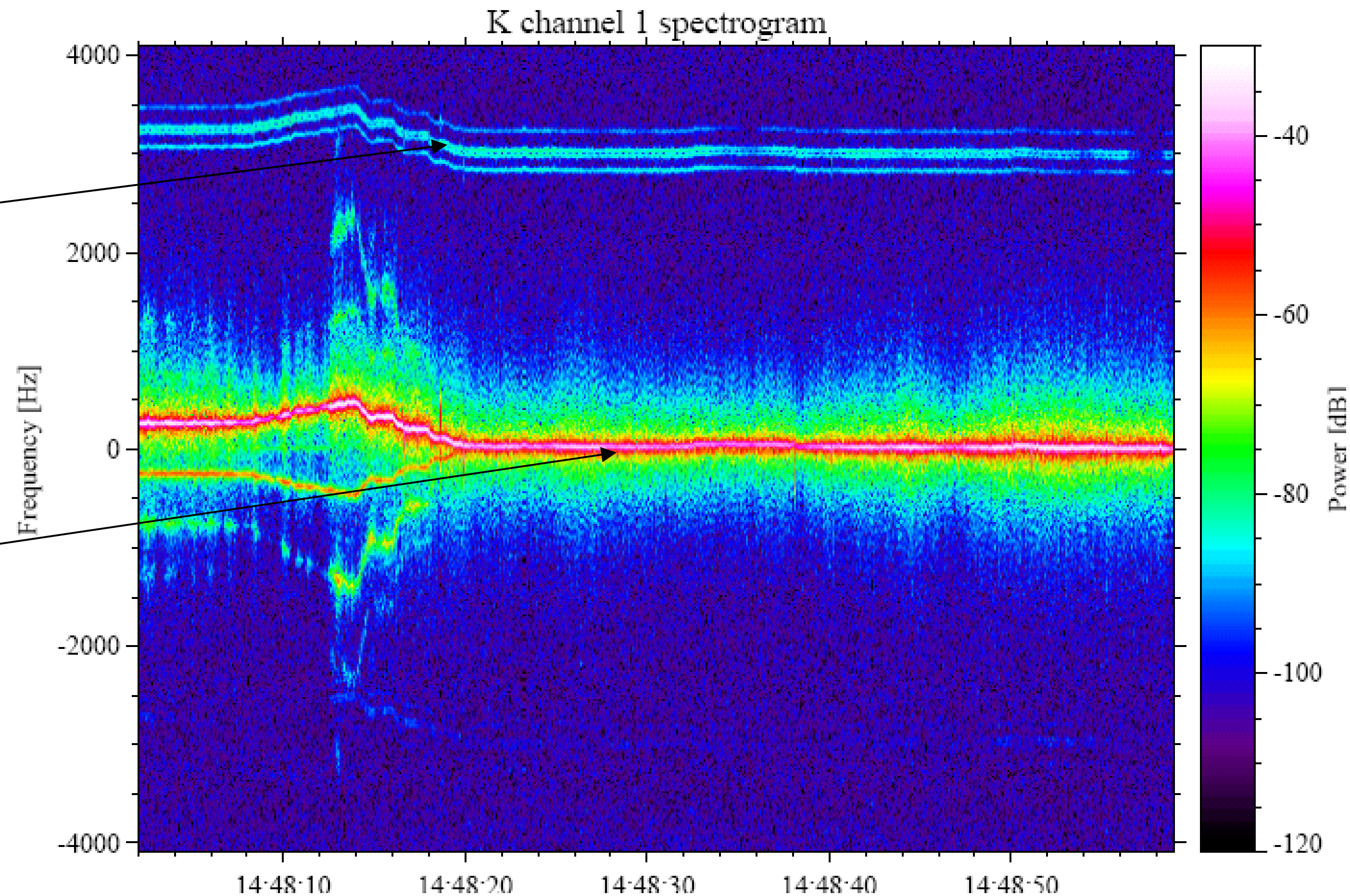
← Wind



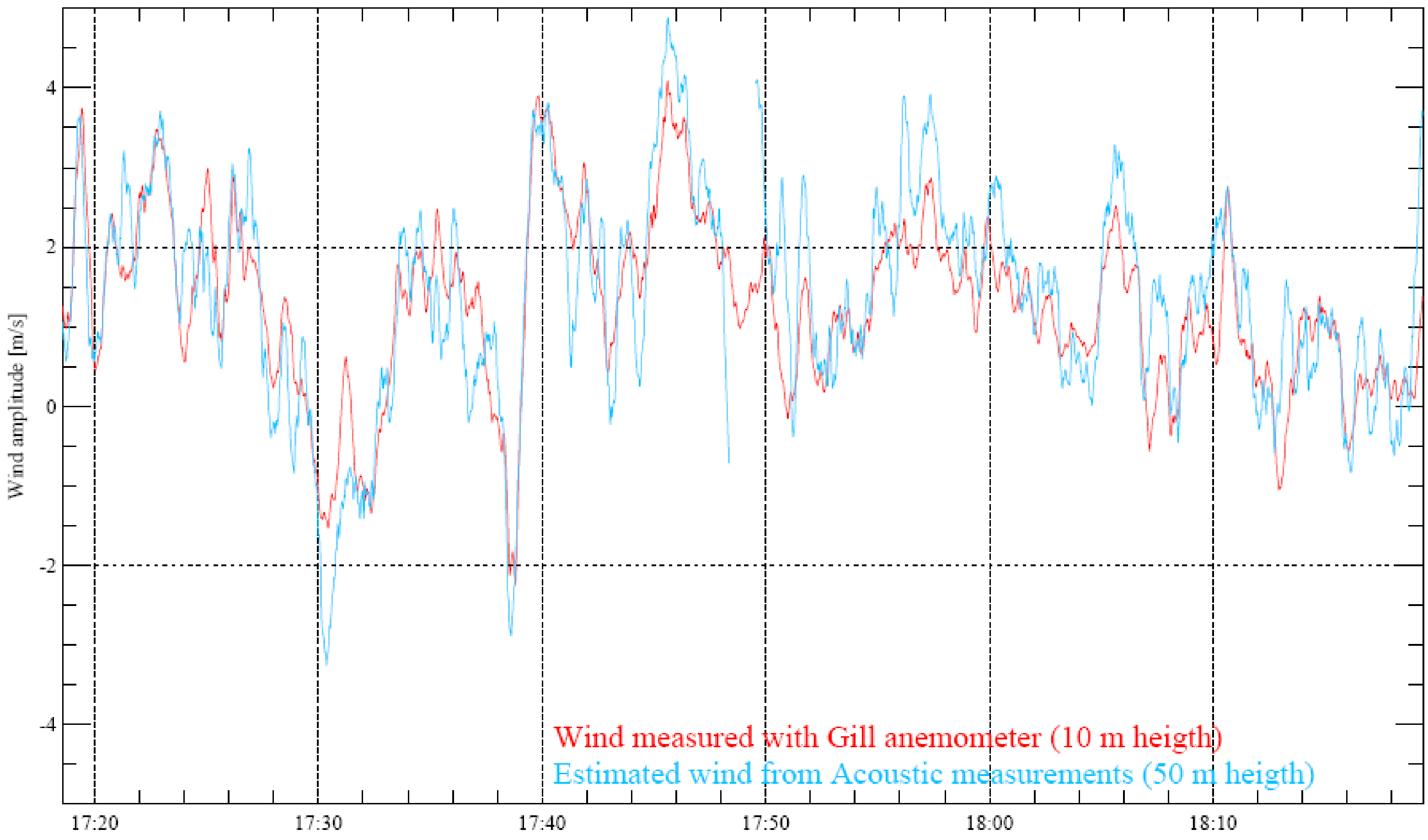
Recieved Signals

Signal scattered by acoustic grid

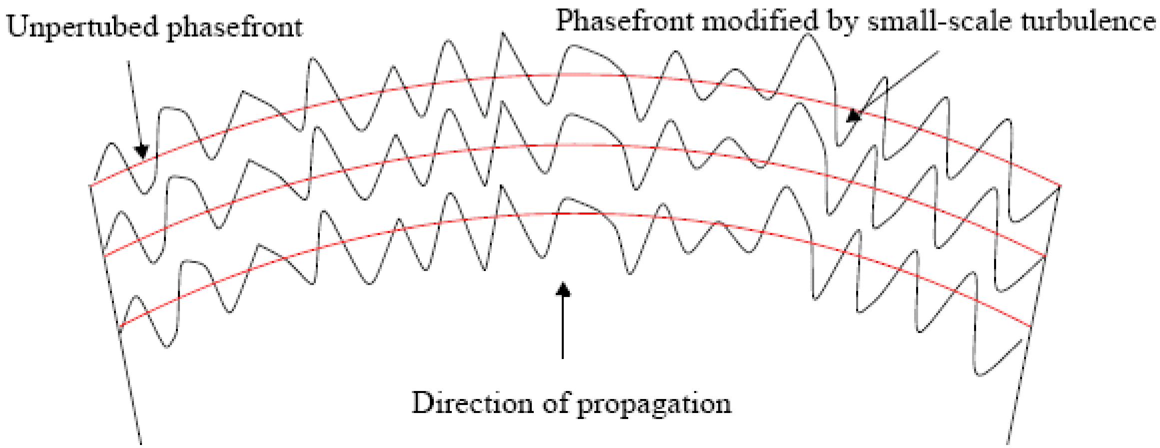
Direct EM signal



Long period wind measurements



Effects from Turbulence



<u>Small scale:</u>

Signal fading

Spectral broadening

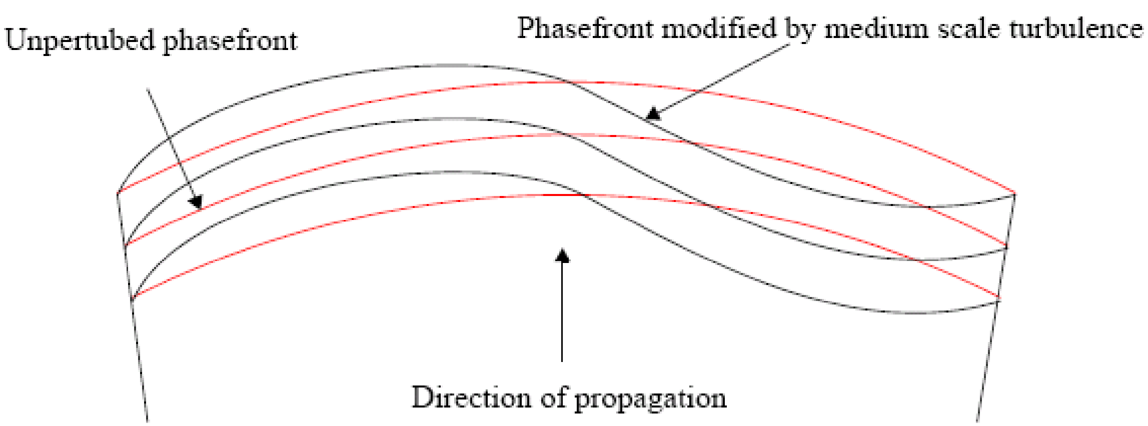
Small correlation in space and time

<u>Medium scale:</u>

Stong flucuations in received signal level

Spectral broadening

Medium correlation in space and time

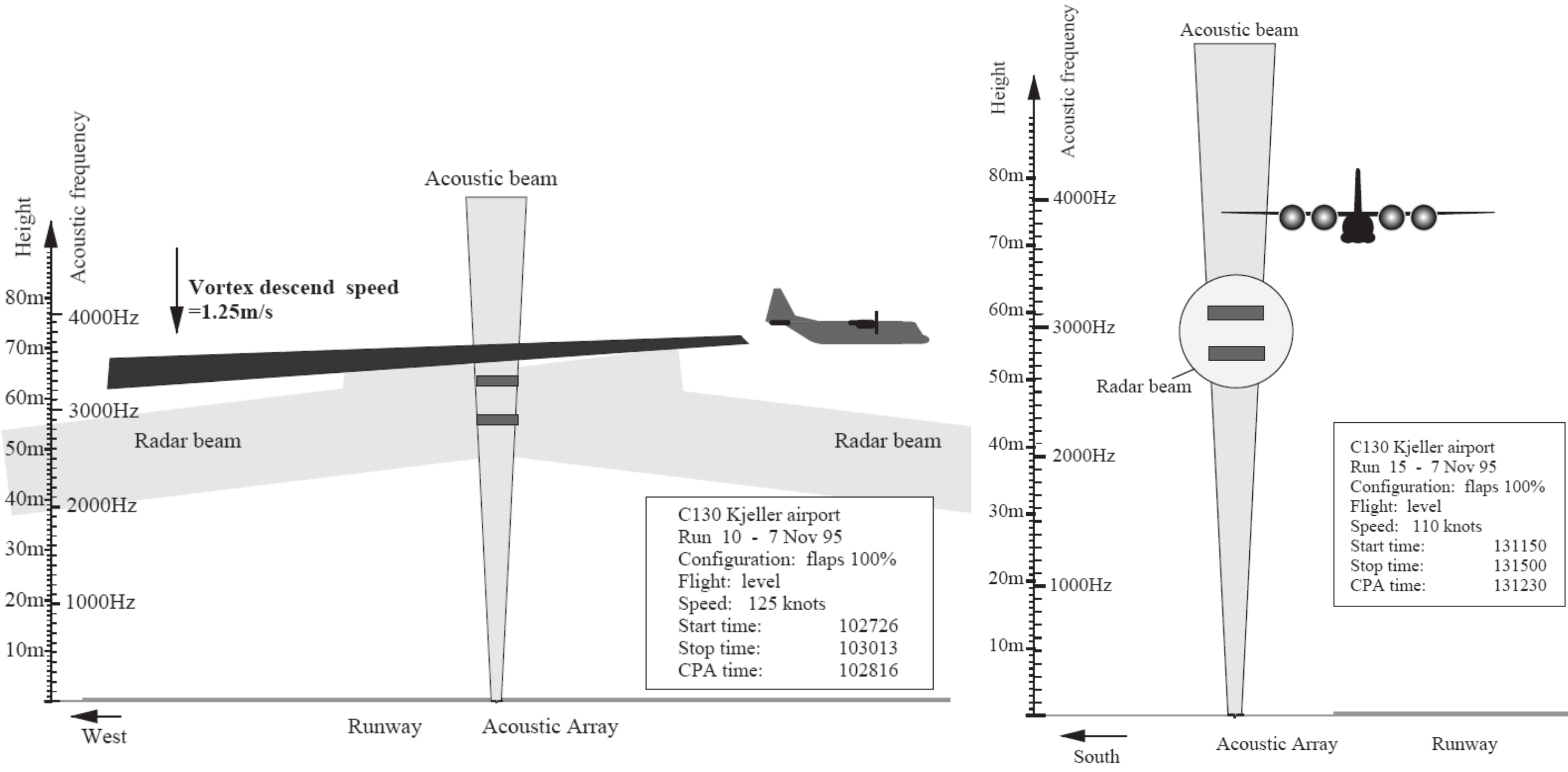


Vertical wind / temperatur

$$F_{aco} = \frac{2F_{rf}}{C_{rf}} 20\sqrt{T^{o}K}\sin(\theta/2).$$

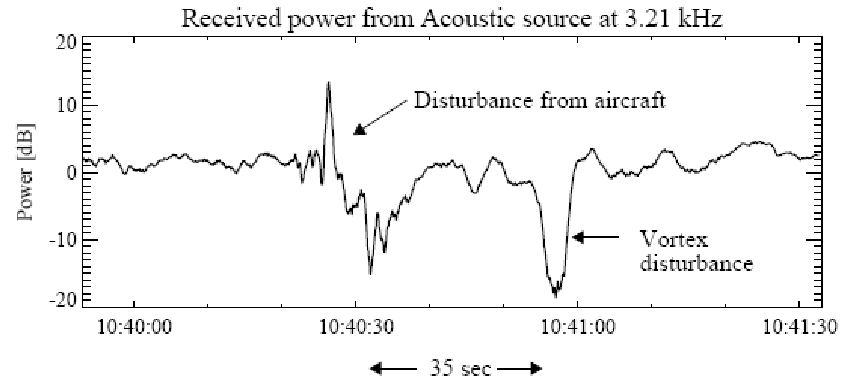
- Acoustic frequency matching height is ambigous with temperature and vertical wind
- Curvature missmatch between EM and acoustic phase front, reducing Bragg Matching
- Exact height of Bragg matching can be found by phase measuremnts on a phased array
- Modulation techniques on Acoustic or EM signal can be used

Vortexes from aircraft

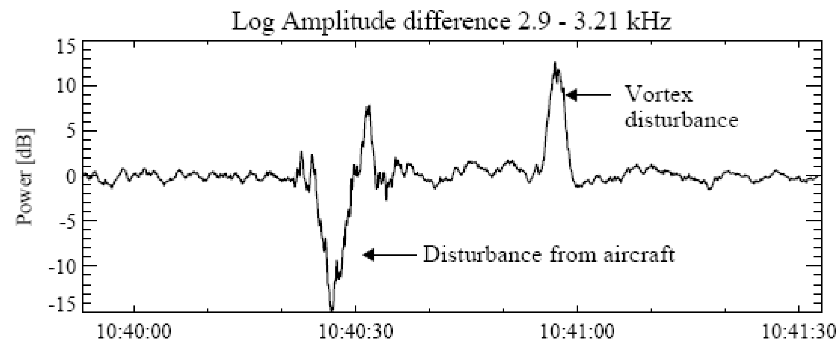


Vortexes from aircraft

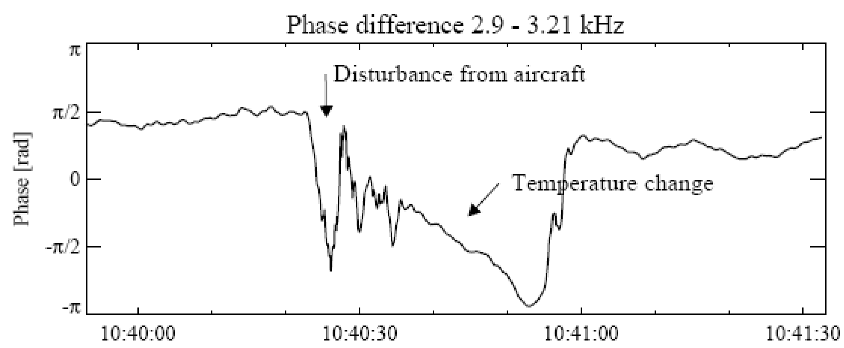
RECEIVED POWER UPPER CELL



LOG AMPLITUDE DIFFERENCE BETWEEN CELLS



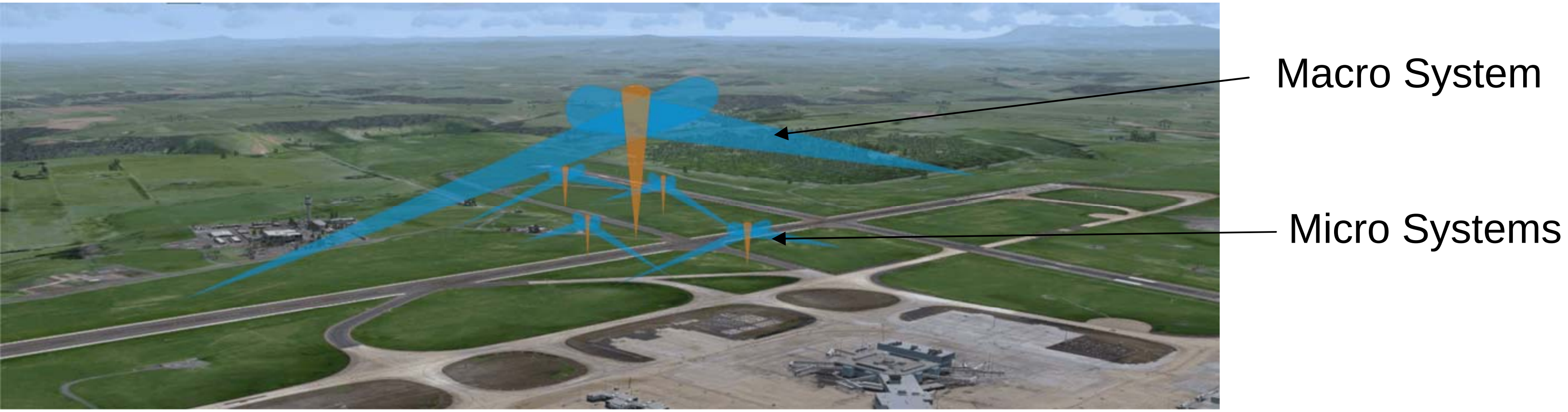
PHASE DIFFERENCE BETWEEN CELLS



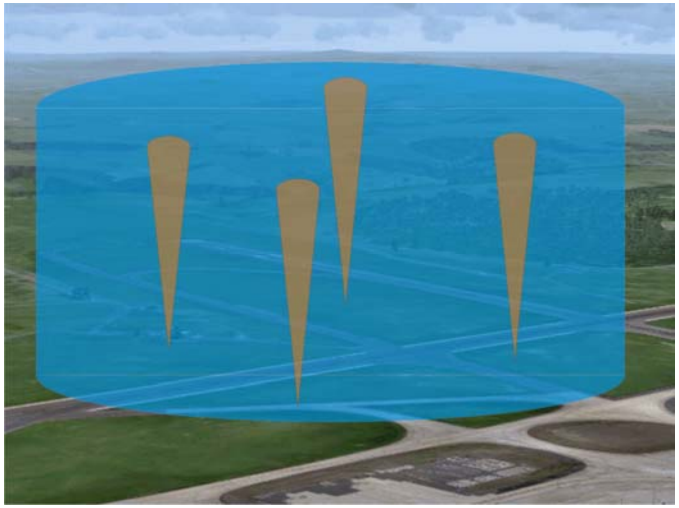
SUMMARY

- The radio acoustic wind bi-static system is sensitive in cross track direction
- Can be extended to multi-static EM
- Narrow and controllable measurement volume
- Several volumes simultaniously
- Scalable concept with respect to frequency , height and antennas
- Can measure Wind, Vortex and Temperature
- Can be added on any X band system

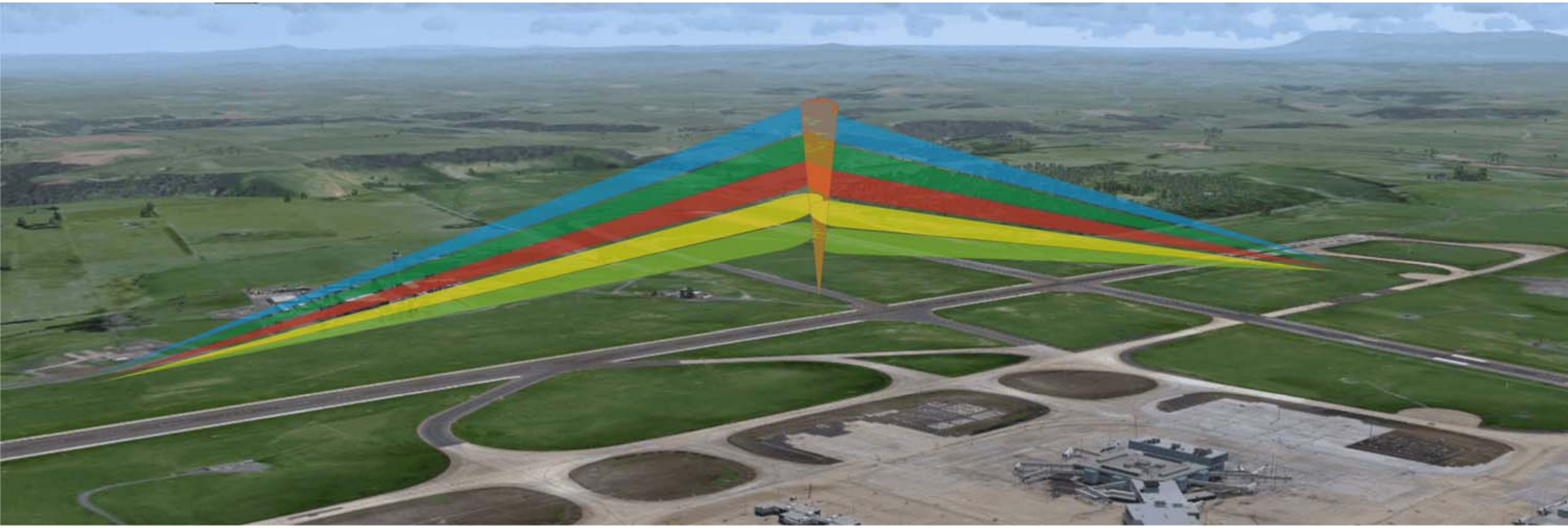
Commercial system



- Surveillance along a column 0-300 meter
- High resolution in time and space
- Parallell measurements in several hights
- 1-D, 2-D or 3-D wind, temperature and Vortices
- Stand alone or as acoustic expansion to existing radar system



Multi-altitude in parallel



The End
www.triad.no