SODARs (SOUND DETECTION AND RANGING)

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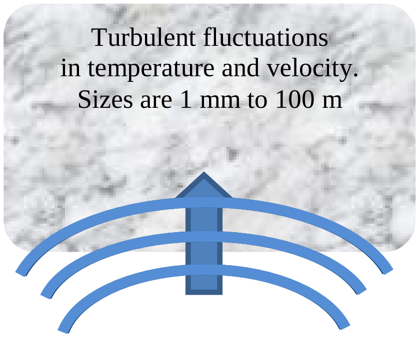
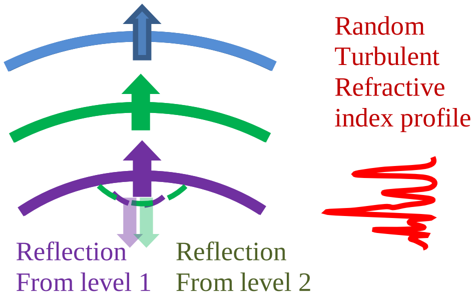
1. DIRECT TURBULENCE MEASURE

Sodars transmit sound upward into the air and detect the echoes that come back from the density fluctuations in the air which are caused by turbulence. Unlike lidars, the signal which sodars receive from the atmosphere is scattered directly from turbulence.



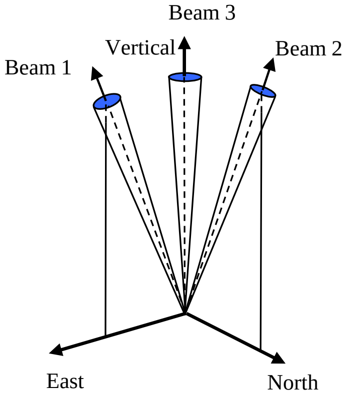
Sound of wavelength λ (about 0.1 m)

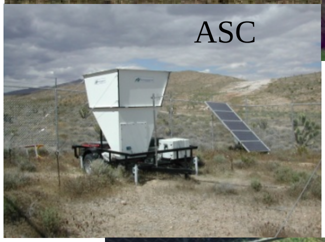
As with lidars, the scattered signal detected at the ground is very weak. The reason that sodars work is *constructive interference* between many sound waves scattered by turbulence. Of course the turbulent density fluctuations don't arrange themselves neatly in ½ wavelength spacing (which would give the maximum constructive interference because all returning waves would add). But turbulence exists over a wide range of scales, so there is always a significant spatial spectral component at ½ wavelength sizes.



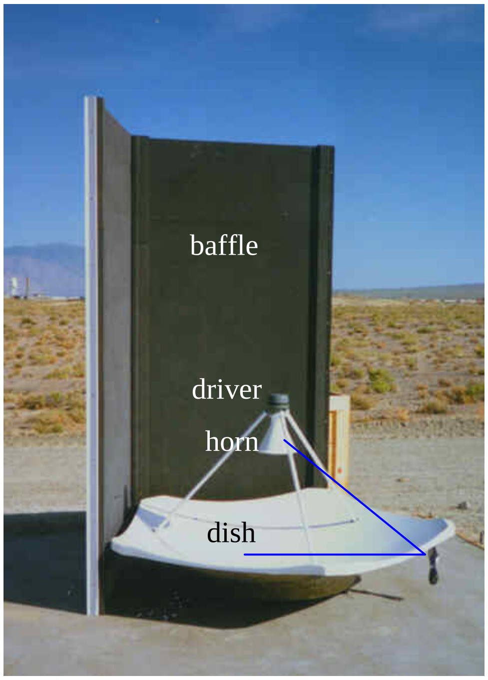
2. BEAM FORMING

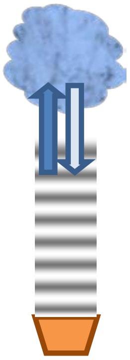
It is necessary to sample the wind in at least 3 directions to obtain the 3 wind vector components u, v, and w. This is done by *beam forming*. The beams are formed either mechanically using 3 or more transmitting speakers together with dish antennas to make directional sound, or via phased arrays of speakers.



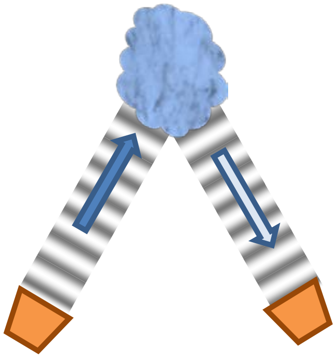


Phased array

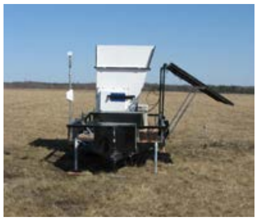




Monostatic
β = 180°



Bistatic
β ≠ 180°



ASC

Second Wind

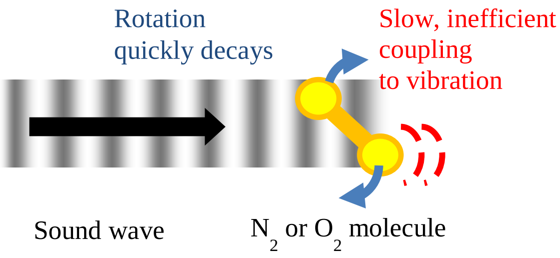
Metek

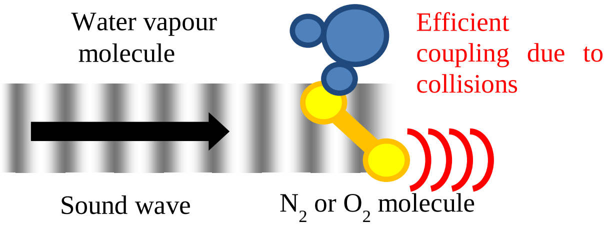
AQSystem

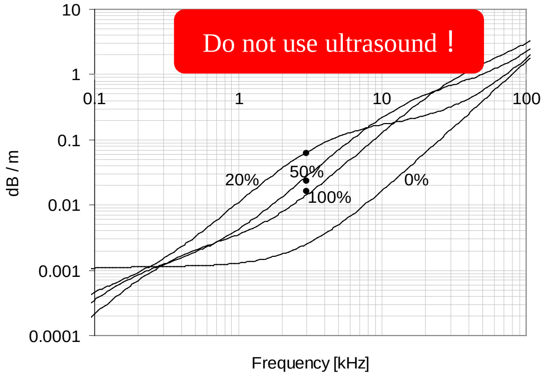
Over 200 AQ500 systems installed in Sweden and more than 50 systems in Europe. The system is designed for arctic weather conditions and can operate in tough climate

3. ABSORPTION OF SOUND IN AIR

For dry air, loss of sound energy to air molecules is very inefficient. But if water vapour is present, collisions between N_2 or O_2 and H_2O give efficient transfer of sound energy to vibration of N_2 and O_2. But at high humidity, N_2 and O_2 are already fully vibrating, so the effect of sound is very small.



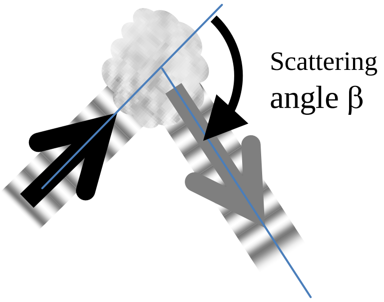


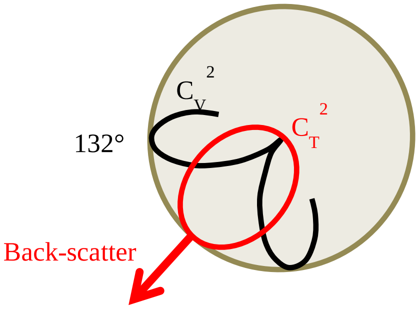


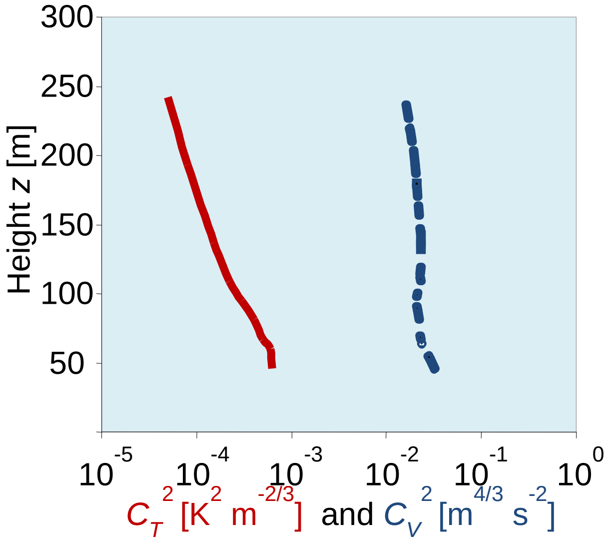
4. THE SODAR EQUATION

$$P_R = 3.25x10^{-4} P_T GA \frac{c\tau}{2} \frac{e^{-2\alpha z}}{z^2} k^{1/3} \frac{\cos^2\beta}{\sin^{11/3}\beta} \left[\frac{C_T^2}{T^2} + 7.3 \frac{C_V^2}{c^2} \cos^2\frac{\beta}{2} \right]$$

Received power P_R, transmitted power $P_T GA$, effective pulse length $c\tau/2$, absorption and spherical spreading $e^{-2\alpha z}/z^2$, frequency dependence $k^{1/3}$, angular dependence, [dependence on temperature fluctuations and velocity fluctuations].

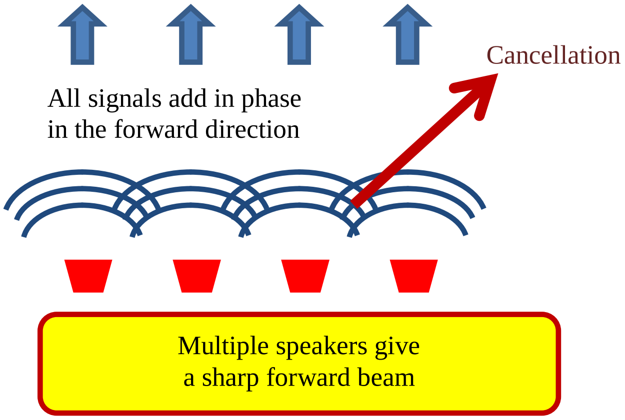




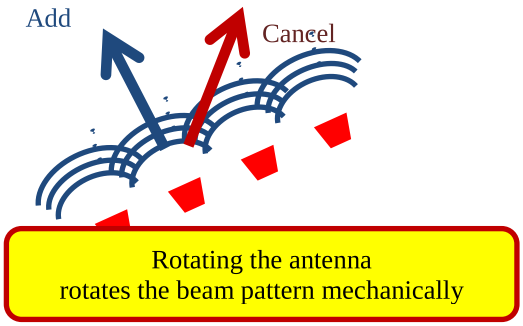


Sound intensity is proportional to $(\text{amplitude})^2$ so is also proportional to $(\text{refractive index fluctuation})^2$. Fluctuations in temperature (a scalar) over separations x are measured by C_T^2 = averaged $[T(x)\text{-}T(0)]^2 / x^{2/3}$. Think of this as a "temperature variance". Fluctuations in velocity (a vector) are measured by C_V^2 = averaged $[V(x)\text{-}V(0)]^2 / x^{2/3}$. Think of this as a "velocity variance".

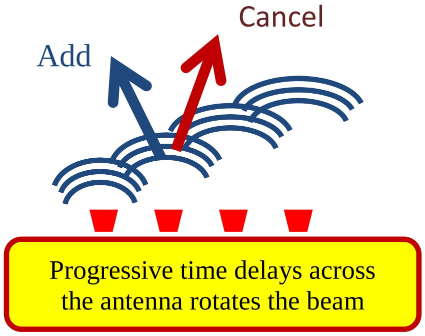
5. PHASED ARRAY ANTENNAS



Multiple speakers give
a sharp forward beam

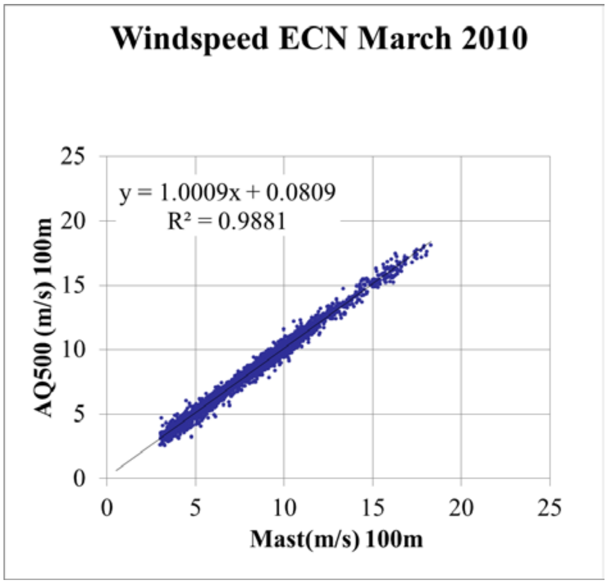


Rotating the antenna
rotates the beam pattern mechanically

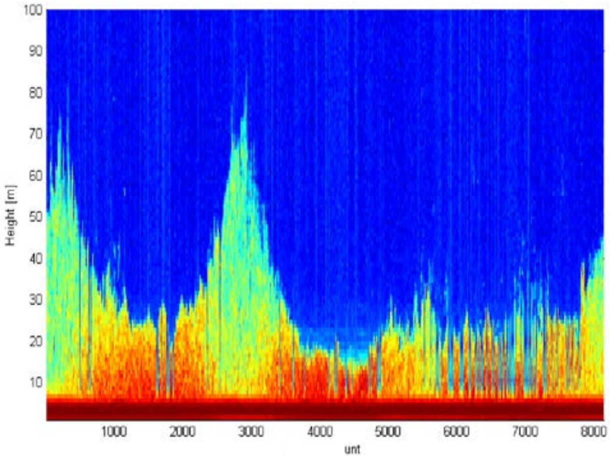


Progressive time delays across
the antenna rotates the beam

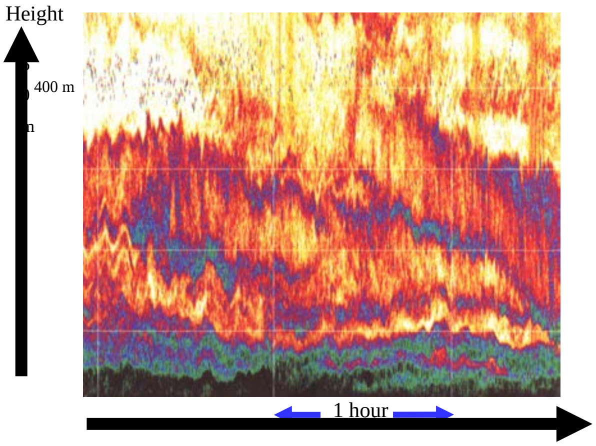
6. EXAMPLES OF SODAR PERFORMANCE

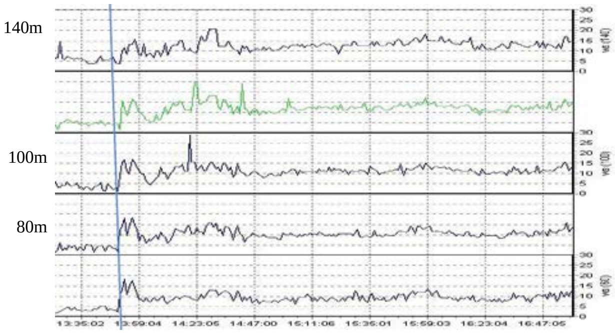


Comparison at 100m.

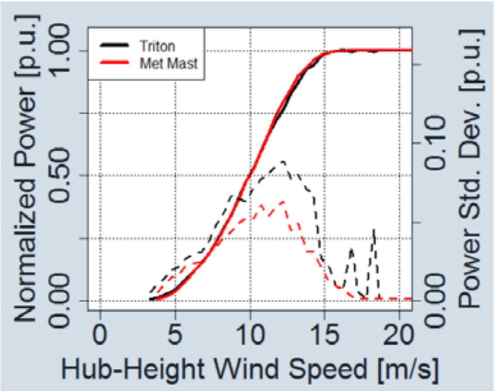


Turbulence measurements in cold surface later with 1m resolution.





Gust event 15 m/s change in 30s



7. COMPARISON WITH MAST WINDS

Remote sensing with LIDAR (laser) or SODAR (sound) measures wind within a *volume*

Direct measurement (cup anemometer, sonic anemometer) measures wind at a *point*

The two methods *only agree in very special circumstances* (when the properties within the remote sensing volume are uniform over that volume)

Most of the remote-sensing vs mast inter-comparisons you will see are limited to

very flat terrain, no ground cover variation, no convective heating, simple wind shear, low turbulence, no fog, no low cloud, no rain

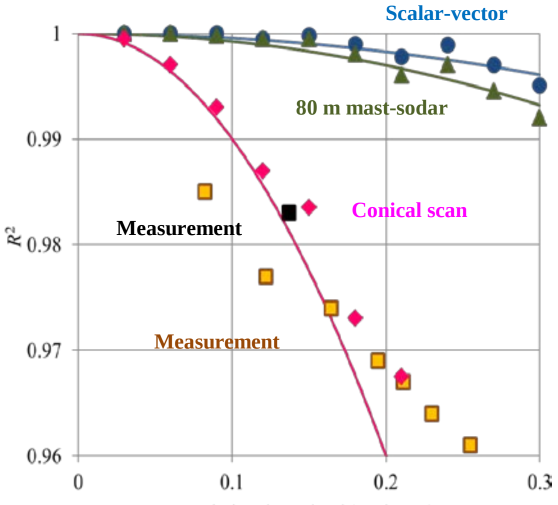
You will **almost never** reproduce these conditions

The rms difference can arise from a number of causes, including

- The difference between scalar (cup-type) and vector (remote-type) measurements
- Remote sensing sampling over spatially distributed volumes
- Remote sensing sampling for each wind estimate spread over time

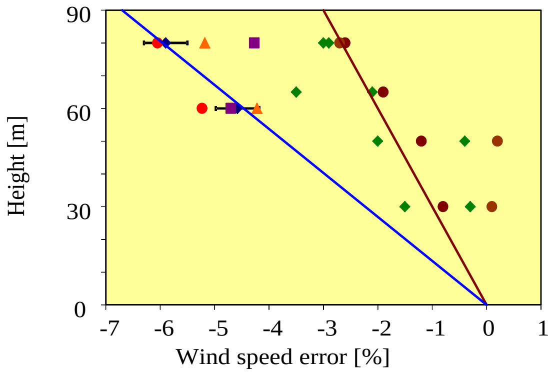
- Spatial separation between the remote sensing volumes and the mast sensor
- Remote sensing in the presence of background noise.

Ultimately, if the site is uniform, turbulence intensity is very low, background noise is minimal, and wind speeds are widely distributed, then a very high R^2 should be achieved by any good quality SODAR or LIDAR remote sensing instrument



Solid circles, triangles, and diamonds from Mont
Carlo turbulence simulations

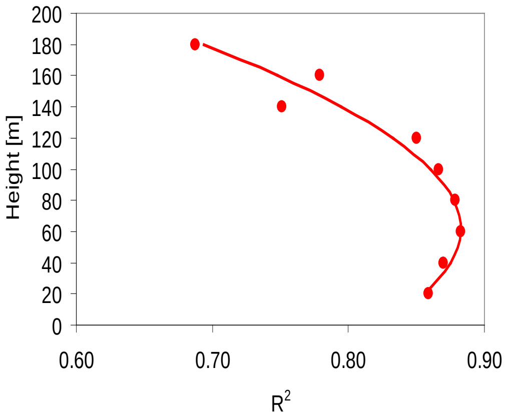
In complex terrain there are also systematic difference



Measurements on a moderate hill
  - ZephIR lidar in green diamonds
  - AQ500 sodar in brown circles

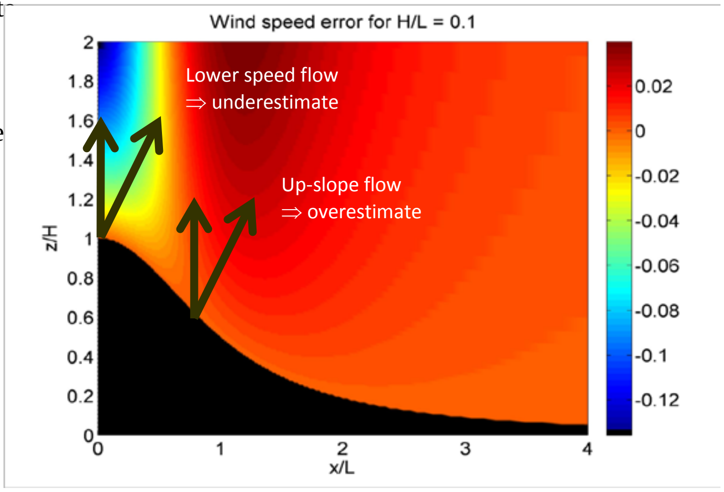
Measurements on a complex site
  - Metek sodar in blue diamonds

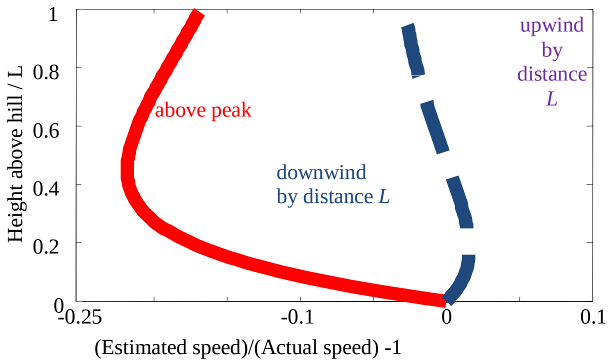
Model results for the complex site
  - bell-hill potential-flow in orange
  - WindSim in purple squares
  - OpenFOAM in red circles



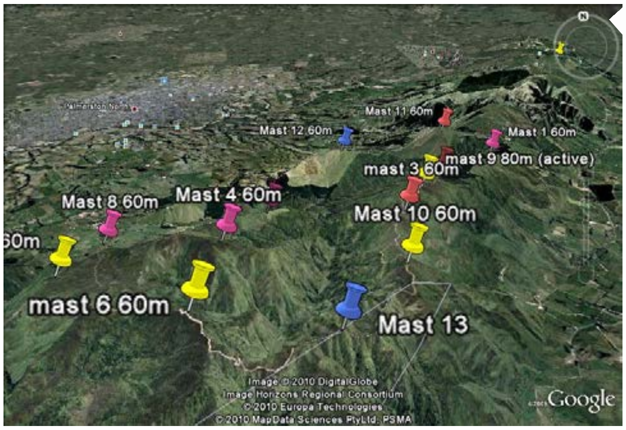
Plot of measured and modelled correlation between winds measured by different beam combinations *on the same 5-beam SODAR* (at a complex site). At 60m, the time taken for air to travel from one beam to another (at the wind speed during these measurements) is equal to the time between acoustic pulses. The shape of this curve is a measure of the spatial correlation for wind.

Behrens P, Bradley S, Wiens T. A Multisodar Approach to Wind Profiling. *J. Atmos Ocean. Tech.* 2010; **27**: 1165-1174.



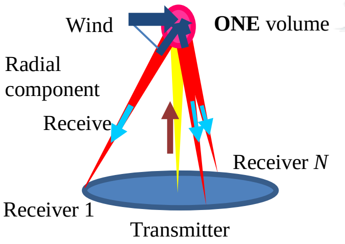


Myres Hill, Scotland



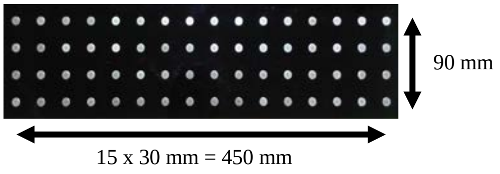
Turitea, New Zealand

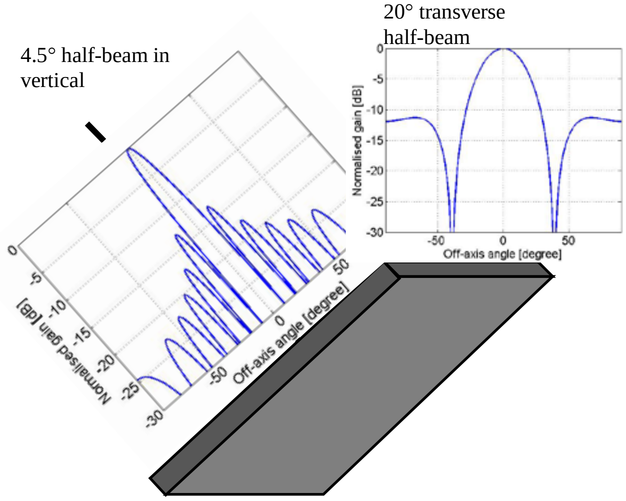
8. BI-STATIC SODAR



Doppler shift, the signal which gives wind information, occurs when there is a component of the wind along either of the transmitted and received beams. A geometry having vertical transmission and oblique reception will give Doppler shift.

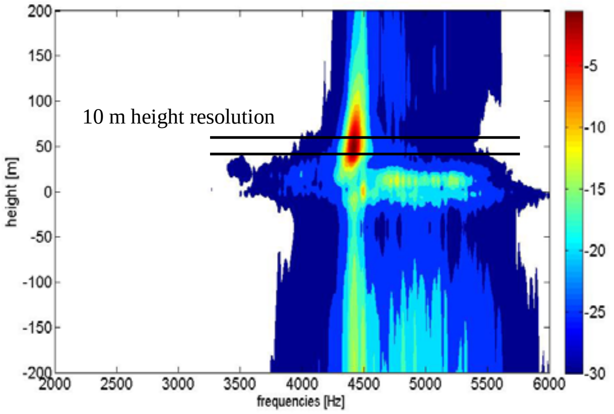
The new ASC/Auckland scanning common-volume system consists of a central transmitter, directed vertically, and 2 inclined phased-array receivers, each at a distance of around 40m from the transmitter, as shown in the photograph

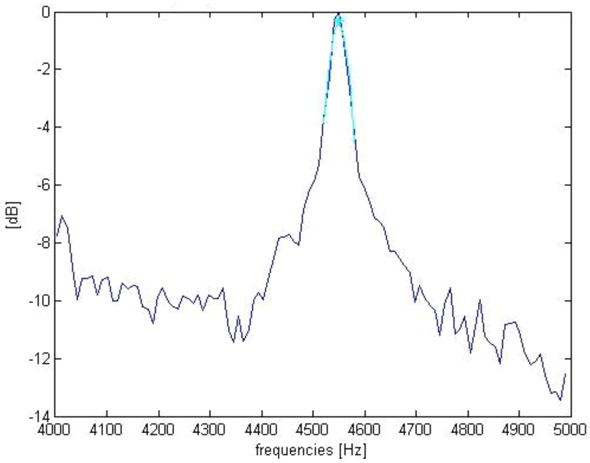


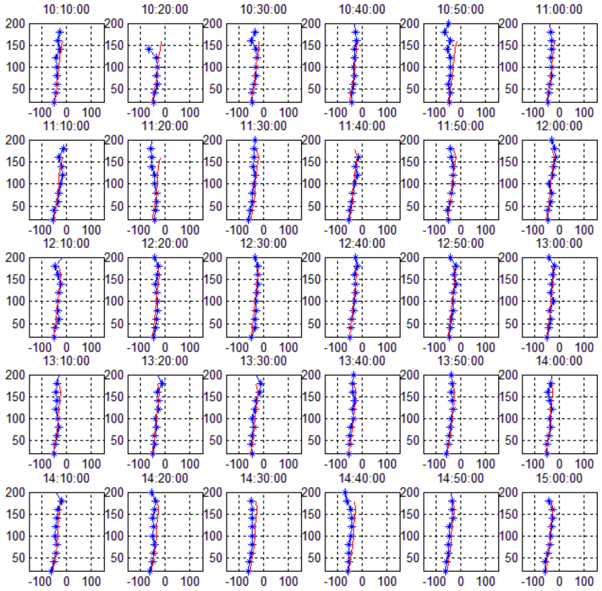


This gives a narrow beam in the vertical (scanning plane) and a broad beam in the lateral direction (which facilitates alignment with the columnar transmitted beam.

Results from scanning the array in both the vertical plane and in frequency are shown in below. The position of the transmitted pulse in space can be clearly seen. With this system it is possible to track the pulse as it ascends the sampled column. A typical received spectrum is also shown







A succession of Doppler profiles, every 10 minutes, for an ASC4000 monostatic sodar (red) and one common volume receiver (blue). The monostatic profiles are corrected to allow for the different Doppler formula in the bistatic mode.

9. SUMMARY

SODARs are a relatively simple, inexpensive, and robust technology.

The conventional intercomparisons between mast and remote instruments depends on the environment (turbulence, range of wind speeds, terrain). R^2 is *not* a property of the instrument!

Recent intercomparisons with mast, SODAR, and LIDAR, suggest there may be little difference. This needs testing by setting up an intercomparison experiment where a sodar and lidar are *treated identically*.

Better "performance" can be obtained by filtering out winds which are rapidly changing. BUT is this a good thing to do?

A bi-static SODAR (now being added as a commercial option to ASC mono-static SODARs) is a common volume approach which removes errors due to complex terrain.