UpWind

CRES CENER QINETIQ USAL VESTAS RISØ-DTU

WP6
REMOTE SENSING
-Remarkable results

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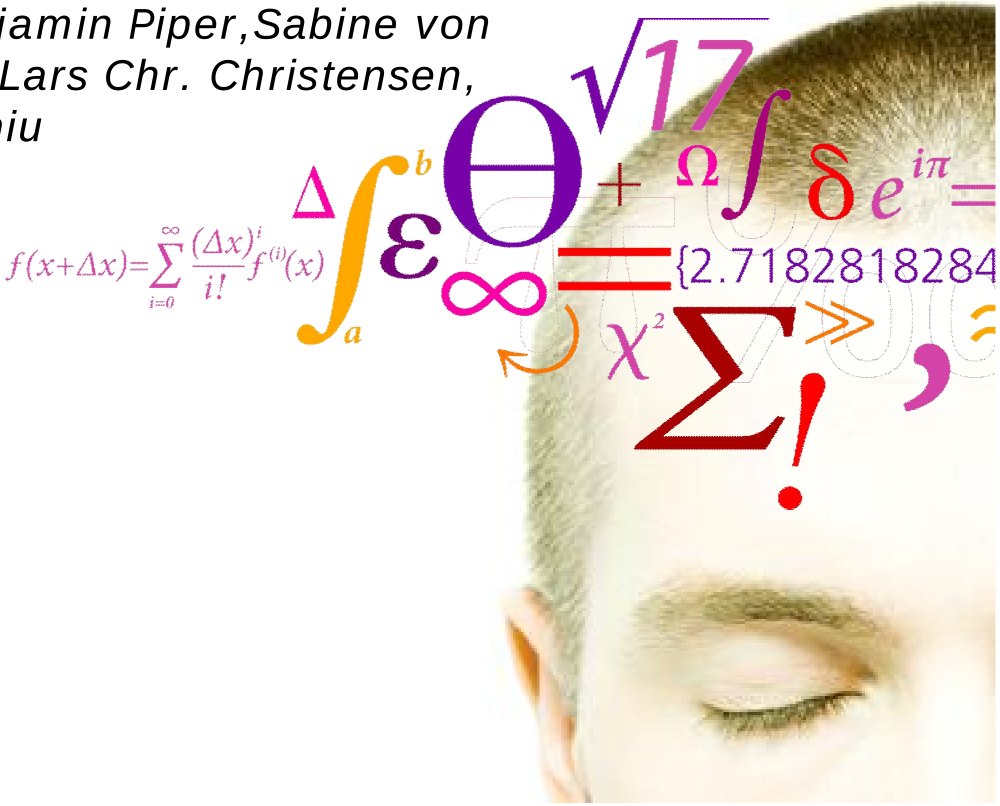
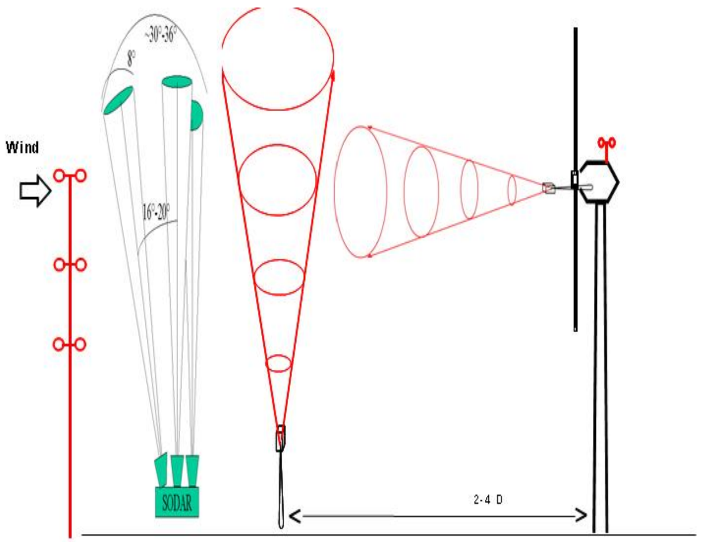
ewec2009 MARSEILLE
Europe's premier wind energy event



Introduction to wp6

- A description of Remote sensing of the wind flow in all stages
- Perform traceable calibrations for the monostatic SODAR and LIDAR's
- Define improvements on the Monostatic SODAR and the LIDAR
- Work on Bistatic SODARs
- Measurements including comparisons in flat terrain (monostatic SODAR, LIDAR, met tower w/t)
- Measurements and inter-comparisons in complex terrain (monostatic SODAR, LIDAR, met tower, w/t)
- Measurements with a LIDAR system mounted on the turbine nacelle in order to measure the near flow field in front of the rotor



Major scientific and technical achievements

- A Development of a calibration system for sodars- testing loudspeakers including simulated atmospheric signal.
- A Development of a new robust method to be calibrate SODAR’s in-situe
- Cloud corrections scheme developed for the Zephir system.
- A substantial understanding and reporting on errors in Lidars both pulsed and continuous systems (QQ and Leosphere).New methodes of analysing data
- Methods developed to understand complex terrain measurements with remote sensing have been made (Script is available for WaspEngineering)
- Bi-static Sodar systems build based on phased array (first system of this kind in the world)
- New method developed for measuring power curves with Lidar’s based on profile measurements.
- The UPWIND work-package is providing scientific background knowledge to the following EC projects NORSEWIND and SAFEWIND

At EWEC2009 a remote sensing session (3 oral presentations from UPWIND and 4 posters)

Relation to upscaling

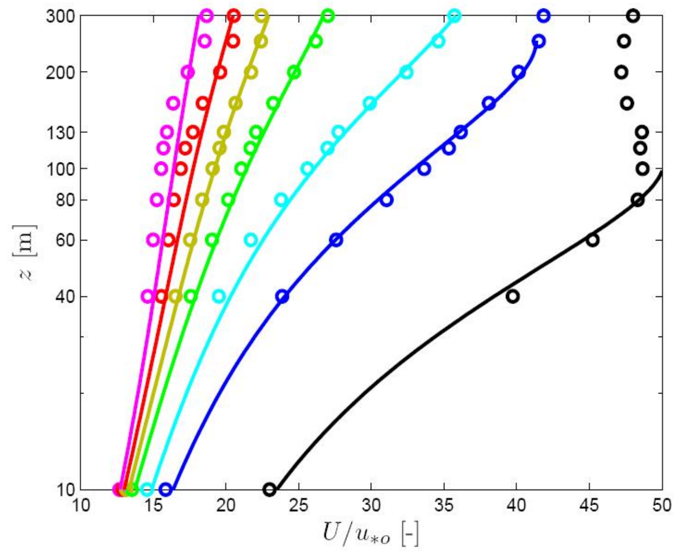
First high altitude measurements of U by LIDAR compared to extended surface layer wind profiles (300m) Alfredo Penaz et al

- Possible to measure the wind climate up til 300 m (500 m)
- In some cases the turbine will cover the whole of the boundary layer

Describing

- Wind shear (low level jets etc)
- Wind wear (as large as 30 degrees over the rotor)
- Turbulence intensities
- Gust ṡ ????

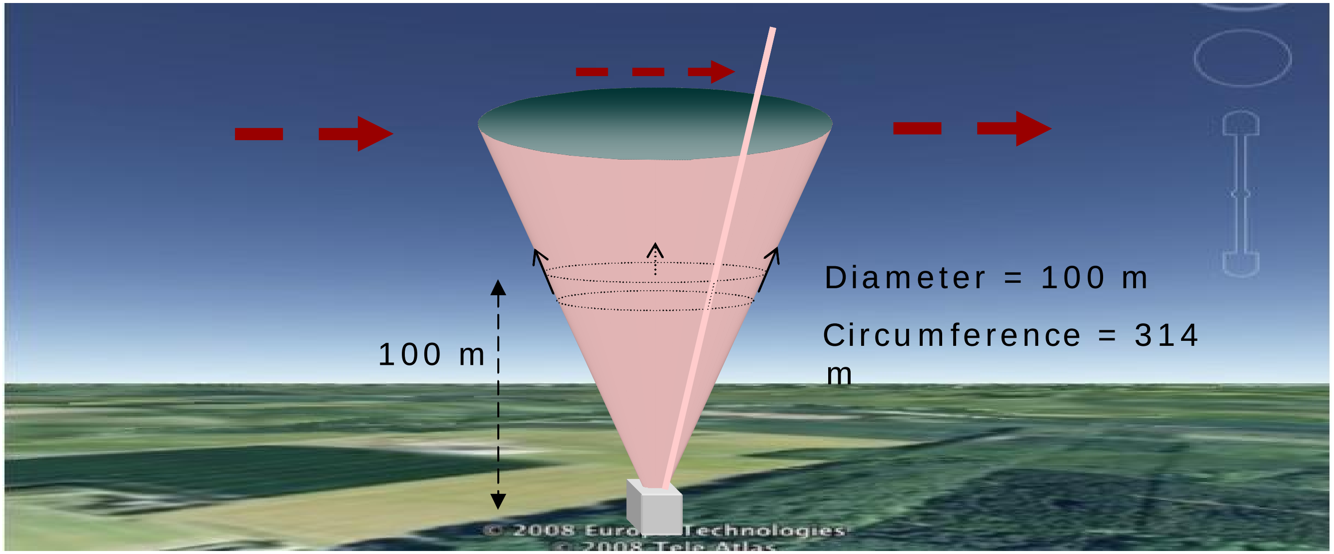
$$\frac{\partial U}{\partial z} = u_{*o}\left(1-\frac{z}{z_i}\right)\left(\frac{1}{\kappa z}\phi_m+\frac{1}{\lambda}\right),$$



A "perfect " lidar

Flat terrain, perfect conically scanning lidar.

- Constructing the u vector:
- homogeneous flow over scan perimeter
- Spatial differences: Zephir: 50 directions   Windcube: 4 directions
- Time difference: Zephir: 1 s/revolution   Windcube: 6 s/revoltion



In average over flat terrain no BIAS but introduction of a standard deviation which depends on the turbulence at the site.

• Plausible error sources in lidar sensing: Due to ”atmosphere ”

Error	Implication	Magnitude	Which instrument
Turbulence Spatial and temporal	Standard Deviation No bias in flat terrain(?)	< 0.1 m/s in Høvsøre?	Conically scanning
Complex terrain	Complex errors Direction dependent biases	Depends (10-20%)	Any one unit system More directions, more options
Rain	Bias on w Standard deviation increase	? From 15 to 50 cm/s	Both
Clouds	Typically positive bias	Mitigated with cloud correction (but gives σ?)	Zephir
Inhomogenuous aerosol distribution (backscattercoeff and correlation duration)	Random distribution Standard deviation Depletion or propagation losses Negative bias	? ?	Both, Zephir more sensitive at 100 m due to the longer tail on the puls(?)
Shear in sample volume	Probably overestimation for typical shears	Minor?	Both
…			

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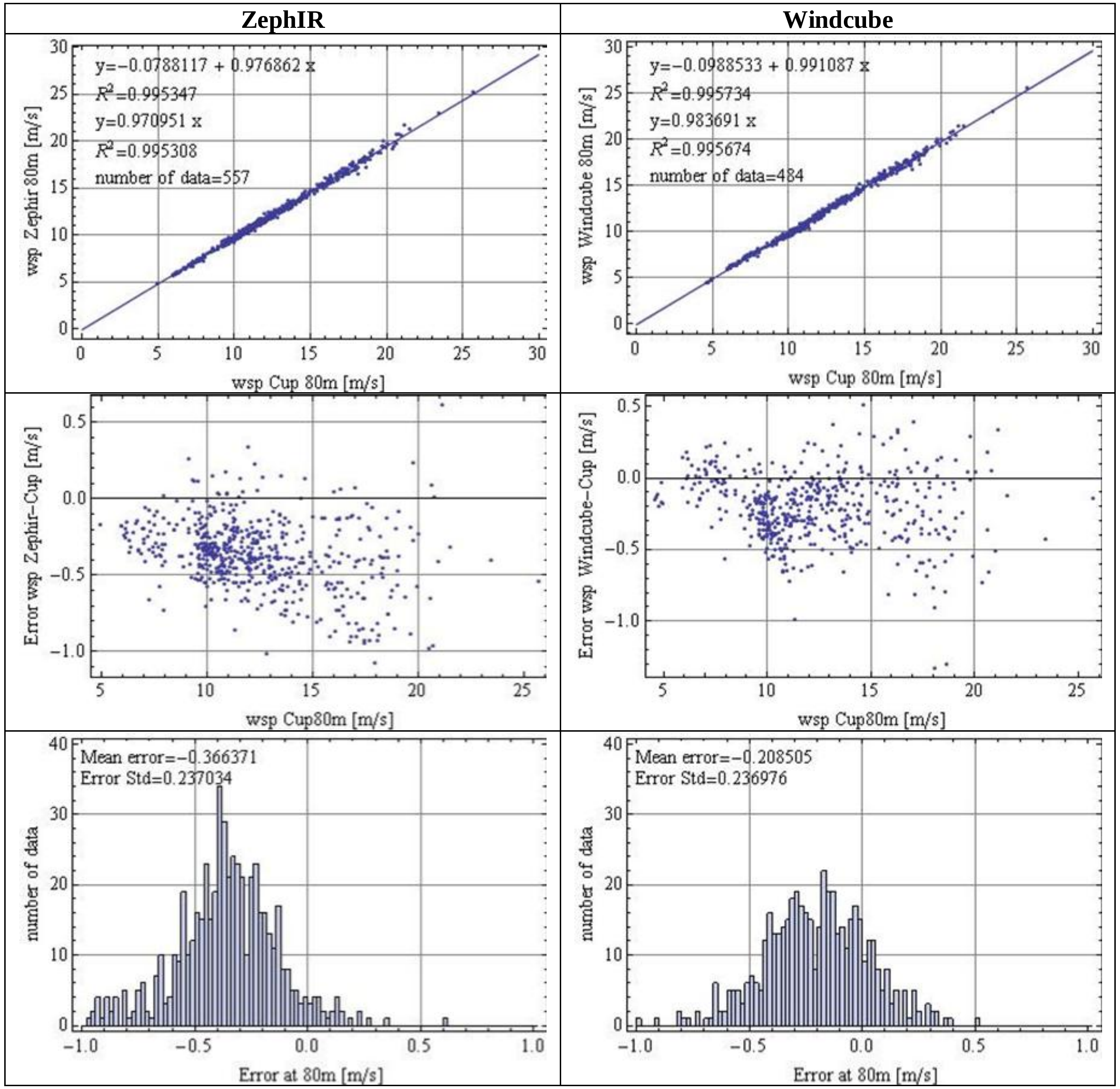
Plausible bias sources in lidar sensing: Due to "machine"

Error	Implication	Magnitude	Which instrument
Error in scan angle	• Gain • Altitude Errror	• +- 3 % < 2 m	Windcube and Zephir (mitigated in 2008?)
Error in center of sample volume	Altitude error	< 5 m in Zephir < 10 m in Windcube	Zephir: Focus error Windcube: Range gate distortion, trigger offset and/or unsymmetric pulse shapes
RIN	Positive Bias for low LOS velocities	Low for wind >4 ms	Zephir
Chirp in pulse	Offset in radial, but solved in construction of u	< 0.5 m/s	Windcube
System tilt	Small gain and irregular altitude errors.	Minor?	Windcube and Zephir
…			

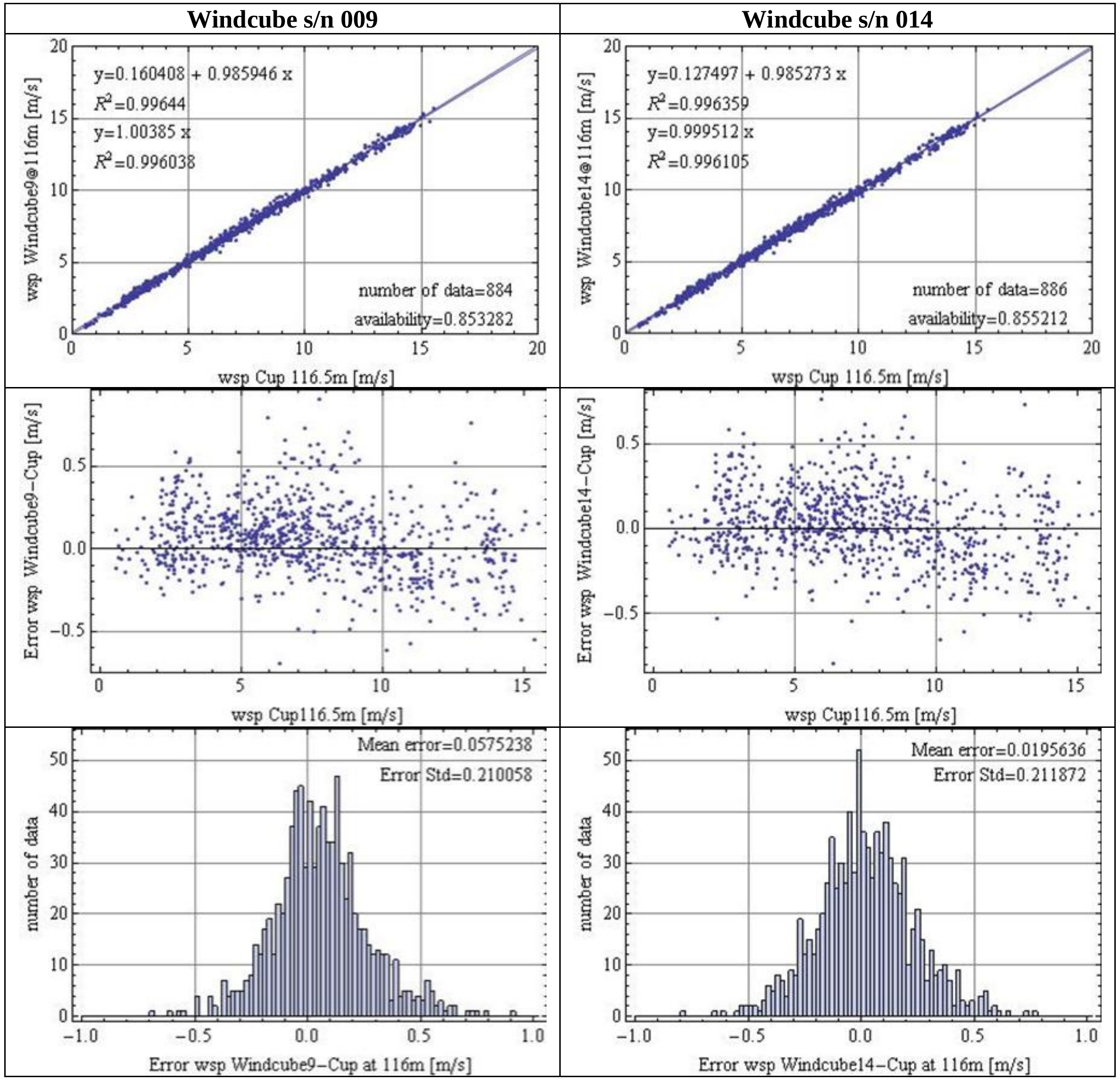
Testing LIDARs at Høvsøre in UPWIND

Høvsøre Large Wind Turbin Test Facility

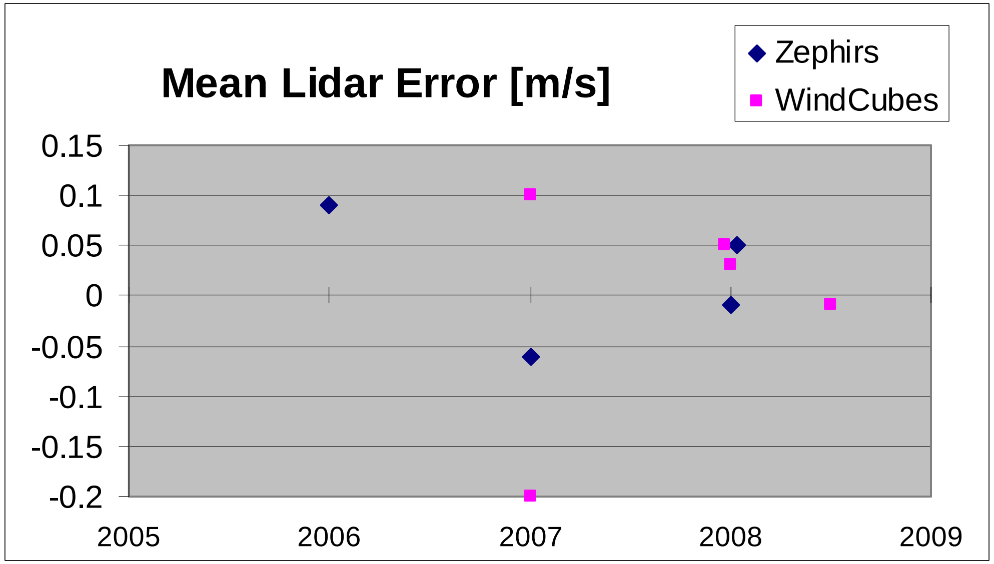
- West coast of Denmark, flat terrain, wide range of horisontally homogeneous wind speed.
- Site equipped with rain and cloud sensors
- 14 Zephirs and Windcubes tested
- 45 months of comparison with class 1 cup anemometers @ 40-116 m (160 m)
- Data from 2 other flat sites evaluated

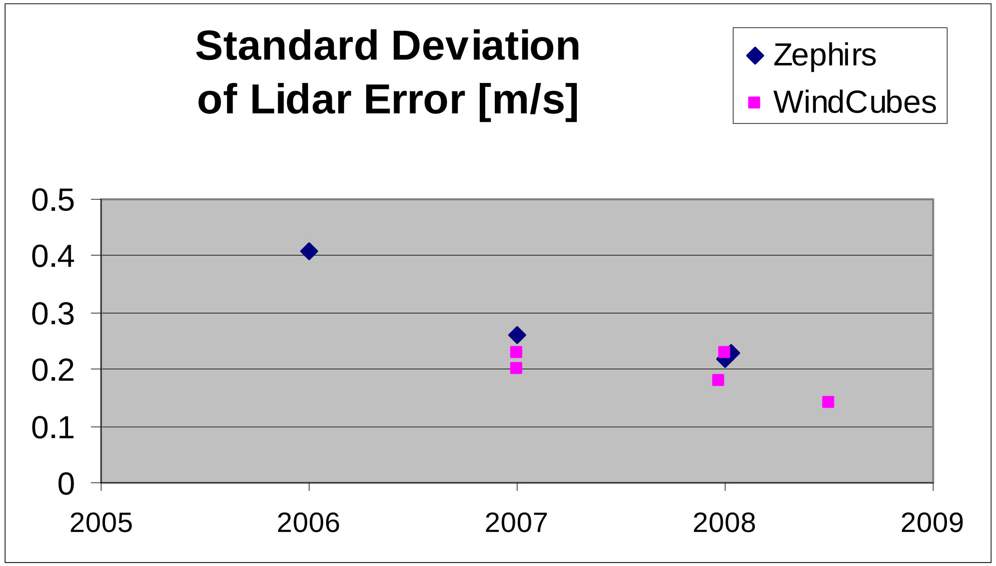

ZephIR
Windcube
y=−0.0788117 + 0.976862 x
R^2=0.995347
y=0.970951 x
R^2=0.995308
number of data=557
wsp Zephir 80m [m/s]
wsp Cup 80m [m/s]
y=−0.0988533 + 0.991087 x
R^2=0.995734
y=0.983691 x
R^2=0.995674
number of data=484
wsp Windcube 80m [m/s]
wsp Cup 80m [m/s]
Error wsp Zephir−Cup [m/s]
wsp Cup80m [m/s]
Error wsp Windcube−Cup [m/s]
wsp Cup80m [m/s]
Mean error=−0.366371
Error Std=0.237034
number of data
Error at 80m [m/s]
Mean error=−0.208505
Error Std=0.236976
number of data
Error at 80m [m/s]

Windcube versus Windcube



Development of Wind Sensing Lidars during UPWIND





2006: Zephir commercial model introduced. Hardware issues.

2007: Ceilometer installed, screening on clouds: positive bias and σ reduced, availability drops. Leosphere introduces Windcube.

2008: Cloud correction: availability increases.

Cone angle accuracy: bias reduced.

2008.5: ?.
Estimator improved: nonlinear problems reduced.
Introduction of the Windicator

Mean < ~±0.05 m/s σ ~0.25

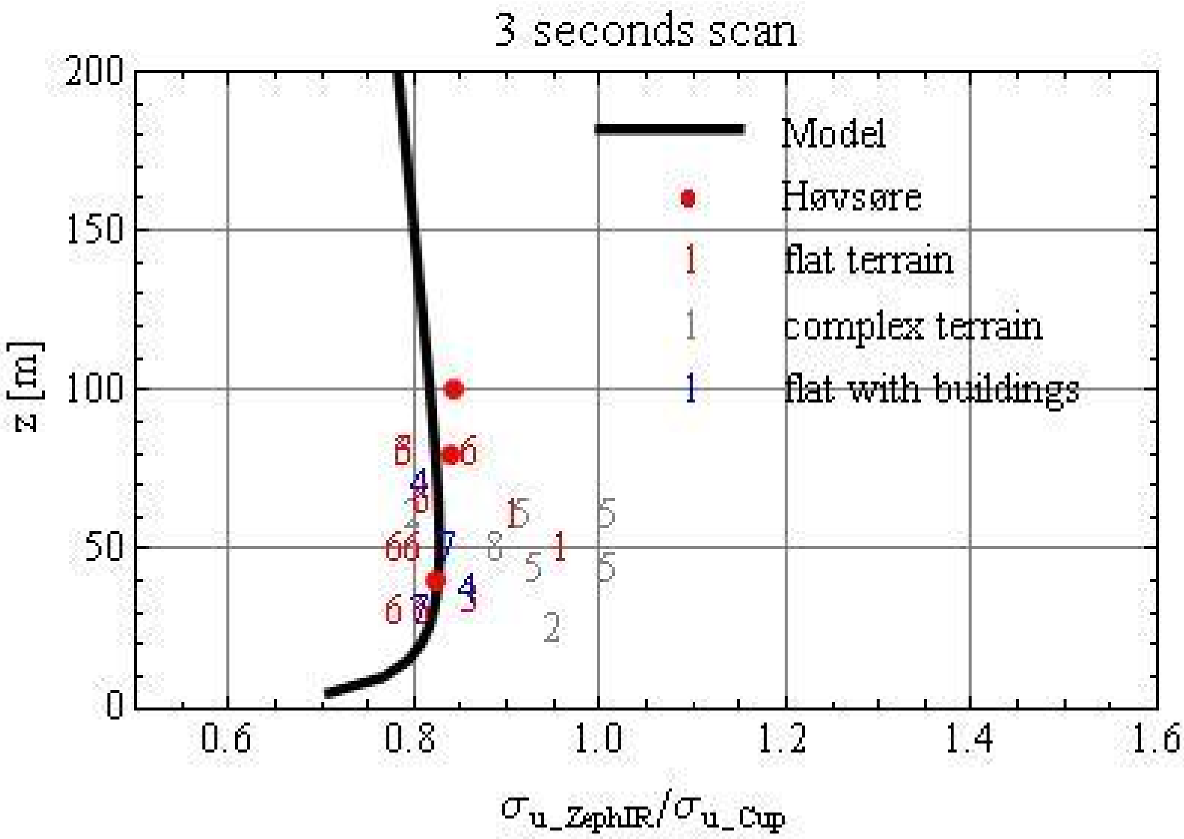
Mean < ~±0.05 m/s σ ~0.15

Conclusions: Precision and Biases in Lidars 2008

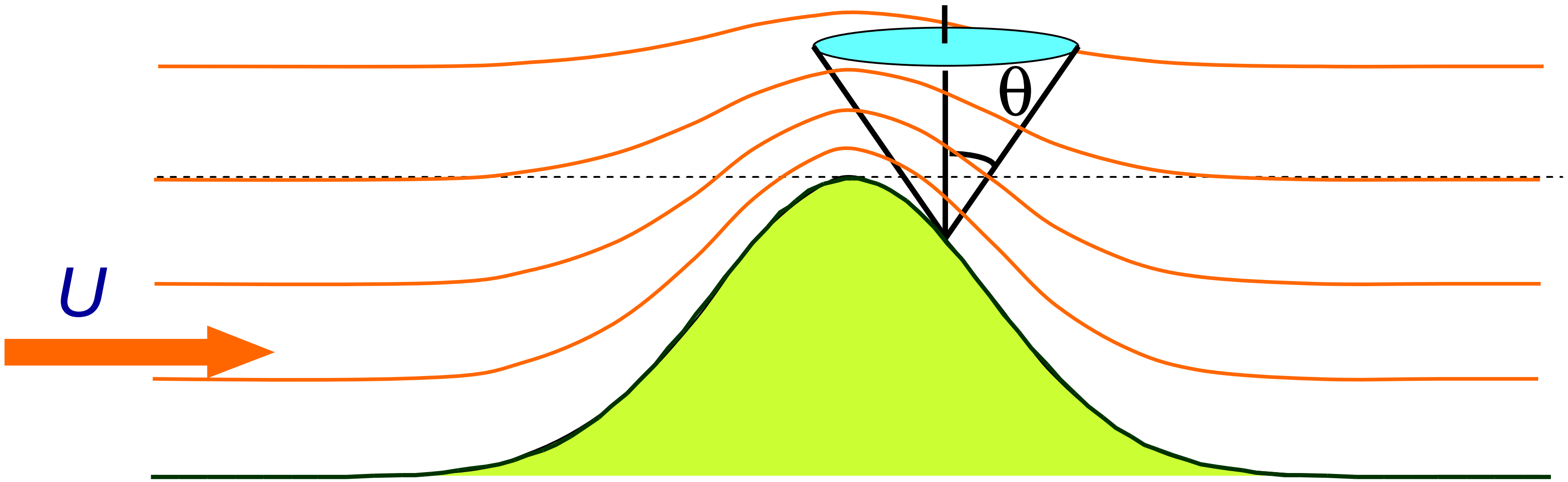
- Typical results in flat terrain 2008
- Mean: < 0.1 m/s
- STDEV: < 0.25 m/s
- Gain: < ± 2%, observed [-6 to +2%] mitigated
- "Altitude" error: < ± 5 m observed [-6 to +9]

Complex terrain à Complex errors observed 10-20%.

Turbulence measured and modeled (Rozeen Wagner et al)



Complex Terrain & Conical Beams



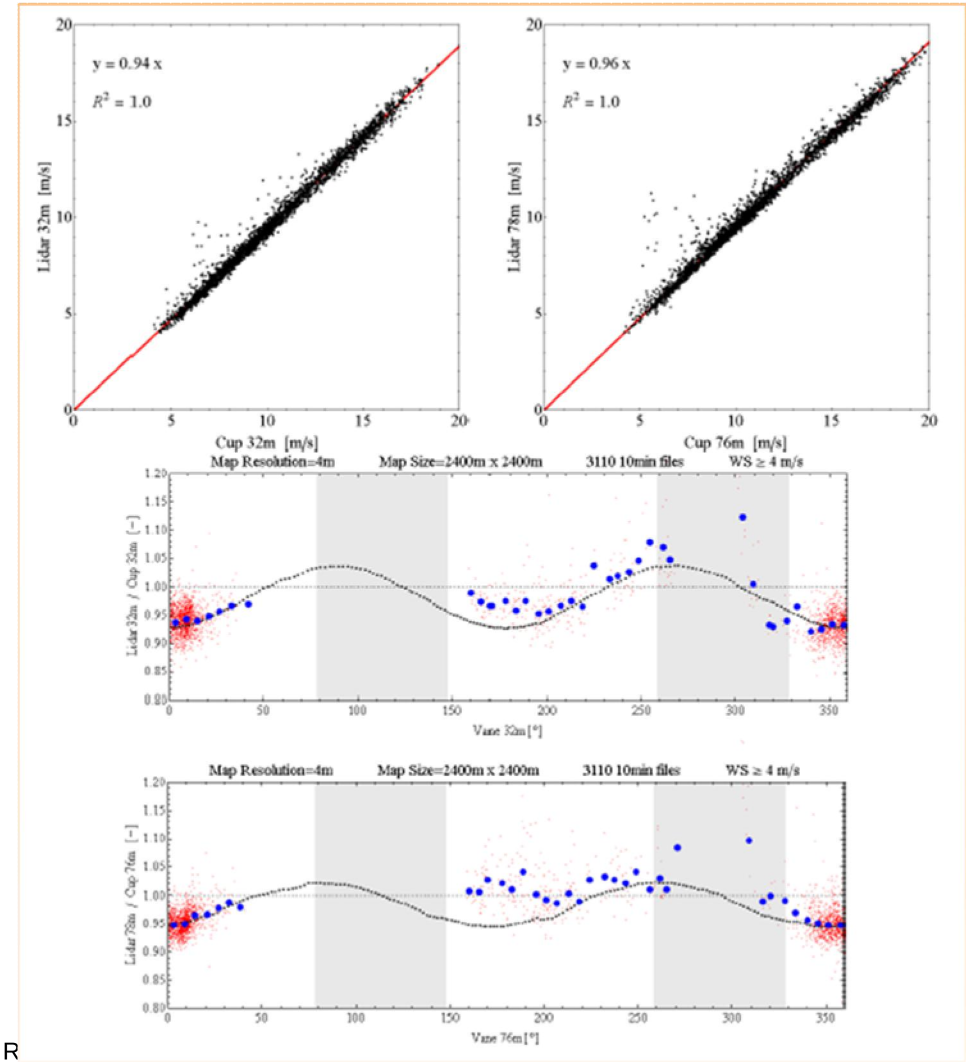
Different parts of cone sample different winds

Example: Dimitri Foussekiss Cres

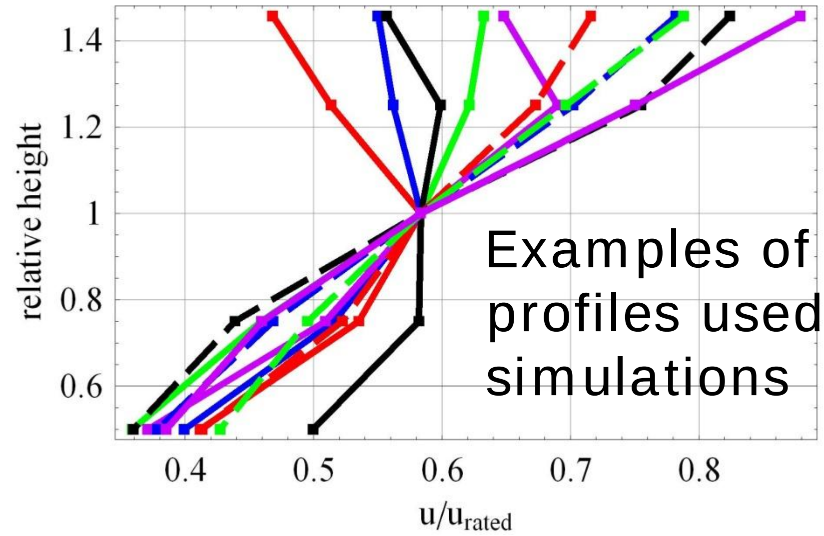
V_{LIDAR} = 0.9995 V_{MAST} + 0.0194 in flat terrain

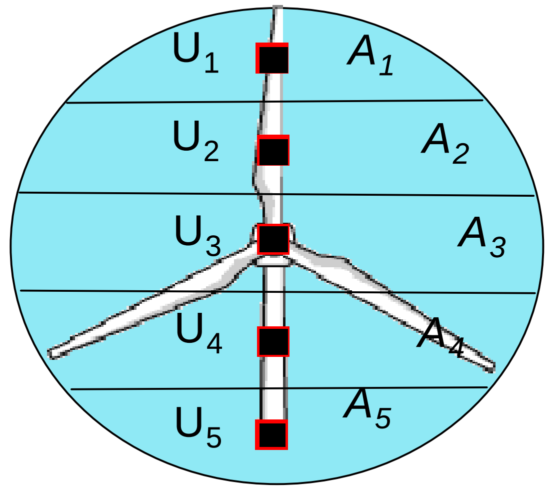
V_{LIDAR} = 0.8753 V_{MAST} + 0.4519 in complex terrain

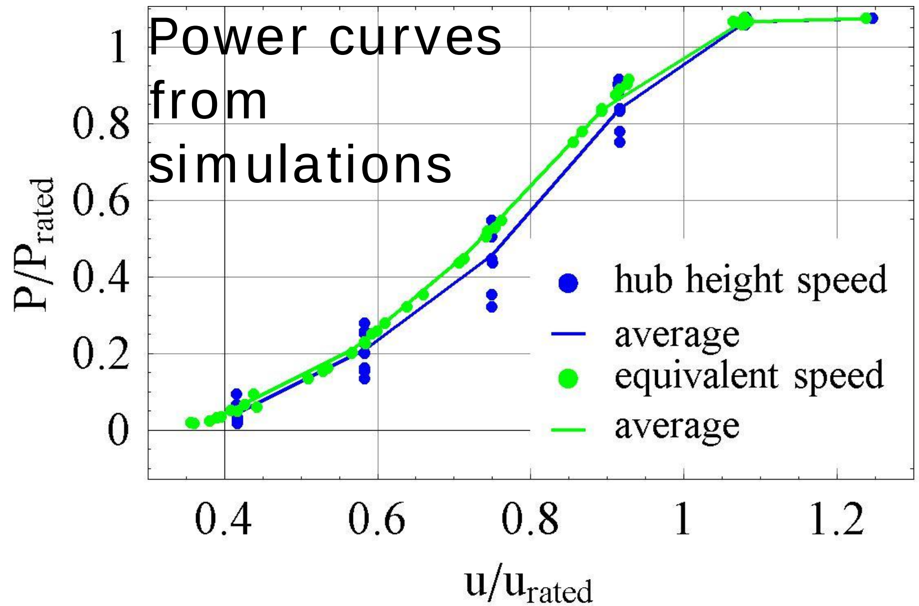
Results and simulations using WENG 2.



aerodynamic simulations







Definition of an equivalent wind speed:

$$U_{Eq} = \sum_i \overline{U_i} \cdot \frac{A_i}{A}$$

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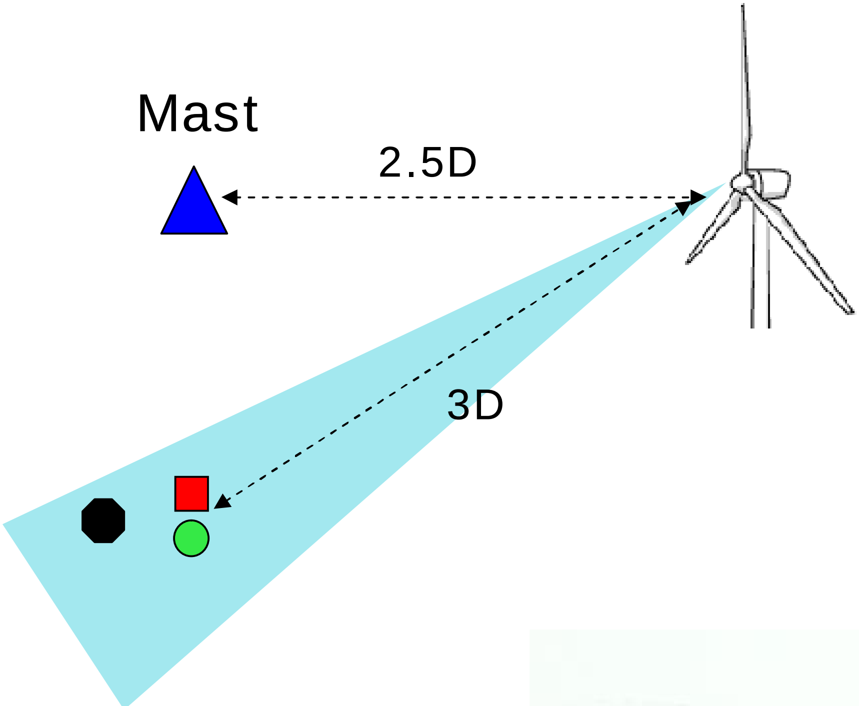
Description of the measurement campaign



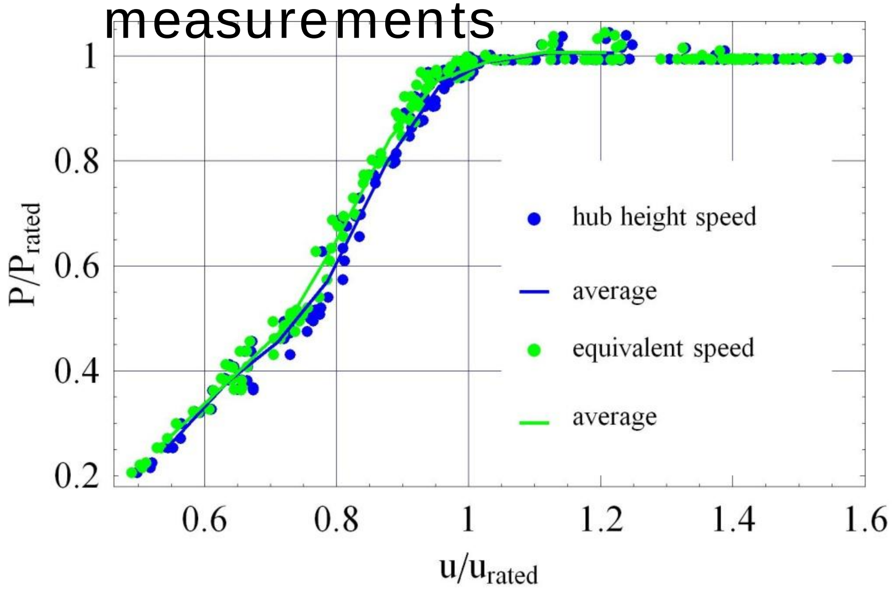
LiDAR Qinetiq ZephiR

LiDAR Leosphere Windcube

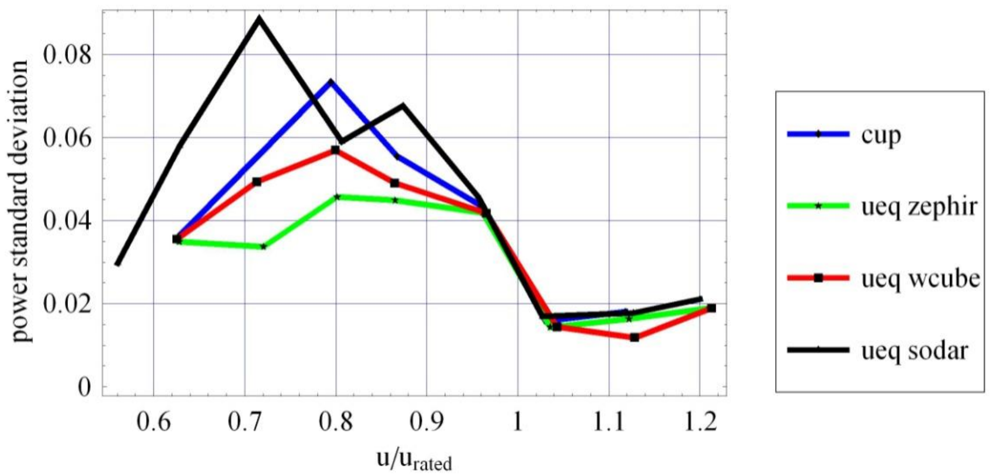
SoDAR AQ500

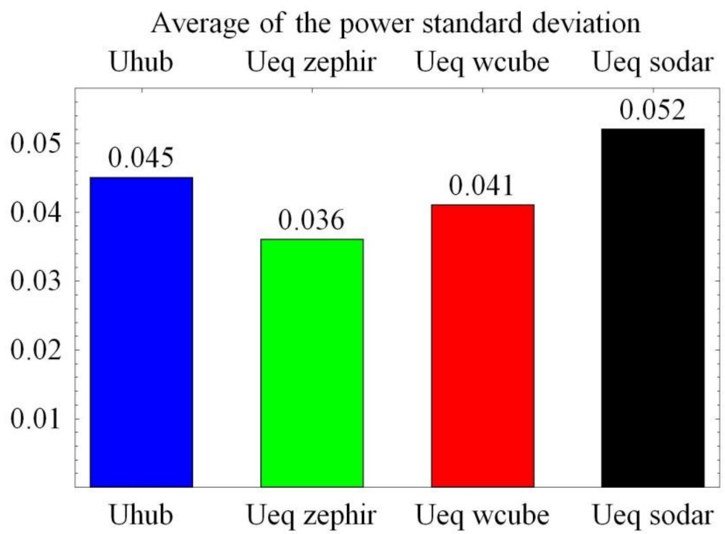
Profile measurement with LiDAR

Power curves from measurements



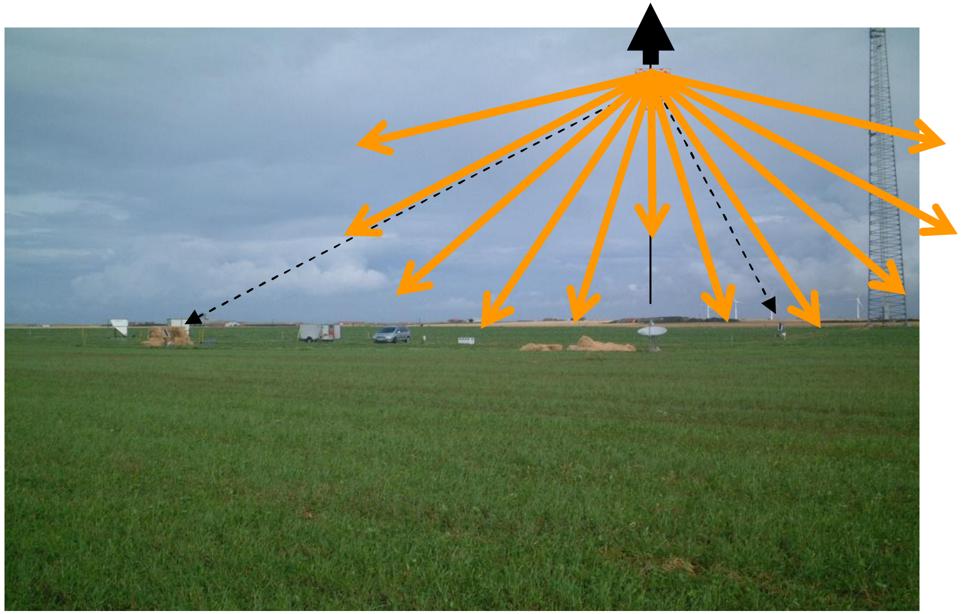
Measurements confirm that the use of an equivalent wind speed reduces the uncertainty in power curve measurement.



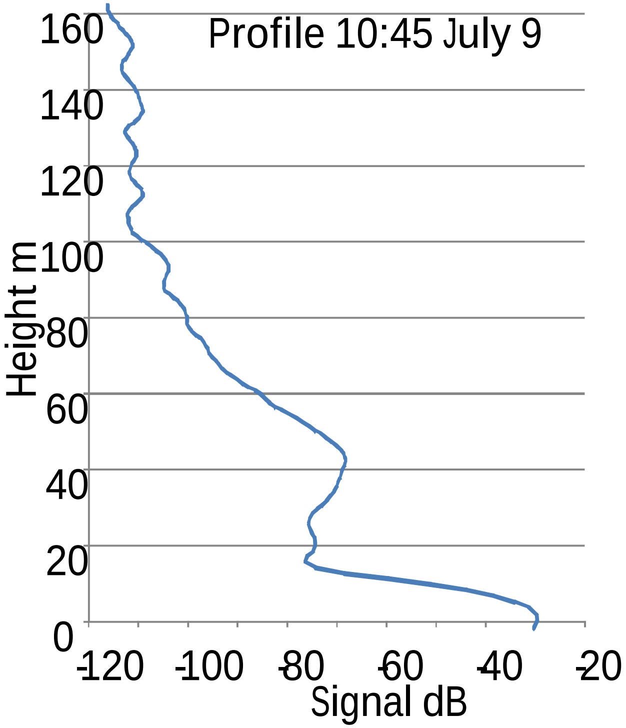


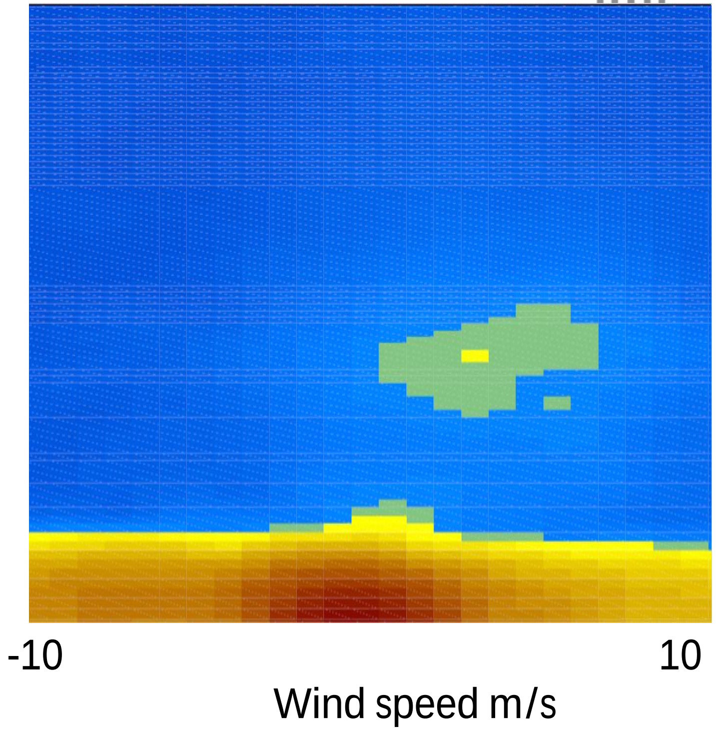
Development of a bi-static SODAR

- A bi-static SODAR uses separated transmitter and receiver
- The turbulent scattering of sound is strongest off-axis. This means a stronger signal than normal SODARs as well as a signal which has a peak intensity at some elevated height, unlike normal SODARs and LIDARs.



- The main advantage is that winds are sensed in a single vertical column, similar to a mast. Other SODARs and LIDARs are not mast-like





- Previous bi-static designs have “stared” at one small volume above the instrument
- We have developed synchronized electronic scanning of two receivers to give wind profiles in a vertical column
- Initial tests at Høvsøre show that fast wind profiles can be obtained (there is only one beam, so profiling is 3 times faster)
- The above measurements show a large direct-signal from the transmitter to receiver. This can be removed in the signal processing. The color plot on the right is a spectrogram showing the localized spectrum peak at one height. The wind profile is derived by concatenating all such spectral peaks in the vertical

How to continue ?

- Turbine mounted LIDARS (still needs to be done)

    - V27 at Risø (prototype)

- Interactions with the control system ?
- Bistatic sodar systems needs to be tested ?

At EWEC2009 a remote sensing session (3 oral presententations from UPWIND and 4 posters)

ISARS2008 4 papers from UPWIND