Remote sensing for wind energy at Risø DTU

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Outline

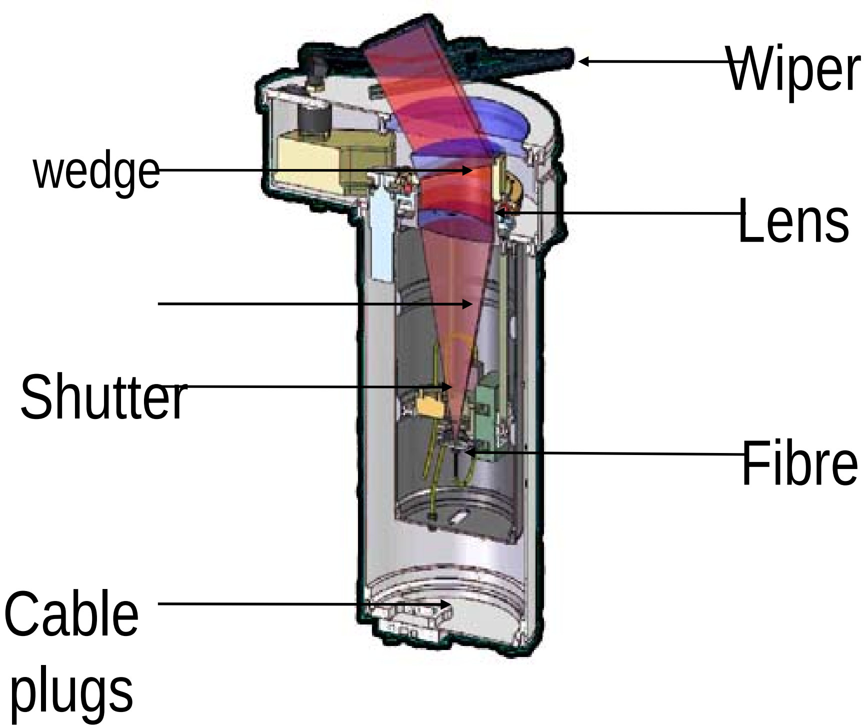
- A very short history of remote sensing at Risø
- What kind of lidars do VEA-Risø own?
- Performance of lidar for wind power resources and power curves
- Other current uses of wind lidars at Risø
- The future: The Windscanner project
- Conclusions and questions

A very short history of wind remote sensing at Risø

- Why remote sensing?
- SODAR, SAR, kites, remotely controled aircrafts
- Early lidars bulky, expensive and not too stable
- 2003: QinetiQ ZephIR lidar. Compact, affordable (?), relatively robust prototype
- 2004? WISE experiment at Høvsøre
- 2006: QQ series production.
- 2006: Leosphere Wind Cube pulsed lidar
- 2007 January: IEA Topical Expert meeting at Risø: State of the sodars, lidars, satellites.
- Dec 2007 – Musketters Experiment (3 crossing lidars)
- April 2008 – Delivery of first modified windscanner ZephiR
- June 2008 RS Summer School and ISARS2008 at Risø

VEA lidars: The QinetiQ ZephIR

- cw, homodyne lidar based on telecom components and a fiber laser from Koheras
- Range determined by focus
- Wind vector determined by conical scanning, assuming horizontal homogeneity



VEA lidars: The Leosphere WindCube

- pulsed, heterodyne lidar based on telecom components and a fiber laser
- Range determined by time of travel
- Wind vector determined by scanning in four directions, assuming horizontal homogeneity

Performance tests at Høvsøre in western Denmark

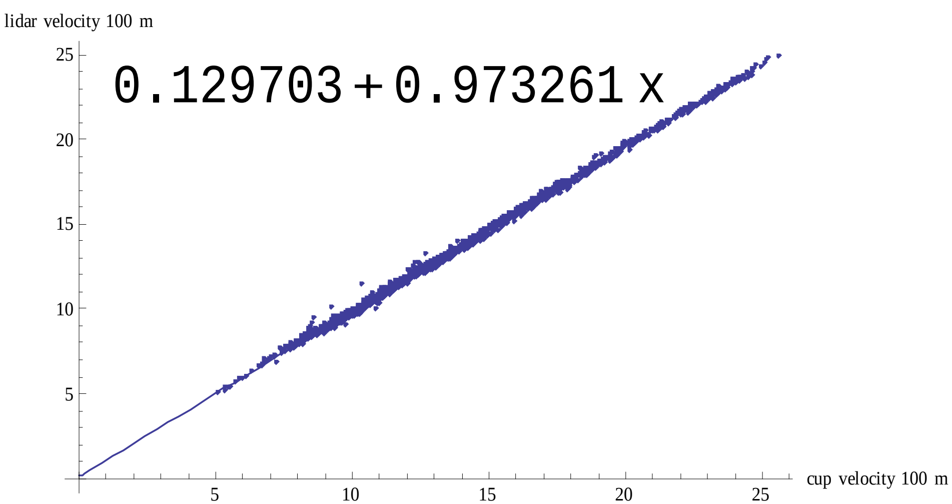
Testing of LIDARS at Risø's wind facililties in Høvsøre

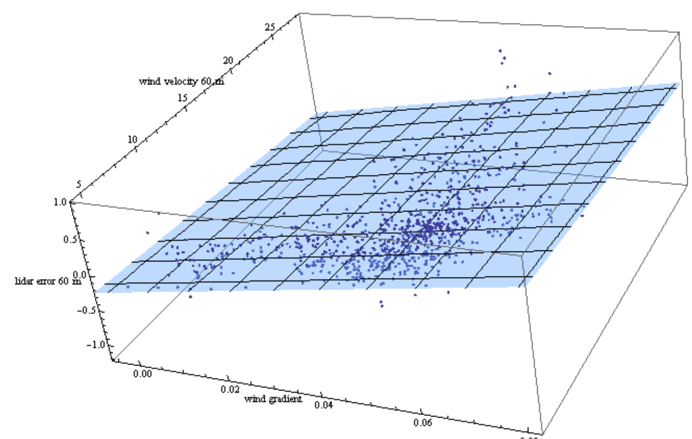
Høvsøre test facility

- **13** Zephirs and Windcubes tested
- **19** months of comparison with cup anemometers at altitudes 40-116 m (160 m)
- Site equipped to screen on clouds, rain, temperature and perturbed wind directions

Results

- Typical gain: **< ± 2%,** observed [+2 to -5%]
- Typical altitude error: **0 - 5 m**
- Typical standard deviation in 10 minute average: 25 cm/s



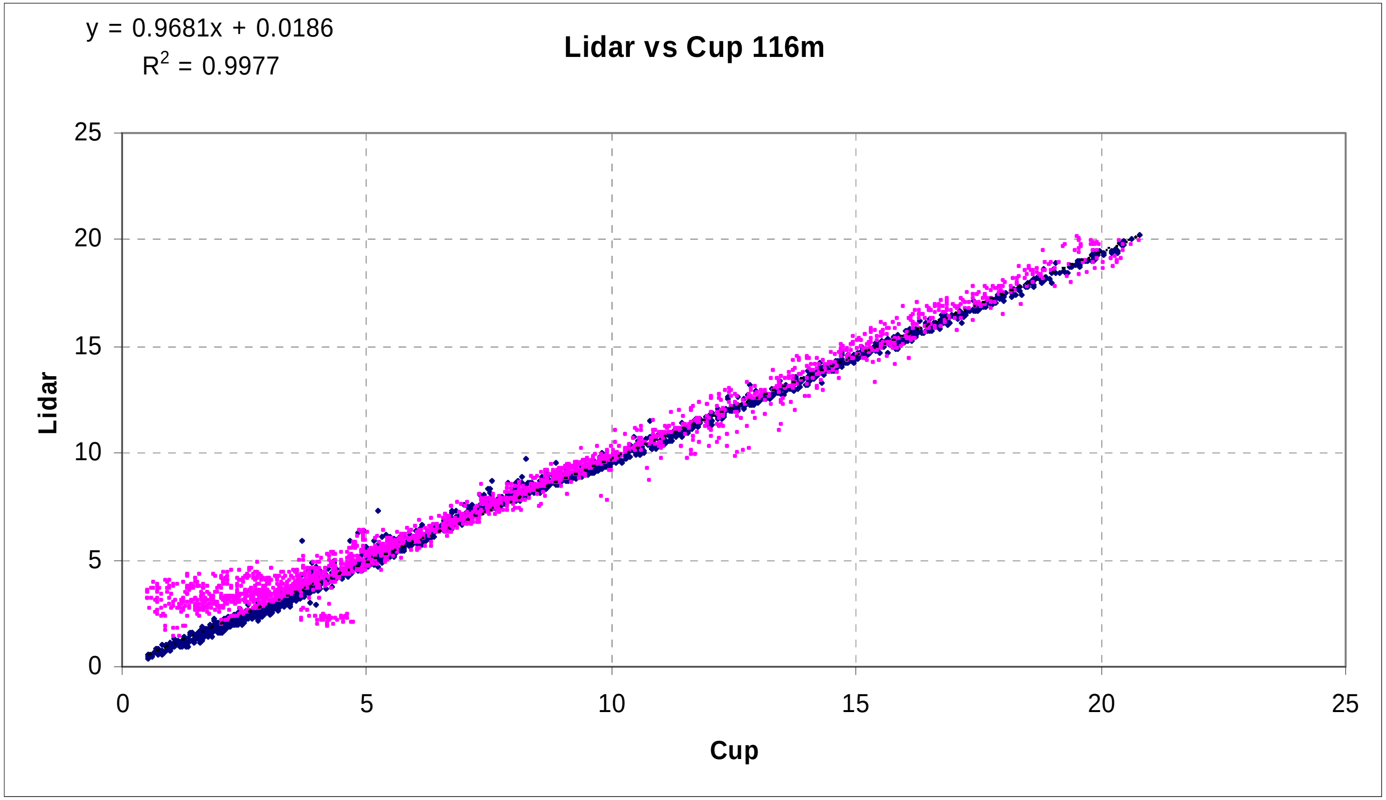


Simultaneous estimation of altitude errors

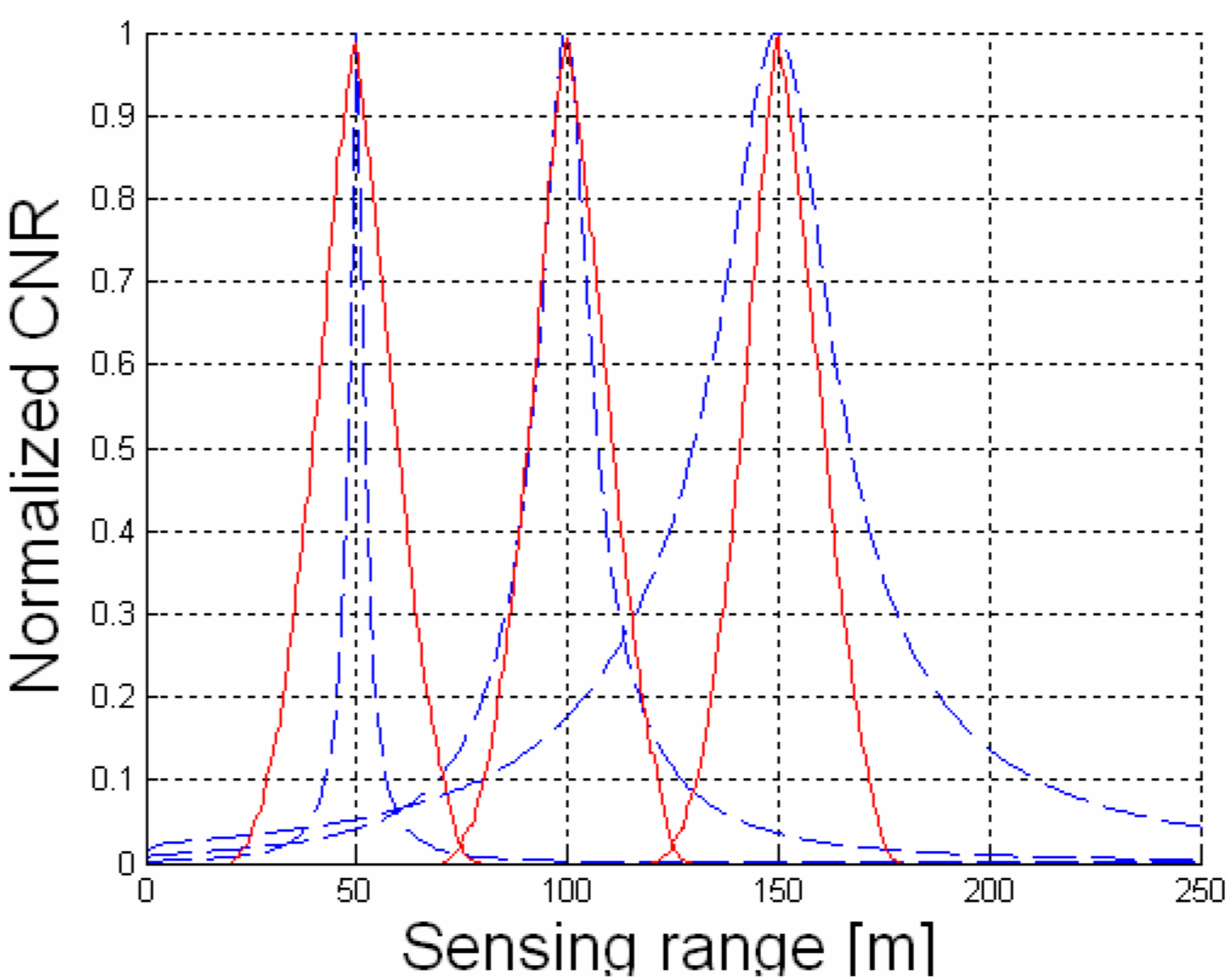
QinetiQ ZephIR 40 m from base of 116 m met tower

Four Leosphere WindCubes on test at Høvsøre

Lidar versus cup – ZephiR and Windcube



Weighting functions for the Windcube and the Zephir



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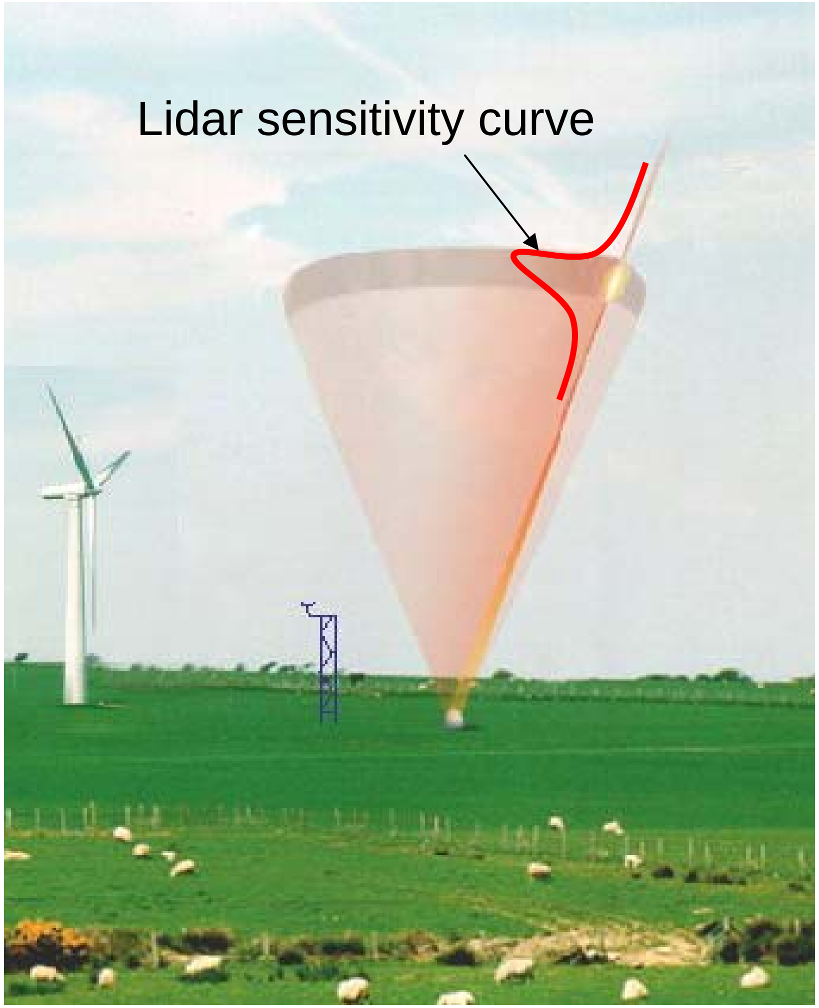
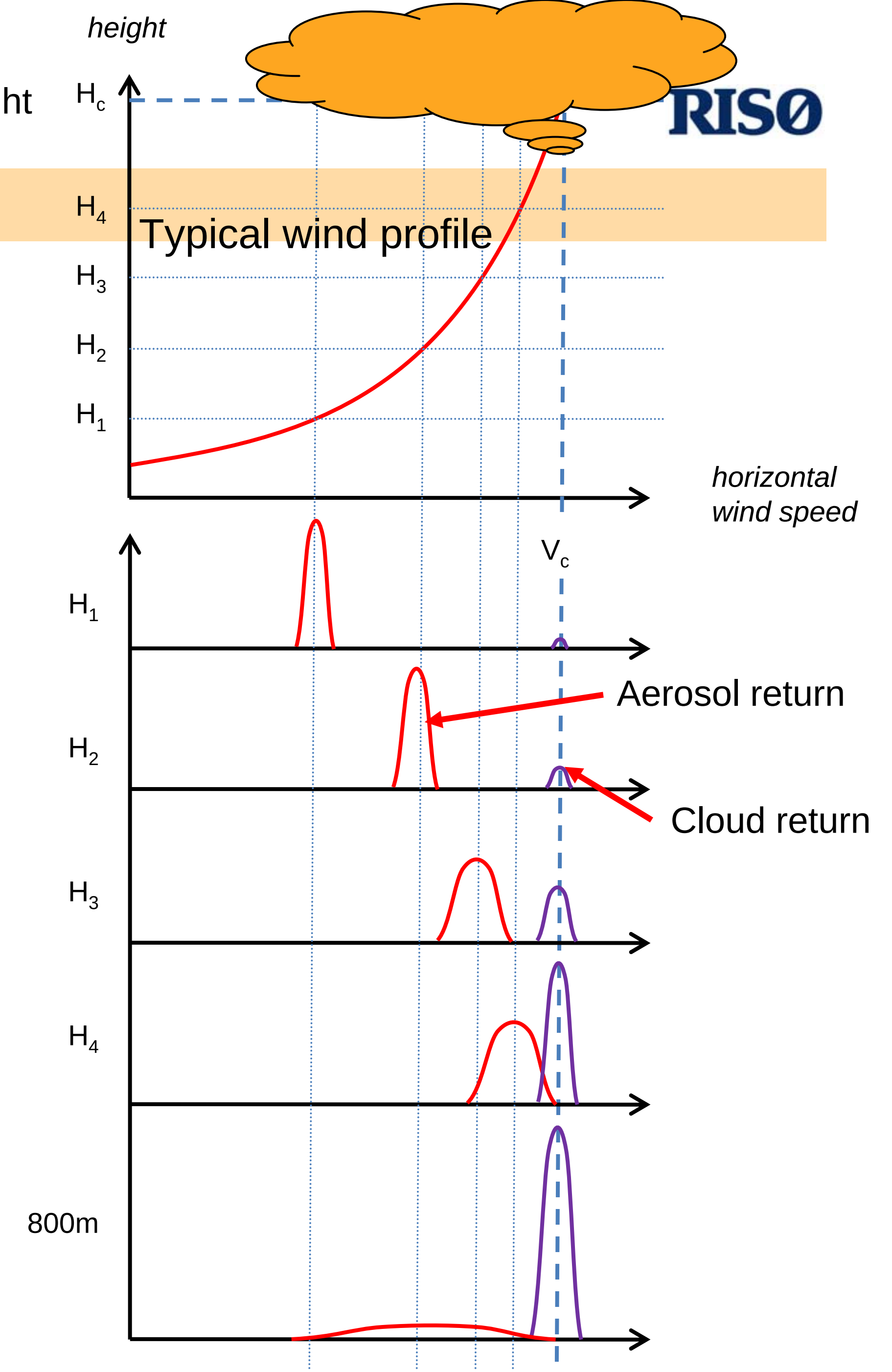
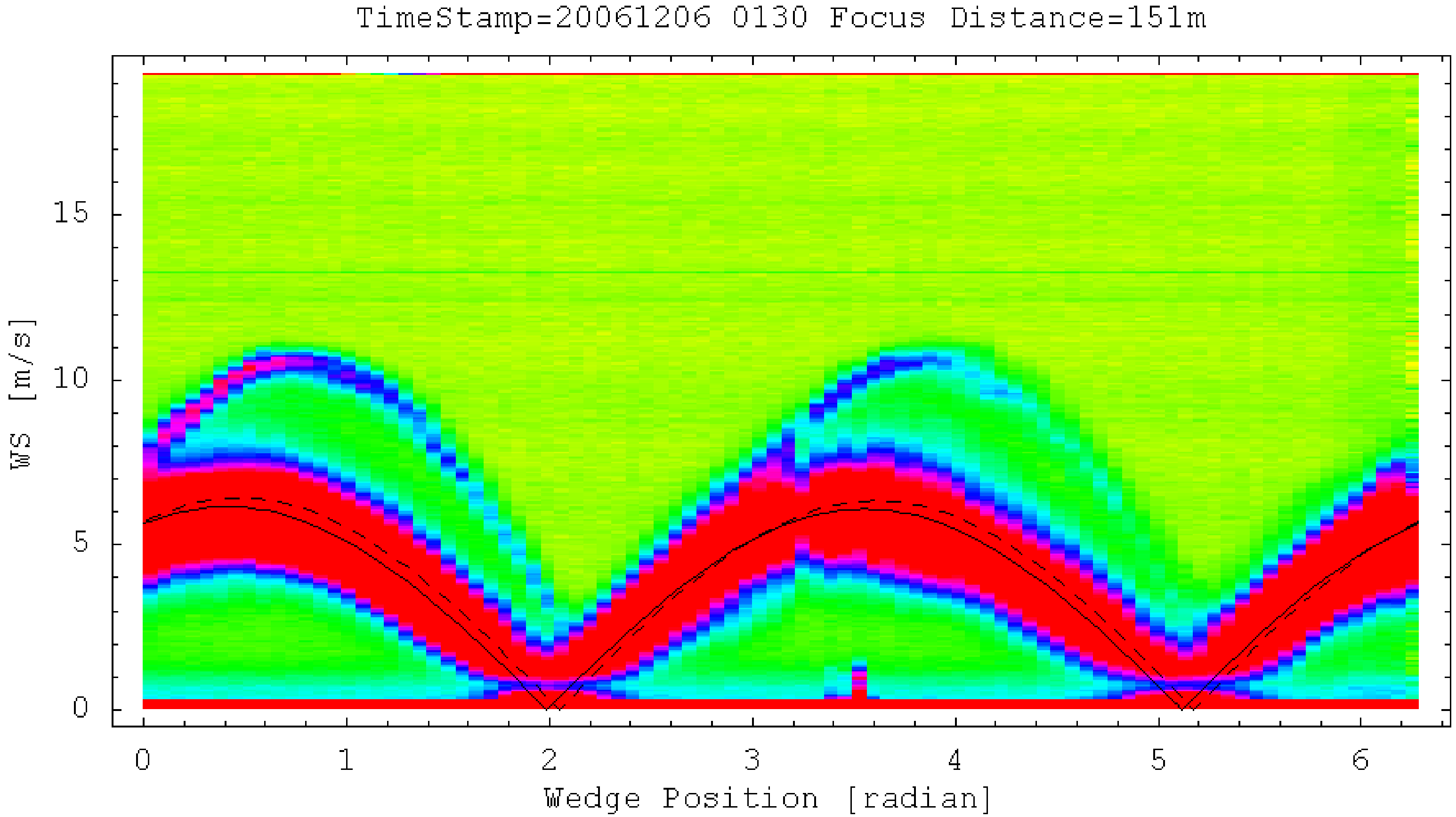
Cloud correction: the problem

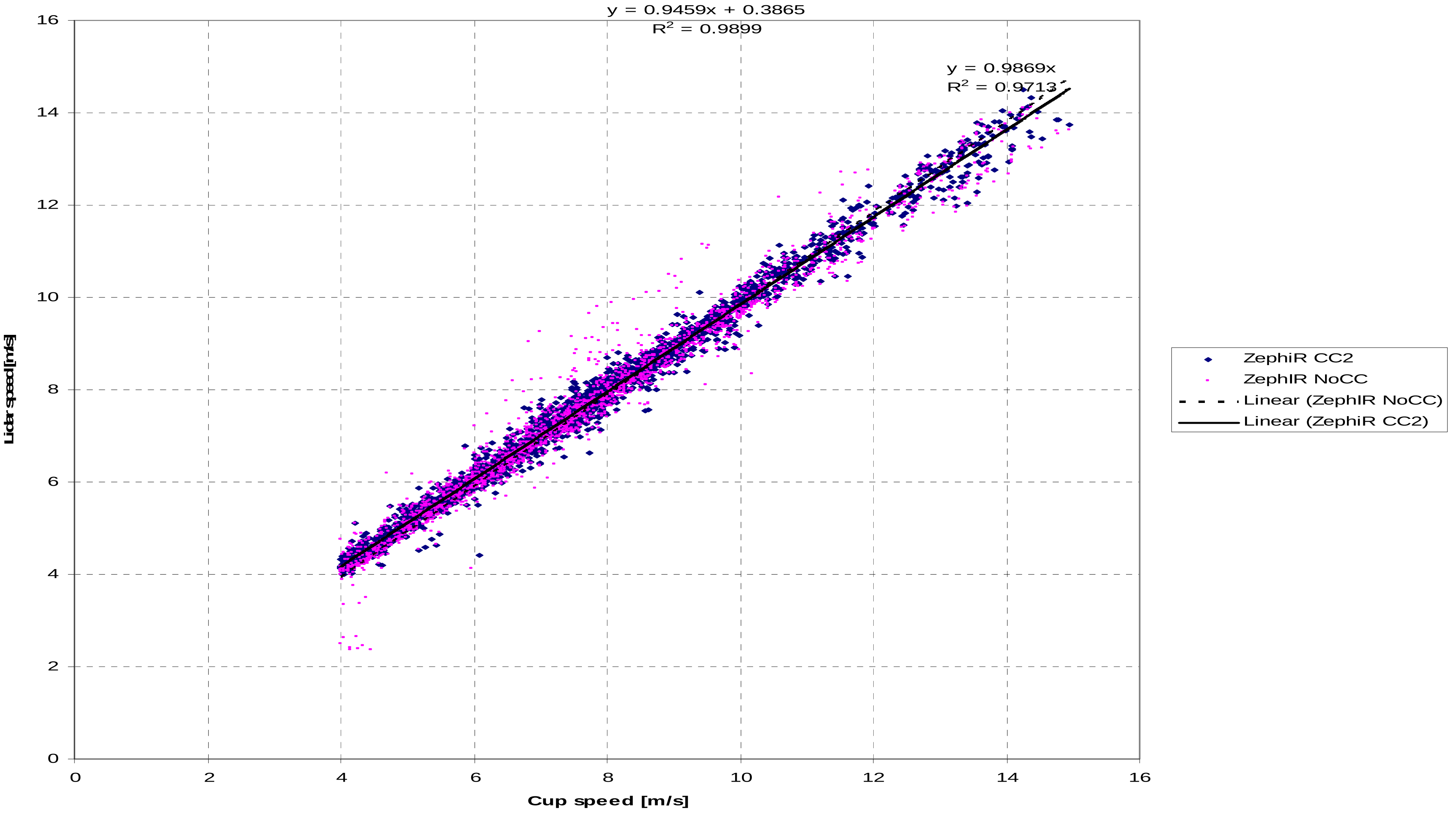




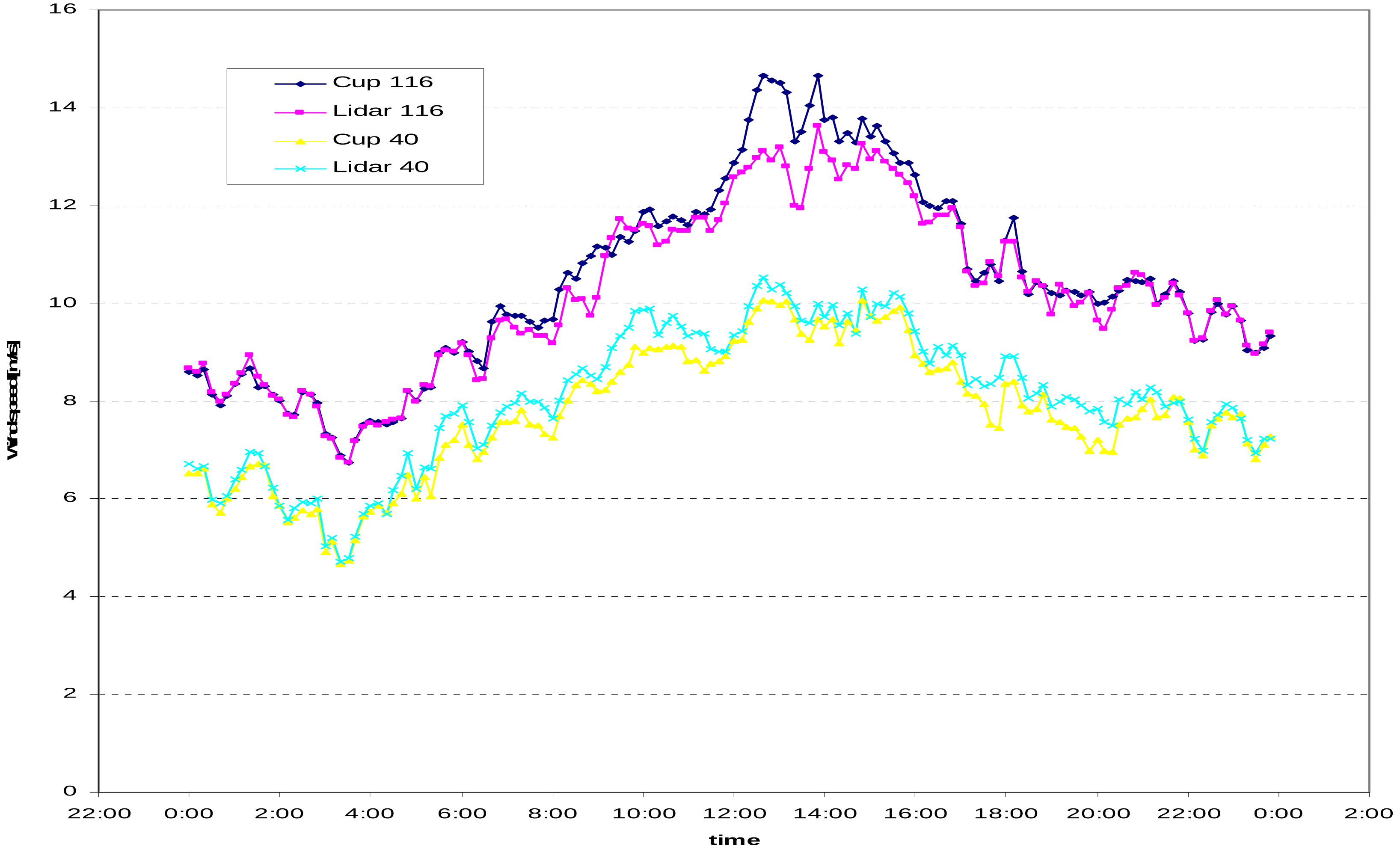
Clouds tend to bias the wind



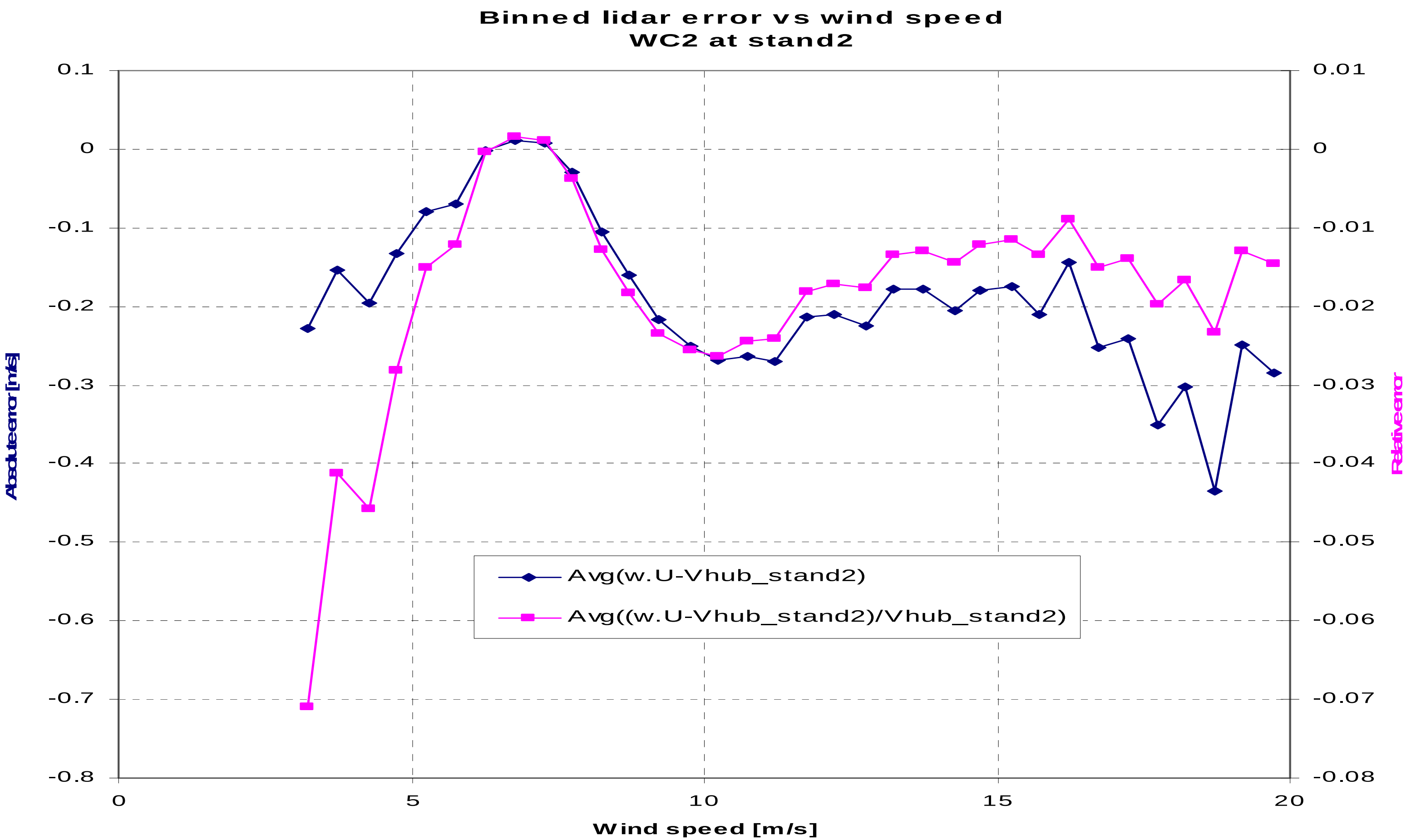
Cloud correction "deconvolutes" the spatial filtering



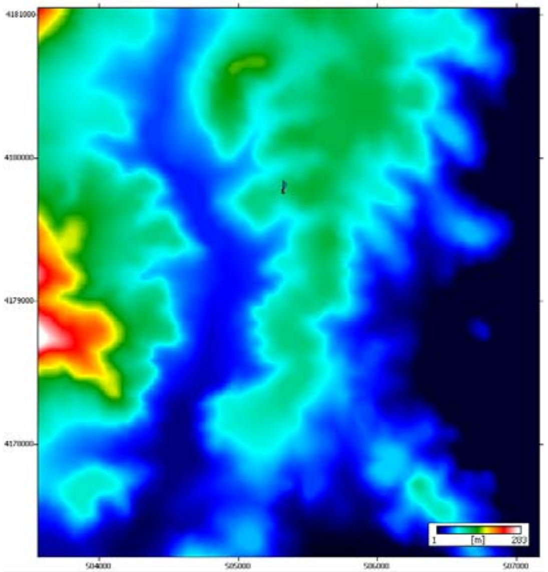
but new problems appear…



WindCube error small - interferes with crucial part of pow. c.

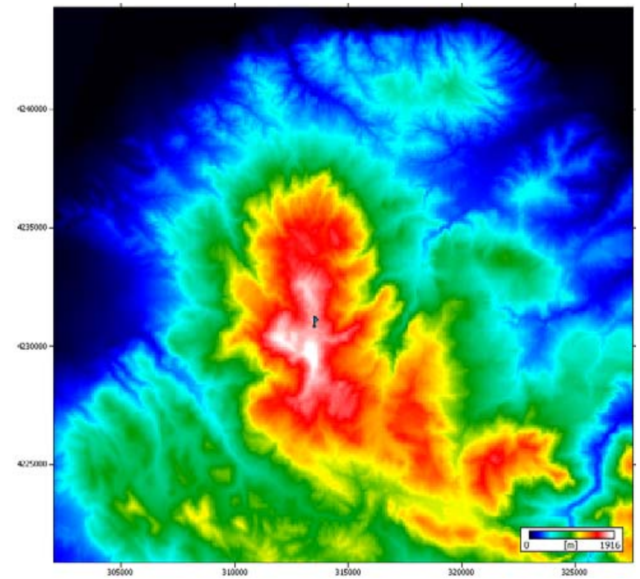


Performance in complex terrain

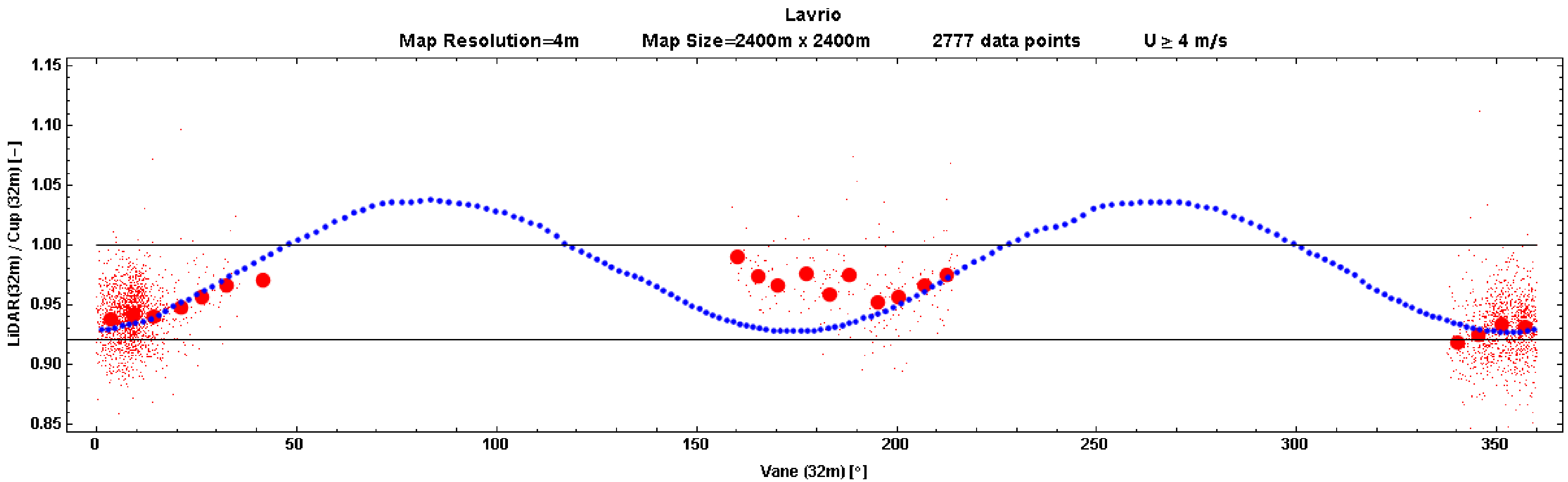


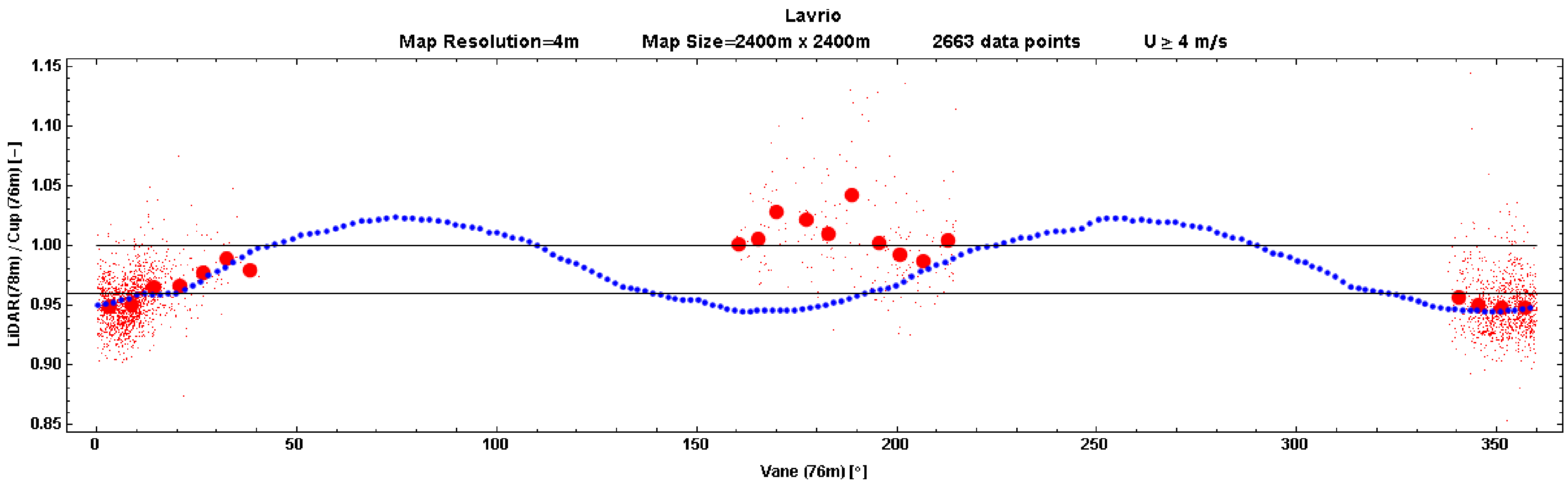
Lavrio

Panahaiko

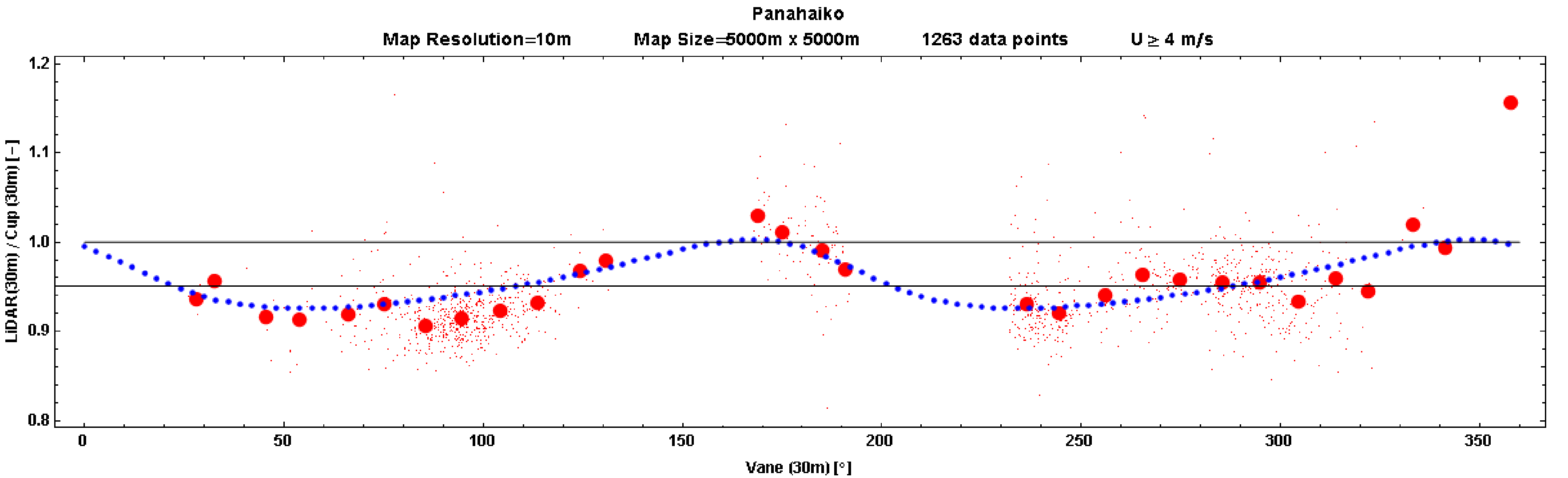


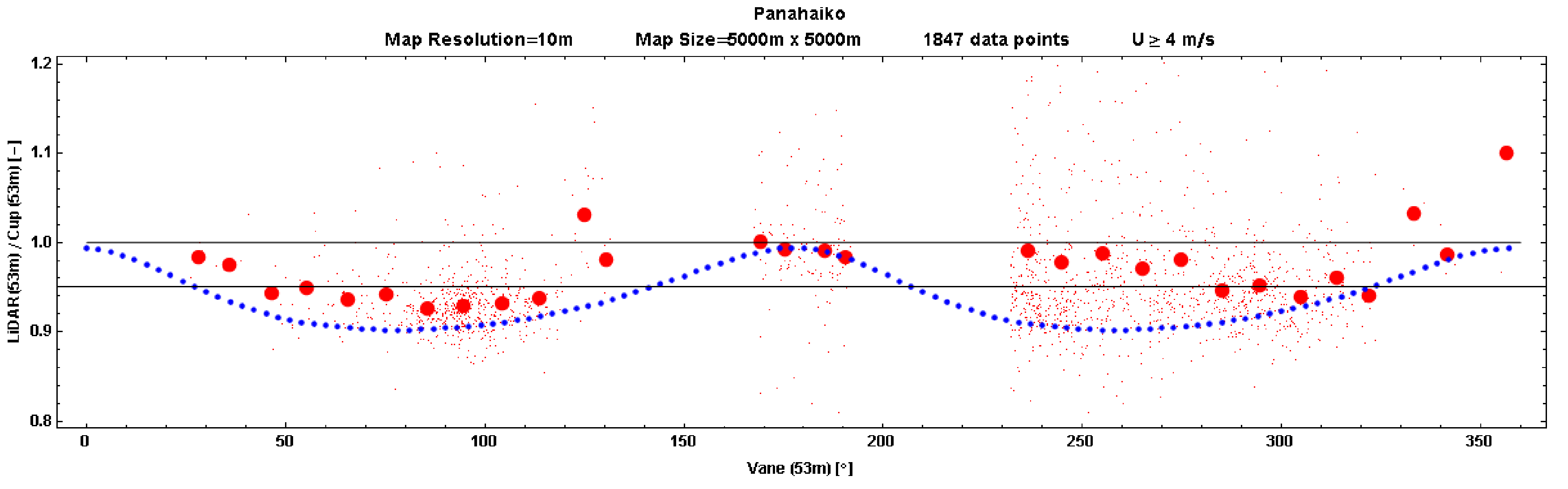
Results; Lavrio





Results; Panahaiko

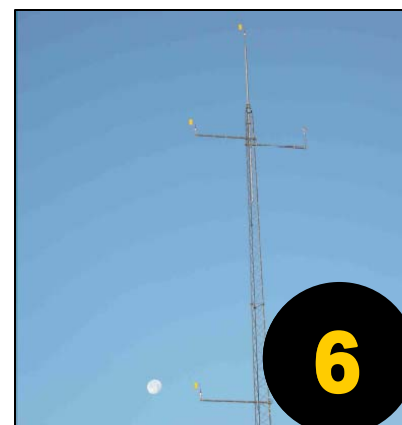




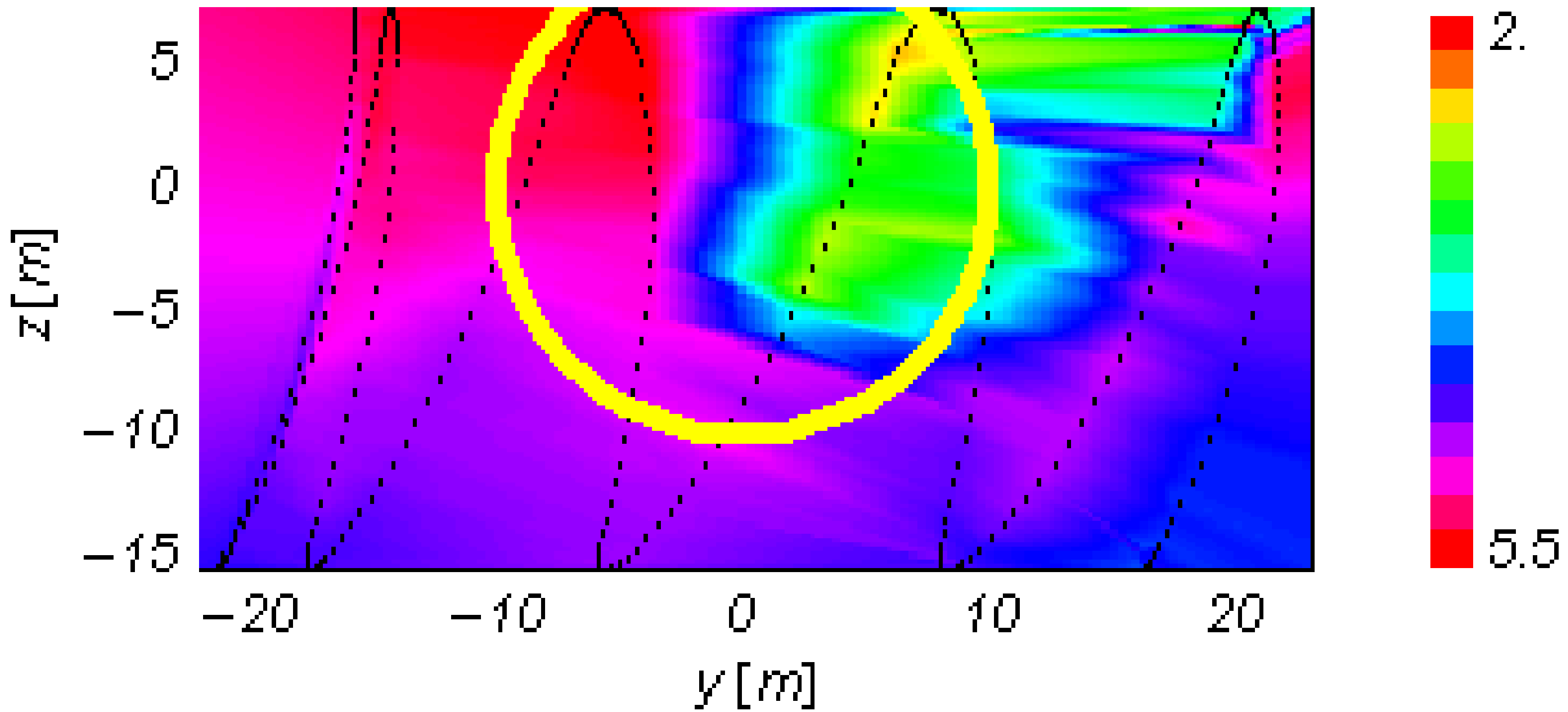
Other current uses of wind lidars at Risø

- Simulations show that use of wind profile reduces the error in power curve measurement. So far, this has proven difficult in practice.
- Investigations of wakes behind wind turbines
- Flow over and around forests

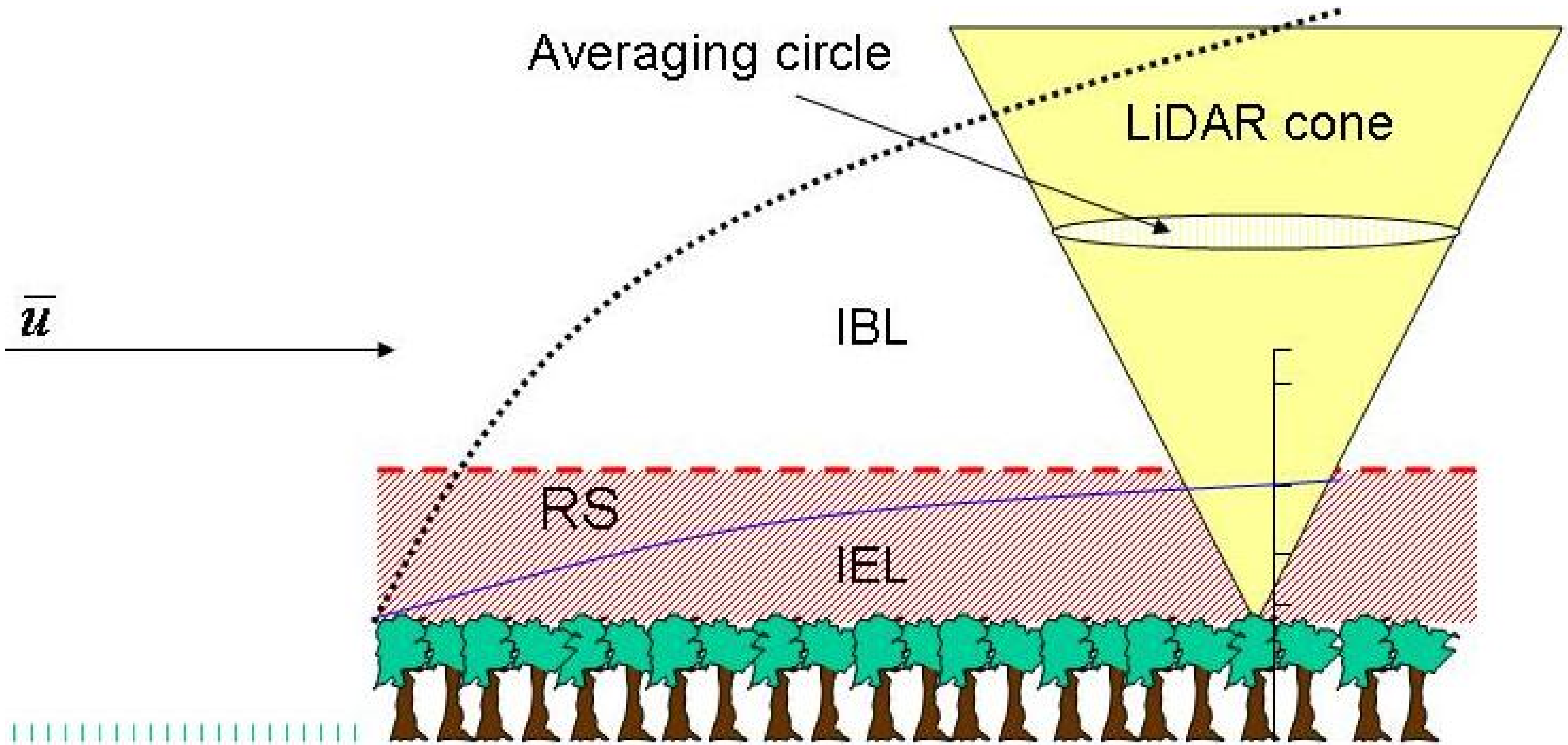
Experimental Setup for wake experiment



2D scans of the wake behind a small turbine



Experiment: 57 m mast and lidar measurements to 175 m



Upwind and downwind variances

The measured radial velocity is (assuming half opening angle = 30 deg)

$$v_r = \left| \frac{1}{2} u \cos\theta + \frac{1}{2} v \sin\theta + \frac{\sqrt{3}}{2} w \right|,$$

The upwind and downwind variances are therefore

$$\begin{aligned} \sigma^2(v_{r,up}) &= \frac{1}{4}\sigma_u^2 + \frac{3}{4}\sigma_w^2 - \frac{\sqrt{3}}{2}\left\langle u'w' \right\rangle \\ \sigma^2(v_{r,down}) &= \frac{1}{4}\sigma_u^2 + \frac{3}{4}\sigma_w^2 + \frac{\sqrt{3}}{2}\left\langle u'w' \right\rangle \end{aligned}$$

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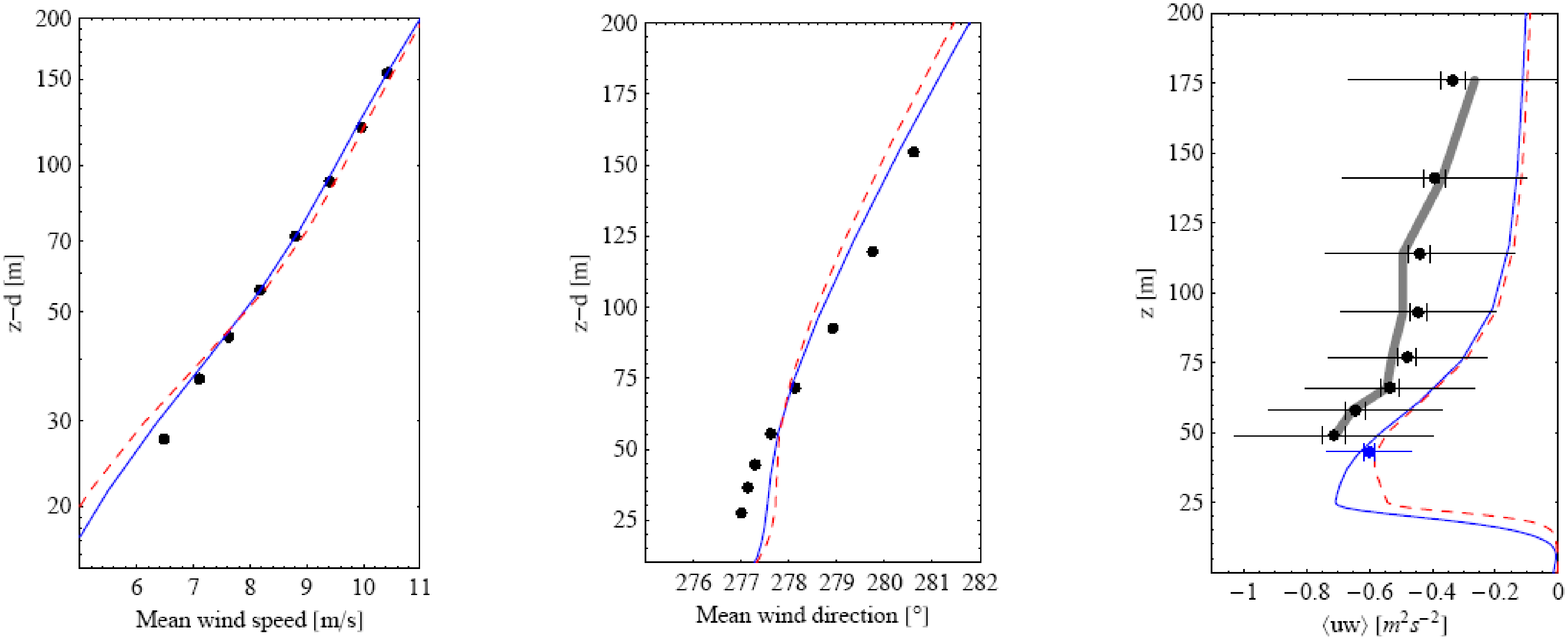
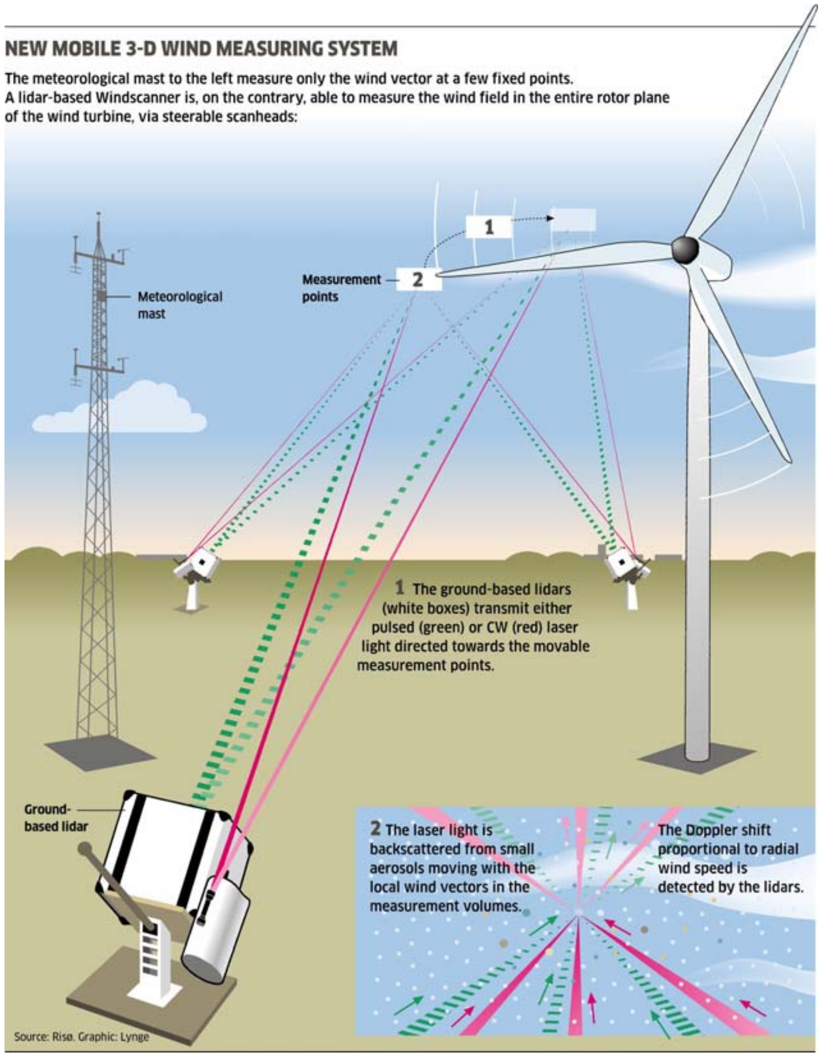
Profiles of wind speed, direction and momentum flux



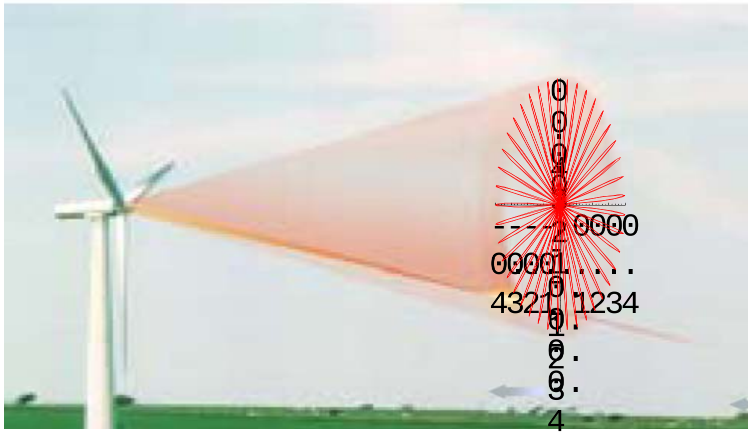
Comparison with forest CFD model by Sogashev and Panferov (BLM, 2006) Winter conditions Summer conditions

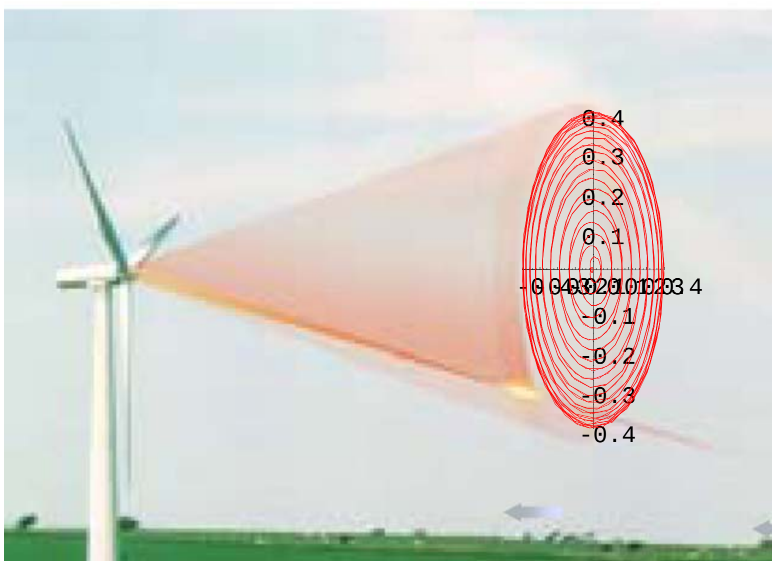
The future: The Windscanner project

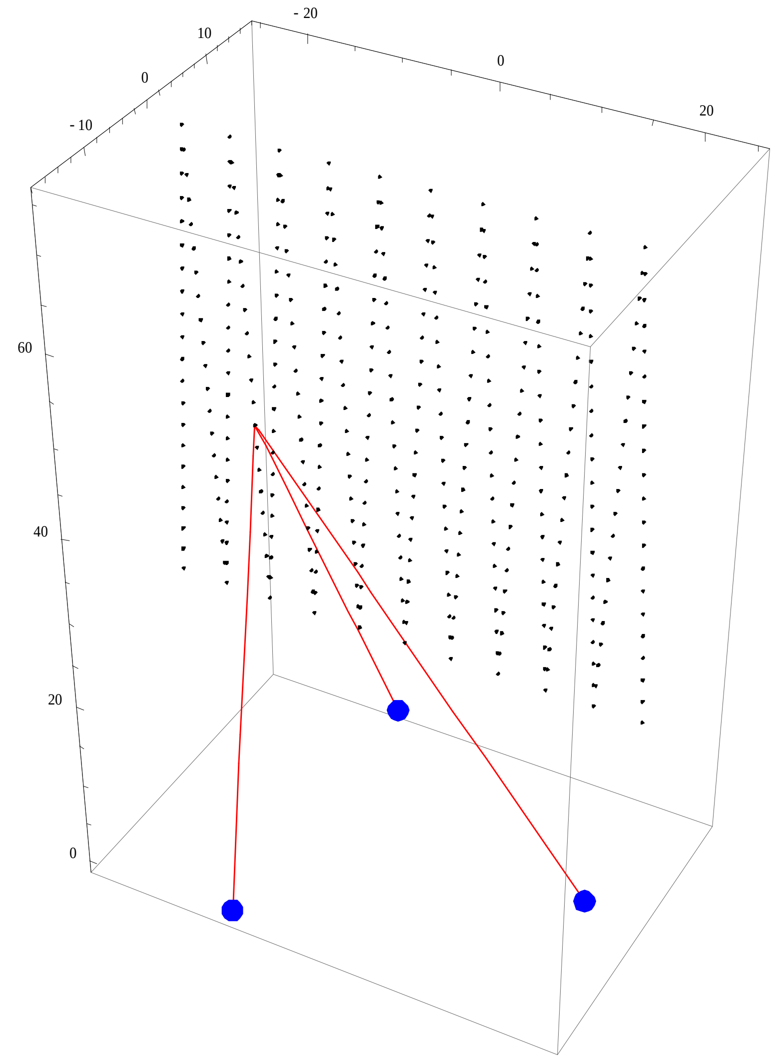
Our vision is to construct a ground based facility for the remote measurement of the three-dimensional atmospheric velocity field in a volume engulfing the huge wind turbines of tomorrow. It will be able to measure the wind vector at several hundred points within that volume every second. We believe that such a tool will make a major contribution to the technological development and penetration of wind energy combined with a leap in the scientific understanding of turbulent atmospheric flow.



Scanning patterns



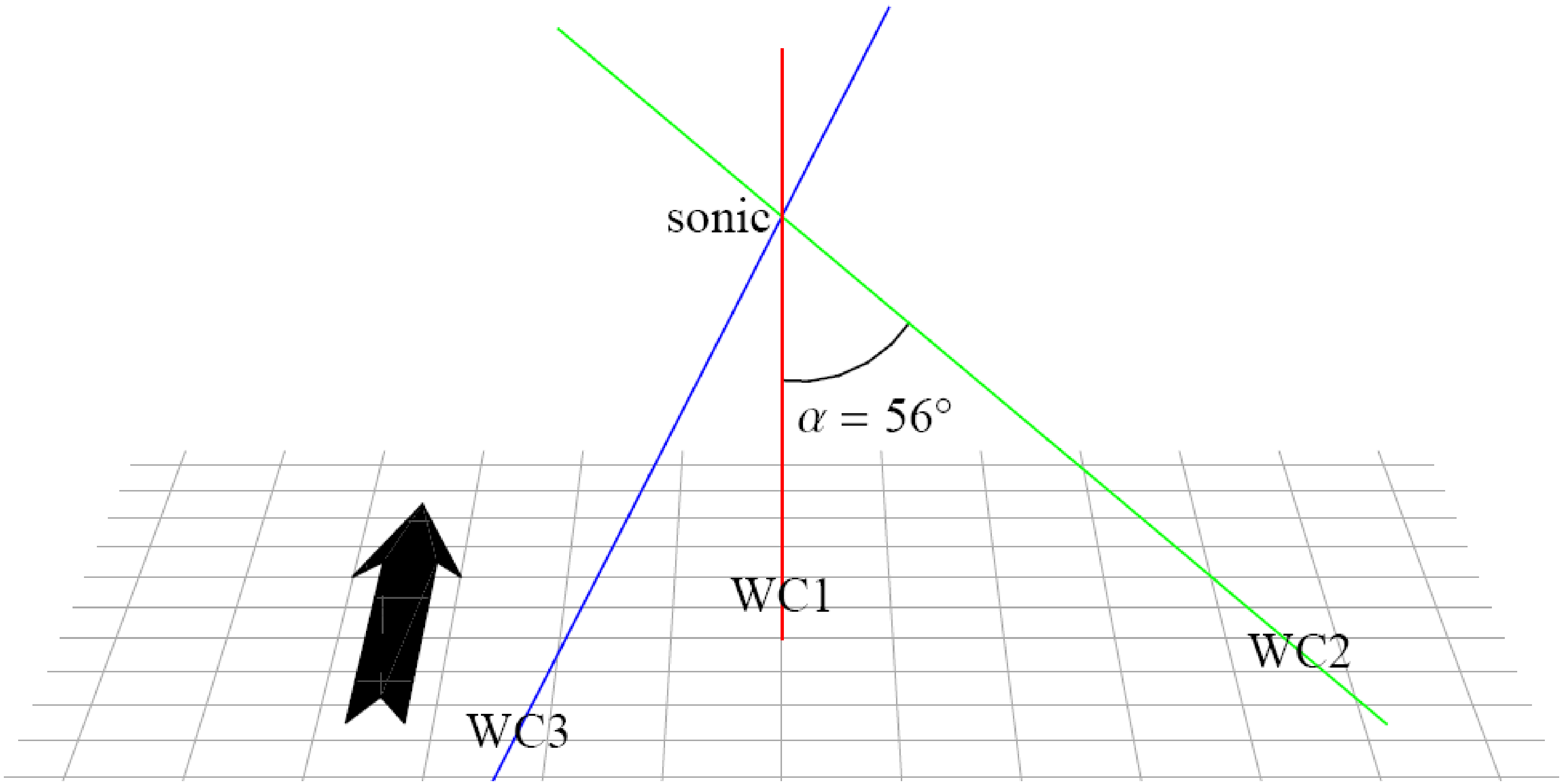


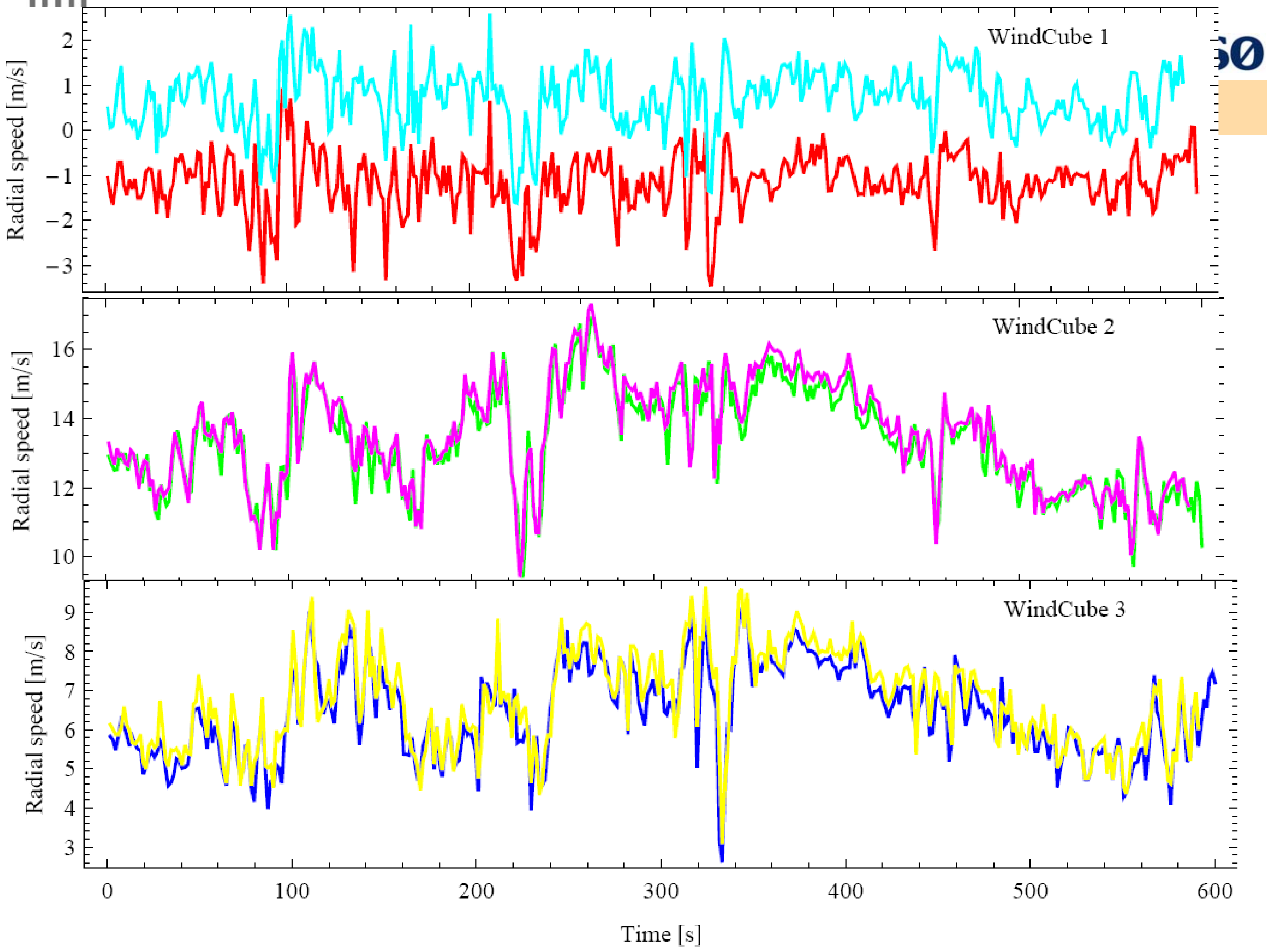


Scanning based on two moving prisms

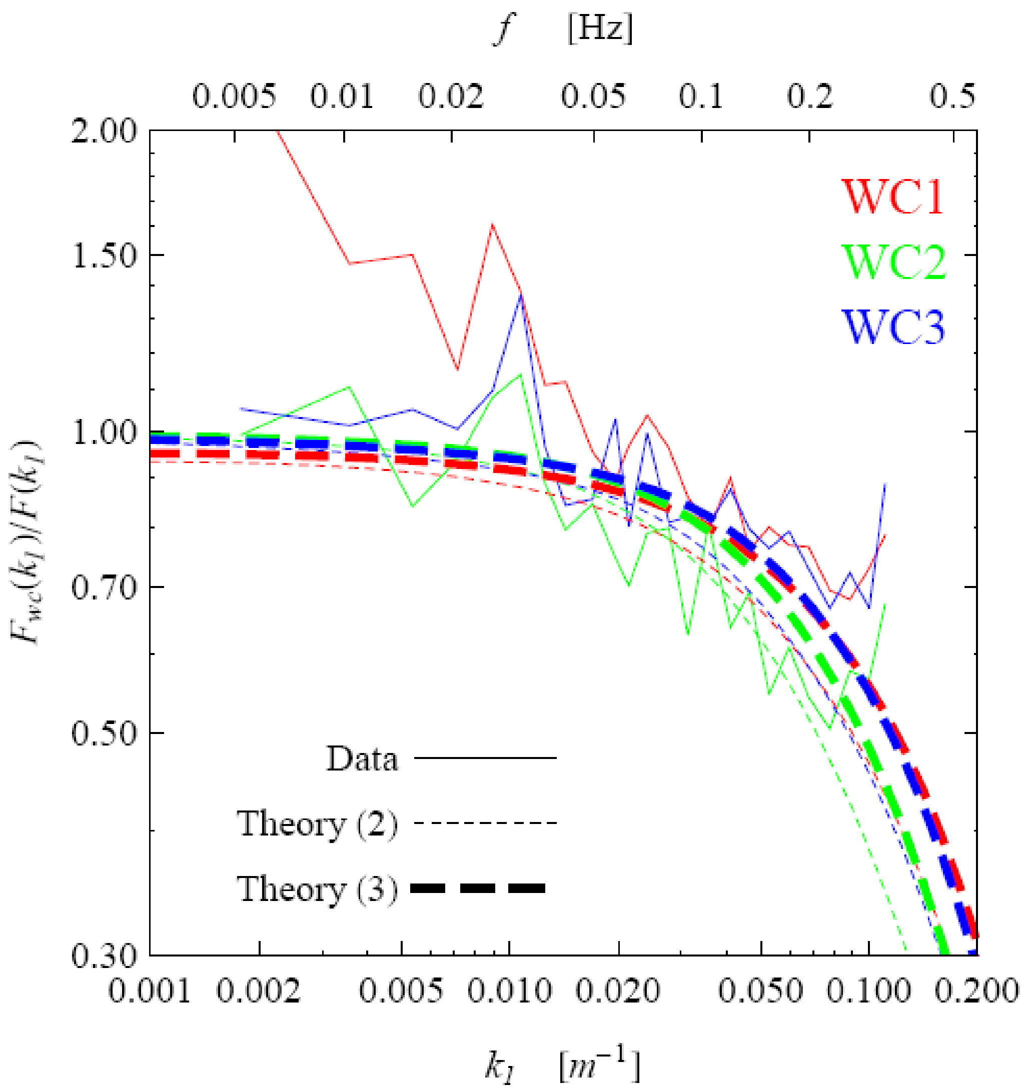
Initial 3D staring: The musketeer Experiment

Musketeer geometry: Three WindCubes




WindCube 1
WindCube 2
WindCube 3
Radial speed [m/s]
Radial speed [m/s]
Radial speed [m/s]
Time [s]
0
100
200
300
400
500
600

Spectral attenuation



Spectral attenuation

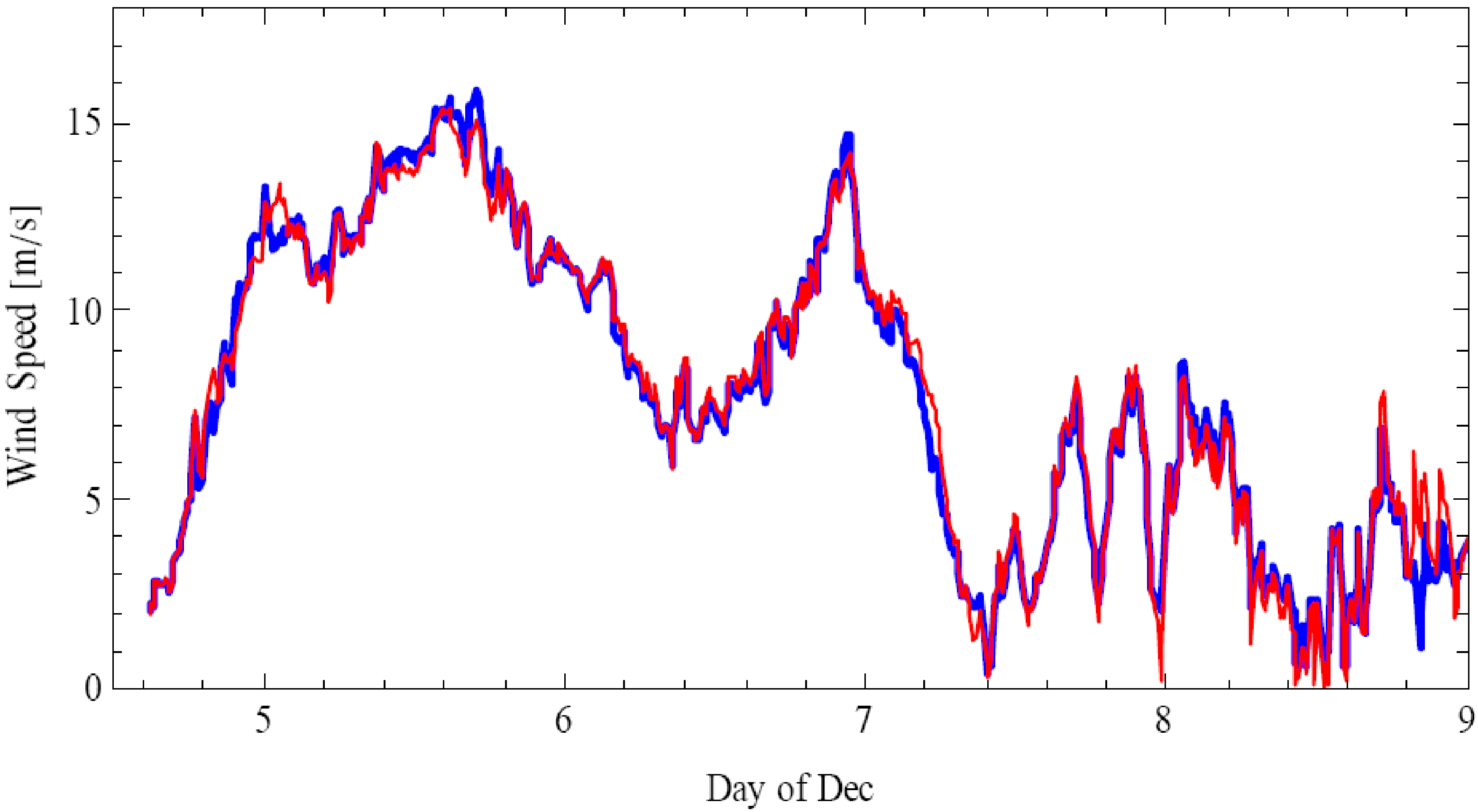
- Fit one-point spectra to the spectral tensor model (Mann, 1994) to obtain an estimate of the 3D-spectral tensor $\Phi_{ij}(\boldsymbol{k})$
- Now the filtered velocity spectrum of the component in the direction of the laser beam is

$$\begin{aligned} F_v(k_1) &= \frac{1}{2\pi}\int \langle v(\boldsymbol{x})v(\boldsymbol{x}+x_1\boldsymbol{e}_1)\rangle\, \mathrm{e}^{-\mathrm{i}k_1x_1}dx_1 \\ &= n_in_j\int\int \varphi(s)\varphi(s')\int\int \Phi_{ij}(\boldsymbol{k})\exp\left(\mathrm{i}\boldsymbol{k}\cdot\boldsymbol{n}(s'-s)\right)dk_2dk_3dsds' \\ &= n_in_j\int\int |\varphi(\boldsymbol{k}\cdot\boldsymbol{n})|^2\,\Phi_{ij}(\boldsymbol{k})dk_2dk_3 \quad . \end{aligned}$$

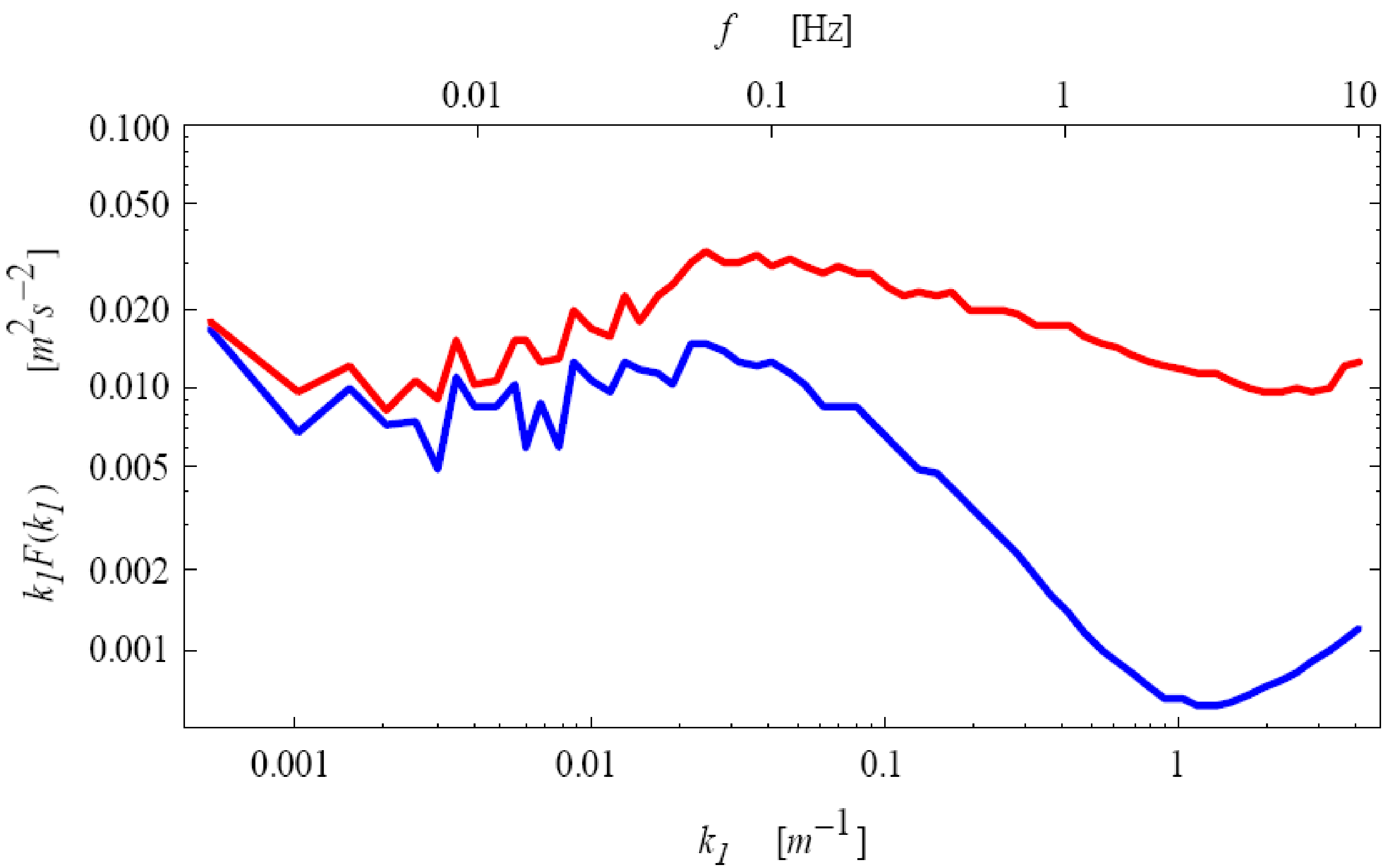
- The lidar wind speed is

$$v(\boldsymbol{x}) = \int_{-\infty}^{\infty}\varphi(s)\boldsymbol{n}\cdot\boldsymbol{u}(s\boldsymbol{n}+\boldsymbol{x})ds$$

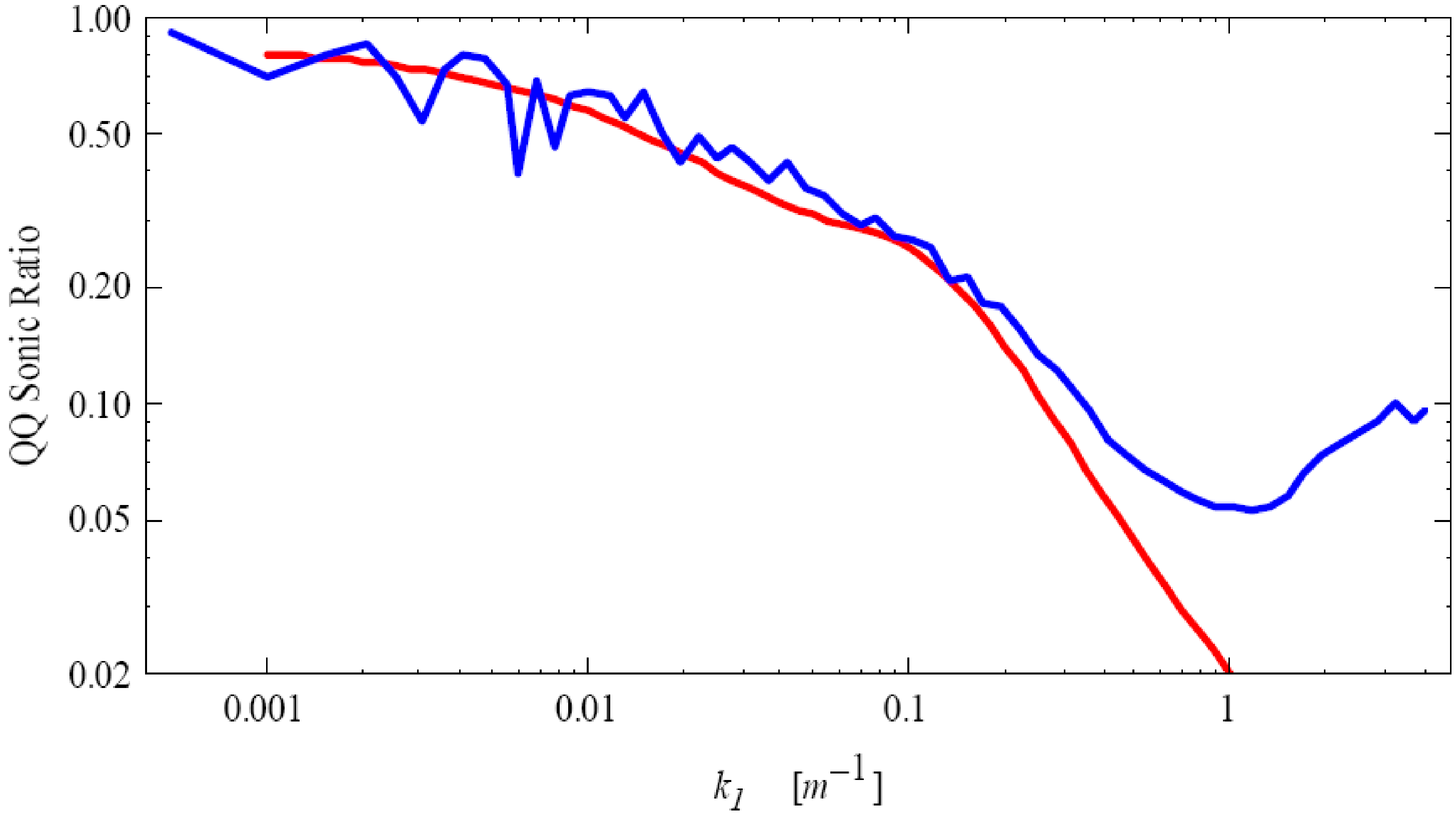
Comparison between staring ZephIR and sonic (10 min ave)



Spectra of fast Zephir and sonic component speeds



Spectral attenuation based on spectral tensor by Mann (1994)



Conclusion

- Two wind lidars (so far) have entered the wind energy market:
  1. Leosphere's WindCube: A pulsed and focused system
  2. QinetiQ's (now Natural Power) ZephIR: A cw focused system
- Their performances are very good, but still some problems, e.g. "fat tails" of the ZephIR sensitivity function
- They are used to study various subjects in wind energy research
  1. Wakes behind turbines
  2. Improvement of power curve measurements
  3. Micro-meteorological experiments
- Our ambition for the future is to construct a 3D scanning lidar system

Thank you for your attention