Wind lidars – Not the final answer in complex terrain!

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Ice and Rocks 3

Zadar, May 6th 2010

Risø DTU – Danish National Laboratory for Sustainable Energy

- **DTU** = The Technical University of Denmark

- Fuel Cells
- Biomass
- Systems Analysis

- **Wind Energy Division** (150 employees)
  - Meteorology
  - Aeroelastics and Aerodynamics
  - Wind turbines
  - Wind energy systems
  - **Test and Measurements**
    - Høvsøre Test Station for Large Wind Turbines

My background

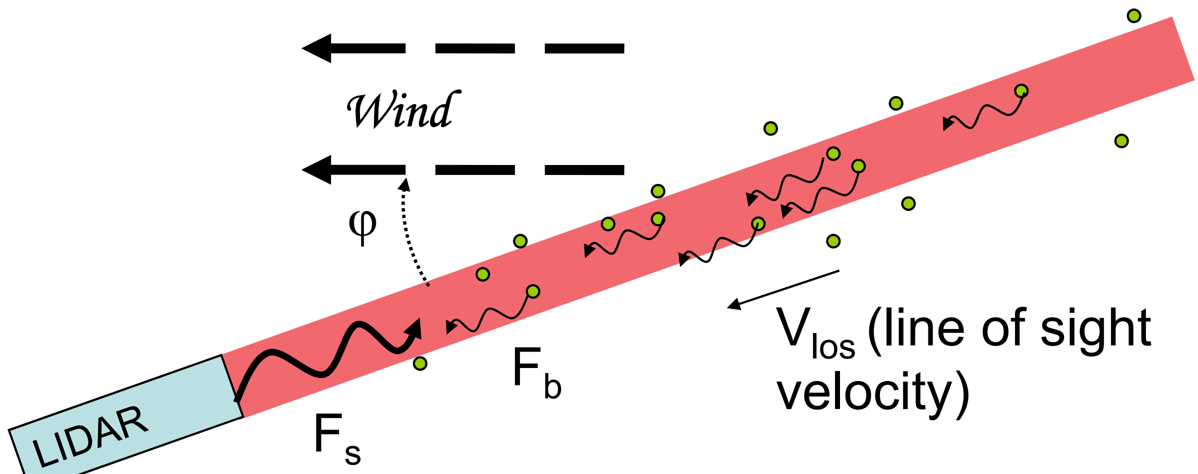
- Senior Scientist in Test and Measurements Program, Wind Energy Division, Risø DTU.
- 5 years lidar experience.
- Work package leader for
  - UpWind WP6 (Remote Sensing)
  - SafeWind WP2 (Remote Sensing)
- Active in IEC 61400-12-1 revision
- Current mission: to get lidars working properly in wind energy.

Overview

- Lidar state-of-the-art
- Problems in complex terrain
- Lidar vs metmast
- Using lidars in complex terrain

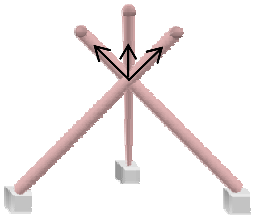
Lidar – state-of-the-art

Basic measuring principle

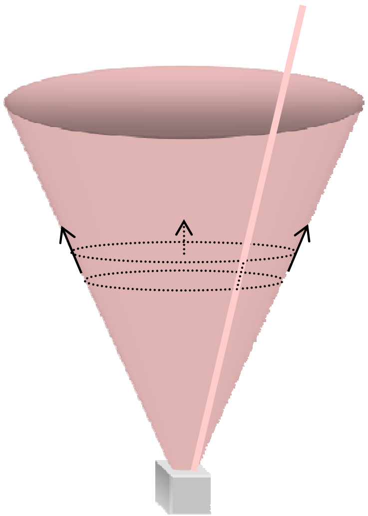


$$F_s - F_b = 2\, V_{los} / \lambda$$

Combining line-of-sight speeds to obtain the horizontal wind speed.



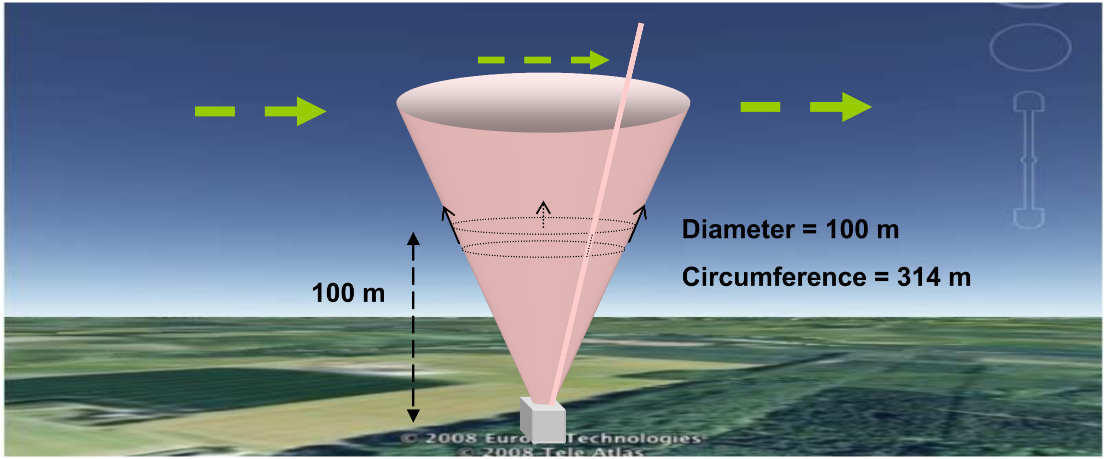
Ideal, no assumptions needed



Practical, we need to assume that the flow is homogeneous

How lidars work – conical scanning

The assumption is that the (mean) flow around the circumference at any height is uniform.



Different lidar types

Leosphere WindCube™

Pulsed

Range-gated

Simultaneous heights

Fixed probe-length

Natural Power ZephIR™

Continuous

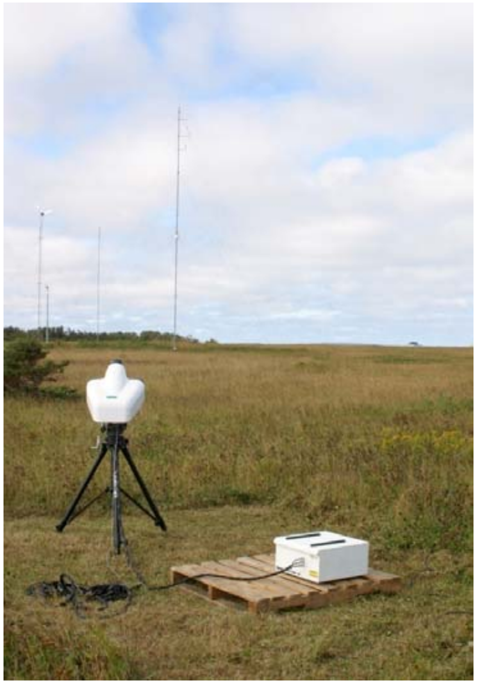
Focused

Sequential heights

Probe-length $f(H^2)$

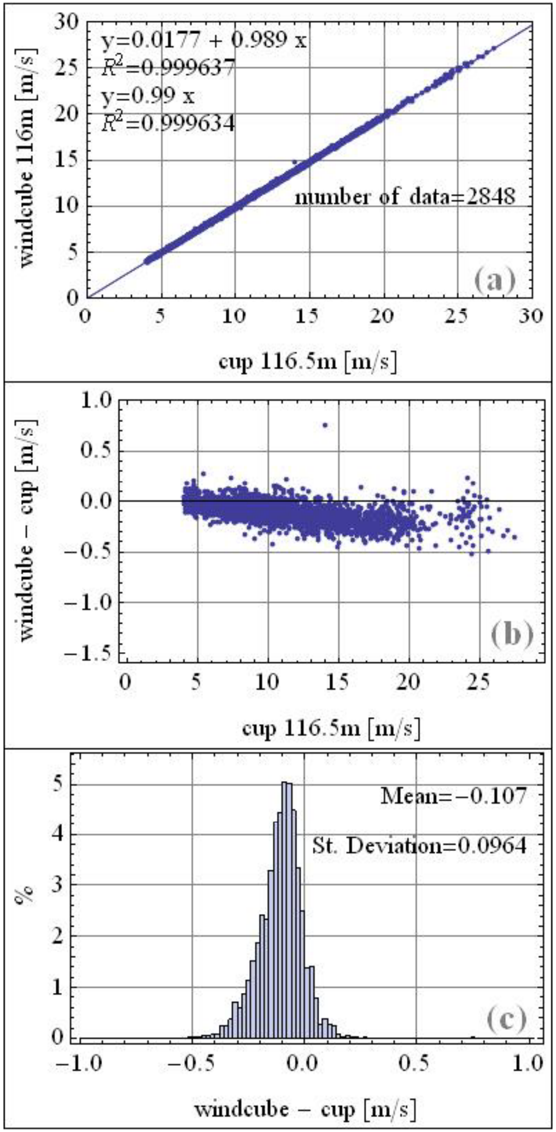
Newcomers

Galion



Vindicator

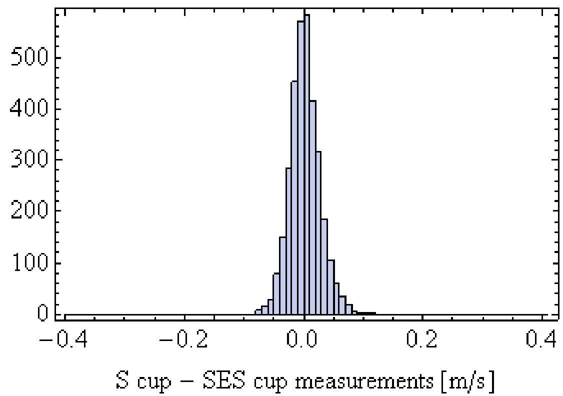
Good lidars are getting accurate
- in flat terrain!



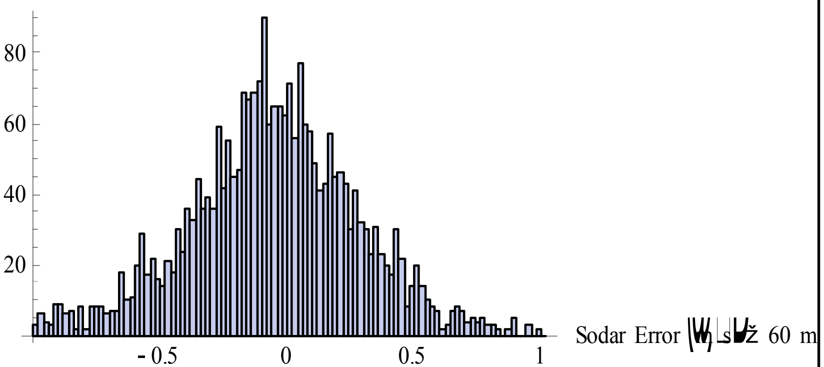
- Best lidars are within ±1.5% of traceable cup (for the heights we can test).
- Very low noise
- Cup anemometer calibration and cup-mast mounting uncertainties are the limiting constraints for assessing lidar accuracy.

Error standard deviation for different sensors - at 60 m height

Cup to cup

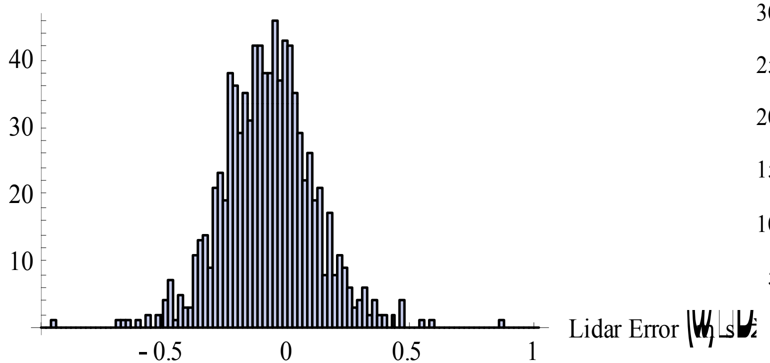


Scintek 2004



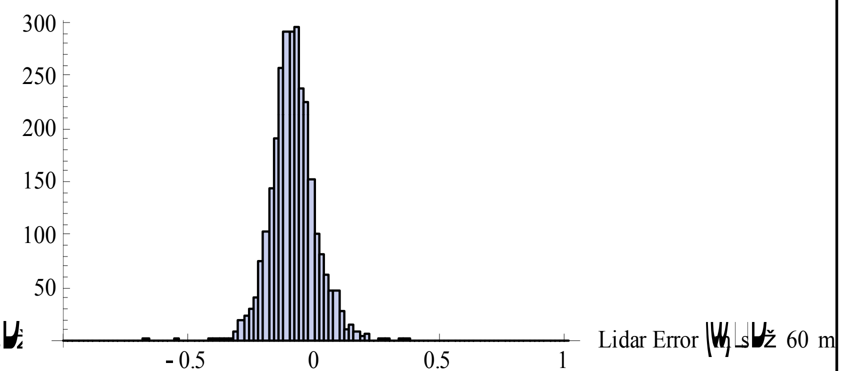
Scintek mean -0.08, STDEV: 0.37

Zephir 2009



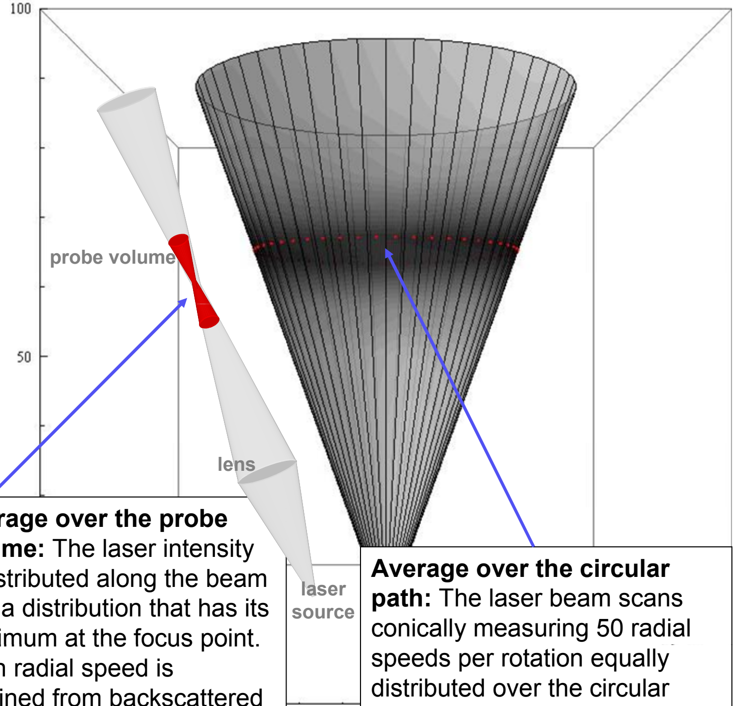
Zephir mean -0.08, STDEV: 0.18

Windcube 2009



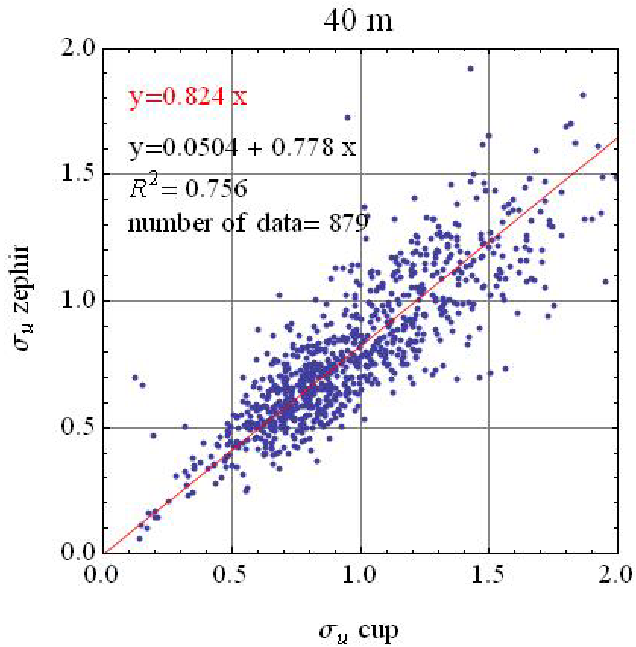
WC mean -0.08, STDEV: 0.09

Turbulence sensed by a lidar – spatial attenuation

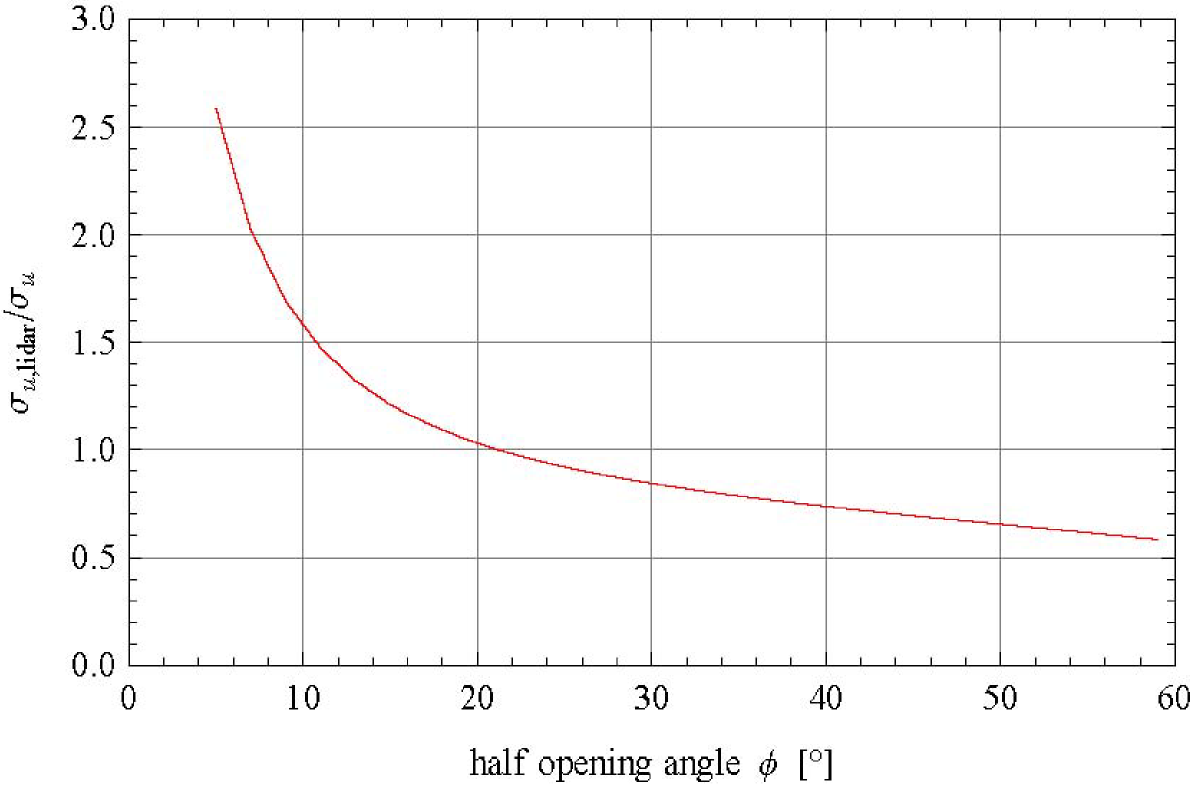


Average over the probe volume: The laser intensity is distributed along the beam with a distribution that has its maximum at the focus point. Each radial speed is obtained from backscattered signals averaged over the probe volume.

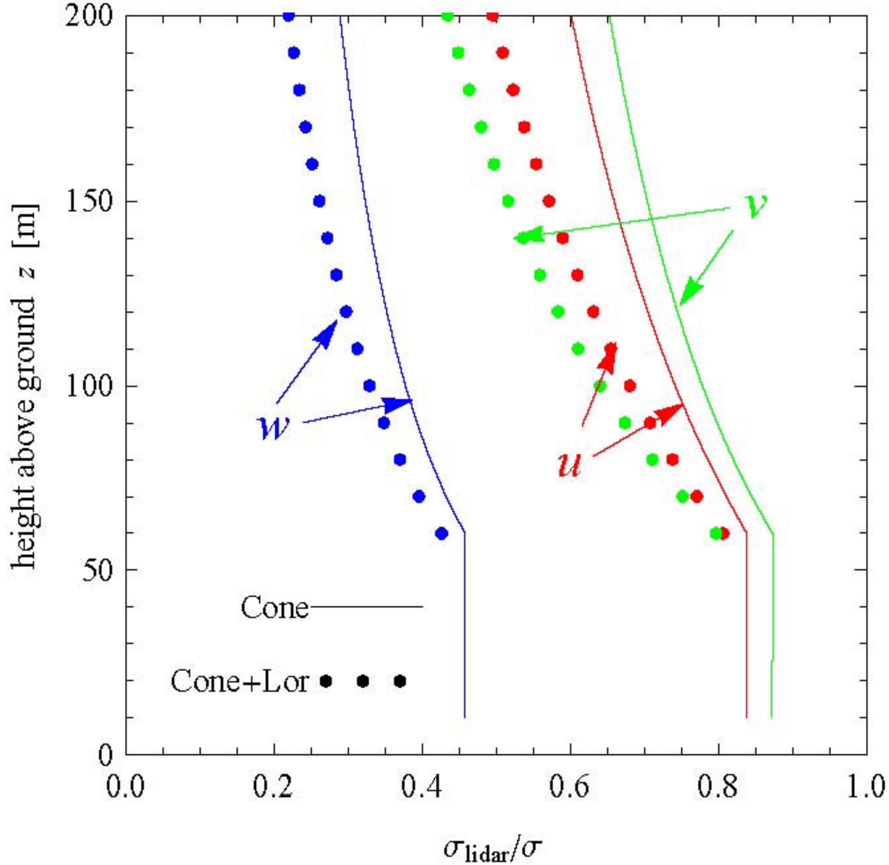
Average over the circular path: The laser beam scans conically measuring 50 radial speeds per rotation equally distributed over the circular path. The wind speed vector is calculated from the 50 (for a lidar scanning for 1second, 150 if it scans for 3 seconds) radial speeds.



The horizontal variance ’seen’ by the lidar depends on the cone angle.



The ratio also varies with height

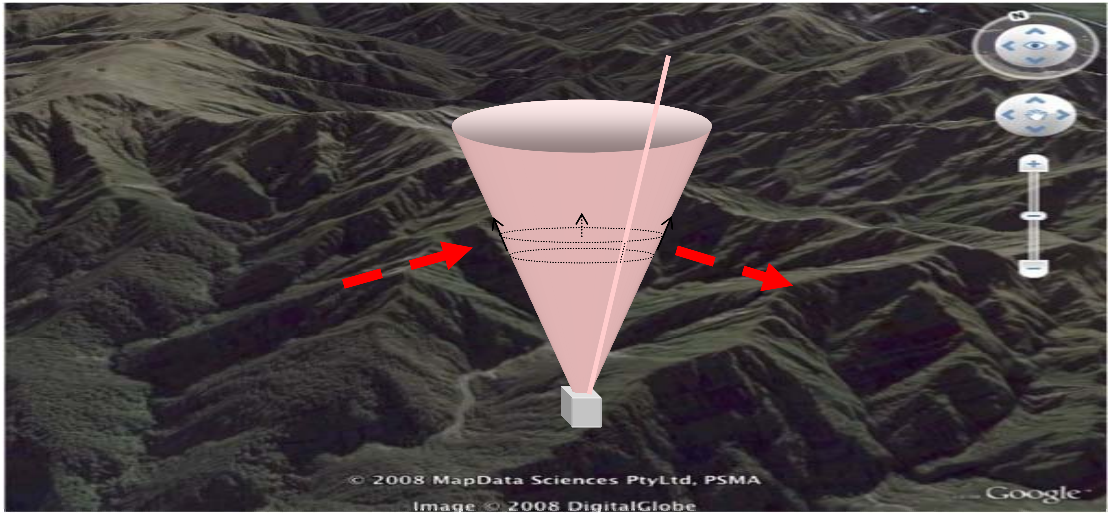


Problems in complex terrain

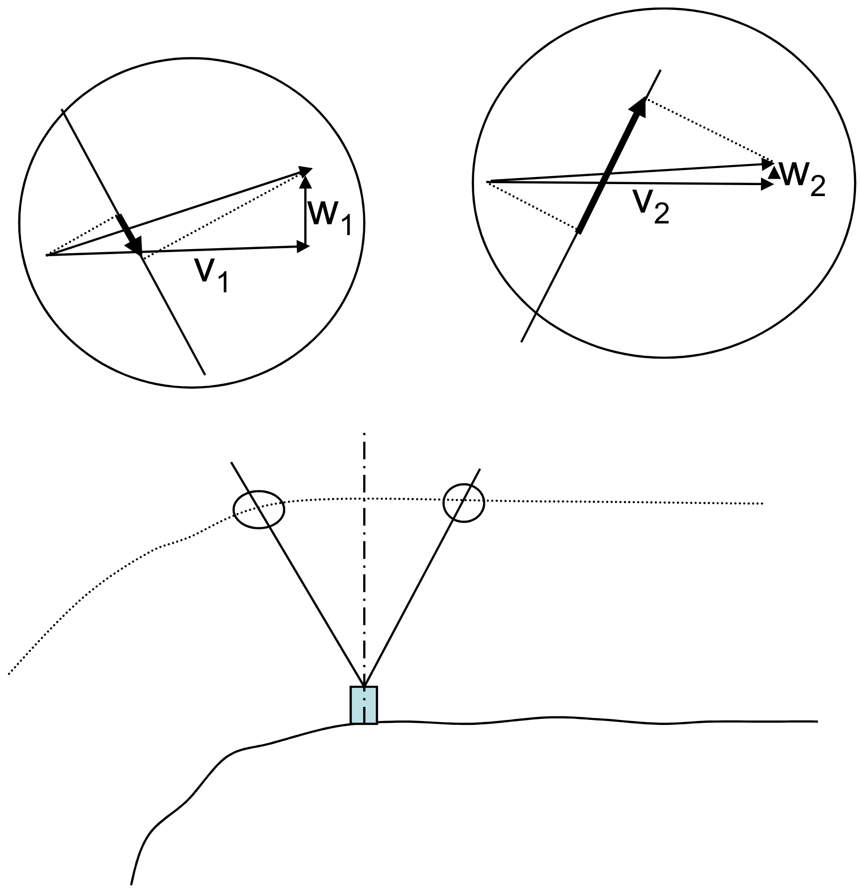
The basic problem

The assumption is that the flow around the circumference at any height is uniform.

This is almost never true in complex terrain.



Where most of the error comes from



The assumption is that w_1=w_2 (and v_1=v_2).

This will clearly not be the case if the flow is curved.

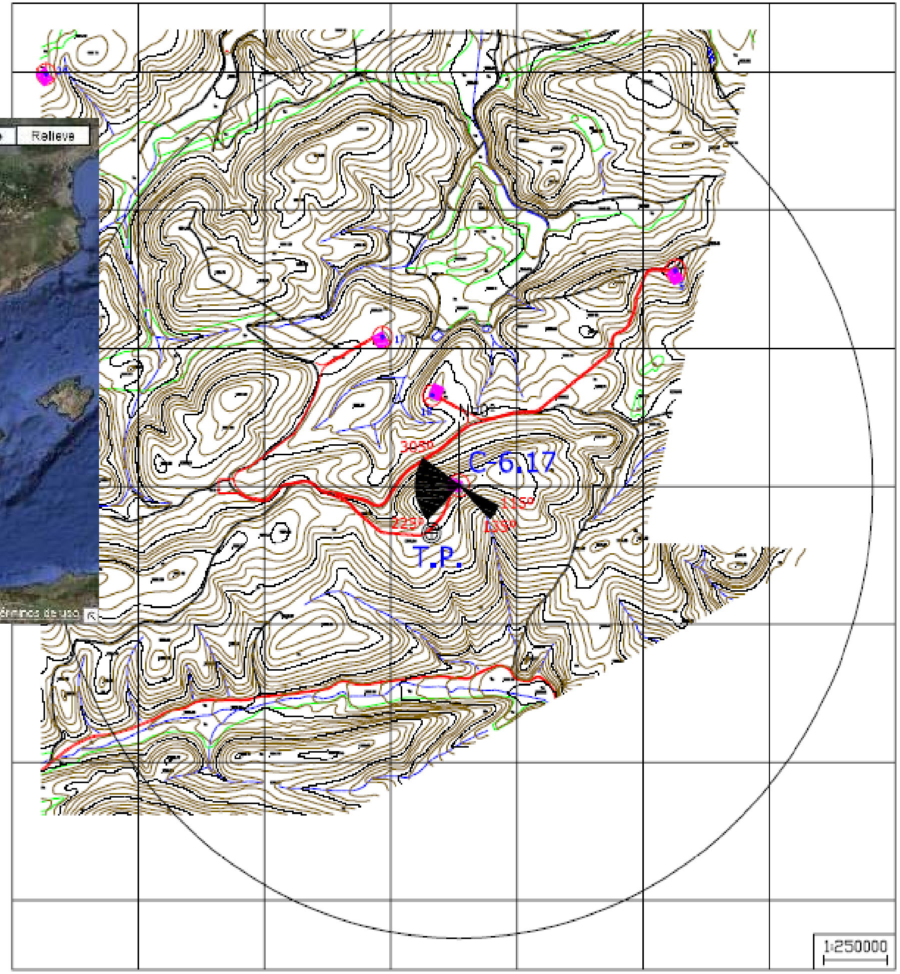
The consequence is a BIG error in calculating v.

You might end up with 10-20% error.

If the flow can be modelled, the lidar errors can be estimated

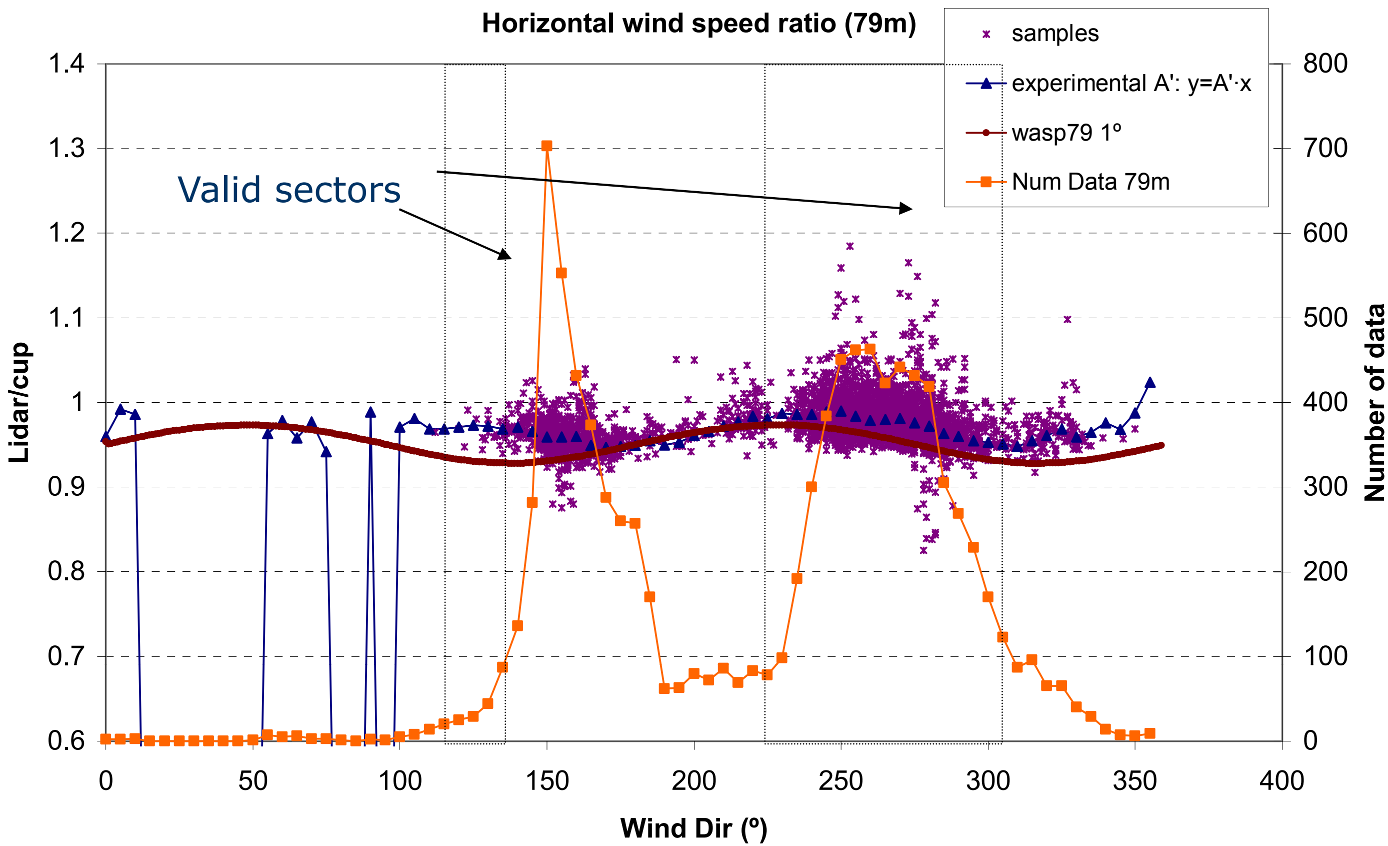
- Model the flow (need to do this anyway).
- At the lidar sensing positions, calculate the x,y,z components of the flow.
- Calculate what the lidar would have sensed as radial speeds (geometry).
- From the 4 (or 50) radial speeds, calculate the 'horizontal' speed the lidar would have reported.
- Relate the simulated lidar horizontal speed to the predicted horizontal speed at the centre of the lidar (or somewhere else).
- This is becoming established practice and lidar manufacturers offer packages to do this.

Measurements by CENER – Paula Gomez

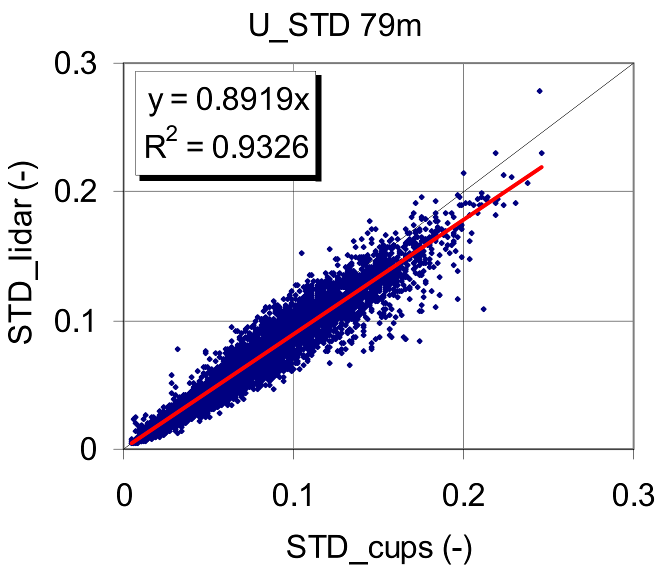


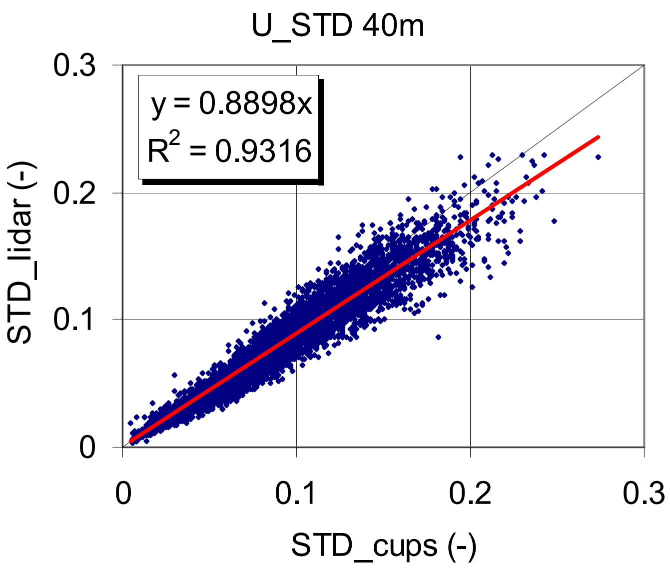

Mast
Lidar

Speed ratios and comparison to WEng



Turbulence comparisons in complex terrain

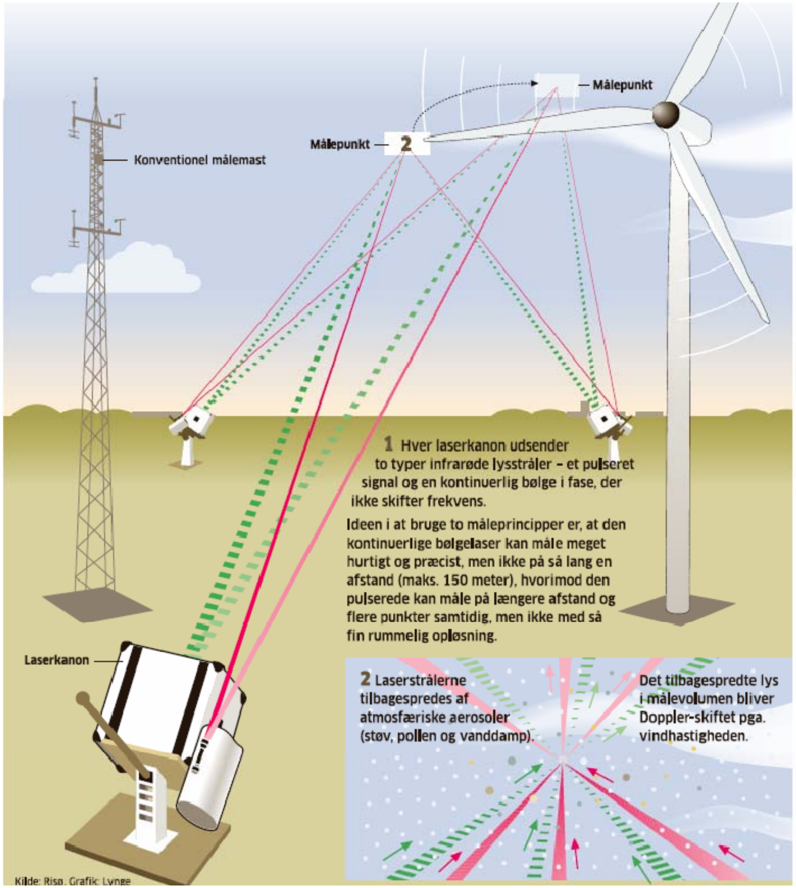




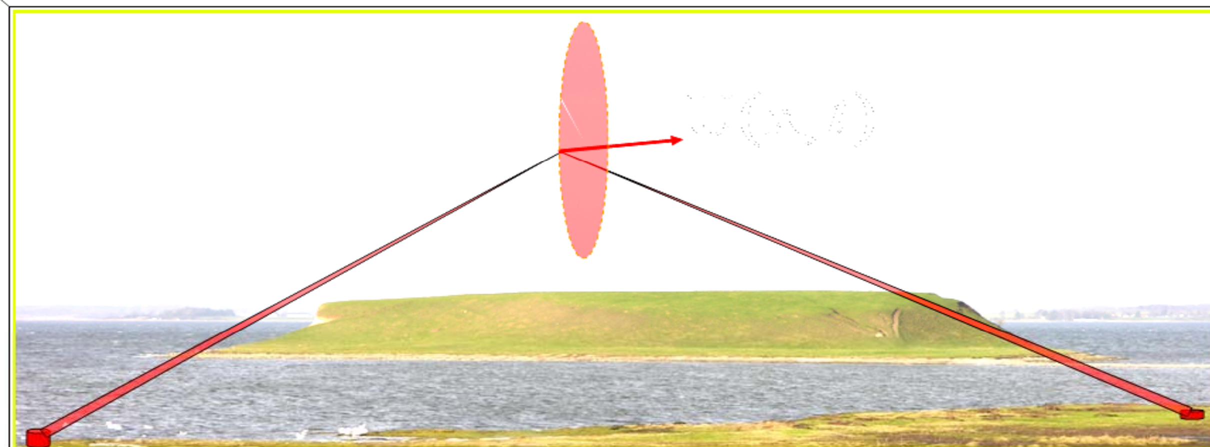
- STDlidar/STDcup~0.9
- Flat terrain results and theoretical analysis (Risø): ~0.8

We can not predict this well yet!

Doing true 3D turbulence measurements – Windscanner.dk



Long range Windscanner for complex terrain



Full Scale Laser Wind Scanner

Lidar vs metmast

Lidar vs metmast - accuracy

- Whilst we ’calibrate’ lidars using cups, we can never do better than the cup accuracy.

- Many mast measurements are not particularly good
  - Mast shadow and flow distortion
  - Bad calibrations

- Even in complex terrain, cup and lidar errors may well be comparable.

- Lidar verification requirements are driving improvements in cup calibration and mounting techniques.

Lidar vs metmast – vertical range

- Large wind turbines require shear measurements over most of the rotor in order to fairly represent the incoming energy in the wind.

- Power curve measurements may require this in the future. Good ones certainly will !

- Wind resource measurements should be made in the same way (over a vertical range comparable to the rotor disk).

- Even with hub-height wind ressource estimates, an actual lidar h-h speed can be much more accurate than an extrapolated value from a lower cup.

- Bottom line – going up in height is ’free’ for lidars, very expensive for cups.

Lidar vs metmast - price

- Assuming lidars can be used many times, their economics appear promising, especially for replacing high masts.

- There are also 'hidden/forgotten' lidar costs
  - Power supply
  - Maintenance
  - Repairs! (renting might be attractive)

- Well conducted lidar resource measurements should reduce the AEP uncertainty, giving more subtle economic benefits.

Lidars vs metmast - reliability

- No contest!
- Lidars improving but there is still a way to go.

Conclusion - Using lidars in complex terrain

- Need a mast as well?
  - No firm rules – maybe the banker's consultant decides!
  - If yes, include some 3D sonic anemometers!
  - If no, do some good CFD modelling and predict the lidar errors

- Measure where the streamlines (tilt) changes least.
  - Avoid hill tops
  - Slopes are not a problem, changing slope is.

- Don't use a CW lidar if there is a lot of low cloud

- Be careful interpreting the turbulence measurements – the (our!) uncertainty is quite high!

- Imperfect measurements are often better than no measurements if you know their limitations.

Thanks for listening!

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