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Turbulence measurement with a two-beam nacelle lidar

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Abstract

The analysis of the turbulence intensity measurement is performed for a lidar measuring horizontally with two beams. First the turbulence intensity measured by such a system was evaluated theoretically. The Mann model of turbulence was used to evaluate the true value of the turbulence intensity of the wind speed and the main effects of the lidar measurement principles on turbulence intensity measurement were modeled:

- A lidar senses the wind speed over the probe volume acting as a low pass-filter and thus cannot resolve high frequency turbulence;
- The horizontal wind speed is retrieved from the combination of the radial speeds measured along two line-of-sights with different orientations; this results in the contamination of the lidar turbulence intensity measurement from the transverse component of the wind field.

~~Secondly~~, the theoretical results were compared to experimental measurements. A two-beam nacelle lidar was placed on a platform at 60m height inside a lattice meteorological mast. The lidar was measuring forward at a range of 80 m. The turbulence intensity measured by the lidar was compared to that measured by the cup anemometer placed on a boom at the same height as the lidar and on the same met mast.

Objectives

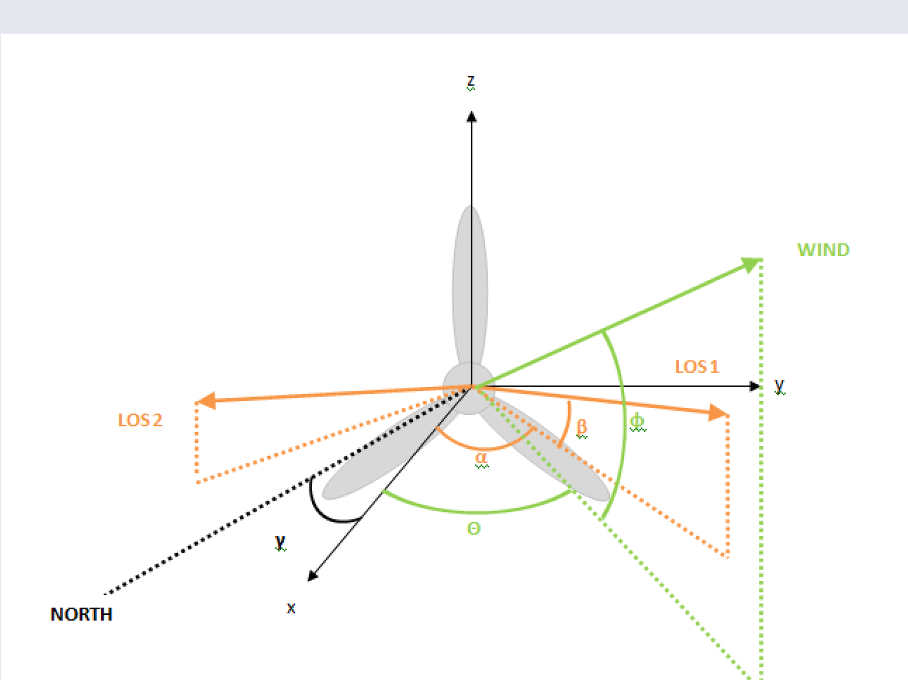
The objectives of this project were

1) to evaluate how well a two-beam nacelle lidar could measure the turbulence intensity;
2) to investigate the main reasons for the systematic deviation observed from the comparison to cup anemometer measurements.

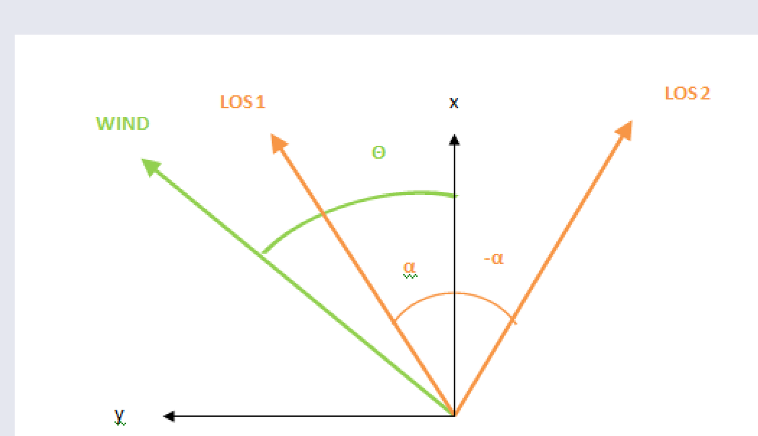
Method

The model:

A theoretical model was developed to estimate the wind speed variances measured by a ground-based lidar in [2]. This model was adapted to the case of a pulsed lidar with two horizontal beam separated by an angle of 30˚. The true variance of wind speed were given by the Mann model [3]. The backscatter intensity along each lidar beam was modeled by a triangular weighting function, with its maximum at the center of the range gate.



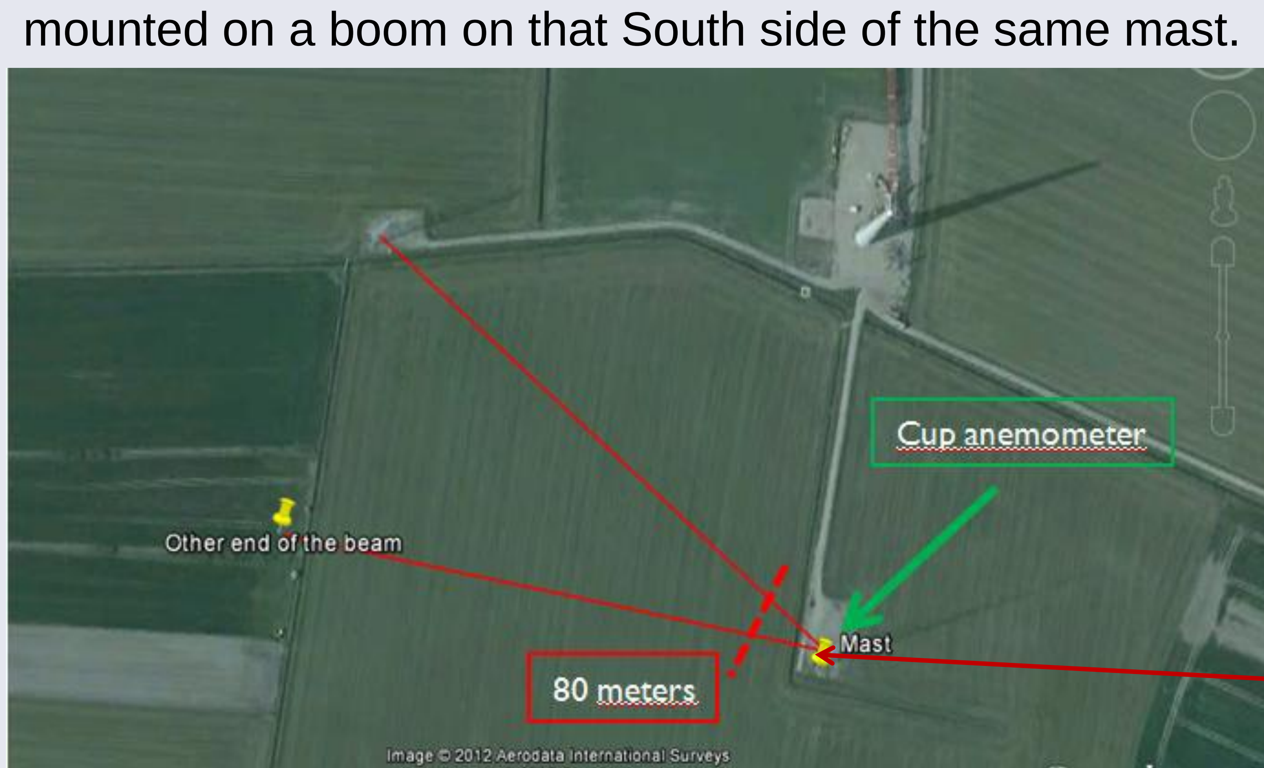
Sketch showing the lidar lines of sight and the wind vector. The x-axis is aligned with the lidar axis. α is the beam half-opening angle; β the beam vertical angle; Θ the horizontal wind direction and φ the vertical flow inclination



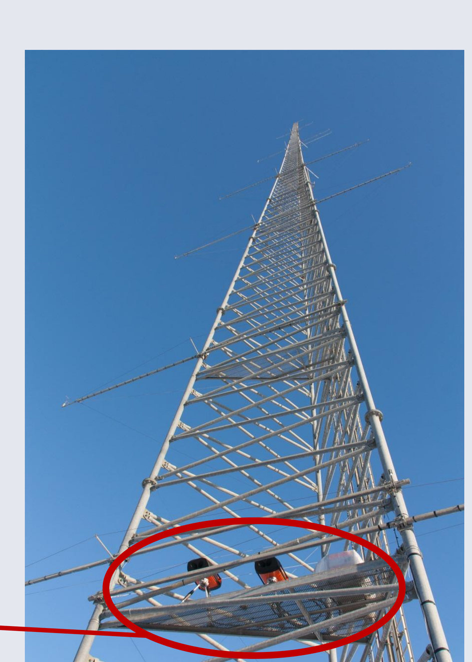
Simplified sketch showing the lidar lines of sight and the wind vector in the horizontal plane. The x-axis is aligned with the lidar axis. α is the beam half-opening angle; Θ the horizontal wind direction.

The measurements:

A Wind Iris lidar was installed on a platform at 60m above the ground inside a lattice mast, with the two lidar beams oriented towards West and North-West. The lidar was measuring at a range of 80m. The 10 minute wind speed variance measured by the lidar was compared to that measured by the cup anemometer mounted on a boom on that South side of the same mast.



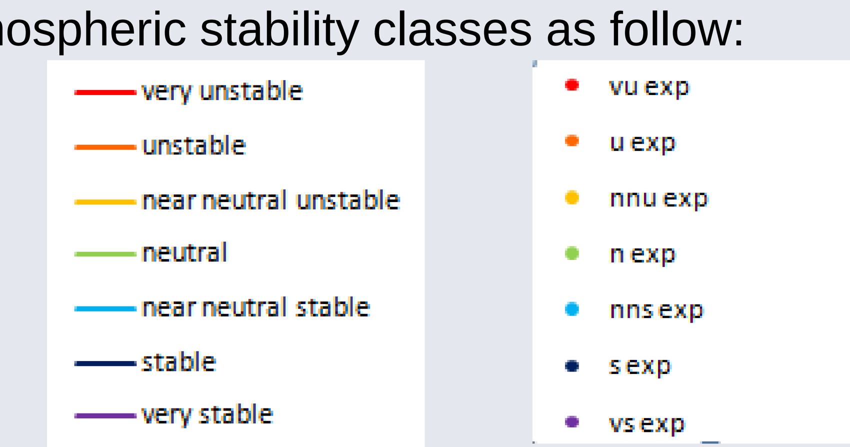
Top view of the experimental set-up

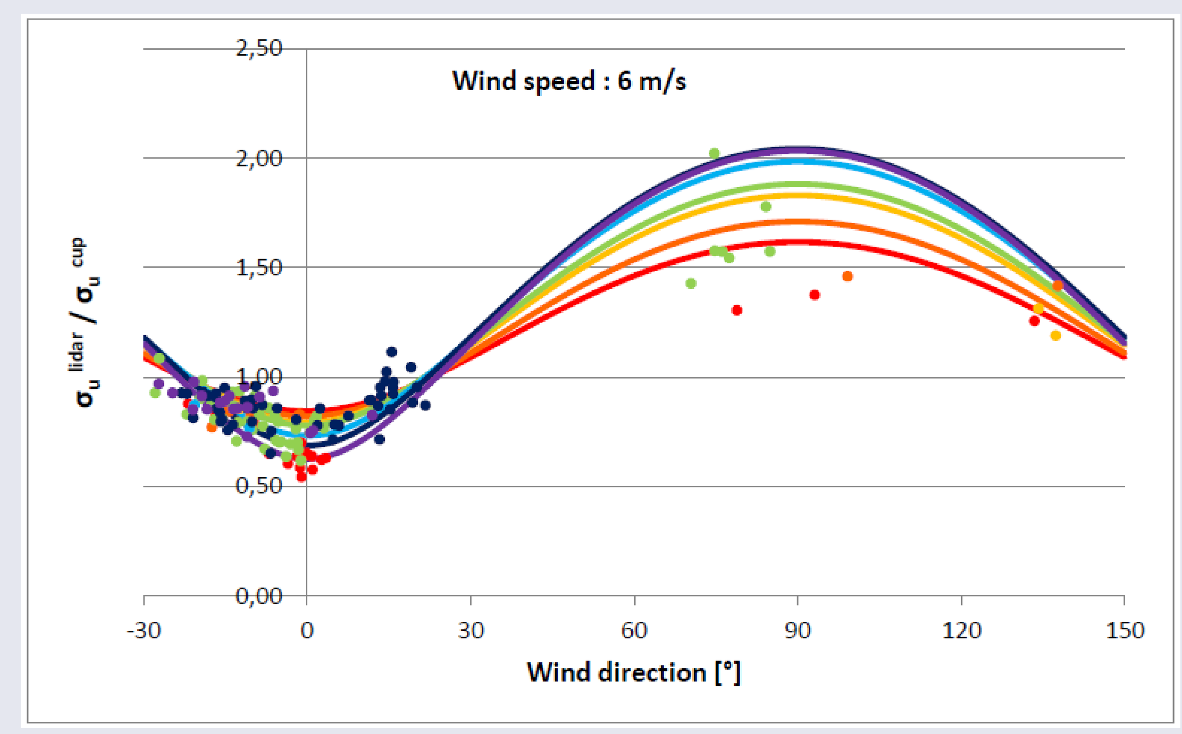


Lidars on the platform in the lattice mast at 60m a.g.l.

Results

The following graphs display the experimental measurement together with the results from the model. The dots represent 10 minute experimental data whereas the plain lines represent the analytical results. The various colors represent the different atmospheric stability classes as follow:

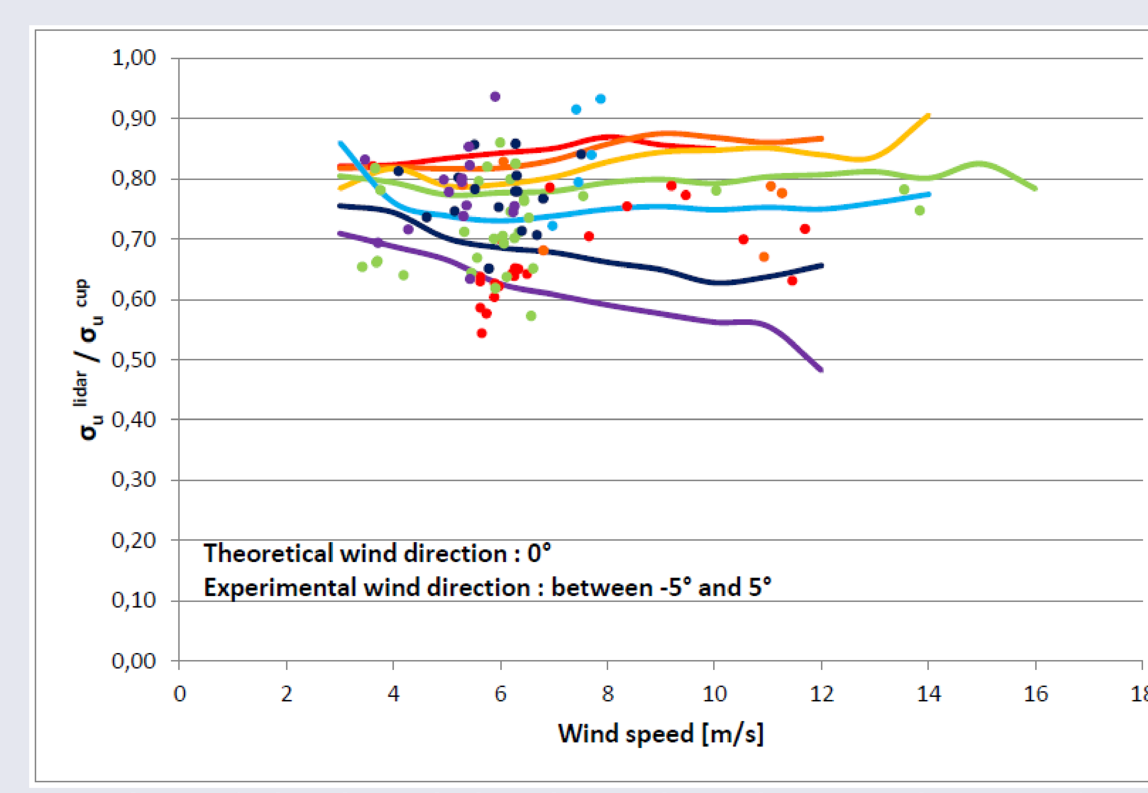




Comparison of the theoretical and experimental systematic errors for the longitudinal component of the wind speed as function of the wind direction relative to the lidar axis, for various atmospheric stability classes (different colours); for the 6 m/s wind speed bin.

The systematic error in the standard deviation measured by the nacelle lidar depends strongly on the wind direction relative to the lidar axis. For a nacelle mounted lidar on a well-aligned wind turbine (small yaw error) this angle would typically be close to 0˚. Thus **a nacelle mounted lidar will normally underestimate the standard deviation of the wind speed**.

According to the model, **the systematic error in the wind speed variance depends clearly on the atmospheric stability** with a 15% underestimation predicted for unstable conditions and 40% for stable conditions. The systematic error does not depend on the wind speed, except for stable conditions. However we have not been able to identify the stability dependence in our experimental data.



Comparison of the theoretical and experimental systematic errors for the longitudinal component of the wind speed as function of the wind speed; for various atmospheric stability classes (different colours); for the 0°wind direction bin.

Conclusions

• **The lidar tends to underestimate the wind speed variance** because of two effects:

- ➢ The lidar senses the wind speed over a volume (defined by the probe volume and the space between the two beams), which prevents the lidar from resolving the small turbulence structures.
- ➢ The horizontal wind speed is retrieved by combining the radial speeds measured in two different directions, separated by an angle of 30˚. The lidar variance measure is contaminated by the transverse component of the wind field.

• The theoretical analysis showed that the ratio of turbulence intensity given by the lidar with respect to the true turbulence intensity is expected to **vary with:**

- ➢ **the direction of the wind relative to the lidar axis orientation;**
- ➢ **the atmospheric stability;**
- ➢ **the wind speed (only under stable conditions).**

• The experimental data confirm the variation of the turbulence intensity reported by the lidar relative to the turbulence intensity measured by the cup anemometer with the relative wind direction. However the influence of the atmospheric stability and wind speed are not particularly evident, because of the poor distribution of the data.

References

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3. The spatial structure of neutral atmospheric surface layer turbulence, J. Mann, J. Fluid Mech., 273, 141-168 (1994)

Aknowledgements

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