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Application-oriented classification of lidar profilers - or: Introducing lidars to power performance

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Classification of lidar profilers
or: how to introduce lidars to power performance testing

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Summary

Commercially available lidars have reached a level of accuracy where they can be considered as serious alternative to standard cup anemometers – especially with significant advantages in large heights or in areas where it is difficult and costly to set up a measuring mast. A further benefit is that lidars can measure wind speeds and wind directions simultaneously at different height levels, why they are particularly suited for the measurement of vertical wind shear.

A standardized application to power performance testing (as well as more generally resource assessment), however, requires a traceable classification scheme that allows for a complete evaluation of the uncertainty of the measurements performed by the lidar.

The procedure, we propose, is based on the verification of a ground-based lidar profiler against a tall meteorological mast that is equipped with reference sensors at different height levels. Following the recommendations for the evaluation of cup anemometers in IEC 61400-12-1, the verification test is analysed in terms of both a calibration and a classification of the tested instrument. In this way, traceability is transferred from the reference sensors to the tested lidar and a respective lidar uncertainty is deduced accordingly.

The work presented here has been carried out as part of the EU FP6 UpWind project (WP 6) and is directly connected to IEC MT12-1 currently revising the IEC 61400-12-1 standard for power performance testing.

In 2009, for this purpose, the Lidar Acceptance Project was initiated to organize the work on lidar testing and classification issues related to IEC standard revision in a satellite group.

Concept of lidar verification

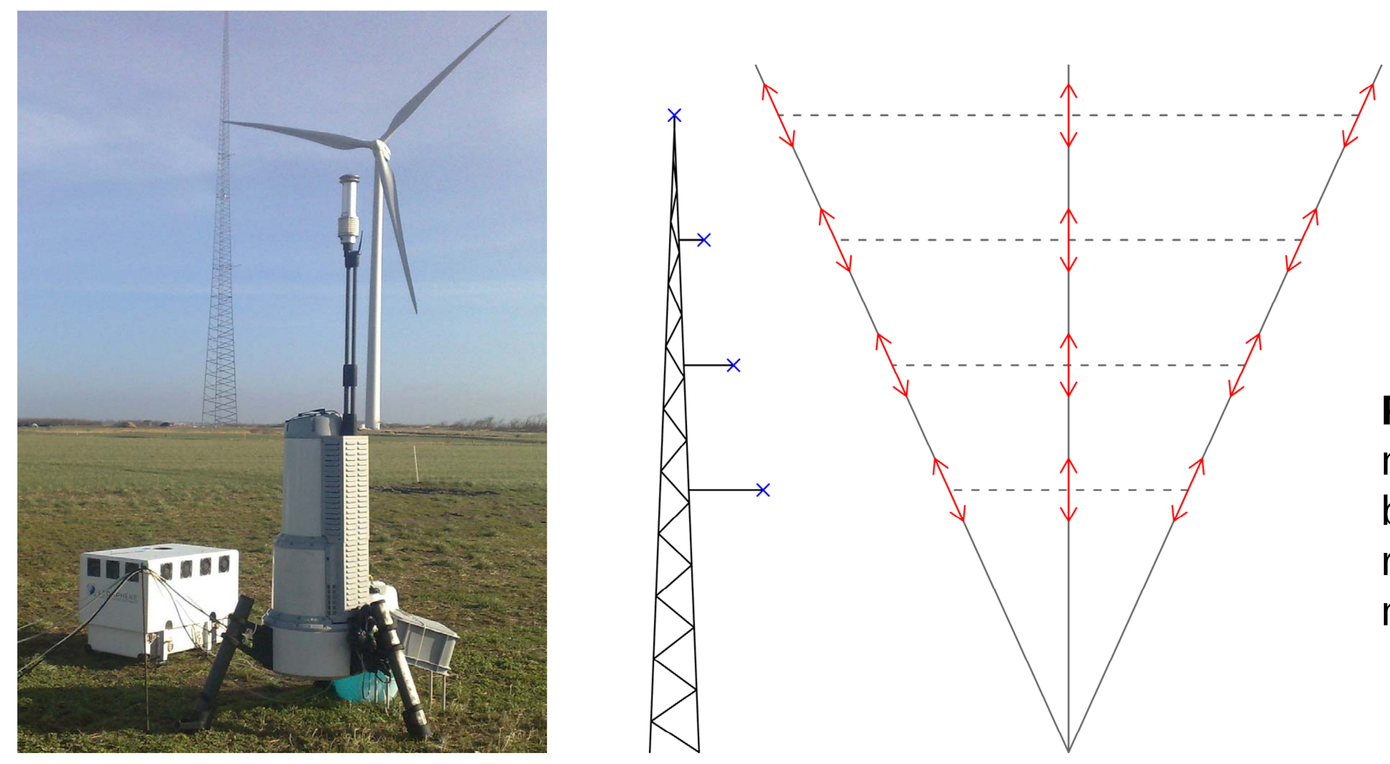


Figure 1: Setup of verification test – meteorological mast equipped with reference sensors and ground-based lidar. Blue crosses show the locations of the reference sensors, red arrows indicate the measuring volume of the lidar.

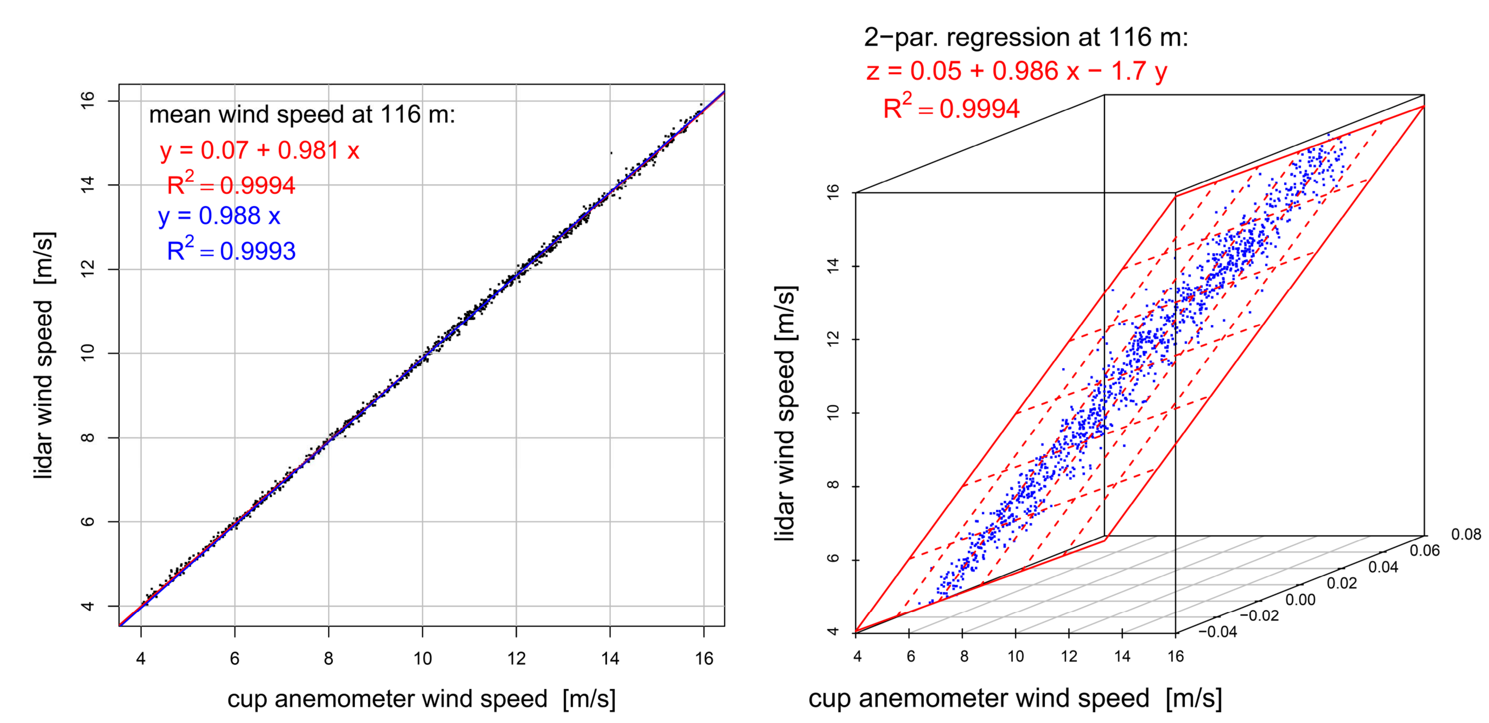
Verification test (= comparison of lidar measurements to traceable reference sensors, ie cup anemometers and wind vanes, at different heights and under a set of pre-defined conditions)

→ analysis of data in terms of different regression models as basis for **lidar calibration** (correction for systematic bias)

→ evaluation of lidar error (= deviation between lidar and reference measurement) as basis for **classification** (uncertainty due to operational characteristics)

Figure 2: Results for different regression models – (left) 1-parametric regression with and without offset ($y = C + k\,x$ and $y = m\,x$, resp.; y: lidar wind speed, x: reference wind speed); (right) 2-parametric regression ($z = D + k_u\,x + k_g\,y$; z: lidar wind speed error, x: reference wind speed, y: wind speed gradient).

For more details about the data, the test site and the procedures of analysis see Ref. 3.



Estimation of uncertainties

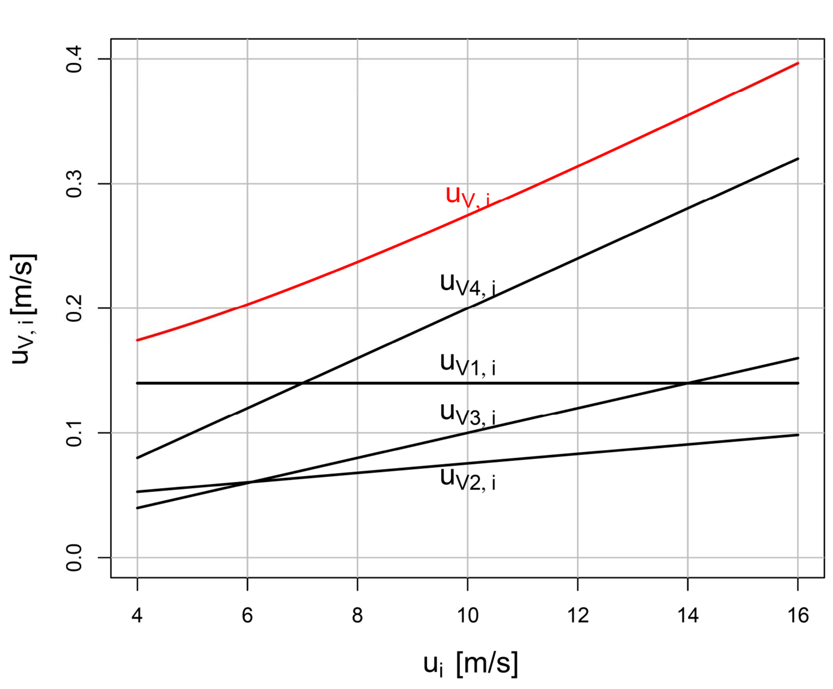


Figure 3: Uncertainty components of cup anemometer measurements according to IEC 61400-12-1 (with typical numbers in parentheses) –

$u_{V1,i}$: uncertainty of anemometer calibration (0.14 m/s),
$u_{V2,i}$: uncertainty due to operational characteristics / classification ($(0.05\ \text{m/s} + 0.005\ u_i)\cdot k / \sqrt{3}$; $k = 1.31$),
$u_{V3,i}$: uncertainty of flow distortion due to mounting effects (1%),
$u_{V4,i}$: uncertainty of flow distortion due to terrain (2%),
$u_{dV,i}$: uncertainty in data acquisition system (-);
$u_{V,i} = (u_{V1,i}^2 + u_{V2,i}^2 + u_{V3,i}^2 + u_{V4,i}^2 + u_{dV,i}^2)^{1/2}$.

Uncertainty budget for lidar measurements:

- reference uncertainty, ie combined uncertainty of cup anemometer measurements ($u_{ref} \equiv u_V$)
- lidar calibration uncertainty – defined by uncertainty of calibration function (if calibration is applied; $u_{lid.\,cal.}$)
- lidar classification uncertainty – estimated by $[\sum_i \varepsilon_i/(N-1)]^{1/2}$ (ε_i: lidar error) with respect to covered range of external conditions ($u_{lid.\,class.}$)

$u_{lid.,\,i} = (u_{ref,i}^2 + u_{lid.\,cal.,i}^2 + u_{lid.\,class.,i}^2)^{1/2}$

\+ additional uncertainty due to mounting / setup of lidar
\+ additional uncertainty due to specific conditions during application not covered by verification test

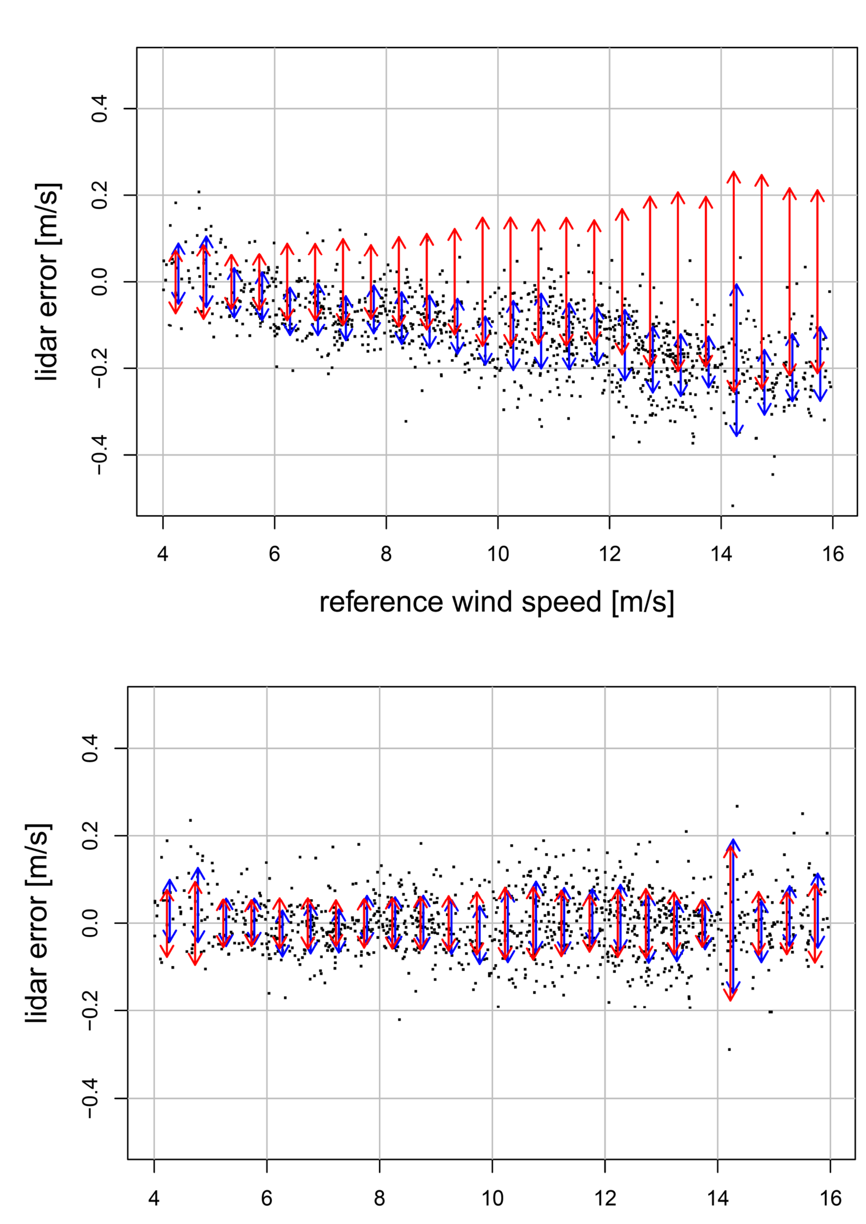


Figure 4: Standard deviation (blue arrows) and square root of second moment (as estimate for symmetric uncertainty; red arrows) of lidar error for individual wind speed bins – (top) before and (bottom) after calibration of lidar wind speed values applying the regression functions (here: results for 2-parametric model).

Discussion

The presented lidar verification scheme prepares basis for
- traceable lidar measurements (to the reference sensors)
- repeatable lidar measurements (with respect to a well defined uncertainty)
- a consistent evaluation of uncertainties (in line with IEC 61400-12-1 and GUM).

Results of the verification test are evaluated as calibration and as classification at the same time – with the drawbacks that the calibration functions depend on the specific external conditions and only a certain range of the possible conditions is covered by the classsification.

The lidar calibration is based on a reference that is itself associated with a significant uncertainty. A necessary assumption is that the reference is un-biased and that the uncertainties are symmetrically distributed (cf. Ref. 2).

Lidar calibrations depend not only on the actual site conditions (eg vertical wind shear, turbulence) but also on the measurement height. Extrapolations between verification test and application are to be considered.

Some (rough) numbers from our observations:
$u_{lid.\,class.} \approx 0.2$ m/s without calibration → 0.1 m/s with calibration;
deviations due to varying external conditions or height extrapolations 0.01-0.02 m/s (but also extreme cases with larger deviations);
$u_{lid.\,cal.}$ negiligible (for all three introduced models)

References

1. IEC 2005 Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines (IEC 61400-12-1 International standard)
2. ISO 1995 Guide to the Expression of uncertainty in measurements (GUM), DS/ENV 13005
3. M Courtney, R Wagner, P. Lindelöw 2008 IOP Conf. Series: Earth and Environmental Science 1, 012021