White Box vs. Black Box Calibration of a 2-Beam Nacelle LiDAR

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Abstract

The two existing approaches of calibrating nacelle mounted LiDAR where tested at the remote sensing test field of Deutsche WindGuard on a LiDAR of type Avent Wind Iris. The calibration campaign focused on the comparison of the two methods.

Procedure

White Box (also Line-Of-Sight, LOS):

1. Calibration of intermediate measurement results, e.g. radial wind speeds
2. Error propagation through reconstruction algorithm to horizontal wind speed

Black Box (BB):

1. Apply reconstruction algorithm
2. Calibration of physical quantity of interest (e.g. horizontal wind speed)

Measurements were performed in the following order:

1. LOS-calibration Beam 0 (Feb. 2017)
2. LOS-calibration Beam 1 (Mar. 2017)
3. Black Box calibration (Apr. – Jun. 2017)

Measurement Setup

The LiDAR was placed on the ground 360 m distant from the reference met mast of DWG's remote sensing test field. The side mounted cup anemometer at 60 m was chosen as reference anemometer. This resulted in a tilted geometry with 9° upward angle to the horizontal plane.

Alignment of the LiDAR was performed by installing a visible guidance laser with a defined offset to the infrared beam. The visible laser was aimed at a retroreflector mounted on the mast at the height of the cup anemometer.

LOS: Beam of interest is located close to the anemometer

BB: Centre between probe volumes is located close to the cup anemometer.

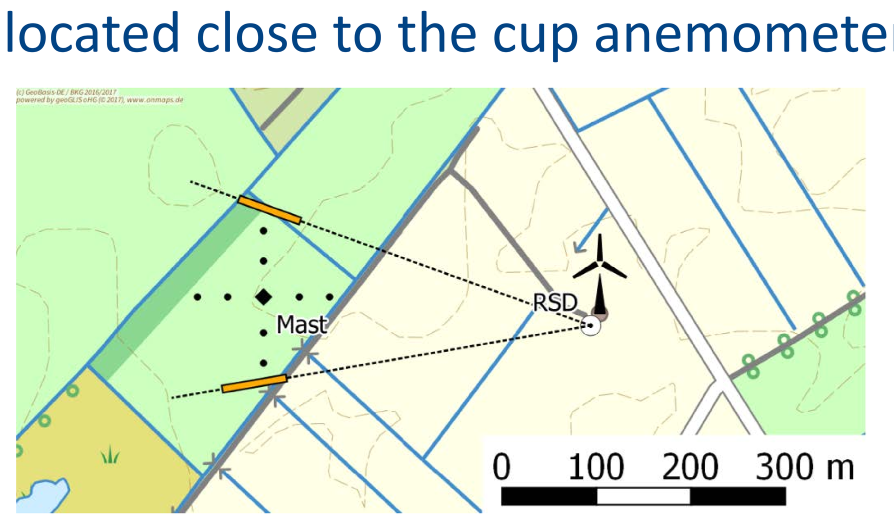

Fig. 1: Sketch of measurement configuration (BB)

References

1. M. Courtney; DTU-Wind Energy-E-0020, 2013
2. A. Borraccino et. al.; DTU Wind Energy-E-0086, 2015
3. GUM, ISO/IEC Guide 98-3:2008

Results

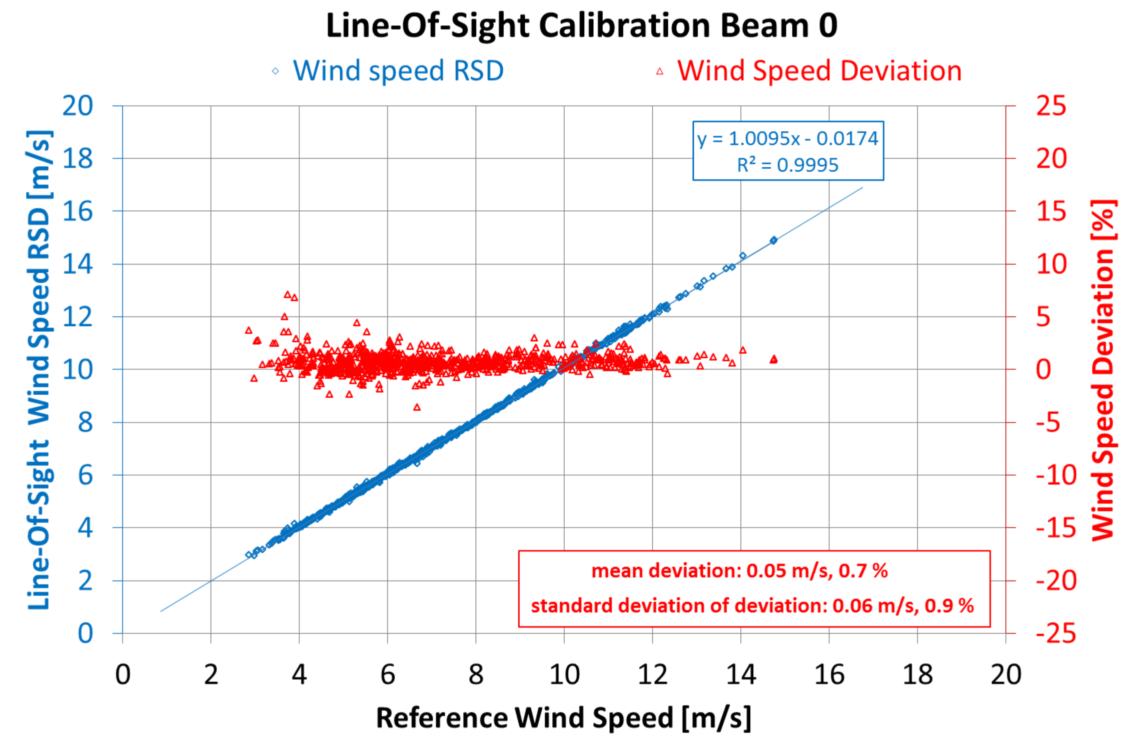

Fig. 2: Scatter of 10-minute data of LOS calibration. Deviations are positive if LiDAR overestimates wind speed. Reference wind speed is the one of the cup anemometer projected onto the direction of the beam.

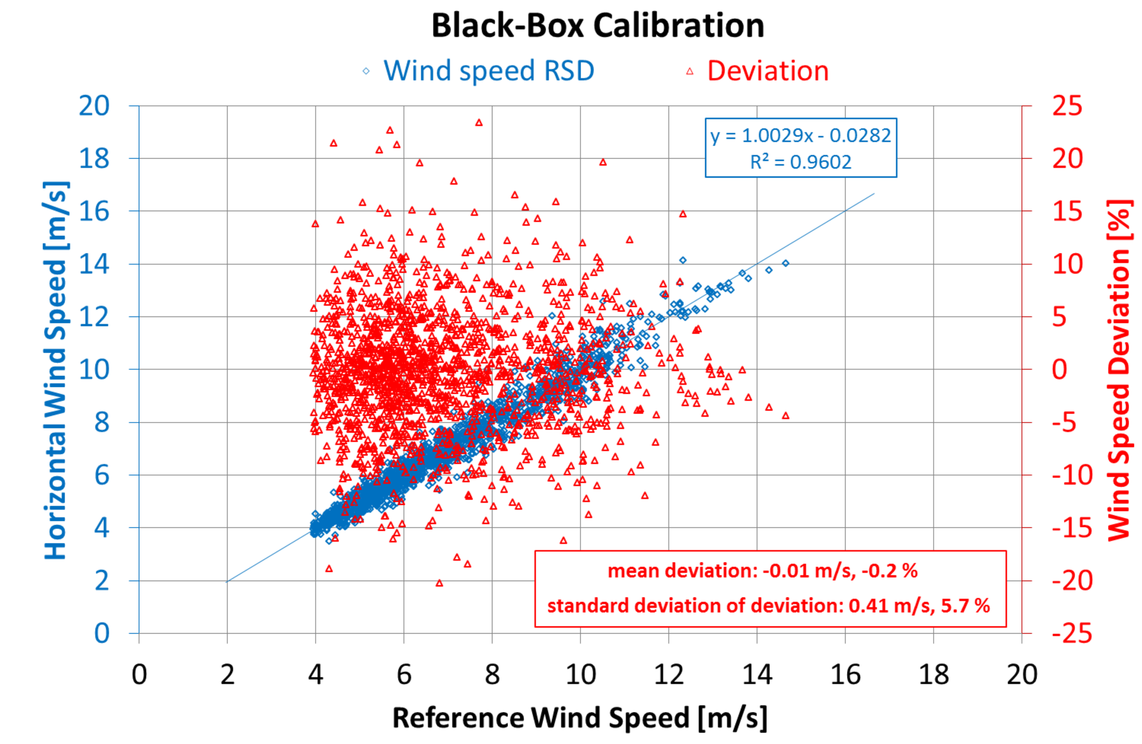

Fig. 3: Scatter of 10-minute data of BB calibration. Deviations are positive if LiDAR overestimates wind speed. Reference wind speed is the one of the cup anemometer projected onto the plane spanned by the beams.

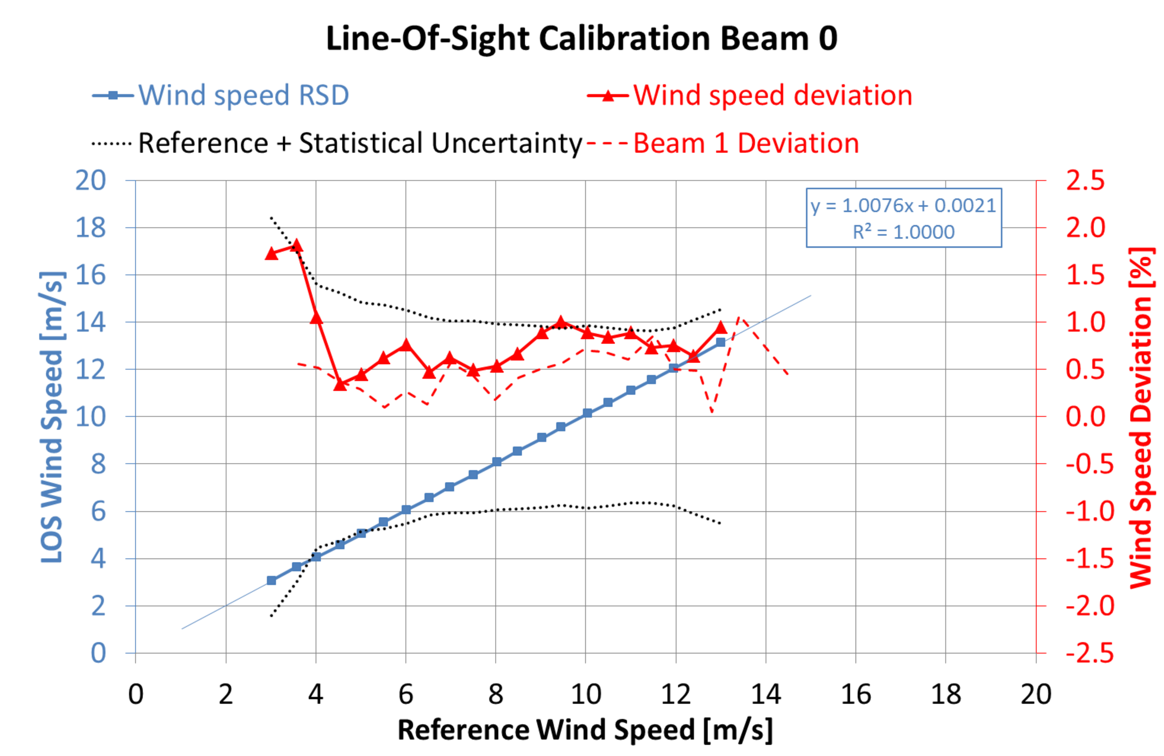

Fig. 4: Bin analysis of LOS calibration. Deviations and reference wind speed defined as above.

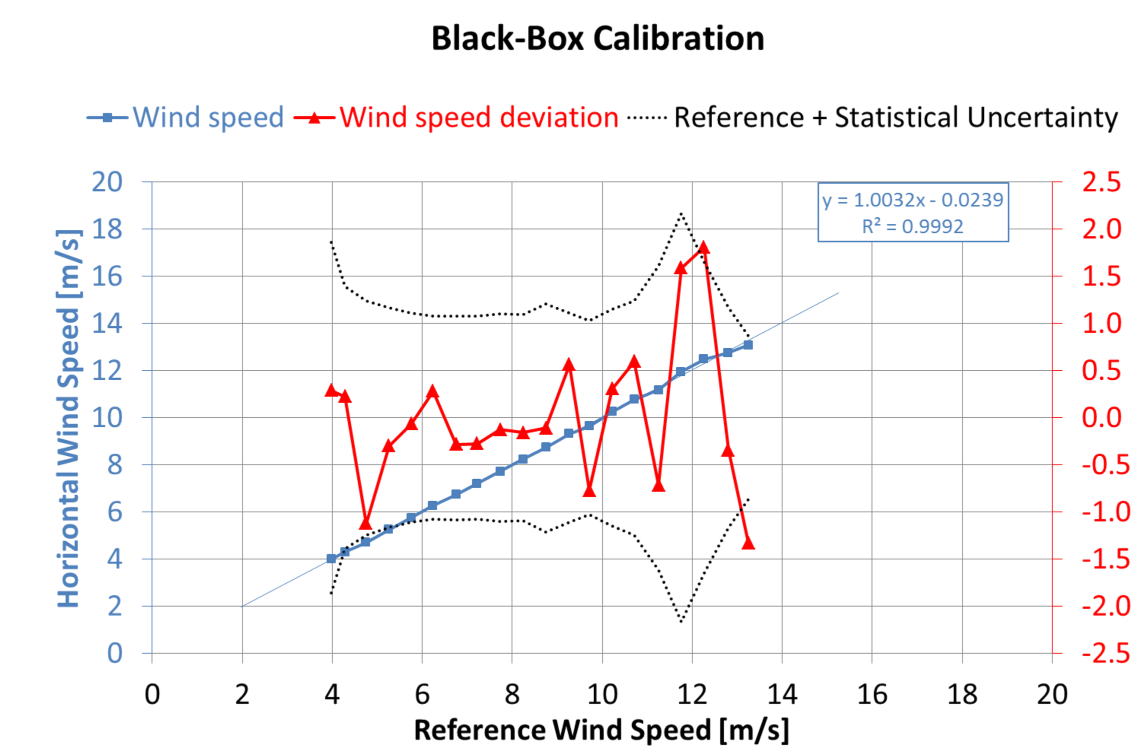

Fig. 5: Bin analysis of BB Calibration. Deviations and reference wind speed defined as above.

Uncertainty Analysis

A comprehensive analysis of uncertainty sources impacting the measurement accuracy was made based on but not limited to existing procedures (e.g. [1], [2]). Table 1 and Figure 6 summarise the considered uncertainty components.

The uncertainty sources were propagated to uncertainties of horizontal wind speed according to methods described in GUM [3].

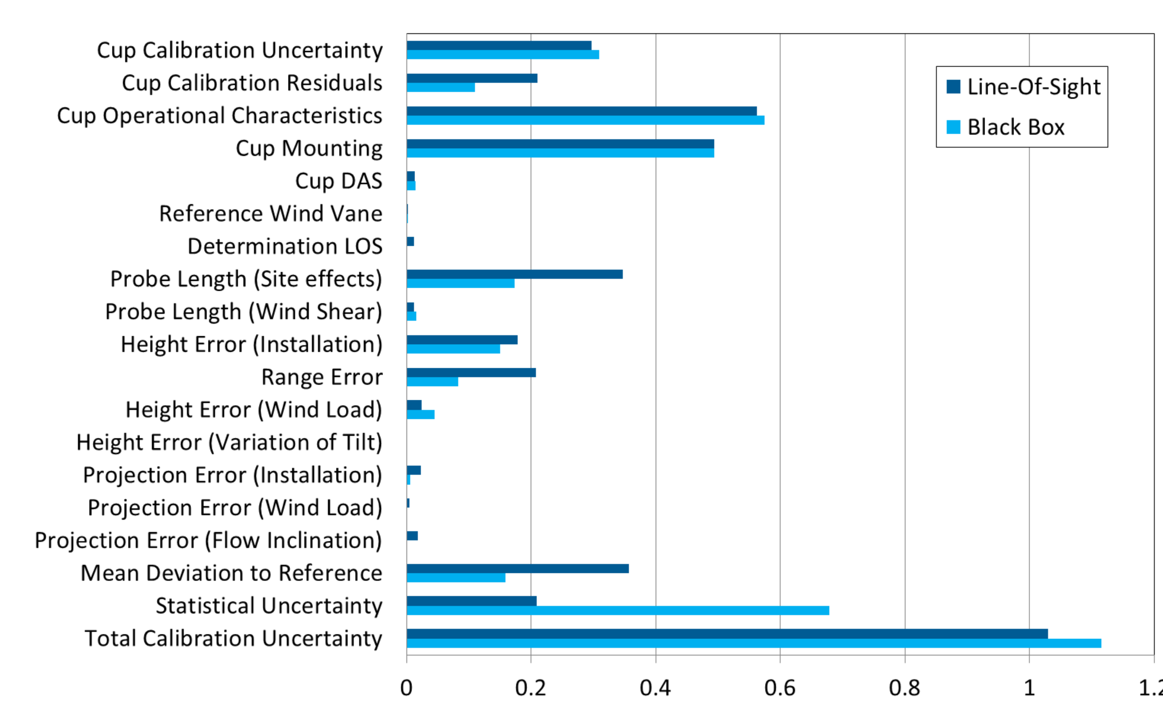

Fig. 6: Impact of individual uncertainty components on horizontal wind speed.

No.	Source	Unc.Type	Correlation over Beams	Uncertainty at 10 m/s [%] LOS	Uncertainty at 10 m/s [%] BB
	Reference Anemometer			**0.833**	**0.835**
1	Calibration Uncertainty	B	1	0.297	0.309
2	Calibration Residuals	B	1	0.211	0.110
3	Operational Characteristics	B	1	0.563	0.575
4	Mounting	B	1	0.494	0.494
5	Data Acquisition	B	1	0.014	0.014
	Relative Wind Direction			**0.012**	**0.002**
6	Reference Wind Vane	B	1	0.002	0.002
7	Determination of LOS Direction	B	0	0.012	0.001
	Probe Length of Wind Iris			**0.348**	**0.174**
8	Site Effects	B	1	0.348	0.173
9	Wind Shear	B	1	0.012	0.016
	Height Error			**0.269**	**0.178**
10	Installation	B	0	0.179	0.150
11	Range Error	B	1	0.208	0.083
12	Pre-tilt by Wind Load	B	1	0.024	0.046
13	Variation of Tilt	B	1	0.000	0.000
	Projection Error			**0.029**	**0.006**
14	Installation	B	0	0.023	0.006
15	Pre-tilt by Wind Load	B	1	0.004	0.000
16	Flow Inclination	B	1	0.018	0.002
	Calibration Measurements			**0.414**	**0.697**
17	Mean Deviation to Reference	B	1	0.358	0.158
18	Statistical Uncertainty	A	0	0.209	0.678
	Total Calibration Uncertainty			**1.029**	**1.116**

Tab. 1: Included uncertainty components and their impact on final measurement uncertainty of horizontal wind speed.

Conclusions

- Both calibration approaches were successfully performed in tilted configuration with acceptable overall uncertainty.
- LOS-calibration results in high correlation and low statistical uncertainty.
- BB-calibration suffers from high scatter, resulting in longer measurement period than LOS-calibration.
- High scatter in BB-calibration reflects impacts on measurement uncertainty not covered by LOS-calibration but potentially present during LiDAR application. Possible solution: Classification of reconstruction algorithm

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