PO.100

Radial wind speed Calibration uncertainty of nacelle-based profiling Lidars

Antoine Borraccino, Michael Courtney and Rozenn Wagner
DTU Wind Energy, Test and Measurements

DTU

Introduction – why calibrating nacelle lidars

Profiling nacelle lidars might be the future of power performance testing ([1]). By avoiding the need to erect expensive met. masts (offshore, complex terrain), they will participate in the global efforts to reduce cost of wind generated electricity.

A measurement has absolutely NO VALUE WITHOUT ITS UNCERTAINTY. Thus, assessing measurement uncertainties of nacelle lidars is essential to developing standard procedures for power curves.

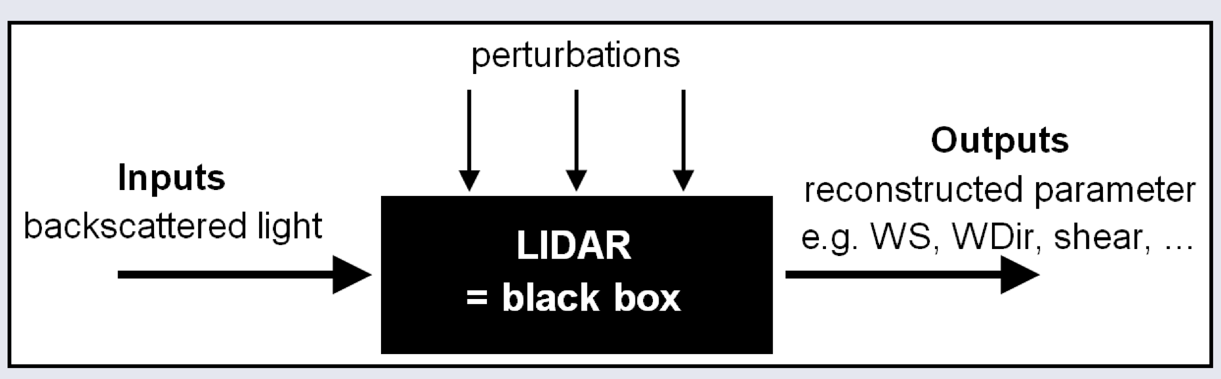
Based on the traceable calibration results from two lidars, the **Avent 5-beam Demonstrator** and the **ZephIR Dual Mode**, we present how to derive radial wind speed uncertainties using the GUM ([2]) methodology and what are the main challenges.

Radial Wind Speed calibration: principles & results

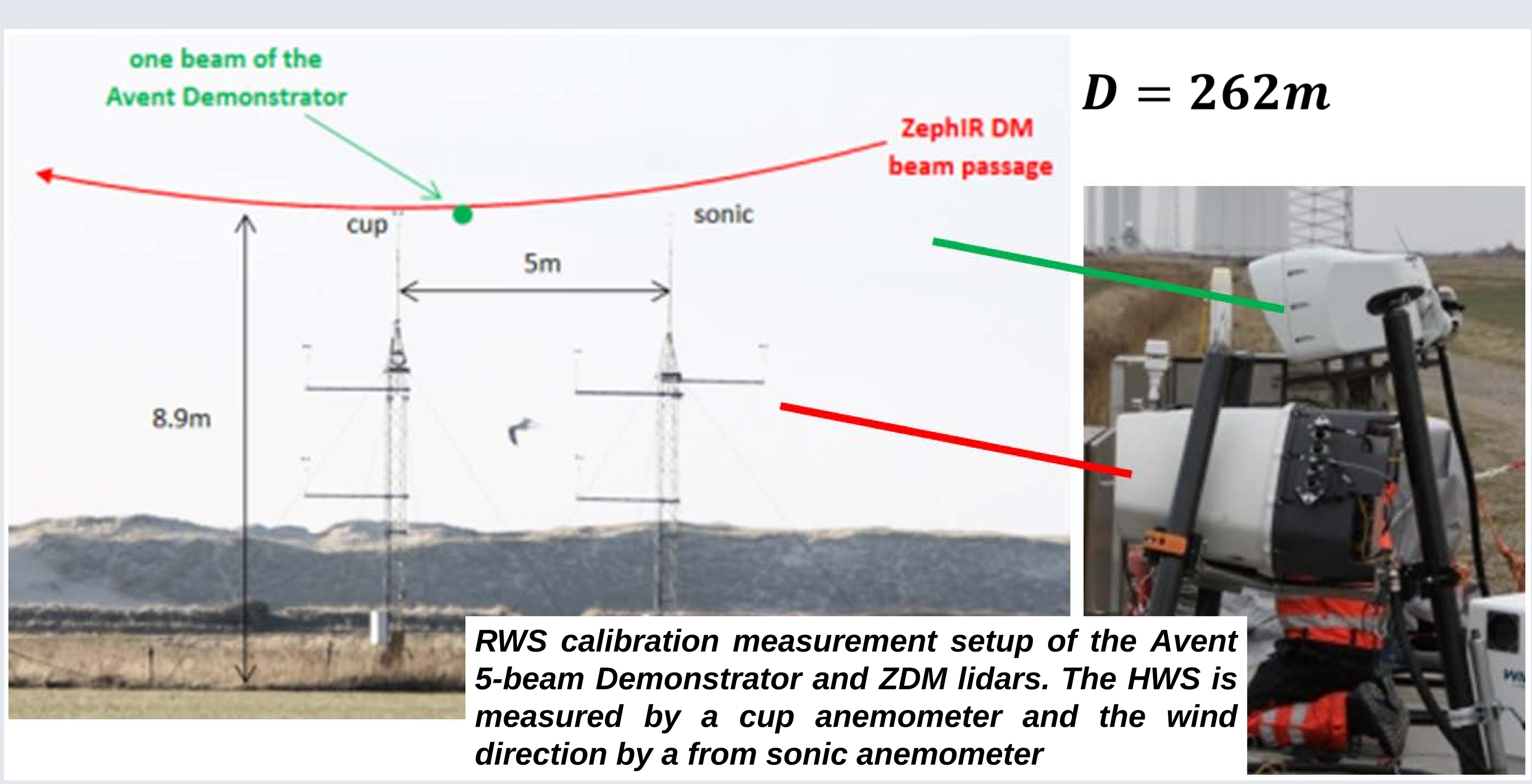
The **RWS – or "white box" – calibration (see [3])** can be applied to all profiling nacelle lidars. In this method, the algorithms' input quantities are calibrated:

- the RWS (generic): the main part of the calibration.
- the beam localisation quantities, e.g. inclinometers (lidar specific)
- the geometry of the scanning pattern (lidar specific)

The uncertainty estimation of any reconstructed parameter is theoretically permitted by the white box approach.

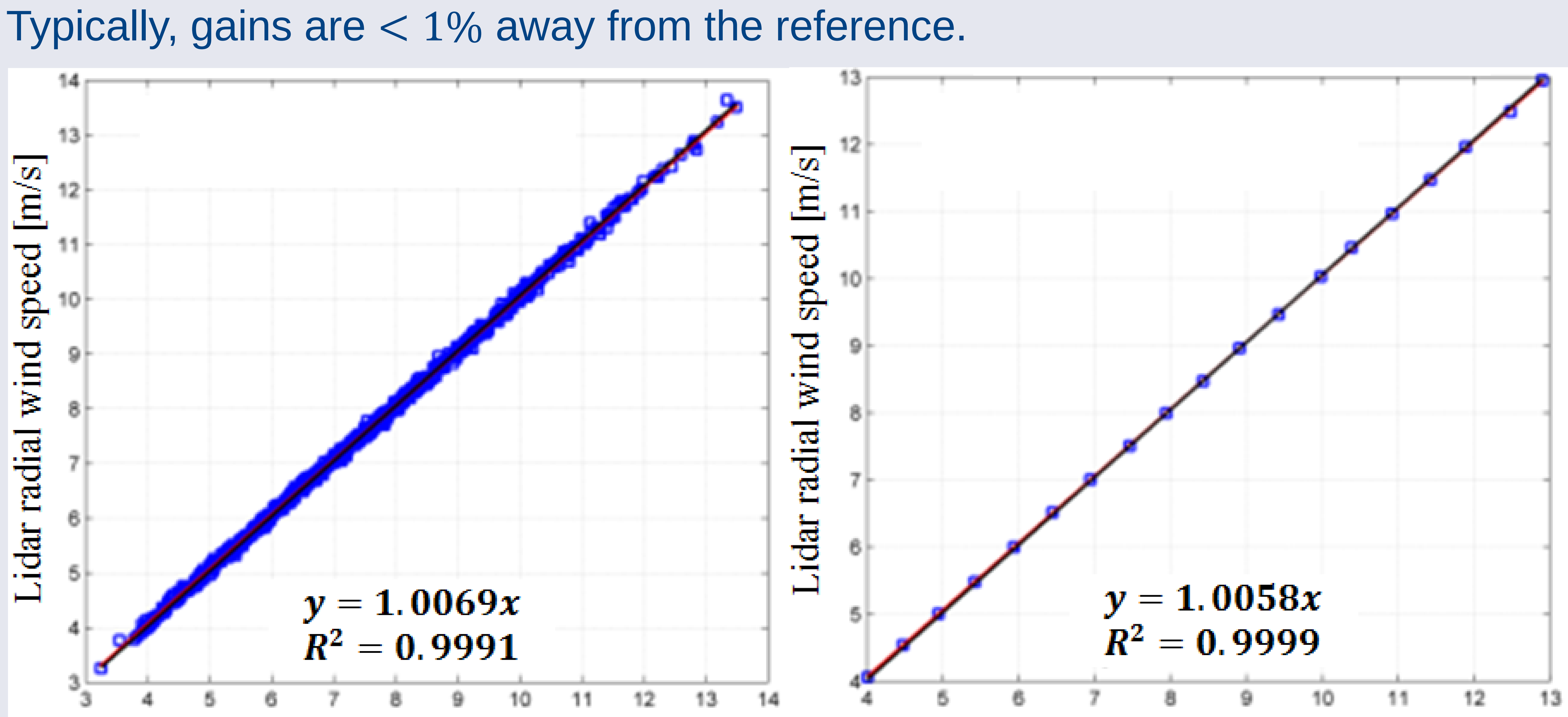


Practically, the 10-min averaged RWS measured by the lidar is compared to a reference wind speed measurement projected onto the Line-Of-Sight (setup below), both in the vertical (tilt) and horizontal (wind dir – LOS direction) planes. The collection of data for one beam lasts ~3-6 weeks.



RWS calibration measurement setup of the Avent 5-beam Demonstrator and ZDM lidars. The HWS is measured by a cup anemometer and the wind direction by a from sonic anemometer

The calibration relation, or transfer function, takes the forme of a simple forced linear regression. These two figures show a high level of agreement between the lidar RWS and reference projected wind speed (left: 10-min, right: binned data) . Typically, gains are < 1% away from the reference.



Questions:

- **How to derive the reference projected wind speed uncertainties?**
- **How to transfer it to the lidar RWS using the calibration results?**

The Guide to Uncertainty in Measurement method

The GUM is a well-established method in metrology to express uncertainties in measurements ([2]). It is an analytic method based on the **law of propagation of uncertainties**. The steps are:

1) Define measurement model: $y_m = f(x_1, x_2, \ldots, x_n)$
2) Propagate uncertainties:

$$U_c = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial y_m}{\partial x_i}\cdot u_{x_i}\right)^2} \quad \text{(for uncorrelated quantities)}$$

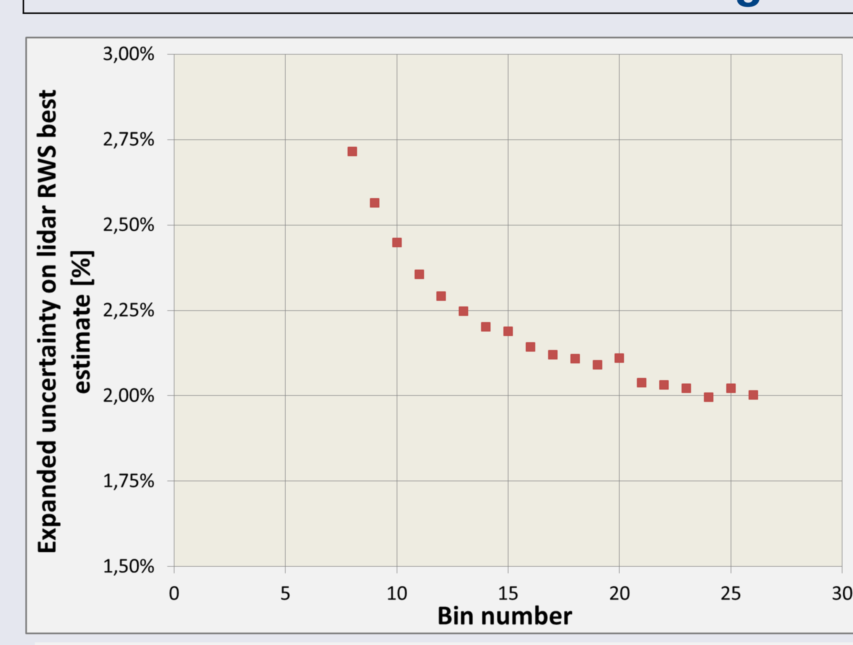
3) Expand uncertainty with coverage factor k ($k = 2 \equiv 95\%$ confidence)

In the RWS calibration, the measurement model is: $y_m = gain \cdot Ref$

where $Ref = HWS \cdot \cos(tilt) \cdot \cos(Wind\ dir - LOS\ dir)$. The uncertainty on the gain is obtained through the regression statistics.
The reference itself is the object of a GUM uncertainty assessment exercise. Each variable of Ref is a source of uncertainty.

Uncertainty results – Cups are a limitation

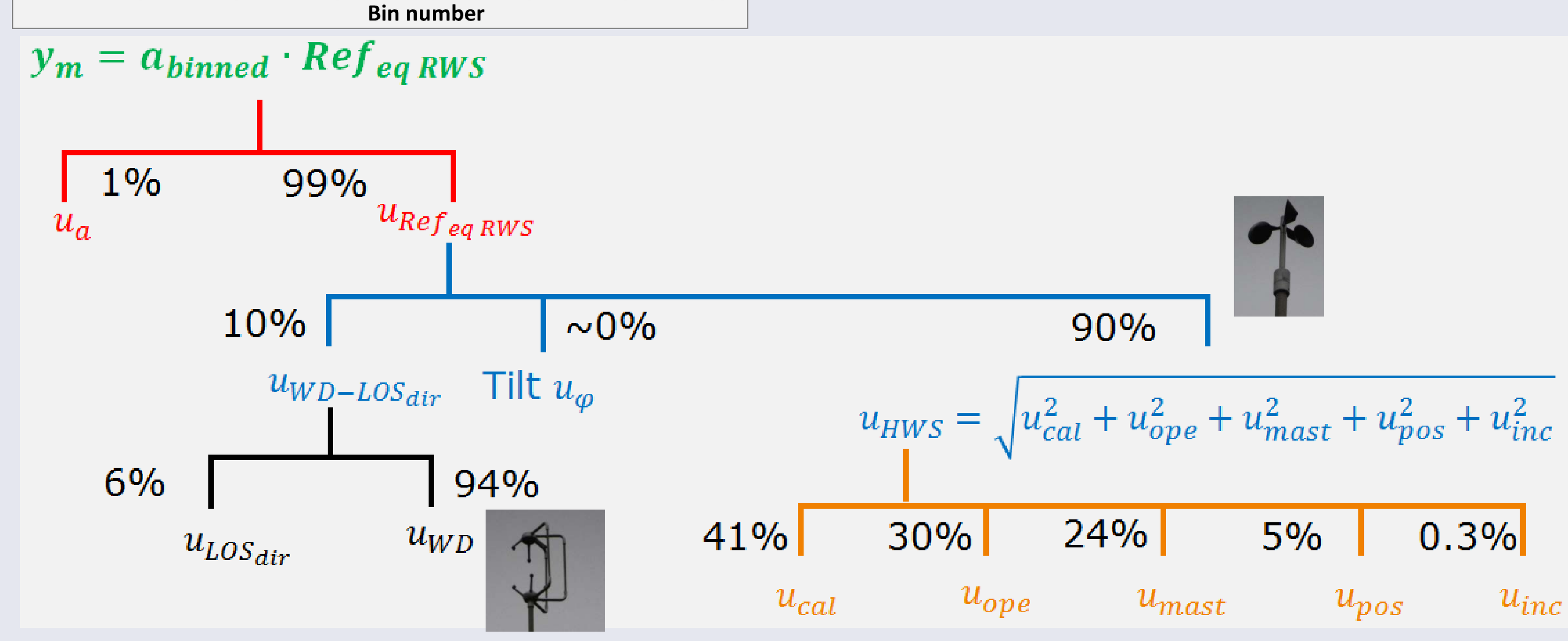
Reference instruments		Calibration process
Cup HWS (IEC proc.)	Wind tunnel calibration (u_{cal})	Tilt of beam (u_{φ})
	Operational (u_{ope})	LOS direction ($u_{LOS\ dir}$)
	Mounting (u_{mast})	Beam positioning (u_{pos})
Sonic WDir	Wind tunnel calibration (u_{WD})	Inclined probe volume (u_{inc})
Forced linear regression gain u_a (k=1, 68% CI)		



Left figure: expanded uncertainties as a function of RWS (bins 0.5 m/s wide)

Combined expanded RWS uncertainties are within 2-3%, higher at low wind speed.

The "tree" structure (fig. below) of the uncertainty assessment shows the contributions of each source.



The prevailing uncertainty source is due to the cup anemometer, particularly the wind tunnel calibration and operational uncertainties (i.e. due to cup sensitivity to external parameters without correcting for them, e.g. TI, T°, inflow angle). **The calibration process adds negligible components to the total RWS uncertainty**.

References

1. Wagner R. et al.: "Power curve measurement with a nacelle mounted lidar", [2014], Wind Energy, Vol: 17, issue: 9, pages 1441–1453.

2. JCGM 100:2008: "Evaluation of measurement data – Guide to the expression of uncertainty in measurement" (GUM)

3. Borraccino A., Courtney M., Wagner R.: "Generic methodology for calibrating profiling nacelle lidars", [2015], DTU Wind Energy E-0086.

4. JCGM 101:2012: "International Vocabulary of Metrology – Basic and General Concepts and Associated Terms".

Acknowledgements

This work is part of the UniTTe project (www.unitte.dk) funded by *Innovation Fund Denmark*.

Innovation Fund Denmark
RESEARCH, TECHNOLOGY & GROWTH

We would also like to thank M. Harris, C. Slinger (ZephIR Lidar) and M. Boquet (Avent Lidar Technology) for their support in this project. Thanks also to all DTU Wind Energy technicians who helped us developing the calibration procedures and setting up the measurement campaigns, particularly A. Ramsing Vestergaard and K. Schrøder.