IEC REWS calculation with 4–beam nacelle lidar

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PO.023

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Abstract

Since its introduction in the norm IEC 61400-12-1:2017 [1], the rotor equivalent wind speed (REWS) became a quantity of interest for wind turbine power performance testing (PPT). The REWS provides an accurate estimate of the kinetic flux passing through the rotor swept area as it accounts for the vertical shear and veer, which have significant impact on large WTG performances. This poster presents and evaluates the algorithm for calculating the REWS using the latest version of the WindCube Nacelle, previously known as Wind Iris.

IEC definition of the REWS

As stated in the second edition of the standard [1] : "The rotor equivalent wind speed is the wind speed corresponding to the kinetic energy flux through the swept rotor area, when accounting for the vertical wind shear. Where the wind speed for at least three measurement heights are available, the rotor equivalent wind speed is defined as:

$$v_{\mathrm{eq}} = \left(\sum_{i=1}^{n_{\mathrm{h}}} v_i^3 \frac{A_i}{A}\right)^{1/3}$$

Where:

- n_h is the number of available measurement heights ($n_h \geq 3$);
- v_i is the wind speed measured at height i;
- A is the complete area swept by the rotor (i.e. πR^2 with radius R);
- A_i is the area of the i^{th} segment, i.e. the segment the wind speed v_i;"

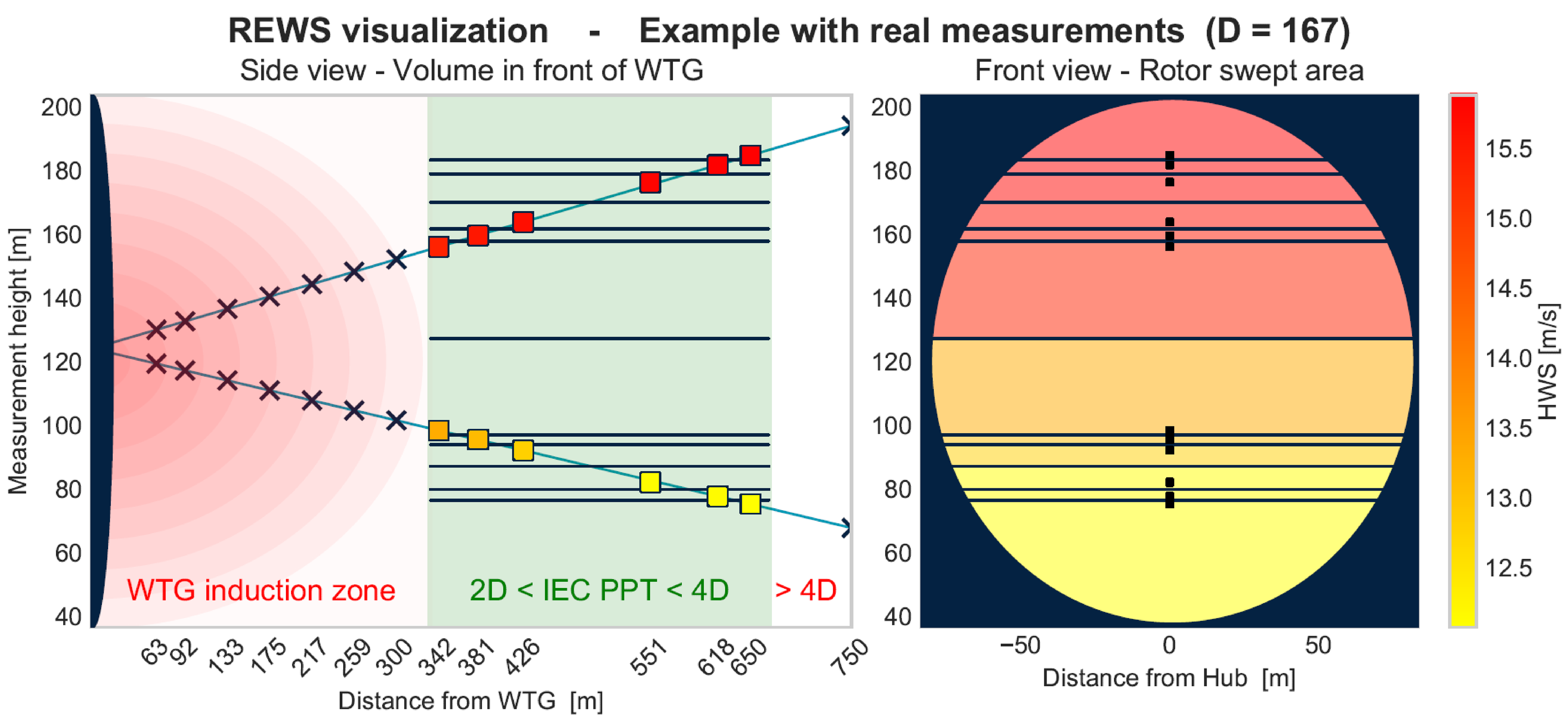
To account for the wind veer, an extended version of the equation is proposed in annex Q and defined as such:

$$v_{\mathrm{eq}} = \left(\sum_{i=1}^{n} \left(v_i \cos(\varphi_i)\right)^3 \frac{A_i}{A}\right)^{1/3}$$

Where ϕ_i is the angle difference between the wind direction at hub height and in segment i. It is this extended version of the equation that we decided to implement in our system and evaluate during the campaign.

Leosphere Implementation

The WindCube Nacelle, with its 2 pairs of beams, provides horizontal wind speeds (HWS) at two heights per range gate. As seen above, the standard requires at least three heights for the REWS computation. An algorithm was developed to fullfil this recommendation. The calculation at a given range gate uses the HWS within a configurable **volume around this gate**. This method benefits from the vertical beam opening, i.e. at each range gate the lidar is sensing a different height.



In the example above, the REWS is calculated using 12 HWS measurements at **12 different heights** without any assumption on a vertical wind shear profile. Therefore, this implementation relies only on the hypothesis of horizontal flow homogeneity, which assumes that wind speed is homogeneous at a given height. In simple terrain, outside the induction zone and wakes, this hypothesis is reliable and is already in use for both WindCube and WindCube Nacelle.

Campaign Setup

A Leosphere WindCube Nacelle, installed on a 8 MW Wind Turbine with 167 m diameter (D) and 120 m hub height is compared to two ground-based WindCube Lidars placed respectively at 395 m and 550 m from the WTG. Measurements were taken at DTU's Østerild wind turbine test field, a flat nearshore terrain in Denmark, between June 2019 and February 2020 - **9 months.** The WindCube Nacelle was compared to the reference sensors on the following wind sectors :

- Sensors at **395 m** - Wind Direction from : **273° +- 10°**
- Sensors at **550 m** - Wind Direction from : **273° +- 15°**

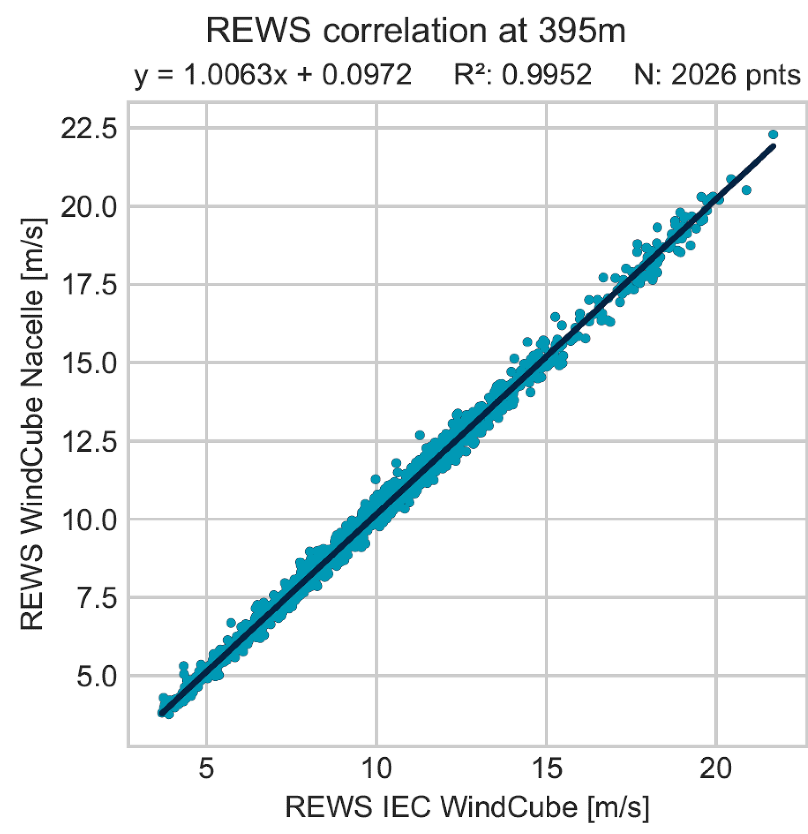
The difference in sector size accounts for wake from a met mast at 380 m.

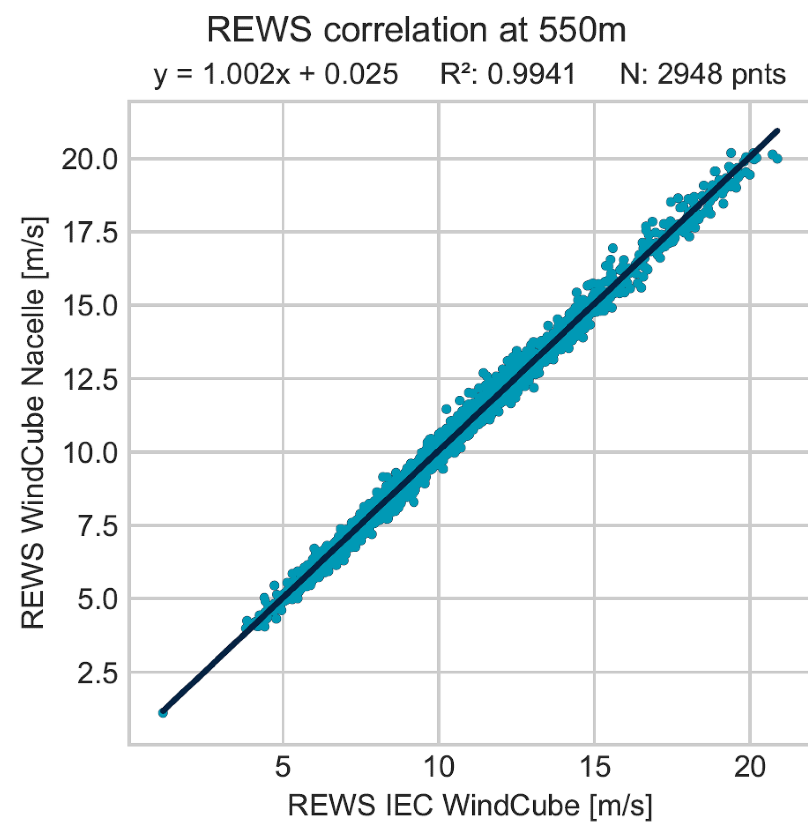
Instrumentation	Type	Measurement Ranges gate / Height [m]	Distance from WTG [m]	Distance from WTG in [D] with D : 167 m
Nacelle-Based Lidar	WindCube Nacelle	50 m - 750 m	**50 m - 750 m**	0.3 D - 4.5 D
Ground-based Lidar n°1	WindCube	40 m - 200 m	**395 m**	2.4 D
Ground-based Lidar n°2	WindCube	40 m - 200 m	**550 m**	3.3 D

Note that the distances of measurement presented here are considered "long rage" for the current state of nacelle-based lidar technology. This study was part of a larger validation campaign of the new generation of WindCube Nacelle.

Campaign Results

REWS calculated from all lidars were compared when wind direction allowed it. Data was filtered so that the REWS from WindCube Nacelle was calculated with at least 4 heights. The data was fitted by linear regression.





Distance from WTG [m]	Gain	Offset	R^2	N# of points in dataset
395 m	1.0063	0.0972	0.9952	2026 (~338h)
550 m	1.0020	0.025	0.9941	2948 (~492h)

- The REWS from nacelle and ground based lidars agree very well and fit results are within the instrument calibration uncertainties.
- The effectiveness of averaging multiple sensing heights is demonstrated.
- Other components of the wind field were compared during this study [2] and could be discussed upon request.

Conclusion

- Our method to calculate REWS with WindCube Nacelle shows **excellent correlation** at both studied range gates (395 m & 550 m) with the IEC REWS calculated using the ground-based lidars.
- The algorithm will be **a new feature in a future upgrade** of the WindCube Nacelle operating system and the calculation volume will be configurable.
- Additional works will be carried out to assess the uncertainty reduction when using REWS measurements for PPT.

References

1. *International Electrotechnical Commission (IEC). Power Performance Measurements of Electricity Producing Wind Turbines; IEC 61400-12-1 Ed. 2; International Electrotechnical Commission: Geneva, Switzerland, 2017*