Study on turbulence measurement using Nacelle-Mounted Lidar

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Abstract

Nacelle-Mounted Lidar (NML) is a proven and cost-efficient solution for performance evaluation of wind turbines, especially thanks to its accurate wind measurements and easy deployment. Nowadays, NML is widely accepted and recognized by wind turbine manufacturers, certification bodies, and wind farm operators.

Turbulence Intensity (TI) is a key parameter for the wind energy industry, as turbulence measurements are critical for wind turbine safety and are becoming increasingly important for turbine Power Performance Testing (PPT).

There is a clear need for detailed comparison of turbulence measurements from NML and cup anemometers in order to better understand the difference of both instruments for turbulence measurement.

In this study, a pulsed NML — WindCube® Nacelle (WCN) — is used for the evaluation of turbulence measurements. Two approaches are used: White Box Comparison (WBC) and Black Box Comparison (BBC).

Objectives

WCN uses four laser beams to directly measure Radial Wind Speed (RWS) along four Lines of Sight (LOS). RWS is then used reconstruct Horizontal Wind Speed (HWS) at hub height. Similarly, WCN can measure LOS TI along each LOS and then calculate Reconstructed TI at hub height.

Objectives of this study are: 1) LOS TI comparison; 2) Reconstructed TI comparison.

Methods: White/Black Box Comparison (WBC/BBC)

For LOS TI and Reconstructed TI, the NML is measuring toward an IEC-compliant met mast used as a reference.

Two approaches are used to compare turbulence measurement:

LOS TI is measured along the lidar LOS. The White Box Comparison (WBC) is used here: Laser beam is shooting toward met mast, allowing for direct comparison of NML and met mast measurements.

Reconstructed TI is calculated at hub height using LOS TI. The Black Box Comparison (BBC) is used here.

Reconstructed TI at hub height is more regularly used than LOS TI for turbine PPT. However, LOS TI is the direct measurement from NML — which could provide interesting information for research applications.

TI is calculated by the following formula[1]:

$$TI = \frac{\sqrt{\overline{u'^2}}}{V}$$

Along the LOS, Turbulent Kinetic Energy (TKE) is also calculated using the following formula[1]:

$$TKE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

Result 1: Time series of raw data

Figure 1 below represents the time series of met mast and NML data: Figure(a) is RWS; Figure(b) is the standard deviation of wind speed, related to turbulence.

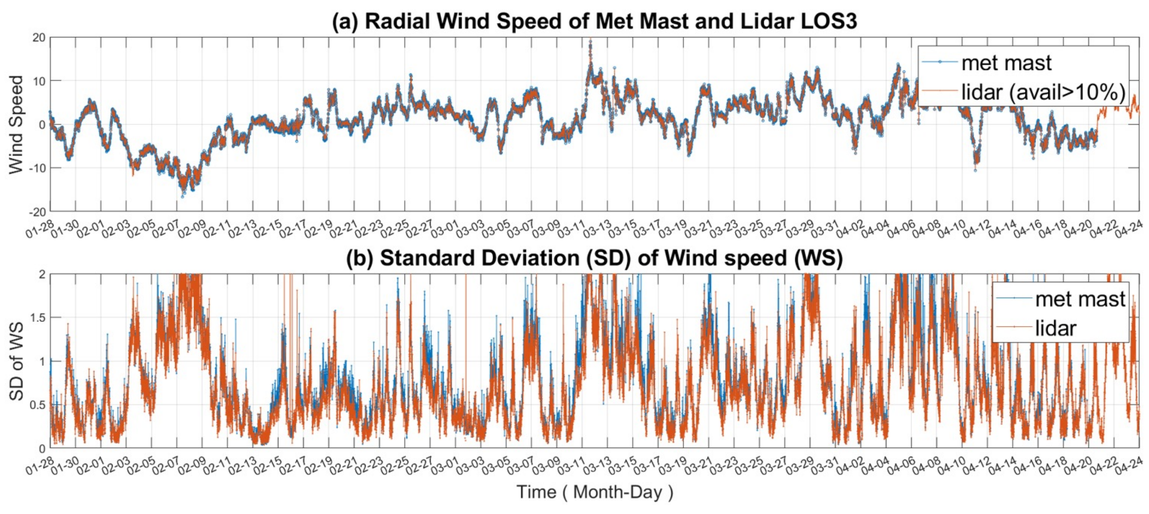

Figure 1 — Time series of met mast and Nacelle-Mounted Lidar (NML)

Result 2: Line of Sight (LOS) TI

LOS TI comparison was conducted at one calibration site in Germany, using the WBC approach. The NML was installed on a 30m platform allowing for the lidar LOS2 to measure horizontally toward a reference sensor mounted on a met mast. Figure 2 shows the comparisons of the following parameters: RWS, TI, and TKE.

These results show: 1) a coefficient of determination (r2) of 0.926 for TI; 2) a coefficient of determination (r2) of 0.986 for TKE; 3) the bin-averaged comparison, showing even better results.

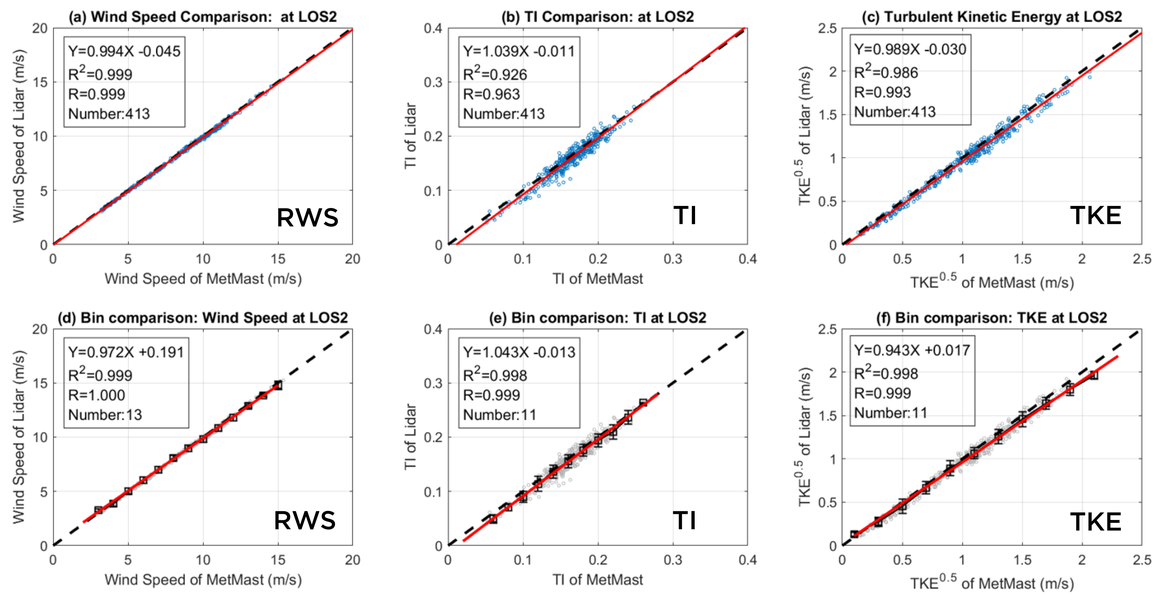

Figure 2 — Comparison of met mast and NML LOS2 of wind speed, TI, TKE (Fig(a), (b), (c): 10min comparison; Fig(d), (e), (f): bin comparison)

Result 3: Reconstructed TI

Reconstructed TI comparison was conducted at a wind turbine test field in Denmark. Measurements were taken between June 2019 and February 2020. A WCN was installed on an 8MW, 167m diameter, 120m hub height offshore wind turbine and compared to a 120m IEC met mast, which was located at 380m in front of the wind turbine.

The comparison of Reconstructed TI shows a very good result: coefficient of determination (r^2) of 0.8337 and linear regression formula Y=0.904X+0.005.

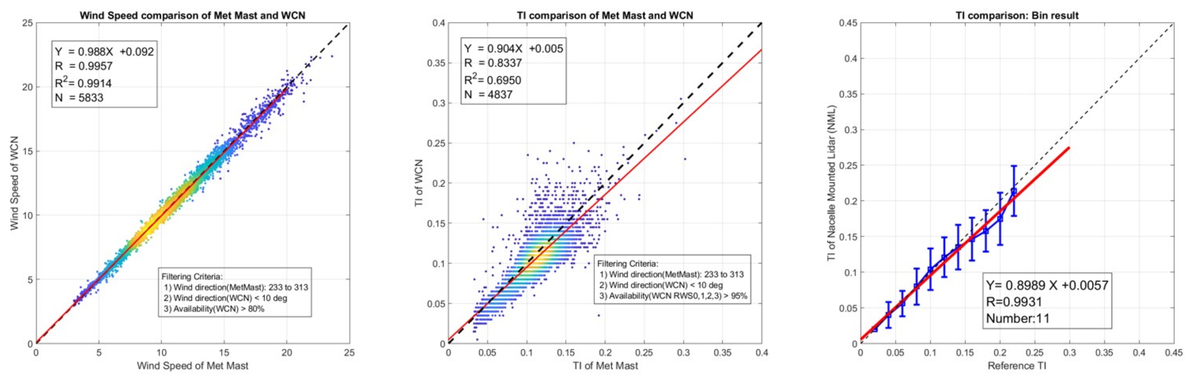

Figure 3 — Comparison of wind speed and TI (Left: 10 minute-averaged wind speed; Middle: 10 minute-averaged TI; Right: bin-averaged TI)

Conclusions

This study contributes to a better understanding of turbulence measurements using Nacelle-Mounted Lidar. Accurate Turbulence Intensity measurement is highly valuable for Power Performance Testing, load monitoring, and other wind-relative applications for the wind energy industry.

This study showed the good correlation of turbulence measurements between Nacelle-Mounted Lidar and met mast — both for LOS TI and Reconstructed TI. We would like to highlight the result of the bin-averaged LOS TI: Y=1.043X-0.013 (R=0.999), which is an important step forward and could be very useful for further research as a reference of TI measurement from lidar.

References

1. T. A. Bonin et al., "Evaluation of turbulence measurement techniques from a single Doppler lidar," Atmos. Meas. Tech., vol. 10, no. 8, pp. 3021–3039, Aug. 2017, doi: 10.5194/amt-10-3021-2017.