Nacelle-Mounted Lidar reduces the uncertainty of Power Performance Testing(PPT) by Met Mast: a fully investigation

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WESC 2023
23 - 26 MAY | GLASGOW, UK

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Agenda

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- Joint Project
- Measurement specification
- Test Setup
- Comparison of Wind Speed
- Result(1): Wind Speed at Hub Height
- Result(2): Wind shear and REWS
- Result(3): Terrain evaluation
- Conclusions

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Joint Project: Power Performance Test

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Objectives

- Extensive field study to prepare for the use of Nacelle Mounted Lidars (NMLs) for Power Performance Testing(PPT) on operational basis
- First joint industry project following the context of the IEC 61400-50-3 standard

Methodology

- 3-month campaign in ENGIE's wind farm (US)
- Onshore flat terrain
- Reference instruments: (1) IEC met mast and (2) WindCube Ground-Based lidar

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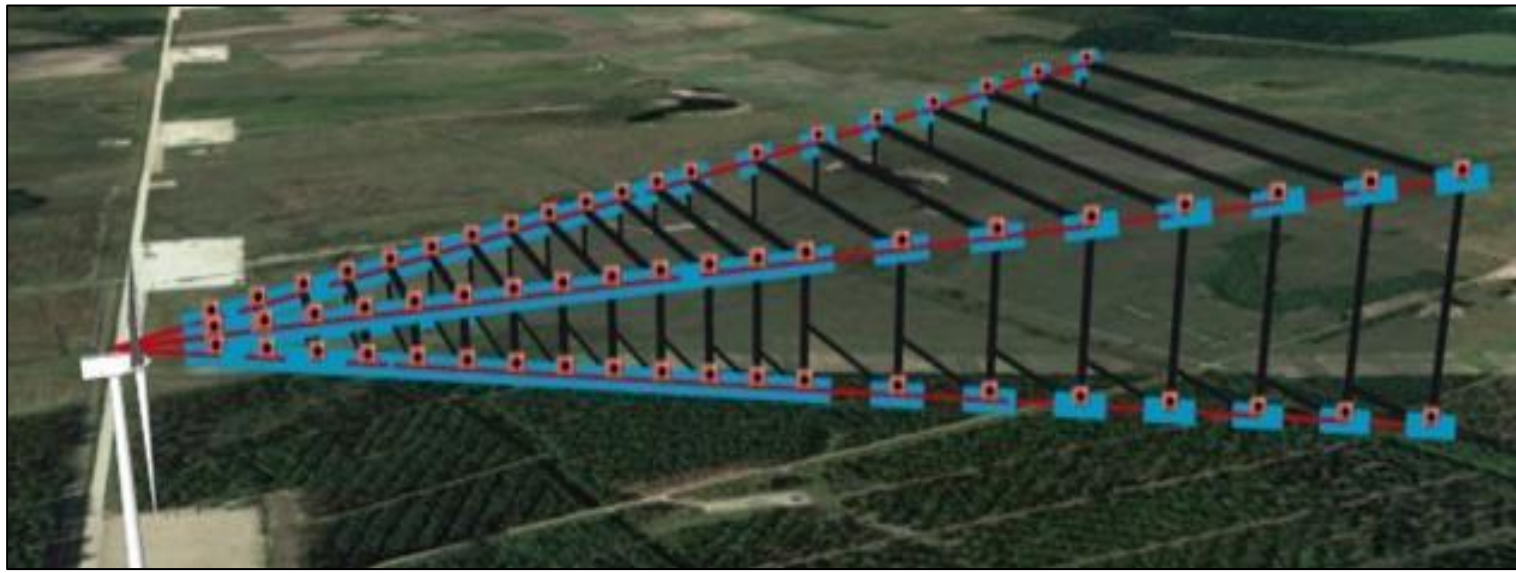
ENGIE

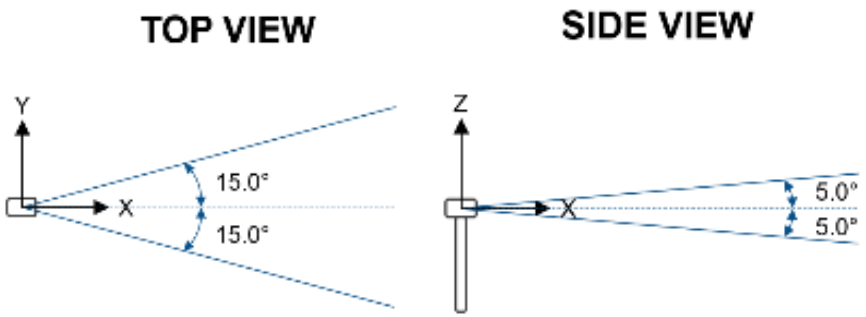
DNV

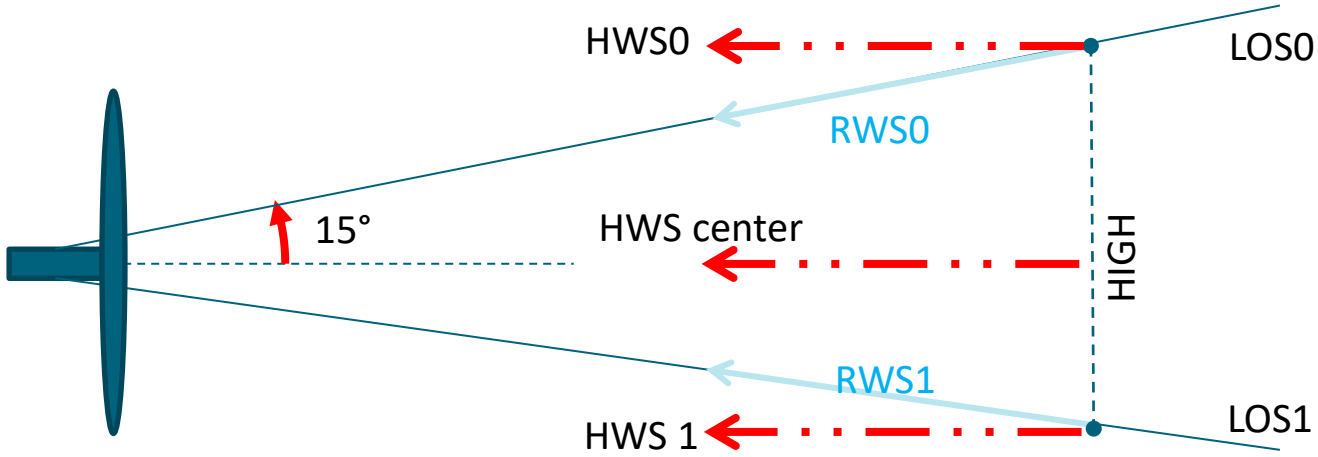
GE Renewable Energy

Measurement specification

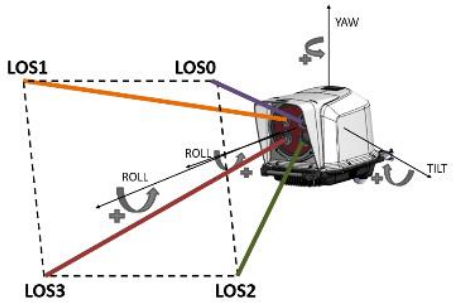
Measurement specifications	
Range	50m to 450m/700m depending on version
Data sampling rate	1 Hz beam swap frequency
Ranges	10/20 user defined distances, simultaneously measured
Speed accuracy	0.1 m/s
Speed uncertainty	< 2%
Direction accuracy	+/- 0.5°
Probed lenght	30m (constant at all range gates)







Test Setup



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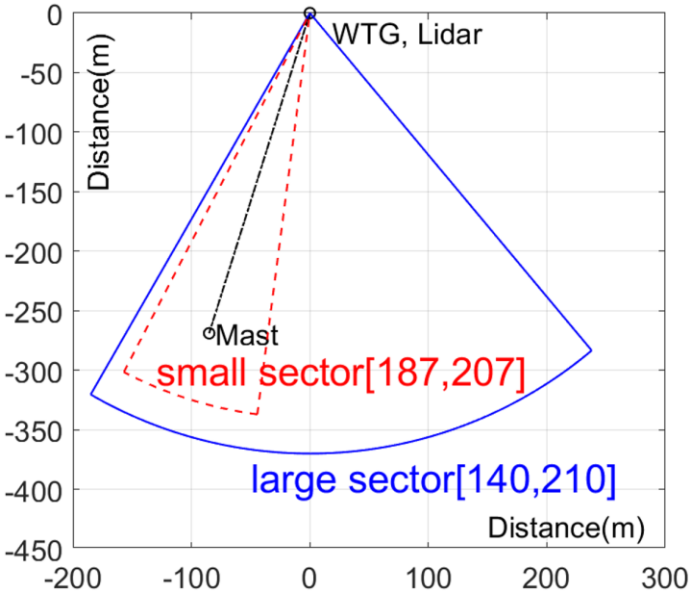
Map



Instrumentation	Type	Distance from WTG [m]	Distance from WTG [D=127m]	Measurement Height [m]
Nacelle-mounted Lidar	WindCube Nacelle	50m-700m	0.4D-5.5D	89m
Met Mast	IEC compliant	282m	2.2D	32m-89m
Ground-based Lidar	WindCube	290m	2.3D	40m-200m

Two wind sectors:

1) 187°-207°: met mast centered wind sector
2) 140°-210°: IEC valid wind sector

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Comparison of Wind Speed

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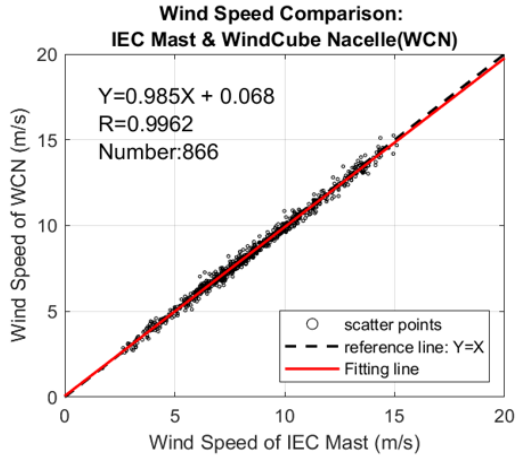
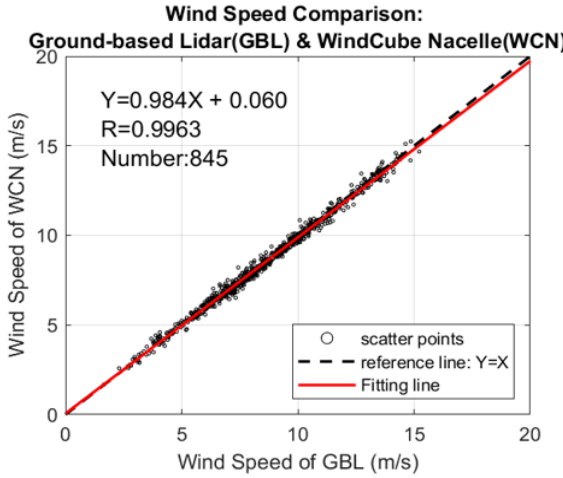
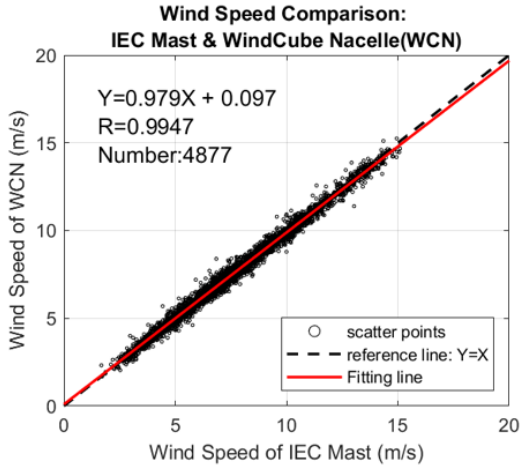
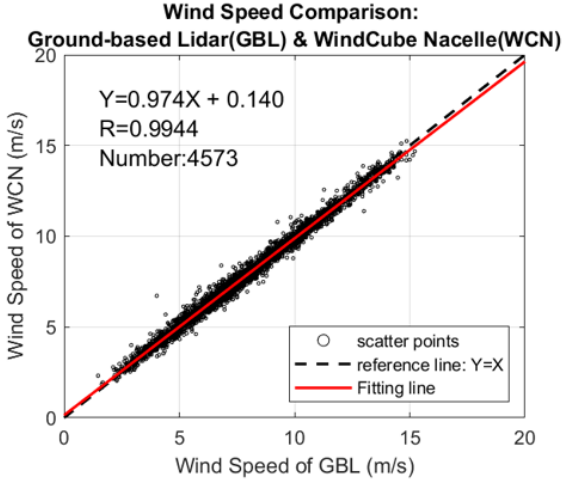
Centered wind sector: **187°-207°**





Valid IEC wind sector: **140°- 210°**

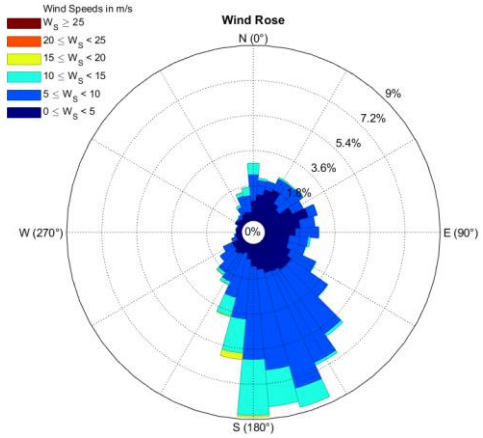


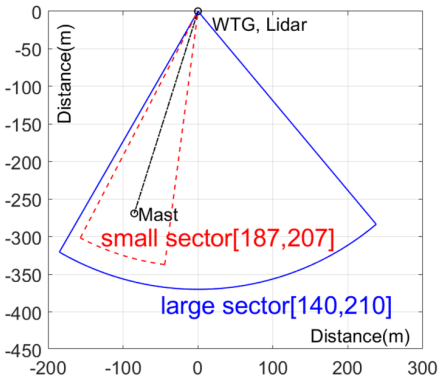


Key take away

- Better wind speed correlation between the IEC met mast and nacelle lidar when using a smaller wind sector.
- Sampling points in small sector is not enough for an accurate PPT.

Sector	ALL	187°-207°	140°-210°
Data points	13743	1232	6507





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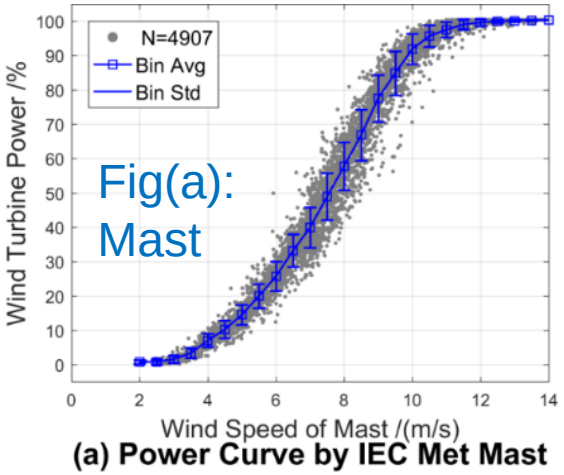
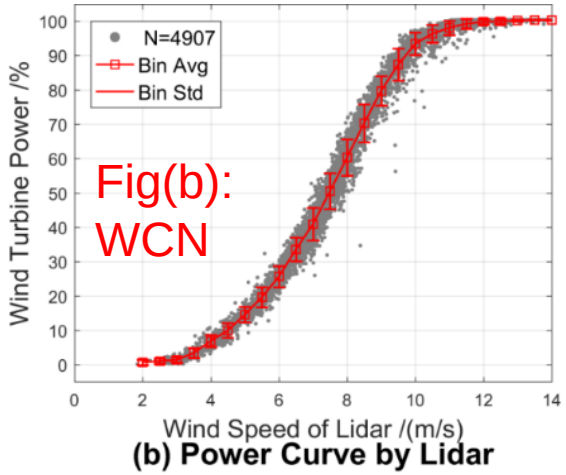
Result(1): Wind Speed at Hub Height

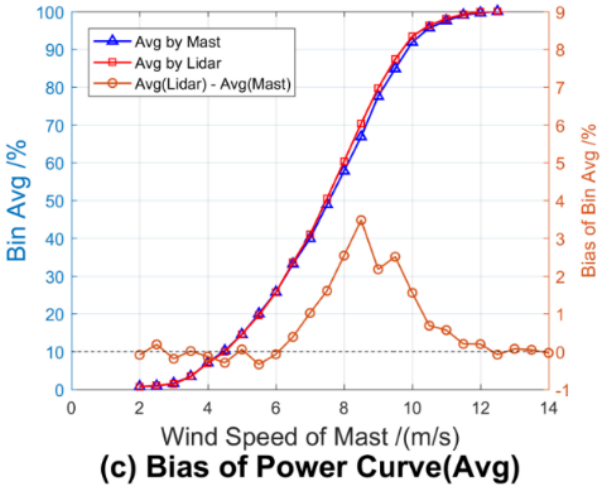
- Fig(a) and Fig(b) show:
  - Scattering points of PPT by WCN are more concentrated than PPT by Met Mast.
- Fig(d) shows the Standard Deviation (SD) by WCN in the bin of wind speed is significantly lower than SD by Met Mast.
- WCN is always measuring the wind speed exactly in front of the wind turbine.



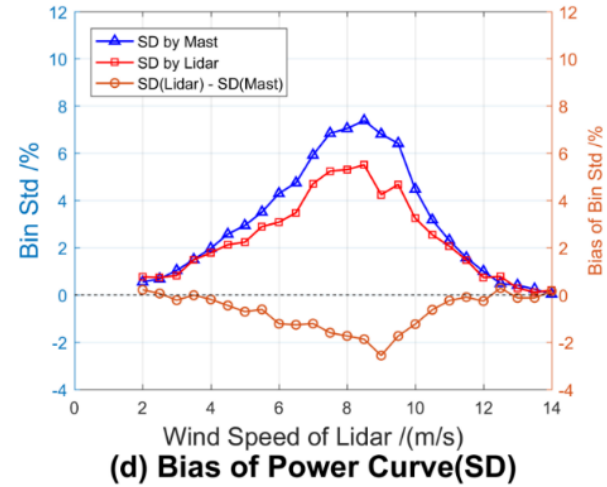
(a) Power Curve by IEC Met Mast



(b) Power Curve by Lidar



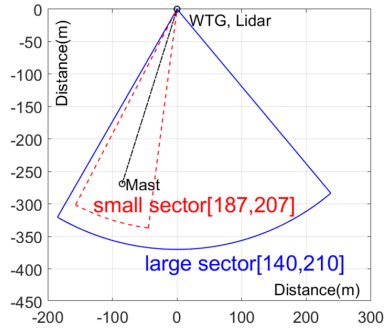
(c) Bias of Power Curve(Avg)

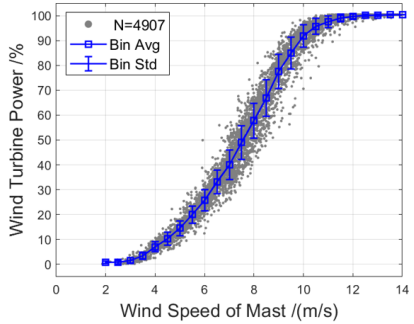


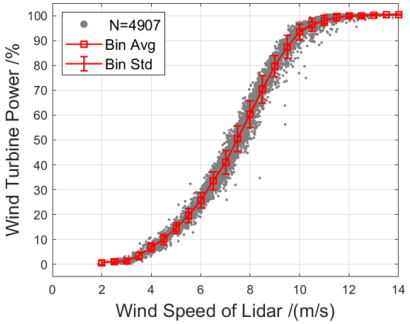
(d) Bias of Power Curve(SD)

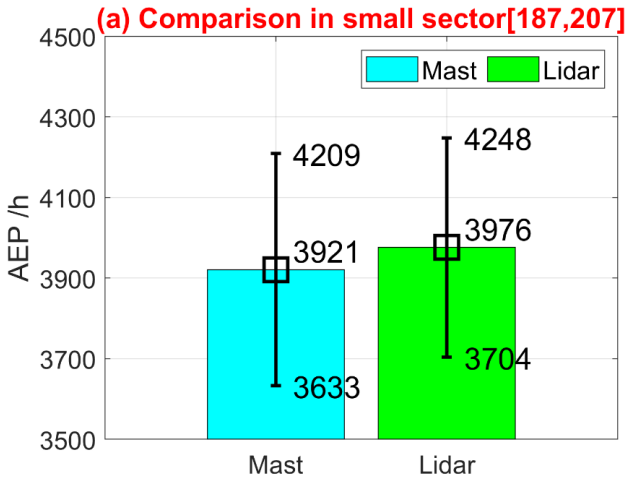
Result(1): Uncertainty on AEP

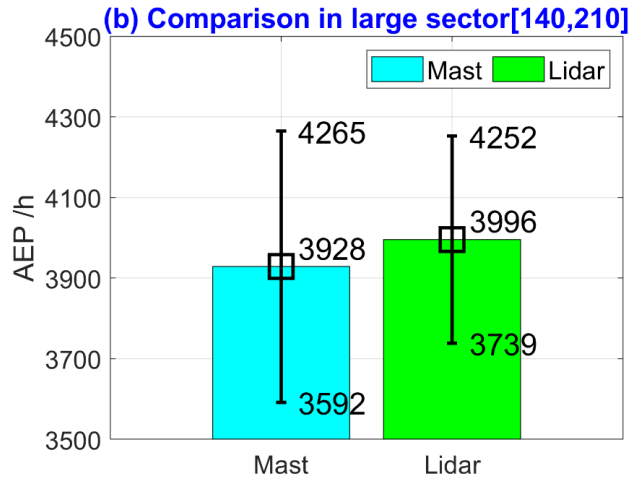
- The evaluation of PPT by two devices on the uncertainty of Annual Energy Production(AEP), assuming wind Weibull distribution.
- AEP Range using large wind sector:
  - Mast: [3592h, 4265h]
  - WCN: [3739h, 4252h]
- The overall uncertainty of NML is within the uncertainty range of Met Mast.





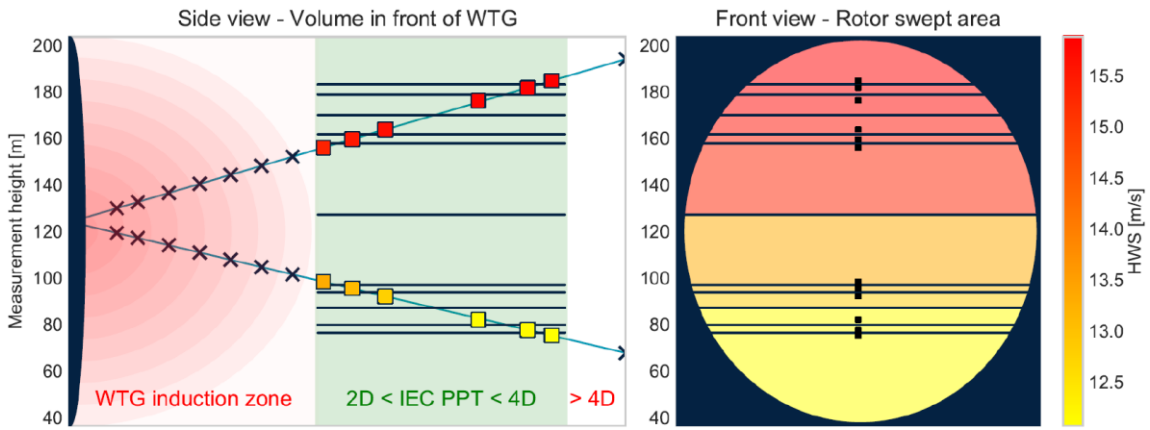




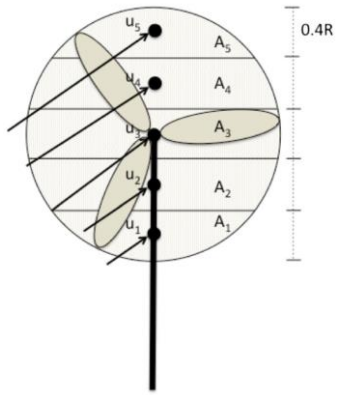


Result(2): Wind shear and REWS

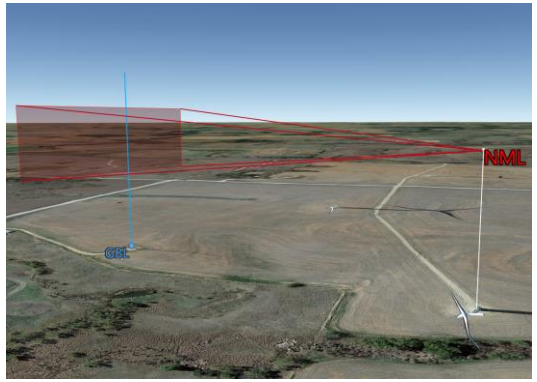
- REWS: Rotor Equivalent Wind Speed
- Definition by IEC 61400-12-1:
  - $v_{eq} = \left(\sum_{i=1}^{n_h} v_i^3 \frac{A_i}{A}\right)^{1/3}$
    - n_h is the number of available measurement heights ($n_h \geq 3$);
    - v_i is the wind speed at height i;
    - A is the complete area of rotor;
    - A_i is the area of the i^{th} segment.
- Result: The measurement of wind shear and REWS by WCN is accurate.



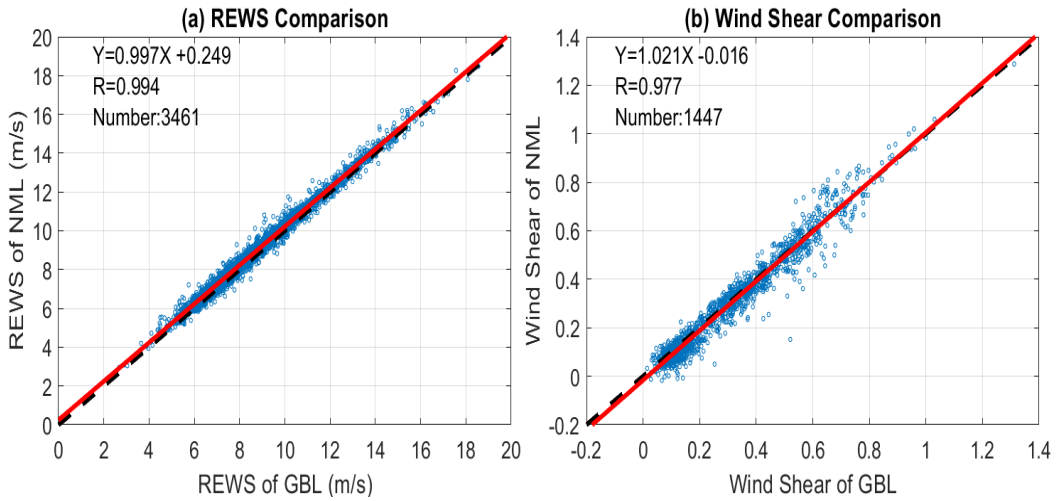
J Tissot. IEC REWS calculation with 4–beam nacelle lidar, WindTech2020, IEC-REWS-Calc-4Beam-Nacelle-Lidar (vaisala.com)



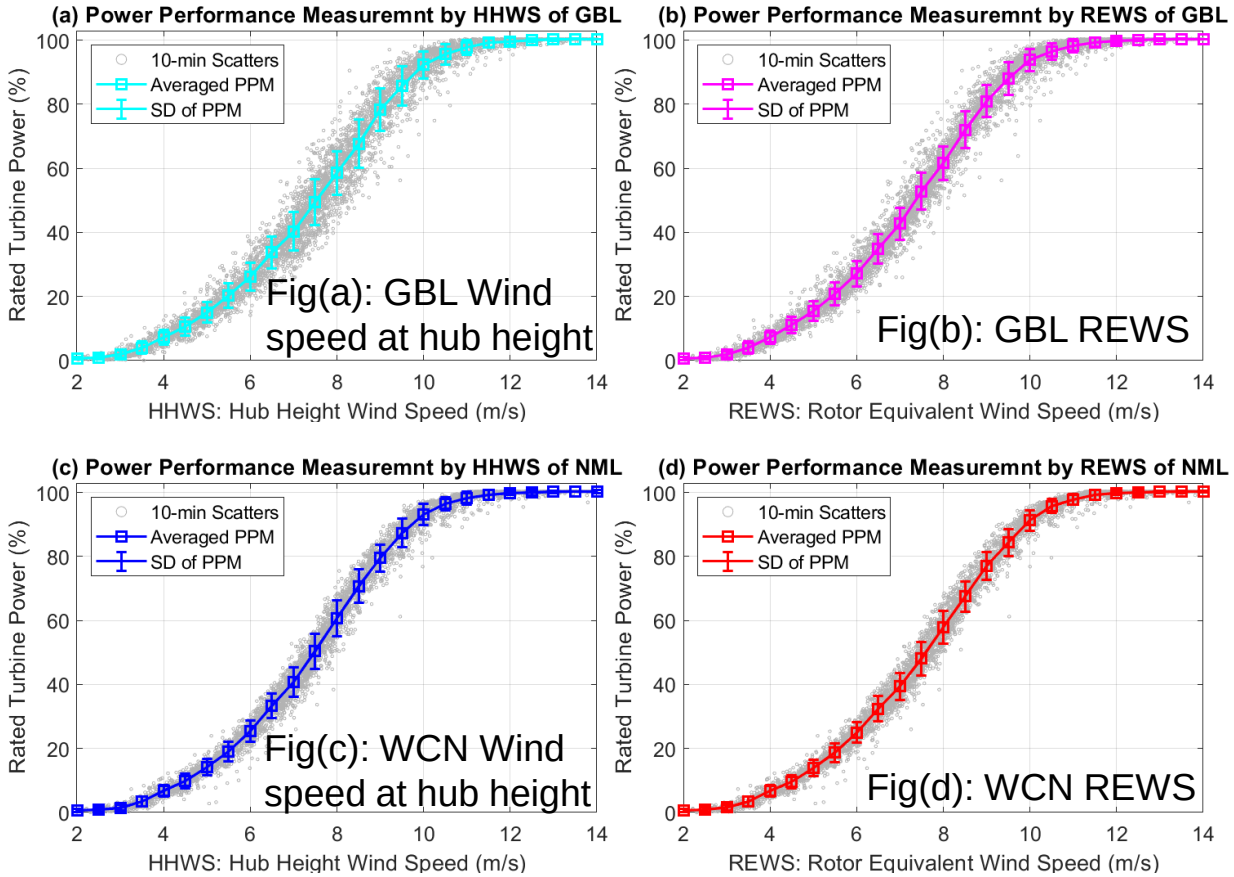
Van Sark.(2019). *Wind Energy*. DOI: 10.1002/we.2319



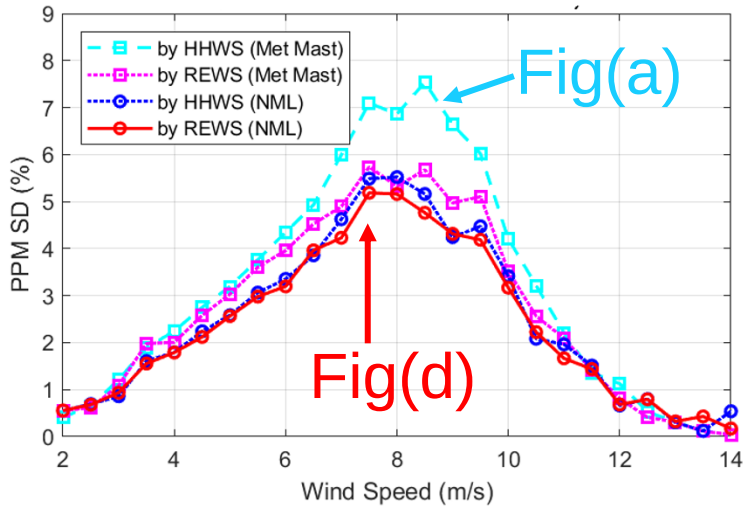
The measurment by GBL and WCN



REWS comparison by GBL and WCN

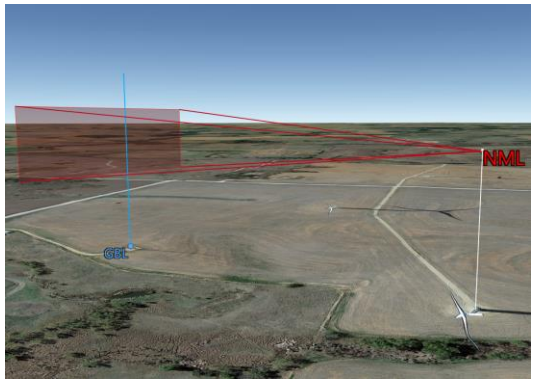


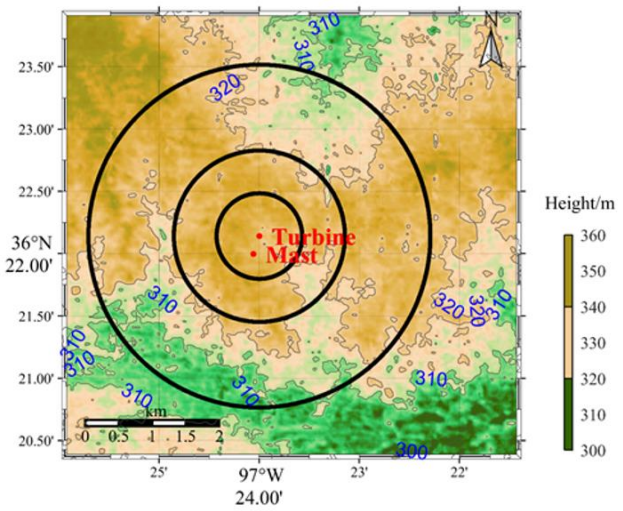
- Results shows some benefits of REWS:
  - REWS can reduce the uncertainty of PPM for both GBL and WCN.
  - PPM by REWS of WCN has the lowest uncertainty, which shows the good potential application for the evaluation of the turbine power performance.

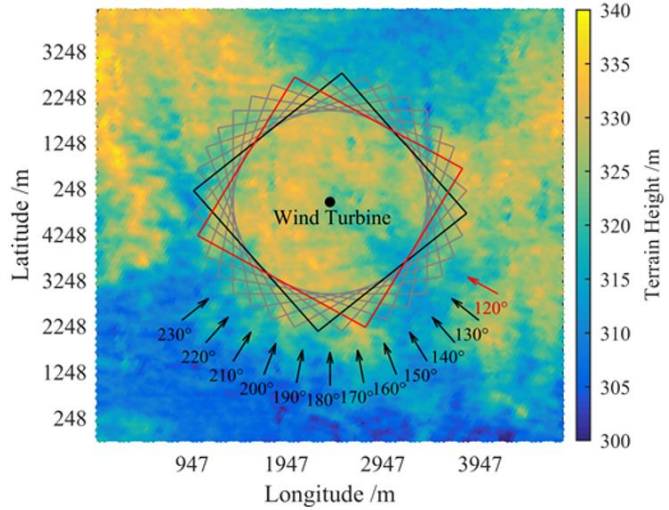


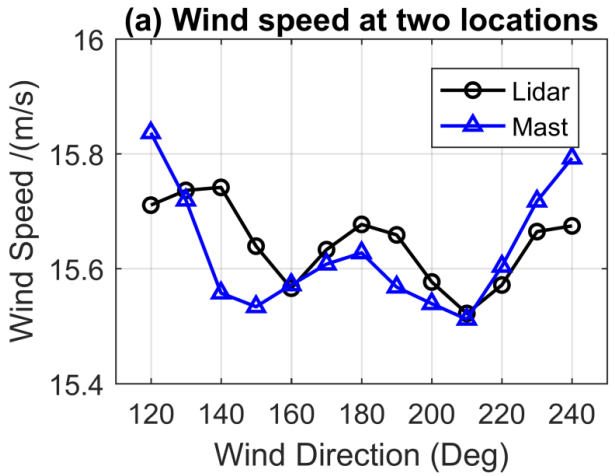
Result(3): Terrain evaluation(on-going)

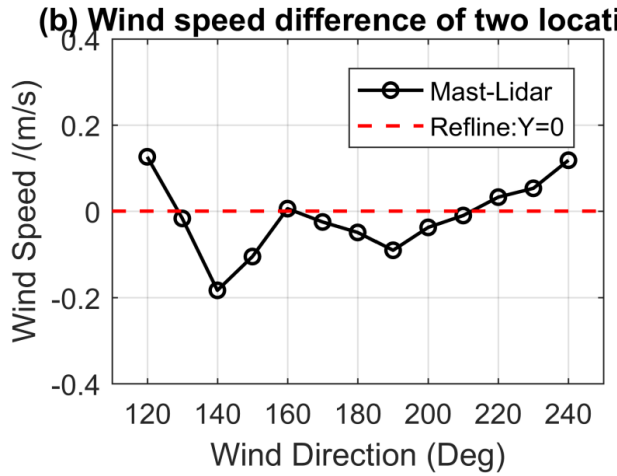
- OpenFOAM is used to simulate the wind field difference at two locations at multiple wind directions.
- The simulation result shows: even in the flat terrain, there is slightly difference of wind field of two locations.
- Idea for further study:
  - WCN measures RWS by 4 beams;
  - Research on RWS and GBL for the spatial difference of wind field.











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Conclusions:

- Conclusions:
  - Better spatial coherence of the nacelle lidar measurements.
  - Difference between power curves measured with IEC met mast and nacelle lidar is <2%.
  - AEP Standard Deviation is lower for Nacelle Mounted Lidar(NML), especially for a winder sector.
  - Industry is ready for PPT using NML on operational basis following IEC-50-3.
  - The measurement of wind shear and REWS by NML is accurate.

- Planning for the next work
  - Investigation on PPT Uncertainty by measurement and simulation;
  - Turbulence Intensity on PPT: TI impact the PPT variation.

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Thank you!

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