A novel method to evaluate the induction zone of wind turbine using nacelle-mounted lidar

VAISALA

PO.189

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Abstract

Nacelle-mounted lidars (NML) are increasingly used for investigating the effects of the induction zone, caused by the blockage effect of wind turbines.

A new method is developed and presented in this study to accurately evaluate the induction zone using NML measurements. The induction zone in front of a wind turbine has been studied using a WindCube Nacelle Long Range pulsed lidar in two projects: in simple/flat terrain and in complex terrain.

Objective

This study aims at better understanding the induction zone and evaluating the accuracy of lidar measurements. This study promotes a new method to evaluate the induction zone and measure the induction factor using NML measurements in simple and complex terrain.

For accurate turbine Power Performance Testing (PPT) in complex terrain, it is critical to measure the free wind speed and to distinguish the blockage effect from the terrain complexity effects on the wind field.

Measurements from two test sites have been studied. The first in simple/flat terrain; the second in both simple/flat and complex terrain depending on wind direction: complex in south direction; simple/flat north direction.

Site	Hub height	Rotor diameter	Terrain complexity
Site 1	120m	167m	Simple/flat terrain (1.0% avg. slope within 8D)
Site 2 (north direction)	84m	112m	Simple/flat terrain (1.2% avg. slope within 8D)
Site 2 (south direction)	84m	112m	Complex terrain (12% avg. slope within 8D)

Method

1. Model

The induction zone model is given by the below formula:

$$\frac{\bar{u}}{\bar{u}_\infty} = 1 - a\left(1 + \frac{2x}{d}\left(1 + \left(\frac{2x}{d}\right)^2\right)^{-0.5}\right)$$

Position $\frac{x}{d}=$	$\frac{x}{d}=0$	$\frac{x}{d}=-0.5$	$\frac{x}{d}=-2.5$	$\frac{x}{d}\to-\infty$
$\frac{\bar{u}}{\bar{u}_\infty}=$	$1-a$	$1-0.3a$	$1-0.019a$	1

2. Measurement

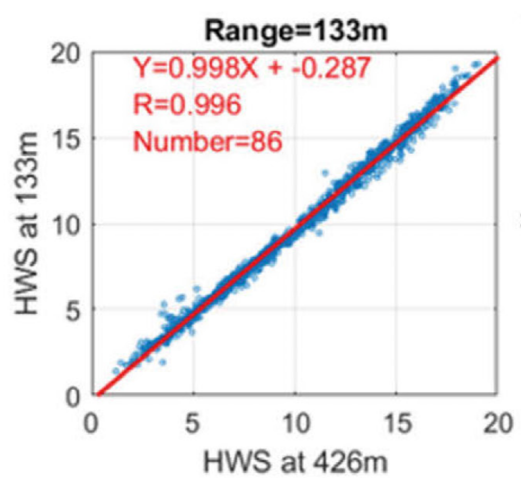
NML is a go-to technology for accurately studying the induction zone of a wind turbine as it can always measure at multiple distances in front of the rotor. Here, a new method is developed to calculate the induction factor using simultaneous lidar measurements at several distances.

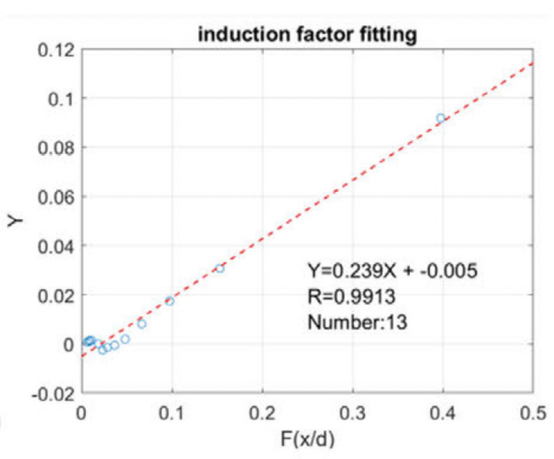
Step 1: linear fit to calculate the wind speed at each range gate in the induction zone. Example: at 217m the fitting function is Y=0.998x-0.287 (if free wind speed is lOm/s, wind speed at 133m is 9.693m/s);

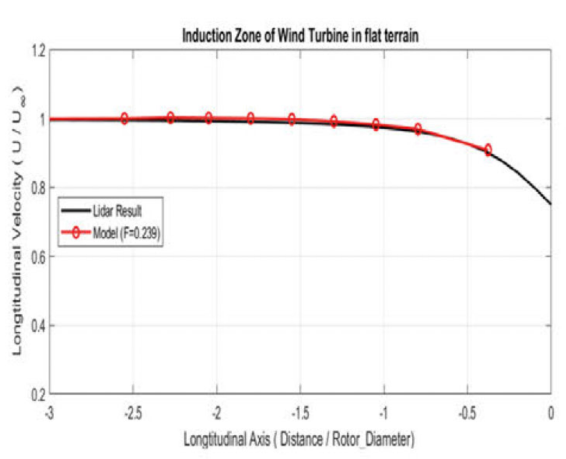
Step 2: linear fit of the induction factor using step 1 results.

If $X \stackrel{\text{def}}{=} \frac{\bar{u}}{\bar{u}_\infty}$, $F(\frac{x}{d}) \stackrel{\text{def}}{=} (1 + \frac{2x}{d}(1 + (\frac{2x}{d})^2)^{-0.5})$, then Y=1-a*F(x/d)

The induction factor in site 1 (simple/flat terrain) is 0.239 in the middle figure.

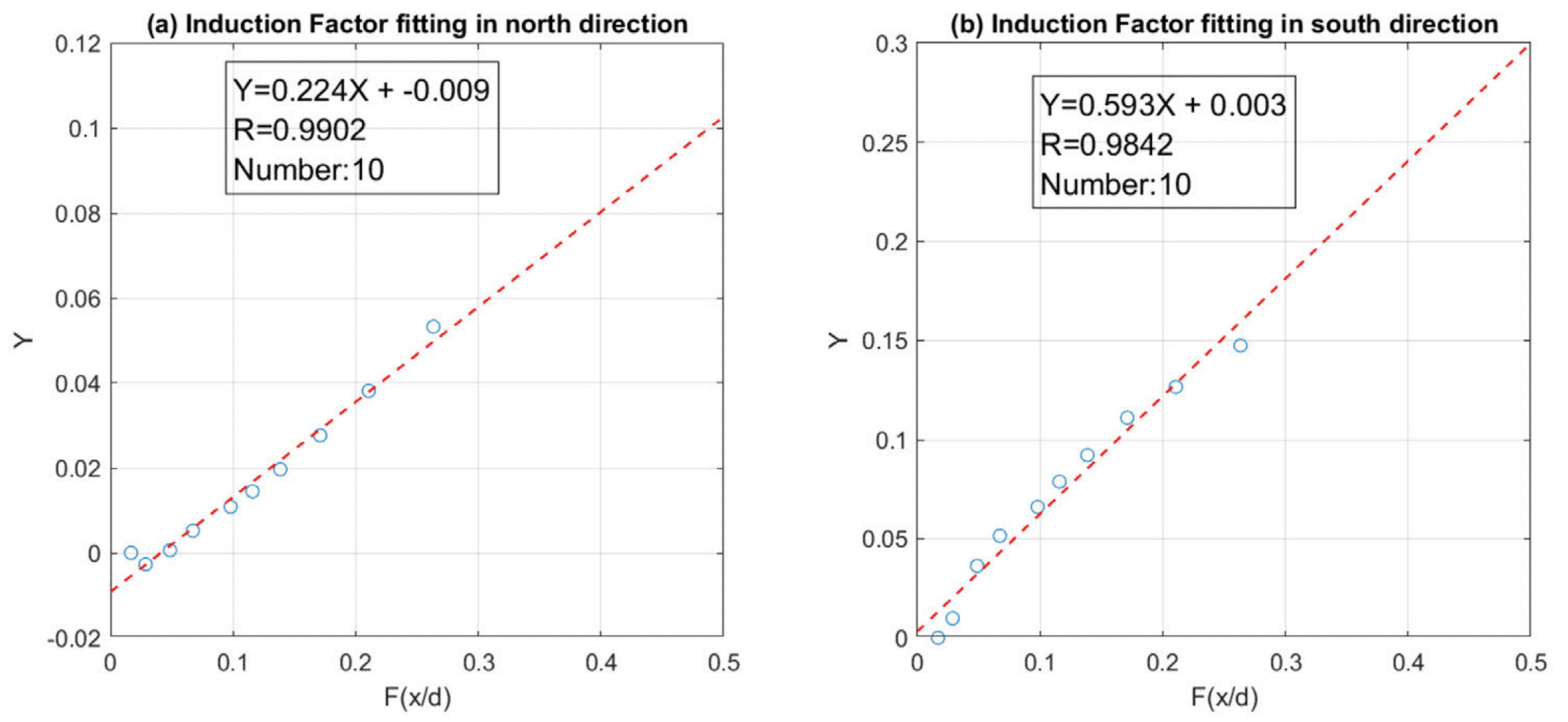






Results

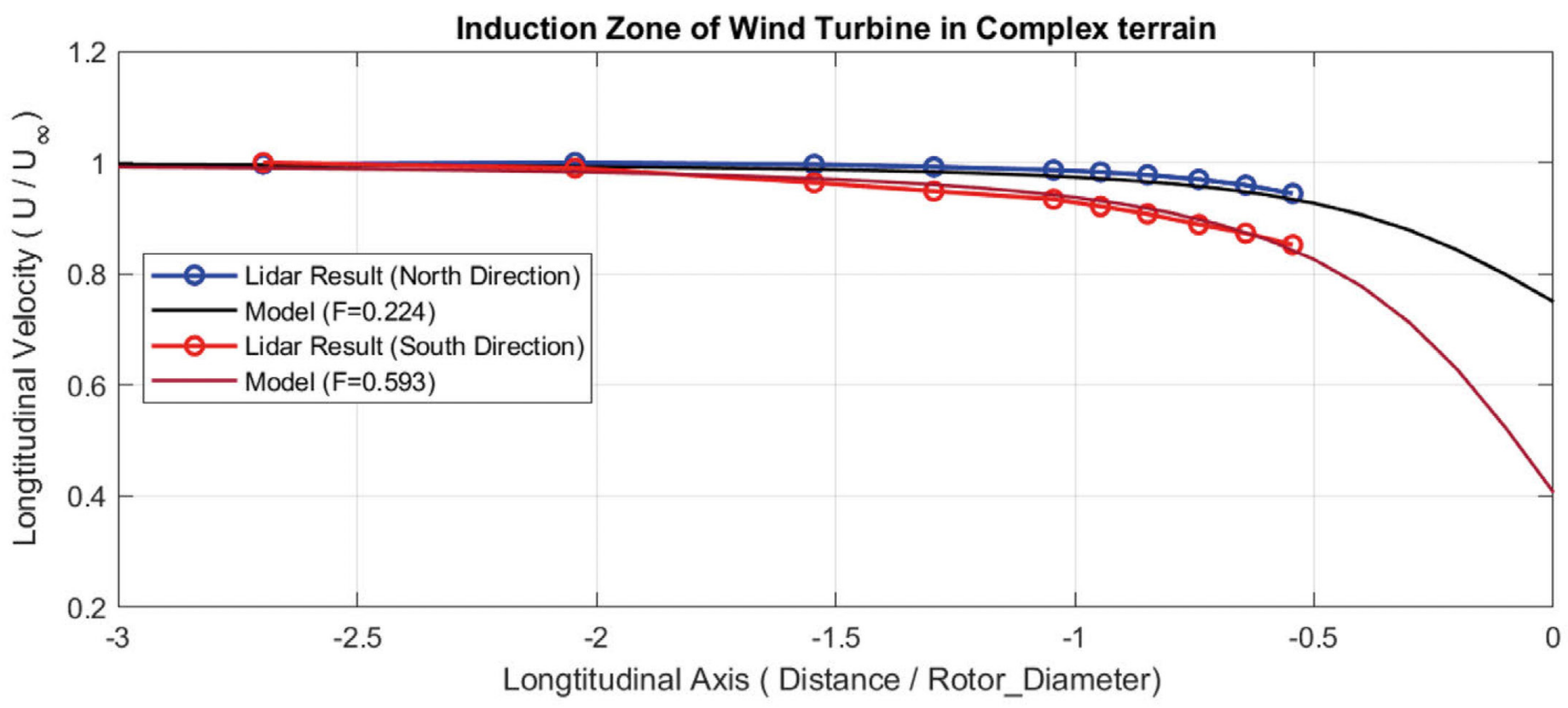
The fitting method was applied to measurements from site 2 for both wind directions. The induction factor in north direction (simple/flat terrain) is close to 0.224, while induction factor in south direction (complex terrain) is close to 0.593



Using this methods highlights the fact that the induction factor varies significantly depending on terrain complexity.

- The induction factor is close to 0.224 (similar to what was measured on site when wind is coming from the north direction (simple/flat terrain);
- The induction factor is close to 0.593, when the wind is coming from the south direction (complex terrain).

Comparing the induction factors from the same wind turbine in two different wind directions — and terrain complexity — we can observe that the induction zone is more compressed in complex terrain.



Conclusion

This study demonstrates the capacity of NML to accurately measure turbine blockage effects. Using measurements at several range gates and a new induction zone fitting method, the induction zone effect can be studied extensively in simple/flat and complex terrain.

This study contributes to a better understanding of the wind turbine blockage effects in complex terrain. Further research is needed in order to complete this understanding and be able to distinguish the blockage effect from the terrain complexity effects on the wind field.

This will ultimately contribute to more accurate PPT with NML in complex terrain using the free wind speed derived from multiple measurements at close distances from the wind turbine.

References

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