Assessment of representative wind speed vertical profiles in the vicinity of offshore windfarms by means of long-range lidar

Juan José Trujillo¹, Priscila Orozco¹, Beatriz Cañadillas¹,², Richard Frühmann¹ and Thomas Neumann¹

¹UL
²Institute of Flight Guidance, Technical University of Braunschweig
Introduction: How do we process vertical profiles?
Introduction: How do we process vertical profiles?

We apply the same principles and analysis techniques as the ones used in conventional ground based lidars.
1- Lidar orientation
How good can we assess our orientation at an offshore site? Is the structure really fixed?
Introduction: What is the difference to conventional onshore?

1- Lidar orientation
How good can we assess our orientation at an offshore site? Is the structure really fixed?

2- Partial scanning and larger domain
What are the consequences of applying partial VAD?
1: Orientation assessment
1- Orientation assessment

<table>
<thead>
<tr>
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<td></td>
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## 1- Orientation assessment

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| **Alternative sensor** | Lidar itself: target nearby objects | • Lidar itself: target nearby objects (complex)  
• Lidar itself: sea surface leveling |
| **Remark**               |                                              |                                                                               |
## 1- Orientation assessment

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**Remark**

Critical due to effect on actual measurement height and *vertical wind shear*

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*Figure (right): Example of a deviation in tilt or roll of 0.1°*
1- Orientation assessment with sea surface leveling

Figure: conical scanning towards the sea with constant elevation angle
1- Orientation assessment with sea surface leveling

**Principle:** the tilt and roll of a cone which better fits the „projected“ ellipse at the sea surface represents the lidar misorientation.

*Figure:* conical scanning towards the sea with constant elevation angle.
1- Orientation assessment with sea surface leveling

**Principle:** the tilt and roll of a cone which better fits the „projected“ ellipse at the sea surface represents the **lidar misorientation**

**Figure:** conical scanning towards the sea with constant elevation angle

**Figure:** backscattered signal intensity after one scan. Blind area at east side due to turbine tower.
1- Orientation assessment with SSL continuously

Data obtained during the X-Wakes campaign at Turbine K01 in GodeWind 1
1- Orientation assessment with SSL continuously

Inclinometer roll bias: +0.05°

Data obtained during the X-Wakes campaign at Turbine K01 in GodeWind 1
1- Orientation assessment with SSL continuously

Inclinometer roll bias: +0.05°

Inclinometer tilt bias: -0.05°

Data obtained during the X-Wakes campaign at Turbine K01 in GodeWind 1
1- Orientation assessment with SSL continuously

Inclinometer roll bias: +0.05°

Inclinometer tilt bias: -0.05°

Data obtained during the X-Wakes campaign at Turbine K01 in GodeWind 1

SSL revealed bias of -0.33 and -0.23° of tilt and roll, respectively, of another scanning lidar used during the NordseeOne campaign.
2: Partial VAD effects
2- Partial VAD simulation
Definition of reference homogenous wind (step 1 of 4)

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<th>Parameters</th>
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<th>VAD</th>
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<tr>
<td>Hor. wind speed (U)</td>
<td>10.00 m/s</td>
<td></td>
</tr>
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<td>Wind direction (φ)</td>
<td>0.0°</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>None</td>
<td></td>
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Diagram:
- Top view: Lidar is placed at the center of the compass, pointing towards 70° east.
- Horizontal view: Lidar is placed on the ground, with an angle of e = 1°.
- Wind direction: From the north to the south.
2- Partial VAD simulation
Definition of reference homogenous wind (step 1 of 4)

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2- Partial VAD simulation
Superposition of noise ("turbulent" wind) (step 2 of 4)

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</tr>
<tr>
<td>Noise: Gaussian (σ/U)</td>
<td>10%</td>
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Wind = 1°

Parameters:
- Ref:
  - Hor. wind speed (U): 10.00 m/s
  - Wind direction (φ): 0.0°
  - Noise: Gaussian (σ/U): 10%

Ref. sinus
- Ref. meas 1
- Ref. meas 2
- Meas 1
- Meas 2

Radial speed (m/s) vs Azimuth (°)

Top view

Horizontal view

W E
Wind
lidar
N S
70°
e = 1°
2- Partial VAD simulation
Application of VAD on “turbulent” wind (step 3 of 4)

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<td>Hor. wind speed (U)</td>
<td>10.00 m/s</td>
<td>10.02 m/s</td>
</tr>
<tr>
<td>Wind direction (φ)</td>
<td>0.0°</td>
<td>356.7°</td>
</tr>
<tr>
<td>Noise: Gaussian (σ/U)</td>
<td>10%</td>
<td>--</td>
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امية: 45°

Radial speed (m/s)

```
Azimuth (°)
```

Ref. sinus
Ref. meas 1
Ref. meas 2
Meas 1
Meas 2
Fit

Top view

Horizontal view
2- Partial VAD simulation
Evaluate VAD RMSE for multiple runs (step 4 of 4)

\[ \text{RMSE} = \sqrt{\frac{\sum (\text{Error})^2}{N}} \]

100x random simulations

Root mean squared error (RMSE)
2- Partial VAD simulation
RMSE for multiple simulations

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<tr>
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<th>Range</th>
<th>Steps</th>
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<tbody>
<tr>
<td>Wind speed (U)</td>
<td>5m/s – 30m/s</td>
<td>5m/s</td>
</tr>
<tr>
<td>Wind direction (φ)</td>
<td>0° – 360°</td>
<td>30°</td>
</tr>
<tr>
<td>Scanning elevation (e)</td>
<td>1° - 9°</td>
<td>2°</td>
</tr>
<tr>
<td>Noise: Gaussian (σ/U)</td>
<td>10%</td>
<td>--</td>
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Wind (U, φ)

Top view

Horizontal view
Conclusions

• A methodology has been presented for measuring vertical profiles based on conventional VAD techniques but with a restricted scanning pattern.

• Lidar orientation based on inclinometer data is not reliable. A calibration is necessary and can be performed onsite with sea surface leveling.

• A simplified simulation approach indicates that “partial” VAD can predict wind speeds and wind directions with RMSE values in the order of magnitude of realistic values. However, Further development of the simulation technique should be done to assess numerically the accuracy of the measurement strategy.
Acknowledgements

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