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

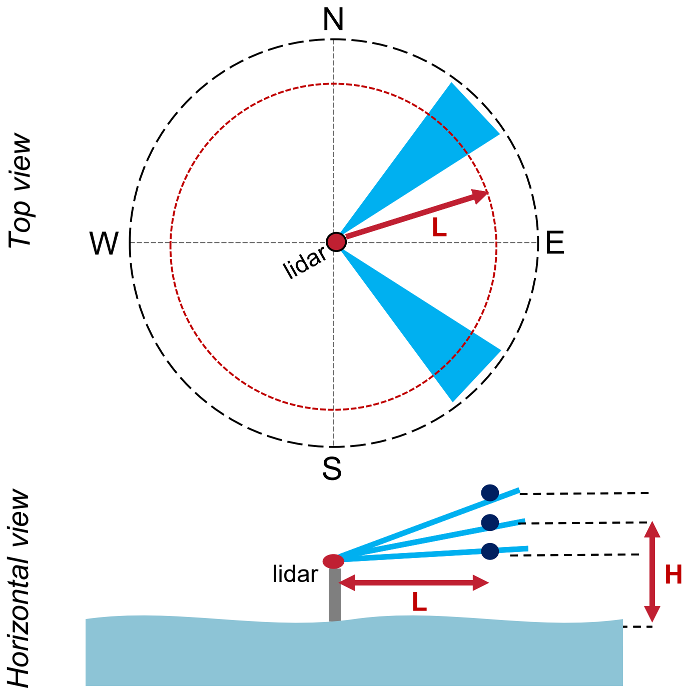
Juan José Trujillo[1], Priscila Orozco[1], Beatriz Cañadillas[1,2],

Richard Frühmann[1] and Thomas Neumann[1]

[1]UL

[2] Institute of Flight Guidance, Technical University of Braunschweig

Introduction: How do we process vertical profiles?



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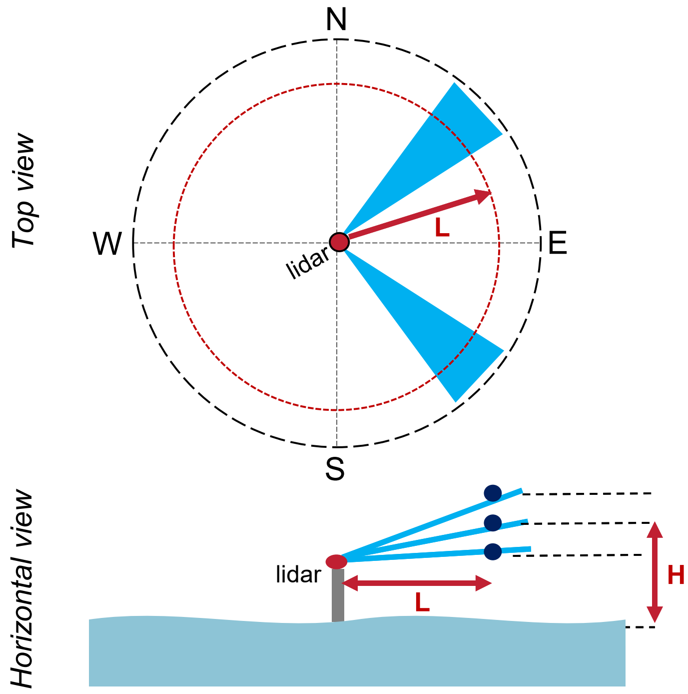
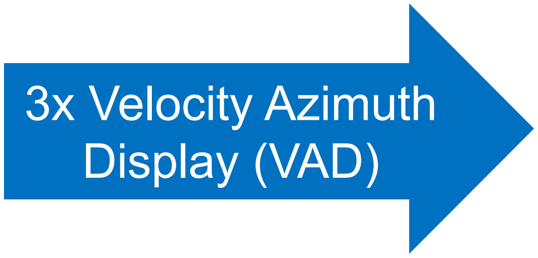




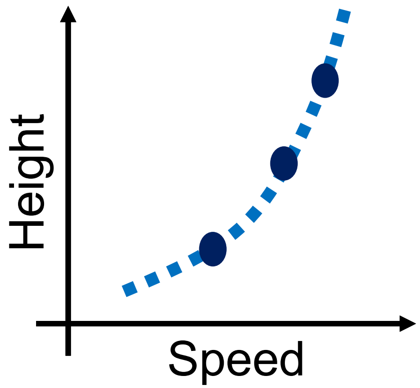


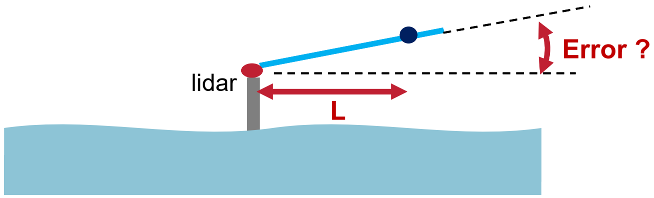
Figure: Wind speed at three heights at distance L

We apply the same principles and analysis techniques as the ones used in conventional ground based lidars

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?



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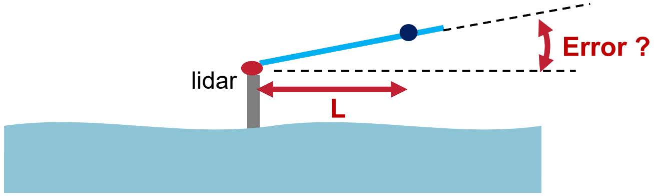
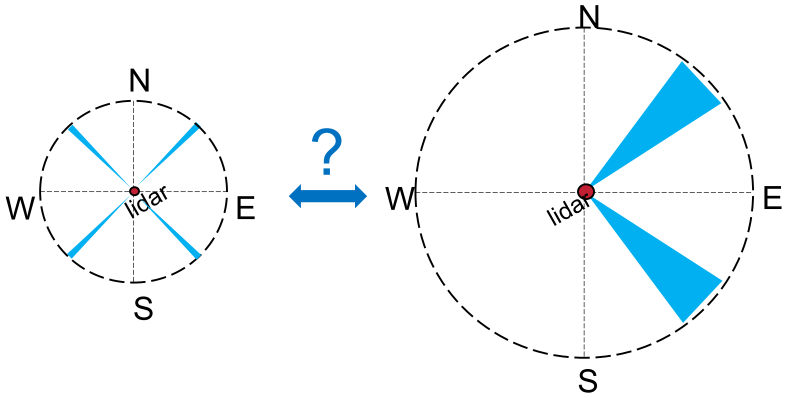


2- Partial scanning and larger domain
What are the consequences of applying partial VAD?



1: Orientation assessment

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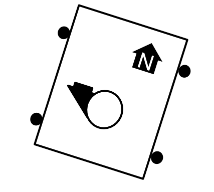
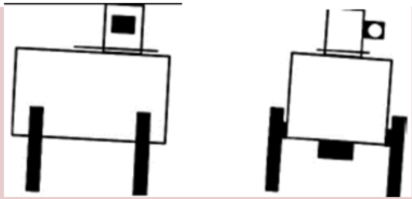
	Azimuth	Tilt and roll
		
Internal sensor	Compass	Inclinometer
Alternative sensor		
Remark		

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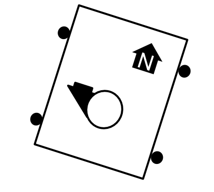
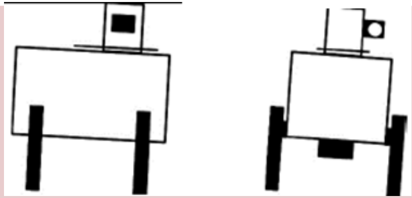
	Azimuth	**Tilt and roll**
		
Internal sensor	Compass	Inclinometer
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Remark		

1- Orientation assessment

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	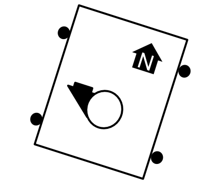	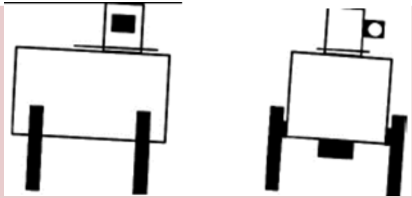
Internal sensor	Compass	Inclinometer
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Remark		

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	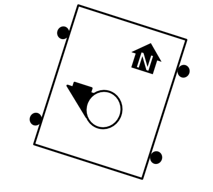	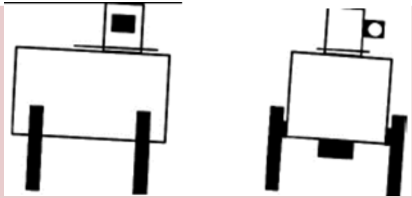
Internal sensor	Compass	Inclinometer
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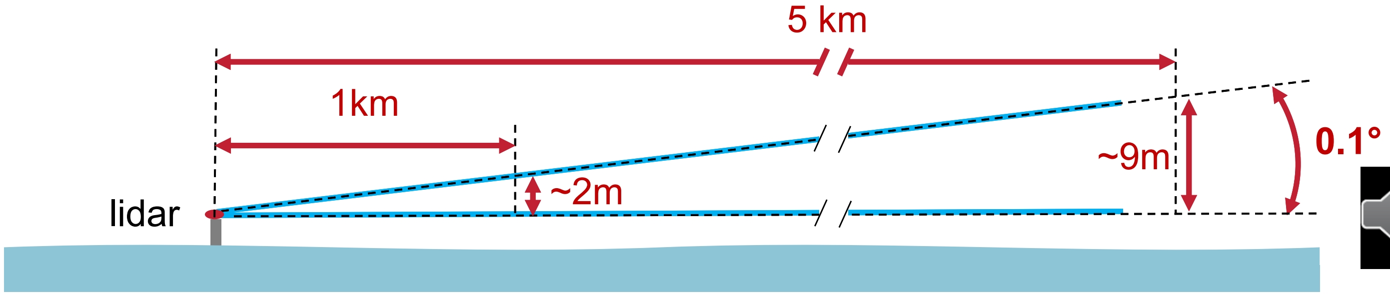
Remark		**Critical** due to effect on actual measurement height and **vertical wind shear**

Figure (right): Example of a deviation in tilt or roll of 0.1°



1- Orientation assessment with sea surface leveling

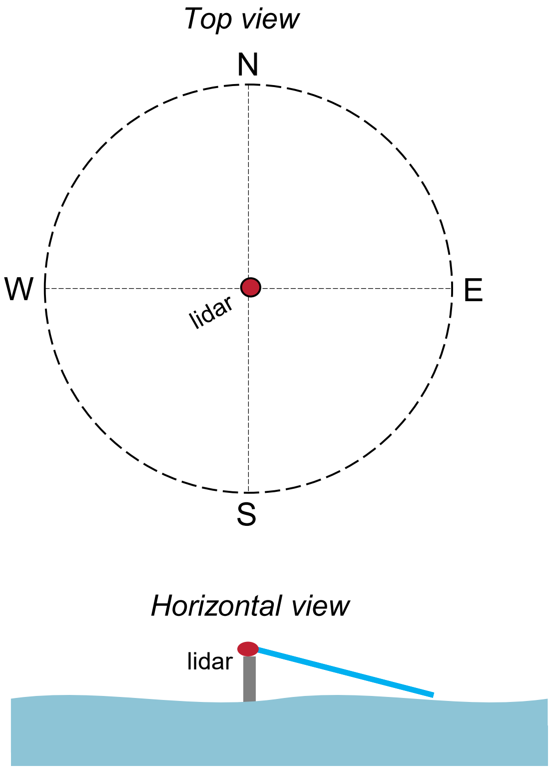


Figure: conical scanning towards the sea with constant elevation angle

1- Orientation assessment with sea surface leveling

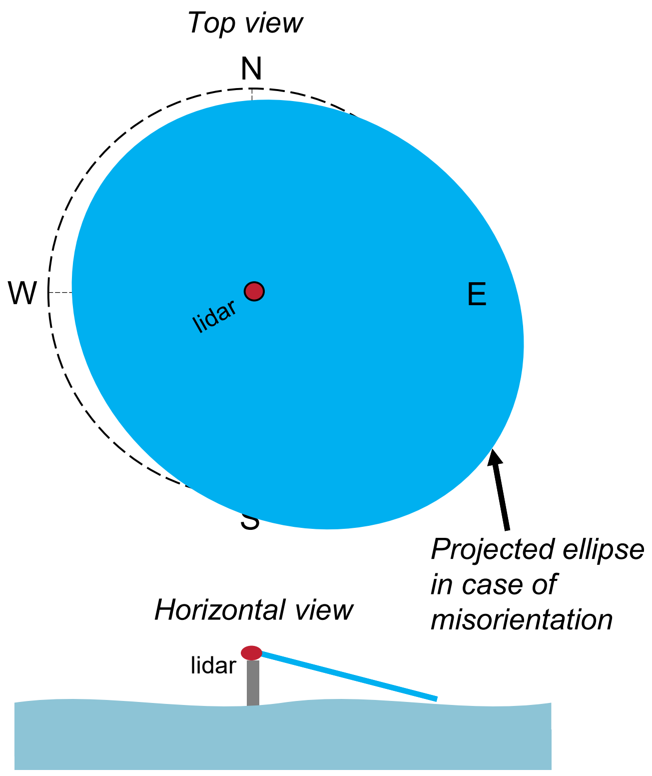


Figure: conical scanning towards the sea with constant elevation angle

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

1- Orientation assessment with sea surface leveling

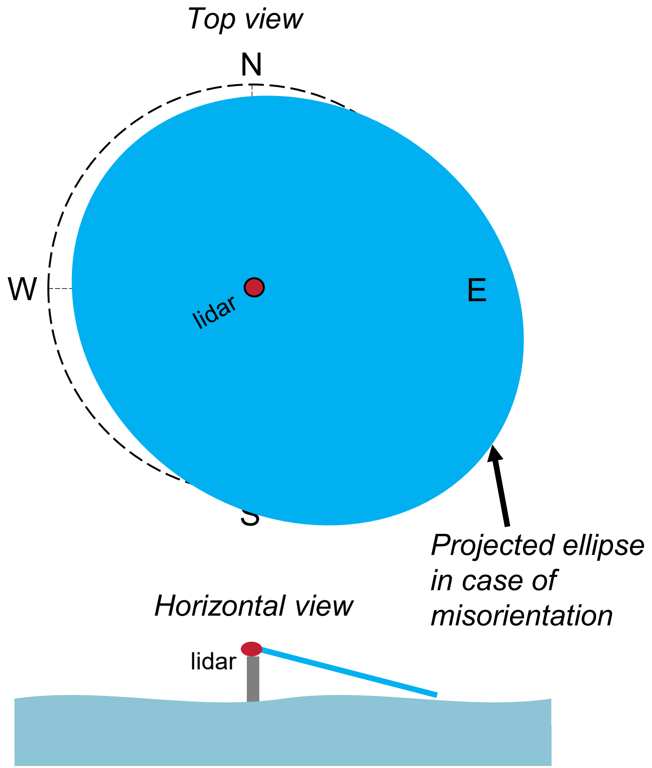


Figure: conical scanning towards the sea with constant elevation angle

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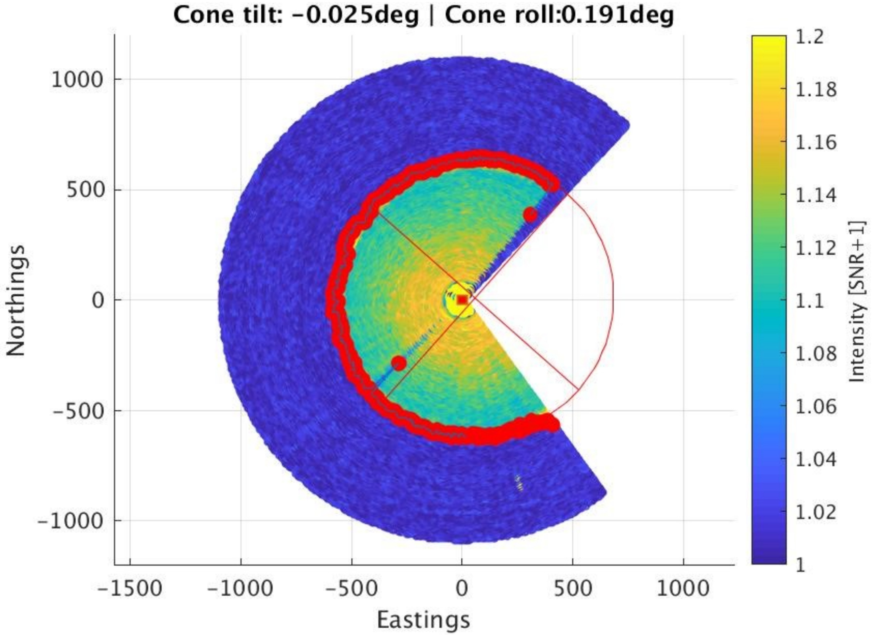
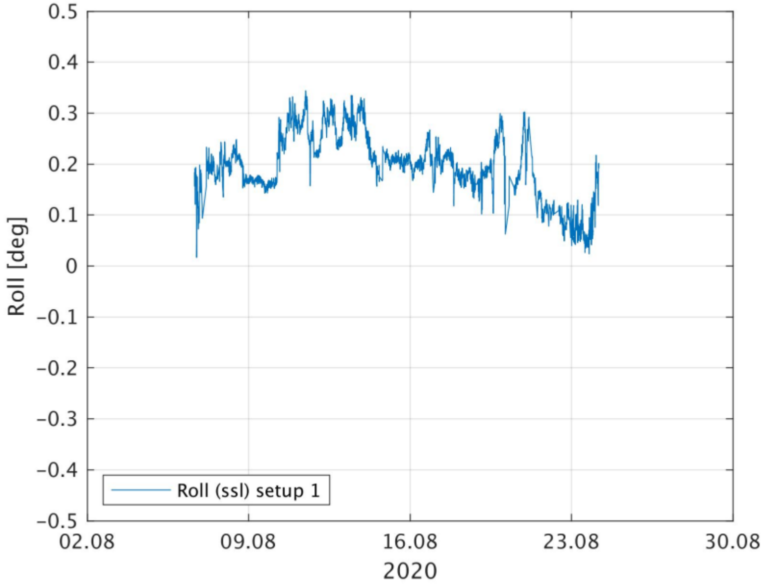


Figure: backscattered signal intensity after one scan. Blind area at east side due to turbine tower.

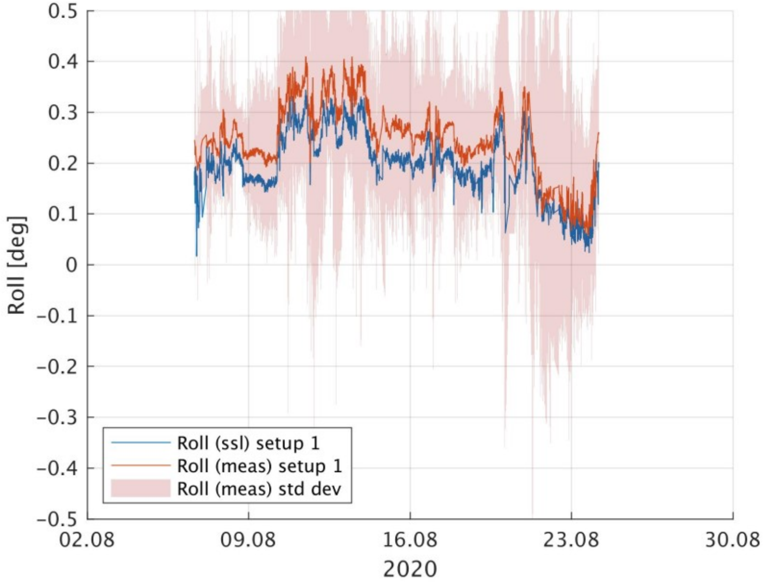
1- Orientation assessment with SSL continuously



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

1- Orientation assessment with SSL continuously

Inclinometer roll bias: +0.05°



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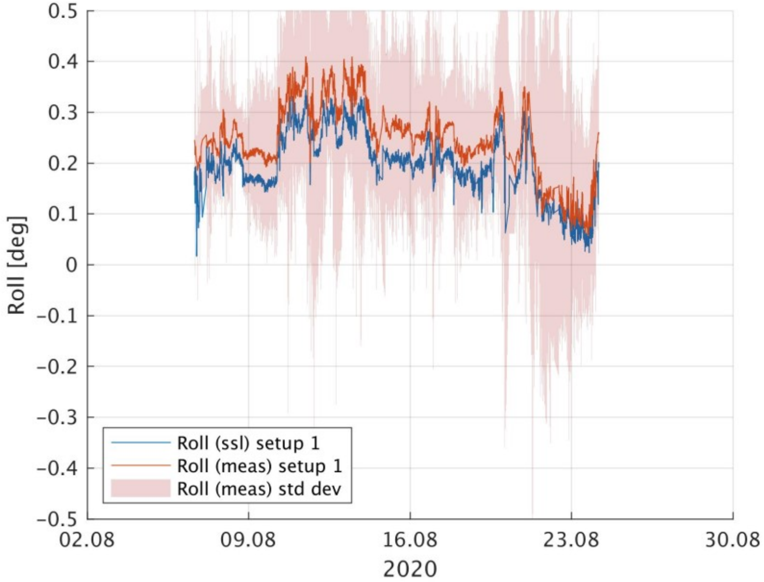
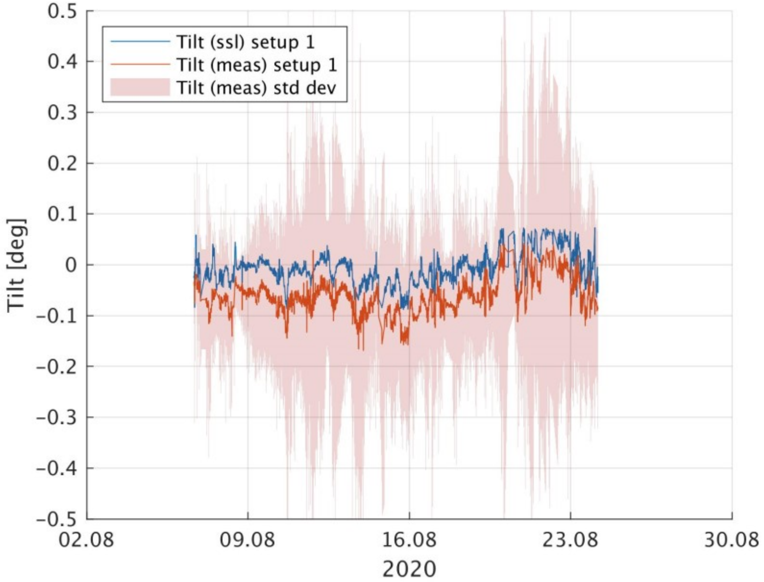


Inclinometer tilt bias: -0.05°



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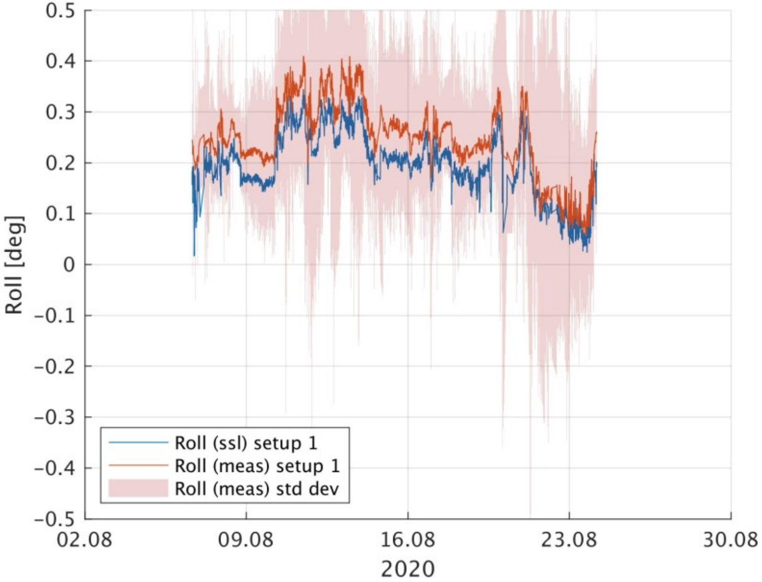

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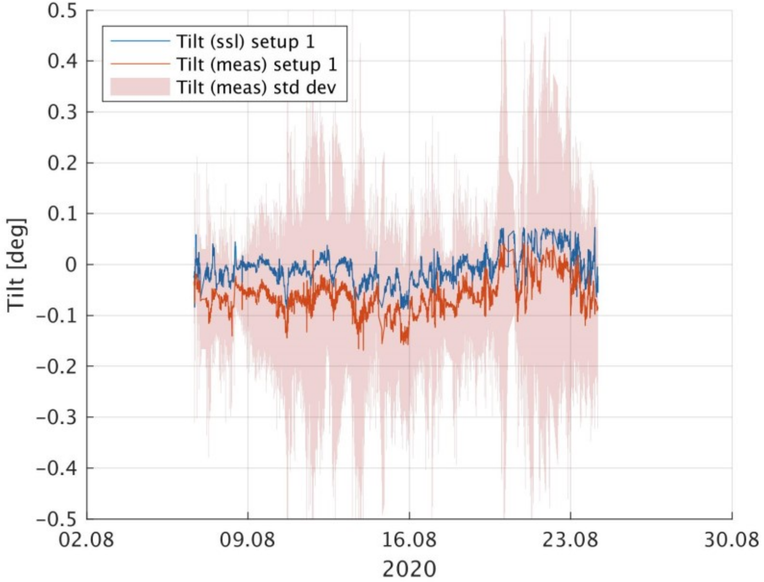


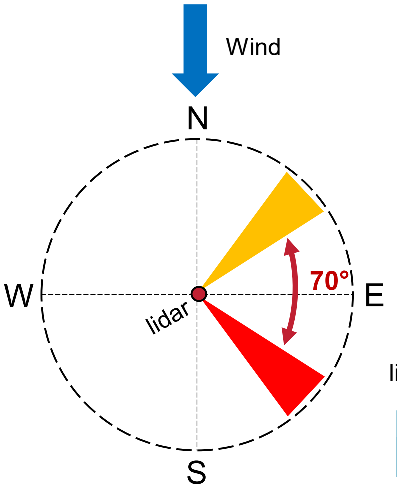
Data obtained during the X-Wakes campaign at Turbine K01 in GodeWind 1

SSL revealed **bias of -0.33 and -0.23°** of tilt and roll, respectively, **of another scanning lidar** used during the NordseeOne campaign

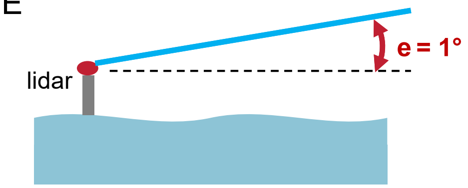
2: Partial VAD effects

2- Partial VAD simulation
Definition of reference homogenous wind (step 1 of 4)

Parameters	Ref	VAD
Hor. wind speed (U)	10.00 m/s	
Wind direction (φ)	0.0°	
Noise	None	



Top view



Horizontal view

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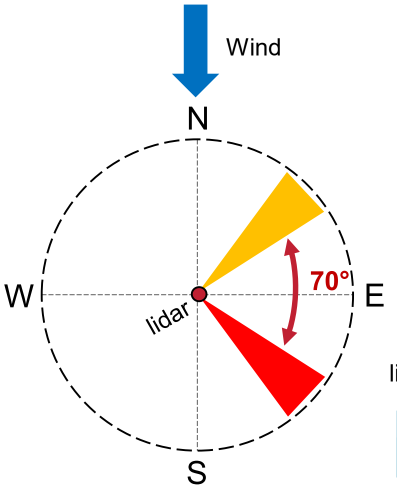

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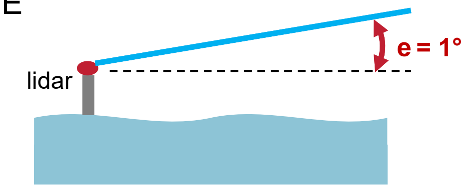

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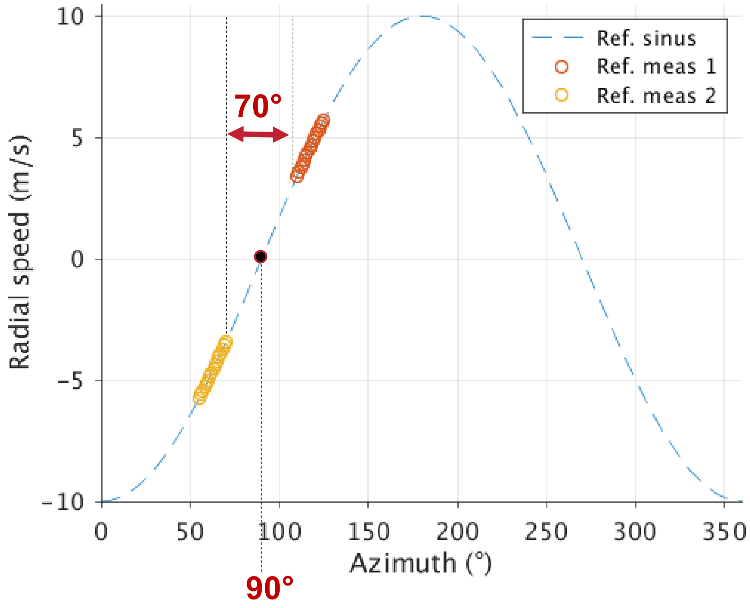
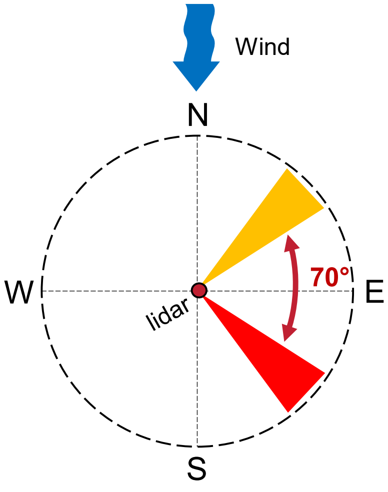
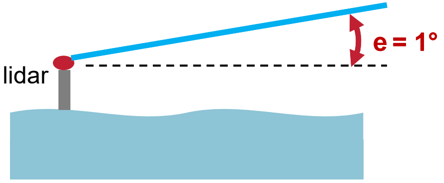


2- Partial VAD simulation
Superposition of noise (“turbulent” wind) (step 2 of 4)

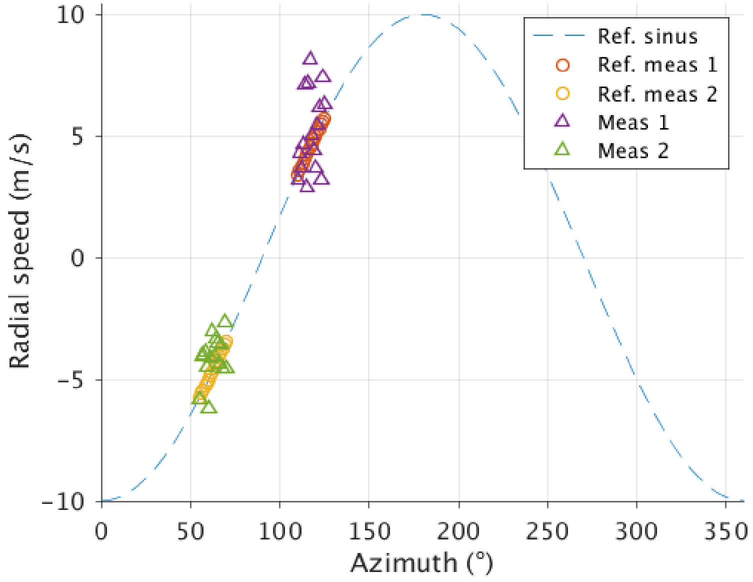
Parameters	Ref	VAD
Hor. wind speed (U)	10.00 m/s	
Wind direction (φ)	0.0°	
Noise: Gaussian (σ/U)	**10%**	



Top view

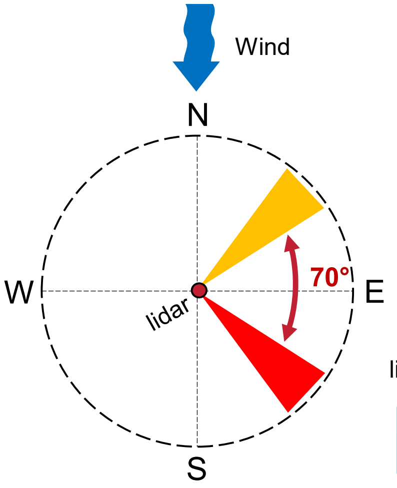


Horizontal view

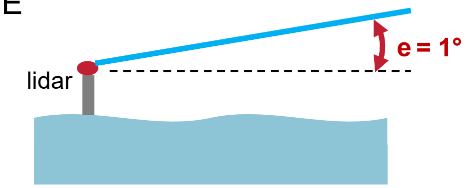


2- Partial VAD simulation
Application of VAD on "turbulent" wind (step 3 of 4)

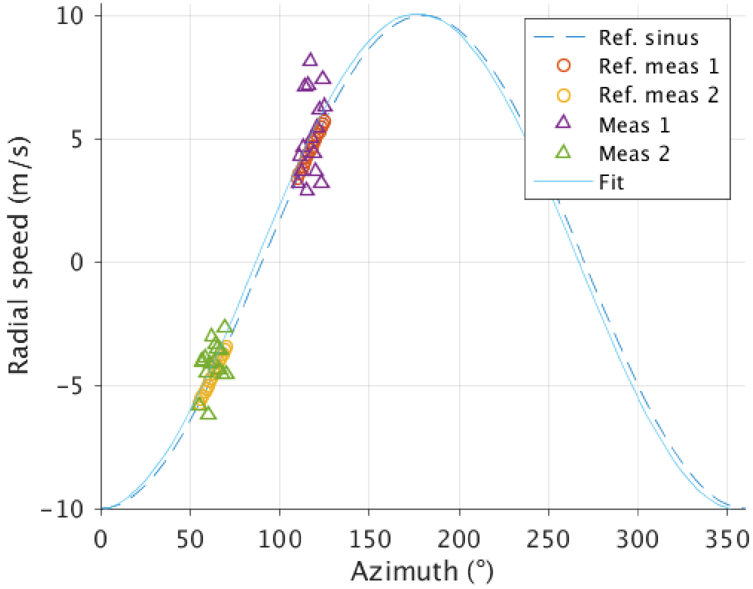
Parameters	Ref	VAD
Hor. wind speed (U)	10.00 m/s	10.02 m/s
Wind direction (φ)	0.0°	356.7°
Noise: Gaussian (σ/U)	10%	--



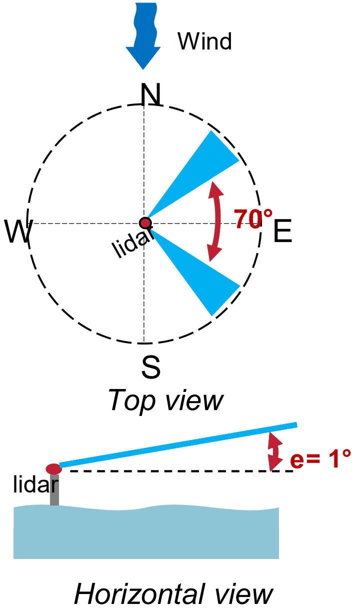
Top view



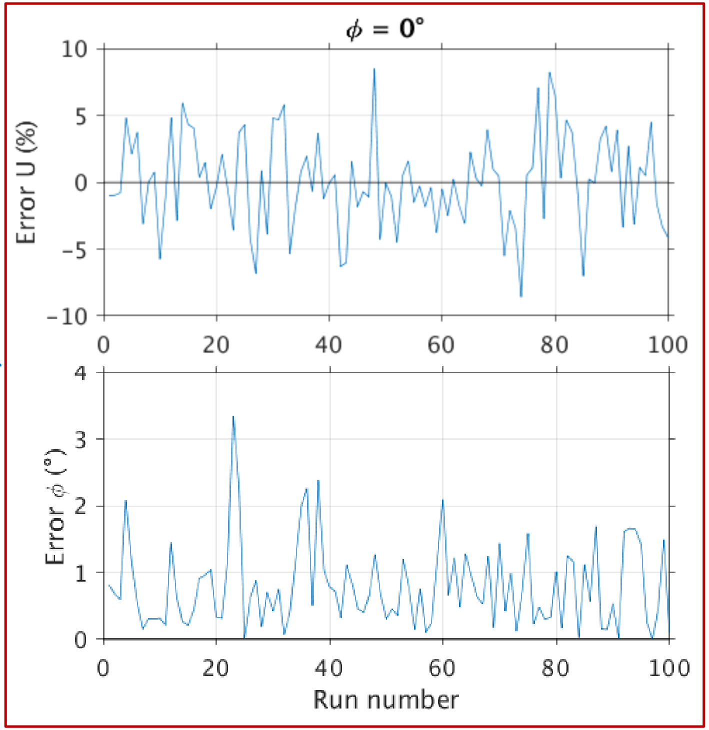
Horizontal view



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



100x random simulations

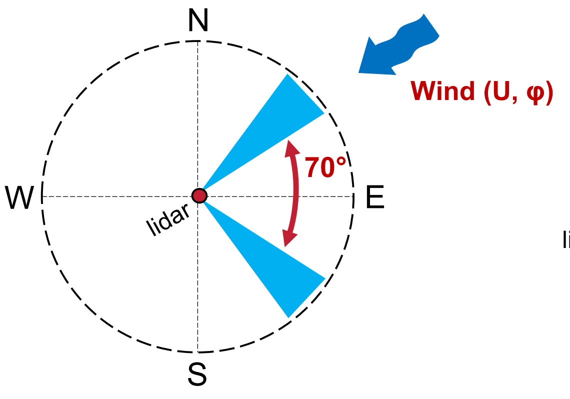


Root mean squared error (RMSE)

$$RMSE = \sqrt{\frac{\Sigma(Error)^2}{N}}$$

2- Partial VAD simulation
RMSE for multiple simulations

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



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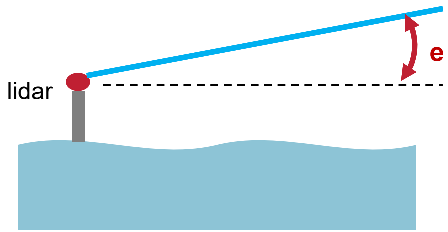

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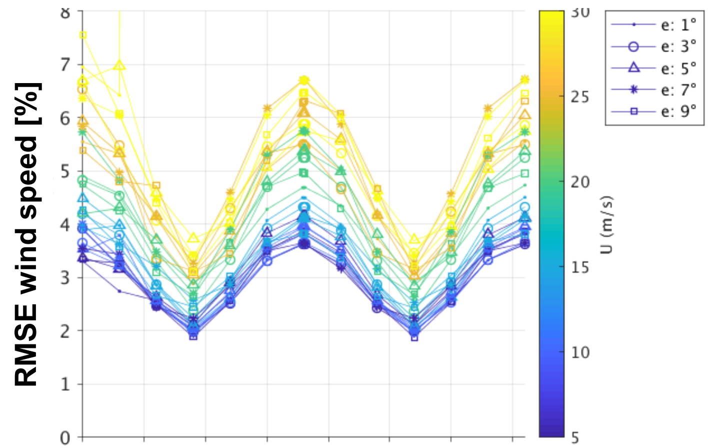

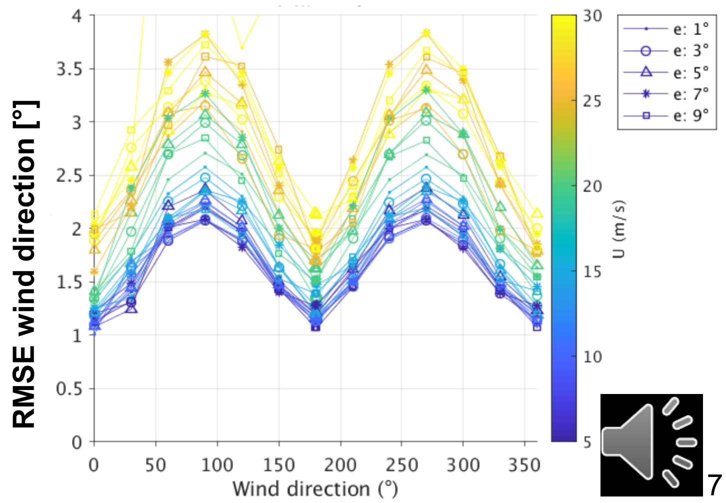

Conclusions

- 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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