Dependence of Floating LiDAR Performance on External Parameters – Are existing onshore classification methods Applicable?

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Outline

- Introduction
- FLS verification vs classification
- Case Study: Fraunhofer IWES LiDAR Buoy
- Resume

Introduction

Floating LiDAR Systems (FLS)

- Commercially available since 2010
- **Several providers** for systems or measurements, number growing
- FLS can **replace offshore meteorological masts** for site assessment, power curve measurements etc…

From: Gottschall et al: Floating lidar as an advanced offshore wind speed measurement technique, WIREs Energy and Environment, 2017 [1]

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Introduction

Technology

Applications

Wind resource assessment (WRA)

Power curve measurements

…

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Technology

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...

[5]

[2,3,4]

Verification Classification

Standards, Recommended practices

Introduction

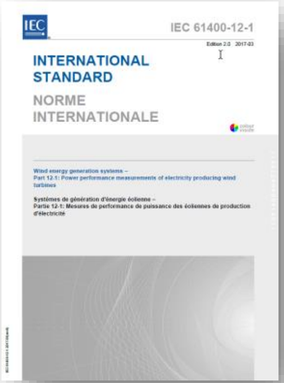
Technology

Applications

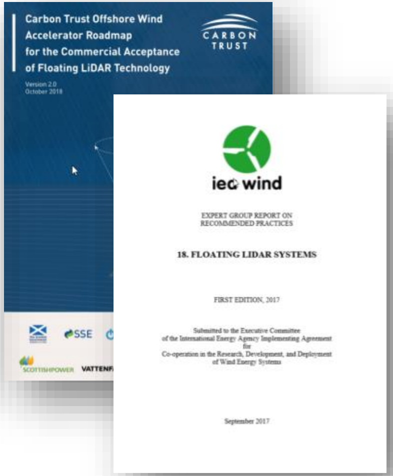
Wind resource assessment (WRA)

Power curve measurements

…



[5]



[2,3,4]

???

Verification
Classification

Standards,
Recommended
practices

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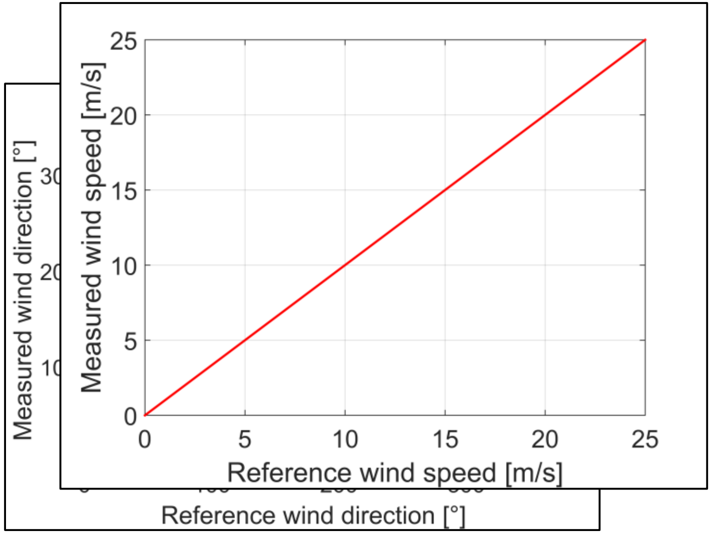
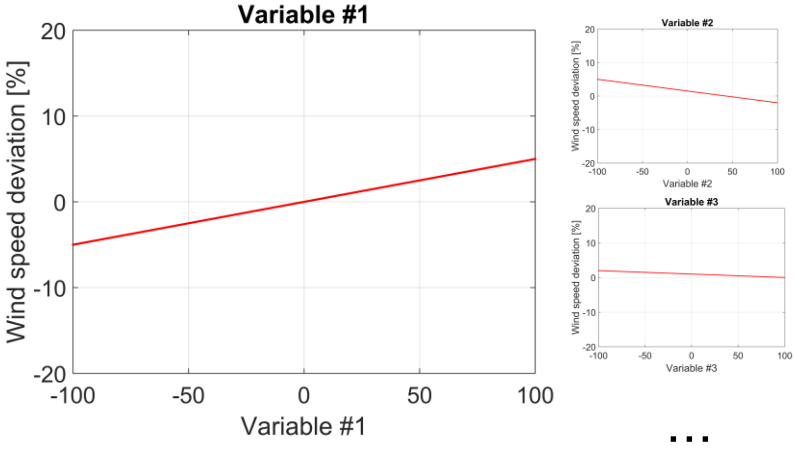
FLS verification vs classification

Verification



- For a distinct system
- For selected conditions
- short term measurement ~1 month

Classification



- For a FLS type
- Correlation WSP deviation and independent variable
- At least 3 months measurement

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Fraunhofer IWES LiDAR Buoy

System

- Hull from light fire buoy, developed in 1980
- Power supply: 3 micro wind turbine, PV, back-up generator, batteries
- LiDAR: WindCube V2 or ZX 300 (ZephIR)
- Weight: ca. 3.5 t

Fraunhofer IWES LiDAR Buoy

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Analysed Measurements (exceeding 6 months, 2016)

- **LiDAR Buoy at FINO3 (Windcube)**
- LiDAR Buoy at FINO1 (ZephIR)

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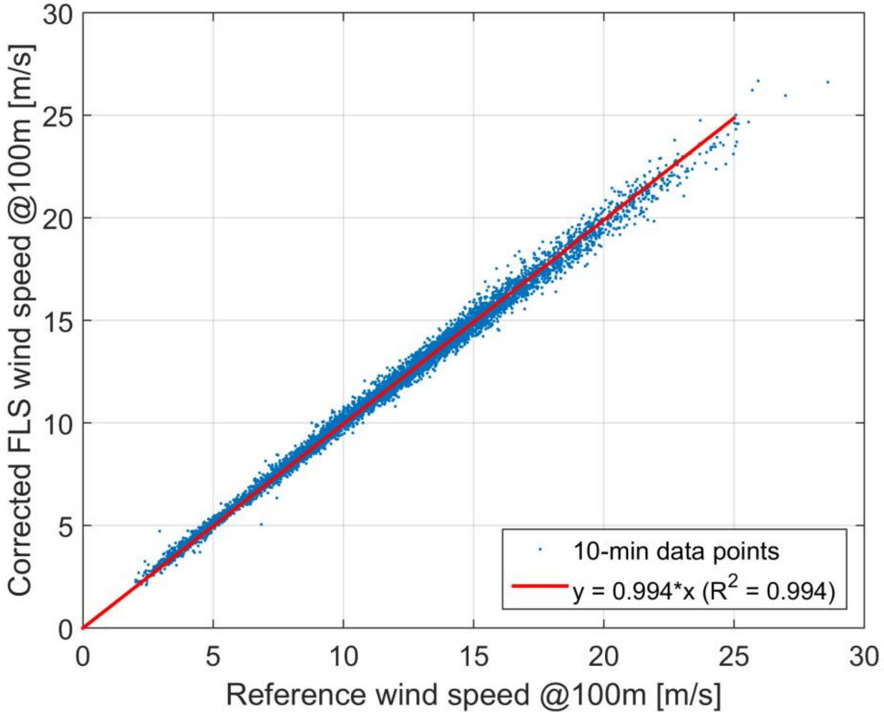
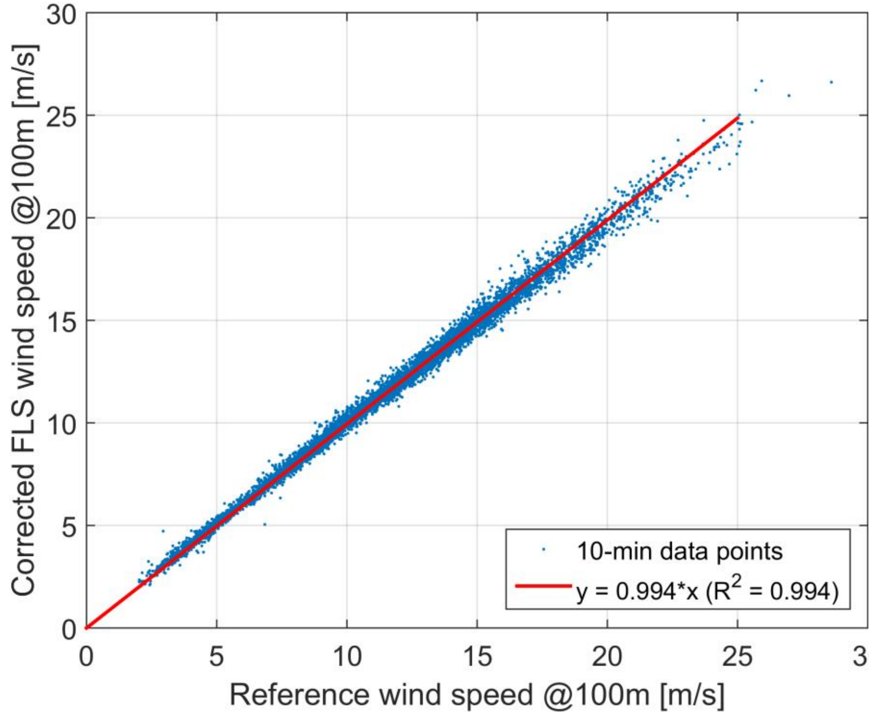
Verification

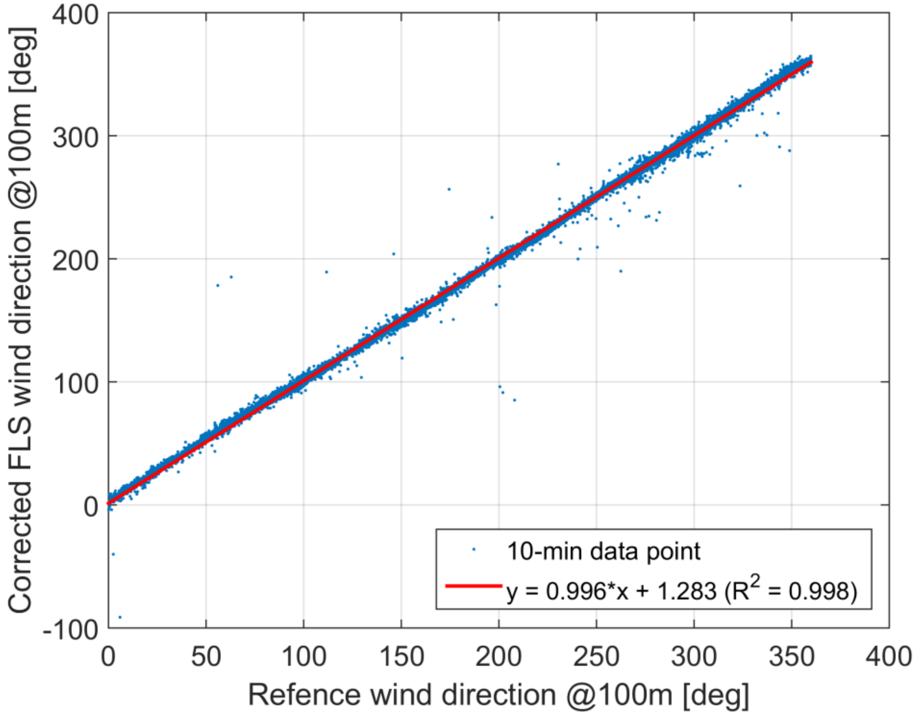
Comparison of FLS wind speed and wind direction compared to reference



Verification

Comparison of FLS wind speed and wind direction compared to reference
-> Key parameter (slope and R^2) exceed Best Practice requirements!





Classification – Environmental Variables

Wind speed deviation (FLS-Reference) vs environmental variables (EV)

Meteorological variables
(defined in IEC 64100-12-1)

- Wind speed
- Wind direction
- Wind shear
- Wind veer
- Temperature and temperature difference
- Air density
- …

Classification – Environmental Variables

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Meteorological variables (defined in IEC 64100-12-1)

- Wind speed
- Wind direction
- Wind shear
- Wind veer
- Temperature and temperature difference
- Air density
- …

Oceanographic variables

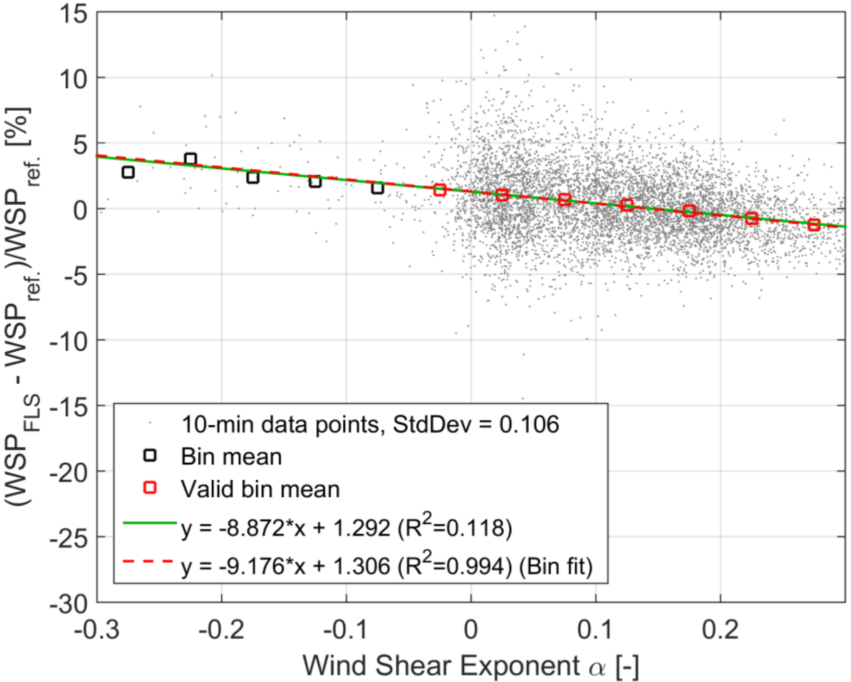
- Wave height
- Wave period
- Water level
- Currents
- …

- Tilting
- Yawing
- Heave
- Translation
- …

Platform motion variables

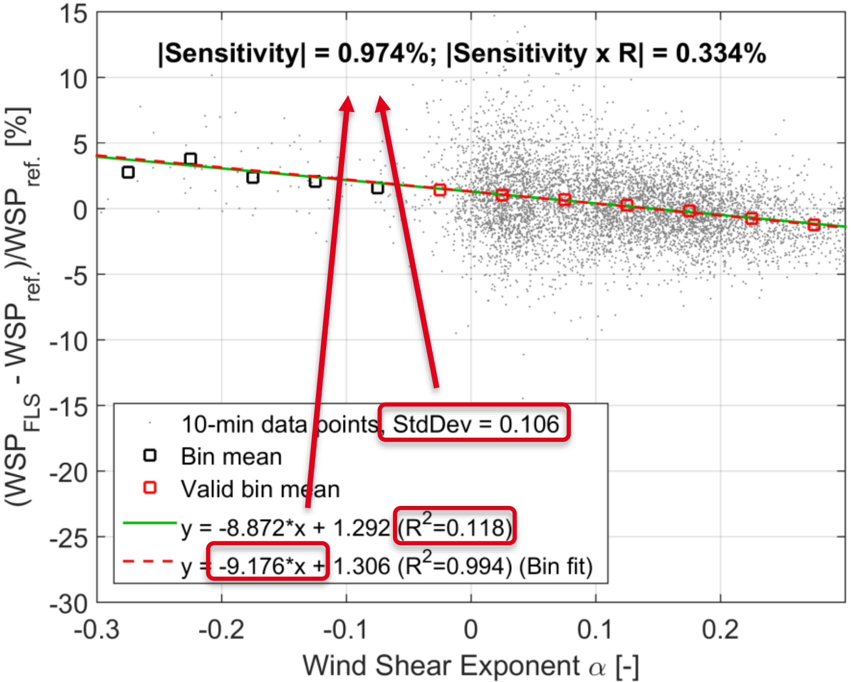
Classification - Sensitivity

Wind shear (example)



Classification - Sensitivity

Wind shear



FLS is sensitive for independent variable, if

- |Sensitivity| > 0.5
- |Sensitivity · R| > 0.1

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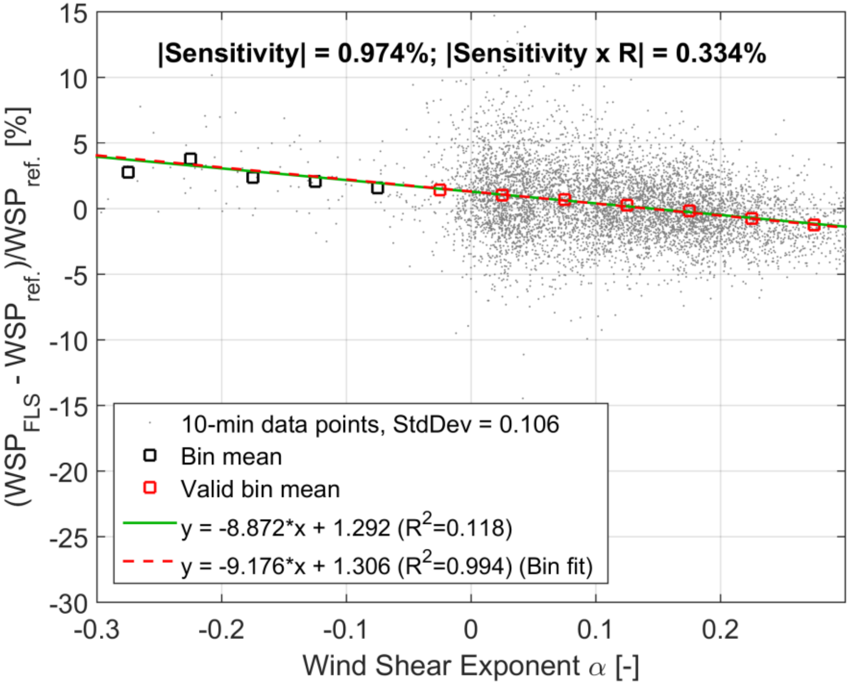
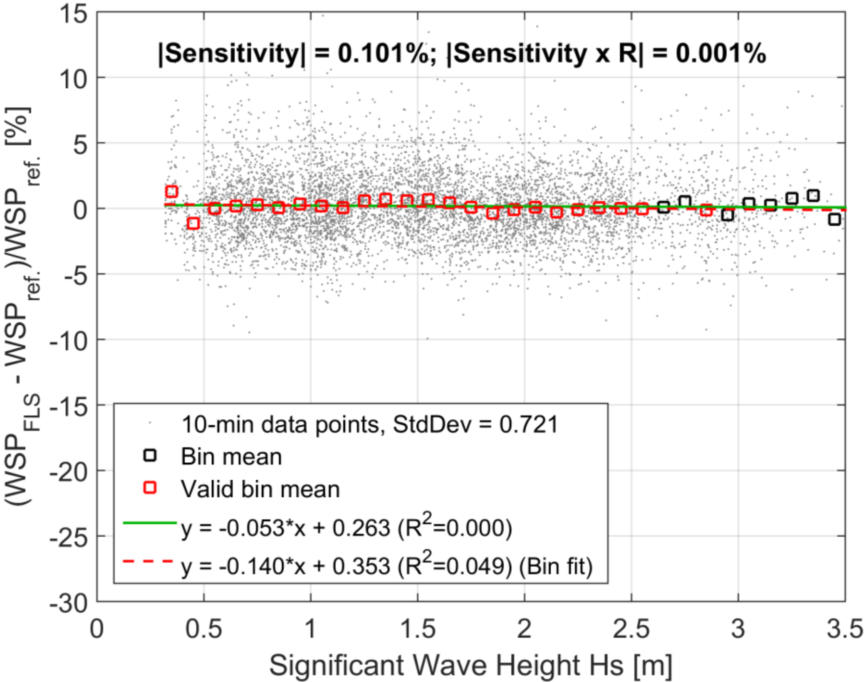
Classification - Sensitivity

Wind shear

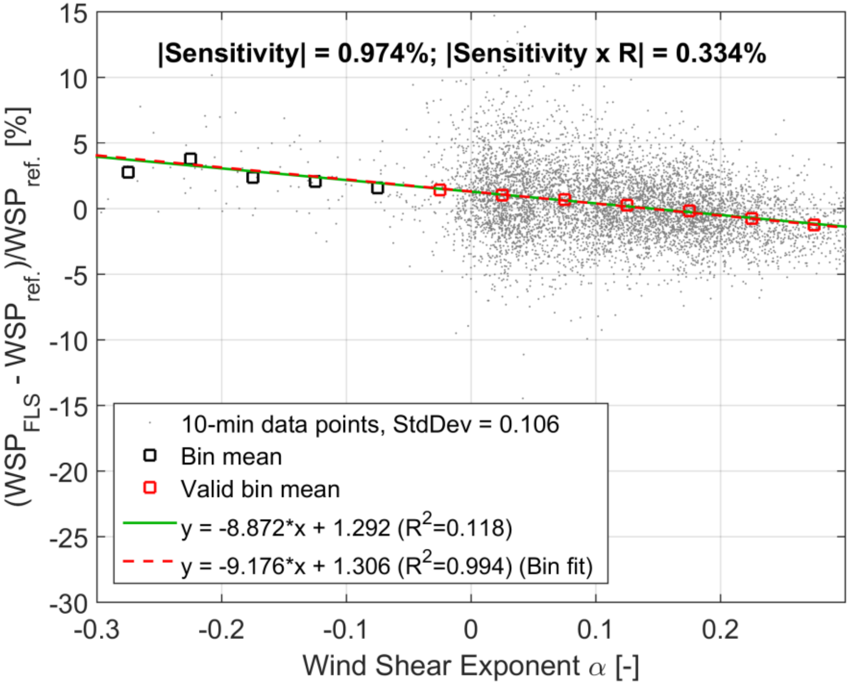


Significant Wave height Hs

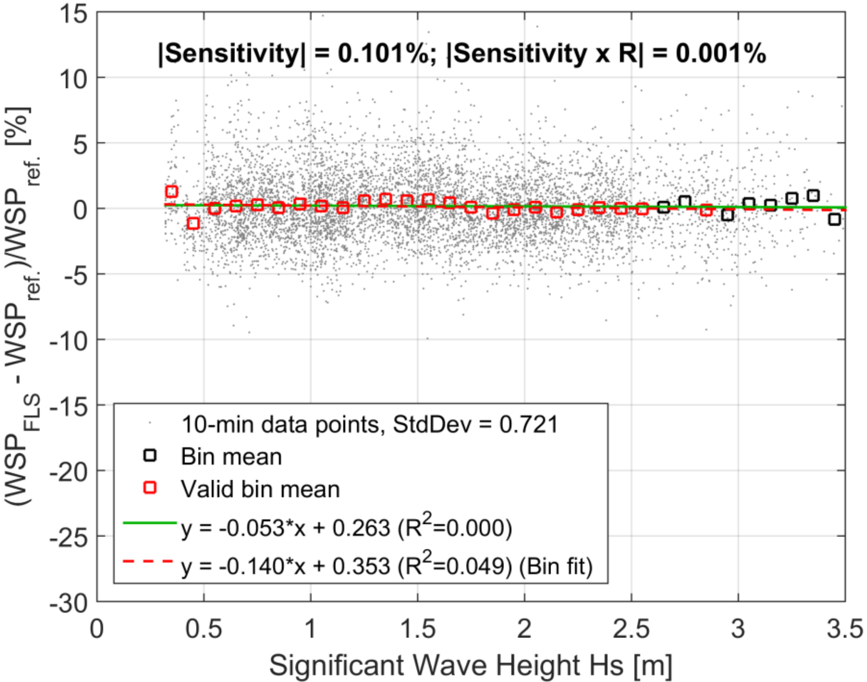


Classification - Sensitivity

Wind shear
Sensitive!



Significant Wave height Hs
Not sensitive!



Classification – Variable Sensitivity Results

LiDAR Quality Parameter and meteorological variables (selection)

Independant variable	std(Independant variable)	m (bin Fit)	Sensitivity m x std	R^2	Sensitivity x R	Sensitive
[-]	[unit variable]	[% unit variable]	[%]	[-]	[%]	
CNR signal quality	5.90	-0.11	**-0.65**	0.01	-0.06	yes
Wind shear exponent	0.11	-9.18	**-0.97**	0.12	**-0.33**	yes
Wind veer	0.13	-9.66	**-1.21**	0.04	**-0.23**	yes
Wind speed	3.16	-0.20	**-0.62**	0.06	**-0.15**	yes
Turbulence intensity Ti	2.27	0.36	**0.81**	0.05	**0.18**	yes
Temperature gradient	0.01	-104.26	**-1.10**	0.01	**-0.13**	yes

Are the variables independent, correlations?

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Classification – Variable Sensitivity Results

LiDAR Quality Parameter and meteorological variables (selection)

Independant variable	std(Independant variable)	m (bin Fit)	Sensitivity m x std	R^2	Sensitivity x R	Sensitive	Considering shear *
[-]	[unit variable]	[% unit variable]	[%]	[-]	[%]		
CNR signal quality	5.90	-0.11	**-0.65**	0.01	-0.06	**yes**	no
Wind shear exponent	0.11	-9.18	**-0.97**	0.12	**-0.33**	**yes**	no
Wind veer	0.13	-9.66	**-1.21**	0.04	**-0.23**	**yes**	**yes**
Wind speed	3.16	-0.20	**-0.62**	0.06	**-0.15**	**yes**	no
Turbulence intensity Ti	2.27	0.36	**0.81**	0.05	**0.18**	**yes**	no
Temperature gradient	0.01	-104.26	**-1.10**	0.01	**-0.13**	**yes**	no

- > CNR, shear, wind speed, Ti and the temperature gradient correlate
- > Veer is an independent variable!

* See Barker Et al. [6]

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Classification – Variable Sensitivity Results

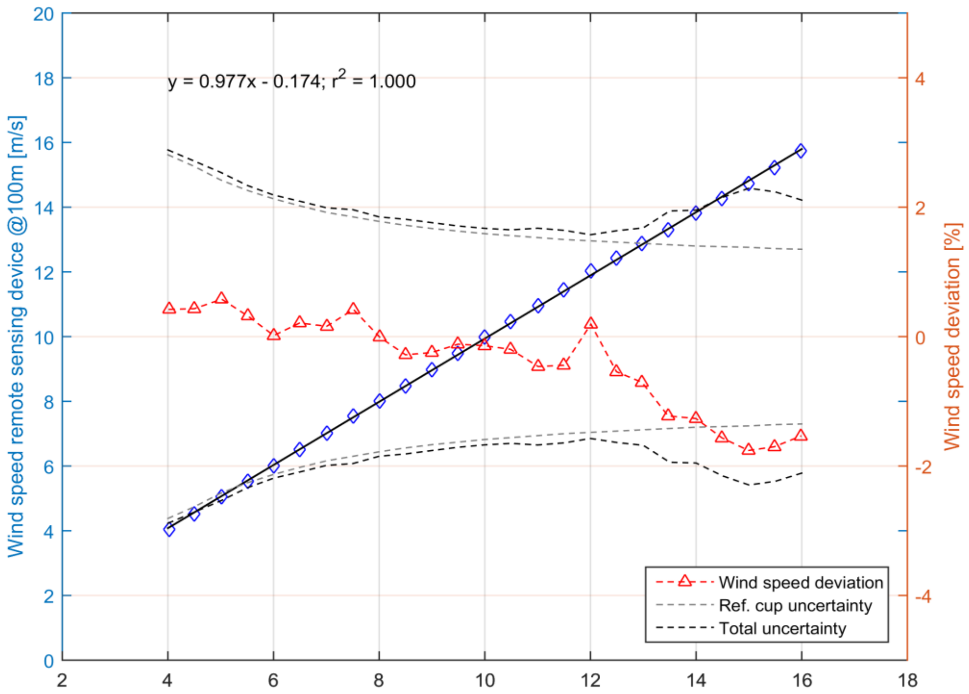
Oceanographic variables and motion variable (selection)

Independant variable	std(Independant variable)	m (bin Fit)	Sensitivity m x std	R2	Sensitivity x R	Sensitive
[-]	[unit variable]	[% unit variable]	[%]	[-]	[%]	
Significant wave height (buoy)	0.721	-0.140	-0.101	0.000	-0.001	no
Peak period Tp (Buoy)	2.289	0.026	0.059	0.000	0.001	no
Current	0.096	-1.382	-0.133	0.002	-0.006	no
Heave range	0.570	-0.219	-0.125	0.000	-0.002	no
Tilt Range	3.811	0.027	0.105	0.000	0.001	no
Yaw increment range	8.559	-0.008	-0.069	0.002	-0.003	no
Static tilt	0.473	-0.387	-0.183	0.002	-0.008	no

- No sensitivities for oceanographic or platform motion variables!

Classification – Final classification

Classification results for FINO1 campaign



-> Most uncertainty comes from reference measurement uncertainty

Classification – Results

For both FLS systems, no sensitivities to oceanographic or buoy motion variables could be identified!

FLS (Windcube)

Independant variable	Sensitivity m x std	Sensitivit y x R	Sensitive
[-]	[%]	[%]	
Significant wave height (buoy)	-0.101	-0.001	no
Peak period Tp (Buoy)	0.059	0.001	no
Current	-0.133	-0.006	no
Heave range	-0.125	-0.002	no
Tilt Range	0.105	0.001	no
Yaw increment range	-0.069	-0.003	no
Static tilt	-0.183	-0.008	no

FLS (ZX/ZephIR) @100m

Independant variable	Sensitivity m x std	Sensitivity x r	Sensitive
[-]	[%]	[%]	
Significant wave height	-0.063	-0.001	no
Peak period Tp (Buoy)	-0.191	-0.007	no
Tm02 (radar)	0.013	0.000	no
Waterlevel	-0.069	0.000	no
Heave range	-0.118	-0.002	no
Tilt Range	0.078	0.000	no
Yaw increment range	-0.054	-0.001	no
Static tilt	0.075	0.002	no

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Classification – Shortcomings

- Which variables are important – do we miss the important ones?
- Bin-fitting process is not necessarily robust
- Use of motion instead of oceanographic variables for system with minor design changes?

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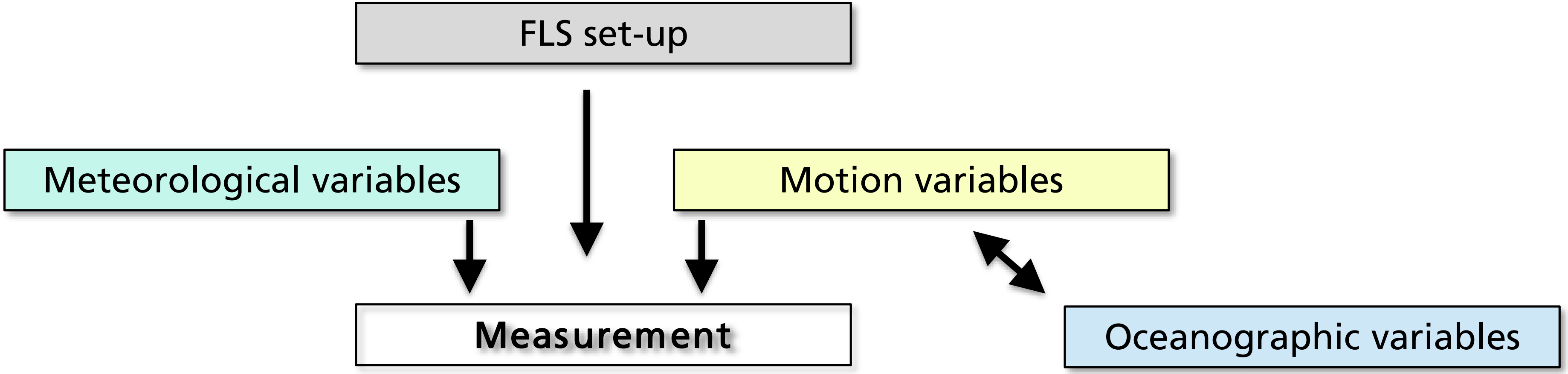

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Resume

- Verification and classification are important for the commercial acceptance of FLS
- Both IWES FLS using Windcube or ZX/ZephIR show no sensitivities to motions or oceanographic variables
- Method of classification (according to IEC) must be adapted for offshore, due to more variables… which variables are important for a measurement sensitivity forecast?

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Thanks a lot for your attention!

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