TESTING AND CALIBRATION OF VARIOUS LiDAR REMOTE SENSING DEVICES FOR A 2 YEAR OFFSHORE WIND MEASUREMENT CAMPAIGN

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Abstract:

NORSEWInD is an EU project that will provide cost effective, high quality offshore wind speed data. For the purpose of the project, the areas being investigated are the Irish Sea, Baltic Sea and North Sea, areas where the greatest economic expansion of offshore wind energy will take place. The project will combine LiDAR remote sensing and satellite techniques as well as classic met mast measurements to provide a high quality, hub height data set covering the whole of the North, Irish and Baltic Seas. One of its objectives is to demonstrate the approach of a basin wide acquisition of the offshore wind field for wind energy purposes such as wind resource assessments by in-situ measurements on various offshore rigs and platforms in the different Seas using remote sensing (RS) techniques such as Wind-LiDAR and SoDAR. About 20 individual RS systems will be deployed on various offshore platforms in the North, Irish and Baltic Seas to collect data over a continuous period of 2 years starting in spring 2009.

Prior to any such offshore deployment, each system needs to be tested thoroughly and calibrated against accepted standards such as a meteorological mast and a reference RS device. This will identify sub-standard systems and generally assure the highest data quality. The paper presents the testing and calibration procedures which have been developed in the NORSEWInD project. These measurements will be performed at the Høvsøre Test Station on the west coast of Denmark, 1km from the North Sea. This will provide near-offshore wind conditions and is therefore fairly representative of an offshore location. We anticipate that the testing and calibration methods adopted for the NORSEWInD project will have general interest throughout the wind energy industry.

1.0 Introduction

NORSEWInD (Northern Seas Wind Index Database) is an FP7 programme that will provide real world, hub height data to the wind industry to aid offshore development. NORSEWInD is novel in that it aims to use physical data acquired offshore as the basis for the end product of an offshore wind atlas for the Baltic, Irish and North Sea Basins.

To achieve this, NORSEWInD will adopt a multi-instrument approach, built around LiDAR (Light Detecting And Ranging)systems deployed in offshore locations, delivering local time series data as well as validation and calibration of Earth Observation data (SAR and QUIKScat).

The clear aim of the project is to increase data availability and reduce data uncertainty, however in order to do this a valid LiDAR validation programme has to be derived and implemented to ensure that each system used on the project is deemed fit for purpose, and is performing to a common standard. Standard remote system testing does not as yet, exist in the wind industry for ground based remote sensing systems.

LiDAR systems and Remote Sensing in general are not new techniques to the wind industry, with a number of papers published that showcase system potential and capabilities when compared to a traditional MEASNET equipped reference mast, [for example 1,2,3,4] however little guidance exists as to what is an acceptable level of performance for ground based remote sensing instruments (LiDAR & SODAR - Sound Detecting And Ranging) within the wind industry.

The aim of this paper is to define a set of acceptance criteria to be applied to LiDAR systems for the wind industry. Wide spread adoption of the technique will lead to a clear methodology to reassure end-users as to a systems capability, as well as a clear set of objectives for system designers.

This paper presents the 1st iteration of the NORSEWInD validation criteria, and preliminary results when the criteria are applied to a Leosphere WindCube LiDAR. The application to a Natural Power ZephIR LiDAR will follow.

2.0 Testing

2.1 Validation Criteria

In order for confidence to increase in the ability of Remote Sensing systems to return valid data for the wind industry, it is important that the system is able to perform to a high standard.

To ensure this NORSEWInD has defined acceptable levels of performance for the LiDAR systems to achieve as compared to a standard, well instrumented, reference mast located at Høvsøre, and managed by Risø DTU.

The acceptance criteria for NORSEWInD are based on:

- Absolute error – difference in reported wind speed between the reference and test instrument based on 10-minute averages;
- Data availability - defined as number of valid data points returned as compared to maximum number of possible points that can be acquired during the test. This is distinct from system availability, which has been set as 100% available for the duration of the test;
- Linear regression gradient – this is based on a single variant regression, with the regression analysis constrained to pass trough origin (y=mx+b; b==0). In addition a tolerance has been imposed on slope values returned at all reference heights, as well as sub-divided into two wind speed ranges;
- Linear regression R-squared values – is the quality of fit value returned from the analysis performed to assess the linear regression gradient value. Again a tolerance associated with variation in R-squared both with height and wind speed range has been imposed.

Table 1 summarises the imposed levels.

Parameter	Criteria	Sub-Ranges (height & speed)
Absolute error	<0.5m/s; Not more than 10% of data to exceed this value	All valid data
Data Availability	Assessed case by case – Environmental conditions dependent	All valid data
Linear Regression - Slope	Between 0.98 and 1.01 <0.015 variation in slope	All heights 4-8m/s & 8-12 m/s
Linear Regression – R^2	>0.98	All heights 4-8m/s & 8-12m/s

Table 1: Summary of acceptance levels for LiDAR systems within NORSEWInD

All comparisons are based on 10-minute average values returned from MEASNET calibrated cup anemometers installed on the test reference mast located adjacent to the test instrument (within 20m)

A minimum number of 600 points from the valid wind sector has been set before analysis will be performed. Wind speed range analysis will not be carried out unless 200 points exist in reach range. In addition to the two WS ranges 4-8m/s and 8-12m/s as of table 1 regressions will be performed for a wider WS range, i.e. between 4 and 16m/s.

No filtering will be applied to the valid data prior to analysis other than for valid wind sectors and for rain periods. All data will be examined with a view to finding unreferenced filter levels for standalone use offshore. The filters and relevant levels will be derived from the LiDAR returned output.

2.2 Test Facility

For the purposes of this test, the Risø DTU test facility at Høvsøre, located in Jutland in Northern Denmark (figure 1) was chosen as the NORSEWInD Validation site for LiDAR. The Høvsøre test facility has been used for a number of remote sensing investigations [5,6], and is currently the best available location for a test of this nature due to its long historic time series and remote sensing case history.

The test facility is primarily used as a research facility within the wind industry, investigating MW class wind turbines, located on 5 purpose built test stands. (figure 2)

Figure 1: Høvsøre test site

Figure 2: Høvsøre test site, showing MW class turbines and met. masts on test stands

Figures 1 and 2 show the line of test stands orientated N-S, parallel to the coastline and about 1.5km from the sea. At the southern end of the line, 200m from the closest wind turbine, there is an intensively instrumented meteorological mast (it can be seen in Google Earth at position 56.441045N, 8.150787E).

Høvsøre is located in very flat terrain but with somewhat inhomogeneous roughness (see Figure 1). To the south is a lagoon, at the closest point, only 900m from the meteorological mast and 1.8 km to the west, the North Sea, separated from the land by a strip of sand dunes 10-20m high. The most homogeneous fetch is from the east – mostly open farmland. The presence of the five wind turbines to the North of the meteorological mast precludes testing with wind from the northerly sectors.

2.3 Reference Instrumentation

In this report the measurement sector is 200°-300°. This sector has been chosen in order to avoid tower wake effect on the cup anemometers (when the wind comes from the north); and turbine 5 wake effect on both the LiDAR and the met. mast instruments (when the wind comes from North-East). This is described in a sketch in Figure 3.

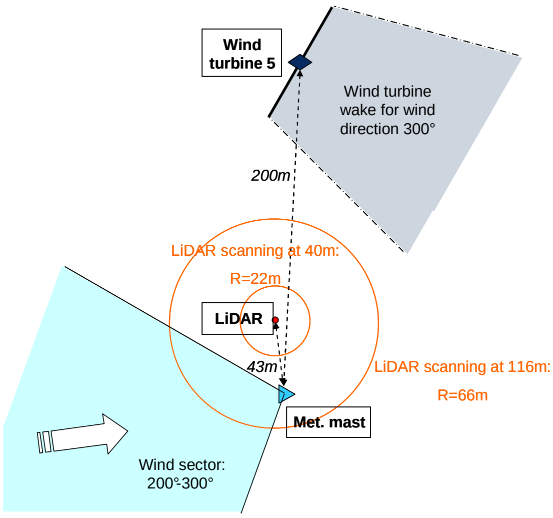

Figure 3: Measurement sector schematic

The met mast at the south end of the wind turbines row has a top-mounted anemometer at 116.5m and measuring stations with both cup and 3-D ultrasonic anemometers at 100m, 80m, 60m and 40m. (see Figure 4). For the purposes of the validation test, the cup anemometers will provide the primary reference time series. Due to its height, intensity of instrumentation and high data quality, this mast is well suited for testing LiDAR profilers. Since there is no problem with backscatter from the mast structure (unlike fixed-echo problems with SODAR testing), it is possible and indeed advantageous to place the profilers close to or directly beside the mast and thus improve the accuracy of the comparison.

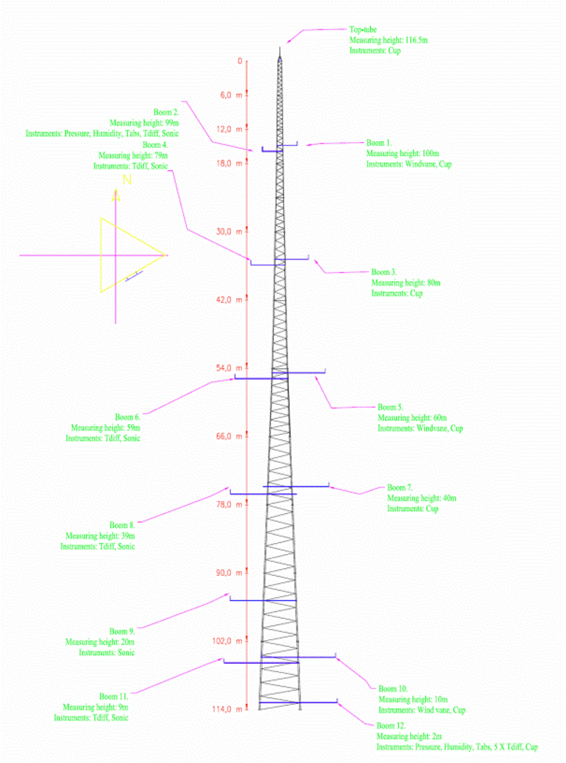

Figure 4: Høvsøre Reference Met Mast

In addition to the reference mast, a ceilometer has been placed close to the LiDAR to measure the cloud base height and sort the data for cloudy and clear sky conditions. Table 2 summarises the reference instruments used for this paper.

In addition to the mast comparisons an inter-comparison analysis between each test LiDAR systems and a permanently present reference project LiDAR will be performed. This will not form the basis of acceptance for the LiDAR under test, but will allow the project to assess how the different systems under test perform relative to each other under variations in shear and local environmental conditions.

Parameter	Sensor	Position
Wind speed at 60m	Cup anemometer 2546a	Serial number 3912PFV 1109 reg. 2183
Wind speed at 80m	Cup anemometer 2546a	Serial number 3913PFV 1109 reg. 2184
Wind speed at 100m	Cup anemometer 2546a	Serial number 3914PFV 1109 reg. 2185
Wind speed at 116.5m	Cup anemometer 2546a	Serial number 3915PFV 1109 reg. 2186
Wind direction at 100.0m	Vane P2633a	Serial number 107 PFV 1214 reg. 0861
Rain at 60.0m	Rain sensor, Thies. F3452a Type 5.4103.10.000	Ser.nr. 0904066.PFV 1516 reg 2018
Cloud base height	Ceilometer	Serial number B5120003 Software version 1.57

Table 2: Summary of reference instrumentation

3.0 Results

For the purpose of illustration, the above validation criteria have been applied to the 1st LiDAR instrument to be tested, a Leosphere Windcube system installed on the 1st December 2008.

3.1 Wind Speed Range distribution

Table 3 shows the number of available points for analysis.

WS range [m/s]	116.5 m	100 m	80 m	60 m
0 to 4	108	108	106	106
4 to 8	116	127	147	173
8 to 12	138	136	132	132
12 to 16	151	156	159	166
16 to 20	81	68	65	43
20 to 24	49	53	42	31
24 to 28	8	3	0	0
Sum	651	651	651	651

Table 3: Available points per wind speed range

The total number of points acquired from the valid analysis sector was 651 10-minute averages. As of table 1 only results for the WS ranges 4-8m/s and 8-12m/s are shown.

3.2 Linear regression

Figures 5 and 6 show the regression analysis performed on the available data at reference heights of 116.5m (Fig. 5) and 100m (Fig. 6).

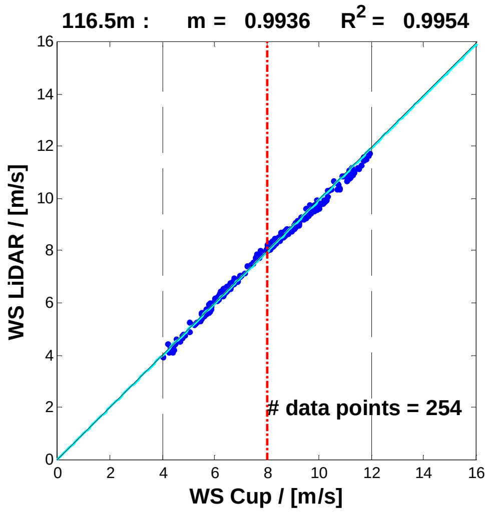

Figure 5: 116,5m Linear Regression constrained through origin. Red line separates the two relevant WS ranges.

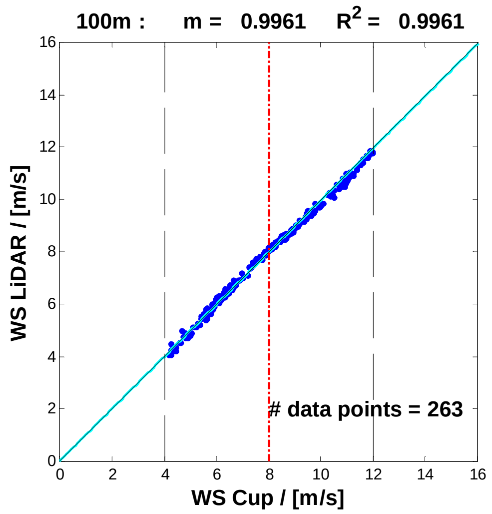

Figure 6: 100m Linear Regression constrained through origin. Red line separates the two relevant WS ranges.

Visual inspection would appear to show a non-linearity around 8m/s. The net effect is a different slope value for the ranges 4-8m/s and 8-12m/s, i.e. a larger slope for the lower wind speed range (compare table 4).

3.3 Applied Validation

Tables 4&5 summarize the validation results as the criteria applied to the valid dataset. Red cells denote fail, with green cells indicating pass.

	R^2			
WS range [m/s]	116.5 m	100 m	80 m	60 m
4 to 8	0,9915	0,9899	0,9917	0,9875
8 to 12	0,9889	0,9922	0,9945	0,9921
Variation	0,0026	-0,0023	-0,0028	-0,0047

	Slope			
WS range [m/s]	116.5 m	100 m	80 m	60 m
4 to 8	1,0093	1,0113	1,0074	0,9949
8 to 12	0,9882	0,9902	0,9883	0,9915
Variation	0,0211	0,0211	0,0191	0,0034

Table 4: Slope and R-Squared values

Meas. Level	116.5 m	100 m	80 m	60 m
Percentage	0,77%	0,46%	0,15%	0,92%

Table 5: Absolute error values

In general the results show that the Windcube passed all criteria apart from slope variation between the 4-8m/s and the 8-12m/s as described above. This non-linear response would provide an area of concern with a resultant action of the system being re-checked by the manufacturer.

Note that since this dataset has been acquired, the manufacturer has reacted by applying a software upgrade to the test system.. The system is now undergoing a re-test with early indications of a notable improvement in results.

4.0 Conclusion

The above test setup has been designed as a LiDAR validation test with an attempt to ascribe values to key wind industry parameters such that a better understanding of the system performance, and hence confidence in its ability can be established.

Whereas the test has been applied to only 1 system in this test, this initial trial of the validation criteria has shown its ability to pick up a system fault, successfully. This resulted in prompt remedial action by the manufacturer.

The clear aim of the test criteria is to establish a well defined set of acceptance values and methodology such that validation tests performed across the industry can have a common base for comparison.

Such a benchmark for both the wind industry to adopt and manufacturers to achieve helps all users to deploy instruments with the knowledge that the system has a suitable case history supporting the systems reported wind speed values.

NORSEWInD will now actively adopt the validation protocol and aim to engage manufacturers in the process such that a transparent and repeatable methodology applicable to all users is achieved. In addition NORSEWInD will look to extend the protocol to include SODAR systems in the near future.

NB. At the time of the conference, NORSEWInD will be able to present further results of the validation phase as applied to a number of both ZephIR and Windcube devices.

Acknowledgements

The authors acknowledge funding for this work from the EC project contract TREN-FP7EN-219048 NORSEWInD.

In addition the authors wish to acknowledge and thank DONG Energy for permission to publish their Wind Cube Validation results.

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