Wind speed at light speed

Summary of Classification of ZX 300e

Algorithm Version 3.10

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UNRESTRICTED

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Executive Summary

This document describes the classification study for the ZX 300e Lidar to the IEC 61400-50-2 standard. It is the first Lidar classification including measurements from 21m right through to 200m making it the most comprehensive Lidar classification available.

ZX Lidars has released the ZX 300e, an evolution of the existing ZX 300 range of vertically profiling wind lidars. As part of this release a classification test was undertaken following the guidelines in the IEC 61400-50-2 standard. This study is applicable to ZX 300e lidars running algorithm version 3.10. The algorithm version has been separated from the firmware version to allow the release of lidar security and quality-of-life improvements without affecting the results of this classification study.

This report outlines the method and results of an internal classification study. This classification report includes measurements from 21 to 200m across 5 campaigns using 3 lidars at 3 sites. The classification criteria are met for all heights from 40m to 200m with two campaigns featuring measurements down to 21m. **The classification report found no environmental variables to be significant resulting in a final accuracy class and resulting standard uncertainty of 0% at all heights** as show in Table 1.

Height (m)	Class (%)	Std Uncertainty (%)
200	0	0
190	0	0
180	0	0
170	0	0
160	0	0
150	0	0
140	0	0
130	0	0
120	0	0
110	0	0
100	0	0
90	0	0
80	0	0
70	0	0
60	0	0
50	0	0
40	0	0
30	0	0
21	0	0

Table 1: Final Accuracy Class of ZX300e algorithm version 3.10

1 Introduction

1.1 Environmental Variables

The following environmental variables are defined in the 61400-50-2 document with specified bin widths and ranges:

Table 2: Environmental Variables defined in IEC 50-2

Variable	Min	Max	Range	Bin Size	Number of Bins	Units
Wind Shear Exponent	-0.4	0.8	1.2	0.05	24	-
Turbulence Intensity	0.03	0.24	0.21	0.01	21	-
Rain	0	1	1	-	2	Boolean
Remote Sensing Device Availability	80	100	20	1	20	%
Wind Direction	0	360	360	5	72	°
Air Temperature	0	40	40	2	20	°C
Air Density	0.90	1.35	0.45	0.05	9	kg m^{-3}
Temperature Gradient	-0.02	0.06	0.08	0.002	40	K/m
Upflow Angle	-3	3	6	0.2	15	°
Wind Veer Gradient	-0.2	0.2	0.4	0.04	10	°/m

1.1.1 Wind Shear Exponent

This will be calculated locally at each mast height by fitting the power law shear profile to the wind speeds measurements above, at, and below each wind speed measurement. For the top and bottom height, only one adjacent height is used.

1.1.2 Turbulence Intensity

Measured by the mast at each measurement height.

1.1.3 Rain

Will be treated as a Boolean. If the mast has a rain sensor it will be used and any rain measurement greater than 0 for a ten-minute period will be considered True. If the mast does not have a rain sensor then the Proportion of Packets with Rain (%) reported by the lidar will be used where non-zero values are treated as positive.

1.1.4 Remote Sensing Device Availability

This is assessed using the percentage of measurement attempts in a 10-minute period that pass quality control. The expected range of this statistic is 25% to 100%. A bin size of 5% will be used. This will be calculated by dividing the packets in average by the max packets in average for each campaign.

1.1.5 Wind Direction

The measurement technique used by the ZX 300 system is rotationally symmetric to infinite order so any dependence on wind direction can be assumed to be an influence from terrain and mast effects. Furthermore, the linear trend treatment as defined in the IEC is not suitable for this circular parameter. Wind direction will be ignored from any sensitivity analysis.

1.1.6 Air Temperature

This will be measured using the lowest temperature sensor available on the mast.

1.1.7 Air Density

This will be measured using a combination of the lowest temperature, humidity and pressure sensors on the mast.

1.1.8 Temperature Gradient

This will be measured by taking the temperature difference between the highest and lowest temperature measurement on the mast and dividing by the height difference.

1.1.9 Upflow Angle

Calculated using the sonic anemometer on the mast closest to the measurement height.

1.1.10 Wind Veer Gradient

Calculated using a straight line fit to all wind directions measured by the mast.

2 Method

The conditions during a specific measurement campaign can be different from those prevailing during the lidar performance verification test. The classification process provides a method by which any additional uncertainty in the measured wind speed due to the influence of these differences on measurement accuracy can be assessed.

The sensitivity of measurement accuracy to environmental variables (EVs) can be measured by considering the difference between the lidar measurement and a reference mast measurement as a function of each EV at a time. The accuracy class of the lidar is evaluated by multiplying these sensitivities by the ranges of the EVs described in IEC 61400-50-2. The approach considers EVs to be independent, and care needs to be taken to avoid double counting any correlated EVs.

2.1 Data Preparation

The following data filters are applied:

a) Met mast data is filtered for specific sectors where the wind field is influenced by wakes from wind turbines and obstacles.
b) The met mast data is filtered for icing by removing all ten-minute timestamps from the mast data where any temperature sensor on the mast measures less than 0.5°C.
c) There is no filtering on rain status.
d) The wind speed differences are only calculated for mast wind speeds between 4.0 m/s and 16.0 m/s.
e) No additional filtering to the lidar data is applied.

2.2 Measuring Sensitivity

At a particular height, h, we collect concurrent measurements of:

- Mast wind speed (m/s) at height h, v_{ref}.
- Lidar wind speed (m/s) at height h, v_{test}.
- Environmental variable (various units) at height h, E.

The percentage difference between the lidar and the mast, d, is then calculated as

$$d = 100 * \left(\frac{v_{test} - v_{ref}}{v_{ref}}\right).$$

2.2.1 Binning the data

The difference data is then binned according to the corresponding value of the EV using the bin sizes and edges defined previously. Bin means, $\overline{E_\iota}$ and $\overline{d_\iota}$, are calculated of the EV and the difference respectively for each bin, where ιindicates the number of the bin. Bins are included in the sensitivity test where they meet the criteria in equation 1 and 2.

$$n_i > \frac{N}{2n_b} \qquad 1$$

$$\frac{\sigma(d_i)}{\sqrt{n_i}} \frac{v_{ref,i}}{100} < 0.03\ ms^{-1} \qquad 2$$

where,

- n_b is the number of bins according to the ranges described above.
- N is the total number of data points
- n_i is the number of data points in bin i
- $\sigma(d_i)$ is the standard deviation of the percentage wind speed deviations in bin i
- $v_{ref,i}$ is the mean value of the reference wind speed in bin i.

2.2.2 Fitting the data

A one-dimensional, two-parameter ordinary least squares (OLS) linear regression analysis is then performed on the $\overline{E_i}$ and $\overline{d_i}$ values that were found to be significant for each environmental variable at each measurement height. The following parameters are calculated from this regression analysis:

- Slope: m
- Intercept: c

The following parameters are calculated from a regression analysis through the 10-minute data in valid bins.

- Coefficient of determination: r^2
- Standard deviation of the independent variable: std
- Mean value of the independent variable: avg

2.2.3 Sensitivity

Sensitivity, S ,is defined as the slope multiplied by the standard deviation of the independent variable: $m \times std$. The sensitivity indicates the extent, as a percentage, that the deviation between the lidar and the mast measurement is changed by a change in the independent variable of one standard deviation.

The sensitivity analysis for a particular EV and at a particular height is considered to be relevant if one of the following two criteria is met:

1) A sensitivity of at least 0.5 is demonstrated $(S > 0.5)$, or
2) A product of correlation coefficient, r and sensitivity S is at least 0.1. $(r \times S > 0.1)$

The sensitivity analysis of an independent variable shall also be relevant for all measurement heights if one of the above conditions is fulfilled for a single height.

Additionally, the measured range EV should cover at least 25% of the bins described above otherwise results derived for these variables would be unrepresentative.

2.3 Calculating Final Accuracy Class

No significant environmental variables were found as part of the classification report which results in a final accuracy class of 0%.

3 Campaigns

This classification is made up of 5 datasets from 3 lidars at 3 locations, as summarised in the table below.

Lidar	Site	Dates	Heights Measured
6003	Hanover (Geo-Net)	2024-06-22 to 2024-09-29	200, 180, 160, 140, 120, 100, 80, 60
6004	Hanover (Geo-Net)	2025-05-23 to 2025-08-24	200, 180, 160, 140, 120, 100, 80, 60, 40
6003	Janneby (Pavana)	2024-11-06 to 2025-03-31	200, 180, 160, 140, 120, 100, 80, 60, 40
6101	UK Remote Sensing Test Site Pershore (ZX & DNV)	2024-11-18 to 2025-03-06	92, 71, 46, 21
6003	UK Remote Sensing Test Site Pershore (ZX & DNV)	2024-03-28 to 2024-06-02 and 2025-06-12 to 2025-08-26	92, 72, 46, 21

In all campaigns, no environmental variables were found to be significant. This results in a final class of 0% at all heights between 40m and 200m. The classification includes measurements down to 21m at one site where no variables were found to be significant.

4 Bibliography

[1] "Wind energy generation systems - Part 50-2: Wind measurement - Application of ground-mounted remote sensing technology (IEC 61400-50-2:2022)," IEC, 2022.

About Us

In 2003 we released the first commercial wind lidar, pooling decades of fibre laser research from the science, security and energy industries. Designed specifically for the wind industry our Lidar has paved the way for many of the remote sensing devices seen in the market today. Our original lidar technology continues to innovate with world firsts such as taking measurements from a wind turbine spinner and being the first to deploy an offshore wind lidar, both fixed and floating. Our Lidars have also now amassed millions of hours of operation across 15,000+ deployments globally spanning two decades of commercial experience. Some of our proudest achievements are listed below; these are the earliest reported examples that we are aware of from open publications.

2003 - The first wind lidar to make upwind measurements from a turbine nacelle
2004 - The first and original commercially available lidar for the wind industry
2004 - The first wind lidar to investigate the behaviour of turbine wakes
2005 - The first wind lidar to be deployed offshore on a fixed platform
2007 - The first wind lidar to take measurements from a turbine spinner
2008 - The first wind lidar to be signed off against an industry-accepted validation process
2009 - The first wind lidar to be deployed offshore on a floating platform
2010 - The first wind lidar to re-finance and re-power a wind farm
2011 - The first wind lidar to be proven in a wind tunnel
2012 - The first wind lidar to be used with very short masts and secure project financing
2012 - The first wind lidar to be accredited for use with no or limited on-site anemometry for project financing by DNV GL
2014 - The largest batch of single-type lidar verifications against an IEC met mast
2015 - The first lidar designed specifically for offshore use, with the longest warranty available - 3 years as standard
2016 - The first wind lidar to support safe lifting on a jack-up vessel
2016 - The first wind lidar SCADA integrated on operational wind farms in replacement of site met masts
2017 - The first wind Lidar to be installed across a wind farm on a Lidar-per-turbine basis, uniquely mapping wakes across a wind farm
2018 - The first wind Lidar to satisfy all criteria for IEC Classification
2019 - The first wind Lidar to take wind measurements from a drone
2020 - The first wind Lidar to be accepted for bankable energy assessments in complex terrain standalone (without a met mast)
2021 - The first wind Lidar to attract more than £150bn+ of investment into wind energy projects
2022 - The first wind Lidar to be fully integrated into a retrofit wind turbine controller for Lidar Assisted Control
2023 - ZX Lidars moves to Willow End!
2024 - The first wind Lidar with a 5 year warranty and 5 year planned service interval as standard
2025 - The first wind Lidar to achieve 21 – 200m IEC Classification and 300m Performance Verifications

Our Products & Services

ZX300e

Onshore vertical profiling wind Lidar

ZX300M

Floating & platform-mounted vertical profiling wind Lidar

ZXTM

Turbine-mounted horizontal profiling wind Lidar

ZX Measurement Services

Wind Data as a Service