Co-located Lidar, Advanced SoDAR, IEC Met Mast Cross-Validation Analysis

PO.302e

Barry Logue [2] F Anthony Crockford [1] Niels LaWhite [2] Federico Montealegre [1]
(1) Ecofys WTTS B.V., Utrecht, The Netherlands (2) Vaisala Inc., Woburn, MA

VAISALA ECOFYS WIND TURBINE TESTING SERVICES

Abstract

Ecofys WTTS and Vaisala Oyj performed a cross-correlation analysis using an advanced SoDAR remote sensor, against a co-located wind LiDAR and Met Mast MM01. The measurements were performed at Test Site Lelystad and the investigation and report is based on the three datasets derived from the ongoing co-located measurement data gathered in the spring of 2016.

The cross-validation analysis of the SoDAR remote sensing device is based on its correlation with the measurements gathered from an IEC compliant Met Mast, with 120 meters of height, located in position #1 143 meters away from the SoDAR at Test Site Lelystad (MM01) and additionally a wind LiDAR measuring next to the SoDAR.

An uncertainty analysis is performed to evaluate the remote sensors sensitivity to various environmental factors.

Parameters	SoDAR	LiDAR
Test ID	Triton SoDAR II	Windcube V2
Serial number	609	WLS7-181
Measurement range	40-200 m agl	40-200 m agl
Beam angles	11.5°	30°
Timestamp interval	10 min	10 min
Timestamp	UTC	UTC
Data period	14.06.2016 to 21.07.2016	14.06.2016 to 21.07.2016
Data columns recorded	Mean horizontal wind speed, Mean wind direction, Mean vertical wind speed, TI, QF	Mean horizontal wind speed, Mean wind direction, Mean vertical, wind speed, CNR, spectrum

Objectives

This study is the first inter-comparison of a wind lidar, Triton sodar, and an IEC-compliant mast. The performance results are presented on the basis of 10-minute mean values of the measured quantities, including:

- Validation of wind speed at 4 measurement heights against Met Mast MM01, and validation of wind speed at 4 measurement heights against the Windcube LiDAR using statistical analysis based on IEC 61400-12-1 (ed. 2 – FDIS) standard;
- Wind speed correlation coefficient and regression analysis;
- Wind direction correlation coefficient;
- Uncertainty of the SoDAR wind speed measurements, per wind speed bin
- Validation of wind direction measurements at two measurement heights against Met Mast MM01
- Validation of wind direction measurements at two measurement heights against LiDAR
- Validation based on the acceptance thresholds of NORSEWInD criteria and against Ecofys WTTS's acceptance thresholds for SoDAR field measurements;
- Confirm spatial affects for both remote sensors when placed equidistance from the MM01 mast.

Methods

For the cross-validation test, the target is to gather at least 180 hours of valid data with 3 data points per 0.5 m/s bin between 4-12 m/s. All additional concurrent valid data points above these bins (e.g. any valid data points between 12 and 16m/s bin) will be taken into account. The validation data analysis evaluates the accuracy of the SODAR measurements based on two international wind industry standards:

- IEC IEC 61400-12-1 Validation procedure and uncertainty evaluation
- Based on the NORSEWInD criteria and Ecofys WTTS' validation criteria for SoDAR

Cross-Validation test definition: The cross-validation procedure evaluates the absolute error and the quality of the linear regression between the SoDAR and the reference MM01's anemometry, and between the SoDAR and the LiDAR reference. It is defined as a short test campaign against IEC and MEASNET certified and calibrated reference instrumentation, providing quantitative traceability of performance to international standards. This specific cross-validation test cycle includes also the correlation analysis to a Windcube V2 LiDAR that is collocated at the measurement test bench. The linear regression between SODAR and the reference anemometer measurements, as well as the SoDAR and the reference LiDAR, evaluates the systematic uncertainties in the SODAR measurements for each 0.5 m/s wind speed bin from 4-12 m/s as well as wind direction.

After all sensitivity tests and statistical analyses, Ecofys analyses the uncertainty of the wind measurements of this SoDAR. The uncertainty calculations are based on IEC 61400-12-1 (ed 2) FDIS. If information is absent in the draft, formulae and definitions were taken from the first edition. The uncertainty resulting from the SoDAR Validation test is divided into 5 separate uncertainties, as summarised as follows: Reference uncertainty (in anemometry); Wind tunnel calibration; Cup anemometer effects according to the anemometer classification; Cup anemometer mounting effects; Mast shadowing; Boom distortion; Lightning rod distortion; Uncertainty of any applied mast correction; Mean deviation of the SoDAR measurements and the reference anemometry measurements; Standard deviation of the measurement of the SoDAR; Uncertainty in mounting effects during the Validation test; Uncertainty of the SoDAR due to non-homogeneous flow within the measurement volume, during the Validation test.

Conclusions

The results of the cross-validation of the SoDAR against the met mast and the LiDAR show excellent agreement between the Lidar and SoDAR. The Met Mast correlation provides an analysis of the spatial variation one may find using a SoDAR at some distance from a reference met mast. As the wind lidar and sodar agree to such a high degree when located equidistant from the met mast it is apparent that the effect is caused by the distance and not a fundamental performance or design issue. This study is the first cross-validation completed using the most widely used wind measurement equipment. The cross-validation result provides the industry with a better understanding of the remote sensing performance in flat terrain.

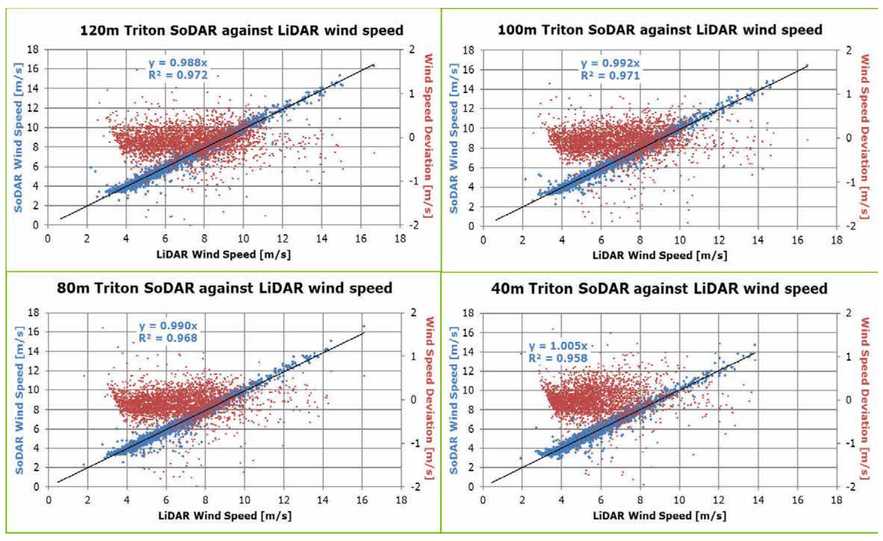

Figure 1. Wind speed comparisons and selected binned wind speed comparisons

For the 120 meter height an indicative uncertainty level in the wind speed measurements of both devices was calculated, for wind speed bins of 0.5m/s between 4 – 14 m/s (available wind speeds). This analysis shows similar low uncertainties in the SoDAR and LiDAR wind speed measurements, in line with first class anemometry. The uncertainty is increased at higher wind speed bins, partly due to relatively fewer data points. The uncertainty levels presented in Figure 2 are indicative calculations for 120 meters, as it is a function of the measurement height and the distance between the SoDAR and mast and could increase for lower measurement heights due to variation in flow across the site.

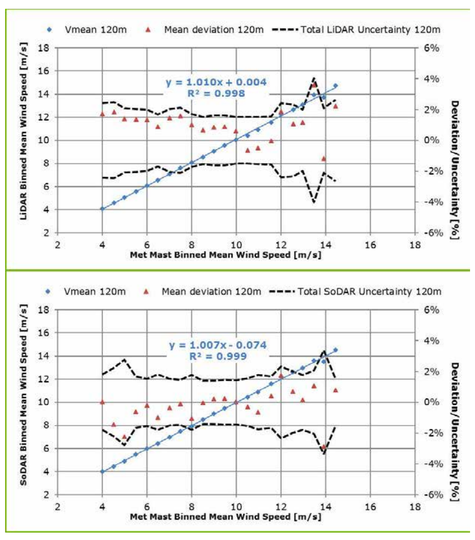

Figure 2 - Uncertainty indication of wind speed measurements at 120m

References

IEC 61400-12-1 (ed 1.0), 'Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines', 2005
IEC, IEC 61400-12-1 Ed. 2 (642/DCV) 'FDIS - Power performance measurements of electricity producing wind turbines', 2015 (in review)
Verhoef and Bergman, Energy research Center Netherlands (ECN), "Vaisala Triton® Wind Profiler 609 validation against meteorological mast 2 at the ECN test site Wieringermeer,"
Kindler, D., Courtney, M., Oldroyd, A., 2009, 'Testing and calibration of various SoDAR remote sensing devices for a 2 year offshore wind measurement campaign, EWEC 2009
Montealegre, Ecofys WTTS 2015, project number WIEWT15389, "SoDAR Verification Test: Triton SoDAR at Test Site Lelystad, 05.03.2015– 29.05.2015."

Ground-based Remote Sensor Uncertainty – a case study for a wind lidar, A. Albers et al,
A Comparison of Remote Sensing Device Performance at Rotsea I. Campbell, RES UK
A Review of Sodar Accuracy, S. Bradley and T. Mikkelsen
LIDAR and SODAR Measurements of Wind Speed and Direction in Upland Terrain for Wind Energy Purposes', S. Land and Eamon McKeogh
Aspects of the Correlation between Sodar and Mast Instruments Winds", Stuart Bradley
Lindelöw-Marsden, P. 'Upwind D1: Uncertainties in wind assessment with SODAR, Riso DTU