PO.112

Repeatability, reproducibility, and uncertainty estimation of a new lidar turbulence algorithm in varying wind conditions around the world

Annika Baltzer[2], Andrew Black[4], Tobias Eichelmann[1], Stephen Etheridge[3], Stefan Flau[3], Armin Haghshenas[1], Zachary Parker[3], Hazem Rabhi[4], Martin Richter-Rose[2], Alessandro Sebastiani[3], Dr. Markus Sommerfeld[2], Dirk Steudel[1]

[1]Nordex, [2]Pavana GmbH, [3]RWE, [4]Vaisala

New lidar TI algorithm meets IEA Wind Task 52 criteria for extreme loads and site suitability in simple and complex terrain

Summary

Today, turbine suitability and loads validation are mostly carried out using cup anemometers. Lidar systems are already widely accepted for measuring wind speed and wind shear measurements. If their ability to measure turbulence can be validated, lidar could carry out all aspects of wind resource assessment. This study examines three key questions about a new lidar turbulence algorithm (Pure-TI) developed by Vaisala:

1. What are the key performance indicators (KPIs) that lidar algorithms should meet to reliably replace cups?
2. How repeatable is the algorithm at the same site, following the KPIs?
3. How reproduceable is the performance at different sites?

Key Performance Indicators

The KPIs below were developed by IEA Wind Task 52's Turbulence sub-group

Damage Index of a timeseries (m ∈ [4, 9, 14])

**not binned*

$$DI = \left[\frac{1}{N}\sum_{i=1}^{N}\sigma_i^m\right]^{\left(\frac{1}{m}\right)}$$

90% Quantile TI (Representative TI, I90)

**binned by V_{hub}*

$$\sigma_{90,V_{hub}} = \overline{\sigma_{V_{hub}}} + 1.28 \cdot std\left(\sigma_{V_{hub}}\right)$$

$$I_{90}\ (V_{hub}) = \frac{\sigma_{90,Vhub}}{V_{hub}}$$

Effective TI (m ∈ [4, 9, 14])

**binned by V_{hub}*

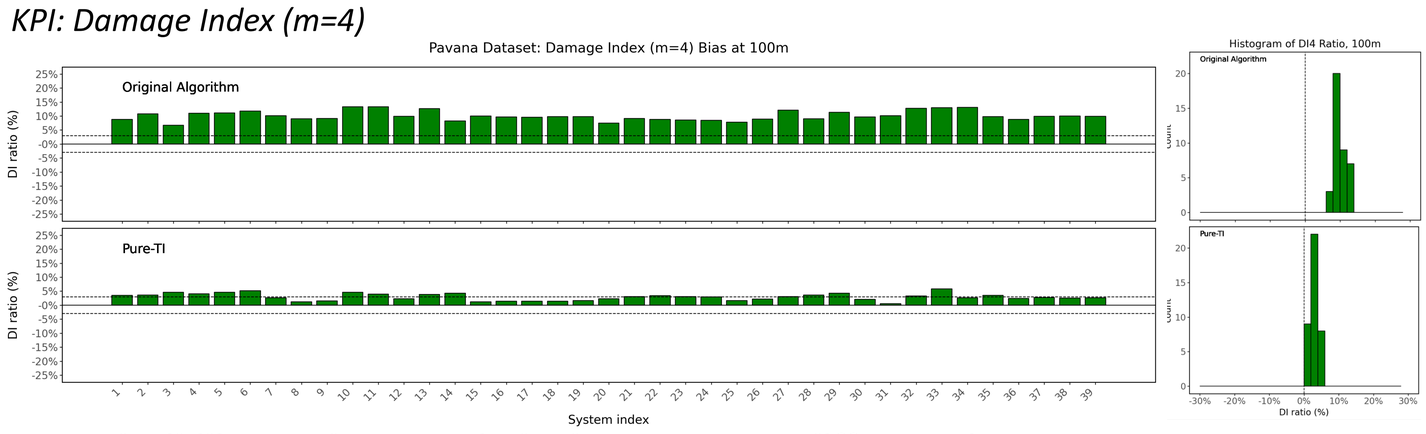
$$\sigma_{eff}(V_{hub}) = \left[\frac{1}{N}\sum_{i=1}^{N}\sigma_i^m\right]^{\left(\frac{1}{m}\right)}$$

$$I_{eff}(V_{hub}) = \frac{\sigma_{eff}(V_{hub})}{V_{hub}}$$

For each metric, techniques are evaluated on whether the bias interquartile range ("IQR", 25th-75th) falls within a passband. For Damage Index, the bias IQR must lie with ±3% of the cup reference. Others listed in Table 1

Repeatability Study – 39 WindCube v2.1s at Pavana Lidar Calibration Site

KPI: Damage Index (m=4)



Pavana 200m Calibration Site

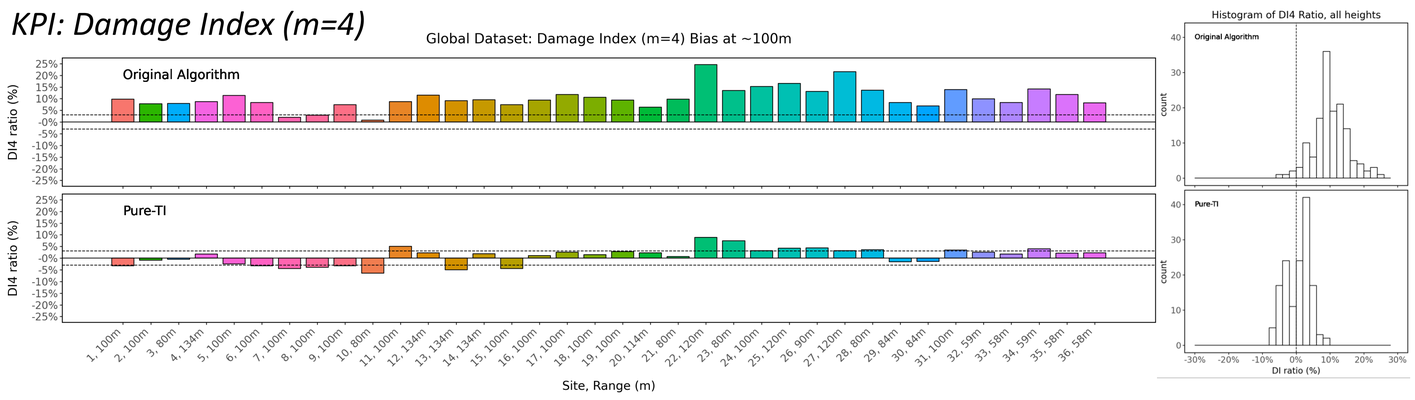
The test site is an IEC-compliant lidar calibration site in Janneby, Germany. The lidar calibration campaigns took place from 2022 to 2024. The typical campaign length is about 6 weeks.

Algorithm	Mean	Std	25th	75th
Original	0.101	0.017	0.067	0.090
Pure-TI	0.029	0.012	-0.021	0.037

Table 1: *DI4 bias mean, std. dev., 25th and 75th quartiles of individual campaigns at 100m height*

Reproducibility Study – 36 WindCube v2.1s at 24 different sites

KPI: Damage Index (m=4)



Global Dataset

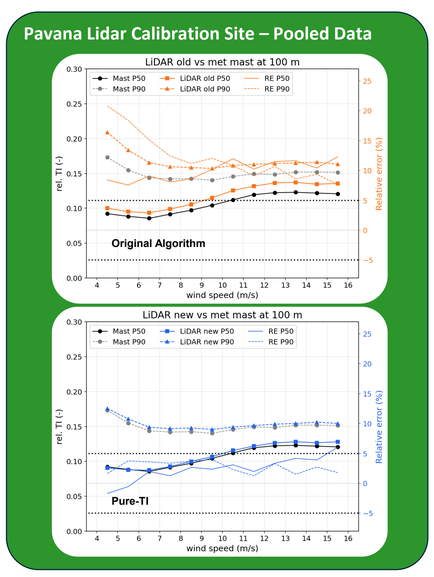


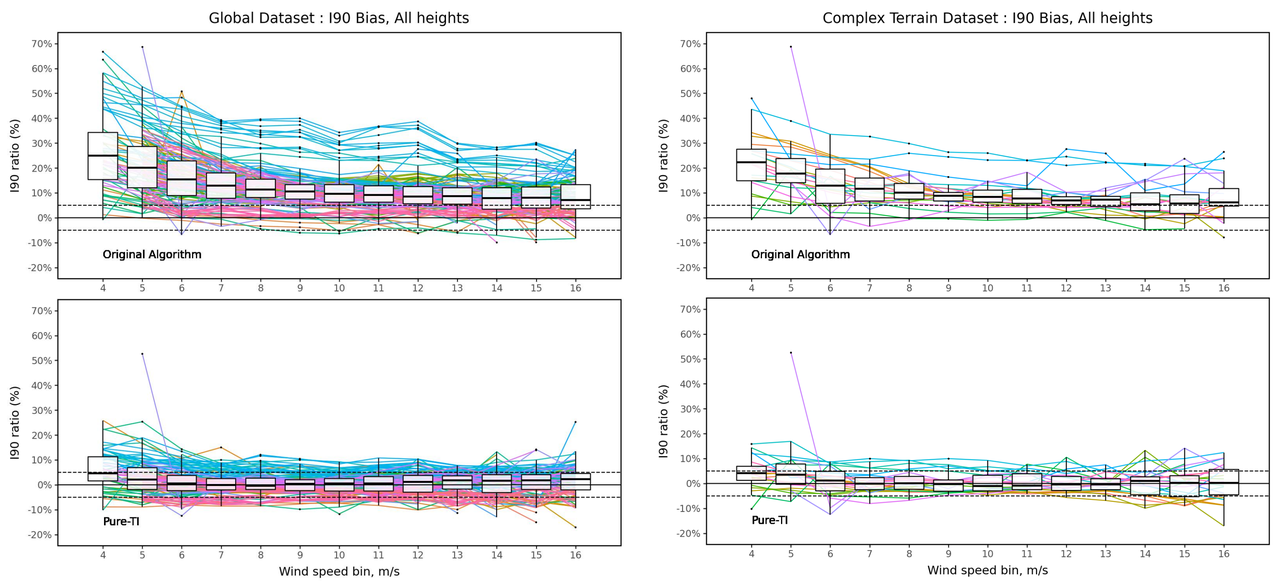
The global dataset includes 9 different countries and 8 campaigns in complex terrain (defined by Modified RIX).

Algorithm	Terrain	Mean	Std	25th	75th
Original	All	0.102	0.051	0.075	0.131
Pure-TI	All	0.005	0.036	-0.031	0.031
Original	Complex	0.107	0.052	0.073	0.125
Pure-TI	Complex	0.013	0.040	-0.021	0.031

Table 2: *DI4 mean, std. dev., 25th and 75th quartiles for Global Dataset, all heights*

KPI: 90th Quantile TI (Representative TI, I90)





TI metric	Passband	6 m/s	7 m/s	8 m/s	9 m/s	10 m/s	11 m/s	12 m/s	13 m/s	14 m/s	15 m/s
90th Quantile	±5%	(-0.024, 0.037)	(-0.021, 0.025)	(-0.019, 0.027)	(-0.024, 0.02)	(-0.026, 0.025)	(-0.026, 0.033)	(-0.03, 0.038)	(-0.018, 0.036)	(-0.031, 0.041)	(-0.019, 0.04)
90th Quantile (complex)	±5%	(-0.03, 0.048)	(-0.025, 0.024)	(-0.025, 0.028)	(-0.031, 0.013)	(-0.03, 0.033)	(-0.025, 0.039)	(-0.028, 0.028)	(-0.025, 0.019)	(-0.046, 0.027)	(*-0.054*, 0.031)
Effective TI (m=4)	±3%	(-0.03, *0.031*)	(-0.028, 0.018)	(-0.023, 0.025)	(-0.028, 0.019)	(-0.03, 0.022)	(-0.03, *0.031*)	(-0.03, *0.033*)	(-0.019, *0.035*)	(*-0.037, 0.038*)	(-0.024, *0.038*)

Table 3: *Percent of Pure-TI bias distribution within interquartile range passband proposed by IEA Task 52 for Representative TI and Effective TI (m=4). Deviations noted in italics.*

Conclusions

In simple and complex terrain, the Pure TI meets the proposed IEA Task 52 IQR passband for Damage Index (m=4). The algorithm meets the criteria for I90 in simple terrain, and in complex terrain up to 14 m/s. For Effective TI (m=4) Pure-TI is within IQR ±3.8% up to 15 m/s. The systems at Pavana show a DI4 standard deviation of 1.2%, 3x smaller than that of the global dataset (3.6%). Pavana pooled data is within the DI4 and I90 passbands.

Next Steps

Work is ongoing among Vaisala, Nordex, RWE, and Pavana to refine techniques for filtering lidar data for load estimation for cast iron (m=9) and glass and carbon fiber components (m=14)

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