ZX Lidars on test at the 200m Pavana mast, Germany © Pavana GmbH

Proven in practice: validating the next generation of wind lidar

The ZX 300e wind lidar brings together proven heritage and cutting-edge validation, offering accurate, finance-grade measurements up to 300 metres. Backed by IEC classification and extensive real-world performance verifications, it provides the wind industry with a reliable, bankable tool for today's largest turbines and most complex terrain.

The global wind industry continues its advances towards ever-larger turbines and taller hub heights. With hub heights now exceeding 150 metres and rotor diameters approaching 200 metres, the ability to measure the wind across the entire rotor span has never been more critical. Accurate and finance-grade measurements remain the cornerstone of energy yield assessments and long-term investment confidence.

In this context, the launch of the ZX 300e marks an important moment for the industry. It has evolved directly from the widely deployed ZX 300 ground-based lidar, itself the first lidar to achieve IEC classification, and benefits from more than 15 years of global field experience.

Furthermore, ZX 300e has not arrived untested: serial production began more than a year ago, with units quietly deployed worldwide either undergoing validation or simply with the evolution sat ready to 'turn-on', ensuring that the system is already well established and proven in practice.

This duality, new to market yet proven through heritage and extensive field validation, is a smart approach. It combines the confidence of a mature platform with the advancements required for modern turbine scales, making it both a fresh launch and an assured choice.

What is wind lidar?

Wind lidar, or Light Detection and Ranging, is an established optical remote sensing technology that applies the Doppler principle to measure wind speed and direction.

As shown in Figure 2, ground-based continuous-wave (CW) lidars such as ZX 300e transmit an eye-safe, Class 1 laser beam into the atmosphere. The beam is scattered back by aerosols such as dust, pollen and moisture droplets that move with the wind. The Doppler shift in the frequency of this backscattered light is directly proportional to the wind velocity along the line of sight.

Figure 1: The ZX 300e wind lidar by ZX Lidars

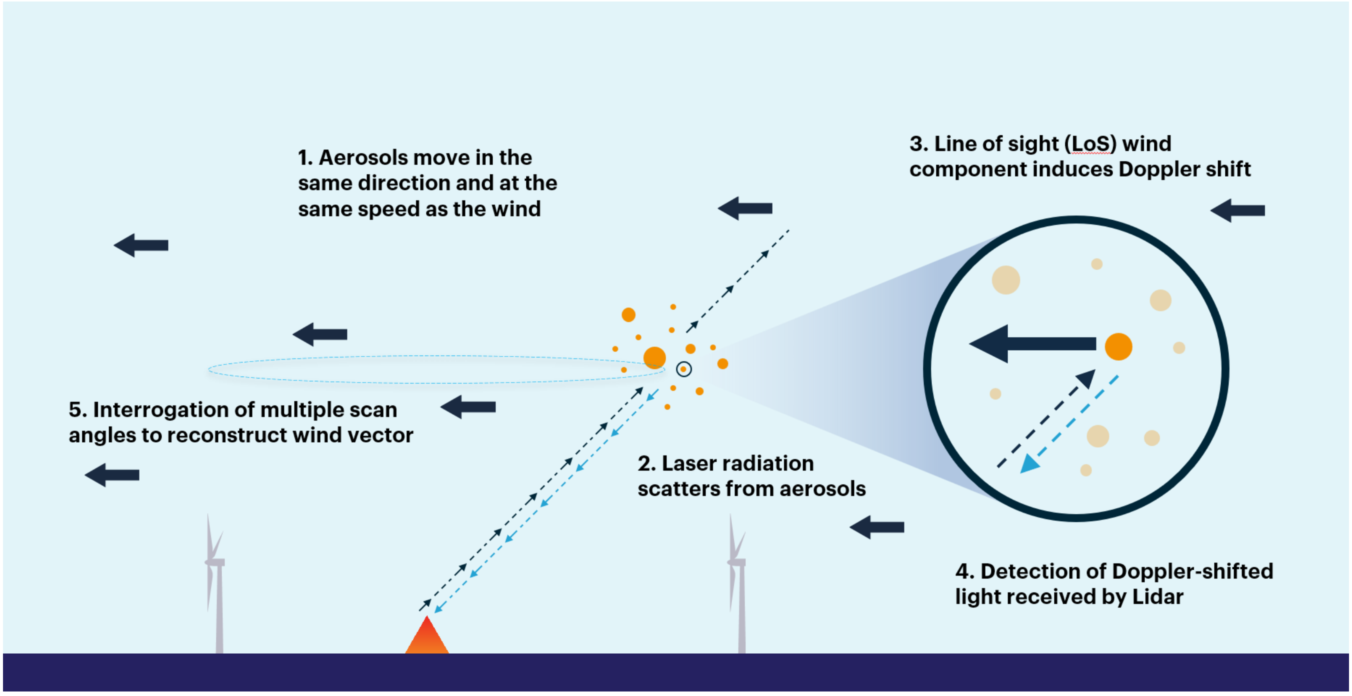

Figure 2: Continuous wave lidar principles

By steering the beam at multiple azimuthal angles and shallow elevations, the lidar reconstructs the horizontal wind vector. It provides a vertical profile of wind speed and direction at discrete heights.

This technique enables the capture of accurate wind data without the need for tall meteorological towers. A single compact, field-hardened system can deliver measurements from near ground level to 300 m. Data are continuous, high-frequency and retrievable remotely in real-time.

Peer-reviewed studies and independent validations, many published in PES, have shown that modern CW lidars achieve equivalence to calibrated cup anemometers when operated in line with international standards. This foundation underpins the acceptance of lidars as finance-grade tools in the global wind industry.

Performance verifications of ZX 300e

Formal performance verification campaigns of ZX 300e began in 2024 and provide direct evidence of the system's reliability and accuracy across different environments. For clarity, these results can be grouped into three main areas: high-mast and 'Midar' comparisons, fleet-wide repeatability and parameter-specific validations.

High-mast verifications

A defining feature of ZX 300e is its ability to measure accurately at the heights demanded by today's turbines. This has been verified through an extensive programme of high-mast comparisons at independent facilities. These campaigns provide a diverse evidence base covering different terrains, seasons and atmospheric conditions.

At Hanover, Germany, operated by Geo-Net Umweltconsulting GmbH, ZX 300e was collocated with a 200 m IEC-compliant mast in flat, low-complexity terrain. Campaigns extended across both summer and winter, ensuring a wide range of stability conditions were captured. Results showed correlation slopes consistently within ±1% and coefficients of determination (R^2) greater than 0.985. Data recovery exceeded 95%, even during periods of high turbulence intensity.

At Janneby, Germany, operated by Pavana GmbH, a second 200 m mast provided an independent test environment characterised by stronger shear, higher turbulence, and transitional seasonal conditions. ZX 300e achieved the same level of accuracy as at Hanover, confirming that its performance is not restricted to a single tall mast location. These mast-based verifications were completed with strict IEC-compliant procedures, providing finance-grade confidence in the results.

At the UK Remote Sensing Test Site, independently verified by DNV AS, one of the most established test sites globally, with 91 m mast, independent oversight and a history of cross-comparisons, provided both long-term reference datasets and independent verification. Campaigns ran for five months through the winter, ensuring challenging conditions were included. Results showed correlation slopes consistently within ±1%, coefficients of determination (R^2) greater than 0.985 and data recovery exceeded 98% at all heights.

An example verification is shown in Table 1 and covers a measurement period of 3 months:

Height (m)	59	79	99	119	139	159	179	199
Gradient	1.008	1.005	1.000	1.002	0.999	0.999	0.996	0.992
R-squared	0.989	0.990	0.990	0.990	0.989	0.990	0.988	0.986
Availability %	99.1	99.1	98.8	98.0	97.6	97.2	96.8	96.6

Table 1: Example of ZX 300e performance verification up to 200 m

Fleet-wide 'Midar' verifications

Confidence in a single or even a small number of verifications is not enough for industry acceptance. Investors and independent engineers demand evidence that every unit in the field performs consistently, and that measurements can be extended beyond the height of any mast. For this reason, ZX 300e has also been subjected to a unique fleet-wide Midar verification campaign.

At the UK Remote Sensing Test Site, more than 25 ZX 300e units were verified using Midar technology, a novel mast + lidar approach where a vertical-profiling lidar mounted to a 91 m mast extends traceable reference measurements far above the mast itself, up to 300 m.

This method provides a defensible and traceable route to demonstrating uncertainty at heights beyond any existing mast.

The results were compelling: correlation slopes consistently within ±1%, coefficients of determination (R^2) greater than 0.985, and repeatability across the fleet within the narrowest ranges yet reported for a ground-based lidar. At 250 m, data availability exceeded 96%, and at 300 m it remained above 94%, as shown in Figure 3, with correlation slopes within ±1.1% and R^2 values remaining greater than 0.985. This represents one of the first independent demonstrations of a ground-based lidar delivering consistent, low-uncertainty data at heights approaching 300 m.

Such fleet-wide consistency directly supports bankability by minimising uncertainty associated with device variability. Developers and operators can deploy multiple ZX 300e units across portfolios with confidence that all units perform equivalently and that measurements remain robust well beyond traditional mast heights.

Parameter-specific validations

Turbulence Intensity (TI)

Turbulence intensity is critical for turbine design, site suitability, and load assessments. Without robust TI measurements, turbine loading can be underestimated, leading to long-term reliability issues or overestimated, inflating project costs unnecessarily. Historically, lidars have faced challenges in replicating cup anemometer TI, which has limited acceptance by independent engineers. The ZX 300e directly addresses this through the METICE (Model Ensemble Turbulence Intensity Cup Equivalence) methodology.

METICE is a machine learning ensemble approach developed by ZX Lidars that combines data from multiple sites, stability regimes and atmospheric conditions to train a model capable of predicting cup-equivalent TI from lidar 10-minute data. ZX 300e has been validated under METICE at more than 17 sites worldwide, including flat and complex terrain, onshore and offshore. Results consistently demonstrate TI Mean Bias Error of +/- 0.02 with a significant percentage of data within +/- 0.01. Similarly, Representative TI Difference was well within +/- 0.03 with a significant percentage of data falling within +/- 0.015. In all cases the KPIs established by industry consortium CFARS (Consortium For the Advancement of Remote Sensing) were met.

These results have been reviewed by independent consultants, developers, WTG OEMs and within CFARS methodologies, providing additional confidence that ZX 300e's TI outputs are fit for finance-grade assessments. This positions ZX 300e as one of the few lidars capable of supplying both mean wind speed and turbulence intensity to a standard suitable for turbine design and certification processes.

Wind direction

Across all verification campaigns, ZX 300e has shown stable and highly accurate directional performance.

Comparisons against mast-mounted vanes at Hanover, Janneby and the UK Remote Sensing Test Site confirmed directional accuracy with negligible offset and no systematic bias detected. These results were consistent across different stability regimes, from calm low-turbulence summer nights to highly turbulent winter storm conditions.

Crucially, the ZX 300e maintained directional accuracy during rapid wind veer events, which are increasingly relevant for large rotors where inflow direction at top and bottom blade tips can differ significantly. Tests showed that ZX 300e was able to capture veer profiles accurately across the full 21–200 m range. This capability supports its use in wake loss modelling, yaw misalignment studies, and site optimisation strategies where precise directional inputs are required.

Together, these validations confirm that ZX 300e can be used with confidence for directional analysis and sector management in addition to standard energy yield assessments.

Complex flow applications

With the global adoption of wind energy, increasingly wind sites are far from flat, or 'simple'. In hilly, forested, or mountainous terrain, wind flows are complex and strongly influenced by topography. This leads to non-homogeneous flows, vertical wind components and curvature effects that challenge both traditional mast-mounted cups and remote sensing devices. The IEC 61400-12-5 standard recognises these challenges and prescribes how complex terrain should be classified, typically into five classes based on slope, ruggedness and the Terrain Ruggedness Index (RIX).

ZX 300e has been validated in such environments using both direct mast comparisons and Computational Fluid Dynamics (CFD) conversion methodologies. At one site where steep slopes and high RIX values classify the site as complex, ZX 300e measurements were compared to a 118 m mast.

Direct comparisons showed that once CFD-based flow conversions were applied, cup equivalence was achieved with gradients of 0.994 and R^2 of 0.988. Directional accuracy was consistently high throughout the dataset. These results demonstrate that ZX 300e delivers finance-grade wind speeds and direction when combined with established CFD workflows.

Beyond accuracy, ZX 300e's inherent 50 Hz sampling and CW architecture make its data output particularly resilient in complex flow conditions. These design features allow the system to capture both horizontal and vertical wind components with minimal distortion, reducing either the immediate need or eventual magnitude of corrections needed.

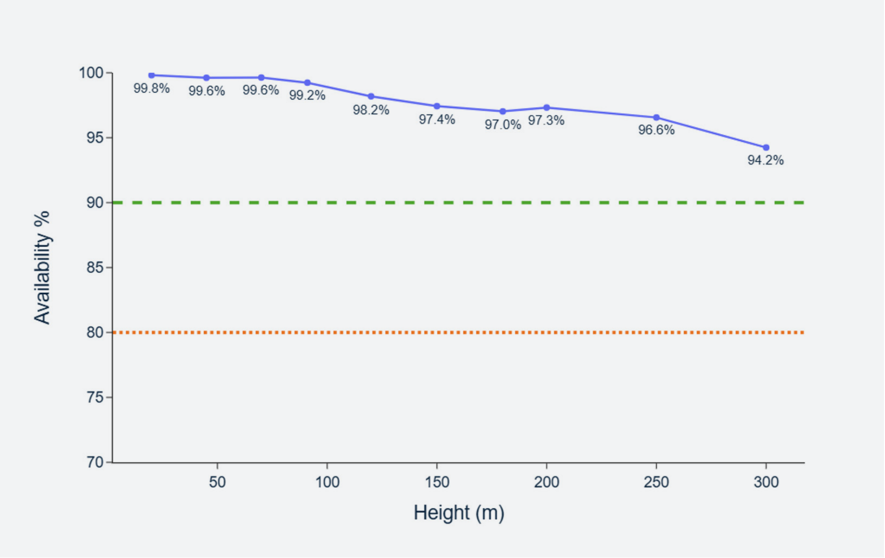

Figure 3: Mean data availabilities of a fleet of ZX 300e up to 300m, with minimum (orange line) and best practice (green line) KPI thresholds exceeded at all heights

ZX 300e has undergone the most comprehensive programme of performance verifications ever applied to a ground-based lidar.

In practice, this means developers can deploy ZX 300e at sites with confidence in all terrain, applying validated CFD conversions when only necessary, and achieve uncertainties at levels acceptable for finance-grade EYAs.

Together, these campaigns and methodologies confirm ZX 300e's capability as a primary measurement device in complex terrain, providing developers with access to sites that were previously constrained by mast limitations. This not only expands the bankable wind resource area but also ensures consistency across portfolios that span both simple and complex flow environments.

Classification as complementary evidence

In addition to the performance verifications highlighted, ZX 300e is also the first wind Lidar to achieve IEC classification across a full order of magnitude in height range, from 21 to 200 m. This was conducted in line with IEC 61400-50-2, and represents a world-first for any remote sensing device.

No other published classification extends across the full rotor span of modern turbines, with most stopping at 120–135 m or featuring a 'blind-spot' towards lower heights above ground level. The ZX 300e, therefore, sets a new benchmark in the industry.

The classification was extensive and went well above the minimum criteria stipulated by the standards, with campaigns covering 5 trial periods, 3 sites, 3 lidars and both summer and winter conditions, in full compliance with IEC requirements.

Results demonstrated final accuracy class and standard uncertainties of 0% across 21 - 200 m, the best possible outcome of an IEC Classification. Even with a factor of almost 10 between the lowest (21 m) and highest (200 m) points, uncertainties remained at 0%. throughout and support ZX 300e's acceptance for finance-grade applications.

This outcome is significant for several reasons. It confirms that ZX 300e is suitable for use across the entire rotor diameter of today's largest turbines, ensuring that measurement uncertainty does not increase with hub height.

It establishes a world-first classification range of 21–200 m, improving upon all previously or recently published 'benchmarks'.

It complements the extensive body of real-world verifications, providing both a formal uncertainty budget and practical deployment evidence.

Together, the IEC classification and the large-scale verifications described in this article create the most complete evidence base yet published for a ground-based Lidar. For stakeholders across the wind industry, this dual foundation reinforces confidence that ZX 300e can be relied upon for both project development and operational monitoring.

Industry implications

The combined results of these campaigns establish ZX 300e as the most extensively validated ground-based lidar, with significant implications across the industry. For developers, it enables faster project development, improved site safety, reduced reliance on tall masts and lower campaign costs.

Operators benefit from a permanent met alternative for operational sites, supporting long-term monitoring and repowering assessments. Consultants and independent engineers gain access to a robust, standards-based evidence set that underpins site suitability, energy yield calculations and due diligence.

Meanwhile, lenders and insurers see reduced measurement uncertainty, directly lowering risk within project finance models.

By combining rigorous scientific validation with practical deployment evidence, ZX 300e retains and raises the benchmark for wind lidars in wind measurement technology.

Conclusion

ZX 300e has undergone the most comprehensive programme of performance verifications ever applied to a ground-based lidar. Mast and Midar comparisons up to 300 m, fleet-wide repeatability across more than 25 units, validated turbulence intensity and wind direction accuracy, and proven application in complex terrain all contribute to its evidence base.

Together with a 21-200 m IEC classification, these results confirm ZX 300e as the most reliable, validated and finance-grade lidar available today.

zxlidars.com

About the authors

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Seyi Latunde-Dada has a background in applied maths and physics and has worked as an algorithm development scientist in a range of sectors, including defence, pharmaceuticals and now wind energy instrumentation.

During his time at ZX Lidars, he has contributed to the evolution of wind reconstruction algorithms as well as the development of future generations of the products including ZX 300e.

Alex Woodward

Alex Woodward is a commercial and marketing leader with over 20 years of experience in renewable energy, currently serving as a Director at ZX Lidars and ZX Measurement Services.

He supports global strategy across wind Lidar product development, brand positioning, and service innovation.

He holds a First-Class BSc in Product Design & Development, a Postgraduate Certificate in Management, and is a Member of the Chartered Institute of Marketing.