ZX Lidars

Wind speed at light speed

Wind Lidars as Permanent Wind Speed Reference Systems on Operational Wind Farms

An Informative Guide

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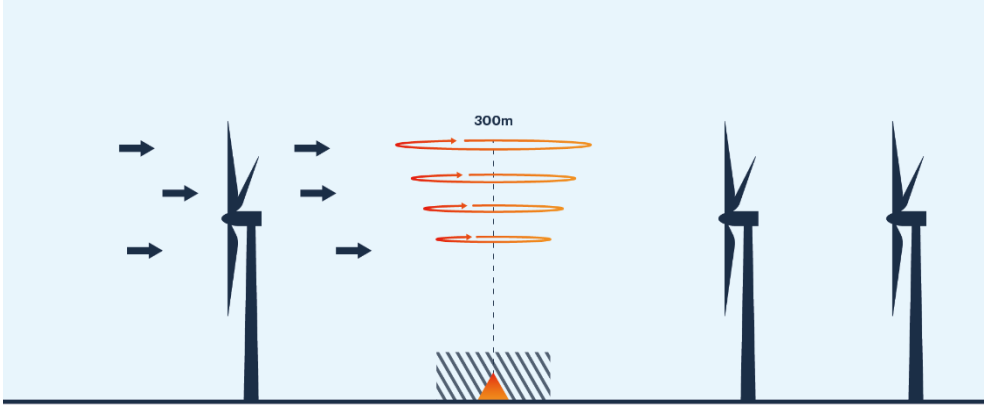
Foreword

ZX Lidars is not a wind energy consultant and does not directly provide consultancy services, yet our position within the industry allows us to impart decades of common Best Practices which are shared in this Reference Guide.

1 Introduction

Wind farm operators are increasingly deploying ground-based Continuous Wave (CW) wind Lidars as permanent met masts on operational sites. These laser-based remote sensing devices measure wind speed and direction at hub height and above, providing continuous reference data for electricity grid compliance, wind farm production forecasting, and wind turbine performance monitoring. This whitepaper examines global practices and regulatory acceptance of permanent Lidars, their onshore and offshore applications, integration with SCADA systems, comparisons to traditional meteorological masts, and the standardization and validation supporting their widespread use within the industry.



General concept for the inclusion of a permanent met Lidar on an operational onshore wind farm.

2 Permanent Met Lidar Applications

2.1 Onshore wind farms

A ground-based wind Lidar unit deployed on an onshore wind farm (with uninterruptible power supply). Permanent Lidars like this serve as virtual met masts, measuring wind speeds at multiple heights (10 m up to hub height and beyond) across the site.

Approach

Ground-based Lidars are typically installed on a low concrete pad at an open, representative location on the site. Once in place, a vertical-profiling Lidar continuously measures wind speed and direction from near ground level (~10m) up to turbine top tip height (often 150–200 m). This enables coverage of hub-height winds and the entire wind shear profile with a single device. Operators often position permanent Lidars a few rotor diameters upwind of a reference turbine, or centrally within the turbine array if possible, to capture free-stream winds.

Benefits

Ground-based Lidars are straightforward to deploy (no mast / tower construction needed) and can be relocated or redeployed as required. The civil engineering activities are greatly reduced. They are used to feed real-time wind data for grid compliance, support performance analysis, and even assist with operational activities like crane lifts during maintenance (by providing local wind readings).

Example reference case

Onshore permanent Lidars have been embraced by major operators – for instance, SSE installed ZX 300 at its 108 MW Bhlaraidh Wind Farm in Scotland, integrating it with the site's SCADA for operational monitoring and to enable turbine power curve measurements in place of a met mast.

2.2 Offshore wind farms

A ZephIR 300M Lidar installed on an offshore substation platform (yellow unit), during fabrication. Integrating Lidars into offshore substations provides hub-height wind monitoring without a dedicated met mast, aiding operational analytics and even helicopter landing safety.

Approach

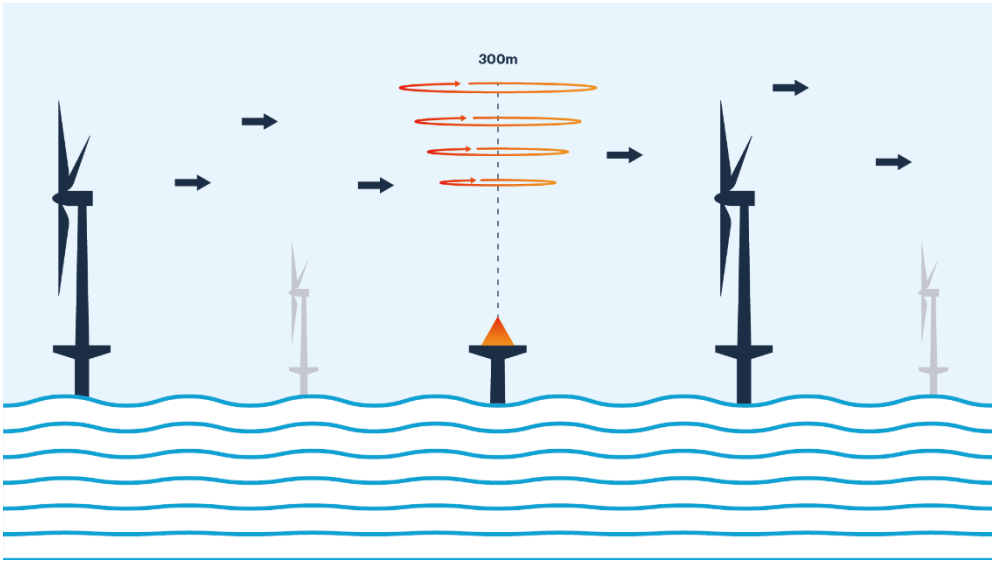
A substation-mounted Lidar is now a recognized best practice for permanent wind measurement offshore. The Lidar unit is typically installed on the roof or an upper deck of the substation platform, where it can scan the winds above the installation location and up to 300 m above platform level. Offshore substation Lidars deliver real-time hub-height wind data to both the wind farm operator and turbine OEM. The data is used for continuous power performance assessment of the turbines, detecting any underperformance or yaw misalignment, and can provide an early warning of wind changes that might affect operations.

Benefit

Offshore wind farms benefit greatly from Lidar technology, since installing and maintaining traditional met masts at sea is exceptionally costly and challenging. This setup leverages existing infrastructure (power, communications, elevation) to avoid the estimated tens of £millions it would cost to build a dedicated offshore met mast. An added benefit is improved safety and logistics: the Lidar's wind readouts support safer helicopter approaches for crew transfer, since the pilot can be fed nacelle-level wind information from the Lidar. This dual role of operational support and met monitoring makes offshore Lidars highly valuable.

Example reference case

Providers like Equans offer a "Meteorological Monitoring Module" where a marinised Lidar (e.g. ZX 300M) is engineered into the offshore substation design. By late 2017 Engie Fabricom (now Equans) had already integrated ZX Lidars into two North Sea offshore substations. Today, it's increasingly expected that new offshore wind farms will include a permanent Lidar on the O&M substation. The offshore wind industry is breaking down barriers and embracing new concepts with clear safety and efficiency advantages by adopting these Lidar solutions.



General concept for the inclusion of a permanent met Lidar on an operational offshore wind farm.

3 Permanent Lidar vs. Traditional Met Mast

Using a Continuous Wave Lidar as the permanent wind reference on a wind farm offers distinct benefits and some differences compared to conventional met masts. The table below summarises key comparisons for operational (post-commissioning) use:

Aspect	Permanent Met Mast (Traditional)	Permanent Wind Lidar (Modern)
Height Coverage	Fixed sensors at a few heights (often below hub height on tall turbines). Coverage may not span full rotor height.	Full wind profile from ~10 m up to hub height and beyond with one device. Measures across entire rotor sweep for better characterization.
Installation & Permitting	Requires construction of a tall tower (60–100+ m) with significant planning permission, environmental impact assessment, and visual intrusion. Location is often 'fixed' too early in the process and is then even more challenging to move post-approval.	Low-profile ground unit (typically <2 m tall) often deemed temporary equipment. Minimal visual impact and usually no formal planning permit needed. Deployment is fast (no heavy civil works).
Maintenance & Safety	Regular maintenance: annual sensor calibration and verification, periodic replacement of anemometers and wind vanes, inspections of tower and guy wires. Involves working at height (climbing) with associated safety risks.	Minimal maintenance: no parts that need to be validated / calibrated regularly; service interval typically 5 years. All servicing done at ground level or by swapping units. Eliminates working-at-height, greatly improving on-site HSE.
Data Quality & Availability	High-quality point measurements (cup anemometer, vane) with well-known characteristics. Can suffer data loss during icing (frozen anemometers) or sensor failure; redundancy often needed. Mast shadowing can affect wind readings in certain directions.	High-quality remote sensing measurements that are IEC-classified to match cup anemometer accuracy. Achieved ~98–99% data availability in field trials. Certain extreme conditions (e.g. heavy fog, low cloud) may attenuate laser signal slightly, but modern CW Lidars handle a wide range of conditions (including clear-air, low-turbulence environments) effectively.
Wind Parameters Measured	Typically measures wind speed (horizontal) and wind direction at instrument heights. Some masts also include temperature, pressure sensors at the mast base or mid-level. Turbulence intensity derived from standard deviation of wind speed (point measurement).	Measures wind speed, direction at multiple heights, plus vertical wind components if configured. Can derive shear, veer, and turbulence intensity. Often includes built-in met pack for temperature, pressure, humidity. Provides a more **representative** hub-height wind vector, since it continuously samples the volume of air the turbine rotor will encounter ahead of time.
Cost Considerations	High capital cost for tall mast procurement, installation (foundations), plus ongoing costs for maintenance, insurance, and potential obstruction lighting. Land lease and permitting can add costs; decommissioning at end of life also incurs cost.	Lower cost of capital cost for a Lidar unit, and **avoids many ancillary costs**: no tall structure to lease land for, no planning delays, and much lower O&M expenses. Overall life-cycle cost tends to be lower. One Lidar can potentially replace multiple met masts across a site's lifetime, increasing cost efficiency.

In summary, for an operational wind farm, a permanent Lidar offers greater flexibility, safety, lower cost, and often equal (or better) data coverage compared to a met mast. The main historical concerns with Lidars – such as needing a reference mast for calibration or questions about turbulence measurement – have been largely addressed by advancements in Lidar technology and standards. Modern continuous-wave Lidars have undergone extensive validation against mast-mounted instruments, showing excellent correlation for wind speed and direction measurements. In practice, operators have found that removing

the mast yields little downside: DNV's analysis of numerous Lidar deployments concluded that adding a short "monitoring mast" next to a Lidar contributes negligible improvement to data accuracy or consistency. In DNV's field tests, none of the Lidars experienced drift or bias that a co-located mast would have caught, and all remained within uncertainty limits when periodically verified against a reference. This evidence has given the industry confidence that a well-maintained Lidar alone can serve as the permanent reference sensor on a wind farm adding a new level of data integrity and insight to operations.

4 Global Practices and Regulatory Acceptance

Growing Endorsement by Grid Operators

Around the world, energy regulators and transmission system operators (TSOs) are formally recognising wind Lidars as acceptable alternatives to tall meteorological masts for operational monitoring. For example, Ireland's TSO EirGrid has explicitly approved the use of ground-based Lidars (ZX 300, ZX Lidars) in lieu of permanent met masts after successful trials. EirGrid requires all wind farms >15 MW to provide real-time met data (wind speed, direction, pressure, temperature) for forecasting and grid operation. In 2020, a ZX 300 Lidar deployed at Energia's Meenadreen wind farm was tested against the existing mast. The Lidar achieved >98% data availability and improved wind-speed-based power output forecasting by 5%, meeting EirGrid's acceptance criteria. Following this trial, EirGrid officially listed the ZX 300 Lidar as an approved permanent measurement device and now allows wind farms to replace met masts with Lidar units while maintaining Grid Code compliance. Several Irish wind farm owners have since rolled out permanent ZX 300 Lidars portfolio-wide in response.

Permanent Lidar installed in support of Ireland's TSO EirGrid

North America

In Canada, the province of Ontario's IESO (Independent Electricity System Operator) has also moved from masts to Lidars for wind farm compliance monitoring. The IESO's market rules mandate that wind farms between 10–100 MW have at least one local meteorological measurement device on site, explicitly allowing technologies such as Lidar. In 2018, Boralex installed a ZephIR 300 Lidar at the 10 MW Port Ryerse Wind Farm to fulfil IESO's requirements, eliminating the need for a permanent met tower. Boralex noted that while upfront costs of a met mast and a Lidar are comparable, over a 20-year

project the Lidar is preferred once one accounts for the mast's land lease, higher maintenance, and visual impact. In the United States, wind operators have increasingly deployed permanent wind Lidars for hub-height monitoring, with regional authorities accepting the data subject to it meeting the necessary accuracy and availability criteria for grid operations.

Other Regions

Across Europe and Asia-Pacific, the trend is similar. Many European wind farms are opting for Lidars to meet TSO data obligations and internal reporting needs. In the UK, for instance, SSE Renewables and Infinis (now Nadara) have replaced permanent masts with ZX Lidars at operational onshore wind farms, satisfying grid-related SCADA data requirements while improving measurement coverage. In the Asia-Pacific region, countries like Australia have piloted upstream Lidars to improve wind power forecasting for the grid, and developers in China and India routinely use ground-based Lidars for both resource assessment and operational monitoring in challenging locations. The global direction is clear: permanent Lidars are accepted as legitimate wind measurement systems for operational wind farms and are endorsed by grid operators.

5 Integration with SCADA and Data Systems

One of the key advantages of modern wind Lidars is their ability to integrate seamlessly into wind farm SCADA (Supervisory Control and Data Acquisition) and data management platforms. Most Lidars support Modbus/TCP connectivity, appearing on the network as a sensor delivering wind data registers that SCADA can poll continuously. For example, the ZX 300 provides a built-in Modbus server on the standard port 502, offering a range of registers for wind speed, wind direction, and other data at multiple heights. Both instantaneous (1-second) readings and averaged values (e.g. 10-minute means) are available through these registers. A typical configuration is to have the Lidar output 1 Hz wind speed and direction at hub height (and possibly other heights of interest) to the wind farm SCADA, which then passes the 10-min average values to the grid operator's telemetry according to grid code requirements. The data resolution is high-frequency – ZX 300 units, for instance, collect quality-controlled 1-second data streams in real time – ensuring that even short gusts or rapid wind shifts are captured for analysis. Many permanent Lidars also include built-in met sensors (pressure, temperature, humidity, rain) so that a full set of meteorological signals can be delivered to SCADA from one system.

In terms of compatibility with turbine OEM systems, Lidars are now essentially "plug-and-play" replacements for met mast instruments. Wind turbine SCADA software typically has inputs for an external met station (for wind speed, wind direction, etc.), originally meant for tower-mounted anemometers and vanes. Lidar data can be fed into these same inputs – either by analog output modules or via digital interface – allowing the turbine controller and park master (wind farm controller) to utilize the data as if it were from a mast.

There have been multiple successful integrations: at A'Chruach Wind Farm (UK), a ZephIR 300 Lidar was integrated into the Senvion turbine SCADA, marking an industry-first where the site operated entirely without a met mast. Similarly, SSE's Bhlaraidh wind farm linked its ZX Lidar to the Vestas SCADA system, which not only satisfied all grid monitoring obligations but also enabled SSE's engineers to use the data for in-house analysis and turbine optimization. In Canada, Boralex tied its permanent Lidar into the Siemens Gamesa turbines at Port Ryerse, directly incorporating the Lidar's feed into the OEM's meteorological system on the turbines. These integrations are typically achieved through Modbus/TCP or OPC data links, configured so that each turbine or the central SCADA can query the Lidar's wind data registers at the desired frequency. A ZX 300, for instance, allows SCADA to poll wind data at multiple heights (e.g. 10 m for quality control, hub height at ~100 m, and a higher level) on demand. The data latency is low (sub-second), and reliability is high – in the EirGrid trial the Lidar delivered over 98% data uptime even through harsh weather. Vendors provide guides for SCADA engineers on mapping Lidar outputs to their systems; for example, the ZX 300 Modbus register map defines blocks for unaveraged vs. 10-min averaged data and includes status flags for data quality. Many operators also aggregate Lidar data into cloud platforms or databases for fleet-wide performance tracking.

Simple Permanent Lidar installation with UPS and Comms cabinet on operational onshore wind farm, Scotland.

With standard protocols and increasingly common adoption, permanent Lidars can be considered just another node on the wind farm SCADA network – one that “is very much plug-and-play” according to SSE’s project lead.

6 Standardisation and Technical Validation

The maturation of Lidar technology for permanent wind measurements is underpinned by rigorous standardization efforts and validation programs. International Electrotechnical Commission (IEC) standards now explicitly include and guide the use of Lidars in wind energy measurements, ensuring they are employed with proper quality controls.

IEC 61400-12-1 Edition 2 (2017)

This is the flagship standard for wind turbine power performance testing. In its second edition, the standard introduced provisions for using remote sensing devices (like ground-based Lidars) as an alternative to met masts for measuring the free-stream wind speed during turbine power curve tests. Annex L of IEC 61400-12-1 Ed.2 outlines conditions under which a Lidar can be used in lieu of a mast, typically requiring a comparative calibration (either a site calibration with a short mast or prior validation of the Lidar's performance). The standard essentially permits "Lidar-assisted power curve measurements" and acknowledges that if all parties (manufacturer, operator, evaluator) agree, a dedicated mast at the test turbine may be omitted. This was a breakthrough that cemented the industry's acceptance of Lidar data as *"finance-grade"* for performance verification. In fact, many modern Lidars like the ZX 300 are fully IEC-classified against this standard (meaning they have an IEC-compliant uncertainty characterization). SSE noted that these IEC changes *"further add value"* to having a permanent Lidar on site, since the same device used for operations can double for any required power curve checks.

Validation and Bankability Programs

Beyond standards, industry groups and independent laboratories have established validation regimes for Lidars. Every reputable wind Lidar model undergoes extensive testing against met masts (often at accredited test sites like those run by NREL, DTU, or Deutsche WindGuard) to demonstrate its accuracy across wind speeds and conditions. Manufacturers publish verification results showing the Lidar's wind speed measurements correlate ~1:1 with calibrated cup anemometers (with low bias and uncertainty). For instance, ZX Lidars reports over 500 individual performance verifications of the ZX 300 against IEC-compliant masts, forming the largest dataset of its kind. This gives financiers and "bank's engineers" confidence in Lidar-derived data. DNV (formerly DNV GL) created a "Lidar performance tier" system: Stage 3 (highest) indicates a Lidar is sufficiently validated to be used standalone for energy yield assessments and operational monitoring without a met mast. ZX Lidars' vertical profiling Lidars were qualified as a Stage 3 and bankable by DNV in October 2012.

To further ensure long-term accuracy, best practice involves periodic checks of the Lidar's calibration. Many operators will send their permanent Lidar back to the manufacturer or a test site for re-validation just once within a ten year period, often coinciding with the recommended service interval (e.g., 5 years). Some keep a spare Lidar unit to swap in during this time to avoid data gaps. Lidar technology has proven very stable over time – as DNV found, none of the Lidars they monitored showed significant drift, unlike mechanical anemometers which can gradually degrade. Still, the industry follows the principle "trust but verify," using reference check-ups (performance verifications) or collocation tests if any doubt arises.

7 Conclusion

Permanent wind Lidars have transitioned from novel instruments to industry-standard reference systems for operational wind farms. Backed by global regulatory acceptance (from EirGrid in Europe to IESO in North America and beyond) and proven in the field by leading utilities, Lidars are now replacing met masts as the continuous eyes of a wind farm. Whether deployed on a remote hillside with a solar panel or atop an offshore substation, these devices provide reliable, accurate wind data that feeds directly into SCADA and grid operator systems. Compared to traditional met towers, they offer broader wind profile insight, lower life-cycle cost, and dramatically reduced safety risk – all without sacrificing data quality. Crucially, evolving standards like IEC 61400-12-1 Ed.2, along with validation by independent experts (DNV, etc.), have solidified the bankability of Lidar measurements.

Case studies from multiple countries demonstrate successful outcomes: better power output forecasting, easier compliance with grid codes, and even enhanced turbine performance monitoring, all enabled by permanent Lidars. As wind farms grow in scale and hub heights continue to rise, the flexibility and capability of Lidar technology make it an indispensable tool. The wind industry is confidently moving into an era where the met mast can be figuratively – and literally – taken down in favour of Lidar, unlocking new possibilities in wind farm operation and analytics while maintaining the rigorous data fidelity that the sector demands.

8 References

This report has cited specific regulatory documents, press releases, and technical standards to provide evidence and examples, including EirGrid's Met Mast Alternatives Study, IESO's data requirements, project case studies from SSE, Boralex, Statkraft, Engie, and others, as well as IEC standards and DNV technical findings, to ensure a factual and up-to-date perspective on the use of wind Lidars as permanent reference systems.

DNV GL, 2020. *Removing the Mast from Lidar Power Curve Testing*. DNV GL Technical Report. [Online] Available at: https://www.dnv.com.

EirGrid, 2020. *Approved Alternatives to Meteorological Mast for Wind-Powered PPMs*, Version 2. EirGrid Group. [Online] Available at: https://www.eirgridgroup.com.

Energia, 2020. *Lidar as an alternative to wind farm permanent meteorological masts*, Poster and Presentation, WindEurope. [Online] Available at: https://windeurope.org.

IEC, 2017. *IEC 61400-12-1:2017 - Wind energy generation systems - Power performance measurements of electricity producing wind turbines*, 2nd ed. International Electrotechnical Commission, Geneva.

IEC, 2022. *IEC 61400-50-1:2022 - Use of remote sensing devices for wind measurements* and *IEC 61400-50-3:2022 - Use of nacelle-mounted Lidars for wind measurements*. International Electrotechnical Commission, Geneva.

Boralex, 2018. *Canadian grid moves from masts to Lidars on operational wind farms*. ZephIR Lidar Press Release, 19 July 2018. [Online] Available at: https://www.zxlidars.com.

ENGIE Fabricom & ZephIR Lidar, 2017. *Wind farm offshore substations get Lidar upgrade*. Press Release at WindEurope Amsterdam, 28 November 2017. [Online] Available at: https://www.zxlidars.com.

Infinis, 2015. *Infinis chooses ZephIR Lidar to optimise operational site performance*. ZephIR Lidar Press Release, 21 September 2015. [Online] Available at: https://www.zxlidars.com.

Infinis & Senvion, 2016. *ZephIR Lidar goes SCADA-integrated with Senvion at Infinis wind farm*. ZephIR Lidar Press Release, 11 April 2016. [Online] Available at: https://www.zxlidars.com.

SSE Renewables, 2017. *SSE opts for Permanent Met ZephIRs at Bhlaraidh Wind Farm*. ZephIR Lidar Press Release, 15 November 2017. [Online] Available at: https://www.zxlidars.com.

Statkraft Ireland, 2019. *Permanent Met Lidars at Irish Wind Farms*. ZephIR Lidar Press Release, 29 August 2019. [Online] Available at: https://www.zxlidars.com.

ZephIR Lidar, 2025. *ZX 300/M Modbus Interface Guide*, Issue 2.33. ZephIR Ltd. [Internal Document].

ZephIR Lidar, Various years. Multiple Project Case Studies and Press Releases. Available at: https://www.zxlidars.com.

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

Our Products & Services

ZX300
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