# Onshore, offshore, worldwide: How lidar is raising the bar for wind measurement



### Trusted and verified, flexible and accurate. Lidar is the modern standard.

Remote sensing once fought an uphill battle for acceptance in the wind industry, but not anymore. Backed by continuous innovation and industry advocacy, lidar is becoming universal — meeting multiple needs and applications, deployable in diverse terrains and environments, and proven onshore and offshore.

Discover the benefits of lidar, how Vaisala's WindCube\* lidar suite leads the pack, and why all types of wind industry organizations choose to lead with it.



Vertical profiling lidars are replacing an estimated 10% of met masts in the onshore market for WRA and operational plants.<sup>1</sup>



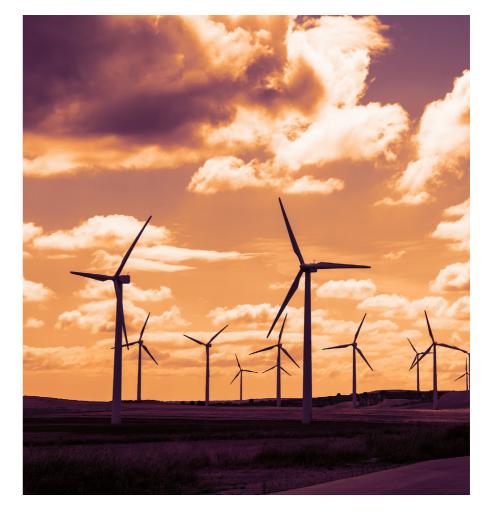
Lidar is expected to fully replace met masts in onshore WRA campaigns in the next two decades.



Around 4,000 wind measurement devices will be needed yearly worldwide.<sup>2</sup>



Today, there is nearly 100% replacement for offshore Wind Resource Assessment (WRA).



2. Vaisala vaisala

<sup>1.</sup> IEA Task 52 (Large-Scale Deployment of Wind Lidar)

### Lidar stands alone

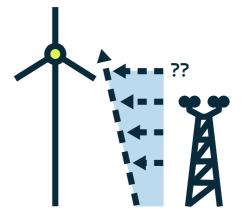
Since the turn of the century, the average hub height of onshore wind turbines has rapidly increased as manufacturers design turbines with greater generating capacities. In 2000, hub heights were typically 60 meters. Today, they are nearly 200 m and getting taller with increasing capacity and rotor diameters — making met masts too impractical, expensive and error-prone for Wind Resource Assessment (WRA).

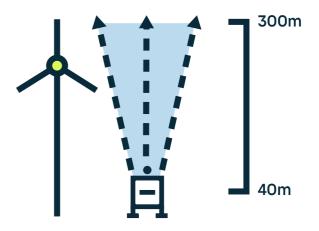
Bank engineers once relied solely on met mast data for evaluating a wind farm's bankability, but this has changed as modern lidar technology is consistently proven for its accuracy and reliability.

As wind farms continue to proliferate and are placed in more challenging geographies — from complex terrain to offshore environments — lidar's mobility, reliability, data accuracy, safety and ease of deployment make it the superior technology for many projects.

"Reducing the vertical and spatial uncertainty factors and being able to measure at higher heights in general is a significant advantage for us, considering the higher hub heights of modern wind turbines."

> Nicolás Briceño Analyst, Wind & Solar Energy, Innergex





### Major milestones in lidar development and acceptance

2004/5 Leosphere and Zephyr pioneer lidar technology in the wind industry	2008 WindGuard completes the first WRA with lidar, accepted by banks	2010 Leosphere introduces lidar fleet management software		2010/11  Leosphere introduces nacelle-mounted lidar and scanning lidar
2016 Lidar information included in MEASNET site assessment guideline and Carbon Trust roadmap for floating lidar	2017 IEC publishes IEC 61400- 12-1, Ed.2 — its standard for wind turbine power performance testing, providing guidance on the use of remote sensing	2018  Vaisala, a global leader in environmental and industrial measurement, acquires Leosphere SAS		2019  Vaisala introduces new WindCube* version and a marine- hardened casing
2019 Japan Renewable Energy Co. (JRE) performs the first commercial Dual Scanning Lidar campaign for offshore WRA in Japan	2022 IEC 61400-50-3 standard is released: WindCube® Nacelle is the first nacelle-mounted lidar to achieve the full classification	2024 IEC 61400-50-4 standard is released (use of floating lidars for offshore wind measurements)	relea asse of th	51400 15-2 standard is ased (framework for essment and reporting the wind resource and egy yield)

### Real-world benefits

With thousands of deployments completed, lidar users have a solid understanding of its most distinguishing benefits — some of which go beyond the data it provides.

- Data validated over thousands of deployments and largescale studies
- No dependence on extrapolated wind flow models; free of hub height limits
- · Limited permitting, easy and fast deployment
- · Little or no on-site construction required
- · Low profile, sturdy; withstands extreme weather
- · Accurate in various environmental conditions
- · Reduces time needed to assess sites for suitability
- · Deployable in remote, offshore, or complex terrain
- · Capital asset that can be redeployed at no extra cost at multiple sites
- · Economical and safe to operate and maintain

### Committed to continuous innovation

The legendary WindCube\* wind lidar suite is unrivaled in its comprehensiveness and value — proven and verified by the biggest names in the industry.

Vaisala continues to lead with innovative solutions in dual lidar, complex terrain, hybrid wind reconstruction, marinized lidar for integration into FLS, lidar-assisted control for integration into manufacturer turbines, and fleet management and reporting software — always with more to come.



"The cost benefits are a big factor; it's much more economical to get wind speed data [with remote sensing rather than met masts] and a thousand times easier."

> Nathan Lehman Energy Analyst, Apex Clean Energy

## Lidar applications in wind energy

### Project development

- Provide quality data and bankable due diligence in almost any terrain and weather conditions
- · Reduce the need for data extrapolation and increase measurement certainty
- · Optimize turbine layout and design
- · Inform turbine choice, optimizing important cost and risk factors

Quantifying the wind resources at a given site is critical to determining its financial and practical viability. Initial site prospecting data informs site selection, while a full resource assessment forms the basis for annual energy production (AEP) estimates investors require.

Prospecting has historically involved construction of one or more met masts along with other equipment. However, met mast construction involves complex construction, planning regulations, land ownership and lengthy permitting. This is especially true in offshore campaigns, where installation requires sea-bed foundations, and construction in dangerous offshore conditions.

Site assessment using lidar can be undertaken more swiftly and more accurately. Lidar can be on-site within hours, and can be used across many types of terrain and in all climates. Developers can easily access multiple sites and conduct a cross-comparison, and lidar units' mobility means that they can also better account for spatial variation across the site and reduce uncertainty in wind flow modeling.

WindCube® vertical profiling lidar has been increasingly used as a standalone measurement device thanks to its proven accuracy and reliability. Its embedded hybrid wind reconstruction algorithm is IEC classified, showing the lowest uncertainty at 120 m and improved sensitivity to turbulences.



### Wind farm operations

Lidar is outstanding for power curve verification, optimizing energy production and returns at existing wind farms. It provides excellent flexibility because it can be moved from one project to another or deployed as a permanent wind monitoring device at multiple locations within operating wind farms.

Nacelle-mounted lidar provides data directly at hub level and across the entire rotor sweep — which is difficult or impossible using other means. WindCube® Nacelle is classified according to IEC 61400-50-3 and has been continuously tested and accepted by leading turbine manufacturers and independent consultants for onshore and offshore PPT..

The range of data nacelle-mounted lidar provides also leads to a greater understanding of how other characteristics, such as atmospheric stability, shear and veer will affect the performance of turbines over time. WindCube® Nacelle has also an embedded Turbulence Intensity (TI) calculation method showing improvements in TI accuracy, and it is validated by industry leaders.

- · Power Performance Testing (PPT), nacelle alignment, wind blockage, and wake studies
- · Nacelle instrument verification (yaw misalignment and transfer function)
- · Permanent monitoring of site conditions
- · Meeting grid operator reporting requirements



### Complex terrain

The WindCube® vertical profiling lidar has been used in simple to moderately complex terrain for many years — made possible by integrated and patented Flow Complexity Recognition (FCR) software. Vaisala has strategic partnerships that enable WindCube® measurements in even more complex terrains using the proven Computational Fluid Dynamics (CFD) correction method. Moreover, Vaisala's Complex Terrain Estimator (CTE) is an innovative tool that helps you estimate possible complex flow lidar errors at the beginning of your measurement campaign.

Vaisala has extensively studied lidar performance in real-world complex terrain environments. In one study, bias using remote sensors was satisfactorily reduced to 0.3 percent. (Met towers were used as controls for the study, though they were found to be unnecessary for data collection.)

### Key takeaways:

- Complex terrain bias can be resolved with the right processing, like with FCR and modelbased corrections
- · Since the initial study, these results have been validated at many complex sites
- · Lidar is an excellent solution for complex terrain one that brings numerous side benefits



### WindCube® lidar suite

As the wind energy industry continues to evolve, so does WindCube\* – the most accurate and proven lidar suite on the market. New capabilities extend the frontiers even further so you can leverage WindCube\* almost anywhere, in all types of environments.



Windcube\*
The industry-standard vertical profiler



WindCube\* Nacelle

Easily deployable nacelle-mounted lidar



WindCube\* Scan

3D scanning for reliable, detailed spacial wind data



WindCube\* Offshore
Ruggedized for floating buoys and fixed platforms in harsh marine environments



WindCube® Insights
Actionable, at-a-glance data analysis and reporting

### Offshore applications: Solution matrix

	Vertical profiler (WindCube <sup>®</sup> )	Vertical profiler for offshore (WindCube <sup>®</sup> Offshore)	Long-range scanning (WindCube <sup>®</sup> Scan)	Nacelle-mounted (WindCube <sup>®</sup> Nacelle)
Prospecting and development  Site prospection Site suitability Wind resource assessment Farm extension	•	•	•	
Construction and commissioning  PPT — contractual power curve  Offshore ship operations for build-up	•	•		•
Operations and life management  Permanent wind monitoring  Weather and obstruction light monitoring  PPT — performance verification  Retrofit and performance increase  Site O&M  Offshore ship operations for maintenance  Minutes/hour/day ahead forecasting  Repowering	•	•	•	•
Turbine development  New turbine prototyping Equipment for turbine control	•			•
Research and development <ul><li>Blocking effect</li><li>Wake losses studies</li><li>Wind farm wake effect</li></ul>			•	

### WindCube® the gold standard

WindCube<sup>®</sup> is the iconic and trusted gold standard in wind lidar. The turnkey product suite offers innovative, reliable, and highly accurate solutions for thousands of customers across the globe. Borne from a passion to advance the field, WindCube<sup>®</sup> continues to take wind energy ever higher through a commitment to four guiding principles:

- · Trustworthy, superior metrology
- · Unrivaled thought leadership
- · Innovative lidars from a one-stop shop
- · Easy, reliable global solution

### Lidar is the clear leader

Lidar offers the wind energy industry a generational leap in technology and business outcomes. The technology is being used all over the world in every wind energy-producing country and region — from Europe to North America, South America, Africa and Asia.

We now have the necessary guidelines and standards that create global confidence, knowledge sharing, and standardization of lidar as an important and expected part of most standard wind energy processes.

Lidar's quality and quantity of data have redefined wind energy and the flexibility available to developers, operators and others. Lidars continue to replace met masts, and are increasingly considered standard equipment in the largest and most demanding onshore and offshore projects.

"WindCube" suite is outstanding in standalone applications. Not only is the lidar very stable and easy to use, but it provides the precise measurements and accurate data we need for Wind Resource Assessments and power curve measurements."

**Matthias Benz** Team Leader, Wind Measurements & IT, JUWI



### Leading with industry classifications and acceptance

**WindCube**\* has been validated by hundreds of independent studies and is accepted by all international standards and guidelines. WindCube\* with hybrid wind reconstruction is classified by Deutsche WindGuard® according to IEC 61400-12-1, edition 2, showing 0.6% standard uncertainty at 120 m.

WindCube® Nacelle is the first nacelle-mounted lidar classified according to the IEC 61400-50-3 standard and enables PPT on any wind turbine, onshore and offshore. It is already accepted by leading turbine OEMs and independent consultants.

WindCube\* Scan Dual Lidar Ready is an innovative approach to WRA proving a comprehensive picture of the wind resource profiles by observing an offshore location from several positions. This solution has been validated and recognized as an important measurement device for reducing uncertainties and accurately measuring TI in offshore conditions.

Vaisala is an active member of IEC working groups IEA Task 52, CFARS, and other industry programs aiming at advancing the use of lidar technology in wind energy.



### Advancing renewable energy

Our renewable energy solutions are guided by several key priorities:

Thoughtful evolution: Remain a pioneer in renewable energy, always providing sensible, trusted solutions at the leading edge of R&D.

Smarter at every stage: Provide end-to-end weather and environment solutions and critical insights throughout the renewable energy life cycle.

**Legacy of leadership:** Extend our proven track record and global trust to reach more customers in more ways.

### Why Vaisala?

We are innovators, scientists, and discoverers who are helping fundamentally change how the world is powered. Vaisala elevates wind and solar customers around the globe so they can meet the greatest energy challenges of our time. Our pioneering approach reflects our priorities of thoughtful evolution in a time of change and extending our legacy of leadership.

Vaisala is the only company to offer 360° of weather intelligence for smarter renewable energy, nearly anywhere on the planet. Every solution benefits from our 85+ years of experience, deployments in 170+ countries, and unrivaled thought leadership.

Our innovation story, like the renewable energy story, continues.

