VAISALA

Ever higher

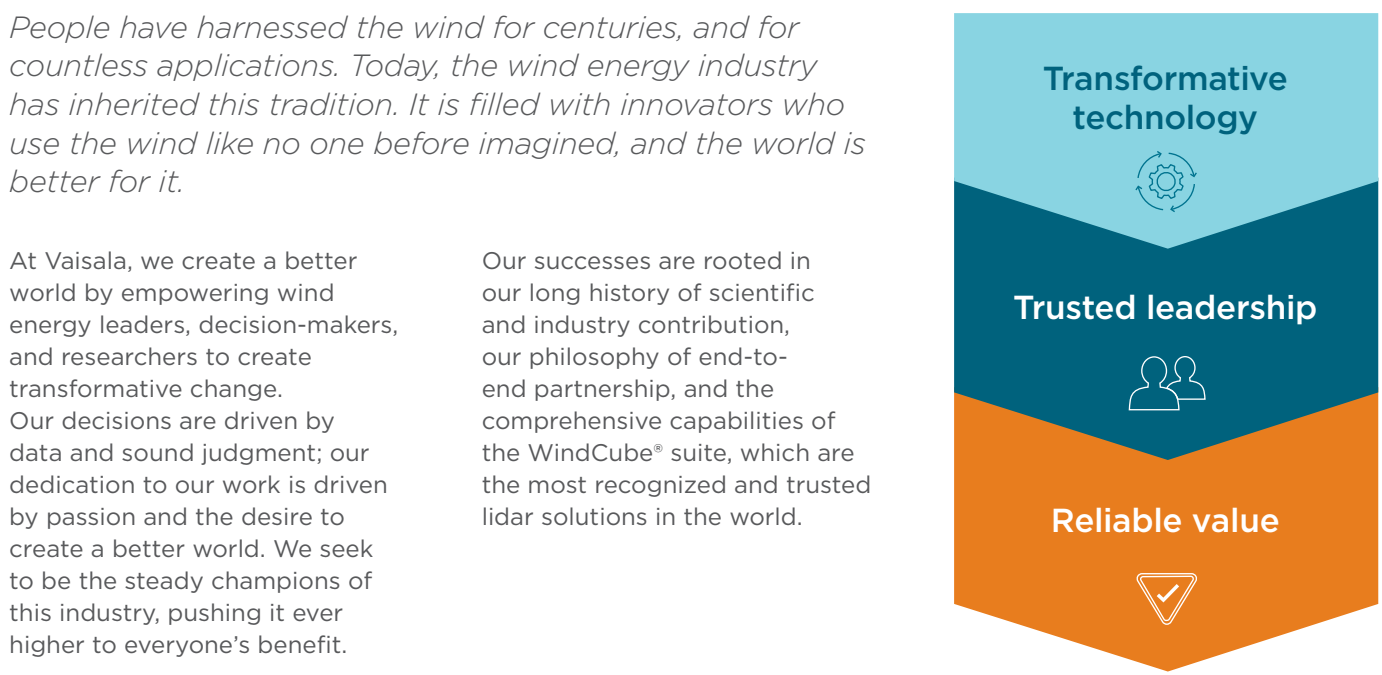
The remarkable science and business outcomes of WindCube® suite of lidars

Smarter wind energy

People have harnessed the wind for centuries, and for countless applications. Today, the wind energy industry has inherited this tradition. It is filled with innovators who use the wind like no one before imagined, and the world is better for it.

At Vaisala, we create a better world by empowering wind energy leaders, decision-makers, and researchers to create transformative change. Our decisions are driven by data and sound judgment; our dedication to our work is driven by passion and the desire to create a better world. We seek to be the steady champions of this industry, pushing it ever higher to everyone's benefit.

Our successes are rooted in our long history of scientific and industry contribution, our philosophy of end-to-end partnership, and the comprehensive capabilities of the WindCube® suite, which are the most recognized and trusted lidar solutions in the world.



The business results of lidar have arrived

In the last 15 years, as wind energy has evolved, lidar has gained acceptance and enthusiasm in all corners of the industry.

In years past, the industry has been slow to adopt remote sensing, in part because it was solely committed to traditional met masts. But today, lidar isn't just accepted — it is necessary.

Technology for today

In 2000, a typical turbine hub height was 60m. Today, hub heights are routinely double that. Experience tells us that erecting a met mast above 60m is difficult and costly, and extrapolating wind measurements far beyond the structure's height introduces error and uncertainty.

Lidar shows almost limitless development potential and already measures across the entire rotor sweep of even the largest turbines. The WindCube vertical profiler, for example, boasts a range of up to 300m with 20 simultaneous measurement heights — ideal for even the largest turbines currently in service or in development, both onshore and offshore.

Due in large part to WindCube's innovations, remote sensing has evolved past previous limitations and is powering wind energy to new heights.

> "The higher the turbine hub heights we're getting, the more uncertain extrapolating shear is from met towers. Today we have at least one WindCube at every development project."
>
> **Phillip Hurlbut**
> Meteorologist,
> Pattern Development

Breaking down the business outcomes

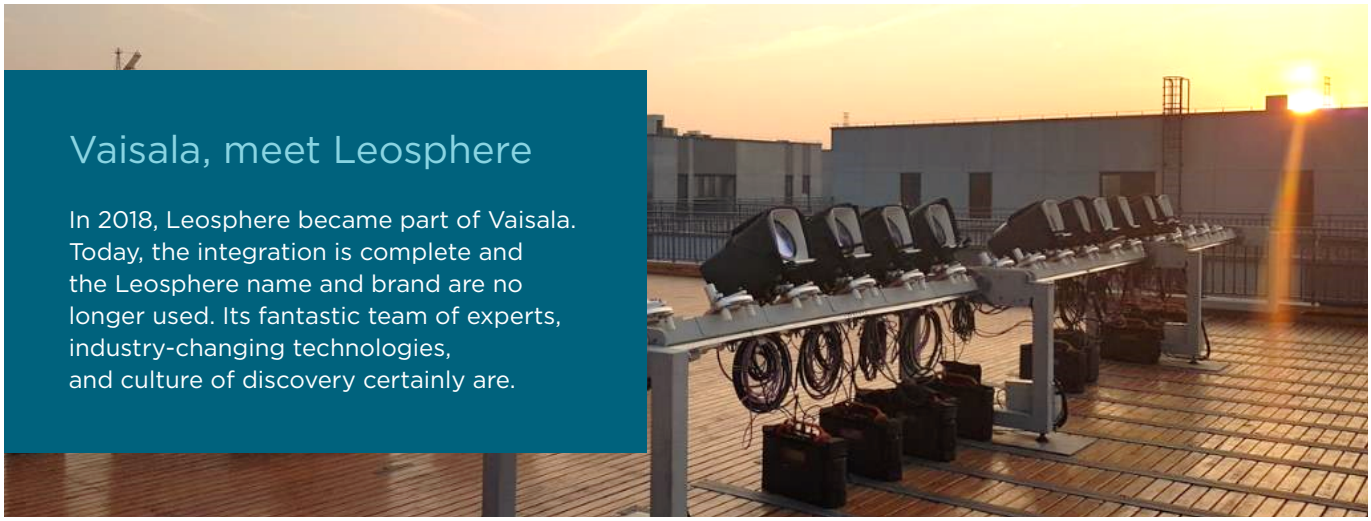
Phase	Lidar capabilities	Business outcomes
Development/funding	• Accurately assess wind characteristics for almost any geography, whether onshore or offshore • Efficiently provide compliant and validated data with drastically enhanced flexibility and time-to-deployment	• Quickly and confidently confirm the bankability of a wind site, securing funding and expediting development • Reduce risk and improve performance forecasting
Operations	• Demonstrate wind farm performance over time, dependably informing corrections or optimizations • Reduce fatigue and loads on critical components	• Recover and enhance profit otherwise lost through non-optimized configurations • Optimize and manage the entire wind farm system in cohesive campaigns • Increase the lifespan of key components
All phases	• Perform reliable contractual and operational Power Performance Testing (PPT) according to industry best practices and the IEC 61400-50-3 standard • Optimize wind farm production and layout through R&D studies such as blocking effect or wake analysis	• Maintain compliance and carry out PPT in ways never before possible • Reduce uncertainty, improve decision-making and performance optimization • Reduce risk, the cost of wind farm projects — and, ultimately, the cost of wind energy
Positioning in the wind energy marketplace	• Supplement or replace met mast systems, solving for past limitations • Open new opportunities for offshore and complex terrain measurement	• Demonstrate innovation to stakeholders • Pioneer new wind energy sites and approaches

How Vaisala powers wind energy

With thousands of real-world deployments validated by industry experts, Vaisala provides customers with ample evidence of lidar's most distinguishing benefits — some of which go beyond the data it provides.

WindCube gives industry leaders a multi-use tool whose flexibility is unmatched and whose wind data is equal to or superior to what met masts offer. Lidar units are mobile, compact, and nondisruptive to landscapes and environments. They can be used temporarily and are easy to repurpose after their initial job is done. And, they offer distinct health and safety benefits over met masts. All of the above contributes to lidars providing exceptional value over long service lives.

WindCube lidar benefits at a glance
Data validated over thousands of deployments and large-scale studies
Removes the need to rely on flow models for vertical extrapolation; free of hub height limits
Limited permitting, easy and fast deployment
Little or no on-site construction required
Low profile, sturdy; withstands extreme weather
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 to operate and maintain
Consistent performance in hot and cold weather and icy conditions
Increased safety for workers



Vaisala, meet Leosphere

In 2018, Leosphere became part of Vaisala. Today, the integration is complete and the Leosphere name and brand are no longer used. Its fantastic team of experts, industry-changing technologies, and culture of discovery certainly are.

The industry's reference lidar

2,000+ WindCube lidar units, 5,000 deployments around the globe

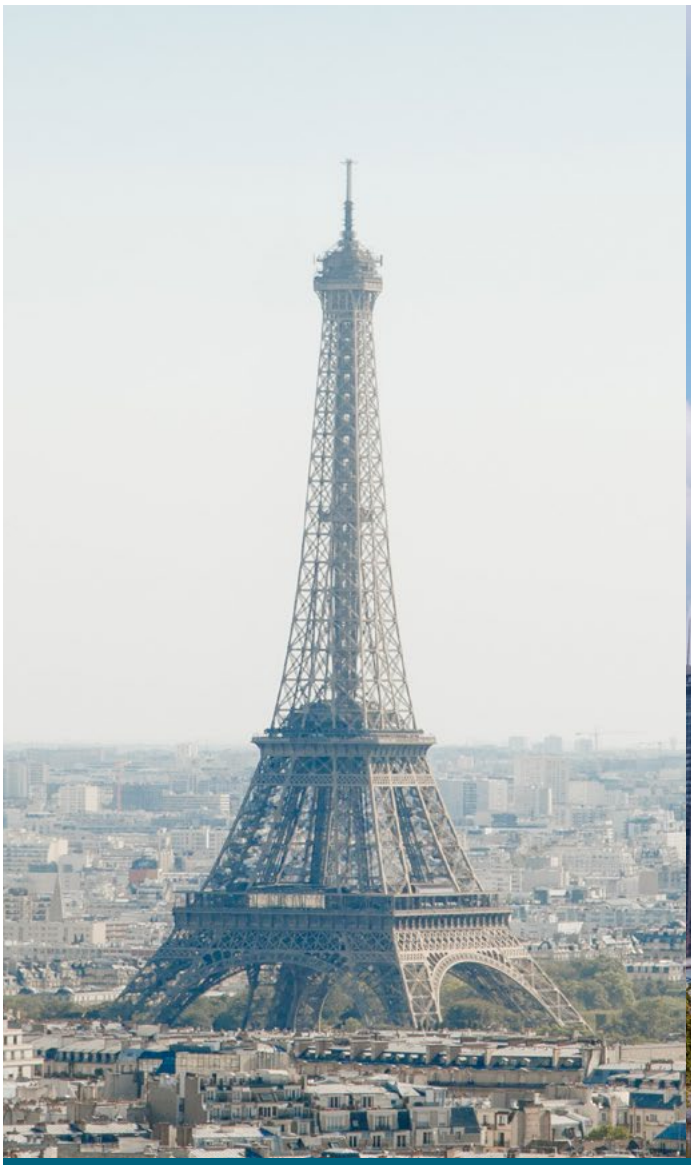
Global company, global capabilities

Vaisala has established truly global reach, which brings several distinct benefits to customers.

First, our size and well-established business practices allow for scalability, worldwide service provision, and stability in changing economic environments. In times of uncertainty, our track record and multinational infrastructure can provide certainty and peace of mind unlike any other lidar provider.

Our network includes two WindCube factories, both of which utilize industry-level manufacturing and related practices, as well as seven global WindCube service centers. This is an enormous asset to our customers because it ensures we can meet demand, provide quick and correct servicing, and leverage the most sophisticated benches, calibration tools, and related technologies.

WindCube: 2 factories, 7 global service centers



Welcome to Paris. And Shanghai.

To satisfy global demand, we built a lidar factory and service center in Shanghai, in addition to our location at Paris-Saclay. The Shanghai factory has been operational since early 2019 and its level of performance has allowed us to progressively increase its capacities. It now manufactures and services the full suite of WindCube lidars.

The experience and feedback collected in each factory enriches our overall manufacturing and quality control practices. Having two sites allows us to increase the quality and repeatability of WindCube systems globally, and we are excited to pass these gains along to our customers as our innovation and growth continue.

"If we're not using remote sensing devices, we're at risk to actually introduce bias. For most of these met masts, we've seen what we call shear relaxation — a 0.9% over-prediction when we use the mast alone, and 1.8% in energy."

Philippe Pontbriand
Energy Resources Director, RES Americas, Inc.

All about data

Today, lidar hasn't just achieved parity with met mast data; it has exceeded legacy systems' ability to collect data, report it, and empower users with bankable conclusions.

Now that lidar has been used around the world on projects large and small, we have learned several key things:

- Lidar data, on its own, is as accurate as met mast data and fully compliant to IEC and other regulatory standards.
- WindCube — unique in the industry — is also capable of hybrid wind assessment, seamlessly integrating scalar and wind vector data for even higher certainty.
- In many situations, lidar is still an ideal complement to met masts — filling in gaps in the data, validating and expanding measurements, and drastically reducing uncertainty.
- The range of data available from lidar is extensive, as is the processing power of lidar units and their related software. These factors improve users' situational awareness and allow for previously unattainable benefits, like out-of-the-box PPT according to industry best practices and the IEC standard.
- Lidar, like any recent advancement, comes with modern, cloud-based management and analytics tools, making its insights more accessible and easier to manage.

Leading in lidar

Reference lidar
for wind energy

15+ years
of scientific lidar innovation

5,000+
customer deployments

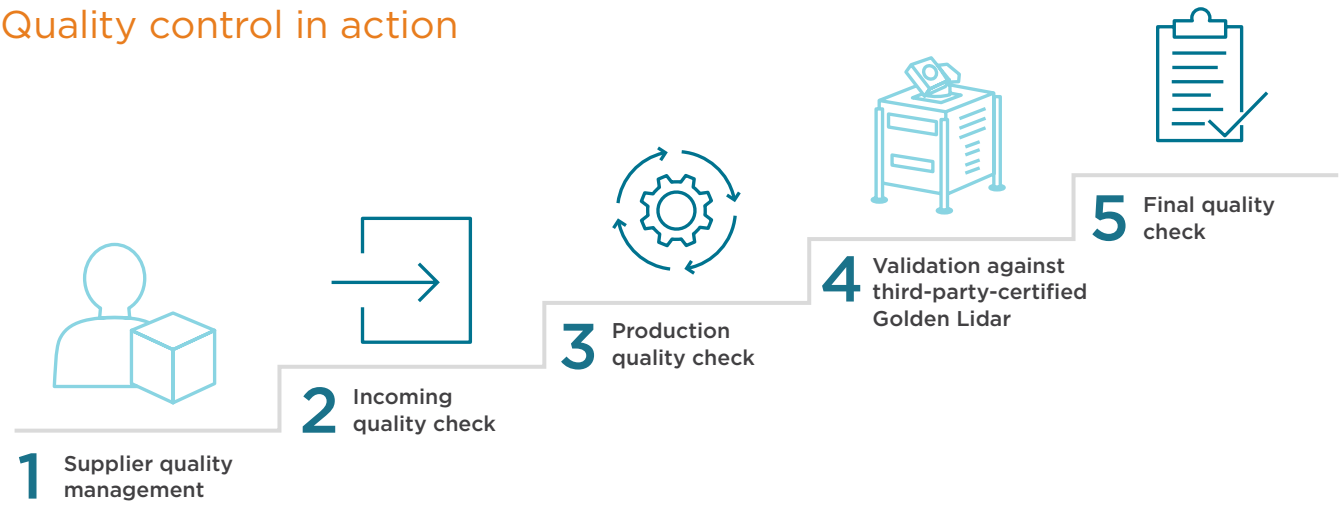
500+
authored/co-authored publications

Industry-level value

Vaisala leads the way with our industry-level manufacturing and servicing practices, meaning that we apply consistent, rigorous quality-control and testing protocols to each lidar unit and component.

This includes using a unique set of benches and soft tools for manufacturing, testing, and calibration. Many of these are patented by us and have accelerated production while ensuring higher and more uniform quality. For example, as each lidar unit makes its way through the process, it passes through more than 150 electro-optical control points, with more than 60 controlled wind parameters.

Quality control in action



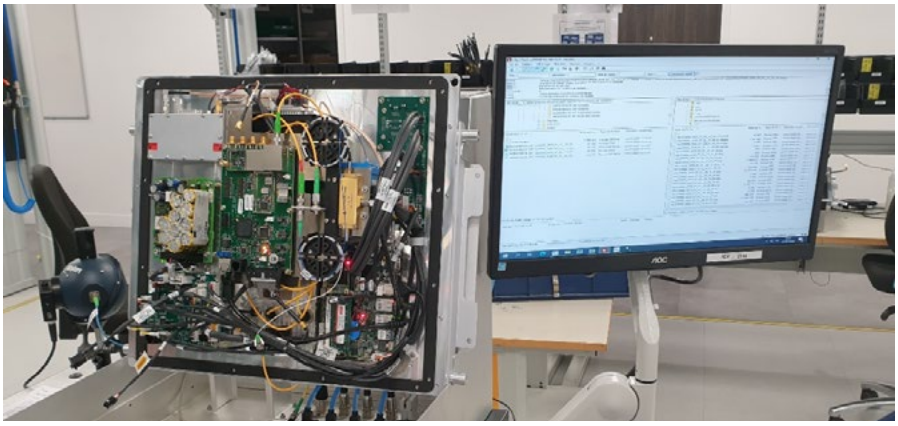
Certification and bankability

Vaisala products meet the latest and most rigorous international verification standards, including ISO 9001, 14001, and 45001. All WindCube products are compliant to the latest IEC standards, and they are recognized and verified by the world's leading independent certifying bodies and research institutes, including DNV, DTU Wind Energy, UL, Deutsche WindGuard, NREL, and AIST.

Each WindCube vertical profiling lidar unit we make is validated against a Golden Lidar and shipped with a document of validation issued by DNV. Vaisala owns several Golden Lidars, which helps us ensure speed and continuity of operations. Our Golden Lidars are certified every two years across more than 20 key performance indicators, and this process is applied for more than 10 years.

This level of rigor gives us:

- Improved speed while achieving full traceability and quality
- The ability to verify at the greatest heights and distances to cover even the largest turbines
- A high degree of certainty in verification results
- Backup capacity using fully certified Golden Lidars
- Weather- and terrain-insensitive processes
- Complete verification across heights, turbulences, and CNR levels



Selected certifications

CERTIFIED ISO 9001:2015 COMPANY

DNV

DTU Wind Energy
Department of Wind Energy

UL DEWI

WINDGUARD Certification

IEC

Industry-leading warranties and support options

Vaisala offers the best warranty in the industry, as well as robust standard and premium service levels. For example, for the WindCube vertical profiler, we provide a 15-day case duration for workshop repairs, and our premium on-site repair option provides guaranteed mean time to repair.

Support extends to ongoing training, including convenient online refreshers through our e-learning platform. These anticipate frequent questions and ensure you get the most from your WindCube investment.

For the WindCube vertical profiler, we also offer a validation continuity warranty, which enables users to maintain IEC-compliant validation during repair or maintenance, as well as a pre-validated, off-the-shelf purchase option that can save up to two months of deployment time. Existing customers can efficiently upgrade to the latest enhanced and certified WindCube units, with warranty extension included.

Vaisala is able to offer these options because our technologies are so reliable, and because we have invested in a global support infrastructure that is unlike any other lidar provider. This provides value well beyond accurate wind data, since when you select WindCube lidar, you also gain the trustworthiness and peace of mind that only we can provide.

Delivering value every step of the way

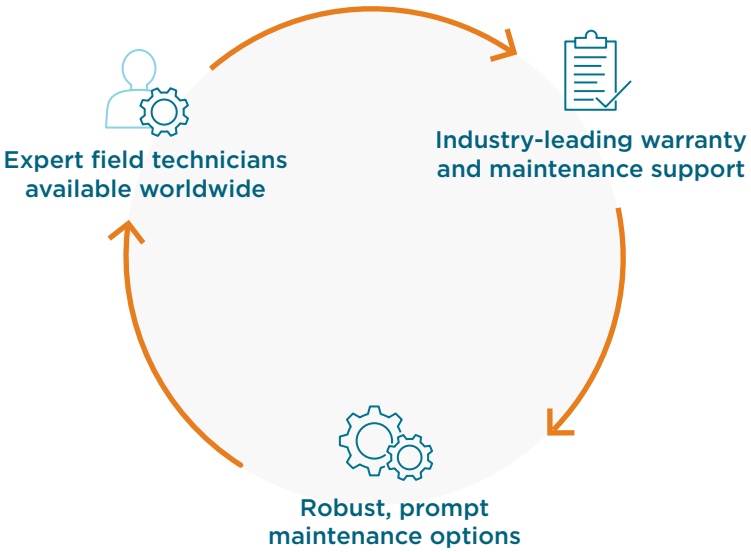
Vaisala provides the most comprehensive solutions and service available, no matter where you are. In addition to our two WindCube factories, we maintain seven global WindCube service centers, and offer a variety of solutions that make deploying and operating lidar even simpler.

Easy, reliable global solution: Robust support offerings

- Extensive training, including online training refreshers, on-site or remotely
- Full maintenance capabilities that maximize operation continuity
- Installation and system integration support
- Technical and scientific support

Innovative lidar solutions from a one-stop shop: Turnkey offerings

- Standalone power supplies
- 4G remote communication
- Security fencing
- Data analysis software



Pulsed lidar technology in depth

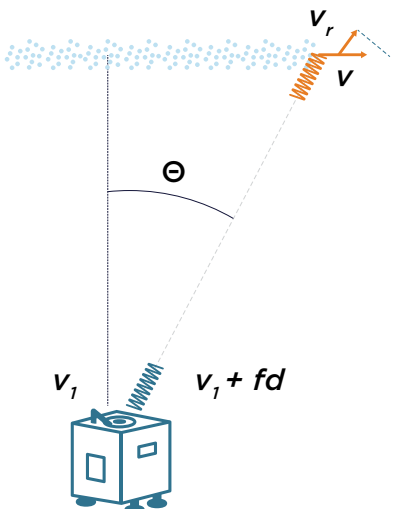
Understanding lidar types

You will see two primary lidar types in the marketplace: pulsed lidar and continuous wave (CW) lidar. Over decades of research and deployments, Vaisala has relied on pulsed lidar technology for a variety of reasons, some of which are explained below. Pulsed lidar requires high-level skills and methodologies, but it is the best technology to use.

Its strengths are highly correlated to the specific needs of wind energy.

Principles and functionality

All lidar types share several key principles. Lidar (an acronym for Light Detection and Ranging, much like "radar" is an acronym for Radio Detection and Ranging) sends light beams into the atmosphere, which are reflected and returned by particulates moving with the wind. Using the Doppler Effect, the lidar unit analyzes the frequency of those reflections and computes a highly reliable wind speed.



Pulsed lidar's strengths are highly correlated to the specific needs in wind energy.

Benefits of pulsed lidar and WindCube technology	
Measures multiple heights simultaneously, providing the full wind profile with no compromises in temporal resolution or accuracy	✓
Multiple heights produce much more data, more quickly (10 heights = 10x faster and 10x more data, for example)	✓
Provides spatial resolution that is constant throughout the entire wind profile	✓
Measures greater height and distance ranges, with constant accuracy	✓
Uses only 5 laser beams, which operate without moving mechanical parts	✓
Can use a unique hybrid wind reconstruction algorithm that combines scalar and vector data for the highest possible accuracy and reliability	✓
Maintains constant accuracy no matter the weather or cloud/aerosol layers	✓
Easy to position almost anywhere because its few (5) laser beams can easily be oriented to avoid obstacles	✓
Provides accurate wind direction over a 0-360° range; not vulnerable to possible 180° error	✓
Can use a 5th (vertical) beam for direct, accurate measurement of vertical wind speed and flow angle	✓
Maintains high data availability and sample rates in a wide range of conditions	✓
Data recovery not affected by strong wind shear or wind turbulence intensity	✓
Uses 50% less power on average	✓

WindCube® The gold standard

WindCube® 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 continues to take wind energy ever higher through a commitment to four guiding principles:

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

"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

WindCube®

The industry standard for accurate, bankable data

Highlights:

- Ground-based wind profiler that covers the entire rotor sweep of today's larger turbines, providing accurate wind measurement up to 300m over 20 simultaneous heights
- Performs hybrid wind assessment, seamlessly combining scalar and wind vector data for reduced uncertainty and unmatched IEC classifications
- Deploys safely, quickly, and easily — no expensive construction or permitting necessary
- Enhanced 4G modem and affordable power packs enable deployment almost anywhere
- Full IEC compliance and data validated by hundreds of independent studies
- Bankable data to secure funding, reduce the cost of equity, and minimize risk
- Embedded FCR correction or full CFD post processing for direct measurement in complex terrain
- Includes WindCube Insights cloud-based data management system
- Services include the industry's best warranty, accelerated workshop repair enabled by Vaisala's seven global service centers
- Premium options for 15-day guaranteed on-site repair, validation continuity, and pre-validation to accelerate and simplify deployment

Applications:

- Wind resource assessment
- Power Performance Testing
- Site suitability and calibration
- Grid-loss compensation and permanent wind monitoring
- Performance verification

"We're pushing for remote sensing devices to provide investors with more confidence. The lidar device delivers cheaper, faster, and safer resource assessment campaigns."

Philippe Pontbriand
Energy Resources Director,
RES Americas, Inc.

WindCube®
Offshore

Vertical profiling lidar purpose-built for buoys and harsh marine environments

Highlights:

- Provides all the benefits of the WindCube industry reference lidar
- Designed with a robust casing specifically for offshore environments
- Integrates into floating buoys and withstands tough marine conditions for fixed placement in lighthouses, substations, and vessels
- Commercial buoys integrated with WindCube lidars validated in accordance with the Carbon Trust roadmap of acceptance
- Cost-effective solution deploys safely, quickly, and easily — no expensive construction or permitting necessary

Applications:

- Wind resource assessment
- Operations
- Optimization
- Research

WindCube®
Scan

3D scanning for reliable, detailed spatial wind data

Highlights:

- Versatile, 360-degree, long-range configurable Doppler lidar system
- Suitable for onshore and offshore development and operations
- Provides large-scale, detailed knowledge of wind conditions, coupled with minimal cost of operation
- Multiple scanning patterns with an operational range of up to 15km; typical measurement ranges up to 3km, 6km, and 10km (depending on model)
- API for configuration and data access
- WindCube Scan Dual Lidar Ready solution gives an even more comprehensive picture of the wind profiles by observing an offshore location from several positions

Applications:

- Wind resource assessment
- Site suitability and calibration
- Wind turbine wake and wind farm blockage effect
- Short-term forecasting
- Power Performance Testing of multiple turbines
- Dual lidar set up

WindCube®
Nacelle

A generational leap in wind turbine testing and optimization

Highlights:

- Classified according to IEC 61400-50-3 standard for nacelle-mounted lidars
- Mounts temporarily on turbine nacelle or fully integrated by manufacturer
- Compatible with all turbine types and suitable for even the largest hub heights and rotor diameters, onshore and offshore
- Lightweight and easy to install and maintain
- Adapted for onshore and offshore applications, with two versions measuring wind conditions up to 450m and 700m respectively
- Simultaneous measurements at multiple user-defined range gates
- Continuous wind direction alignment; reliable contractual and operational PPT according to industry best practices and the IEC standard
- High correlation with IEC met mast measurements; optimizes energy production, lowers costs, reduces loads, and improves turbine design
- Well-suited for turbine underperformance diagnosis and corrections, and verification of turbine upgrades

Applications:

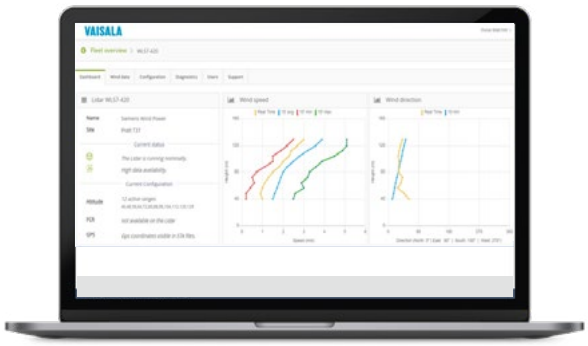
- Power Performance Testing
- Warranty power curve
- Yaw misalignment correction
- Nacelle transfer function calibration
- Fatigue and extreme load reduction
- Wind turbine design and production enhancement
- Wind turbine class upgrade

WindCube® Fleet Insights

Actionable, at-a-glance data analysis and reporting

Highlights:

- Supports both WindCube and WindCube Nacelle lidars
- Secure, cloud-based, and user-friendly, with customizable, real-time alerts and notifications providing enhanced system visibility and reduced response times
- Extendable from one WindCube or WindCube Nacelle campaign to full fleet management, so it can grow with users' operation without new procurements
- Simple data export and access capabilities provide business-critical insights immediately, on any device
- Flexible user access rights for security and functionality across an entire team



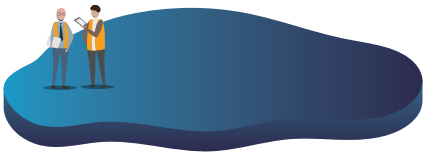
WindCube® Analytics Insights

Efficient Power Performance Testing and analysis

Highlights:

- Makes reliable PPT available to any user of WindCube Nacelle
- Produces ready-to-use IEC tables and annual energy production (AEP) calculations in just a few clicks, and offers built-in templating for using Scada data from any type of turbine
- Proactively displays which IEC paragraph/standard it is referring to while in use
- Provides improved data visibility and decision-making for the whole wind farm, whether used for development or ongoing operations

WindCube suite key applications summary

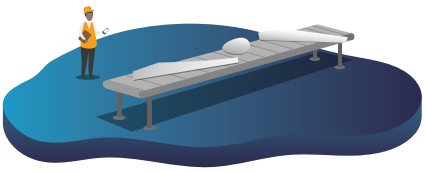


Project developers

Wind resource assessment: Provide quality data and bankable due diligence in almost any terrain and weather conditions, onshore or offshore

Optimizing wind farm layout and turbine choice: Inform turbine choice, optimizing important cost and risk factors

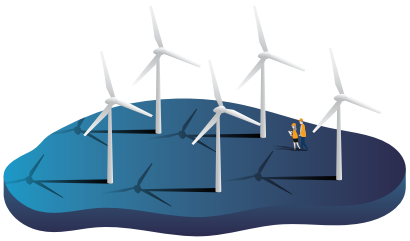
Wind monitoring: Ensure real-time wind awareness for successful construction and deployment



Manufacturers

IEC-compliant turbine testing, validation, and prototyping: Verify product performance or upgrades in real-world environments

Feedforward Lidar-Assisted Control: Bring new LAC functionality to market efficiently and cost-effectively



Wind farm operators

Reliable contractual and operational PPT: Power curve data and compliant analysis

Nacelle instrument verification: Yaw misalignment and transfer function

Permanent monitoring of site conditions: Meeting grid operator reporting requirements, conducting wind monitoring for maintenance or upgrade operations

Research and development

Blockage effect and wake studies

Wind farm control

Optimization of offshore wind farm layout

Why Vaisala for renewable energy?

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 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 environmental 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.

Vaisala is the only company to offer 360-degree weather and environmental monitoring solutions — from sensors and systems to digital services and actionable intelligence — nearly anywhere on the planet (and even on Mars). Every Vaisala solution benefits from our 85+ years of experience, pioneering deployments in 170+ countries, and unrivaled thought leadership.

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

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windcubelidar.com