The WINDCUBE Lidar and its operational use in wind engineering

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LEOSPHERE/AVENT 8 products to serve 4 markets
The only Lidar one-stop-shop to rely on at each stage of the wind farm life cycle

Over 500 wind Lidars operating worldwide

- Ground based Lidar
- Scanning Lidar
- Turbine mounted Lidar
- Floating Lidar

DEVELOPMENT

COMMISSIONING

OPERATIONS & MAINTENANCE

REPOWERING / RESELL
WINDCUBE Lidar technology Overview
DOPPLER Pulsed LIDAR technology

- Light frequency is shifted by Doppler effect due to aerosols speed
- Aerosols speed = wind speed
- Only radial component is affected by Doppler shift
- Doppler shift is measured by heterodyne detection
- Multiple height measurements per line of sight

\[ \omega_l + 2\pi f_d \]
WINDCUBE v2: vertical wind profiler based on doppler pulsed LiDAR technology

- **Measurement range**: 40 to 200 m
- **Frequency**: 1 Hz
- **Measurement range gates**: 12 simultaneously
- **Wind speed accuracy**: 0.1 m/s
- **Wind speed range**: 0 to 60 m/s
- **Wind direction accuracy**: 2°
- **Consumption**: 45 W
- **Weight**: 45 kg
WINDCUBE v2

- More than 400 systems sold and measuring
- Stage 3 validated by DNV GL
- Accepted as bankable data
- Used as reference tool
  - German TRL 6 standard (remote sensors)
  - IEC 61400-12-1 Power Curve revision
  - IEC 61400-15 Site assessment
- Validated by independent third parties
Offshore Wind resource assessment

- Cost-effective, accurate, offshore wind resource assessments
  - Validated by DNV GL
  - Accepted by major developers

![Graph showing data availability and acceptance criteria for FLiDAR measurement height (m)].

![Graphs depicting correlation between FLiDAR wind speed and direction with National Renewable Energy Centre mast wind data].
They all use the WINDCUBE v2
Long Range WINDCUBE scanning LIDAR

- Full 3-D hemispheric scan capacity up to 10 km
- Scenarios fully configurable (PPI/RHI/DBS/LOS, spatial and temporal resolution, rotation speed)
- Continuous measurement (no time loss)
- Product: Radial Wind Speed, CNR, Wind Speed, Direction, Availability

Based on the WINDCUBE v2 technology

The measurement range depends on the presence of aerosols, the environmental conditions and how the system is parametered.
Scanning modes

**DBS – Doppler Beam Swinging**
Conical scan or variation
Vertical profile of the horizontal velocity

**RHI - Range-Height Indicator**
Elevation changes, azimuth fixed
Vertical cross sections, shear

**PPI - Planned-Position Indicator**
Azimuth changes, elevation fixed
Horizontal wind field
Metrological performances

How is the measurement range defined?
- LEOSPHERE has written a specific protocol according to Aviation Weather standards with Clear Atmosphere definition and specific low elevation PPI scanning scenario

Radial wind speed measurement
- The raw data output from the Scanning Lidar is the radial wind speed
- The acceptance/rejection threshold is calibrated at LEOSPHERE to ensure RWS accuracy.
- Radial wind speed accuracy correlation curve to projected radial wind speed of a cup
Horizontal Wind speed reconstruction

- Scanning scenario defined as a tradeoff for wind speed and direction retrieval (even with orthogonal wind direction) and number of samples per 10min averaged
- Best current scanning scenario (45° sector scan at 3°/sec) and retrieval accuracy assessed with DTU Wind Energy at Hovsøre Test Facility

Effect of increasing wind direction orthogonality
Control Lidar metrology

- Pre-deployment site survey with data availability simulation: innovative tool that requires both fine lidar technology modelization capacities and atmospheric content science.

- On-site deployment requires applying a specific protocol for azimuth and elevation angles calibration on hard targets with known coordinates and heights.
3rd party verification campaign

**Objective:** having a correlation curve between the wind speed of the WINDCUBE and a cup at a specific distance

- Two offers are available:
  - @ DTU: a 116 m cup placed at 1.6 km
  - @ DNV GL: a 100 m cup placed at 1.7 km

**Established track record:**
- DTU report with **WINDCUBE 200S**: "...the WINDCUBE scanning Lidar system from LEOSPHERE could be a suitable tool for offshore wind resource assessment applications, scanning offshore from the coast or an alternative to masts for power curve measurements..."
- DTU report with **WINDCUBE 100S**: "The W100S Lidar has undergone an inclinometer calibration, a range calibration and finally a calibration of the measured horizontal wind speed. (...) The agreement between the Lidar and cup wind speeds is excellent."
- DNV GL campaign for **2 WINDCUBE 400S**: the correlation curves appear to be satisfactory for the WRA application.
Operational Applications
Offshore Wind Resource Assessment

- Evaluation (quality and quantity) of the wind resource of a site before the construction of a wind farm
  - Reduce the uncertainty
  - Optimize the cost of financing

- WINDCUBE 100S/200S/400S Scanning LIDAR:
  - Allows **measuring offshore from the coast** in the range of the Lidar (3 to 10 km).
  - Strong reduction in the **horizontal uncertainty**
  - Multiple scan patterns to optimize the wind resource assessment campaign
  - Precision depends on prevailing winds
Wind flow validation

Wind measurement in complex terrain
- Multiple PPI scans at various elevation angles to analyze flow features over the terrain and validate wind flow models.
- Wind comparison against a met mast and Lidar remote sensing devices
- 10 min average shear evaluation for optimization of the repowering
Other applications - Lysefjorden bridge

- A LiDAR is being introduced for a **three month campaign in Norway** to correlate the local wind flow with the vibrations measured on the bridge.
- Will allow to optimize the bridge design for future projects.
Wake measurement

- Evaluation of the wake of a single or multiple wind turbines
  - Measure inflow and outflow parameters
  - Validating advanced wake models
  - Estimate the energy loss
  - Reducing the uncertainty in the AEP by a better measurement of the wake deficit

- LEOSPHERE’s offer
  - Wind Iris
  - WINDCUBE Scanning Lidar
Wind Farm Forecasting

- Using a 100S scanning LiDAR for wind power forecasting to anticipate additional power supply
- The scanning Lidar provides upwind wind data that is integrated in a forecasting model
Objectives
- Assess potential of Lidars for power performance verification offshore. Could it replace a mast?

Method using two different lidars:
- Sector scanning lidar (Windcube 100S) on turbine transition piece platform
- Nacelle mounted lidar (Wind Iris)

IEC compliant met mast for reference
Offshore deployment

IEC compliant met mast

Wind Iris

WINDCUBE 100S
**Offshore power curve output**

**DTU validation campaign**
- Inclinometers offset [2]
- Reconstructed horizontal wind speed
- Horizontal wind speed measurement uncertainty: 1.9% to 2.9%
- 3.5 months

**Power curve**
- Good data availability
- Good comparison lidar/mast on average
- Lidars power curves uncertainty very close to cup power curve uncertainty

*Real world offshore power curve using nacelle mounted and scanning Doppler Lidars, EWEA 2015, Copenhagen*
Future operational applications?

- **Dual-Doppler Lidar Measurements**
  - Intersecting Lidar beams to retrieve accurate wind information
  - Effect of Orthogonality eliminated

- **Windscanner.eu** - simultaneous measurement of the 3-D components of the wind
  - **Turbulence intensity** measurement
  - All applications in complex terrain
  - **Fine flow** structure characterization
Scientific support

Bring support to the customer for some specific application / project

A 3-step project

- **Definition of the technical proposal:** optimization of the deployment strategy with a clear definition of the scanning patterns.
- **Data post-processing** from the radial wind speed into horizontal wind speed vector and direction at the various locations.
- **Analysis report:** A full data analysis report to provide data quality check, correlation curves, statistical analysis (along wind vs. orthogonal wind, uncertainty, RMSE, averaging time etc.).
Conclusions
General conclusion

- Strong cumulative operational track record for the **WINDCUBE v2 vertical profiler** accepted as standard in the industry.

- Wide range of applications with the WINDCUBE Scanning Lidar that all tackle the issue of **reducing the uncertainty** for performance and AEP optimization.

- Major applications validate wind models thanks to measurement campaigns.
Thank you !
Wind Energy Scales of Interest

- **1 s**
- **1 min**
- **10 min**
- **1 hour**

**Spatial Resolution (m):**
- 1000
- 100
- 10

**Time Resolution:**
- Forecasting
- Wind Resource Assessment
- Wind farm / turbine wake
- Turbulence Gusts