Parameters of innovation

eBook

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Current TI measurement practices

Turbulence Intensity is one of the most important wind-related parameters to measure, and is widely used in many wind energy industry applications.

Site suitability studies:

TI measurements are used to define the turbine types which can be installed on the considered site. It is also used to define the optimal location of turbines within a wind farm.

Performance assessments:

Wind farm production is directly affected by wind speed fluctuation. Clear assessment of local TI during Wind Resource Assessment (WRA) and Power Performance Testing (PPT) campaigns are essential to understanding the local wind fluctuations and verifying turbine performance.

While lidar TI measurement is still approaching full acceptance, it is used for onshore applications if the cost of a met mast is not justifiable or as a complimentary point of measurement above a met mast. At the same time, several industry players are researching motion-compensated TI measurements using Floating Lidar Systems for offshore applications.

Current lidar use cases:

- Dual Scanning Lidar: Accurate TI measurements offshore have been demonstrated in Japan, and the next step is global acceptance
- Machine Learning to correct WindCube TI: The effectiveness of post-correction has been validated on five onshore sites in northern Europe; All key performance indicators show substantial improvement
- Nacelle-mounted lidar: A newly-developed TI algorithm demonstrates good results
- Floating Lidar Systems: Ongoing research projects with France Energies Marines and other industry players

Free download: Machine learning improvements to WindCube Turbulence Intensity measurements at five sites in Northern Europe

By Andrew Black
Research and Application Engineer at Vaisala

On the Vaisala blog: WindCube Nacelle TI algorithm

Learn about a newly-developed TI algorithm that is demonstrating good results.

WindCube Nacelle TI measurement campaign

Vaisala recently published an informative white paper, Turbulence Intensity Measurements with WindCube Nacelle, written by Vaisala scientist Zhi Liang.

The paper fills a gap in the availability of comprehensive reports that demonstrate how nacelle-mounted lidar – and particularly WindCube Nacelle – provides accurate TI measurements suitable for use in the wind energy industry.

Key algorithm for accurate measurements

There are four steps in the overall TI calculation algorithm used by WindCube Nacelle:

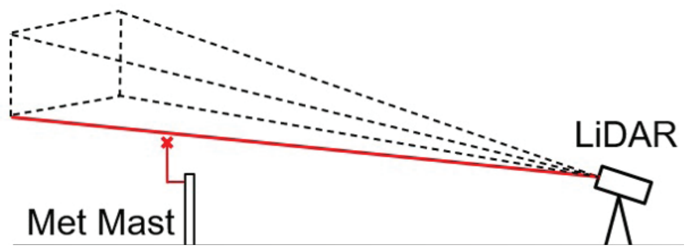
- Compute 10 minutes averaged wind speed and Standard Deviation for each of four beams using 1 Hz data.
- Divide Standard Deviation by line-of-sight mean wind speed to calculate the TI for each beam.
- Compute TI+ and TI- using the mean TI from the two upper and lower beams.
- Compute TI at hub height from TI+ and TI- by a logarithmic interpolation law.

A new filtering method was added in Step 1 that removes the wind speed outliers for the Standard Deviation calculation. This significantly improved TI measurement accuracy.

Measurement approach

The measurement approach is very important to understand the capability on TI accuracy. Two common approaches to compare nacelle-mounted lidar measurements with an anemometer are White Box Comparison and Black Box Comparison.

White Box Comparison can be used to evaluate the direct capability of TI measurement of the laser itself, while Black Box Comparison provides the final accuracy of TI after the Wind Field Reconstruction (TI at hub height). For wind energy applications, the 10-min averaged wind speed and TI are widely used.



White Box Comparison:

Results of turbulence measured by WindCube Nacelle are quite promising. The lidar measures wind speed and turbulence along the LOS and provides 1Hz data, which provides information for the spatial and temporal structure of the atmosphere turbulence.

Black Box Comparison:

Two sites were used, one in Denmark and the other in the USA. Results show high correlation coefficient and accuracy of TI measured by WindCube Nacelle compared to the met mast as well as high data coverage percent of valid TI measurements.

Results

The high accuracy and data coverage implies that using nacelle-based lidar for TI measurement is ready for industrial applications.

White Box Comparison

- Correlation coefficient of TI line-of-sight varies from 0.923 to 0.955; slope varies from 0.978 to 1.030
- Correlation coefficient of Total Kinetic Energy along line-of-sight direction varies from 0.984 to 0.994
- The slope of Total Kinetic Energy along line-of-sight direction varies from 0.968 to 0.986

Black Box Comparison

- Correlation coefficient is 0.916 and 0.932 with slopes of 0.951 and 1.029
- Data coverage percent of valid TI is high: 83.7% and 71.9%
- Global accuracy of TI measurements is high: bias is within 4.9%

Conclusion

The results of the three measurement campaigns provide comprehensive and useful information on measuring TI using nacelle-mounted lidar. The resulting high measurement accuracy and data coverage proves that WindCube Nacelle is ready for industrial applications of TI measurements.

This white paper shows the improvement of TI measurement and provides contributions to future measurements of the temporal-spatial structure of turbulence in the low Atmospheric Boundary Layer.

POWSEIDOM: Deriving TI from pulsed lidar

France Energies Marines, a French National Research Institute, is dedicated to the development of offshore renewable energy in France. Through various research programs and collaborations with industrial and academic partners, the institute aims to advance the understanding and implementation of offshore renewable energy technologies.

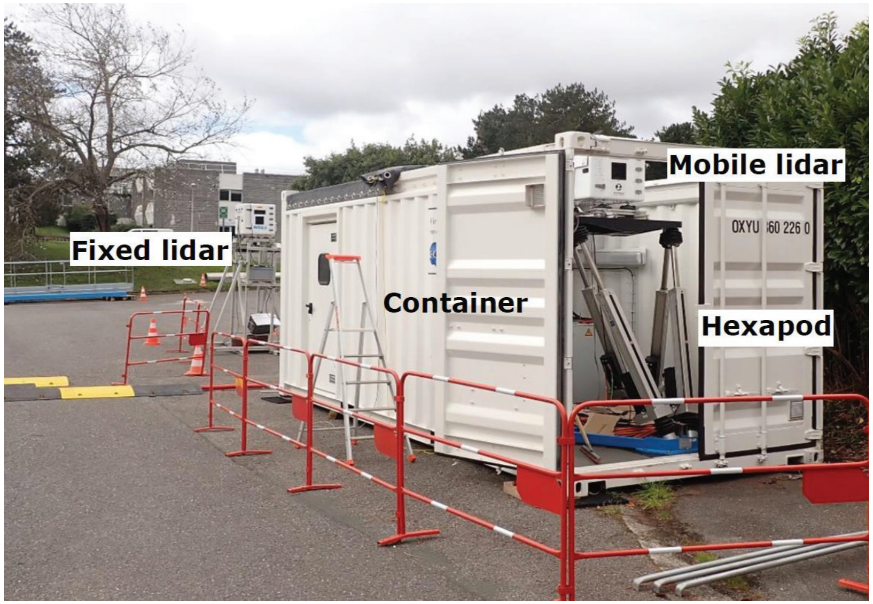
One of their projects, POWSEIDOM, focuses on improving TI measurements using ground-based and floating lidars. France Energies Marines started POWSEIDOM in 2021, using a WindCube Offshore vertical profiling lidar to develop a methodology to measure TI, and then apply this methodology to data collected on a small island in the Gulf of Lion in the Mediterranean Sea.

Primary goals

- Characterize the impact of motion on TI measurements
- Develop motion compensation algorithms for floating lidar systems
- Improve profitability for future offshore wind farms in the Mediterranean Sea

Harnessing the Mediterranean Sea

The Mediterranean Sea is an important area for future wind farm deployment in France. Several pilot wind farms are planned within the next two to three years, and by the end of the decade, two commercial wind farms with a capacity of 250 MW each are scheduled for deployment.



Ground-based wind lidar TI measurement

Researchers are using two lidar configurations for the ground-based TI measurement: A commercial configuration with a sampling rate of one wind vector per second, and a prototype configuration with a sampling rate four times higher.

With the higher sampling rate of the prototype configuration, researchers can capture smaller eddies and collect more information about the physics of the environment.

Data retrieval methods

TI from lidar measurements can be retrieved using two methods:

1. Standard method: Computation of the second-order statistics of the three velocity components directly from the reconstructed velocity components, which have been already computed based on the line-of-sight velocities. The standard method generates an overestimation of TI.
2. Variance method: Computation of second-order statistics of the three velocity components based on the second-order statistics of the line-of-sight velocities. The variance method generates an underestimation of TI.

This ongoing project aims to improve the accuracy of TI measurements using both lidar configurations, with the variance retrieval method providing a reduced TI reconstruction by 20% compared to the standard method. Researchers continue to explore further improvements and refinements to the methodology.

Motion-induced errors

The amplitude of motion has a significant impact on error with both the standard and variance methods, while the period of motion has a relatively low impact on error.

- Standard method: Cross-contamination and inter-beam volume averaging (the energy of eddies is attenuated or amplified for specific wavenumber).
- Variance method: Intra-beam volume averaging (underestimation of TI), and neglecting the component ux'uy' (Valid only when the wind direction is aligned with one the beam pairs (1-3 or 2-4).
- Future work: Address the limitations of the variance method by developing a technique for the reconstruction of ux'uy' and reducing the probe length.

Gulf of Lion WindCube wind lidar deployment

The project is in operation from December, 2022 through at least December, 2023. Using the prototype measurement configuration, the WindCube is collecting ground-based measurement of offshore turbulence. Once researchers have collected a full year of data, it will be available as the first-ever database of offshore Mediterranean wind and turbulence data.

Photo courtesy of France Energies Marines

Floating wind lidar TI measurement

France Energies Marines is conducting an experiment to characterize the quantification of the impact of motion on TI measurement using floating lidar. At a test site at IFREMER in France, researchers installed a WindCube Offshore lidar on a hexapod, which they could manipulate to simulate the movement of a buoy.

Researchers aimed to study the influence of a single rotation — around one single axis — and rotation around two and three axes. They installed a fixed lidar to provide TI measurements as a reference.

Project highlights

- Quantification of the impact of the rotational degrees of freedom on line-of-sight turbulence velocity fluctuations, σ
- Compare ground-based and mobile (prototype) lidar configurations
- About 45 hours of measurements collected between Oct. 6 and Nov. 9, 2022
- Single and coupled rotation

See the hexapod in action

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.

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