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TURBULENCE INTENSITY MEASUREMENTS FROM A VARIETY OF DOPPLER LIDAR INSTRUMENTS

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Abstract

The effect of turbulence on wind turbines is difficult to quantify, and would result in an increase or decrease of wind turbine power based on atmospheric conditions. Several studies have shown a negative impact on wind turbine fatigue loads due to increase in turbulence. In this paper, the current state-of-art for turbulence intensity measurements from a variety of lidar measurements such as, lidar profilers, scanning coherent Doppler lidars (CDLs) and buoy based lidars will be presented. Ten-minute averaged turbulence intensity estimates from lidar profilers are compared to tower estimates. Various turbulence parameters from scanning lidar measurements accounting for the pulse information shows promise. Sample turbulence intensity estimates from buoy lidar simulations, after accounting for motion compensation effects of the buoy lidar, are presented. Spatial turbulence measurements could be a valuable input for wind farm developers for wind farm site selection and a valuable input into improving various CFD or meso-scale models. The effect of volume averaged turbulence, compared to point turbulence is also evaluated.

Objectives

Conglomeration of measurements from several campaign studies have been analysed to calculate turbulence. The objective of this paper is to investigate and analyse the current accuracy and capabilities of various remote sensing devices in measuring turbulence. Given the constraint that various devices observe different scales of motion in the atmosphere, the added value in measuring turbulence is invaluable for wind resource assessment.

WindCube Profiler

In this section, turbulence estimates from WindCube V2 profiler have been evaulated and compared to co-located tower measurements for moderately complex sites. Turbulence intensity (TI) is calculated as:

$$TI = \frac{Std(U)}{Mean(U)}$$

Where,

U = Horizontal windspeed

The average FCR® corrected winds are used in this case for TI calculation, as FCR is shown to reduce the bias and improve correlations with the mast for several cases (reducing sensitivity to wind speed and direction). Figures 1 and 2 show average difference in TI when compared to a co-located met mast at two moderately complex sites. The results show that during low winds the Lidar over estimates TI while at wind turbine operating region (4 to 20 m/s) and higher the TI is calcualted very accurately by lidar profilers in complex terrain conditions.

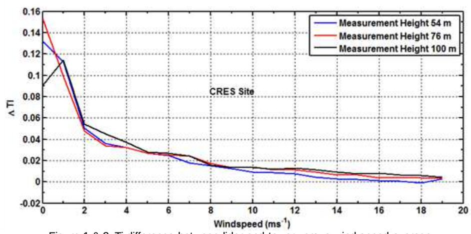
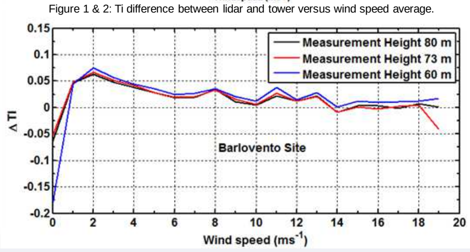


Figure 1 & 2: Ti difference between lidar and tower versus wind speed average.



WindCube Scanning Lidar

Scanning Doppler lidars are capable of measuring various scales of motion in the atmosphere. Depending on the scanning parameters inputted into the system various atmospheric motions can be studied.

In this section, the ability of scanning Doppler lidar to estimate turbulence is shown. The velocity structure function method is applied to calculate dissipation rate, integral length scale and velocity variance, assuming a theoritical model for isotropic wind fields. Corrections for turbulence measurements have been considered to address the complications due to inherent volumetric averaging of radial velocity over each range gate, noise of the lidar data, and the assumptions required to estimate effects of smaller scales of motion on turbulence quantities (Frehlich et al. 1998, Krishnamurthy et al. 2011).

The radial velocity structure function is given by:

$$D_v(s) = \left\langle \left[v'(r,\phi,\theta) - v'(r+s,\phi,\theta) \right]^2 \right\rangle$$

Where V' is the radial velocity fluctuations.

And considering the Von Kàrman Isotropic model, we can estimate various turbulence parametes as shown below.

$$D_v(s) = C_v \varepsilon^{2/3} s^{2/3} \qquad \varepsilon = \left[\frac{2^{4/3}\pi}{\sqrt{3}\,\Gamma(1/3)\Gamma(4/3)C_v} \right] \frac{\sigma_v^3}{L_o} = 0.933668 \frac{\sigma_v^3}{L_o}$$

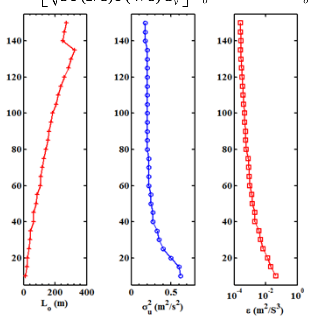
Where

ε – Dissipation rate

σ_v – Velocity Variance

L_o – Outer Integral Length scale

Figure on the right, Shows vertical profile of various parameters estimated with a PPI scan using WindCube 200S device.Future validation of the accuracy of various Turbulence parameters is in progress.



Bouy Lidar

Since the cost of building met-masts offshore is expensive, bouy lidars provide a very attractive option of the ability to have offshore measurements at a minimal cost.

The ability of buoy lidars to measure turbulence is evaluated in this section. Due to waves offshore, significant amount of yaw and pitch correction are needed to be performed to estimate the position of the lidar beam at any given point in time and space.

Simulations are performed to model various wave-like motions and a statistical model has been developed at Leosphere to account for instantaneous pitch and yaw corrections on the lidar beam. Figure 4 below shows the pitch, yaw and translational motions simulated and statistical model tracking various undulations at different frequency.

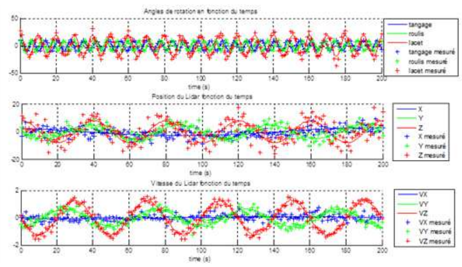


Figure 4: Yaw and pitch motion compensation for a Buoy Lidar from a simulation

Figure 5 shows the reconstructed horizontal windspeed and turbulence intensity after motion compensation algorithm.

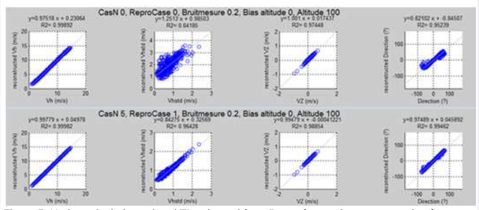


Figure 5: Horizontal windspeed and TI estimated from Buoy after motion compensation for two test cases.

Conclusions

The accuracy of turbulence intensity from lidar profiler measurements compare well with tower measurements. The ability of scanning lidars to measure turbulence can provide an invaluable tool for wind farm developers and improve siting of wind turbines. The buoy lidars are simulated to measure accurate wind speeds and turbulence, accounting for motion compensation, and are currently being used in several studies for offshore wind resource assessment.

References

1. Frehlich, R., S. Hannon, and S. Henderson, 1998: Coherent Doppler Lidar Measurements of Wind Field Statistics. *Boundary-Layer Meteorology*, **86**, 233-256.
2. Krishnamurthy, R., Calhoun, R., Billings, B. and Doyle, J. (2011), Wind turbulence estimates in a valley by coherent Doppler lidar. Met. Apps, 18: 361–371. doi: 10.1002/met.263
3. Leosphere WindCube Offshore (http://www.flidar.com/?page_id=82)
4. M Boquet et al., Technical report WINDCUBEv2+FCR ® validation on complex sites and application for wind resource analysis