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Quantifying the Effect of Lidar Turbulence Error on Wind Power Prediction

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1) Can We Replace Meteorological (Met) Towers with Lidars?

Lidars can measure mean wind speeds accurately, but not turbulence (e.g., Sathe et al. 2011). This is a major barrier to the adoption of lidars.

Path to acceptance: Lidars must measure turbulence intensity (TI) accurately under conditions important for wind power production.

Research Questions:
1) How do errors in lidar TI affect errors in power prediction?
2) How can lidar TI estimates be improved for wind energy applications?

Figure 1. Galion lidars deployed near met tower at the National Wind Technology Center. Photo by Andrew Clifton, NREL 24390

2) Is Turbulence Intensity Important?

TI has the strongest influence near rated wind speed.
→ Positive fluctuations will not result in a power increase, but negative fluctuations will lead to a power decrease.

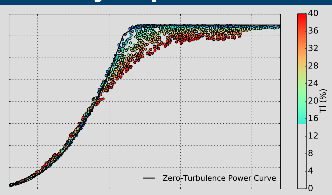

Figure 2. Simulated power curves for the 1.5-MW WindPACT turbine

3) What Affects Turbulence Intensity Error?

Noise: Inherent to instrument, also related to limited number of scatterers in probe volume

Variance contamination: Caused by instrument scanning strategy

Volume averaging: Lidar obtains measurements from a probe volume, so smaller scales of motion are not measured

The magnitude of these error sources depends on atmospheric stability. Stability affects the size of turbulent eddies, the degree of wind shear, and the magnitude of TI → impact on power

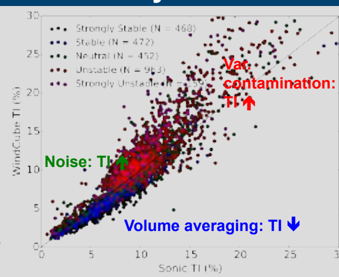

Figure 3. Sonic versus lidar TI for the Atmospheric Radiation Measurement site

4) How Can We Model the Impact of TI on a Wind Turbine?

A power prediction model for a 1.5-MW turbine was trained using results from the aero-elastic simulator FAST (Clifton et al. 2013; Figure 2).

Inputs: Hub-height wind speed, TI, shear, turbine operating range
Output: 10-min mean power

TI estimates were obtained from two sources: sonic anemometers on towers (point measurements) and co-located lidars (volume averages)
Power error = Power (sonic TI) – Power (lidar TI)

Data were obtained from the U.S. Department of Energy's Atmospheric Radiation Measurement site in Oklahoma, where a WindCube lidar was deployed from November 2012 to July 2013 near a 60-m tower. Data were used from a 60-m measurement height ("hub height").

5) Is TI Error Important?

Largest TI errors occur at lower wind speeds (< 10 m s^{-1}), but power prediction errors are small.

Near the rated wind speed of 11.5 m s^{-1}, even small TI errors result in large power prediction errors.

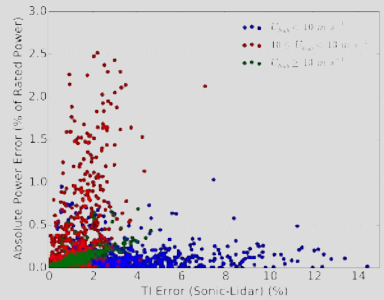

Figure 4. Power error (% of rated) versus TI error

6) How Does Stability Affect Power Prediction Errors?

Unstable conditions: Lidar overestimates TI because of variance contamination
→ Power underestimate

Stable conditions: Lidar underestimates TI because of volume averaging
→ Power overestimate

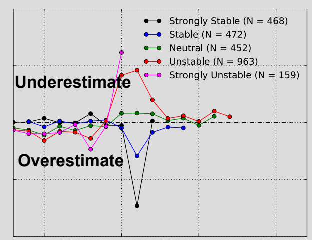

Figure 5. Error in predicted power with shear parameter used as a proxy for atmospheric stability

7) How Can We Improve Lidar TI Estimates?

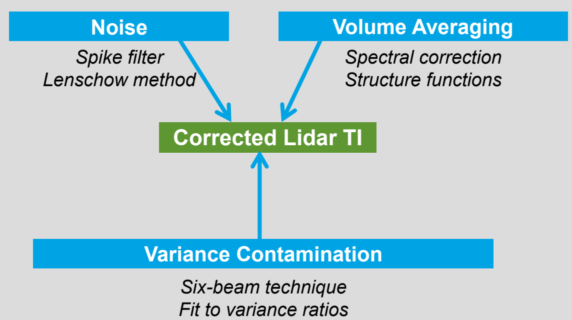

Figure 6. Diagram of physics-based corrections for lidar TI

8) Do Corrected Lidar TI Estimates Improve Power Prediction?

Correction options: Wind speeds were calculated with the velocity azimuth display technique; spike filter, spectral correction and ratio of u to w variance were used to correct TI.

Table 1. Regression line slope of original and corrected lidar TI compared to sonic TI

Stability	Slope Original	Slope Corrected
Strongly Stable	0.88	0.95
Stable	0.93	1.00
Neutral	1.05	0.98
Unstable	1.12	1.01
Strongly Unstable	1.27	1.15

Table 2. Mean Absolute Error (MAE) of predicted power from lidar measurements compared to predicted power from sonic

Stability	MAE Original (kW)	MAE Corrected (kW)
Strongly Stable	1.49	1.09
Stable	1.76	1.77
Neutral	2.57	3.01
Unstable	2.96	2.58
Strongly Unstable	1.52	1.15

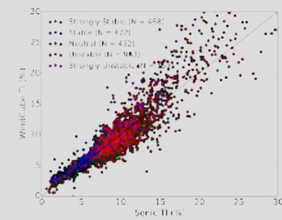

Figure 7. Sonic versus corrected lidar TI for data shown in Figure 3

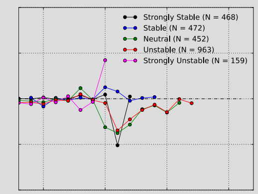

Figure 8. Predicted power error with corrected lidar TI

9) Conclusions

1) Small lidar TI errors can result in large power prediction errors (> 2% of rated power) when hub-height wind speed is near rated
-Improvement in lidar TI estimates should focus on this wind speed region

2) Lidar TI estimates can be improved through the use of physics-based corrections. These corrections generally improve power prediction, but not for all stability classes.
-More research needed on how well the corrections perform for different stability classes.

References

Clifton, A., L. Kilcher, J.K. Lundquist, and P. Fleming, "Using machine learning to predict wind turbine power output." *Environ. Res. Lett.* (2013), **8**, 024009.

Sathe, A., J. Mann, J. Gottschall, and M.S. Courtney, "Can wind lidars measure turbulence?" *J. Atmos. Oceanic Technol.* (2011), **28**, 853–868.

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