Wind Speed Frequency Distribution Validation of Extrapolated Wind Speeds from Tower Measurements Using Lidar Data

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Background / Objective

Hub height wind speeds are often predicted by extrapolating mast height (typically 58 to 60 m) wind speeds using wind shear coefficients derived from at least two tower-based measurement levels and the power law. There have been numerous studies to validate extrapolated hub height predicted wind speeds using data from tall (> 60 m) towers and ground-based remote sensors. However, little emphasis has been placed on validating the extrapolated hub-height wind speed frequency distribution (WSFD).

The WSFD is often approximated with a Weibull distribution[1]. While the Weibull scale parameter profile mimics the wind speed profile, the shape parameter has a unique vertical profile. It increases from the surface to a maximum located at around 100-200 m, and then decreases with height[2]. The shape of the profile is related to the balance between the diurnal variation of the meteorological conditions in the surface layer and the variability of the synoptic conditions in the Ekman layer above it.

Prediction of gross energy is a function of the hub height wind speed frequency distribution and power curve. Even if hub height wind speeds are accurately predicted, a bias in the predicted shape of the WSFD can lead to a bias in predicted gross energy. These biases can be further exacerbated by increasing extrapolation distances as turbine hub heights continue to increase with time.

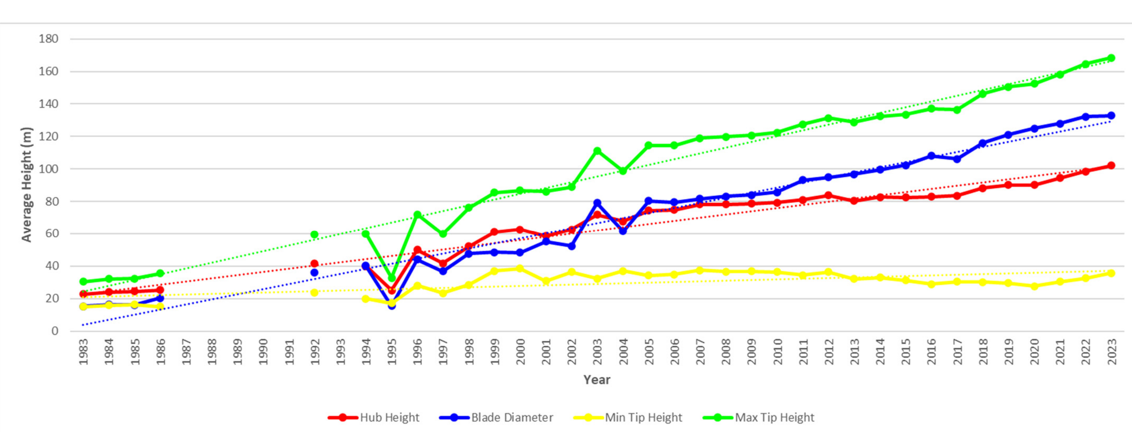


Figure 1: Over the last 20 years, extrapolation distances have increased 1.3 m per year between 60 m and average hub height[3]. As of 2023, the average extrapolation distance was 42 m!

Methodology

- Quality control mast and lidar data and then create fully concurrent merged mast and lidar data set (eliminate temporal bias).
- Compute lidar wind speed at mast height (e.g., 59 m) via power law interpolation (e.g., 50 and 60 m).
- Bias correct lidar profile such that lidar wind speed at mast height is the same as mast height wind speed.
- Compute wind shear coefficient (α) from at least two mast wind speeds (e.g., 32 and 59 m).
    - α ~ f(Month x Hour [12x24], Direction x Hour [16 x 24], Month x Hour x Direction [12 x 24 x 16], 10-min time step)
    - filter out low wind speeds (e.g., < 3 m/s) to avoid bias in average wind shear.
- Extrapolate mast height wind speed to hub height (e.g., 104 m) using power law.
- Compute the biased corrected lidar wind speed at hub height (e.g., 104 m) via power law interpolation (e.g., 100 and 120 m).
- Compute bias in hub height predicted wind speed from mast data against biased corrected lidar wind speed at hub height.
- Back solve for an adjusted wind shear exponent and compute percent difference from mast wind shear.
- Use adjusted wind shear matrix with power law to predict hub height wind speed.

Results

Figure 2: Mast height scatter plots of wind speed, wind direction and temperature.

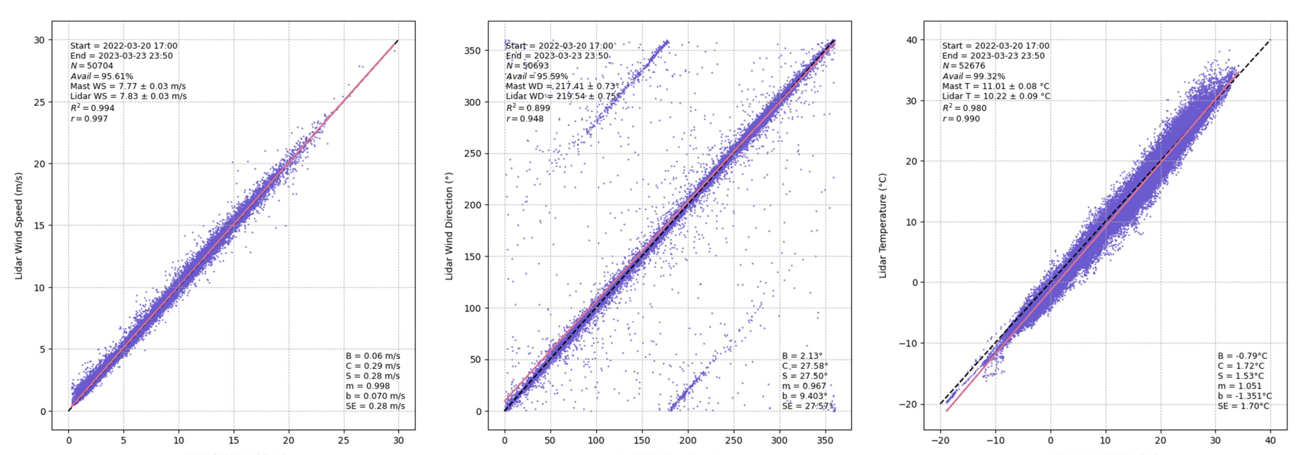


Figure 3: Mast height wind roses.

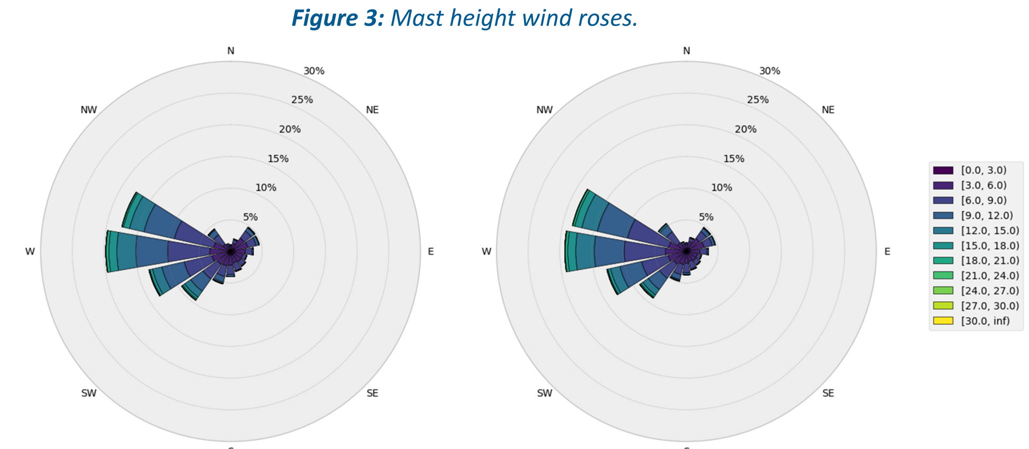


Figure 4: Mast height frequency distributions of wind speed, wind direction and temperature.

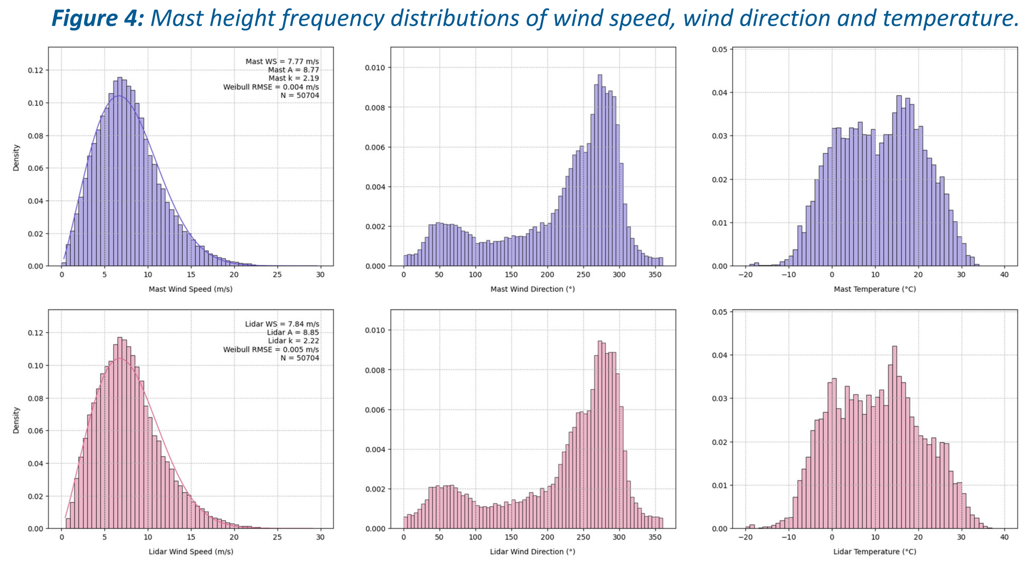


Figure 5: Mast (blue) and lidar (red) profiles.

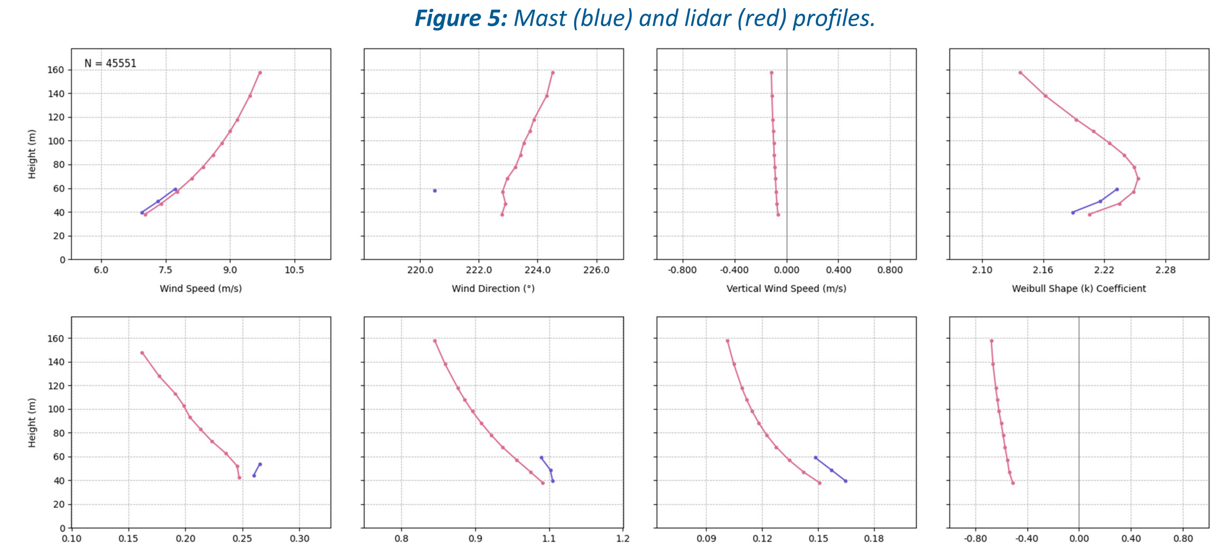


Figure 6: Wind speed and Weibull shape parameter profiles with (a) 12 x 24 matrix extrapolation, (b) wind shear adjusted by constant offset and (c) wind shear corrected by a 12 x 24 adjusted matrix.

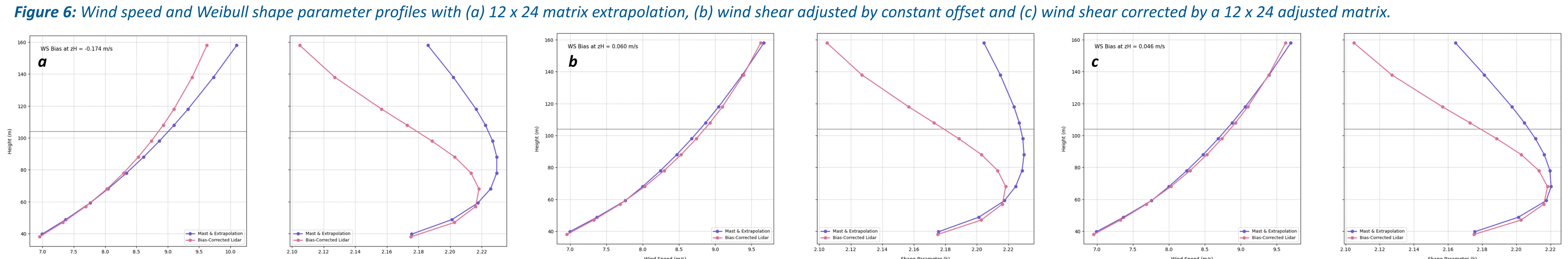
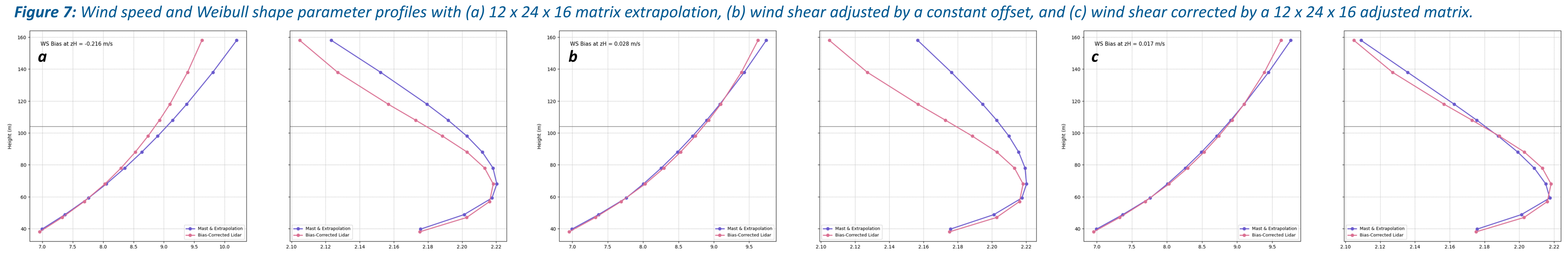


Figure 7: Wind speed and Weibull shape parameter profiles with (a) 12 x 24 x 16 matrix extrapolation, (b) wind shear adjusted by a constant offset, and (c) wind shear corrected by a 12 x 24 x 16 adjusted matrix.



Conclusion / Discussion

Hub height predicted wind speed and WSFD from tower-based measurements are validated with concurrent bias-corrected lidar data. Comparative statistics are computed for hub height predictions using several variants of the wind shear exponent.

While adjusting the mast wind shear exponent by a constant factor may lead to a more accurate predicted hub height wind speed, there is the potential of overestimating the Weibull shape parameter, especially at higher hub heights.

Overestimation in the Weibull shape parameter will generally lead to an over estimation of gross energy even if the mean wind speed is accurately predicted. Depending on the WSFD, power curve and extrapolation distance, the gross energy can be over predicted by 1 to 3%. Thus, care must be taken in predicting the hub height WSFD.

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References

[1]Tuller, S. E., and A. C. Brett, 1984: The characteristics of wind velocity that favor the fitting of a Weibull distribution in wind speed analysis. *Journal of Applied Meteorology and Climatology*, **23**, 124-134.

[2]Emeis, S., 2001: Vertical variation of frequency distributions of wind speed in and above the surface layer observed by sodar. *Meteorologische Zeitschrift*, **10**, 141-150.

[3]United States Wind Turbine Database (USWTDB) https://eerscmap.usgs.gov/uswtdb/

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