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Constraining uncertainties in nacelle-mounted lidar power performance measurements

BACKGROUND

Nacelle-mounted lidar (NML) is a valuable measurement approach for power performance measurements (PPM):

- Lower cost and fewer construction risks (vs. masts).
- Characterization of directly incoming wind field.
- Characterization of blockage effects.

Adoption of NML for PPM may be limited by industry unknowns regarding the magnitude of measurement uncertainties.

For four-beam pulsed NMLs, **pre-tilt configuration is a primary design control** that can be optimized based on:

- Turbine tilt-vs-wind load relationships.
- Lidar beam angles and measurement target distance.
- Installation precision; wind conditions during install.

OBJECTIVE

Determine the sensitivity of NML PPM uncertainty to pre-tilt design and installation accuracy.

To what extent do differences between NML beam-pair measurement heights and turbine hub height affect overall PPM AEP uncertainty?

Is PPM AEP uncertainty more sensitive to pre-tilt under specific PPM configurations?

To what extent should PPM designers prioritize minimizing measurement height error using:

- Pre-measurement of turbine tilt-vs-wind load response.
- Optimization of NML pre-tilt design.
- NML installation precision, including prioritizing installations during minimal wind speeds.

METHODS

- Nine-month NML and turbine performance data set from an active wind farm in Southern California.
- Synthesis of lower beam-pair measurement height data as a function of hypothetical target measurement distances and pre-tilt configurations; assuming:
  - Shear characterization is unaffected by the height of the upper and lower wind speed measurements.
  - Blockage effects are negligible.
- Calculation of AEP uncertainty per IEC 61400 50-3 and 12-1 across hypothetical configuration scenarios.
  - Includes measurement height uncertainty term (IEC 50-3) accounting for error between beam-pair measurement height and turbine hub height.
- Interpretation of AEP uncertainty sensitivity to NML pre-tilt configuration.

RESULTS

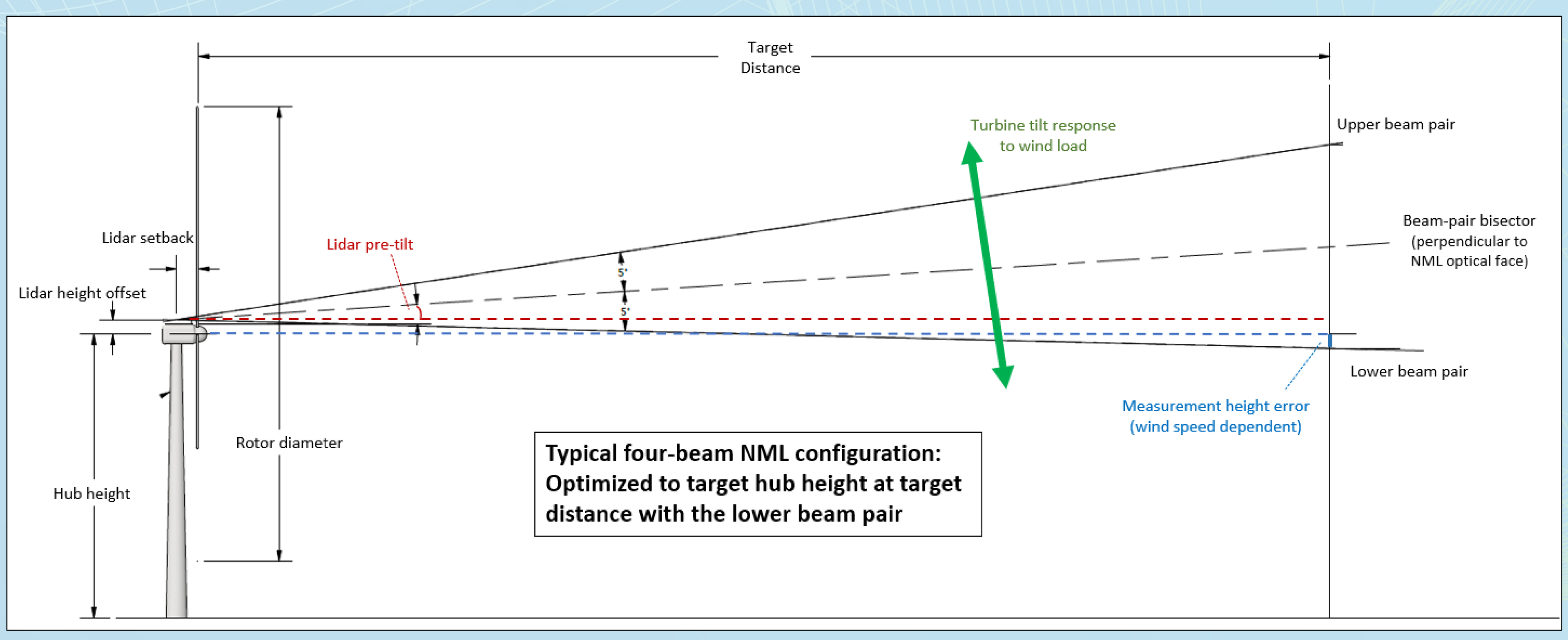
Pre-tilt: measured from horizontal to the lidar-beam bisector; positive upwards.

Measurement height error: offset between lower beam pair height and hub height at target distance.

Shear: characterized from lower and upper beam-pair measurements.

Maximum energy-weighted wind speed: wind speed most heavily weighted in AEP calculations; a function of the convolution of the power curve with the wind speed distribution.

Applicability: The uncertainty results are specific to this testing configuration; the sensitivity of uncertainty to pre-tilt may be representative for other applications.



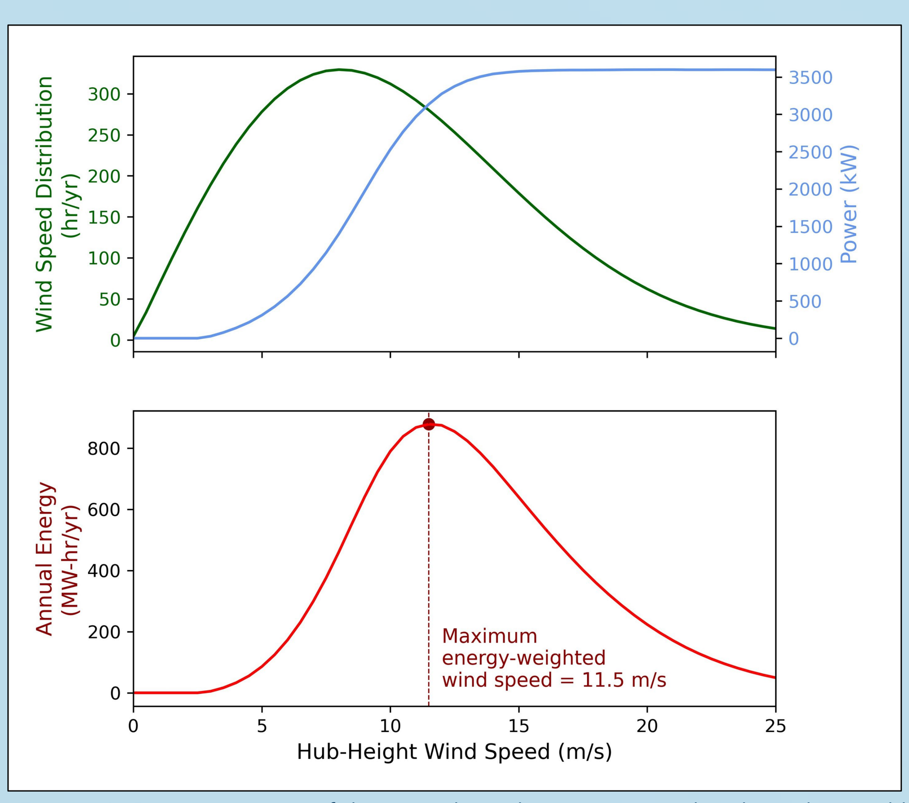


Figure 1: Determination of the most heavily energy-weighted wind speed bin.

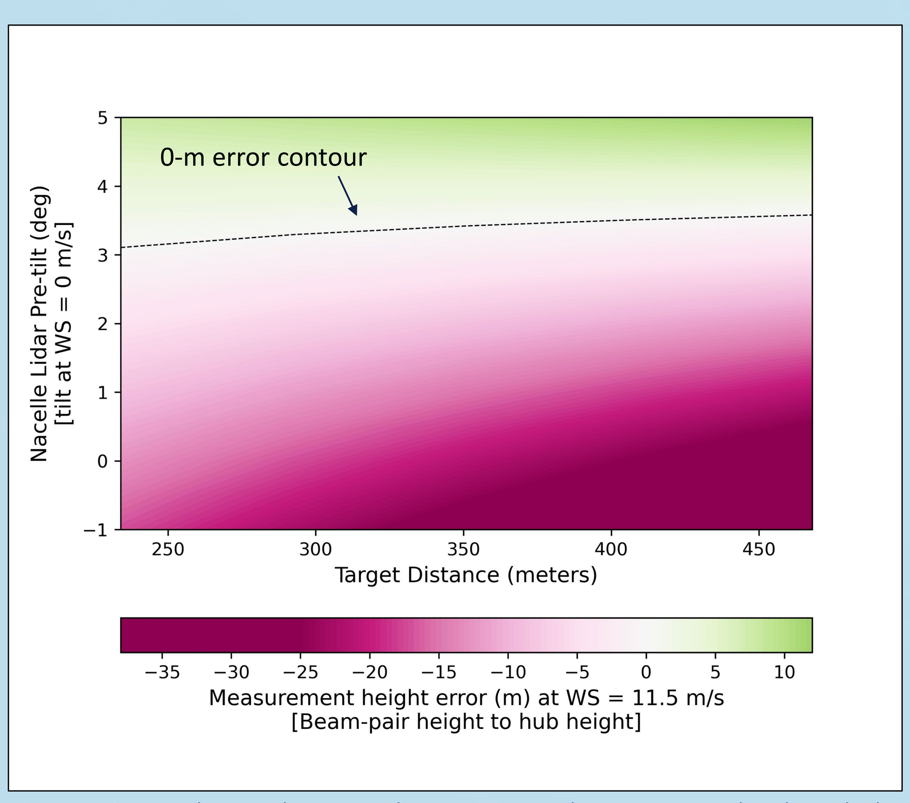


Figure 3: Height misalignment between NML beam pair and turbine hub height at the most heavily weighted wind speed (11 m/s) over a range of pre-tilt and target measurement distance configurations.

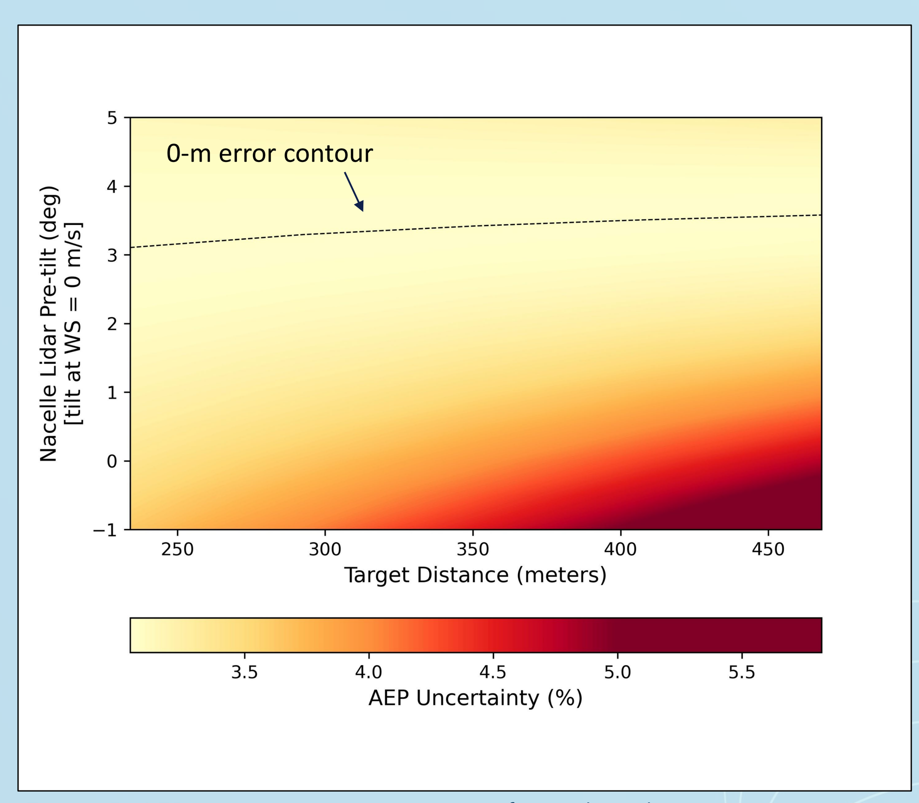


Figure 5: AEP uncertainty over a range of pre-tilt and target measurement distance configurations.

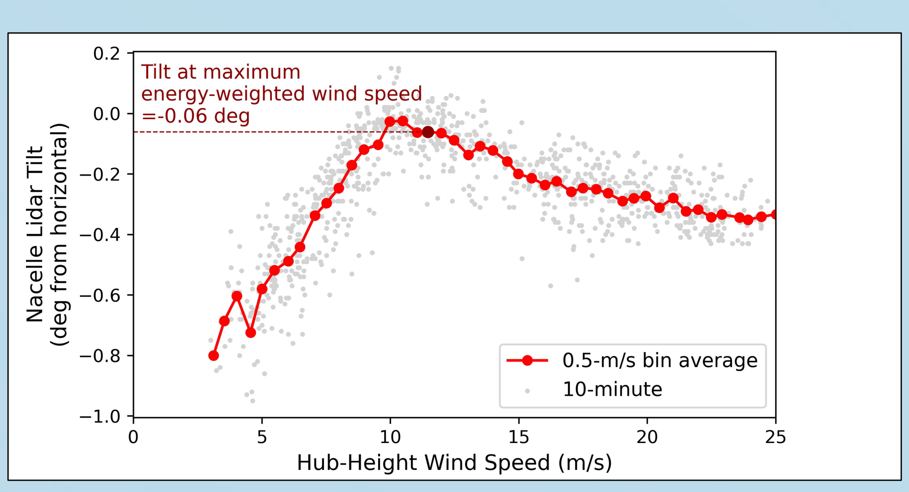


Figure 2: Determination of turbine tilt response at the most heavily energy-weighted wind speed bin.

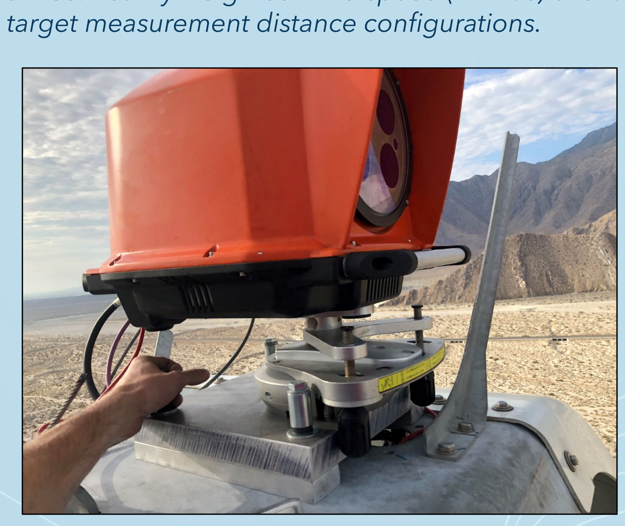


Figure 4: Four-beam NML lidar installed on the test turbine.

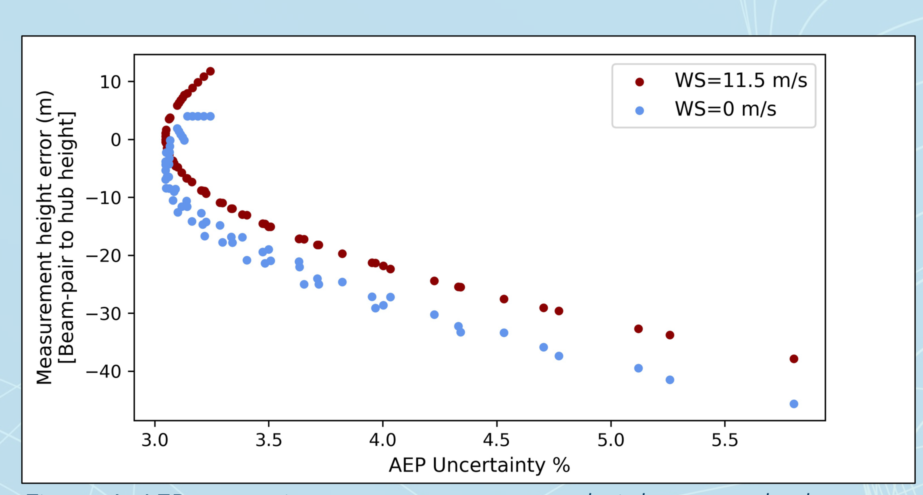


Figure 6: AEP uncertainty versus measurement height error at both zero and the most heavily weighted wind speed (11 m/s).

CONCLUSIONS

- Minimizing measurement height error at the most energy-weighted wind speed can serve to minimize measurement height-related PPM uncertainty.
- PPM AEP uncertainty is sensitive (0.5-1.0%) to pre-tilt configuration at scales of +/- 2°.
- PPM AEP uncertainty is more sensitive to pre-tilt configuration as target distances increase, under high-shear conditions, and when the turbine tilt-response to wind load is greater.
- Height-correcting wind speed measurements mitigates some of the uncertainty sensitivity to pre-tilt configuration (not shown); the post-correction sensitivity is highly dependent on shear conditions.

ACKNOWLEDGEMENTS

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