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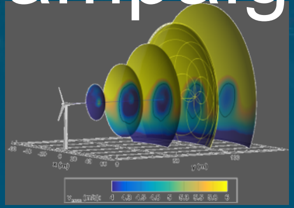
Sandia National Laboratories

Validation of Inflow Creation Methods Using Data Assimilation Against SCADA Data: Trends from a field campaign



PRESENTED BY

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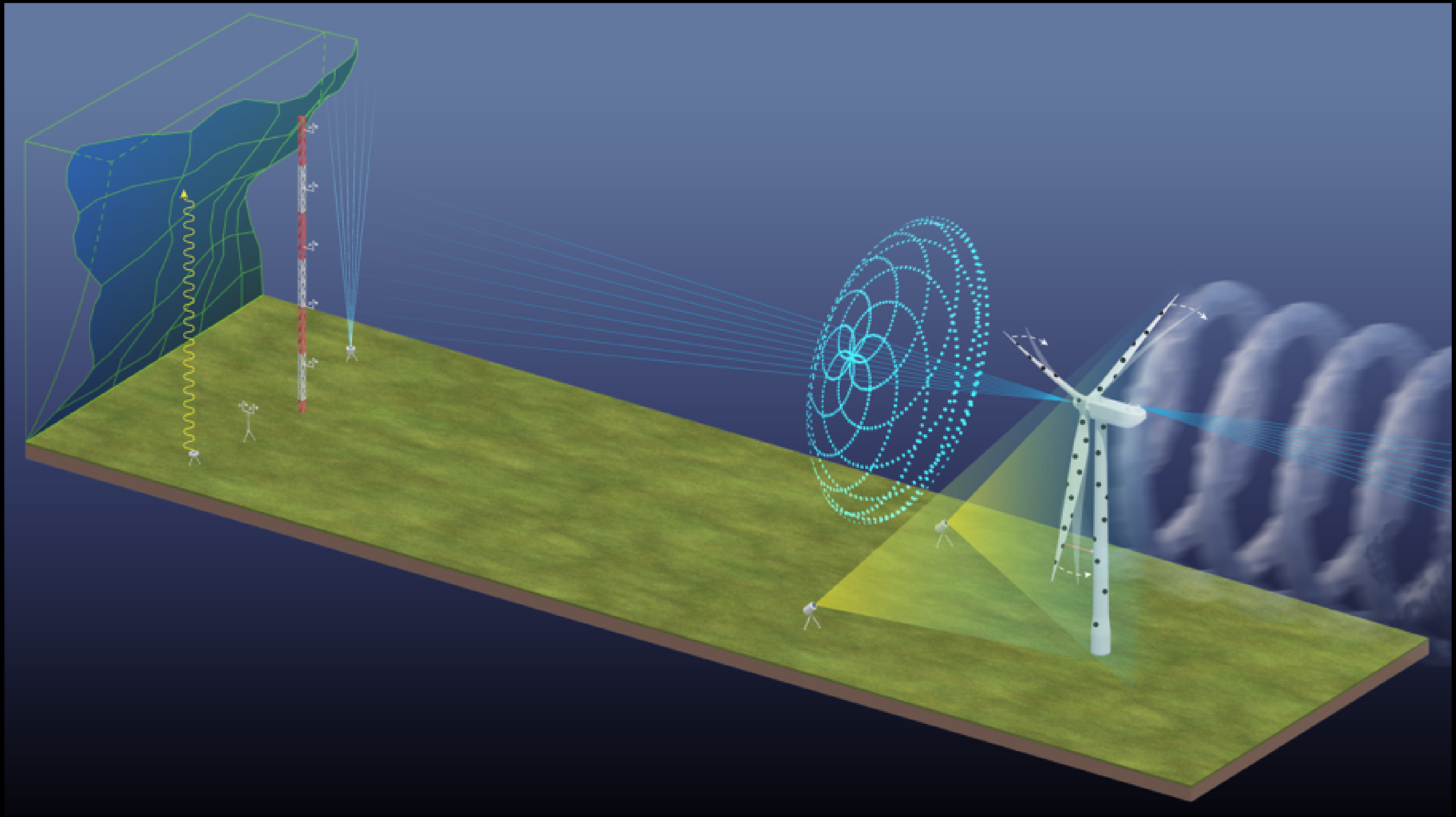
Rotor Aerodynamics, Aeroelastics, Wake (RAAW)

- Collaborative field experiment with SNL, NREL, and GE Vernova
- Goal: Collect field data relevant to modern wind turbines for validation of codes and models



Motivation

- Loads drive wind turbine designs, so predicting them is important
- What are the critical inputs to improve predictions?
  - Inflow is most important
- Will a higher fidelity inflow improve a lower fidelity simulation?

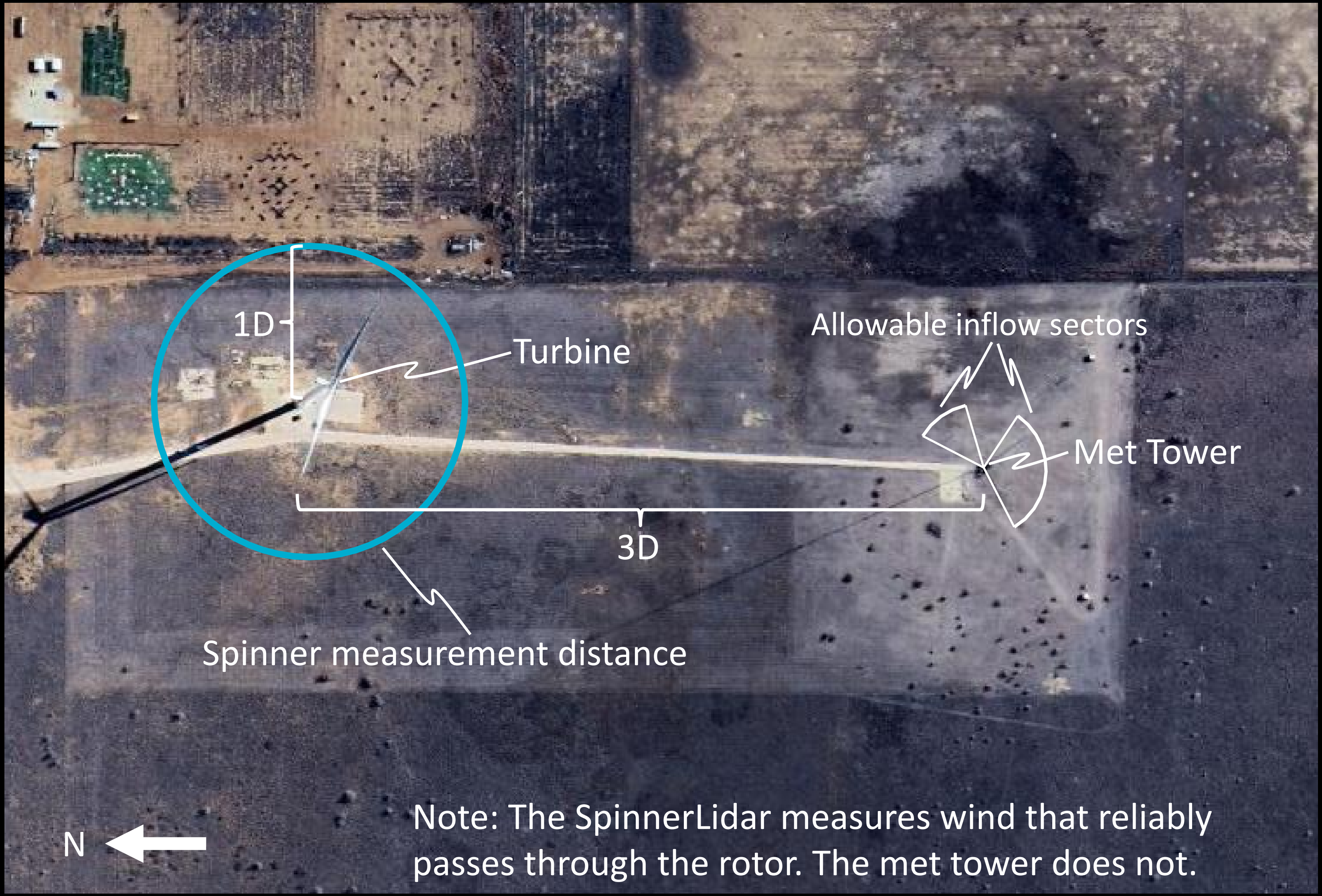
This study primarily evaluates the importance of accurate inflow modeling to accurate load predictions by comparing:

- Standard met tower-derived modeled inflows (TurbSim)
- Direct conversion of SpinnerLidar measurements to inflows

Overall method

- Two sets of inflows are created
  - A standard method using TurbSim and met tower measurements as inputs
  - A custom method that converts SpinnerLidar measurements into OpenFAST compatible inflows
- All inflows are run in OpenFAST with a calibrated model of the P3 turbine
  - Note: OpenFAST model was calibrated using TurbSim, including ROSCO (controller)
- Results are compared on a one-to-one time basis with P3 data

Site layout


1D
Turbine
Allowable inflow sectors
Met Tower
3D
Spinner measurement distance
N
Note: The SpinnerLidar measures wind that reliably passes through the rotor. The met tower does not.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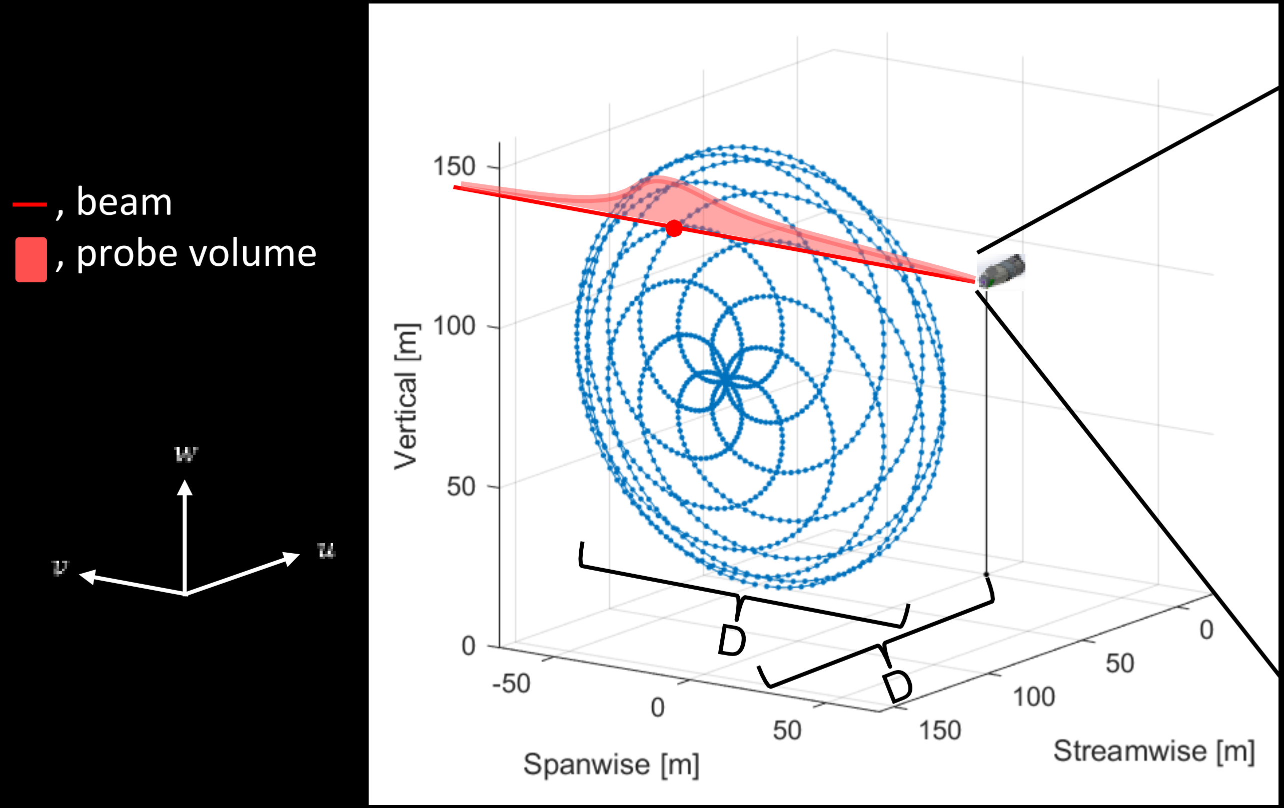
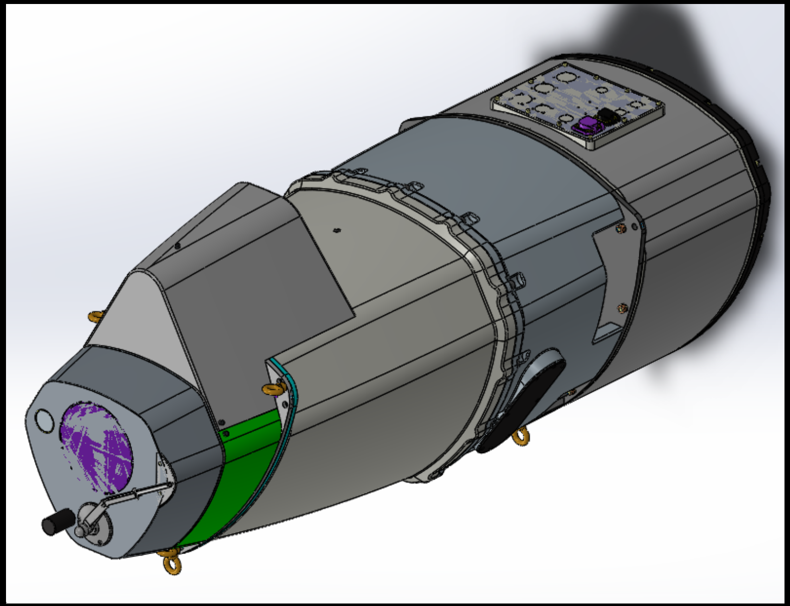
What is the SpinnerLidar?

- Modified ZephIR continuous-wave Doppler lidar with 2D scan head developed by DTU
- Max range ~135 m
- 977 points in rosette pattern on a spherical surface in 2 s
- Lorenzian probe volume averaging





SpinnerLidar inflow method

- Projection: A pre-processing step provides *u* and *v* velocity components through a projection method
- Lagging: Data are lagged using met and turbine wind speed measurements
- Induction removal: Induction effects are corrected for (see next slide)
- Interpolation: Data are interpolated onto a grid to be compatible with OpenFAST

Induction removal

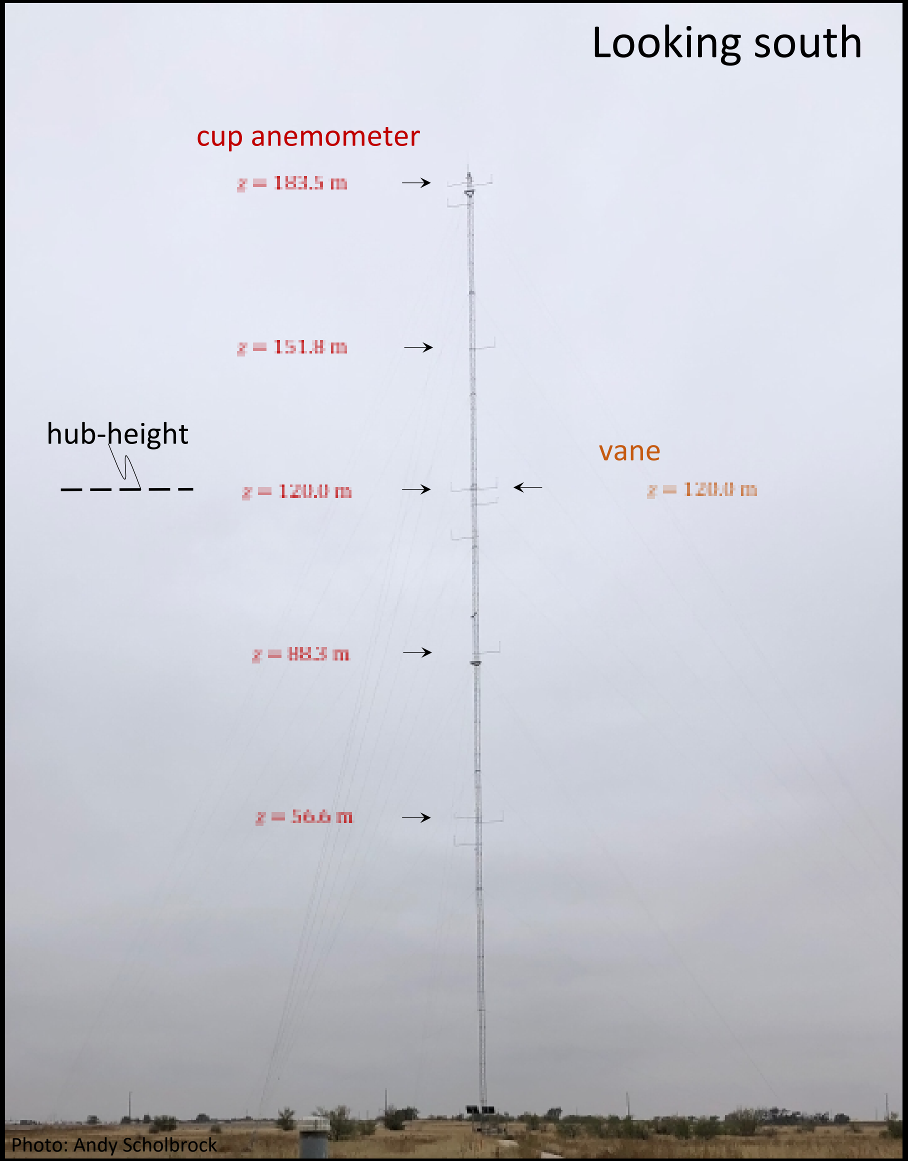
Axial induction factor: requires thrust from turbine and density from met tower

- Using method from Medici, 2011.

$$\frac{U(x)}{U_\infty} = 1 - a\left(1 + \frac{2x}{D}\frac{1}{\sqrt{1+\left(\frac{2x}{D}\right)^2}}\right)$$

- This is 1-D
- Original data from SpinnerLidar are at $x \approx -1D$
- Plug in SpinnerLidar for $U(x, y, z, t)$ data and solve for $U_{\infty,derived}(\infty, y, z, t)$

Met tower data



To make TurbSim inflows from met data:

- Mean hub-height wind speed (cup)
- Mean hub-height TI (cup)
- Shear exponent (calculated across all 5 cups)

These data are used with the IEC Kaimal turbulence model to produce inflows.

Note: TurbSim inflows using met data use six seeds and simulation results are averaged.

Data filtering

Quantity filtered per 10-minute bin	Filter, to keep
Mean wind speed	[3, 25] m/s
Mean wind direction	[37, 80] and [120, 250]
Mean yaw misalignment	< 15 degrees
Std. dev. of yaw	< 10 degrees
Turbine state	“run”
Spinner focal distance	1D
Spinner number of scans	> 285 scans (one scan = 2 s)
Specific dates/times	Normal operation, no other tests

Avoids waking met instruments with tower or turbine

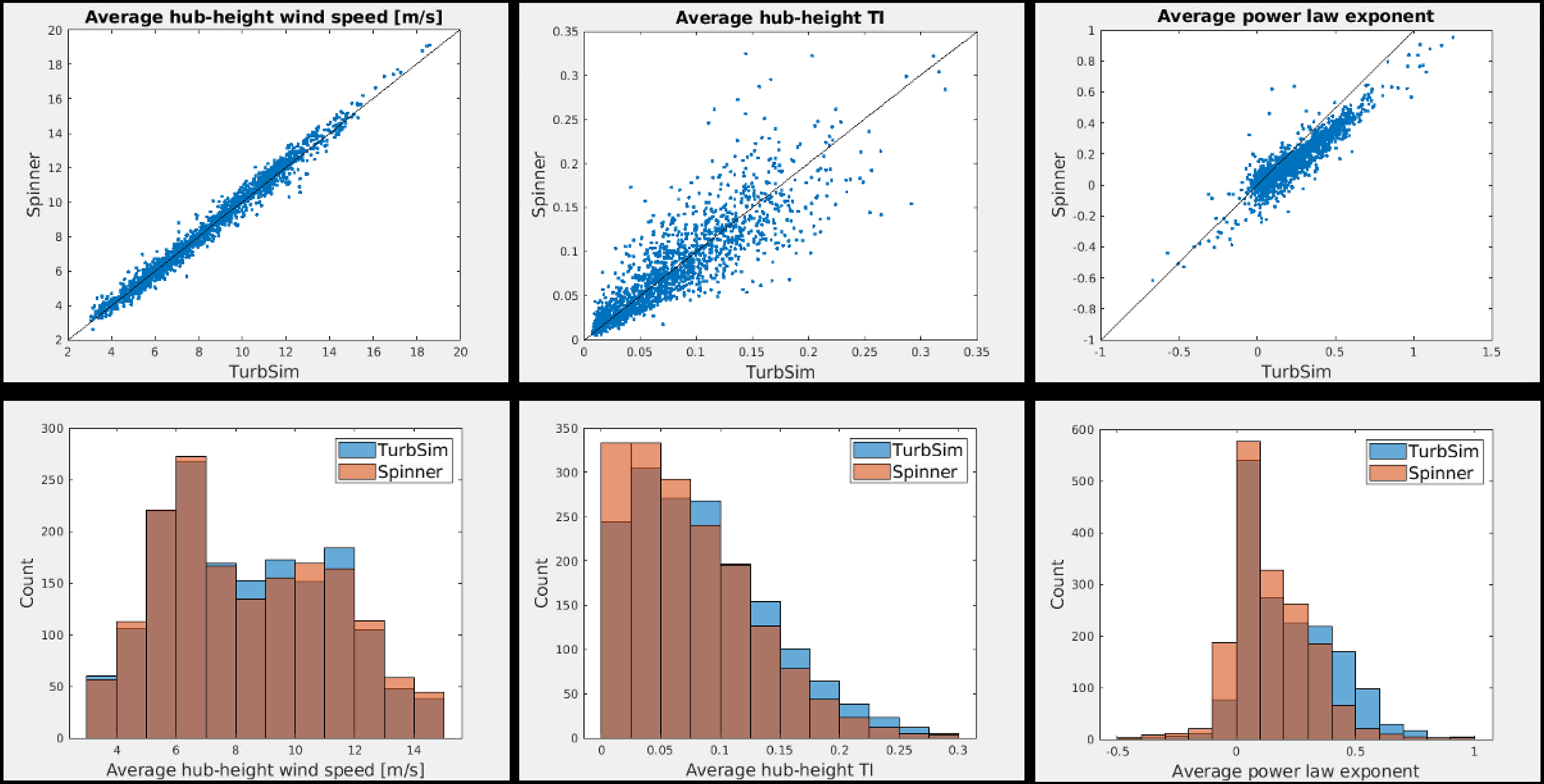
“Favors” Spinner method by minimizing advection delays

Quantity filtered per 10-minute bin	Filter out
cups, sensors for density, hub-height vane	Any NaNs (these have prior QA/QC)
Turbine: tower bottom fore-aft, nacelle wind speed	More than 1 s of consecutive NaNs or 5% of bin
SpinnerLidar	More than 4 s of consecutive NaNs or 5% of bin

The turbine tower load is used to calculate thrust, which is needed for induction removal. The nacelle wind speed is needed for lagging.

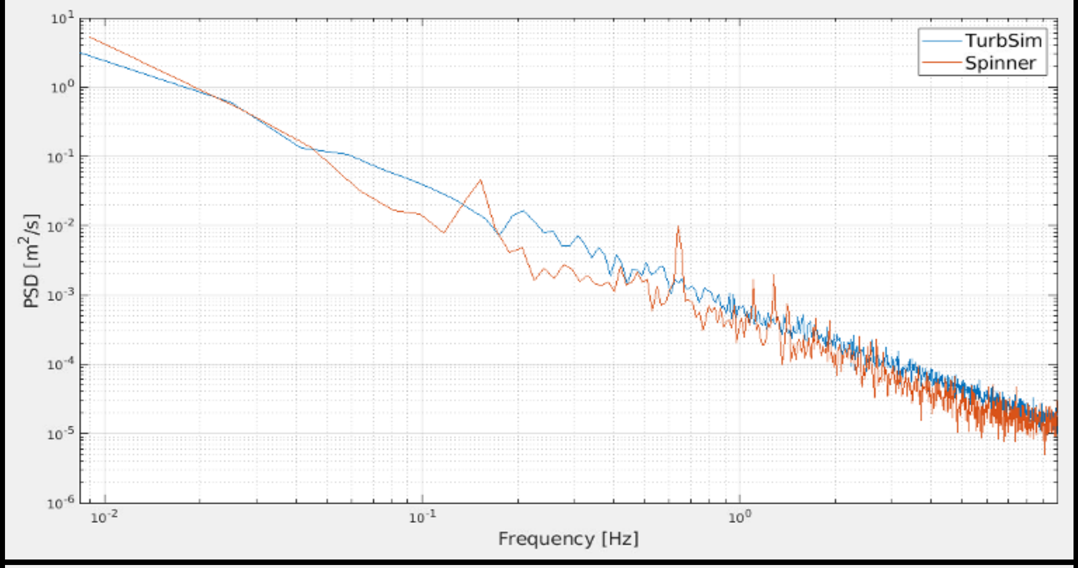
1687 10-minute bins (281.2 hrs) remained for inflow creation and OpenFAST runs.

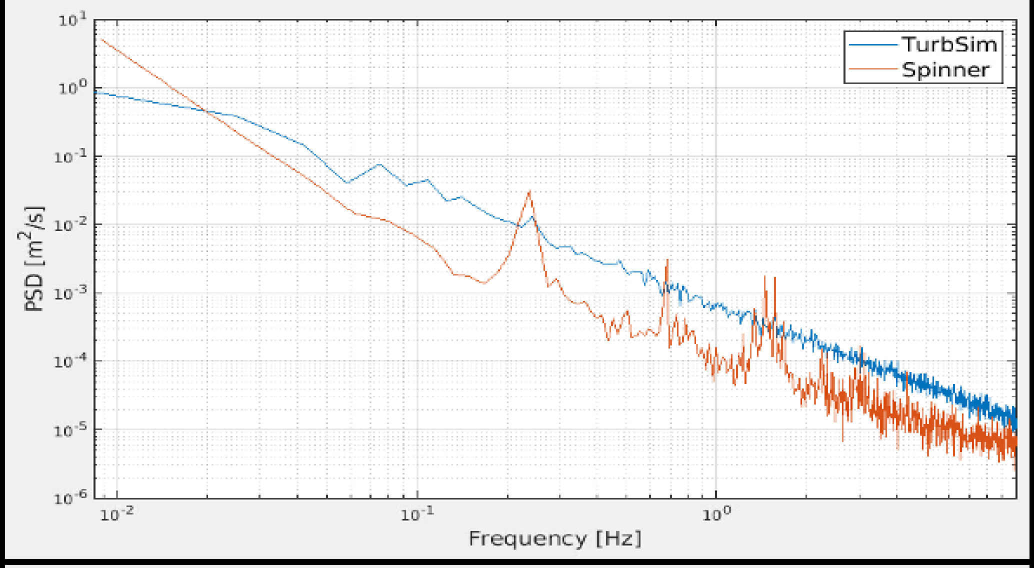
Comparisons of inflow conditions

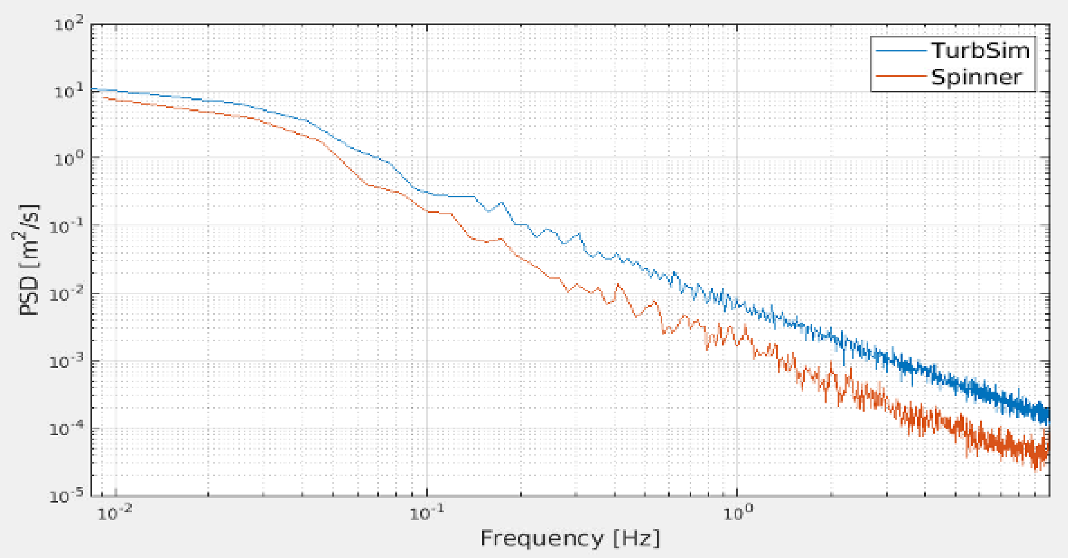


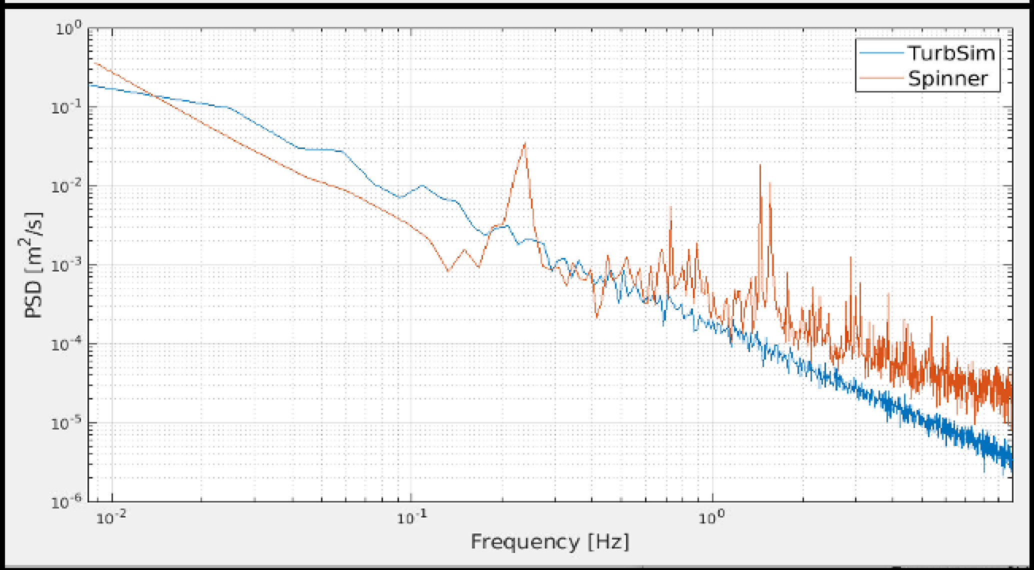
Inflow spectra

Spectra of *u* at hub height center from four random 10-minutes bins:





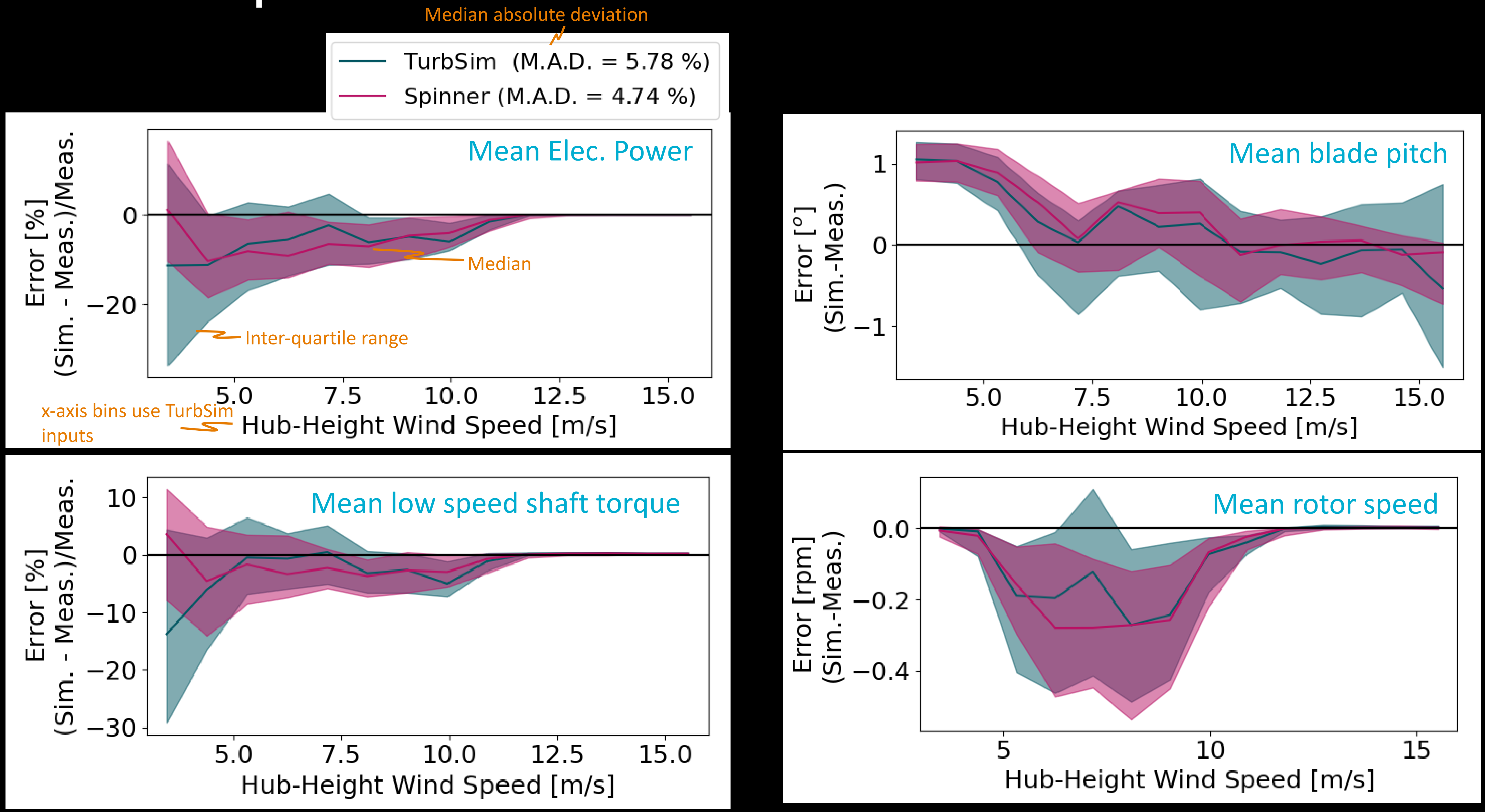




Notes on results

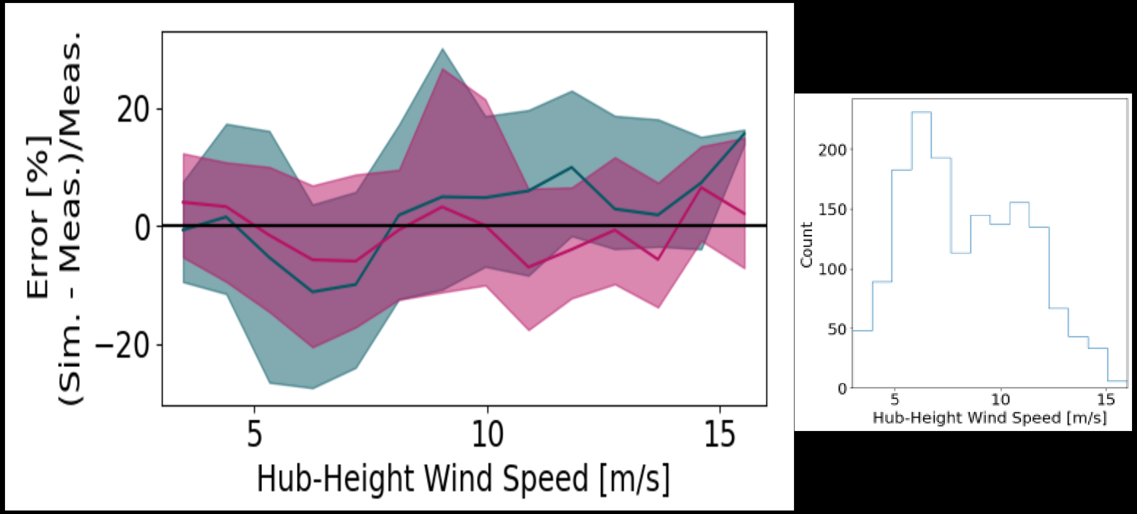
- Overall, TurbSim and Spinner provide very similar results.
- *I am only showing results with larger differences*.
- We hypothesize that Spinner inflows should improve one-to-one matching of turbine response time series
  - But we cannot show the time series (they're proprietary)
  - Instead, we focus on damage equivalent loads (DELs)
    - DEL calculations are dependent on frequencies and amplitudes within the time series, so they are useful as a proxy for one-to-one time series comparisons

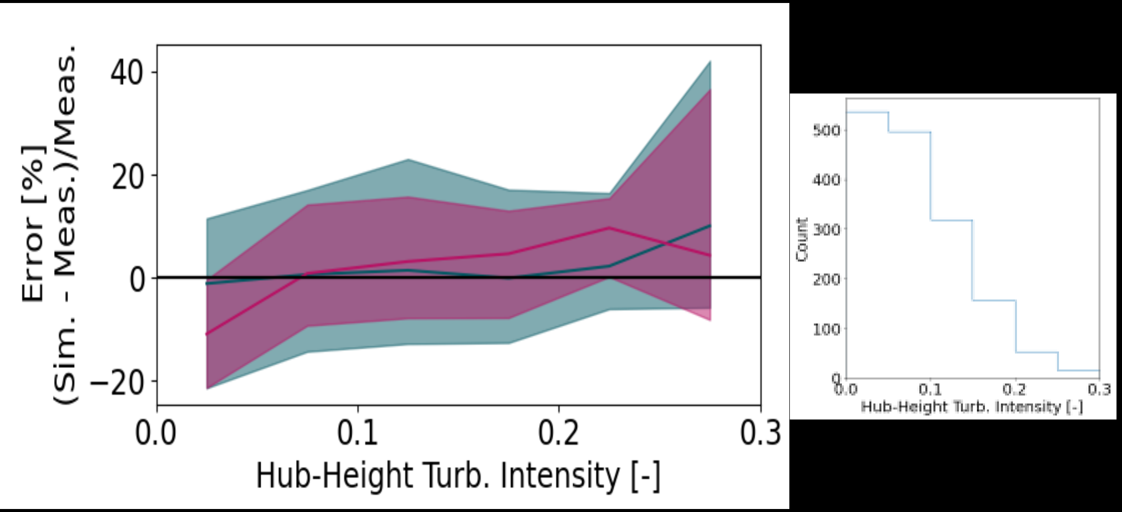
Basic operation

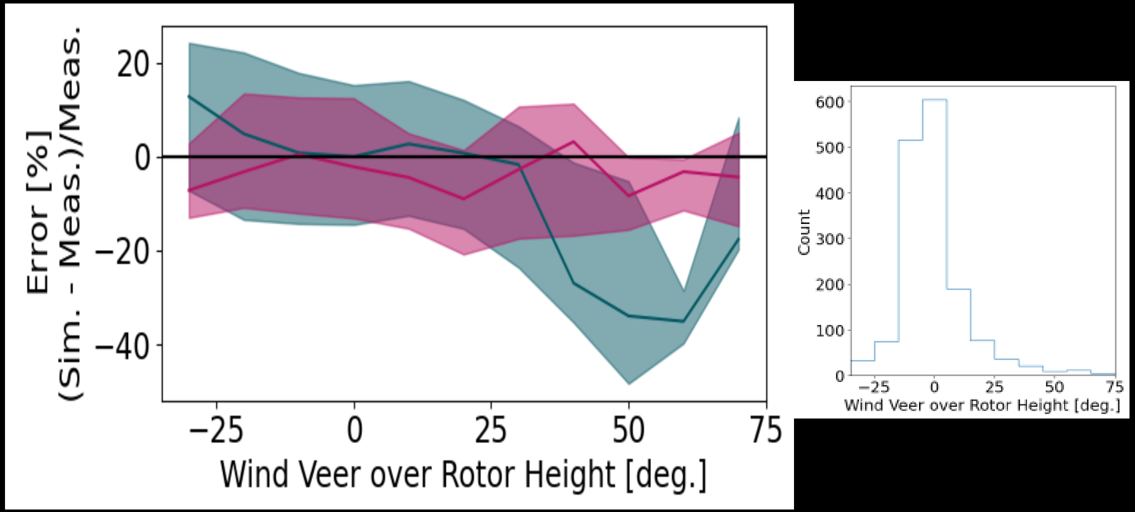


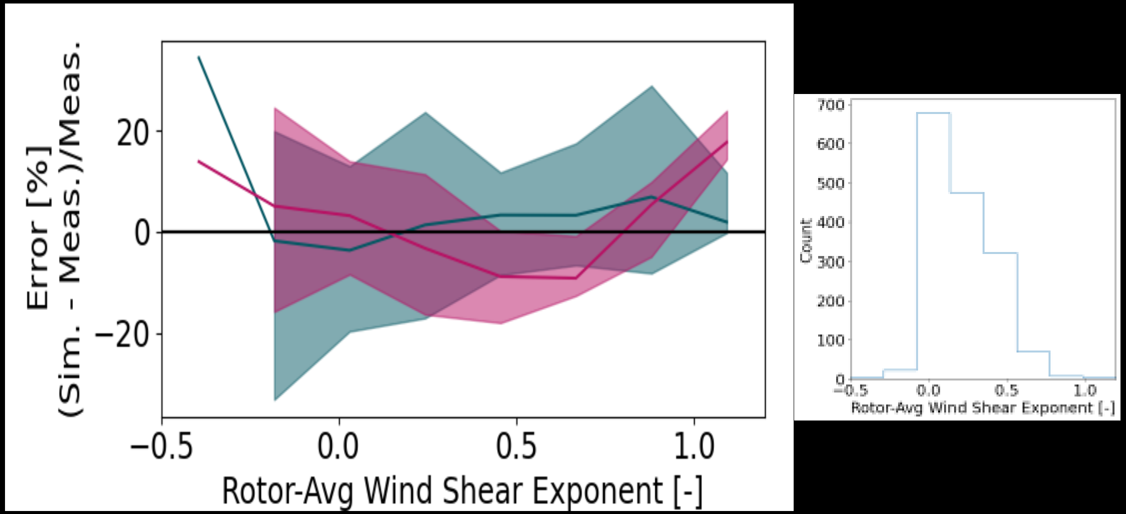
Blade root flap moment DEL

TurbSim (M.A.D. = 14.15 %)
Spinner (M.A.D. = 11.57 %)

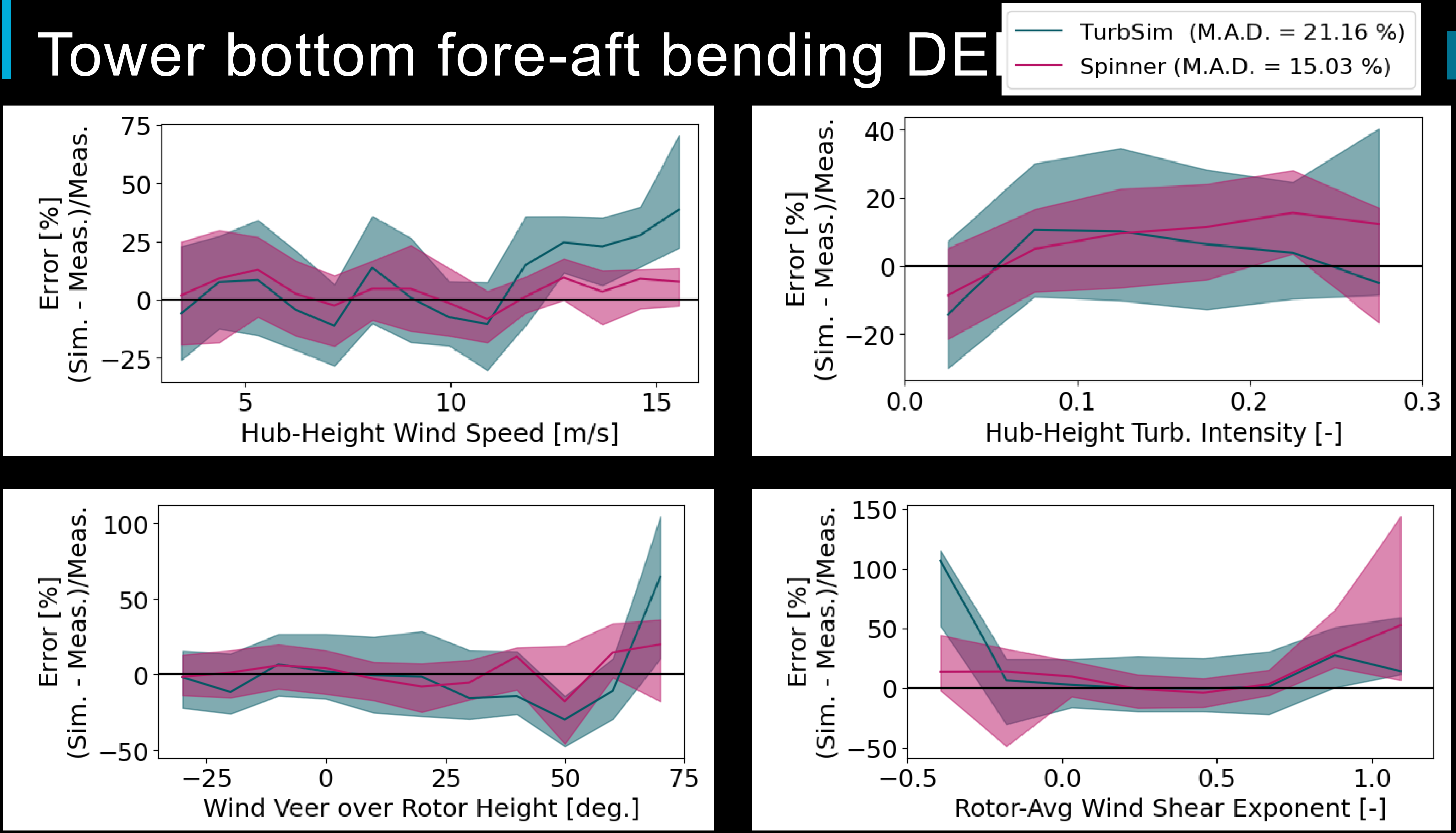




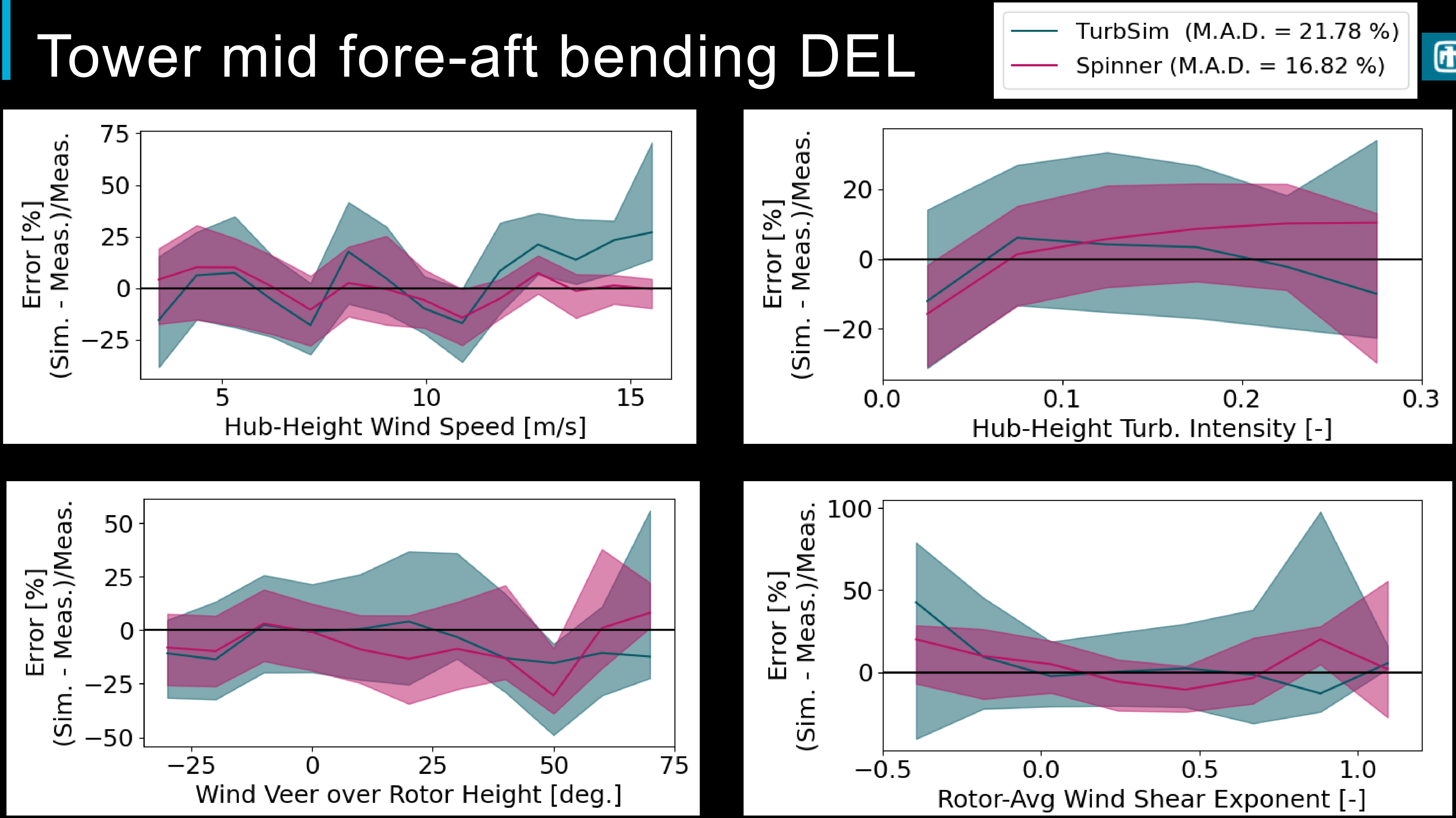




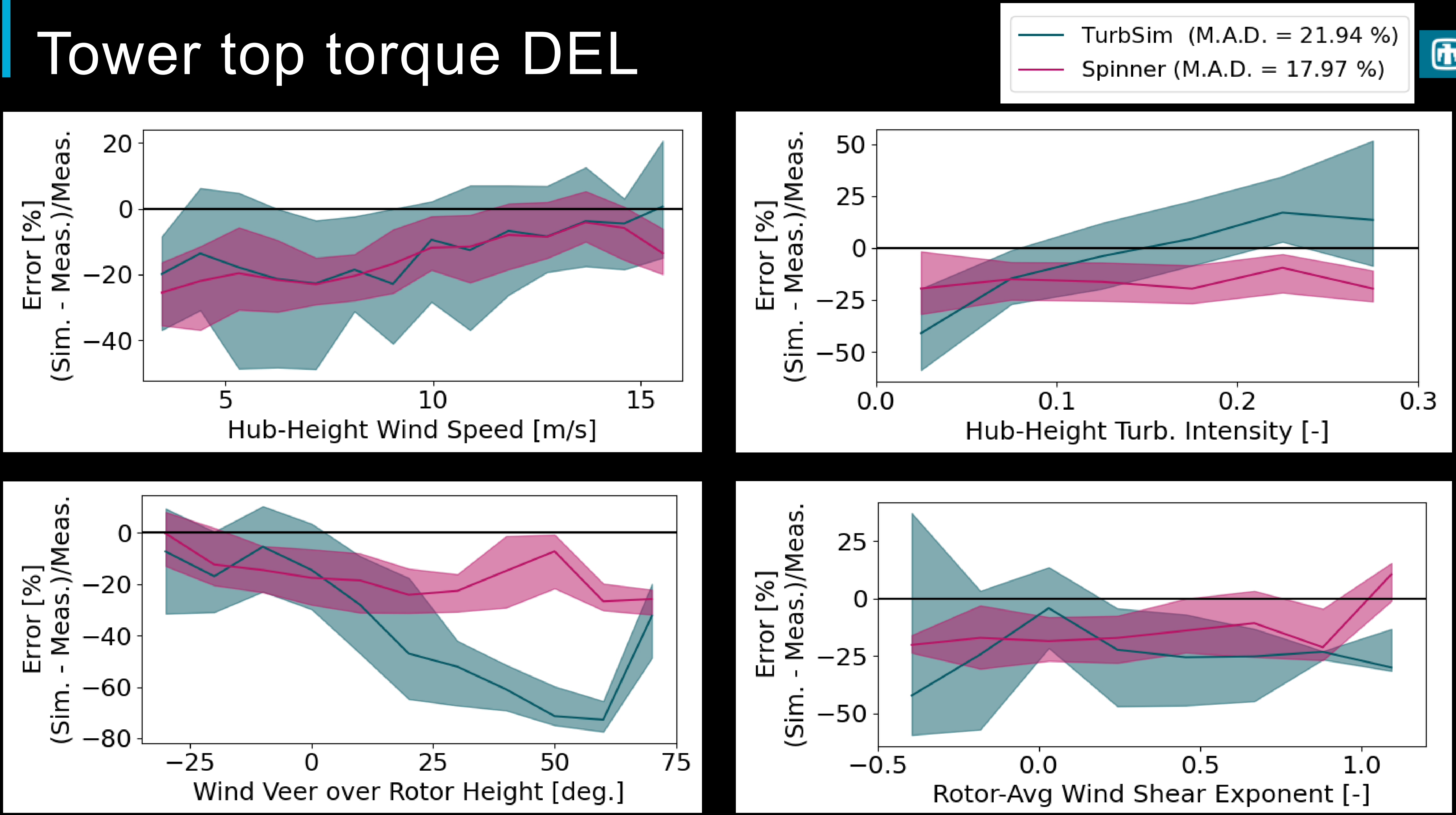
Tower bottom fore-aft bending DEL



Tower mid fore-aft bending DEL



Tower top torque DEL



Conclusions

- Across most metrics, TurbSim and Spinner inflow methods provide very similar results
- For several DELs, Spinner shows marked improvement at more extreme inflow conditions such as high wind speeds, veer, and/or shear

DEL	Improvement in M.A.D. with Spinner	Where improved
Blade root flap moment	2.58	High wind speeds, probably high veer
Tower bottom fore-aft moment	6.13	High wind speeds, probably high veer
Tower mid fore-aft moment	4.96	High wind speeds
Tower top torque	3.97	Probably high veer, mid-high shear

Future work:

- Uncertainty analyses
- Improved induction removal
- Spinner turbulence correction
- Repeat with rotor position control