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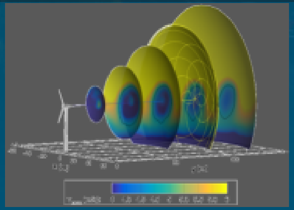
Sandia National Laboratories

Simulation Planning for AMSIT Field Experiment Planning



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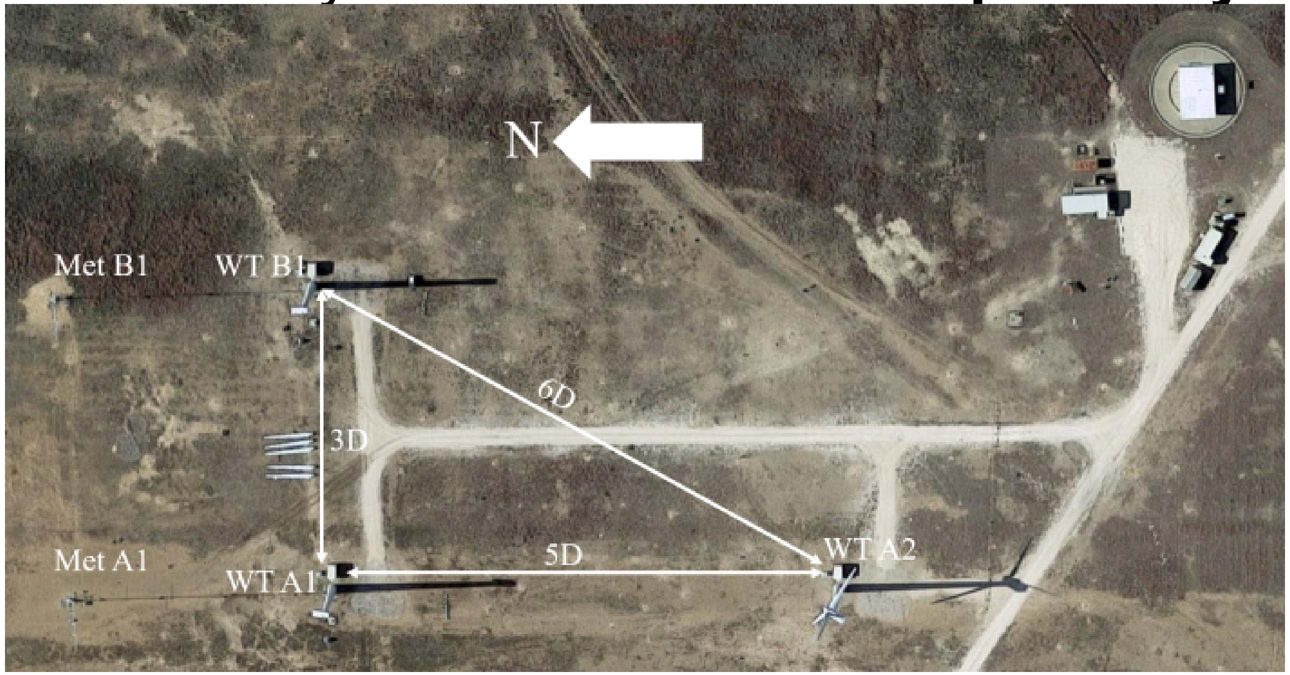
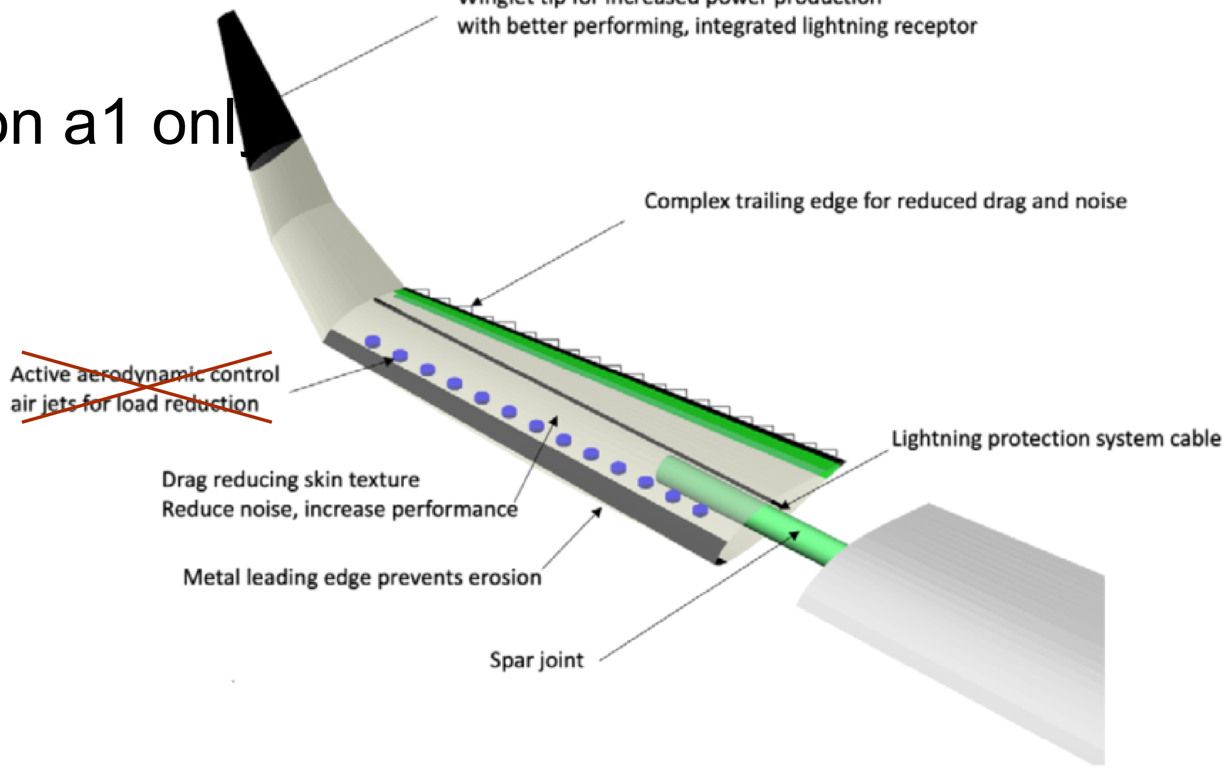
What's AMSIT?

- Additively Manufactured, System Integrated Tip
- In ~1 year, we will field test a V27 rotor with an AMSIT and compare to a baseline V27 rotor
- We hope to test them **simultaneously** on a1 and b1, but…
- We may have to test them **sequentially** on a1 only



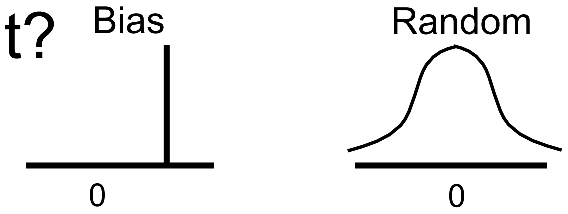


Field testing is hard

- Field testing can have high uncertainties due to many sources of error, both random and bias
- We will likely be looking for small differences between the two rotors, e.g., an increase in power of ~4%
- But the uncertainty of differences is larger than the uncertainty of individual measurements…

Quick Refresher on Uncertainties

What determines the uncertainty of a measurement?



Uncertainty comes from bias and random errors. In context…

Bias errors will probably be from differences in inflows if measurements are not simultaneous and more or less co-located and from any differences in the turbines if we use two. Bias errors may be mitigated by binning data to compare similar conditions.

If you can say the "same" experiment was done for the control and treatment, then bias errors are equal and subtract to a negligible magnitude when looking at differences.

Random errors will primarily come from the inflow.

They can be quantified using a bootstrap technique and can be minimized by ensuring the data set is long (in time not number of points) enough.

	Sequential testing	**Simultaneous testing**
Bias errors	Potentially large differences in inflows	Probably small differences in turbines and inflow
Random errors	From inflow, but not same	From inflow, but probably same

Uncertainty in Control and Treatment

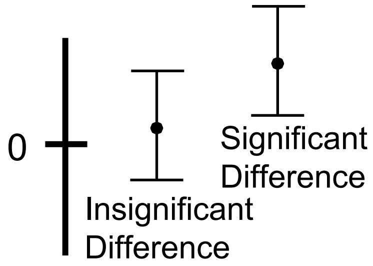
Let P_1 and P_2 be the powers produced by two rotors and the expected difference between them be

$$D = P_1 - P_2.$$

The uncertainties in measuring P_1 and P_2 are δP_1 and δP_2, respectively, then the uncertainty in D is

$$\delta D = \sqrt{\delta P_1^2 + \delta P_2^2}$$

using the root-sum-square the combine the individual uncertainties.



To simplify, assume that $\delta P_1 = \delta P_2$, then

$$\delta D = \sqrt{2}\delta P_1 \approx 1.4\delta P_1.$$

Finally, $D \pm \delta D$ does not contain zero in its interval, then the result is significant.

In words, it's more difficult to measure the difference between two measurements because their individual uncertainties produce an uncertainty in the difference that is 40% larger.

For example, if we expect $P_1 = 1.04P_2$, then $D = 0.0385P_1$, which means that $\delta D < 0.0385P_1$ for the result to be significant. This in turn means that $\delta P_1 < 0.0272P_1$, which is probably a difficult level of accuracy to achieve.

Questions we need to answer…

- What QoI do we care about most?
  - Power, thrust, root bending moment
- What size difference do we expect in those QoI between the two rotors?
  - TBD, but all small
- What uncertainty do we expect in the measurement of those QoI?
  - TBD and depends on method, but possibly large
- How does the amount of data affect the uncertainty?
  - Will definitely reduce random error and more data will allow for finer binning to reduce bias error
- How does this ultimately influence how we should conduct the field test to achieve significant differences in the QoI?
  - May tell us how long to test and/or that it would be better to focus on certain conditions

Proposed Simulations To Help

- Use TurbSim/OpenFAST
- Realistic ranges of conditions at SWiFT (wind speed, TI, shear, veer)
- Baseline V27, AMSIT V27, and one more with larger expected differences

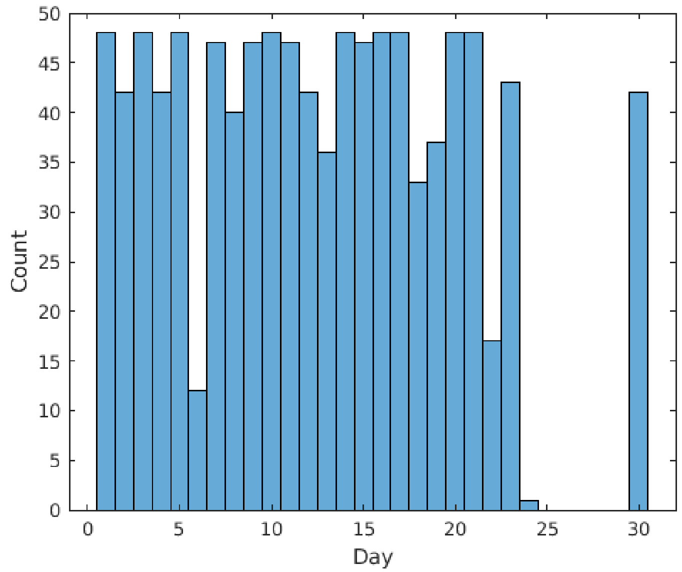
Setting Up TurbSim

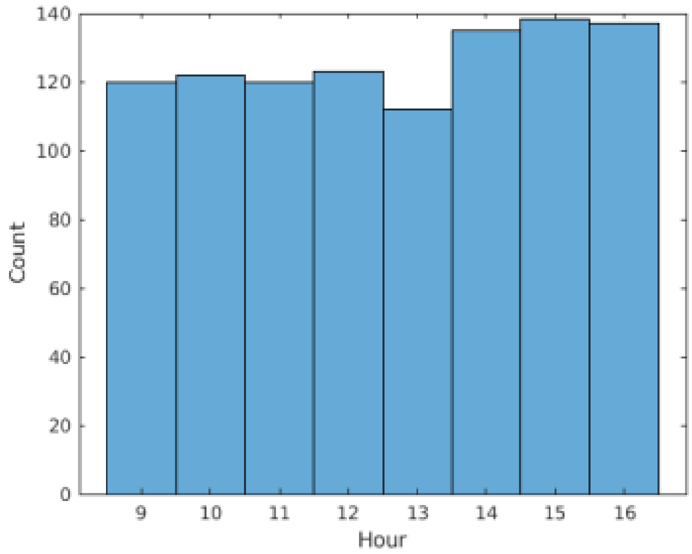
- TurbSim needs hub height wind speed, TI, shear exponent, and veer as inputs
- Met data resources:
  - ~1.5 years of TTU met tower data,
  - lots of a1 met tower data, and
  - some b1 met tower data
- Need to represent three inflows:
  - Baseline inflow to a1
    - ✓, September, 2021
  - Simultaneous inflow to b1
    - Not enough data from b1 for this, so we'll have to explore other options
  - Later inflow to a1
    - ✓, October, 2021

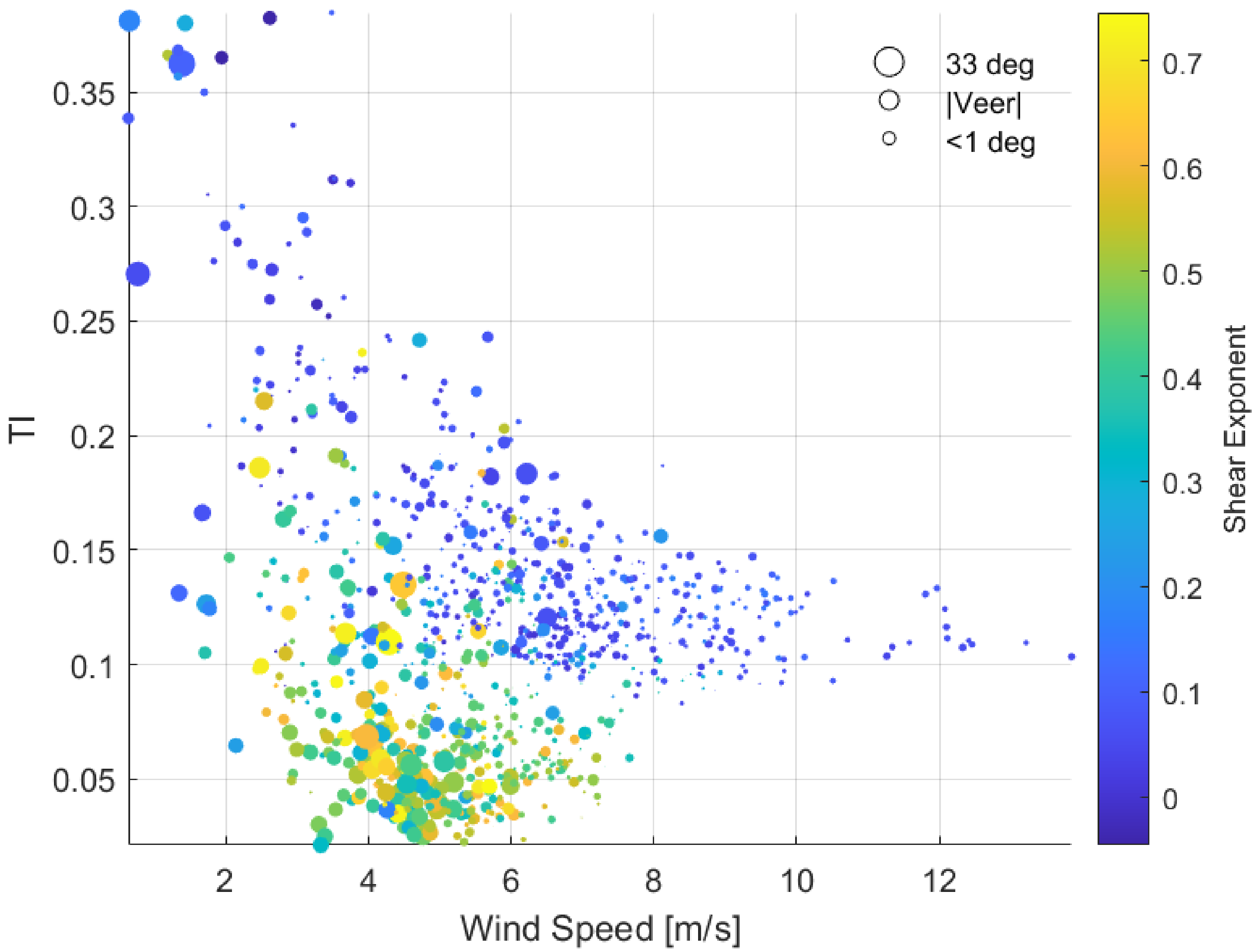
Steps To Set Up TurbSim Inputs

- Could produce TurbSim inputs from assumed distributions, but we have real data
- Gather data from meta1 (just 2021) and metb1 (2019-2021) from September and October (expected testing months)
  - Check that bins are not correlated to ensure independence of inputs
  - High level filtering of data
  - Put into bins and pull out average hub height wind speed, TI, shear, and veer

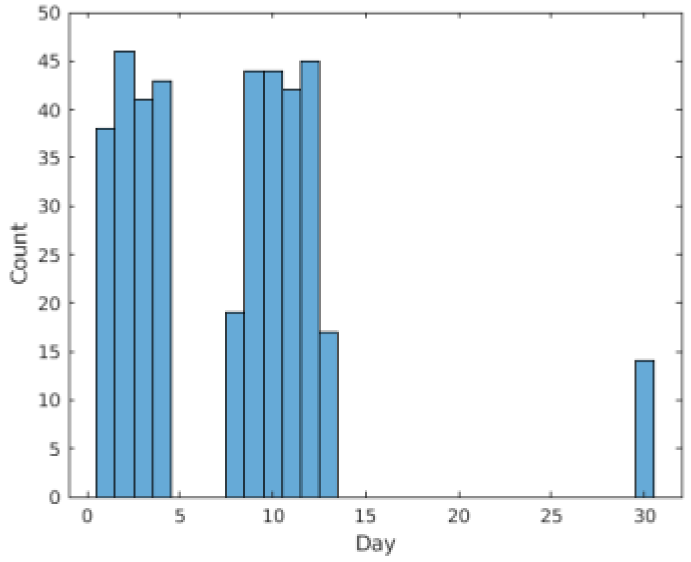
Example of Result – September, a1

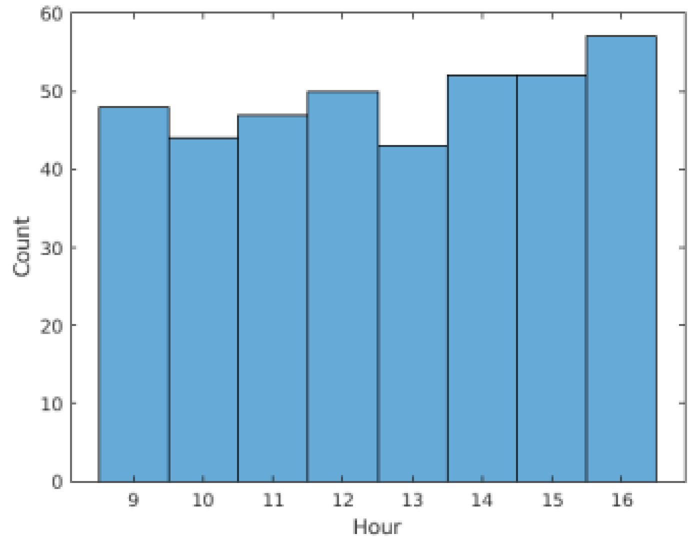


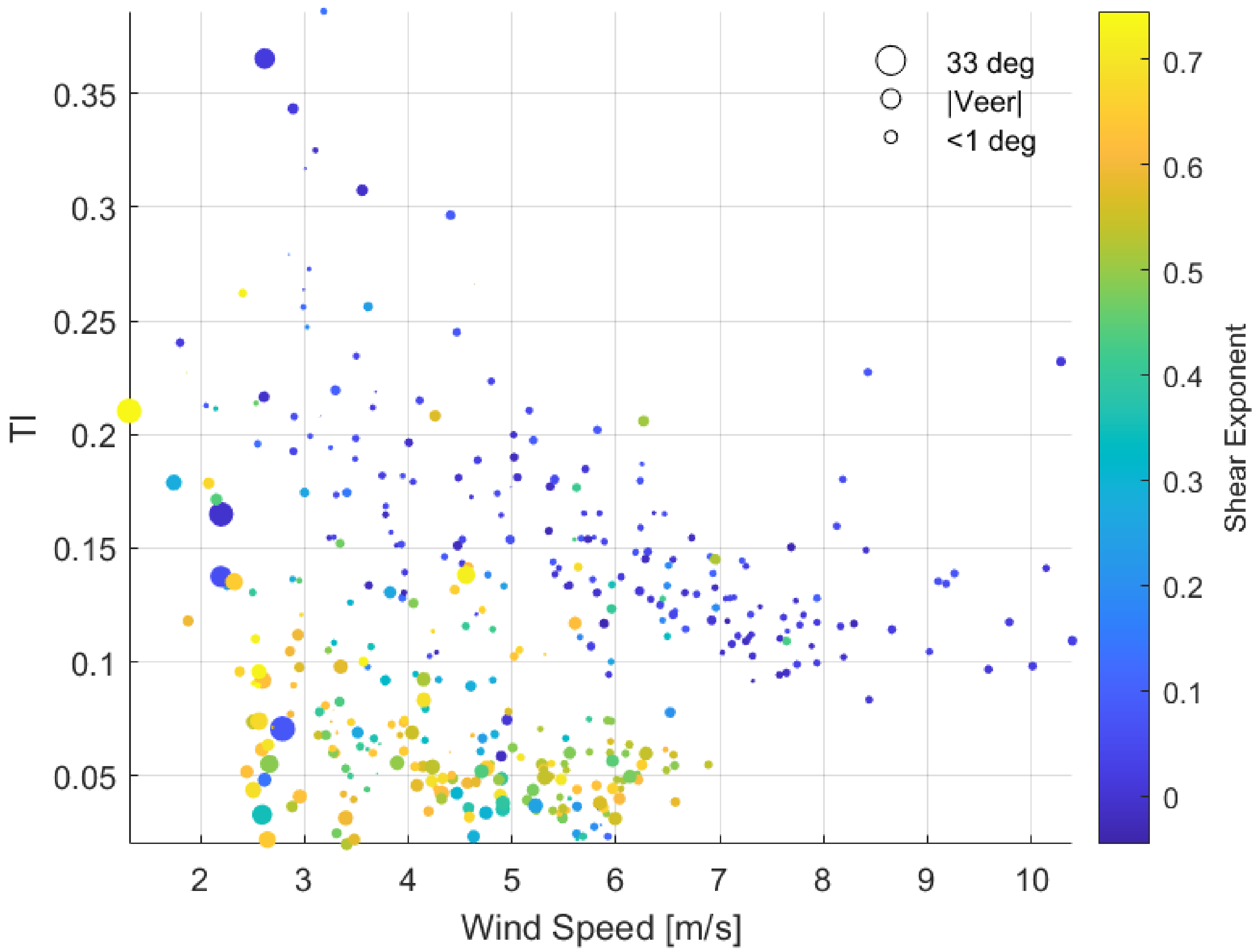




Example of Result – September, b1







TurbSim Inputs

Number of TurbSim Inputs Acquired

	September	October
meta 1	1007	1269
metb 1	400	395*

*Not technically needed

Questions to answer about TurbSim

- How will we back-calculate from TurbSim/OpenFAST results how much field data is needed to get the equivalent in binned data?
  - Each TurbSim/OpenFAST simulation is implicitly a bin. We'll also run them a long time to allow for further binning. Then repeat binning with met data to determine field time needed.
- How long should the TurbSim/OpenFAST simulations be, i.e., how much data do we need in a bin?
  - TurbSim drives velocity distribution toward Gaussian. Reaches $R^2 = 0.99$ after 1 hr.
- Does TI affect convergence time?
  - It does not appear to affect it.
- What is more important: total points or total time?
  - Total time is more important to fill out tails than the total number of point, so lower sample rate is acceptable to reduce processing time.
- How does six seeds, 10 minutes each compare to one seed for 60 minutes?
  - Longer sims have higher standard deviations because they capture more in the tails.

What about the rotors?

- Three rotors:
  - Baseline V27 ✓
  - AMSIT rotor – in progress
    - Small expected changes in QoI
    - Working on verifying OpenFAST model of winglet
    - Will alter polars to reflect changes in lift/drag due to surface texturing
    - May need to update weight distribution and dimensions
  - A third one – TBD, maybe just bigger?
    - Want one with a higher expected change in QoI
    - Academic interest in parameterizing how what can be significantly measured changes with more/better data

Next Steps

- Finish OpenFAST model of AMSIT rotor
  - Validate winglet design in OpenFAST against results from WindDVE
  - Modify polars and test
- Design a third rotor
  - A “V28.3” (28.3 m diameter V27) would produce ~10% more power
  - An AMSIT rotor with relaxed loading constraints

Thanks!

Questions?

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Backup slides

Questions we have

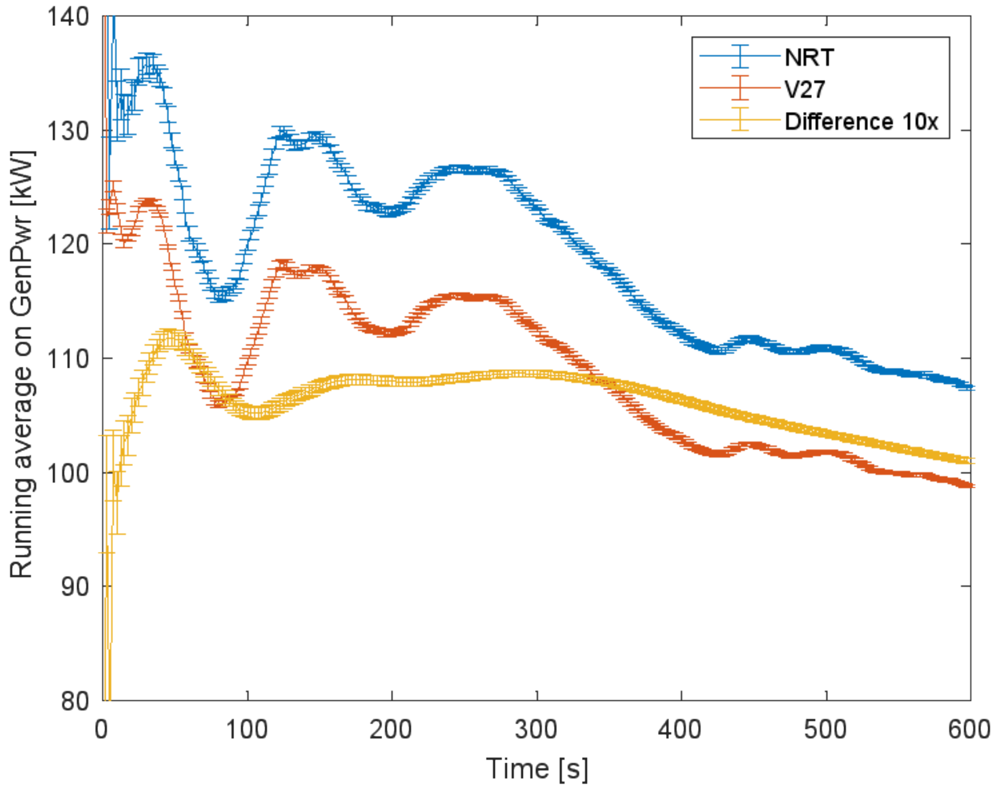
- How good do our turbine/rotor models need to be?
  - OK if discrepancies from “true” are constant offsets since we only care about differences
- How will the discrepancy in the number of a1 vs b1 simulations affect results?
  - Could randomly select inputs from a1 to match number available from b1
  - Or use 5 minute samples from b1 to get twice as many inputs out of it
- How valuable would actual simultaneous data from a1 and b1 be?
  - Should we find a case study for a month when both were recording?
- Will this be an unwieldy amount of data to process?
  - Don’t necessarily need to output at a high rate

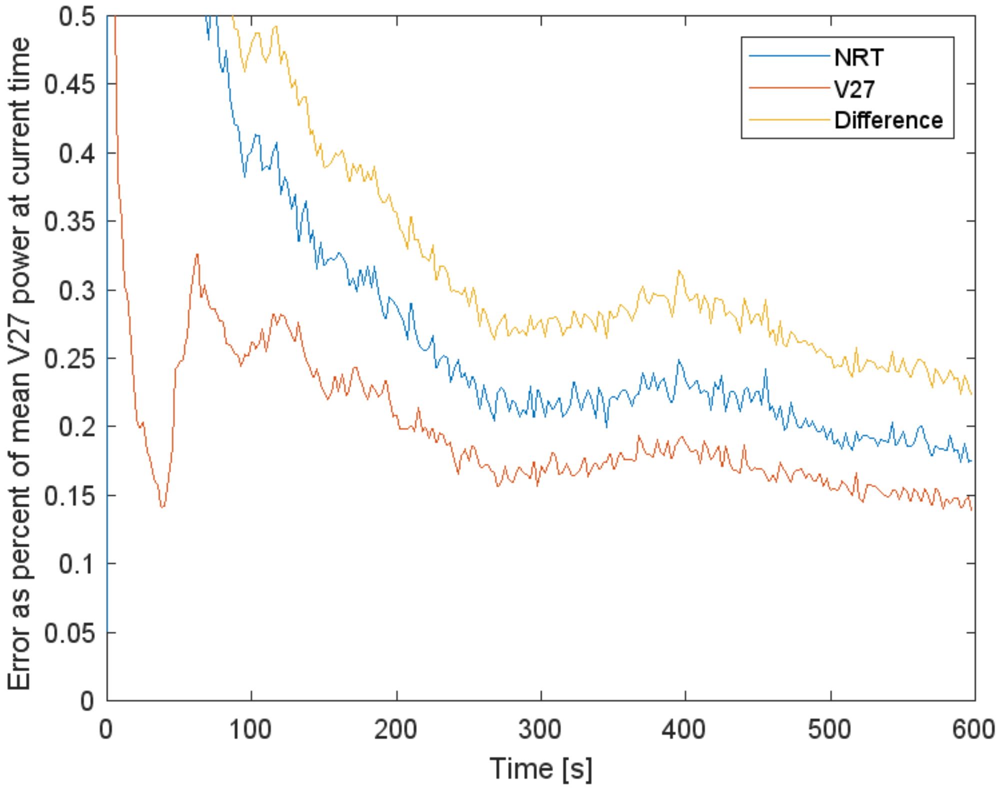
Simulated Simultaneous Testing

10 minute OpenFAST BEMT simulation with TurbSim inflow of NRT and V27

Identical inflows, so similar to simultaneous testing, but ONLY one 10 minute dataset.

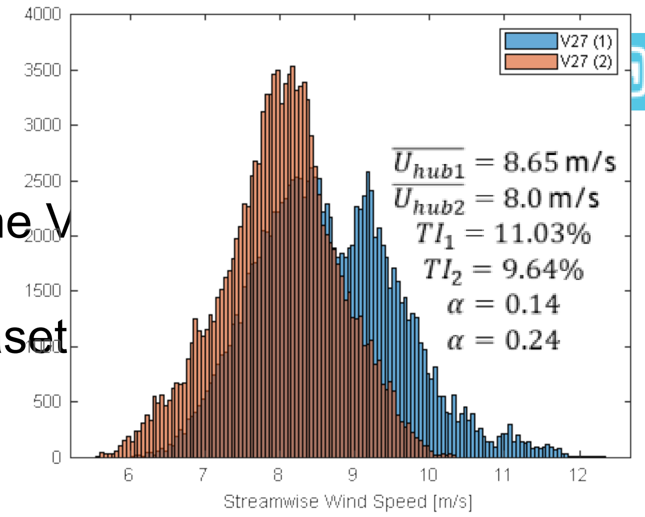
Errorbars calculated with a running bootstrap





Results improve with time and uncertainty in the difference is always higher than the individual uncertainties.

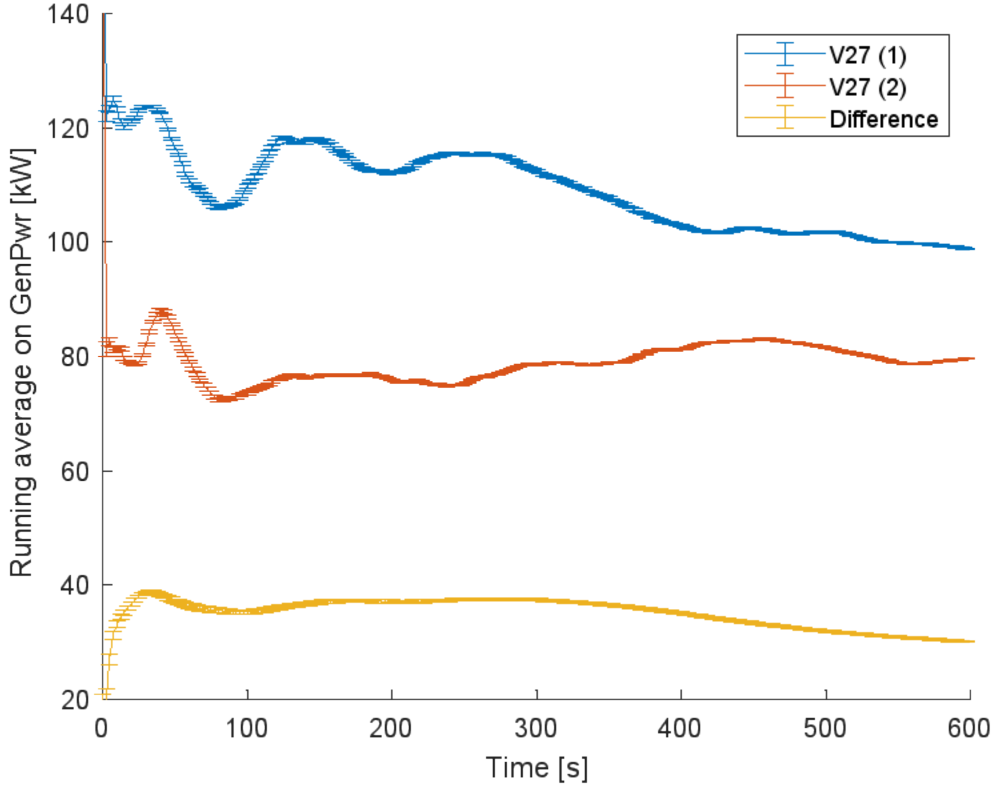
Simulated Sequential Testing

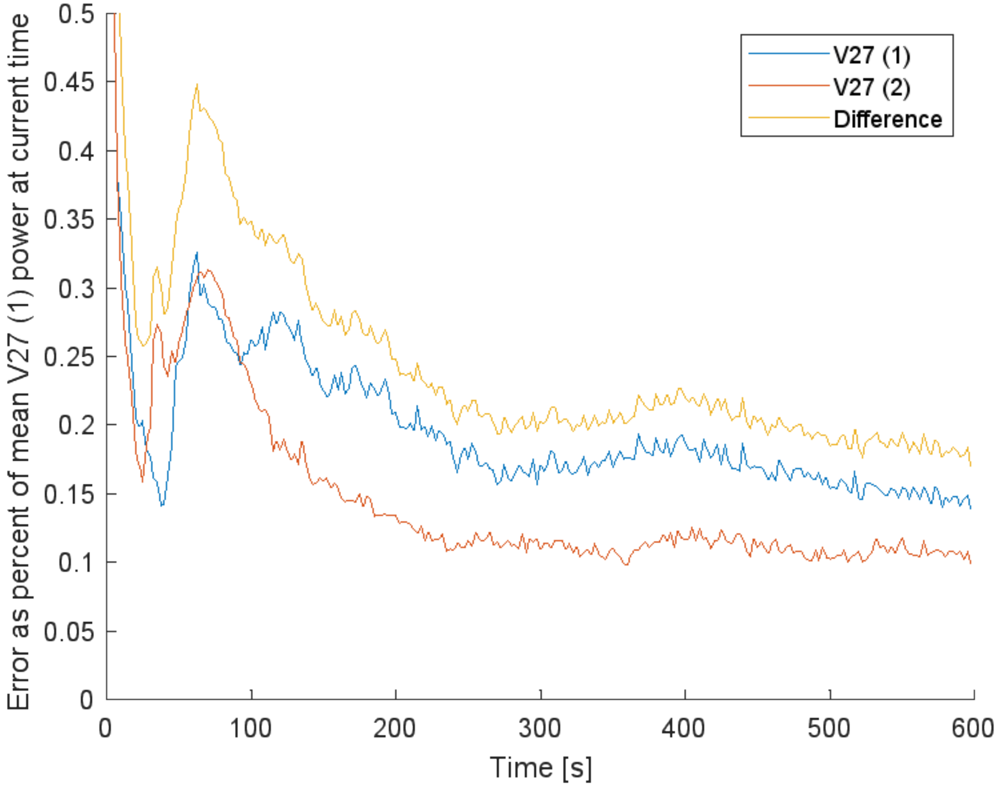


10 minute OpenFAST BEMT simulation with two different TurbSim inflows of the V

Different inflows, so similar to sequential testing, but ONLY one 10 minute dataset

Errorbars calculated with a running bootstrap





Results improve with time and uncertainty in the difference is always higher than the individual uncertainties.

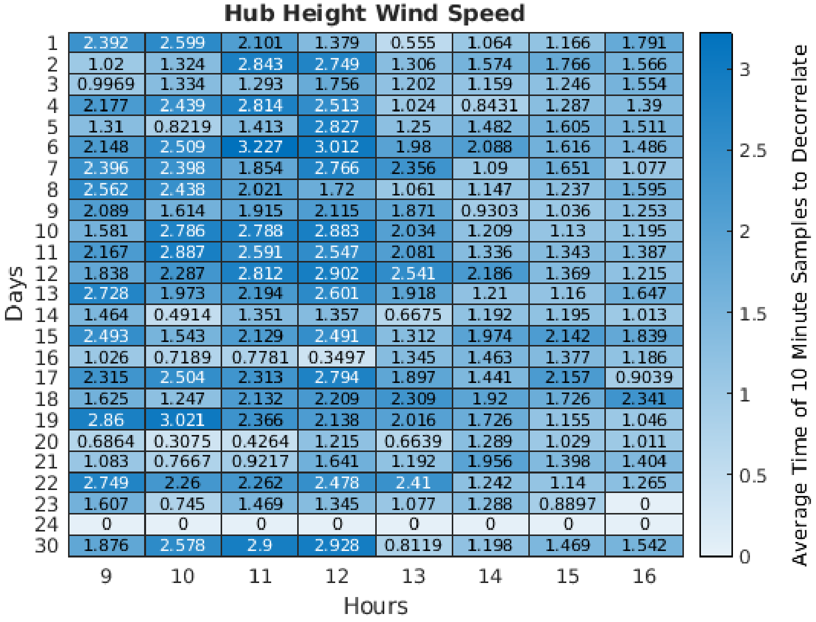
What is bootstrapping?

- So you've done an experiment and have a dataset and want to estimate statistics,
- But the distribution of the data is complicated or unknown,
- And it'd be real hard to repeat the experiment a bunch to get the data you really need,
- Then bootstrap it!
- That is, resample the dataset with replacement to create at least 100 "new" datasets and calculate your statistics of interest on each of those and average the results.
- There. It's like you just repeated your experiment.
- No, this isn't cheating if you do it right.

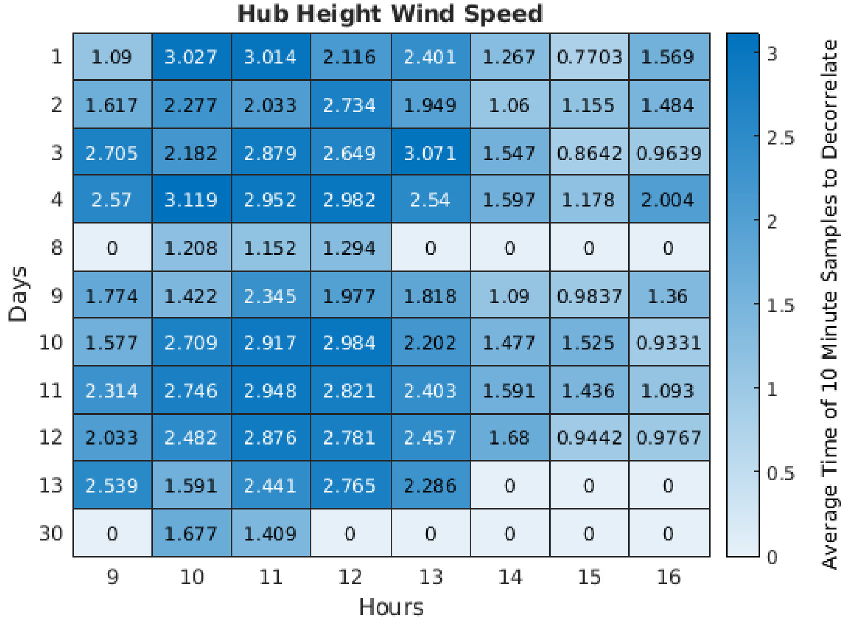
Checking for Correlations

- If any TurbSim variables remain correlated for over 10 minutes, then they do not represent independent 10 minute samples of the inflow
- meta1 and metb1 data from September and October were filtered for working hours, 9 AM-4 PM
- Autocorrelation times were calculated as the time to the first zero-crossing for each 10 minute bin and then averaged for each hour

September meta1



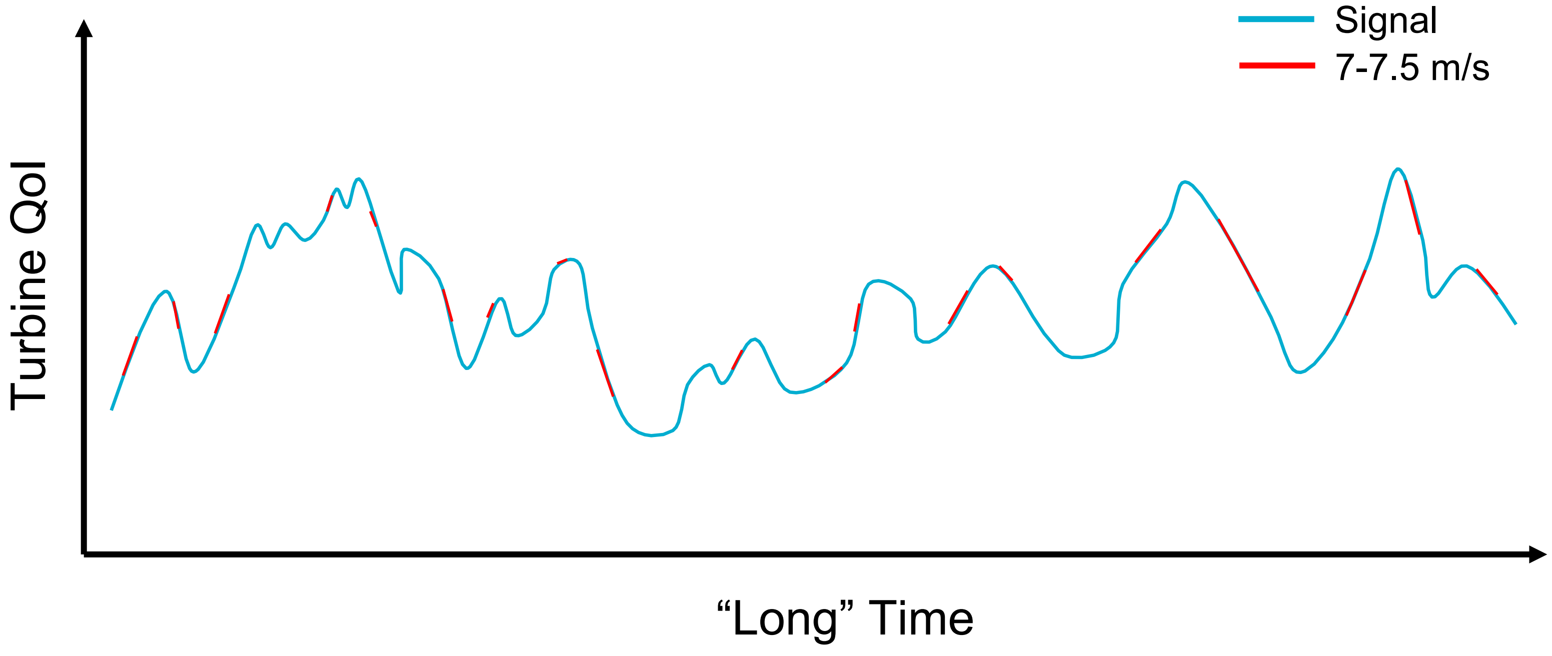
September metb1

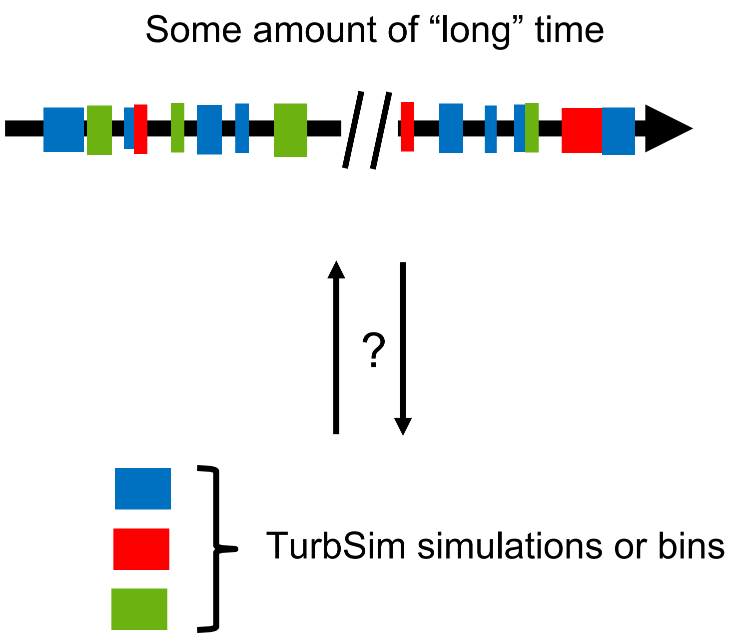


High Level Data Filtering

- Used the already QA/QC’d TTU met data to produce acceptable ranges of values
- Considering September-October and 9 AM-4 PM, calculated the 95% interval for TI, shear exponent, and veer
  - Hub height wind speed: “Visual” filtering, sonics are very reliable and no calculations are needed
  - 0 < TI < 0.4
  - -0.5 < shear exponent < 0.75
  - -35 < veer < 35

Going Between Simulation and Field Data



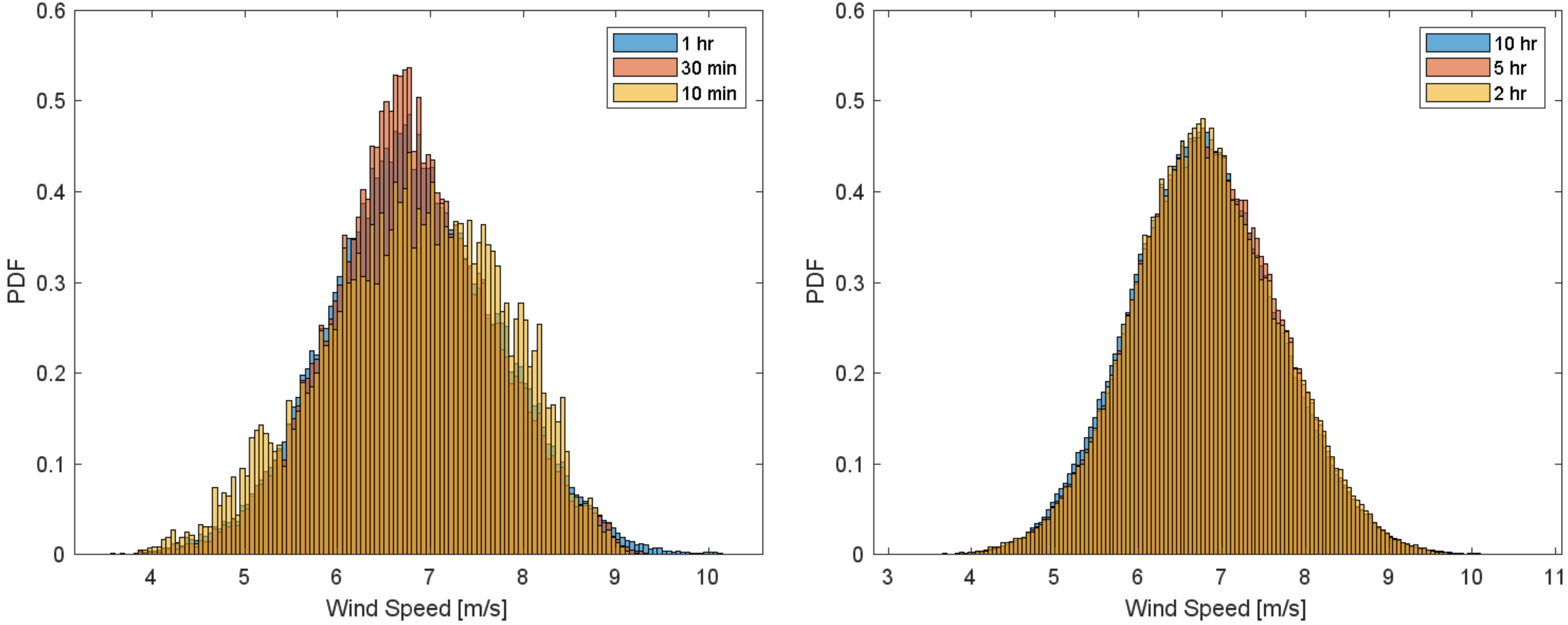


- TurbSim is implicitly binned because inputs are averages
- Raises many questions…

How long should TurbSim/OpenFAST run?

- Standard is 10 minutes
- But our goal is to know how much data we need, so more is better
- And we'll only use one seed since that's a better match to field data

Histograms of *U*

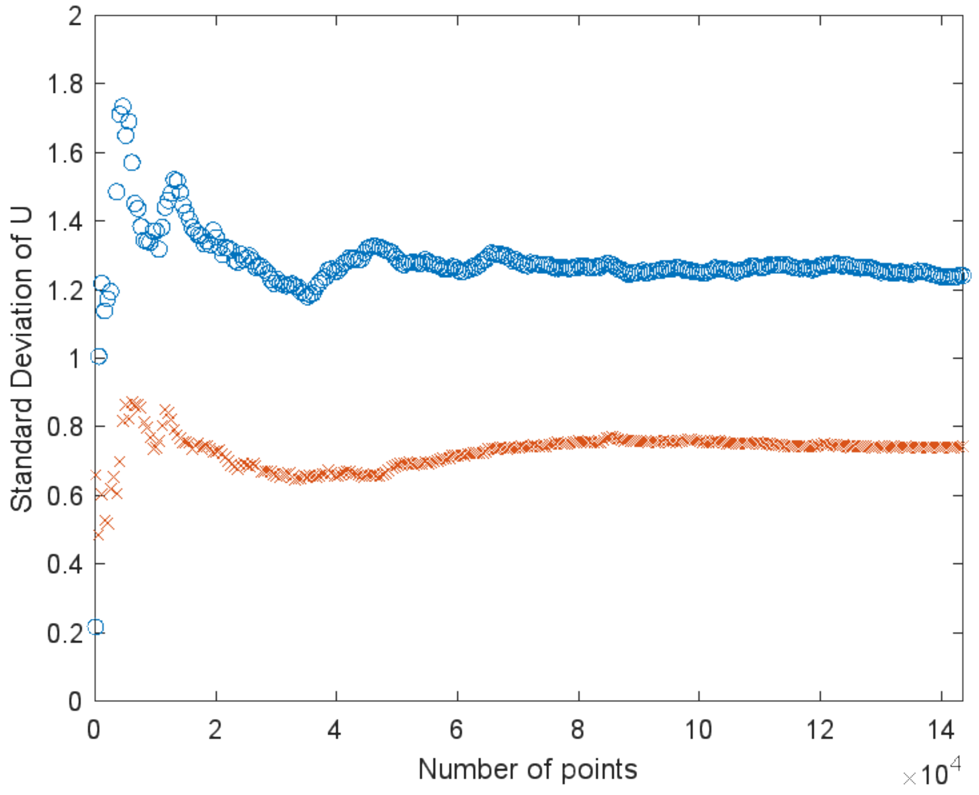


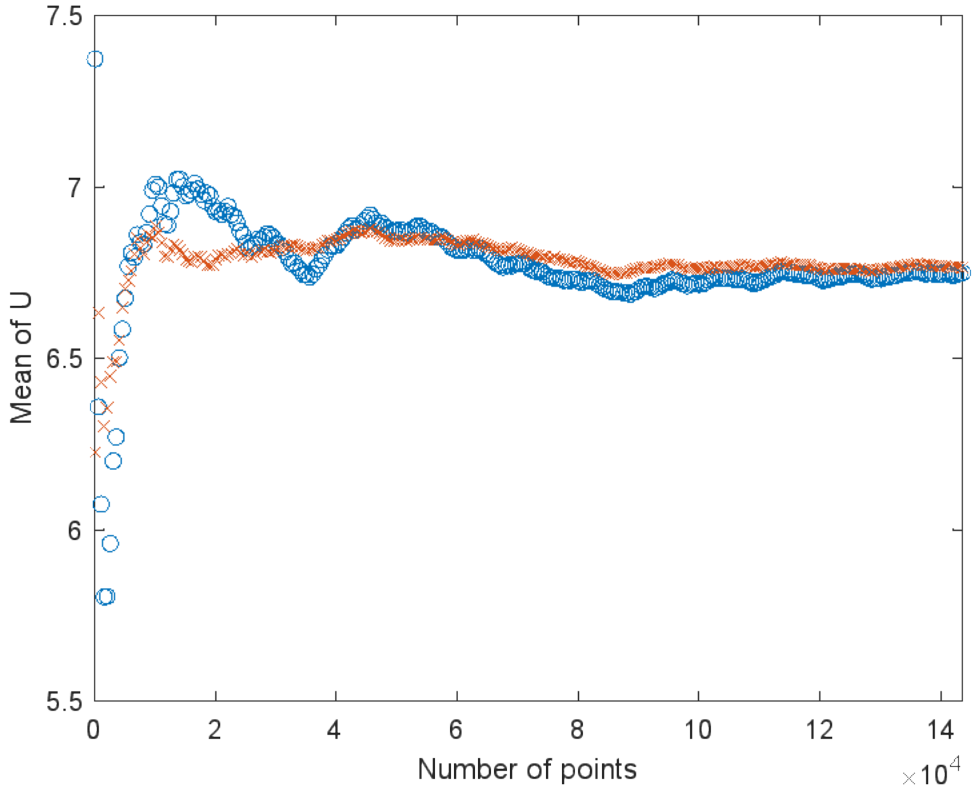
TurbSim prescribed distribution is Gaussian

From TurbSim/OpenFAST to Field Data

- Though simulations from TurbSim/OpenFAST are each implicitly a “bin”, we’ll do enough long simulations that we can aggregate the data – we don’t care about time series
- Then we can rebin on different parameters
  - Wind speed
  - TI
  - Shear
  - Stability?
- Quantify how the binning affects the uncertainty of the QoI
- Given best binning procedure, repeat it with met data to determine how much field data we need to get the same bins (in definition and amount of data in each)

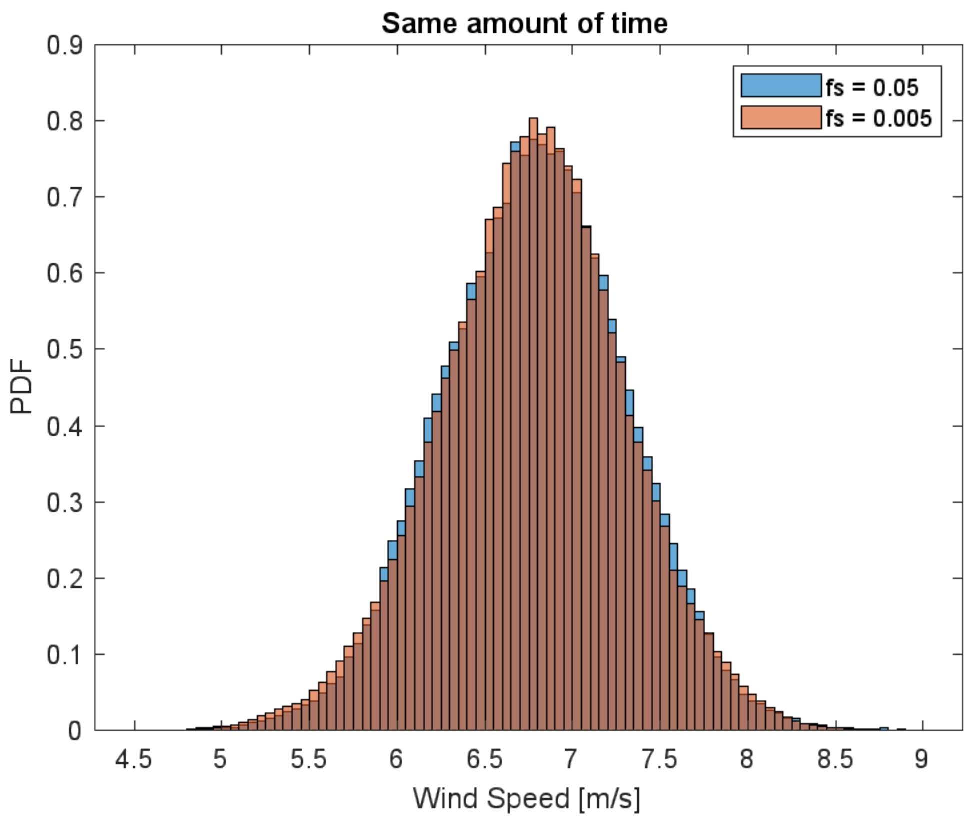
Convergence of different TI levels

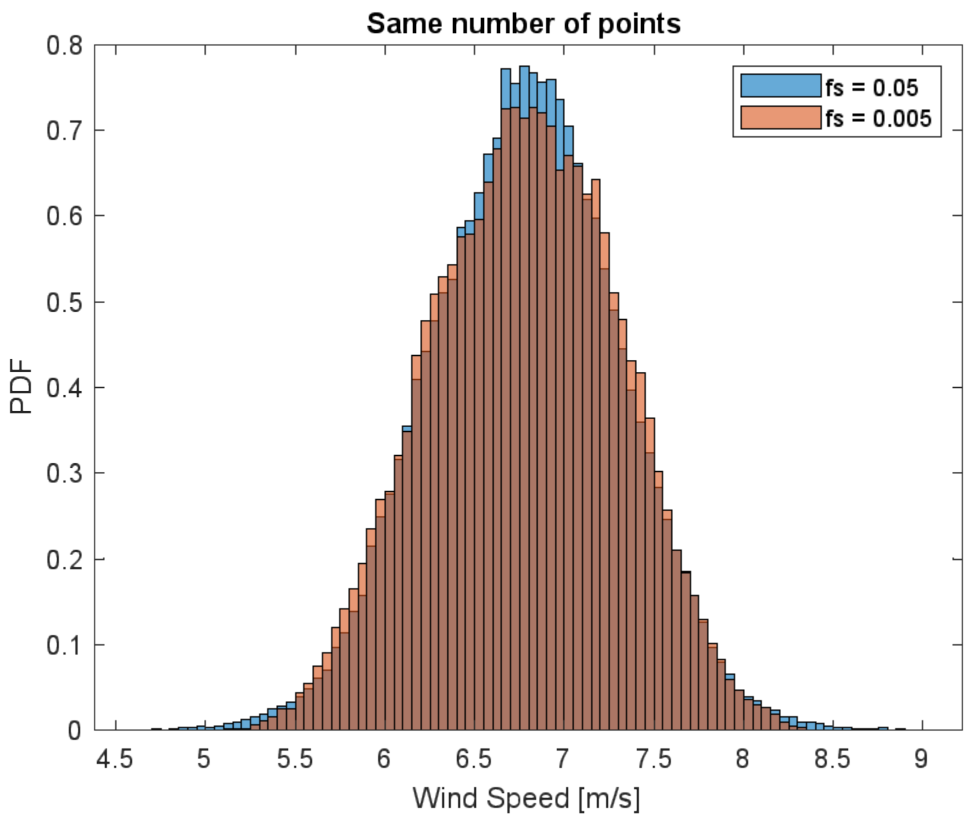




Visually, it looks like the high (blue) and low (red) TIs converge at the same rate, all else being equal.

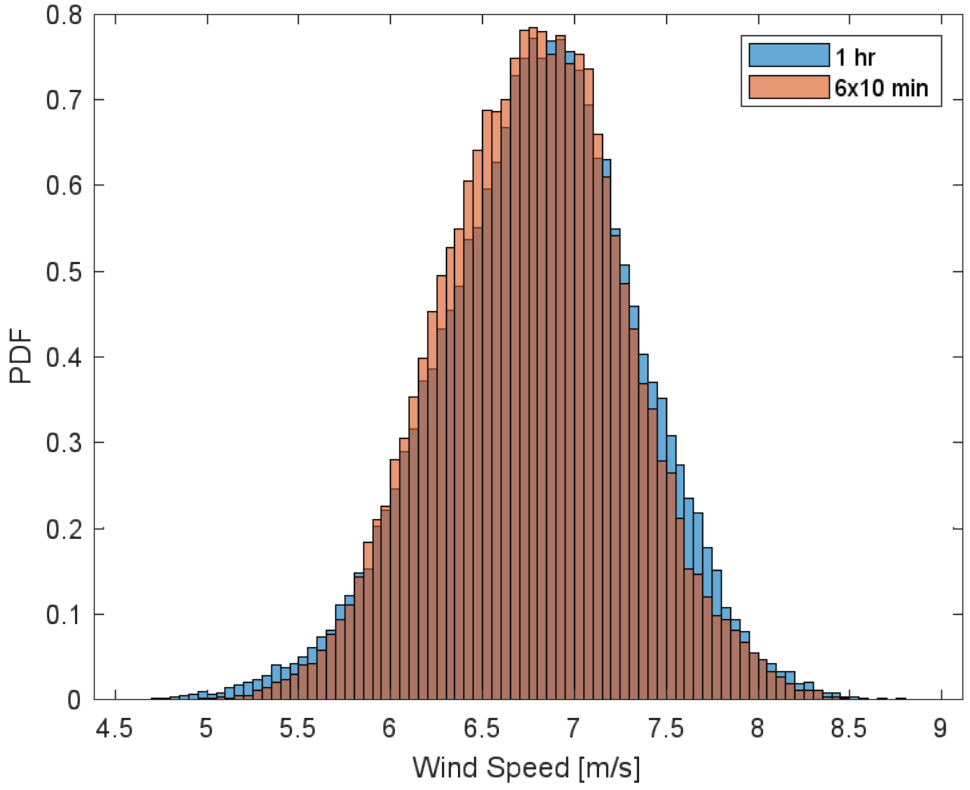
Comparing different sample rates





Looks like they approach more similar distributions with the same amount of time and not number of points. Note, the lower sample rate has more data in its tails than the high sample rate when they have the same number of points.

1 hr compared to 6x10 mins



	Mean	Std. Dev
6 – 10 min	6.7554	0.7171
1 hr	6.8022	0.7466
2 hr	6.7641	0.7413

The increase in standard deviation between the six 10 min sims and the 1 and 2 hr ones suggests that the aggregate of the six 10 min sims is missing some data in the tails.