Environmental Influences on Turbine Performance

Recent results

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GE Wind Validation

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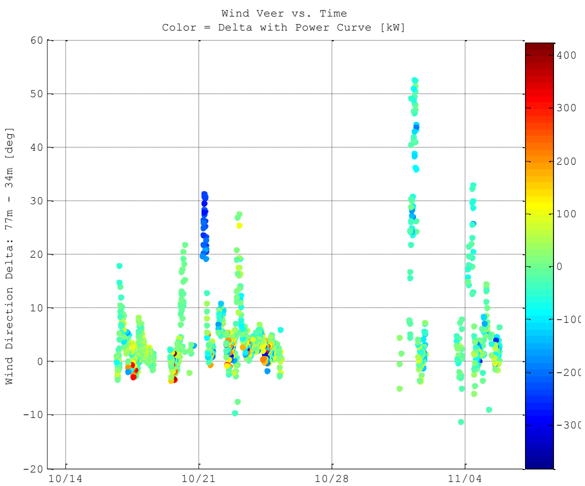
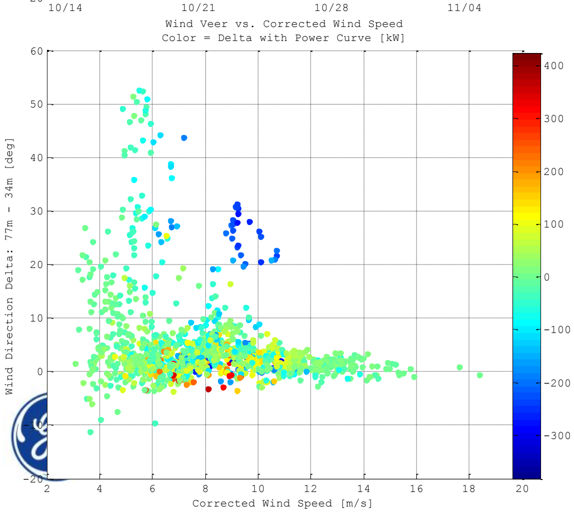
Overview

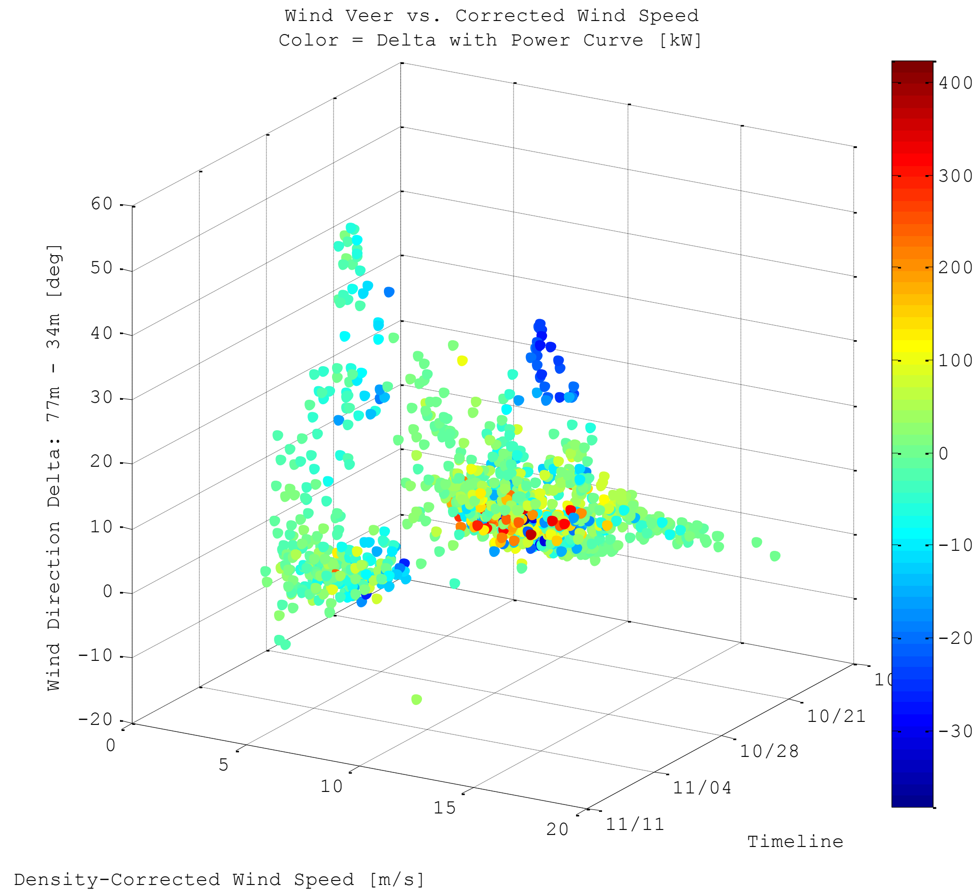
- It is known in the greater wind turbine power performance community that environmental factors outside the standard TI/shear behavior influence performance
- Recent campaigns undertaken on turbines support added attention to other known environmental phenomena:
  - Wind Veer: direction difference in incoming wind speeds as a function of elevation
  - Directional performance drops: the greater picture
  - Met mast placement as a function of prevailing winds and relative to the tested turbine
  - Rotor-equivalent wind speed

Wind Veer

- At one site, over four hours of consecutive data with 10min avg wind speed > 8.5 m/s, and directional delta bet. lower tip and hub height > 22° → strong under-performance
  - Post-campaign in-situ calibration verified there was no offset between the two wind vanes at elevation → no incorrect bias

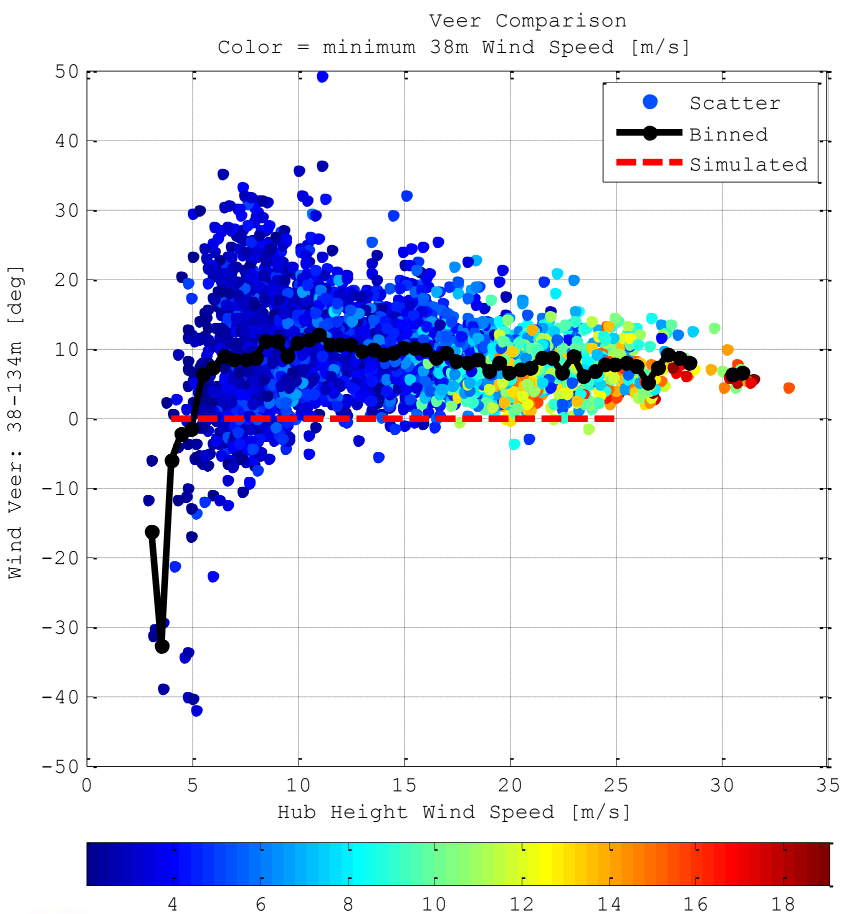


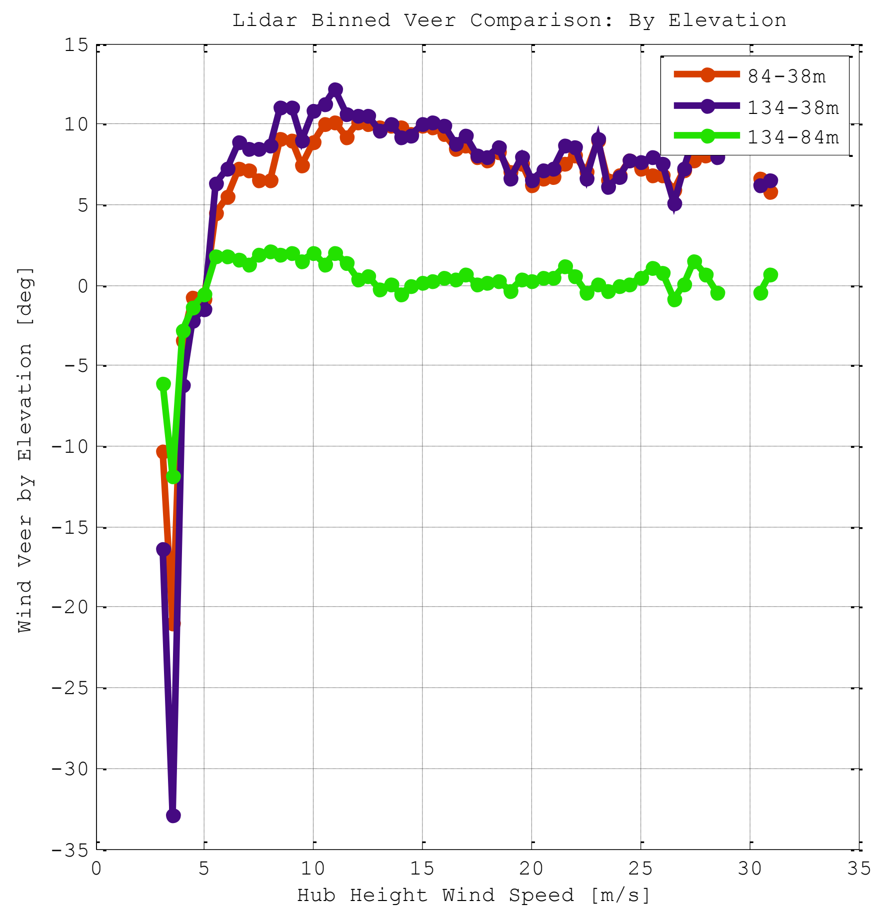




Wind Veer

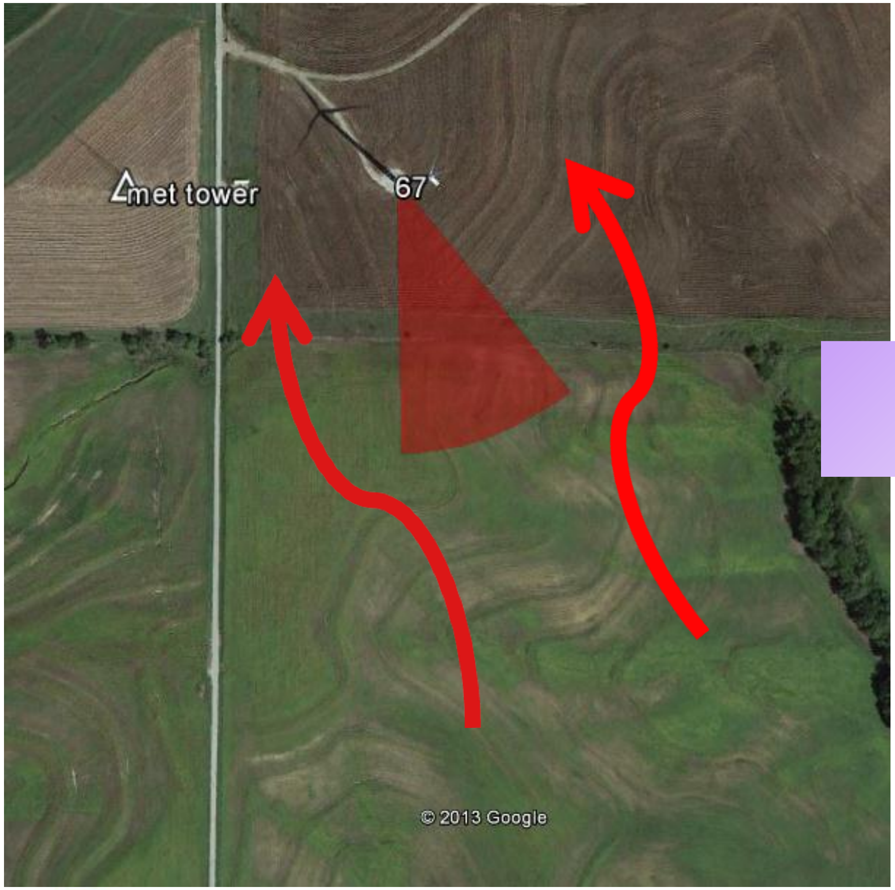
- Lidar data shows another site with binned 10min average veer ~10° between lower tip and hub heights

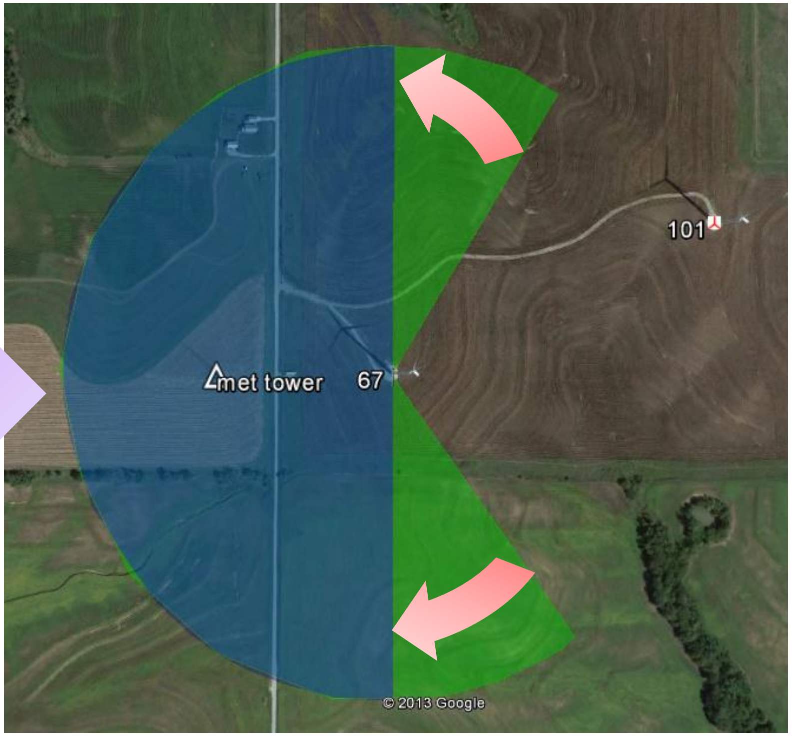




Directional Dependence

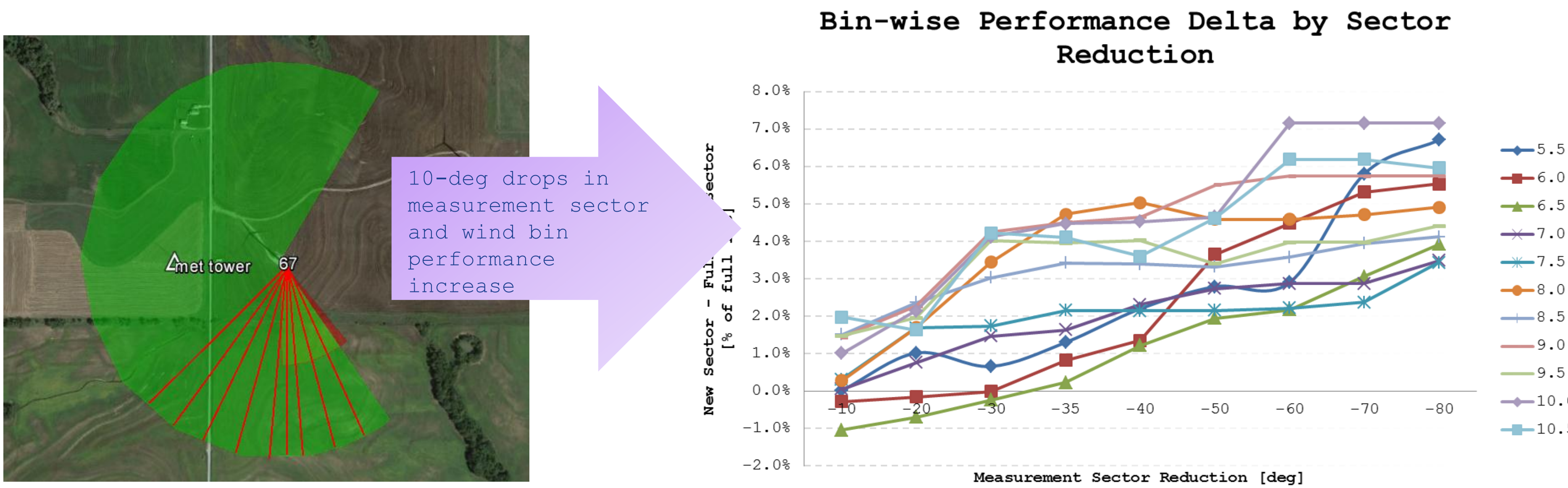
- On a site with a site calibration, flow around turbine could be accelerated at the met tower, skewing performance data





Directional Dependence

- Looking at the bin-wise performance trend as the sector is reduced reveals strong evidence for discarding data
- Systematically reducing measurement sector shows strong increase in bin-wise performance
  - Faster wind moving around turbine ‘back pressure’ zone
  - Faster wind hits met mast → ‘artificially’ drops turbine performance

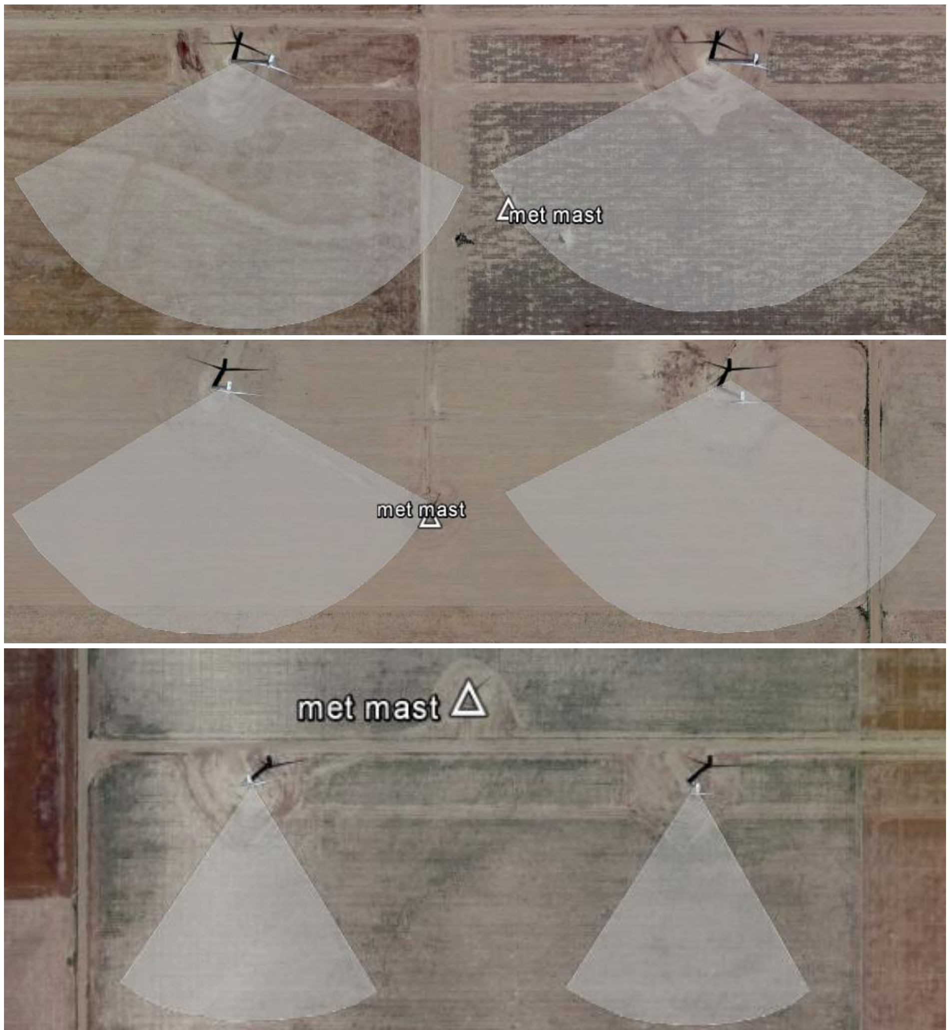


Takeaways:

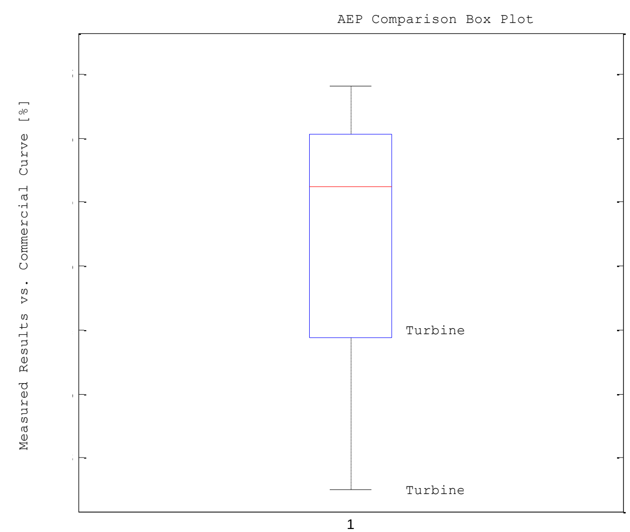
- Though further reduction of the measurement sector could be warranted and would improve results, cuts were limited to 65° of total available sector, or 26% total reduction

Met Mast Placement

- Placement of the met mast need not 'blindly' follow IEC criteria → could skew results
- At one large, flat site, six turbines selected for power performance testing, serviced by three met masts → Performance of machines with met behind is much worse than met-in-front turbines

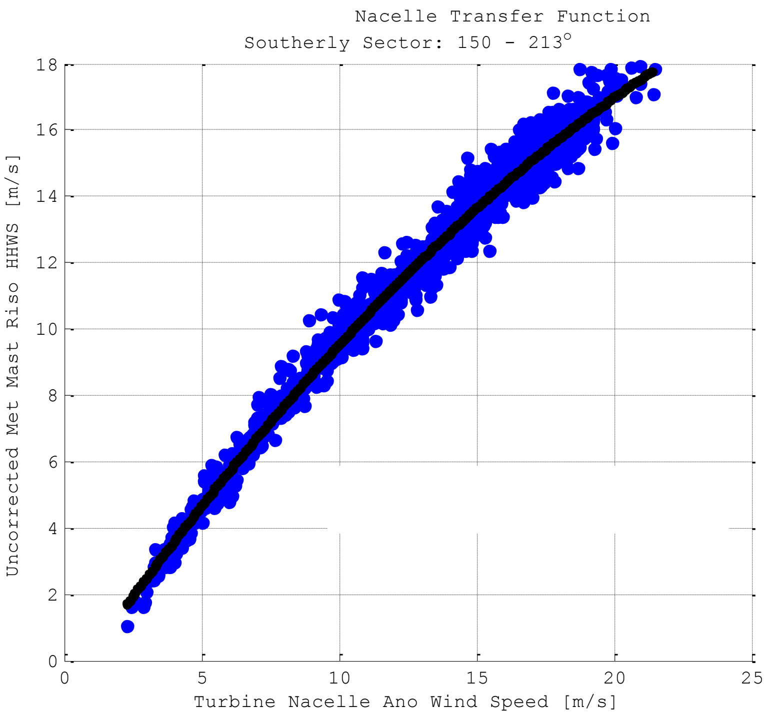


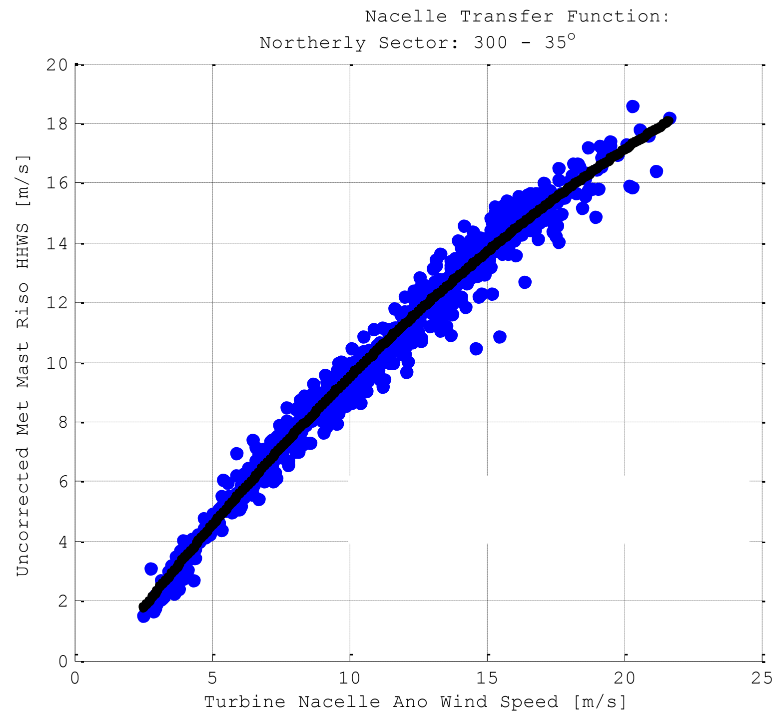
- One mast servicing two turbines
- Mast is at least 'upwind' of operational turbines for 4/6 machines
- For two turbines the met mast is 'behind' the machines → does this accurately capture the free stream wind speed hitting the turbine?



Nacelle Transfer Function: Quadratic

- Compare the quadratic NTF with data from the south and north
- Theoretically, there should be no change between the two when not correcting for density → just the raw ano:ano comparison
- Data does show a change in the TF – slight, but potentially significant





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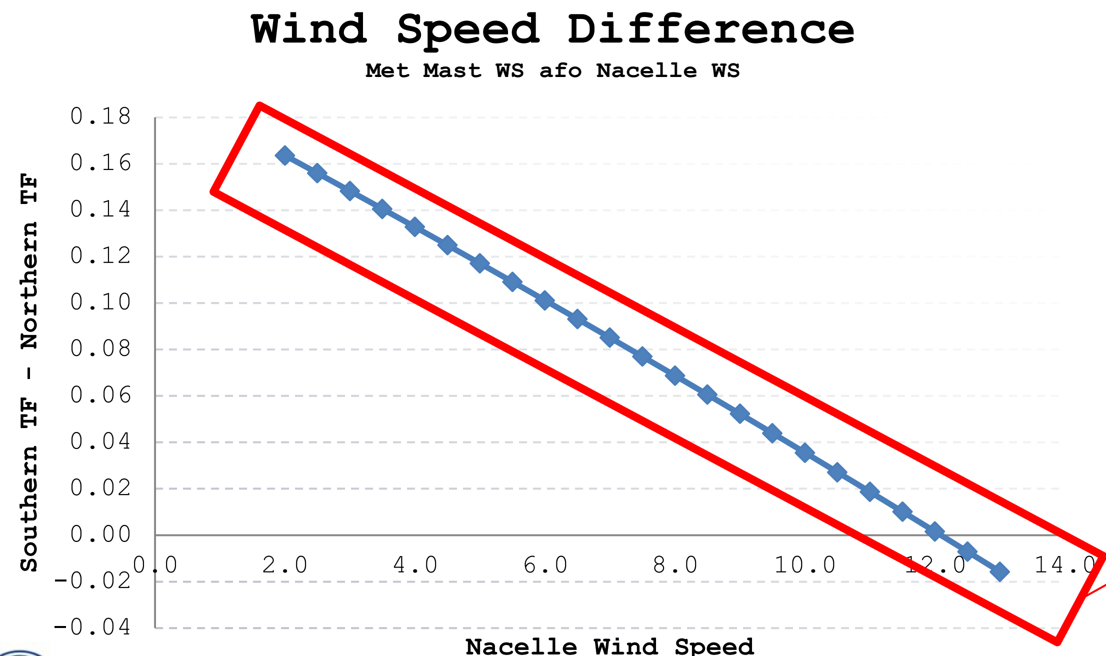
Nacelle Transfer Function: Quadratic

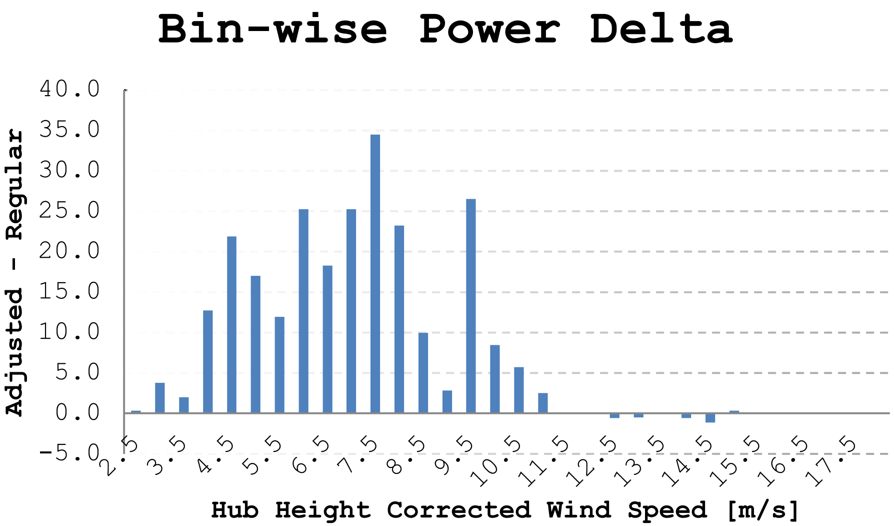
- Assume the nacelle anemometer is accurate as a baseline against which a met tower can be compared from both → major assumption
- What is the impact of those different transfer functions?
- When winds are southerly prevailing, the met tower reads a "higher wind speed"
- Compare the transfer functions to see the magnitude of the difference

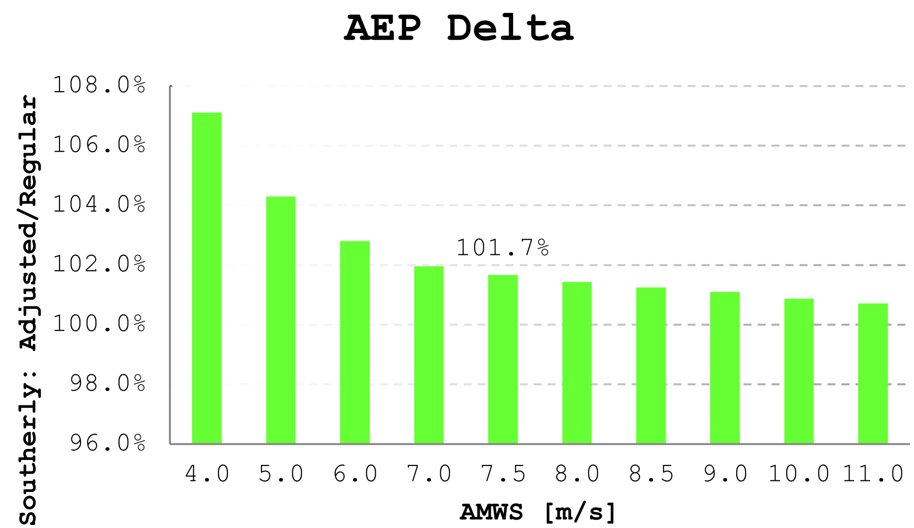


What happens if this 'adjustment' is applied to the southerly data?

Nacelle Transfer Function: Quadratic

- Expectedly, the power curve improves because the wind speeds were adjusted downward on a bin-wise basis
- Magnitude is significant
- Unable to perform ‘controls’ on the other turbines due to their being waked from the north by neighboring turbines





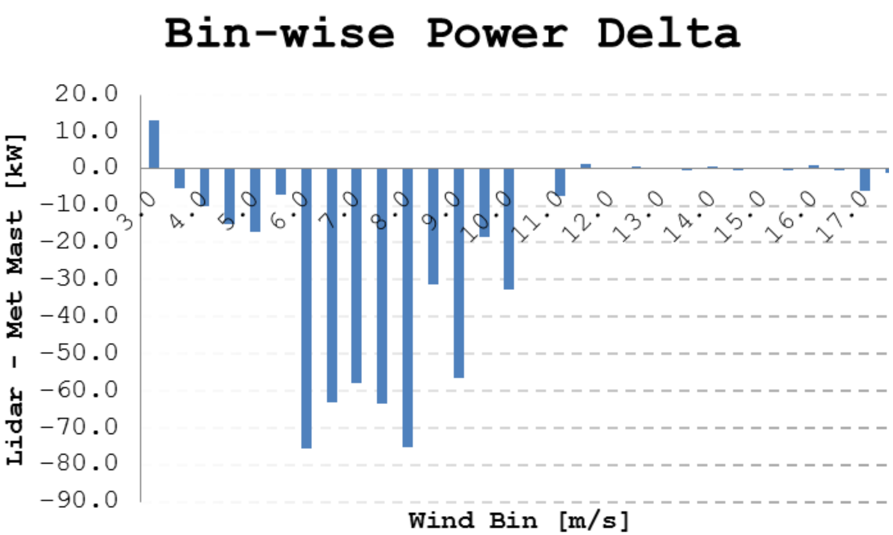
Takeaways:

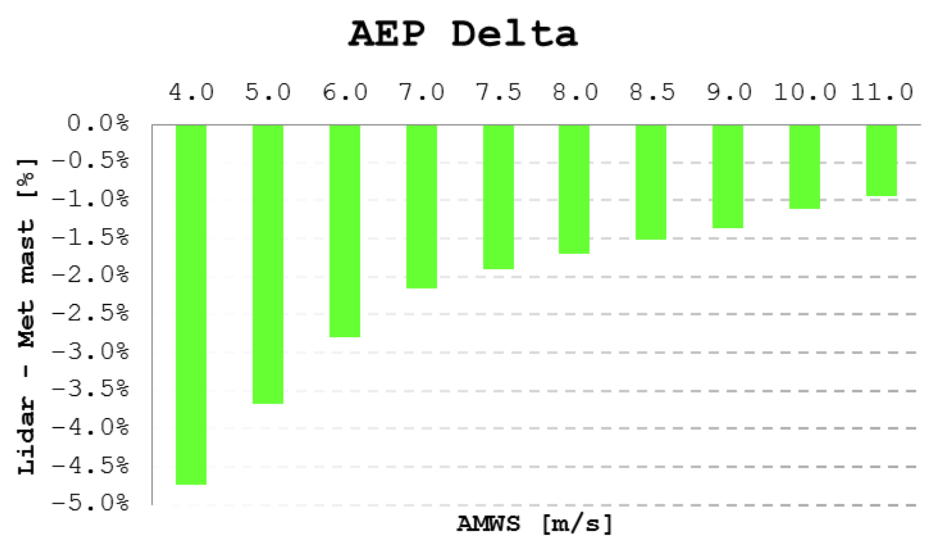
- ‘Adjusting’ the southerly met readings to match northerly NTF shows a bias in the reading
- Impact on power curve could exceed 1% AEP

Rotor Equivalent Wind Speed

- A ground-based lidar was placed near the met tower at a validation campaign, allowing the calculation for rotor-equivalent wind speed as compared to a single hub height anemometer
- Keeping all other variables constant, the resulting power curve calculation with the existing rotor-equivalent wind speed was comparatively lower: 1 – 2% Relative AEP drop

$$V_{eq} \cong \left(\sum_{1}^{n} {V_n}^3 * v \right)^{\frac{1}{3}}$$





Takeaways:

- A combination of larger rotors and high wind shear can create situations where turbines can't capture all energy available in a stream tube

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Conclusions

- Wind veer is being observed with more intensity and frequency at tested sites
  - Strong veer 'events' are correlated with underperformance
  - Should be considered in site assessment and turbine performance evaluation
- Directional dependence indicating that large measurement sectors may be good for quickly filling capture matrices, but perhaps less advantageous for accuracy
  - In existing campaigns, directional breakdown of performance should be considered, if possible.
- Met mast placement → is there an aversion to placing met towers up-wind of turbines?
  - Selection of turbines and met mast placement should receive scrutiny by all parties
  - Recommendations:
    - Place met mast in at least one section of the calculated measurement sector up-wind of the turbine with a strong probability of experiencing the prevailing wind during the measurement campaign
    - If directional dependence is expected, quantification of performance impact can be calculated
- Rotor equivalent wind speed could be dropping measured performance
  - Especially with large diameters and high wind shears, the wind speed used for analysis should be carefully considered