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Quantification of the Impact of NRG Sensor Drag on Yield Assessments

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Presentation Overview

- Problem Definition
- Fundamental Causes
- Methods of Detection
- Impact on Yield Calculation: Method
- Impact on Yield Calculation: Results
- Uncertainty Analysis: Case Study
- Conclusions



Problem Definition

- GENIVAR Investigation Timeline
  - GENIVAR'S observation of field data revealed 'sensor drag' with NRG#40 and SecondWind C3 cup anemometers
  - GENIVAR focused its efforts to understand the NRG#40 problem
  - GENIVAR and NRG cooperated to improve drag detection method and characterize the behavior

Problem Definition

- Client concerns arose related to yield calculations
  - Can quality assurance mitigate the problem?
  - Can an estimate of the P50 error be made?
  - Can an estimate of the impact on the P90 be made?

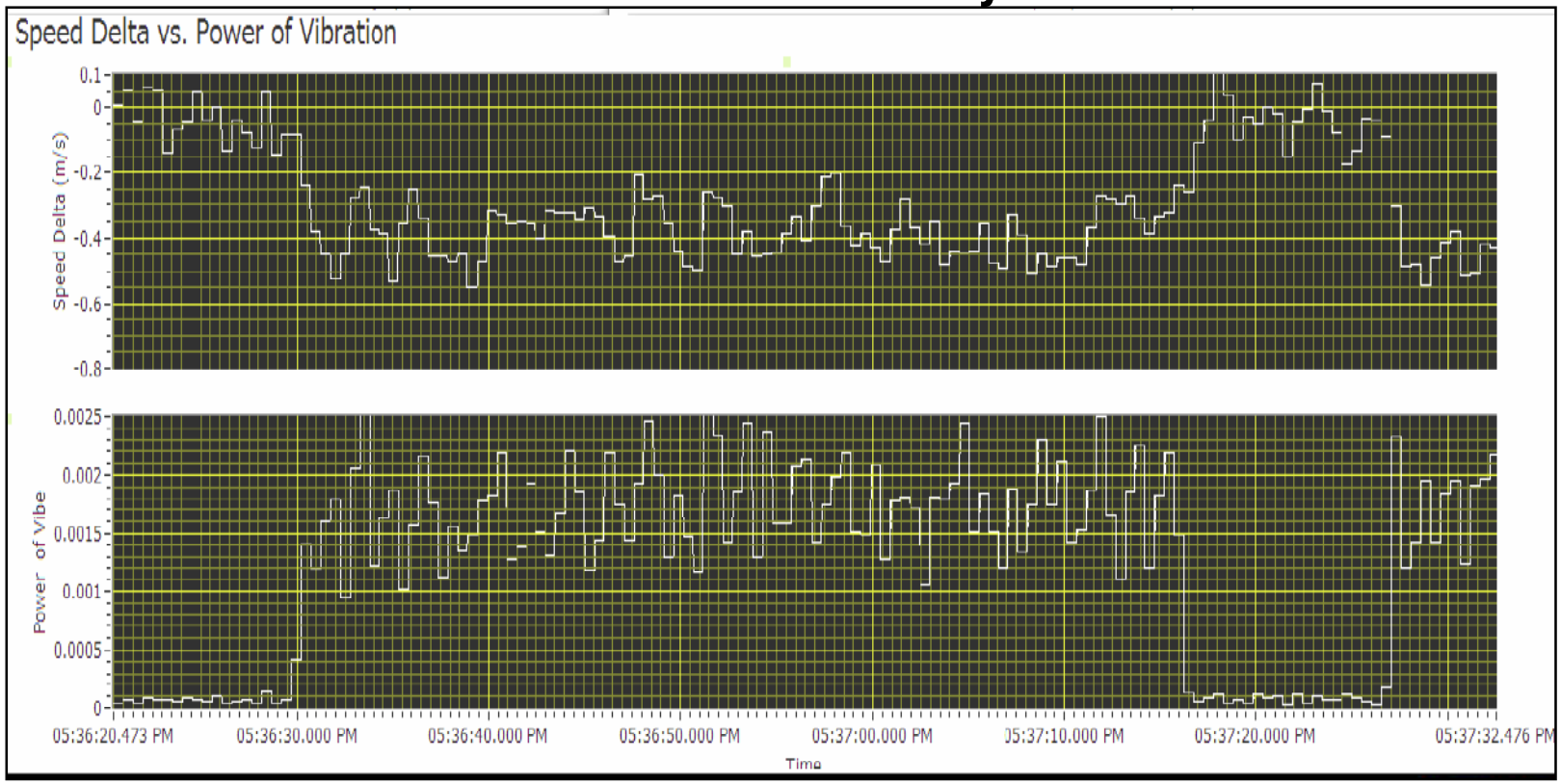
Fundamental Causes

- Tower, logger, and sensor epoxy eliminated as root cause
- Regular wear
- Evaluation of **Vibratory Mode*** in wind tunnel
  - Drag occurs sporadically
  - Sensor slows down by approximately 0.3 to 0.6 m/s
  - Typically occurs as wind speed is decreasing
  - Higher frequency of drag occurs in 4-10 m/s range
  - NRG currently confirming wind tunnel tests on tower mounted sensors

*Source: Owen Clay, NRG #40 Anemometer Performance, AWEA Wind Resource and Project Energy Assessment Workshop, September 24-25, 2008

Fundamental Causes: Vibratory Mode

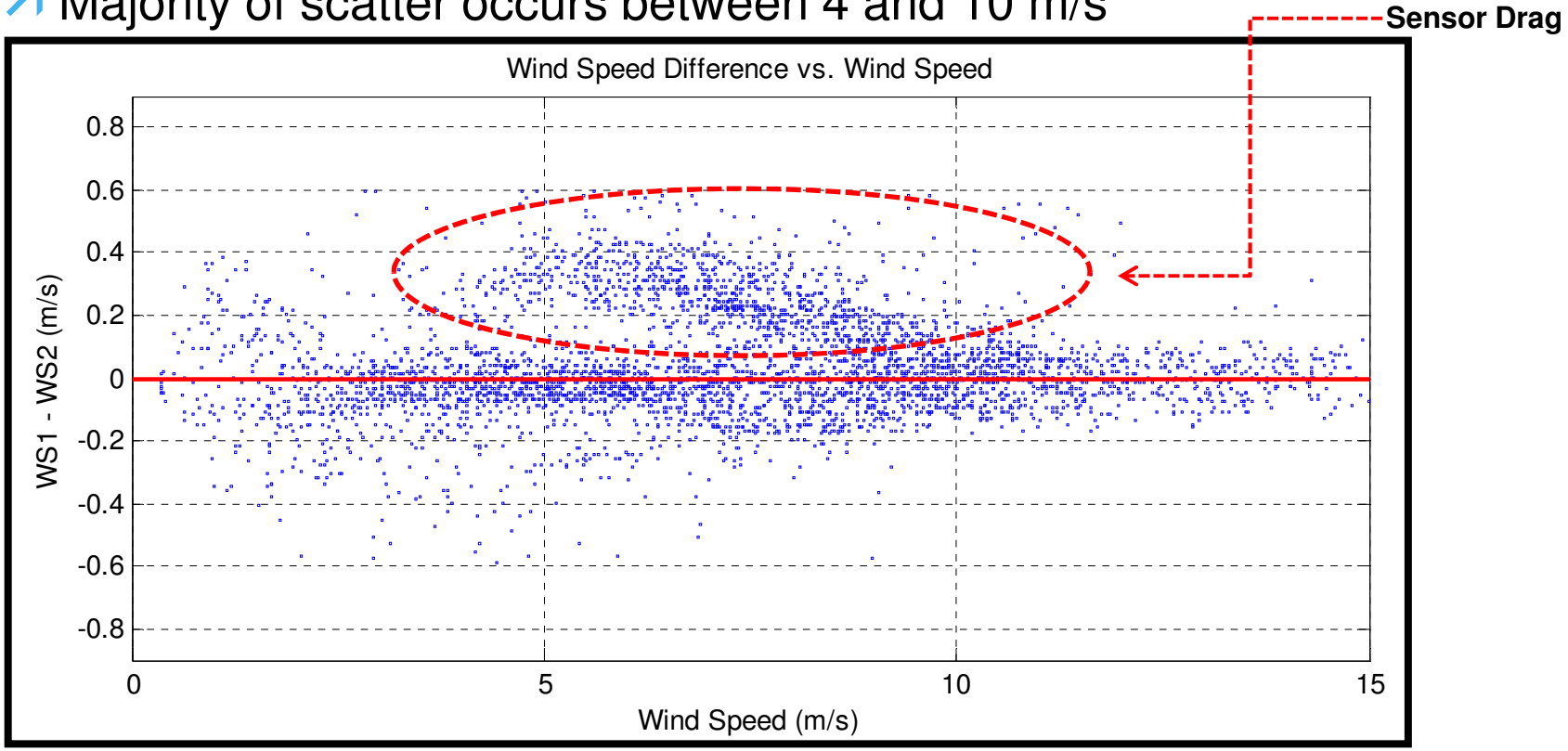
- NRG tests illustrate the onset of **Vibratory Mode**



*Source: Owen Clay, NRG #40 Anemometer Performance, AWEA Wind Resource and Project Energy Assessment Workshop, September 24-25, 2008

Fundamental Causes

↗ Majority of scatter occurs between 4 and 10 m/s



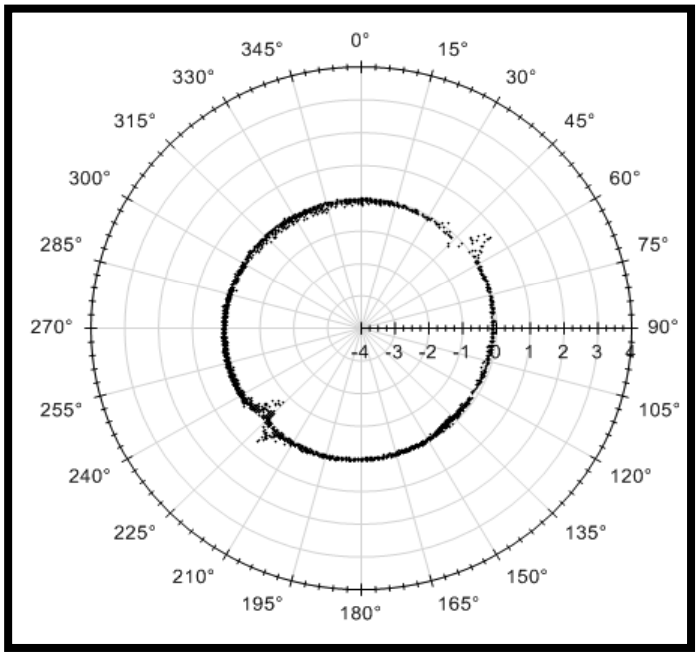
Top-level tower data, 10-minute averaging period

Drag Detection Methods

- Qualitative: WindServer™ Tower Shadow Plots
  - Polar plot of Wind Speed difference (ΔWS) vs. Wind Direction (WD)
- Quantitative: Wind Speed Error Analysis
  - Analysis of the distribution of ΔWS of redundant sensors
    - High ΔWS Standard Deviation indicates sensor drag

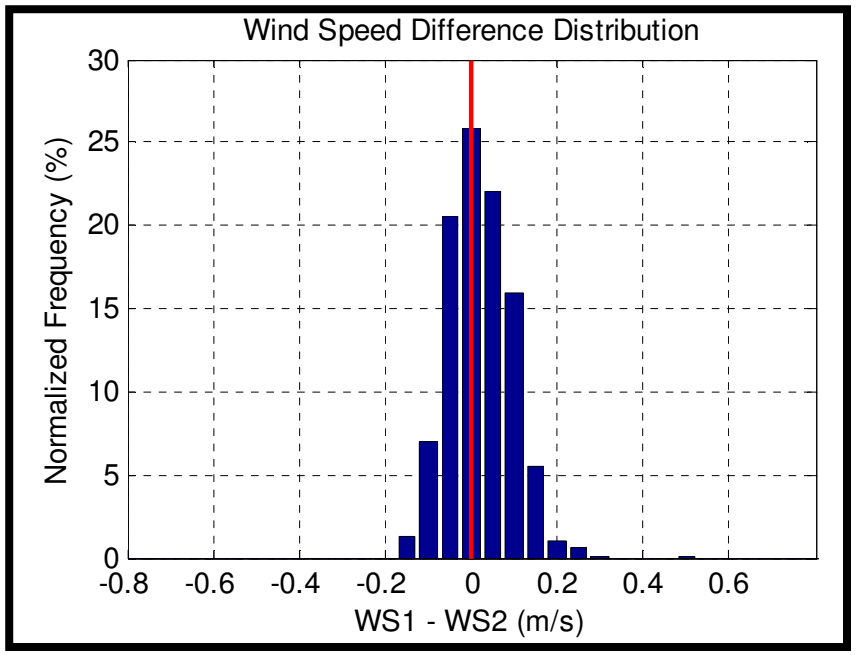
Drag Detection – WindServer™ Tower Shadow

No drag



Courtesy: WindServer™

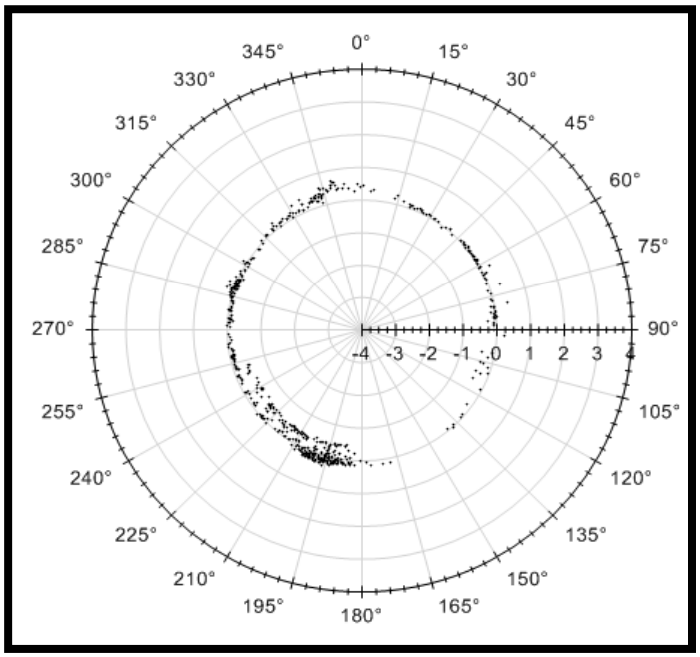
No drag



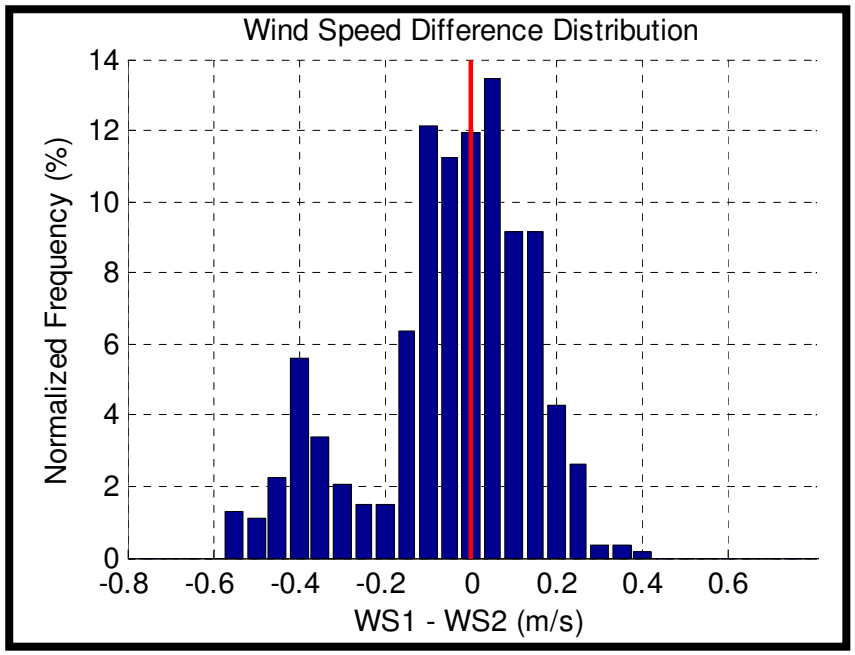
1 month of data, WS > 4m/s, Temp > 5˚C

Examples of Different Drag Characteristics

- Drag is different for each sensor: 1 month of data



Courtesy: WindServer™



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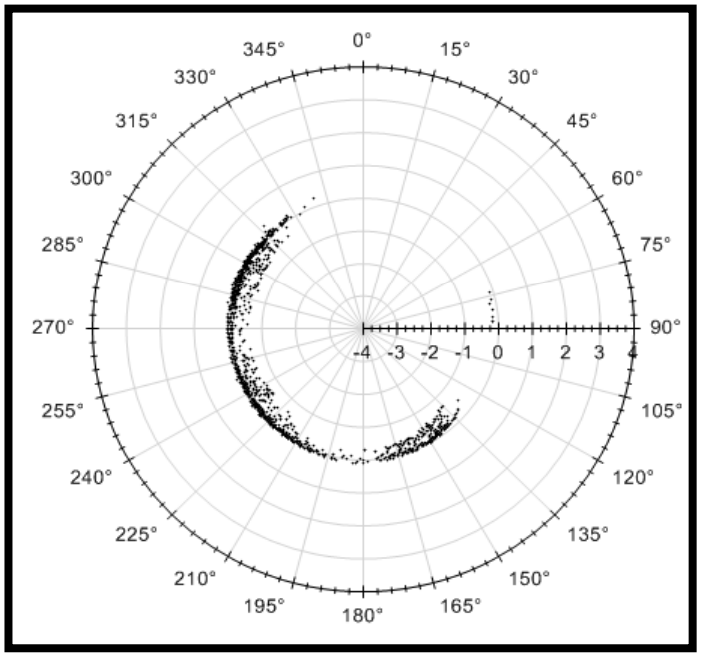
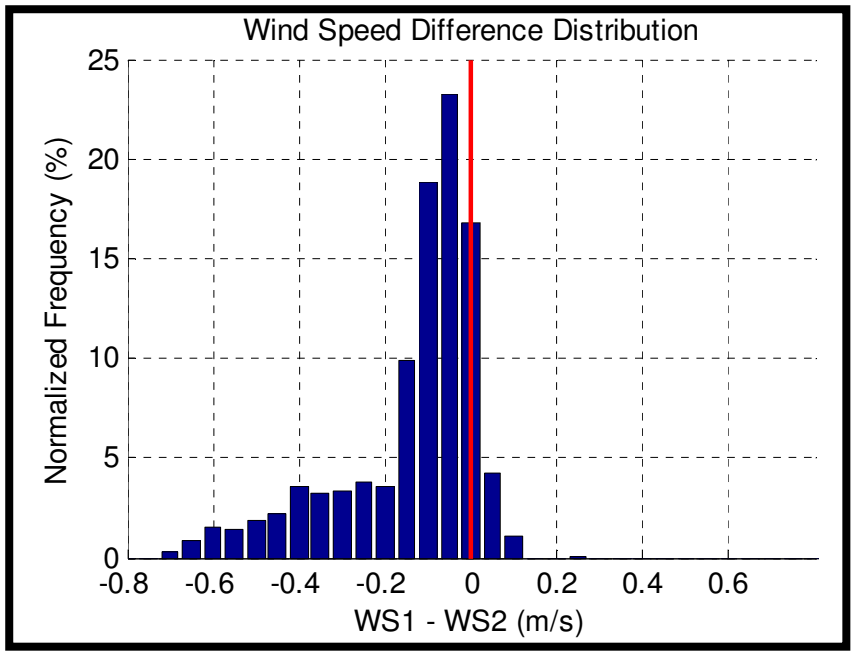


Courtesy: WindServer™



1 month of data, WS > 4m/s, Temp > 5˚C

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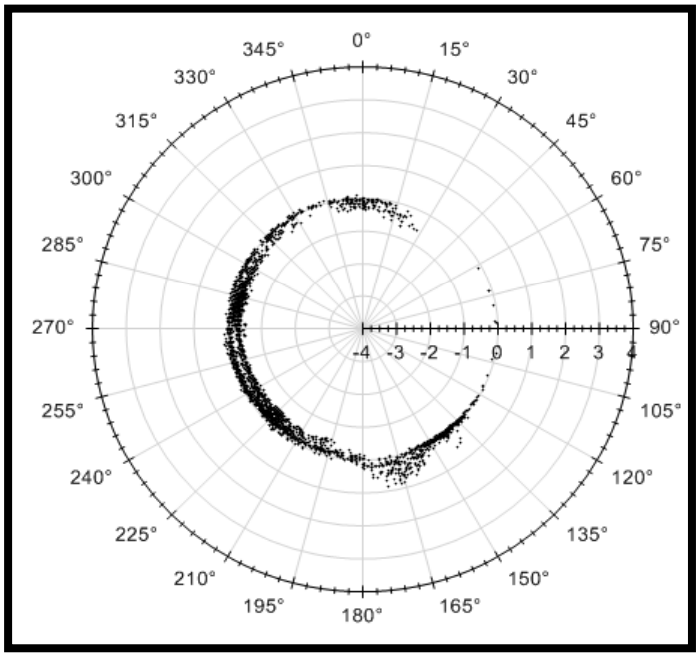
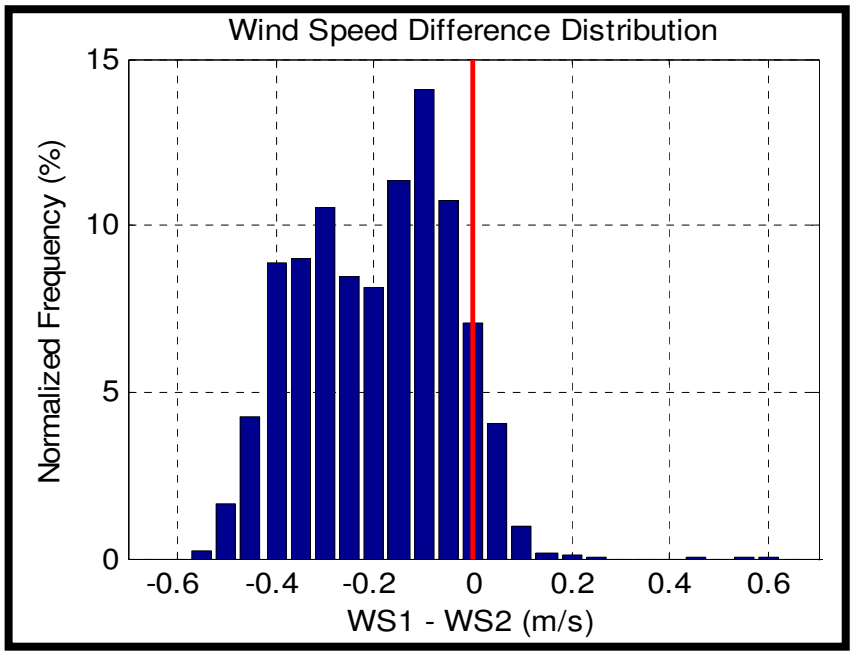


Courtesy: WindServer™



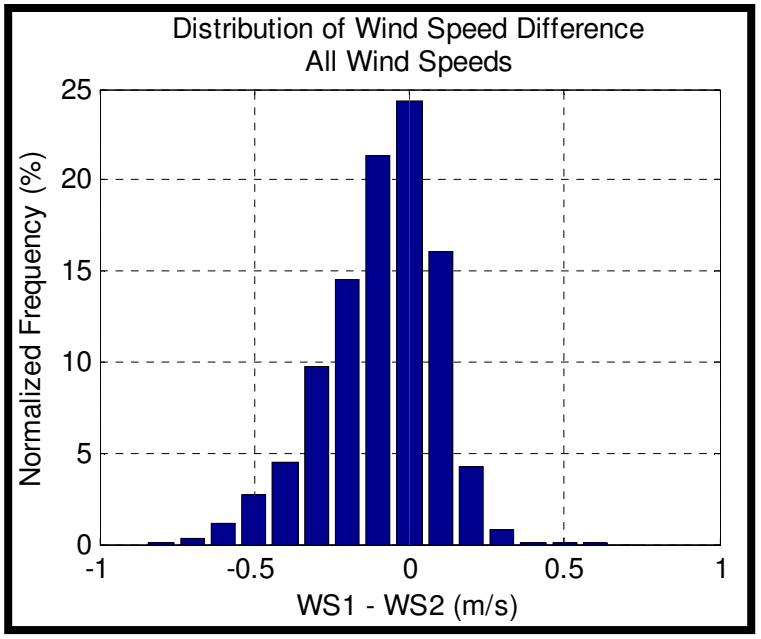
1 month of data, WS > 4m/s, Temp > 5°C

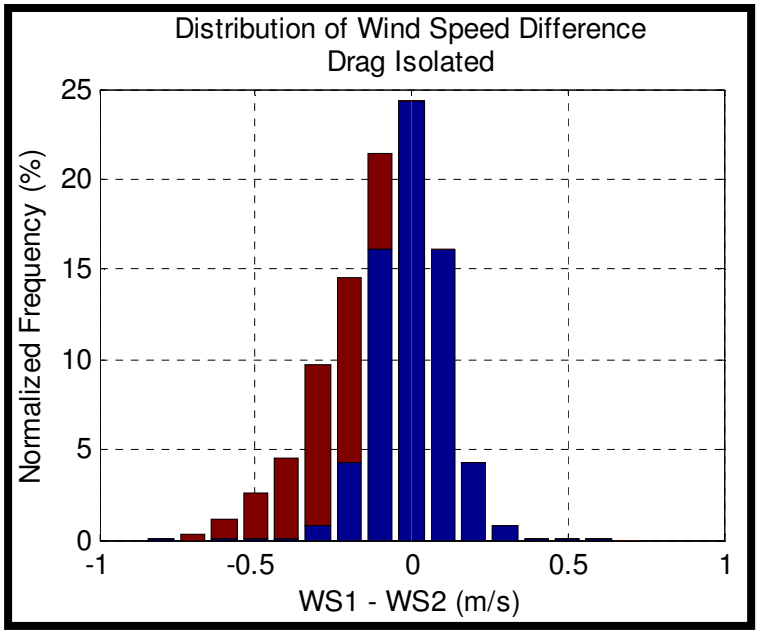
Impact on Yield Calculations: Method

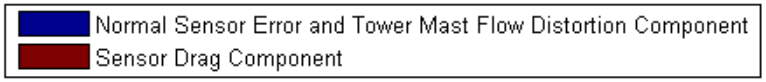
- Quantify the effect of drag on a yield calculation
  - Characterized drag from a sample of 33 top-level sensor pairs
  - Applied representative drag error to non-dragging data
  - Calculated yield for various scenarios:
    - Tower configurations
    - Quality assurance

Impact on Yield Calculations: Results

- Isolate single-sensor drag
  - Taken from sample of 33 pairs of sensors with single sensor drag, for one month

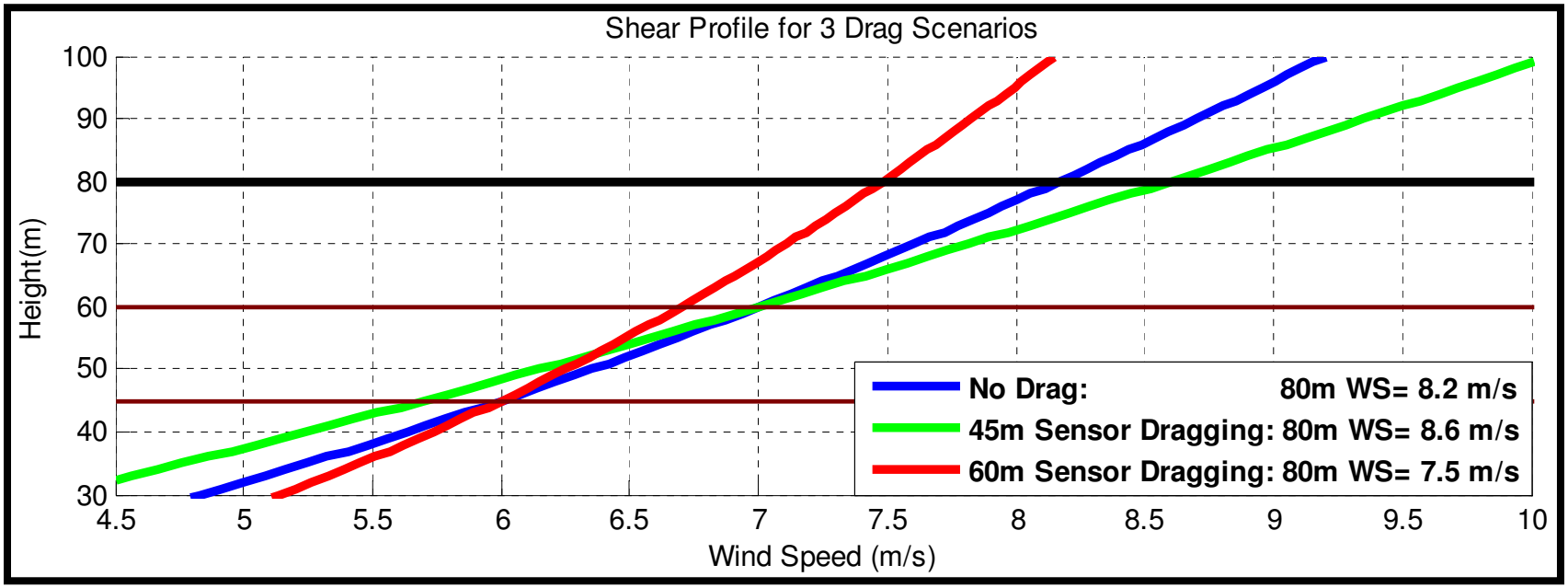






Impact on Yield Calculations: Results

- Sensor drag at top monitoring heights underestimates yield
- Sensor drag at lower monitoring heights overestimates yield due to exaggerated shear



Impact on Yield Calculations: Results

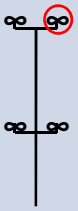
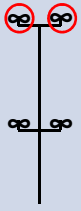
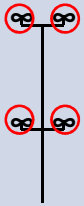
- Percent error of P50 yields relative to non-dragging yield calculation

Maximum Yield Error*

Average Yield Error*

Minimum Yield Error*

*Based on 33 cases examined

Typical Quality Assurance - Averaged Wind Speeds, Filtered Tower Shadow		
 -0.5% -1.8% -3.6%	 -0.5% -3.3% -7.5%	 1.5% -2.2% -7.5%
 1.5% 0.7% -0.5%	 3.3% 1.4% -0.5%	 3.3% 0.1% -3.6%
 1.5% -0.6% -3.6%	 3.3% -1.4% -7.5%	

- Yields based on Class II wind regime and representative Class II turbine technology



Impact on Yield Calculations: Results

- Percent error of P50 yields relative to non-dragging yield calculation

Maximum Yield Error*

Average Yield Error*

Minimum Yield Error*

*Based on 33 cases examined

GENIVAR WindServer™ – Quality Assurance		
 0.0% -0.1% -0.3%	 0.0% -1.2% -5.9%	 0.1% -1.2% -5.9%
 0.1% 0.0% 0.0%	 2.8% 0.7% 0.0%	 2.8% 0.6% -0.3%
 0.1% -0.1% -0.3%	 2.8% -0.5% -5.9%	

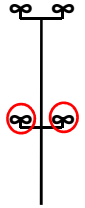
- Magnitude of yield error due to drag can be **reduced** with GENIVAR quality assurance



Uncertainty Analysis: Case Study

- Assume **P50** yield of **100** GWh/annum with 8% standard uncertainty
  - This results in **P90** = **89.8** GWh/annum
- For the following scenario there is additional drag uncertainty

  Maximum Yield Error* = 2.8%
  Average Yield Error* = 0.7%
  Minimum Yield Error* = 0.0%



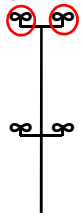
- Over estimated Yield due to drag
  - $\mathbf{P50_{drag}}=(P50 + \varepsilon_{avg\ drag})=\mathbf{100.7}$GWh/annum
  - $\mathbf{P90_{drag}}=(P50 + \varepsilon_{avg\ drag}) - z_{P90}(\sigma_{all}^2 + \sigma_{drag}^2)^{0.5}=\mathbf{90.3}$GWh/annum

*Based on 33 cases examined

Uncertainty Analysis: Case Study

- Assume **P50** yield of **100** GWh/annum with 8% standard uncertainty
  - This results in **P90** = **89.8** GWh/annum
- For the following scenario there is additional drag uncertainty

  Maximum Yield Error* = 0.0%
  Average Yield Error* = -1.2%
  Minimum Yield Error* = -5.9%



- Under estimated Yield due to drag
  - $\mathbf{P50_{drag}}=(P50 + \varepsilon_{avg\ drag})=\mathbf{98.8}$GWh/annum
  - $\mathbf{P90_{drag}}=(P50 + \varepsilon_{avg\ drag}) - z_{P90}(\sigma_{all}^2 + \sigma_{drag}^2)^{0.5}=\mathbf{88.5}$GWh/annum

*Based on 33 cases examined

Conclusions

- Methods for detecting sensor drag have been developed
- Redundant sensors are key for detection and mitigation
- Higher frequency of drag occurs in 4-10 m/s range
- Drag error is different for every sensor and yield error is dependant on the tower configuration
- The range of yield errors for **average** sensor drag is -**3.3%** to **1.4%**
- Ongoing Quality Assurance is effective in reducing yield errors