Mapping of Geographical Trends of Wind Shear and Frequency of Extreme Wind Shear Events Across the Great Plains

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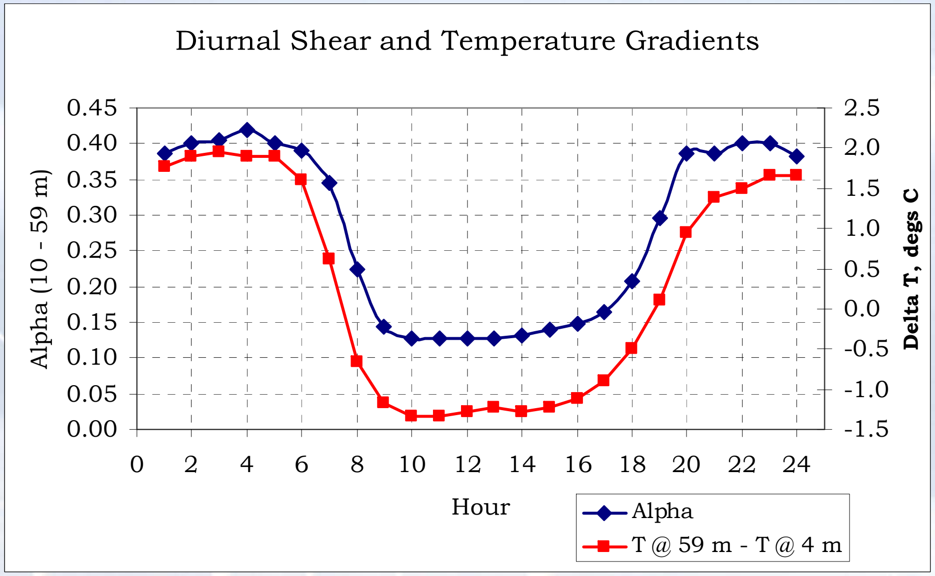
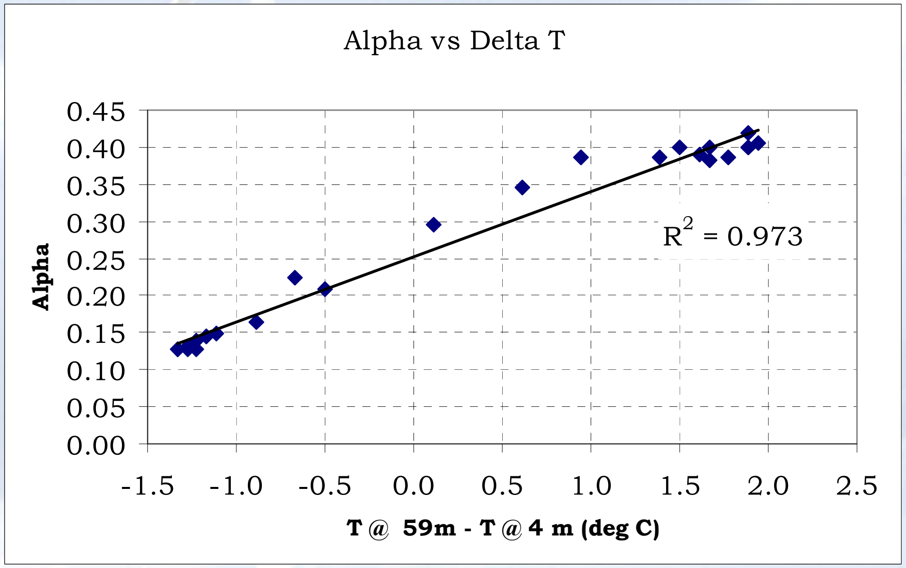
Introduction

- High mean shear means higher hub height WS and more energy. This is good, right?
- Shear varies by T-O-D. Large gradients of WS across turbine rotor with high shear
- As rotor diameters increase so do the magnitudes of WS gradients
- WS gradients produce varying angles of attack and result in higher cyclical loading
- Investigation of frequency of high shear in regions of major wind development
- Performed modeling of loads with FAST

Diurnal Shear and Vertical Temperature Gradients

- High shear associated with stable nocturnal boundary layer & temperature inversion





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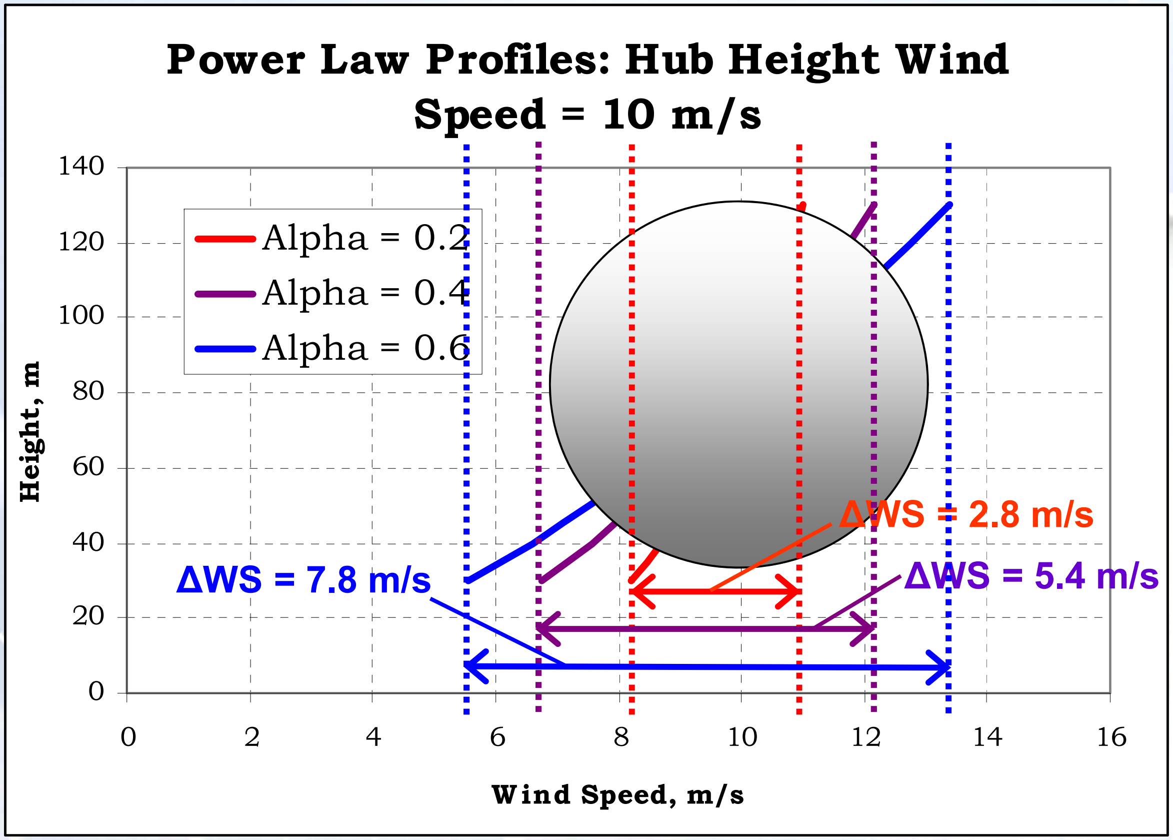
Wind shear and Power Law Profile



Power Law Shear Profile

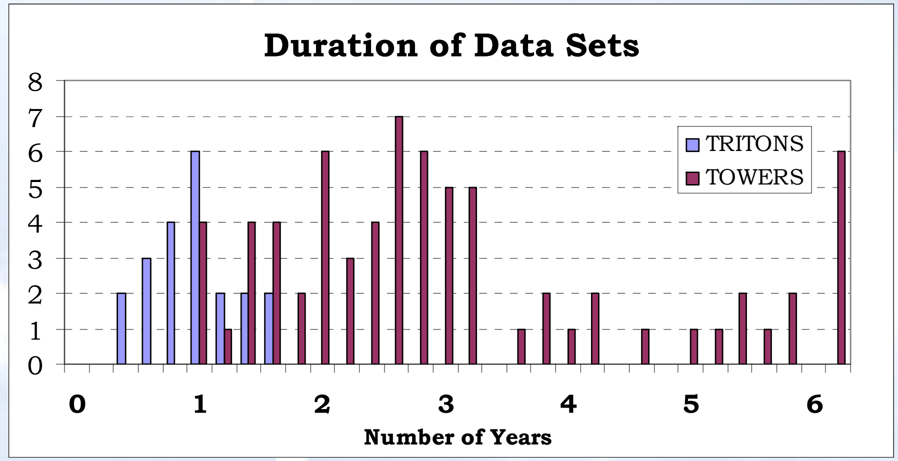
$$\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha}$$

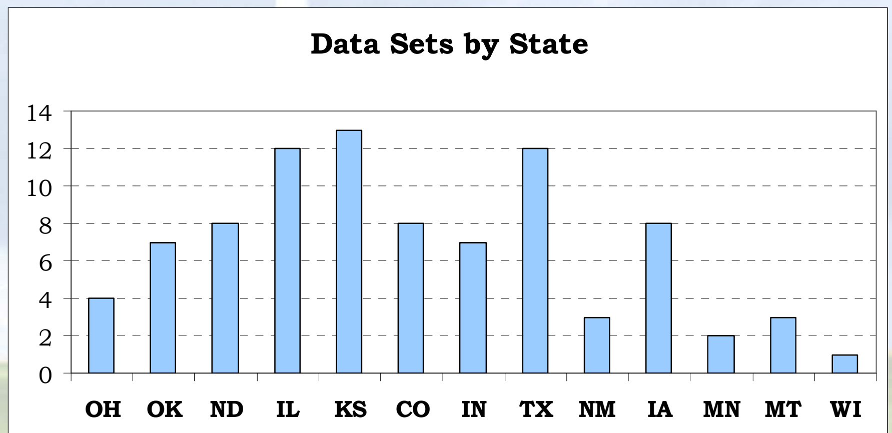
Alpha

Note: Assumes an 80 m hub height and 100 m rotor diameter

Summary of Data Sets Used in Study

- **Total Number of Sites = 88**
  - **21 Triton SODARs**
  - **67 Met Towers**
    - **2 – 40 m**
    - **22 – 50 m**
    - **43 – 60 m**
- **Average Duration of Data set = 2.6 years**
  - **Average Triton Data set duration = 0.9 years**
  - **Average Tower Data set duration = 3.0 years**
- **Sites in 13 different States:**
    - **OH, OK, ND, IL, KS, CO, IN, TX, NM, IA, MN, MT, WI**





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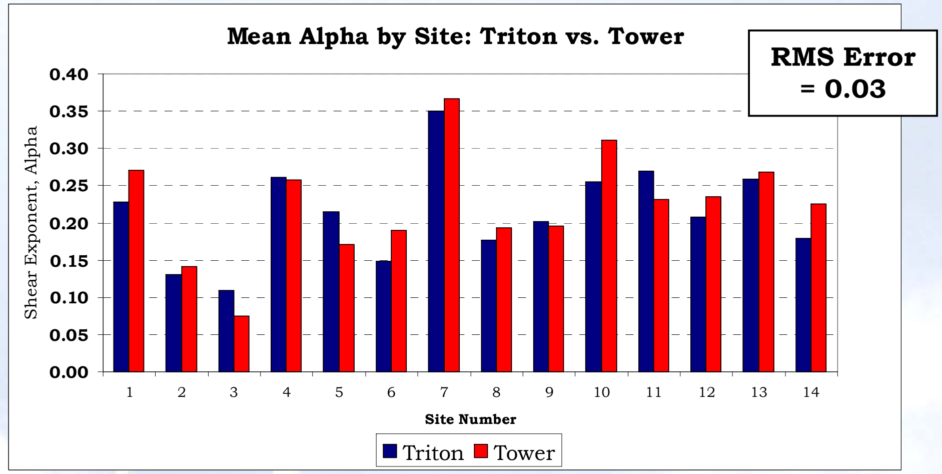
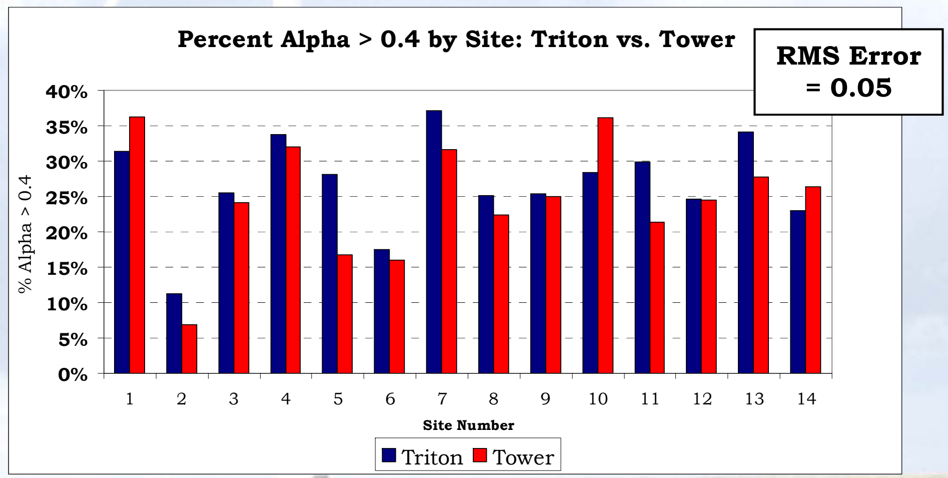
Methodology Outline

- Performed QC of tower and Triton data
  - Tower data: removed periods of icing and faulty sensors
  - Triton data: applied min. quality factor (90%) and max. vertical wind speed (+/- 1.5 m/s) filters
- Calculated best-fit power law exponent (α) using valid data at all levels up to 120 m (Triton) or top of tower: analyzed all hours, day (07 – 18 hr) and night (19 – 06 hr)
- Estimated hourly WS at 80 m at tower sites
- Calculated distributions of α and 80 m wind speed for periods of high shear ($\alpha > 0.4$)

Triton – Tower Shear Comparison

- Analyzed shear measured by Triton and at near-by met tower at 14 sites
- Compared mean α and frequency of α > 0.4 (RMSE = 0.03 & 0.05)
- Found that α distributions were quite consistent between Tritons and towers





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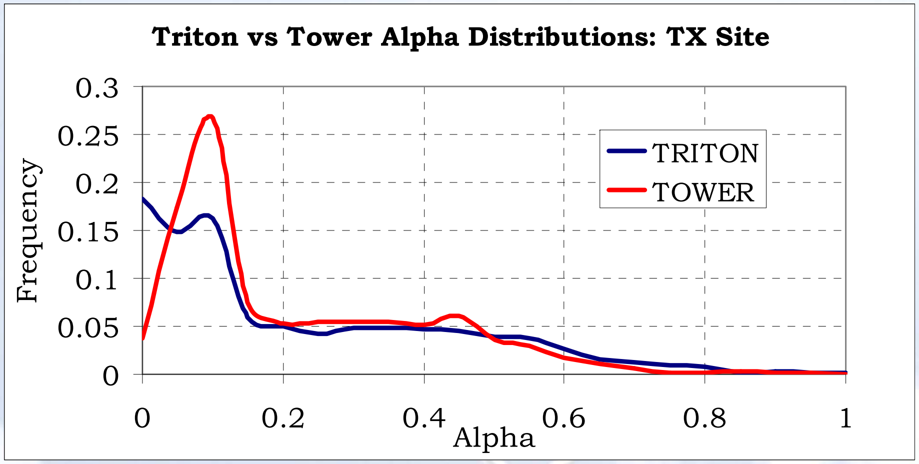
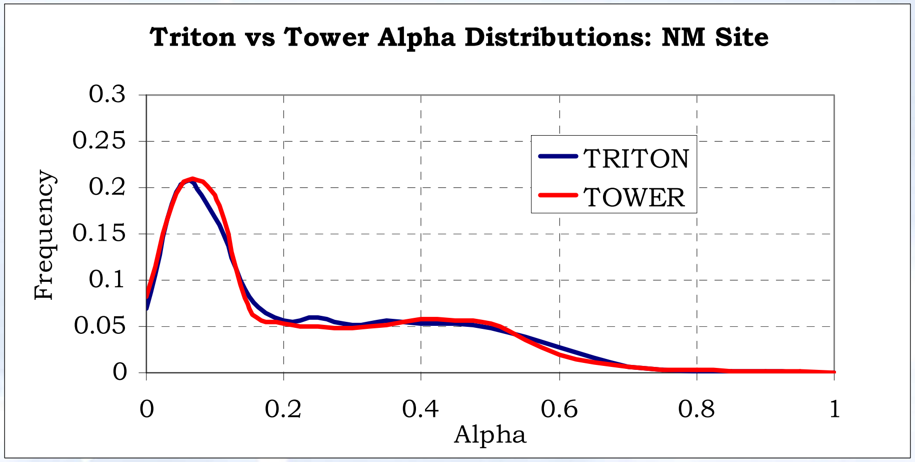
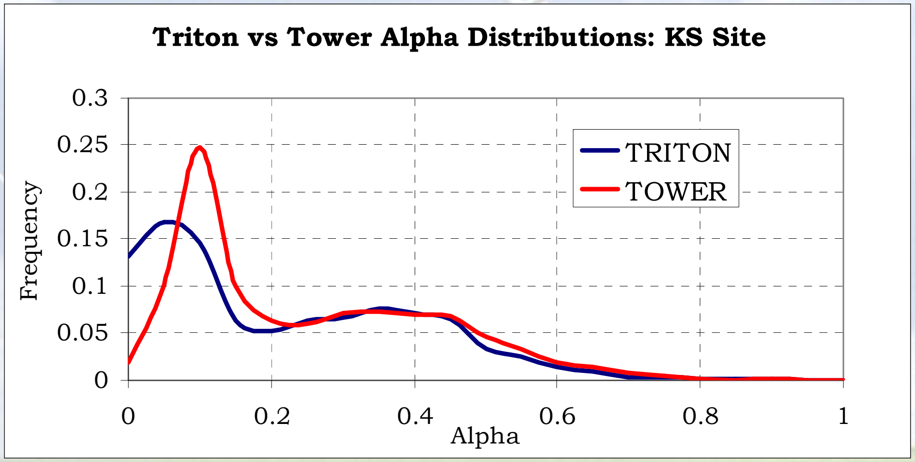
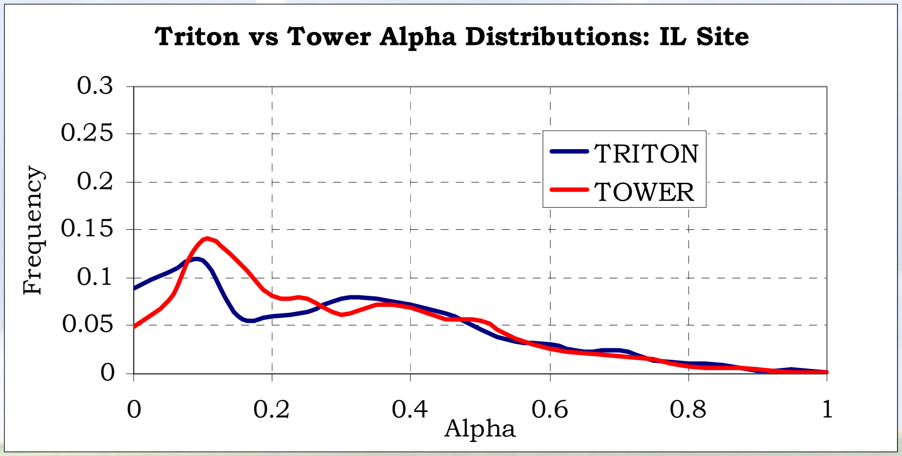
Triton vs. Tower α Distributions









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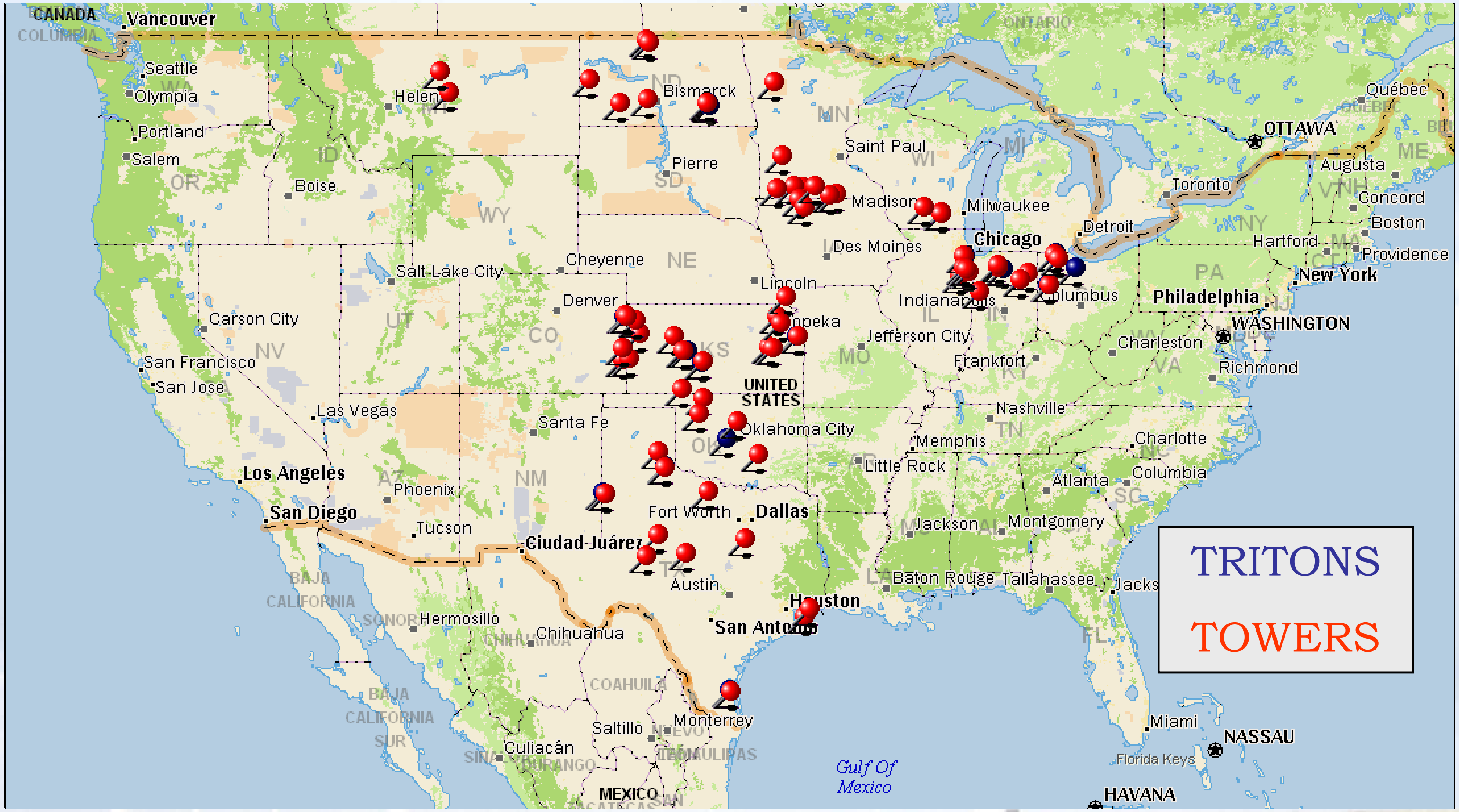
Sites Included in Study



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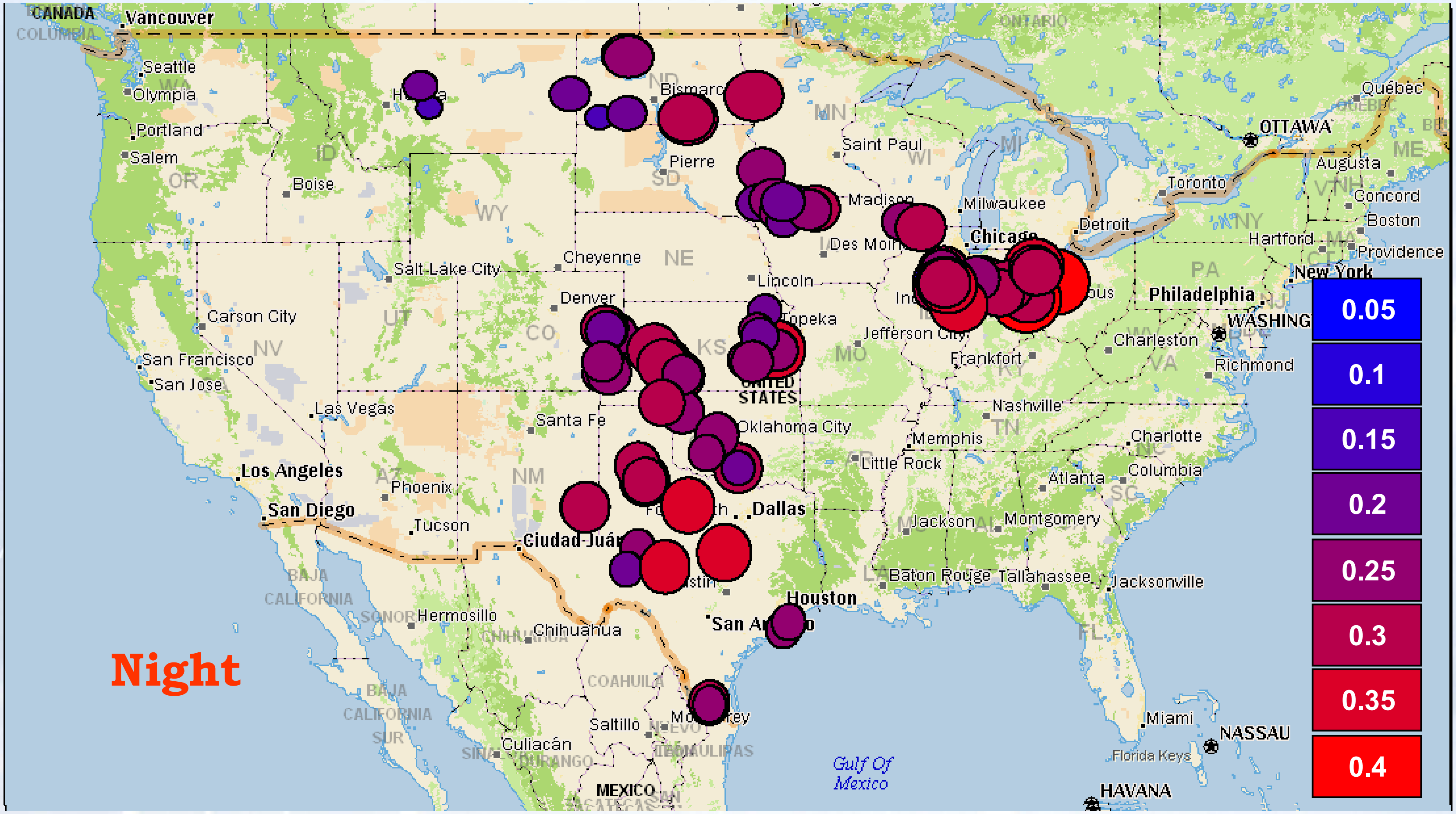
Mean α: All hours, day & night



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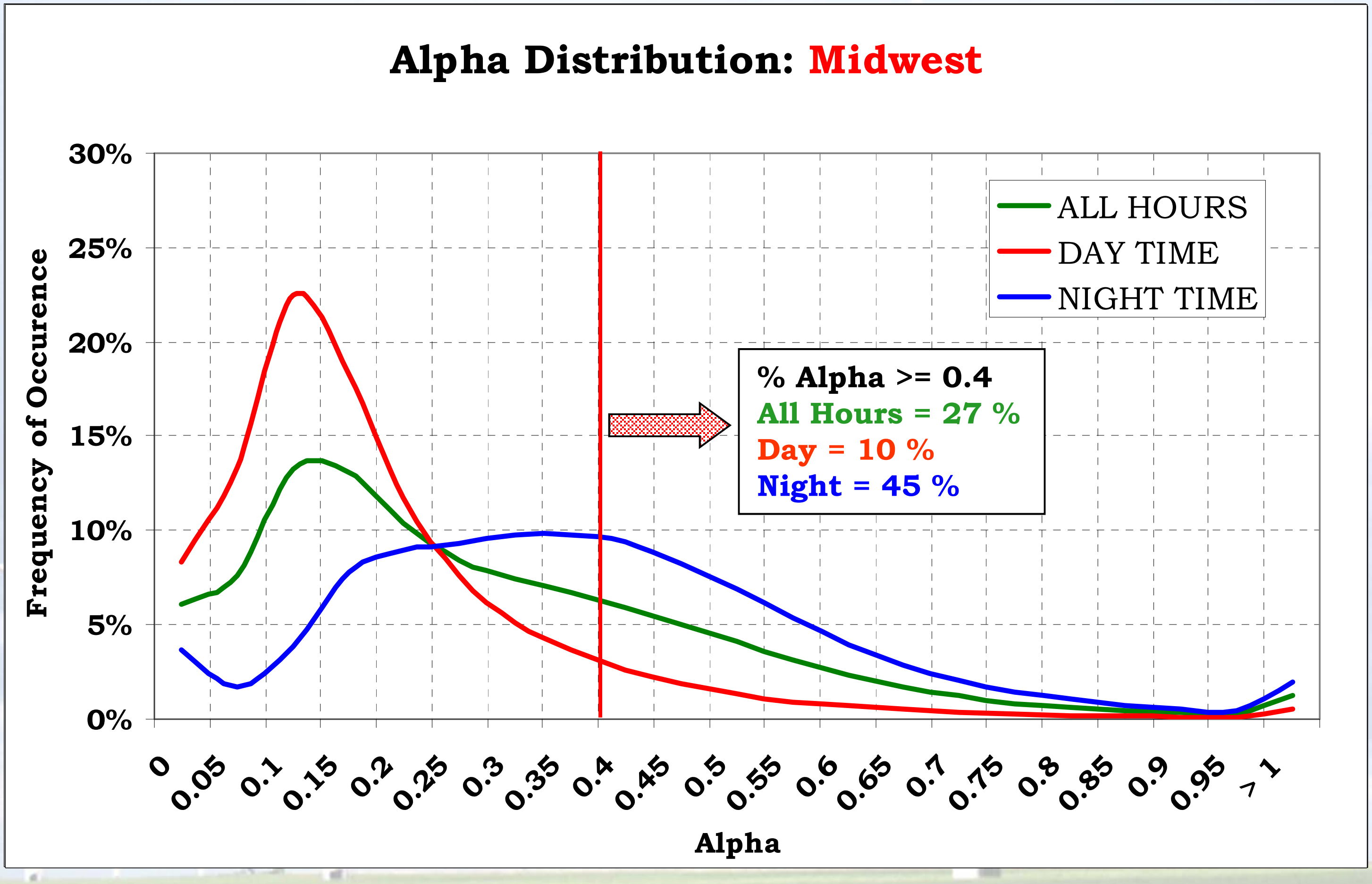
Triton & Met Tower α Distributions



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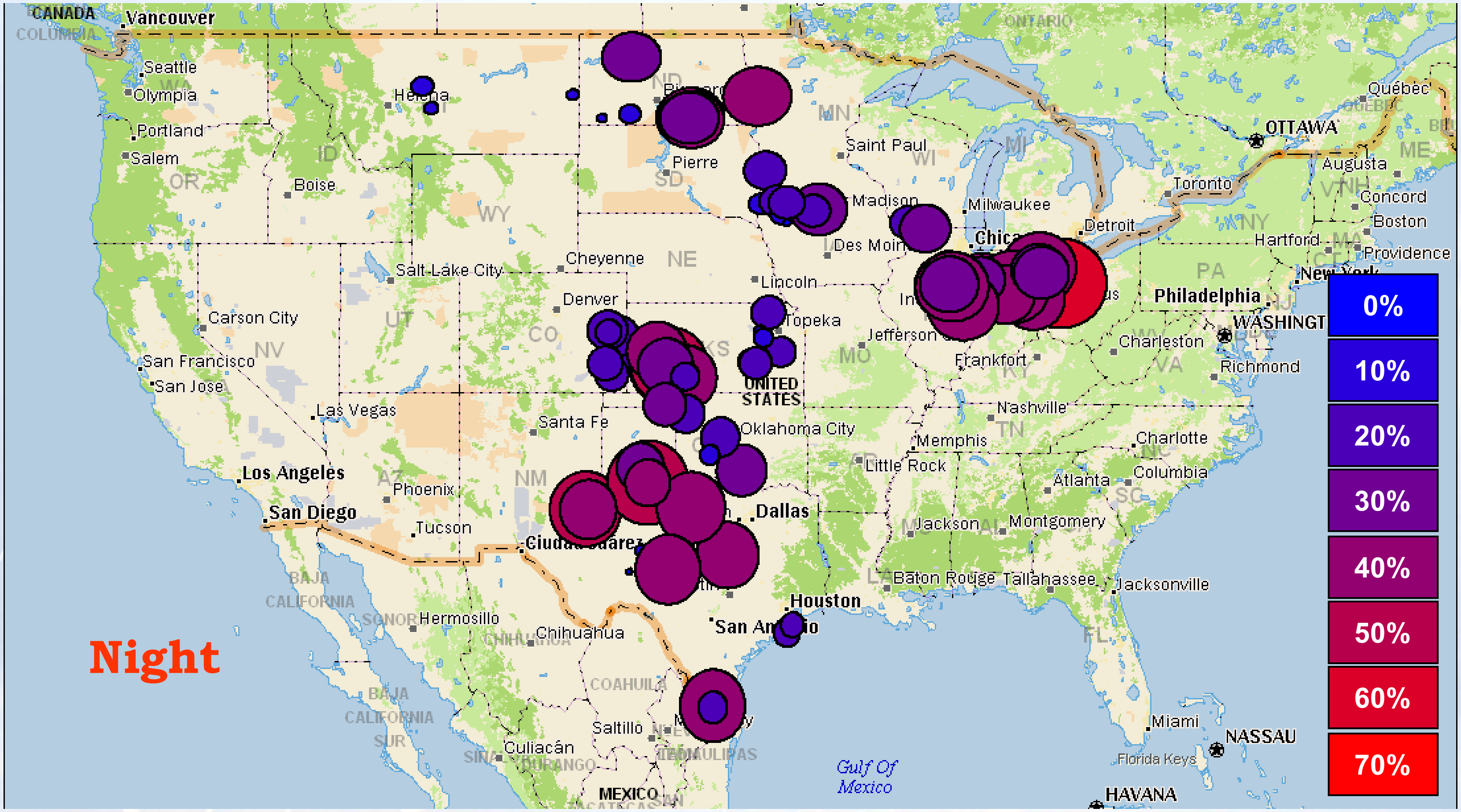
Frequency of High Shear (α > 0.4)



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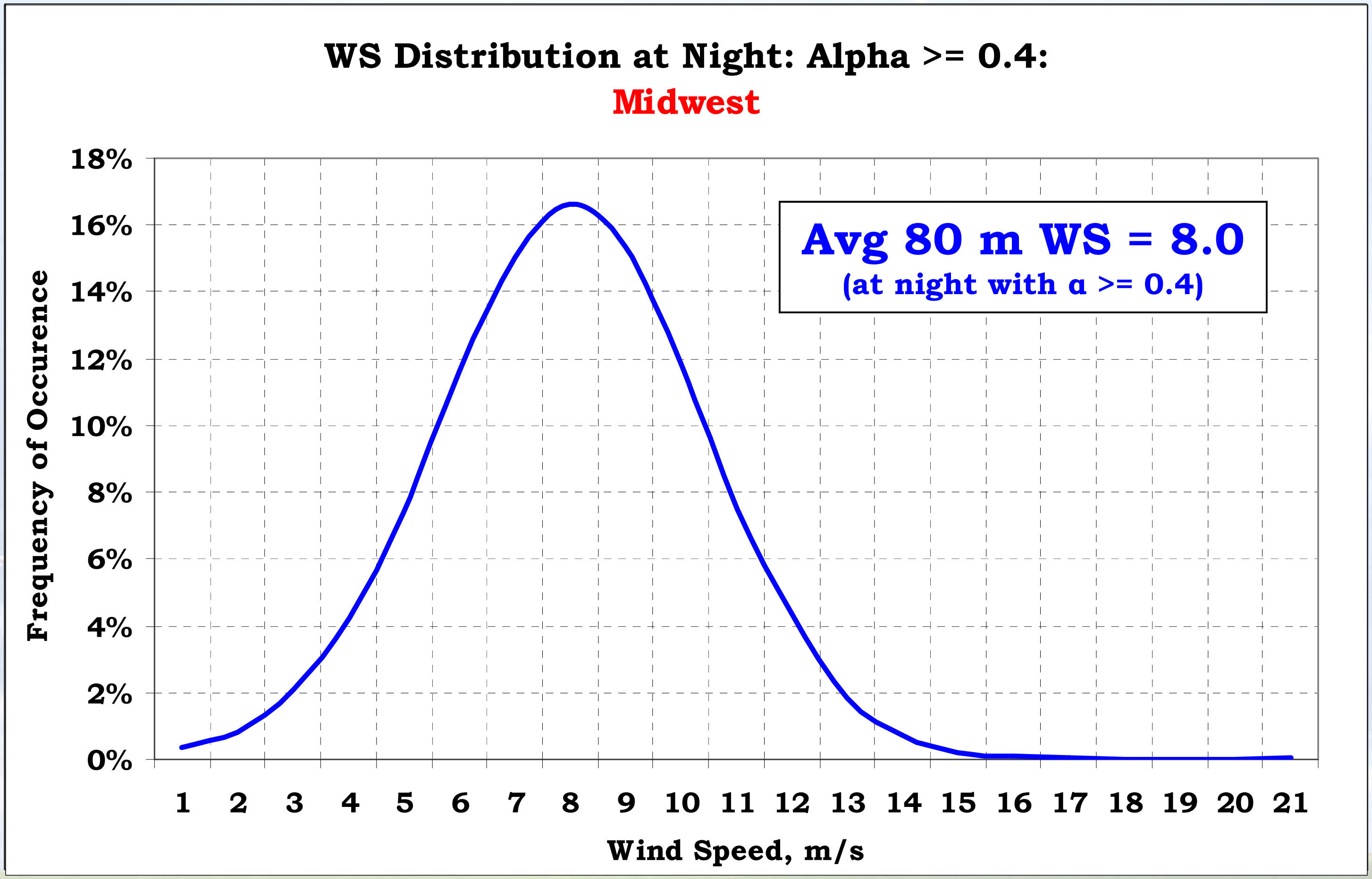
Nighttime WS Distributions: α >= 0.4



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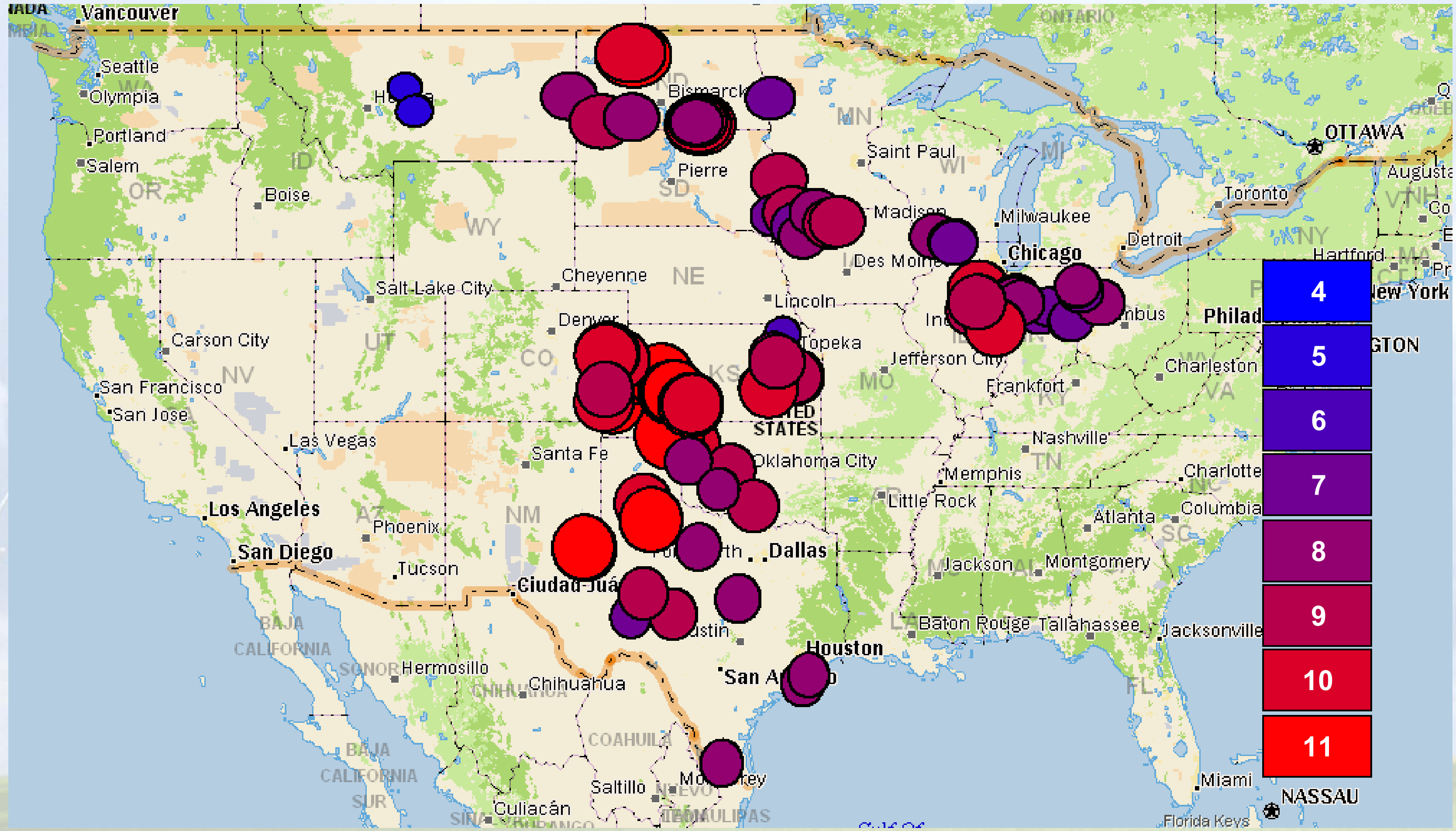
Nighttime Mean 80 m WS (m/s) With High Shear Conditions ($\alpha > 0.4$)



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Wind shear and its effect on wind turbine components

- Blade lift a function of angle of attack of wind: f(WS, blade pitch,RPM,airfoil)
- Differential WS across rotor produces differential lift & loading on rotor and other turbine components
- What is the magnitude of differential loading?
- Modeled loads with FAST code

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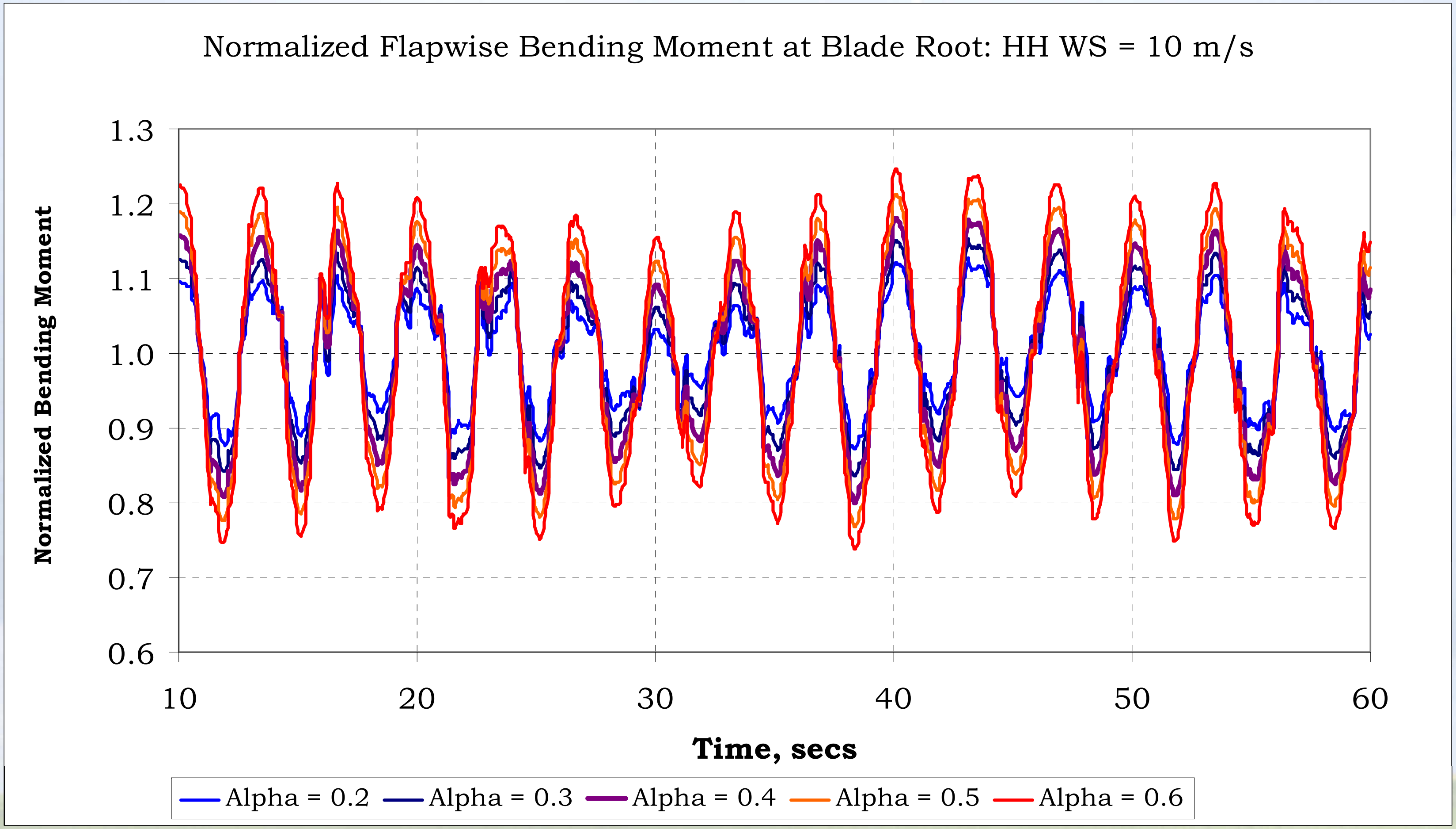
Summary of FAST Modeling

- FAST (Fatigue, Aerodynamics, Structures, and Turbulence) :
  - Developed by NREL for prediction of wind turbine loads and responses
- ‘Simple’ 2 MW turbine: 100 m RD, 80 m HH
- Constant speed rotor, fixed pitch
- Modeled for hub height wind speeds = 8, 10 & 12 m/s with α = 0.2, 0.3, 0.4, 0.5 and 0.6
- Observed the change in modeled bending moment at the blade root

FAST Model Results (10 m/s) – Flapwise Bending Moments



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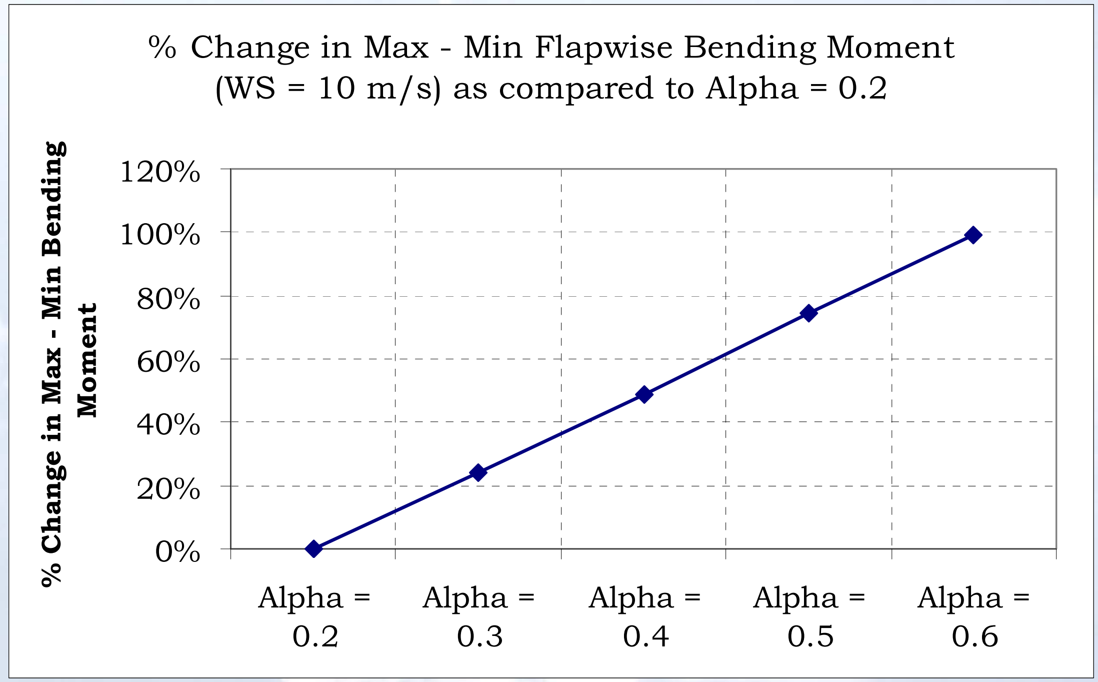
Results of FAST model

- Cyclical loading increases with shear
- Difference between max and min bending moment doubles as α increases from 0.2 to 0.6



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Conclusions

- Frequencies of shear ($\alpha >= 0.4$) quite high across much of the Great Plains and upper Midwest
  - At night, on average, frequency > 35%
  - For all hours, on average, frequency > 20%
- High shear associated with above-average HH WS & large Δ in WS & power density across rotor
- High shear and WS produces increased loading on blades & likely other components
- What will be the long-term effects on fatigue life and performance of wind turbines?
- Do turbine designs account for these conditions? They should!