Wind Shear and Turbulence Profiles at Elevated Heights: Great Lakes and Midwest Sites

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Background

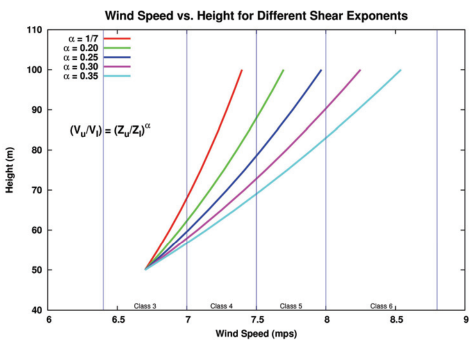
- Considerable uncertainty exists in extrapolating wind resource data available from typical measurement heights (50 m – 60 m) to turbine hub-heights of 80 m – 100+m
- Numerical model data and available wind maps for heights of 80 m – 100 m are largely unvalidated
- Tall-tower and remote sensing (sodar & lidar) wind data are needed to evaluate wind shear and turbulence profiles over turbine rotor heights that can extend well above 100 m

Objectives

- Analyze wind resource characteristics at elevated heights (50 m – 200+m) including shear and turbulence profiles for some areas of the Great Lakes and Midwest
- Show case studies and comparisons for
  — Indiana towers located in areas of different surface roughness
  — Iowa towers with heights up to 200+m and different surface roughness

Variation in Average Wind Shear

- Measurement data indicate that average wind shear exponents at elevated heights, such as 50 m – 100 m, can vary considerably among sites
- Considerable uncertainty can exist in estimates of wind speed at 80 m – 100 m heights from extrapolation of data at 50 m
- Even in areas of similar wind climate, such as northern Indiana, variations in surface roughness and terrain among sites can cause average shear exponents to vary from about 0.2 to 0.35 between 50 m – 100 m

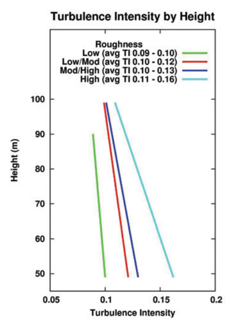


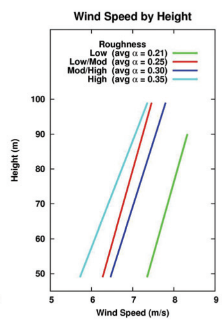
Indiana Analysis

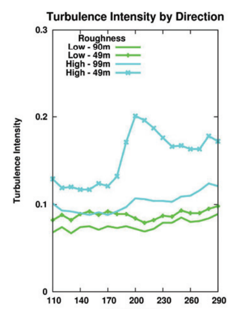
- Four tall towers located in different types of surface roughness
- Highest anemometers 90 m – 100 m
- Approximately one year of data collected from each site
- Wind shear and turbulence profiles evaluated by roughness type and height
- Wind speeds of at least 3 m/s required for the analysis
- Data excluded from directions with tower shadow effects

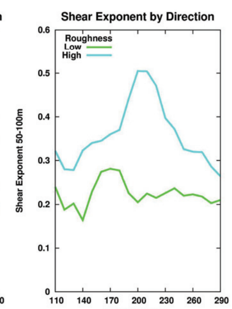
Carthage, IN – Low/moderate roughness, prevailing strong winds from S-SW

Goodland, IN – Low roughness, prevailing strong winds from S-SW





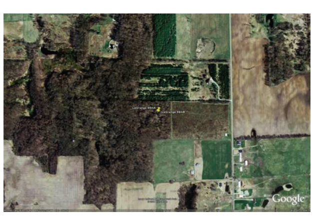


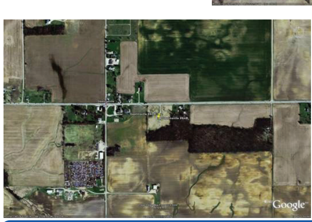


Indiana Analysis Results

- Notable variations in the annual wind shear exponents at elevated heights (50 m – 100 m) among the 4 sites
  —Highest shear exponent (0.35) at site with highest surface roughness
  —Lowest shear exponent (0.21) at site with lowest surface roughness
- Notable variations in the turbulence intensity (TI) profiles among the 4 sites
  —Considerable TI difference at 50 m (16% vs 11%) between high and low roughness sites
  —Significant TI difference at 100 m (11% vs 9%) between high and low roughness sites
- Analysis of shear and TI by wind direction highlight the effects of surface roughness, especially in the prevailing wind directions

LaGrange, IN – High roughness, prevailing strong winds from S-SW

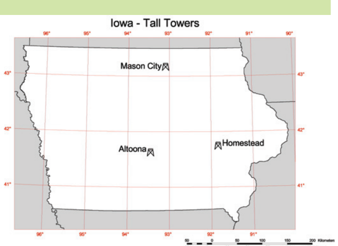


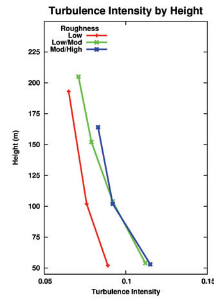


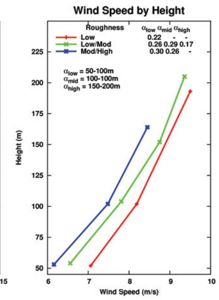
Geetinsville, IN – Moderate/high roughness, prevailing strong winds from S-SW

Iowa Analysis

- Three very tall towers with measurements at several heights from about 50 m – 200 m
- Approximately one year of data collected at each site
- Terrain and surface roughness conditions varied among the sites
  —Mason City, exposed hilltop site in rolling terrain, low roughness
  —Homestead, exposed site in rolling terrain, low/moderate roughness
  —Altoona, exposed site in rolling terrain, moderate/high roughness near town
- Wind shear and turbulence profiles evaluated by height, roughness and time of day
- Wind speeds of at least 3 m/s required for the analysis
- Data excluded from directions with tower shadow effects
- Data excluded for heights with insufficient data
  —Excluded 157 m at Mason City and 213 m at Altoona





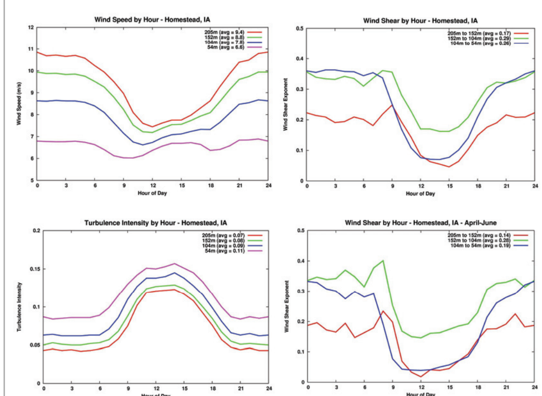


Iowa Analysis Results

- Profiles of average shear exponents differ among the 3 sites
  —Low layer (50 m –100 m) shear exponents varied by site's surface roughness type
  —Mid layer (100 m – 150 m) shear exponents can be similar or exceed those at heights of 50 m –100 m
  —Upper layer (150 m – 200 m) shear exponent less than lower layers
- Average TI profiles differ among sites
  —Lowest TI at low roughness site, at all heights
  —TI decreases with height, but there is less decrease at the low roughness site than other sites

Iowa Iowa Analysis Results – Homestead Diurnal Variations

- Diurnal variations in average wind speed increase with height, from <1 m/s at 50 m to >3 m/s at 200 m
- Average shear exponent is highest in 100 m – 150 m layer, especially during April – June
- Nocturnal shear exponent decreases above 150 m
- Average turbulence intensity is very low at night, especially at heights above 100 m



Conclusions

- Analysis of tall-tower data proved beneficial to evaluate and better understand the variability of wind shear and turbulence profiles at elevated heights
- Surface roughness effects on wind shear and turbulence profiles can be significant at heights up to 100 m
- Wind shear exponents at heights of 100 m –150 m can exceed those at heights of 50 m –100 m
- Large differences in shear exponents at elevated heights can exist among sites, even in local areas of similar wind climate

Recommendations

- Measurement data at elevated heights are needed to validate model-derived wind resource estimates and shear extrapolations
- Use of tall towers and remote sensing equipment (sodar and lidar) provide opportunities to evaluate wind resource characteristics at elevated heights