Wind Resource and Wind Shear Characteristics at Elevated Heights

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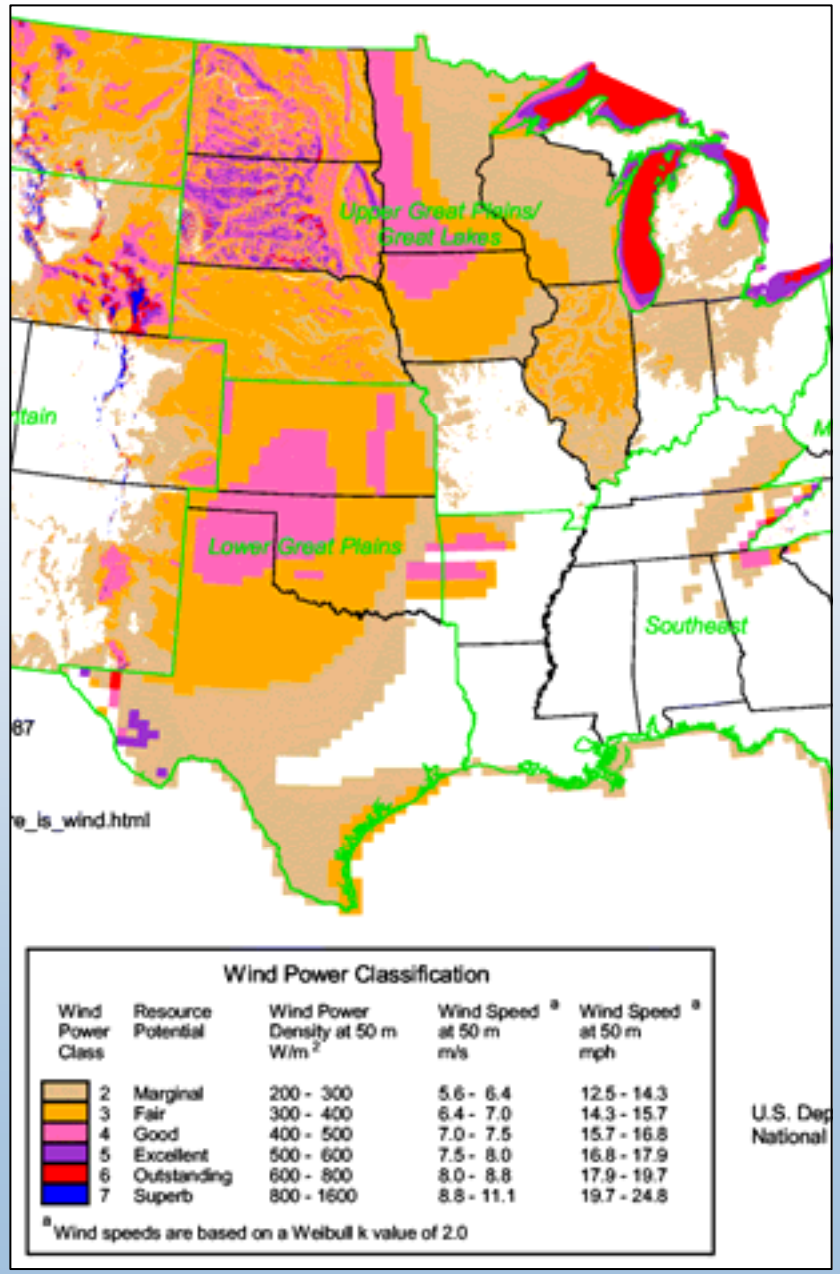
WPA Summit Meeting
June 8, 2006 Pittsburgh, PA

Objectives

- Analyze wind resource and wind shear characteristics at tall tower sites for diverse areas of the Midwest and Central Plains
  - Turbines hub heights are now 70-100 m above ground
  - Wind measurements at 70-100+ m have been rare
- Show case studies and comparisons for some areas of the Midwest (Indiana) and Central Plains (Kansas)
- Present conclusions about wind resource and shear characteristics for prime wind energy development regions

Background

- Tall tower measurements on existing communication towers established during past 5 years supported by:
  - U.S. DOE State Energy Program and Wind Powering America
  - State/university initiatives
  - Other research programs
- NREL obtains time series data from a variety of sources
- Primary areas of investigation to date
  - Central Plains (Windpower 2006 paper by Schwartz and Elliott)
    - 13 tall towers were used in the study, 11 tall towers had highest anemometer at 100-110 m, Kansas had 6 towers
  - Indiana (special study for RPS meeting on Indiana wind resources)
    - High-resolution wind maps by AWS Truewind at 70 m and 100 m
    - 5 tall towers with highest anemometers at 90-100 m

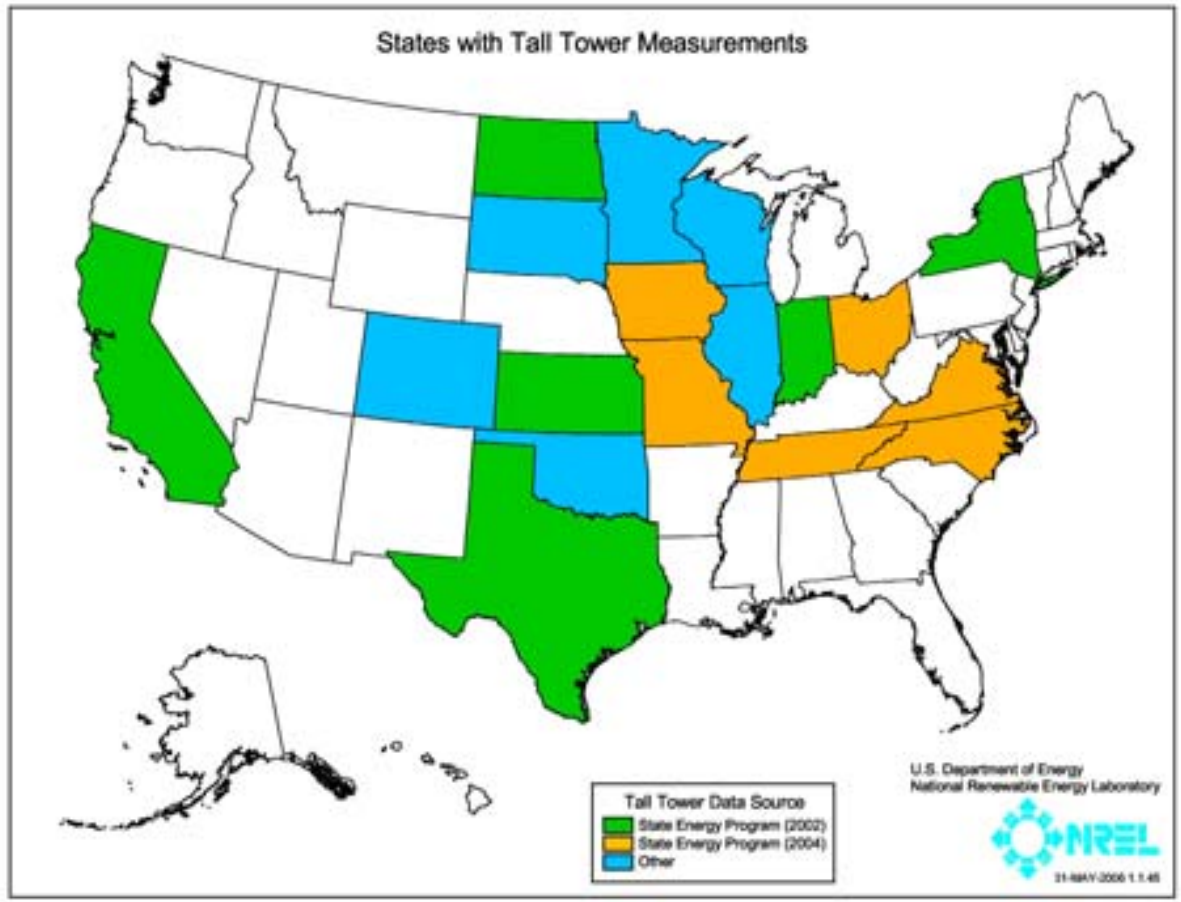


50-m Wind Power Map for Central U.S.

- Considerable uncertainty exists in extrapolating 50-m wind resource to heights of 80-100 m
- Available wind maps for heights of 80-100 m are unvalidated
- Tall-tower wind measurement data needed to examine the wind shear and make more accurate estimates at elevated heights

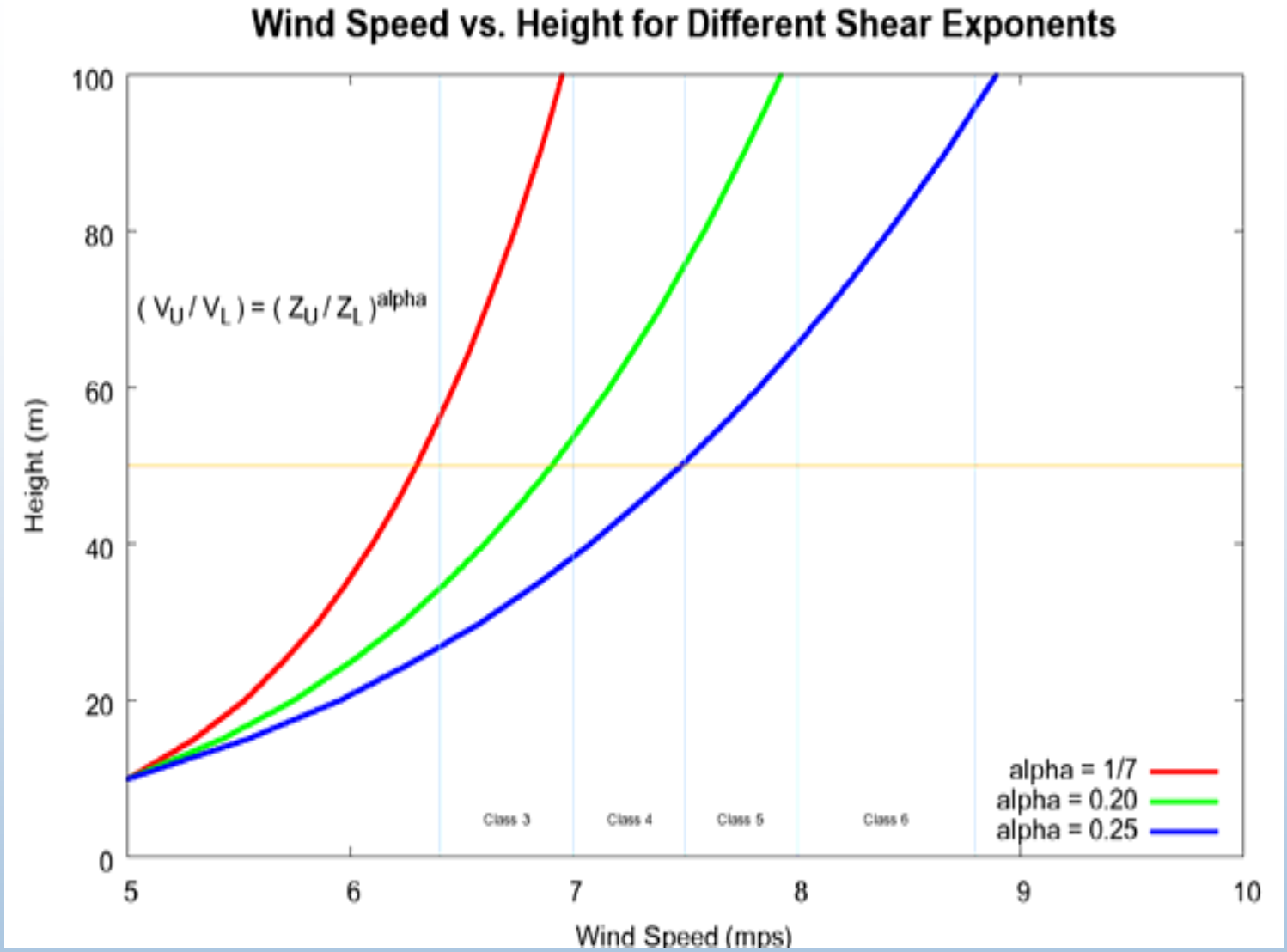
Current Tall Tower Measurements

- DOE State Energy Program (SEP) 2002 and 2004
  - 12 states
  - 35-40 towers
  - NREL provides technical support
- Other Tall-Tower Data
  - At least 6 states

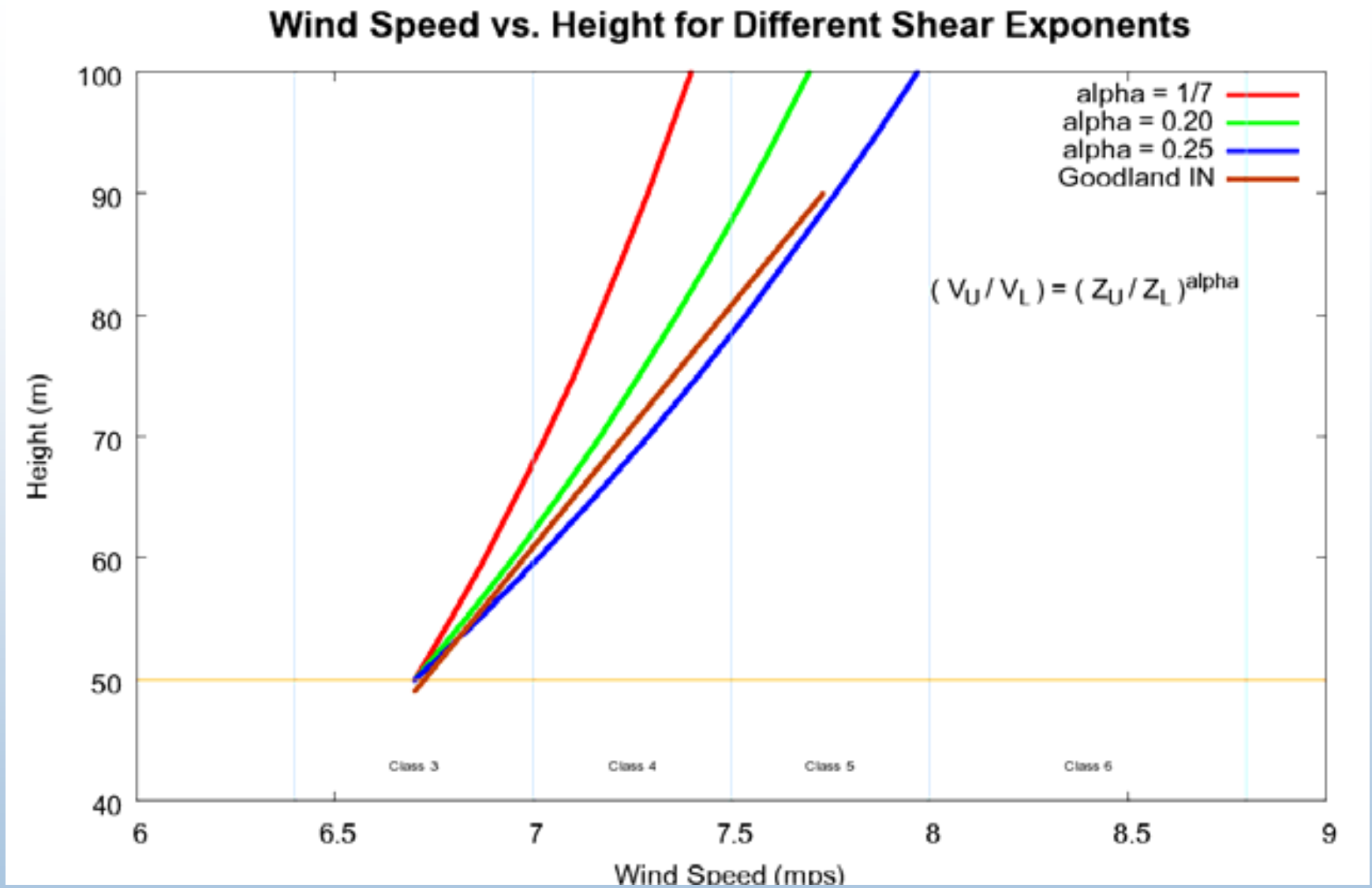


Tall Tower site on the Great Plains.

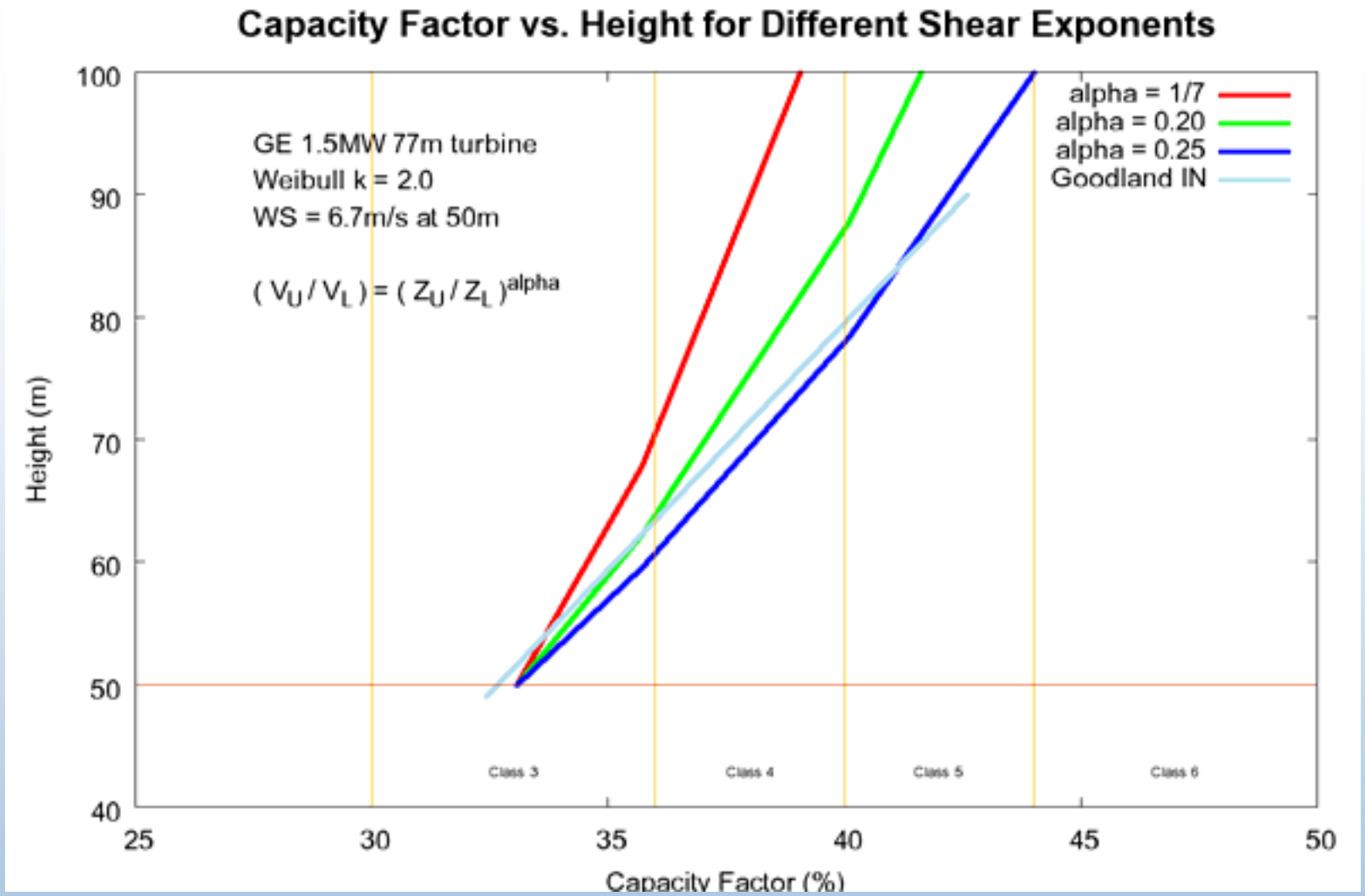
Communication towers are frequently used for measuring wind energy characteristics at heights up to 100 m or above.



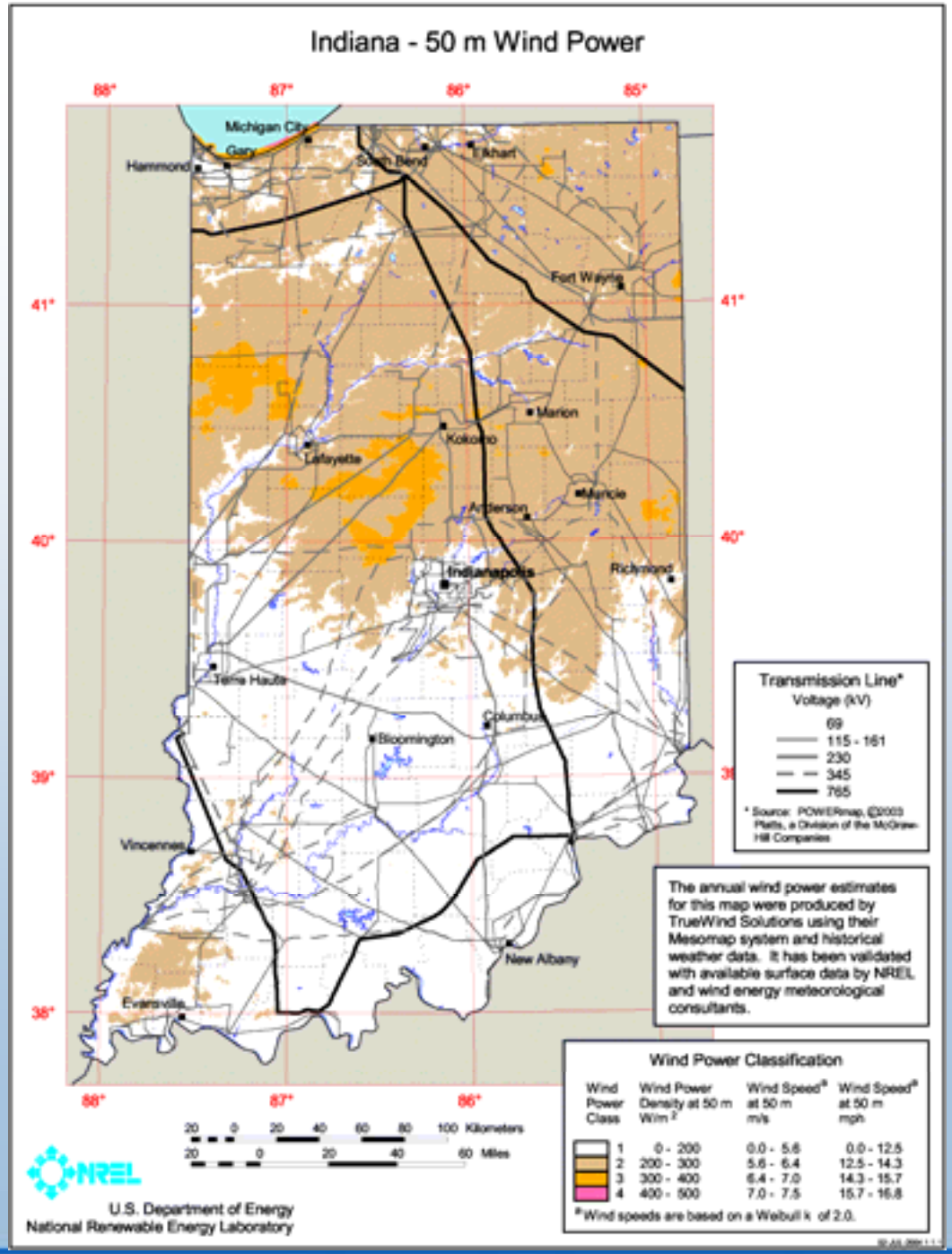
Annual average shear exponents can vary from 1/7 to 0.25, causing considerable uncertainty in vertical extrapolations of wind resource



- **Even if 50-m wind resource is known, potential variations in shear exponents cause considerable uncertainty in wind resource at heights of 80-100 m**
- **Measured shear exponent at Goodland is 0.235, with much higher wind resource at 90 m than estimated by 1/7 shear estimate**

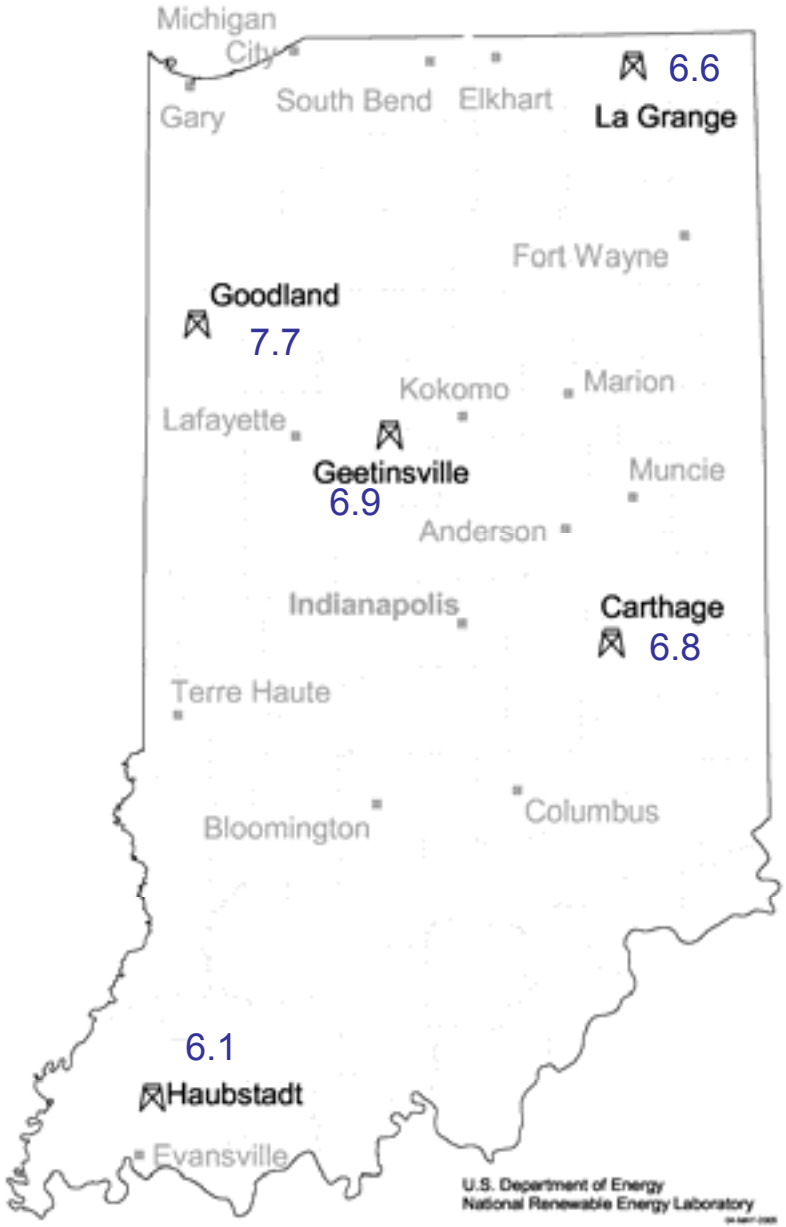


- **High wind shear locations can have considerably higher capacity factors at 80-100 m than low shear locations, given similar capacity factors at 50 m**
- **Goodland's capacity factor of 42.5% at 90 m is considerably higher than would be estimated by using typical shears of 1/7 to 0.2**



Indiana Wind Power Map – 50 m Height

- This is the standard wind map product posted on WPA web site
- AWS Truewind used numerical modeling to produce initial wind map estimates
- NREL and consultants used available measurement data to validate the initial estimates
- This final map (produced in 2004) includes the revisions from validation
- Additional map products were produced for heights of 70m and 100m but not validated
- Tall-tower wind measurement program (5 sites) began in 2004

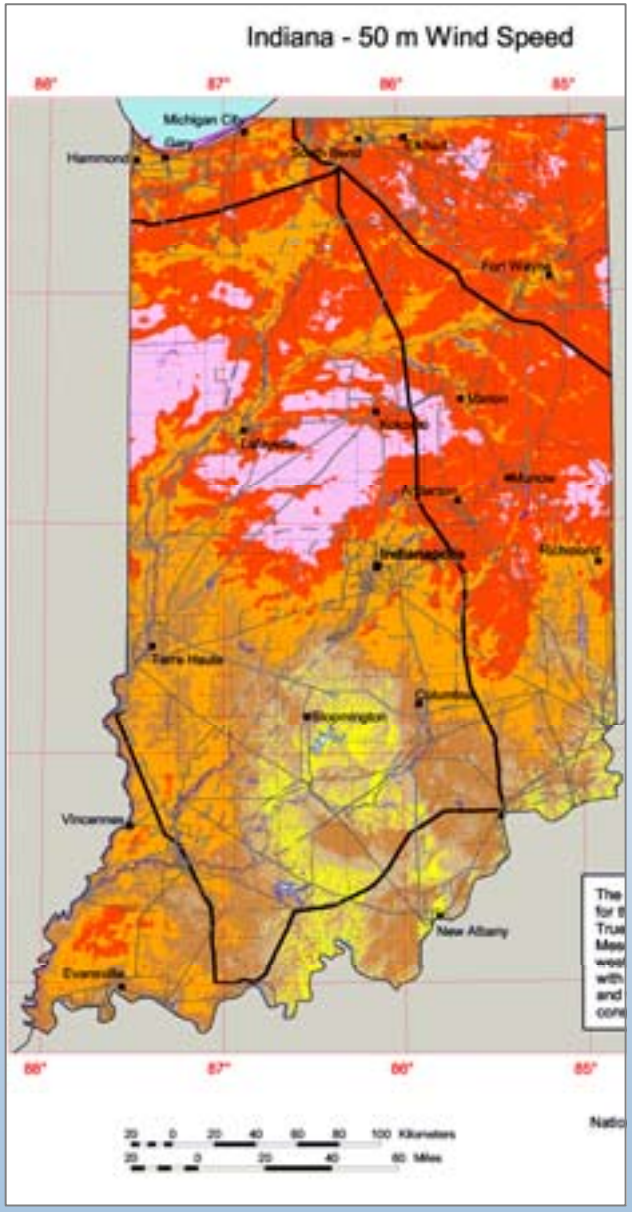


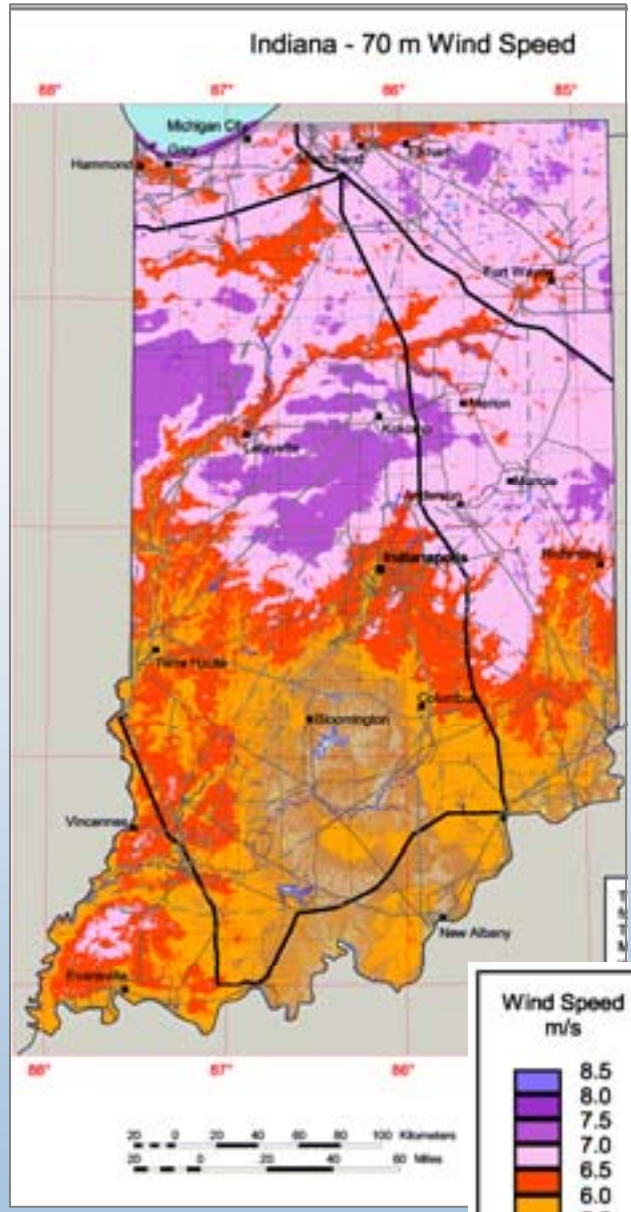
Indiana Tall Tower locations with average wind speeds (m/s) at 99-m height

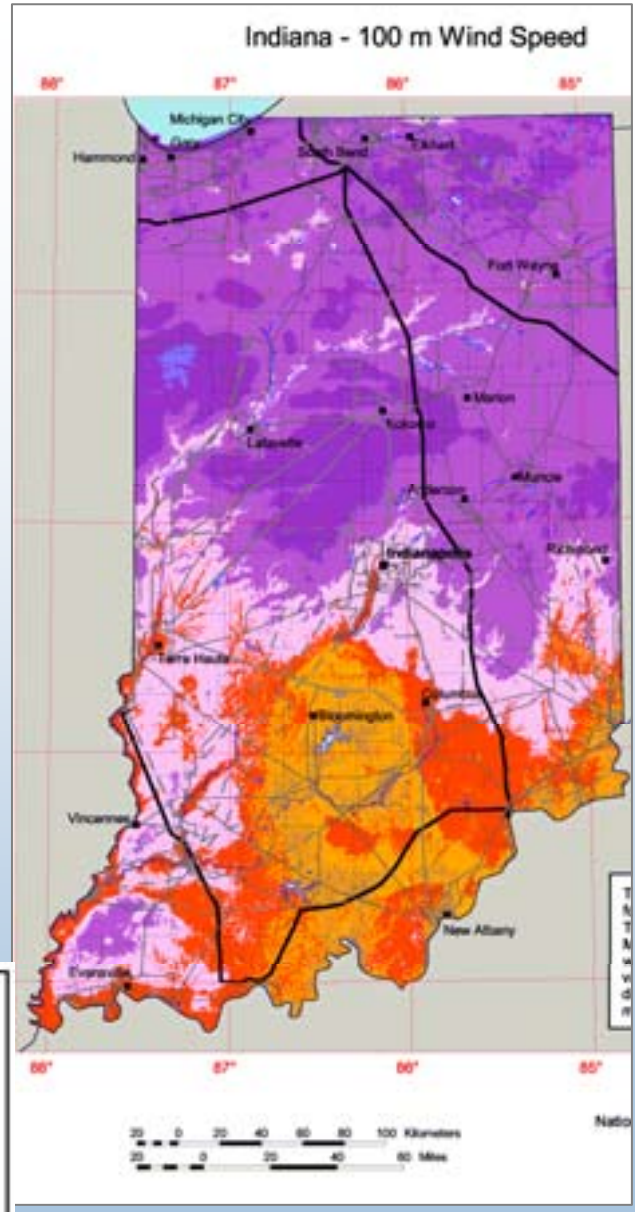
One year of data (mostly 2004). These data became available after wind resource maps were produced.

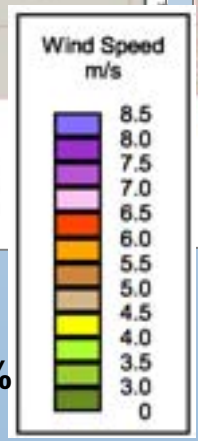
Goodland's speed based on 90 m measurement
- **Capacity factors* at Goodland**
- **42% at 90-m height**
- **32% at 50-m height**

***Capacity factors for GE 1.5 MW turbine with a 77-m rotor diameter**









Best areas 6.5-7 m/s
Capacity factors 30-35%

Best areas 7-7.5 m/s
Capacity factors 35-40%

Best areas 7.5-8.2 m/s
Capacity factors 40-45%

Methodology for Estimating Indiana's Wind Electric Potential at 70-m and 100-m Heights

We calculated a range of wind speeds and capacity factors for Indiana wind resources at 70-m and 100-m heights. The wind speed ranges (after 12% power losses) were used to estimate the windy land area and wind potential at map heights of 70m and 100m.

Wind potential was estimated assuming 5 MW of installed wind capacity per square kilometer of available windy land, after environmental and land-use exclusions. Capacity factors were based on the GE 1.5 MW 77-m turbine. If the assumed power losses increase, the wind speeds must also increase to maintain the same capacity factor.

No Power Losses		Capacity Factor	12% Power Losses	
50-m Class (equivalent)	Speed m/s	(%)	Speed m/s	50-m Class (equivalent)
Class 3	6.5 – 7.1	30 – 36	7.0 – 7.6	Class 4
Class 4	7.1 – 7.7	36 – 42	7.6 – 8.3	Class 5
Class 5	7.7 – 8.3	42 – 46	Not applicable	

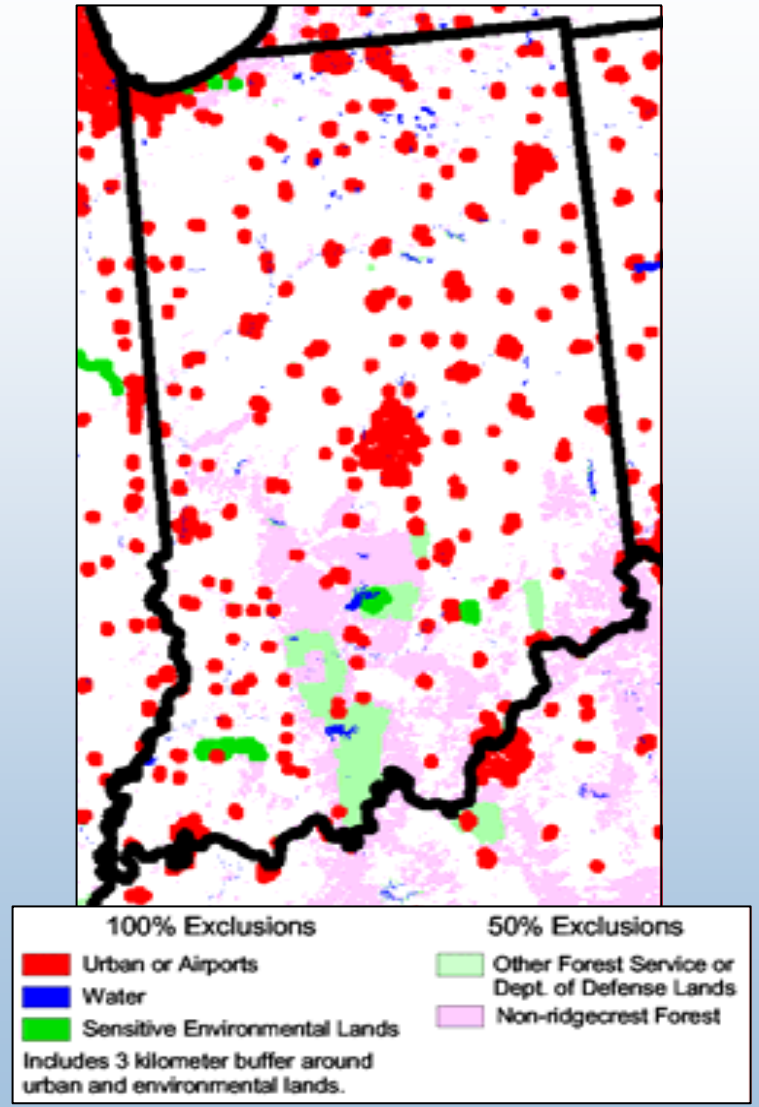
Estimates of Indiana's Wind Electric Potential (Installed Capacity)

Assumes **12% Power Losses**

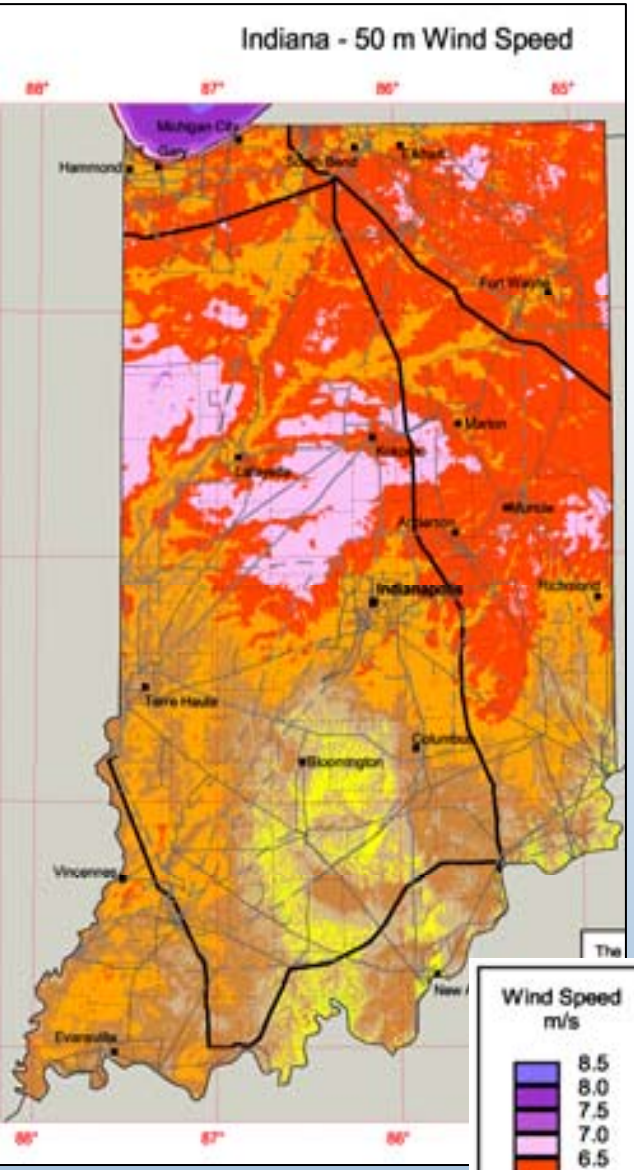
	70-m Height	**100-m Height**
Class 4	42 GW	161 GW
Class 5	0 GW	37 GW
Total	**42 GW**	**198 GW**

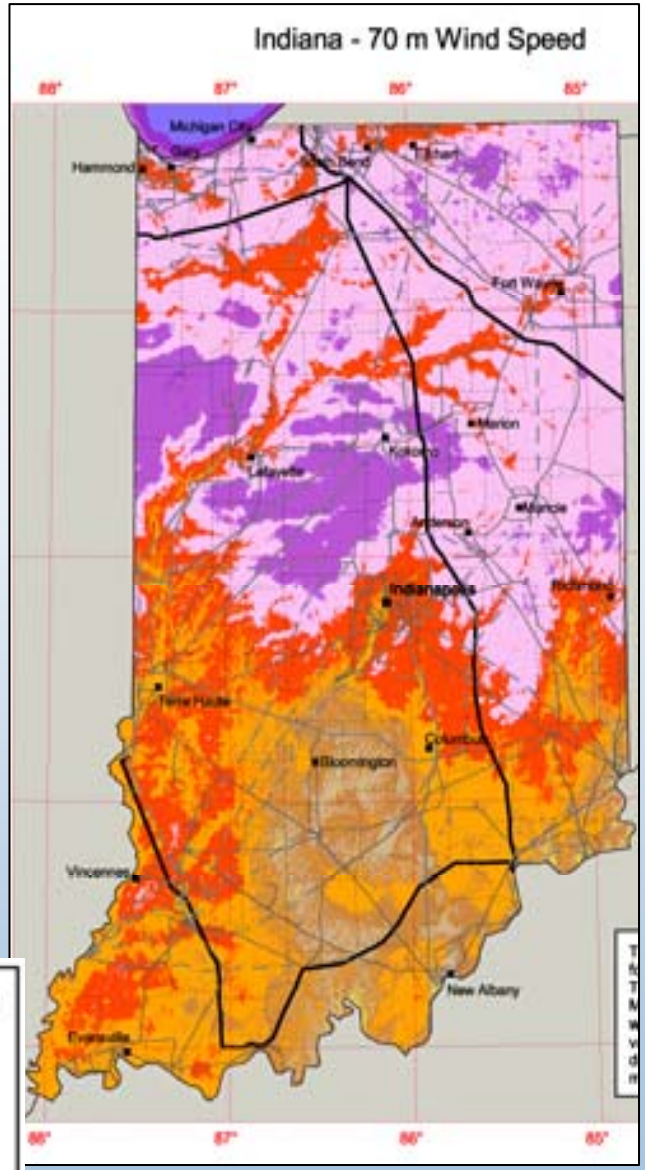
Areas Excluded from Developable Wind Potential

1) Potentially sensitive environmental lands:
   - National Park Service and Fish and Wildlife Service
   - Wildlife, wilderness, recreation areas, and other specially designated areas on federal land (predominantly Forest Service and BLM lands)
   - Some state and private environmental lands where data was available
   - Half of the remaining U.S. Forest Service and Department of Defense lands to represent current dedicated use of land
2) Potentially incompatible land use:
   - Urban areas, airports, wetlands and water bodies
   - Half of non-ridge crest forested areas
3) Other factors:
   - Slopes greater than 20%
   - A 3 kilometer area surrounding environmental and land use excluded areas (except water bodies)
   - Small, isolated class 3 and greater resource areas using a minimum density criteria



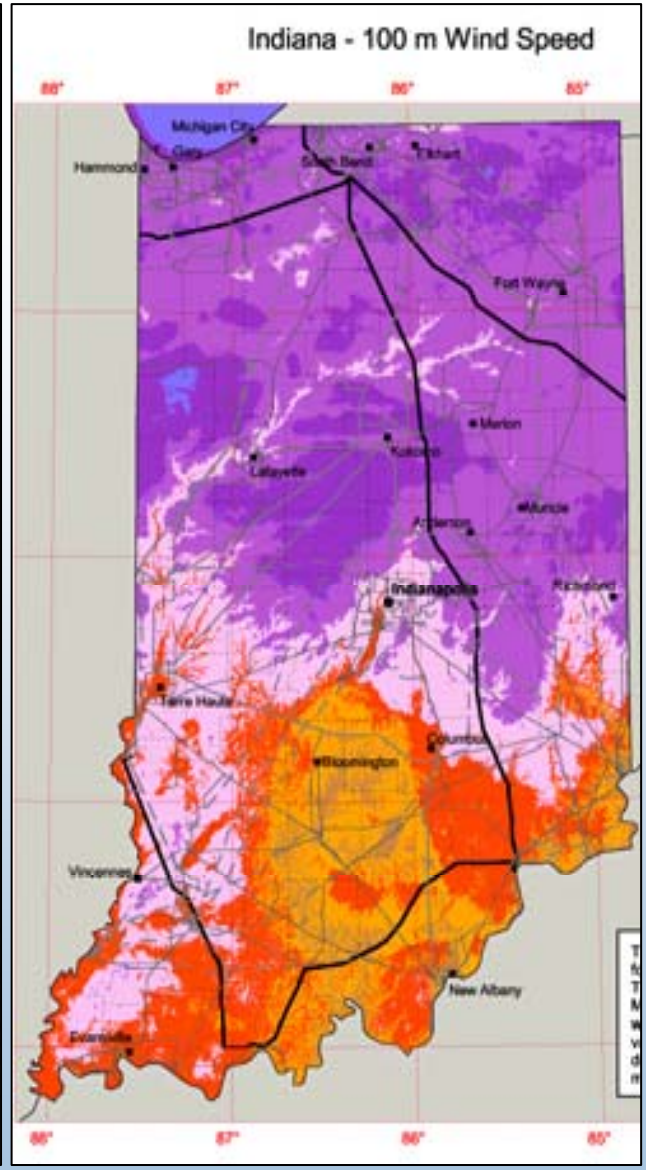
11% of the raw Class 3 and better lands excluded at 70 m (12% loss case)
19% of the raw Class 3 and better lands excluded at 100 m (12% loss case)





Wind Potential (Installed Capacity) for 12% Power Loss Scenario
30-36% Capacity Factor: 42 GW

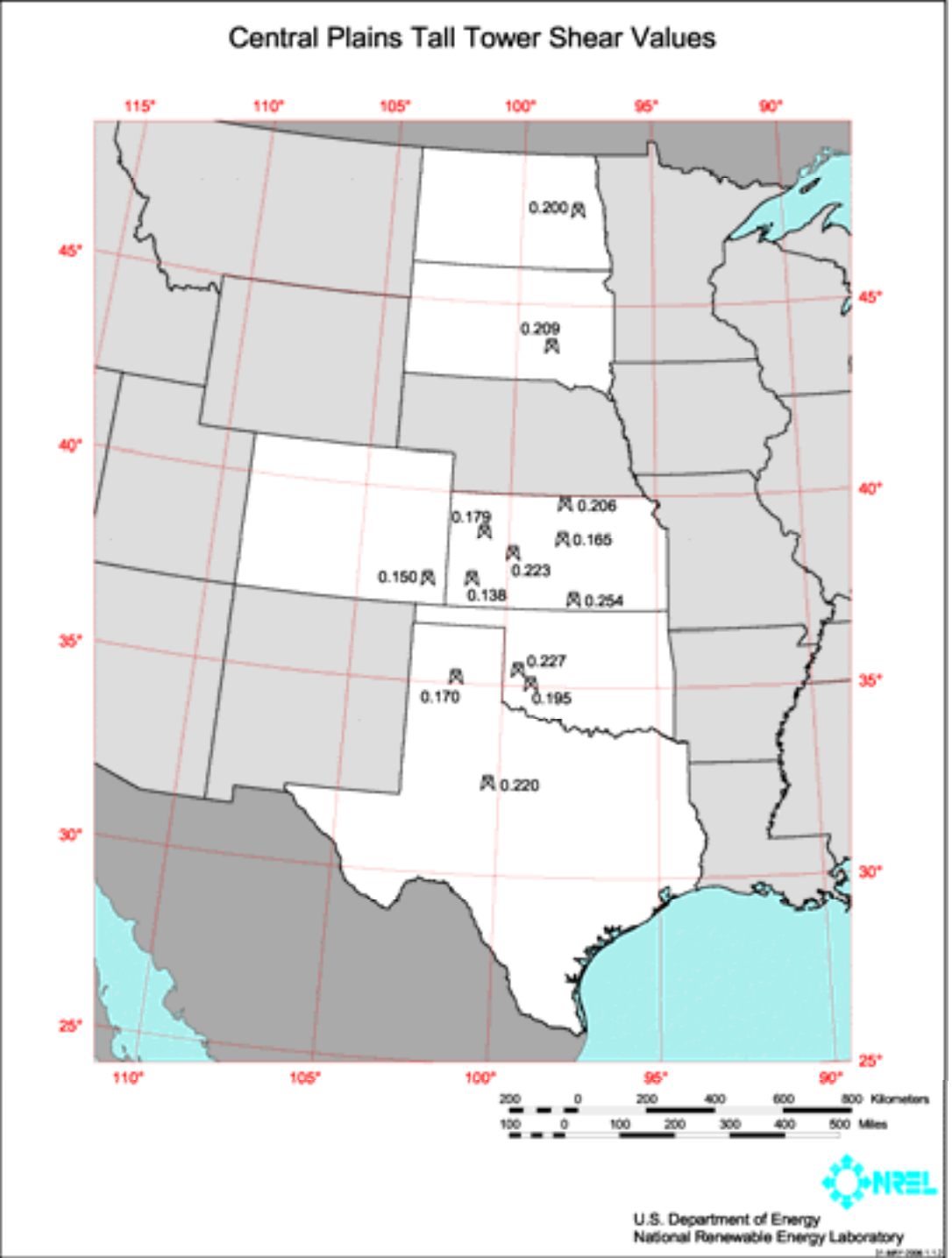
Total: 42 GW



Wind Potential (Installed Capacity) for 12% Power Loss Scenario
30-36% Capacity Factor: 161 GW
36-41% Capacity Factor: 37 GW
Total: 198 GW

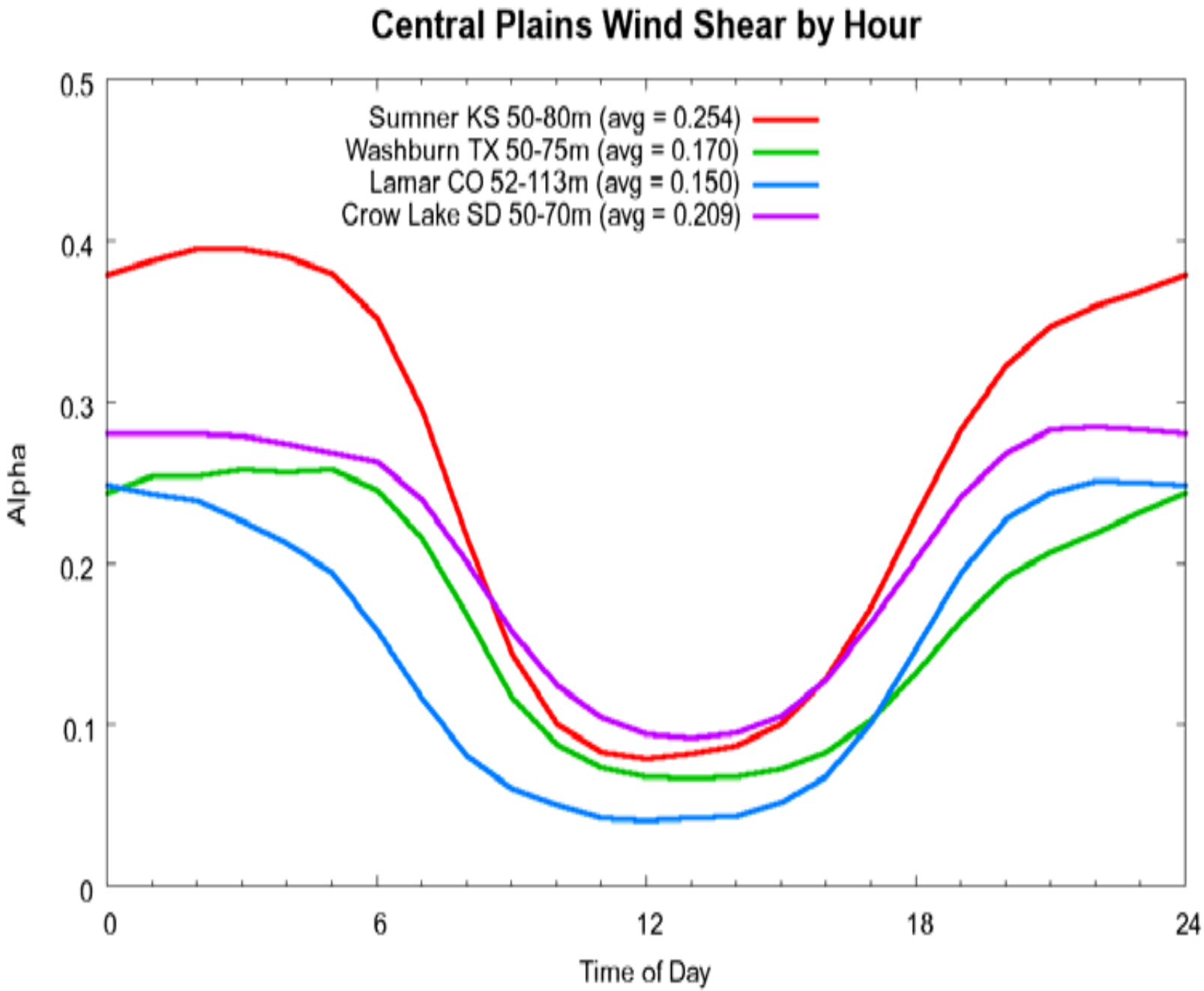
Wind Shear Characteristics Analyzed From Tall Tower Data in Plains and Midwest

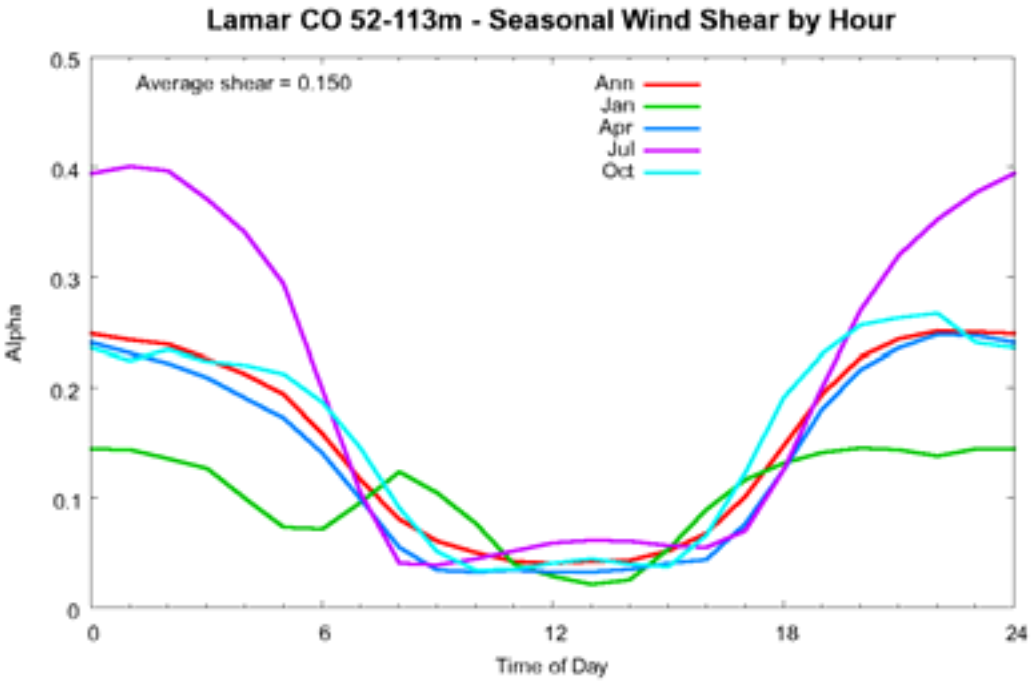
- Annual average
- Diurnal variability
- Seasonal variability
- Shear variation by prevailing wind directions
- Investigate wind shear variation by height
- Variations within and among geographic regions

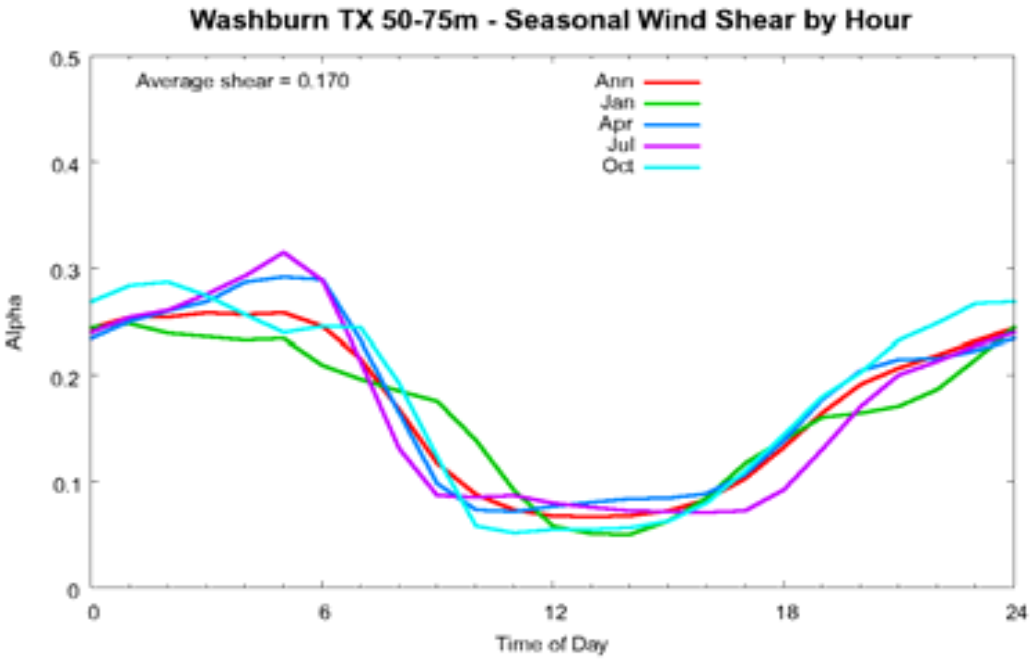


Shear Climate Summary

- Annual average shear between 0.15 and 0.25
- Greater variation of annual wind shear between towers within a region than between the southern and northern Plains and the Midwest
- Diurnal shear pattern similar throughout region
  - Daytime shear is 0.05-0.1
  - Nighttime shear between 0.25-0.40
  - Some seasonal variations among towers
- Winds from south had higher shear than winds from north
  - South winds shear 0.2-0.3
  - North winds shear 0.1-0.2


Central Plains Wind Shear by Hour
Sumner KS 50-80m (avg = 0.254)
Washburn TX 50-75m (avg = 0.170)
Lamar CO 52-113m (avg = 0.150)
Crow Lake SD 50-70m (avg = 0.209)
Alpha
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
Time of Day

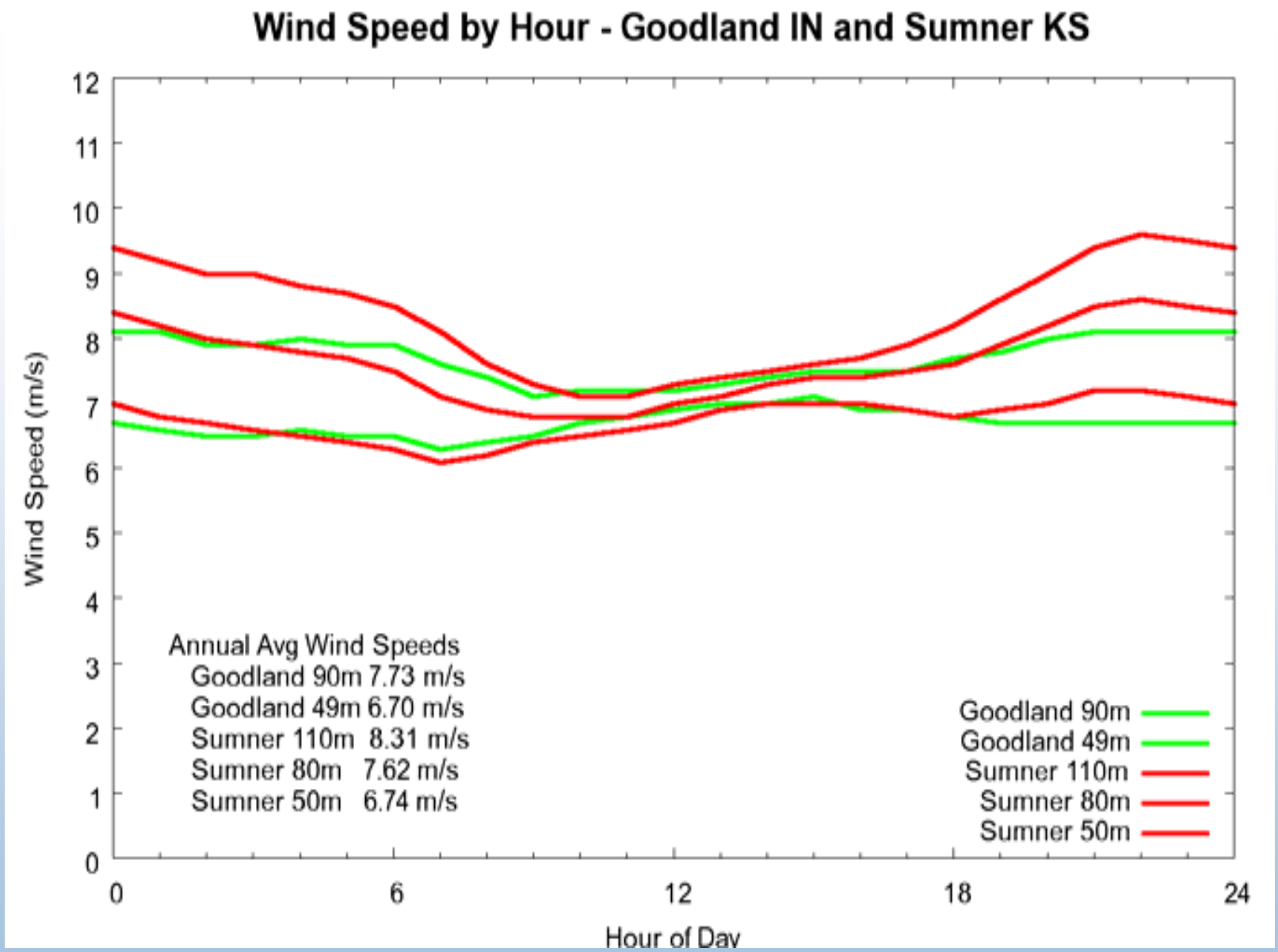




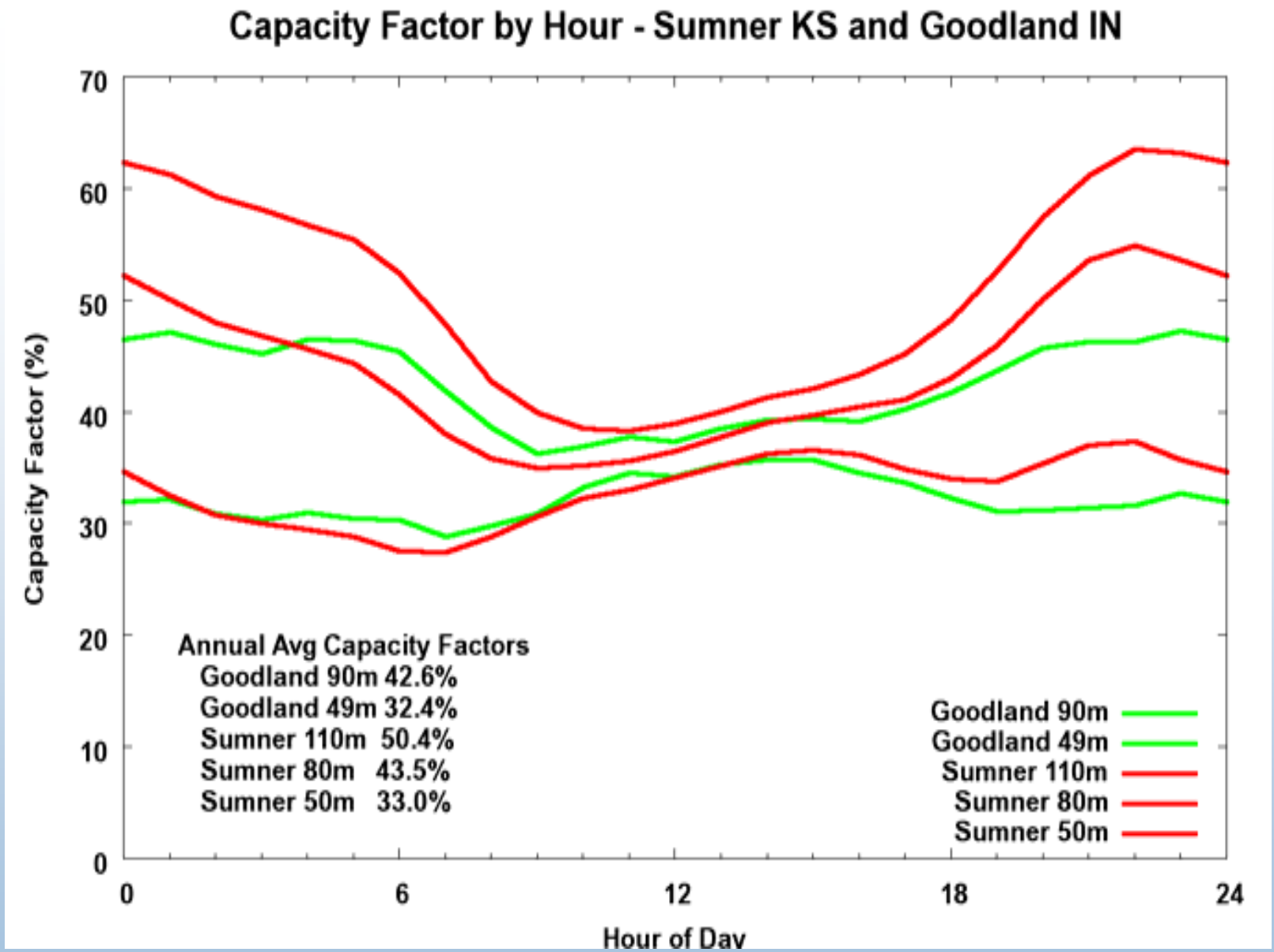
Seasonal and Diurnal Wind Shear

- Lamar CO has much larger nocturnal shears in summer than in winter

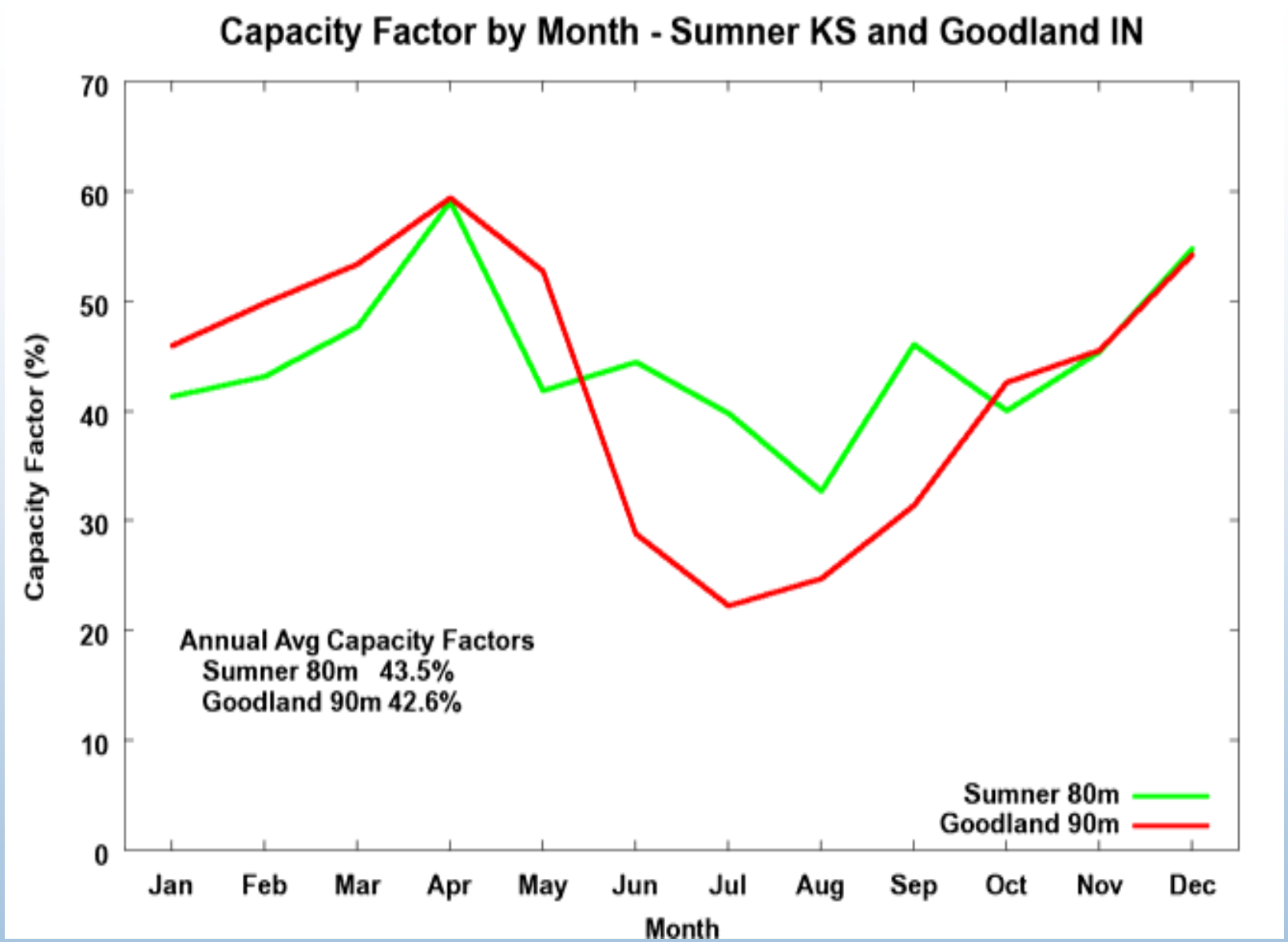
- Washburn TX has similar nocturnal shears across the seasons



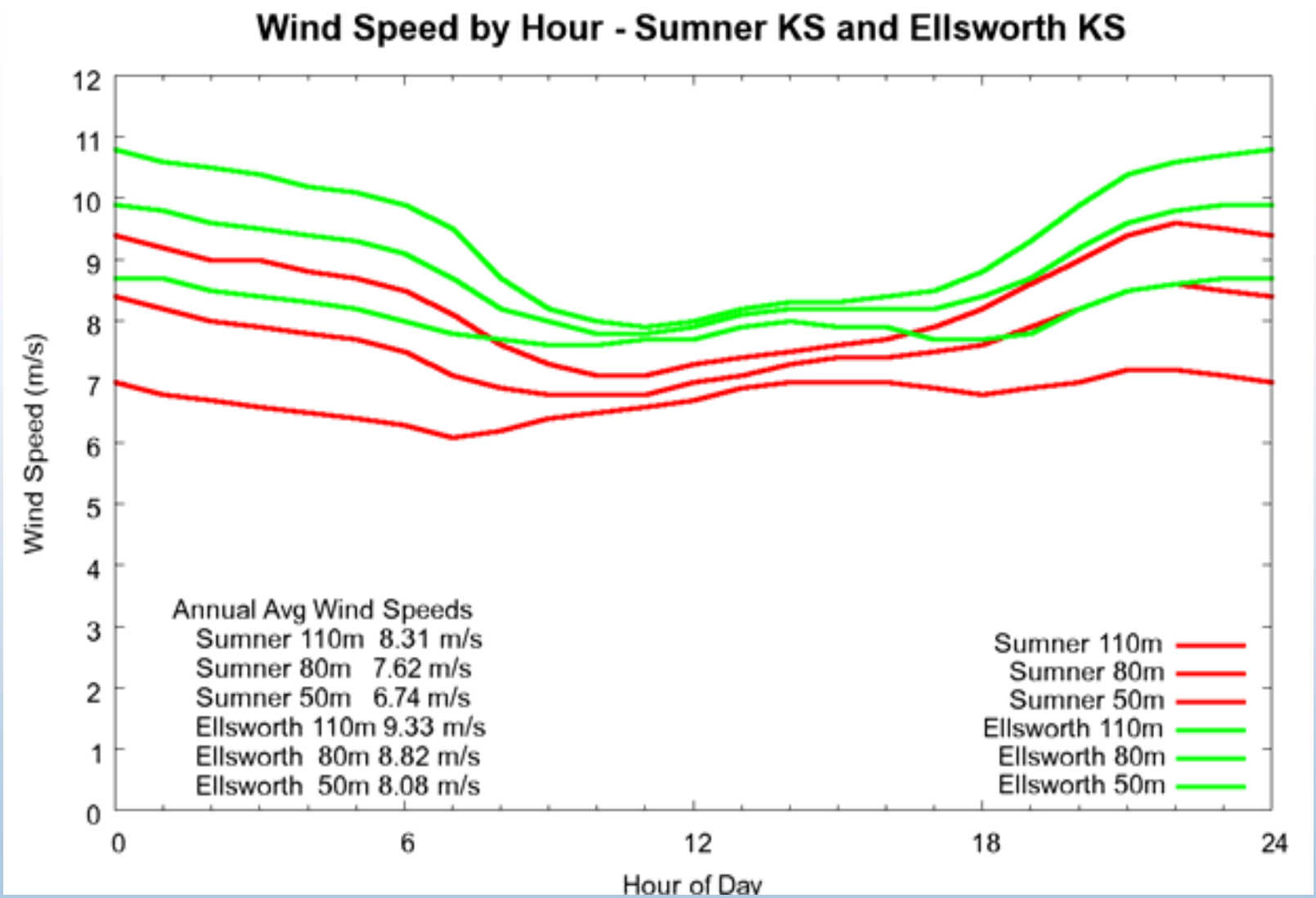
Goodland IN and Sumner KS have similar wind resource and wind shear



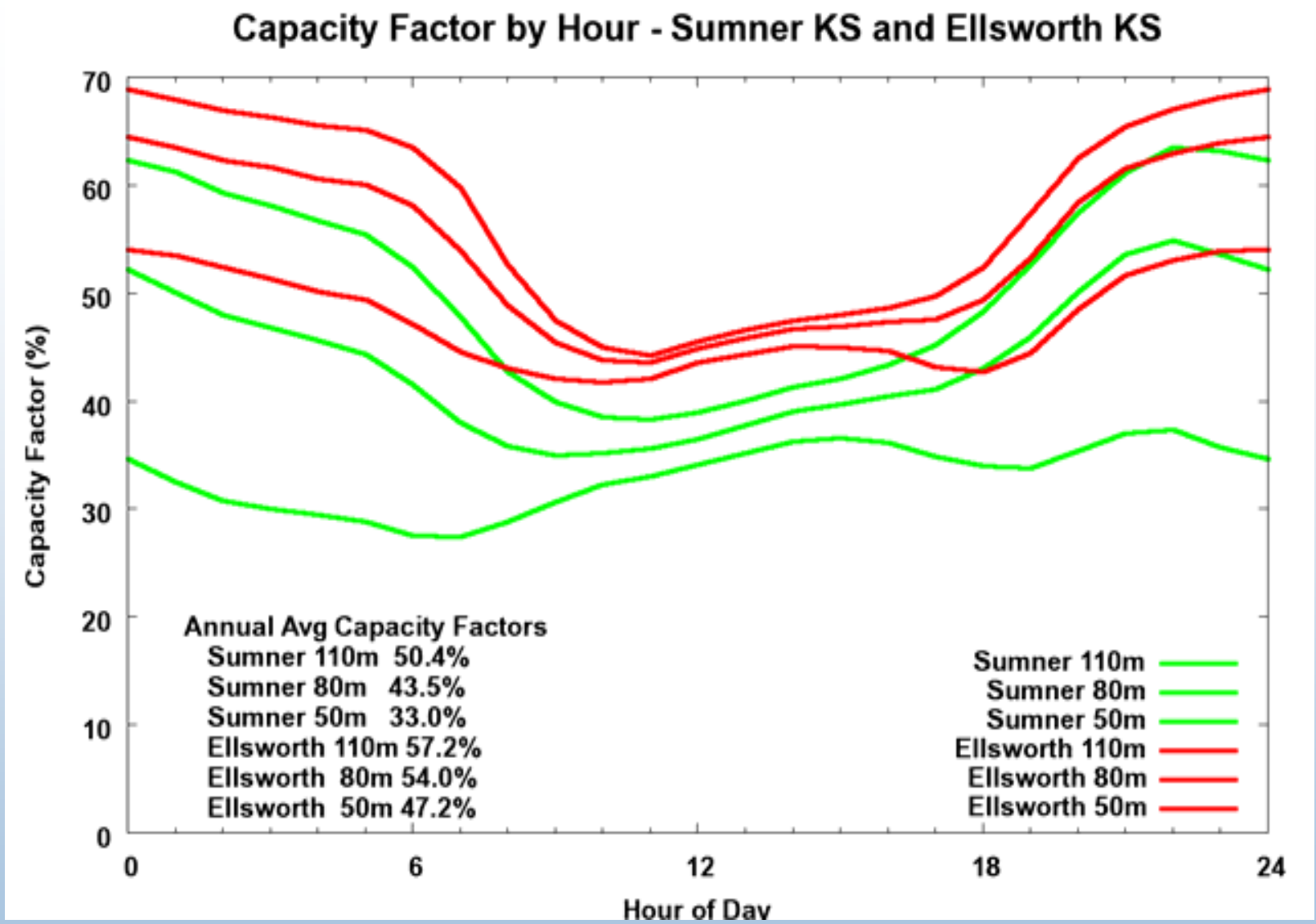
Goodland IN and Sumner KS have similar capacity factors and both locations have large increases in capacity factors between 50 m and 80-90 m heights



Goodland IN has larger seasonal variations than Sumner KS in capacity factors at 80-90 m



- **Comparison of wind resources at two locations in central Kansas**
- **At 50m, Sumner is Class 3 and Ellsworth is Class 4-5**
- **Wind shear is greater at Sumner than Ellsworth, and speed differences decrease with increased height**



- Comparison of capacity factors at two locations in central Kansas
- Capacity factors increase more rapidly with height at Sumner than at Ellsworth
- Difference in capacity factors halved at 80-110 m compared to 50 m

Conclusions

- Tall-tower data from Midwest and Plains regions indicate many locations can have high annual average wind shear (0.2-0.25) at heights between 50-100 m
  - At these locations, Class 3 sites at 50 m can have Class 4-5 equivalent wind resource at 80-100 m heights and gross capacity factors exceeding 40%
- Variations of annual wind shear within a region can be greater than variations among different regions
  - Within a region, less energetic wind resource locations at 50 m tend to have greater wind shear than more energetic locations
- Additional tall-tower data are needed to characterize the wind resource and wind shear in wind energy development regions