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Wind Shear Characteristics at Central Plains Tall Towers

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Windpower 06 Conference
June 5, 2006 Pittsburgh, PA

NREL/PR-500-39989

Objectives

- Analyze wind shear characteristics at tall tower sites for diverse areas in the central plains (Texas to North Dakota)
  - Turbines hub heights are now 70-100 m above ground
  - Wind measurements at 70-100+ m have been rare
- Present conclusions about wind 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
- 13 tall towers were used in the study
  - 11 tall towers had highest anemometer at100-110 m
  - 2 tall towers the highest anemometer was at 70-85 m

Central Plains Tall Tower Locations

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Texas - 2 towers
Oklahoma - 2 towers
Kansas - 6 towers
Colorado - 1 tower
South Dakota – 1 tower
North Dakota – 1 tower

Power Class at 50 m

2 L Class 3 300-349 W/m^2

6 H Class 3 350-399 W/m^2

2 L Class 4 400-449 W/m^2

2 H Class 4 450-499 W/m^2

1 L Class 5 500-549 W/m^2

Technical Approach

- Create "clean" tall tower data sets
- Use wind speed shear exponent α from $(v/v_o) = (z/z_o)^{\alpha}$ for wind shear characteristics
  - Shear exponent does not tell all about shear conditions but is easy to use in comparative analysis
- General analysis methodology
  - Anemometer data from levels at or near 50 m up to 110 m
    - 2 or 3 measurement levels per tower
  - Calculate wind shear statistics by averaging all α values from individual measurements between levels with speeds of at least 3.0 m/s at same time
  - Average data exclusion is 9%

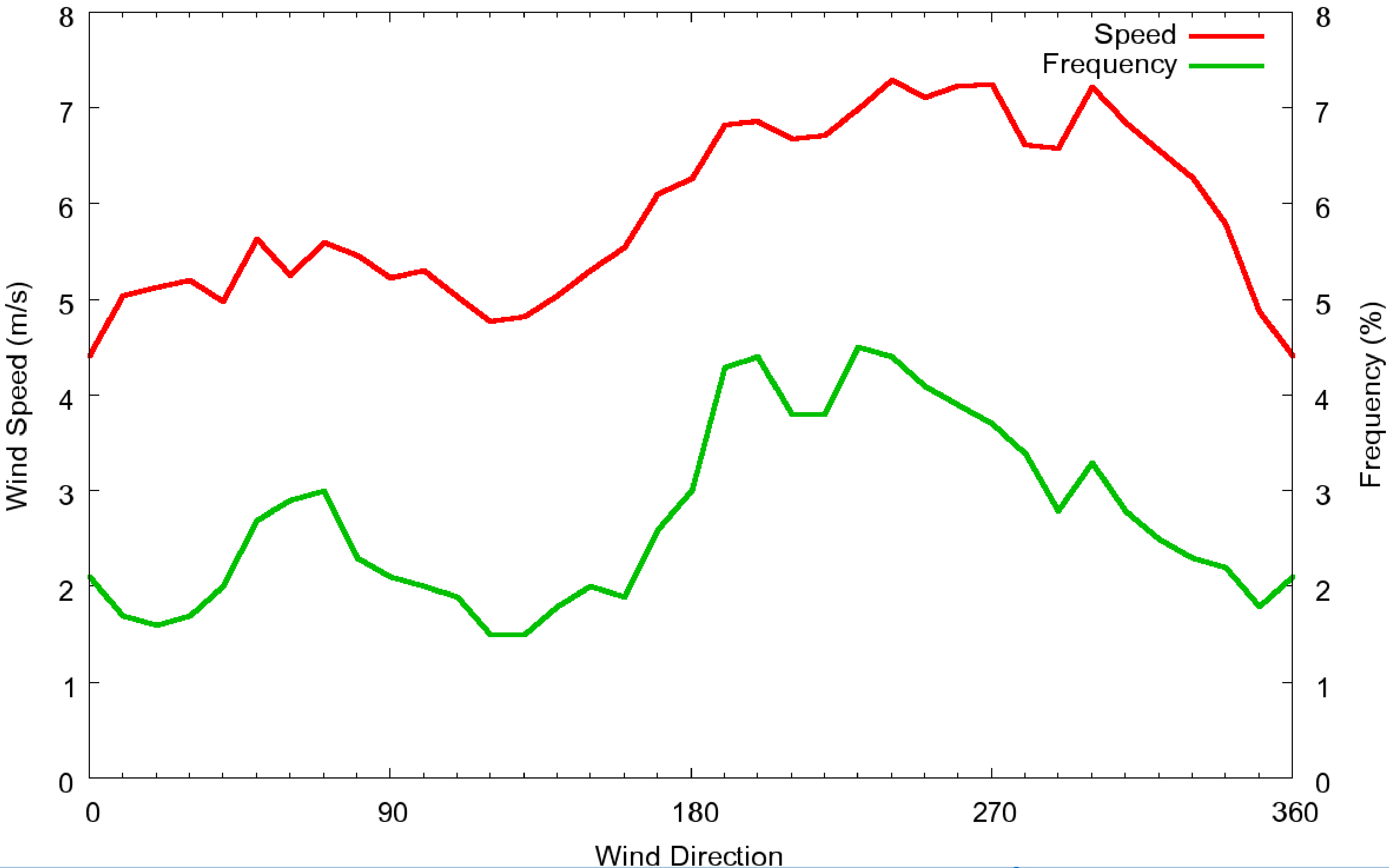
Wind Shear Characteristics

- Annual average
- Diurnal variability
- Seasonal variability
- Shear variation by prevailing wind directions
- Investigate wind shear variation by height

Tall Tower Data Sets

- Create "clean" data sets for analysis (original intent)
  - Use data from set of anemometers on same side of tower judged by:
    - Overall data quality
    - Data recovery rates
    - Minimal tower effects
- Tower effects on the quality of data posed a greater challenge in creating data sets for analysis than was anticipated
  - Wind speed and frequency by direction analysis used to identify tower effects
  - Subjective decisions made to determine "least biased" levels used for analysis

Bryan, OH 100m Speed and Frequency by Direction



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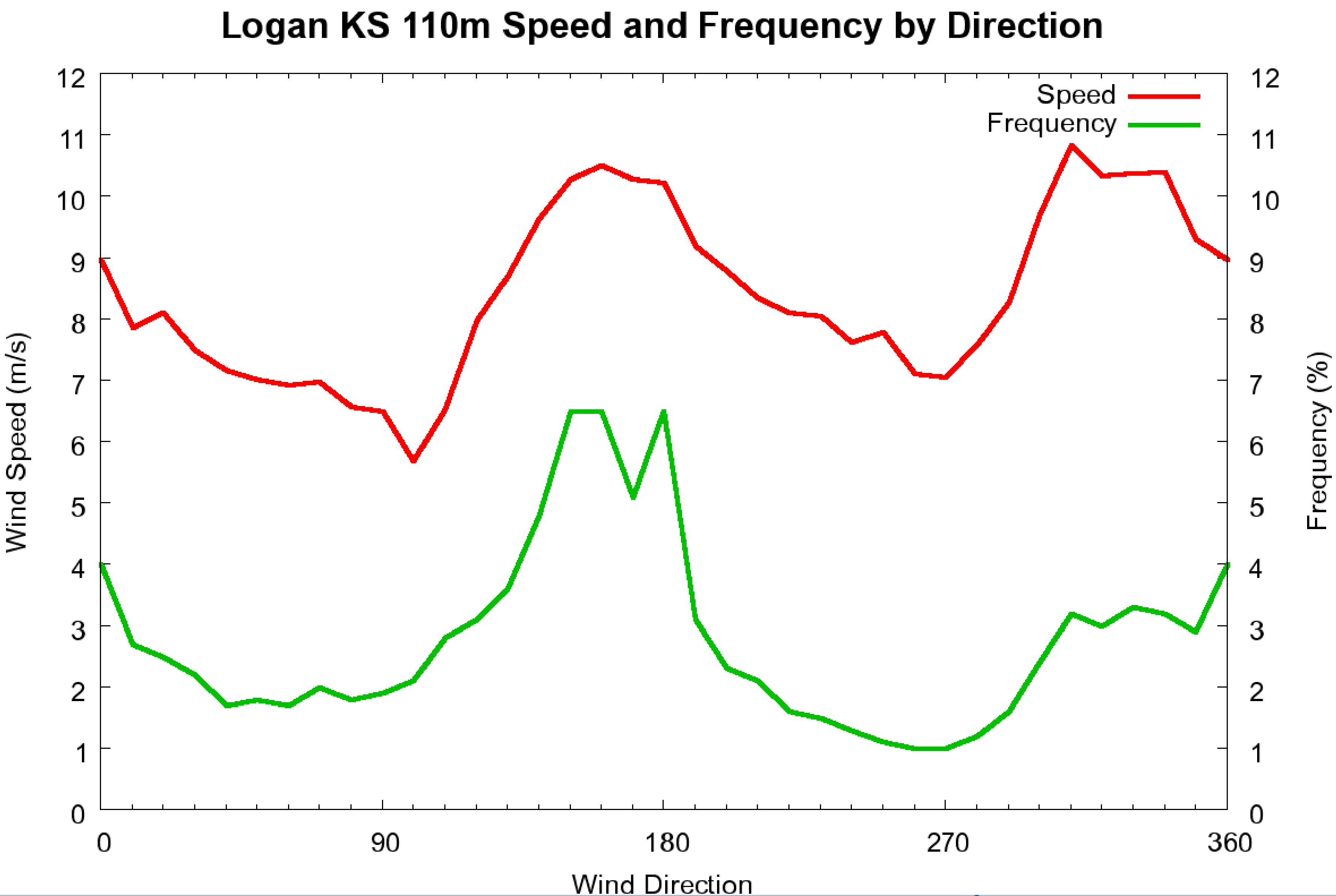


Logan KS 110m Speed and Frequency by Direction
Speed
Frequency
Wind Speed (m/s)
Frequency (%)
Wind Direction
0
90
180
270
360
0
1
2
3
4
5
6
7
8
9
10
11
12

Tower Effect Summary

- 8 out of 13 towers had at least one level affected
- Tower effects are common, but sometimes subtle and changes to measured speed not easily defined
  - Tend to lower measured speed
  - Does not necessarily affect all levels on a tower equally
  - Quite sensitive to wind direction

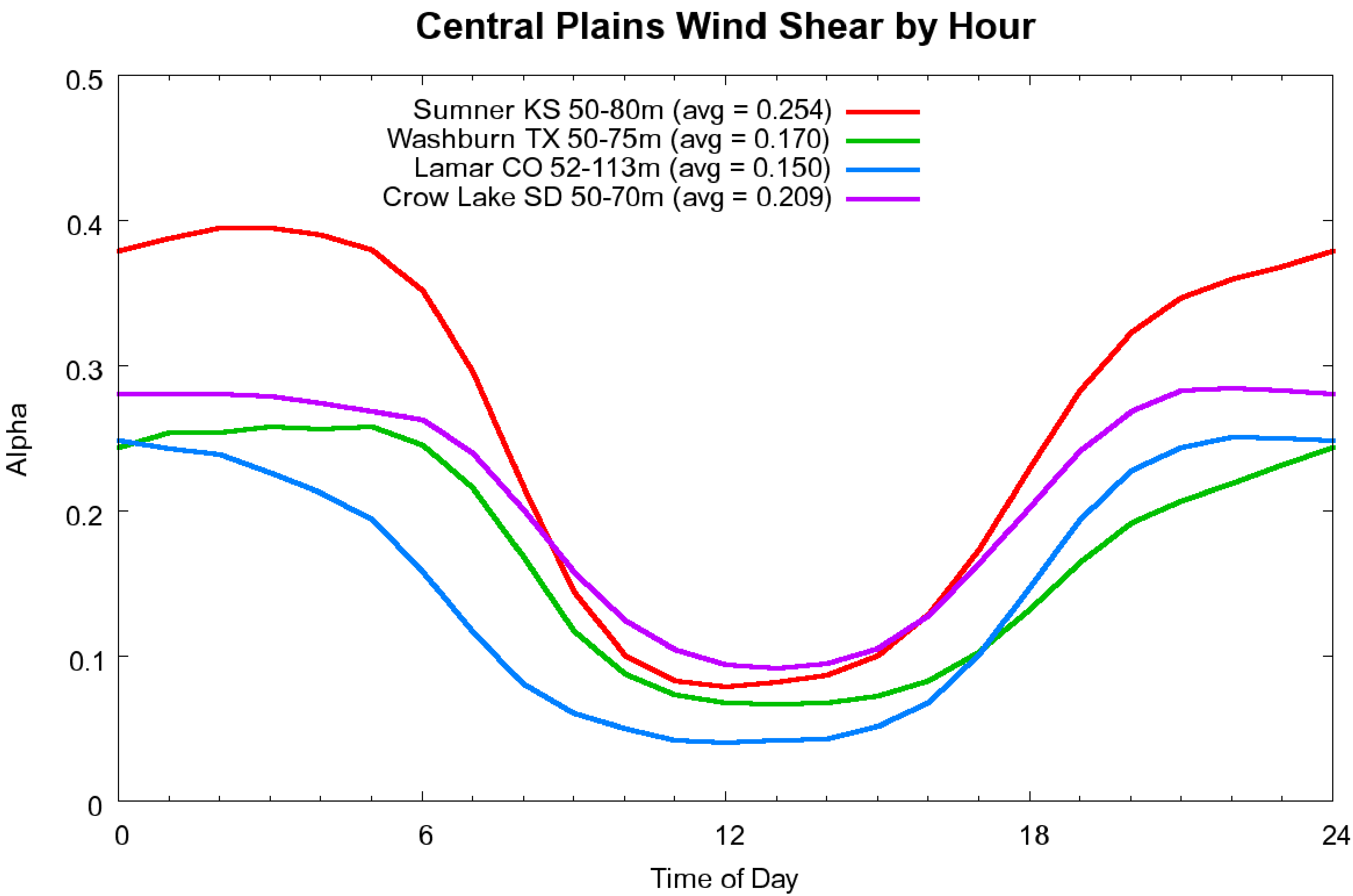
Analysis Features

- Statistics based on short periods of record (about 2 years) and variable data quality
- α is very sensitive to tower effects
  - Example: if 50 m speed = 7.0 m/s and 80 m speed= 7.6 m/s then α =.175
  - If tower effect is + or – 0.1 m/s then α could vary from .117 to .223
- Tower effects made it difficult to determine exact α values for measurement layers
  - Values judged to be within 0.05 range of measurements
  - Despite tower effects, trends in seasonal, diurnal, and direction shear variability still can be discerned

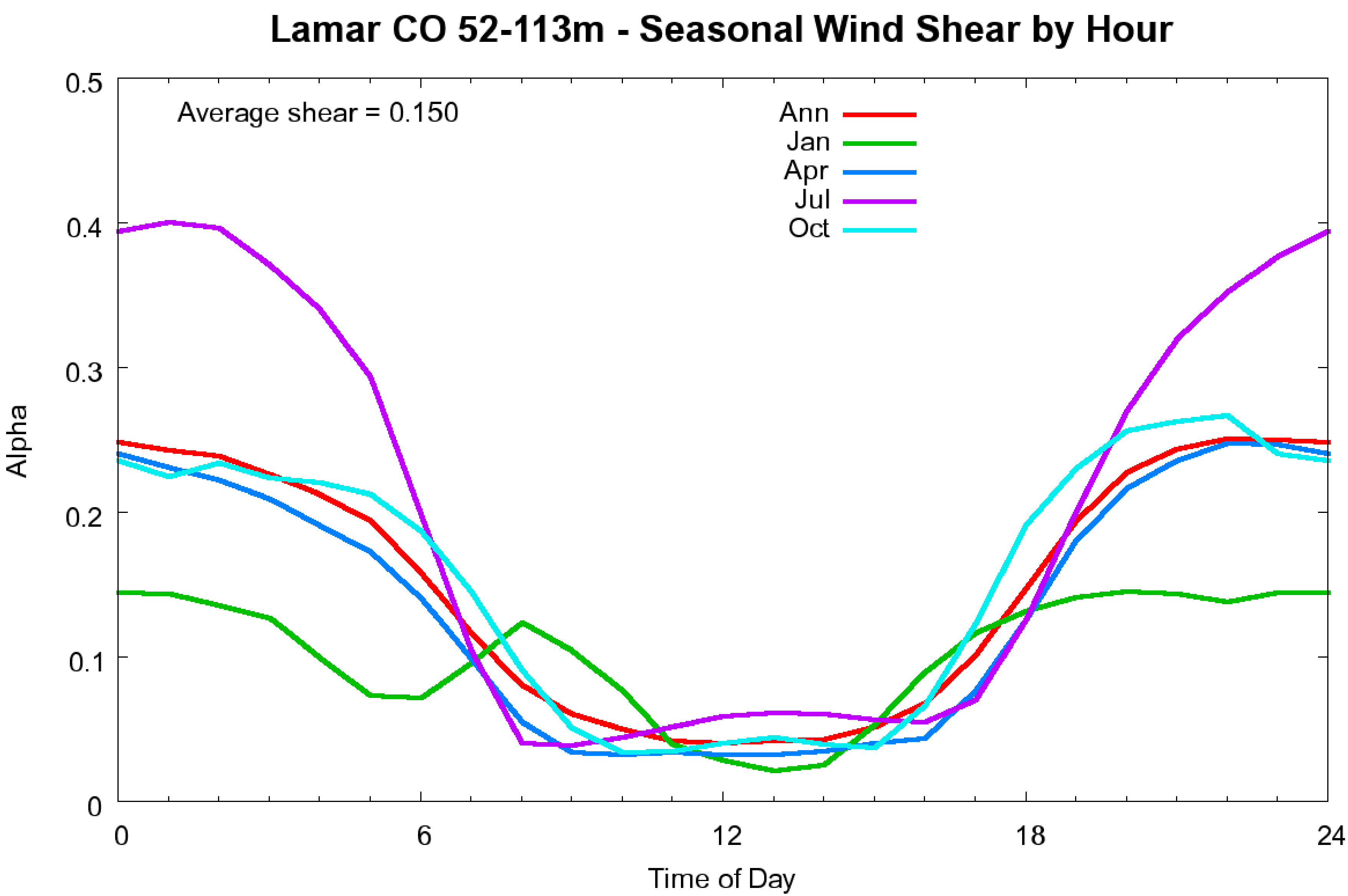
Central Plains Tall Tower Locations Used in Analysis

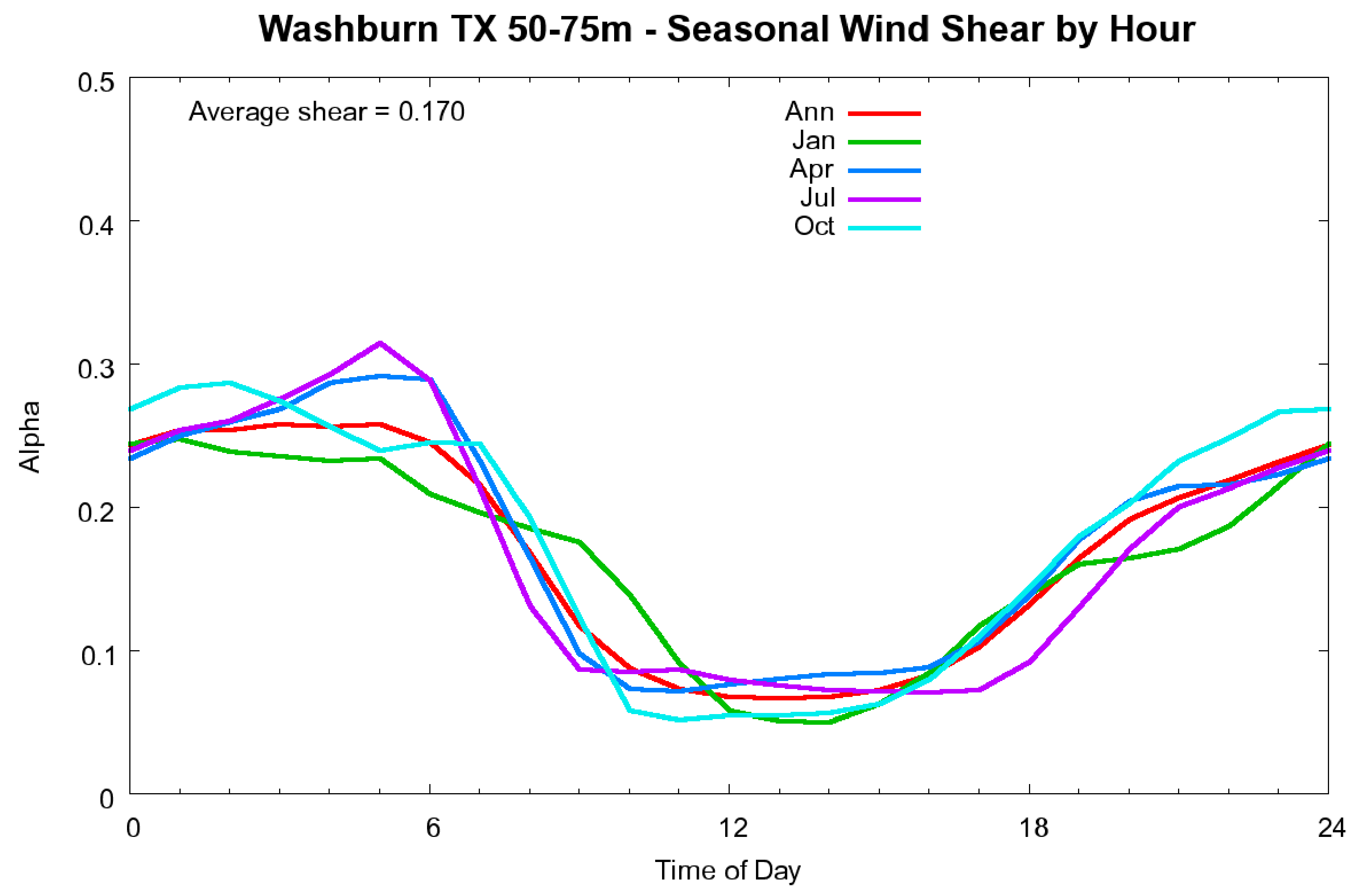
Site Name	Anemometer Heights	From	To	Shear (α)
Lamar, CO	(3) **52 113**	10-05-2001	09-16-2003	0.150
Ellsworth, KS	**50** (80) **110**	04-18-2003	09-02-2005	0.165
Kearny, KS	**50 80** (110)	04-29-2003	09-02-2005	0.138
Sumner, KS	**50 80** (110)	06-11-2003	09-02-2005	0.254
Jewell, KS	**50** (80) **110**	04-23-2003	09-04-2005	0.206
Ness, KS	**50** (80) **110**	06-04-2003	09-03-2005	0.223
Logan, KS	**50 80** (110)	05-01-2003	09-03-2005	0.179
Hobart, OK	**40 70** (100)	04-01-2002	12-31-2003	0.195
Elk City, OK	(10) **40 70** (100)	10-30-2003	08-31-2005	0.227
Sweetwater, TX	**50** (75) **100**	05-17-2003	03-02-2005	0.220
Washburn, TX	**50 75** (100)	09-05-2003	10-03-2005	0.170
Crow Lake, SD	**50 70**	12-26-2001	12-31-2005	0.209
W. Finley, ND	(10, 41) **56 85**	08-07-2003	04-30-2005	0.200

Anemometer heights in **bold-face** were used in shear analysis.

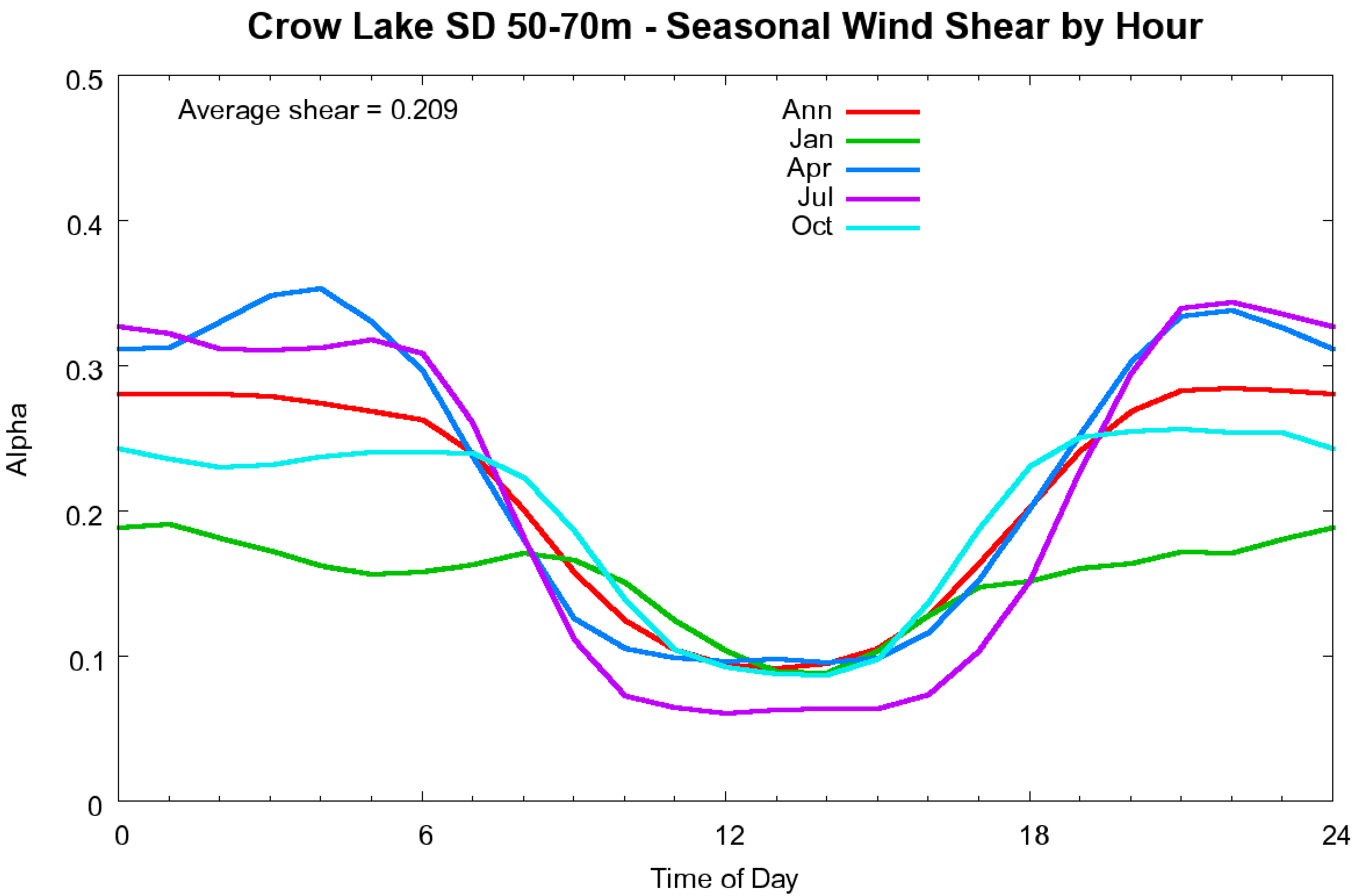


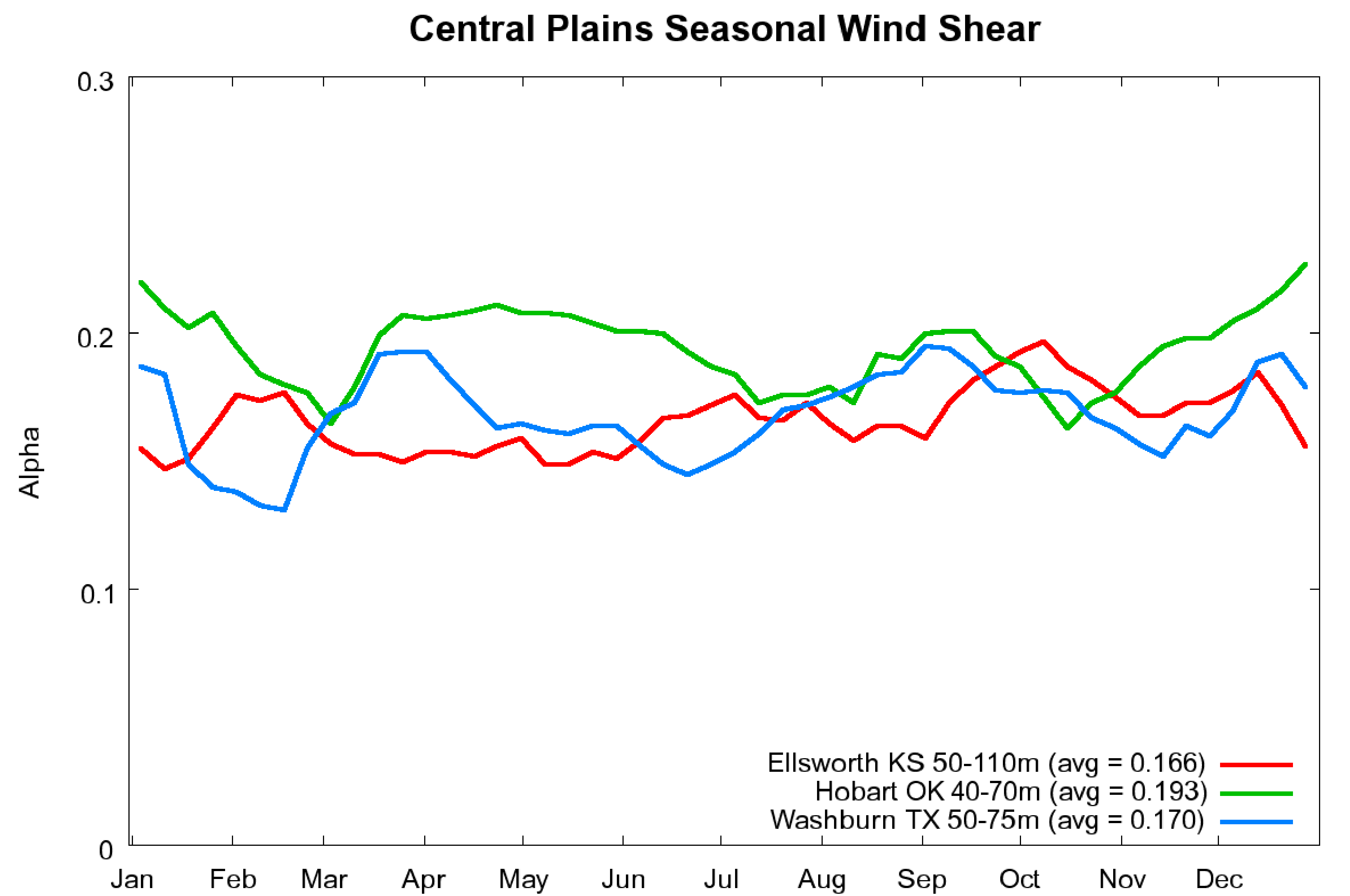
Central Plains Wind Shear by Hour
Sumner KS 50-80m (avg = 0.254)
Washburn TX 50-75m (avg = 0.170)
Lamar CO 52-113m (avg = 0.150)
Crow Lake SD 50-70m (avg = 0.209)
Alpha
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
Time of Day


Lamar CO 52-113m - Seasonal Wind Shear by Hour
Average shear = 0.150
Ann
Jan
Apr
Jul
Oct
Alpha
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
Time of Day



Washburn TX 50-75m - Seasonal Wind Shear by Hour
Average shear = 0.170
Ann
Jan
Apr
Jul
Oct
Alpha
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
Time of Day


Crow Lake SD 50-70m - Seasonal Wind Shear by Hour
Average shear = 0.209
Ann
Jan
Apr
Jul
Oct
Alpha
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
Time of Day



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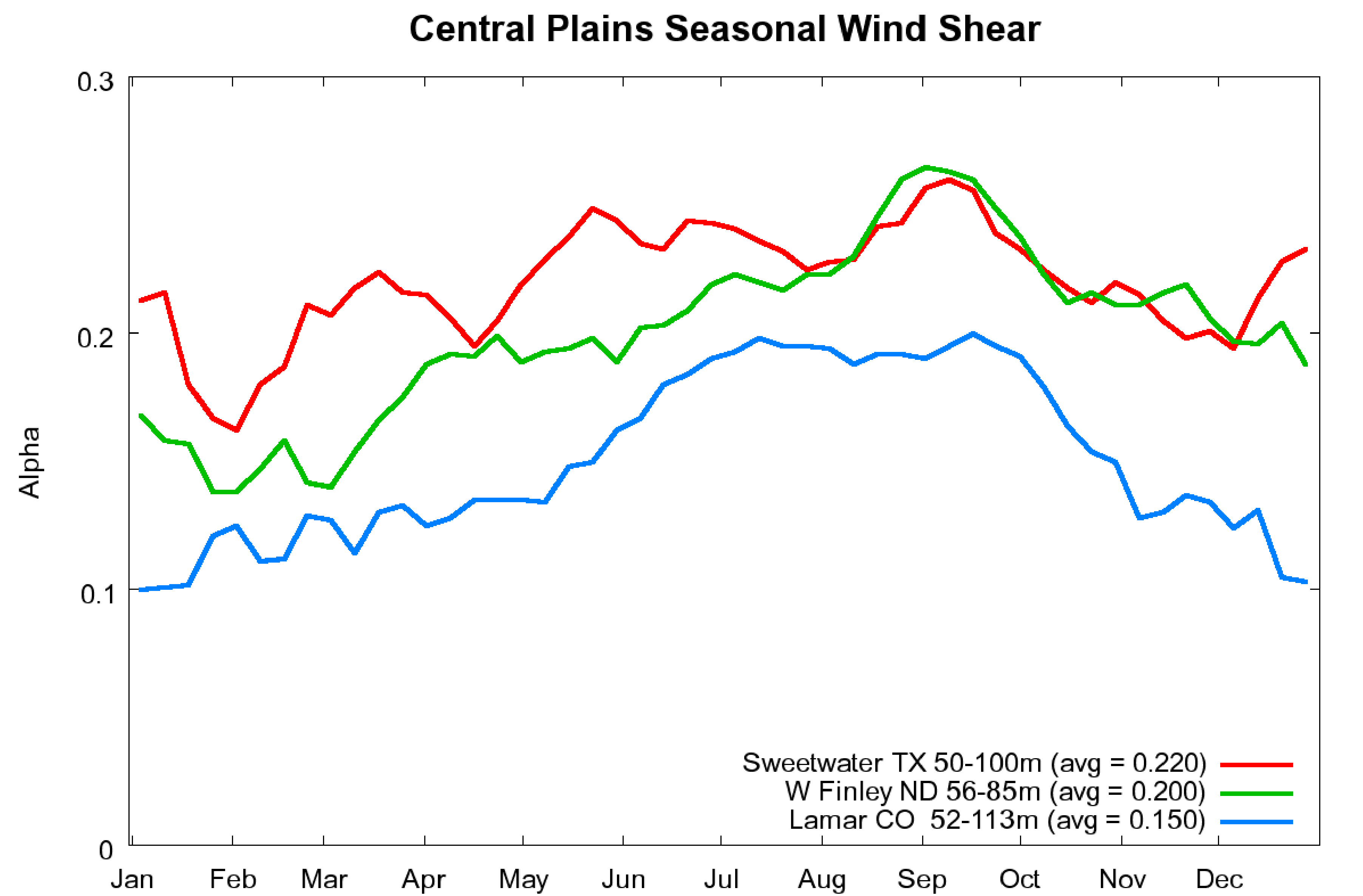
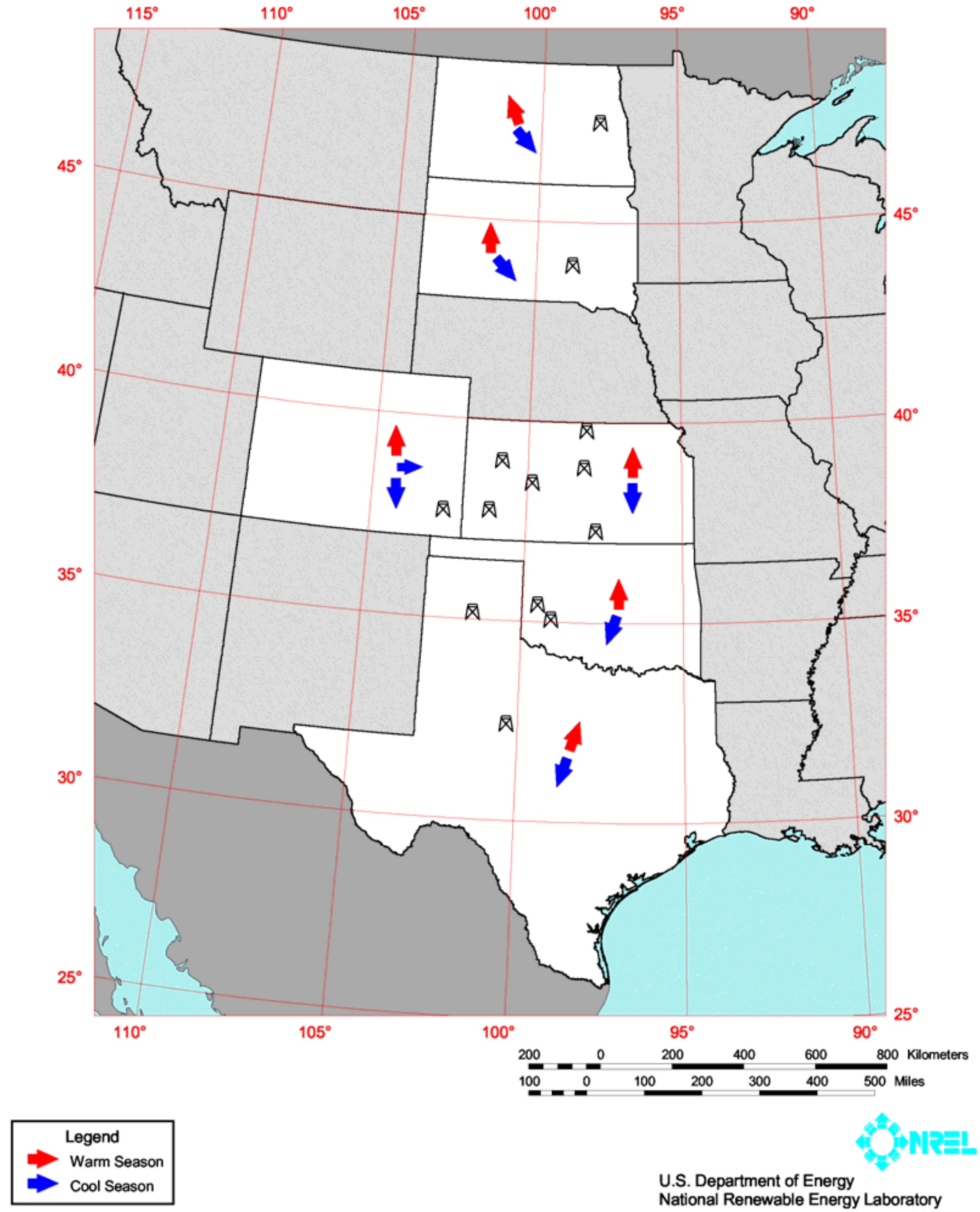

Central Plains Seasonal Wind Shear
Alpha
0.3
0.2
0.1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Sweetwater TX 50-100m (avg = 0.220)
W Finley ND 56-85m (avg = 0.200)
Lamar CO 52-113m (avg = 0.150)

Prevailing Wind Directions in the Central Plains



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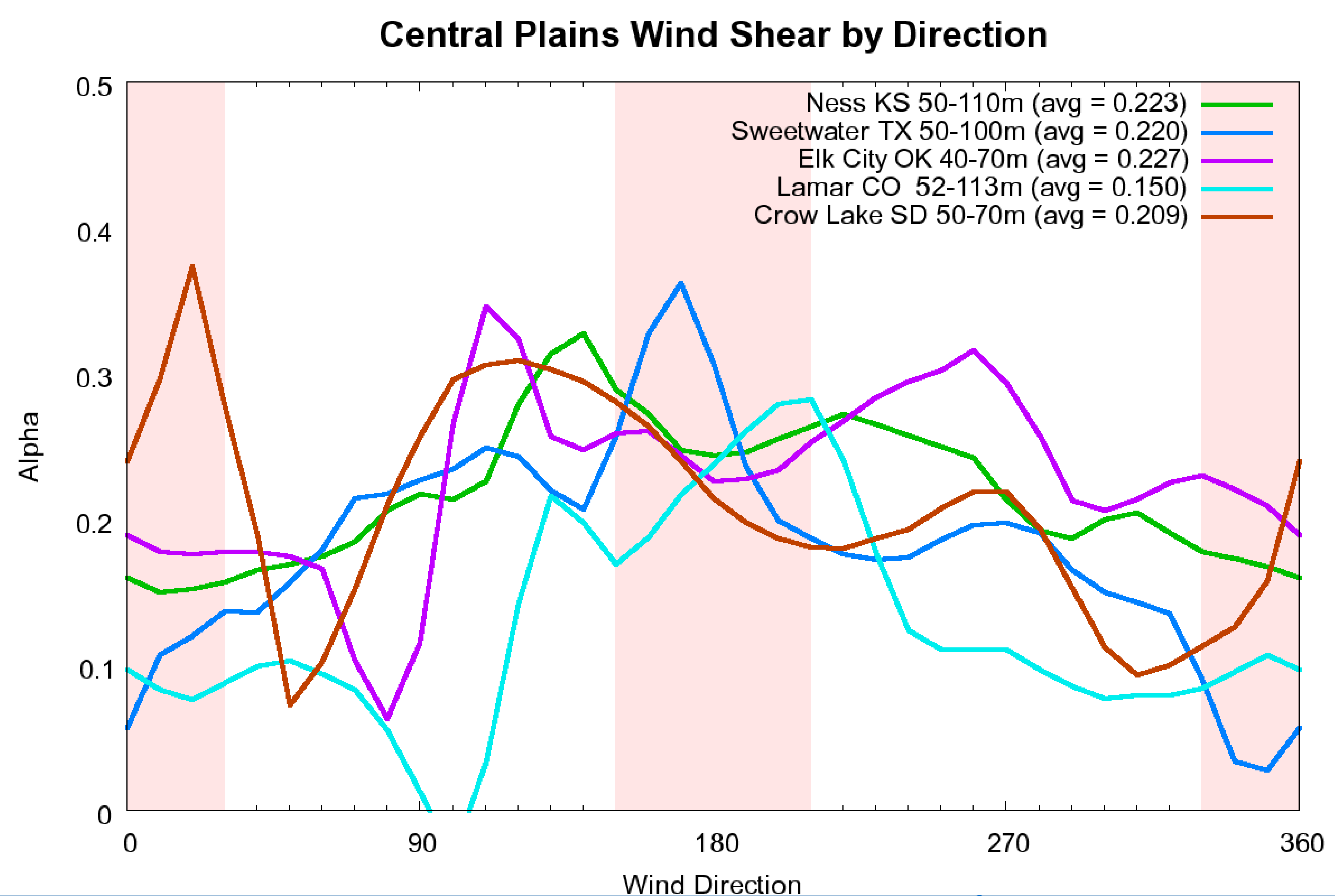
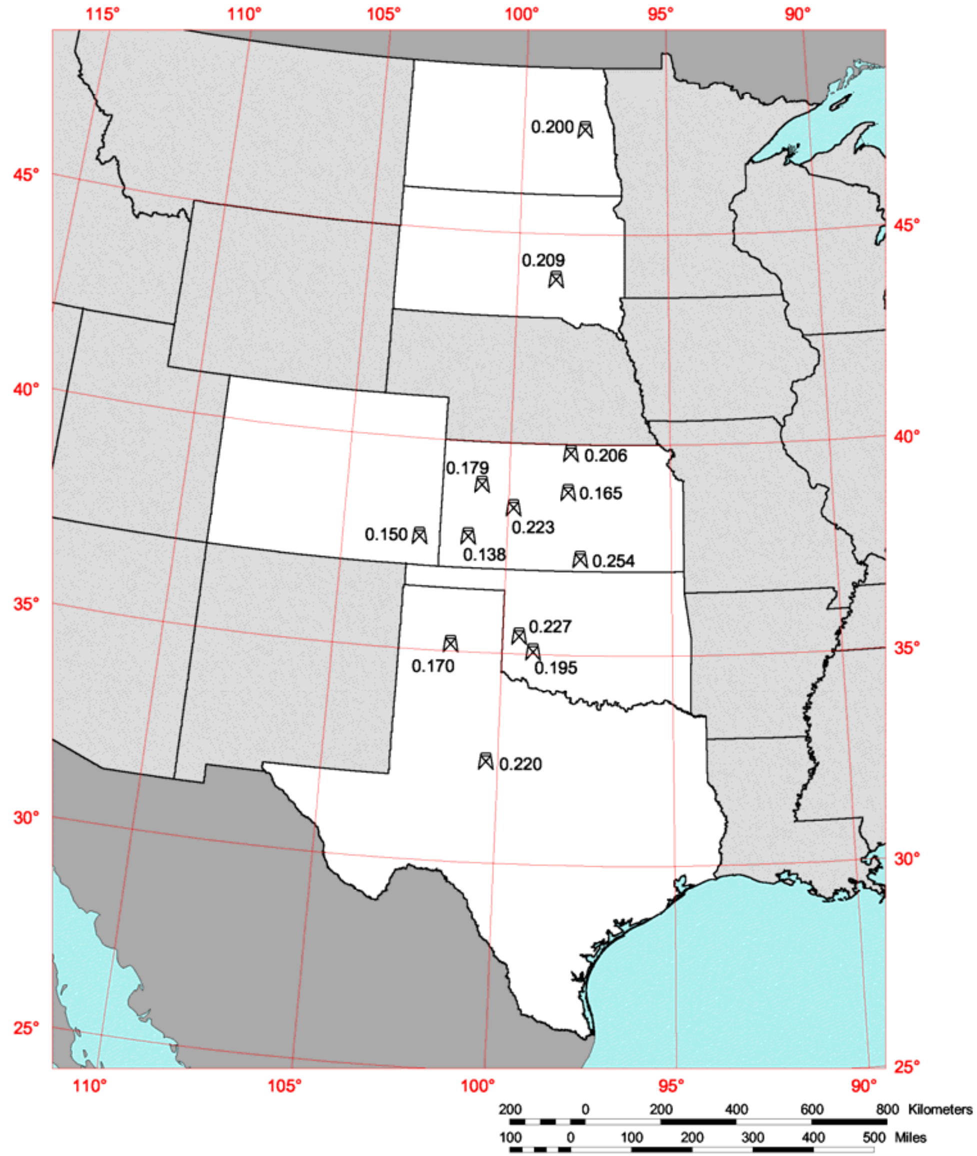

Central Plains Wind Shear by Direction
Ness KS 50-110m (avg = 0.223)
Sweetwater TX 50-100m (avg = 0.220)
Elk City OK 40-70m (avg = 0.227)
Lamar CO 52-113m (avg = 0.150)
Crow Lake SD 50-70m (avg = 0.209)
Alpha
0.5
0.4
0.3
0.2
0.1
0
0
90
180
270
360
Wind Direction

Central Plains Tall Tower Shear Values



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Shear Climate - Overall and Diurnal

- Annual average α between 0.15 and 0.25
- Greater variation of annual wind shear between towers within a region than between the southern and northern plains
- Limited data in Kansas indicate annual average α consistent with height
- Diurnal shear pattern similar throughout region
  - Daytime α is 0.05-0.1
  - Nighttime α between 0.25-0.40
  - Some seasonal variations among towers

Shear Climate - Directional and Seasonal

- Winds from the south exhibited higher shear than winds from the north
  - South winds generally had α values 0.2 – 0.3, north winds 0.1 - 0.2
- Some differences in the seasonal pattern of wind shear
  - Northern Texas, Oklahoma, and Kansas exhibited flat shear distributions
  - Central Texas, Colorado, and the Dakotas had highest shears from Jul. to Oct. and lowest shears Jan. to Apr.

Lessons Learned and Conclusions

- Tower effects are common
  - Attempt to minimize effects but unlikely to eliminate them
- Do not accept wind shear information from tall towers at face value
- Need accurate wind direction data to help assess possible tower effects
  - Only 60% of the measurement levels across the 13 towers had high-quality direction data
- Thank you to all organizations who have collected tall tower data
- Long live tall towers!