JP2.11 A Tall Tower Study of the Impact of the Low-Level Jet on Wind Speed and Shear at Turbine Heights

Ali Koleiny
Keith E. Cooley
Neil I. Fox
University of Missouri-Columbia, Columbia, Missouri

1. INTRODUCTION

In 2006 ten tall communication towers were outfitted with anemometers and wind vanes at heights up to 150 m across the state of Missouri (Figure 1). The majority of the towers are located in northwest MO where the best wind resource is thought to be. One tower is located in Raytown in the Kansas City suburbs, and two are located in the southwest. The primary goal of this network was to improve the wind climatology at heights corresponding to those at which modern utility scale wind turbines operate. In this work a complete year of observations is used to further investigate the wind resource in Missouri. Redburn (2007) concluded that the 100 m wind map produced by AWS Truewind Ltd. overestimated the observed tall-tower wind speeds.

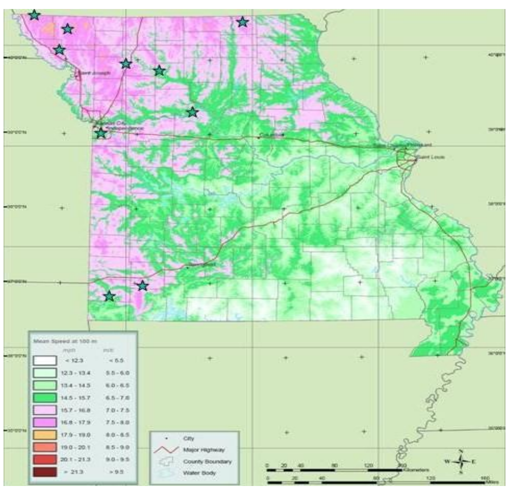

Figure 1. The green stars represent the location of each tall tower location overlaid on the AWS Truewind map of projected wind speeds at 100 m.

Initially it was seen that a strong diurnal variation in wind speed occurs at all towers with the maximum mean wind observed at night (Figure 2). This was seen as preliminary evidence of the importance of the low-level jet. However, very little has been done previously to determine the contribution of the nocturnal LLJ to the available wind resource in this part of the Great Plains. Knowledge of this contribution by the LLJ at such heights can allow wind farm developers to more efficiently harness wind power.

* *Corresponding author address:* Ali Koleiny, 302 ABNR Building, Univ. of Missouri-Columbia, Dept of Soil, Environmental, and Atmos. Science, Columbia, MO, 65211; email: akgv7@mail.missouri.edu

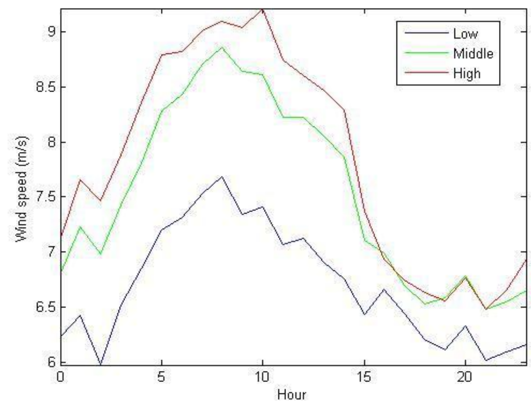

Figure 2. Average diurnal wind speed variations at Blanchard tall tower during February 2007 (time in UTC).

A comparison was made between the wind conditions during periods when the low-level jet is active compared to times when it is not at heights relevant to wind power applications. In particular, it is found that wind speed and shear at these heights are greater when the jet is present. The magnitude of these increases is important when assessing the likely wind power potential in an area, but also has application to wind farm operations when energy output is being forecast. Most notably, wind farm operators are concerned about rapid changes in wind speed that increase or decrease power generation over a short period. Such changes are frequently the result of low-level jet formation in the Midwest.

2. A SHEAR BACKGROUND

Wind shear can be assessed in a couple of ways. In previous wind energy application studies, use of the shear exponent alpha, α (dimensionless), has been calculated to infer the turbulent flow in the vicinity of these operational turbine heights. However, α tends to raise more questions about its true effectiveness in assessing the existing turbulence, which will be discussed further. Therefore, calculations of friction velocity, u_* (m s^{-1}), will also be calculated and compared to those of α during the same time period.

2.1 Alpha

The power law equation gives rise to the shear exponent α, as seen in equation (1). Typically it is used to estimate higher level wind speeds, given knowledge of some reference level wind speed and corresponding height. It is often assumed that the shear exponent has an assumed value of 0.143 under neutral conditions.

$$\frac{u_2}{u_1} = \left(\frac{z_2}{z_1}\right)^{\alpha} \tag{1}$$

However, more recent wind energy studies have used equation (1) to obtain α as a measure of the existing shear in the hub-height vicinity. The drawback to the power law is that it is empirical in nature and has no real underlying physical basis. Given this equation, it can be inferred that it does not take into account either the effects of surface roughness or the stability of the atmosphere.

2.2 *Friction Velocity*

The logarithmic wind profile employs similarity theory and gives rise to an expression for the friction velocity, which provides a measure of the vertical flux of horizontal momentum. Values of friction velocity can be determined from performing field experiments, and give this shear measure a much stronger physical basis. Larger values indicate a higher amount of mechanical turbulence in the atmosphere. Equation 2 shows a common form of the logarithmic law equation.

$$u(z) = \left(\frac{u_*}{k}\right)\ln\left(\frac{z}{z_0}\right) \tag{2}$$

Unlike the calculation for the shear exponent, this measure of shear accounts for stability and roughness of the surface. The major drawback of measuring shear in this manner is that the log wind profile assumes constant stability over the entire layer.

3. DATA AND METHODOLOGY

Regional reanalyses acquired from the National Centers for Environmental Prediction (NCEP) were used to identify potential nocturnal LLJ events affecting tall-tower locations between the times of 00 Z and 12 Z using a modified version of criteria used by Walters and Winkler (2004). As a result, Table 1 outlines each identified jet event throughout the 12-month period (September 2006 through August 2007). The same number of possible nocturnal jet events identified during each month were then compared with an even number of days when the LLJ is not thought to be present. For example, by looking at the month of September, there were 9 days where a jet max appeared at or below 850 mb and 14 days that month where no jet max appeared to be occurring. To compare an even number of jet days to non-jet days for that month, 9 of those 14 non-jet days were chosen for purpose of analysis.

Observational Period	LLJ Events (at or below 850 mb)	Non-Jet Days Only
September 2006	9	14 (9)
October 2006	14 (11)	11
November 2006	18 (8)	8
December 2006	20 (2)	2
January 2007	20 (8)	8
February 2007	18 (6)	6
March 2007	18 (7)	7
April 2007	8	15 (8)
May 2007	15	16 (15)
June 2007	4	26 (4)
July 2007	3	28 (3)
August 2007	11	19 (11)

Table 1. Summary of jet events during each month.

To determine wind speed differences in jet and non-jet periods, observational data from the towers were analyzed for corresponding days in which a possible jet event is either occurring or is not. Comparisons of alpha and friction velocity also accompany calculations of average wind speeds for the same jet and non-jet event days each month. Three of the tall towers are not included in the study, as they either did not begin collecting data until the latter part of 2007, or did not record reliable wind speed data for the period of interest.

4. RESULTS AND DISCUSSION

Calculations of wind speeds, alpha, and friction velocity are presented in this section. To give an effective picture of the observed wind data at turbine heights across the state, the Blanchard, Raytown, Chillicothe, and Monett data will be used herein. The first three of these towers each have instruments at similar heights (~65 m, ~95 m, and ~140 m), but are situated in differing environments. The Monett tower has instruments at lower heights (50m, 60m and 70m), but is representative of southwest Missouri. As such, it is easier to determine the differences in the wind in different parts of the state.

4.1 Mid-Level (90-100m) Wind Speeds

Generally, each tower followed the same trend at the mid-level anemometer heights for both the jet and non-jet time periods. The Blanchard tower in the far northwestern corner of the state experienced stronger wind speeds at the mid-levels compared to the other towers discussed in this section (Figure 3). The Raytown tower experiences relatively weak wind speeds at similar heights throughout the jet and non-jet periods, probably due to its location with respect to the KC metropolitan area (Figure 4). An interesting artifact of the Monett data reveals that Monett has a quite impressive resource of wind. The mid-level anemometer heights at Monett are approximately 60 m above the base of the tower, 30-40 m lower than the mid-level winds at the Blanchard, Chillicothe, and Raytown towers. The Monett jet and non-jet curves in Figure 6 are similar to the Raytown curves, and even the Chillicothe curves in Figure 5 as well. The difference between the jet and non-jet periods tends to be a bit larger in the late fall towards the end of 2006. As spring arrives in 2007, the difference in the spread between the jet and non-jet curves becomes less. This appeared to be a common artifact of the data for all the towers, possibly as a result of seasonality changes.

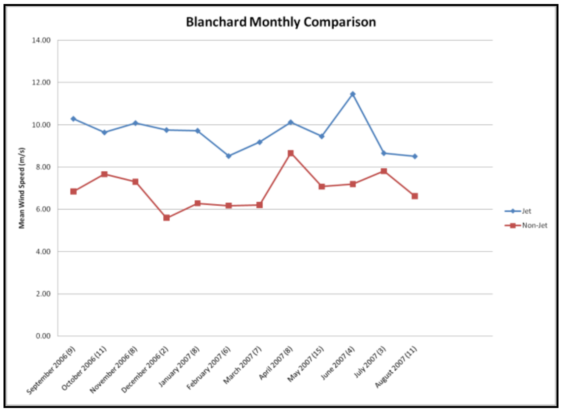

Figure 3. Blanchard mid-level wind speeds during jet and non-jet periods.

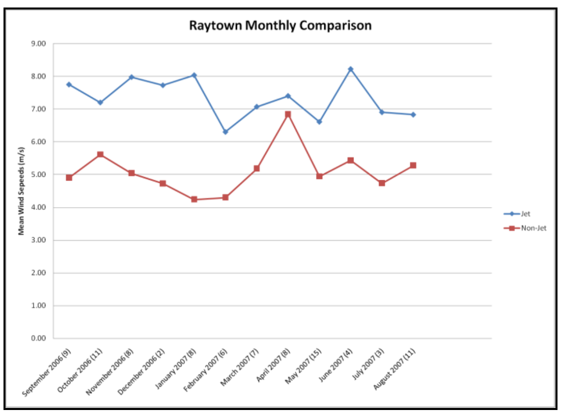

Figure 4. Raytown mid-level wind speeds during jet and non-jet periods.

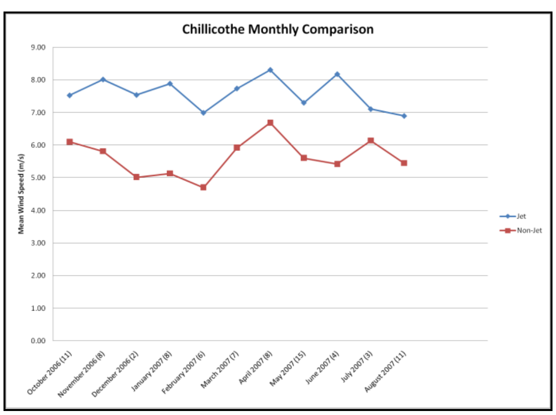

Figure 5. Chillicothe mid-level wind speeds during jet and non-jet periods.

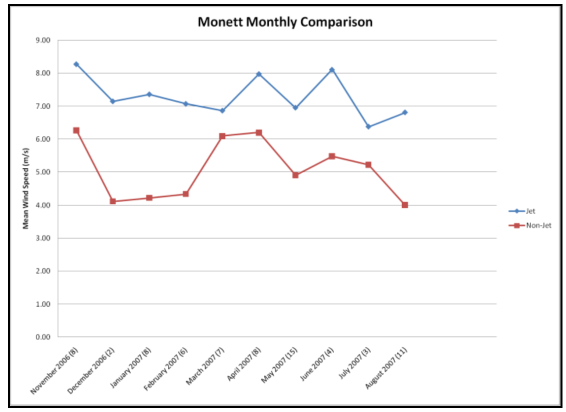

Figure 6. Monett mid-level wind speeds during jet and non-jet periods.

4.2 Alpha Calculation

When investigating differences in α between towers, the Blanchard, Raytown, and Chillicothe towers were grouped and plotted against each other due to the similarity in their anemometer heights. Trends in α calculated for the Blanchard, Raytown, and Chillicothe towers during the jet and non-jet periods are displayed in Figures 7 and 8 respectively. Since the Monett tower has significantly different anemometer heights, the jet and non-jet curves are plotted against each other and displayed in Figure 9.

Figures 7 and 8 show very similar trends in α during the jet and non-jet periods for the three towers. Raytown appears to have the greatest variability in α throughout the observational period for both the jet and non-jet curves. The Blanchard and Chillicothe trends appear to mirror each other a bit more as compared to the Raytown curves.

When α was averaged over the whole observational period, the Blanchard tower had just a slightly higher mean value during the jet period opposed to the non-jet period. The Raytown tower had a significantly higher value in the non-jet period curve compared to the jet curve, while the Chillicothe tower had only a slightly higher mean value for the non-jet period curve.

Similarly, comparing the jet and non-jet period curves at Monett (Figure 9) reveals that the jet period had a slightly higher mean α value during the jet period as well. Since these entire mean values were only slightly higher in the jet periods for these two towers, the result does not appear to be all that significant or conclusive.

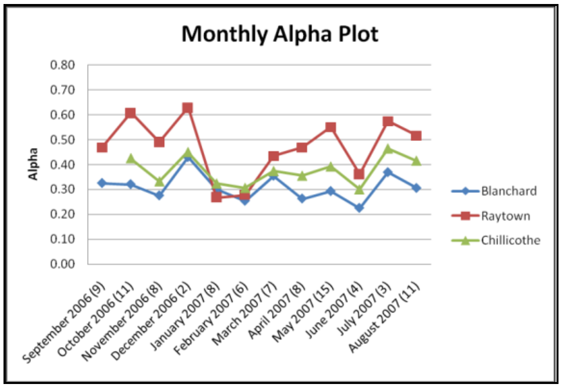

Figure 7. Trends in alpha during the jet periods at the Blanchard, Raytown, and Chillicothe towers.

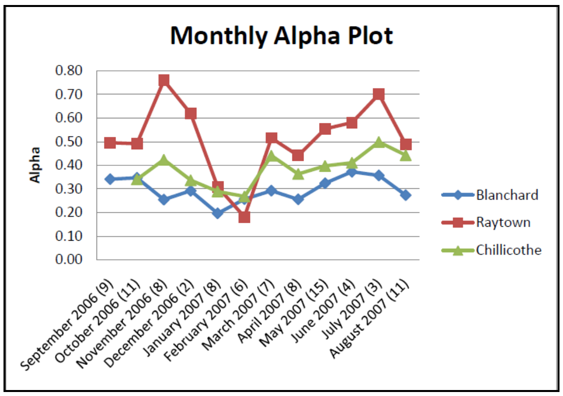

Figure 8. Trends in alpha during the non-jet periods at the Blanchard, Raytown, and Chillicothe towers.

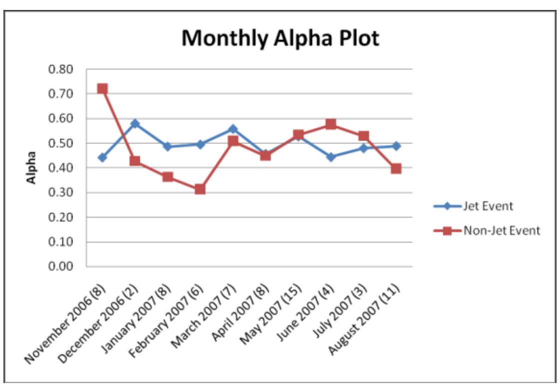

Figure 9. Trends in alpha during both the jet and non-jet periods at the Monett tower.

4.3 Friction Velocity Calculation

The friction velocity trends in Figures 10 and 11 appear similar to the alpha trends in Figures 7 and 8. The major difference is that when the friction velocity is averaged over the whole observational period, every tower had a higher mean value during the jet event periods over the non-jet event periods. Somewhat noteworthy, the Blanchard and Chillicothe friction velocity trend curves are almost identical to one another during the jet periods whereas Chillicothe had a consistently higher α compared to Blanchbard for the same data set. This seems to illustrate that α is not only a function of the wind shear, but also of the mean wind speed, with lower wind speeds giving higher values of α.

Similarly, comparing the jet and non-jet period curves in Figure 12 reveals that Monett also has a higher mean friction velocity during the jet period. The mean friction velocities appear reasonable for all four towers focused on in this section.

As the friction velocity does not have a dependence on mean wind speed it is apparent that there is more shear during jet events than when the jet is not present.

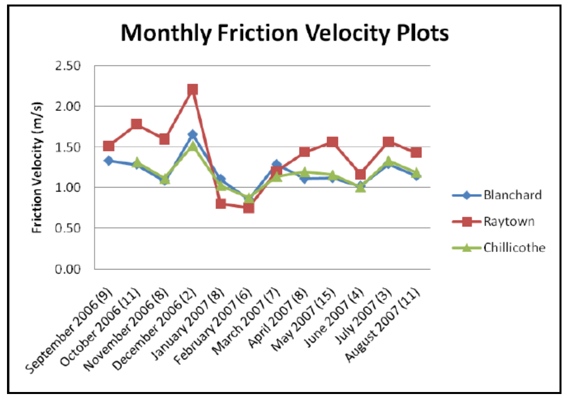

Figure 10. Trends in friction velocity during jet periods at the Blanchard, Raytown, and Chillicothe towers.

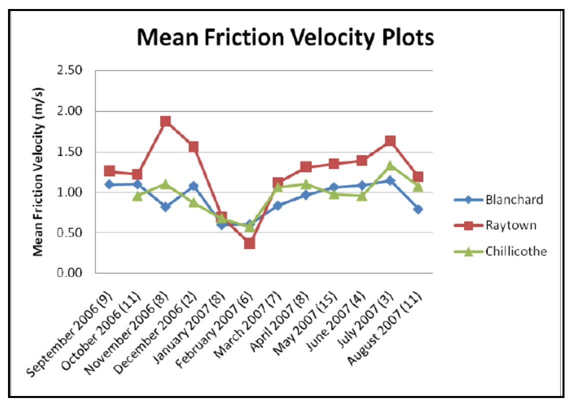

Figure 11. Trends in friction velocity during non-jet periods at the Blanchard, Raytown, and Chillicothe towers.

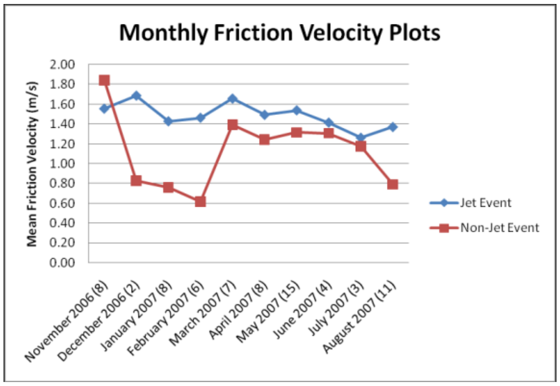

Figure 12. Trends in friction velocity during both the jet and non-jet periods at the Monett tower.

5. CONCLUSIONS

As wind power density is a function of wind speed cubed, these results show that there is substantially more wind power available at turbine heights when the low-level jet is active than when it is not.

The calculations of friction velocity show that wind shear is also increased during low-level jet periods. However, this signal is not clear when using α as a measure of wind shear. This is because this parameter increases with lower wind speeds and so the increase in wind shear during low-level jet episodes is offset by the increase in wind speed.

6. REFERENCES

Redburn, R., 2007: A Tall Tower Wind Investigation of Northwest Missouri. M.S. Thesis, Dept. of Soil, Environmental, and Atmospheric Sciences, The University of Missouri-Columbia, 109 pp.

Walters, C. K., and J. A. Winkler, 2001: Airflow configurations of warm season southerly low-level wind maxima in the Great Plains. Part I: Spatial and temporal characteristics and relationship to convection. *Wea. Forecasting,* **16,** 513–530.

ACKNOWLEDGEMENTS

This research was funded the Missouri Department of Natural Resources, Ameren UE, Aquila, Kansas City Power and Light, and Empire District Electric Co.