15th Australasian Wind Engineering Society Workshop
Sydney, Australia
23-24 February 2012

Improved Characterisation of Wind Shear for Determination of Fatigue Loading on Wind Turbines

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Abstract

Wind shear is known to vary diurnally on many sites. This is thought to be due to thermal mixing during the day promoting low shear and thermal stratification at night causing high shear. However, the current method of comparing the shear with hour of day does not capture the seasonal variations. An alternative method is presented where the wind shear is analysed relative to sunrise and sunset. This approach shows promise in giving greater accuracy in determining the range of shear seen by wind turbines on sites and thus better determining the fatigue loading over the life of the wind turbine.

Introduction

The variation in wind speed (V) with height (h) can be characterised by the power law exponent (α) as shown in equation (1).

$$\frac{V_{h_1}}{V_{h_2}} = \left(\frac{h_1}{h_2}\right)^{\alpha} \qquad (1)$$

This study will focus on wind shear derived from 10 minute average wind speed values. A discussion of extreme wind shears can be found in Hansen et al (2004).

Wind shear is known to vary on many sites from day to night. It is thought this is due to the daily solar cycle and the absorption and radiation of heat from the earth's surface. Generally thermal stratification at night is believed to promote high wind shear and increased thermal mixing during the day to promote low wind shear

This effect is site specific with surrounding topography, water bodies, diurnal temperature variations and synoptic weather patterns influencing the extent to which it occurs. It has been studied for both inland and costal sites from meteorological (Hahn, 1981, Haeger-Eugensson, 1999) and wind energy perspectives (Schwartz & Elliot, 2006 and 2007). It is noted that in some of these sites low-level jets (>100 m) were also encountered. It is not know whether these exist on the site to be examined in this paper. A discussion of these phenomena can be found in Kelley et al (2004).

Wind shear is an important for determining the fatigue loading on wind turbines. The international wind turbine design standard (IEC 61400-1 Ed. 3.1) uses an average wind shear exponent of 0.2. As diurnal patterns in wind shear are site specific and some sites do not experience strong effects, these conditions are not covered by the standard. However, the standard does require for site assessments that the wind shear is assessed and notes that high shear values for extended periods have been noted in some areas associated with highly stratified flow or severe roughness changes and the assumed conditions in the standard are not intended to cover these cases.

Past work (Swalwell et al, 2008) looked at the effect of high diurnal variation wind shear on loading of wind turbines. The results found that the shear variations did alter the loading on wind turbines but the effect was mitigated by the corresponding variation in mean wind speed. For this study the diurnal variation was characterised by hour of day. However, a strong seasonal effect was noted, see Figure 1. This was attributed to the large range in temperature seen on this site across the year and the different times of sunrise and sunset over the year. This paper examines whether using sunrise and sunset times directly can better characterise the wind shear from site measurements.

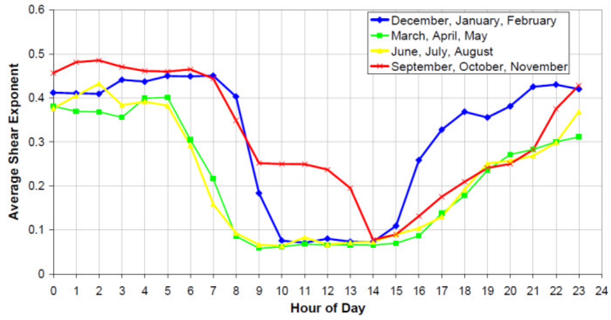

Figure 1. Diurnal wind variation by season for a Chinese site from Swalwell et al (2008).

Methodology

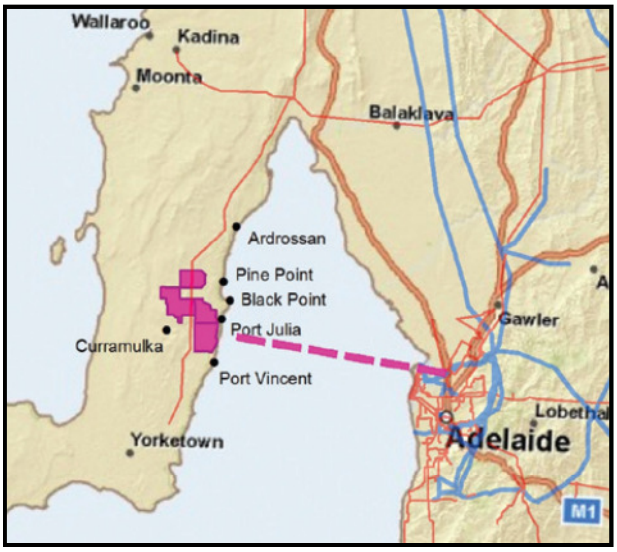

Figure 2. Location of the proposed CERES project (in pink) relative to the Adelaide. Illustration from www.theceresproject.com.au.

Wind data measurements from the proposed CERES wind farm have been analysed. The location of the CERES project is shown in Figure 2. There were over 4 years of data available from a 40 m mast on the site and a month of data from a 100 m mast on site. The masts have high quality cup anemometers and wind vanes on multiple levels. The measurements were corrected so that they were relative to AEST with no allowance for daylight saving. 10 minute average measurements of wind speed, wind direction and turbulence intensity (defined as standard deviation of the wind speed over the average wind speed) have been analysed in this paper. Because of commercial considerations the mean wind speed and turbulence intensity data has been presented as without numerical values.

Sunrise and sunset were calculated for the year 2007 by the online tool http://aa.usno.navy.mil/data/docs/RS_OneYear.php.

Results

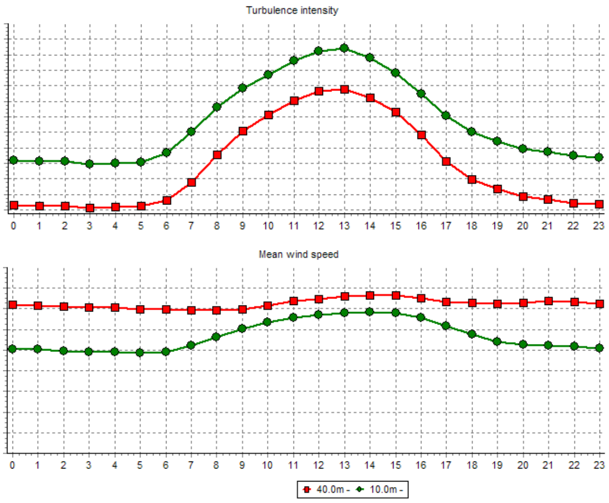

Figure 3. The average turbulence intensity and wind speed over three years of site measurements on the 40 m mast. The scale of the graphs has been removed to preserve data confidentiality.

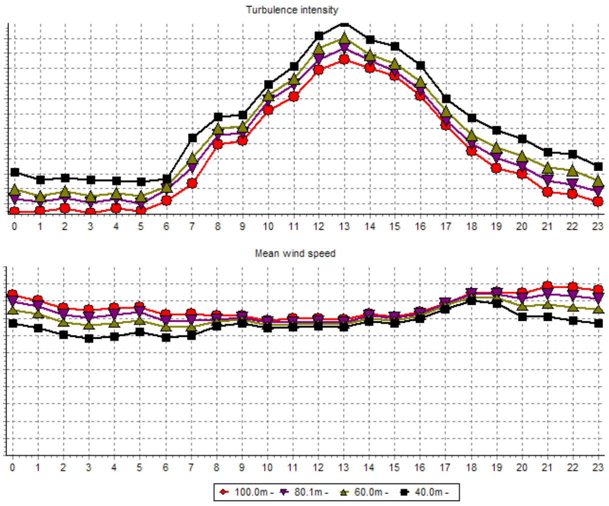

Figure 4. The average turbulence intensity and wind speed over one month of site measurements on a 100 m mast. The scale of the graphs has been removed to preserve data confidentiality.

Figure 3 shows a strong diurnal variation in turbulence and wind speed on the 40 m mast. This diurnal variation is also seen on the 100 m mast in Figure 4. The wind speed at 40 m on both masts show a diurnal profile with stronger winds during the day and reduced wind speeds at night. However, for the upper heights on the 100 m mast the profile is reversed with the higher winds occurring at night. This is attributed to thermal mixing during the day reducing the wind speed at higher heights and decreasing the wind speeds at lower heights. The thermal stratification at other night has the opposite effect. However, there was insufficient data available from the 100 m mast to examine the effect of time from sunset or sunrise on wind shear.

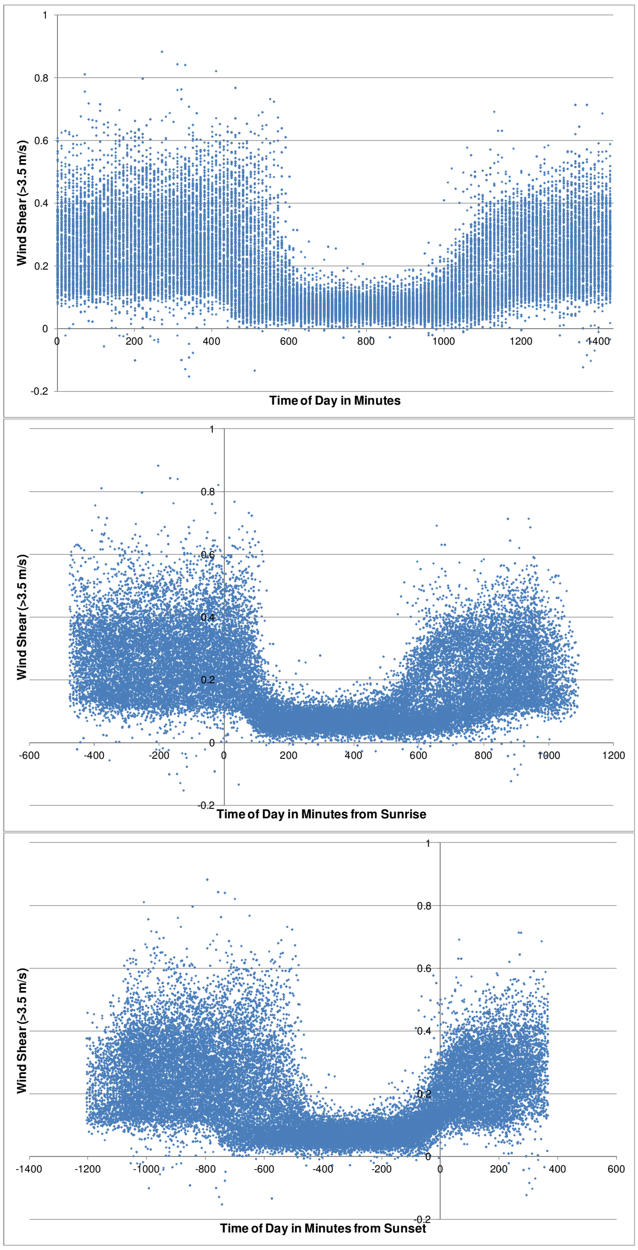

Figure 5. 10 min wind shear exponent values in minutes after midnight (upper), minutes before or after sunrise (middle) and minutes before or after sunset (lower) for one year of data.

These trends are even clearer when looking at the average values, see Figure 6. For this figure the sunrise and sunset data offset times were rounded to the closest 10 minutes and the averages and standard deviations in these 10 minute bins are shown relative to midnight, sunrise and sunset. In addition the wind shear exponent was filtered to only show values when the wind speed at the upper height was greater than 3.5 m/s and 8 m/s. This showed that the diurnal trend exists even at higher wind speeds.

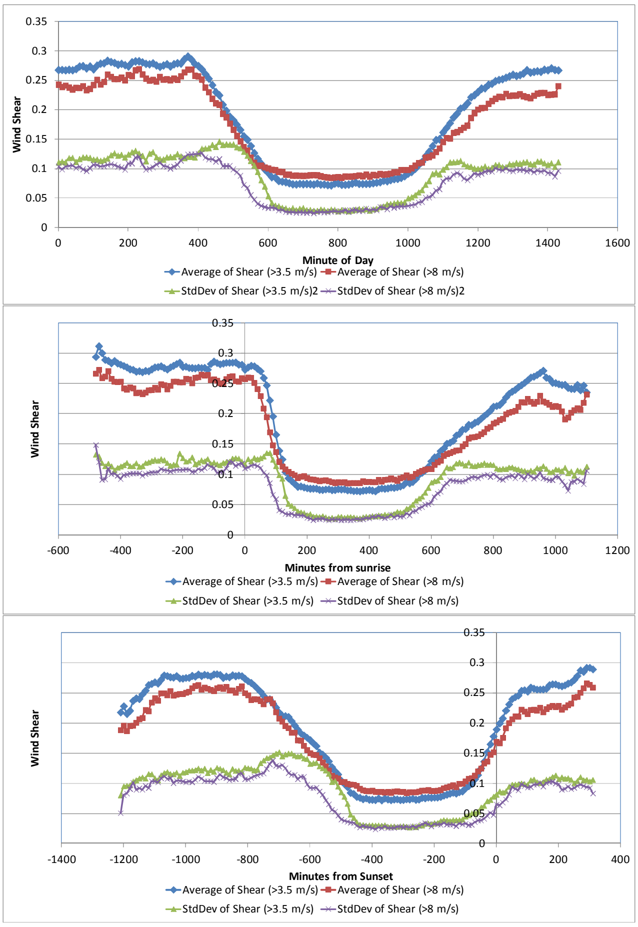

Figure 6. Average wind shear exponent in 10 min increments in minutes after midnight (upper), minutes before or after sunrise (middle) and minutes before or after sunset (lower) for one year of data.

Conclusions

The wind shear exponent is known to vary diurnally on many sites. The alternative method presented of analysing the shear variations relative to sunrise and sunset shows promise in giving greater accuracy in determining the range of shear seen by wind turbines on sites and thus better determining the fatigue loading over the life of the wind turbine.

Acknowledgments

The author would like to thank the CERES project for allowing the use of their wind data.

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