IMPROVING WIND ENERGY FORECASTS USING A BIAS CORRECTION

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1. INTRODUCTION

Wind energy is emerging as a significant contributor to electricity generation around the world (Sanchez 2006), and Australia is well placed to harness greater wind energy within its electricity industry due to substantial wind resources (Archer and Jacobson 2005). Maximizing the value of wind energy requires forecasting in the short and longer term. Thus as wind energy makes up an ever greater component of our energy supply, there is greater interest in developing models to produce accurate, mesoscale, near-real-time, wind-focused forecasts for wind-farm sites. Preventing fluctuations in the power production of a wind-farm from affecting the continuity of electricity supply to the consumer is of particular interest to the wind industry. There are a number of weather phenomena that have the ability to rapidly change wind conditions and affect wind-farm operation. One such extreme wind event occurred on the 31st August 2005 causing power output for the Woolnorth wind farm to suddenly drop and remain at zero for close to 3 hours, and has been discussed in detail in Kay *et al.* (2009a). It is these events that it is extremely important to be able to predict. This paper therefore concentrates on improving the predictions of the extreme wind event described above by applying a form of bias correction methodology to a time series of 24 hour NWP forecasts. By applying the bias correction we minimize the systematic errors in future wind speed forecasts by using a knowledge of the bias in past errors.

2. DATA AND FORECAST MODEL

The data for this study focuses on the wind farm at Woolnorth, situated on the North-western tip of Tasmania. It was developed in three stages across two nearby sites known as Bluff point and Studland Bay. The Bluff point site has a generation capacity of 64.75 MW, achieved using 37 Vestas wind turbines each supplying 1.75 MW. This study focuses on the Bluff point site alone. More details on the layout and specifics of the wind farm measurements can be found in [*]Kay *et al*. (2009a). Measurements of wind speed are taken as the average wind speed from each of the 37 wind turbines (60m a.g.l.) and data is available at 10 minute intervals. To be consistent with the NWP forecast hours, the wind speed has been averaged over the preceding hour. The NWP used for this analysis is the MesoLAPS 12.5 km model from the Australian Bureau of Meteorology (BoM) (Puri *et al*. 1998). All forecasts are made at 12UTC and are a 24 hour time series. We have concentrated on forecasts made at a height of 45m because this is the height closest to the hub height of the wind turbine.

3. BIAS CORRECTION METHODOLOGY

A main error found in NWP forecasts is bias (Woodcock and Engel, 2004). Bias causes the mean of the historical distribution to deviate from the true value (i.e., produce readings that systematically over-predict or under-predict). The basic premise of bias correction is that by knowing the bias from past forecasts one can correct for the under or over prediction seen in a previous forecast by adding or removing the bias factor to the next forecast. In developing a bias methodology there a few factors to consider – the bias method to use, the historical data sample size (bias window), and what parameter will best represent the centre of the historical distribution. The bias parameter chosen for our study is the trimean or Best Easy Systematic (BES) estimator (Wonnacott and Wonnacott, 1977; Turkey, 1977).

$$BES = (Q_1 + 2Q_2 + Q_3)/4 \qquad (1)$$

where Q1, Q2 and Q3 are the 25%, 50% and 75% quartiles respectively. The quartiles statistically divide the distribution into the lowest 25% of the data, the median and the highest 25%. The BES is a measure of the centre of a distribution. It is calculated as a weighted average of the distribution's quartiles and median, weighting the median more heavily. This calculation combines the weighting of the median on the 'centre' value without losing information about the extreme values within the distribution. Another advantage of using the BES is that it is more resistant to fluctuations within a historical data sample.

We will now elaborate on the process used to obtain and apply the bias correction. Once the bias parameter has been chosen, it is necessary

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to determine what bias window is best to use. The historical sample or bias window can affect the accuracy or improvement of the new forecast (Woodcock and Engel, 2004). Various bias windows were investigated and the results showed that increasing the bias window past 48 hours only made a minimal difference in results (see Kay *et al*. 2009b for more details). The BES has therefore been estimated using error statistics over a 48 hour bias window, with the observations and forecasts made at hourly intervals. The BES is then added or subtracted from the next hour's original forecast to produce a bias Corrected Prediction (CP) depending on whether the previous hour's forecast was over-predicted or under-predicted. A negative forecast error indicates an over-predicted forecast and a positive forecast error indicates an under-predicted forecast.

The bias correction methodology alone enhances the forecast accuracy, but there are other factors that warrant further correction. The resolution of NWP models is often too coarse to predict the fine scale winds that a wind farm may experience, and NWP models are also not geared towards the detailed wind predictions required for wind energy purposes (Archer and Jacobson 2005). The NWP produces forecasts hourly, however wind speed and direction can change extremely quickly, hence hourly forecasts often can miss the fine scale changes that occur. Another problem that occurs with a NWP is that the forecast grid point is not at the exact location of the wind farm. These factors can lead to less than perfect forecasts, and therefore after the initial bias correction, an extra correction (referred to in the text below as a Double Corrected Prediction – DCP) was also made to the bias Corrected Prediction to improve not just the accuracy but also the timing and location errors associated with the forecast. The correction simply makes use of a weighted observation from the wind farm taken 10 minutes before the hour and combines that with a weighted CP forecast to gently smooth out any errors that may be associated with the forecast timing and sudden wind speed changes due to the fine scale winds that may have occurred within the past and next forecast hour. This smoothing function relies on the smoothing factor α to control the closeness of the most recent observation and the CP forecast:

$$\boldsymbol{DCP = \alpha O_t + (1-\alpha)CP} \qquad (2)$$

where $0<\alpha<1$. DCP is the new prediction, and the observations from the wind farm are represented by O_t. Various smoothing factors were investigated and it was found that setting $\alpha = 0.5$, evenly weighting the observation and CP, provided results that best smoothed out timing errors and large errors in the forecast, but also worked well when the forecast errors were small.

4. RESULTS

Figure 1, shows the wind speed (observed – blue line, and NWP prediction from a 12UTC forecast – green dashed) and corresponding power output of the Bluff point wind-farm over a 48 hour period for the extreme wind event that occurred on the 30th-31st August 2005. All predictions and measurements have been hourly averaged for easy comparison with the NWP. Hourly averaging however smooths out the extreme variability in power output that is observed with sudden changes in wind speed (see Kay *et al.* 2009a for more details on the relation between the fine scale winds and power output). The important features that the hourly data illustrates are the sudden and complete drop in power output around 00:00 UTC on the 31st August. This occurred because the wind speed exceeded 25 ms^{-1}, which is the cut-off speed when the wind turbines shut-down to prevent them from being damaged. The meteorological features causing this extreme event are a deepening low pressure system, accompanied by a strong front and trough following closely behind, which kept winds high for a prolonged period (Kay *et al.* 2009a). The other important feature of Fig. 1 is the NWP model's inability to predict this wind speed event. The NWP model mis-timed the increase in wind speed, and also the duration of the high wind event. The NWP model also under-predicted the wind speed for a majority of the time over the 48 hour period. The event in Fig. 1 illustrates how important it is to predict the weather as accurately as possible, aiming to know any weather related lapses in power production well in advance. The bias correction methodology is therefore applied to the period in Fig. 1 with the aim of improving the forecast accuracy and timing of critical wind speed changes. Figure 2 displays the bias corrected forecasts, CP and DCP for both 48 hour and 7 day bias windows, along with the observations from Woolnorth and the original 12UTC predictions. The 48 hour bias window performs better overall, and making use of the wind farm observations for the DCP predictions has smoothed some of the timing problems that occurred. The major dip in wind speed (see Fig. 2) before the sudden increase at 0:00 UTC on the 31st August has eliminated the 'out of phase' error that originally occurred with the NWP predictions, however, the smoothed correction does not fully capture the wind speed dip. There are however noticeable improvements in the magnitude, and timing of other wind speed changes.

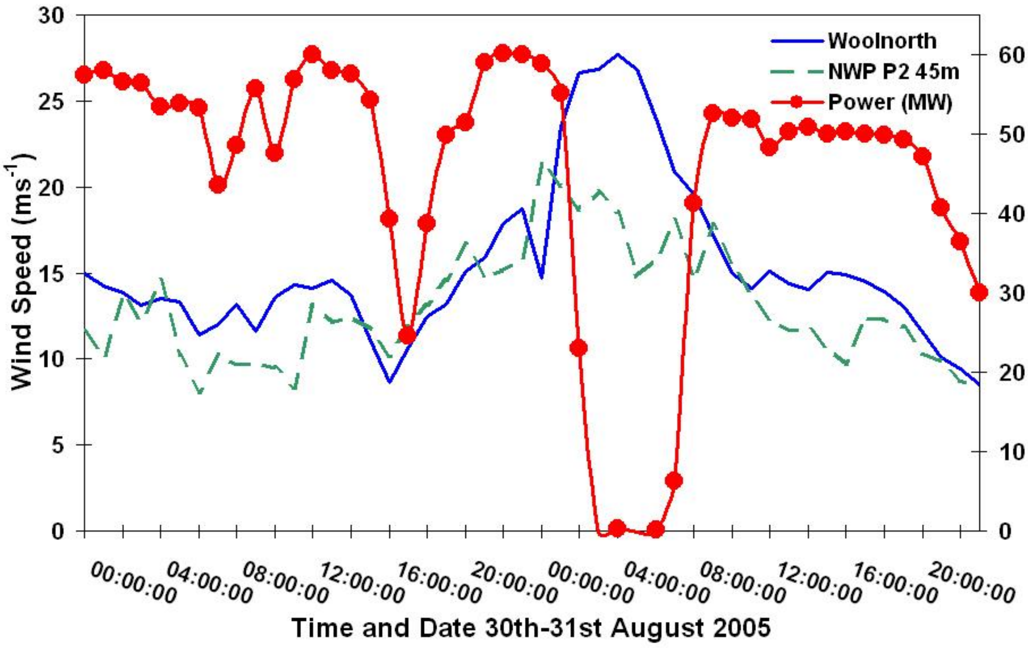

Figure 1. Wind speed (observations and 12 UTC predictions) and power for the 30th to 31st August 2005, showing the relationship between changes in wind speed to sudden swings in power.

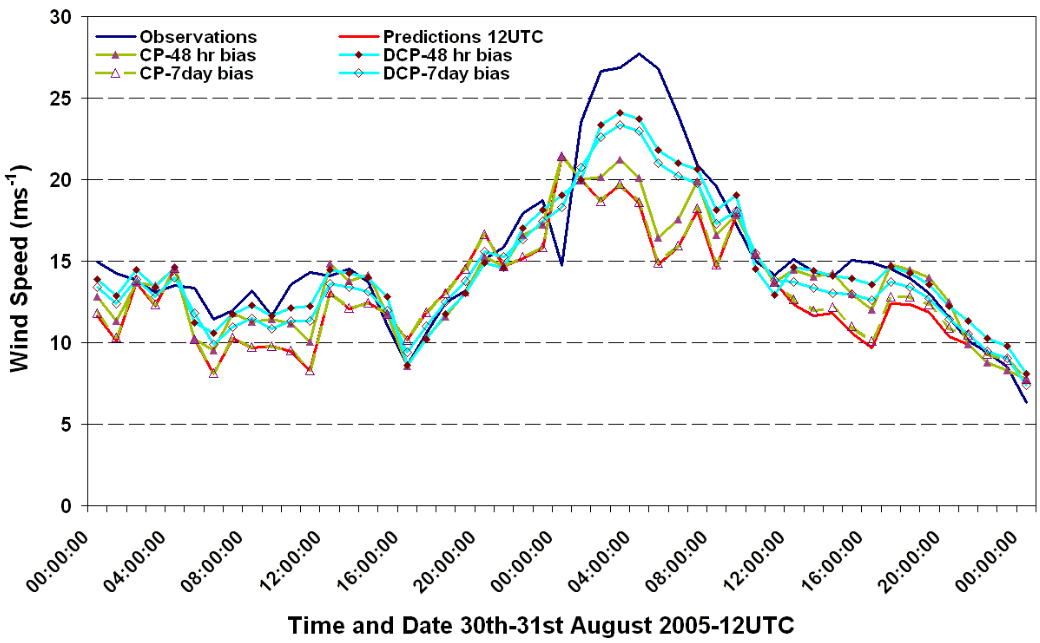

Figure 2. NWP predictions, observations and bias corrected forecasts, CP and DCP of wind speed at 12 UTC for the 30th – 31st August 2005 with a 48 hour and 7 day bias window.

To quantify how the bias forecasts have performed, the error statistics for the original predictions, CP and DCP are shown in Figure 3 (a),(b),(c) respectively. Results to date have concentrated on the wind speed ranges 5 – 15 ms^{-1}. This wind speed range is important because small changes in wind speed within this range can cause large changes in power output due to the cubic relationship between wind speed and power. The error statistics shown are for a more extensive time series, covering late July to mid September 2005. All forecast error statistics for Fig. 3 have been plotted in instances where the observations fell between 5 – 15 ms^{-1}. A spread of values outside the wind speed range on the x-axis indicates an incorrect prediction, and the y-axis indicates whether it was a positive error (under prediction) or negative error (over prediction) that occurred. By applying the bias correction we see a reduction in the spread of errors from the original prediction and this is especially evident for the DCP prediction. We have successfully managed to reduce the spread of forecast error in the y-axis by half when implementing the DCP correction. This is particularly important for periods where forecasts over predicted wind speeds greater than 15ms^{-1} as this would erroneously indicate to the wind farm operators that the wind farm should be at full power when it actually is not.

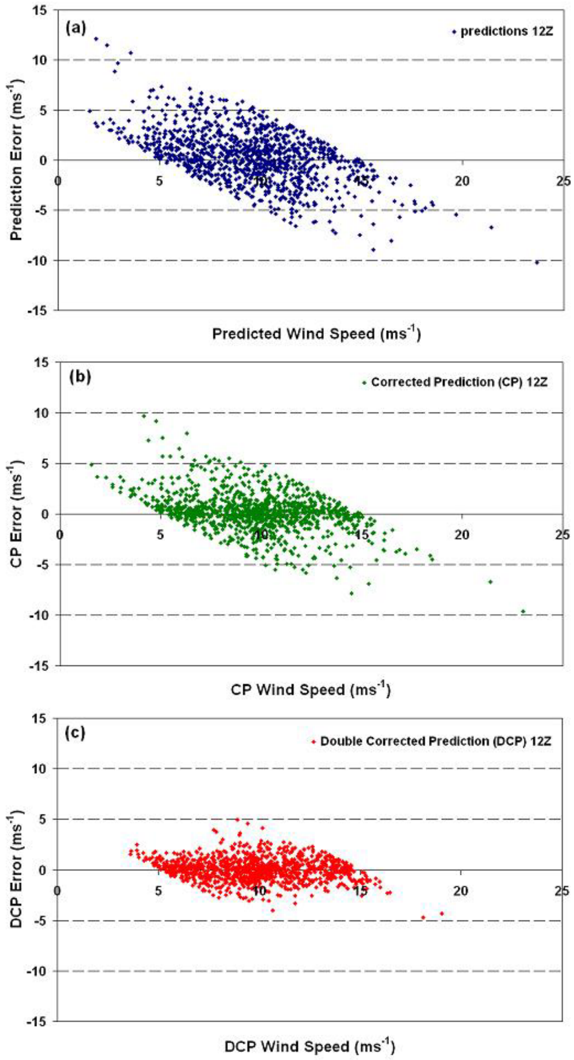

Figure 3. Error statistics for **a**. the original predictions, **b.** Corrected Predictions (CP) and **c.** Double Corrected Prediction, DCP for a period of 2.5 months in the wind speed ranges 5 – 15 ms^{-1}. All predictions made at 12 UTC.

4. CONCLUSION

The ability to forecast the power output of a wind-farm is necessary to maintaining a stable and continuous electricity supply to the consumer. This work has investigated the application of a correction to the original NWP model, making use of actual wind farm measurements to improve wind speed forecasts in terms of their accuracy, and to some extent, timing. Often these forecast biases can be quite location dependent, and in terms of high wind speed ranges, there is often a systematic under prediction of the wind speed event. Initial results from applying the bias correction methodology to an extreme wind event have proved promising for hourly forecasts. Forecasts for the wind energy sector are typically made for the short to medium term, usually up to 72 hours ahead. Other timescales may also be required depending on the power system requirements. A continuation of this work will aim to apply the methodology for longer forecast periods and include a correction for wind direction. As the bias will vary seasonally, longer time scales and seasons will also need to be validated.

5. References

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