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Accuracy of noise predictions for wind farms

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Summary

To maximise the energy output of wind farms whilst still meeting the relevant noise regulations, it is important that an accurate environmental noise prediction method be used when designing a new wind farm. This paper compares compliance measurements from operational wind farms to the prediction results from the commonly applied noise model. When comparing noise modelling results to compliance measurements it is important to recognise that there are a number of different measurement methods and even noise descriptors used when determining compliance levels near wind farms. The difference in measured levels (and therefore modelling accuracy) from the use of different compliance measurement methods is presented. Additionally, this paper examines the influence of wind speed and direction, wind shear, temperature gradient and turbulence on wind farm noise levels, and the importance of these factors in the accuracy of noise modelling. Overall, the findings suggest that the accuracy of current prediction methods for wind farm noise is reasonable, and that there is not a significant risk of under-prediction.

1 Introduction

Predictions of environmental noise from wind farms are important component of the planning stage for new facilities to be located near to noise sensitive receivers. The noise limits defined by regulatory authorities will often constrain the layout and number of turbines that can be sited within the wind farm, which will in turn constrain the potential power generation capacity.

An understanding of the accuracy of environmental noise predictions is critical for any assessment of wind farm noise. Overly conservative predictions may needlessly reduce the capacity of facilities, and make achieving national renewable energy targets more difficult. Under-prediction of noise levels may result in non-compliance with the noise limits, leading to forced reductions in power output to achieve the limits that would not have been considered during project financing.

This paper presents a summary of the results of recent studies conducted by the authors into noise prediction accuracy for wind farms. It is primarily focussed on the accuracy of the ISO 9613-2 methodology (ISO, 1996) as this is the method most widely used for the prediction of wind farm noise in Australia. It also includes a discussion of the:

- effect of topography on prediction accuracy
- influence of different meteorological conditions on prediction accuracy including wind speed/direction, wind shear, temperature gradient and turbulence.

Noise levels presented in this paper are A-weighted noise levels as predictions and measurements of A-weighted levels are required for compliance for with noise criteria within Australia.

2 Noise measurement process

2.1 Measurement procedure

The accuracy of noise predictions for wind farms will depend on the manner in which wind farm noise is measured at receptor locations away from the wind farm. Different methods of measuring wind farm noise will result in variations in measured noise levels. It is therefore important that noise predictions are undertaken with an understanding of the measurement procedure to be employed when assessing compliance at the operational wind farm.

The measurement procedures employed most commonly in Australia and New Zealand are defined in:

- New Zealand Standard NZS 6808:1998 (Standards New Zealand, 1998).
- New Zealand Standard NZS 6808:2010 (Standards New Zealand, 2010).
- South Australian *Wind farms environmental noise guidelines* (SA EPA, 2009).

Both NZS 6808 and the SA Guidelines require the measurement of A-weighted $L_{90,10min}$ noise levels (or $L_{95,10min}$ noise levels in the case of NZS 6808:1998) over a typical period of two to four weeks to obtain sufficient data across the range of wind speeds from cut-in to rated power. The measured noise levels are plotted with wind speed and a polynomial regression curve fitted to the data to determine the combined wind farm and background noise level. If required to demonstrate compliance, the wind farm noise level is calculated through the logarithmic subtraction of the pre-construction background noise levels from the combined noise levels.

A key difference between the above documents is that the SA Guidelines require compliance to be demonstrated based on data collected in the worst case wind direction for each measurement location. That is noise levels measured during winds within 45° of the downwind direction from the nearest turbine(s). While NZS 6808:2010 states that consideration of specific wind directions may be required

in certain situations, standard practice is to consider noise levels measured under all wind directions. A previous study by the authors of this paper found that, at sites within Australia, measured wind farm noise levels under the SA Guidelines were 0.2 to 1.5 dB(A) higher than those measured under NZS 6808:2010 (Cooper, Evans & Najera, 2012).

It should also be noted that two relatively recent Australian documents have specified the use of the L_{eq} rather than L_{90} metric for compliance measurements:

- Australian Standard AS 4959:2010 (Standards Australia, 2010).
- Draft *NSW Planning Guidelines: Wind farms* (NSW DPI, 2011).

Due to difficulties associated with the measurement of L_{eq} wind farm noise levels, both documents require the L_{eq} level to be determined through the measurement of L_{90} with the addition of a fixed value from 1.5 to 2.5 dB(A). The L_{90} wind farm noise level is determined through similar procedures to those employed in the SA Guidelines and NZS 6808:2010. Previous measurement evidence indicates that the difference between the L_{eq} and L_{90} wind farm noise levels is no higher than 1.5 dB(A) (Cooper, Evans & Najera, 2012), but even a correction of that magnitude will directly impact on the measured compliance level and therefore accuracy of noise predictions.

This paper primarily considers the measurement methodology of the 2009 SA Guidelines. The presented prediction accuracy results can be applied to the other methodologies, as long as appropriate adjustments are made.

Internationally, noise measurement procedures vary from those employed in the 2009 SA Guidelines. For example, in Ontario there is a requirement for complaint situations that $L_{eq,1min}$ levels are measured directly at the receptor, with audio recording and on/off measurements used to assist in filtering out the influence of background noise (Ontario Ministry of the Environment, 2009). In the UK, ETSU-R-97 (UK DTI, 1996) only specifically requires the measurement of wind turbine noise (as an $L_{90,10min}$) level at critical wind speed conditions, where the margin of compliance is likely to be lowest.

These differences in the Ontario and UK documents would not be expected to significantly alter the measured level with respect to the Australian procedures in cases where measured noise levels are controlled by wind turbine noise (and not background noise). The noise prediction accuracy presented in this paper can be broadly applied to these documents, with due consideration of differences between L_{eq} and L_{90} noise levels.

In some other countries, measurement of wind farm noise at receptor locations is not specifically required. In Denmark, noise from operational wind farm sites is assessed by measuring sound power levels at the turbine and using agreed calculation procedures to determine the noise levels at receptor locations (Danish Ministry of the

Environment, 2011). This removes the problem of background noise influencing measurement results at receptors but an understanding of prediction accuracy is still important.

2.2 Influence of background noise

A factor that complicates the measurement of wind farm noise at receptor locations is the influence of background noise on measurement results. As wind farm noise levels are often close to the background noise level in the environment, it can be difficult to obtain accurate measurements with which to determine the accuracy of previous noise predictions. In effect, measurements at receiver locations are of the combined wind farm and background noise level rather than solely the wind farm noise level.

Guidelines used in Australia and New Zealand allow for the logarithmic correction of measured L_{90} levels with the wind farm operating by measured pre-construction background noise levels to provide a reasonable estimate of the wind farm noise level. However, pre-construction noise measurements are often undertaken well in advance of post-construction measurements on wind farm projects and can significantly vary across years and between seasons (Delaire & Walsh, 2009). Corrected levels can therefore not always be taken as a reliable estimate of the actual wind farm noise level.

In order to minimise the influence of background noise in our previous study (Evans & Cooper, 2012a) each measurement site was selected such that it was as far away as possible from potential sources of background noise (e.g. trees, occupied dwellings), and such that the noise level at the site was typically controlled by turbine noise. In addition, only wind speeds where the L_{90} noise level appears to be consistently controlled by turbine noise were considered in our analysis. These wind speeds have been selected based on analysis of the measurement data and observations made on site during the measurements.

As an example, Figure 1 presents measurement results for one measurement site (Site B3 in Table 1), indicating a wind speed range of 4 to 12 m/s where the measured noise level is controlled by turbine noise. This is evident due to the small spread of the measurement data when compared to wind speeds where background noise causes significant variation between measured levels at the same speed. It was also noted during repeated visits to that measurement site that, within this wind speed range, measured noise levels were controlled by wind turbine noise. Note that, at lower wind speeds, there are a number of measurements where the turbine clearly cut-out due to low wind speed during the measurement period.

When a site has wind speeds at which the noise levels are turbine-controlled, collected data has suggested that the measured noise levels are repeatable and there is no significant variation in noise level over time. For example, compliance measurements have been repeated at Site B3 on three occasions over a period of

approximately four years. The measured noise levels across the turbine-controlled wind speed range between these periods varied by less than 1 dB(A) from that presented in Figure 1, when assessed under the 2009 SA Guidelines. Note that this variance may increase where NZS 6808 measurement procedures are used as the proportion of wind in particular directions may vary between measurement periods, whereas the 2009 SA Guidelines require only particular wind directions to be considered.

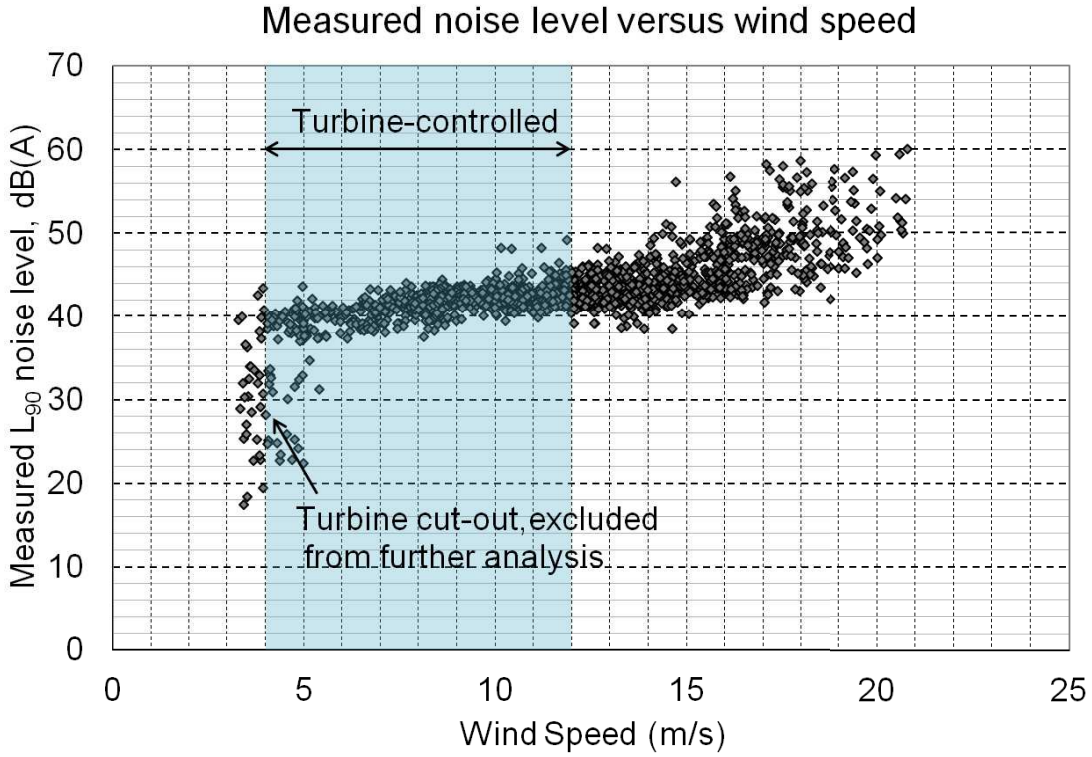

Figure 1 – Example of measured noise levels versus wind speed with turbine-controlled wind speed range, Site B3

3 Noise prediction accuracy

In 2012, the authors presented a study into the accuracy of wind farm noise predictions from a number of noise models (Evans & Cooper, 2012a). The study considered 13 measurement sites at six different wind farms with differing topographies between the wind farm and the measurement locations. The wind farms also had varying layouts with some comprising turbines on a ridgeline above the receivers and others a grid of turbines.

Only the predictions undertaken using the ISO 9613-2 methodology are presented here as it represents one of the most widely used noise prediction models for wind farms. It is recommended as a suitable noise prediction method by both the SA Guidelines and NZS 6808:2010.

3.1 Noise model

The noise model for each wind farm site was created in the SoundPLAN Version 7.0 software (produced by Braunstein + Berndt GmbH). The noise model for each site included the following:

- 1 m or 10 m spaced topographical contours
- turbine coordinates provided by the site operator
- measurement locations determined by handheld GPS
- receiver points set at 1.5 m above ground height
- sound power levels for the turbines measured at one or two turbines at each site in general accordance with IEC 61400-11 Edition 2.1 (IEC, 2006)
- average temperature of 10°C and humidity of 80%
- search radius of 20 km in the SoundPLAN calculation module.

Two different ground absorption values were used at each site for the comparison – completely reflective ground (G=0) and 50% absorptive ground (G=0.5).

Sound power levels for typically two of the turbine models installed at each site were measured in general accordance with IEC 61400-11 Edition 2.1. Minor deviations from the Standard were not considered likely to affect the measured sound power levels. At the sites where sound power levels for two turbines were measured, the difference between the two was less than 1 dB(A) at any particular wind speed, with the average sound power level used for those sites.

The measured sound power levels were compared against the measured environmental noise levels at each of the sites. At every site, the change in measured noise level across the turbine-controlled wind speed range demonstrated good correlation with the change in sound power level across that range. This suggested that there is no increase in the propagation of noise from the turbines to the measurement locations due to changes in the wind speed, but this is further discussed in Section 5.1.

As an example, Figure 2 compares the measured noise levels for Site B3 against the measured sound power levels (reduced by approximately 60 dB) for the turbines at that wind farm. Similar results were obtained for all of the measurement sites.

3.2 Comparison of predicted and measured noise levels

Table 1 presents the difference between the predicted and measured wind farm noise levels for each of the 13 sites (Evans & Cooper, 2012a). The differences are shown as the predicted noise level less the measured noise level such that positive numbers represent over-prediction and negative numbers under-prediction. A description of the topography between the measurement location and the nearest turbines is also presented. Note that flat sites have a height difference of less than 10 m between the turbine base and measurement site, and that the steady downward slopes may still have slight convex features over certain areas.

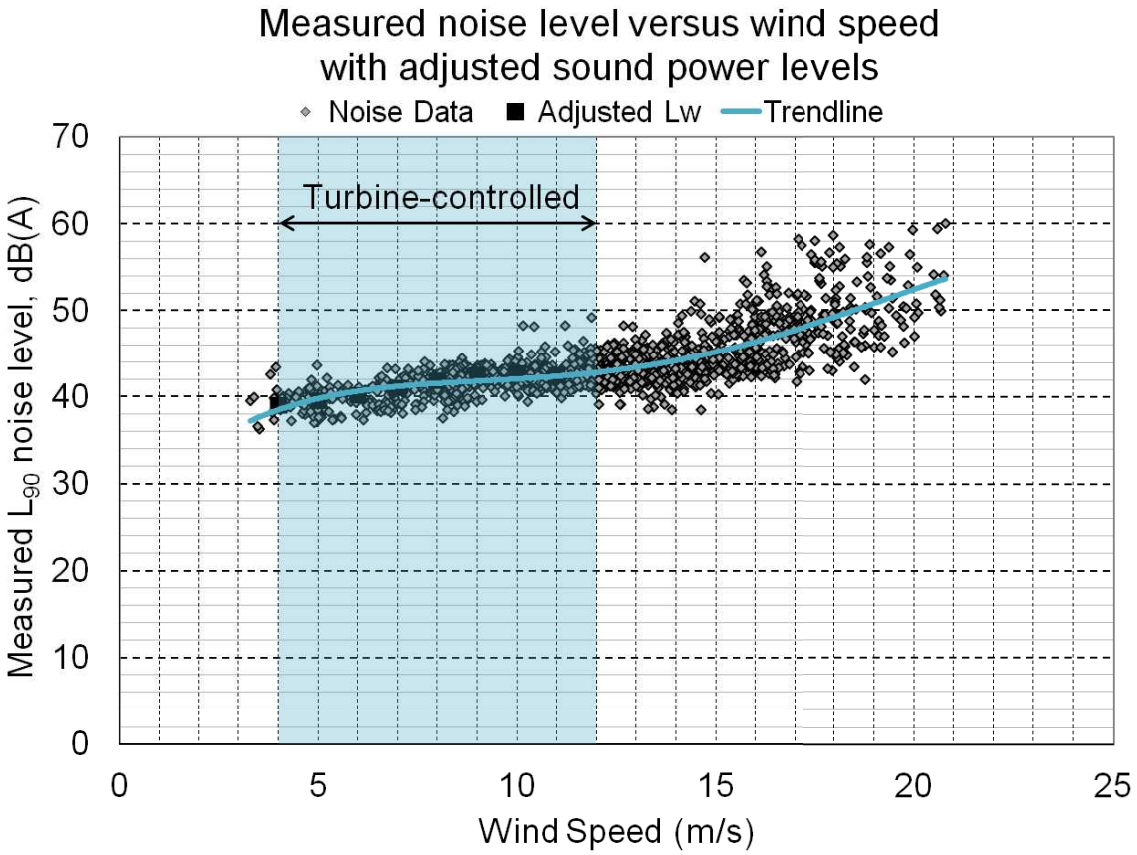

Figure 2 – Comparison of measured noise levels and measured sound power levels at Site B3

Table 1 – Difference between predicted and measured wind farm noise levels

Site	Approximate distance to nearest turbine, m	Topography description	Predicted – measured, ISO 9613-2 G=0	Predicted – measured, ISO 9613-2 G=0.5
A1	1000	Steady downward slope	5.8	2.2
A2	800	Steady downward slope	5.4	2.2
A3	800	Concave downward slope	-0.4	-3.5
B1	1500	Concave downward slope	-0.7	-3.8
B2	1000	Slight concave slope	1	-2.4
B3	1000	Concave downward slope	-0.4	-3.4
B4	3000	Concave downward slope	-0.3	-4.8
C1	600	Flat	2.9	1
C2	300	Flat	2.9	0.1
C3	700	Flat	2.6	-0.6
D1	300	Flat	3.2	0
E1	1200	Flat	2.5	-1.2
F1	700	Flat	2.1	-1

Note that the sound power levels and predictions are for L_{eq} noise levels but are compared to measured L_{90} noise levels as this is standard practice in South Australia. The measured L_{90} noise levels would need to be increased by a maximum of 1.5 dB for locations where the measurement of L_{eq} levels is required during compliance.

Table 1 demonstrates that, with completely reflective ground (G=0), predicted wind farm noise levels are generally conservative. It is only at Sites A3, B1, B3 and B4 that this method marginally under-predicts noise levels and even then only by a maximum of 0.7 dB(A). Note however that no correction for background noise was applied to any of the measurements sites in the study. While sites were selected on the basis that there appeared little influence of extraneous noise, actual turbine levels would be lower than total measured noise levels.

With 50% absorptive ground (G=0.5), the accuracy of the noise predictions increase for a number of sites (C, D, E and F), being within 1 dB(A) of the measured levels. However, the chance of an under-prediction of the order of 2 to 5 dB(A) arises for some sites. It should be noted that the maximum under-prediction of 4.8 dB(A) occurs at a site located 3 km from the nearest turbine. At this distance, the under-prediction would be of no consequence with regards to compliance with relevant noise criteria.

Based on the comparison for the 13 different measurement locations, it appears that topography plays an important role in the accuracy of predicted noise levels. This is most clearly evident at measurement sites A2 and A3, which are located the same distance away from, but on different sides of, the same small group of wind turbines. The only significant difference between the two sites is the topography from the nearest turbines to the measurement site. On one side (to A2) the ground slopes steadily down from the turbine to the measurement location. On the other side (to A3) the ground slopes sharply down from the turbine before levelling out towards the measurement location (a concave slope).

The ISO 9613-2 method with 50% absorptive ground is typically within ±1 dB(A) of the measured noise levels at Wind Farms C, D, E and F where the topography between the turbines and house was best described as flat. Yet at Wind Farm B, where the topography is concave between the nearest turbines and receivers, this method can under-predict noise levels by up to 4 dB(A) at a distance of 1500 m. This is despite topographical information being included in the computer noise models for all sites included in this study.

The influence of topography on the accuracy of noise predictions is discussed further in Section 4.

3.3 Receiver height

The predictions upon which the differences in Table 1 are based were carried out for a receiver height of 1.5 m above ground. We note that in the UK, wind farm noise

modelling is typically carried out based on a ground absorption of G=0.5 and receivers set at a height of 4 m above ground (Institute of Acoustics, 2013).

The predicted noise levels for the 13 sites were recalculated with the receivers set at a height of 4 m. For 50% absorptive ground (G=0.5), the predicted noise levels at a height of 4 m were 1 to 2 dB(A) higher than those at 1.5 m. This can therefore be considered a method of increasing the conservatism of the predicted noise levels using this specific methodology. However, in the UK it is offset by a correction of typically -2 dB applied to the sound power levels to adjust L_{eq} to L_{90} (Institute of Acoustics, 2013).

Note that there is no difference in predicted noise levels with receiver height for completely reflective ground (G=0).

4 Influence of topography

As shown in Table 1, the intervening topography between turbines and measurement locations appears to influence the accuracy of noise predictions, even in these cases where topographical information is already included in the noise model.

The ISO 9613-2 methodology with G=0.5 appears to provide reasonably accurate predictions for flat sites, and conservative predictions for sites with steady downward slopes. However, the methodology appears to under-predict noise levels for sites with concave slopes and the use of completely reflective ground (G=0) is required to obtain reasonably accurate predictions. This finding is consistent with that of Bass, Bullmore and Sloth (1998) who stated, with reference to the ISO 9613-2 method:

> *Where the ground falls away significantly between the source and receiver ... it is recommended that 3dB(A) be added to the calculated sound pressure level.*

It is important to note at this point that there is no obvious difference between the ground at any of the measurement sites in Table 1 that would lead to a change in the ground absorption properties. All sites are in typical rural areas and it would be expected that a ground absorption factor of 0.5 or higher would be suitable for noise predictions for noise sources at standard height. The effect of adopting a value of G=0 is therefore to provide an approximate 3 dB adjustment to the predicted levels rather than actually reflecting the ground absorption condition at the site.

Figure 3 and Figure 4 show the cross-sectional topography for Site A2 (steady slope) and Site B1 (concave slope), two sites where a significant difference in prediction accuracy was noted. It is clear that there is a direct line of sight from turbine to receiver in both cases and that the topography was not providing any shielding in the case of Site A2 where the ISO 9613-2 methodology over-predicted. A possible mechanism for the increase in measured turbine levels relative to predicted levels at Site B1 is a focussing effect from the concave slope.

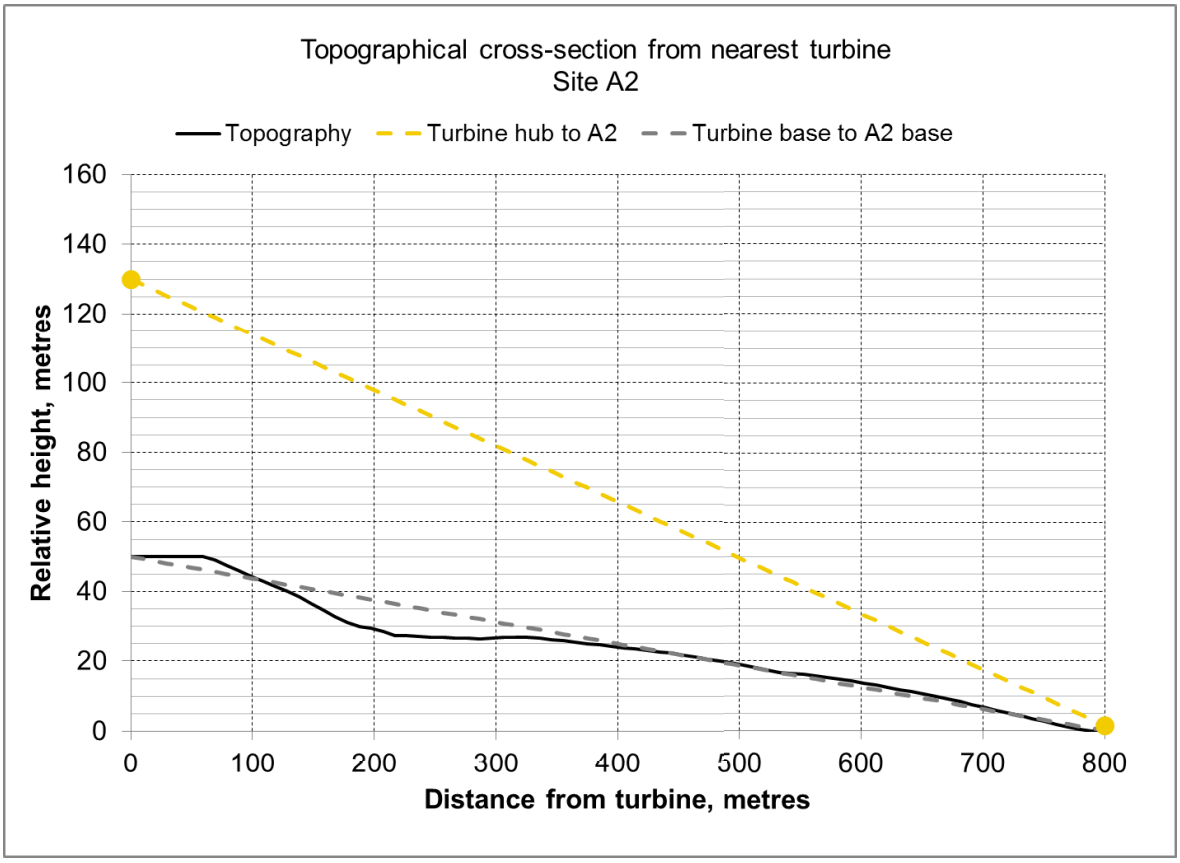

Figure 3 – Cross-section from nearest turbine to Site A2 (steady slope)

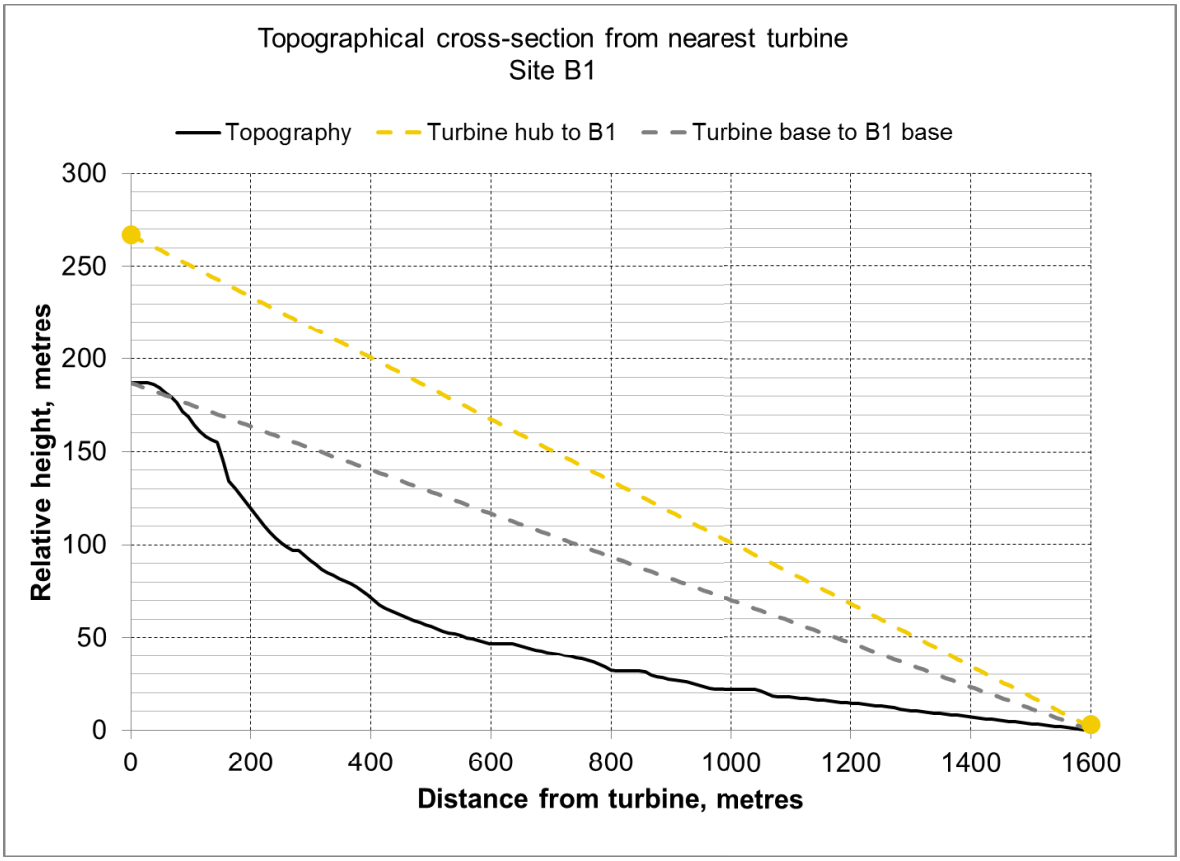

Figure 4 – Cross-section from nearest turbine to Site B1 (concave slope)

The UK Institute of Acoustics (2013) has suggested that a correction of +1.5 dB(A) be added to predicted noise levels using ISO 9613-2 with G=0, where the mean height above ground of the direct line of sight from source to receiver (h_m) meets the following condition:

$h_m \geq 1.5 \times (abs(h_s - h_r)/2)$

h_S: height of source above local ground

h_r: height of receiver above local ground

This condition would be met for Site B1, B3 and B4 but not for A3. However, the under-prediction at A3 using G=0 is relatively minor (0.4 dB).

Further work is required to refine noise modelling for wind farms here, including the investigation of ray tracing models to assist in the prediction of wind farm noise. However, based on current knowledge, the UK method would appear to provide a reasonable method to reduce the chance of an exceedance of noise criteria at sites with concave slopes.

Finally, we note that the predictions used in the assessment are all based on measured sound power levels rather than manufacturer warranted sound power levels. Our experience is that manufacturer warranted levels are normally higher than measured levels, such that any modelling for new sites will incorporate an additional margin of safety. On this basis, it appears unlikely that predictions for a new site which use the ISO 9613-2 methodology and hard ground will be exceeded.

5 Effect of meteorological conditions

5.1 Wind speed and direction

While it has an important role in the noise emissions from wind turbines, wind speed does not appear to have a significant influence on the propagation of turbine noise to receiver locations. This is shown in Figure 2 where it can be seen that the increase in noise levels at the measurement location closely match the shape of the turbine sound power curve across the turbine-controlled wind speed range.

The authors undertook a study into changes in propagation with wind speed based on simultaneous measurements undertaken at approximately 120 m, 500 m and 1 km from the end of a line of wind turbines (Evans & Cooper, 2012b). Figure 5 presents the decrease in turbine noise levels with wind speed between the 120 m and 1 km measurement locations for both downwind (±45°) and upwind (±45°) periods. It can be seen that the propagation loss is relatively steady with wind speed although it does appear to increase by approximately 2 dB from 5 to 11 m/s for downwind periods. This suggests that the upper end of the turbine-controlled wind speed range at some sites (as highlighted in Figure 1 for Site B3) may be somewhat influenced by the increased background noise, with noise models therefore slightly more likely to over-predict noise levels at higher wind speeds. However, overall there

does not appear to be a significant relationship between wind speed and noise propagation.

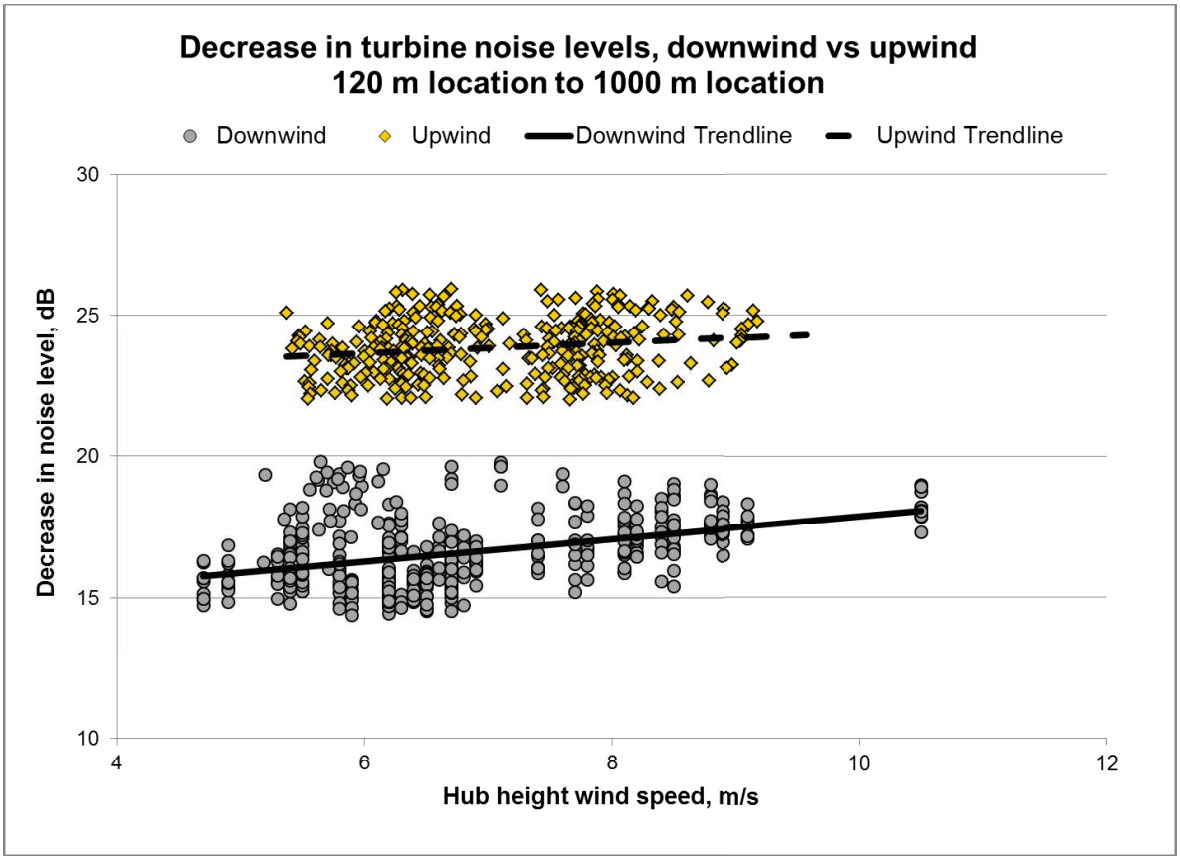

Figure 5 – Decrease in turbine noise levels with wind speed, 120 m to 1 km

The same study also considered propagation loss under different wind directions. As can be seen in Figure 5, there was a substantial increase in propagation loss under upwind periods relative to downwind. The study also found that propagation loss under crosswind conditions was marginally lower than under upwind but still considerably higher than under downwind (Evans & Cooper, 2012b).

While this indicates that downwind represents the worst case scenario for turbine noise from a particular turbine, our first study found that there is only a marginal difference of approximately 1 dB(A) between wind farm noise levels measured under the SA Guidelines, which only consider downwind periods, and NZS 6808:2010, which considers all wind directions (Cooper, Evans & Najera, 2012). This small difference in measured levels between the downwind and all direction assessments is a result of individual turbines being in different relative directions to a measurement location, such that it is rare for all turbines to be directly upwind or downwind at the same time.

5.2 Wind shear

Vertical wind shear refers to the change in wind speed with height above the ground, with higher values of wind shear occurring during stable night time conditions. While

wind shear is known to increase noise propagation for noise sources at relatively low height, there is little evidence to suggest that it substantially affects the propagation of noise from sources located as high as wind turbines. Søndergaard (2012) found that wind shear was “without any real influence” on noise propagation under Danish conditions.

As a preliminary review of the effect of wind shear on noise propagation, measurements were taken at a site approximately 1.5 km away from a wind farm. The house was located relatively near to a meteorological mast recording 10-minute average wind speed at several heights from near ground level to hub height, allowing calculation of wind shear. The measured $L_{90,10min}$ noise levels were correlated with wind speed for a 10-day period at the site and a polynomial trendline fitted to the data. A good spread of shear values across the typical wind speed range enabled a robust analysis via this method as it could be susceptible to error where higher shear values were limited to particular wind speeds. As the site was subject to considerable influence from background noise at times, only night time data collected between 11 pm and 5 am was used for the analysis.

Figure 6 presents the deviation of each measured $L_{90,10min}$ noise level from the trendline referenced against the 10-minute average wind shear. While there is considerable spread in the data, indicative that wind turbine noise did not always control measured noise levels, the data suggests that there may be a slight decrease in wind turbine noise propagation with wind shear. There does not appear to be an increase in either propagation (or noise emission) given the data collected at the site.

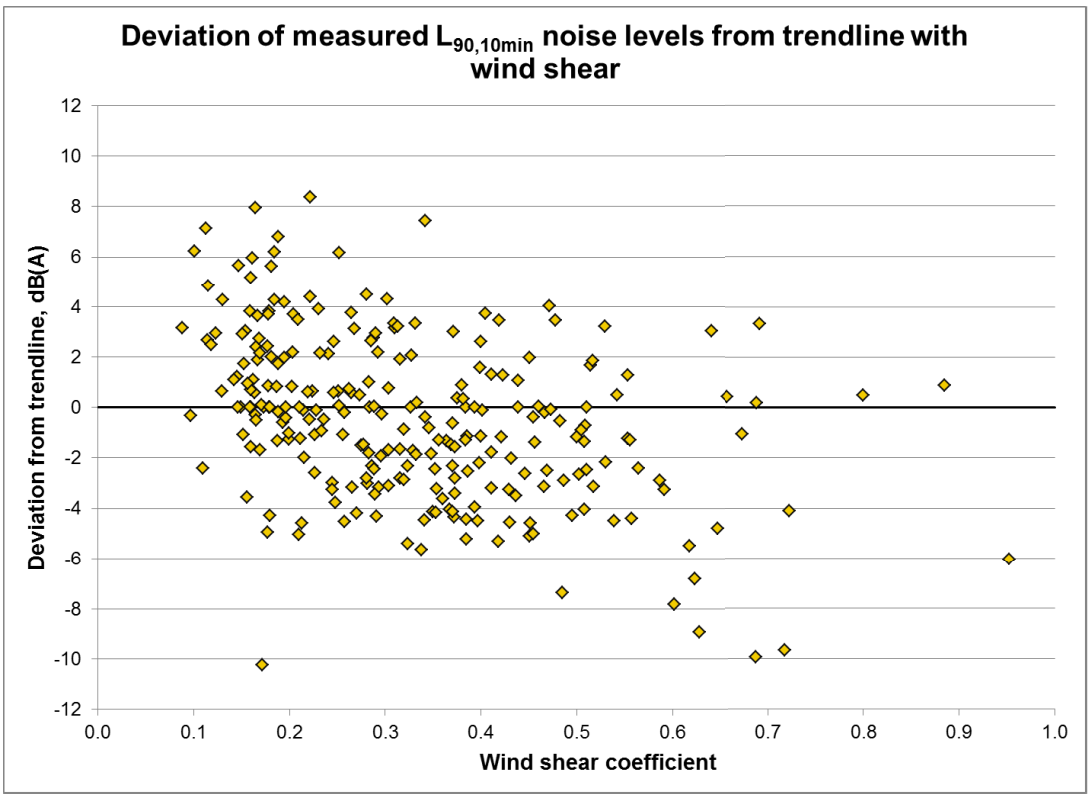

Figure 6 – Deviation of turbine noise levels from trendline with wind shear

Further analysis is currently underway by the authors at sites where various height wind speed measurements at the mast make wind shear determination possible, and where noise levels are more often controlled by wind turbine noise. This data will be published by the end of the year.

It is important to note that wind shear does have an important role in influencing the background noise at a receiver location and therefore would potentially influence the perception of wind turbine noise at receivers. During a period of higher wind shear, the turbine sound power level that would normally be masked due to background noise at the residence may be coupled with a period of low wind (and therefore low background noise) at a receiver location.

5.3 Temperature gradient

Temperature gradient is another key factor on noise propagation for low height noise sources but there is little data as to the potential effect on the propagation of wind turbine noise. Under stable conditions, temperature inversions may occur.

The mast at the wind farm site discussed in Section 5.2 also provided 10-minute average temperature gradient values from the bottom to the top of the mast, making a preliminary analysis of the effect of temperature gradient possible. The night time data collected included periods both under standard negative temperature gradients as well as under temperature inversions. The inversions were found to closely follow the periods of higher wind shear previously analysed in Figure 6 so it is considered unlikely that temperature inversions would significantly increase noise propagation.

Figure 7 presents the deviation of each measured $L_{90,10min}$ noise level from the trendline referenced against the 10-minute average temperature gradient for the nearby mast. A negative value on the horizontal axis indicates a standard temperature profile while a positive value indicates a temperature inversion.

There does not appear to be a strong relationship between temperature gradient and wind turbine noise propagation at the site. There is perhaps a slight downward trend as temperature gradients increase towards an inversion, indicating that noise propagation from wind turbines may marginally decrease under inversions. However, the relationship is not strong and the results suggest that temperature gradient does not substantially affect noise propagation from the turbines.

It is important to note that as identified for the wind shear analysis, this site was susceptible to influence from background noise at times. The further analysis of wind shear data discussed previously will also include further analysis of temperature gradient.

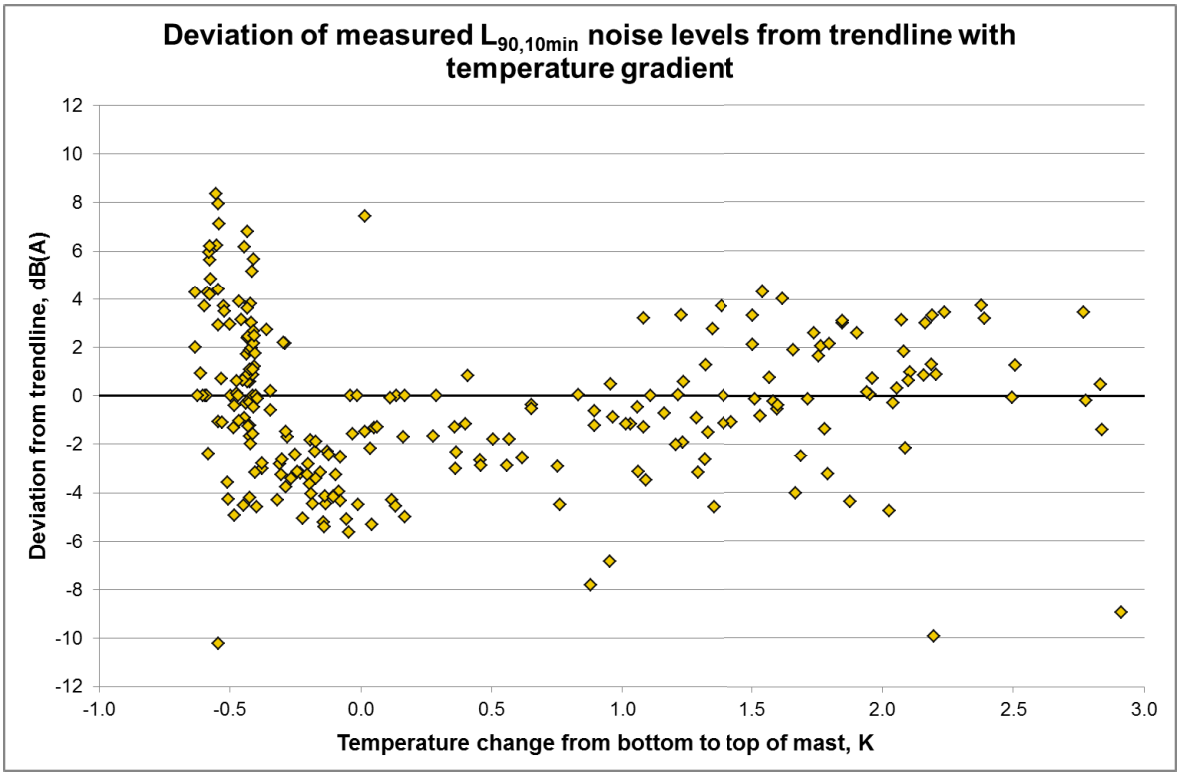

Figure 7 – Deviation of turbine noise levels from trendline with temperature gradient

5.4 Turbulence

Turbulence occurs in unstable atmospheric conditions and therefore is not normally expected to be a factor increasing noise propagation for noise sources, as opposed to wind shear and temperature inversions. An element of turbulence will always be a natural part of the atmosphere immediately downwind of wind turbines. However, in certain situations, turbines may be operating in the wake of other turbines leading to inflow turbulence.

An investigation into sound power measurements conducted at a site where a turbine was located in the wake of another turbine for particular wind directions (Cooper & Evans, 2012) found that there was no substantive increase in noise emissions during turbulence. While there was a relatively minor increase at low wind speeds, it was theorised that this is offset by the actual reduction in the wind speed at the turbine hub resulting from the turbulence. The increase in sound power levels at low wind speeds did include an increase in low frequency noise levels, however not above the low frequency noise levels produced by the turbines when operating in non-turbulent conditions at medium to high wind speeds. There was no apparent change in low frequency noise emissions of the turbines when operating in the wake of an adjacent turbine at medium to high wind speeds.

Noise propagation under turbulent inflow conditions remains unresolved (Søndergaard, 2012) but it is not expected to result in noticeable increases in noise propagation. All of the measurements upon which the differences in Table 1 are based would have included turbulence as they were conducted when the

measurement location was downwind of the nearest turbines. Given that the noise prediction methods were relatively accurate for these scenarios, it appears unlikely that turbulence would increase noise propagation.

6 Conclusion

This paper presents the findings of studies conducted by the authors into the accuracy of noise predictions for wind farms using the ISO 9613-2 methodology. A study into the accuracy of predictions at 13 sites across six wind farms found that:

- The ISO 9613-2 methodology is unlikely to result in significant under-predictions of wind turbine noise at receiver locations with the use of an appropriate ground absorption factor to adjust for apparent topographical effects.
- In the case of a concave slope from turbine to receiver a ground absorption factor of 0 should be used for predictions. The current correction factor suggested by the Institute of Acoustics should also be considered where it is warranted by the topography.
- For flat sites, a ground absorption factor of 0.5 is likely to be more appropriate.
- Further work is required to reduce the chance of considerable over-predictions at sites with steady downward slopes. Under-prediction does not appear to be a risk at these sites with current prediction methods.

A preliminary analysis of noise propagation under different meteorological conditions was also undertaken. It appears that periods of high wind shear and temperature inversion do not result in increases in noise propagation for wind farms, despite their known effects on noise sources located close to the ground.

Overall, the accuracy of current wind farm noise models is good, especially considering the uncertainty that exists in the prediction of other noise sources such as road traffic noise and industrial noise. Based on investigations undertaken by the authors, there is not believed to be a risk of significant under-prediction of wind farm noise at receiver locations when good practice noise modelling procedures are employed.

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