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A study of background noise levels measured during far-field receptor testing of wind turbine facilities

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Summary

This study presents an assessment of the background noise levels measured across a range of wind facilities in southern Ontario. Background sound levels are measured during wind turbine shutdowns as part of the acoustic compliance auditing required for nearly all Ontario wind facilities. The background measurement data plotted against ground level and hub height wind speed to determine the impact wind speed has on ambient sound levels. An examination of the variation in sound level conducted at sites having nearby features such as trees and roadways to determine their effects on background sound levels. Finally, the average spectral content of background sound in different conditions is compared with a typical far-field wind turbine spectrum to determine the important frequencies of interest in far-field measurements, as well as the conditions that might make an accurate determination of facility-only sound level difficult or even impossible.

It was found that fluctuations in sound level of 10-20 dB are common, particularly in the presence of roadways or nearby trees. Forested areas also provide an elevated sound level at high wind speeds, even if the immediate vicinity around the microphone is open field. Hub-height wind speeds were determined to influence background sound levels and require consideration along with the ground level wind speed, particularly at low ground level wind speeds. It was also found that background sound levels regularly exceed turbine sound levels at frequencies above 1000 Hz, even at low wind speeds. At high wind speeds, background sound levels were found in some cases to exceed the turbine sound level at all frequencies, which would make a determination of turbine-only sound level in these conditions exceedingly difficult.

1. Introduction

An accurate measurement of any noise source requires a careful consideration of the background sound level present during the measurement. For wind facilities, this consideration of background noise is particularly important, because both the sound output of the wind facility and the background sound vary with wind speed. Increasing wind speed for both conditions corresponds to an increase in background sound level.

This consideration for background noise becomes even more important in the case of far-field noise measurements, which are often conducted at distances of 500 metres or more from the facility. These are typical conditions present during compliance testing or complaint evaluations performed on wind facilities in Ontario and other jurisdictions. Aercoustics has conducted extensive testing of wind facilities in Ontario, where the measurement protocol for compliance testing prescribes a requirement to periodically turn off the wind turbines and measure background sound. This has enabled Aercoustics to collect a variety of background sound measurements across several different wind facilities.

In this study, different background noise datasets are examined to determine important factors associated with background sound levels in the context of wind turbine noise measurements. Wind speeds at different heights are compared and the surrounding area of each monitor is categorized to determine which parameters are important in categorizing and filtering background sound and selecting an appropriate measurement location. Lastly, an assessment of the spectral content of background sound levels in different wind conditions is compared to a typical far-field wind turbine spectrum, to determine the impact of background noise compared to a 40 dBA wind turbine level.

Given the increasing prevalence receptor testing as the method of choice for many jurisdictions to evaluate wind facility compliance, the understanding of background sound levels and their impacts on the sound measurements is of great importance.

2. Measurement Methodology

The measurement data used for this study was obtained from long-term measurement equipment installed at a variety of locations across several wind farms in southern Ontario. Measurement campaigns typically last anywhere between 4 to 16 weeks and must follow a measurement protocol published by the Ontario Ministry of the Environment [1].

2.1 Measurement Equipment

Data in this study was collected using measurement equipment installed near a wind facility and configured to remotely record sound levels and meteorological (MET) information every night. The equipment synchronously captures acoustic and MET data at heights of 4.5 meters and 10 metres, respectively. The microphone is fitted with a primary and secondary windscreen to reduce the effect of wind generated self-noise. The 10-metre [1] weather station measures a range of weather parameters for each interval. A picture of a typical measurement apparatus is shown in Figure 1.

Figure 1: Measurement apparatus

[1] Wind speed at 10-metres is referred to as “ground level wind speed” in this paper.

These measurement stations are typically installed at distances ranging from 500 to 800 metres from the nearest wind turbines. All measurements are unattended, conducted nightly from 10 pm to 5 am with data downloaded wirelessly at regular intervals. A total of 1,700 hours of background measurement data was assessed in this study.

2.2 Measurement Parameters

The data presented in this study was captured in 1-minute intervals. The overall LA_{eq}[2], 1/3rd octave band level, and L90 was recorded for each interval. Weather data recorded includes wind speed, wind direction, temperature, pressure, humidity, and precipitation.

Acoustic and weather data are acquired synchronously by the same data acquisition system. Turbine operational information was obtained separately from the wind facility SCADA system; this data was available in 10-minute average intervals.

2.3 Measurement Environments

The measurement locations in this study represent a range of conditions typical of southern Ontario. Terrain surrounding most of the wind facilities is flat, open fields dotted with patches of trees. Roadways pass through and around most facilities, with traffic levels anywhere from small regional roads, major highways, and everything in between. Forested areas range in size from a few dozen metres to multiple kilometres across. Many of the houses in these areas are surrounded by narrow tree lines for shelter against the wind. Tree noise and roadway noise is prevalent and pervasive in most background measurements, particularly at high wind speeds.

Measurement locations were categorized based on the nearby features surrounding the microphone as well as the presence and proximity of forested areas and major roads. In total, data from 40 separate measurement campaigns measured at 21 different locations across 8 wind facilities were examined.

For the current discussion, a sample of these datasets is presented. The background measurement data from a selected 4 monitoring locations are compared more closely. A summary of the locations and their surrounding environment is presented in Table 1. The locations of the features presented in this table are with reference to the “front” direction pointing towards the nearest turbine.

Table 1: Description of Monitoring Locations and Surrounding Environment

Location ID	Immediate Surroundings	Distance to Nearest Forest	Distance to Nearest Roadway (and traffic level)
Site A	Front: open field Side: trees, 25m Back: open field	100m	340m (Infrequent traffic)
Site B	Front: open field Side: trees, 15m Back: house, 75m	130m	15m (infrequent traffic)
Site C	Front: open field Side: open field Back: forest, 50m	50m	40m (infrequent traffic)
Site D	Front: open field Side: house, 50m Back: open field	500m	15m (moderate traffic)

[2] Energy-equivalent sound level, A-weighted

The wind facilities measured in this study are all modelled to a 40 dBA limits (Class III environment), representative "areas dominated by natural sounds having little or no road traffic"[3]. It is not an uncommon notion in the acoustic community that rural ambient environments are very quiet, which would imply that receptor measurements of wind turbine noise shouldn't be adversely impacted by background noise. This notion is usually based on experiences of noise levels in rural environments during calm conditions (i.e. low wind speeds). Since wind turbines to not operate in calm conditions, it is important that background sound levels be measured during conditions when the turbines would otherwise be operating.

Background noise variation in this study is presented in the form of sound level histograms sorted by wind speeds or 1/3rd octave frequency. High concentrations of measurements are represented by darker colours in each plot. Figure 2 shows an example of this plotting technique for a site located 500 m from a forested area. The x-axis is ground level wind speed in this example.

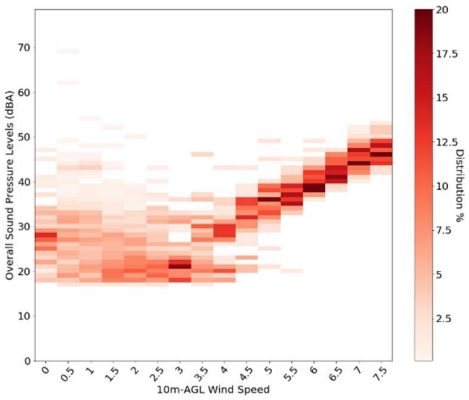


Figure 2: Sample Histogram

3. Results and Discussion

Background sound levels are filtered and categorized by different parameters and presented in this section. These plots show the typical variety of background sound levels observed at each measurement location with respect to wind speed, measurement season, and 1/3rd octave frequency. These comparisons illustrate the important parameters to consider when measuring background levels for wind turbine noise testing. Of particular interest are the background spectra comparisons to a typical far-field wind turbine spectrum. These plots show that in certain conditions the background sound levels have the potential to dominate noise from the wind turbine at all frequencies.

3.1 Overall Sound Level and 10-metre Wind Speed

The overall LA_{eq} (OASPL) is plotted against the measured ground level wind speed in Figure 3. Several different site conditions are plotted and compared. The horizontal line across each plot is 40 dBA, which represents the permitted sound level limit for all the wind facilities in this study. Each increment on the y-axis of each plot represents a change of 10 dB, and each increment on the x-axis represents a change of 0.5 m/s. The x and y axis ranges are the same for all plots.

[3] Per Ontario Ministry of the Environment document NPC-232 [2].

Figure 3: OASPL vs. Ground Level Wind Speed for Sites A-D

Figure 3A: Open field

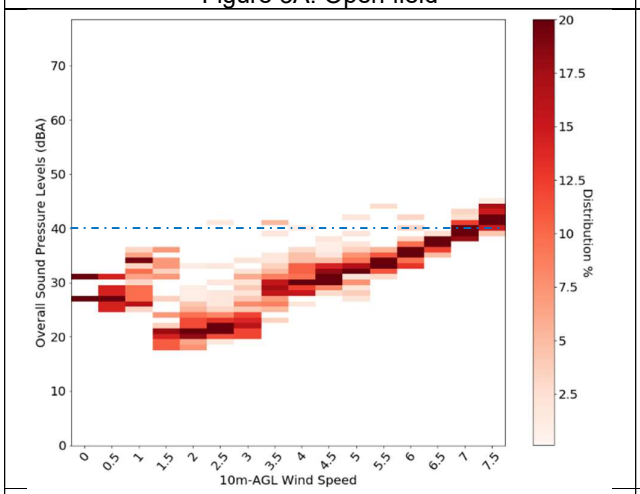


Figure 3B: Adjacent trees <25m

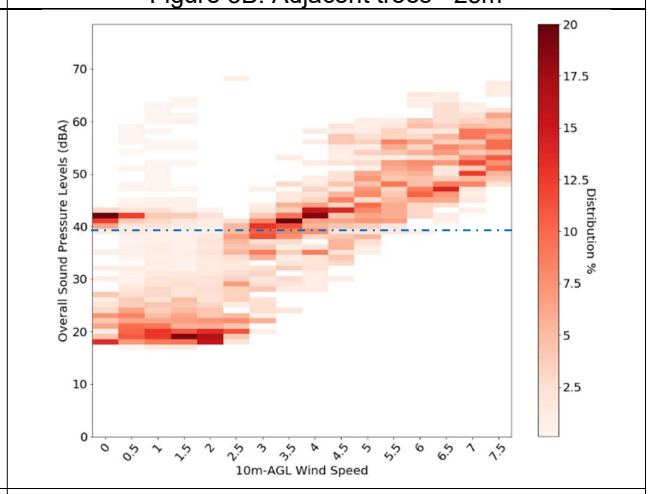


Figure 3C: Forest <100m

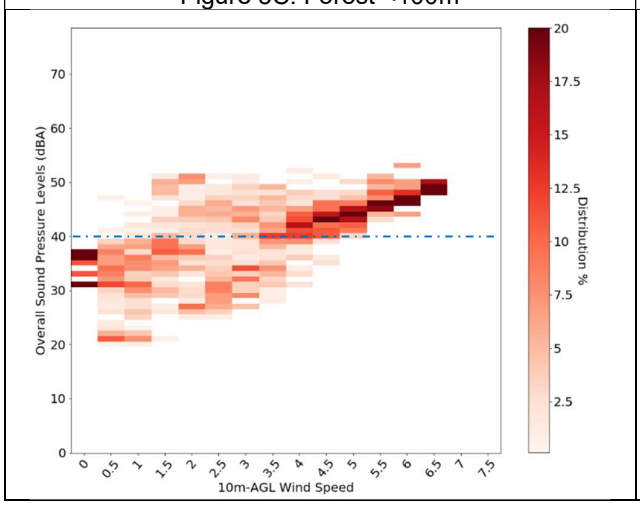
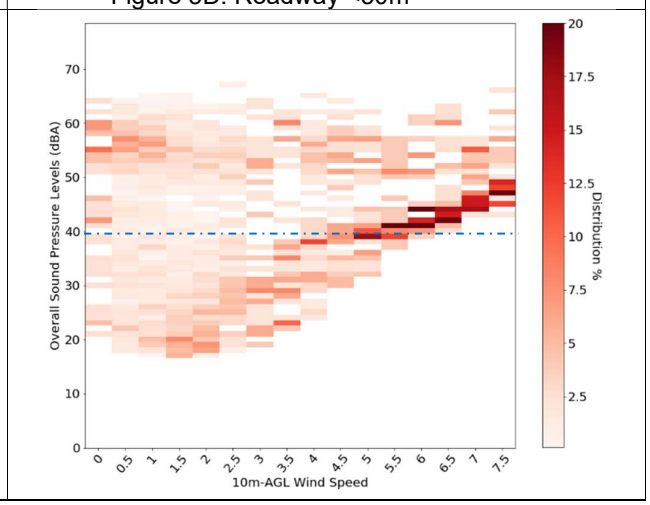


Figure 3D: Roadway <50m



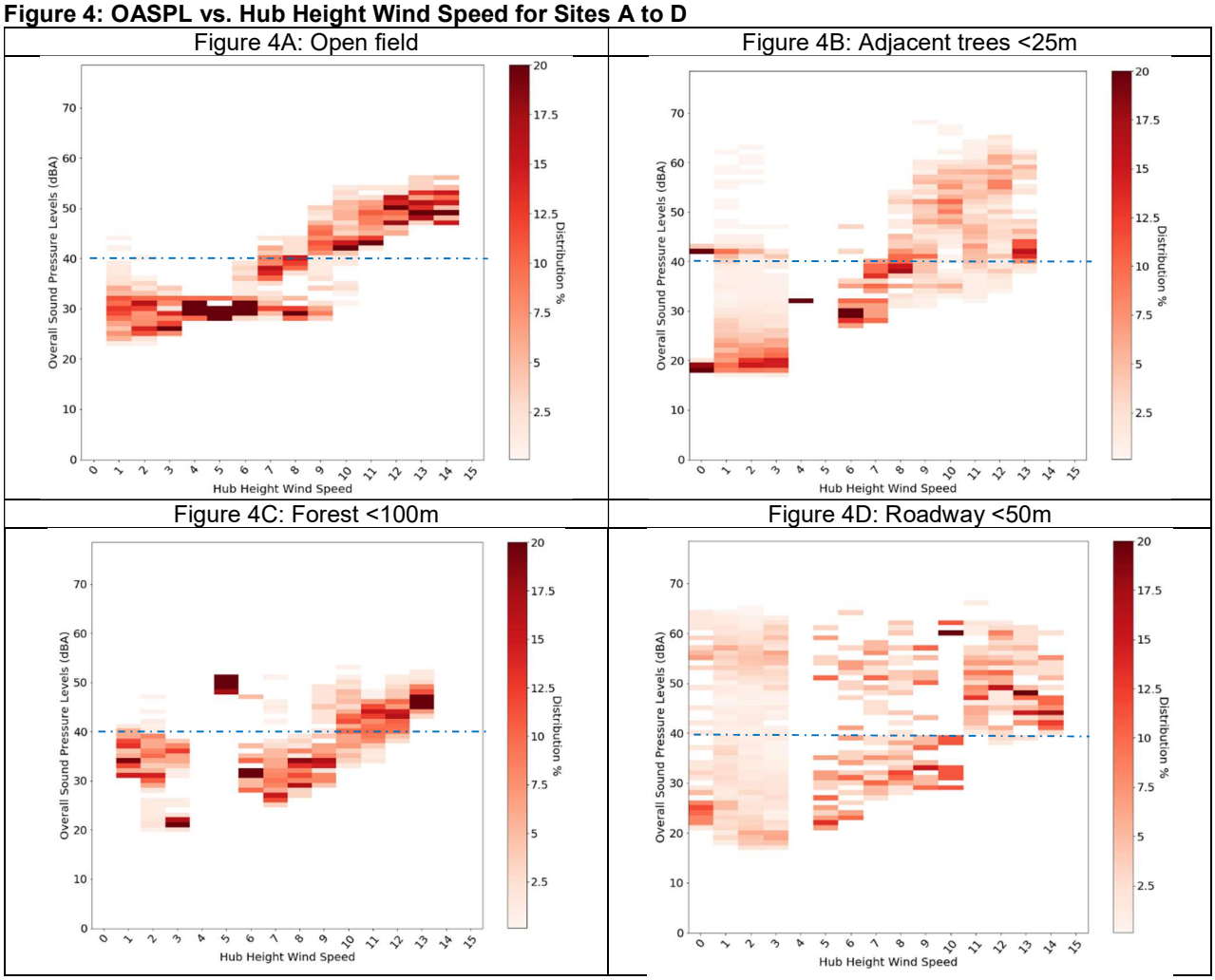
The figures above show a positive correlation between background sound level and ground level wind speed. This is no great revelation, as it has long been accepted that the sound levels increase with ground level wind speed at the monitoring location. Each monitor appears to have an increasing floor, or minimum noise level, as wind speed increases. However, the variation in sound level above this floor is quite pronounced at different sites, depending on the nearby features.

Data in Figure 3A is from an open site and shows a high concentration of sound levels near the sound floor. Figure 3D, on the other hand, is near a roadway that has intermittent but regular vehicle pass-bys, which cause significant fluctuations in sound level. Figures 3B and 3C represent sites that have trees adjacent the monitor (3B) or a forested area in the vicinity (3C). The impact of the tree noise presents both a more rapid increase in sound level with wind speed as well as an increase in the variation in sound level at lower wind speeds. This variation at low wind speed implies that there are other factors that are affecting the measured background sound level when the ground level conditions at the monitor are calm.

3.2 Overall Sound Level and Hub Height Wind Speed

To further investigate the effect of wind speed on sound level, the overall LA_{eq} is plotted against the measured hub-height wind speed in Figure 4. Each increment on the y-axis represents a change of 10 dB, and each increment on the x-axis represents a change of 0.5 m/s. The x and y axis range is the same for all plots. The horizontal line across each plot is drawn at 40 dBA.

Figure 4: OASPL vs. Hub Height Wind Speed for Sites A to D



The above figures show similarities to the trends observed in 3.1, with increasing sound levels measured with increasing hub height wind speed. The wind speed at hub-height can change independent of ground level wind speed, expressed as variations in wind shear[4]. This means that high hub height wind speeds can be present at low ground level wind speeds during high wind shear conditions. Given the findings in Figure 4, the variation in background sound level observed at low ground level wind speeds in Figure 3A-D may be explained by different wind shear conditions at low ground level wind speeds.

For a more illustrative example, sound level is plotted against ground level wind speed in Figure 5, with the colour of each point representing the hub-height wind speed. This plot shows that

[4] Wind shear characterizes the difference in wind speed with elevation.

variation in hub-height wind speeds can explain much of the variation in background sound level observed at low ground level wind speeds. That is, increasing wind speeds at high elevations (hub height) also have the effect of raising the background sound level at the measurement location.

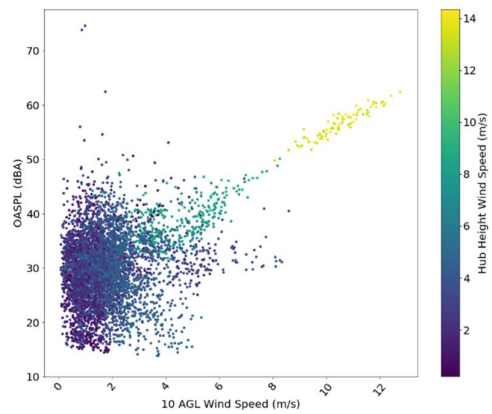


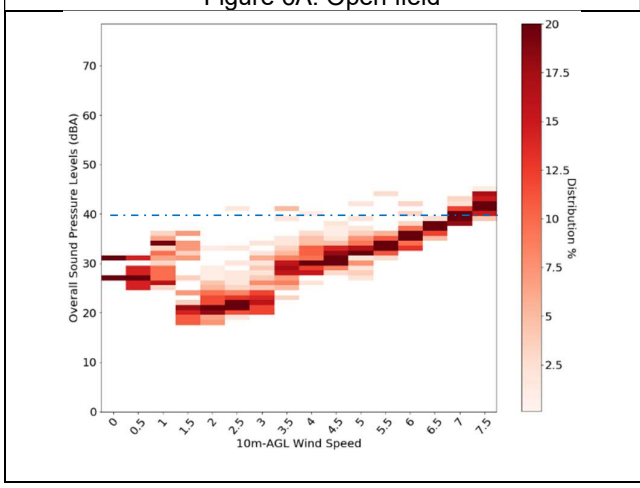
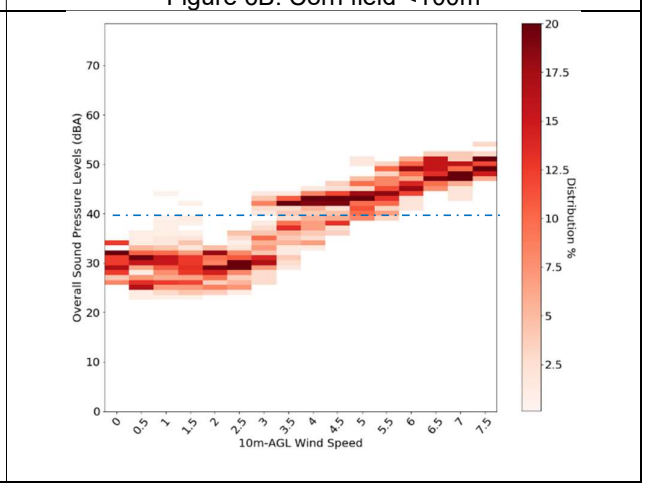
Figure 5: OASPL vs Ground Wind Speed (hub height wind speed indicated by colour)

This finding is particularly important in the case of high wind shear conditions, where turbine sound levels are compared to background sound levels at low ground level wind speeds near the monitor. Typically, measurements conducted when the wind turbines are operating will naturally have high hub height wind speeds, since turbine power output is correlated to hub-height wind speed. Background measurements, on the other hand, can have a variety of hub-height wind speeds for each ground level wind speed. When using measurements of the background to isolate the turbine noise through ambient subtraction, the resulting turbine noise would be overestimated if the background sound level contains low hub-height wind speed conditions, as those conditions are found in this study to be quieter than high hub-height conditions for the same ground level wind speed.

3.3 Seasonal Variation in Background Sound Level

The two figures below (Figure 6A and Figure 6B) represent measurement data from the same location, during different times of the year. Figure 6A was measured in the spring months and Figure 6B was measured in the fall months. The most notable difference between the two measurement periods was that during the fall months, the field adjacent the monitoring location (100 metres away) was planted with corn. It is suspected that the noise from the corn is the reason for the increased sound levels at high wind speeds between the two periods. The increase is not trivial, upwards of a 10 dB difference at some wind speeds.

Figure 6: Seasonal Comparison of Background Noise at Site A

Figure 6A: Open field	Figure 6B: Corn field <100m
	

The sound levels in Figure 6B show background noise elevated above 40 dBA starting at ground level wind speeds of 3 m/s, in contrast to sound levels in Figure 6A which remain largely below 40 dBA until 7 m/s. These figures show that even at the same measurement location, the background sound levels can vary significantly depending on changes in the surrounding landscape between seasons.

3.4 Average 1/3rd Octave Spectra – Turbine ON vs. Background

The findings presented so far show that background sound levels are highly dependent on wind speed (ground level and hub-height), transient sources (such as road traffic) and nearby features such as crops and trees. Furthermore, it was found that in many locations the overall background sound level regularly exceeded the 40 dBA sound level of the wind turbines being measured. For further study, an evaluation of the spectral content of the 1/3rd octave band noise levels is performed. For comparison, a typical wind turbine spectrum is plotted for each graph, representing the noise from the facility that would be the subject of the measurement[5].

Figure 7 shows the 1/3 octave band spectra for Sites A to D with ground level wind speeds at 5 m/s. These figures illustrate a typical shape of background noise spectra at different sites in relation to the turbine noise. High frequencies are dominated by background in all cases, and in some cases even middle and low frequencies are dominated by background noise.

Figure 7: Spectral Comparison of Background Noise at Sites A to D at 5 m/s Ground Wind Speed. 40 dBA turbine spectrum plotted in blue.

Figure 7A– Open field

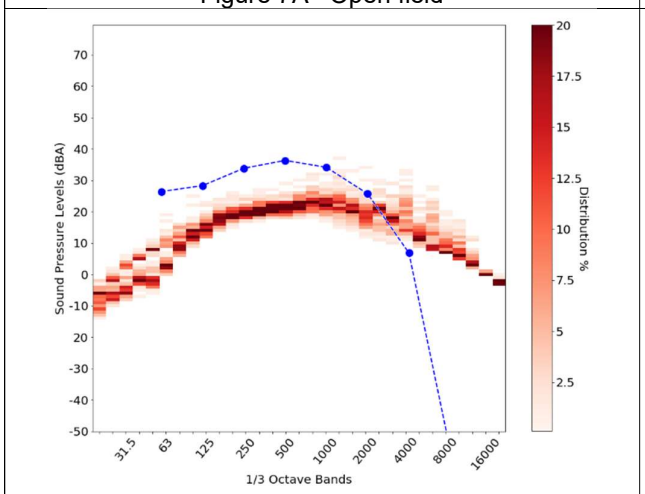


Figure 7B – adjacent trees

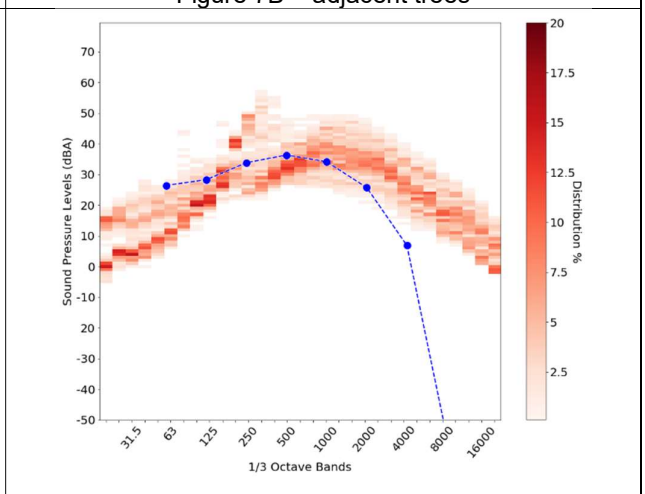


Figure 7C – forest in the area

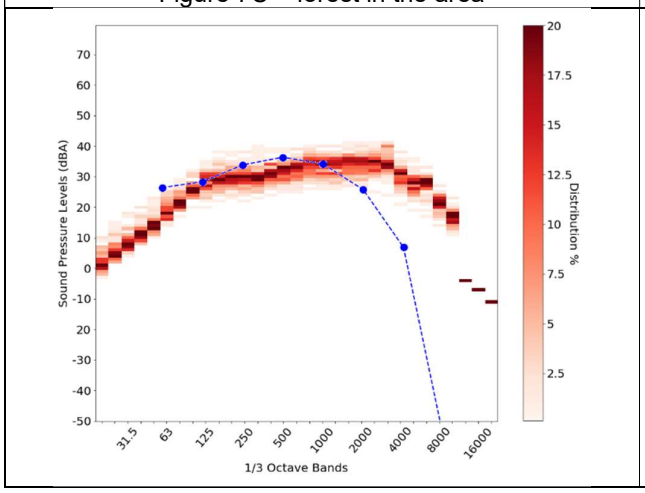
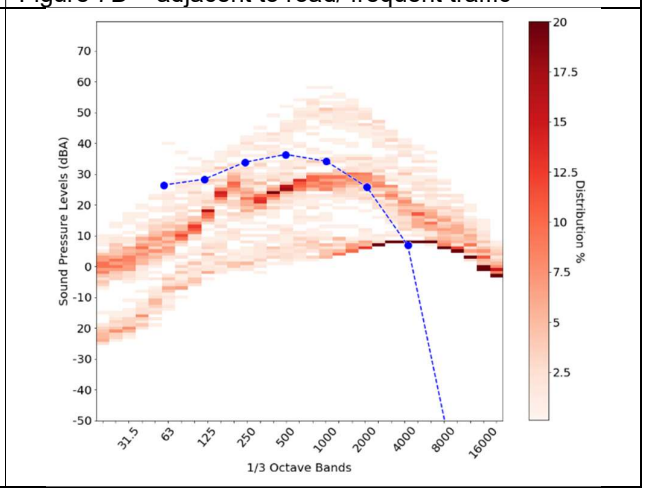


Figure 7D – adjacent to road/ frequent traffic



Of the locations above, only Site A (open field) has a good separation between the wind turbine noise and the background noise, but only at 1000 Hz and below. For Site B (adjacent trees), around 40% of the background data is higher than the turbine spectrum levels and around 70%

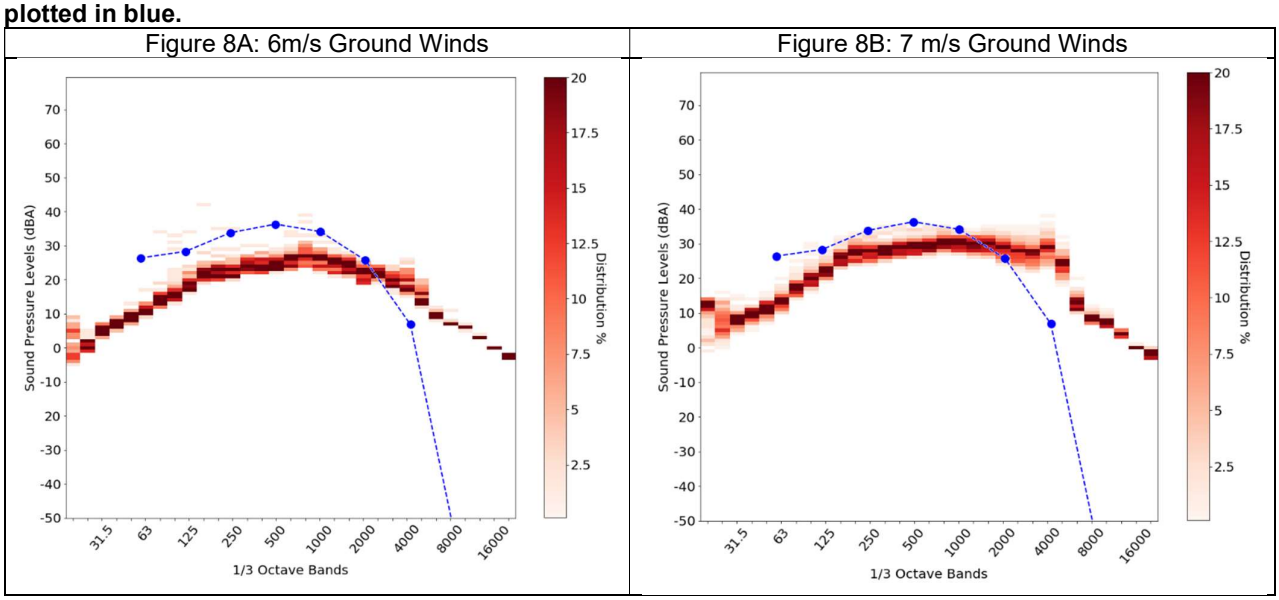
[5] Wind turbine spectrum at a location predicted to be 40 dBA.

of the data collected does not satisfy the 6 dB signal to noise ratio criteria for good quality data[6] at octave bands of 1000 Hz and below. Similar conditions were found in Site C, indicating that the presence of trees – whether a nearby tree line (Site B) or a distant forested area (Site C) – will elevate background sound levels to the point where the levels regularly exceed a 40 dBA turbine spectrum.

The location at Site D (adjacent roadway) shows greater variation in the distribution of the sound levels. This variation is likely attributed to varying traffic levels at different times of the night. There appears to be a concentration of sound levels in the middle this data set which may represent the average amount of road traffic noise experienced at this site. The impact of traffic is also shown in Figure 3D and 4D to cause large variations in measured noise level that are independent of wind speed.

For open locations like Site A (shown in Figure 7A), the background levels are generally quite low; allowing for a good signal to noise below 2000 Hz octave bands. This location represents a site having a very quiet ambient environment. However, even for low ambient sites, the quality of the signal drops with increasing wind speed. Figure 8 shows the background spectra at Site A for 6 m/s and 7 m/s. The signal to noise ratio between overall background and turbine levels drops to less than 6 dB at 6 m/s and less than 3 dB at 7 m/s.

Figure 8: Spectral Comparison at Site A at 7 m/s and 6 m/s ground wind speeds. 40 dBA turbine spectrum plotted in blue.

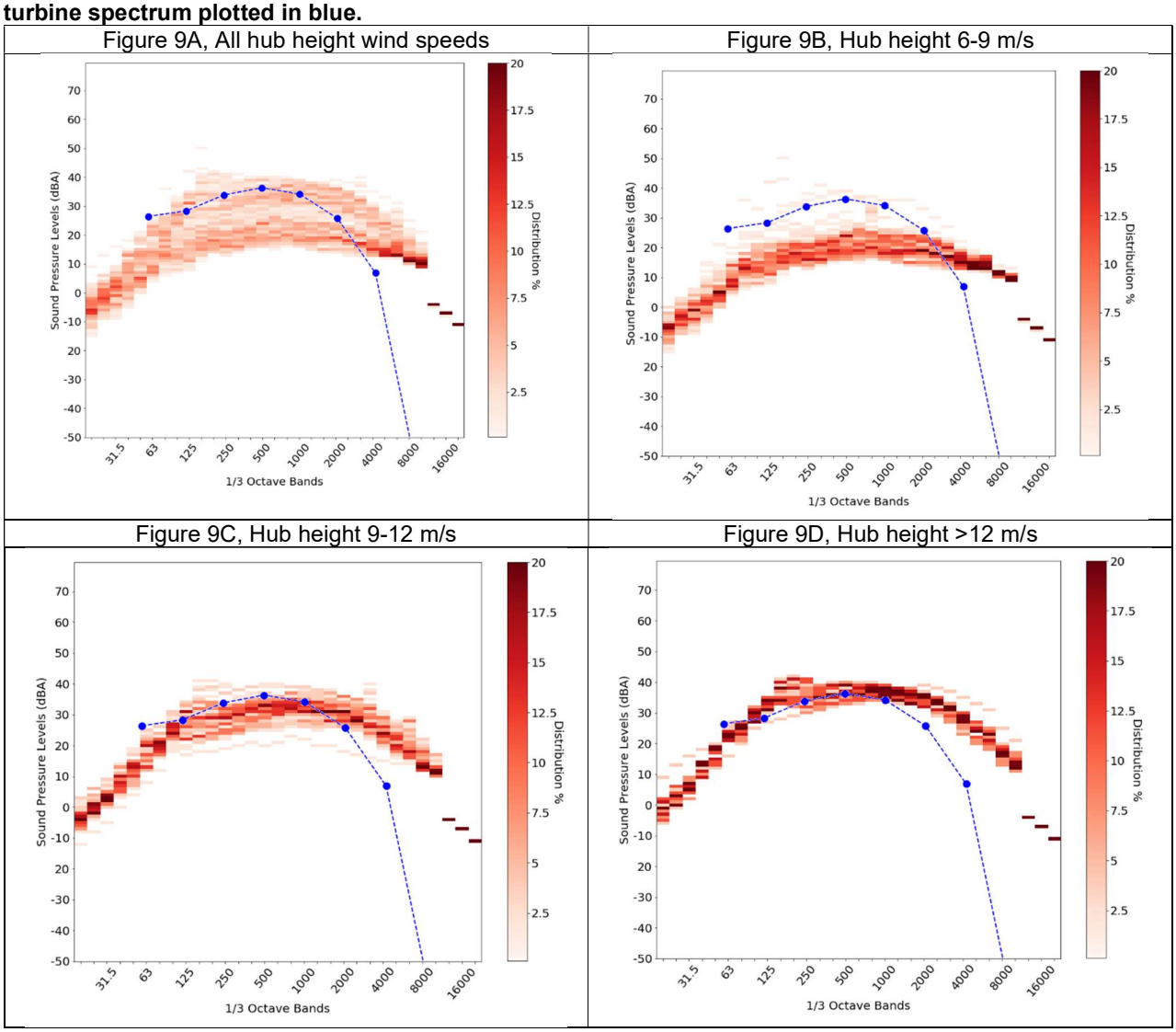


These findings show that low ground level wind speeds are most appropriate for collecting high-quality measurement data, and even then only for frequencies of 1000 Hz and below. This limits a suitable assessment to periods having high wind shear, which may or may not occur on a regular basis depending on the environmental conditions that are typical for the monitoring site.

Given the findings of 3.2, hub height wind speed must be considered during low ground level wind speed conditions. To that end, Figure 9 shows the background 1/3rd octave spectra at a ground level wind speed of 3 m/s for different hub height wind speed conditions. Site C was chosen for illustration, having open fields immediately adjacent the monitor and a forested area starting 50 metres behind it.

[6] Threshold for "good quality" data is taken from the IEC 61400-11 standard for wind turbine noise testing [3].

Figure 9: Spectral Comparison at Site C for 3 m/s Ground Winds with different Hub Height Winds. 40 dBA turbine spectrum plotted in blue.



The above figures show a big influence of hub height windspeeds on the measured background spectra. When all hub-height data is plotted (Figure 9A), a large variation in spectral sound level is apparent. However, when this data is broken down by range of hub-height wind speed, the impact on the background is clearly visible. At medium (Figure 9C) and high (Figure 9D) hub-height winds, the 40 dBA turbine spectrum is almost completely overshadowed by background noise.

In Figure 9B, the turbine only sound levels could be resolved above the background spectrum. Comparing the average octave levels at this hub height wind speed bin, there is a >6 dB signal to noise ratio for the 250 Hz to 1000 Hz band. It is important to note however that in these conditions (6-9 m/s hub height wind speed) the wind facility will likely not be generating its maximum output (both power and noise). Most of the southern Ontario wind facilities have turbines that reach their rated power and noise output in the 9-12 m/s range. The turbine spectrum shown above represents the noise from the wind facility at this rated condition. Therefore the most representative background noise for this condition would be shown in Figure 9C.

4. Conclusions

This study has examined the variation in background sound levels across several wind facilities in southern Ontario. It was found that consideration should be given to both the ground level and hub height wind speed, the latter being particularly important to avoid underestimating the background sound level in low ground level wind speeds. An assessment of the spectral shape of background sound in different wind conditions was also examined. It was found that high wind speeds (both ground level and hub-height) increase the background sound level so much that the turbine sound level can be overshadowed at almost all frequencies, particularly when the sound level of the wind turbines is low (around 40 dBA).

High wind shear conditions and locations having large amounts of open area on all sides of the measurement location are ideal for an accurate determination of wind turbine sound level. These conditions may not always be achievable at some facilities, and in these situations it would be more appropriate to conduct far-field testing at locations closer to the wind facility in order to maximize the signal-to-noise level between wind turbines and background sound. Although, it is acknowledged that some regulators require compliance testing be done at the residence, and so this is not always possible.

These findings are important in the consideration of the practicality and cost of conducting post-construction audits in locations having high ambient sound level. At many locations, an accurate determination of turbine-only sound level at a nearby receptor will be hampered by the presence of background noise. The most appropriate solution in these cases would be to measure at a position closer to the wind facility in an area likely to generate low ambient sound levels.

References

[1] Ministry of the Environment and Climate Change, “Compliance Protocol for Wind Turbine Noise,” Government of Ontario, Toronto, 2017.

[2] Ministry of the Environment, “NPC-232-Sound Level Limits for Stationary Sources in Class 3 Areas (Rural),” Government of Ontario, Toronto, 1995.

[3] IEC TC88, “61400-11 Wind turbines - Part 11: Acoustic noise measurement techniques,” International Electrotechnical Commission, Geneva, 2012.