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METHODS OF IDENTIFYING EXTRANEOUS NOISE DURING UNATTENDED NOISE MEASUREMENTS

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Noise assessments for proposed wind farm developments can often involve medium-term unattended background noise monitoring for periods of two to six weeks. Conventional monitoring procedures involve recording background noise levels (L_{A90}, L_{A95}) at 10 minutes intervals to collect upwards of 1440 data points. This noise data is typically filtered to remove periods which are likely affected by rain and/or high wind speeds at the microphone and thereafter correlated with synchronised wind speeds measured at the wind farm site and a regression curve is derived which estimates variations in background noise level due to changes in wind speed. While this process includes some filtering for rain and high wind speeds, the analysis can be prone to influence from extraneous noise sources which may not be representative of the underlying ambient noise environment. Examples of extraneous noise include seasonal insect noise and atypical intensive operation of seasonal farming equipment. Recent advances in noise monitoring equipment provide methods to better identify periods of extraneous noise. Several such methods are discussed in this paper including capture of 1/3 octave band noise data for frequency based filtering and collection of periodic audio samples which can allow for particular noise sources to be better identified through listening assessment. These methods can be particularly useful for wind farm noise assessments but also have wider application to general unattended noise measurement surveys.

1. Introduction

Guidelines and standards relevant to the assessment of noise from wind farms can often detail noise limits and post-construction commissioning requirements which include a dependence on background noise levels (L_{A90}, L_{A95}) at relevant assessment positions around a wind farm. Examples of such documents include ETSU-R-97[1] and its associated Institute of Acoustics Draft Good Practice Guide[2i], NZS 6808:1998[3]; NZS 6808:2010[4]; the South Australia EPA Wind Farm Guide-

[i] The IOA document *Discussion document on "A good practice guide to the application of ETSU-R-97 for wind turbine noise assessment"* is dated July 2012. At the time of writing, the final version of this guidance document is due for release on 21 May 2013.

lines 2003[5] and 2009[6]; AS 4959:2010[7][ii], and; the New South Wales Draft Wind Farm Guidelines 2011[8] (Guidance Documents). This dependence on background noise levels demands an ability to collect noise level data that is sufficiently representative of the underlying ambient noise environment, including how background noise levels may vary with wind speed. To this end, the Guidance Documents generally require medium-term unattended background noise monitoring for periods of two to six weeks. The collected noise data is typically filtered to remove periods which are likely affected by rain and/or high wind speeds at the microphone. The data is then correlated with synchronised wind speeds measured at the wind farm site and a regression curve is derived to estimate variations in background noise level with changes in wind speed. While this general process includes some filtering for rain and/or high wind speeds at the microphone, it can be prone to influence from extraneous noise sources meaning the collected data may or may not be representative of the underlying ambient noise environment. Recent advances in noise monitoring equipment provide more accessible methods for identifying some types of extraneous noise such as seasonal insect noise. A filtering process is proposed herein based on capture of one-third octave band noise level data and collection of periodic audio samples.

2. Wind farm assessment overview

2.1 Noise limits

A unique feature of noise limits applied to wind farms is that they can vary with wind speed, a situation which is summarised in Section 4.1 of AS4959:2010 as follows:

> *In order to determine the acceptability of predicted wind farm noise levels at relevant receivers, it is necessary to consider the unique noise characteristics of both the wind farm and the noise environment of the area around the actual or proposed wind farm. Wind farms are often proposed for areas with rural characteristics where background noise levels are likely to be low, particularly at wind speeds around the cut-in wind speed of a typical WTG when it begins to generate both electricity and noise.*
>
> […] *As a noise source, it is a unique characteristic of a WTG or wind farm that the noise level from each WTG will increase with increasing wind speed and that the background noise within the ambient noise environment at receivers will generally also increase under these conditions (due to wind influenced noise from vegetation, foliage etc.). It is therefore possible that the minimum noise level limit set by a Relevant Regulatory Authority may be exceeded by the background noise itself before it is exceeded by noise from a WTG or wind farm.*
>
> *In recognition of this characteristic, it is therefore recommended that the Relevant Regulatory Authority allow the minimum noise level limit to be exceeded, provided the wind farm noise level does not exceed the background noise level by a specified amount.*

AS4959:2010 goes on to nominate a generic structure for noise limits which takes account of variations in background noise level with wind speed:

> *At each nominal wind speed, the noise limit should be the higher of—*
>
> *(a) minimum noise level limit; or*
>
> *(b) background noise levels plus the specified amount.*

The other Guidance Documents noted above provide a similar form of noise limits, typically with a minimum noise level limit in the range 35-45 dB and, for Component (b) of the limits, a 5 dB margin above background noise levels.

[ii] AS 4959:2010 is not widely used for wind farm noise assessment in Australia as it does not prescribe noise limits. Notwithstanding this, AS4959:2010 includes a number of useful comments regarding wind farm noise assessment and is therefore referenced and quoted in this paper.

The approach to quantifying changes in background noise level with wind speed as required by Component (b) of these noise limits is concisely summarised by Item 19 of the Executive Summary for ETSU-R-97:

> *The variation in background noise level with wind speed will be determined by correlating* [background] $L_{A90, 10min}$ *noise measurements taken over a period of time with the average wind speeds measured over the same 10-minute periods and then fitting a curve to these data.*

An example of such a regression curve is shown in Fig 1 below, using measured pre-construction background noise level data from a proposed wind farm site in Australasia. The blue line shows the background noise level ($L_{A90,10min}$) versus wind speed regression curve. The black curve shows the resulting noise limit, with a minimum noise level limit of 40 dB and a 5 dB margin for the component of the noise limits which depends on background noise levels.

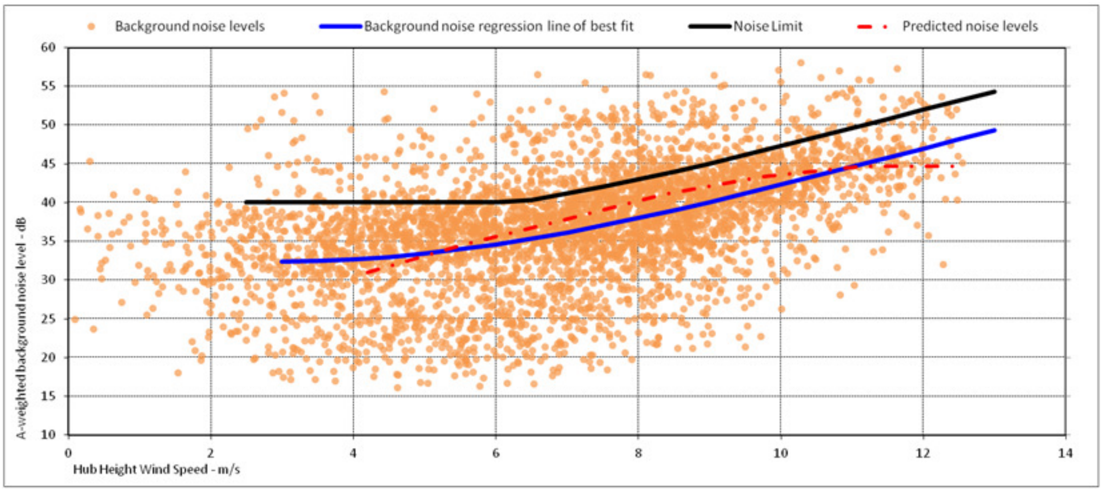

Figure 1. Example noise limits for a wind farm noise assessment

2.2 Compliance assessment

During the planning phase of a wind farm, compliance can typically be assessed by comparing wind speed dependent noise limits with predicted wind farm noise levels. An example of such a compliance assessment is demonstrated in Fig 1 where predicted wind farm noise levels, shown by the red dashed curve, are compared with noise limits, shown by the black curve, across a range a relevant wind speeds. The wind speed profile for the predicted wind farm noise levels in Fig 1 is typical of those encountered using modern, pitch-controlled wind turbines whose sound emission tends to increase with increasing wind speed until a peak around the wind speed of rated power (typically above 8 m/s at hub height) with sound emission decreasing moderately at wind speeds above rated power. As in this example, the point of transition or “knee” between the minimum noise level component of the noise limits and the background noise component of the limits can often be significant to the assessment of a wind farms noise emission as the wind speed where predicted wind farm noise is closest to the noise limit. To put this another way, a critical feature of this form of noise limits is the onset of the background dependent component of the limits.

2.3 Assessment sensitivity

A wind farm case study by Delaire & Walsh[9] found that pre-construction background noise level data collected over different months and/or years at a given assessment position can in some cases produce differences in regression curves of several decibels. These differences have been attributed to variations in wind speed distribution across measurement periods rather than, for example, any clear seasonal, wind direction or other effects. While variations in background noise level of this magnitude, say 1-3 dB, would in many cases be expected to correspond to a negligible or just noticeable subjective change in sound level, they could have a much more significant impact on a wind farm's layout and design[10]. Due to the relatively large number of sources that can influence the total predicted wind farm noise level, as well as the typical separating distances between turbine locations and surrounding assessment positions, significant wind farm layout modifications may only give rise to fractional changes in predicted noise levels. This apparent disparity between the magnitude of variations in background noise level regression analysis and the sensitivity of changes in wind farm layout is of relevance in the pursuant sections, where it is shown that filtering extraneous noise can in some cases change a background noise level regression curve by several decibels. While filtering extraneous noise can be considered an improvement to existing analysis methods, it will not necessarily reduce the potential inherent variability in background noise monitoring results as, for example, encountered by Delaire & Walsh.

2.4 Measuring background noise levels

Conventional monitoring procedures, as are detailed in the above referenced Guidance Documents, involve collecting broadband background noise levels (L_{A90}, L_{A95}) with appropriate equipment at 10 minutes intervals to collect upwards of 1440 data points. For example, Section 3.1 of the SA Guidelines 2009 includes the following comments:

> *Background noise levels should be collected for continuous 10-minute intervals using sound level meters or loggers of at least Class 2 certification in accordance with Standard AS IEC−61672. The lower limit of the instrument measurement range must be chosen to provide accurate measurements which might be limited by the noise floor of the data acquisition device.*

Monitoring methods include requirements to filter the data set for periods affected by either rain or wind induced noise over the microphone. Section 6.3.1 of AS4959:2010 states that data points "*…should not be included in analysis that may be adversely influenced by microphone wind effects* […] *or rain periods.* Similarly, Section 7.2.4 of 6808:2010 notes that *"extraneous sound levels caused by events, including precipitation, insects, fauna, and so on, should, as far as is practical for an unattended monitoring exercise, be identified and removed from the data set."* Comment C7.2.4 goes on to note that methods "*…for identifying extraneous sound events include octave-band spectrum measurements and asking residents to keep an activity log during measurements."* As this comment suggests, measuring sound level spectra such as octave and one-third octave bands can assist with identifying time periods that are affected by certain types of extraneous noise that can be characterised by discrete frequency content. Examples include noise from insects, birds and frogs as well as some types of mechanical equipment, all of which could be difficult to conclusively identify from broadband A-weighted noise levels alone.

3. Supplementary analysis methods

3.1 One-third octave band noise monitoring

Unattended logging of one-third octave band noise levels is now readily available across a range of sound level metres, including the 01dB DUO which is used by MDA.

The 01dB DUO is a low noise floor Class 1 noise monitor with the ability to measure one-third octave band noise levels down to 6.3Hz together with recording audio samples at set intervals. Measured 1 s one-third octave band noise levels are post-processed using the 01dB dBTrait analysis software to determine statistical indices across the frequency range.

The 01dB DUO can integrate Vaisala weather stations and includes a built-in 3G modem, GPS receiver and weatherproof microphone. The unit can be used for medium to long term noise monitoring when powered by a solar panel.

3.2 Review of one-third octave band data

Fig 2 below presents a waterfall plot and time history plot one-third octave band noise logging ($L_{A90,10min}$) over a 24 hour period along with an example one-third octave band spectrum for a 10 minute time interval. The observable periods of high noise levels at frequencies around 10 kHz suggest that results are potentially influenced by extraneous noise. In the time history plot (lower right) broadband $L_{A90,10min}$ levels are shown by the blue line while the $L_{A90,10min}$ levels at 10 kHz are shown by the yellow curve. It can be seen that, during certain periods of the day, the background noise levels in the 10 kHz one-third octave band converge towards the broadband $L_{A90,10min}$ levels. This pattern is consistent with noise from insects which can vary with time of day and can be dominated by high frequency content. A listening study of audio samples collected during this monitoring campaign confirmed insects as the source of the observed extraneous noise.

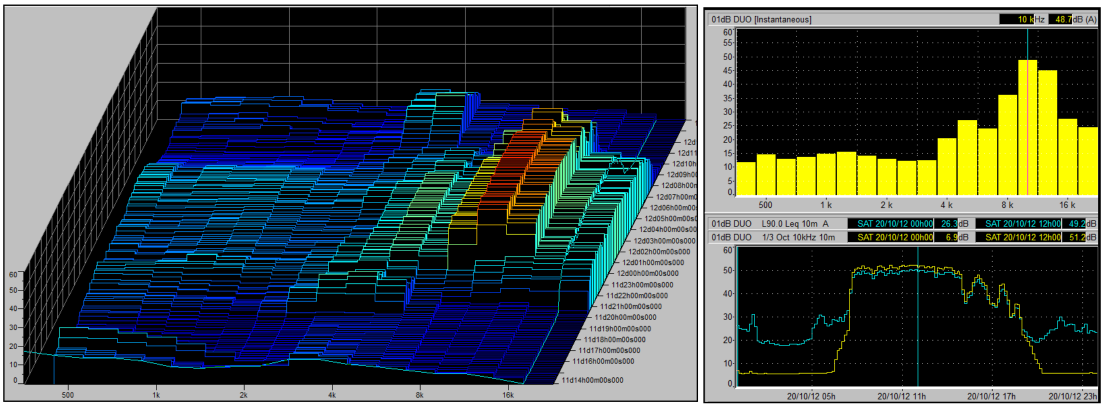

Figure 2. Example plots of one-third octave band monitoring results (01dB dBFA & dBTrait screen shots)

3.3 Analysis approach

From the examples of one-third octave band monitoring results above, a number of different methods for identifying potential extraneous noise begin to present themselves such as comparison of broadband and one-third octave band A-weighted levels and time-of-day filtering. It is considered that suitable filtering methods would require at least a degree of semi-automation, for example as could be carried out in a spreadsheet, in order to efficiently handle the comparatively sizeable amounts of data captured during medium-term one-third octave band monitoring. Terlich[11] proposes an analysis method which identifies time periods with one-third octave bands noise levels that are potentially affected by extraneous noise and, it's understood, corrects the broadband A-weighted background noise levels during the identified time periods by removing the affected one-third octave bands. Terlich does not detail how potentially affected time periods are identified: it is assumed that this is done by visual inspection of the data. While such a method is not likely to cause issue for measurements with a duration of a few days, it could prove cumbersome for longer surveys. It is also not clear how the broadband A-weighted levels are corrected for removal of the identified one-third octave band noise levels, in particular for statistical levels such as the L_{A90} where the one-third octave band levels need not sum to equal the broadband level. It is expected that this filtering method would lead to underestimating background noise levels during identified periods which could in turn result in a compromised data set. An alternative filtering method is proposed below.

3.4 Proposed filtering method

Periods are identified as being potentially influenced by extraneous noise where both of the following conditions are satisfied.

- **Condition (a)** the maximum one-third octave band A-weighted background noise level (L_{90}, L_{95}) for a given time interval is within 5 dB of the broadband A-weighted background noise level for that interval.
- **Condition (b)** the identified one-third octave band A-weighted background noise level (L_{90}, L_{95}) is greater than a nominal minimum level, for example, 20 dB.

In other words, where a particular one-third octave band level dominates the broadband A-weighted noise level for a given time interval, and the one-third octave band level is sufficiently high, the associated time period can be marked as potentially affected by extraneous noise. This process can be repeated for all time intervals to identify a set of potentially affected periods. If audio data is also collected during the monitoring survey, either continuously or at regular intervals such as the first minute of each 10 minute time interval, then a listening study of relevant samples of audio can then be carried out to better identify the source(s) of potential extraneous noise. If extraneous sources are positively identified, it is proposed that the affected time period(s) be removed from the data set rather than attempt a correction of the measured levels for that period. Additionally, a sensitivity analysis can be carried out to review the influence of the extraneous noise sources on the larger data. This filtering process has been developed pragmatically, through trial and error using data sets collected in the field. The 5 dB criteria nominated in Condition (a) is intended to identify only those periods where particular one-third octave band levels significantly influence the broadband A-weighted levels for that period. The 20 dB level threshold in Condition (b) is intended to prevent identifying periods which show a frequency peak according to Condition (a) but which occur at low sound levels. Examples of data processed using the proposed filtering method are shown in the case studies which follow.

4. Case study

Fig 3 shows an example of results of a pre-construction background noise level ($L_{A90,10min}$) monitoring campaign for a proposed wind farm site. The blue and orange points in Fig 3 show the entirety of the data set. A third order regression curve determined for this data set is shown by the solid blue curve with associated noise limits shown by the solid black curve. The blue dots represent data that has been identified from the proposed filtering method as being influenced by extraneous noise in the 10 kHz one-third octave band. A listening study confirmed that the identified periods are affected by insect noise. The orange dots in Fig 3 represent the data set after filtering for insect noise and the resulting regression curve and associated noise limits are shown by the blue and black dashed lines, respectively.

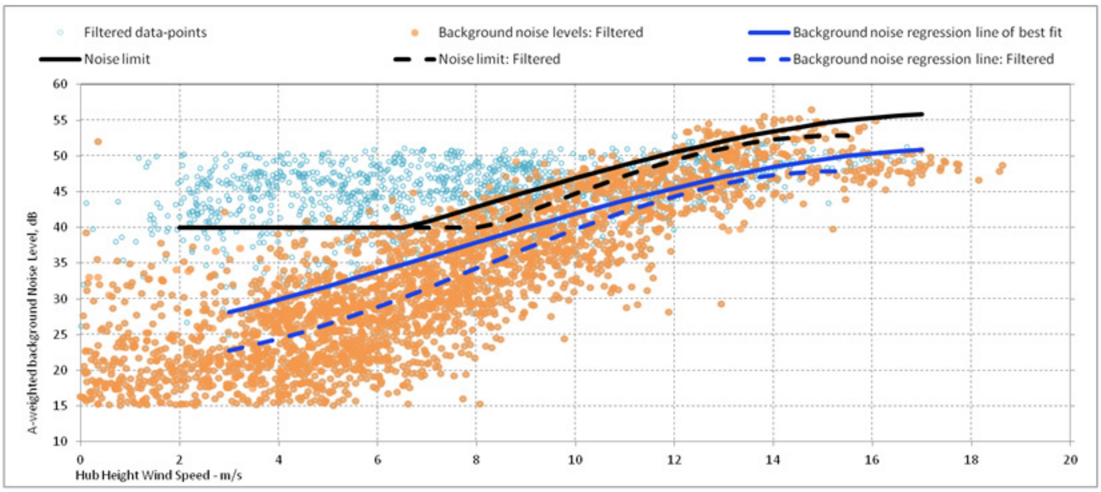

Figure 3: Data filtering outcomes, Example A

It can be seen that the filtered noise limit is equal to or lower than the unfiltered noise limit at all assessed wind speeds. In particular, the knee of the unfiltered noise limit is at 6.5m/s compared to 8m/s for the filtered data set: a difference that could have a significant impact on the layout design of the wind farm. For the data set in Fig 4 below, insect noise has again been identified through the filtering process as an extraneous noise source. The filtered data set is shown by the orange dots. In this example, removing the identified data from the regression analysis has a limited influence on the resulting noise limits.

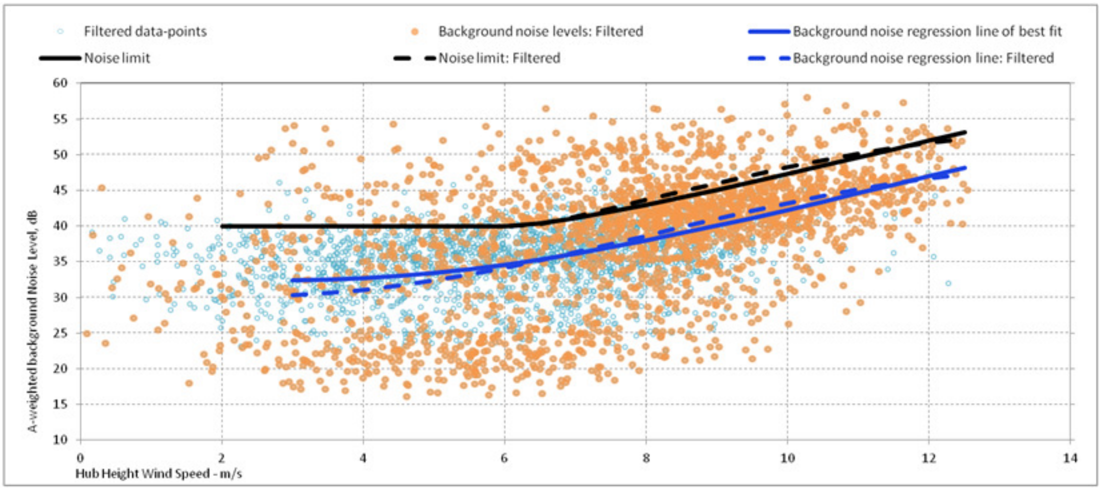

Figure 4: Data filtering outcomes, Example B

Fig 5 shows the results of applying the proposed filtering method to a night-time data set[iii] and again periods shown by blue dots have been identified as being influenced by insect noise. As per the first example, the knee of the filtered noise limit is at a higher wind speed than occurs for the unfiltered data. At wind speeds above the knees the filtered noise limit rises steeply and is at a higher level than the unfiltered noise limit, likely due to the sparseness of data at the extremes of the wind speed range. As noted above, Guidance Documents typically recommend removing any identified periods affected by extraneous noise which, in turn, suggests that the filtered data set should be used to establish noise limits in most cases. However, this example demonstrates that the proposed filtering method should be used with a degree of discretion, ideally with a supporting sensitivity analysis, to confirm that filtering results are appropriate.

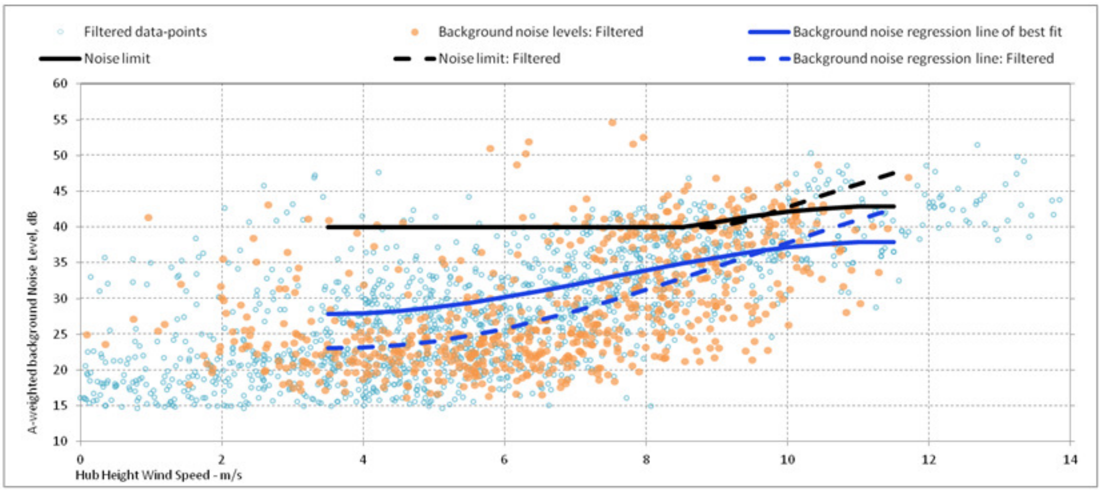

Figure 5: Data filtering outcomes, Example C

[iii] Separation of night-time data (2200-0700hrs) is required in accordance with some of the Guidance Documents

5. Conclusion

An improved ability to identify and remove periods of extraneous noise from unattended noise monitoring results can improve the quality and reliability of collected data and may also reduce the need for re-monitoring caused by corrupted or unusable data. A one-third octave band filtering process has been proposed to identify periods of extraneous noise that can unduly influence results of unattended background noise level measurements. The process is primarily intended to identify noise from seasonal sources such as insect and frog noise but is also likely to be applicable to some types of mechanical noise. In relation to wind farm noise assessments, the filtering process can lead to changes in regression curves as demonstrated by several example data sets. In turn, the filtering process can change noise limits, including the noise limit knee which can be a significant factor influencing the layout and design of a wind farm. While the data sets considered here have related to pre-construction background noise monitoring, the filtering methods could equally be applied to unattended monitoring of post-construction noise levels for compliance or commissioning measurements once the wind farm is built and operational. Similarly, the filtering methods are likely to be useful for unattended background noise level monitoring for general environmental noise assessments for developments other than wind farms.

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