Report on Harmonic Prominence Analysis at Ferter, Girvan, Scotland

April 2021

International Acoustics Research Organization

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A. BACKGROUND

Ferter is one of a number of residences near Barrhill, Scotland situated near several of Industrial Wind Turbine (IWT) power stations, the closest of which are Arecleoch, Kilgallioch and Mark Hill. The residents wish to study the noise characteristics from the IWTs in these wind power stations to investigate and test the correlation of these noise characteristics to health impacts.

Disclaimer

a. The authors of this review are not party to anti-technology sentiments.

b. Wind turbines are considered by the authors as welcome additions to modern technological societies.

c. The review provided herein has one, and only one, agenda - that of pure scientific inquiry.

d. In no way can or should this scientific review be construed as a document arguing for or against the implementation of wind turbines, or any other industrial complexes.

e. There are no commercial, financial or professional agreements (contractual or otherwise) between the authors of this Review and any persons or parties involved in the wind turbine sector or persons or parties who stand against the implementation of wind turbines.

f. This Report was provided *pro bono*.

Goal

To investigate the infrasound and low frequency noise at the Ferter residence, with particular regard to noise immission from neighbouring wind power stations, and test their correlation with health symptoms.

Ethics Approval

This research was performed as part of the Citizen Science Initiative for Acoustic Characterization of Human Environments (CSI-ACHE), the research protocols for which have been approved by the New Zealand Ethics Committee (application number NZEC19_12).

B. DATA GATHERING

1. Recordings were taken at the Ferter residence between March 13th and March 18th, 2021, by residents using an SRA System from Smart Technologies, Palmerston North, New Zealand.

Figure 1: Ferter house and surroundings.

2. The microphones were placed in the upstairs Snooker Room at the south end (Blue channel, see Figure 2) and the north end (Red channel, see Figure 3) on stands.

Figure 2: Snooker room facing south (left) and north (right), showing blue microphone position. (Red microphone position in the distance, at right.)

Figure 3: Snooker room facing north, showing red microphone position.

3. The Snooker room is 8.7 m east-west and 8.3 m north-south.

4. The blue microphone was placed near the south-facing window, 1.13 m from the window and 2.86 m from the west wall.

5. The red microphone was placed 1.20 m from the north-facing window and 1.20 m from the east wall.

6. Weather information was downloaded from the MetroBlue site for the Barrhill weather station, with data in one-hour intervals.

C. ANALYSES

1. Every 10-minute file in the recording interval (midnight, 14th March 2021 to midnight, 18th March 2021) was processed.

2. Standard frequency analysis was carried out using narrow-band filters of 1/36th octave adhering to both ANSI® S1.11-2004 and IEC 61260:1995 standards.

3. Sonograms were produced for each 10-minute interval as well as a harmonic analysis to identify harmonic series, and a harmonic prominence analysis (see Annex 1).

4. Prominence is the level of a peak above the background as shown in Figure 4.

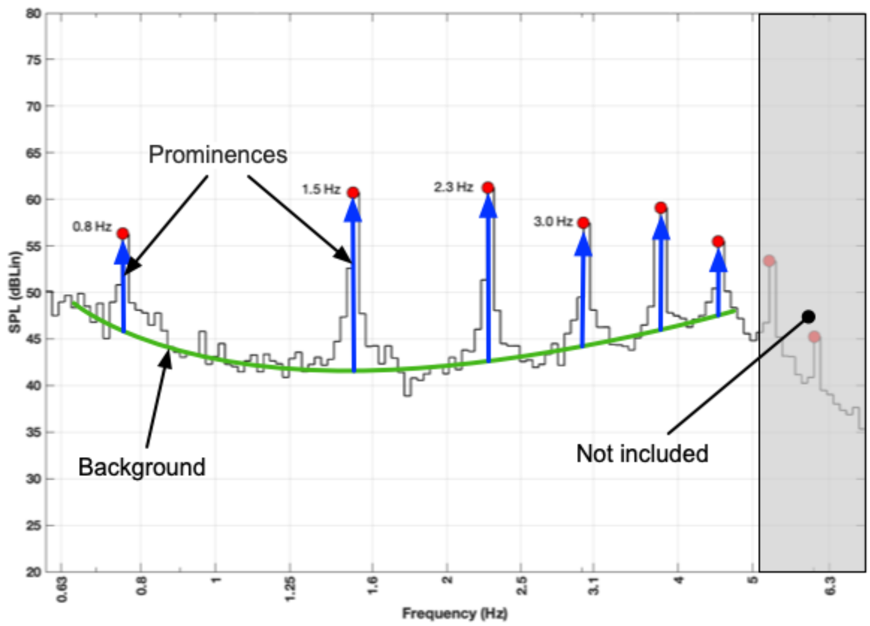

Figure 4: Prominence of a series of harmonic peaks (blue) above the background (green).

5. The harmonic and harmonic prominence analyses from the entire recording period were used to identify the most significant harmonic series, and its fundamental frequency. A further harmonic prominence analysis was then run on the entire recording period at this fundamental frequency.

6. The harmonic prominence analyses were combined to produce time-of-day plots indicating the levels of harmonic prominence for the identified fundamental frequency.

7. Harmonic prominence wind roses were created from the harmonic prominence analyses and weather data from the Barrhill weather station (55°05'18.2"N 4°47'02.0"W), which lies 9.16 km almost southwest of Ferter.

D. RESULTS AND DISCUSSION

Frequency Analysis

1. Figures 4 and 5 show representative results for each of the two channels. In this case 'representative' means that the features shown were present in the large majority of the recordings, both more and less pronounced. Other features were present in some of the recordings.

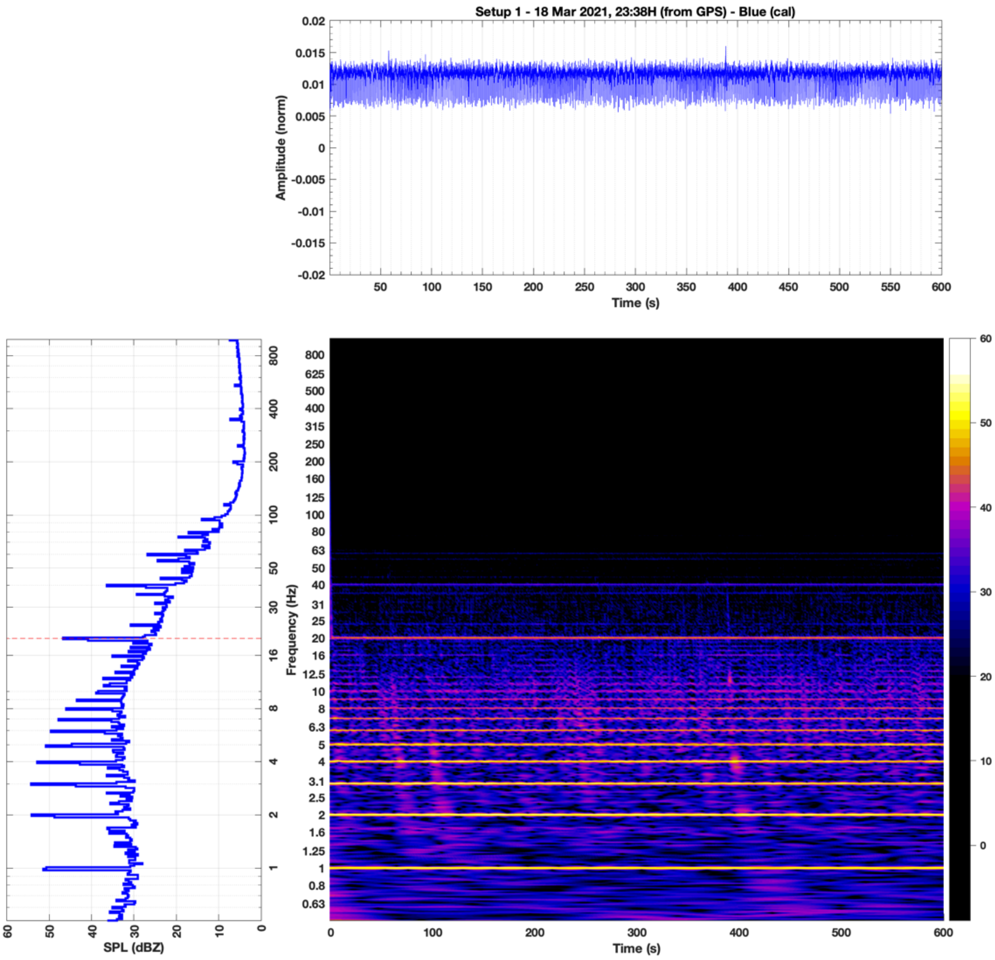

Figure 5: Representative sonogram (bottom right), periodogram (bottom left) and time signal (top) for the Blue channel of the recording.

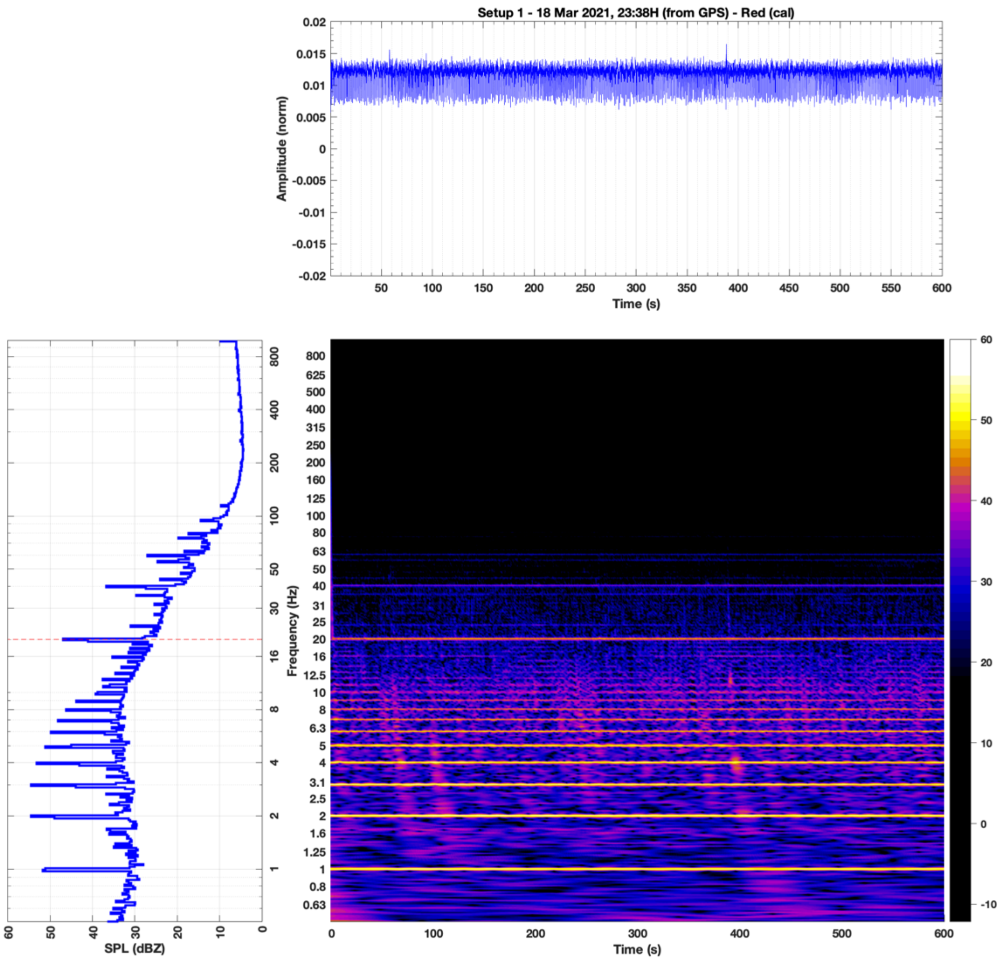

Figure 6: Representative sonogram (bottom right), periodogram (bottom left) and time signal (top) for the Red channel of the recording.

2. Both are dominated by a harmonic series in the infrasound region (below 20 Hz) of the spectrum (horizontal lines in the sonograms and peaks in the periodograms of Figures 5 and 6).

3. The level of the background noise in this region of the spectrum does not often exceed 35 dB.

4. The fundamental frequency of the harmonic series is 1 Hz as indicated in the following harmonic analysis (see figure 7).

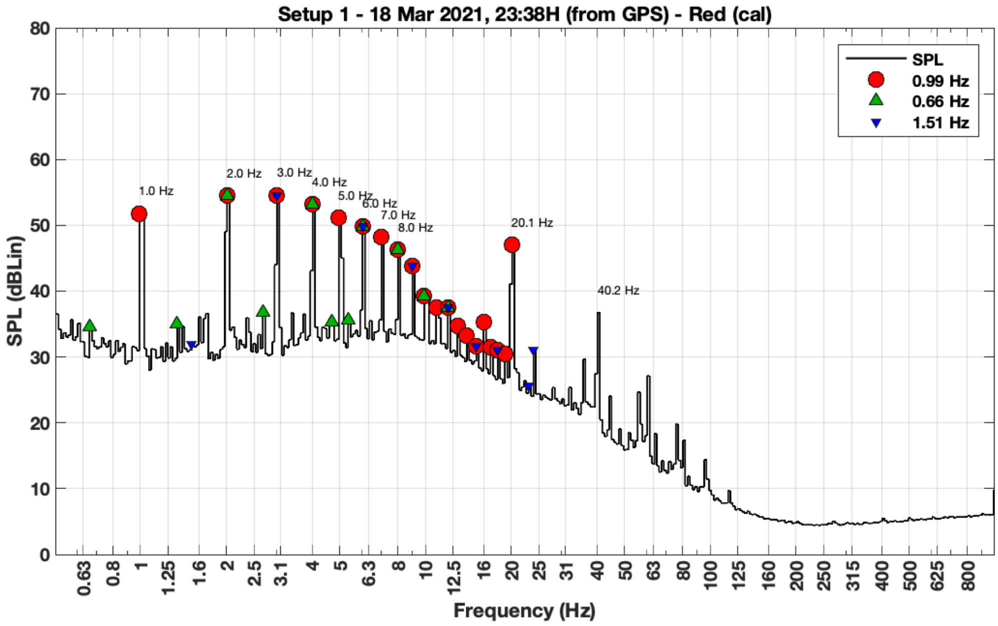

Figure 7: Harmonic analysis of the Red channel (Figure 6).

5. Such a harmonic series is indicative of Wind Turbine Acoustic Signature (WTAS).

6. The IWTs in two of the neighbouring wind power stations, Arecleoch and Mark Hill, are manufactured by Gamesa, models G80-2000 and G87-2000, respectively. These are asynchronous turbines with constant blade-pass frequencies of 1 Hz when running at operational speed.

7. This harmonic series is the WTAS of the turbines in one or both of Arecleoch and Mark Hill.

8. The Kilgallioch wind power station has Gamesa model G114-2500 IWTs, which are also asynchronous but with a blade-pass frequency of 0.75 Hz.

9. This 0.75-hertz series shares the harmonic frequency of 3 Hz with the 1-hertz series, which completely dominates the former series. A harmonic prominence analysis at this blade-pass frequency cannot, therefore, be made as the 1-hertz series is present for almost the entire recording period.

10. The tone at 20 Hz (horizontal line at 20 Hz in the sonograms and peak at 20 Hz in the periodograms of Figures 3 and 4) is of unknown origin but varies in level with the WTAS, which indicates that it is associated with it. It appears to be the fundamental frequency of another harmonic series with peaks at 20, 40, 60 and 80 Hz and may represent a resonant frequency of the wind turbines, such as flexing of the blades or from the mechanical power train.

11. Other tones appear in the audible range of between 20 and 125 Hz at regular intervals (see Figure 8). For instance, one series of tones at 16.0, 35.8, 55.7, 75.7 and

95.3 Hz, 1) have a common difference of 19.9 Hz, 2) are 4 Hz less than the 20-hertz harmonic series, to within the resolution of the filter bands. Similarly, another series of tones at 23.9, 44.2, 63.7 and 83.3 Hz are 3.9 Hz greater than the 20-hertz harmonic series within the resolution of the filter bands. Neither of these series are, however, harmonic series, as their lowest frequency is not the difference between each harmonic.

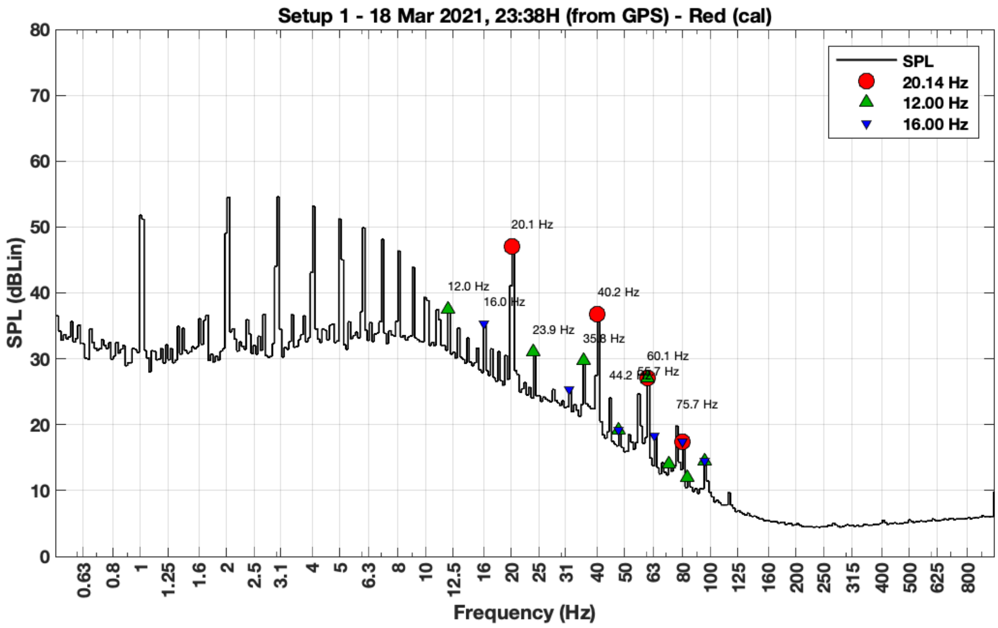

Figure 8: Harmonic analysis of the Red channel

12. In previous recordings at the site, underground-heating pumps produced peaks in the frequency spectrum. For these recordings the heat pumps were turned off between 17:30 and 18:30 on the 16th of March. Figure 9 shows that the features in the periodogram from 18:00 on the 16th of March match those at other times when the heat pumps were turned on. There are differences above 125 Hz where details appear when the pumps are off, which are not there when the pumps are on. Clearly, these are not, therefore, related to the pumps.

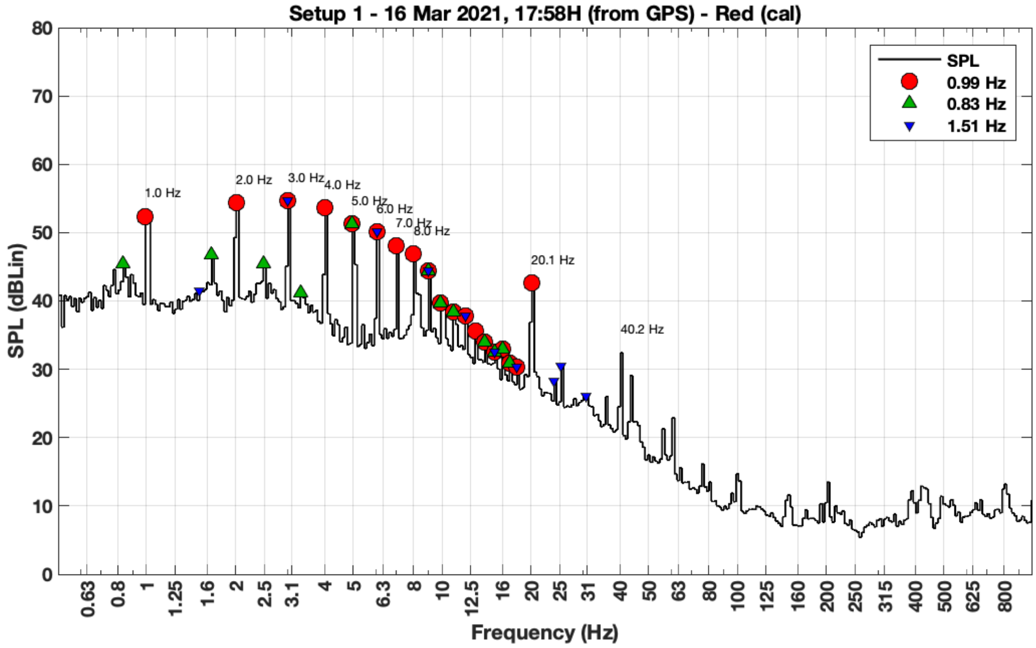

Figure 9: Periodogram of 18:00 on March 16th, 2021 when the heat pumps were turned off.

Time-series Analysis

1. The time-series signals for 10 seconds of both channels from Figure 5 and Figure 6 are show in Figure 10.

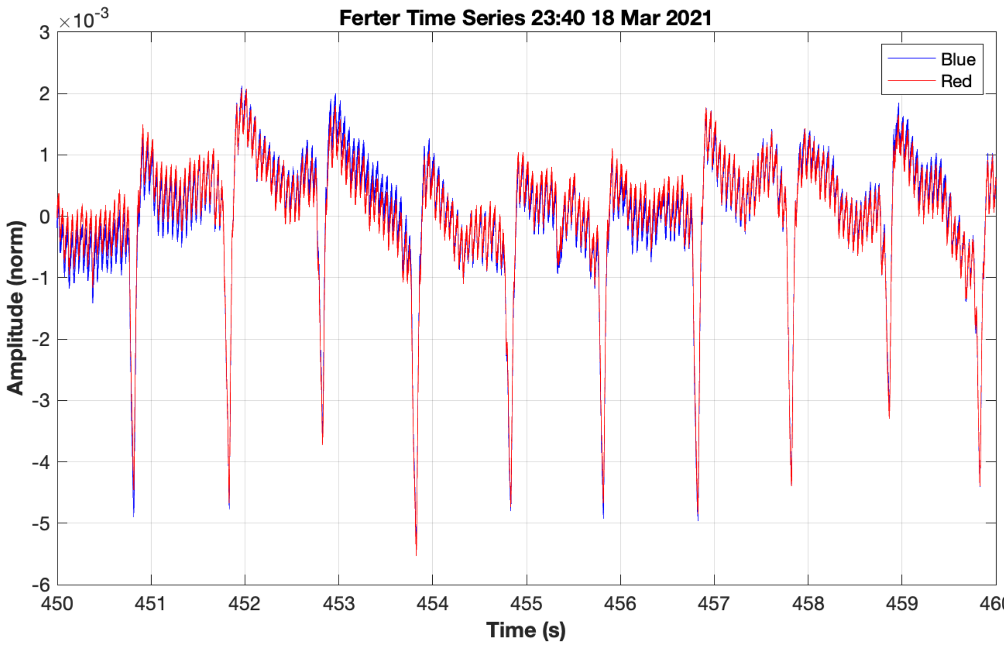

Figure 10: A 10-second section of the time-series signal from Figure 5 and Figure 6.

2. The large, negative-going pulses from the IWTs are clearly seen recurring every second, simultaneously in both recording locations.

3. Figure 11 shows the same 10 seconds of recording but converted into sound pressure level (SPL) in deciBels with an averaging time of 5 ms. Also shown in the same figure is the average sound level over the entire 10-minute recording ($SPL_{eq\ 10min}$) and the sound level of the largest harmonic peak of the WTAS (at 3 Hz).

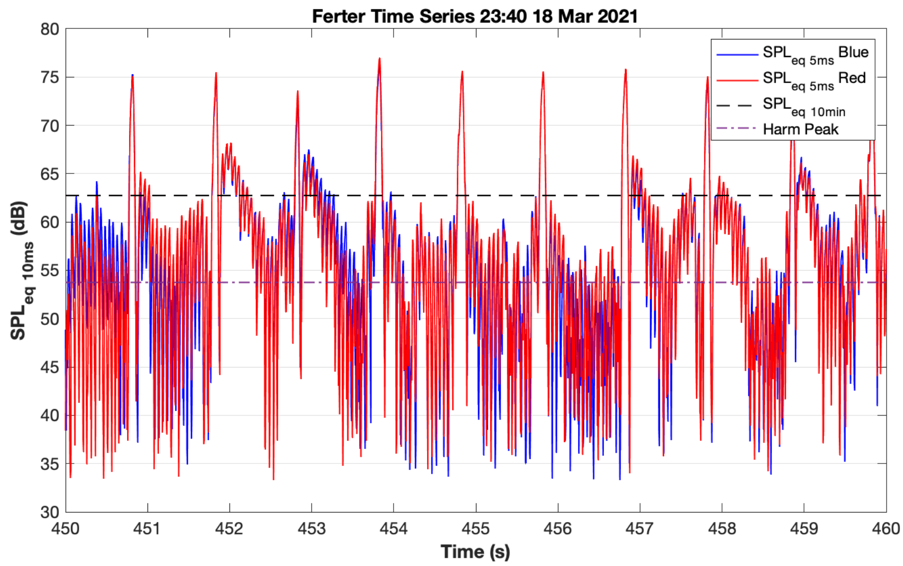

Figure 11: The $SPL_{eq\ 5ms}$ of the same 10 seconds shown in Figure 10.

4. The negative-going pulses of Figure 10 have changed to positive-going pulses (peaks) in Figure 11, since reducing the local pressure requires energy just as increasing the local pressure does.

5. While the traces from the two channels differ, due slight differences in ambient noise between both sides of the snooker room, the peaks are seen to be the same for both. This suggests that the source of the pulses is distant from the snooker room.

6. Note that the sound levels here are much higher than in the periodograms of Figures 5 through 9, as the levels here represent the total sound over all frequencies i.e., each pulse includes the energy from all of the harmonics. Thus, the periodograms show average sound levels of roughly 35–40 dB while the overall, zero-weighted sound levels ($SPL_{eq\ 10min}$) are close to 63 dB (dashed line in Figure 11).

7. The $SPL_{eq\ 5ms}$ is numerically almost identical to the instantaneous peak value converted into deciBels. Since this measure causes fewer issues computationally, and provides more clarity in graphs, it will be used instead of the instantaneous peak value.

8. The WTAS pulses occur at 1-second intervals and have a peak level of 75 dB or more. (Normal conversation is considered to be roughly 65 dB.)

9. The peaks are distinct throughout most of the recording(s) suggesting that the immissions come predominantly from one or two IWTs.

10. Averaging the sound levels over 10 minutes does not adequately represent impulsive sound, such as the WTAS seen here. For instance, a gun fired sometime during a 10-minute recording might not materially increase the 10-minute average sound level but would clearly be very significant.

Harmonic Prominence Analysis

1. A harmonic prominence analysis was used to identify if there was evidence of significant harmonic series within the recording periods. Figures 14 and 15 show the harmonic prominence for each 10-minute recording, plotted against its fundamental frequency (top) as well as the frequency histogram of the fundamental frequencies, i.e., number of 10-miinute recordings with a given fundamental frequency.

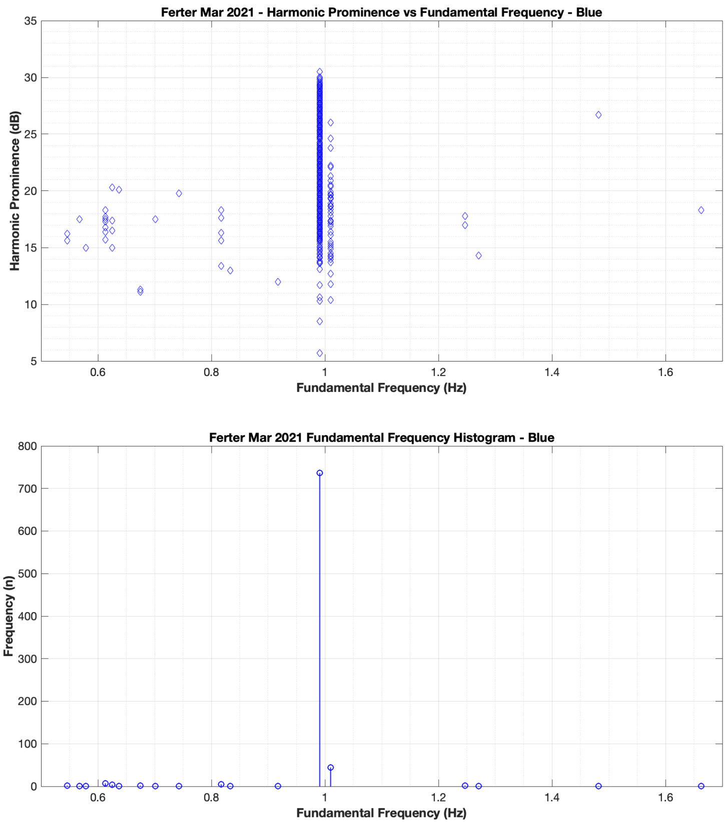

Figure 14: Harmonic prominence for each 10-minute recording period as a function of its fundamental frequency (top) and a frequency histogram of the fundamental frequencies of each 10-minute recording period (bottom).

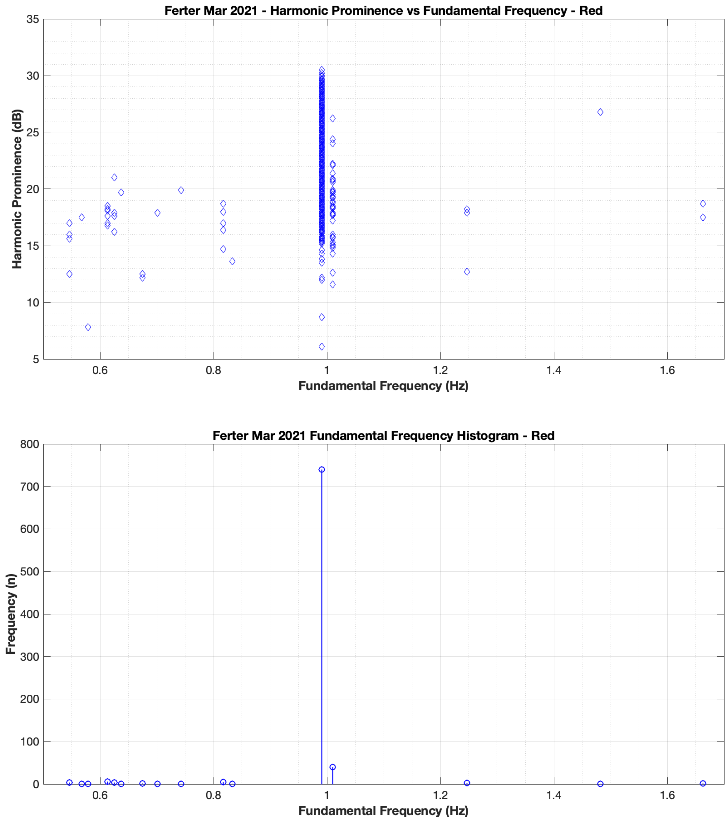

Figure 15: Harmonic prominence for each 10-minute recording period as a function of its fundamental frequency (top) and a frequency histogram of the fundamental frequencies of each 10-minute recording period (bottom).

2. Figures 14 and 15 indicate that virtually all of the recordings over this recording interval are dominated by a harmonic series with a 1-hertz fundamental frequency. The twin peaks, just above and below this frequency, indicate that there is a small amount of variation in the frequency over this time.

3. These results (as well as Figures 5 to 15) support carrying out a harmonic prominence analysis with a 1-hertz blade-pass frequency over the two recording intervals. This produced the following Time-of-day plots (see Figures 16 and 17). These show the harmonic prominence for each 10-minute recording as a horizontal bar, with the colour showing the severity of the harmonic prominence in deciBels. The vertical axis is the time of day and the horizontal axis is the day (date).

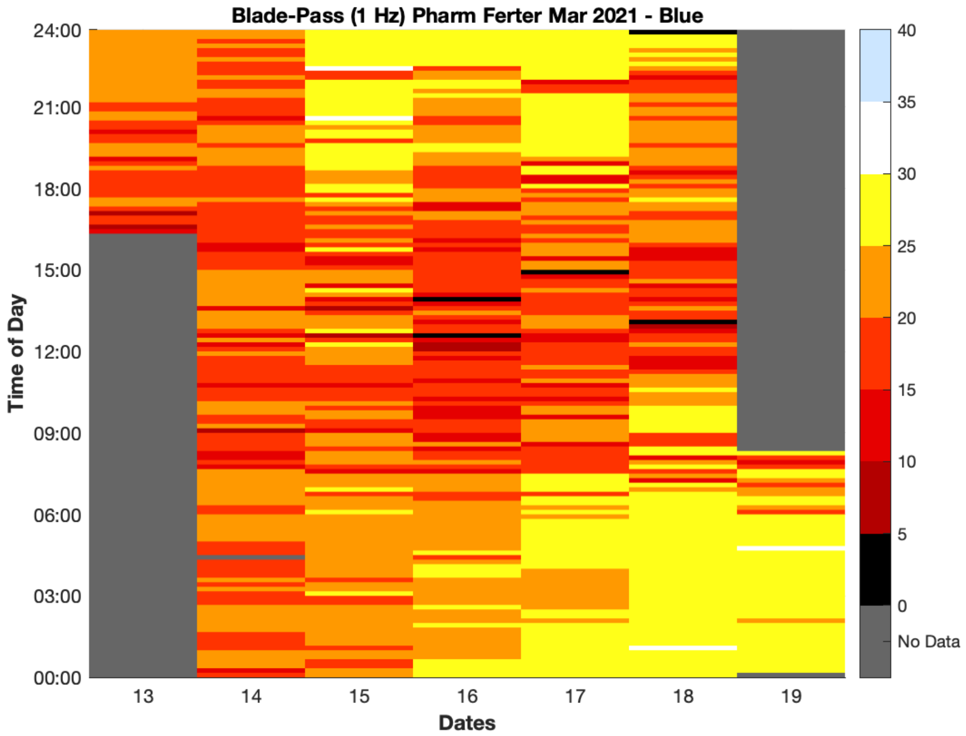

Figure 16: Blade-pass Harmonic Prominence Time-of-day for Blue channel from March 14th to March 18th, 2021. (Grey represents no measurement.)

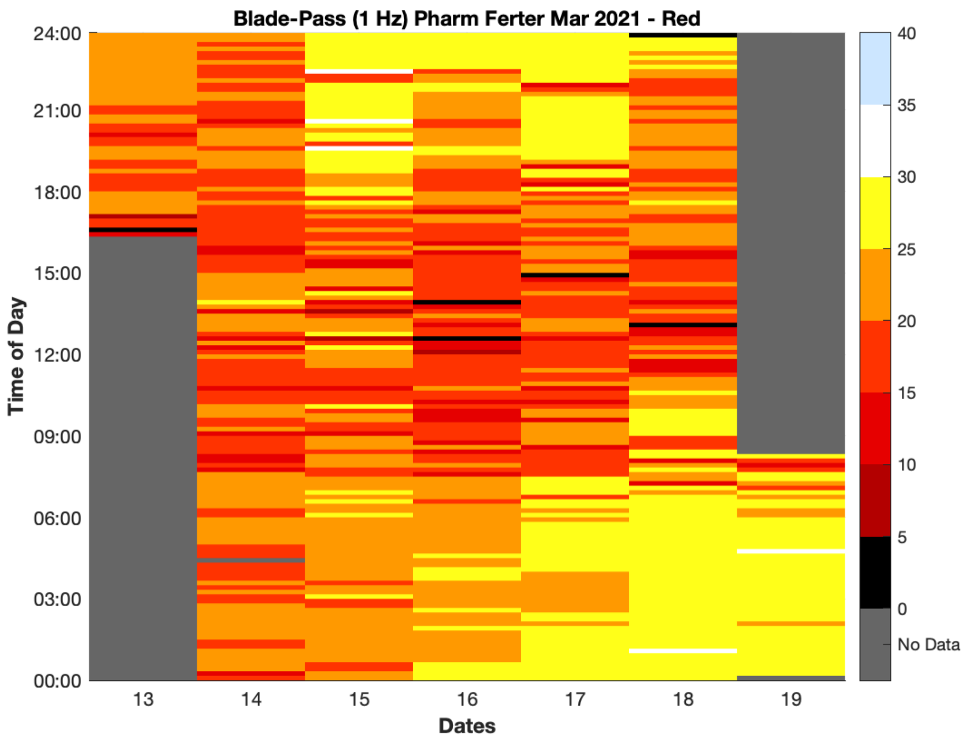

Figure 17: Blade-pass Harmonic Prominence Time-of-day for Blue channel from March 14th to March 18th, 2021. (Grey represents no measurement.)

4. Both of these plots show that the harmonic prominence levels ranged between 5 and 30 dB over most of the recording period, apart from four 10-minute intervals (black bands), which were less than 5 dB.

5. The authors of this report have never encountered levels as high and as sustained as these plots show.

6. The harmonic prominence analysis was combined with the weather data from the Barrhill weather station to generate the following four harmonic prominence wind roses (see Figures 18 and 19). The direction of each sector indicates the wind direction, the length represents the number of 10-minute samples and the colours represent the severity of the harmonic prominence in deciBels.

7. Barrhill weather station is roughly 9.2 km southwest of Ferter. Weather recorded there will be indicative of weather at, and between, the three surrounding wind power stations.

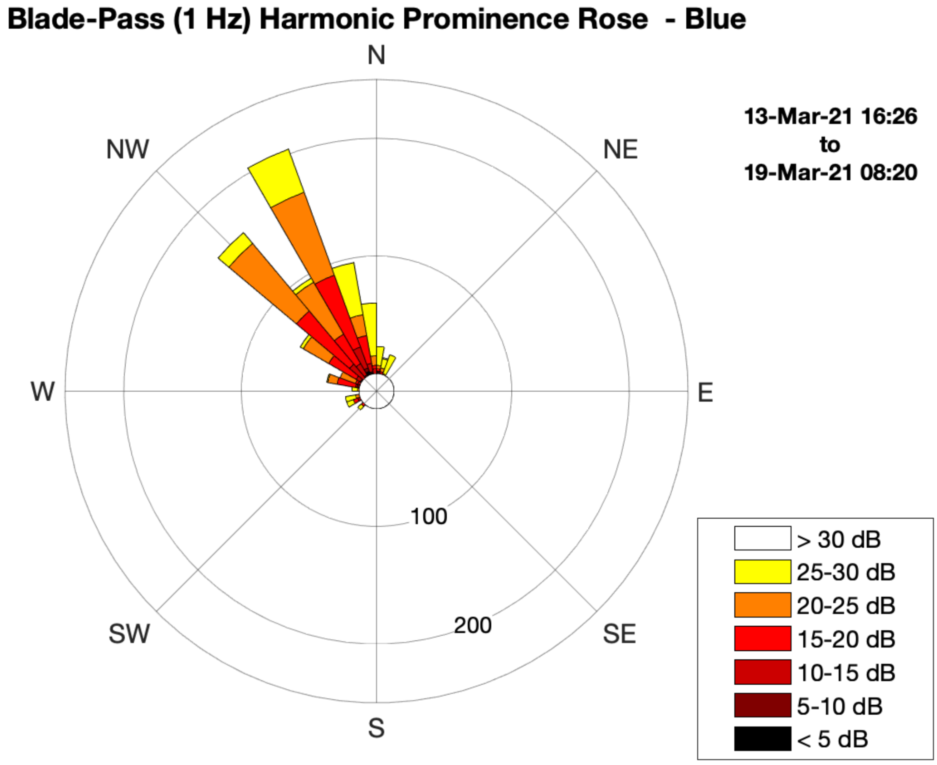

Figure 17: Harmonic Prominence Wind Rose for the Blue channel for March 13th to March 19th, 2021.

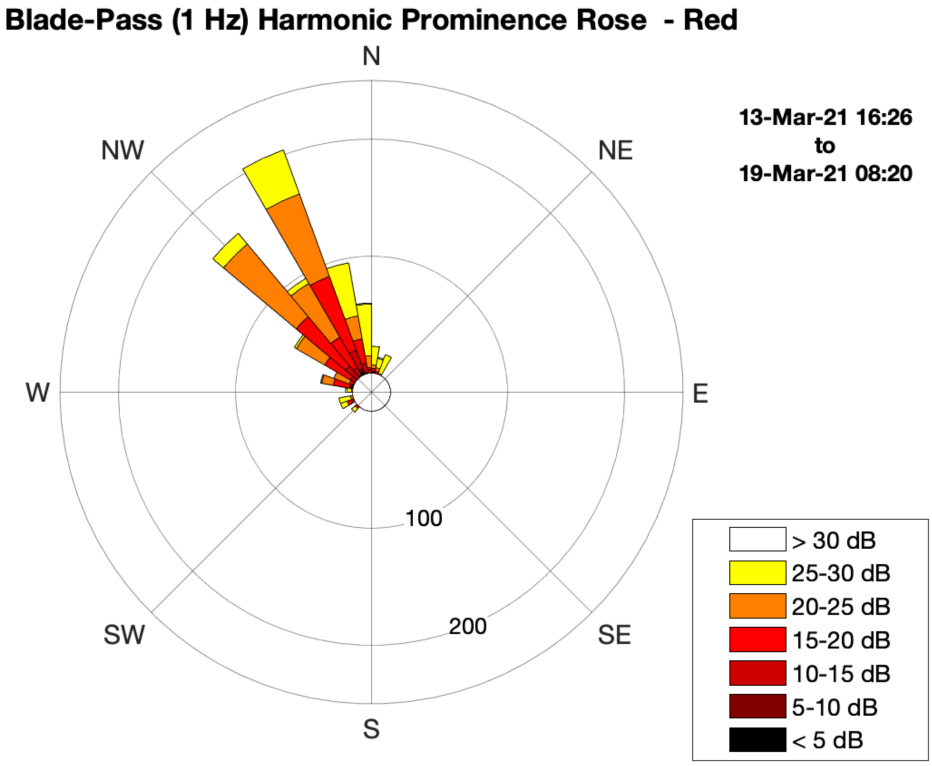

Figure 18: Harmonic Prominence Wind Rose for the Red channel for March 13th to March 19th, 2021.

8. The wind at the Barrhill station over the recording period is seen to come almost entirely from the north-northwest and northwest during the recording period.

9. The largest proportion of severe levels (yellow and white, 25–35 dB) of harmonic prominence occur when the wind comes from between the north and north-northwest. As the wind tends further west the proportion at this severity level drops away.

10. The Mark Hill wind power station is west-southwest of the Ferter residence (see Figure 19), while the Arecleoch wind power station is much further to the west. This suggests that neither of these two wind power stations are the source of the WTAS. The wind power stations to the north-northwest of Ferter are Hadyard Hill and Assel Valley. These are fitted with Siemens SWT-2.3-101 and Nordex N90 IWTs, respectively, which have a BPFs of approximately 0.80 Hz and 0.90 Hz, respectively, and so cannot be the source of this WTAS.

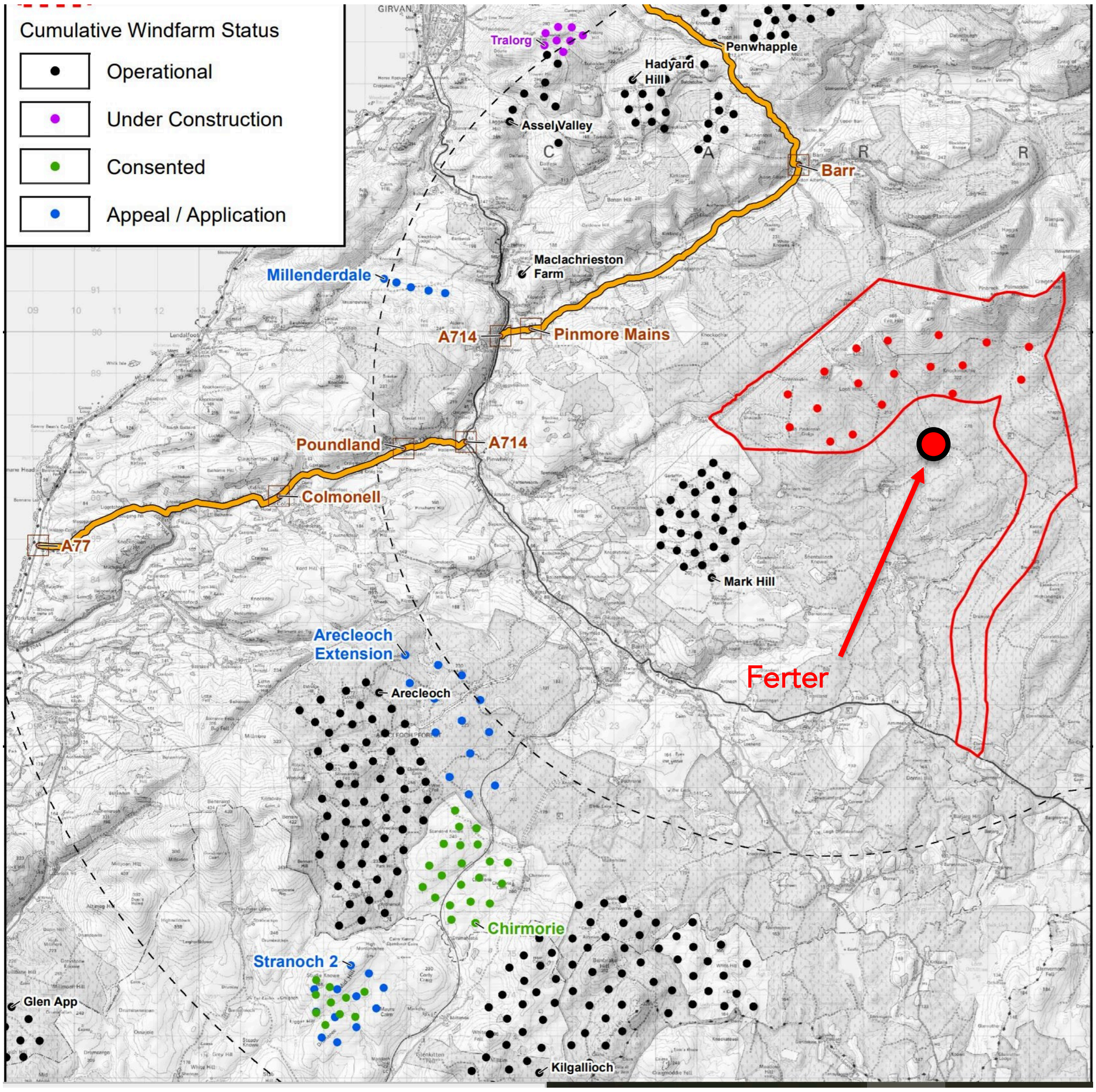

Figure 19: The Ferter residence and surrounding windfarms.

11. Ferter is sheltered from north-westerly winds, by the hills to the northeast and lies up a shallow valley that rises from southwest to northeast. It can be expected that north-westerly winds will bend towards the east as they pass the end of the hills north of Ferter, through the Mark Hill wind power station and into the sheltered valley in which Ferter lies. The valley will also act as a waveguide to infrasound, focusing this to some extent as the valley narrows.

E. CONCLUSIONS

1. The recordings taken over the interval from March13th to March 19th, 2021 were dominated by wind-turbine acoustic signature which is suspected to have come from the Mark Hill wind power station.

2. Harmonic prominences measured over this interval were consistently between 15 and 30 dB in both measurement sites. Levels consistently this high have never before been measured by the authors.

3. The majority of the mornings of March 18th and 19th had harmonic prominence levels over 25 dB.

4. The wind at Barrhill weather station, the closest measurement site to Ferter, was predominantly from the northwest and north-northwest.

5. Most of the severe harmonic prominence levels (> 25 dB) occurred while the wind was from the north-northwest and the north.