Report on Harmonic Prominence and Correlation Analyses at Shalloch Well, Girvan, Scotland

May 2021

International Acoustics Research Organization

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A. BACKGROUND

Shalloch Well is one of a number of residences close to Barrhill, Scotland situated near several 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 Shalloch Well residence, with particular regard to noise immission from neighbouring wind power stations.

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 Shalloch Well residence between March 20th and March 27th, 2021, by residents using an SRA System from Smart Technologies, Palmerston North, New Zealand.

Figure 1: Shalloch Well house and surroundings.

2. The microphones were placed in the upstairs in the main building in the East Bedroom (Red channel, see Figure 2) and the West Bedroom (Blue channel, see Figure 3) on stands.

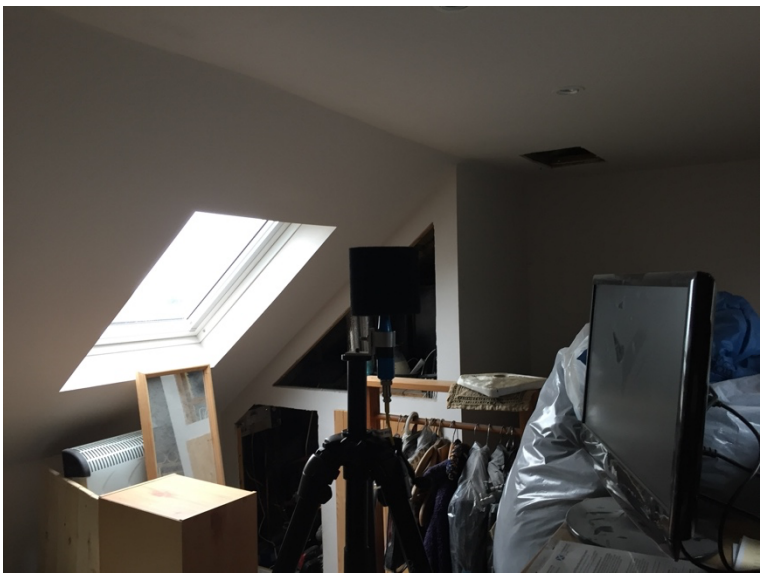

Figure 2: Blue microphone in the West Bedroom.

Figure 3: Red microphone in the East Bedroom.

3. The West Bedroom is 4.14 m east-west, and the East Bedroom is 4.26 m east-west. Both bedrooms are 2.10 m at the highest point and 3.50 m north-south.

4. The red microphone was placed 2.14 m from the east wall, 2.00 m from the hall door, 1.85 m from the south window (Velux), and 1.65 m from the north window (Velux).

5. The blue microphone was placed 2.60 m from the west wall, 1.66 m from the hall door, 1.90 m from the south window (Velux), and 1.52 m from the north window (Velux).

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 (16:20, 20th March 2021 to 18:40, 27th 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 local background as shown in Figure 4.

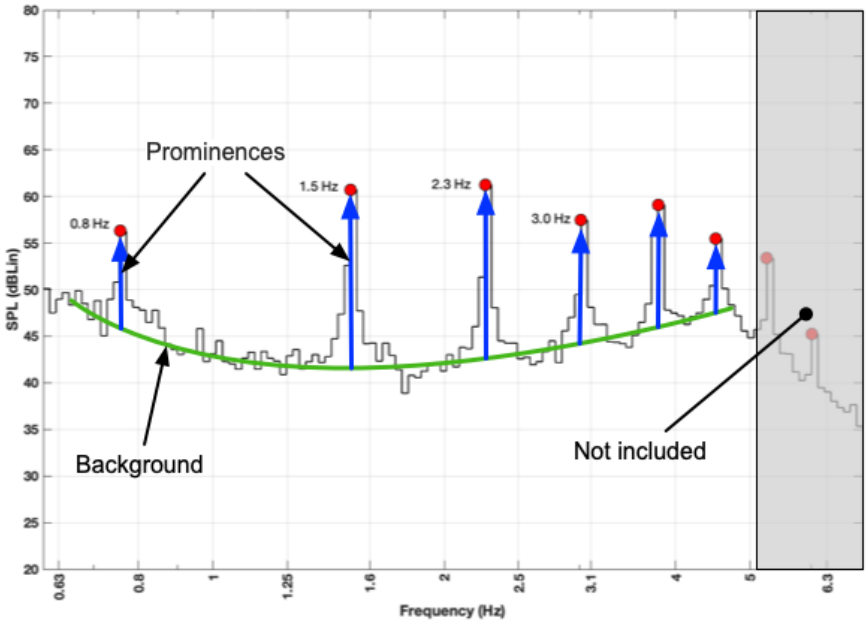

Figure 4: Prominence of a series of harmonic peaks (blue) above the local background (green).

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 sound pressure level (SPL) of the peak used for the harmonic prominence measure (i.e., the peak with the largest prominence) can be measured as a means of determining whether increases in harmonic prominence are driven by an increase in the SPL of the harmonic peaks (a stronger WTAS signal) or by a decrease in the local background noise (same WTAS signal strength).

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

8. Harmonic prominence wind roses and sound pressure level 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 5.69 km almost southwest of Shalloch Well.

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.

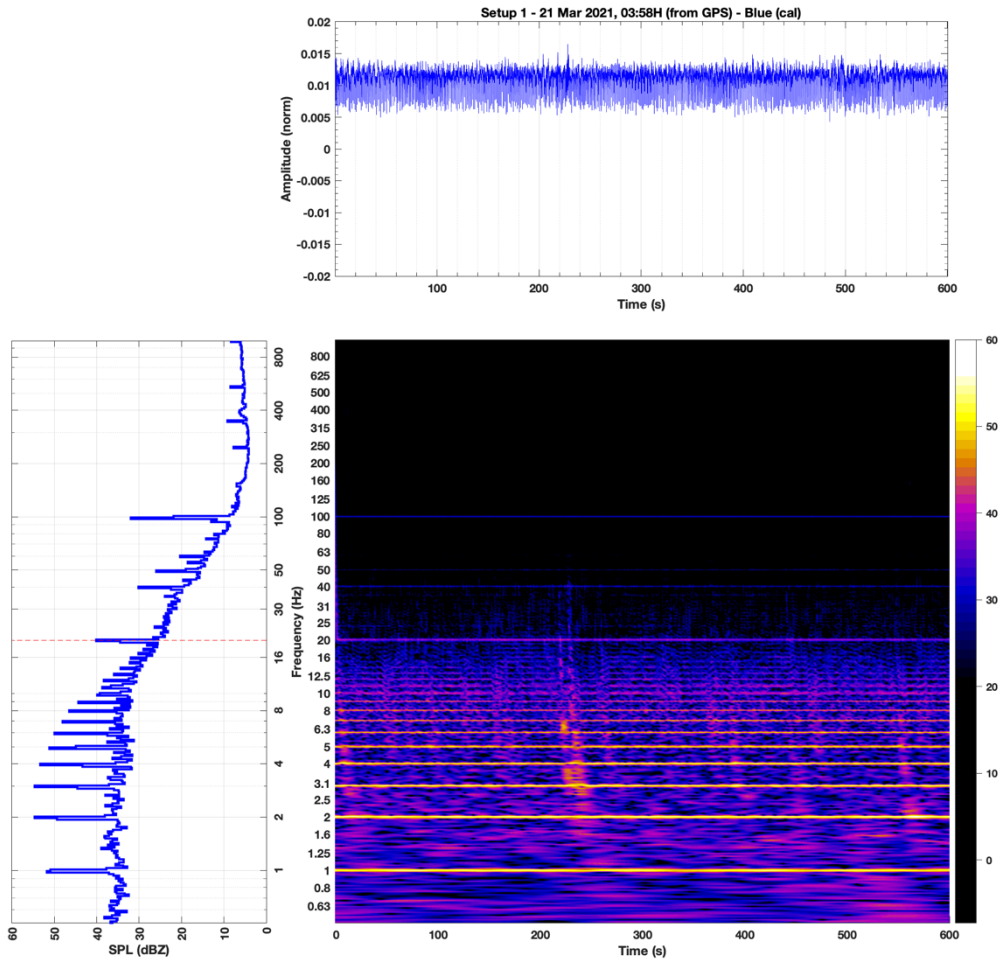

Figure 5: Representative sonogram (bottom right), periodogram (bottom left) and time signal (top) for the West Bedroom recording.

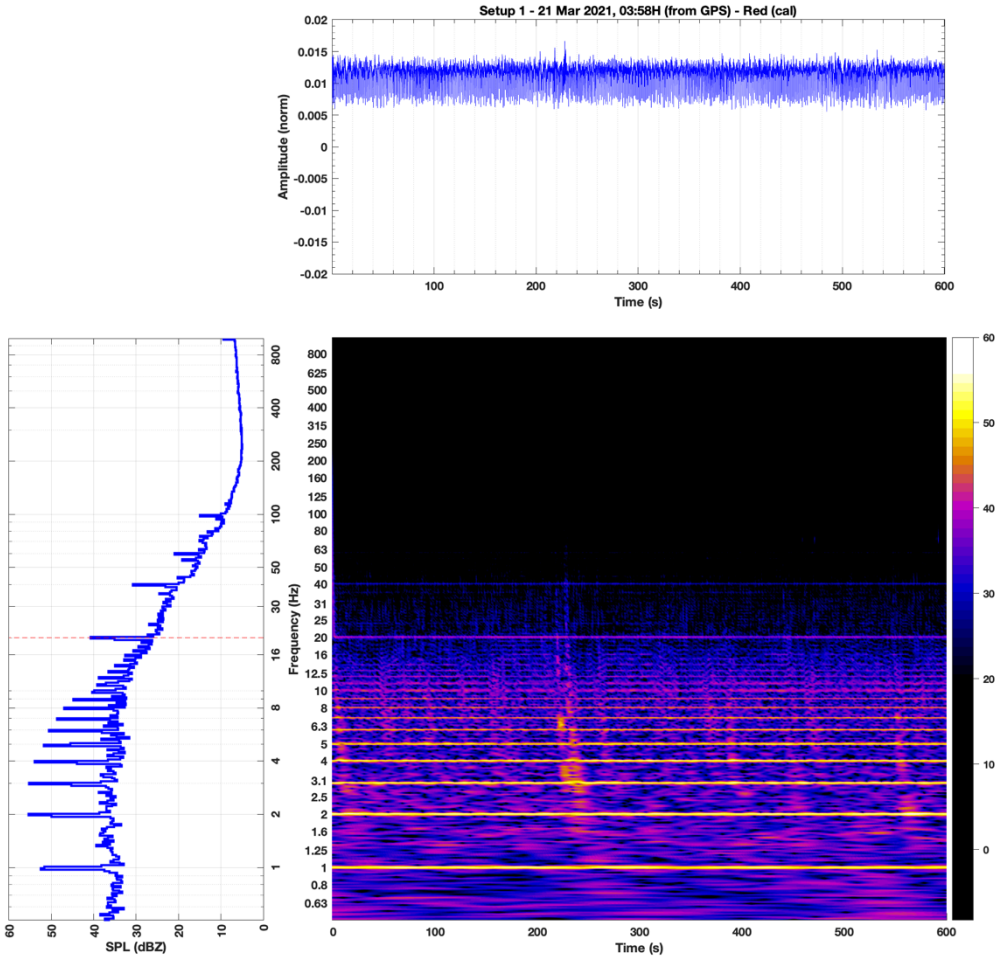

Figure 6: Representative sonogram (bottom right), periodogram (bottom left) and time signal (top) for the East Bedroom recording.

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 local background noise in this region of the spectrum does not often exceed 40 dB.

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

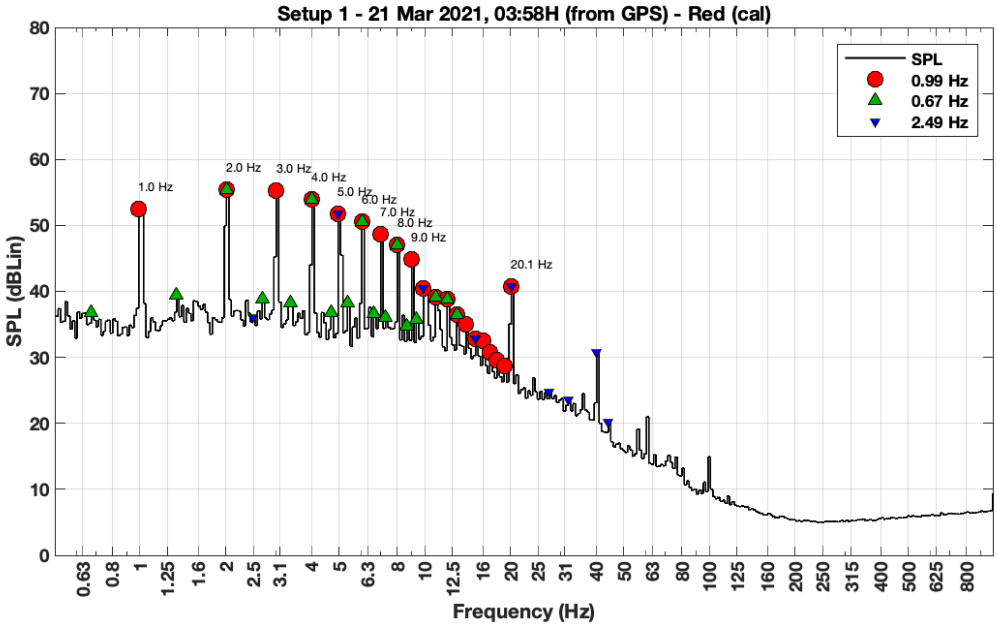

Figure 7: Harmonic analysis of the East Bedroom (Figure 6).

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

6. The IWTs in closest of the neighbouring wind power stations, 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. The more distant Arecleoch wind power station also includes the same model of Gamesa IWTs.

7. No other wind power stations within at least 30 km have 1 Hz as a BPF, thus this harmonic series is the WTAS of the turbines in Mark Hill or, possibly Arecleoch.

8. The Kilgallioch wind power station, roughly 9 km to the southwest, has Gamesa model G114-2500 IWTs, which are also asynchronous but with a blade-pass frequency of 0.75 Hz.

9. The Hadyard Hills wind power station, roughly 11 km to the north-northwest, has Siemens SWT-2.3-101 IWTs, which are asynchronous with a BPF of close to 0.8 Hz.

10. The Assel Valley wind power station, roughly 11.6 km to the north-northwest, has Nordex N90 IWTs, which are asynchronous with a BPF of close to 0.9 Hz.

11. 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.

12. Examination of the time-series signals shows that the 20-hertz ripple is stable over a 10-minute interval (Figure 8), peaks maintaining synchronisation with successive 1/20th second marks (vertical lines). The 1-hertz pulse train wanders, being, overall, slightly less than 1 Hz. The pulse moves right in relation to the 1-second marks between the start and end of the 10-minute interval.

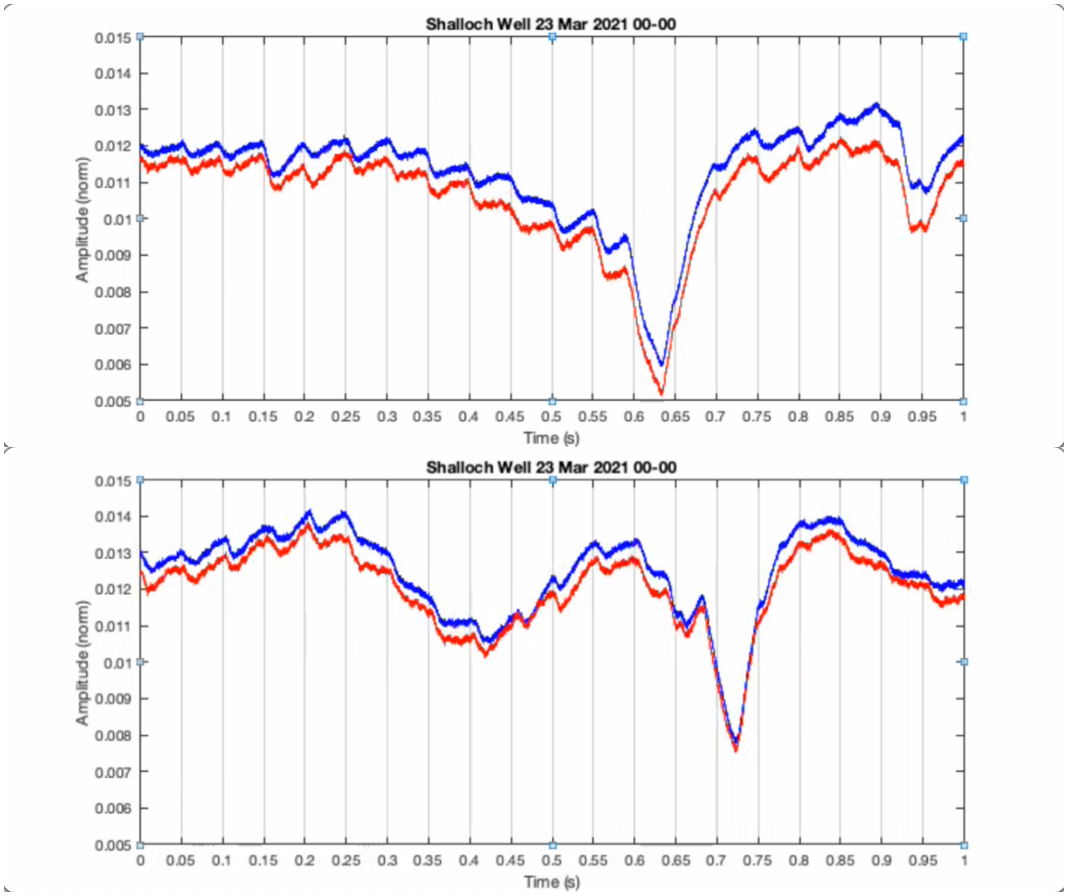

Figure 8: Time-series signal of both channels from near the start (top) and near the end (bottom) of the 10-minute recording from 23rd March 2021 starting at midnight. Both graphs begin on a 1-second boundary from the start of the recording.

13. The fact that the pulse of the 1-hertz signal, caused by the blades, does not maintain its synchronisation with respect to the 20-hertz signal, means that it is not directly associated with the motion of the blades themselves.

Time-series Analysis

1. The time-series signals for 10 seconds of both channels from Figure 5 and Figure 6 are shown in Figure 9.

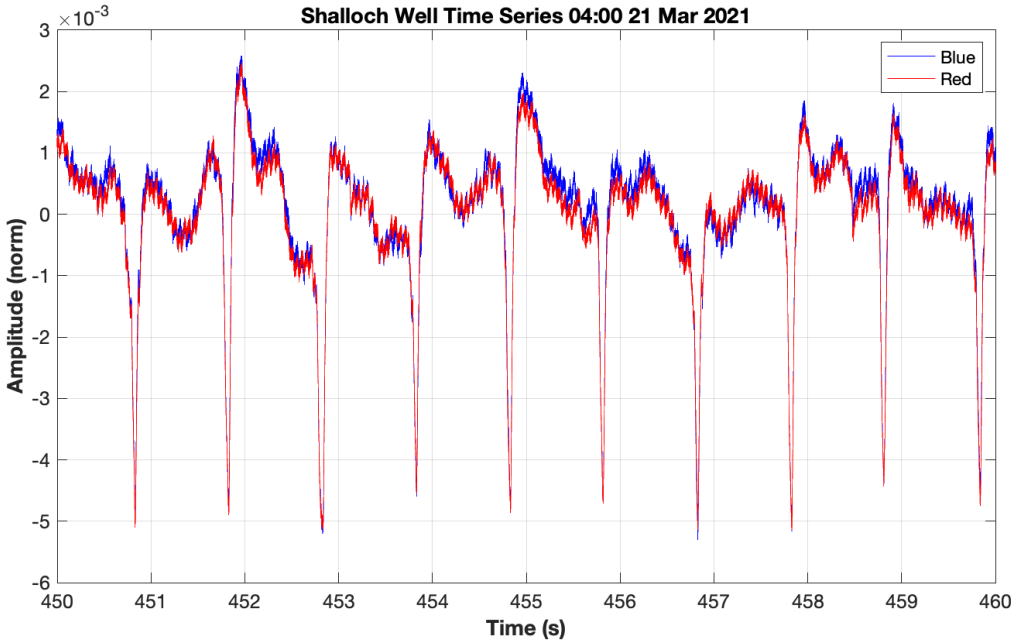

Figure 9: A 10-second section of the time-series for both channels (East and West Bedrooms) from Figure 5 and Figure 6.

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

3. Figure 10 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).

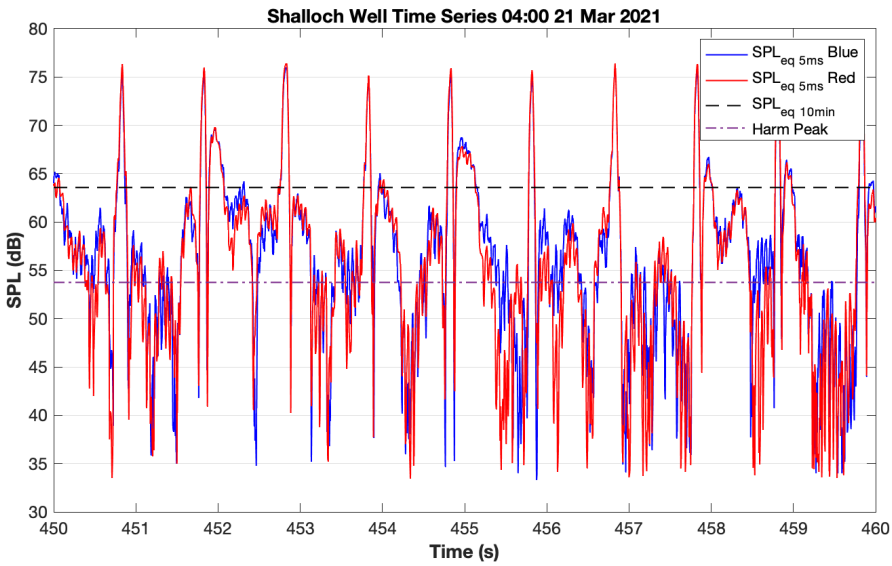

Figure 10: The $SPL_{eq\ 5ms}$ of the same 10 seconds shown in Figure 9.

4. The negative-going pulses of Figure 9 have changed to positive-going pulses (peaks) in Figure 10, 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 the two rooms at opposite ends of the upper floor, the peaks are seen to be the same for both. This suggests that the source of the pulses is distant from either of the two rooms.

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 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 55 dB (dashed line in Figure 10).

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 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 11 and 12 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-minute recordings with a given dominant fundamental frequency.

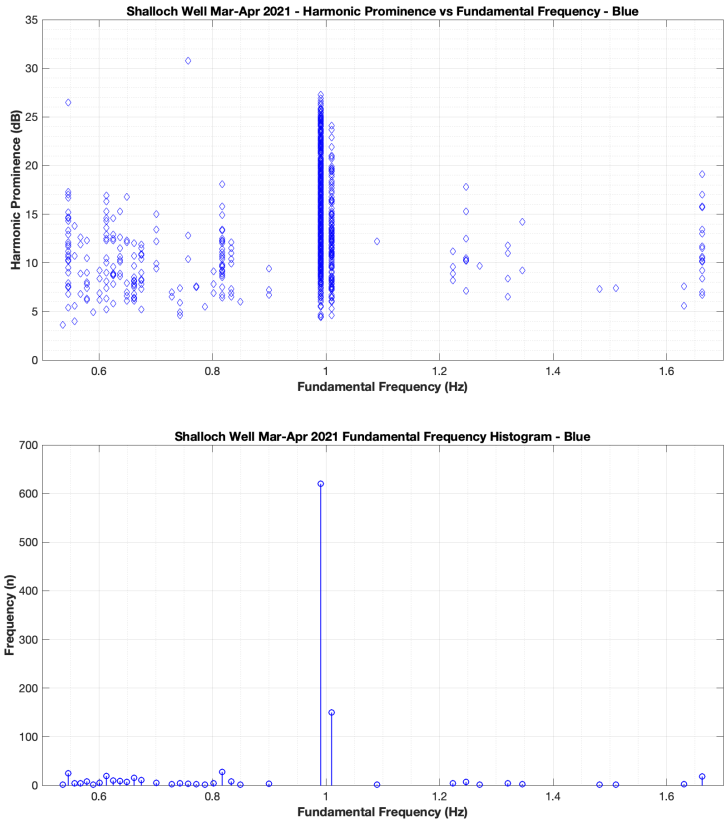

Figure 11: Harmonic prominence for each 10-minute recording period as a function of its fundamental frequency (top) and a frequency histogram of the fundamental frequencies of each 10-minute recording period (bottom). East Bedroom.

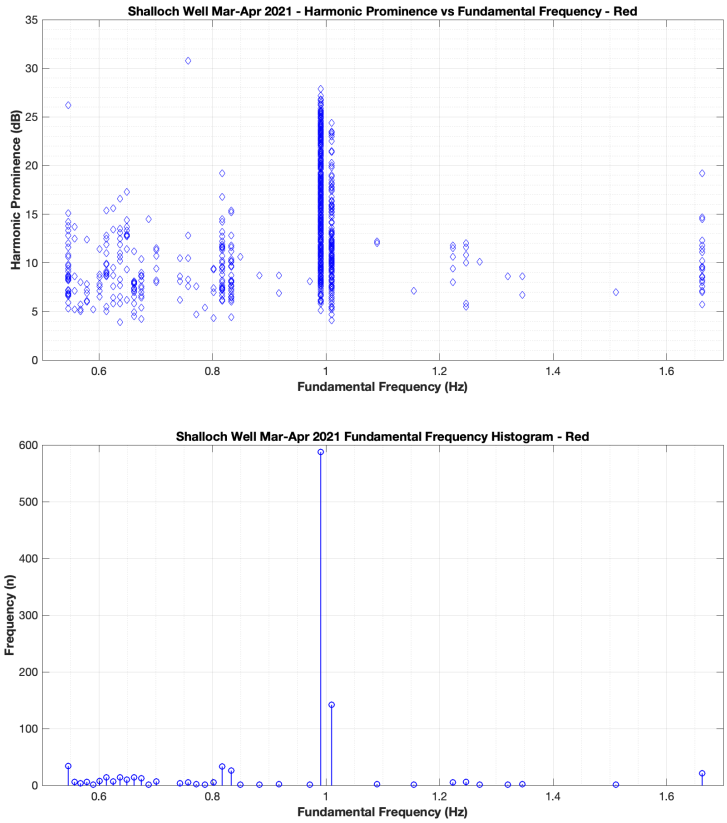

Figure 12: Harmonic prominence for each 10-minute recording period as a function of its fundamental frequency (top) and a frequency histogram of the fundamental frequencies of each 10-minute recording period (bottom). West Bedroom.

2. Figures 11 and 12 indicate that virtually all the 10-minute intervals over this recording period 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 10) 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 13 and 14). 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).

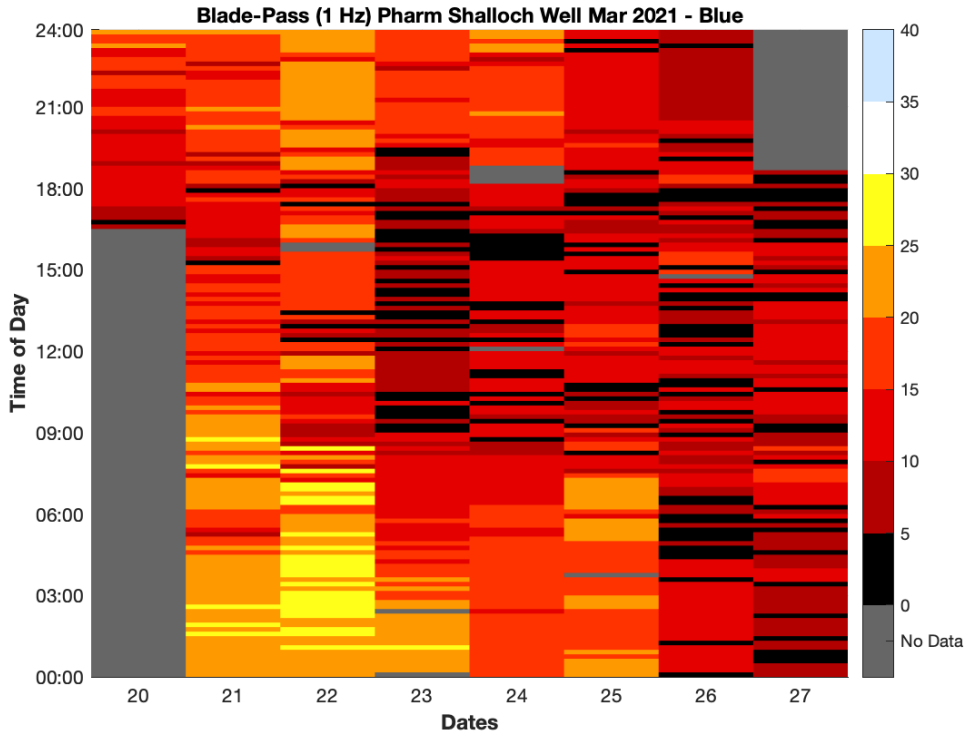

Figure 13: Blade-pass Harmonic Prominence Time-of-day for the West Bedroom from March 20th to March 27th, 2021. (Grey represents no data.)

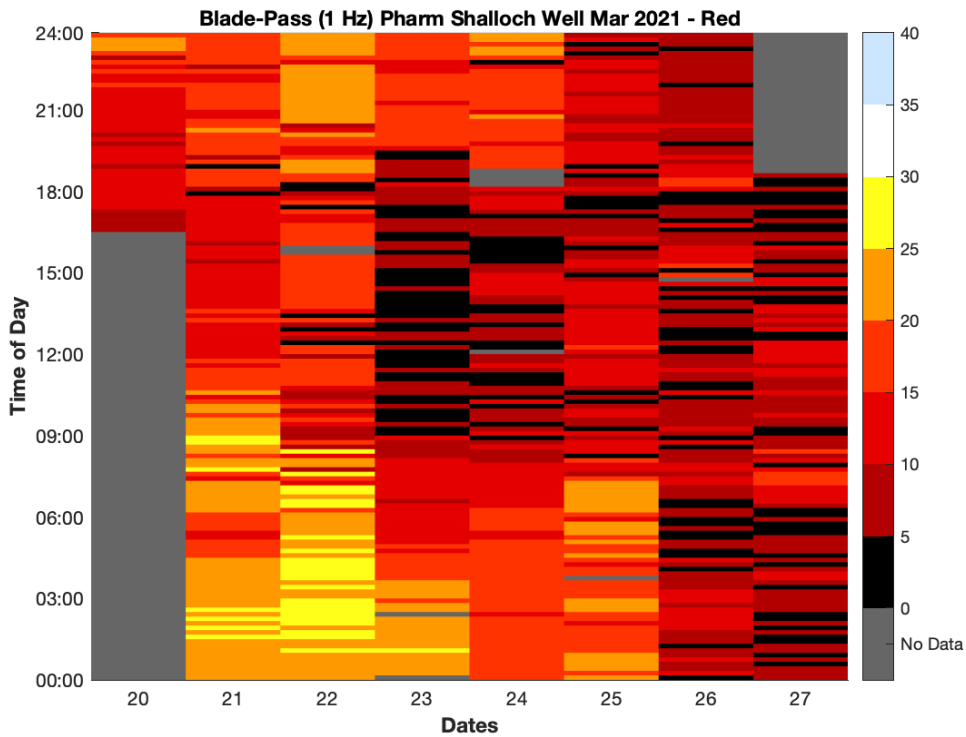

Figure 14: Blade-pass Harmonic Prominence Time-of-day for East Bedroom from March 20th to March 27th, 2021. (Grey represents no data.)

4. Both plots show that the harmonic prominence levels ranged between 0 and 30 dB over the recording period, mostly between 5 and 20 dB.

5. 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 15 and 16). 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.

6. Barrhill weather station is roughly 5.69 km southwest of Shalloch Well. Weather recorded there will be indicative of weather at, and between, the three wind power stations surrounding it.

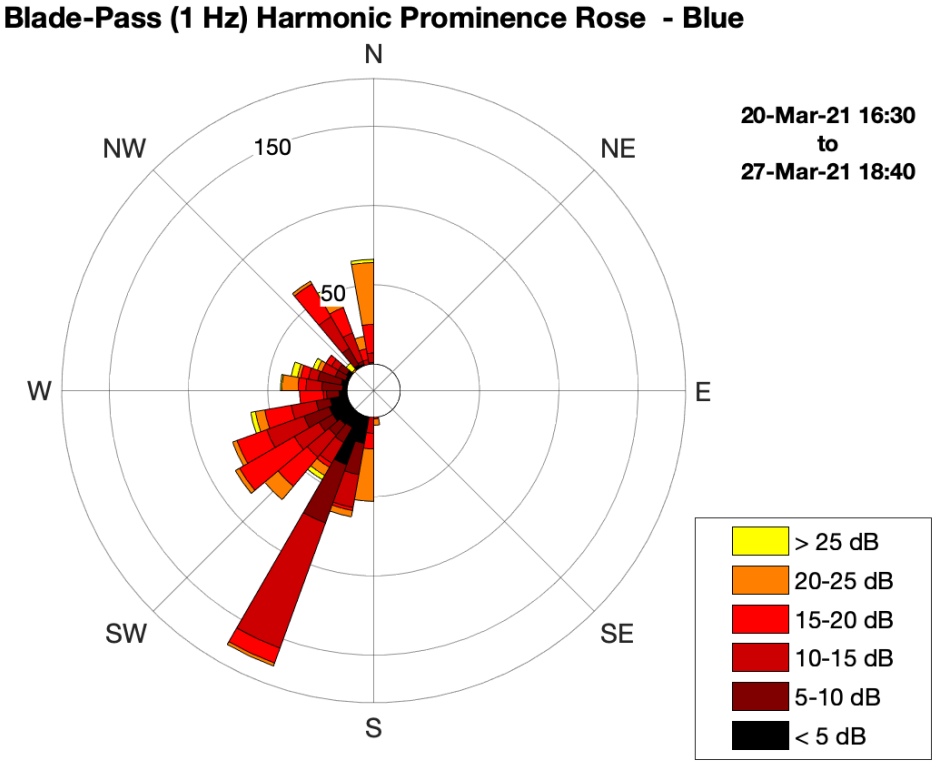

Figure 15: Harmonic Prominence Wind Rose for the West Bedroom for all wind speeds from March 20th to March 27th, 2021.

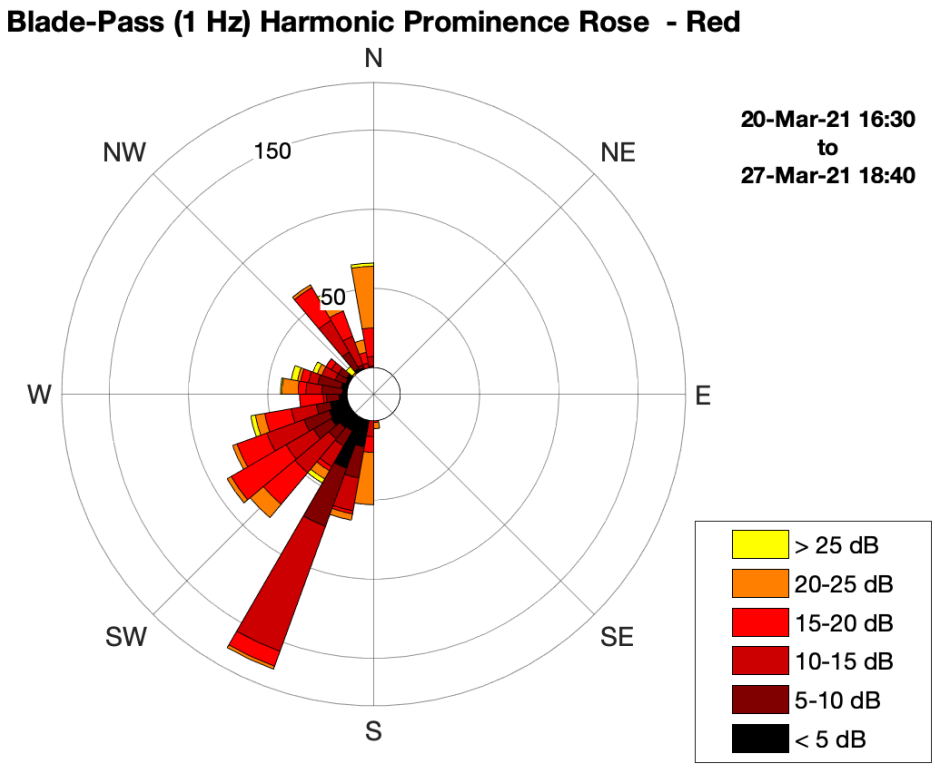

Figure 16: Harmonic Prominence Wind Rose for the East Bedroom for all wind speeds March 20th to March 27th, 2021.

7. The two wind roses can be seen to be virtually identical, as might be expected since the two rooms are the same size and directly across a hallway from each other.

8. The wind at the Barrhill station over the recording period is entirely from the two western quadrants, with south-southwest being the most common direction.

9. The largest proportion of severe levels (yellow, 25–30 dB) of harmonic prominence occur when the wind comes from between the southwest and north-northwest.

10. Mark Hill wind power station lies east of Shalloch Well covering an arc from roughly southwest to northwest.

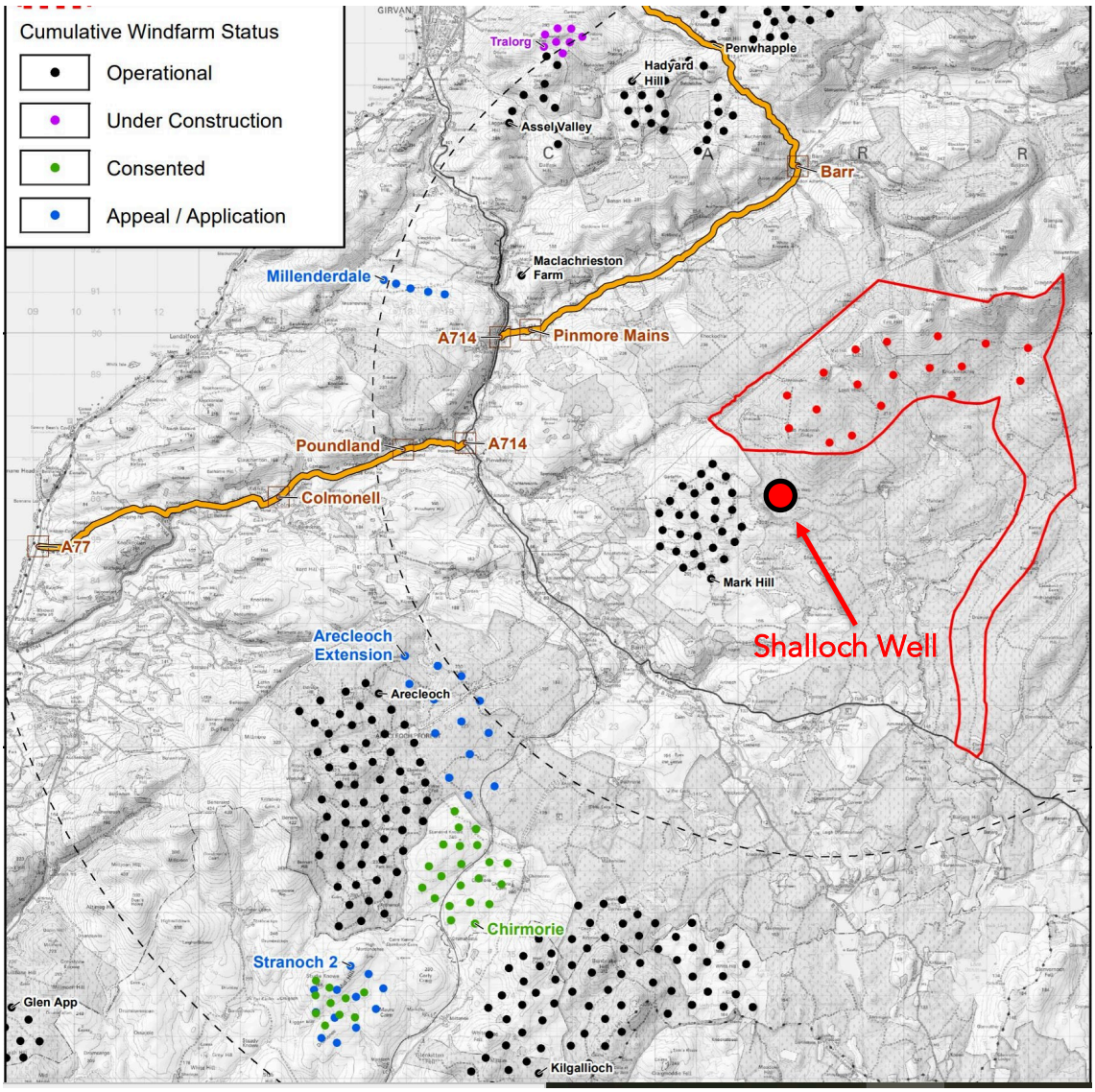

Figure 17: The Shalloch Well residence and surrounding windfarms.

E. CONCLUSIONS

1. The recordings taken over the interval from March 20th to March 27th, 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 5 and 20 dB in both measurement sites. Levels consistently this high have never before been measured by the authors.

3. The morning of March 22nd had harmonic prominence levels over 25 dB.

4. The wind at Barrhill weather station, the closest measurement site to Shalloch Well, was predominantly from the west-northwest through to the north-northwest during the most severe episodes.