Closing In on the Wind Turbine "Sasquatch" – Whose Name is "Annoyance"

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Hello, thanks for listening.

It's a privilege to send greetings to the 10th Wind Turbine Noise Conference from Canada.

But, in a virtual presentation, how do you know it the greetings are real?

It's like the topic I'll discuss, *"closing in on the wind turbine "sasquatch" – whose name is "annoyance."*

But a "sasquatch" is only imaginary, isn't it? So how can we show annoyance is real?

Let's see.

Is annoyance real?

- Let's use references from past Wind Turbine Noise Conferences

WTN Conference	Total # of Papers	# of Mentions of "Annoyance"
WTN 2005	29	78
WTN 2013	72	406
WTN 2021	40	438

- The data suggests "annoyance" has not gone away
- Our objective is to replace a "subjective" assessment of annoyance with an "objective" (measureable) one

We'll begin by using real references from past wind turbine noise conferences.

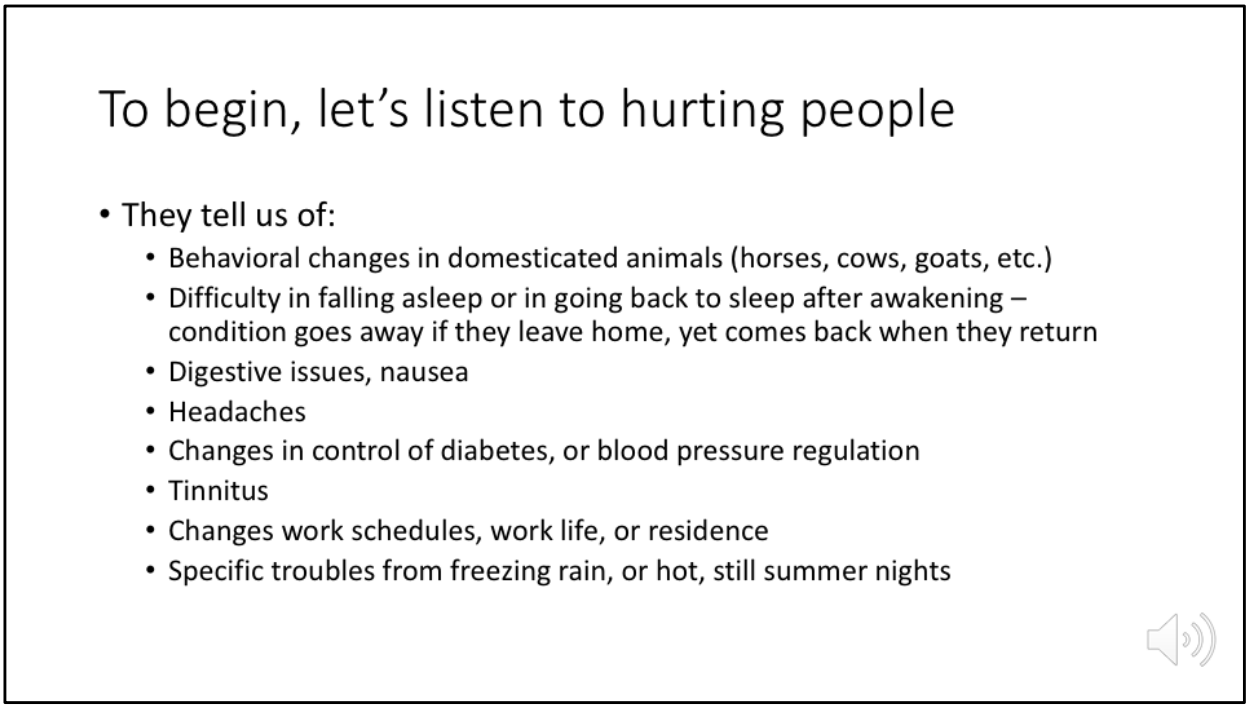
The First Wind Turbine Noise Conference in 2005 had 29 papers, which used the word "annoyance" 78 times.

By 2013, the paper count had more than doubled to 72, but mentions of "annoyance" increased by over 5 times to 406.

The last conference in 2021 had fewer papers, at 40, but mentions of annoyance continued to grow to 438.

It seems that discussion of annoyance keeps increasing, which does not sound like it is imaginary.

Our objective here is to replace a subjective assessment of the term "annoyance" with an objective, or measurable one.



We'll begin, by listening to what hurting people tell us.

They speak of behavioral changes in animals – those animals do not have prejudices, so why should their behavior change if something is imaginary?

People speak of difficulty falling asleep, or difficulty going back to sleep after they awaken. A condition that goes away if they leave home, but comes back when they return.

They speak of digestive issues, nausea, headaches, changes in control of diabetes, or blood pressure, and of tinnitus.

They tell us of needing to change work schedules because they cannot sleep properly, or the need to leave their regular employment because they could not function normally, or even to leave their homes.

In their stories, they tell of specific issues when freezing rain occurs, or on hot summer evenings.

Listening, non-judgmentally, we can hear they are clearly hurting, even if they do not know why.

Mining the data on hand

- Spot measurements near, and away from wind turbines since 2007
- Short duration attended recordings since 2011
- Two years of continuous acoustic recordings from mid 2018 to mid 2020 at one site ~ 787 m from the nearest wind turbine, and local spot recordings at a second site in the same array
- 9 months of continuous acoustic recordings from a site ~ 537 m from the nearest wind turbines (of a different type) from 2020 through 2023, along with some simultaneous recordings > 6 km from the same wind turbines
- Resident complaint data filed with the Ministry of the Environment at the sites near wind turbines
- Could any link be established between the complaints and the sound?

To put a finger on the reason, we will look at hard data we do have.

- We have spot measurements taken since 2007.
- Then there are short duration attended recordings taken since 2011, with increasingly sophisticated equipment.
- We have 2-years of continuous acoustic recordings taken using 90 mm primary and 450 mm secondary wind screens, from mid 2018 to mid 2020 at one site 787 m from the nearest wind turbine, with 16 turbines within 3 km. and spot recordings at a second site in the same array with the closest turbine at 703 m and 18 within 3 km.
- Then we have a further 9 months of data recorded between mid 2020 and early 2023, at a home 537 m from the nearest wind turbine, with 19 within 3 km.
- We also have the logs of complaints these families filed with the Ontario Ministry of the Environment.
- Could we mine this real data of recordings and complaints, to see if there was a correlation?

Data analysis suggests a hypothesis

- In general we think that a 3 dB change in dBA value can be perceived by most people
  - lets consider cases where the difference between LA90 (typically the background levels) and LA10 (typically the loudest sounds occurring ≤ 10% of the time) is ≤ 3dB as representing those cases that might not readily be perceived
  - Lets look for simultaneous cases when the full spectrum shows LZ10-LZ90 is ≥ 6 dB (two 3 dB changes, potentially more readily perceived)
- There was a good match – between the annoyance complaints and the recorded conditions at the time of the complaint matching those conditions, suggesting a possible hypothesis:

Annoyance can be predicted for LZ10-LZ90 ≥ 6 dB while LA10-LA90 ≤ 3 dB

We read the general understanding that most people can perceive a 3 dBA change in sound level.

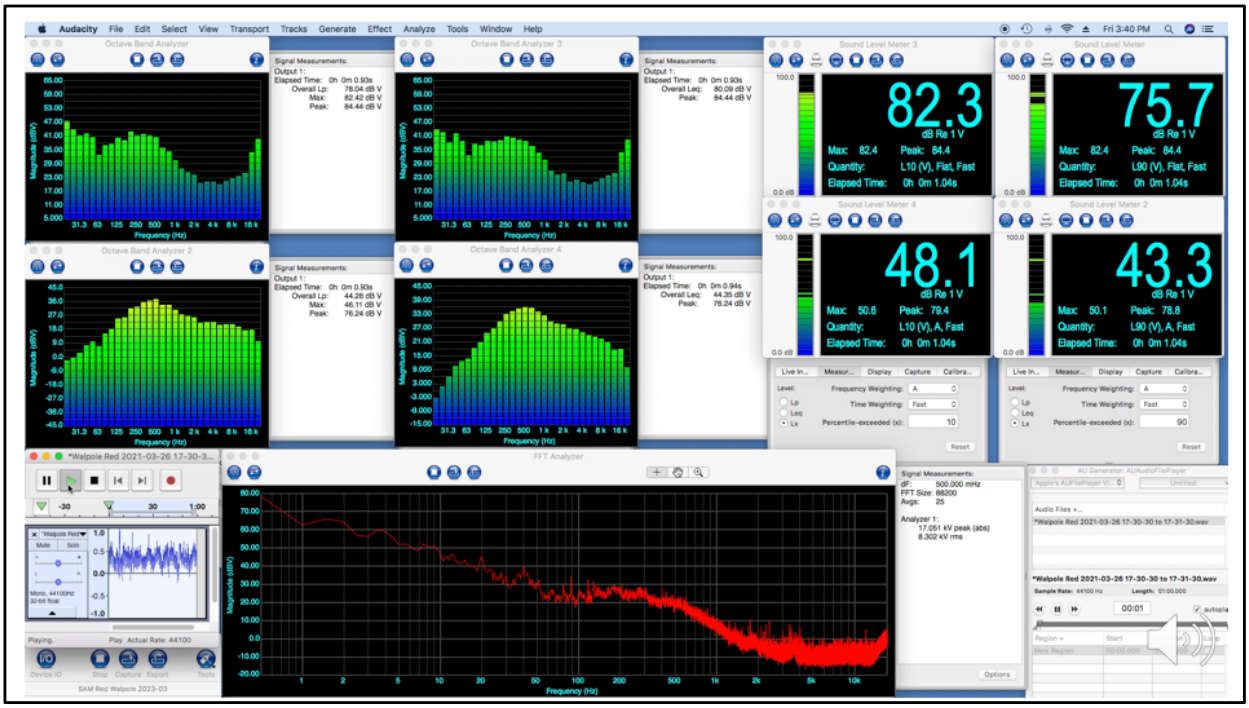
So we thought, let's examine the cases revealing a difference between the 2 minute LA90 sound level (the level present 90% of the time, typically considered to be background) and the 2 minute LA10 sound level (the loudest levels present less than 10% of the time). If this difference was less than 3 dB, than possibly the change might not be perceived.

With that, let's look at the simultaneous conditions showing a difference between the loudest 10% of the full spectrum sound level (called unweighted, flat, or Z weighted) compared to the background 90% of that same full spectrum sound If this difference was over 6 dB (or 2 full 3 dB increases) then we might expect the difference would probably be perceived.

What we found was a good correlation between the times of the logged complaints and the existence of LA conditions that might not be perceived, but LZ conditions we expected would, suggesting a possible hypothesis, which was:

Annoyance can be predicted for LZ10-LZ90 ≥ 6dB, when at the same time LA10-LA90 ≤ 3dB.

So we set out to test that hypothesis.



We've analyzed thousands of samples, using the tools of the application "Electroacoustics Toolbox." Here's a sample display of a 1 minute analysis (shortened from the normal 2 or 3 minutes analysis for this presentation). The upper right shows calibrated sound level meters for LZ10 and LZ90 above meters for LA10 and LA90. The left side shows one-third octave spectral analyzers. LZeq is in the top centre, and a real time LZ at it's left. Below the LZ analyzers are the comparable LA filtered analyzers. An unweighted FFT display of the one minute sound file is shown at the bottom of the display. It uses a hann window with a 17 kilo Hz span. There is 0.5 Hz resolution, a 50% overlap between each calculation, and displays the average of the last 25 calculations for each line. A small audacity window at the lower left allows tracking a visual presentation of the waveform, and provides an audio file as a listening aid.

Let's watch and listen to a sample being processed.

What did we just witness?

This was the analysis of a time categorized by the resident as 7/10 in annoyance. Note that this resident considers a 7/10 event as the minimum level that would be logged with the Ministry.

Here we saw the LZ10 – LZ90 difference to be 7.3 dB, and the LA10 – LA90 difference to be 2.6 dB, so this would meet the Criterion established in the hypothesis. At the same time, the 1 minute LZeq was 78.6 dB and the 1 minute LAeq was 44.1 dB.

Testing the hypothesis – could it just be the wind?

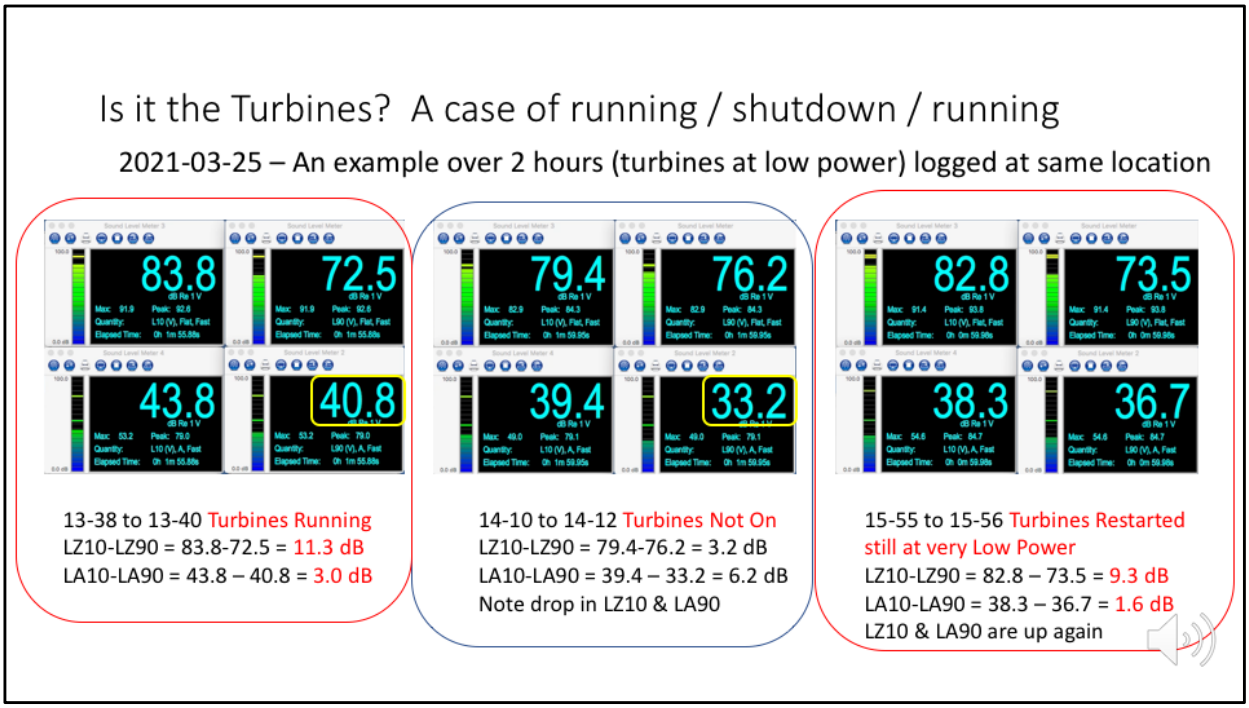
- Closely examined data from times turbines shut down or started up (as wind speeds do not change appreciably over the short transition)
- Also compared data recorded simultaneously at the site ~ 537m from turbines, and at a site > 6 km to the same wind power array
  - same terrain, same proximity to roadways, closely matched environmental conditions (wind, temperature, pressure, humidity, precipitation, etc.)
- Tested analysis microphones against Level 1 IEC 61094-4 compliant ACO Pacific 7046 free field microphone to ensure consistent readings
- Extended data set to test at regular 1 or 2 hour intervals, to ensure not only testing complaints, but sampling all conditions
- Looked at months of data

It was important to test the hypothesis to ensure that the measurements being recorded were actually related to the wind turbines, and not just to the wind itself.

Close examination was given to cases where the wind turbines shut down or started up.

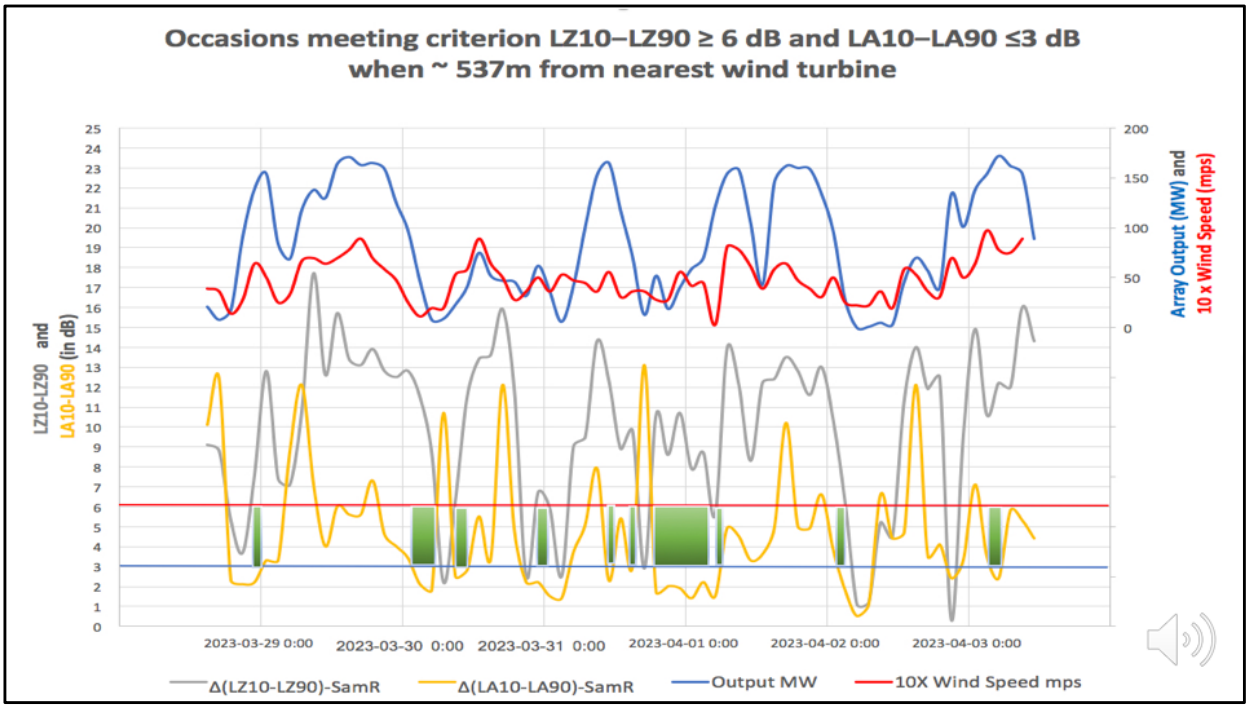
- At some times these might just be due to wind speed falling below the operational threshold,
- In other cases, the turbines were shut down due to the electrical system operator offering the turbine operators the option of shutting down (while still being paid for possible output) during times the system demand was lower than baseload generation available.
- Recordings were also made of data recorded simultaneously at the site ~ 537 m from turbines and a second site > 6 km from the nearest turbine of the same wind turbine array.
- Additional recordings were made to ensure the microphones used were consistent in output with a Level 1 IEC 61094-4 compliant ACO Pacific 7046 free field microphone.
- The data set was extended to ensure data was recorded at regular 1 to 2 hour intervals, to sample all conditions proportionally, and not just to sample

complaints.



Here's an example of a shut down and restart at low power conditions. The left side shows the criterion test before the shutdown where (LZ10-LZ90=11.3 dB while LA10-LA90 = 3 dB). Just after the shut down, you can see the 7.6 dB drop in LA90 from turbines operating to shut down.

The subsequent restart is also shown on the right.



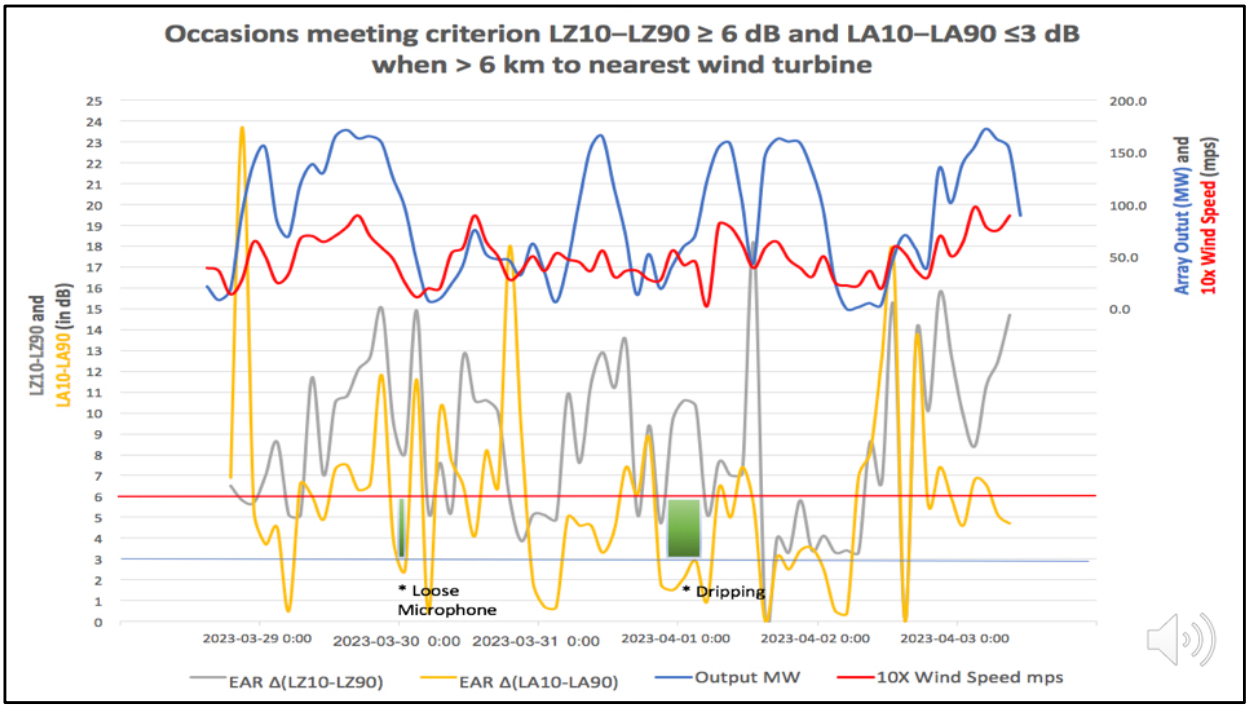
This chart shows the test to see if the proposed hypothesis was met during a week from measurements taken at the site ~ 537m from the nearest wind turbine.

The top of the chart shows the wind turbine array output in blue on a scale from 0 to 200 MW. The top also shows the wind speed in red measured at the nearest Environment Canada monitoring station, recorded as 10 x the actual wind speed to match the chart scale from 0 to 200 metres per second, so the actual wind speed shown is from about 0 to 10 metres per second. As expected, the turbine output tracks the wind speeds up and down quite closely. (Wind shear is not as significant a factor this early in the spring as it is in the summer).

The bottom of the chart shows in grey the difference between LZ10 – LZ90, as it ranged from near zero to near 18 dB. In yellow we see the difference between LA10 – LA90 as it varied from near zero to about 13 dB for this week.

The flat red line at 6 dB on the chart shows the minimum value for LZ10-LZ90 to meet the criterion limit of being ≥ 6 dB, while the flat blue line at 3 dB shows the maximum value for LA10-LA90 to meet the criterion of being ≤ 3dB.

The Green shaded areas shows the times when the criterion LZ10-LZ90 ≥ 6dB and LA10-LA90 ≤ 3 dB was met. While the first case on the left, and the last case on the right show this occurring when the turbine output and wind speeds were high, in the majority of the cases, the criterion was met when the turbine output was less than 50 MW and the wind speed was not at it's highest values.



In contrast, this chart shows the conditions for the hypothesis test at the site > 6 km to the nearest wind turbines for the same week.. The blue turbine output and red wind speeds are identical to the last chart.

However, in this chart, the higher wind speeds generally accompany higher values of LA10-LA90. In this case the distant wind turbines are not raising the LA90 values as they did near the wind turbines. As a result, here we see a higher difference between LA10-LA90, thus failing the criterion test.

Only 2 examples appear to meet the criterion of LZ10-LZ90 ≥ 6 dB while LA10-LA90 ≤ 3 dB. However, on doing a listening test, it was clear that these situations were due to an increase in LZ10 due to either rain drops “drumming” on the microphone protective cover, or a loose microphone rattling in the secondary wind screen. Neither of the conditions were due to the wind, or wind turbines.

Summarizing 136 hours of data near & far

~ 537 m from nearest wind turbine

- 4 wind turbines within 1 km, 19 within 3 km
- 35 hours meet criterion
- Listening confirms all 35 meeting the criterion show a cyclical acoustic signature

> 6 km from nearest wind turbine (same array)

- 5 hours seem to meet criterion, but listening test reveals:
  - 3 due to water dripping on microphone,
  - 2 due to loose microphone rattling in the wind screen,
- Thus 0 hours meet criterion

Summarizing, the 136 hours of simultaneous recordings near and far from the wind turbines, showed the following:

537m from the wind turbines, 35 hours (about 26% of the cases) meet the criterion, and listening tests confirmed all these samples demonstrated the cyclical acoustic signature.

> 6 km from the wind turbines, none of the cases truly meet the criterion, but were only due to artifacts of a loose microphone or rain drops drumming on the microphone protective cover.

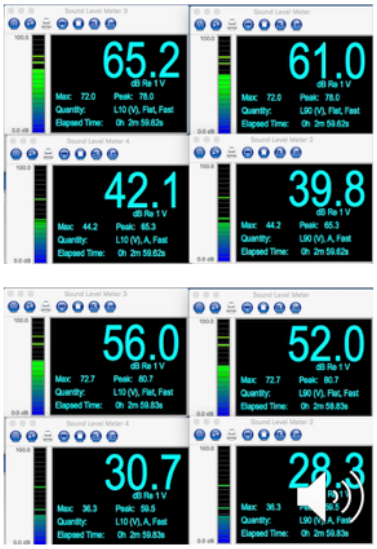
One limitation of criterion – some high power cases

Case 1: (2 turbines in 1 km, 16 in 3 km)

- Before shutdown
  - Turbines 60% output
  - Wind 5 mps
  - LZ10-LZ90 = 4.4 dB
  - LA10-LA90 = 3.7 dB
- After shutdown
  - Turbines 0%
  - Wind 5 mps
  - LZ10-LZ90 = 4.6 dB
  - LA10-LA90 = 1.5 dB
  - Note ~10 dB drop in dBA values

Case 2: (6 turbines in 1 km, 13 in 3 km)

- Before shutdown
  - Turbines 60% output
  - Wind 5 mps
  - LZ10-LZ90 = 4.2 dB
  - LA10-LA90 = 2.3 dB
- After shutdown
  - Turbines 0%
  - Wind 5 mps
  - LZ10-LZ90 = 4.0 dB
  - LA10-LA90 = 2.4 dB
  - Note ~11 dB drop in dBA values



However, it became clear that the criterion was not predicting annoyance during some conditions we expected it might. We found it tended to under-predict expected annoyance for some situations.

This page gives examples recorded at two sites shortly before and shortly after the wind turbine array was shutdown from high power due to excess generation on the electrical system.

In this case, the wind turbine array output dropped from > 60% to zero on the shutdown. Wind speed did not change appreciably between recording of the acoustic conditions with wind turbines operating to the conditions with the wind turbines shutdown. You can note the drop in each parameter of a bit less than 10 dB in the dBZ values, and a bit over 10 dB in the dBA values,

However, neither case 1, nor case 2 predicted annoyance using the criterion.

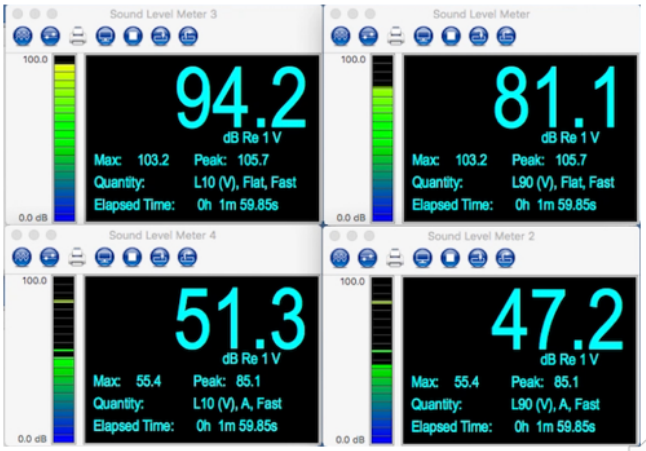
A further limitation of criterion – high winds

Example:
Site ~ 537m from nearest turbine, 19 within 3 km

- Wind speed ~ 6.7 mps
- Turbine output 157 MW

LZ10-LZ90 = 13.1 dB
LA10-LA90 = 4.1 dB

Higher winds tend to prevent triggering the criterion.



This slide shows a second condition that prevented the criterion from being met.

It was found that high wind speeds tended to drive up all sound levels, and prevent the criterion from being met.

Summarizing 236 recent hours of recordings

- 19 hours met criterion for the 126 hours when turbine output > 50%
- 23 hours met criterion for the 110 hours when turbine output < 50% (but above zero)
- Hence ~ 18% of operating hours met the annoyance criterion
- However, this matched annoyances reported, in that annoyances tend to be reported when turbines are most intrusive (or dominating)

When we summarize the most recent 236 hours of recordings made at the home ~ 500 metres from the nearest wind turbine, we find that 19 hours met the criterion during the 126 hours when the turbine output was > 50%. During the 110 hours when the turbine output was < 50%, 23 of the hours met the criterion.

Hence, about 18% of the operating hours met the annoyance criterion.

However, the conditions present for annoyances flagged by the criterion, tended to match the annoyances over time by the residents. It suggested that annoyances tend to be reported when turbines are most intrusive, or dominating.

Conclusions

- The annoyance criterion LZ10-LZ90 ≥ 6 dB while LA10-LA90 ≤ 3 dB is not perfect at predicting annoyance in all cases.
- It tends to under-predict annoyance during high wind speeds, or high power situations.
- However, it tends to match actual annoyance reports, by detecting situations when wind turbines dominate the environment.
- While it does not replace criteria for assessing LAeq, tonality, or accurate measurements of amplitude modulation, it is quick to assess, and is useful for screening to predict annoyance.
- It can be a useful additional tool in the regulatory tool-kit to predict & assess when citizens may be impacted by wind turbine annoyance.

To conclude:

The criterion LZ10-LZ90 ≥ 6 dB and LA10-LA90 ≤ 3 dB is not perfect to flag all expected cases of annoyance.

It tends to under-predict annoyance during high wind speeds, or high power conditions.

However, it tends to match actual annoyance reports, by detecting situations when wind turbines dominate the environment.

While the annoyance criterion does not replace the need for criteria to assess LAeq, tonality, or accurate measurements of amplitude modulation, it is quick to assess, and is useful for screening to predict annoyance.

It can be a useful additional tool in the regulatory tool-kit to predict and assess when citizens may be impacted by wind turbine annoyance.

Last Words

- Like the “sasquatch”, wind turbines matter most when they become a bother.
- The difference is that wind turbines are real.
- This paper provides a better picture of the wind turbine “sasquatch” named “annoyance.”
- Real measurements give a clear prediction for annoyance.
- There is a real basis for annoyance reported from wind turbines.
- Thanks for listening.

Like the "sasquatch" wind turbines matter most when the become a bother.

The difference is that wind turbines are real.

This paper provides a better picture to identify the wind turbine "sasquatch"

It shows evidence that real measurements of readily available data give a clear indication for when annoyance will occur

There is a real basis for annoyance reported from wind turbines.

Thanks for listening. I look forward to your discussion questions.