Long term wind turbine sound monitoring

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ABSTRACT

In the DLR Windpark WiValdi, consisting of two wind turbines, extensive measurements of sound and meteorology have been conducted. In the context of long-term wind turbine sound monitoring, the data from such measurements are used to understand and decipher physical effects of sound propagation. This kind of data suffers sometimes for reliability, because of many changing conditions and situations around the microphone. Therefore, in three different phases the sound of various sources were captured.

Before the turbines were installed, initial measurements were made to identify background noise, followed by additional measurements to assess the impact of new installed weather masts on the sound field. Ultimately, the exact state (such as rotation speed, pitch, yaw, etc.) of the wind turbines shall be reported, to relate weather and operational conditions to the associated sound levels.

This presentation illustrates how all these measurements are used to create a consistent picture of the noise situation around the wind park depending on specific weather situation and discusses the need of accuracy. We document the limitations and uncertainties associated with the measurements and show these limitations when interpreting and reporting the results to ensure users in understanding the reliability and confidence level of such data.

1. INTRODUCTION

With the DLR *Windpark WiValdi as a real scale laboratory it is intended to c*over the entire process chain – from whole-system turbine planning, innovative rotor concepts, turbine technology and operational management, to their environmental impact and acceptance research, as well as the integration of wind turbines into the power grid. The research wind park WiValdi is located in Northern Germany approximately 40 km to the North Sea. The research wind farm is designed to operate for at least 20 years and features a unique set of wind turbines which are equipped with an unprecedented number of sensors [1].

Figure 1 shows the two wind turbines together with several meteorological masts. A detailed knowledge and understanding of the atmospheric conditions associated to the site will enrich future research at WiValdi in multiple ways.

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One aspect is the research on sound emission and sound propagation into the environment depending on various meteorological conditions. This shall be illustrated here.

Figure1: DLR *Windpark WiValdi with the two wind turbines and the meteorological masts*

To estimate the expected sound pressure level in the field, a first guess was performed using an engineering model (CandaA® [2]) with roughly traffic density estimation as sound source and the correlating noise emission. The results are presented in Figure 2. Traffic density is based on counting data, DTV: Average daily traffic volume vehicles/24h. Average value over all days of the year of the motor vehicles passing a road cross-section in 24 hours. We used here 5200 cars per day.

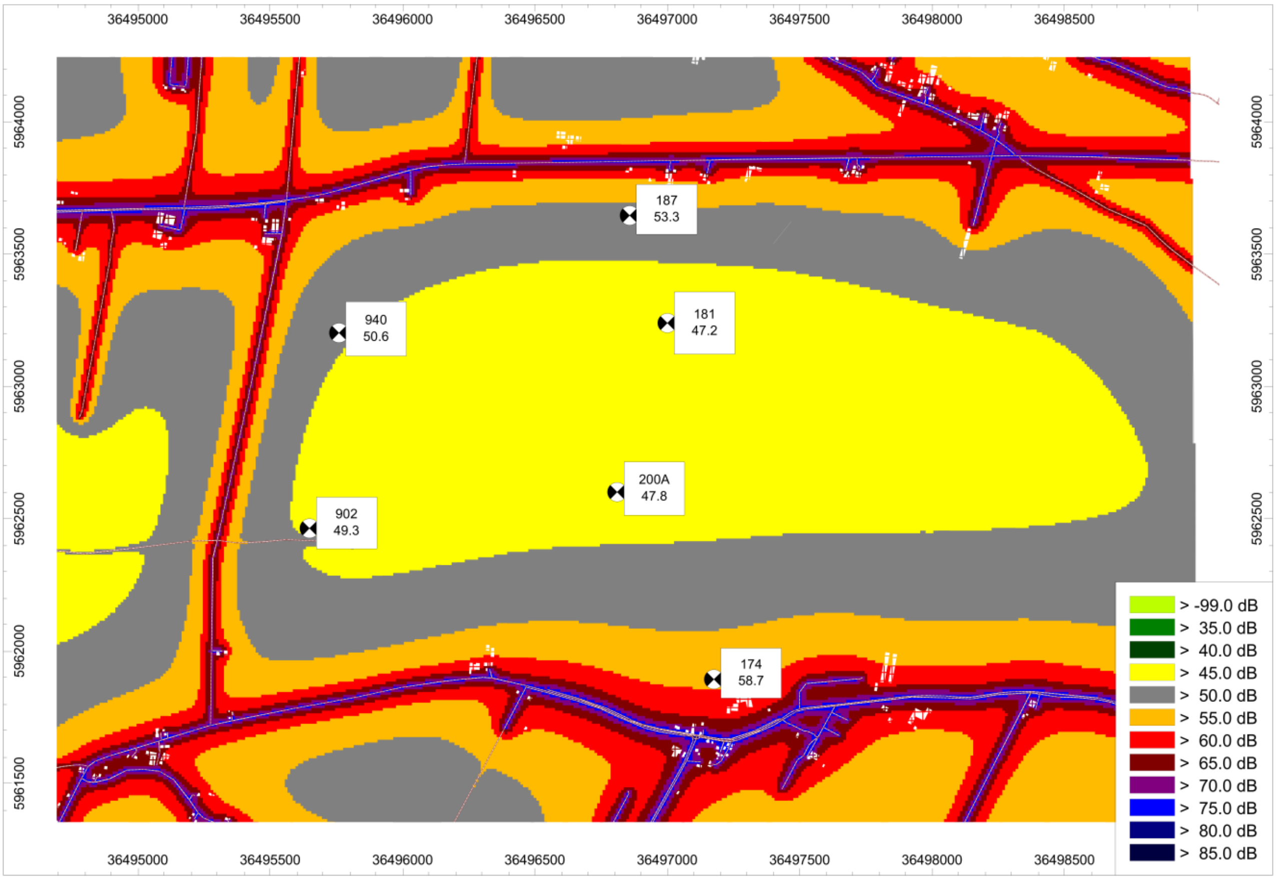

Figure 2: Map and noise estimation with estimated road emission for all roads. The quite region in the center of the wind park reflects the noise propagation range by distance from the roads. The labels contain the microphone number and the calculated SPL in dB(A).

2. MEASUREMENTS

The measurements, conducted from March 23,2021 to March 25, 2021 and September 14, 2021, to September 19, 2021, primarily aimed to determine the ambient noise background level in the vicinity of the DLR Research Wind Park WiValdi before the installation of wind turbines (WT) and the MET-masts. Additionally, the synchronization and level differences of the microphones were analyzed, and the influence of meteorology on sound propagation was determined.

During14th to 19th of September 2021 the campaign from March was repeated more or less. The microphones were placed at nearly the same positions as in march. Different weather conditions were expected, as well as different human activities in the area. The farmer's tasks on his field and the construction work on the building site have changed.

During the third measurement campaign from 23th to 29th of March 2023 the meteo masts presented in Figure 1 were erected already and it should be checked if they produce additional sound. The wind turbines were not ready before starting the present analysis but will be included later in similar way.

2.1. Microphones

For the measurements were used three types of Noise Monitoring Stations (NMS) for environmental noise surveillance. Firstly, three single SV 279PRO NMS, housing SVAN 979 Class 1 sound level meter, designed for outdoor use with broad-band measurement capabilities. They are referred here by the last three digits of their serial number (174, 181 and 187 respectively). Secondly, two SV-307 Class 1 NMS utilize innovative MEMS microphone technology. They are also referred here by the last three digits of their serial number (902 and 940). Lastly, the SV 200A 4G NMS stands out with its noise directivity detection feature, employing built-in microphones for identifying and locating dominant noise sources in both vertical and horizontal directions. All NMS adhere to ISO standards, utilize electrostatic actuator for system checks, and the last three integrate accurate GPS for precise localization and time synchronization.

2.2. Locations

The microphones were distributed in the area of the wind park to catch different possible sound sources and to cover the area more or less with equidistant sound measurements. Furthermore, there was the intention to describe the soundscape in the vicinity to residents to be able to quantify any possible additional noise after mounting the wind turbines.

Table 1: co-ordinates of the six microphones in March 2021

Microphone Nr	Latitude	Longitude
200A	53'48'43.9707	9'13'58.9171
174	53'48'18.8900	9'14'18.5690
181	53°49'8.3259	9°14'9.1185
187	53°49'25.9977	9°14'20.1438
902	53'48'40.9416	9'12'48.8308
940(1)*	53'49'7.6007	9'12'52.5051
940(2)*	53°49'8.5769	9°14'9.6537

Table 1 specifies the co-ordinates of the microphone locations in March. For September the locations were closely the same in terms of coordinates, but slightly different in relation to possible sound source of human activities. This is presented in Figure 3, which intends to give an impression of the surroundings of the microphones

Figure 3: View on the single microphone sites during the measurement in march 2021. At the beginning of the measurements all six microphones were placed together to intercalibrate them in terms of sound pressure level as well as their internal clocks (upper right frame).

3. RESULTS OF THE FIRST TWO MEASUREMNET CAMPAIGNS

To reflect the meteorological situations, Figure 4 represents the wind speed and direction measured with a LIDAR system on site in two different heights i.e. 60 and 100m agl. respectively. During the two days in March (Top) the wind situation was relatively constant without strong variations. Wind blowing from western directions and wind speed varying around 5m/s. In September (bottom) there was much more fluctuation in both direction and speed.

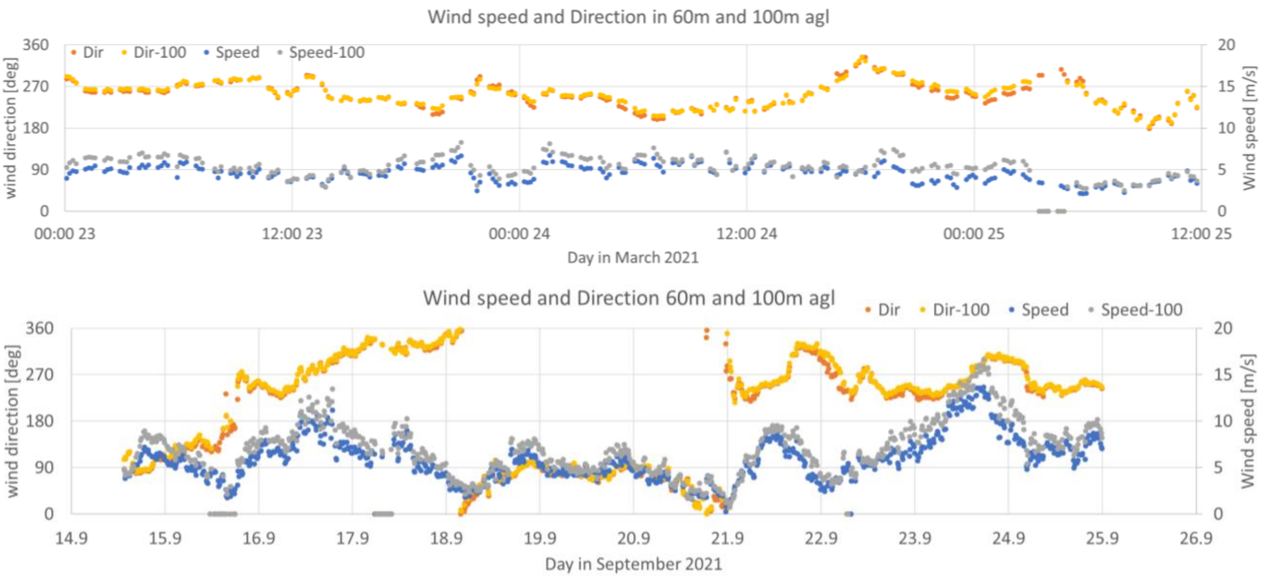

Figure 4: wind speed and direction measured with a LIDAR system on site in two different heights i.e. 60 and 100m agl. Respectively. Top measurements in March 2021 bottom in September 2021

The total results for the measurements in March 2021 are presented in Figure 5 on the righthand side. According to the expectations described before. The loudest locations are around microphone 181, 174 and 187. The lowest noise level was recorded at microphone 902 and 200A. Microphone 940 was located at two positions and represents here an average of both measurements. The high level could be explained due to influence of pump house close to microphone 181.
Nevertheless, the measured avg. SPL is higher than the calculated SPL presented in Figure 2. Also, the difference between the results at single microphones does not match very well.

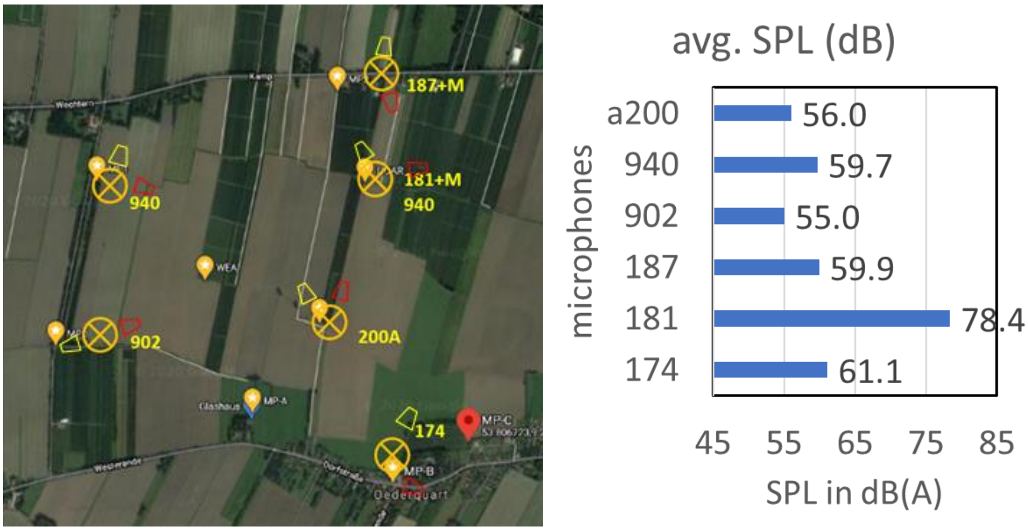

Figure 5.: Set-up of microphones in the Krummendeich test field in March 2021 and their average sound pressure level

During14th to 19th of September 2021 the campaign from march was repeated more or less. The microphones were placed at nearly the same positions as in march. Different weather conditions were expected, as well as different human activities in the area. The farmer's tasks on his field and the construction work on the building site have changed.

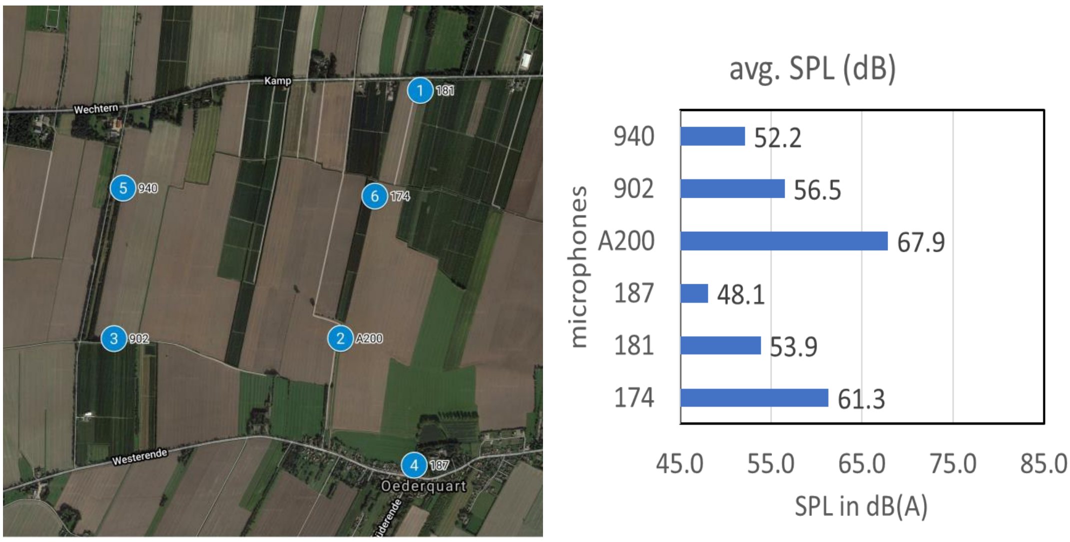

Figure 6.: Set-up of microphones in the Krummendeich test field in September 2021 (left) and average SPL

A comparison of measurements taken in March and September presented in Table 3 reveals significant variations between individual sites. These variations are likely due to different factors shortly mentioned in the table under notes and explained later.

Table 2: Comparison of the sites sound pressure level:

MP Nr.	**Identification name**	**Station number (March/Sept)**	**March - Avg SPL [dB(A)]**	**Sept. - Avg SPL [dB(A)]**	**Diff in dB(A) (Sept.-March)**	**Note**
MP-1	Kamp	187 / 181	59.9	53.9	-6	slightly diff. position
MP-2	Apfelgarten	200A	56	67.9	11.9	Rain; mic malfunction
MP-3	Infotafel	902	55	56.5	1.5	Ok
MP-4	Oederquart	174/187	61.1	48.1	-13	diff. position
MP-5	Neue Chausse	940	59.7	52.2	-7.5	Different time range
MP-6	Pumpenhaus	181/174	78.4	61.3	-17	Different position

A deeper understanding of the specific measurements and site characteristics of each station is required to determine the exact cause of each difference.

Explanations in detail:

1. MP-1: The Position of the microphone was changed a bit away from the main road and closer to the newly built entrance to the Wind Park. Larger distance from the main road may cause a lower SPL.
2. MP-2: Due to the heavy rain in September, the microphone in the quiet area was unfortunately damaged and did not measure valuable noise. The higher values in September are not reliable.
3. MP-3: The best coincidence of both measurements, small difference between March and September at this location.
4. MP-4: Although the position was only changed by perhaps 100m, the sound conditions are completely different. In March, the measurements were influenced by the restaurant's cooling system. We tried to eliminate this in September by increasing the distance to the restaurant. Furthermore, influence of nearby buildings strongly screen the sound from roadside in the village. Special attention must be paid on this.
5. MP-5: As already mentioned, the measurement of microphone 940 consisted of two measurement phases in March, which is why the values were higher than those in September.
6. MP-6: This was the largest shift of position between the two measurement phases. Whereas in March the microphone was placed really close to the pump house, in September we tried to avoid this strong influence and placed the microphone as far as our power supply reached. The new distance to the pump house of about 120m revealed in clearly lower noise values.

To conclude from the data and to prove the above explanations one need to deepen the data analysis into special and short time phases as well as to regard the spectral distribution of the noise events.

As an example, the diurnal cycle of measurements on 20.09.2021 for the Station 181, located close to the main road 'Kamp', present the parameters LAeq (red) and LAeq (1h, green) from the original File L8.SVL - Logger results. Figure 7 shows the diurnal variation of noise, which is determined mainly due to two causes: a) human activities and road traffic and b) correlation with the diurnal variation of wind speed, which causes e.g. the noise of rustling trees. Road traffic noise by passing cars is clearly visible with the sharp peaks during night time hours. The lowest SPL values can be observed during 0:00 and 4:00 with ca 25 dB(A), what is really quiet.

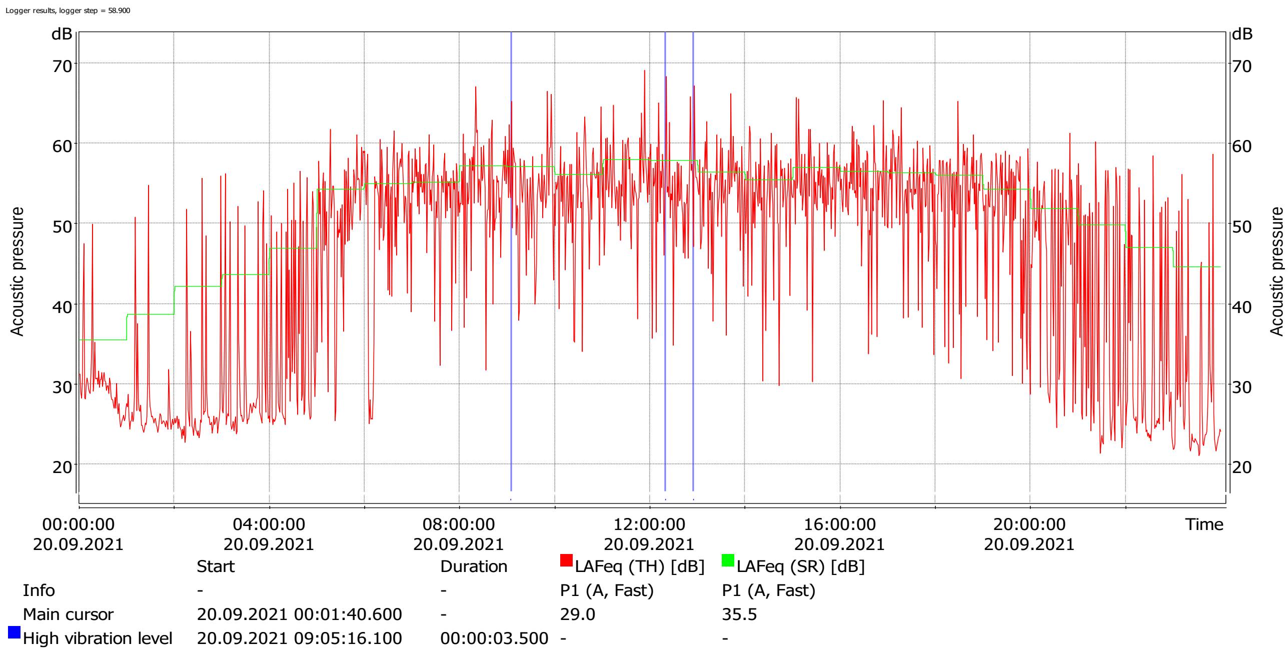

Figure 7: Sound Pressure Level (SPL, red) on 20.09.2021 with high temporal resolution and 1h-averaged SPL (green). Blue lines indicate noise events, where the trigger caused sound file wav-recording.

Day and night SPL at the different microphones in March and September show, that during night the SPL is generally lower than during the day, what was confirmed in phase 3.

4. RESULTS OF THE THIRD MEASUREMNET CAMPAIGN

The third phase was provided from 23. – 29. March 2023. The MET-masts were erected and the WT was under construction. The measurements were provided only with two microphones and intended to demonstrate the influence of the MET-mast on the sound field. Here we analyzed less the local aspects in the field, but more to temporal variation between day (6:00-18:00) and night (18:00-6:00). As one can observe overall the nighttime mostly was less loud than the daytime. Table 3. Presents the avg SPL for that campaign.

Table 3: total avg SPL for day and nighttime conditions during March 23rd – 29th

	Total (24h)	**DAY 6 - 18**	**Night 18 – 6**
SV-181	54.74	56.27	51.49
SV-187	51.13	53.30	45.55

Figure 8 demonstrates the daily difference between day and nighttime for both microphones (top: 181 and bottom: 187, respectively). As one can observe, there are nights that are louder than the day (Saturday, Sunday at microphone 181). In working day cases, during the day the SPL is higher than during the night.

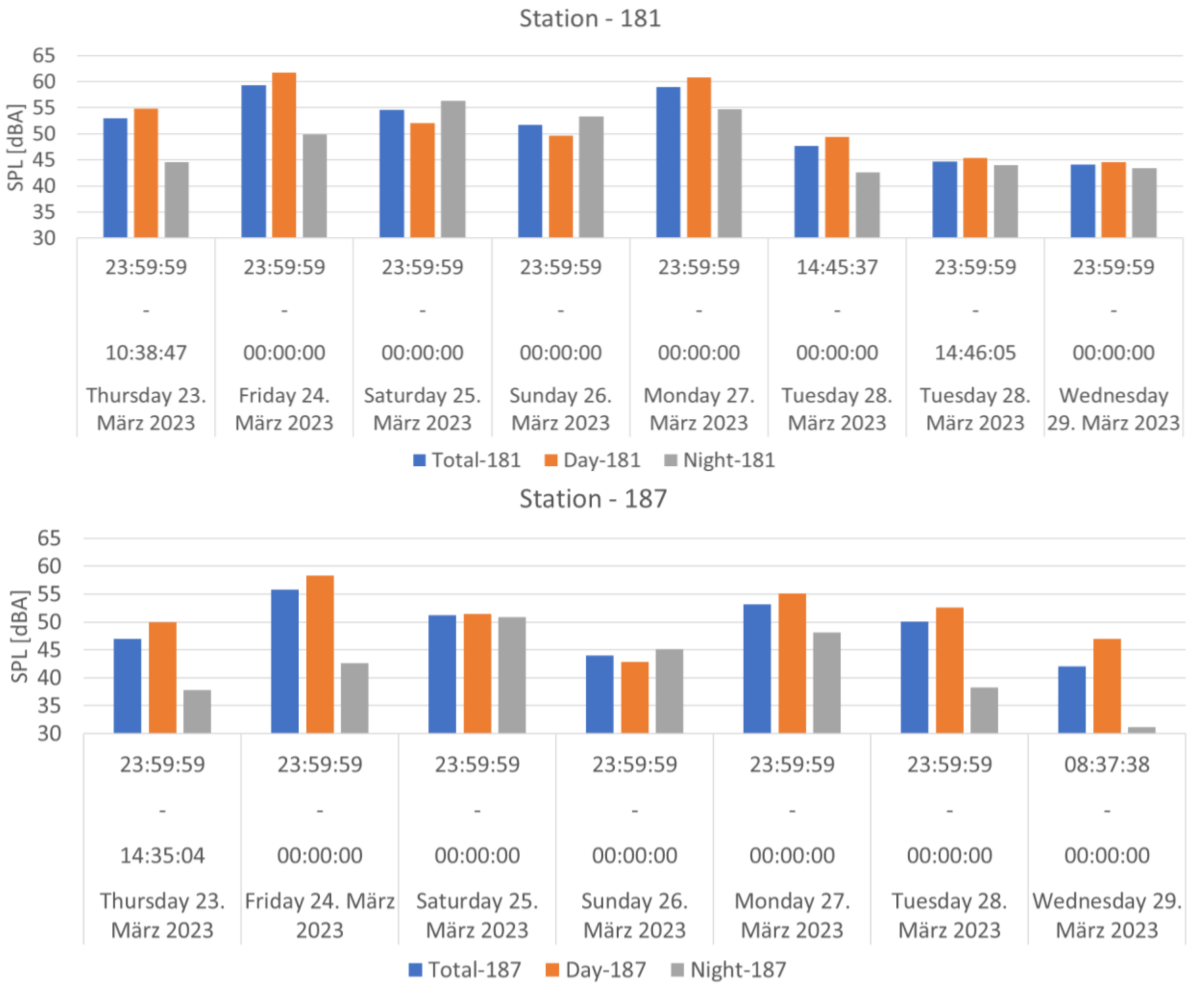

Figure 8.: daily variation of sound pressure level (SPL in dBA) comparing day and night. Microphone 181 location closer to the MET -mast

4.1. Special sound sources

To understand the reasons for different results from the measurement data itself, one must look into details during the measurements. The notes of single exceptional events (e.g. airplane overflight, agricultural activities, etc.) causing higher noise values might be helpful. Further, the spectral signature of noise events and if detectable time synchrony of noise events at different locations is helpful to understand the variability in these noise measurements.

Figure 9 and Figure 10 show the frequency dependent SPL along a certain time. At both microphones one can observe an increased level around 7:00 over all frequencies. Figure 9 contains in the opposite to Figure 10 also low frequency noise below 31.5 Hz. Also in Figure 9 closer to the mast one can observe certain frequencies (around 315Hz or 1000Hz) with generally higher values than at Station 187 (Figure 10).

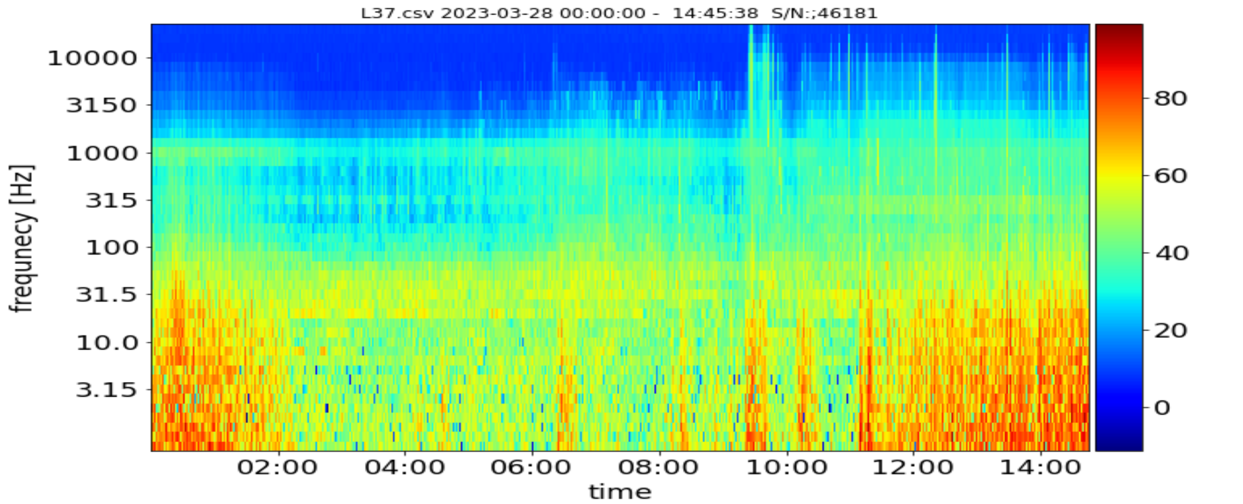

Figure 9: Spectrogram with a frequency range from 3.15 Hz to 10kHz at Station SV-181 close to the MET-mast in the timeframe from 0:00 – 14:38 .

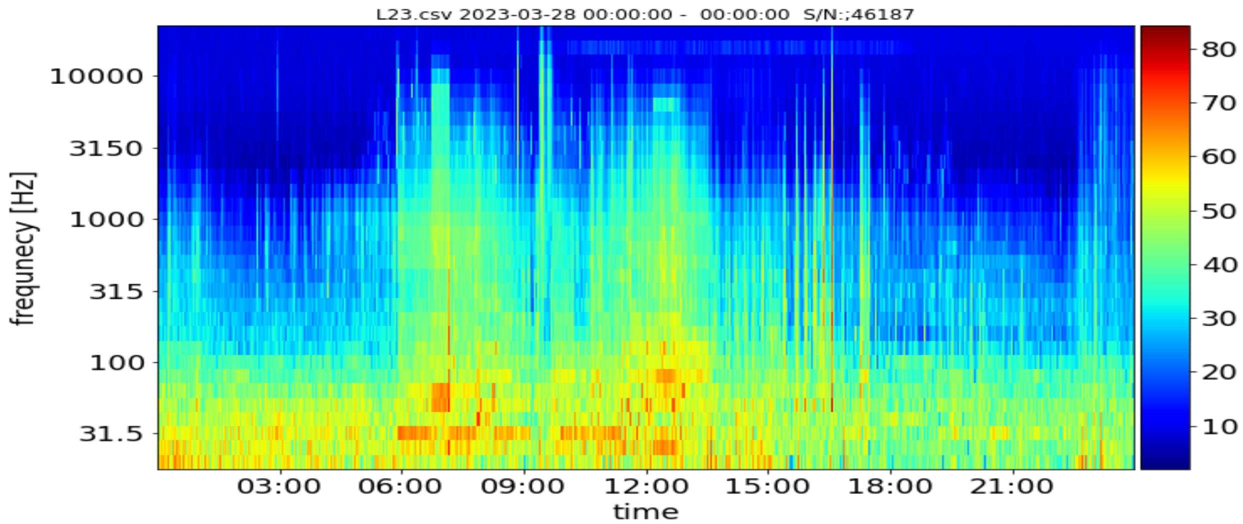

Figure 10.: Spectrogram with a frequency range from 31.5 Hz to 10kHz at Station SV-187 about 250m away from the MET-mast mast in the timeframe from 0:00 – 23:59.

5. CONCLUSIONS

This article illustrates how all our measurements are used to create a consistent picture of the noise situation around the wind park depending on specific weather situation and discusses the need of accuracy. We document the limitations and uncertainties associated with the measurements and show these limitations when interpreting and reporting the results to ensure users in understanding the reliability and confidence level of such data.
The results achieved can be summarized as follows:

- Representativity: Positioning of microphones in the vicinity of special sources as roads, trees, machines (pump) can alter the measurement up to 10 dB, when changing this position by 100m further away from the source.
- Meteorological influence (wind direction) could not be proven during analysis and measurement,
- Rain significantly disturbs the measurement
- Lowest sound pressure levels (quietness) was found to be about 25dB at night for short time range.

- Single noise events can only be identified by recording the sound and listening to the event or by good logging and probably good notes.
- Using engineering models to reflect the general sound situation, one needs good input data of buildings and traffic density
- For analysis of sound events one need high temporal resolution of measurement and taking short time range (about 3 Minutes) into account. The time stamp of the measurement should be proven exactly

ACKNOWLEDGEMENTS
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