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Noise propagation at short range farfield position investigated by simultaneous measurements in the nearfield and the farfield.

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Summary

To improve the accuracy of propagation models for long distance sound propagation it is important to compare measurements and predictions for different factors that affect the sound propagation, such as atmospheric conditions and terrain. A common problem in performing long distance measurements on a sound source is obtaining a good signal-to-noise ratio. This paper compares measured and calculated values at 500 m distance from a single wind turbine located at a test site. Comparisons are made for a range of wind speeds under monitored atmospheric conditions.

1. Introduction

Part of the environmental noise assessment of wind farms involves using propagation models to predict the sound pressure level (SPL) at neighbour dwellings at distances located at distances from around 500 m from the wind farm. This paper compares measured and calculated SPL at a position 500 m downwind from a wind turbine located at Test Centre Høvsøre, Denmark. The advantage of the test site is the possibility to stop all other turbines in the farm for a long period of time while performing measurements on a single turbine. Further, the test site at Høvsøre has meteorological masts which record details about atmospheric conditions at several heights above ground. Finally, test sites are generally chosen in places with low background noise which is critical for obtaining a good signal-to-noise ratio when measuring at a long distance from a sound source.

This paper presents comparisons between measured and calculated results for the SPL at 500 m downwind from a single turbine. Prediction were made using a simple transmission loss method described in the Danish statutory order for wind farms (BEK 1736), as well as the NORD2000 propagation model. For commercial reasons, no turbine specific details are provided in this paper. For this reason, only level differences are shown.

2. Wind Turbine Test Centre

2.1 General

Measurements were carried out from 17:15 on December 18. 2018 to 01:20 on December 19. 2018 on a wind turbine at Test Centre Høvsøre, Denmark. The site is in flat, rural farm land close to the seashore far from major roads and other noise sources. There are 4 additional turbines on the site, which were stopped during the measurements.

2.2 Weather conditions during measurements

Weather data for the site were provided by the Department for Wind Energy at The Technical University of Denmark (DTU). These include readings of temperature and relative humidity in both 2 m and 100 m height in addition to wind speed measurements at 10, 40, 60, 80, 100 and 116.5 m height. Data with a resolution of 10 minutes exists for the entire measurement period. The range of weather conditions during measurements is shown in Table 1.

Table 1. Recorded weather conditions during measurements.

December 18. 2018 – December 19. 2018					
Height above ground	Temperature [˚C]	Relative humidity [%]	Atmospheric pressure [kPa]	Wind speed [m/s]	Wind direction [Degrees]
2 m	4.5 – 5.4	89.7-96.4	99.5-99.9	-	-
10 m	-	-	-	4.5 – 8.1	127 - 158
100 m	3.8 – 4.7	91.5-98.0	100.2-100.6	7.6 – 11.6	132 - 161

2.3 Measurement setup

Two microphones were placed downwind of the turbine, one in the standard IEC 61400-11 ed. 3 (IEC) measurement position, and the other 500 m from the turbine at 1,5 m height. Operational parameters were streamed from the turbine and used to determine the wind speed at hub height according to IEC. The turbine was stopped 3 times to measure background noise. An anemometer placed at 10 m height was used to determine the wind speed during background noise measurements. Weather data with 10 min resolution was assumed constant over each 10 min interval. All measurements were synchronized. Periods with high transient background noise at either the reference or the 500 m position were discarded from the analysis. Time periods were identified as total noise or background noise in the analysis. It was too dark to take pictures during measurements; however, examples of the setup from similar measurements on other sites are shown in Figure 1.

Figure 1. Examples of microphone setup at 500 m position (left) and reference position (right).

2.4 Measured Sound Power Levels

The sound power level of the turbine was determined according to IEC. A microphone was mounted on a reflective plate on the ground and placed in the reference distance downwind from the turbine. A secondary wind screen was used. Measured SPL were corrected for the influence of the wind screen in 1/3-octave bands and the +6dB reflection from the measurement board.

2.5 Measured Sound Pressure Levels at 500 m position

The microphone 500 m from the turbine was mounted on a tripod at 1.5 m above the ground. The microphone was placed in open, ploughed farmland with no nearby vegetation or reflecting structures. A secondary wind screen was used. At the time of writing this paper the insertion loss of the secondary wind screen has yet to be accurately determined. Consequently, the results are not corrected for the influence of the wind screen.

3. Results

Results from the measurements are averaged over 1-minute periods. All SPL's are A-weighted. In general, the simple propagation model (BEK 1736) was used to predict the SPL, $L_{pA,BEK\ 1736}$, at 500 m from the turbine based on the sound power level, L_{WA}, of the turbine.

3.1 Background noise

Figure 2 shows a time series plot of the wind speed and background noise during the measurement period. The measured background noise was lower at the 500 m position than at the reference position. This is probably due to noise from the turbine cooling fan which is less pronounced far from the turbine. However, there is a better signal-to-noise ratio (SNR) at the reference position, than at the 500 m position since the turbine noise is more prominent close to the turbine. For both positions the background noise increases with wind speed. Particularly at high wind speeds there is a poor SNR at the 500 m position. To rule out the influence of wind speed in the comparisons, results were split into 0.5 m/s wide wind speed bins.

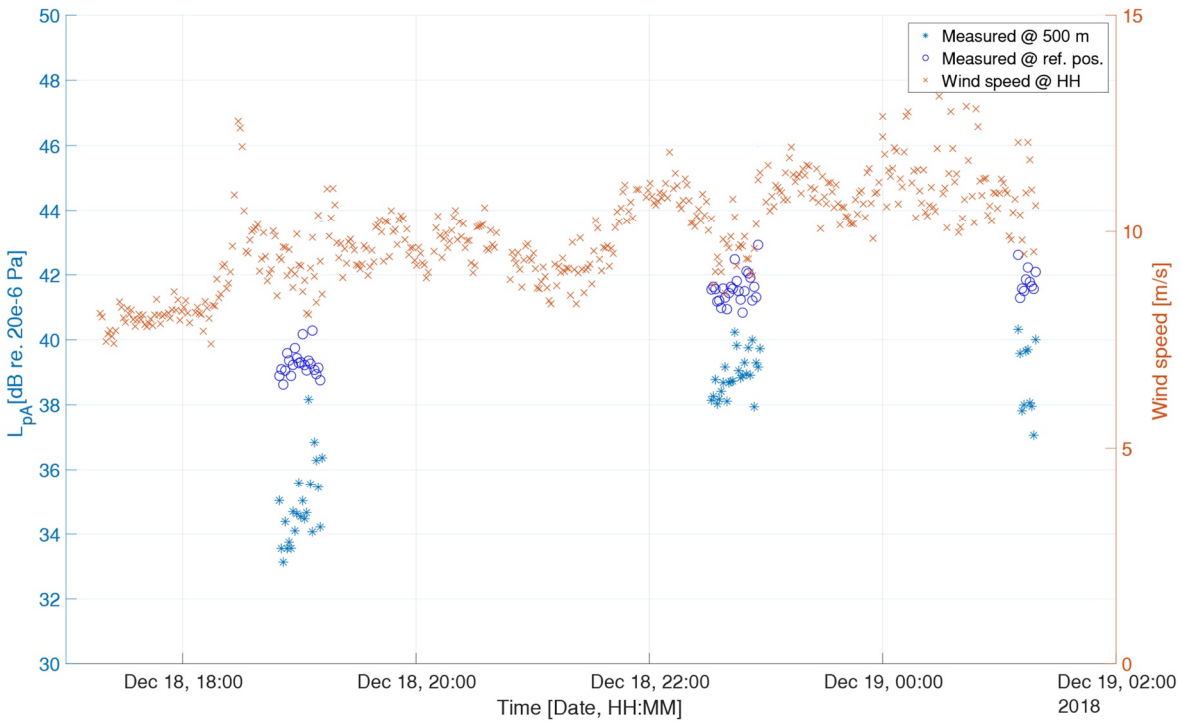

Figure 2. Time series plot of hub height wind speed and background noise levels.

3.2 Comparing 1/3-octave band spectra

For each wind speed bin all 1-minut periods of total noise were corrected for the bin average of the background noise in 1/3-octave bands. The average 1/3-octave SPL in each bin was determined. Figure 3 shows the difference in measured and predicted SPL at 500 m, $L_{pA,meas,f}$ - $L_{pA,BEK\ 1736,f}$, as a function of frequency. Above 3 kHz the predicted SPL at 500 m is small compared to the directly measured SPL. This is because air absorption increases drastically above 2 kHz. This results in predicted levels far below background noise in 500 m measurement at high frequencies. Therefore, 3.15 kHz is chosen as the upper limit for the comparisons. For hub height wind speeds below 10 m/s there is a fairly good agreement between $L_{pA,meas,f}$ and $L_{pA,BEK\ 1736,f}$. At 11 m/s $L_{pA,meas,f}$ is dominated by background noise, resulting in an overestimation of the turbine noise. Based on experiences with the insertion loss of secondary wind screens like the one used in the 500 m measurement, it is thought that the dip in ΔL between 1 to 4 kHz can be explained by the lack of a wind screen correction. However, this needs further investigation.

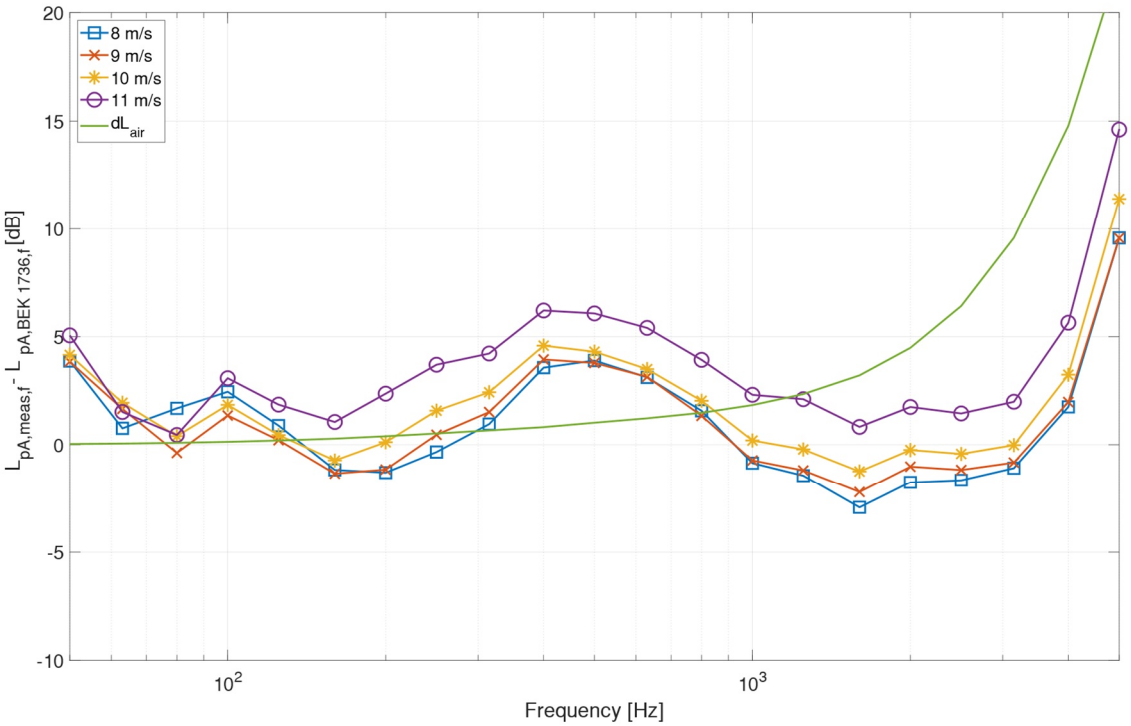

Figure 3. Difference between measured and calculated (BEK 1736) 1/3-octave SPL as a function of frequency. The predicted air attenuation, dL_{air}, is shown for reference.

3.3 Comparison between total levels

The total measured and predicted SPL's were calculated as the sum over 1/3-octave bands from 50 Hz to 3.15 kHz for each 1-minut period. A time series plot of the difference between the measured and calculated total SPL's, in addition to hub height wind speed, is shown in Figure 4. We can observe that ΔL is sensitive to changes in wind speed. Since the prediction model is independent of wind speed, the changes are likely the result of increasing background noise at the measurement position as wind speed increases. There is an abrupt change in ΔL around 21.00-22.00 o'clock when the wind speed exceeds 10 m/s. Since the wind speed was low during daytime and high during night-time it is not possible to do a day-night comparison of the level difference in wind speed bins. However, based on the increase in level difference during high wind periods during daytime, it is more likely that the change is caused by the increasing wind speeds than day-night differences.

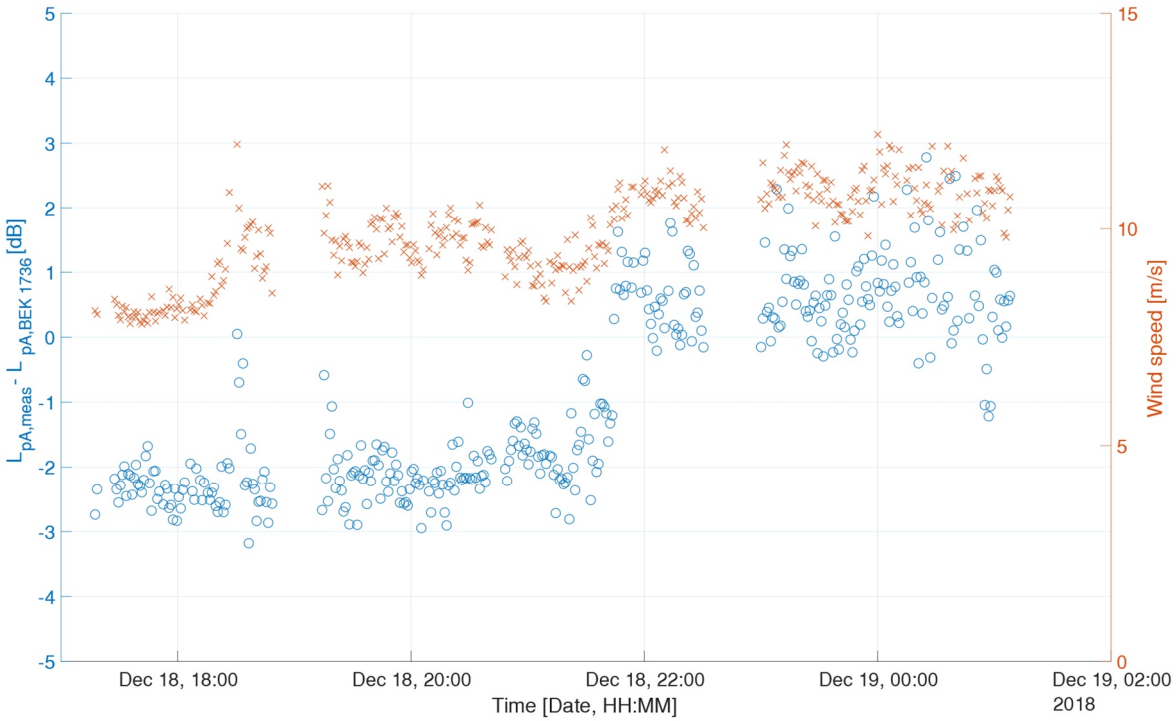

Figure 4. Time series of the difference between measured and predicted SPL and hub height wind speeds.

The air density was calculated from the from the measured temperature and pressure at 100 m height, using the ideal gas law. ΔL as a function of the calculated air density for wind speed bins from 8 m/s to 11.5 m/s is shown in Figure 5 and Figure 6.The results indicate that there could be a tendency towards lower values of ΔL with increasing air density.

The wind shear factor was calculated from the difference between the hub height wind speed and the wind speed measured at 10 m. ΔL as a function of the wind shear factor for wind speed bins 8 m/s to 11.5 m/s is shown in Figure 7 and Figure 8. Increasing wind shear factor means relative higher wind at hub height compared to wind at 10 m height. Thus, one would expect to see increasing values for ΔL with increasing wind shear due to low background noise near the ground and increased sound emission from the turbine. However, there is no observed influence of the wind shear factor on ΔL.

The relative humidity (RH) was measured in 2 m height above ground by the test centre meteorological mast. ΔL as a function of the RH for wind speed bins 8 m/s to 11.5 m/s is shown in Figure 9 and Figure 10. The variations in RH during measurements was small. There is no clearly observed correlation between ΔL and RH.

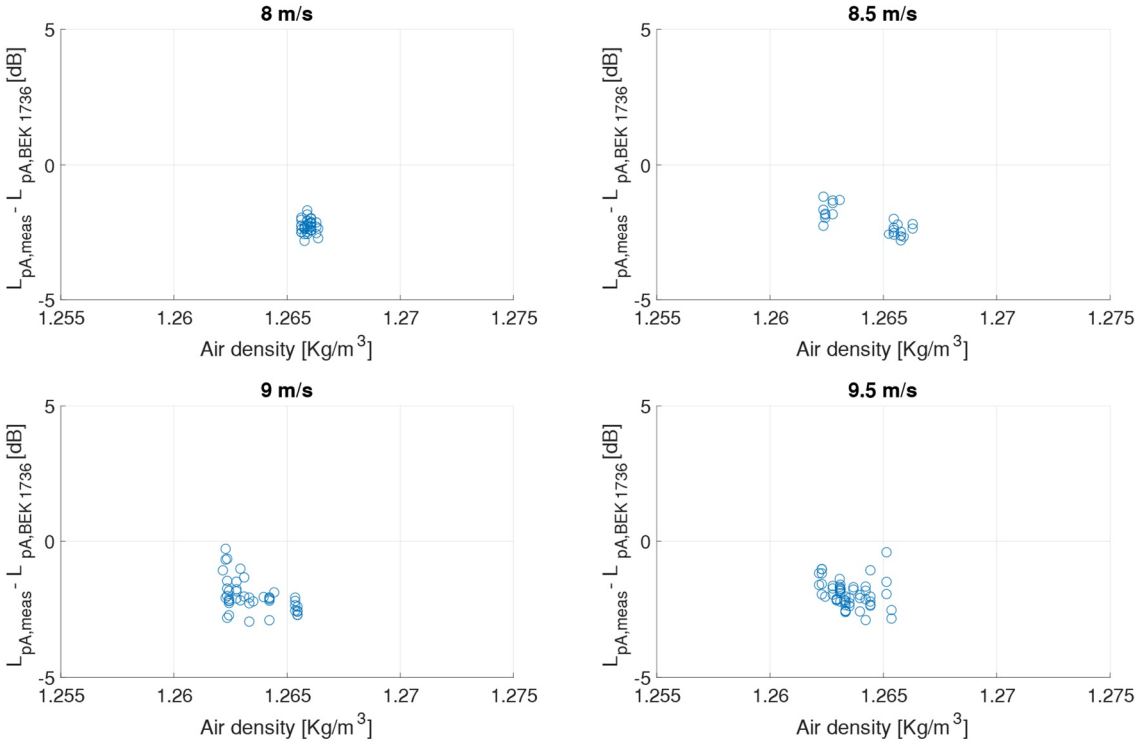

Figure 5. Difference between measured and predicted SPL as a function of air density for hub height wind speeds 8 m/s to 9.5 m/s.

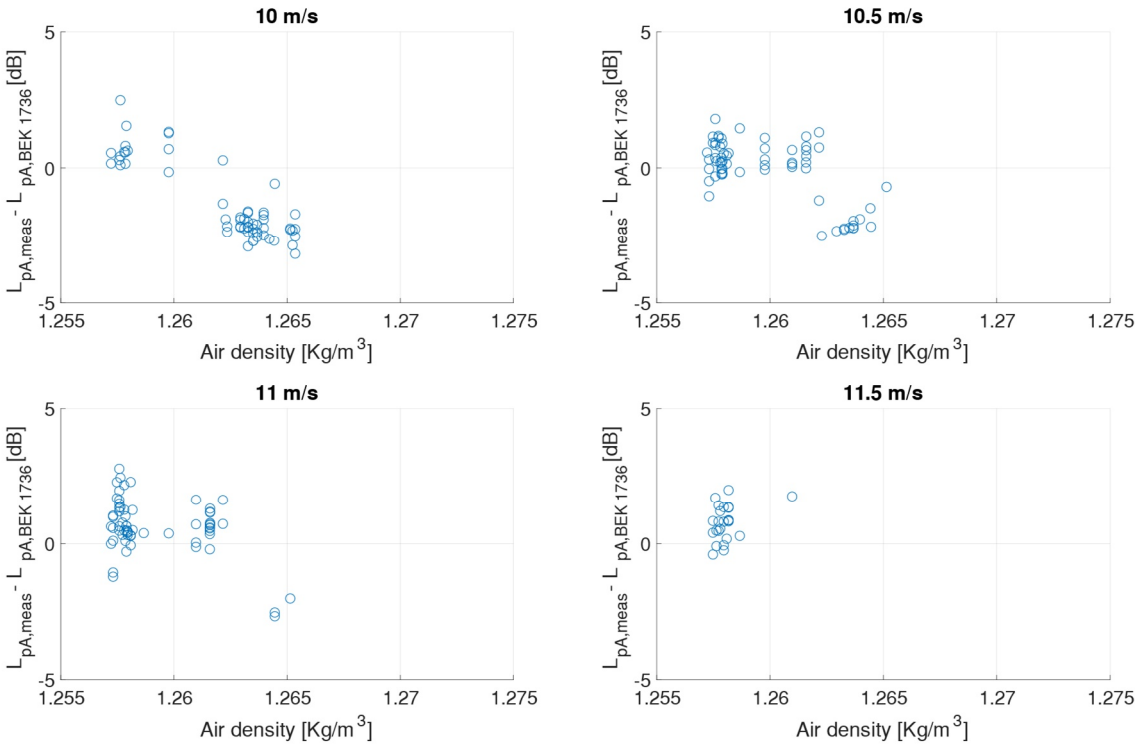

Figure 6. Difference between measured and predicted SPL as a function of air density for hub height wind speeds 10 m/s to 11.5 m/s.

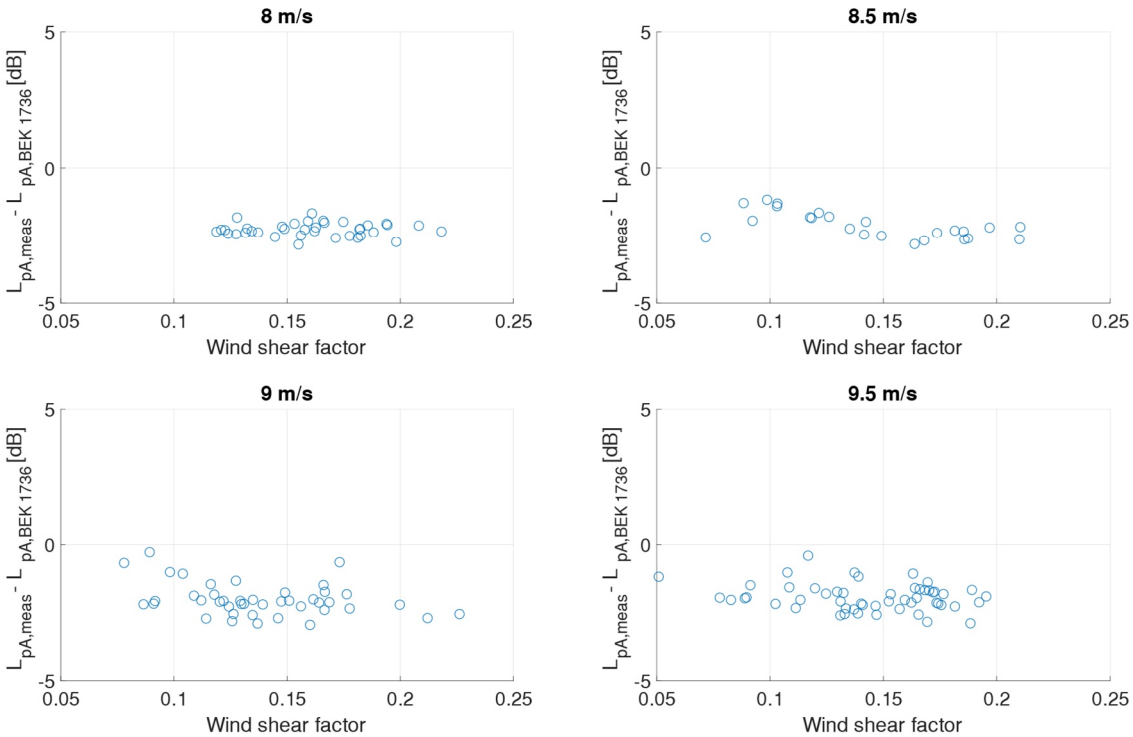

Figure 7. Difference between measured and predicted SPL as a function of wind shear factor for hub height wind speeds 8 m/s to 9.5 m/s.

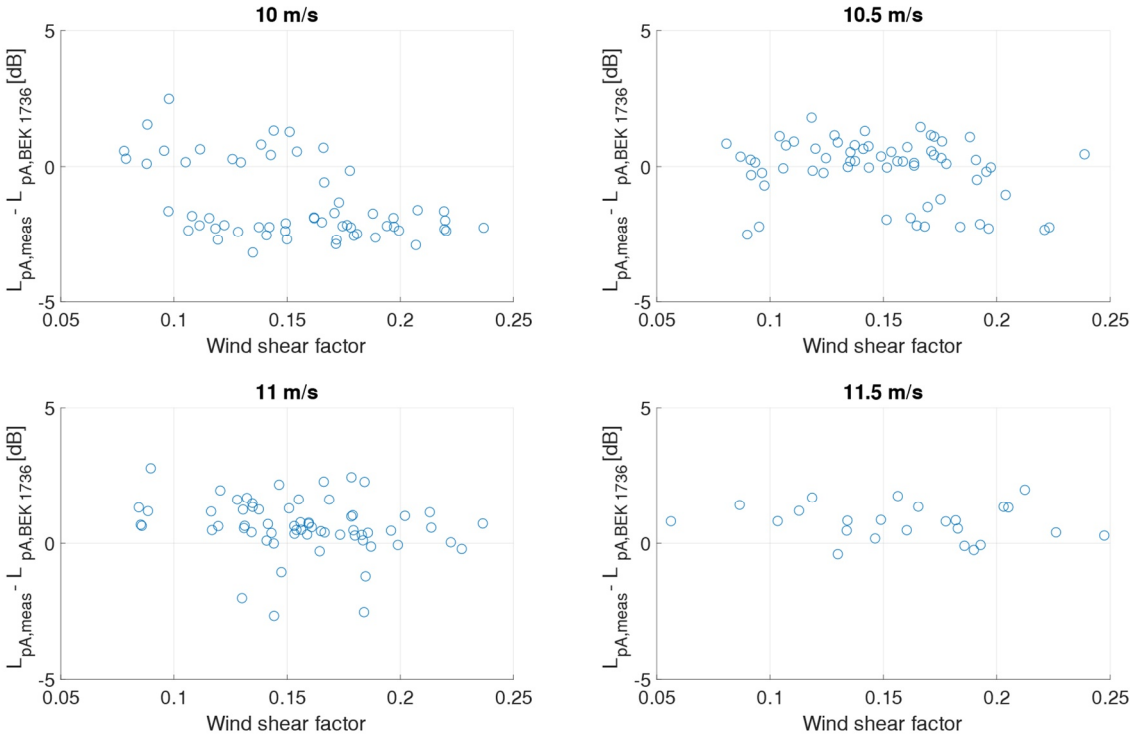

Figure 8. Difference between measured and predicted SPL as a function of wind shear factor for hub height wind speeds 10 m/s to 11.5 m/s.

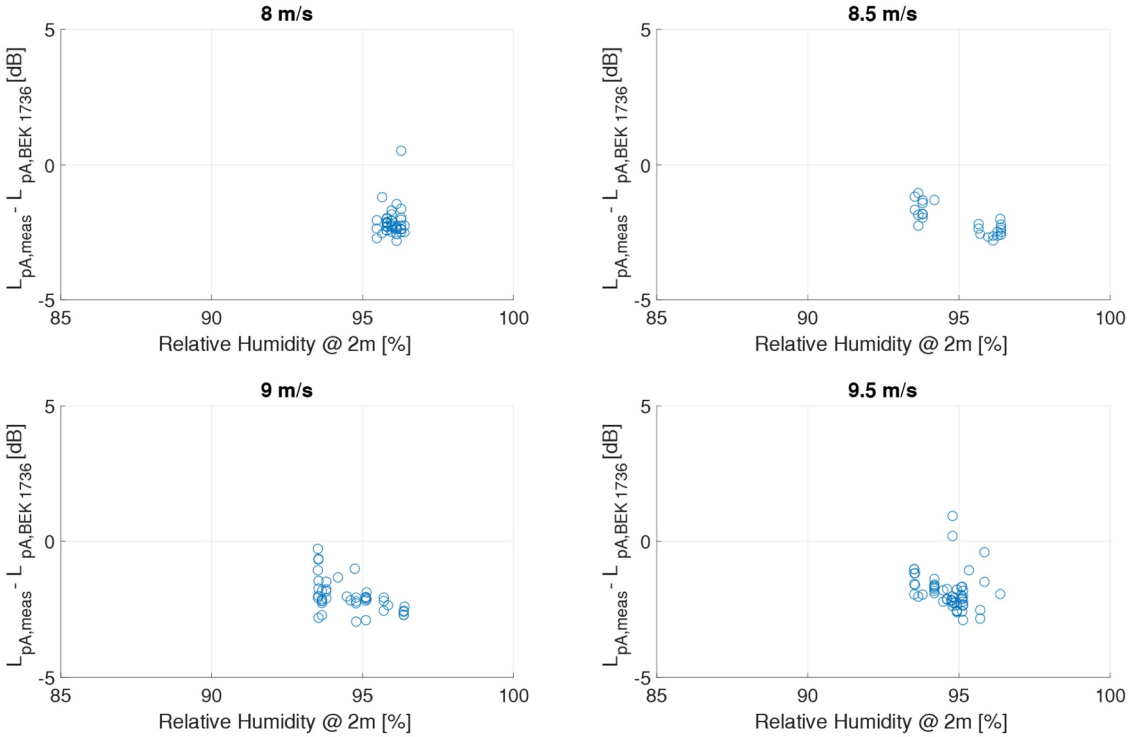

Figure 9. Difference between measured and predicted SPL as a function of relative humidity at 2 m for hub height wind speeds 8 m/s to 9.5 m/s.

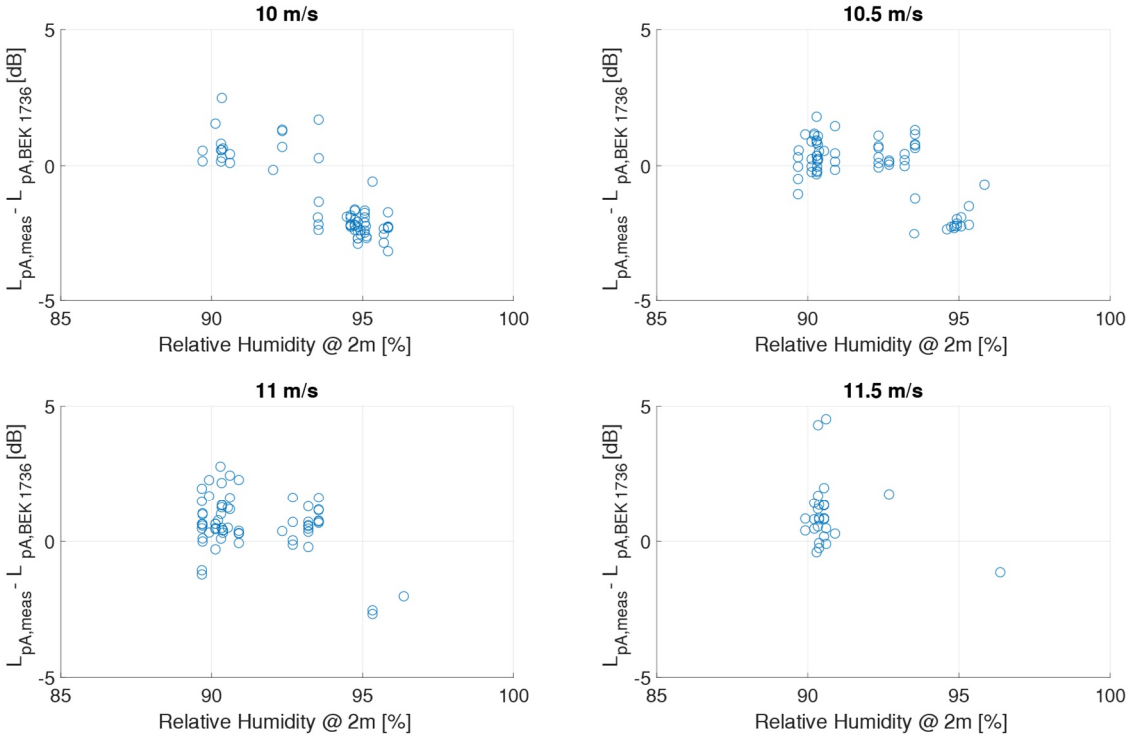

Figure 10. Difference between measured and predicted SPL as a function of relative humidity at 2 m for hub height wind speeds 10 m/s to 11.5 m/s.

3.4 Comparing BEK 1736 and NORD2000 results

A SoundPlan 8.0 model implementing the NORD2000 method was set up. The wind turbine was input as a point source placed at hub height. To compare the prediction method to the measurement with the best SNR, calculations were performed for 8 m/s hub height wind speed. The average values of temperature, atmospheric pressure, relative humidity and temperature gradient were calculated for the 8 m/s bin and input to the model. The input parameters are shown in Table 2.

Table 2. Input parameters for the NORD2000 predictions model.

Wind speed [m/s]	Temperature [˚C]	Relative humidity [%]	Atmospheric pressure [kPa]	Relative humidity [%]
8	5	93	99.7	93
Roughness length [m]	Flow resistivity [kNsm^{-4}]	Temperature gradient [˚C]	C_w^2 [m$^{4/3}$s^{-2}]	C_t^2 [Ks^{-2}]
0.05	80	-0.07	0.12	0.008

The differences between measured and predicted results using BEK 1736 and NORD200, respectively, are presented in 1/3-octave bands in Figure 11. The disagreement of the models around 200 Hz can be explained by the fact that BEK 1736 has a simple constant terrain correction of +1.5 dB, whereas the NORD2000 model predicts a decrease in SPL caused by interference with the ground reflection, depending on the relative height of the receiver above terrain. The NORD2000 method seemingly overestimates the destructive interference caused by the ground reflection.

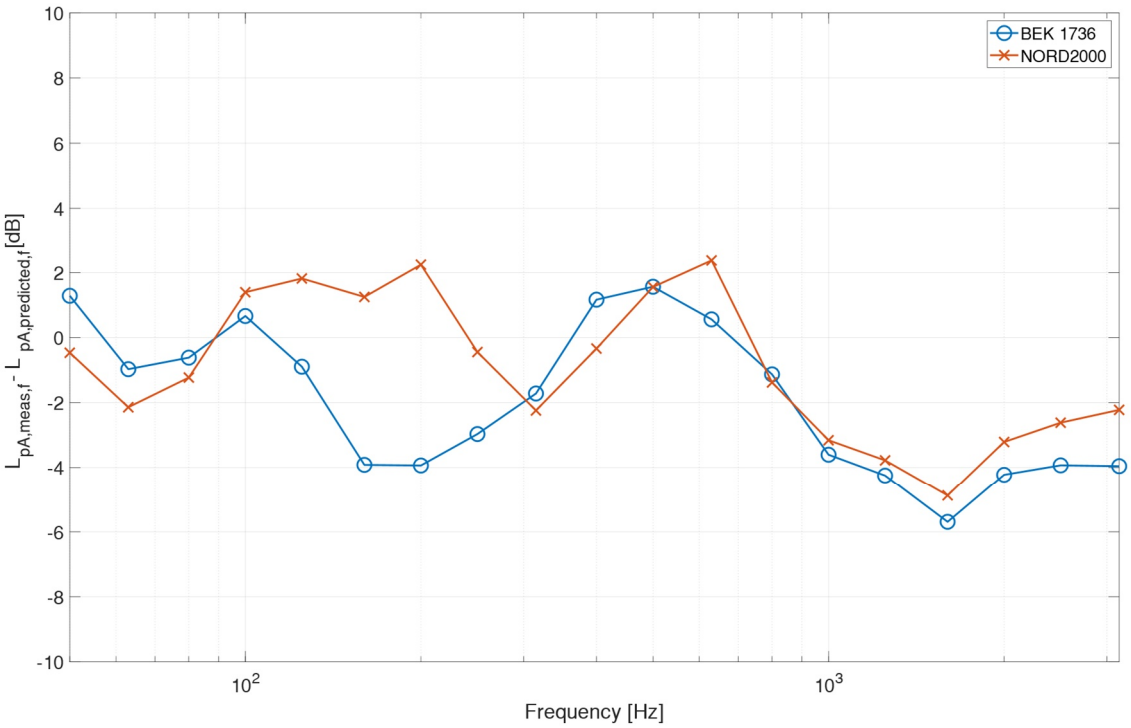

Figure 11. Difference between measured and predicted (BEK 1736) SPL (circled line) and Difference between measured and predicted (NORD2000) SPL (crossed line) as a function of frequency for 8 m/s hub height wind speed.

Both predictions models calculate slightly lower total levels than those measured directly. Part of the explanation is probably the difficulty of obtaining an adequate SNR at 500 m distance from the source, which leads to overestimation of the turbine noise. Another likely explanation is the lack of correction for the secondary wind screen for the 500 m measurement.

4. Conclusions

Comparisons were made between measured and calculated sound pressure levels at 500 m from a single turbine at Høvsøre Test Centre. It was shown that it is possible to get useful measurements by placing a microphone on a tripod at 500 m distance from a turbine. The level difference was sensitive to changes in wind speed due to decreased SNR at the 500 m position for high wind speeds. For future comparative studies it is therefore recommended to choose a far field position which is shielded from the wind. The far field position should be removed from vegetation and other sources of wind generated background noise. Additionally, it is important to use a secondary wind screen to limit wind generated noise in the microphone. The comparisons showed poor agreement between measured and predicted levels above 3.15 kHz due to air absorption. For calculating total levels, it is therefore recommended to limit the upper frequency to between 3-4 kHz. The measured 1/3-octave SPL from 1-4 kHz is lower than the predicted SPL. This is believed to be caused by the lack of correction for secondary wind screen for the 500 m measurement. Future work will necessitate determining the insertion loss of the secondary wind screen. The difference in measured and predicted total SPL's showed either no or very small correlations to the atmospheric conditions. Future work should aim to acquire data with a wider range of atmospheric conditions to draw conclusions on the accuracy of the propagation models for varying meteorology.

5. Acknowledgements

We would like to thank Siemens Gamesa Renewable Energy A/S for allowing us to use data from the measurement.

We would like to thank DTU Wind Energy for providing weather data from the test site.

References

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[2]. The Danish EPA, 2015 BEK 1736 Bekendtgørelse om støj fra vindmøller. (Statutory Order on Noise from Wind Turbines; Statutory Order no. 1736).