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Long term hydro sound measurements at the Alpha Ventus offshore wind farm focussing on pile driving noise

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Abstract

At the end of June 2009 a hydro sound recording system was installed at the FINO 1 platform which is close to the first German offshore wind farm Alpha Ventus. Since then the system has been continuously recording underwater sound with high resolution. The hardware concept allows to handle both “sea state zero noise” and “pile driving noise” by using two hydrophones with different saturation.

Data archived up to now covers construction noise of Alpha Ventus wind turbines and pile driving noise from other distant offshore installation works. Detection criteria for pile driving noise were elaborated based on evaluations of several hydro sound measurements performed since 2003 in the German Bight and the Baltic Sea. The sound recordings were scanned for construction noise and provide an extensive pool of data for the current research project HYPROWIND. Combined with data from temporary measurements of wind farm construction noise this underwater sound data base is interesting especially with regard to improvements of sound propagation calculation methods and is also able to provide data for consideration of cumulative effects within extended construction periods.

These experiences help to optimize future monitoring systems for offshore wind turbine construction noise, which are planned to be installed as part of further research projects.

Introduction

During the installation of offshore wind turbines significant emissions of underwater noise are radiated into the marine environment. This noise and the methods of avoidance are currently a major subject in the planning permission process of offshore wind farms in Germany. Especially during pile driving, hydro sound potentially might cause temporary (TTS) or even permanent threshold shifts (PTS) to marine animals. Potential banishment out of their common habitat or physical damage might harm sensitive marine mammals.

Hydro sound measurements during offshore wind farm construction works are often hard to realize and cost intensive due to the weather depended time schedule of installation works. An effective acoustic monitoring of offshore construction and operation noise requires a long term recording system, which is able to operate stand-alone and can be installed independently of the installation works.

Prior experience with hydro sound measurements

The German wind energy institute DEWI is involved with several research projects dealing with hydro sound from wind turbines [1] – [6] during installation processes as well as during operation. Further topics of the actual investigations are the interactions between physics and biology, standardisation, measurement of source levels, underwater sound propagation and mitigation of pile driving noise.

Figure 1: Alpha Ventus pile driving action

Taking part in working groups together with biologists it became clear that relevant acoustic parameters and evaluation methods have not been clearly defined and standardised yet. Therefore a recording system must allow post processing of any kind. Practical experience with temporary pile driving noise measurements showed that a hydrophone should be installed near the sea floor. Cables and ropes have to be fixed, because any movement might cause structure born noise which has to be avoided. The measurement results and the extrapolation to the dimensions of future wind turbine foundations (e.g. monopiles with more than 5 m diameter) show that the recording system has to be sensitive for background noise as well as for peaks of impulsive sound pressure up to more than 200 dB $_{re\ 1\mu Pa}$.

Conception and realization of the recording system

Because of the high dynamic range, two different hydrophones were chosen for an autonomous underwater sound recording station:

- a “sensitive hydrophone” for background noise and far distant pile driving, which might saturate in cases of pile driving noise from installations nearby and
- a “low gain hydrophone”, specialised for high sound pressure levels expected from near pile driving.

These two hydrophones were mounted in a protective body. The construction takes care to keep the sensors out of turbulences due to tidal stream. Flexible parts like cables and ropes were tightly attached to the construction (Figure 2). The concept includes signal amplifiers to be installed close to the sensors. The “sensitive hydrophone” (Bruel & Kjaer 8106) is a built-in amplifier type and the amplifier of the “low gain” hydrophone (Bruel & Kjaer 8105) is mounted on the ground of the microphone carrier construction.

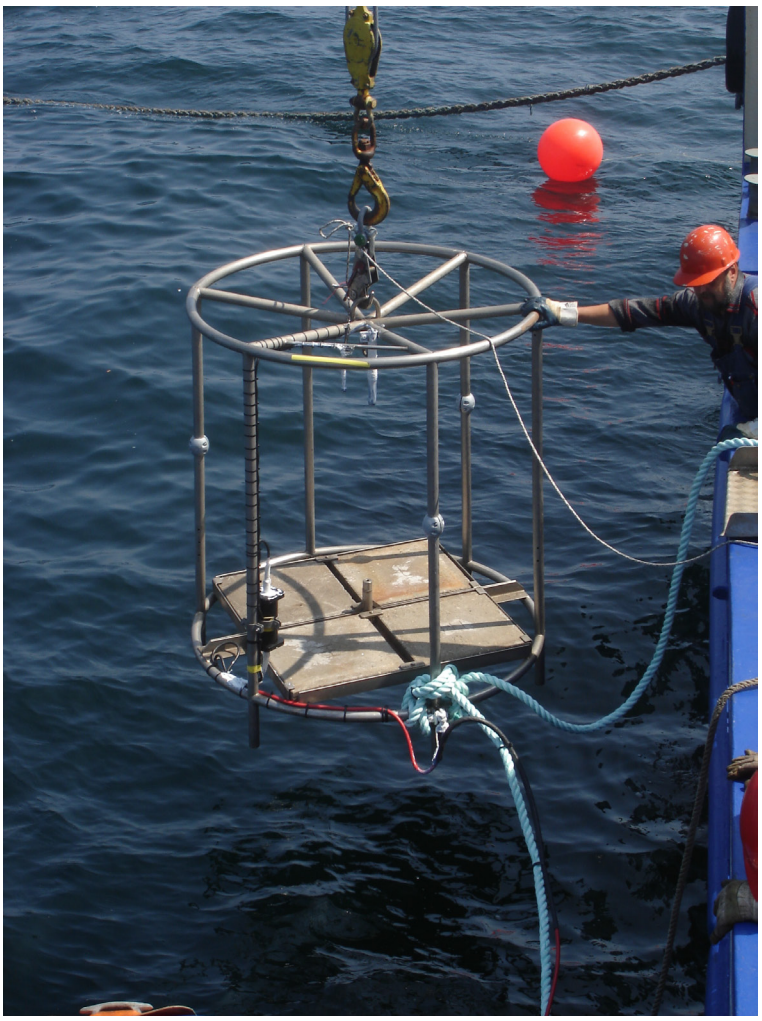

Figure 2: Mount of hydrophones

The hydrophones were installed in the North Sea at 54°0.9’ W, 6°35.32’ E. They were built up by divers at a distance of 75 m from the FINO 1 research platform. FINO 1 stands for the first “Forschungsplattform in Nord und Ostsee” and was set up in 2003 as base for extensive meteorologic and oceanographic measurements. It is sited 45 km north of Borkum island (Figure 3). The installation of the hydro sound measurement station was completed at the beginning of July 2009. Thus until now a nearly complete time series of sound pressure levels of about 16 month was obtained.

Figure 3: FINO 1 platform

One single cable connects the hydrophones and the recording system, which is placed inside the FINO 1 measurement container and is part of the DEWI data acquisition system. The hydrophone signals are continuously stored on hard discs, uncompressed and with a sample rate of 48 kHz and 24 Bit resolution.

The FINO1 research platform is sited close to the first German offshore wind farm Alpha Ventus. The wind farm consists of twelve 5 MW wind turbines, set up in a rectangular pattern. The installation of the foundations was completed in August 2009. The hydrophone position is at a distance of approximately 400 m to the nearest turbine of the wind farm.

The distance to the source of the sound is important information for the interpretation of the measurement results. The position the Alpha Ventus test field and of the hydro sound measurement station is illustrated in Figure 4. Here, blue lines indicate distances between the hydro sound measurement station and possible sources for pile driving as the wind turbines of the Alpha Ventus test field and BARD Offshore 1 which is under construction since March 2010.

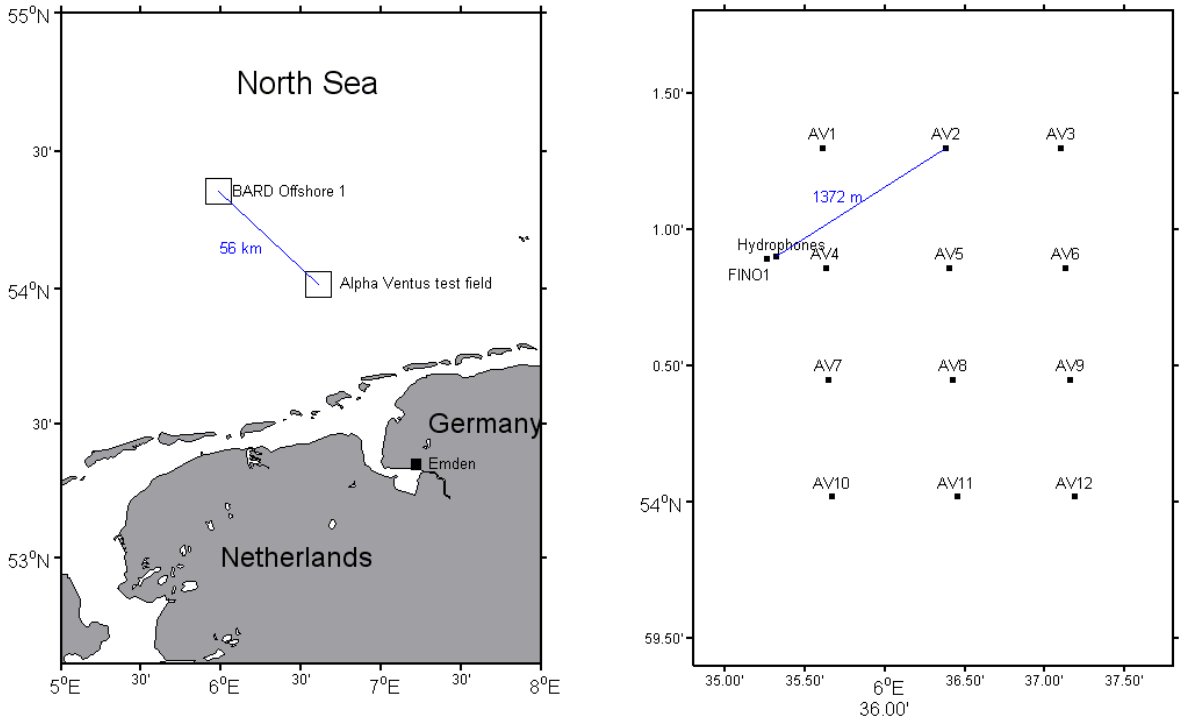

Figure 4: Location of Alpha Ventus test field in the North Sea (left) and position of the hydro sound measurement station and Alpha Ventus wind turbines (right)

Measurement results

The obtained measurements are divided into two topics, depending on the distance of the sound source:

- measurement of long-range sound and
- measurement of pile driving noise coming from neighbouring sources.

In the latter case the installation works of the Alpha Ventus foundations certainly belong to the last category. As Alpha Ventus is a test site, schedules of the works are documented and can be accessed. The installation of the foundations ended at the end of August 2009. Thus any other sound regarded as pile driving noise can be ascribed to far distant works in other wind farms. As far as we know no pile driving was announced after August 2009 and in 2010 except for the BARD Offshore 1 wind farm. The timescale of detected pile driving noise correlates to published notes about the progress of the installation works of the wind farm.

The following illustration Figure 5 presents the statistical distribution of 30-second averages of the equivalent continuous sound pressure levels L_{eq} between July 7, 2009 and August 26, 2009. The data was recorded by the low gain sensor (Bruel & Kraer 8105). During this period of time 4 wind turbines of Alpha Ventus were installed. The highest value at about 130 dB can be identified as close to the lower limit of the “low gain” canals dynamic range. Not visible in this figure, at 130 and 131 dB the total number of hours rises up to 190. In addition enhanced background noise due to general installation activities (e.g. traffic) has influenced the distribution. A further concentration is obvious at sound pressure levels above 150 dB with a maximum at 159 dB, which can be related as pile driving noise. The total time of pile driving is 42.5 h.

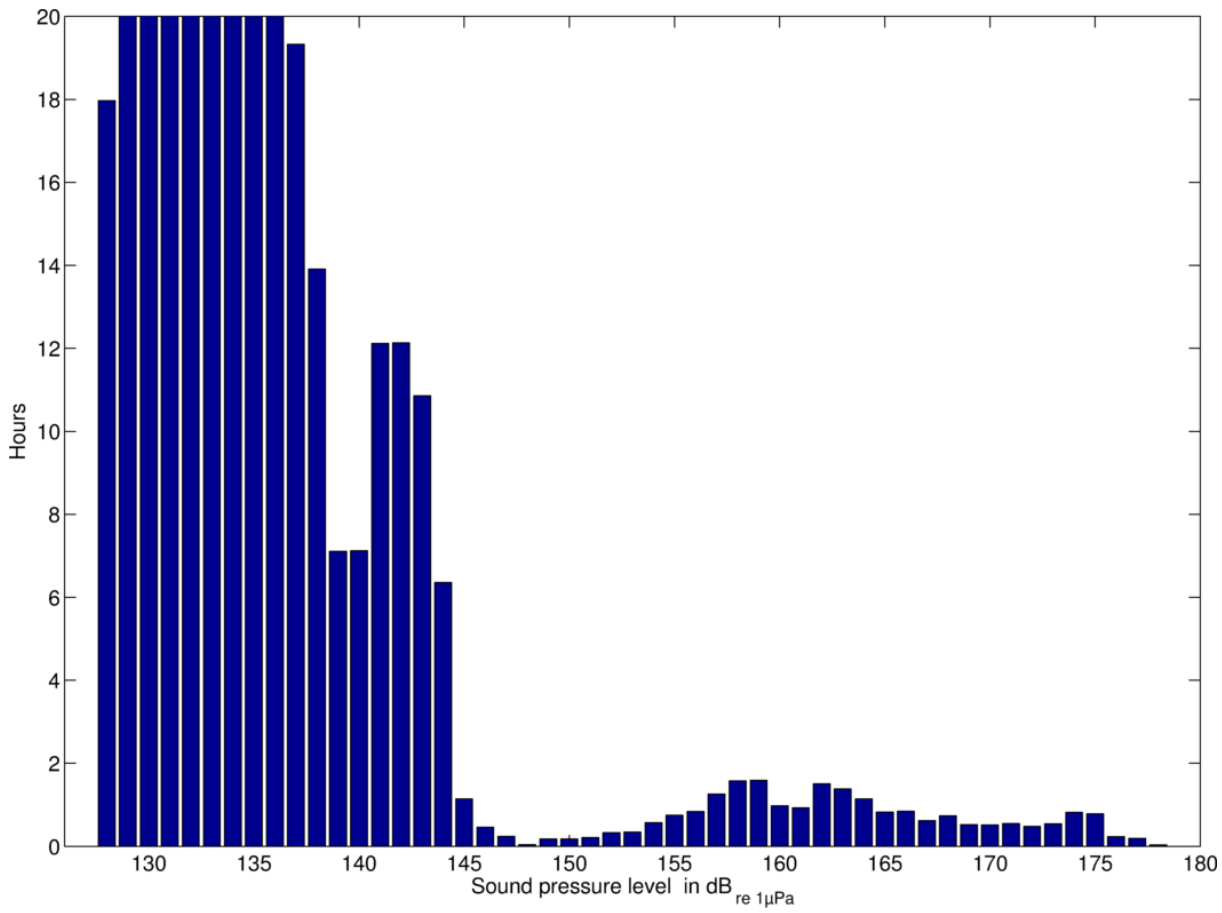

Figure 5: Distribution of L_{eq} (30-second averages), July 7, 2009 to August 26, 2009

A second example is presented in Figure 6. Here the sound pressure level distribution measured by the sensitive sensor Bruel & Kraer 8106 between April 1, 2010 and November 17, 2010 is shown. The maximum occurrence of background noise (in this context: “not pile driving noise”) is at about 120 dB. This sound pressure level is lower than the one observed in the time period shown before (Figure 5), because the high gain hydrophone was under saturated in the range of the lower background noise. Furthermore, a rise in the distribution above 129 dB can be observed, which includes distant pile driving noise.

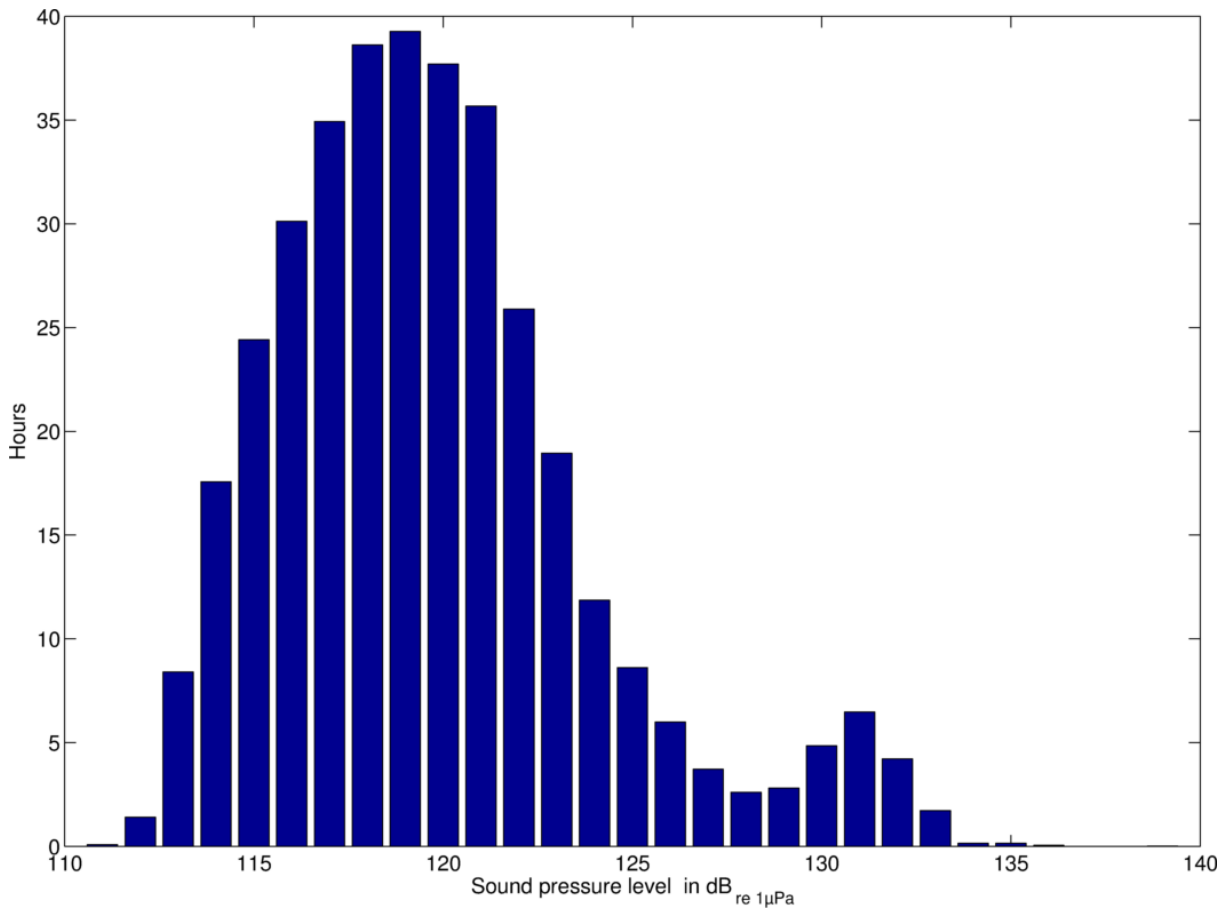

Figure 6: Distribution of L_{eq} (30 s averages), May 1 to 31, 2010

The following figures give examples of results of each kind of measurement tasks “long-range” and “close surroundings”. Because of the availability of high resolution raw data additional assessments of any kind are possible.

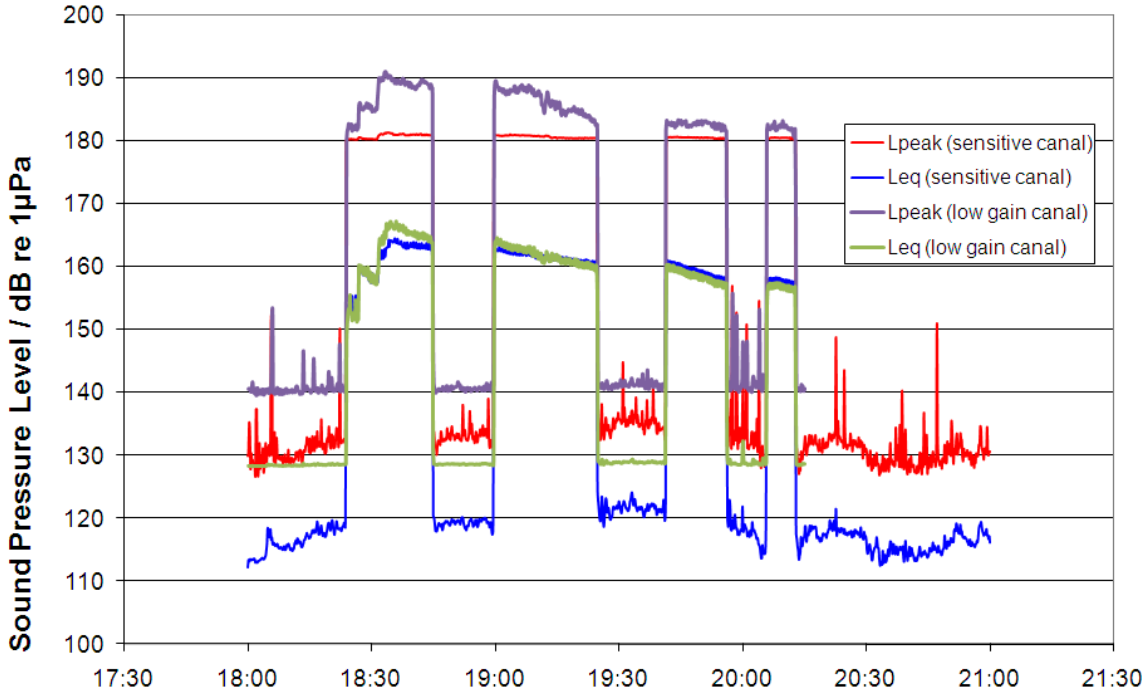

Figure 7: Example of approximately 1400 m distant pile driving noise (L_{eq} as 10 s averages), obtained on July 14, 2009

Figure 7 shows time series of pile driving noise from installation works in the neighbourhood of the hydrophones. is the saturation of the “sensitive” hydrophone at approximately 180 dB is clearly visible. The under saturation of the high gain microphone for levels lower than 130 dB is also visible. During this time period presented in Figure 7 the western pile of the wind turbine AV2 (see Figure 4) was driven.

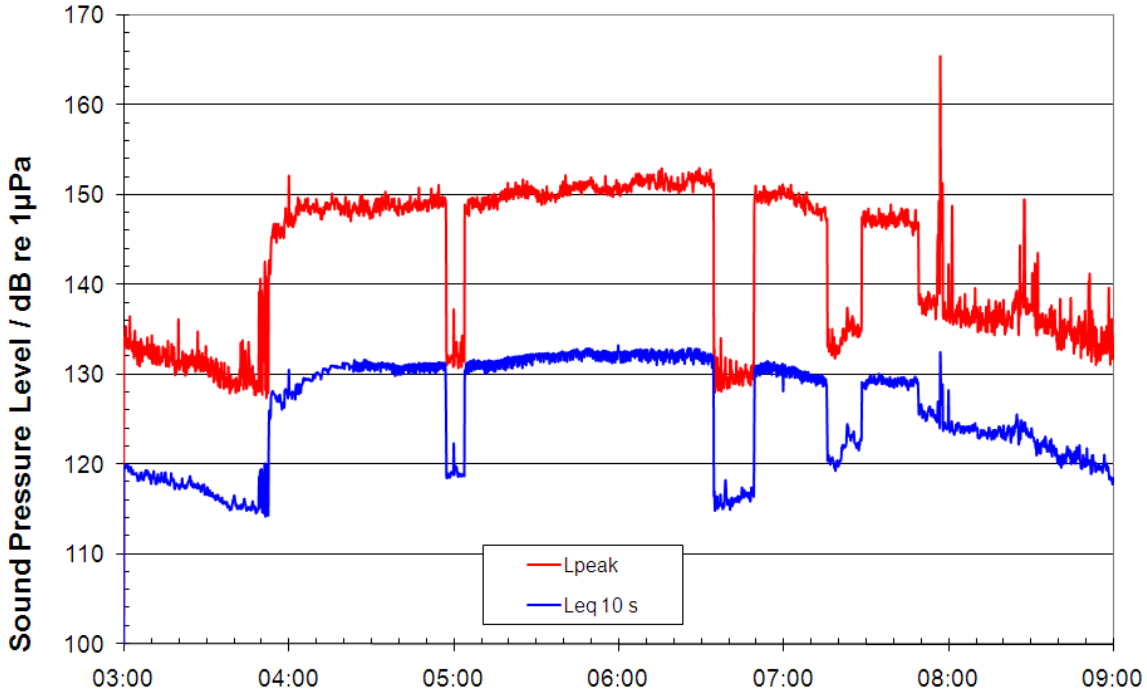

Figure 8: Example of far distant pile driving noise (L_{eq} as 10 s averages), obtained on May 9, 2010

A time series that can be allocated to far distant pile driving noise (Figure 8) show an increase of 13 dB of L_{eq} at the start of the hammering. Values of L_{peak} values become up to 20 dB. This demonstrates that the pile driving noise is fairly different from the background noise and that sound from even further distant construction works might be detectable.

Figure 9 presents a time series of sound pressure obtained on July 14, 2009 starting at 19:00 UTC. The upper graph shows a sequence of 10 strokes that occurred during pile driving. Here the western pile of the wind turbine AV2 was driven, which is located at a distance of approximately 1400 m. These events clearly stick out of the background noise. The frequency of the strokes at this point is 32 strokes per minute.

The bottom graph of Figure 9 illustrates the sound pressure during one stroke. The duration of this event can estimated to about 0.11 seconds.

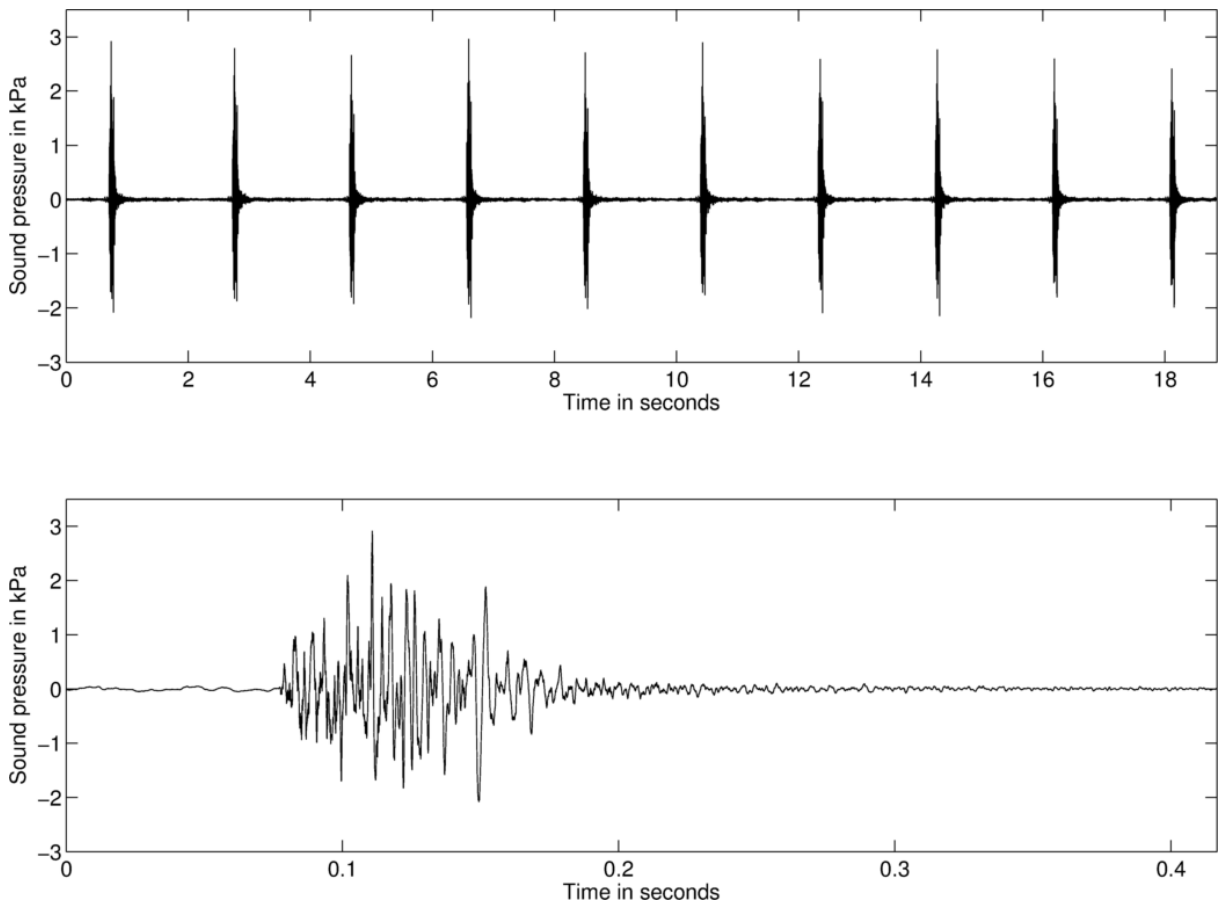

Figure 9: Amplitude and frequency of strokes
of nearby pile driving on July 14, 2009

In comparison Figure 10 shows a time series of sound pressure measured on May 9, 2010 at 4:00 UTC, when pile driving was performed in a greater distance. Single strokes can be identified easily as well, but the significant noise is stretched by dispersion to a much broader signal. The frequency of the hammering sequences is 23 strokes per minute.

The bottom graph of Figure 10 presents the sound pressure during one stroke. The duration of this event is much longer than pile driving in the direct vicinity of the hydrophone (see Figure 7) and can be estimated to approximately 1.7 seconds.

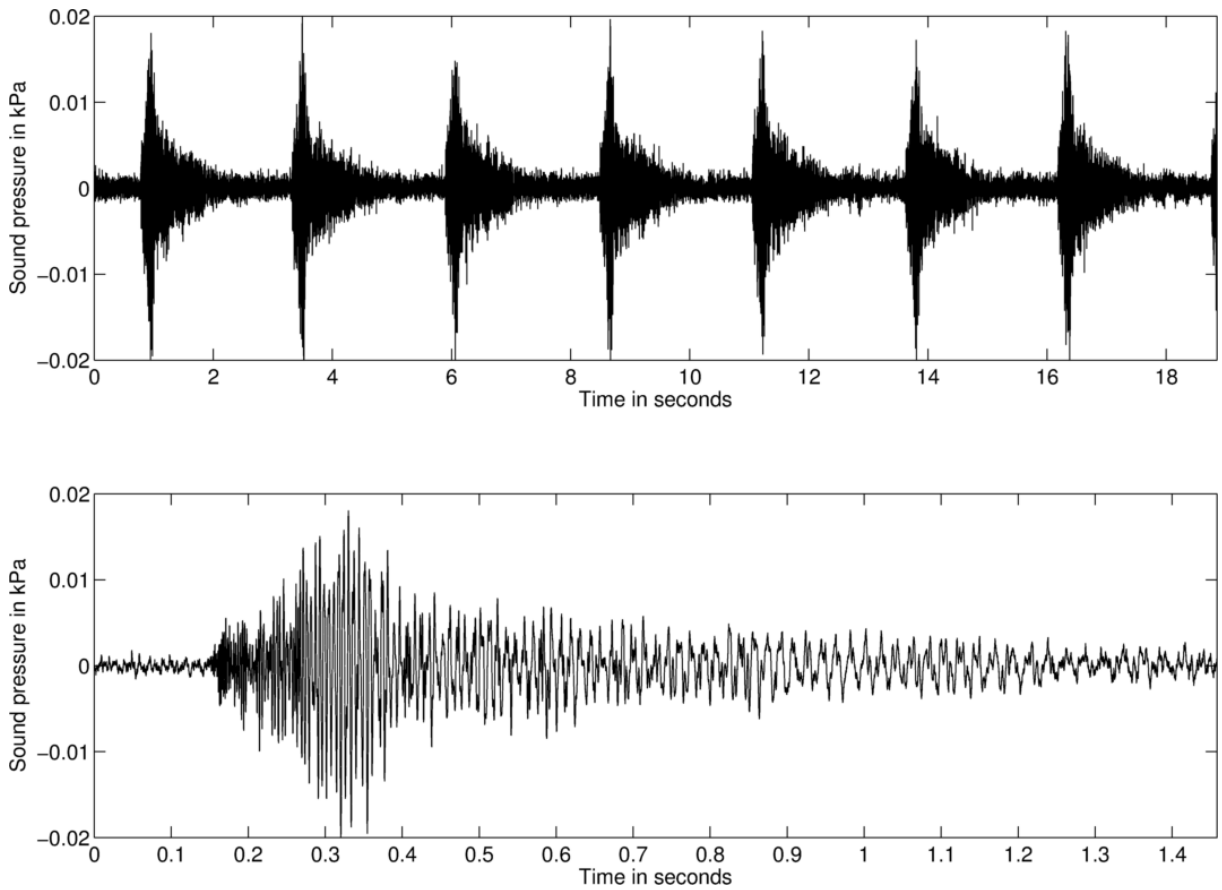

Figure 10: Amplitude and frequency of strokes
for far distant pile driving on May 9, 2010

Pile driving noise is not only characterised by impulsivity andfrequency of the strokes typically in the range of 20 to 50 per minute, but also by spectra showing maxima in the range of 150 Hz to 300 Hz. One-third octave band spectra of pile driving noise from near and far distant sources are presented in Figure 11. It has to be underlined that the two spectra shown in Figure 11 differ with regard to the measurement distance and also the sources of noise, because pile dimensions, hammers and impact energy are not the same.

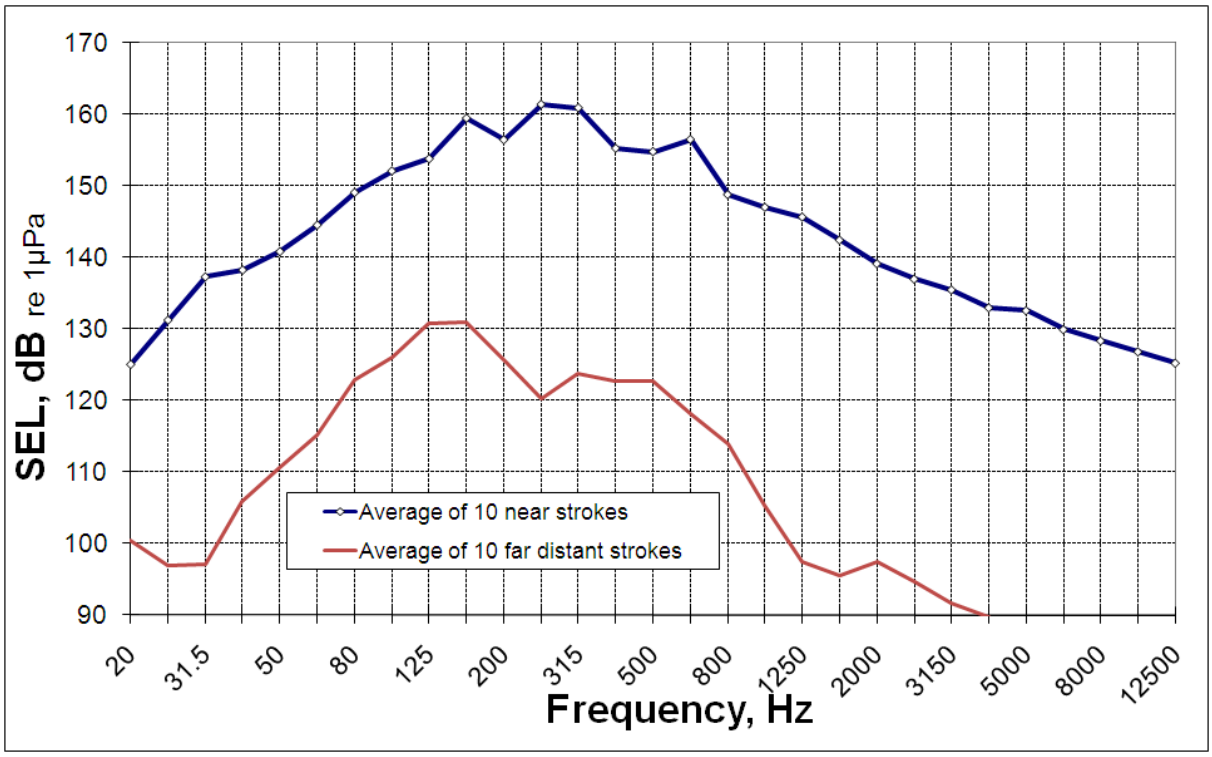

Figure 11: One-third octave band spectra of pile driving noise from near and far distant sources

Conclusions

The FINO1 underwater sound recording station has been working continuously since July 2009 and demonstrates the feasibility of long term hydro sound measurements under hard offshore conditions. In this case even with low maintenance costs. The dynamic range of sensors and recording system allows collecting pile driving noise from both close and far distant sources. The data can be scanned for pile driving sound. A simple “threshold method” used as first attempt can detect noise from wind farm installation works more than 50 km away. Because of the characteristic acoustic finger print of pile driving noise, the automatically monitored area will enlarge by a factor of 2 to 3 applying more sophisticated scanning methods in the future. Even with progress in automatic pile driving noise detection tools still the human ear will stay the last instance. Thus the requirements of a sound recording, which can be listened to in cases of doubts, will last. Permanent operating real time scanning tools might trigger recordings of possible pile driving events and thus help to reduce the quantity of stored data in the future. The concept for the next DEWI long term underwater sound recording station will be similar, because the high availability of a simple but reliable recording system has been proved.

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