Project no. 265863

ACCESS

Arctic Climate Change, Economy and Society

Instrument: Collaborative Project
Thematic Priority: Ocean.2010-1 "Quantification of climate change impacts on economic sectors in the Arctic"

D2.45 – Measuring, Modelling and Mitigating Noise Pollution in the Arctic

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	X
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

Objectives

The objectives of the acoustic measurements during OATRC2013 were twofold:

- to deploy two **long-term sound recorders** to be moored in the water column for at least 12 months to characterize the Arctic soundscape in the region, possibly detect marine mammals vocalizations and ice-breaking noise.

- to deploy **opportunistic sound buoys recorders** along ODEN tracks, to record ambient noise, ice-breaking sound, propeller noise, as well as transient sounds produced on board by machinery, all of the above to better understand sound propagation in ice-covered waters.

The aim of the tasks involved in this Deliverable was to develop and apply mathematical models describing shipping noise propagation in the Arctic waters.
•Analysis of the effects of different noise sources
•Basis for the development of models for noise exposure and sound dosage of mammals

The models that will be developed for the particular Arctic region must be based on in situ recordings since the specific oceanographic configuration of the water column will introduce considerable propagation loss and variations compared to other regions of the world.

Based on the existing technology already implemented in deep-sea observatories (European Sea-floor Observatories Network of Excellence, ESONET) by the task leader, the fieldwork included a specific acoustic system for:

a) the real-time monitoring of noise radiated by ships and determine areas of acoustic impact;

b) the real-time monitoring of the presence of cetaceans in the area of interest
- to develop a standard protocol for the measurement and computation of the emitted sound levels that allows comparison between different marine regions.

We used the autonomous buoys and recorders developed under Tak 2.4.5.

1. Sound Recorder Deployment (Arctic Soundscape)

The long-term deployment units (2) consist of two EA-SDA14 RTSYS recorders whose technical specifications follow:

Standalone recorder specification
- Digitization 24-bit
- Sampling frequency: 78 kHz
- Internal memory: 128 GB
- Additional storage space with SSD: 600 GB
- Power provided by D-cells- LISO 12
- Capacity to record for 1 year in a 7% duty cycle
- Differential preamplified Aguatech scientific hydrophone
- External framework that allows mounting the device to a mooring cable

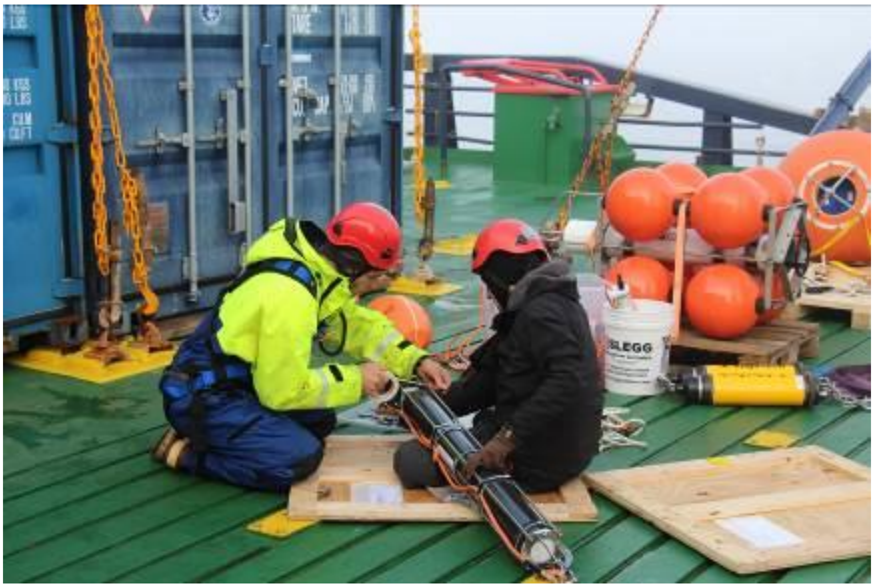


Figure 1. Mounting of the first unit of RTSYS- EA SDA14 before deployment on August 22, 2013.

The two recorders were successfully deployed at mooring position 3 on August, 22 and at mooring position 1 on August 23 (Figure 2). It is expected to recover the units next year (summer 2014) or in the following year depending on opportunities of coming back to the region.

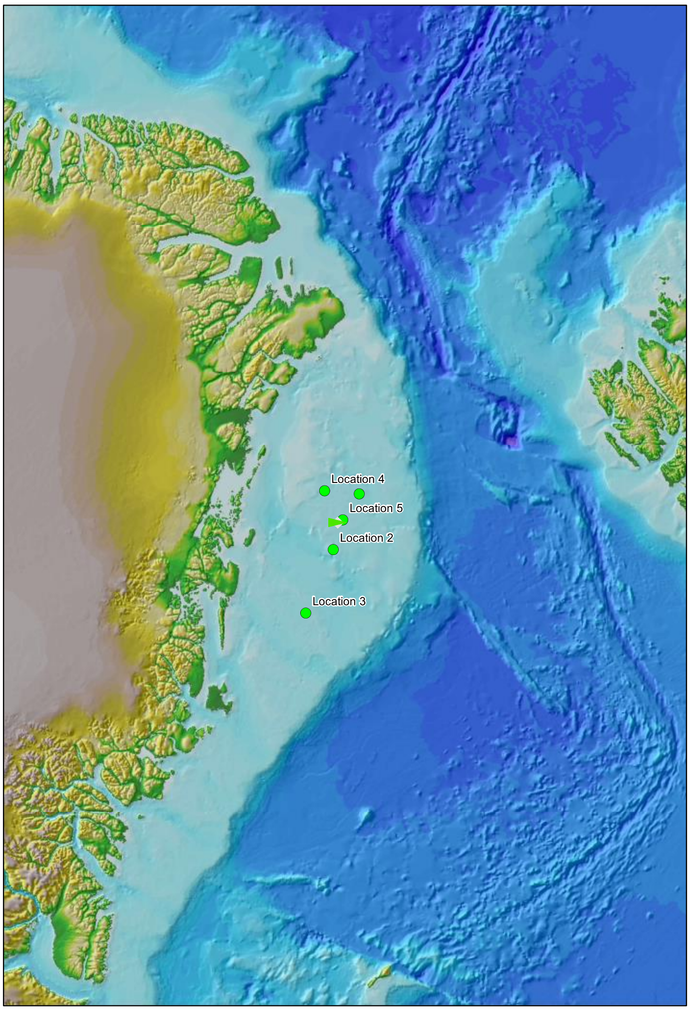


Figure 2. Mooring positions during OATRC2013. The two units of EA SDA14 were deployed at stations 3 and 1 on August 22 and 23, respectively (position 1 is east to Position 4 on the map).

Acoustic Buoy Deployment (Noise Propagation Recordings)

Two units of RTSYS BA-SDA14 were custom designed and assembled to meet the recording requirements. The technical specifications follow:

BASDA14 for artic noise measurements:

- 900W.H rechargeable battery packs + charger
- 4 hydrophone inputs -24Bits (Aguatech Scientific Hydrophones)
- GPS
- SDCard 128GB embedded storage (over 12 days of autonomous recording)
- very low power compact integrated Flasher -continuous emission
- iridium modem
- ARGOS beacon
- AIS transponder

Figure 3. A BA SDA14 unit is ready for deployment on the deck, August 26, 2013.

Previous to the deployment of the two units of BASDA14, preliminary tests were conducted with an autonomous recording system, BCUBE, designed and developed by the Laboratory of Applied Bioacoustics, of the Technical University of Catalonia, BarceloneTech (UPC) and SONSETC, S.L., with the objective of characterizing the acoustic charges to be used along with the deployment of the acoustic buoys.

The BA-SDA14 units were successfully deployed on three occasions, on August, 24, 28 and 30, 2013. Unfortunately, the recording parameters originally set to meet the very high sensitivity of the hydrophone and record the low frequency components of the acoustic charges, prevented to gather usable data during the first deployment (August 24, 2013) and extract any useful information on the sources. The setting was accordingly tuned-up for the successive deployments.

The recorded data from the buoys (noise level measurements, spectrograms, audio streams) are made available from http://www.listentothedeep.net/oden2013.

Ice-station recordings of acoustic charges

Taking advantage of the deployment of an ice-station on August 25, and August 26, after deploying the mooring at position 4, it was decided to make use of holes drilled on the ice station by other members of the cruise to record and characterize the acoustic sources from the ODEN. BCUBE autonomous recordings were made directly from the hole into the water. (Figure 4).

Figure 4. Overview of the OATRC2013 ice-station on August 26, 2013. Jürgen Weissenberger and Jan Durinck are positioned at the far end in the picture, at hole number 2, ready to deploy the recordings.

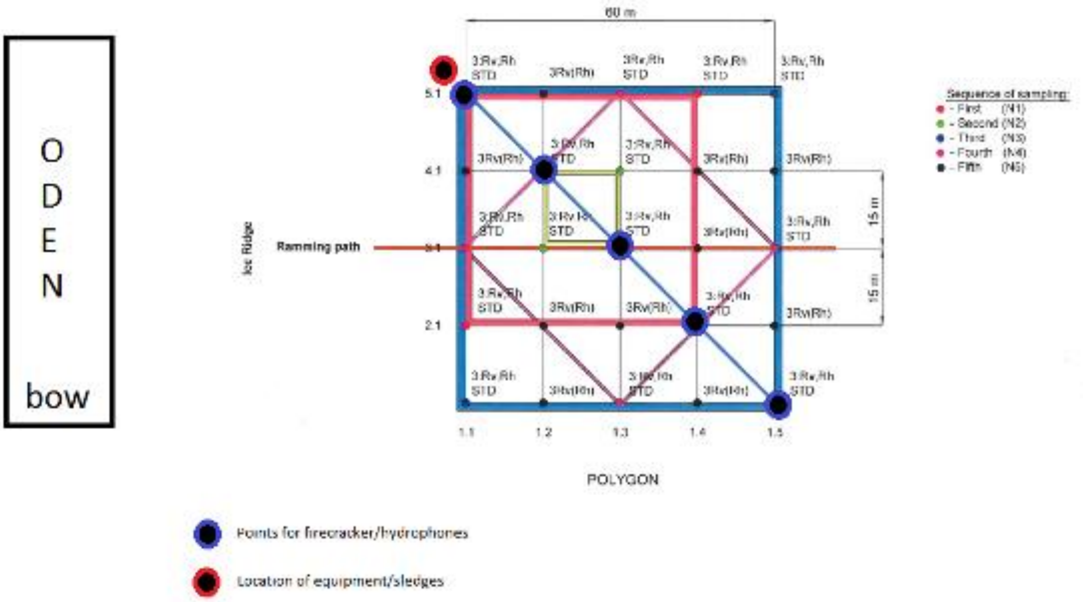
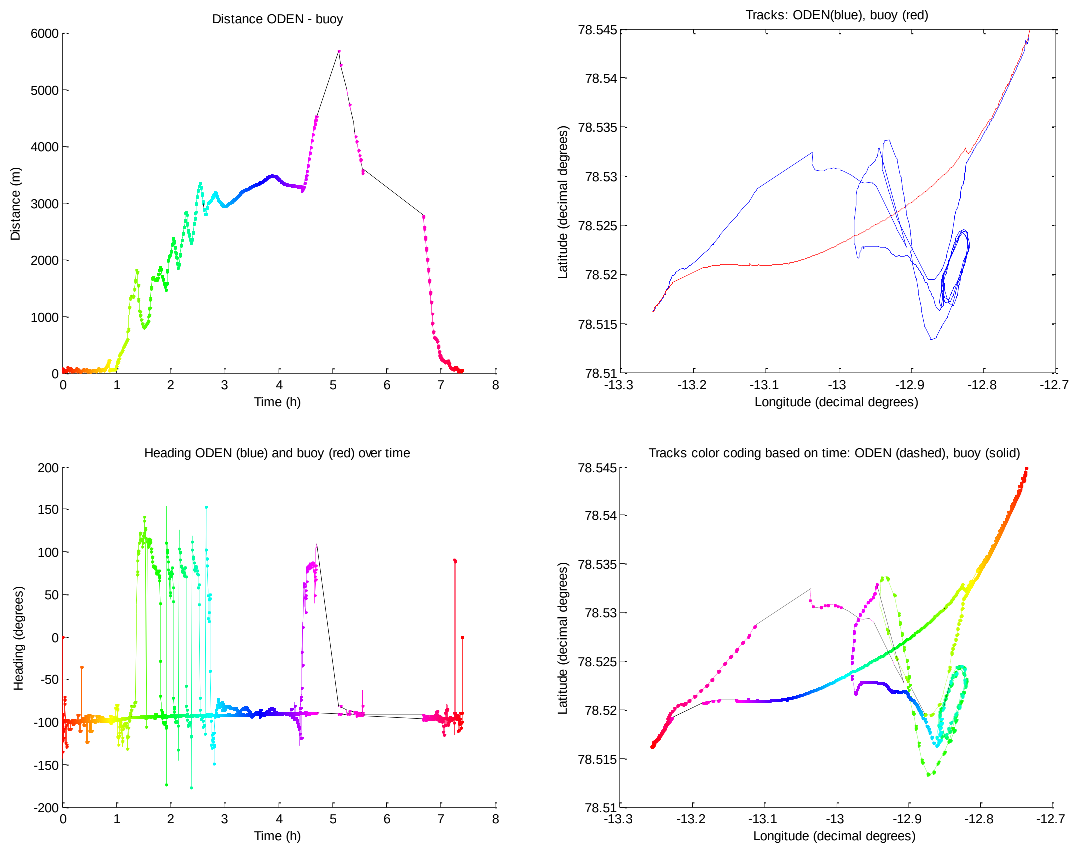


Figure 5. Map of the ice-station polygon, showing the distribution of the holes used for the acoustic measurement, August 26, 2013.

Data August 28

Overview of Deployment Scenario

One buoy was deployed on August 28 for about 7 hours. An overview of the deployment scenario during those hours is provided in Figure 6. The top left image shows the distance between the ODEN and the buoy. The colour coding of the graph is used in subsequent images to indicate the time since deployment. The black sections in this image indicate missing data. The supplied AIS data was missing a few hours. The furthest measured distance was around 5.5 km. The top right image shows the tracks of both the ODEN and the buoy. The centre left image shows the same, except that the tracks have been colour coded based on deployment time to be able to associate the ship manoeuvres with the buoy position. The centre left image shows the heading of the buoy and the ODEN. The bottom left image shows the angle between the buoy and the ODEN. This last information could be used to infer the noise directivity of the ship, but more importantly allows associating noise levels with ship distance under the same relative angle.



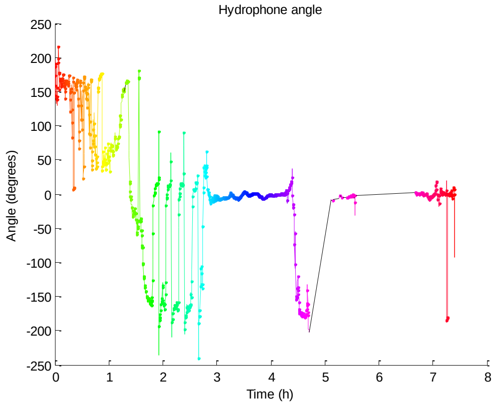
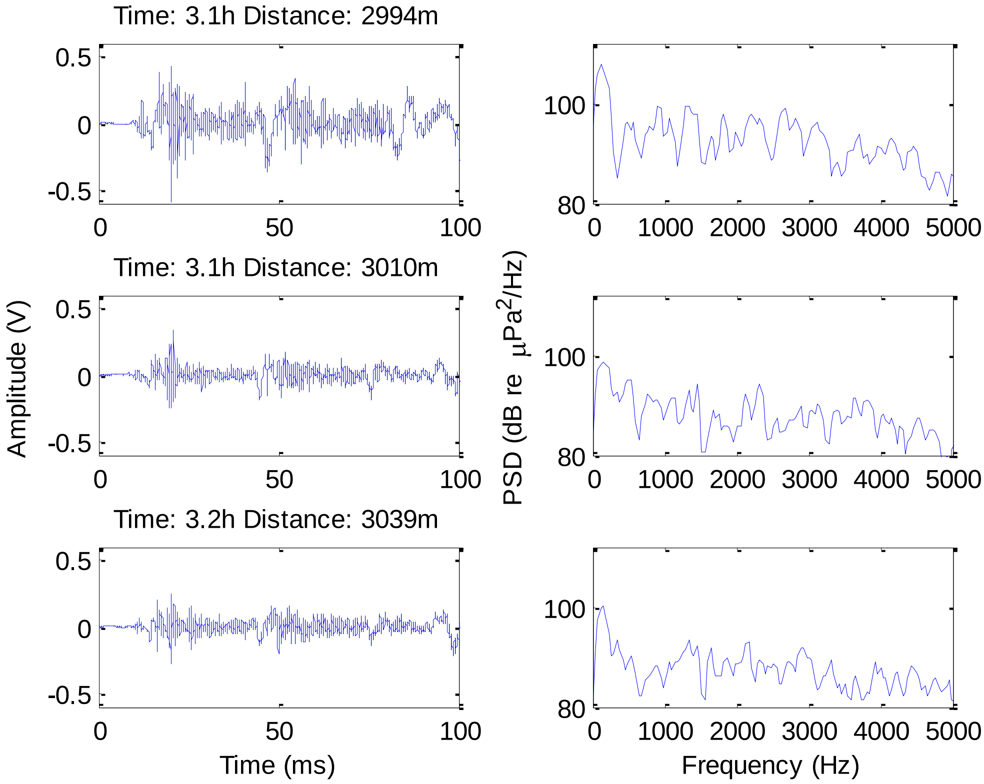
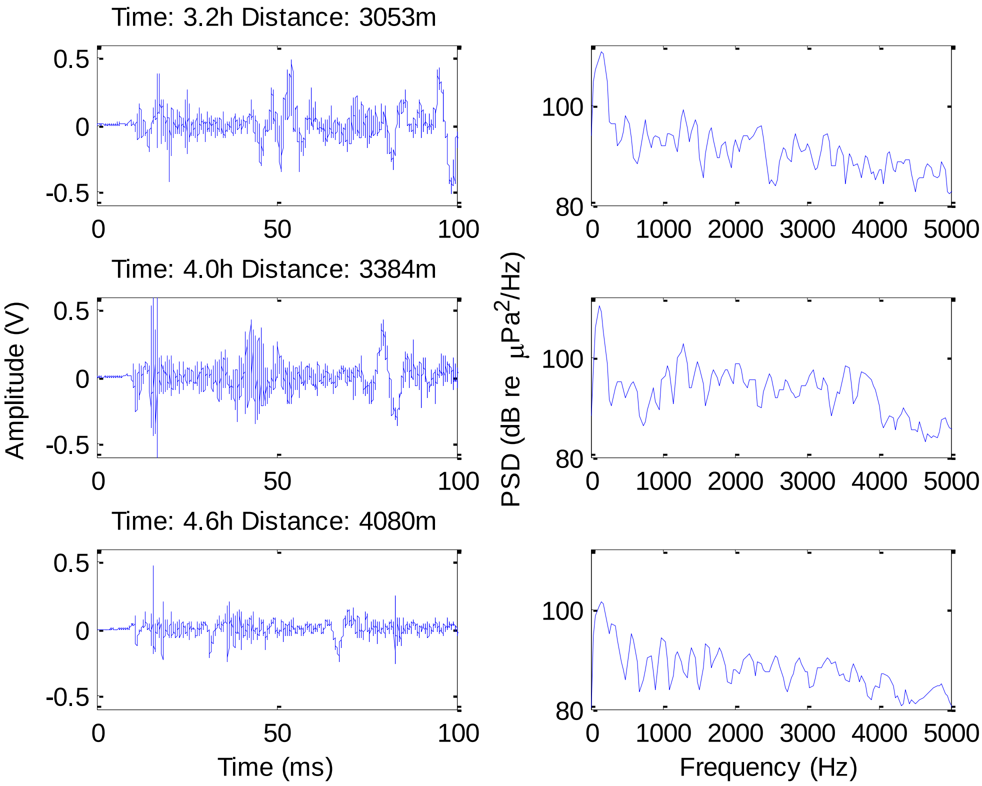
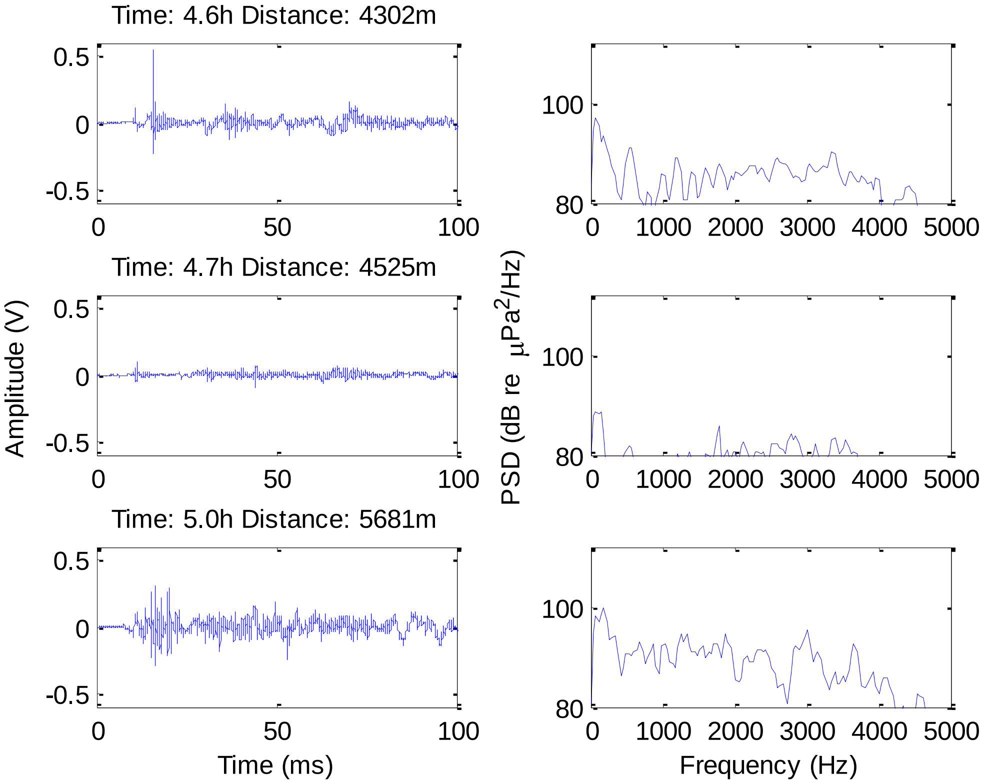


Figure 6. Overview of ODEN and buoy tracks, their distance and headings on August 28. Colour encoding indicates time since deployment.

Noise Measurements




Time: 3.2h Distance: 3053m
Time: 4.0h Distance: 3384m
Time: 4.6h Distance: 4080m
Amplitude (V)
Time (ms)
PSD (dB re μPa²/Hz)
Frequency (Hz)


Time: 4.6h Distance: 4302m
Time: 4.7h Distance: 4525m
Time: 5.0h Distance: 5681m
Amplitude (V)
Time (ms)
PSD (dB re μPa²/Hz)
Frequency (Hz)

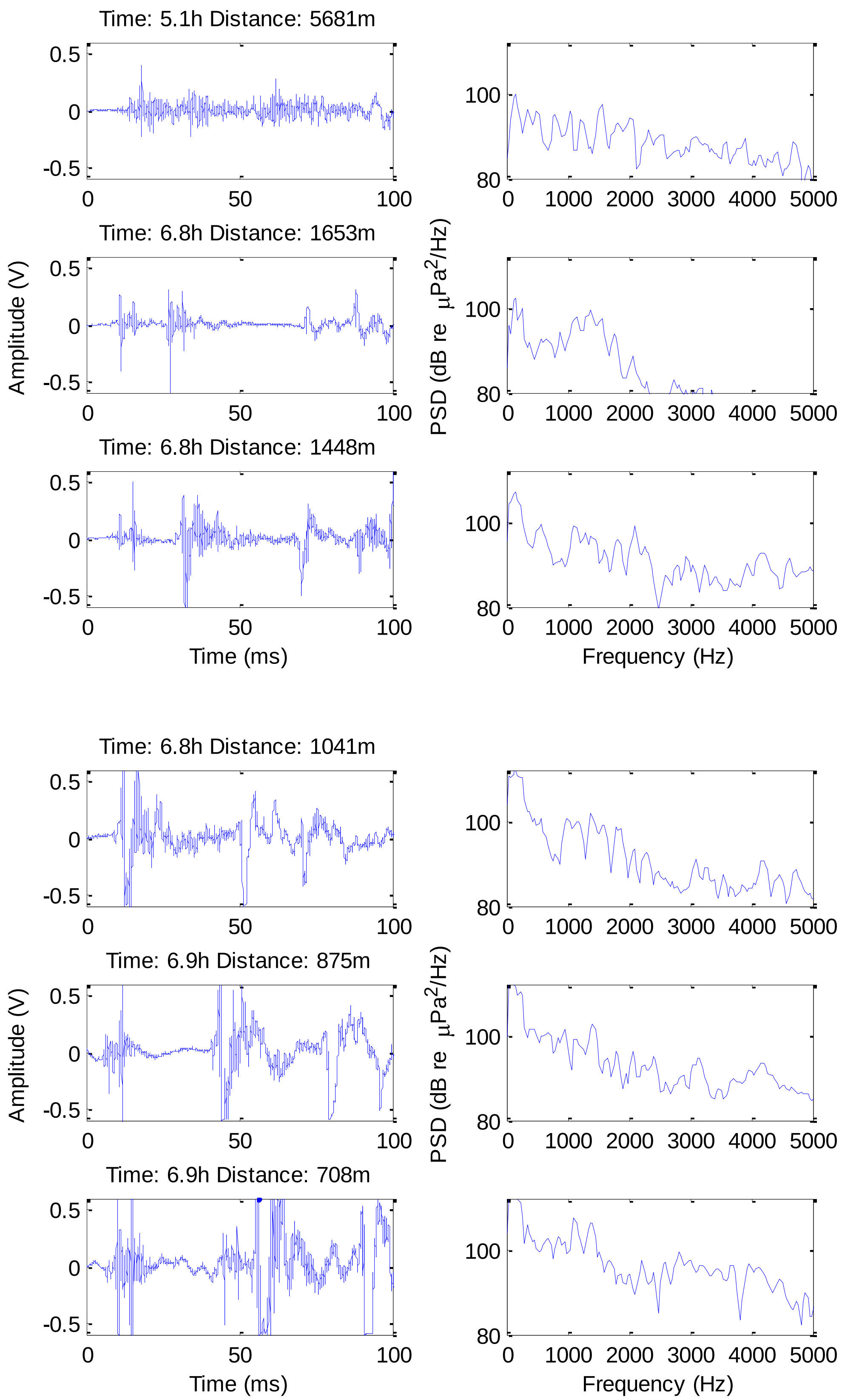


Figure 7. Amplitude and power spectral density of acoustic charges fired at different distances.

Side scan sonar

Looking for other sources of opportunity the ODEN provided two. One acoustic source was the side-scan sonar that was running almost continuously during the deployment. Depending on the position and orientation of the ODEN the energy received from the sonar could differ. 8 gives an example spectrogram of 4 low frequency sweeps and 10 high frequency signals. The high frequency part was not always apparent. Often only the broadband sweep of the low frequency part was visible in the spectrum. 9 shows received levels at the buoy of the sonar (low frequency sweep) and background noise recorded at the same time. The levels were computed by manually selecting four consecutive sweeps and a time interval immediately following the sweep. Each box shows the variation of received levels of these four sweeps. Unfortunately the variability in the sweep was often quite high, probably due to its directional character and the orientation of the ship. Figure 10 gives a better comparison between each selected sweep and the noise that was surrounding it. Often the sweep noise barely exceeded the noise generated by the ship. To be able to use the side-scan sonar as an acoustic source, its use should probably be better coordinated to ensure moments where the ship has the same orientation to the hydrophone.

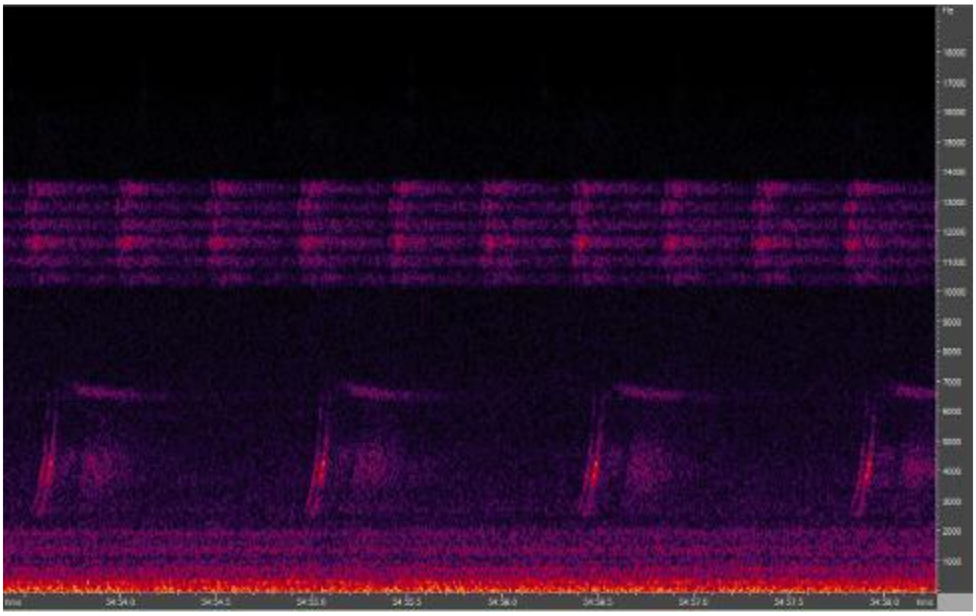
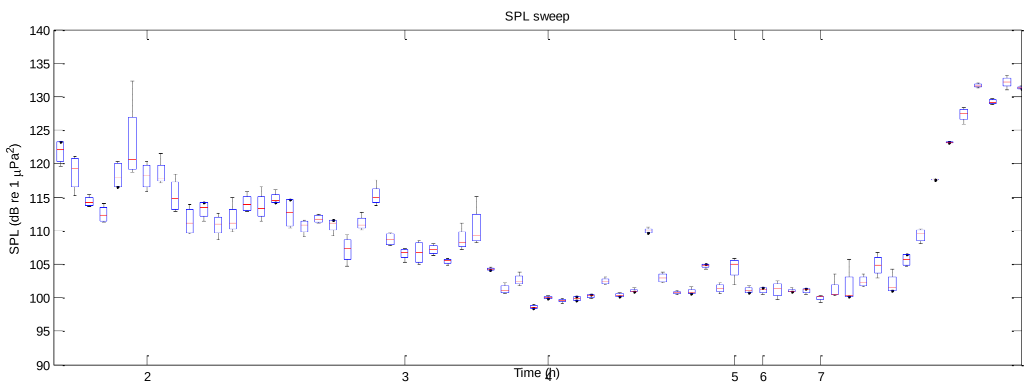


Figure 8. Side scan sonar with energy in 2500 - 7000 Hz and 10 - 14 kHz bands.



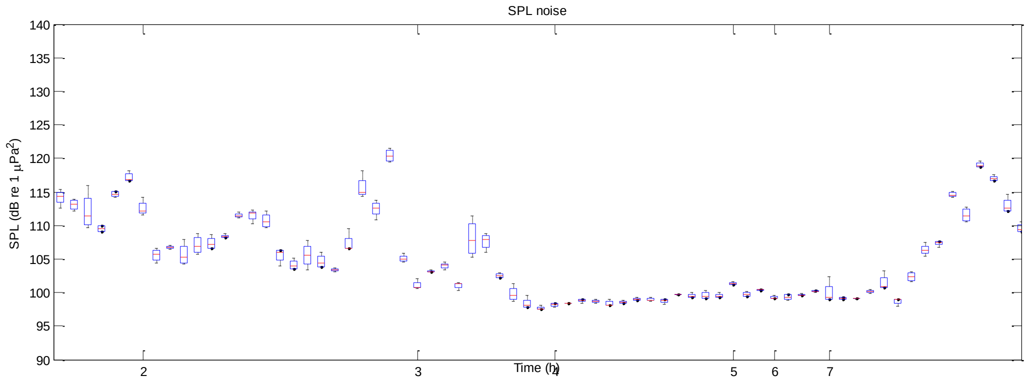


Figure 9. Received levels of the side-scan sonar and background noise levels at the same time (August 28). The time axis is not linear.

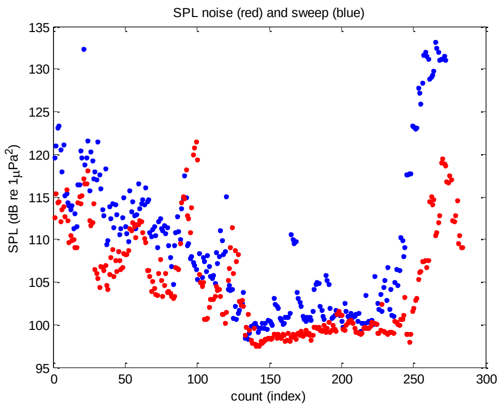


Figure 10. Comparison of background noise and side-scan sonar noise (August 28).

ODEN engine noise

Another obvious source was the engine noise (Figure 11) of the ODEN itself. Figure 12 shows the received level at the buoy during ODEN operations for a number of third octaves. The received level was not computed when there was signal saturation. The green positions correspond to the circling track in Figure 6 where the ship was performing ice breaking and constantly changing its angle to the hydrophone. They show a large variability between received levels and ship distance making them unsuitable for transmission loss estimations. Bluish colors have a large vertical variability with a large difference in received levels while not covering a long distance; on the other hand, the purple-pink transition has a more horizontal variation with very similar received levels (except at 31 Hz). Neither seem useful for loss estimations. However, when the ship was returning to the buoy in order to retrieve it again (reddish colors) it maintained a fairly constant angle to the hydrophone and shows a clear linear relation between distance and received sound pressure level. Additionally, the short time it took to reach the buoy should mean that the hydrophone position stayed more-or-less at a stable depth, not influencing a change in received levels. Therefore, this part of the recording will be used for the transmission loss estimation later in this report. It is not clear why the green levels were so much higher than the returning purple/red levels. It could be due to the particular e.g. ship maneouvering , hydrophone displacement or a change in the propagation path (ice).

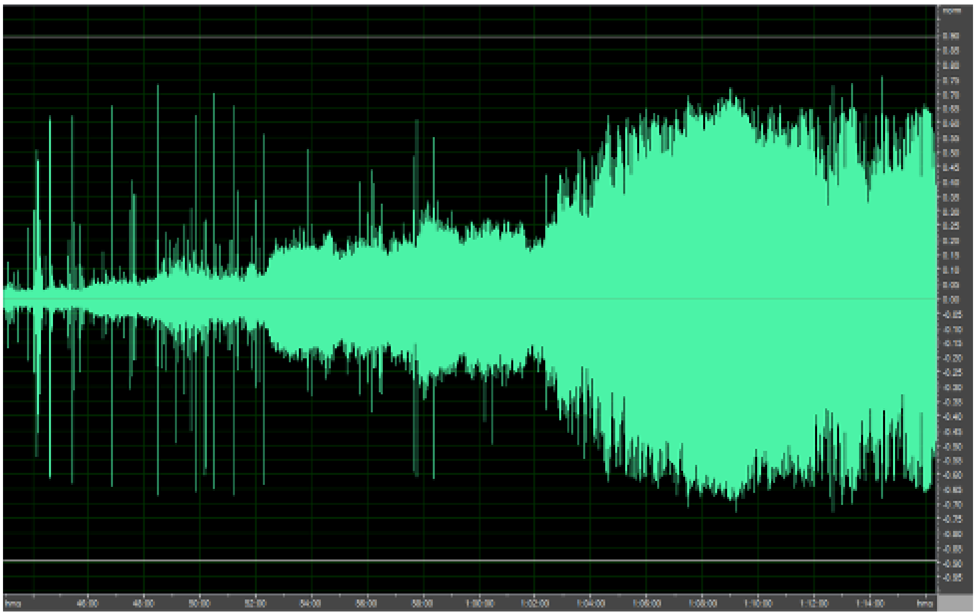


Figure 11. Increase of ODEN engine noise returning to the buoy (30 minutes).

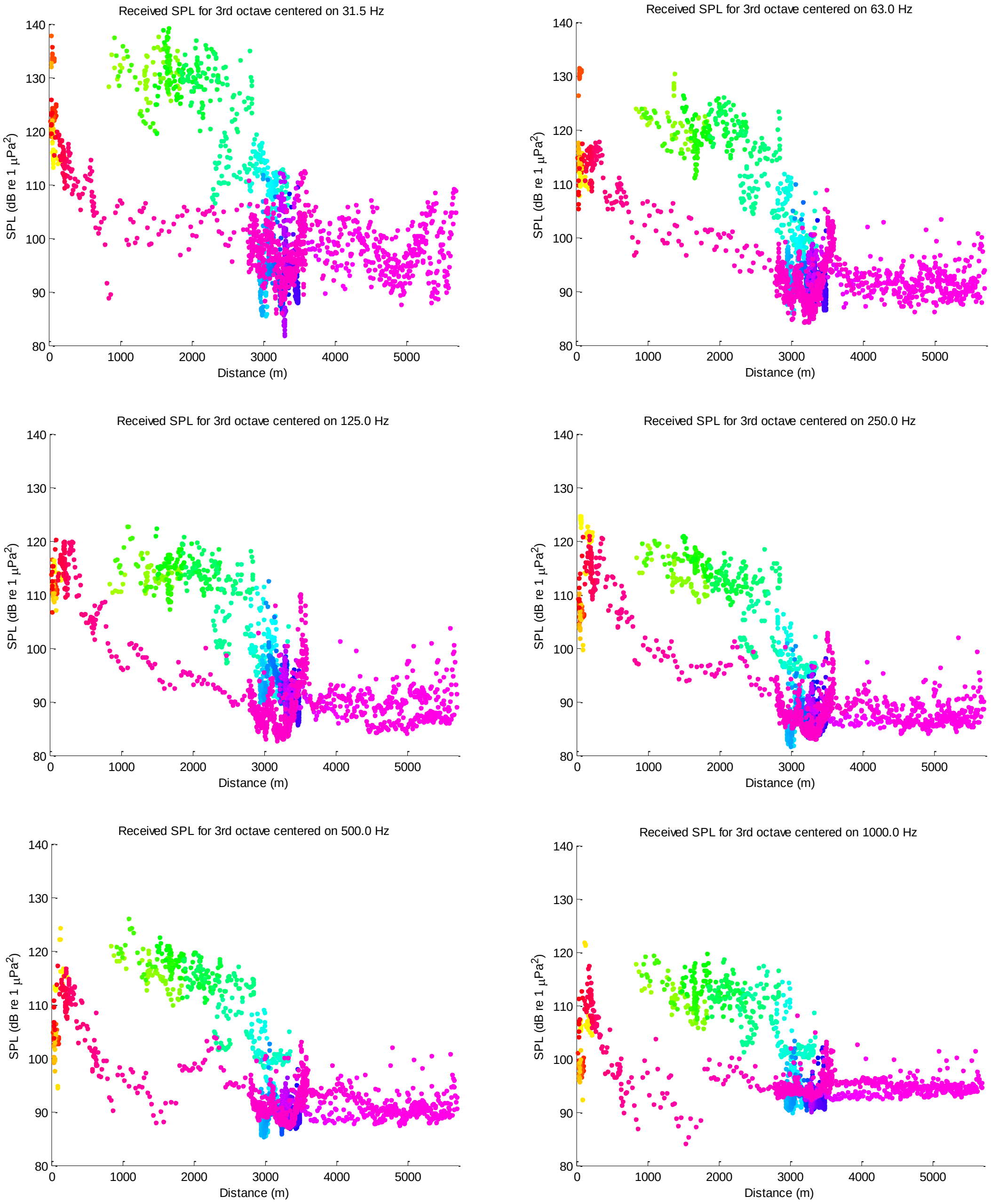
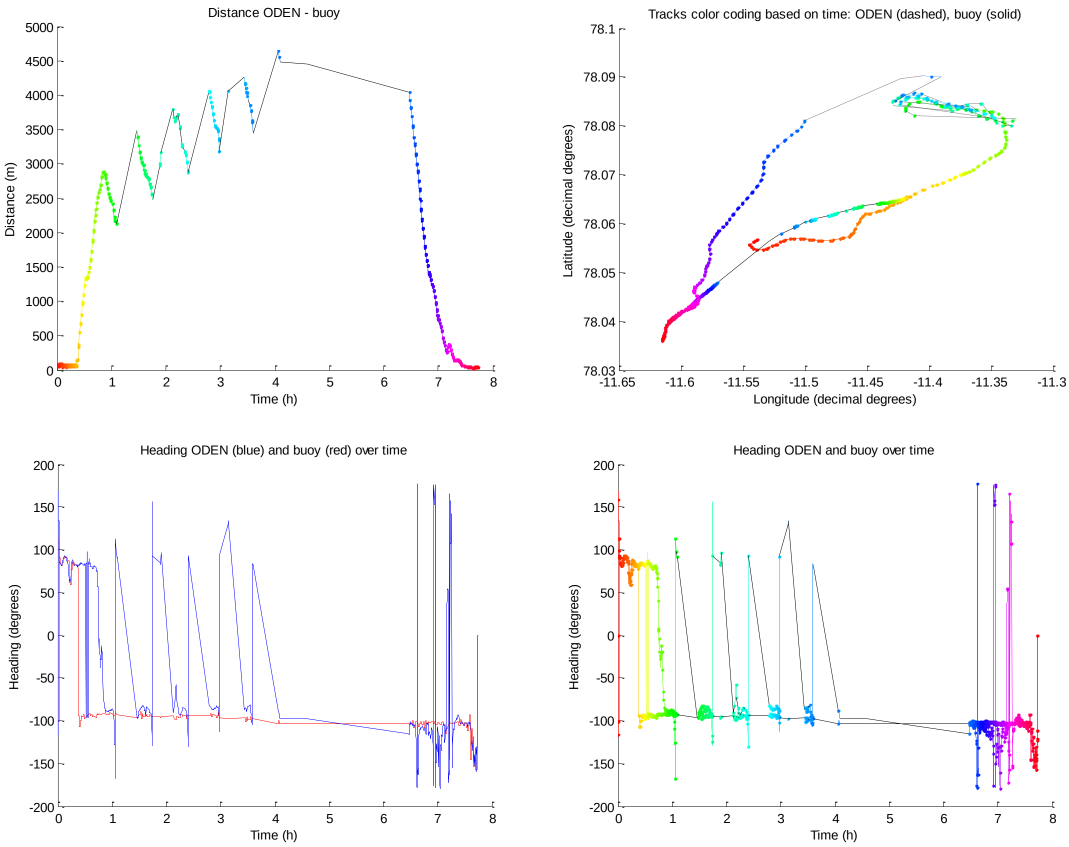


Figure 12. Received level from the ODEN (August 28) during the deployment; time is colour encoded according to Figure 6.

Data August 30

Overview of Deployment Scenario

On August 30 the second buoy was deployed for about 8 hours. Figure 21 shows the same information as in Figure 6 (nb. the color encoding does not indicate a same time delay from T0 as in the previous figures). Again there was some missing data (Figure 21, top row) indicated by black lines. The furthest measured distance between the ODEN and the buoy on this day was around 4500 m. During this deployment a second ship was in the area performing a seismic survey with an airgun.



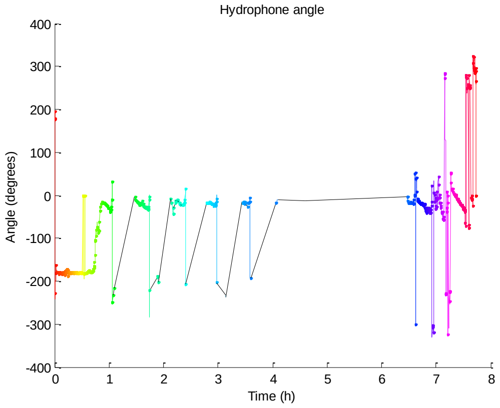


Figure 13. Overview of ODEN and buoy tracks, their distance and headings on August 30. Colour encoding indicates time since deployment.

Noise Measurements

Seismic exploration

The seismic exploration (Figure 14) that was performed during the deployment could have been very useful to obtain information on transmission loss, considering that the source level would have been constant. Unfortunately the position of the airgun was not available at the writing of this report. Additionally, most received shots did show saturation. Instead of the main pulse a different part of the signal should be used for any estimation. Figure 15 shows two shots fired only 47 seconds apart. The first shot (red) shows saturation in the main peaks while the later shot (green) was recorded properly. Such a large difference in a short time interval indicates that there would have been some difficulties in using the shots. It might be caused by changes in the depth or orientation of the source and receiver. The same figure does show that an earlier or later component of the shot might be useful for comparison if the shape of shot remained similar for the whole campaign duration.

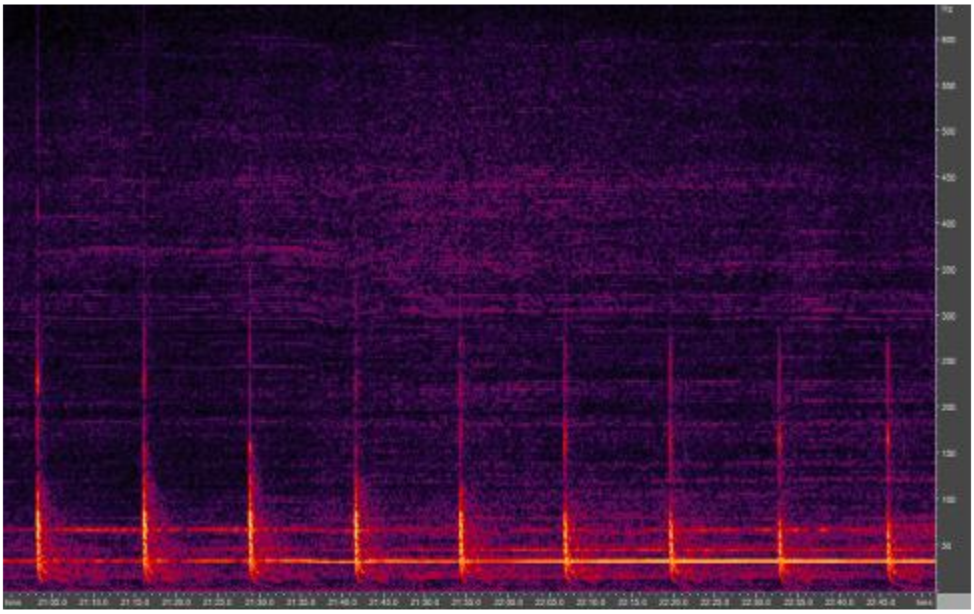


Figure 14. Spectrogram of airgun shots ~13 seconds apart with main energy below 300 Hz.

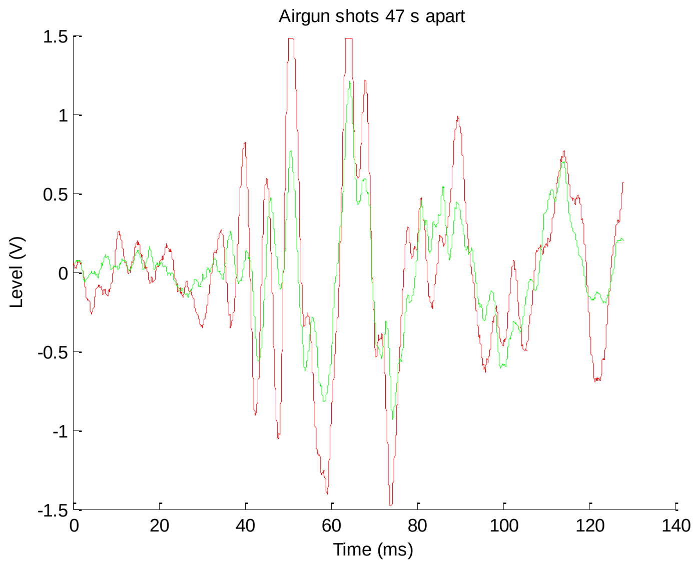


Figure 15. Two airgun shots fired around 13:09 (UTC) on August 30.

Side scan sonar

The side scan sonar (Figure 16; Figure 7) was evaluated in the same way as done in Figure 9 and Figure 0, regularly selecting four segments containing the sonar sweep and four noise segments directly after the sweep. The sweep sound levels again showed a fairly large variation in received level, with minimal variance while the ship was returning to the buoy. The sweeps themselves were again considered not useful for transmission loss estimates, but the return track of the ship did show its usefulness.

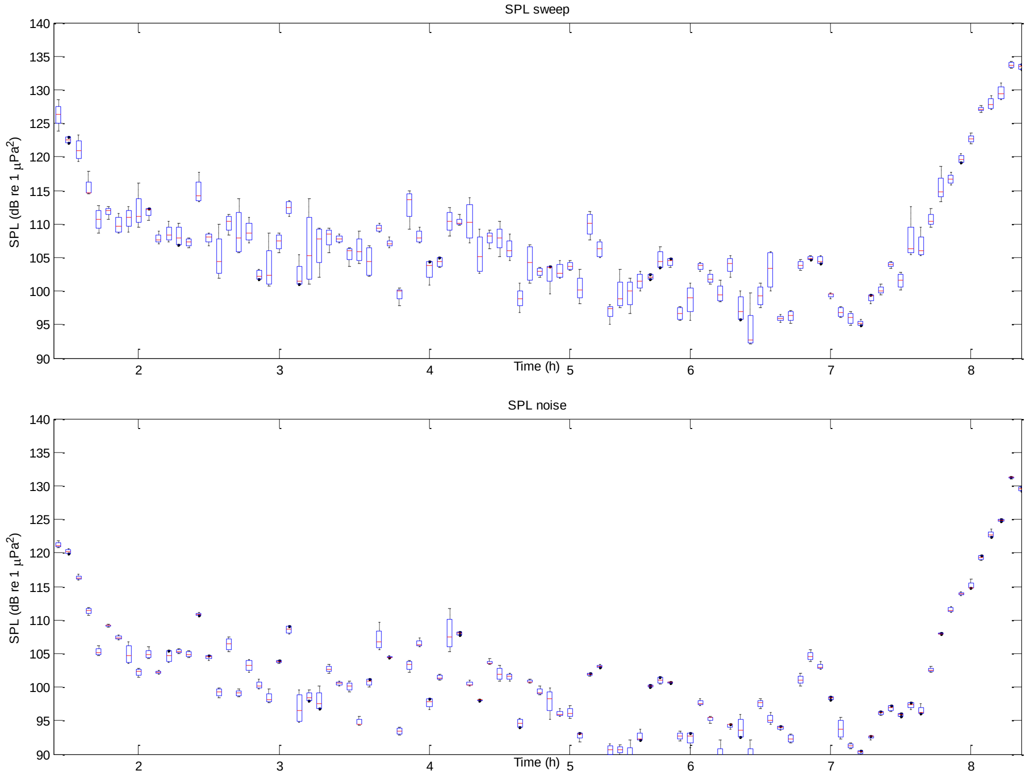


Figure 16. Received levels of the side-scan sonar and background noise levels at the same time (August 30). The time axis is not linear.

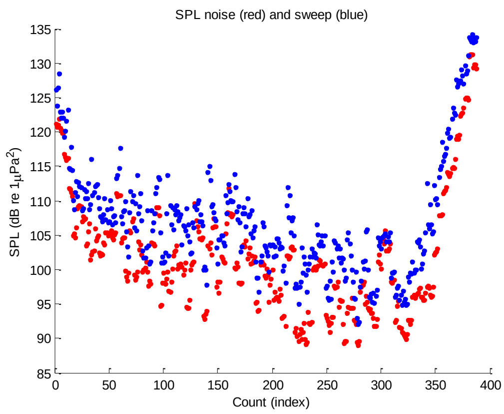
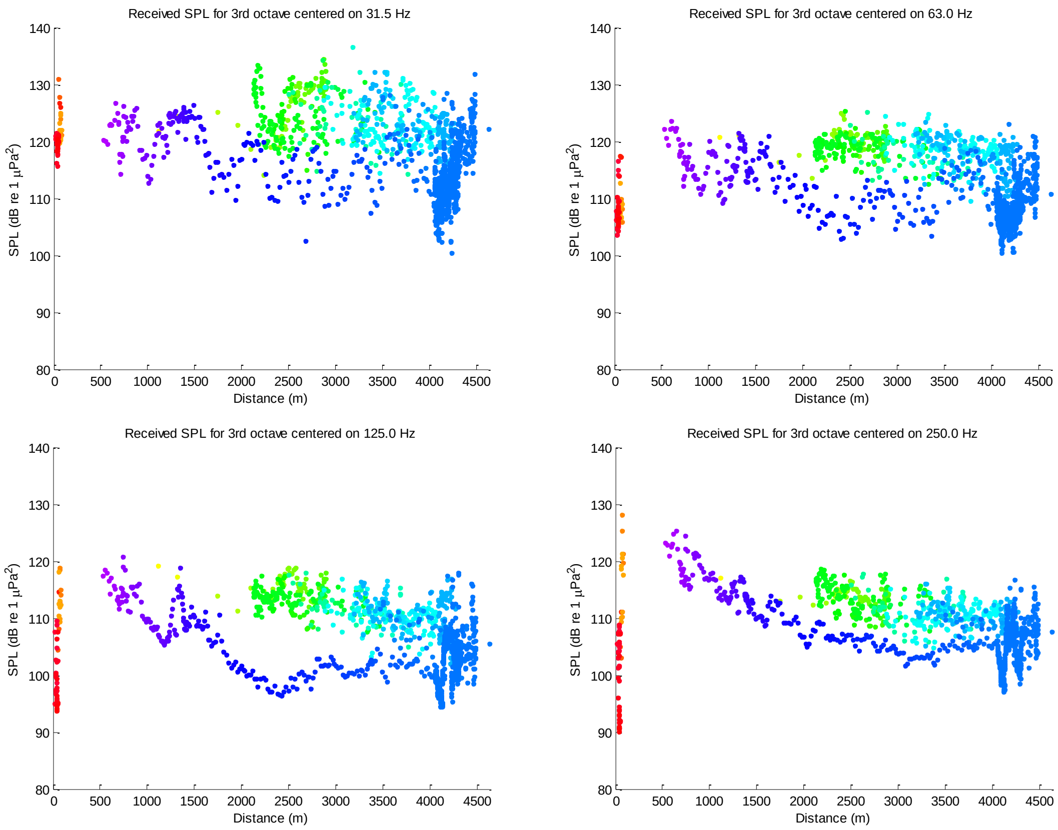


Figure 17. Comparison of background noise and side-scan sonar noise (August 30).

ODEN engine noise

The ODEN engine noise (Figure 18) was assessed in the same way as done in Figure 12. Since segments with saturation were rejected there was less data available to construct these plots than on the 28th due to the saturating airgun shots. Comparing the maximum and minimum received levels to those on the 28th it seems that the levels on the 30th were restricted to a narrower range. The maximum levels on the 30th were lower than on the 28th although the median levels and the minima were higher. Many maxima may have been removed due to saturation; it is unclear why the overall level was higher.

On the 30th the manoeuvring (green/bluish points) did not create sound levels that were much higher than normal operation. At distances beyond 4 km there was no clear relationship between distance and received level, but the return of the ship (blue and purple) starting from around 4 km did provide data with relative little variance at each distance. It is unclear what created the bump especially visible at 125 Hz with subsequent lower received levels. The higher frequencies show a more continuous increase in level with shorter distances. The wavy patterns shown in all images may be related to phase interaction of multiple waves.



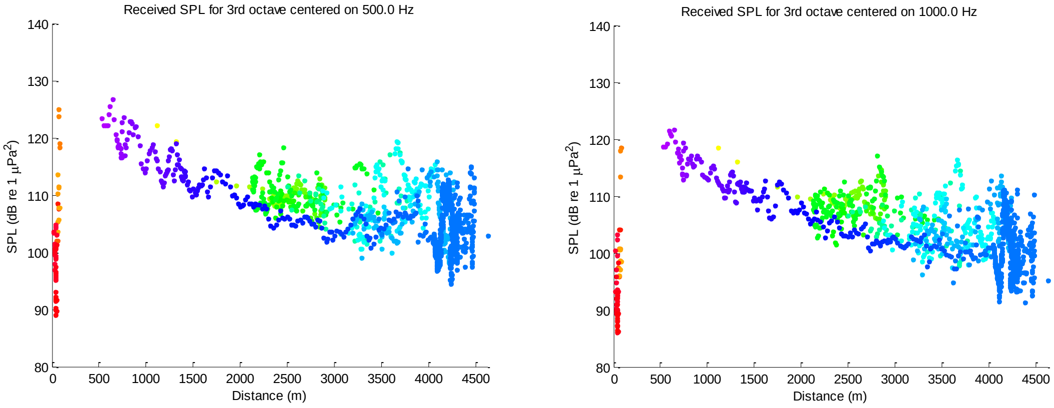
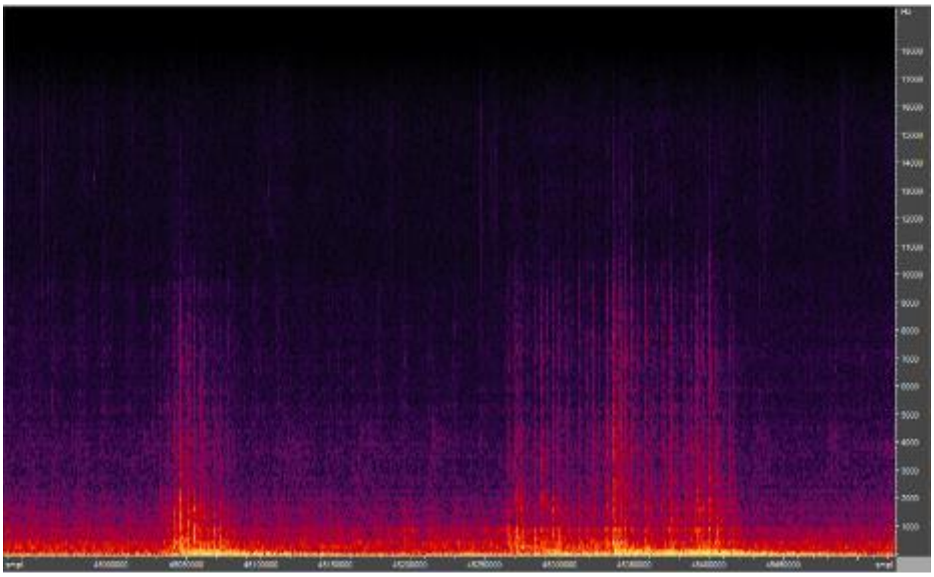


Figure 18. Received level from the ODEN (August 30) during the deployment; time is colour encoded according to Figure 13.

Other Acoustic Sources

Ice breaking

There were many recordings of ice being broken by the ODEN. A typical example of the spectrogram of ice breaking is shown in Figure 19 (top). The impulsive nature of the noise is very similar to that of certain shipping engines. The other two rows in Figure 719 display the power spectral density at two different distances. Each line represents a different source: blue – ice breaking, red – ODEN, black – background noise. For background noise measurements it was difficult to guarantee that the ODEN was not also included and should be considered a high estimate. The left images show the full frequency range while the right images show a zoom down to 1500 Hz to be able to view identify low frequency levels. At 2650 m distance the three sources can be clearly separated. Although there is a markable difference between ODEN and background noise between 10 and 14 kHz, the ODEN probably contributing to the black line. This follows from the background measurement at 4000 m which was lower at higher frequencies (which also be explained by a change in hydrophone position) and the ODEN is clearly dominant at frequencies over 10 kHz. At 4 km the ice breaking noise was only clearly distinguishable at the lower frequencies for these samples.



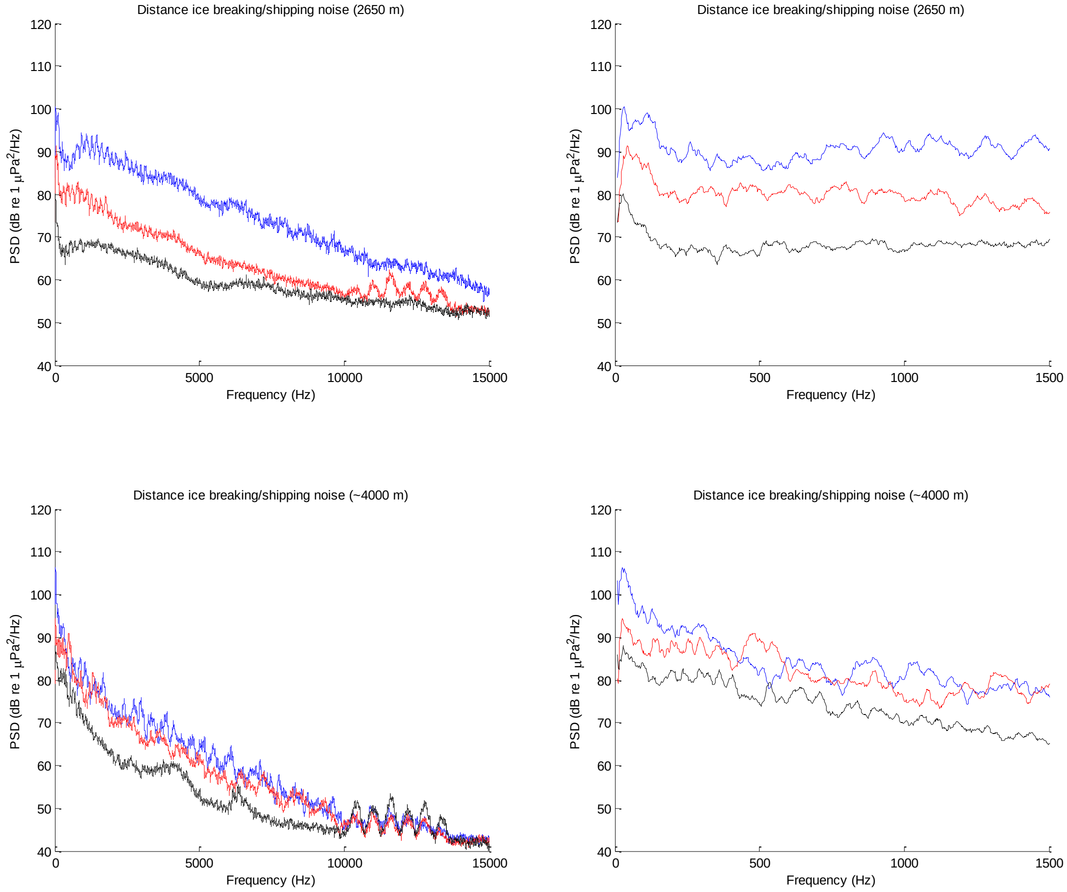


Figure 79 Top: Spectrogram of a typical recording of ice breaking noise. The two other rows show the power spectral density measured at different distances of ice breaking (blue), the ODEN (red) and the background noise (for as far it was possible to measure it without the ODEN in the background). The left image shows frequencies up to 15 kHz while the right image presents a zoom to assess the low frequency levels.

Narwhals

Not many cetacean signals were recorded, but a few whistle-like signals were automatically detected (Figure 20, green arrows) and manual inspection showed whistles (Figure 21, top). The most likely species was the narwhal, but in an attempt to confirm this a second typical narwhal signal was sought manually in the recordings. This species produces pulsed calls starting at low frequencies which may have energy content up to 100 kHz (Marcoux et al., "Variability and context specificity of narwhal (Monodon monoceros) whistles and pulsed calls", 2011, MMS 28(4): 649-665); biosonar from most other species does not contain such low frequency content. In the bottom image in Figure 21 a pulsed call can be seen left from the center. The combination of the two signals makes a narwhal most likely.

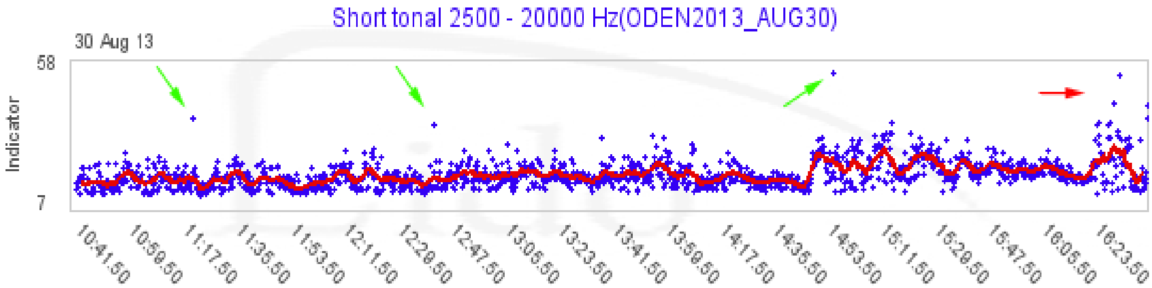


Figure 20. Short tonal detector output: green arrows indicate verified whistle content; red arrow human speech. High baseline levels were caused by the side scan sonar.

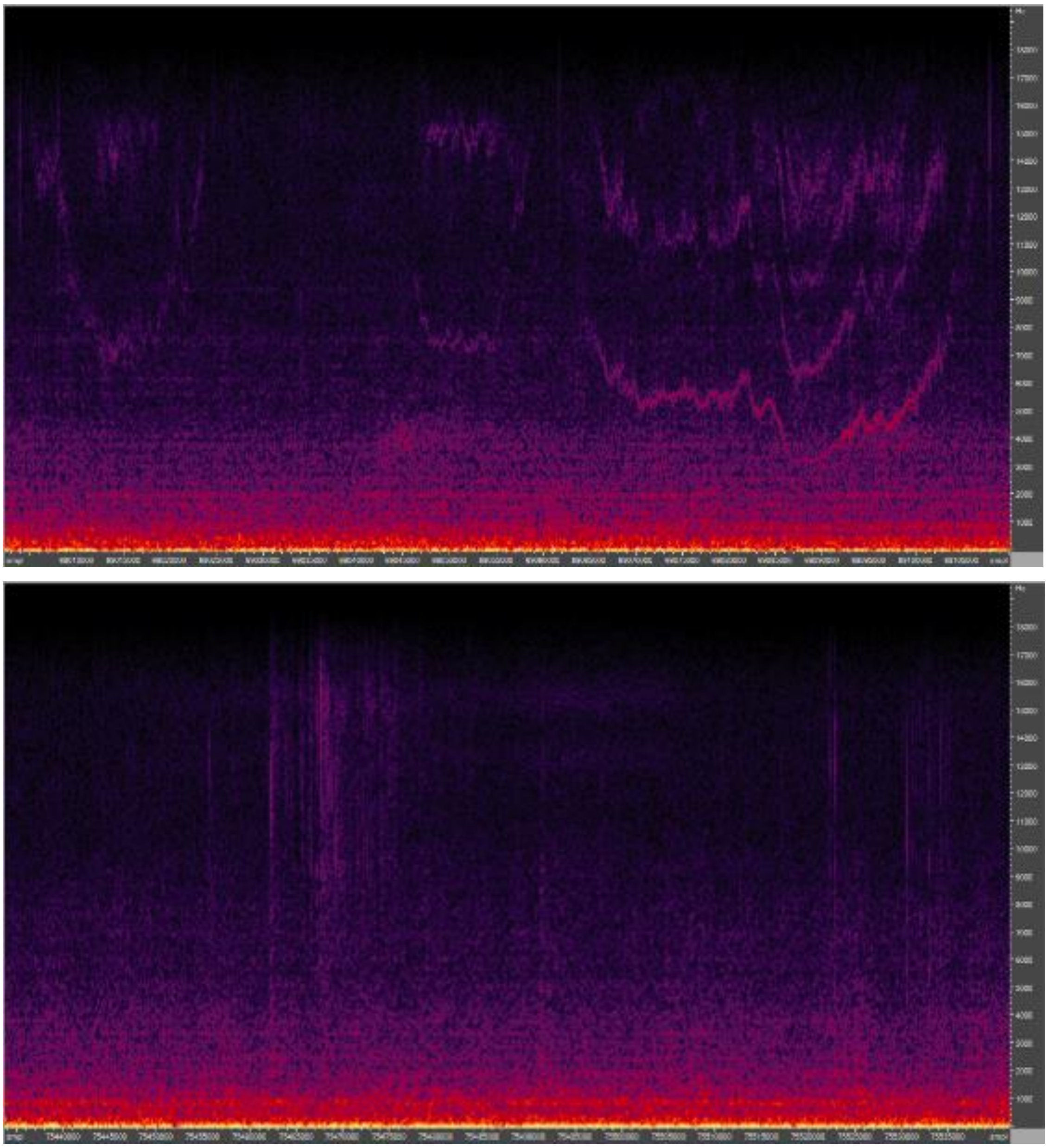
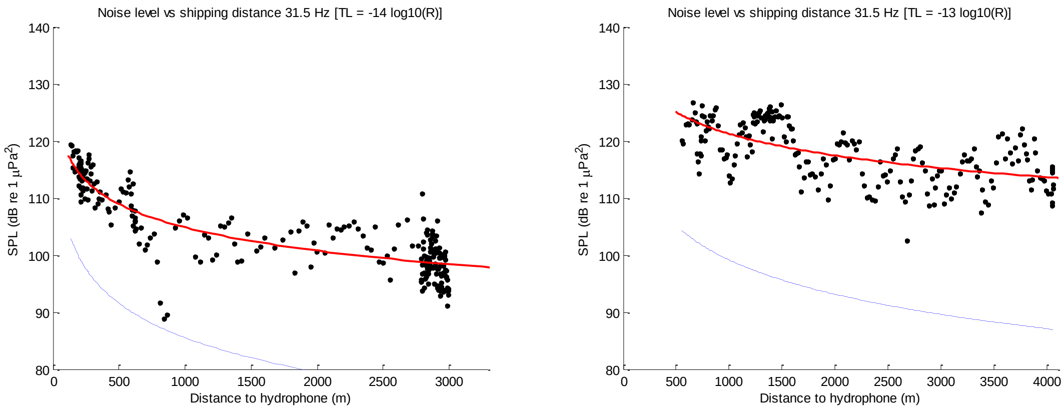
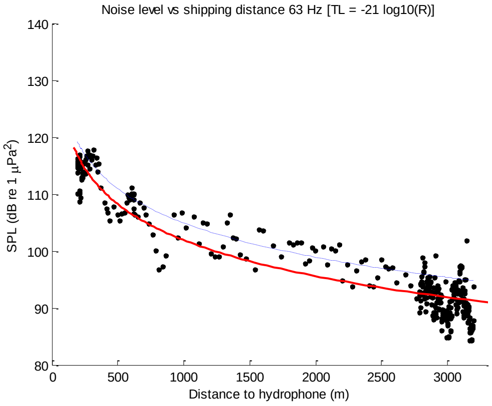


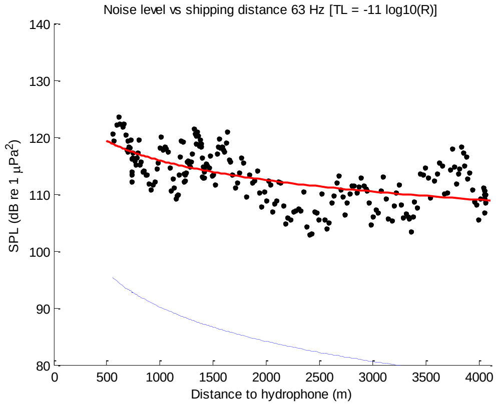
Figure 21 Cetacean vocalizations (2013-08-30, 12:37:15), likely from a narwhal. On top whistles and on bottom a pulsed call.

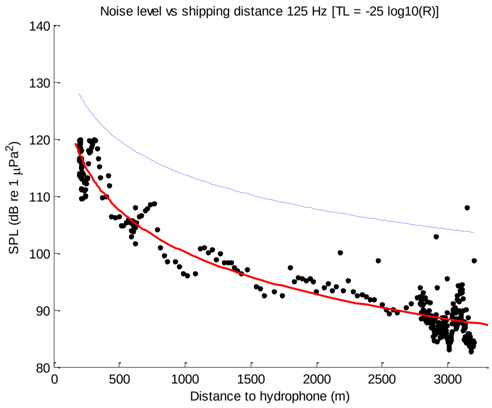
TL Estimation

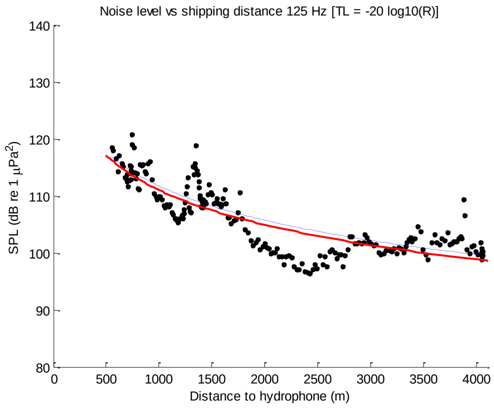
The transmission loss was estimated using the third octave levels measured in Figure 12 and Figure 18. Figure 22 shows the results from the 28th on the left and the 30th on the right. The black dots are the measurements while the ODEN was returning to the buoy. The red line is a logarithmic fit on the measurement and the blue line shows the spherical loss using the intercept from the fit. As was observed before, the levels were consistently lower on the 28th. On the 30th there is an increasing loss with increasing frequeny, which is not visible on the 28th. The slope on the 30th changes from -13 to -24, indicating a larger than spherical loss. Unfortunately the real source level is not know, making it impossible to verify the drop of level in the first 500 meters from the estimated intercept. There may be an effect of the interaction of multiple waves close to the source, leading to a low transmission loss, while at a larger distance from the source the reverberations no longer have an influence leading to a much higher loss (and overestimation of the intercept). To properly model the loss at close and far distances the nearby recordings should be made with a source/hydrophone combination that does not saturate. The progation loss estimated based on the data in Figure 22 is probably more reliable at larger distances.

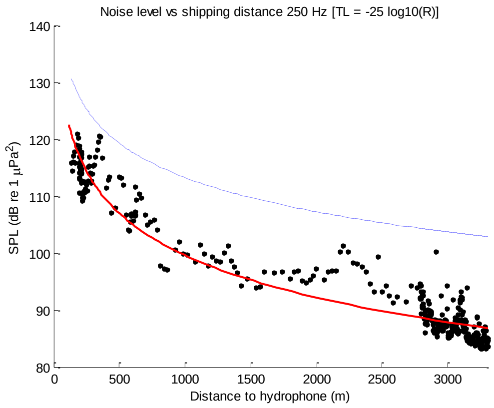


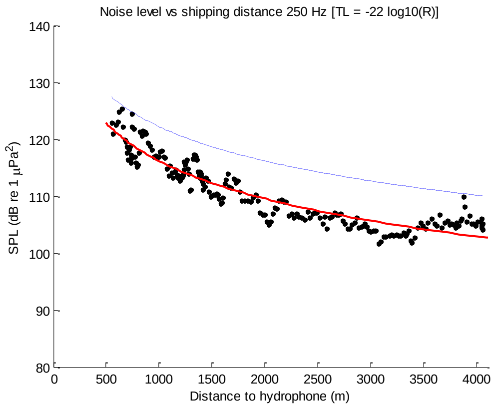

Noise level vs shipping distance 63 Hz [TL = -21 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)

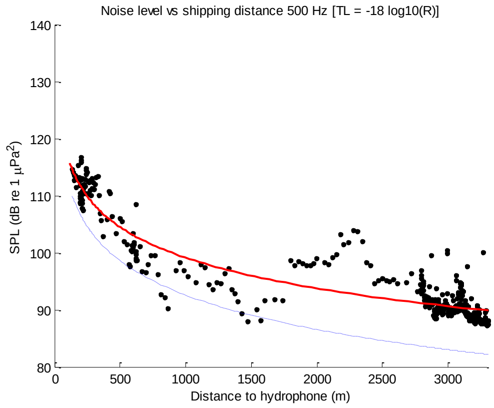

Noise level vs shipping distance 63 Hz [TL = -11 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)

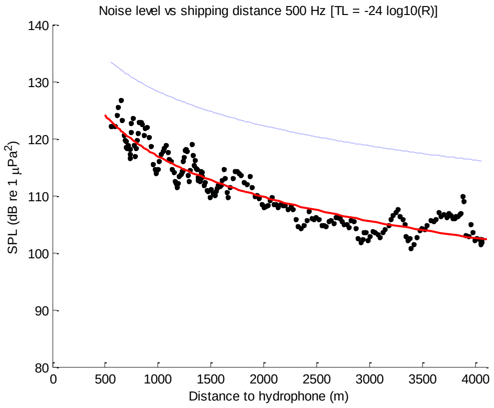

Noise level vs shipping distance 125 Hz [TL = -25 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)


Noise level vs shipping distance 125 Hz [TL = -20 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)


Noise level vs shipping distance 250 Hz [TL = -25 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)


Noise level vs shipping distance 250 Hz [TL = -22 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)


Noise level vs shipping distance 500 Hz [TL = -18 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)


Noise level vs shipping distance 500 Hz [TL = -24 log10(R)]
SPL (dB re 1 μPa²)
Distance to hydrophone (m)

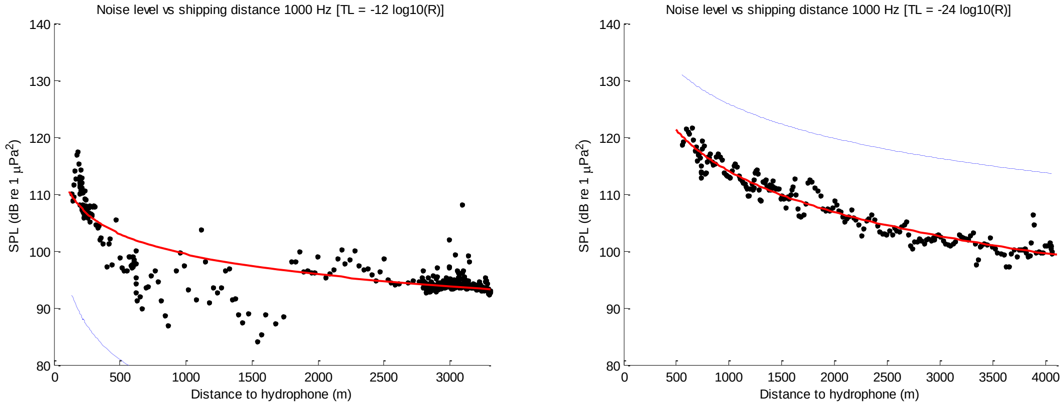


Figure 22. SPL versus distance during the ODEN return on the 28th (left) and 30th (right) in black. The red line is a logarithmic fit; the blue line is spherical loss using the intercept from the fit.

Conclusions

The ODEN-2013 cruise has provided acoustic recordings of ship-, ambient-, airgun- and ice-breaking noise. Additionally some marine mammal recordings were made. The engine noise of the ODEN-2013 was a good source when it was maintaining a constant angle with respect to the hydrophone. Especially data from a distance of more than ca. a kilometer is expected to be suitable for propagation loss estimation.

To improve the measurements in a future expedition the following recommendations are made:

1. An acoustic source with a known source level should be used to be able to properly prepare the acquisition system. For higher frequencies (over ~200 Hz) a calibrated transducer could be used; for lower frequencies the ship engine could be used as indicated below in point 5.
2. The source should always be used at the same depth and position relative to the ship.
3. The recording system should use 2 hydrophones with different sensitivities to allow nearby high level recordings and distant low level recordings.
4. The position and depth of the hydrophone(s) should be maintained constant.
5. If possible, a run with the ship from or to the buoy should be made at constant course and speed.
6. Ambient noise recordings will be improved if the equipment (engine, generator, sonar) on the ship can be switched off more often at different times of the day.

The protocol was initially meant to provide some modelling on sound TL and mitigation recommendations, but the lack of calibrated sources made impossible projecting the results further than what is presenting in this report. As a consequence, the mitigation aspect,will be developed in D4.57 together with the planned environemental risk assessment in relation to noise.