Underwater Sound Sources Characterisation Study

Energy Island, Denmark

JASCO Applied Sciences (Deutschland) GmbH

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Executive Summary

JASCO Applied Sciences (JASCO) was contracted by Fugro Netherlands Marine (Fugro) on behalf of Energinet Eltransmission A/S (Energinet) to undertake a sound source characterisation (SSC) study for a variety of sources commonly used for underwater geophysical surveys. The study took place at the North Sea Energy Island concession site offshore of Denmark where Energinet is engaged in the permitting process for the construction of a renewable energy facility to connect several wind farms to the Danish energy grid.

The aim of the study was to determine the effective source levels (ESLs) of the tested sources, to understand how their received levels varied with range and to determine how they may impact marine mammals.

JASCO deployed three autonomous multichannel acoustic recorders (AMARs) from the MV *Fugro Pioneer* between 18 and 20 Sep 2021 to collect underwater sound recordings during activation of a 'sparker', a multi-beam echosounder (MBES), a side scan sonar (SSS) with and without high-precision positioning system (USBL), and a parametric sub-bottom profiler (SBP). For each of these sources, data were collected individually, i.e., with only one source activated, and also with all sources activated simultaneously as would normally occur during a geophysical survey. In addition, a control test was run with all sources off; in this case, the vessel signature represented the baseline background noise. Data were collected along the survey track line with one fixed instrument and perpendicularly along a transect line at 100, 500, 750, and 2000 m from the survey line. For the sparker source only, additional data were collected at 5 and 10 km.

The measurement results were used for regression analysis, to determine the relationship between received noise level and distance from the source. The primary results are 1) estimates of the distance at which the sound exposure levels for a full survey vessel fall below the temporary and permanent hearing threshold shift isopleths for marine mammals; and 2) the distance at which the 125 ms sound pressure level, weighted for the hearing of very high frequency cetaceans (i.e., harbour porpoise) falls below 100 dB re 1 µPa². These values are summarized in the tables below.

Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) thresholds for auditory frequency weighted marine mammal listening groups and their respective exceedance distances. The dash indicates threshold not exceeded.

Weight	Threshold (dB re 1 µPa²)		Fitted range (m)		90%CI Range (m)	
	TTS	PTS	TTS	PTS	TTS	PTS
LFC	179	199	--	--	9.8	--
HF	178	198	2	--	5.5	--
VHF	153	173	332.8	7.2	502.2	16.9
PW	181	201	--	--	0	--

Distance in meters to the 125 ms VHF auditory frequency weighted SPL of 100 dB re. 1 µPa², based on regression analysis of best fit as well as 90% confidence interval.

Equipment	Fitted range (m)	90%CI range (m)
Sparker	1721	2161
SBP	597	731
SSS with USBL	2705	2986
Full Survey	1975	2278

For the full results, the reader is referred to the Technical Summary as well as the respective results sections of the report.

Technical Summary

JASCO Applied Sciences (JASCO) was contracted by Fugro Netherlands Marine (Fugro) on behalf of Energinet Eltransmission A/S (Energinet) to undertake a sound source characterisation (SSC) study for a variety of sources commonly used for underwater geophysical surveys. The study took place at the North Sea Energy Island concession site offshore of Denmark where Energinet is engaged in the permitting process for the construction of a renewable energy facility to connect several wind farms to the Danish energy grid. The aim of the study was to determine the effective source levels (ESLs) of the tested sources, to understand how their received levels varied with range and to determine how they may impact marine mammals. The marine mammal species groupings defined in Southall et al. (2019) have been employed in this analysis. Results for low frequency (LF, e.g., minke whales) and high frequency (HF, e.g., dolphins) cetaceans as well as phocid seals in water (PW) are also presented. The acoustical terminology recommended in ISO standard 18405 (2017) were followed.

JASCO deployed three autonomous multichannel acoustic recorders (AMARs) from the MV *Fugro Pioneer* between 18 and 20 Sep 2021 to collect underwater sound recordings during activation of a ‘sparker’, a multi-beam echosounder (MBES), a side scan sonar (SSS) with and without high-precision positioning system (USBL), and a parametric sub-bottom profiler (SBP). For each of these sources, data were collected individually, i.e., with only one source energized, and also with all sources activated simultaneously as would normally occur during a geophysical survey. In addition, a control test was run with all sources switched off; in this case, the vessel signature represented the baseline background noise. Data were collected along the survey track line with one fixed instrument and perpendicularly along a transect line at 100, 500, 750, and 2000 m from the survey line. For the sparker source only, additional data were collected at 5 and 10 km to further our understanding of how the sound from this source propagates and whether it was detectable at such distances.

The hydrophone data were analysed to detect each sound pulse and then to quantify the sound exposure level (SEL), the 0.125 second sound pressure level (SPL), and the peak sound pressure level. For each metric the received sound levels (RL) were fit to linear models in the form RL = ESL + $A\log_{10}$(range) + B*range. The parameter A represents the geometric spreading loss coefficient of the sound and is generally between 10 and 20. B describes extra attenuation due to scattering and absorption of the sound that increases linearly with range. ESL is the effective source level, which is a measure of how loud the source is, however, it is not the same as monopole source level (MSL) that measures the true intensity. MSL can be used for predicting sound as a function of distance using acoustic propagation models. The ESL may only be employed with the A and B terms that were computed at the same time as the ESL and are only valid for the environment in which they were measured.

The results showed that sound levels decreased with range as one would expect from theory; the decay of the sounds varied according to source type. Key findings included:

- The sparker ESL was estimated at 188 dB re 1 μPa^2 based on the regression for the SPL_{125ms} (Confidence Interval, CI, of 90%) over the broadband range 0.1–128 kHz with peak energy between 200–300 Hz in the endfire direction. The interval between sparker pulses was ~250 ms. The sparker pulses were detectable above background noise until 2 km both in the endfire and broadside directions but not at 5 and 10 km; at the latter distances, silent intervals between pulses could not be clearly identified. The pulses appeared to decay with a propagation loss coefficient (A) of ~16.
- The sub-bottom profiler ESL was 237 dB re 1 μPa^2 (SPL_{125ms}, CI: 90%) with peak energy of the primary frequency between 85–110 kHz; at closest point of approach (CPA) along the survey line, its secondary frequencies were also visible at 8–12 kHz. The interval between pulses for this source was less than 125 ms (~73 ms); as such, this should be considered a continuous source (de Jong et al. 2021). The decrease in levels with range is greater in the attenuation of higher

frequencies (*B* ~ 4 dB/km). The source also appears to have a strong downward beampattern, which caused *A* ~ 44. Past 500 m from the source, the sound was barely detectable above background noise.

- The multibeam echosounder had its main frequencies in the 200 to 400 kHz range and as such was outside the recording bandwidth of the monitoring hydrophones (sampling at 256 kHz yielded a maximum analysis frequency of 128 kHz); no subharmonics of the source were detected in the analysis frequency range and received levels at all stations were comparable to the vessel only pass.
- The side scan sonar operates at frequencies between 100 and 900 kHz depending on the beam angle. The SSS also has a USBL beacon for high precision navigation on that operates between 25 and 40 kHz. When the USBL beacon was active it was detectable at 2 km distance; the ESL estimated for this operating condition was 184 dB re 1 μPa^2 (SPL_{125ms}, CI: 90%) with an inter pulse interval of approximately 550 ms. The USBL source appears to be omnidirectional; the geometric spreading coefficient was *A* ~ 15, with an absorption term of *B* ~ 10 dB/km (which agrees well with absorption of seawater (François and Garrison 1982a)). Apart for the difference attributable to the presence and absence of the USBL, the spectra measured were almost identical to the vessel only passage.
- The test conducted with all sources active measured the total noise radiated from vessel with all sensors operational in their survey configuration with energy attributable to the vessel, sparker, and USBL beacon, and sub-bottom profiler. Due to the diverse nature of the sources, their levels, and their broad frequency ranges, all the marine mammal hearing groups are relevant for consideration during survey activities. The pass with all sources active was evaluated against the Southall et al (2019) thresholds for Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) for VHF cetaceans. The thresholds for continuous sound exposure were used since the interval between pulses was less than 125 ms and most sources only had energy in discrete frequency bands. The results showed that the PTS threshold of 173 dB re 1 μPa^{2}s for the SEL is exceeded within less than 10 m from the source; the TTS threshold of 153 dB re 1 μPa^{2}s for the SEL is exceeded within ~333 m from the source (Figure 44). Based on the regression analysis conducted, the sound levels for all sources combined fell below a VHF-weighted sound pressure level 100 dB re 1 μPa SPL_{125ms} at ~2 km from the source (Figure 46).

Absolute source levels were not calculated as part of the scope of work; however, these could be obtained by applying inversion modelling to the data set.

1. Introduction

JASCO Applied Sciences (JASCO) was contracted by Fugro Netherlands Marine (Fugro) to undertake a sound source characterisation (SSC) study for Energinet Eltransmission A/S (Energinet) that involved data collection, analysis, and results interpretation with a focus on understanding potential impacts on marine mammals. The scope of the study was to determine the source characteristics for various acoustic instruments that are commonly employed during geophysical surveys and to estimate the propagation loss (PL) at the Energy Island site in the North Sea, Denmark (Figure 1) for use in future environmental impact assessment (EIA) studies.

In June 2020, the Danish Folketing (Parliament) decided to prepare to construct two energy islands in Denmark, one in the North Sea and one in the Baltic Sea. These islands will serve as the focal point for power connections and servicing of offshore wind farms. The energy island in the North Sea, planned to be constructed on the site where this study occurred, will have a capacity of 3 GW in 2030 and 10 GW in the longer term.

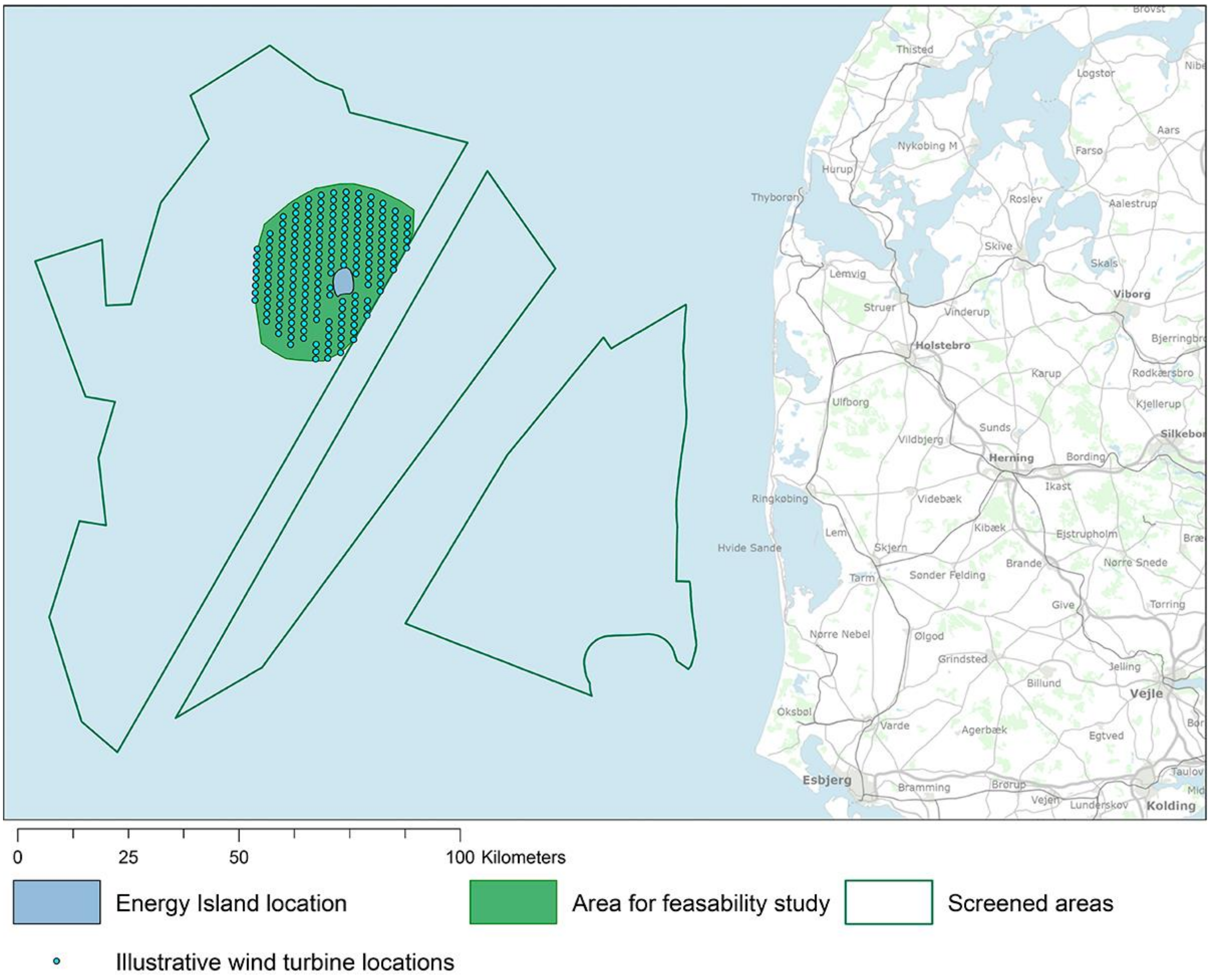


Figure 1. Map of areas indicating the location of island and offshore wind in the North Sea. Source: The Danish Energy Agency (2021).

1.1. Changes to Sound as it Travels in the Ocean

A key question in the study of underwater sound is how a sound changes in nature as it propagates from its source to a receiver some distance away. Understanding and modelling sound propagation in the ocean is a complex topic that is the subject of numerous textbooks. This section provides a descriptive overview of key sound propagation concepts to assist with the results presented in this report. These concepts are integral to interpreting how sounds emitted by a source are transformed into those received some distance away. The sounds are transformed by: 1) geometric spreading; 2) reflection, scattering and absorption at the seabed and sea surface; 3) refraction due to changes in sound speed with depth; and 4) absorption. This section does not address method 3, as sound refraction plays only a minor role in shallow water, such as the Energy Island Development area.

At one extreme, the echolocation clicks of porpoises at 130 kHz travel only 500 m before becoming inaudible (Au et al. 1999). At the other extreme, sounds from fin whales (20 Hz) and low-frequency energy from seismic airguns (5–100 Hz) can be detected thousands of kilometres away under the right conditions (Nieukirk et al. 2012).

Geometric spreading losses: Sound levels from an omnidirectional point source in the water column are reduced with range, a process known as *geometric spreading loss*. As sound leaves the source, each spherical sound wave propagates outward, and the sound energy is spread out over this ever-expanding sphere. The farther you are from the source, the lower the sound level you will receive. The received sound pressure levels at a recorder located a distance R (in m) from the source are $20\log_{10}R$ dB lower than the source level (SL) referenced to a standard range of 1 m. But, the sound cannot spread uniformly in all directions forever. Once the waves interact with the sea surface and seabed, the spreading becomes cylindrical rather than spherical and is limited to the cylinder formed by the surface and seabed with a lower range-dependent decay of $10\log_{10}R$ dB. Thus, the water depth is a key factor in predicting spreading losses and thus received sound levels. These spherical and cylindrical spreading factors provide limits for quick approximations of expected levels from a given source. In very shallow waters, sound rapidly attenuates if the water depth is less than a quarter of a wavelength (Urick 1983).

Absorption, reflection, and scattering at the sea surface and seabed: If geometric spreading were the only factor governing sound attenuation in water, then at a given distance from a source, sound levels in shallow waters would almost always be higher than those in deep waters. In shallow water, however, the sound interacts more often with the seabed and sea surface than sound travelling in deep waters, and these interactions reflect, absorb, and scatter the sounds. The sea surface behaves approximately as a pressure release boundary, where incident sound is almost completely reflected with opposite phase. As a result, the sum of the incident and reflected sounds at the sea-surface is zero. At the seabed, many types of interactions can occur depending on the composition of the bottom. Soft silt and clay bottoms absorb sound, sand and gravel bottoms tend to reflect sound like a partially reflective mirror, and some hard yet elastic bottoms, such as limestone, reflect some of the sound while absorbing some of the energy by converting the compressional waves to elastic shear waves.

Absorption by sea water: As sound travels through the ocean, some of the energy is absorbed by molecular relaxation in the seawater, which turn the acoustic energy into heat. The amount of absorption that occurs is quantified by an attenuation coefficient, expressed in units of decibels per kilometre (dB/km). This absorption coefficient depends on the temperature, salinity, pH, and pressure of the water, as well as the sound frequency. In general, the absorption coefficient increases with the square of the frequency, so low frequencies are less affected. The absorption of acoustic wave energy has a noticeable effect (>0.05 dB/km) at frequencies above 1 kHz. For example, at 10 kHz the absorption loss over 10 km distance can exceed 10 dB, as computed according to the formulae of François and Garrison (1982b, b).

1.2. Ambient Ocean Soundscape

The ambient, or background, sound levels that create the ocean soundscape are comprised of many natural and anthropogenic sources (Figure 2). The main environmental sources of sound are wind, precipitation, and sea ice. Wind-generated noise in the ocean is well-described (e.g., Wenz 1962, Ross 1976), and surf sound is known to be an important contributor to near-shore soundscapes (Deane 2000). In polar regions, sea ice can produce loud sounds that are often the main contributor of acoustic energy in the local soundscape, particularly during ice formation and break up. Precipitation is a frequent noise source, with contributions typically concentrated at frequencies above 500 Hz. At low frequencies (<100 Hz), earthquakes and other geological events contribute to the soundscape (Figure 2).

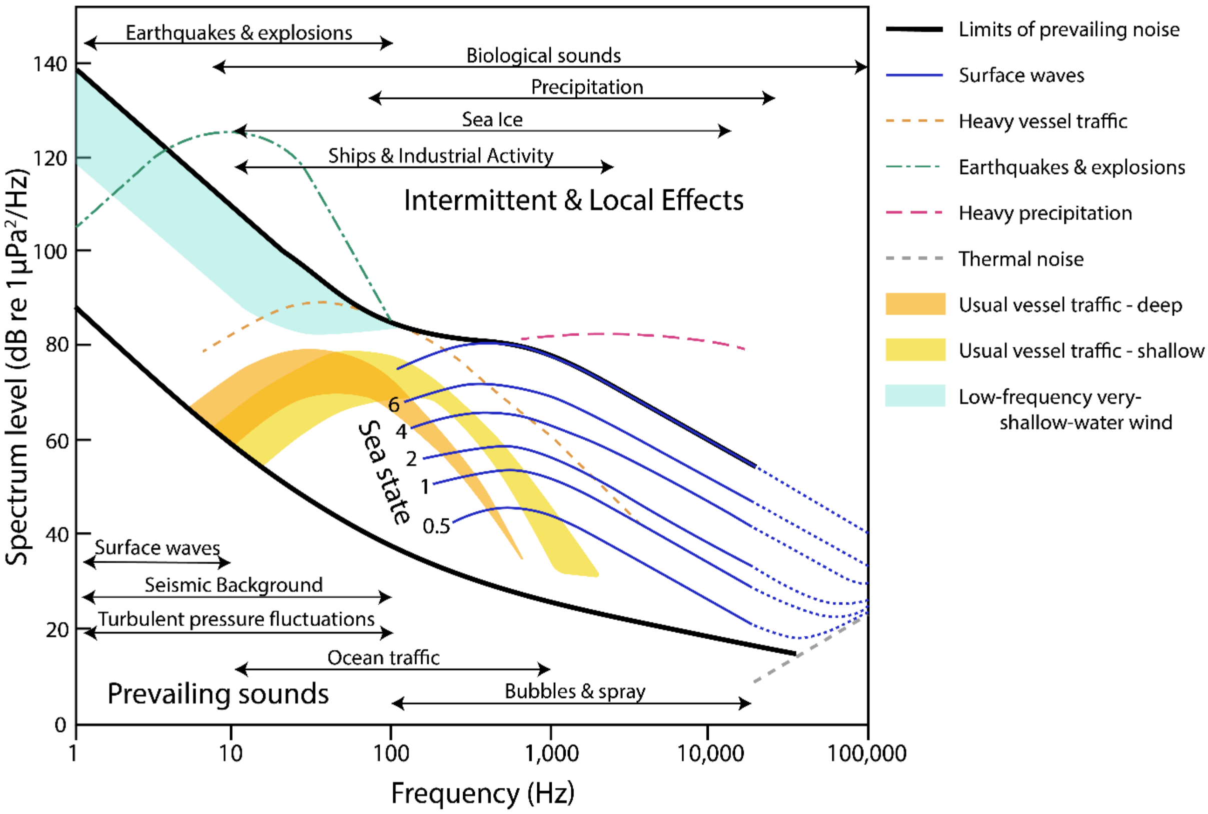


Figure 2. Wenz curves describing pressure spectral density levels of marine ambient sound from weather, wind, geologic activity, and commercial shipping (adapted from NRC 2003, based on Wenz 1962). Thick lines indicate limits of prevailing ambient sound.

2. Methods

JASCO collected underwater sound emission data using three Autonomous Multi-channel Acoustic Recorders (AMARs) that were deployed in the Energy Islands lease area (Figure 3; Table 5) in a configuration designed to capture sound levels as a function of range and direction from the sources. AMARs 1, 2, and 3 were deployed perpendicular to a test track of the vessel MV *Fugro Pioneer*. The *Fugro Pioneer* enabled four acoustic sources (a sparker, sub-bottom profiler, multi-beam echosounder and side scan sonar[1] with attached ultra-short baseline beacon – see Section 2.1) at different times as they passed at multiple distances from the recorders. The vessel was required to transit along a test track of 4 km. For the tests with the sparker source, additional lengths to the test track were requested by the client as well as two additional tracks parallel to the instruments at 5 and 10 km distances (Figure 4). The AMARs were deployed at 0, 100, and 750 m from the source, then each test was repeated after retrieving AMARs 2 and 3 and re-deploying them at 500 and 2000 m perpendicular to the vessel track line (Figure 4).

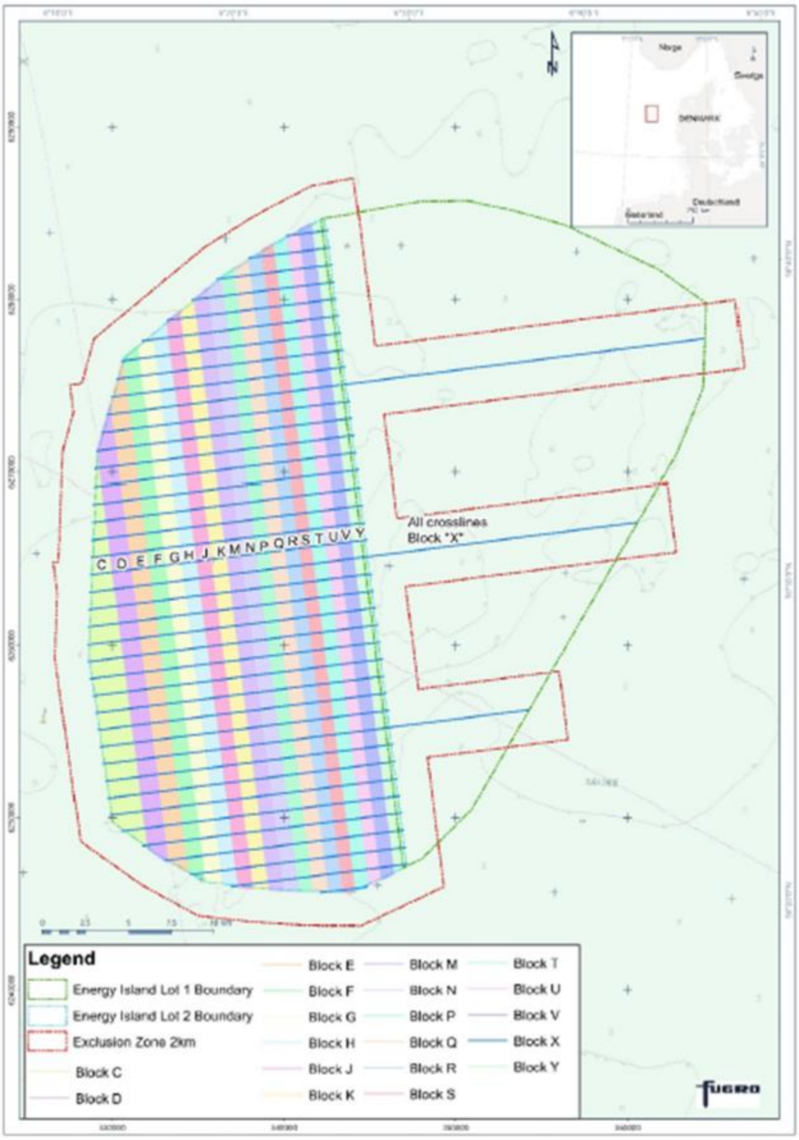


Figure 3. Map of the planned acoustic monitoring area (provided by Fugro).

[1] Only the USBL was detectable as the SONAR frequencies were outside the AMAR frequency range.

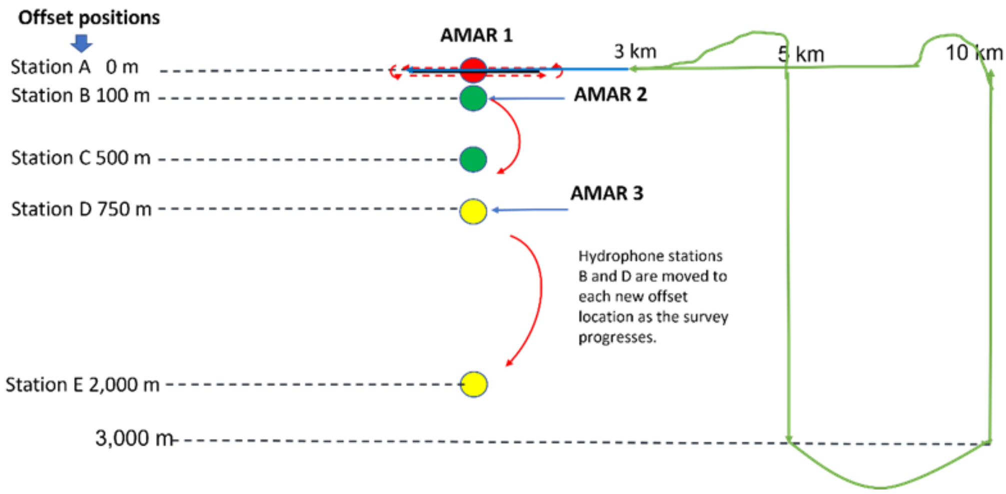


Figure 4. Recorder deployment geometry and test track for the sound source characterization (SSC) tests. Circles indicate the AMAR stations (red for the static AMAR 1 along the sail line, green for the AMAR 2 that was moved from 100 to 500 m between two sailings with the same sources, and yellow for AMAR 3 that was moved from 750 m to 2 km). The blue line indicates the standard sailing line for all the tests; the green lines and arrows indicate the additional sailing lines for the tests (including direction of travel) with the sparker source.

2.1. Measured Sound Sources

The following sound sources were tested:

- Sparker,
- Sub-bottom profiler (SBP),
- Multibeam echo-sounder (MBES),
- Side scan sonar (SSS) with and without high-precision acoustic positioning (USBL).

The sources were activated one at a time to record their signature individually and then all together in the same way as they would usually be operated during a standard geophysics survey. Furthermore, tests were run with all the sound sources off to measure the standalone vessel signature for the MV *Fugro Pioneer* (see Appendix A). The standard positioning systems, i.e., vessel Single-Beam Echo-Sounder (SBES) and survey SBES, were switched off during the tests.

Summary specifications of each source are described in the Sections 2.1.1 to 2.1.4 and their technical specifications in Appendix D. The test sequence, including times of activation and deactivation of each source as well as time at which the sensor passed on top of AMAR 1, were recorded on board by Fugro personnel and shared with JASCO to support the data processing effort (Table 2).

The relative position of each source when deployed from the *Fugro Pioneer* is presented in Appendix A.2, and their depth in Table 1 For the SSS, the depth varied according to the test run.

Table 1. Depth at which sources were deployed from the *Fugro Pioneer*. Times are given in UTC.

Source	Date	Start time	End time	Line name	Time for alt/depth	Altitude (m above seabed)	Depth (m below water line)
SSS only	2021 Sep 18	16:03	16:35	ENT4A01_01	16:20	6.1–6.7	27.6–27.8
SSS + USBL	2021 Sep 18	16:51	17:24	ENT4A02_01	17:06	7.5–8.5	26.2–26.8
SSS only	2021 Sep 19	17:46	18:20	ENT4B01	18:06	5.0–6.9	27.0–29.3
SSS + USBL	2021 Sep 19	18:35	19:07	ENT4B02	18:53	4.7–5.3	28.3–29.1
USBL	Same for all lines: see Table 2					28.93	4.5
MBES	Same for all lines: see Table 2					29.9	3.5
Sparker	Same for all lines: see Table 2					22.9	10.5
SBP	Same for all lines: see Table 2					30.2	3.2

SSS: side-scan sonar; USBL: high precision positioning system; MBES: Multi-beam echo sounder; SBP: Sub-bottom profiler

Table 2. Test sequence including operational time of each source. Times are given in UTC. Red shading: source not active; green shading: source active.

Line name	Date	Start time	End time	Vessel speed (kn)	Sensor requirement					Sensor time		Time at which sensor passed over Station A
					MBES	SBP	SSS	Sparker	SBES survey & SBES vessel	On	Off	
AMAR Locations Stations A, B, and D												
ENT0A01_01	18 Sep 2021	11:09	11:42	4						-	-	11:26
ENT0A02_01		11:56	12:27	4.5						-	-	12:12
ENT1A01_01		12:51	13:22							12:38	ON	13:07
ENT1A02_01		13:32	14:03							ON	14:03	13:48
ENT2A01_01		14:14	14:46							14:05	ON	14:31
ENT2A02_01		14:56	15:27							ON	15:28	15:13
ENT4A01_01		16:03	16:35				USBL beacon off			15:51	ON	16:20
ENT4A02_01		16:51	17:24				USBL beacon on			SSS ON USBL: 16:37	SSS & USBL: 17:27	17:06
ENT3A01_01		19:33	20:10							Soft start 19:08	20:10	19:55
ENT3AT1_01		20:12	20:35							20:10	20:35	-
ENT3AP1_01		20:36	21:14							20:36	21:14	-
ENT3AT2_01		21:16	21:53							21:16	21:53	N/A
ENT3AP2_01		21:55	22:34							21:55	22:34	-
ENT3A02_01		22:37	00:17							22:37	00:17	00:01
ENT5AT21	19 Sep 2021	00:20	01:11							00:20	01:12	-
ENT5A01_01		01:12	01:48							01:12	01:49	01:35
ENT5AT22		01:52	02:32							01:52	02:33	-
ENT5A02_01		02:36	03:17							02:36	03:18	03:01
AMAR Locations Stations A, C, and E												
ENT0B01	19 Sep 2021	13:28	13:58	4.5						-	-	13:43
ENT0B02		14:08	14:39							-	-	14:24
ENT1B01		14:53	15:23							14:45	ON	15:08
ENT1B02		15:33	16:03							ON	16:04	15:49
ENT2B01		16:15	16:45							16:05	ON	16:30
ENT2B02		16:53	17:23							ON	17:32	17:09

ENT4B01		17:46	18:20				USBL beacon off			17:32 SSS 17:32 USBL	SSS ON 17:34 USBL off	18:06
ENT4B02		18:35	19:07				USBL beacon on			18:31 USBL	19:07 USBL and SSS	18:53
ENT3B01		20:44	21:22							20:20 Soft Start	21:22	21:07
ENT3B02		21:43	22:18							21:22 Soft Start	22:19	22:04
ENT5AT21		22:22	23:12							22:19	23:13	-
ENT5B01_01		23:15	23:57							23:06 MBE 23:07 SBES 23:08 USBL 23:10 SBP 23:15 SPK	23:58	23:38
ENT5AT22		23:59	00:15							23:59	00:15	-
ENT5B02_01	20 Sep 2021	00:15	00:56							00:15	00:56	00:40

2.1.1. Sparker Source and Streamer

A sparker is a sub-surface imaging sound source that generates an acoustic pulse by discharging an electrical spark between electrodes located on the tips and a ground point on the sparker body, in the conducting medium of seawater. This type of equipment is used to obtain the geology of the seabed with high resolution.

The sparker source and streamer recorder configuration are summarised in Table 3. The sparker source was towed behind the vessel at a fixed distance of 45 m and at 0.5–1 m depth and operated at a frequency of 0.2–0.3 kHz. See Appendix D.1 for more details. The sparker was operated at full power during these operations.

Table 3. Specifications of the streamer multichannel Ultra High-Resolution (UHR) equipment.

Streamer	
Manufacturer	Geometrics
Model	LH-16 GeoEel
Group interval	1 m
No channels/length	48 m
Fold	24
Offset source-near group	<10 m
Depth control	None
Tension control	3 × Adaptive drogue
Manufacturer	Fugro
Model	StarfixNG
Configuration/ volume	360 tip/900 J 900 J (300, 300, 300) 360 (160, 120, 80) Tips Tip depth 0.7, 0.92, 1.12 m
Power supply	3 × CSP1200-Nv

Seismic recorder	
Manufacturer	Geometrics
Model	CNT-2
Recording medium	Hard drive
Sample rate	0.125 ms
Record length	100 ms
Auxiliary channels	
Filters	65 Hz at 18 dB/octave low-cut filter for addressing SOL/EOL noise analysis
Manufacturer	Fugro
Location model manufacturer	Fugro
Location model	Layback and offset to be used for positioning
Location	Layback and offset to be used for positioning

2.1.2. Sub-bottom Profiler (SBP) Innomar SES-2000

Sub-bottom profilers are used to determine physical properties of the sea floor and to image and characterise geological information a few metres below the sea floor.

The sub-bottom profiler was a hull mounted SES-2000 manufactured by Innomar. For the SSC, the SBP was configured as:

- 8–12 kHz frequency, and
- Max ping rate depended on water depth.

The SES-2000 is a parametric sonar that generates the low frequencies by mixing together sounds at higher frequencies (in this case around 100 kHz). These sonars are known to be highly directional (downward looking). See Appendix D.2 for more details. The SBP was operated at 80% of full power during this operation.

2.1.3. Multi-Beam Echo Sounder (MBES) Kongsberg EM2040

The EM2040 is a hull-mounted multibeam echosounder (MBES) used to map the sea bottom. The EM2040 has dual-receive multi-ping functionality manufactured by Kongsberg. For the SSC, the MBES configuration was:

- 400 kHz frequency, and
- Max ping rate depended on water depth.

See Appendix D.3 for more details. The MBES was operated at full power during this operation.

2.1.4. Side Scan Sonar (SSS) EdgeTech 4200

Side-scan sonar is used to efficiently create an image of large areas of the seafloor. It is generally used for mapping the seabed for a wide variety of purposes, including creation of nautical charts and detection and identification of underwater objects and bathymetric features. Side-scan sonar imagery is also a commonly used tool to detect debris and other obstructions on the seafloor that may be hazardous to shipping or to seafloor installations.

The side scan sonar used was an EdgeTech 4200. For the SSC, the SSS was configured as follows:

- USBL positioning was used, as this is Fugro's standard operational setup. One test was performed with the USBL turned off and a return pass with it turned on.
- 300/600 kHz – Dual frequency simultaneous operation
- 100% power output
- 75 m range setting, and
- Altitude 8–12% of range.

See Appendix D.4 for more details.

The SSS is typically operated in conjunction with a high-precision positioning system, referred to as ultra-short baseline (USBL) positioning system. This is required to ensure that the readings from the side-scan sonar can be positioned correctly. The USBL emits a ping generally every second; the interval can be adjusted but its precision is proportional to the repetition rate; therefore, short intervals of time are preferred to obtain accurate readings. The spacing between the SSS and the USBL is generally a few meters but can reach up to ~100 m. The SSS was towed at variable depth (Table 1) and variable distance from the vessel ranging from 86 to 117 m for the noise trials. The SSS was operated at full power during these operations.

2.2. Acoustic Data Acquisition

Data was recorded and stored on Autonomous Multichannel Acoustic Recorders (AMARs) Generation 4 (G4) manufacturer by JASCO. This section describes the configuration of the acoustic recorders and the deployments.

2.2.1. Acoustic Recorders

Each AMAR was fitted with two omnidirectional hydrophones (GeoSpectrum Technologies Inc); the sensitivity of each is presented in Table 4. The AMAR hydrophones were protected by a hydrophone cage, which was covered with a Lyra shroud to minimise noise artifacts from water flow. The AMARs recorded continuously at 256,000 samples per second for a recording bandwidth of 10 Hz to 128 kHz. The recording channel had 24-bit resolution. Acoustic data were stored on two 512 GB internal solid-state flash memory cards. Appendix B provides details about the calibration procedure and results; instruments were calibrated before leaving JASCO's facility in Dartmouth, Canada, prior to shipment, and then again onboard the *Fugro Pioneer* before and after each deployment, in accordance with best practice guidelines (Robinson et al. 2014). The sensitivities measured during the on-board tests were validated against the calibrations at the Dartmouth facility. For the data analysis, the pre-shipment calibration values were used.

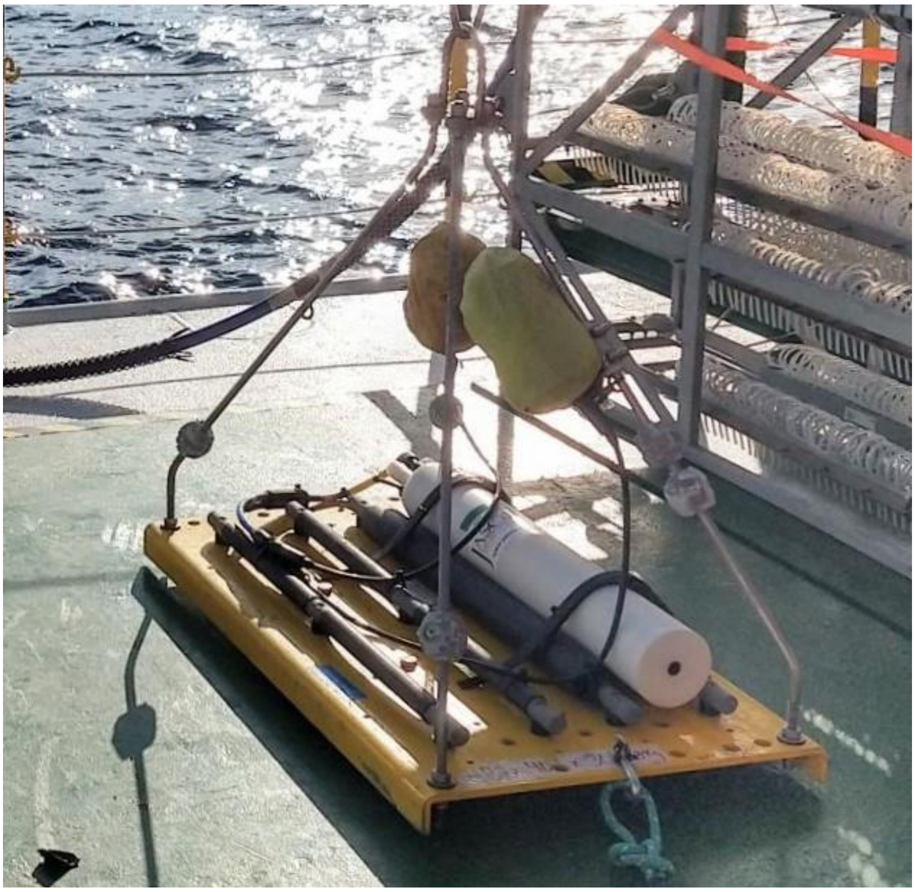


Figure 5. Photo of a baseplate before deployment with fitted with hydrophones and an Autonomous Multichannel Acoustic Recorder (AMAR) Generation 4 (G4) (white tube). The hydrophones are not directly visible as they were covered by the yellow flow shields).

Table 4. List of instruments deployed at each station and relative hydrophone model and sensitivity.

Station ID	AMAR	Hydrophone 1: Model/serial number Sensitivity (dB re 1V/µPa)	Hydrophone 2 Model/serial number Sensitivity (dB re 1V/µPa)
A	621	M36-V35-900 /G000311 −164.3	M36-V0-901/G000462 −219.2
B	623	M36-V35-900 /G000306 −1634.2	M36-V0-901/G000461 −219.6
C	623	M36-V35-900 /G000306 −1634.2	M36-V0-901/G000461 −219.6
D	624	M36-V0-901/G000307 −163.9	M36-V0-900/D000760 −200.7
E	624	M36-V0-901/G000307 −163.9	M36-V0-900/D000760 −200.7

2.2.2. Deployment Locations

Instruments were deployed from the *Fugro Pioneer* at the coordinates planned during the preparation stages of the project. The proposed locations were de-risked using the already acquired survey data and have been positioned >500 m away from all existing infrastructure, in locations with a flat seabed. Positions reported in Tables 5 and 6 correspond to the readings from the MBES scouting performed to confirm the equipment positions following deployment. Two sets of coordinates are presented because the equipment was initially deployed at positions A, B and D on 18 Sep 2021 and retrieved the following day to be re-deployed at locations C and E. AMAR 1 was not retrieved and re-deployed, in accordance with the operations plan; therefore, the slight discrepancy in deployment coordinates for position A may be due to the MBES readings or some slightly movement of the instrument related to weather conditions (Figure 6).

Therefore, to collect data for each source at all 5 distances relative to the source, two test runs were performed for each test, except for the sparker 5 and 10 km lines. Test run 1 refers to tests conducted with AMAR 2 deployed at 100 m and AMAR 3 at 750 m, while Test run 2 refers to tests performed with AMAR 2 deployed at 500 m and AMAR 3 at 2000 m. For each test run, two passes were performed, i.e., reciprocal lines. Note that for the test performed for the side scan sonar, one line was run with the USBL inactive and its reciprocal pass with the USBL active. AMAR 1 (Station A) was never moved and therefore always placed along the survey line.

Table 5. As-laid deployment locations of each recorder during the first set of tests. Latitude, longitude, and depth.

Location	Station ID	Instrument	Latitude	Longitude	Depth (m)
0 m	A	AMAR 1	N 56°54’95.99	E 06°27’02.71	33.50
100 m	B	AMAR 2	N 56°54’97.59	E 06°27’18.84	33.00
750 m	D	AMAR 3	N 56°55’07.22	E 06°28’23.18	31.80

Table 6. As-laid deployment locations of each recorder during the second set of tests. Latitude, longitude, and depth.

Location	Station ID	Instrument	Latitude	Longitude	Depth (m)
0 m	A	AMAR 1	N 56°54’95.84	E 06°27’02.96	33.20
500 m	C	AMAR 2	N 56°55’03.29	E 06°27’85.66	32.80
2000 m	E	AMAR 3	N 56°55’25.83	E 06°30’25.60	32.30

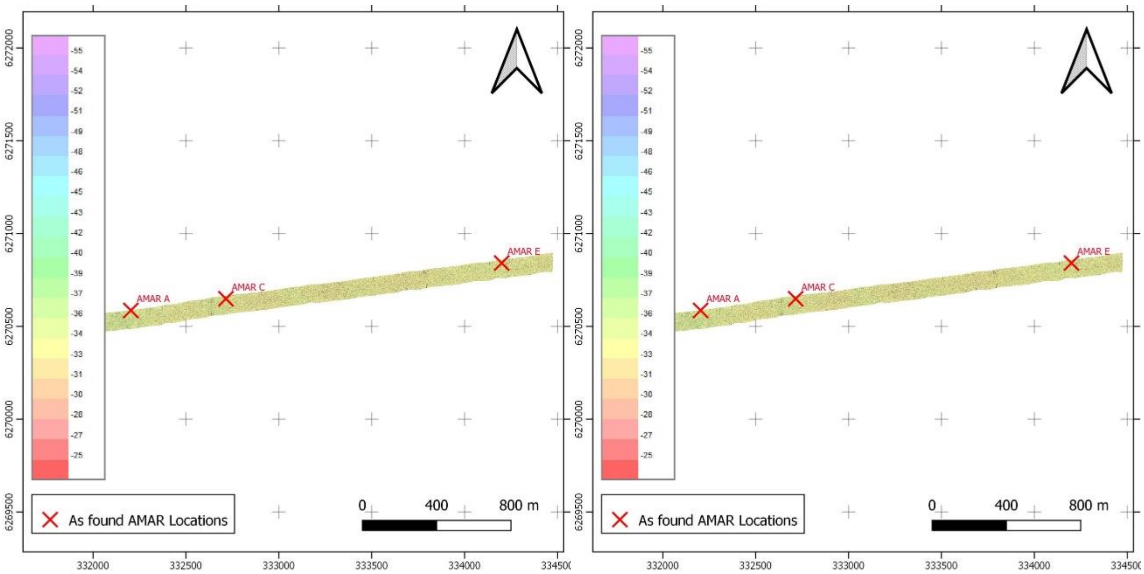


Figure 6. Maps of the deployment locations from the Multi-beam echo-sounder, (MBES) (as provided by Fugro for (left) AMARs A, B, and D during the first tests and (right) AMARs A, C, and E during the second tests.

2.2.3. Conductivity, Temperature, and Depth (CTD) Casts

The conductivity, temperature, and depth of the water column were measured by Fugro both days of testing, i.e., 18 and 19 Sep 2021 (Figure 7).

A marked change in sound speed is visible on all CTD casts collected between 20 and 25 m depth that appears to be related to the change in water temperature. Fugro reported that this type of CTD profile was present on site since survey work started in May 2021; whereas, at the end of September, after a storm event, a smoother profile for well-mixed waters could be observed. Therefore, the recorded CTD appears to be representative of the standard conditions on site.

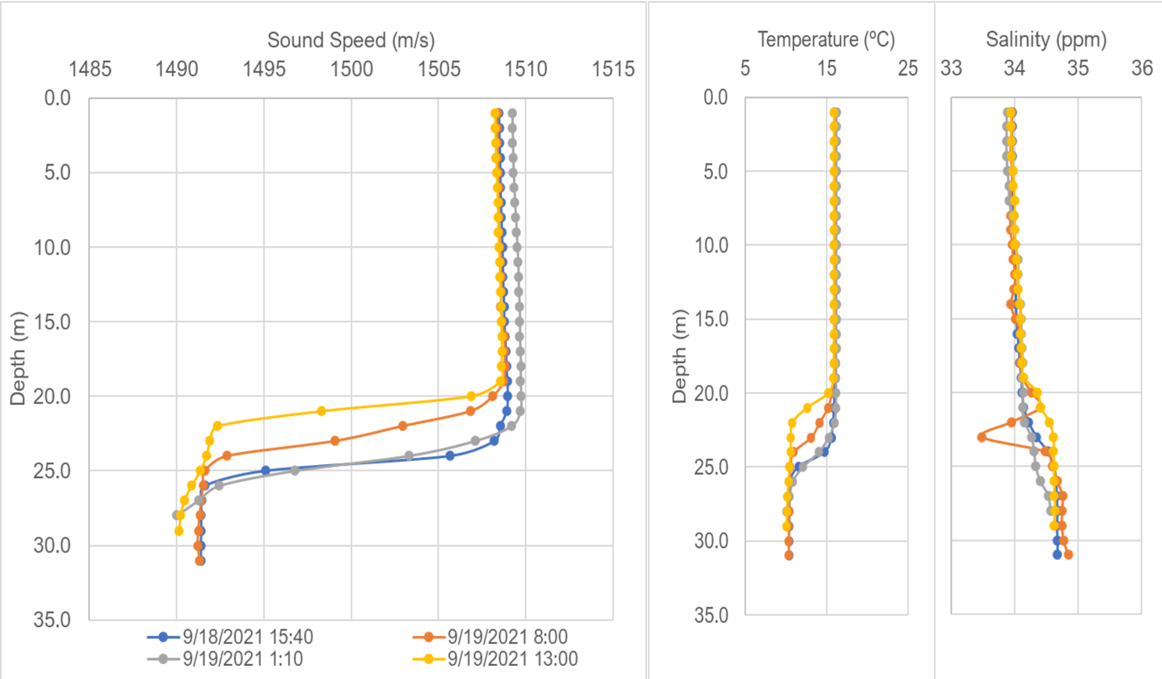


Figure 7. Sound speed (left), temperature (middle) and salinity (right) over depth measured at the study site measured at various time intervals during the two days of testing.

2.3. Acoustic Data Analysis

The acoustic data analysis methods are detailed in Appendix C. Acoustic terminology and analysis are in accordance with ISO standard 18405 (ISO 2017).

Acoustic data were downloaded from the SD cards of the AMARs, and two identical copies of the data were created on separate hard drives. Only one hard drive copy was used for processing to ensure a pristine backup of the data was available, in addition to the original on the SD cards. Data were visually and acoustically inspected by the JASCO field team with remote input and support from JASCO's main office. Spectrograms were generated using JASCO's PAMlab software.

The digital recording units were converted to micropascals (µPa) by applying the hydrophone sensitivity, the analogue circuit frequency response, and the digital conversion gain. Individual pings were automatically identified, whenever possible, using an Teager-Kaiser impulse detector (see Supplemental Materials for Martin and Barclay 2019), and then inspected for accuracy. When necessary, manual refinement of the annotations was implemented to ensure each peak was captured correctly for further processing. The magnitude of each identified pulse was quantified by computing the peak pressure level (PK), 90% energy duration SPL, and SEL of the identified time window surrounding the pulse. Furthermore, the SPL over a flat 125 ms time-window was calculated to specifically comply with the project's requirements. The SPL_{125ms} was calculated to assess impacts on marine mammals based on Tougaard et al. (2015). A flat window duration of 125 ms recommended by Martin and Barclay (2019) was employed here rather than the fast-time approach used in Tougaard et al. (2015).

For each of the sources and recording positions, the acoustic closest point of approach (CPA) was identified and noted in a dedicated log. The analysis undertaken for ambient sound levels and individual sources is described in more detail in the following sections. Different methodologies were used depending on the type of source given that some were impulsive (e.g., sparker) and others continuous (e.g., vessel) (European Commission 2017).

2.3.1. Background Noise Levels

As the survey vessel was always in the recording area, background noise levels were defined as when the vessel was at the beginning of its transit along the 5 and the 10 km survey lines. The vessel was present on site and running survey lines throughout the study period, including night-time; therefore, a true background noise profile could not be obtained. During transit between survey lines, the sparker was kept running on low power mode for mitigation purposes.

The SPL over 125 ms was calculated to describe the loudness of the background noise and also the SPL over 1 s duration. The former is presented for the frequency range 100 Hz to 128 kHz while the latter for the frequency range 10 Hz to 128 kHz.

2.3.2. Vessel Characterisation

The MV *Fugro Pioneer* vessel underwater sound emissions were analysed to establish the baseline conditions against which to evaluate the other sources.

Level one, two and three analyses were performed on the vessel passes from CPA at Station A. Level one consists in the identification of narrow band and broadband tonals, and surface or subsurface contact. Level two analysis is aimed at identifying sources of signals, i.e., engine, generator, pole motors, transients, tonal, swaths. Level three analysis matches sources of radiated noise/signals to specific drivetrain components and calculates ratios e.g., Electrical Rotations Per Minute (ERPM) to propeller shaft speed (SRPM). Furthermore, blade and shaft measures can be estimated and related back to prime mover if/where possible for surface contacts.

The analyses were performed by passive aural listening and visual examination of the spectrograms using a 0.15 Hz resolution (frame length 2 s, time stamp 0.125 s) and a Hamming window.

The vessel sound levels were characterized with SPL calculated by averaging the 125 ms Hamming weighted time windows with 50% overlap, in the seconds surrounding the CPA. The SPL were computed for the *Fugro Pioneer* transiting over AMAR A at a 4.6 kn nominal speed.

2.3.3. Per Pulse Sound Levels

For each pulse recorded, the slant range to the source was computed from the GPS coordinates of the AMAR deployments and the time-referenced navigation logs from the MV *Fugro Pioneer*. The navigation positions were offset to account for the position of the sparker relative to the vessel's GPS antenna.

The magnitude of each recorded pulse was quantified by computing the peak pressure level (PK), 90% SPL, and SEL of the pulse (Appendix C). The digital recording units were converted to micropascals (μPa) by applying the hydrophone sensitivity, the analogue circuit frequency response, and the digital conversion gain. An automated feature detection algorithm picked the start and end times of the individual pulses in the acoustic data. These automated detections were supplemented with manual validation as required. Each pulse was then analysed as follows:

1. A frequency filter at was applied to remove the self-noise of the survey vessel data recorded and improve the automated detector performance (100 Hz high pass for the sparker, 20–30 kHz band-pass for the USBL, and 90–105 kHz for the SBP).
2. The PK was computed.
3. The cumulative square pressure was computed over the duration of the pulse.
4. The 90% energy pulse duration (T_{90}) was determined, and the SEL over this 90% pulse duration was then computed.
5. The 90% duration SPL was computed by subtracting $10 log_{10}$ of the 90% duration from the 90% duration SEL.

2.3.4. Sound Level Compared to Range

To estimate the distance to sound level thresholds, the 90% SPL as a function of range were fit with one of the following empirical propagation loss equations:

$$90\%\ \mathrm{SPL} = \mathrm{ESL} - A\log_{10} R \quad (1)$$

$$90\%\ \mathrm{SPL} = \mathrm{ESL} - A\log_{10} R - BR \quad (2)$$

where R is the slant range from the source to the acoustic recorder (m), ESL is the effective source level (dB re 1 μPa^2), A is the geometric spreading loss coefficient (dB), and B is the volumetric absorption loss coefficient (dB/m). One of these equations was fit to the SPL by minimising (in the least-squares sense) the difference between the trend line and the measured SPL. This best-fit line was then shifted up by increasing the constant ESL term until the trend line exceeded 90% of all the data points to yield the 90th percentile fit, which conservatively estimates the distance to the sound level thresholds.

2.3.5. Sound Exposure Levels

Marine mammal frequency-weighted (see Section 2.4) sound exposure levels (SEL) were computed for the individual pulses for each source recorded at each AMAR for low-, high- and very high-frequency cetaceans (LF, HF, and VHF cetaceans, respectively) and phocid seals in water (PW). The auditory frequency weighting functions from Southall et al. (2018, 2019) were employed. In order to compare the survey SEL to the thresholds recommended in Southall et al. (2019), the SEL for the passage of the vessel over a ±2 km track were accumulated.

2.3.6. Auditory Frequency Weighted Sound Pressure Levels

To provide an indication of the harbour porpoise sensation level to survey sounds, JASCO was requested to compute the per-pulse sound pressure level weighted with the VHF auditory frequency weighting function specified in Southall et al. (2019) using an integration window of 125 ms. This is an indicative measure of sensation level that must be interpreted with caution, ideally by comparison to a behavioural response metric that was computed in the same fashion. For purposes of this analysis a threshold of 100 dB re 1 μPa^2 was requested. The maximum per-second weighted 125 ms SPLs were employed in the analysis. Auditory frequency weighting functions are described in Section 2.4.

2.4. Marine Mammal Auditory Frequency Weighting

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if the noises are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007, Van Parijs et al. 2007, Southall et al. 2019).

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The auditory weighting functions for marine mammals are applied in a similar way as A-weighting for noise level assessments for humans. The new frequency-weighting functions are expressed as:

$$G(f) = K + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \quad (3)$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in US National Oceanic and Atmospheric Administration's (NOAA's) technical guidance that assesses acoustic impacts on marine mammals (NMFS 2018), and in the latest guidance by Southall et al (2019). The updates did not affect the content related to either the definitions of frequency-weighting (Table 7) functions or the threshold values, however the group naming did change, with the mid and high-frequency cetacean groups from NMFS (2018) being referred to as high and very-high frequency cetaceans in Southall et al (2019). The Southall et al (2019) naming convention is used here. Figure 8 lists the frequency-weighting parameters for each hearing group and shows the resulting frequency-weighting curves.

Table 7. Parameters for the auditory weighting functions recommended by Southall et al (2019).

Functional hearing group	*a*	*b*	*f₁* (Hz)	*f₂* (Hz)	*K* (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
High-frequency cetaceans	1.6	2	8,800	110,000	1.20
Very-high-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

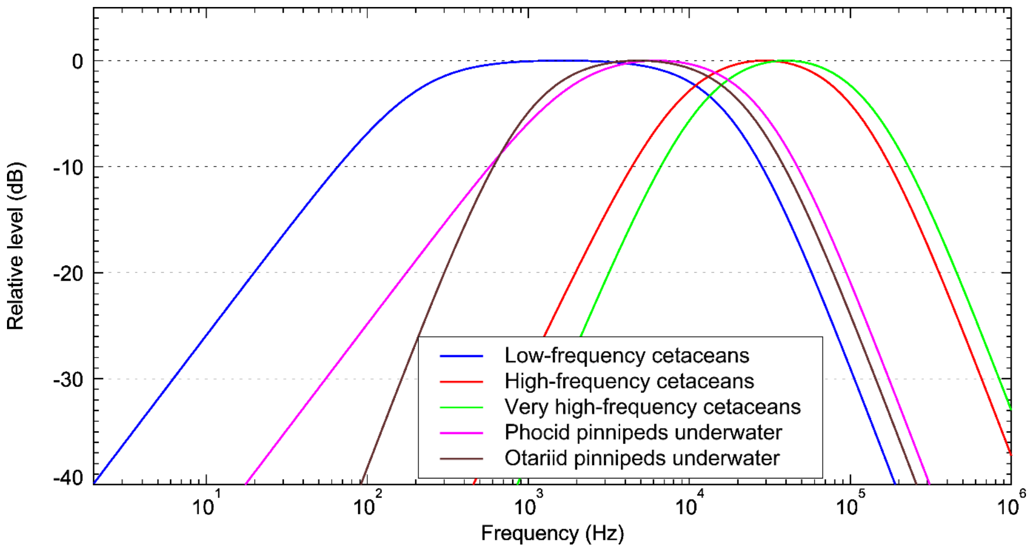


Figure 8. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall (2019).

3. Results

3.1. Received Levels

This section presents the received levels for each individual test conducted presented by source type, including the vessel baseline, for all monitoring stations. Results are presented in the following formats:

- Spectrograms and amplitude around CPA time at each monitoring station for a single pass of Test Run 1 and a single pass of Test Run 2;
- Spectrograms and amplitude of the full test tracks for the sparker source along the 5 and 10 km survey lines; and
- Spectral density plots for each of the sources at CPA for the different monitoring stations, unweighted and weighted according to marine mammal hearing groups. The tabulated results associated with these plots are presented in Appendix F.

3.1.1. Background Noise Levels

There were no periods during which neither the survey vessel nor the sparker were not operating in the vicinity of the recorders. Figure 9 represents median received levels for the full runs of the 5 km and 10 km survey lines combined at stations A, B, and D; given that Station A was the furthest away from the transiting vessel, this location would be most representative of the background noise on site while the profiles of Stations B and D present peaks at 300 Hz and 500 Hz, respectively, that are attributable to the sparker whose peak frequencies fall in these decidecade bands, as will be discussed in the next sections. An analysis time window of 125 ms was employed in this analysis in order to be comparable with the 125 ms analysis window used for assessing possible behavioural response by porpoise. The decidecade levels are presented from 100 Hz because the resolution for the short time window of 125 ms is not sufficient to present reliable data below this frequency. The unweighted median broadband level was 108.5 dB re 1µPa^2 at Station A, 108.9 dB re 1µPa^2 at Station B, and 112.2 dB re 1µPa^2 at Station D.

Figure 10 represents the same data but averaged over a 1 s time window and therefore presented for the frequency range 10 Hz to 128 kHz. Representation of the background noise levels according to this metrics allows comparison with ambient noise levels as reported for the JOMOPANS project (Merchant et al. 2018, Putland et al. 2021), as will be discussed in Section 4. The unweighted median broadband levels were 110.8 dB re 1µPa^2 at Station A, 111.0 dB re 1µPa^2 at Station B, and 112.6 dB re 1µPa^2 at Station D.

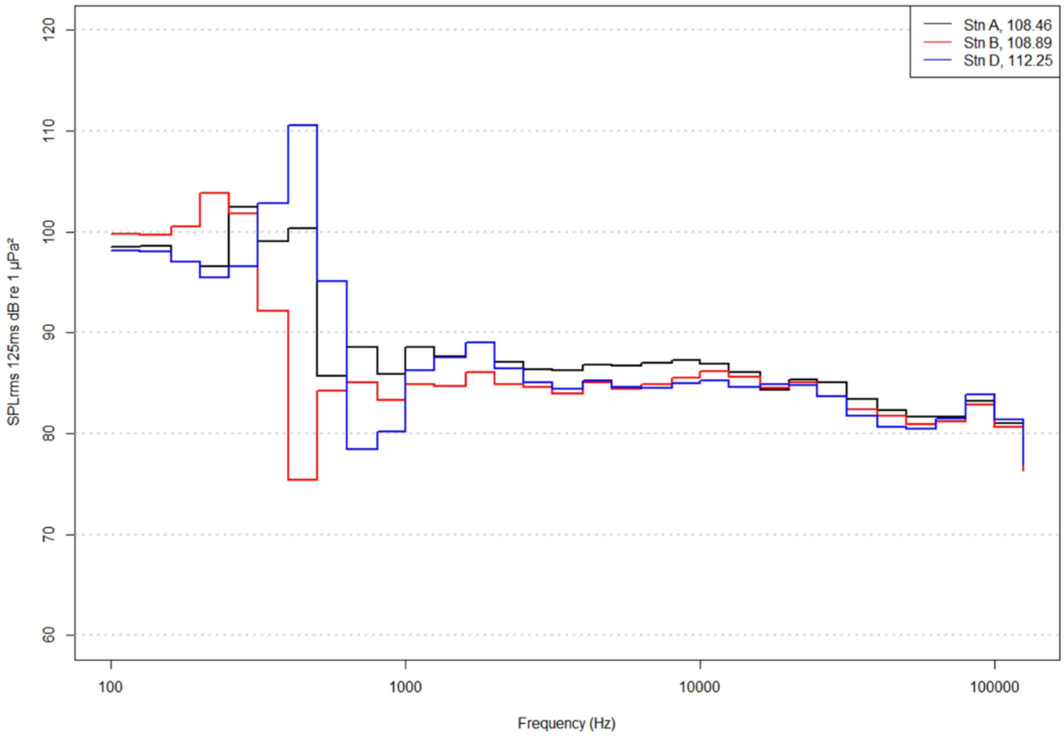


Figure 9. Median background noise levels by decidecade. Note SPL is the mean square level across the 125 ms window. The broadband level in the frequency range 100 Hz to 128 kHz is presented in the legend next to the relevant station ID.

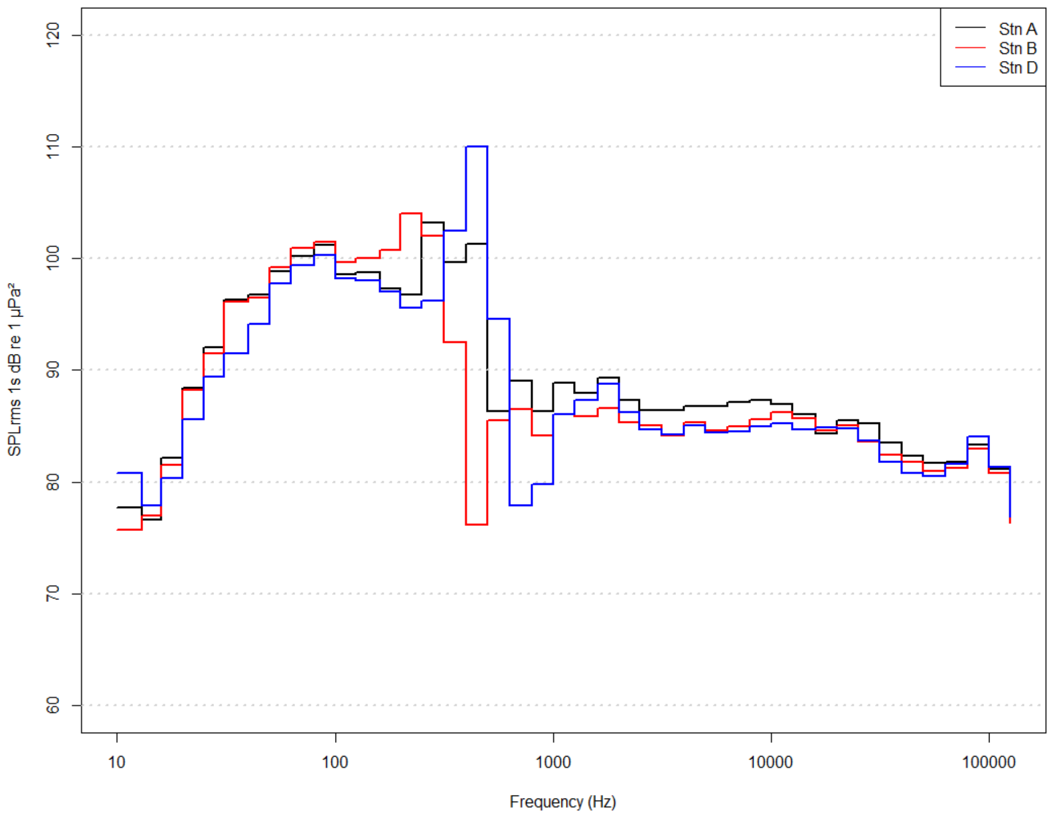


Figure 10. Median background noise levels by decidecade for the SPL_{rms} level averaged over a 1 s window. The broadband level in the frequency range 100 Hz to 128 kHz is presented in the legend next to the relevant station ID.

3.1.2. Vessel MV *Fugro Pioneer*

Underwater sound that radiates from vessels is produced mainly by propeller and thruster cavitation, with a smaller fraction of noise produced by sound transmitted through the hull, including engines, gearing, and other mechanical system noise. Sound levels tend to be the highest when thrusters are used to position the vessel and when the vessel is transiting at high speeds. A vessel's sound signature depends on the vessel's size, power output, propulsion system (e.g., conventional propellers versus Voith Schneider propulsion), and the design characteristics of the given system (e.g., blade shape and size). A vessel produces broadband acoustic energy with most of the energy emitted below a few kilohertz. Sound from onboard machinery, particularly sound below 200 Hz, dominates the sound spectrum before cavitation begins—normally around 8–12 kn on many commercial vessels (Spence et al. 2007). Noise from vessels typically raises the background sound level by tenfold or more (Arveson and Vendittis 2000).

During the baseline survey test, i.e., vessel transiting with all sources switched off, the vessel was kept at a constant speed of 4.5 kn for all tests except Test 1 Pass 1 during which the speed was lower at 4 kn (Table 2). The speed of 4.5 kn was used because this is the typical tow speed when sources are switched on; therefore, all other tests were performed at that speed.

The closest point of approach (CPA) was clearly identifiable with a distinct Lloyds' mirror effect visible in the spectrogram (Figure 11). Lloyd's mirror is a pattern of constructive and destructive interference between the direct and surface reflected arrivals of radiated noise, as the path difference varies by multiples of λ/2. It can be identified as a stack of broad U shapes, centred about CPA.

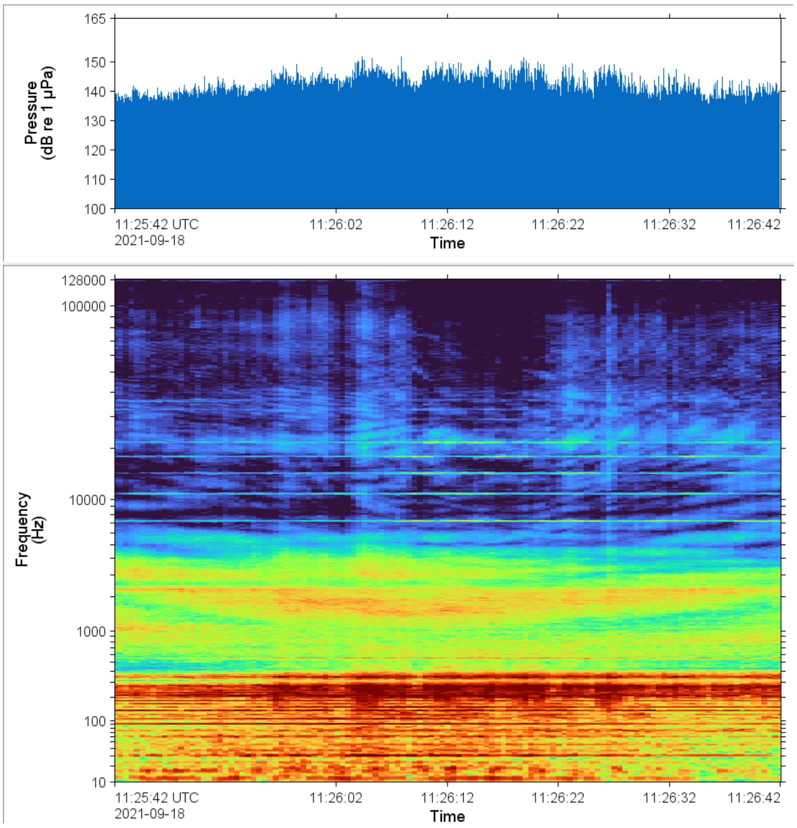


Figure 11. Station A – Test 1 Pass 1: Waveform (Top) and spectrogram (bottom, 10 Hz to 20 kHz 10 s interval) of the closest point of approach (CPA) time for the for the vessel pass only Test 1 Pass 1 at 4 kn (0.02 Hz frequency resolution, 1 s time window, 0.5 s time step, and Hamming window, normalised across time).

An audible blade flutter and minor blade slap were identified with a fundamental frequency of 3.151 Hz (fluke rate, FR) and three harmonics (Figure 12). No evidence of cavitation from azimuth flukes was found. Turns per knot (TPK) would not apply on Controlled Pitched Propeller (CPP) systems at the various angles of incidence but is attainable with level 3 analysis and a known blade RPM. The estimated blade rate was 189 RPM during Station A CPA. Shaft components were not seen as expected. The blade appears to be directly coupled to the thruster pod. The fluke count was not possible. Blade flukes degrade very rapidly over frequency.

Blade observed at 15.054 Hz without any auxiliary systems running (Figure 12). Vessel speed acoustically at 4.632 kn based on TPK value of 7.8 due to pitch.

The centre frequency of Alternating Current (AC) 6-pole motor was overlapping with blade at ~30 Hz. Discrete blade can be seen to 100 Hz at CPA. Hotel load AC pole motors fed by gensets are quiet and visible only to 550 Hz (Figure 12, right).

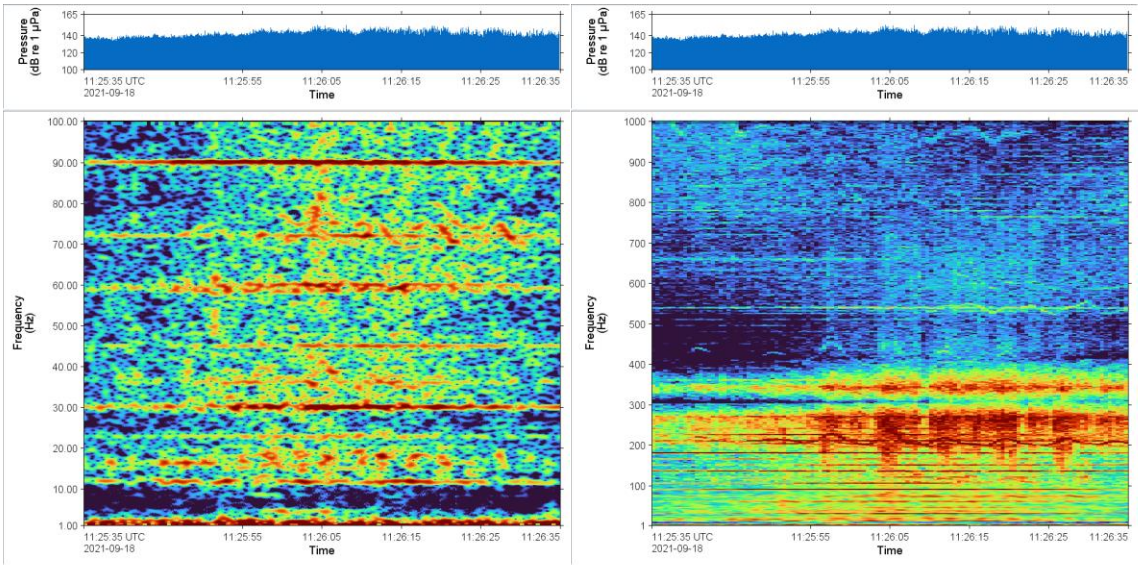


Figure 12. Station A – Test 1 Pass 1: Waveform (Top) and spectrogram (bottom) of the closest point of approach (CPA) time for the for the vessel pass only Test 1 Pass 1 at 4 kn for the band 1–100 Hz (left) and 1–1000 Hz (right) (0.15 Hz frequency resolution, 2 s time window, 0.125 s time step, and Hamming window).

Some high-frequency sound components were noticeable during the CPA (Figure 13); these were investigated further for Station A during the vessel only passes, as well as the tests ran with only the MBES and SSS sources active (see Figures 22 and 23 for spectrograms and waveform figures for these tests).

The following frequencies were identified that are linked to the vessel characteristics; these are continuous tones that are visible around CPA for each of the tests:

- Around CPA 32 kHz fundamental frequency, first and third harmonic. This is a very discrete monopole source, electrically driven
- Around CPA, 3.5 kHz tone and regular harmonics up to 22 kHz, electrically driven from the power generation of the 2 diesel engines compatible with 50 Hz system (Figure 13).

Furthermore, multiple harmonics are visible pre and post CPA due to the vibrations of the vessel (Figure 13).

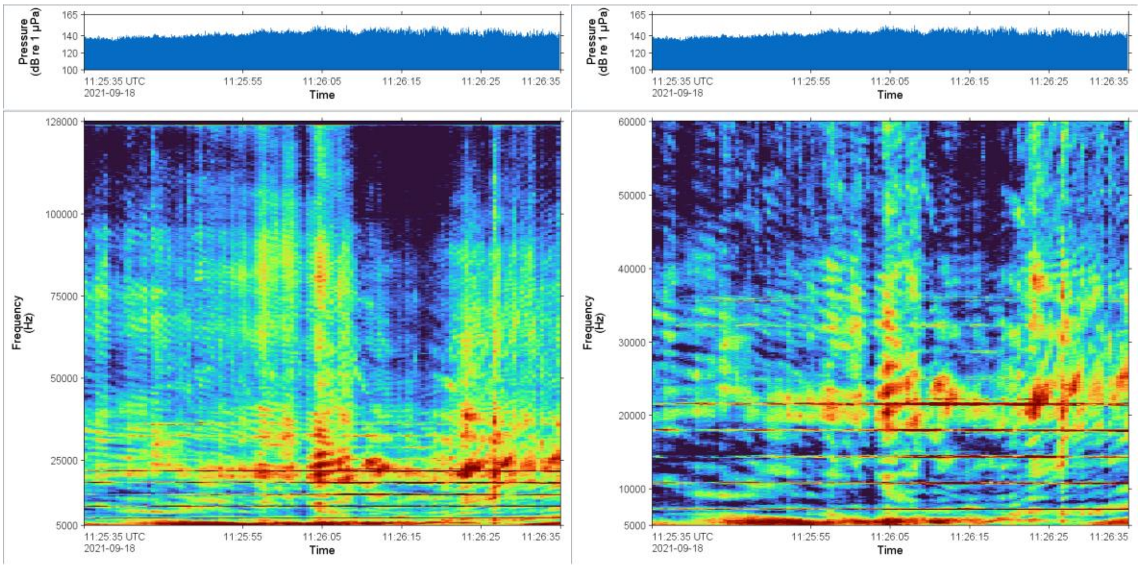


Figure 13. Station A – Test 1 Pass 1: Waveform (Top) and spectrogram (bottom) of the closest point of approach (CPA) time for the for the vessel pass only Test 1 Pass 1 at 4 kn for the frequency range 5–128 kHz (left) and 5–60 kHz, right) (0.15 Hz frequency resolution, 2 s time window, 0.125 s time step, and Hamming window).

The Radiated Noise Level (RNL) for the vessel passes was estimated to be 167.2 dB re 1µPa^{2}m^2 based on the average of all vessel passes; individual RNL per pass are presented in Table 8. RNL is obtained by adding 20*log$_{10}$(CPA Slant Range) to the received sound pressure level. This is considered a very quiet vessel.

Table 8. RNL in the broadband frequency range 10 Hz to 128 kHz calculated for each survey line of the MV *Fugro Pioneer*.

Test	Speed (kn)	Slant range Station A at CPA (m)	RNL (dB re 1µPa^{2}m^2)
Test 1 Pass 1	4	31.4	166.1
Test 1 Pass 2	4.5	30.8	167.0
Test 2 Pass 1	4.5	31.0	171.5
Test 2 Pass 2	4.5	30.8	164.3

3.1.3. Sparker Source and Streamer

The sparker source was set to pulse every 1 meter and towed at a speed of 4.5 kn for all tests, which corresponds to two shots for every second. Multiple pulses were therefore recorded during the transects at each of the recording stations, as shown in Figure 15.

The peak frequency of the sparker was between 0.2 and 0.8 kHz, depending on the distance of the monitoring station. The sparker pulses were clearly visible against the ambient noise at all stations; indeed, it was possible to obtain impulse metrics results for this source at all the measured locations along the main survey line (Figure 15).

Conversely, although sparker pulses are visible in the spectrograms along the 5 km (Figure 16) and 10 km (Figure 17) lines that were run parallel to the main survey line, individual peaks could not be automatically detected against the ambient clearly enough to allow analysis of individual impulses. Metrics were therefore obtained through manual annotation of the spectrogram at the time corresponding to the reported CPA according to the vessel tracks. The amplitude and spectrograms for the full survey lines at 5 km (Figure 16) and 10 km (Figure 17) perpendicular to the main survey line are presented in this section for Station A, while the ones recorded at Stations B and D are presented in Appendix F.2.

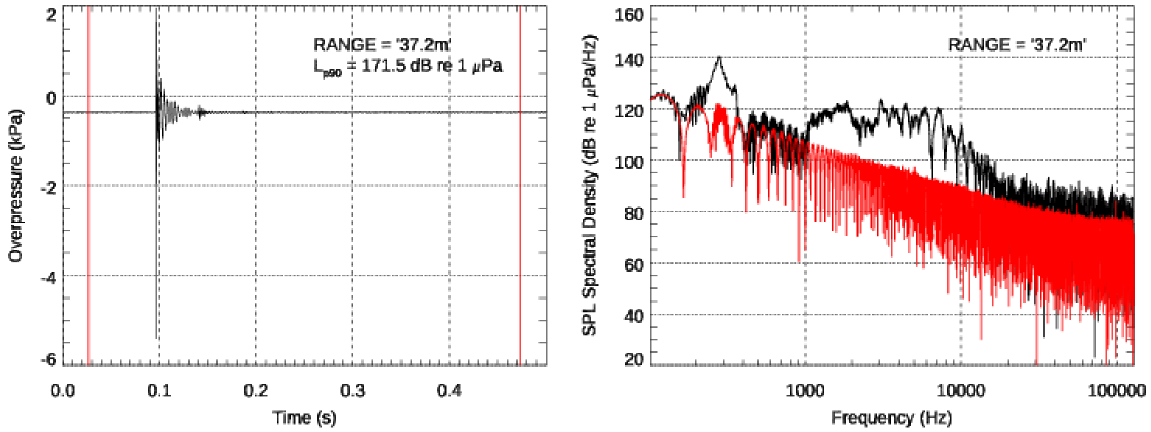


Figure 14. Sparker main survey line: Waveform (left) and spectrum (right) of a pulse recorded at the closest point of approach (CPA) at 19:55 on 18 Sep 2021 (Test Run 1 Pass 1). In the spectrum the black curve is for the duration shown by the red bars in the waveform display. The red curve is the ambient noise recorded just prior to the pulse, using a window of the same length.

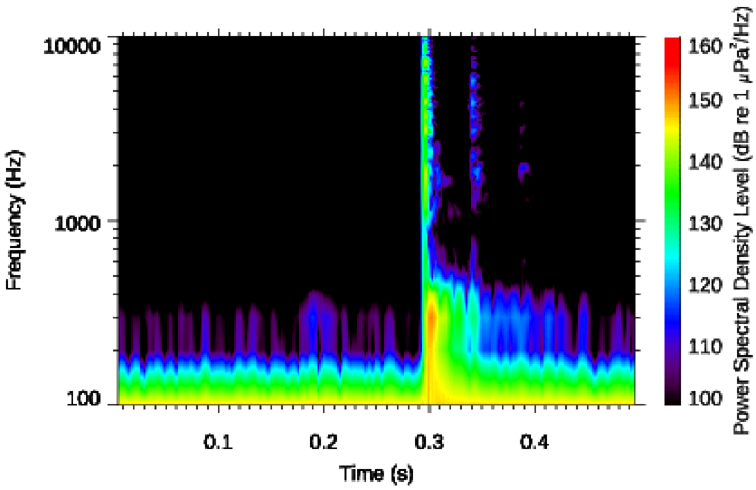


Figure 15. Sparker main survey line: Spectrogram (100 Hz frequency resolution, 0.01 s time window) of a pulse recorded at the closest point of approach (CPA) at 19:55 on 18 Sep 2021 (Test Run 1 Pass 1).

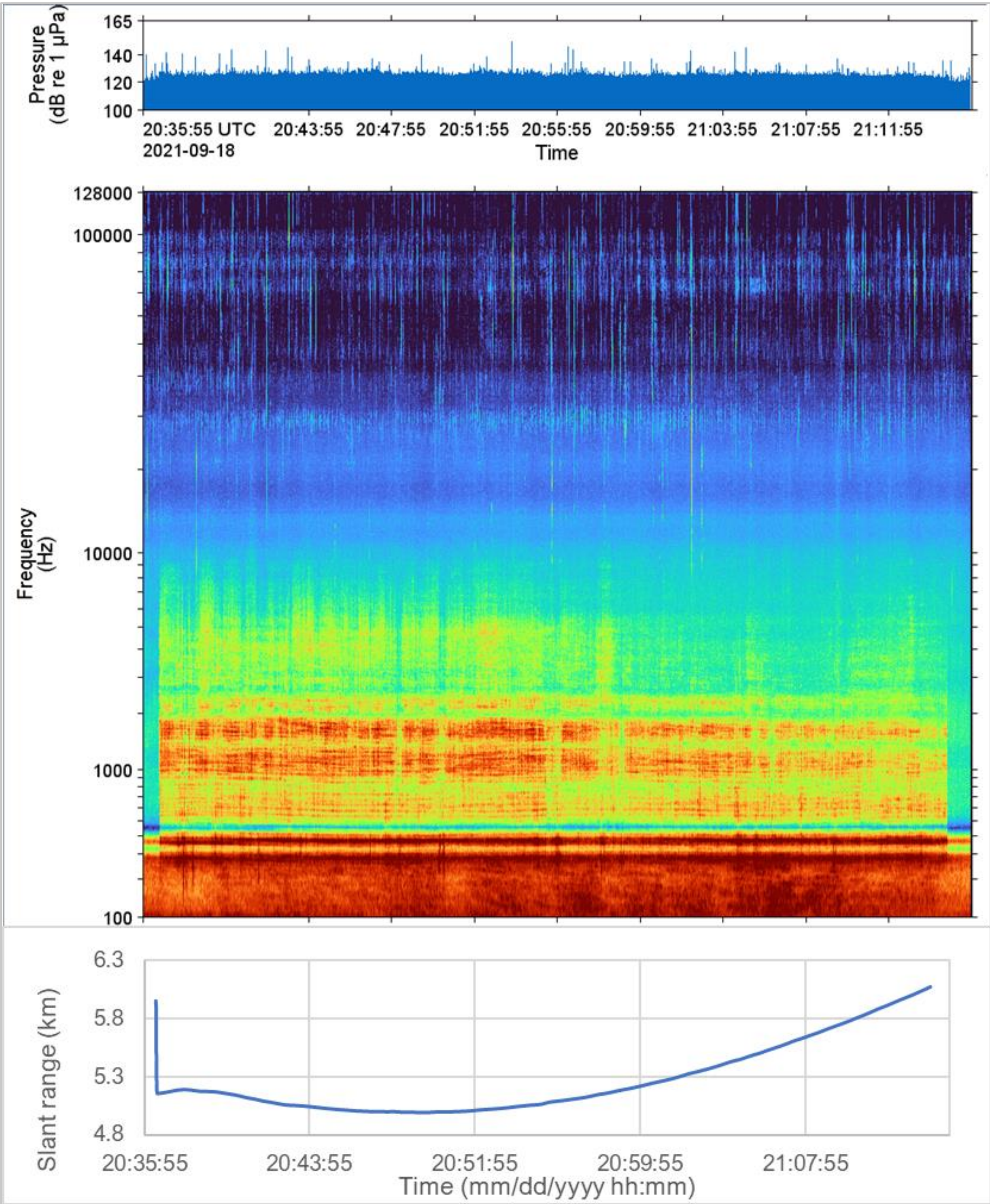


Figure 16. Sparker 5 km survey line: (Top) Waveform and (bottom) spectrogram of the full survey line run at 5 km perpendicular to the main survey line recorded at Station A (2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, and Hamming window, normalised across time).

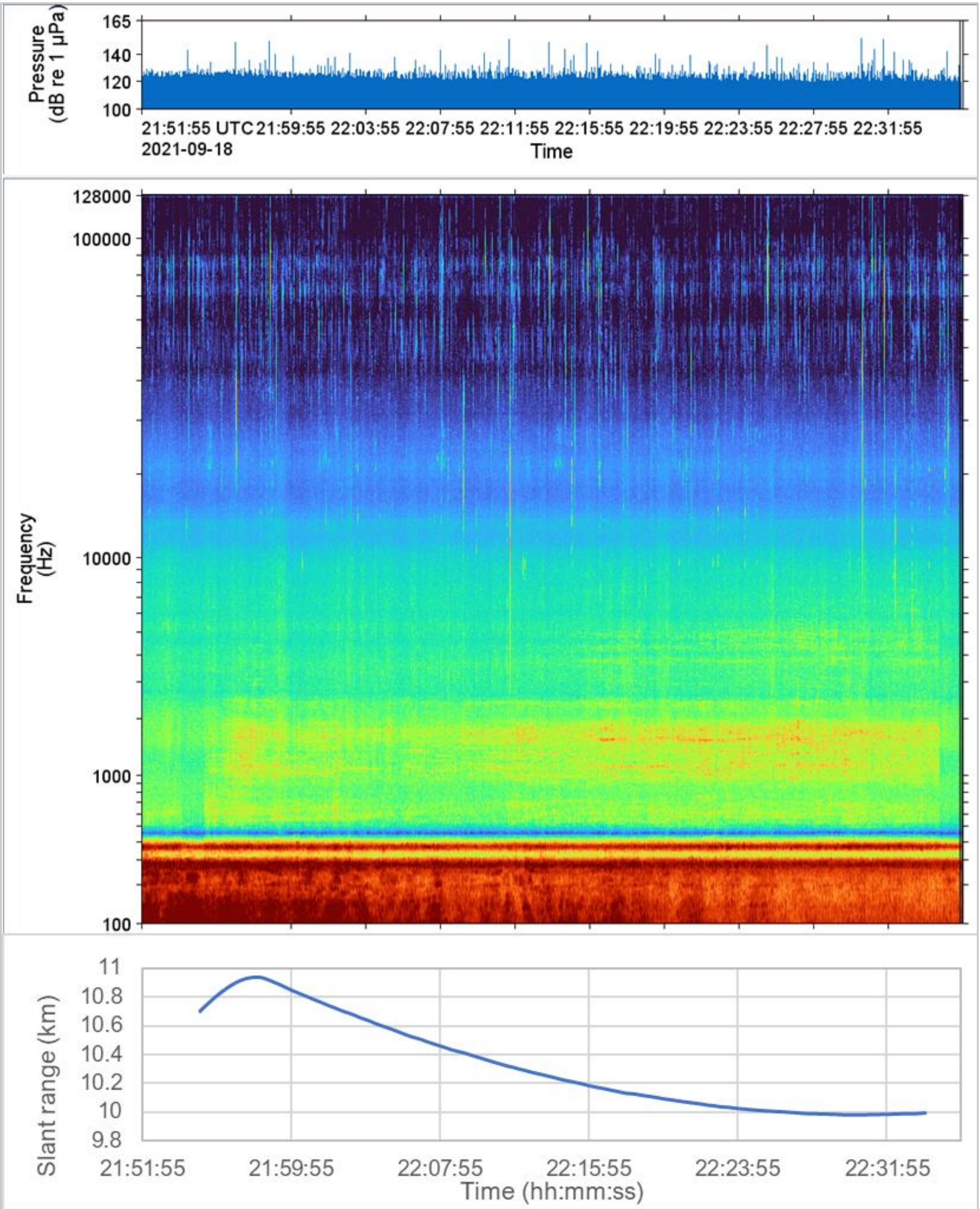


Figure 17. Sparker 10 km survey line: (Top) Waveform and (bottom) spectrogram of the full survey line run at 10 km perpendicular to the main survey line recorded at Station A (2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, and Hamming window).

Table 9. Sparker RL in the broadband frequency range 100 Hz to 128 kHz calculated for each survey line. N.A. indicates the station did not exist for that portion of the test, as Stations B and D were moved to stations C and E part way through the campaign (i.e., T1 vs T2). The peak and per pulse SEL metrics are generate based on detected impulses, while the SPL 125 ms metric is the 125 ms mean square SPL of the received waveform.

Metric	Test	A	B	C	D	E
Lpeak (dB re 1μPa)	T1P1	195.2	177.8	N.A.	160.7	N.A.
	T1P2	194.6	181.4	N.A.	166.0	N.A.
	T2P1	196.0	N.A.	166.5	N.A.	148.1
	T2P2	194.6	N.A.	168.8	N.A.	150.8
	5 km	136.7	134.4	N.A.	128.2	N.A.
	10 km	124.1	136.8	N.A.	122.2	N.A.
Per Pulse SEL (dB re 1μPa^2 s)	T1P1	156.1	141.1	N.A.	136.6	N.A.
	T1P2	155.6	144.1	N.A.	134.0	N.A.
	T2P1	156.8	N.A.	137.5	N.A.	123.3
	T2P2	156.2	N.A.	135.1	N.A.	122.2
	5 km	116.7	115.7	N.A.	108.8	N.A.
	10 km	104.6	116.4	N.A.	103.4	N.A.
SPL_{125ms} (dB re 1μPa)	T1P1	165.1	150.1	N.A.	145.6	N.A.
	T1P2	164.6	153.1	N.A.	143.0	N.A.
	T2P1	165.8	N.A.	146.5	N.A.	132.3
	T2P2	165.2	N.A.	144.1	N.A.	131.2
	5 km	125.7	124.7	N.A.	117.8	N.A.
	10 km	113.6	125.4	N.A.	112.4	N.A.

3.1.4. Sub-bottom Profiler Innomar SES-2000

The sub-bottom profiler is a parametric source that generates pulses at a set of specific frequencies. A parametric echosounder simultaneously transmits two pulses of slightly different high frequencies (e.g., 100 and 115 kHz). Their interaction generates by interference a new low-frequency pulse (with the difference frequency, in this case 15 kHz).

The 100–120 kHz pulses were clearly visible at Stations A (Figures 18 and 19) and B but no longer so at Station C and farther away from the source (Appendix F.3). The secondary low frequencies were only visible at Station A, but elevated SEL levels at around 15 kHz were noticeable in the decidecade-bands (Sections 3.2–3.3).

High received levels were measured near the source, at Station A, while much lower levels were received at the other stations. As can be seen in (Appendix F.3) the sounds were clearly identifiable at CPA for Station A when the source runs on top of the instrument while off-axis. The main frequency pulses are also visible at Stations B and C but not the secondary frequencies (Appendix F.3). As the vessel towed the source, the sound was not as clearly identifiable in all its frequency components.

Received levels decreased with range, as one would expect (Table 10).

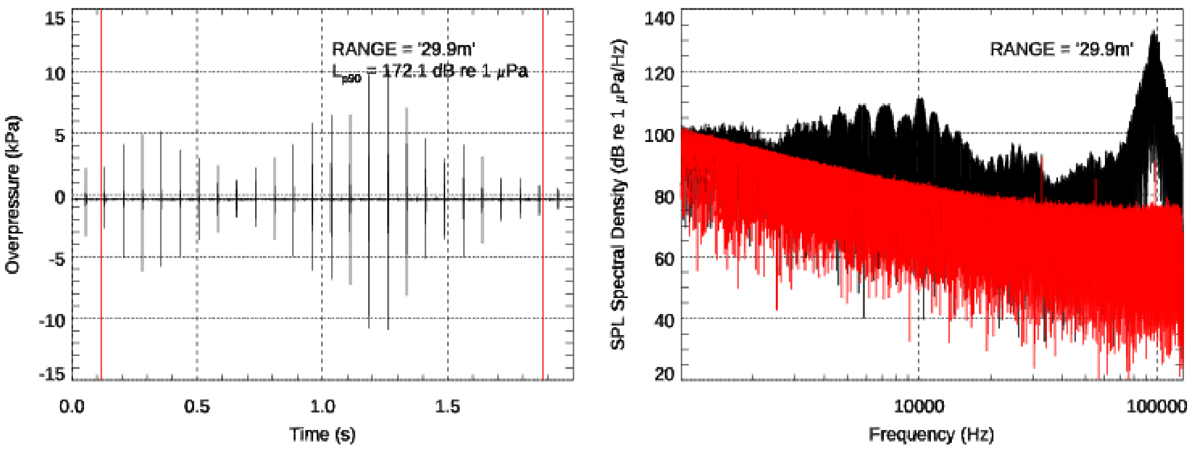


Figure 18. Sub-bottom profiler main survey line: Waveform (left) and spectrum (right) of a series of pulses recorded at the closest point of approach (CPA) at 14:31 on 18 Sep 2021 (Test Run 1 Pass 1). In the spectrum. the black curve is for the duration shown by the red bars in the waveform display. The red curve is the ambient noise recorded just prior to the pulse, using a window of the same length.

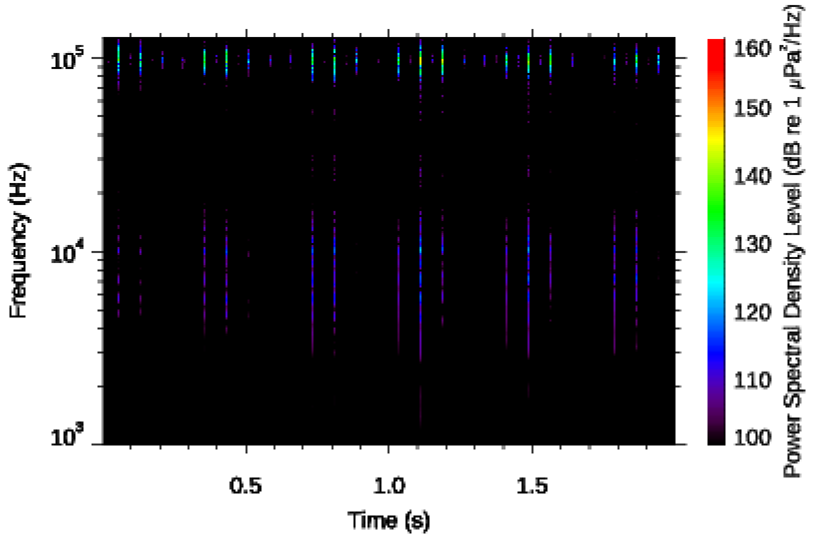


Figure 19. Sub-bottom profiler main survey line: Spectrogram (200 Hz frequency resolution, 0.005 s time window) of a series of pulses recorded at the closest point of approach (CPA) at 14:31 on 18 Sep 2021 (Test Run 1 Pass 1).

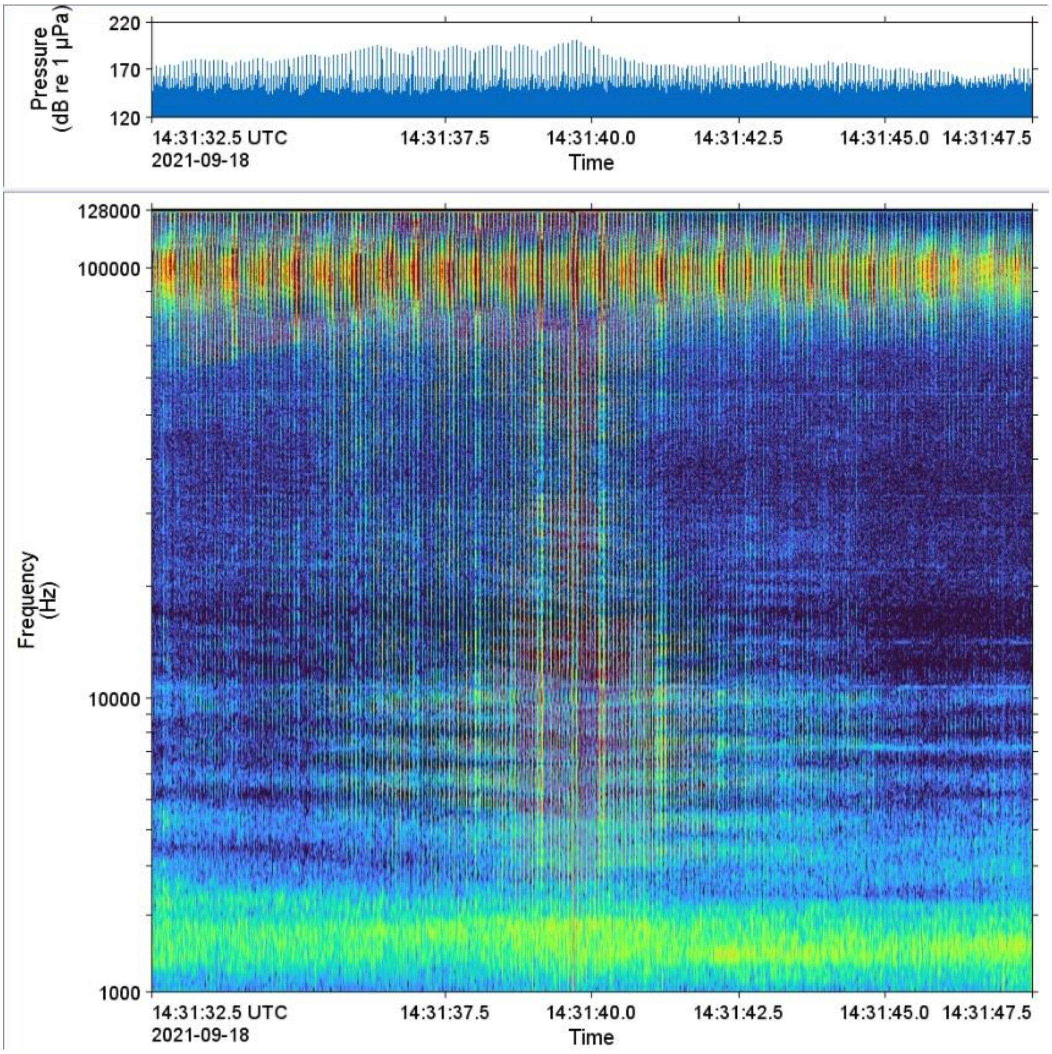


Figure 20. Sub-bottom profiler main survey line: Spectrogram (1 Hz frequency resolution, 0.01 s time window) of 15 s recorded at the closest point of approach (CPA) at 14:31 on 18 Sep 2021 (Test Run 1 Pass 1).

Table 10. Sub-bottom profiler RL in the broadband frequency range 90–105 kHz for the Lpeak and SEL metrics and in the frequency range 100 Hz to 128 kHz for the SPL metrics calculated for each survey line recorded at closest point of approach (CPA). N.A. indicates the station was not deployed for that portion of the test, as Station B and D were moved to stations C and E part way through the campaign (i.e., T1 vs T2). The peak and per pulse SEL metrics are generate based on detected impulses, while the SPL 125 ms metric is the 125 ms mean square SPL of the received waveform.

Metrics	Test	A	B	C	D	E
Lpeak (dB re 1μPa)	T1P1	201.0	158.8	N.A.	136.8	N.A.
	T1P2	185.5	153.3	N.A.	142.9	N.A.
	T2P1	196.0	N.A.	126.7	N.A.	130.8
	T2P2	183.0	N.A.	132.4	N.A.	132.1
Per Pulse SEL (dB re 1μPa^2 s)	T1P1	162.4	118.7	N.A.	94.4	N.A.
	T1P2	147.1	117.0	N.A.	100.4	N.A.
	T2P1	154.8	N.A.	85.7	N.A.	89.4
	T2P2	146.0	N.A.	88.8	N.A.	92.4
SPL_{125ms} (dB re 1μPa)	T1P1	149.9	137.7	N.A.	128.0	N.A.
	T1P2	142.7	137.0	N.A.	125.8	N.A.
	T2P1	149.3	N.A.	127.0	N.A.	118.6
	T2P2	144.2	N.A.	117.7	N.A.	113.4

3.1.5. Multi-Beam Echo Sounder (MBES) Kongsberg EM2040

The MBES was set to operate at 400 kHz; this frequency was above the maximum frequency range that could be detected by the study instrument's configuration. As a result, the MBES was not visible in the recorded data set, as shown in Figure 22. The received levels measured for this test were comparable to those of the test conducted with all the sources switched off for the 100 Hz to 128 kHz broadband frequency range.

The same tonals observed in the vessel pass could be seen during these passes. In depth analysis of the high frequencies showed doppler shifted pairs for the pre- and post- CPA, as described below:

- Pre-CPA MBES fundamental frequency 32,955 Hz, first and third harmonic. Very discrete monopole source. Source: electrically driven.
- Pre-CPA MBES fundamental frequency 54,925 Hz, first and second harmonic. Source: electrically driven.
- Post-CPA MBES fundamental frequency 32,796 Hz, first and third harmonics. Very discrete monopole source.
- Post-CPA MBES fundamental frequency 55,880 Hz, first and second harmonic. Very discrete monopole source. Diesel generators audible, as were azimuth electrical sources.

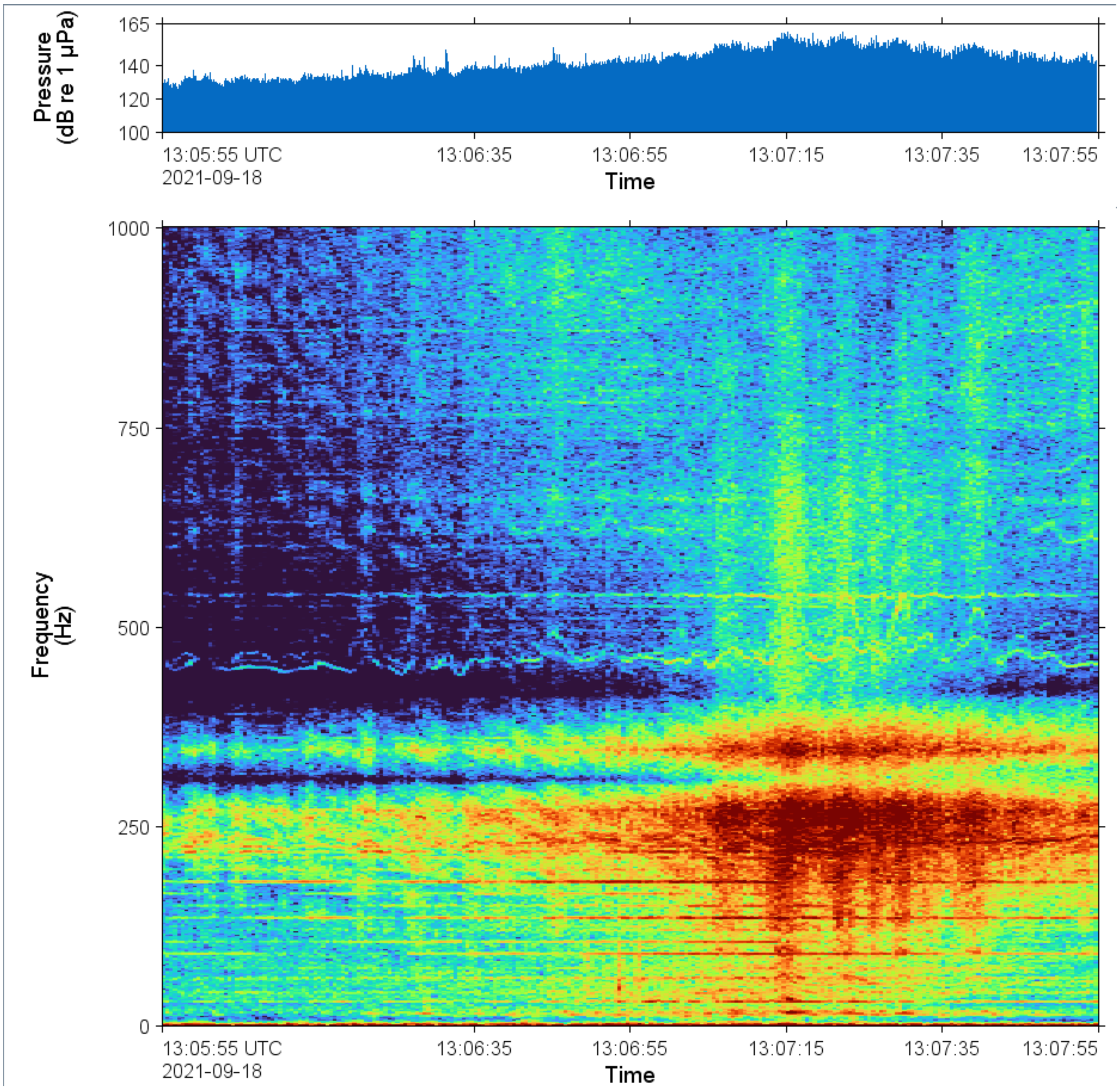


Figure 21. Multi-beam echo sounder test – Frequency range 1–1000 Hz: (Top) Waveform and (bottom) spectrogram for data recorded at Station A, (Test Run 1 Pass 1, right column) as the vessel was transiting over the instrument at Station A (0.2 Hz frequency resolution, 1 s time window, 0.5 s time step, and Hamming window).

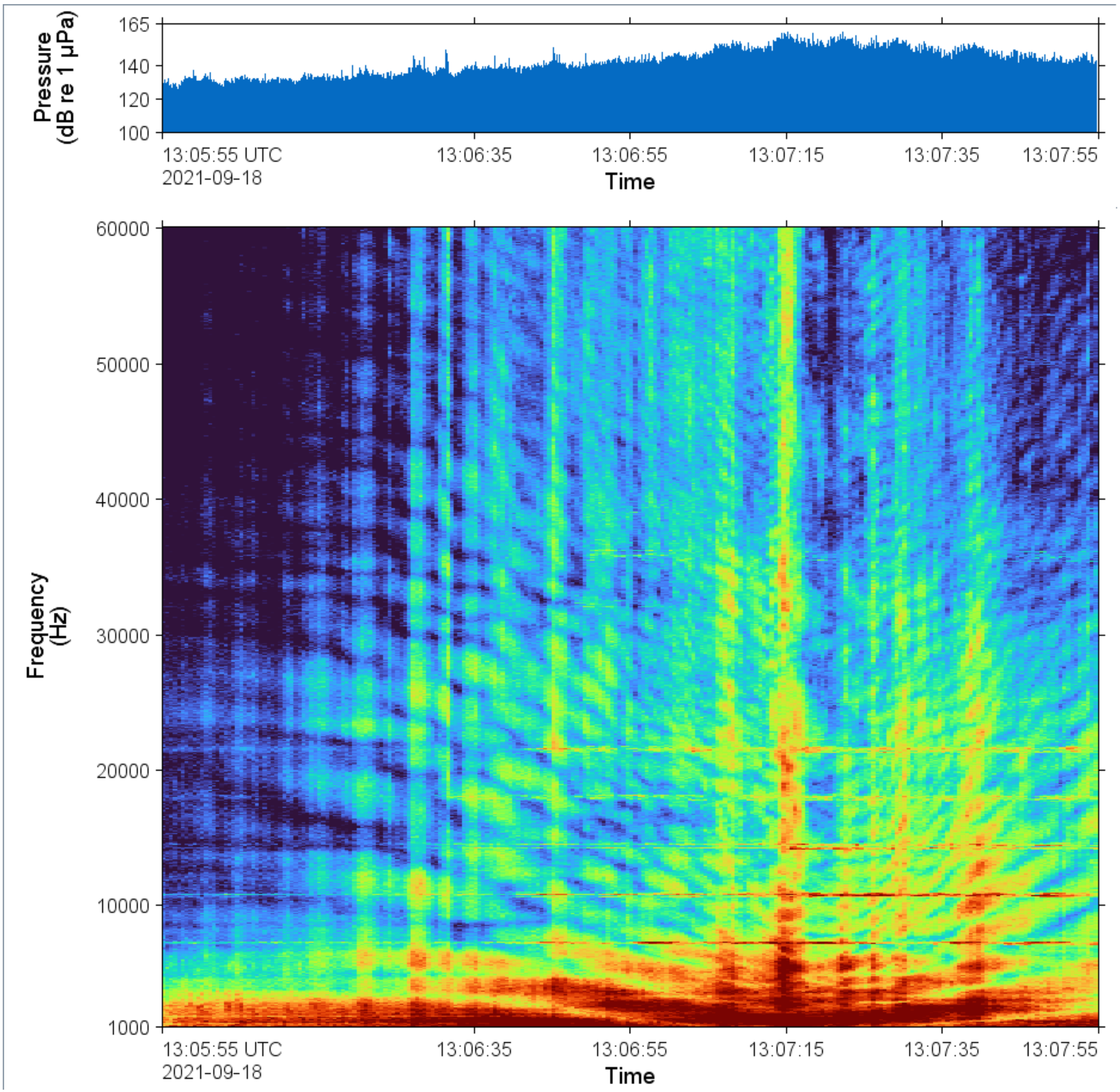


Figure 22. Multi-beam echo sounder test – Frequency range 1–60 kHz: (Top) Waveform and (bottom) spectrogram for data recorded at Station A, (Test Run 1 Pass 1, right column) as the vessel was transiting over the instrument at Station A (0.2 Hz frequency resolution, 1 s time window, 0.5 s time step, and Hamming window).

3.1.6. Side Scan Sonar (SSS) EdgeTech 4200

The side scan sonar used was a EdgeTech 4200 and operated with a standard setup with 100% power output emitting pulses at two frequencies simultaneously. Specifically, these were 300 and 600 kHz. These frequencies were above the maximum frequency range of the acoustic recording equipment configuration; therefore, the signal of the side scan sonar was undetectable in the recordings, as shown in Figure 23.

A USBL positioning was also used as this is normally active during standard operations. The USBL operated during the second pass of each test. A clear series of impulses was detectable against the background noise levels. The peak frequency of the pulses is visible at around 25 kHz (Figures 24, 25, and 26).

For the SSS pass without the high-precision positing USBL beacon active, the same levels and frequency components were observed as for the vessel pass. For both tests with and without USBL, high-frequency electrical sources were noted that are attributable to the vessel:

- SSS only test (position beacon off): No discernible difference in high-frequency monopole sources at a fundamental frequency of 32,991 Hz showing first and third harmonics.
- SSS only test (position beacon off): No discernible difference in high-frequency monopole sources at a fundamental frequency of 55,154 Hz showing first and second harmonics.
- SSS with USBL beacon on. No discernible difference in high-frequency monopole sources at a fundamental frequency of 32,955 Hz showing first and second harmonics. Some masking by active positioning beacon.
- SSS with USBL beacon on. No discernible difference in high-frequency monopole sources at a fundamental frequency of 55,402 Hz showing first and second harmonics. Some masking by active positioning beacon.

Amplitude and spectrogram representations of the tests run for the SSS without and with USBL for all monitoring stations are presented in Appendix F.5 and F.6, respectively.

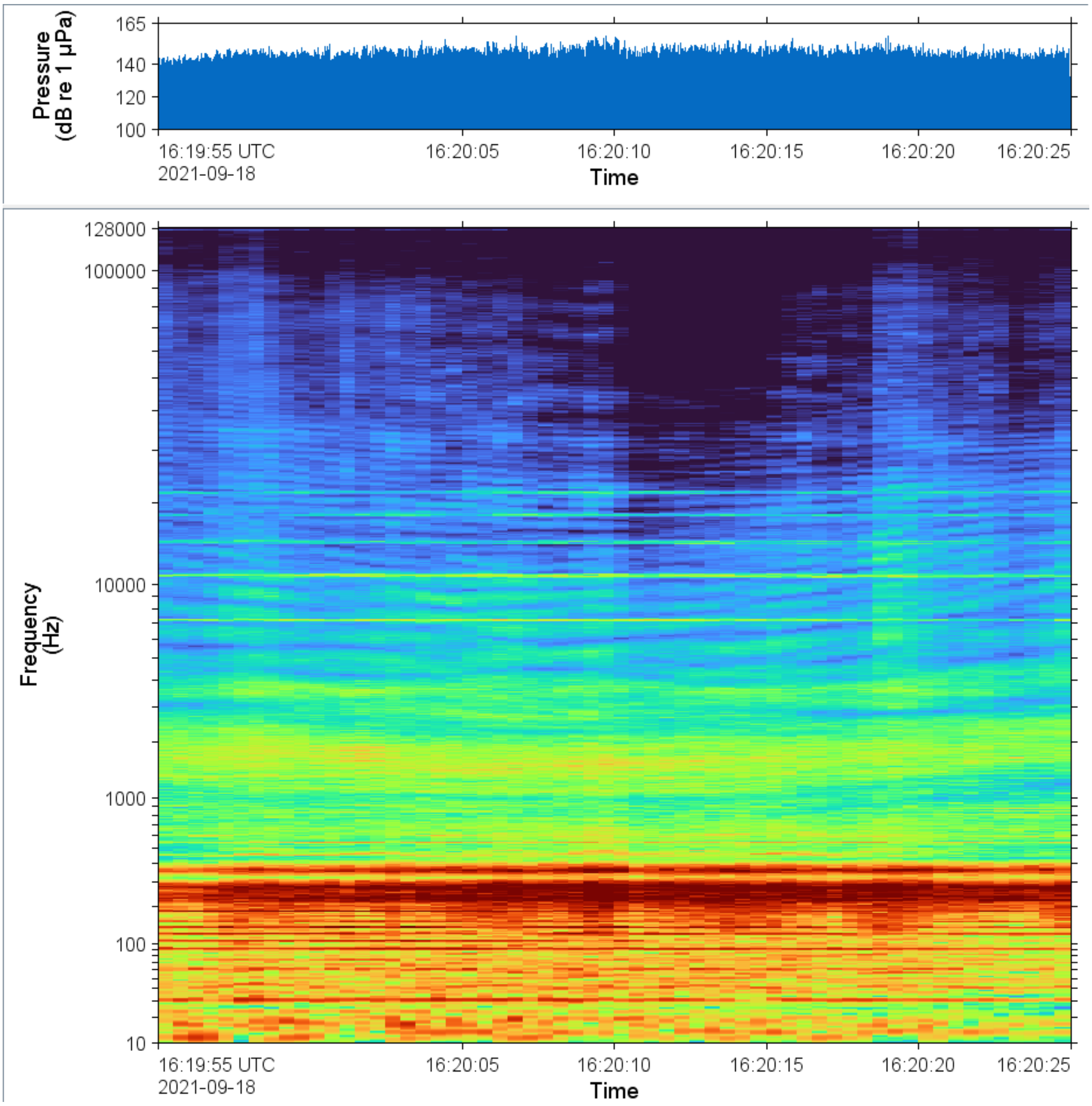


Figure 23. Side scan sonar without USBL: (Top) Waveform and (bottom) spectrogram of the test run with SSS on but positioning beacon off recorded at Station A as the vessel was transiting over the instrument(0.2 Hz frequency resolution, 1 s time window, 0.5 s time step, and Hamming window).

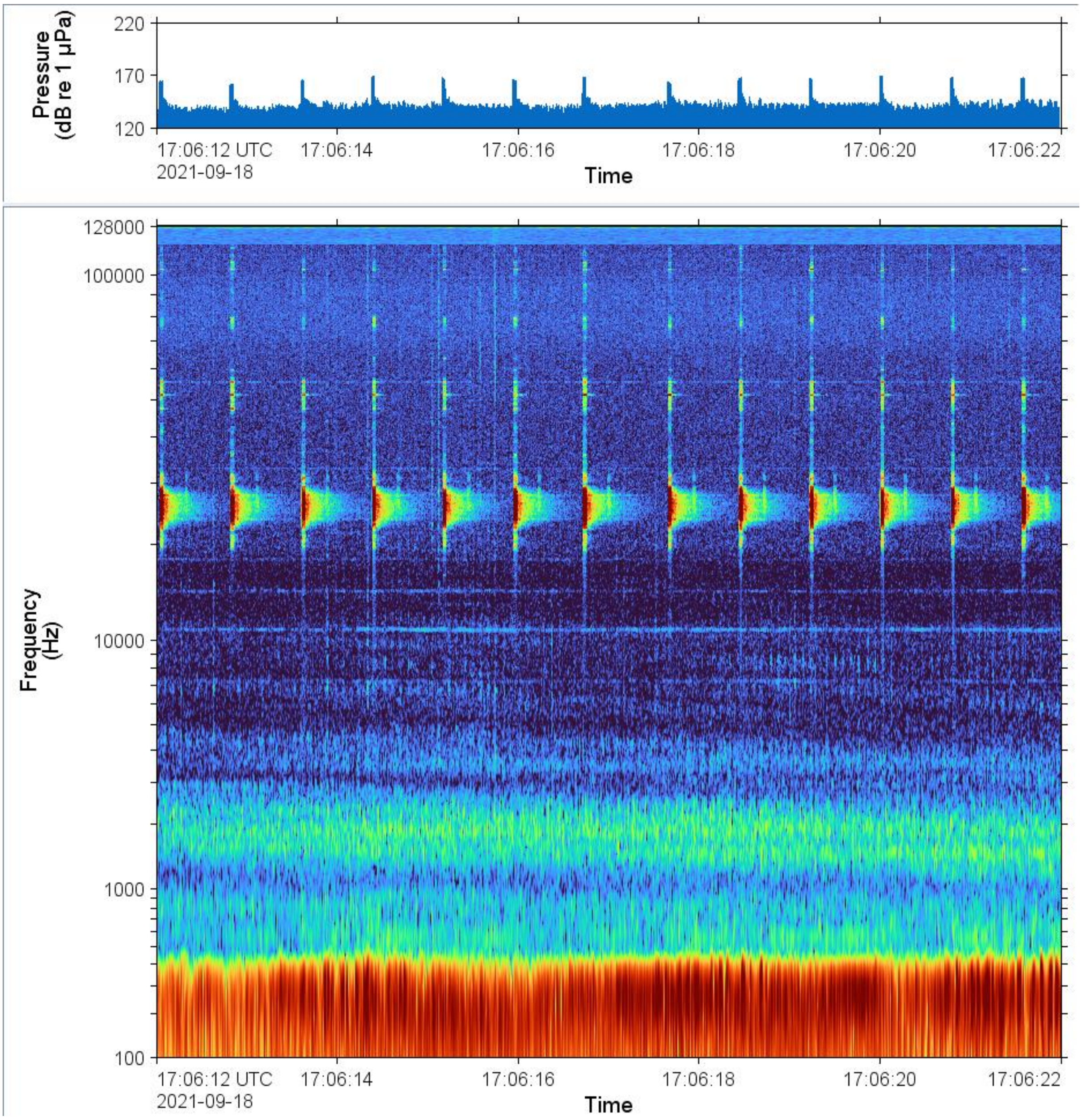


Figure 24. Side scan sonar with USBL positioning beacon: (Top) Waveform and (bottom) spectrogram of the USBL recorded at Stations A as the vessel was transiting over the instrument (2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, and Hamming window).

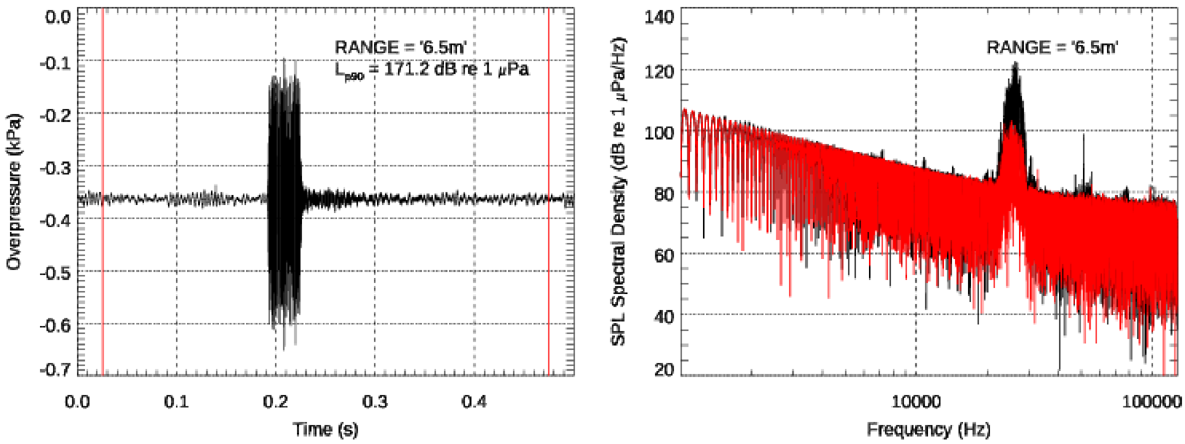


Figure 25. USBL main survey line: Waveform (left) and spectrum (right) of a series of pulses recorded at the closest point of approach (CPA) at 17:06 on 18 Sep 2021 (Test Run 1 Pass 1). In the spectrum the black curve is for the duration shown by the red bars in the waveform display. The red curve is the ambient noise recorded just prior to the pulse, using a window of the same length.

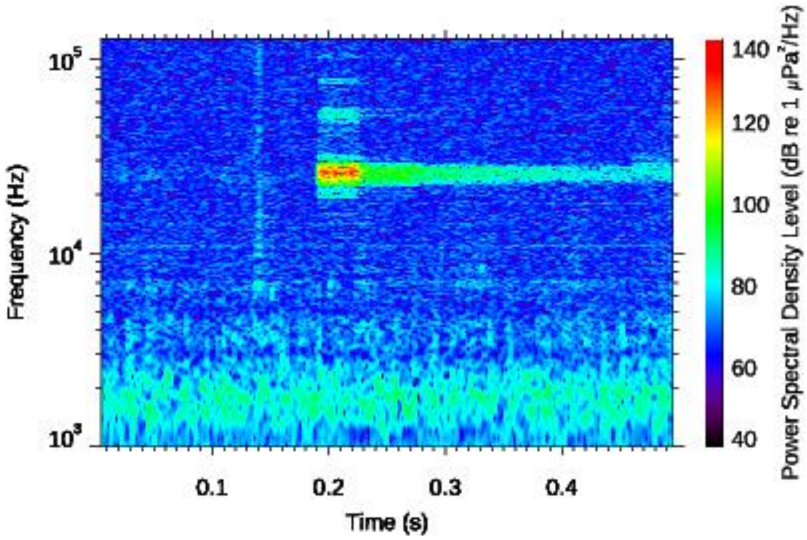


Figure 26. USBL main survey line: Spectrogram (100 Hz frequency resolution, 0.01 s time window) of a pulse recorded at the closest point of approach (CPA) at 17:06 on 18 Sep 2021 (Test Run 1 Pass 1).

Table 11. USBL RL in the broadband frequency range 20–30 kHz for the Lpeak and SEL metrics and in the frequency range 100 Hz to 128 kHz for the SPL metrics calculated for each survey line. N.A. indicates the station was not deployed for that portion of the test, as Station B and D were moved to stations C and E part way through the campaign (i.e., ,T1 vs T2). The peak and per pulse SEL metrics are generate based on detected impulses, while the SPL 125 ms metric is the 12 5 ms mean square SPL of the received waveform.

Metrics	Test	A	B	C	D	E
Lpeak | (dB re 1μPa)	T1P2	169.4	164.8	N.A.	142.9	N.A.
	T2P2	171.7	N.A.	155.9	N.A.	144.2
Per Pulse SEL (dB re 1μPa^2 s)	T1P2	148.2	140.4	N.A.	120.2	N.A.
	T2P2	148.9	N.A.	122.8	N.A.	104.8
SPL_{125ms} (dB re 1μPa)	T1P2	155.1	147.9	N.A.	130.4	N.A.
	T2P2	152.6	N.A.	131.2	N.A.	119.1

3.1.7. All Sources Combined

A set of tests were run with all sources active at the same time since this configuration is normally active during a site survey.

The same characteristics that were noticed for the sources individually were observable when all sources were operating simultaneously; note that time of arrival differs by source (Figure 27). For example, the SBP sounds were detectable before the loudest pulses (corresponding to CPA) of both the vessel and the sparker source (Figure 27); the difference in CPA time for the different source that were towed from different points of the vessel (Appendix A.2) is also noticeable in the regression analysis (Section 3.2) where a peak in level for the sparker source does not correspond to the CPA that is referred to the SBP. Furthermore, the positioning system pings sometimes overlapped in timing with the sparker sources (Figure 28); as such, more variability in received levels, especially when looking at the sound exposure metrics, was noticeable in this test compared to the ones of the individual sources.

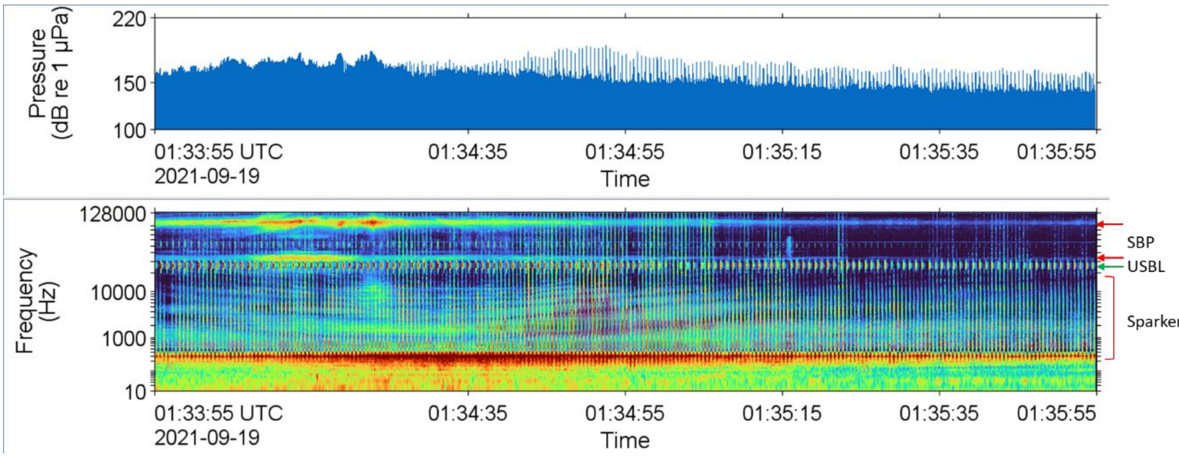


Figure 27. All sources: (Top) Waveform and (bottom) spectrogram of the test ran with all sources active recorded at Station A as the vessel was transiting over the instrument (2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, and Hamming window)).

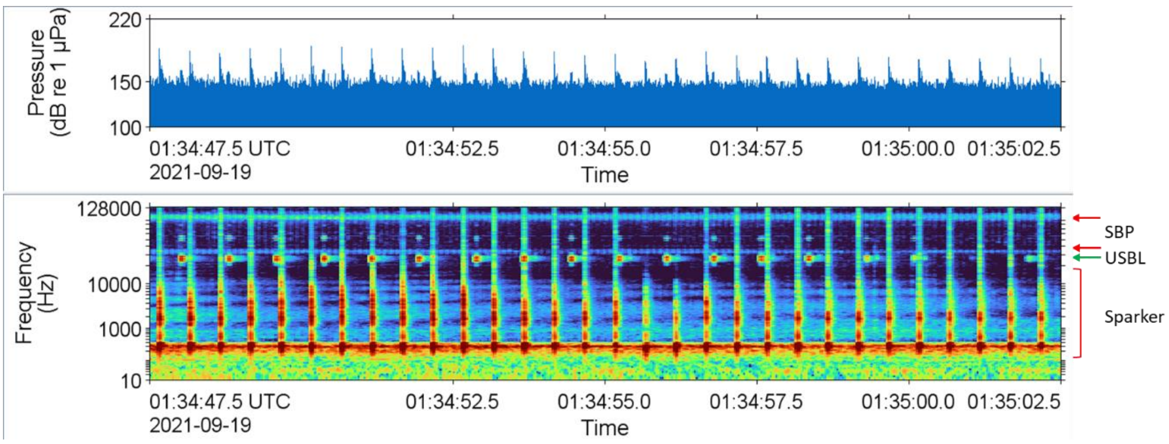


Figure 28. All sources – USBL and sparker overlap: (Top) Waveform and (bottom) spectrogram of the test ran with all sources active recorded at Station A as the vessel was transiting over the instrument (2 Hz frequency resolution, 0.125 s time window, 0.03125 s time step, and Hamming window)).

3.2. Effective Source Levels and Propagation Coefficients

Effective source levels were estimated based on the regression analysis conducted for the measurements collected at the different stations and are presented here based on the SPL_{125ms} metric for the 90% confidence interval of the regressions. Received levels versus range were obtained for each of the monitoring stations; the data presented for Station A represent the full run along the main survey line with the overpass directly above Station A, at which point the incident angle of the source was close to 0. The results presented for the other stations, i.e., Stations B to E, represent a different set of incident angles when the vessel is still running along the main survey line; the data included for the regressions for the off-axis direction (i.e., broadside) are limited to 5 m either side of the CPA. In this case however the receiver stations were placed perpendicularly to the survey line; when the vessel was hitting CPA, i.e., passing over Station A, the horizontal distance to the other monitoring stations was 100, 500, 750, and 2000 m for Stations B, C, D, and E, respectively.

The ranges presented in Figures 29 to 31 represent the slant range (m) between source and receiver. Results are shown for the following sources:

- Sparker (Figure 29)
- Sub-bottom profile (Figure 30)
- SSS with USBL (Figure 31)

In all cases presented, a decay of sound levels with range can be observed, as one would expect according to theory. The rate of the decay varies according to source that is being tested and the test run/pass. However, the rate of decay is quite similar between tests and passes for the same source. In some of the regression plots, at 500–2000 m from the source a few spurious peaks (background or self-noise) are present; these are identifiable because their level remains constant independently of the range. Their presence does not impact the regression equations because they are very few points compared to the overall number of pulses; as such, these have not been manually removed.

For the sparker and sub-bottom profiler sources, a better fit with the $ALog_{10}$ model was found compared to the $ALog_{10}R+B*R$ for the broadside direction. In cases where B is positive, or the coefficient of regression (R^2) was too low, the $ALog_{10}R+B*R$ regression equation was rejected. The data for the USBL source fitted well using the $ALog_{10}R+B*R$ model in both directions.

The results presented combine both passes (i.e., reciprocal lines) and tests, except for the USBL where a single line was run with this source active for each test. The results showed the following:

- For the sparker, a good fit was found for the track along the survey direction (endfire) but not for the broadside direction. The ESL (Table 12) was estimated at 188 dB re 1μPa^2 SPL_{125ms} in the endfire direction with a coefficient of attenuation with distance of 16 (Table 13). Note that the 5 and 10 km lines were dropped from the analysis because no impulses could be resolved above ambient levels.
- For the sub-bottom profiler, a good fit could be found for both the survey (endfire) and the broadside directions. The results show a wide spread of data along the line of best fit that may be due to the fact that the source is very directional. Indeed, the CPA received levels at Station A showed great variability (Table 10). The ESL (Table 12) was estimated at 237 dB re 1μPa^2 SPL_{125ms} in the endfire direction with a coefficient of attenuation with distance of 44.3 (Table 13) and 255 dB re 1μPa^2 SPL_{125ms} in the broadside direction with an attenuation coefficient of 55.9.
- For the USBL, a good fit was found for both track lines with the $Log_{10}R + R$ model. The ESL (Table 12) was estimated at 184 dB re 1μPa^2 in both end fire and broadside directions with attenuation coefficients of 14.6 (Table 13).

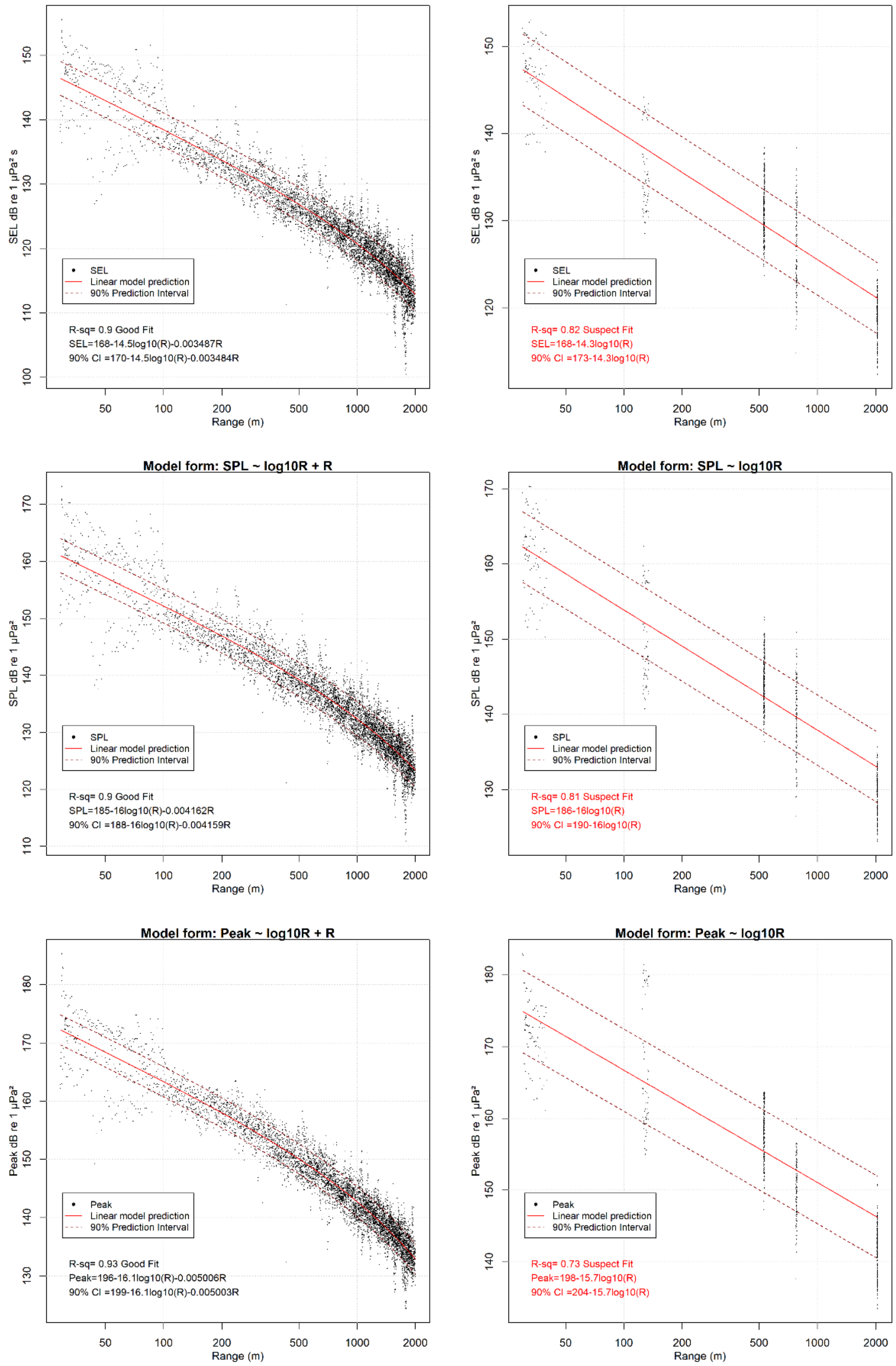


Figure 29. Sparker: Sound exposure level (SEL, top panel) sound pressure level (SPL, middle panel) 125 ms and Lpeak (bottom panel) compared to range at the sound source verification (SSV) site in the endfire direction (left) and the broadside direction (right). The solid line is the best fit of the empirical function to the SPL. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

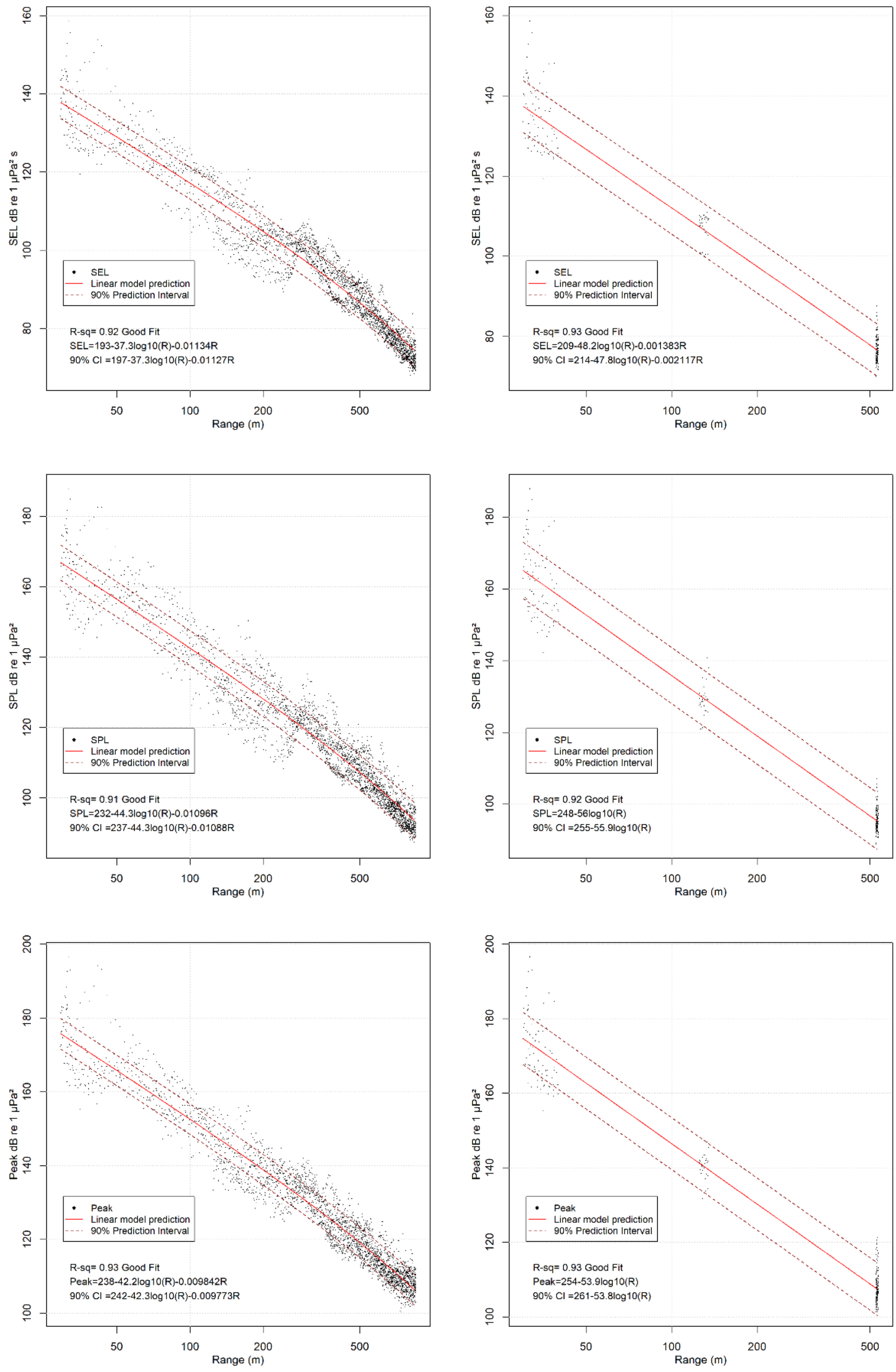


Figure 30. SBP: Sound exposure level (SEL, top panel) sound pressure level (SPL, middle panel) 125 ms and Lpeak (bottom panel) compared to range at the sound source verification (SSV) site in the endfire direction (left) and the broadside direction (right). The solid line is the best fit of the empirical function to the SPL. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

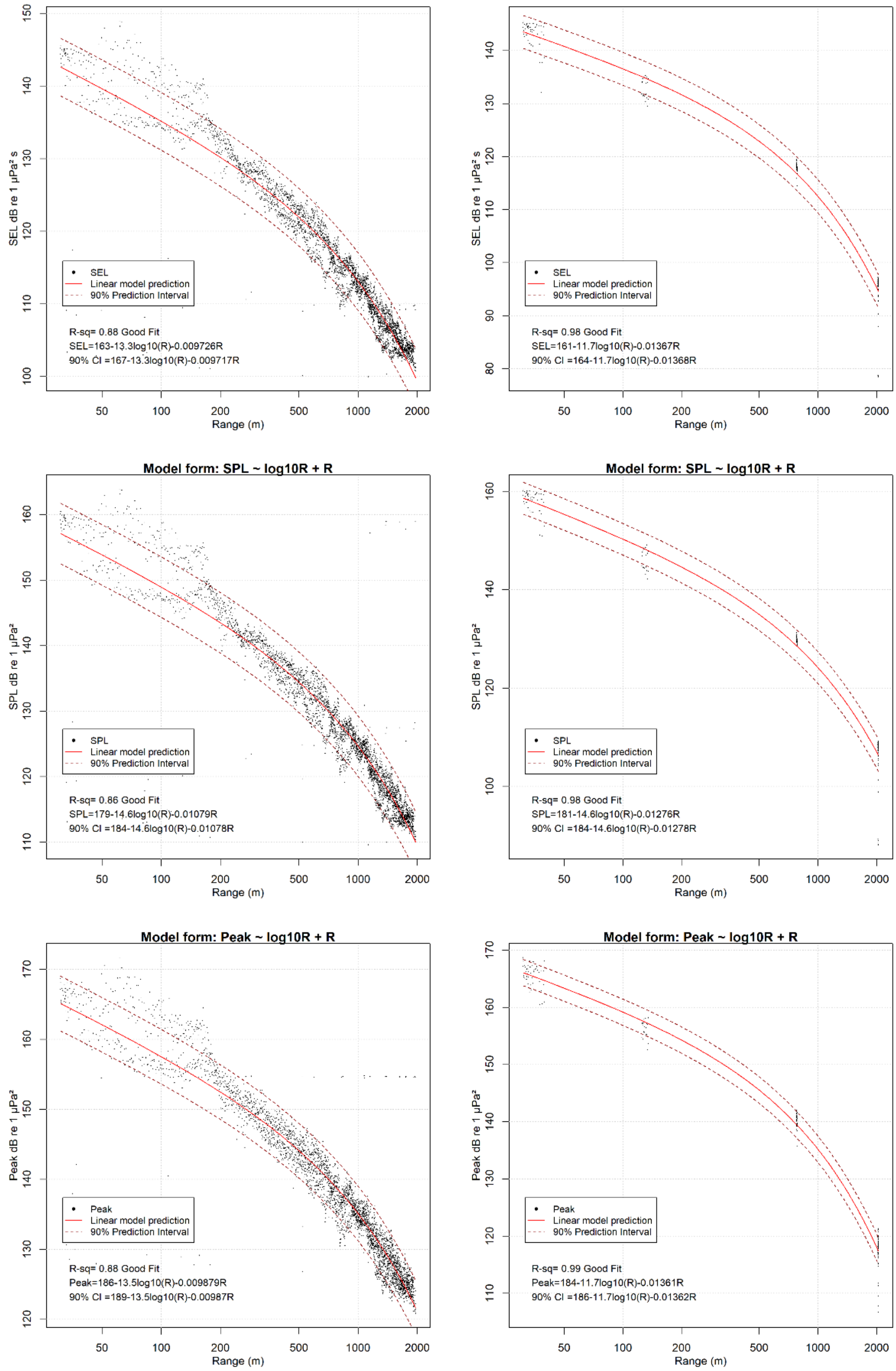


Figure 31. USBL: Sound exposure level (SEL, top panel) sound pressure level (SPL, middle panel) 125 ms and Lpeak (bottom panel) compared to range at the sound source verification (SSV) site in the endfire direction (left) and the broadside direction (right) for the pass with the USBL beacon active. The solid line is the best fit of the empirical function to the SPL. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

Table 12. Broadband effective source levels for SPL_{125ms} (dB re 1µPa^2) calculated for each of the sources individually. Values in bold indicate non-good fits with the log10R+R nor the 10R model.

Survey line	Sparker	SBP	SSS with USBL
Endfire	188	237	184
Broadside	**190**	255	184

Table 13. Attenuation calculated for each of the impulsive sources individually based on the SPL_{125ms} metrics. Values in bold indicate non-good fits with the model.

Frequency	Sparker	SBP	SSS with USBL
Endfire	16.0	44.3	14.6
Broadside	**16.0**	55.9	14.6

3.3. Marine Mammal Exposure

This section presents the marine mammal weighted sound pressure levels for each of the sources and the stations (Table 14), measured around CPA time; the results presented are still filtered for the frequency bands described in Section 3.1.

These show the following:

- The vessel source produces most energy in the frequency range of 200 to 300 Hz and is most relevant for low frequency cetaceans and phocid mammals in the water (Figure 32). The results are seen to decrease across stations with slight variations in shape being attributed to the different days the stations were run.
- The Sparker produces most of its energy in the 200–300 Hz frequency range with trace amounts of energy up to the full frequency spectrum (Figure 34). As such, this source is most relevant for low frequency cetaceans and phocid mammals in the water as well as some high frequency cetaceans (Figure 33). The residual energy at very high frequencies results in a slight peak being noticeable in the marine mammal HF and VHF weighted functions between 70–100 kHz compared to other frequency bands.
- The sub-bottom profiler has primary frequencies in the 85–100 kHz range for bottom tracking and secondary frequencies between 8 and 12 kHz for sub-bottom imaging, spanning the range of all marine mammal listening groups (Figure 36).
- The multibeam echosounder had its main frequencies in the 200 to 400 kHz range and as such was outside the detection range of the monitoring hydrophones with 256 kHz and a maximum detectable frequency of 128 kHz. Figure 38 is therefore similar to the ship only pass between 100 Hz and 100 kHz.
- The side scan sonar was set to operate at 300 and 600 kHz and had a USBL beacon for navigation on board that operates between 20 and 30 kHz. The Side Scan sonar is again undetectable on the installed hardware, however the two cases of beacon state, not active and active are detectable and presented in Figures 39 and 40, respectively. Apart for the difference attributable to the presence and absence of the USBL, the spectra are almost identical. Depending on the mode of operation, the Side Scan Sonar and USBL beacon are most relevant for the HFC and VHFC listening groups.
- The all sources pass in Figure 42 demonstrates the total noise radiated from vessel with all sensors operational in their survey configuration with energy attributable to the vessel, sparker, and USBL beacon, and sub-bottom profiler. As some of these sources are towed behind the

vessel and some are hull mounted, there is no single point source and therefore no CPA – with the noise being generated in a distributed manner around the vessel. As such the maximum received noise level was attributed to be the acoustic CPA, which generally coincides with the Sparker source. Due to the diverse nature of the sources, their levels, and their broad frequency ranges, all the marine mammal hearing groups are relevant for consideration during survey activities. Peak energies of the individual sources described above are clearly discernible.

Range regressions for the 125 ms SPL weighted for VHF cetaceans are also presented for the sparker (Figure 35), SBP (Figure 37), and USBL (Figure 41) for both the endfire and broadside directions.

Table 14. Auditory frequency weighted SPL_{125ms} for different marine mammal hearing groups.

Range (m)	Source	SPARKER					SBP					SSS with USBL				
	Weight	LFC	HF	VHF	PW	UW	LFC	HF	VHF	PW	UW	LFC	HF	VHF	PW	UW
35	stn A	147.2	124.9	122.3	136.7	148.5	136.4	134.8	136.5	125.5	141.7	136.1	143.2	142.7	139.4	143.6
150	stn B	139.3	129.1	126.5	136.4	139.9	124.2	115.7	117.3	111.7	127.6	125.6	131.8	131.3	127.9	132.7
540	stn C	132.8	117.5	114.2	129.1	133.0	117.1	95.2	94.5	107.3	119.1	116.1	119.8	119.3	116.3	121.5
780	stn D	124.1	102.7	99.3	114.6	124.9	113.6	92.8	92.0	101.9	115.2	115.5	119.0	118.5	115.3	120.6
2040	stn E	119.3	101.8	97.6	114.6	119.6	104.8	93.0	92.1	97.9	108.4	106.2	95.6	94.8	99.0	114.4

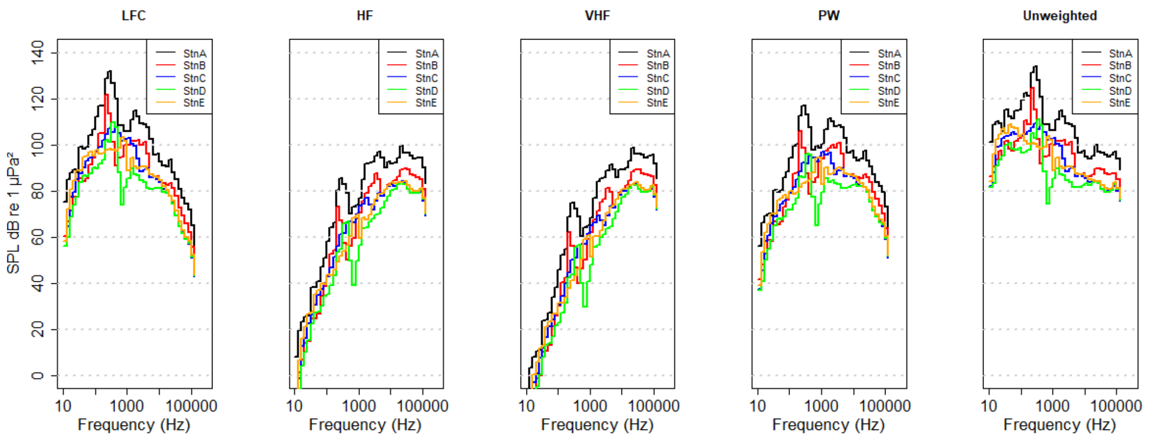


Figure 32. Vessel only: weighted and unweighted decidecade sound pressure level (SPL) plot for each AMAR Each solid line represents the median of a 5 m window around the nominal CPA.

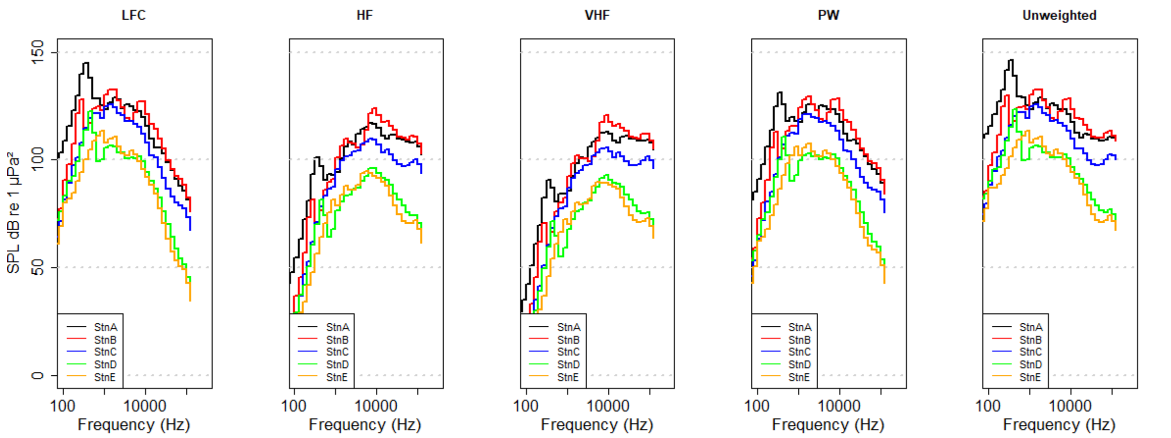


Figure 33. Sparker: weighted and unweighted decidecade Sound Pressure Levels (SPL) (100 Hz high pass filter) plot for each AMAR Each solid line represents the median of 5 m window around the nominal CPA.

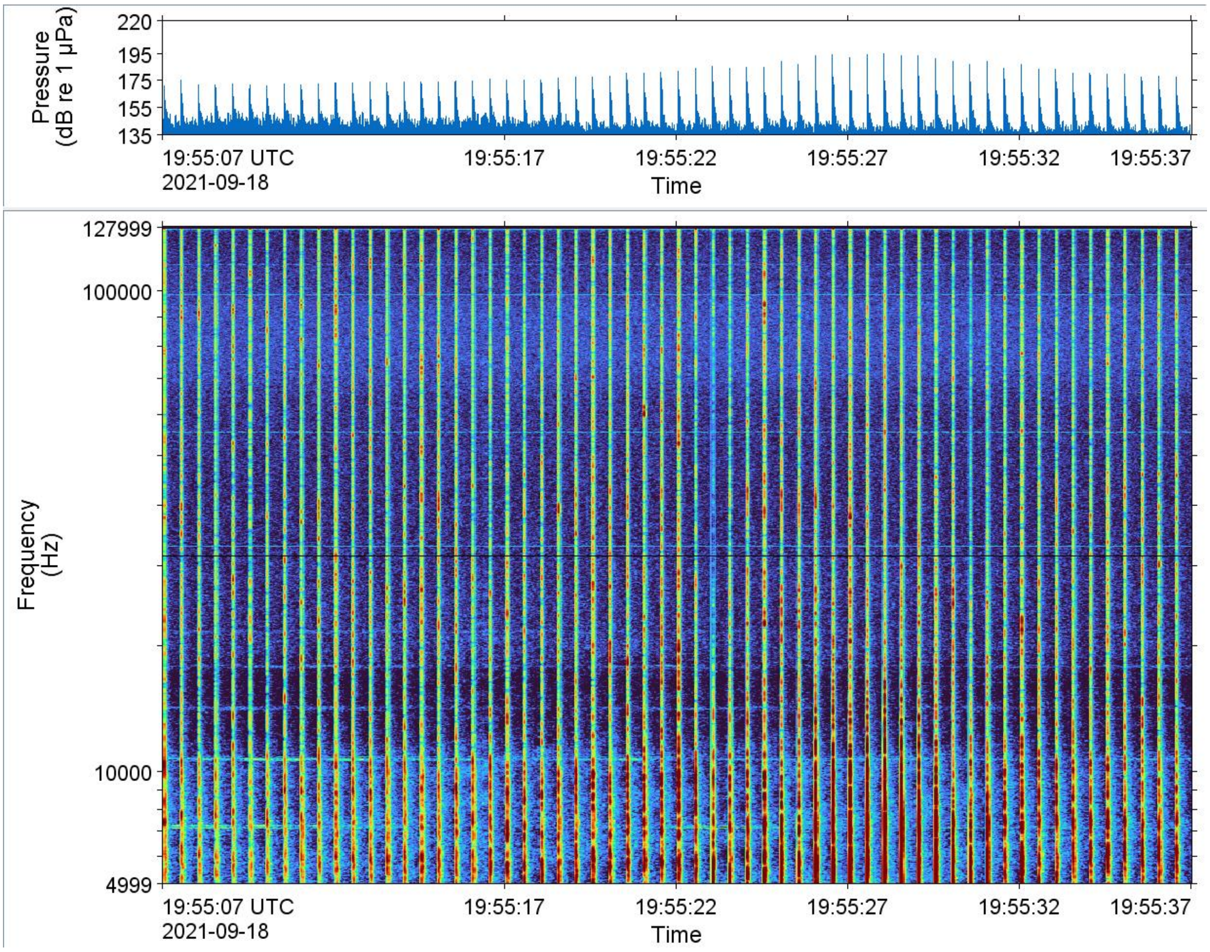


Figure 34. Sparker: Spectrogram (1 Hz frequency resolution, 0.01 s time window) of 30 s recorded at the closest point of approach (CPA) at 19:54 on 18 Sep 2021 (Test Run 1 Pass 1).

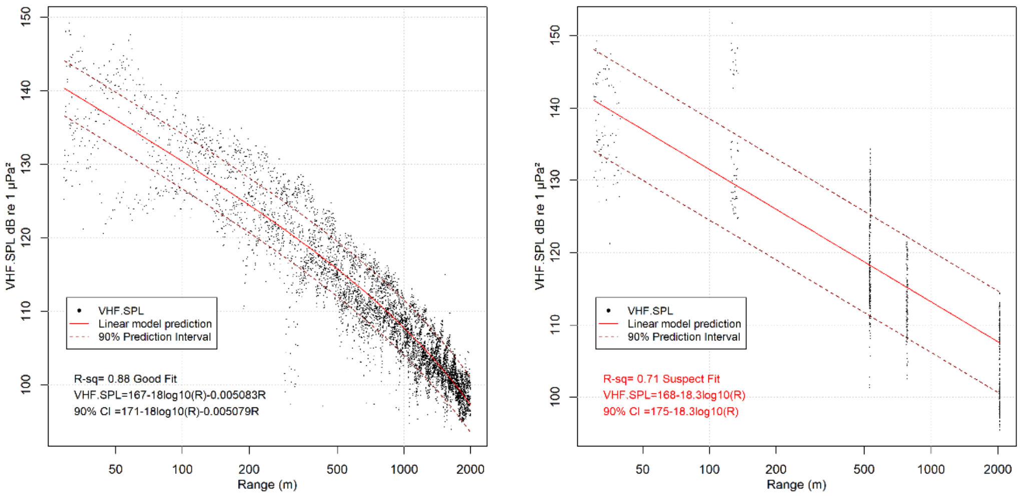


Figure 35. Sparker: 125 ms VHF weighted SPL compared to range at the sound source verification (SSV) site along the main track line (endfire direction, left) and broadside direction (right). The solid line is the best fit of the empirical function to the SPL for the entire duration of the transect. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

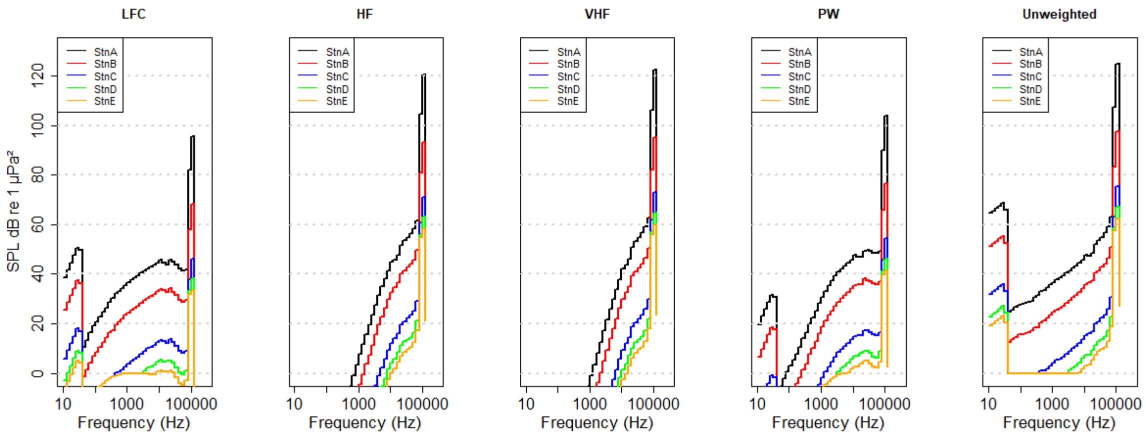


Figure 36. Sub-bottom profiler: weighted and unweighted decidecade sound pressure level (SPL; 90–105 kHz band-pass filter) plot for each AMAR. Each solid line represents the median of a 5 m window around nominal closest point of approach (CPA).

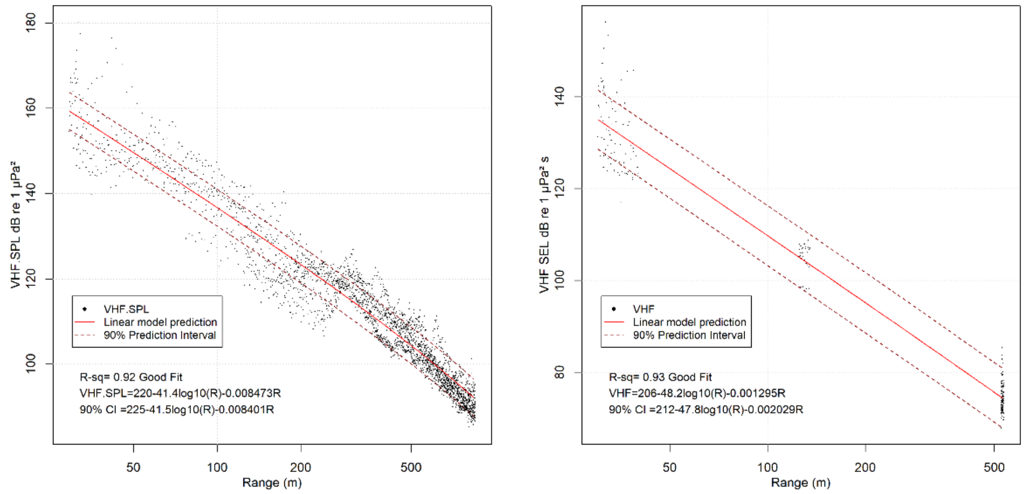


Figure 37. Sub-bottom profiler: 125 ms VHF weighted SPL compared to range at the sound source verification (SSV) site along the main track line (endfire direction, left) and broadside direction (right). The solid line is the best fit of the empirical function to the SPL for the entire duration of the transect. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

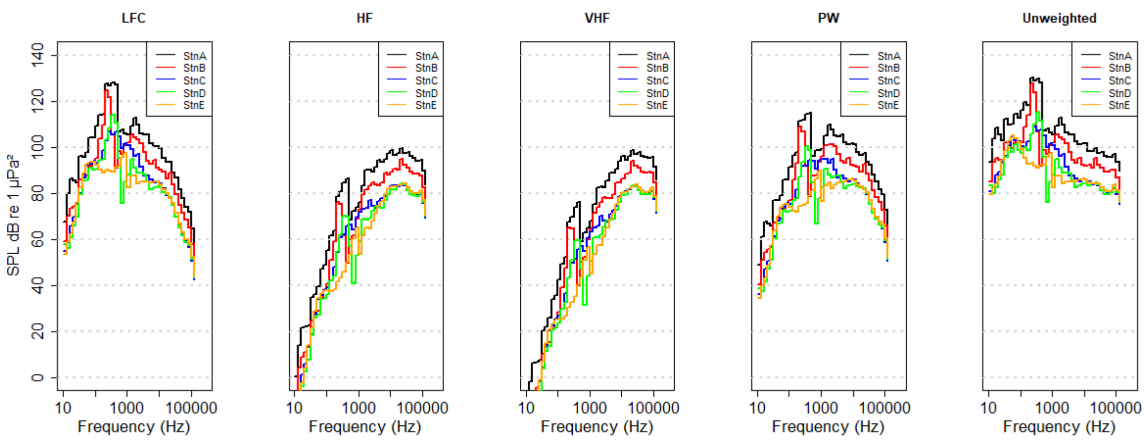


Figure 38. Multi-beam echo-sounder: weighted and unweighted decidecade Sound Pressure Levels (SPL) plot for each AMAR Each solid line represents the median of a 5 m window around the nominal closest point of approach (CPA).

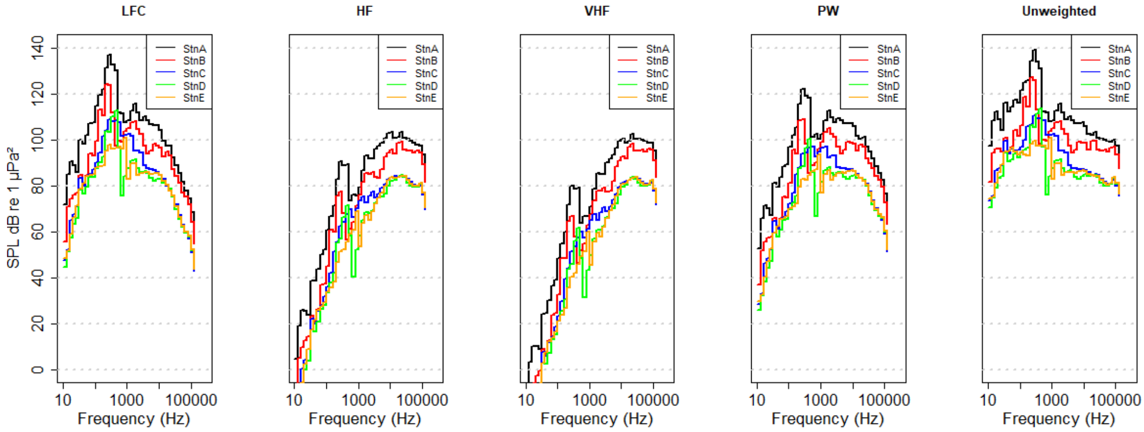


Figure 39. Side scan sonar without USBL: weighted and unweighted decidecade Sound Pressure Levels (SPL) plot for each AMAR Each solid line represents the median of a 5 m window around the nominal closest point of approach (CPA).

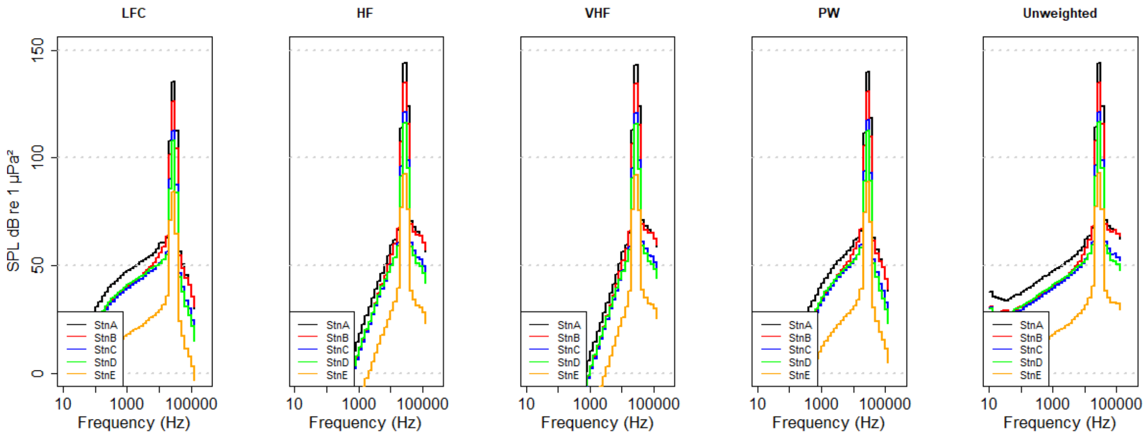


Figure 40. Side scan sonar with USBL: weighted and unweighted decidecade Sound Pressure Levels (SPL)(20–30 kHz band pass filter) plots for each AMAR. Each solid line represents the median of a 5 m window around the nominal closest point of approach (CPA).

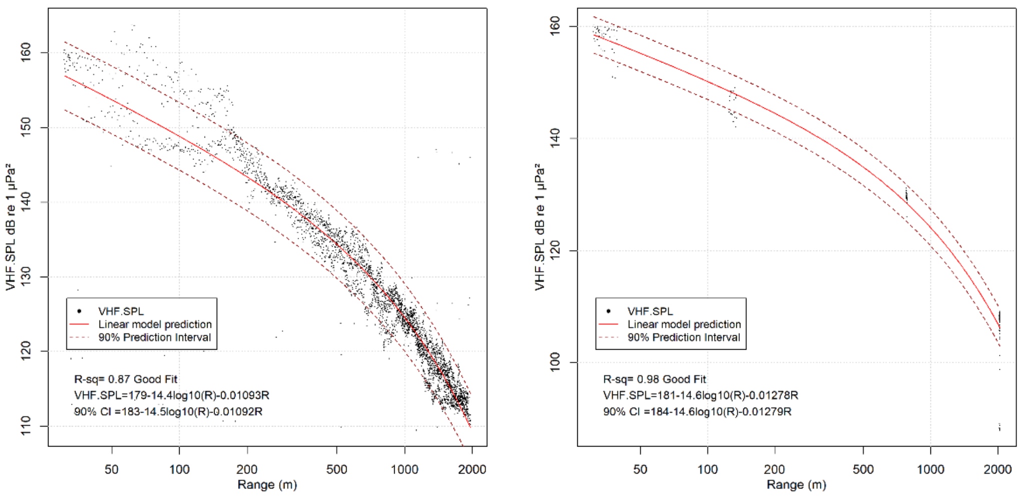


Figure 41. Side scan sonar with USBL: 125 ms VHF weighted SPL compared to range at the sound source verification (SSV) site along the main track line (endfire direction, left) and broadside direction (right). The solid line is the best fit of the empirical function to the SPL for the entire duration of the transect. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

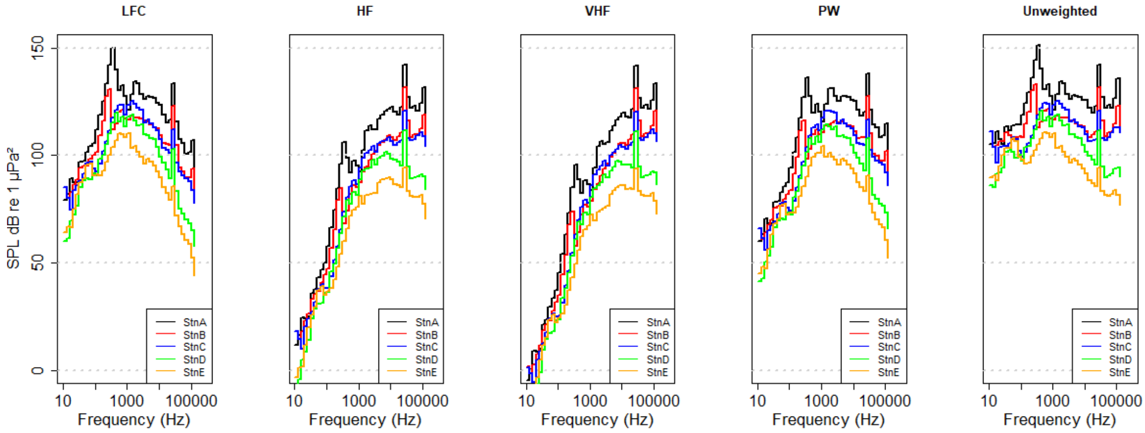


Figure 42. All sources: weighted and unweighted decidecade Sound Pressure Levels (SPL) plot for each AMAR. Each solid line represents the median of a 5 m window around the nominal CPA.

3.3.1. Cumulative Exposure

The survey track with all sources active at the same time was analysed separately to estimate the cumulative exposure for the LFC, HF, VHF, and PW listening groups for the entire duration of a survey pass.

The data for both tests was combined for the regressions presented in Figure 43. The results show a decay in weighted sound levels with range according to the generalized equation 2 , indicating greater than cylindrical spreading loss. The levels presented may be compared to the PTS and TTS thresholds for continuous sources[2] weighted for very high frequency cetaceans presented in Southall et al (2019). Table 15 details the thresholds and exceedance ranges based on Southall et al. (2019). Of note is the VHF best estimate and 90% CI ranges of 332 and 502 m, respectively. Other listing groups had Exceedance ranges less than 20 m from the source.

[2] Although individual sources such as the sparker and USBL are classed as impulsive; the survey with the combination of sources is better assessed against the continuous descriptor.

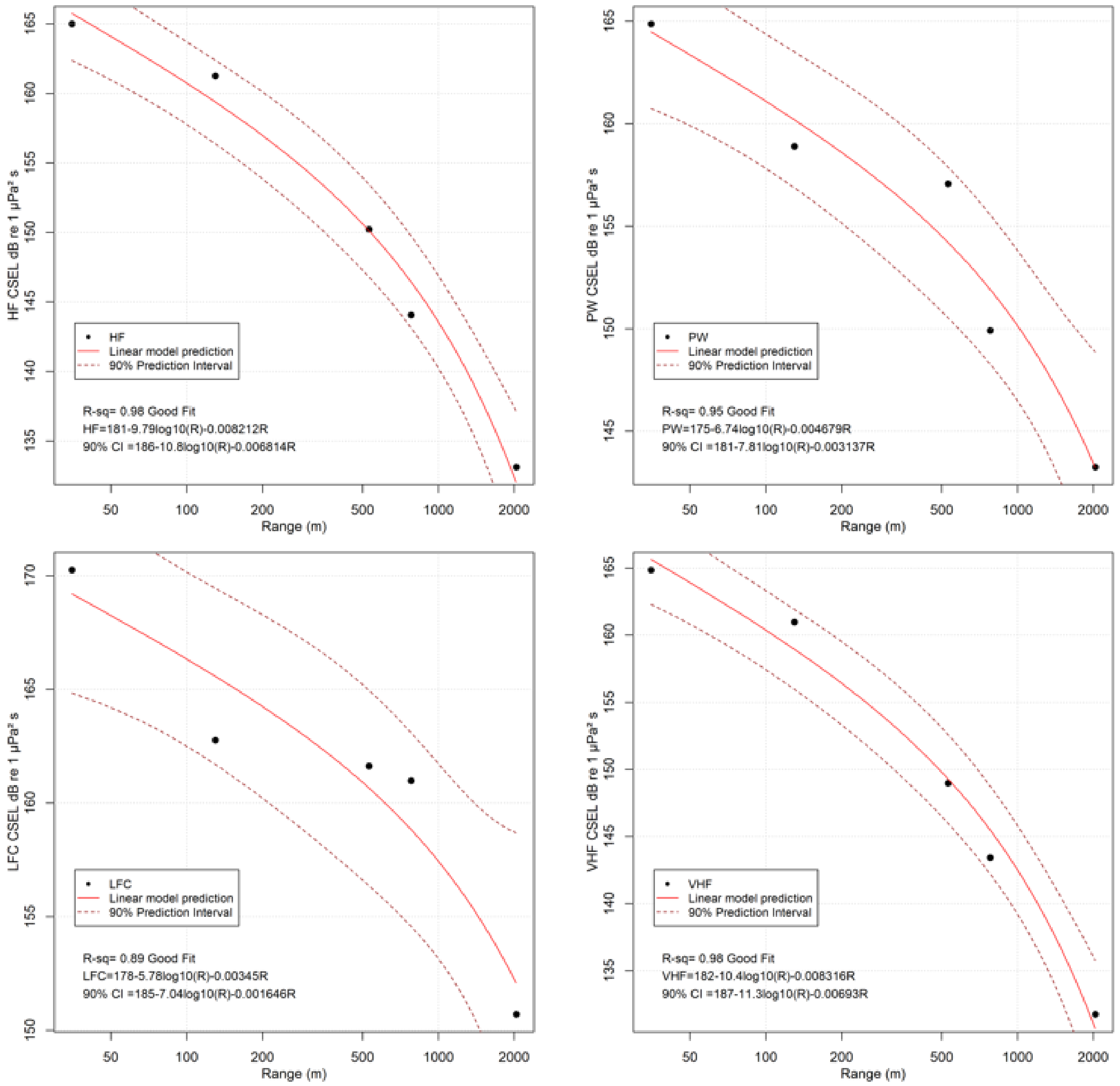


Figure 43. All sources: Cumulative weighted sound exposure level (SEL) compared to range at the sound source verification (SSV) site The solid line is the best fit of the empirical function to the SEL for the entire duration of the transect. The dashed line is the best-fit line shifted up to exceed 90% of the SEL (i.e., the 90th percentile fit).

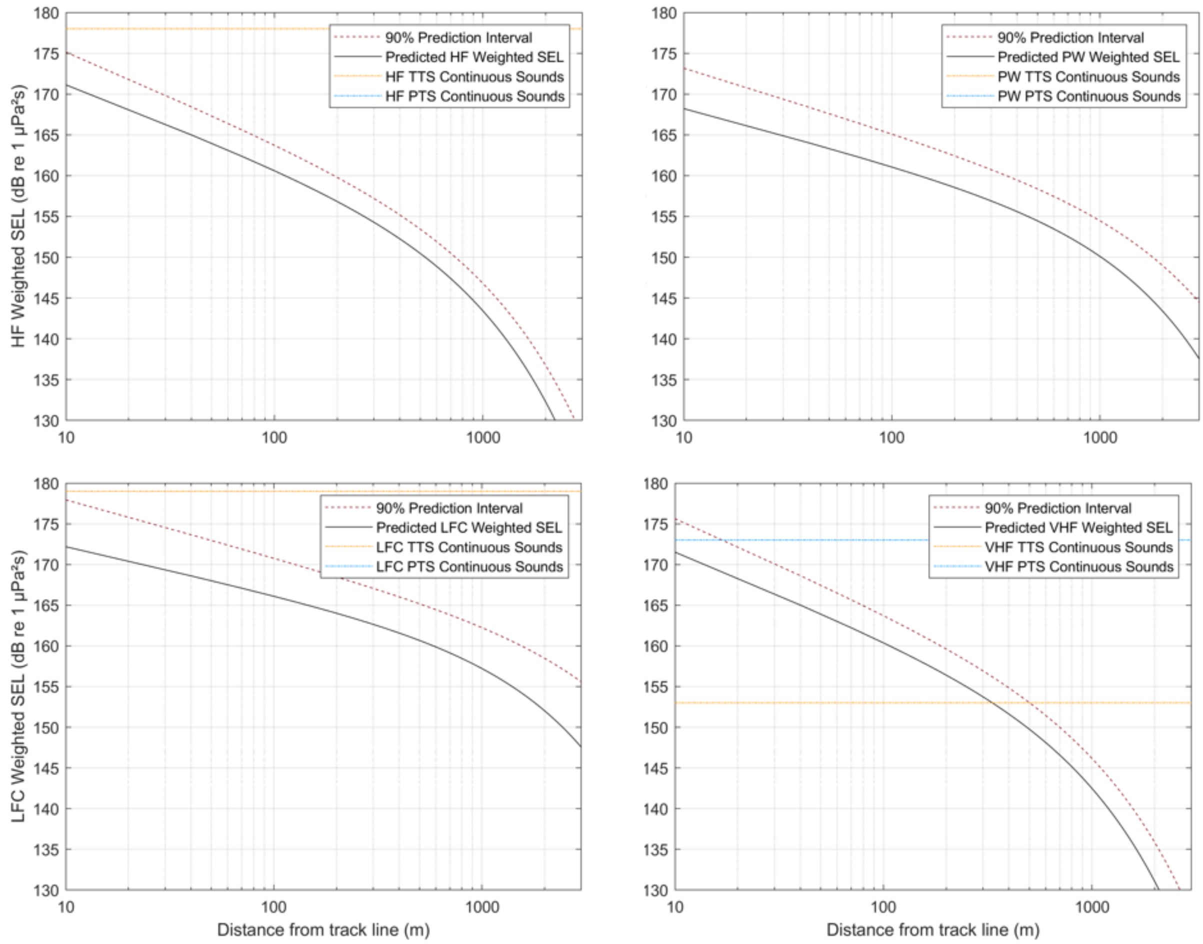


Figure 44. Prediction of the weighted SEL as a function of distance using the fit from Figure 43, highlighting the applicable thresholds for continuous sounds described in Southall et al (2019).

Table 15. TTS and PTS thresholds for weighted CSEL listening groups and their respective exceedance ranges, based on Figure 44. N.A. indicates threshold not exceeded.

Weight	Threshold		Fitted range (m)		90%CI range (m)	
	TTS	PTS	TTS	PTS	TTS	PTS
LFC	179	199	N.A.	N.A.	9.8	N.A.
HF	178	198	2	N.A.	5.5	N.A.
VHF	153	173	332.8	7.2	502.2	16.9
PW	181	201	N.A.	N.A.	0	N.A.

3.3.2. 125 ms Sound Pressure Levels

As discussed in Section 2.3.6, the auditory frequency weighted 125 ms sound pressure levels as a function of range to the vessel are of interest for estimating sensation levels and potential disturbance of marine mammals. The weighted 125 ms SPL measured as the vessel passed Station A are shown in Figure 45, which yielded regression coefficients that were extrapolated to determine when the sound levels would fall below 100 dB re 1 μPa² (Figure 46.). The sound level model is intended for predicting the received level at distances between those at which measurements were made (i.e., between 10 and 2000 m). The accuracy of the predictions decreases when the sound levels are extrapolated beyond the measurements, however, in this case the distance to a VHF weighted SPL of 100 dB re 1 μPa² was of great interest. The fitted 100 dB re 1 μPa² exceedance range for the VHF listening group is 1975 m, and the 90% CI range is 2278 m. Fits fall on or below the weighted received levels from the 5 and 10 km passes[3]. Note that for the HF and VHF data, the weighted SPLs are the same, which suggests those values (~95 dB re 1 μPa²) represent ambient background levels. The values included in the regressions are far enough above this background that it does not need to be considered in the analysis. The broadside direction is not presented as the CPA for the various instrument passes are not simultaneous.

[3] Note that these levels are sparker only, as the all sensor passes were not run on the 5 and 10 km lines.

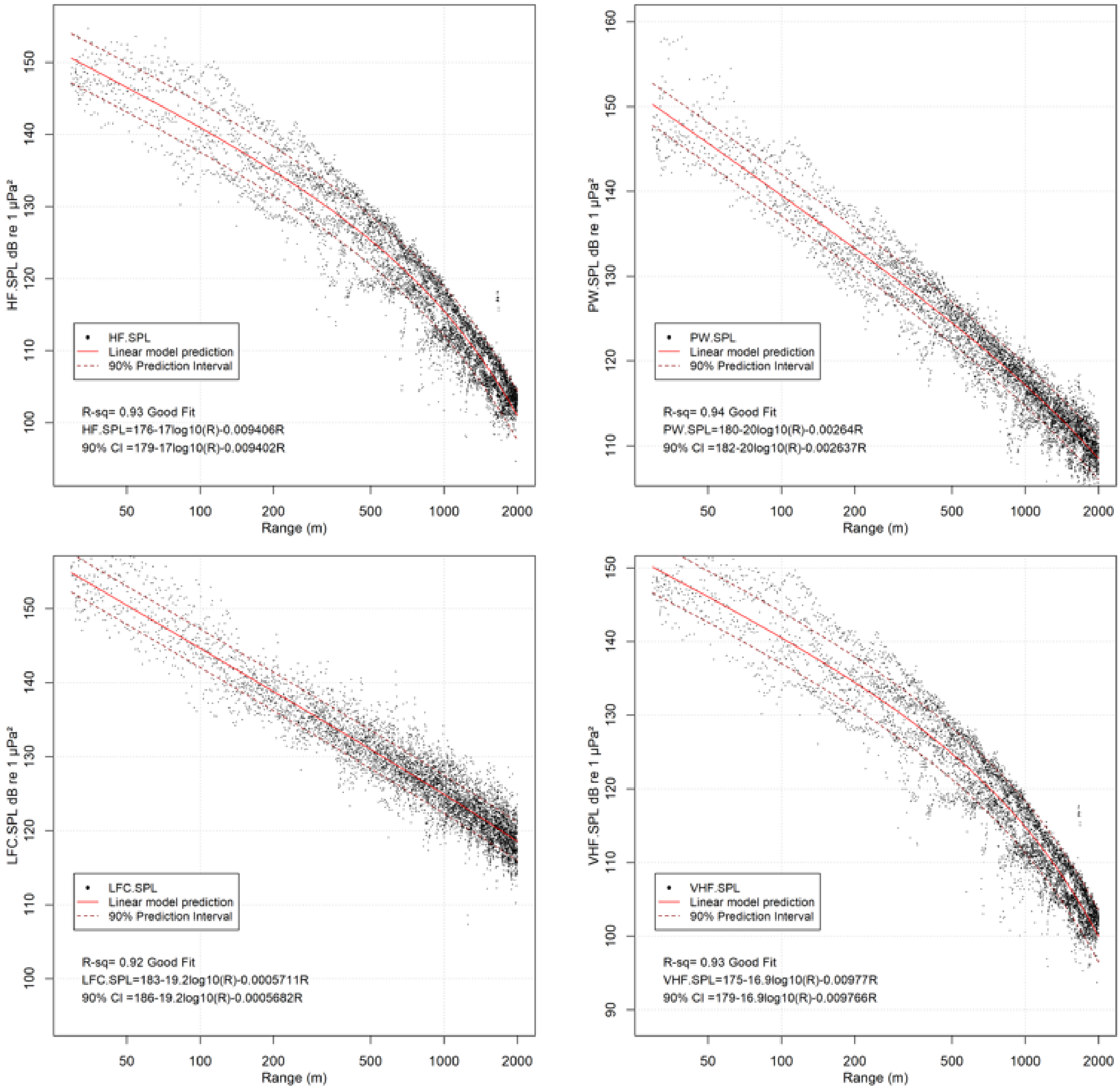


Figure 45. All sources: 125 ms weighted Sound Pressure Levels (SPL) compared to range at the sound source verification (SSV) site along the main track line (endfire direction). The solid line is the best fit of the empirical function to the SPL for the entire duration of the transect. The dashed line is the best-fit line shifted up to exceed 90% of the SPL (i.e., the 90th percentile fit).

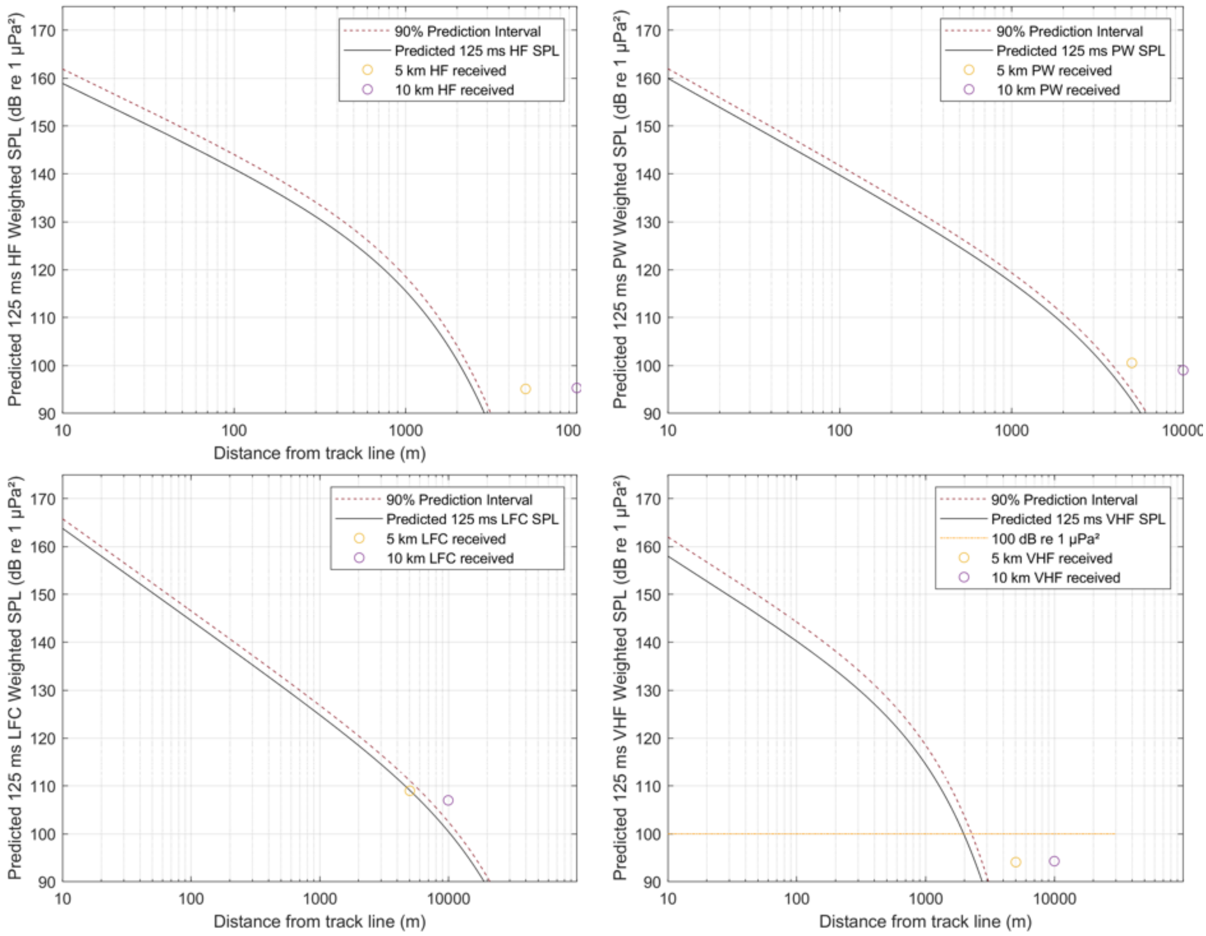


Figure 46. Prediction of the 125 ms weighted Sound Pressure Levels (SPL) for all sources as a function of distance to the survey vessel using the fit from Figure 45. Points are the weighted received levels from 5 and 10 km, respectively.

4. Discussion and Conclusion

This study is one of the first to investigate the source levels and characteristics of diverse acoustic sources used for geophysical surveys. Individual sources have been the modelled and monitored independently in previous studies; however, this investigation represented a unique opportunity to understand the sound field associated with all sources used during a typical geophysical survey. The configuration of sources is considered realistic and representative of the types of surveys conducted in shallow waters to investigate sites such as offshore wind farms.

The tests were designed to isolate each source to characterise its frequency components and determine its contribution to the soundscape. The only source that could never be switched off was the vessel *Fugro Pioneer* itself and for this reason test runs were recorded with the vessel running the same survey lines with the acoustic sources silent. The positioning system of the vessel was also switched off during these tests to minimise the vessel contribution to the soundscape. A true ambient sound profile could not be collected because the vessel was always present on-site running production survey lines as the study needed to be scheduled around logistical constraints; however, the profile for the ambient sound was obtained when the vessel was as far away as possible for any one recorder.

This chapter discusses the findings of the source characterisation for each individual source (Sections 4.1 to 4.6), including implications for marine mammal exposure and mitigation actions (Section 4.7), and draws some conclusions on the study limitations and possible further work (Section 4.8).

4.1. Background Noise Levels

The background noise levels that are most representative of the ambient conditions are for the station that was farthest from the vessel, i.e., Station A. At this location the broadband SPL_{125ms} was 108.5 dB re 1µPa^2. Ambient sound levels for the Danish North Sea were measured at the Horns Reef site as part of the JOMOPANS project (Fischer et al. 2021), which also investigate the window duration for the calculation of the SPL (i.e., 1 s) (Merchant et al. 2018). A 1 s window duration was proposed as a compromise between frequency resolution that should be sufficiently long to represent the 63 Hz and 125 Hz that are used as indicators for the Marine Strategy Framework Directive (MSFD) Descriptor 11 Criterion 2 (D11C2) for continuous noise but short enough to resemble the integration time of ~0.1 s of mammalian hearing (Merchant et al. 2018). The reported ambient level for Horns Reef (monthly median) for all the available months of monitoring ranged between SPL 100–110 dB re 1µPa in the band 20–20,000 Hz (Putland et al. 2021). These are comparable with those recorded on site that ranged between 110–112 dB re 1µPa for the same time averaging and frequency range, even though a contribution from the sparker being run is noticeable below 500 Hz (Figure 10).

4.2. MV *Fugro Pioneer* Vessel Operation

The MV *Fugro Pioneer* signature was analysed in depth by aural and visual investigation of the passes recorded at Station A around CPA.

The vessel RNL was estimated at 167.2 dB re 1µPa^{2}m^2 running at ~4.5 kn indicative of a very quiet survey vessel; furthermore, no sign of cavitation was found when the vessel was running the survey tracks, as would be expected given the speed.

Minor blade slap resulting in minor blade flutter is evident on all CPP systems. This is especially true for high RPM units on traditional geared reduction ratio systems or in this case where no cavitation is present, minor blade slap can be caused on shallow drafted vessels driven merely by fluid dynamics around the hull; a vessel's hydrodynamic performance. Other factors, such as tunnel thrusters, if used for maintaining course over ground, can add to this effect by exciting water around the hull during forward movement of the vessel causing hydrodynamic performance to be degraded when cycling on to maintain steerageway causing flow induced resonance (FIRs) on the vessel's hull. The same is true if Azimuth thrusters are at angles calculated automatically without human interaction on DP vessels.

Since Azimuth thruster units rotate 360 degrees, and contain the motor and propeller shaft, it reduces noise and vibration as seen in these captures. Azimuth thrusters significantly reduce a vessel's acoustic footprint under 500 Hz by eliminating a) traditional prime mover main engine(s) to b) gearbox reduction to c) shaft and couplings and d) eventually to the propeller(s). Hydraulic noise to geared or combinations of geared and hydraulic power sources to large rudders is also absent when Azimuth thrusters are utilized and the resultant acoustic signature <300 Hz is reduced drastically. The use of Azimuth thrusters also has other benefits outside of acoustics such as reduced fuel consumption and added manoeuvrability at any speed and ease of station keeping.

Steady-state monopole sources are present throughout the dataset which only fluctutate slightly with a) vessel aspect/range to recorder and b) vessel speed. Vessel speed differences had a negligable effect on acoustics at higher frequencies as they are electrically produced and not directly coupled to the azimuth propulsion units. It is believed that these electrical sources are directly related to azimuth power generation. Electric propulsion is a common and popular choice in modern offshore vessels and warships due to fuel savings, emmission reductions, Emission Control Area (ECA) regulations, redundancy, space, maintenance costs and ultimetely reduced noise and vibration which leads to less acoustic transmission compared with traditional prime-mover to gearbox setups.

AC motors and generators (gensets) are clearly present in the analysis conducted. It is not known from initial analysis if asynchronous alternating current (AC) motors are running while gensets may be synchronous in this particular vessel. Although traditional gearbox noise pollution is not present in the signature of this vessel there does seem to be some relationship between the use of non-traditional gearbox between AC motor and propeller.

This vessel exhibits azimuth thrusters with controllable pitch propellers (CPP) in the files analysed with electrical motors being rafted and/or not directly coupled as per most prime movers. The electric drive technology will be the primary exciter in the higher frequencies. It is not known however if these high frequency monopole sources are related to power transformers and EMC (electromagnetic) noise causing harmonic distortion; that would require a more in-depth analysis on rapid voltage to current changes and/or what frequency converters or DC capacitors are used for this vessel and AC losses and AC pole motor slippage rates. It is also unclear if this vessel uses PMW (pulse width modulation) which would induce EMC noise in the higher frequencies. Transformations based on rectifiers or PMW will cause steady-state acoustic noise at higher frequencies – again this is an unknown on this vessel without level 4 analysis on the power generation and powertrain. It is well known however that a PWM type transitor switching will create acoustic noise from the various AC motors. This common mode noise is almost always present with switching noise from PWM drives.

It is also unknown if this vessel utilizes redundant power units which are normally comprised of various rectifiers, DC capacitor, inverters and secondary water cooling. New electrical drive systems are more commonly using bypass switches, multi-speed motors, controlled pitch propellars and some form of layered semiconductor rectifer to reduce common mode noise.

4.3. Sparker Source

The sparker used for the survey was manufactured by Geophysical Services Offshore (GSO) 360 tip source configured to fire at 900 kJ at a regular interval of one pulse per meter, which corresponded to approximately two pulses every second. The technical sheet does not specify an absolute source level for this source nor a range for the emitted frequencies (Appendix D.1). This study found that the pulse from the sparker peak energy was between 200–300 Hz, as desired according to the survey setup; in addition, considerable energy was contained up to 10 kHz. The frequency content of the pulse was fairly consistent across the survey line and between stations, however, as one would expect the pulse attenuated with distance, with higher frequencies decaying more rapidly. At Station E, i.e., 2 km from the source, the sparker peaks were still clearly detectable above background noise levels; however, this was not true for the 5 and 10 km survey lines.

Levels decreased with distance as one would expect from theory; the propagation loss for this source calculated for the tests on the Sparker was 16, indicative of an intermediate spreading approximating spherical absorption. The range regression for the 125 ms VHF weighted SPL showed that at ~1.5 km from the source along the endfire direction, the levels fall below 100dB re 1µPa (Figure 35). The regression for the broadside direction for this source was a dubious fit and may therefore not be relied upon.

4.4. Sub-bottom Profiler

The sub-bottom profiler was a parametric source with a primary transmitting frequency at ca. 110 kHz and emitting multiple secondary frequencies in the band 2–22 kHz. Due to the limited sampling frequency, it was not possible to determine whether harmonics multiples of the primary transmitting frequency are generated by this source. The characteristics observed in the recordings matched those reported by the manufacturer (Appendix D.2). The absolute source level reported for the primary frequency by the manufacturer is >247 dB re 1µPa; however, it is not clear if this SL refers to a single frequency or an octave centre frequency or a broadband level. In any case, since estimation of the absolute source level was outside the scope of the work this was not compared to the recorded levels.

While the pulse was clearly visible with all its frequency components at CPA along the survey line (i.e., at Station A), the secondary frequencies were hardly visible off-axis, indicative of the fact that this source is highly directional. The propagation loss for this source calculated for the tests on the SBP was greater than spherical spreading (coefficient of ~44).

The received 125 ms mean square SPL, weighted for VHF cetaceans, for this source ranged from 189.3 dB to 151.8 dB re 1µPa at Station A during the instrument overpass. The range regression for the 125 ms VHF weighted SPL showed that the levels fall below 100dB re 1µPa at ~500 m from the source along the endfire direction and ~150 m in the broadside direction (Figure 37).

4.5. Multi-beam Echo Sounder

The source level and characteristics of the multi-beam echo sounder could not be determined due to the limitation in sampling frequency applied to the data collection; however, it was possible to determine that this source did not present any sub-harmonics in the frequency range 10 Hz to 128 kHz and therefore it did not contribute to an increase of the sound levels in the monitored frequency band compared to the standard vessel pass. The multi-beam echo sounder is hull mounted and was run at a similar speed as the vessel only test; no differences in the vessel sound emissions were noticed for the passes with the MBES compared to the baseline.

4.6. Side Scan Sonar

The source level and characteristics of the side scan sonar could not be determined due to the limitation in sampling frequency applied to the data collection. Two types of tests were run for this source. The first tests were run with the SSS switched on and the high-precision positioning system switch off; this was done to compare the results with the baseline vessel only track but does not represent the typical survey setup. The SSS is regularly used with the high-precision positioning system (USBL) switched on; as such, the second set of tracks was run with this equipment active.

While the SSS only tests showed no increase in sound levels compared to the baseline, despite this instrument being towed, the tests ran with the active USBL showed substantial increase in received levels. This source had a distinct signature at 25 kHz and emitted a regular ping approximately every 1 s that could be detected above the ambient for the entire monitoring range, i.e., up to 2 km from the source both on and off axis. As previously mentioned, activation of the USBL is a necessary part of the side scan sonar survey because it allows to determine the positions with a high level of precision. This system emits a sound that needs to be detected by the receivers on the vessel that is less than 100 m away. The interval between pulses can be adjusted by the user but it directly affects the precision of the readings; as such, a short interval between pulses is required. A lower source level may be desirable for mitigation purposes since from the survey perspective there is no need for the sound to be received further than a few hundred meters from it while this study showed that the sound can still be detected above ambient at 2 km distance. Furthermore, since the source level (Table 12) is high enough to potentially cause injury to marine mammals, mitigation prior to its implementation should be implemented.

The repetition rate of the USBL almost matched that of the sparker, however, there was limited energy overlap as a function of frequency. As such, the two sounds did not mask each other but their energy contribution at different frequency bands added, leading to a further increase in sound levels compared to the individual source tests. The propagation loss for this source calculated for the tests on the SBP was 14.4, indicative of intermediate spreading loss.

The 125 ms SPLs, weighted for VHF cetaceans, with the active USBL were 162.8 dB and 150.7 dB re 1µPa at Station A during the instrument overpass. Levels reached less than 120 dB re 1µPa at a distance of ~1 km from the source in both endfire and broadside directions.

The range regression for the 125 ms VHF weighted SPL showed that the levels fall below 100 dB re 1 µPa beyond the 2 km range at which monitoring was performed in both directions (Figure 37).

4.7. Marine Mammal Exposure

The study was aimed at characterising the sources typically used for geophysics surveys in view of determining their impacts on marine mammals, specifically the LFC, HF, VHF, and PW listening groups.

While the sparker source produces high intensity pulses that may be categorised as impulsive, the way in which it is used means that animals will be exposed to multiple pulses over an extended period, much like for a seismic survey carried out with traditional airguns. As such, in the context of understanding behavioural reactions and masking it is relevant to assess the exposure level for typical survey durations to develop and appropriate mitigation plan. The peak energy of the sparker is relatively low frequency and therefore most impactful to low frequency cetaceans and pinnipeds; while for very high-frequency cetaceans, other measured sources have the potential to generate larger impact ranges.

The parametric sound bottom profiler emits a loud pulse at 110 kHz, with several sub-harmonics at lower frequencies, that is within the best hearing range of the harbour porpoise. While the pulse has the potential to cause injury to marine mammals within a few meters from it, the sound attenuates very rapidly. Based on what was observed in this study, at 500 m from the source (Station C), the sound was barely discernible above the background noise. As such, effective mitigation could consist of visual and/or acoustic monitoring for the presence of marine mammals prior to operating the source to ensure clearance of a pre-determined area before conducting the survey.

The impact of the multi-beam echo-sounder and of the side scan sonar operated without positioning system could not be assessed unequivocally; however, the fact that no increase in background noise levels during the tests conducted for the application of these sources confirms that no subharmonics were detectable below 128 kHz. Based on these data, it appears that these sources do not emit substantial sound levels within the frequencies of best hearing of any of the marine mammal species. Nevertheless, there is still potential that these sources may be detected and lead to masking or behavioural impacts for very high frequency cetaceans. Furthermore, porpoises and other mammals can be impacted by sound also outside their audibility range if signals area sufficiently loud to cause physical damage. This type of impact could not be assessed because it would require knowledge of the source level of the sources.

The cumulative exposure analysis for the test with all sources combined show that levels decrease more rapidly than expected according to the cylindrical spreading law but less rapidly than the intermediate spreading (i.e., 15LogR+R) which is often applied as a simplified spreading loss model for the North Sea region. During this type of surveys, marine mammals would be exposed to a combination of continuous and impulsive sounds, as defined in the Marine Strategy Framework Directive (MSFD) (European Commission 2017). Specifically the vessel represents a continuous sound source (Descriptor 11 Criterion 2, D11C2 of the MSFD) as well as the SBP due to its brief inter pulse interval of ~73 ms (de Jong et al. 2021) while the sparker and USBL sources are classified as impulsive (D11C1 of the MSFD). Considering that the repetition rate of the sparker and USBL can be set by the user according to the survey requirements, care should be taken in considering the expected inter pulse interval in impact assessments based on the predicted survey operation mode.

When the sources are active all at the same time the quiet periods in between pulses are less than 125 ms. Therefore, a survey of this type could be assessed as a cumulative operation against threshold levels that are specified in the literature for continuous sources when all sources are active simultaneously, e.g., Southall et al (2019), (Tougaard et al. 2015), Gomez et al. (2016). The results showed that the PTS thresholds for the SEL is typically not exceeded while the TTS threshold for the SEL is exceeded within ~10 m from the source (Figure 44, Table 15), save for the VHF listening group, with cumulative PTS and TTS ranges of 7.2 and 332.8 m (90% CI of 16.9 and 502.2 m) respectively. Based on the regression analysis conducted the fitted 100 dB re 1 μPa² VHF exceedance range is

1975 m, with a 90% CI range of 2278 m (Figure 46). The sound levels from the USBL and sparker measured within 2 km of the vessel were always above the background sound levels.

4.8. Limitations

In this study effective source levels were calculated based on the regressions obtained from the sound levels versus range results presented in Section 3.2. While the effective source levels provide a useful indication of the energy introduced in the environment by these sources, monopole source levels are needed for predictions of sound levels at a different location. Monopole source levels were not part of the project; however, these could be obtained applying inversion modelling to the data set. Important environmental inputs that would be required for such work, such as the sound speed profile and soil profile, are available for the area and period of the measurement.

The sampling frequency employed 256 kHz and provided a usable frequency range of 128 kHz. The usable frequency range includes the best hearing frequencies for all marine mammal groups, including very high-frequency cetaceans such as harbour porpoises. The audible frequency range of the VHF group expands beyond the recorded frequency range; however, they are not believed to be highly sensitive at the frequencies of the multibeam echosounder or the side scan sonar. Given the time to procure appropriate hydrophones, future assessments could collect data to characterize these sonars and the overlap between their outputs and VHF cetacean hearing.

Due to project constraints, survey setup could not be implemented to investigate source directionality. Such a study would have required deploying directional hydrophones and/or vertical arrays. This type of data could have provided useful information to advise marine mammal mitigation strategies.

Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017).

1/3-octave

One third of an octave. *Note*: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec).

1/3-octave-band

Frequency band whose bandwidth is one one-third octave. *Note*: The bandwidth of a one-third octave-band increases with increasing centre frequency.

90%-energy time window

The time interval over which the cumulative energy rises from 5 to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% sound pressure level (90% SPL)

The sound pressure level calculated over the 90%-energy time window of a pulse.

absorption

The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

acoustic impedance

The ratio of the sound pressure in a medium to the volume flow rate of the medium through a specified surface due to the sound wave.

acoustic self-noise

Sound at a receiver caused by the deployment, operation, or recovery of a specified receiver, and its associated platform.

ambient sound

Sound that would be present in the absence of a specified activity, usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

annotation

A labelled selection of a period of time and frequency within a spectrogram as created by a human analyst during **manual analysis**.

attenuation

The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

audiogram

A graph or table of hearing threshold as a function of frequency that describes the hearing sensitivity of an animal over its hearing range.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

automated detection

The output of an **automated detector**.

automated detector

An algorithm that includes both the **automated detection** of a sound of interest based on how it stands out from the background and its automated classification based on similarities to templates in a library of reference signals.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

background noise

Combination of ambient sound, acoustic self-noise, and sonar reverberation. Ambient sound detected, measured, or recorded with a signal is part of the background noise.

bandwidth

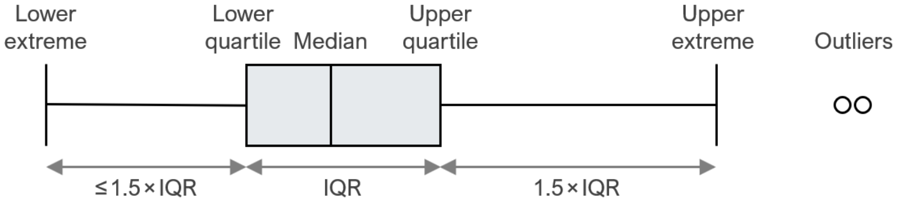
The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI S1.13-2005 (R2010)).

bar

Unit of pressure equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 10^5 Pa or 10^{11} µPa.

box-and-whisker plot

A plot that illustrates the centre, spread, and overall range of data from a visual 5-number summary. The box is the interquartile range (IQR), which shows the middle 50% of the data—from the lower quartile (25th percentile) to the upper quartile (75th percentiles). The line inside the box is the median (50th percentile). The whiskers show the lower and upper extremes excluding outliers, which are data points that fall more than 1.5 × IQR beyond the upper and lower quartiles.



boxcar averaging

A signal smoothing technique that returns the averages of consecutive segments of a specified width.

broadband level

The total level measured over a specified frequency range.

broadside direction

Perpendicular to the travel direction of a source. Compare with endfire direction.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

conductivity-temperature-depth (CTD)

Measurement data of the ocean's conductivity, temperature, and depth; used to compute sound speed and salinity.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period . A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade. *Note*: An alternative name for decidecade (symbol ddec) is "one-tenth decade". A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a "one-third octave".

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

endfire direction

Parallel to the travel direction of a source. Also see **broadside direction**.

effective source level (ESL)

For sound levels from a human source measured at multiple distances, the received sound levels (RL) are often fit to linear models in the form RL = ESL + $A\log_{10}$(range) + B*range. The parameter A represents the geometric spreading loss coefficient of the sound and is generally between 10 and 20. B describes extra attenuation due to scattering and absorption of the sound that increases linearly with range. ESL is the effective source level, which is a measure of how loud the source is, however, it is not the same as monopole source level (MSL) that measures the true intensity. MSL can be used for predicting sound as a function of distance using acoustic propagation models. The ESL may only be employed with the A and B terms that were computed at the same time as the ESL and are only valid for the environment in which they were measured.

energy source level

A property of a sound source obtained by adding to the sound exposure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^{2}s.

energy spectral density

Ratio of energy (time-integrated square of a specified field variable) to bandwidth in a specified frequency band f_1 to f_2. In equation form, the energy spectral density E_f is given by:

$$E_f = \frac{2\int_{f_1}^{f_2} |X(f)|^2 \, \mathrm{d}f}{f_2 - f_1},$$

where $X(f)$ is the Fourier transform of the field variable $x(t)$

$$X(f) = \int_{-\infty}^{+\infty} x(t) \exp(-2\pi i f t) \, \mathrm{d}t \, .$$

The field variable $x(t)$ is a scalar quantity, such as sound pressure. It can also be the magnitude or a specified component of a vector quantity such as sound particle displacement, sound particle velocity, or sound particle acceleration. The unit of energy spectral density depends on the nature of x, as follows:

- If x = sound pressure: Pa^2 s/Hz
- If x = sound particle displacement: m^2 s/Hz
- If x = sound particle velocity: (m/s)^2 s/Hz
- If x = sound particle acceleration: (m/s^2)^2 s/Hz

The factor of two on the right-hand side of the equation for E_f is needed to express a spectrum that is symmetric about $f = 0$, in terms of positive frequencies only. See entry 3.1.3.9 of ISO 18405 (2017).

energy spectral density level

The level ($L_{E,f}$) of the **energy spectral density** (E_f). Unit: decibel (dB).

$$L_{E,f} := 10 \log_{10}\left(E_f / E_{f,0}\right) \, \mathrm{dB} \, .$$

The frequency band and integration time should be specified.

As with **energy spectral density**, energy spectral density level can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement). The reference value ($E_{f,0}$) for energy spectral density level depends on the nature of field variable.

energy spectral density source level

A property of a sound source obtained by adding to the energy spectral density level of the sound pressure measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^{2}s/Hz.

Fourier transform (or Fourier synthesis)

A mathematical technique which, although it has varied applications, is referenced in the context of this report as a method used in the process of deriving a spectrum estimate from time-series data (or the reverse process, termed the inverse Fourier transform). A computationally efficient numerical algorithm for computing the Fourier transform is known as fast Fourier transform (FFT).

flat weighting

Term indicating that no frequency weighting function is applied. Synonymous with unweighted.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

Global Positioning System (GPS)

A satellite based navigation system providing accurate worldwide location and time information.

harmonic

A sinusoidal sound component that has a frequency that is an integer multiple of the frequency of a sound to which it is related. For example, the second harmonic of a sound has a frequency that is double the fundamental frequency of the sound.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hearing threshold

The sound pressure level for any frequency of the hearing group that is barely audible for a given individual for specified background noise during a specific percentage of experimental trials.

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See **hearing group**.

hydrophone

An underwater sound pressure transducer. A passive electronic device for recording or listening to underwater sound.

impulsive sound

Qualitative term meaning sounds that are typically transient, brief (less than 1 second), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile drivers.

isopleth

A line drawn on a map through all points having the same value of some quantity.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

manual analysis

Human examination of acoustic data via visual review of spectrograms and/or aural inspection of data.

manual detection

The output of **manual analysis** as recorded in an **annotation**.

masking

Obscuring of sounds of interest by sounds at similar frequencies.

median

The 50th percentile of a statistical distribution.

mid-frequency (MF) cetacean

See **hearing group**.

multiple linear regression

A statistical method that seeks to explain the response of a dependent variable using multiple explanatory variables.

M-weighting

See **auditory frequency weighting function** (as proposed by Southall et al. 2007).

N percent exceedance level

The sound level exceeded *N* % of the time during a specified time interval. Also see **percentile level**.

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

particle motion

See **sound particle motion**.

particle velocity

See **sound particle velocity**.

peak sound pressure level (zero-to-peak sound pressure level)

The level ($L_{p,pk}$ or L_{pk}) of the squared maximum magnitude of the sound pressure ($p_{\rm pk}^2$). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 µPa^2.

$$L_{p,\rm pk} := 10 \log_{10}\left(p_{\rm pk}^2/p_0^2\right) \,\mathrm{dB} \;= 20 \log_{10}\left(p_{\rm pk}/p_0\right) \,\mathrm{dB}$$

The frequency band and time window should be specified. Abbreviation: PK or Lpk.

peak-to-peak sound pressure

The difference between the maximum and minimum sound pressure over a specified frequency band and time window. Unit: pascal (Pa).

percentile level

The sound level not exceeded *N* % of the time during a specified time interval. The *N*th percentile level is equal to the (100−*N*)% exceedance level. Also see ***N* percent exceedance level**.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

phocid

A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

phocid pinnipeds in water (PPW)

See **hearing group**.

pinniped

A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

point source

A source that radiates sound as if from a single point.

power spectral density

Generic term, formally defined as power in a unit frequency band. Unit: watt per hertz (W/Hz). The term is sometimes loosely used to refer to the spectral density of other parameters such as squared sound pressure. ratio of **energy spectral density**, E_f, to time duration, Δt, in a specified temporal observation window. In equation form, the power spectral density P_f is given by:

$$P_f = \frac{E_f}{\Delta t}.$$

Power spectral density can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement).

power spectral density level

The level ($L_{P,f}$) of the **power spectral density** (P_f). Unit: decibel (dB).

$$L_{P,f} := 10 \log_{10}\left(P_f / P_{f,0}\right) \text{ dB} .$$

The frequency band and integration time should be specified.

As with **power spectral density**, power spectral density level can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement). The reference value ($P_{f,0}$) for power spectral density level depends on the nature of field variable.

power spectral density source level

A property of a sound source obtained by adding to the power spectral density level of the sound pressure measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^2/Hz.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure. Unit: pascal (Pa).

propagation loss (PL)

Difference between a source level (SL) and the level at a specified location, PL(x) = SL − L(x). Also see **transmission loss**.

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound **levels**, e.g., the reference value for expressing sound pressure level in decibels is 1 μPa.

Quantity	Reference value
Sound pressure	1 μPa
Sound exposure	1 μPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 μm/s^2

shear wave

A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called a secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

sensation level

Difference between the sound pressure level and hearing threshold at a specified frequency. Unit: decibel (dB).

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s.

$$L_E := 10 \log_{10}(E/E_0)\,\mathrm{dB} \;= 20 \log_{10}\left(E^{1/2}/E_0^{1/2}\right)\,\mathrm{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound exposure spectral density

Distribution as a function of frequency of the time-integrated squared sound pressure per unit bandwidth of a sound having a continuous spectrum. Unit: Pa^2 s/Hz.

sound field

Region containing sound waves.

sound intensity

Product of the sound pressure and the sound particle velocity. The magnitude of the sound intensity is the sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

sound particle acceleration

The rate of change of sound particle velocity. Unit: metre per second squared (m/s^2). Symbol: *a*.

sound particle motion

smallest volume of a medium that represents its mean physical properties.

sound particle displacement

Displacement of a material element caused by the action of sound, where a material element is the smallest element of the medium that represents the medium's mean density.

sound particle velocity

The velocity of a particle in a material moving back and forth in the direction of the pressure wave. Unit: metre per second (m/s). Symbol: *v*.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level

The level (L_p) of the time-mean-square sound pressure (p^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_p := 10\log_{10}\left(p^2 / p_0^2\right)\,\mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL .

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

soundscape

The characterisation of the ambient sound in terms of its spatial, temporal, and frequency attributes, and the types of sources contributing to the sound field.

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^2.

spectrogram

A visual representation of acoustic amplitude compared with time and frequency.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

thermocline

The depth interval near the ocean surface that experiences temperature gradients due to warming or cooling by heat conduction from the atmosphere and by warming from solar heating.

transmission loss (TL)

The difference between a specified level at one location and that at a different location, TL(x1,x2) = L(x1) − L(x2). Also see **propagation loss**.

unweighted

Term indicating that no frequency weighting function is applied. Synonymous with flat weighting.

validated detection

The output of an **automated detector** that has been subsequently validated by a human analyst.

very high-frequency (VHF) cetacean

See **hearing group**.

very low-frequency (VLF) cetacean

See **hearing group**.

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Appendix A. MV *Fugro Pioneer*

A.1. Vessel Datasheet

EQUIPMENT SHEET OFFSHORE SURVEY

FUGRO
M.V. FUGRO PIONEER

M.V. Fugro Pioneer has been built to the highest standards demanded of a modern internationally operating multi-purpose survey vessel.

The diesel electric propulsion, specially designed hull, resilient engine mounts and rudder propellers maximize station keeping and navigational control while ensuring acoustically quiet running at survey speeds.

Designed with consideration for safety and environment, Fugro Pioneer is a compact flexible platform supporting a wide range of offshore services with a typical operational profile of geophysical, geotechnical survey operations up to 1000m WD.

It's limited 3m draft adds to its capabilities to operate in shallow water nearshore. The vessel can easily be configured to support light ROV and environmental operations. The 53 metre-long vessel is prepared for dynamic positioning and equipped with state-of-the-art survey equipment.

State of the Art Kongsberg Dual Head Dual Ping Multibeam in retractable moonpool system.

Limited draft makes it specifically suitable for survey nearshore.

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EQUIPMENT SHEET OFFSHORE SURVEY

M.V. FUGRO PIONEER

Technical specifications

General info

Name	Fugro Pioneer
Classification society	DNVGL
Flag state / Port	Bahamas Maritime Authority / Nassau
Build(er)	September 2014 – Damen Shipyards Galati
IMO / Call sign	9701645 / C6BH3
Official Number	7000674

Dimensions

LOA.	53.7 m
Beam	12.5 m
Draught (summer) max.	3.1 m + 0.26 m blister
Tonnage	1322T
Deck area aft	250 m²
Deck strength	5T / m²
Deck load	81,6T

Accommodation

Cabins	30+4 Bunks / 10x Single cabins, 10x Double cabins
Crew (Typical)	11x Marine Crew, 20x Survey Crew
Recreational	1x Dayroom, 1x Gym
Work Offices	2x Survey, 1x Meeting room

Machinery

Propulsion	2x Azimuth thrusters (electric)
Bow thrusters	1x Tunnel thrusters (electric)
Cruising speed	10 kn
Survey speed	Variable as required
Maximum speed	11.2 kn

Electrical power

Diesel generator sets	4x 372 kW
UPS supply survey	1x 30VA, 220vac

Capacities

Fuel capacity	305 m³
Fuel consumption (FOC l/day)	Survey 3t / Stationary (DP) 4.2t / Transit 6t
Potable water capacity	115 m³
Water making	6 m³/d

Control and navigation

DP System	Imtech DP-0
Radar	Fagenuk Bridgemaster FT CAT1/2 S-band and X-band
Electronic chart	Imtech ECDIS (Single)
DGPS	1x Koden KGP920 / 2x Fugro Starpack
Magnetic compass	Sperry Jupiter

Deck Machinery

Deck crane aft	Palfinger PK65002 MD
Storage crane forward	Palfinger PK15000 MC
Hydraulics Ring Main system	300 bar / 200 ltr.
A-frame aft (geophysical)	2x 3/6T SWL
A-frame side (geotechnical)	1x 9T SWL
CTD winch/davit	1x 300 kg / 1000 m (environmental sampling)
Tugger winch aft deck	4x 3T SWL
Moonpool	Rectangular 1630x883 mm (free space)

Communications

GMDSS	Motorola - 3x VHF Handheld
Vsat	2x Seatel 5009 Ku-band
Iridium	Iridium Openport (Fall back)
UHF / VHF Radios (Operational coms)	Motorola - 2x VHF Handheld / 3x UHF Mobile / 9x UHF Portable
CCTV Camera system	Orlaco
TVRO	Intellian t40W

Safety

MOB boat	RIB
Life rafts	6 x 20 persons
Survival suits & Life jackets	44 pcs
Lifeline Pulley System	Yes
Personal Locator Beacons (PLB)	SeaMarshall

Survey equipment

DGPS Positioning	Fugro Starfix Starpacks
Navigation package	Fugro Starfix Suite
Acoustic positioning	Kongsberg HiPap 501 incl Cymbal
Motion Reference Unit	Hydrins + Octans
Echosounder	Simrad EA400
Draft monitoring	2x Rosemount Pressure Sensors
Multibeam Echosounder	Kongsberg Maritime EM 2040 (Dual head/ Dual ping)
Side Scan Sonar	Edgetech 4200 (100/600)
Sub Bottom Profiler	Hullmount Array/ Fugro Glog, Boomer, Sparker
Magnetometer	Geometrics G-882
Geophysical tow winch	2x EMCE (3.5Te/ 4000 m/ Rochester)
Geotechnical hoisting winch	1x EMCE (9Te/ 1500 m/ 19 mm)
Seismic Compressor	Wartsila Water Systems Ltd Hamworthy 185E MK2
2D-Seismic gear	as required
Geotechnical sampling	as required
Environmental sampling	as required

Fugro N.V.
Veurse Achterweg 10
2264 SG, Leidschendam
The Netherlands
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Email: offshoresurvey@fugro.com
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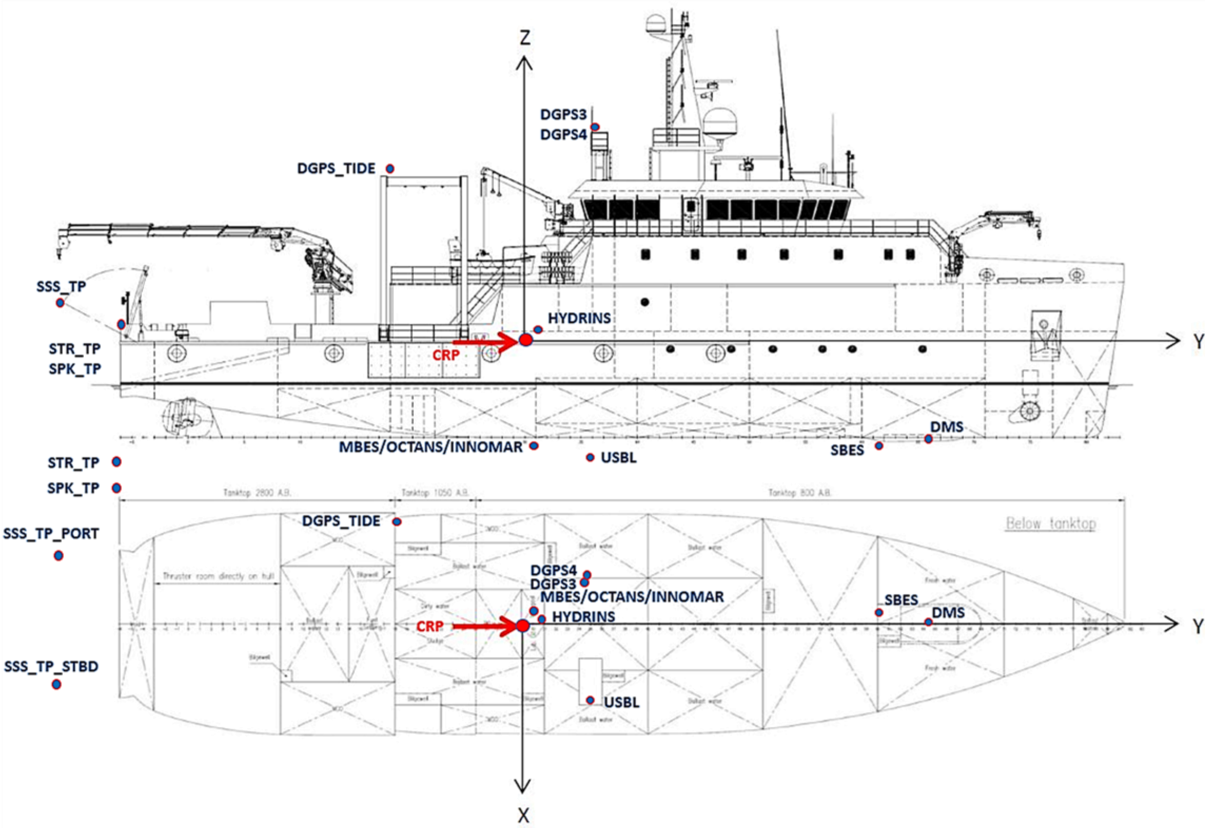
A.2. Sources Locations



Appendix B. Recorders Calibration

B.1. Pre-shipment Calibrations

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Please return if found.

CALIBRATION LOG

Doc# 00191

Calibration Type: MOB

Recorder Type: AMAR G4 | Board/Recorder S/N: 826 | Unit S/N: 621

Date YYYY-MM-DD	Cal performed by	Location	PM	Alternate PM
2021-08-16	S. Fenton	Dartmouth Office		

Project #	Project Name	Project Site (link)	PM	Alternate PM
P001631-001	2021 Energy Island Denmark SSV	https://jascoweb.jasco.com/Projec	Federica Pace	N/A

Rec Firmware Ver.	Cal Model	Cal Kit #	Cal S/N	Air Temp (°C)	Recorder Temp (°C)
2.4.9	42AC	16	364724	23.5	23.5

Amb Pressure Source	Amb Press Source S/N	Ambient Press (hPA)	Calibration file(s) path:
Lab Baro	160754626	1013	\\jso-dmfs02\Products\AMAR\mobilizations\EnergyIslandDenmarkSS

Conditions	H-phone Model:	M36-V35-900	M36-V0-901						
	H-phone S/N:	G000311	G000462						
	Paired HEC S/N:	HEC-254	HEC-341						
	Channel:	1	2	3	4	5	6	7	8
	Channel Gain (dB):	13.98	13.98						
	Channel Resolution (bit):	24-bit	24-bit	24-bit	24-bit	24-bit	24-bit	24-bit	24-bit
	Channel Sample Rate (sps):	256 ksps	256 ksps						
	H-phone FAT Sens @250 Hz (dBV):	-164.32	-219.22						
	H-phone Factory Sens @250 Hz (dBV):								
Results	Cal Start (UTC):	18:06:23	18:08:57						
	Cal Stop (UTC):	18:08:23	18:10:57						
	System Gain @250 Hz (dB re FS/µPa):	-163.40	-218.70						
	H-phone Sens @250 Hz (dB re 1 V/µPa):	-164.32	-219.62	13.06	13.06	13.06	13.06	13.06	13.06
	Digitization Gain (dB re FS/V):	-13.06	-13.06	-13.06	-13.06	-13.06	-13.06	-13.06	-13.06
	MOB/FQT H-phone Sens Check:	OK	OK	Questionable	Questionable	Questionable	Questionable	Questionable	Questionable
	FAT H-phone Sens Check:								
	SysGain Check:	OK	OK	OK	OK	OK	OK	OK	OK

[redacted]

NOTES:
2-1 voltage splitter cable HEC-659

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CALIBRATION LOG

Doc# 00191

				Calibration Type	MOB
Recorder Type:	AMAR G4	Board/Recorder S/N:	749	Unit S/N:	623

Date YYYY-MM-DD	Cal performed by	location		
2021-08-16	S. fenton	Dartmouth Office		
Project #	Project Name	Project Site (link)	PM	Alternate PM
P001631-001	2021 Energy Island Denmark SSV	https://jascoweb.jasco.com/Projec	Federica Pace	N/A

Rec Firmware Ver.	Cal Model	Cal Kit #	Cal S/N	Air Temp (°C)	Recorder Temp (°C)
2.4.9	42AC	16	364724	23.8	23.8
Amb Pressure Source	Amb Press Source S/N	Ambient Press (hPA)	Calibration file(s) path:		
Lab Baro	160754626	1013	\\iso-dmfs02\Products\AMAR\mobilizations\EnergyIslandDenmarkSS		

Conditions	H-phone Model:	M36-V35-900		M36-V0-901						
	H-phone S/N:	G000306		G000461						
	Paired HEC S/N:	HEC-173		HEC-217						
	Channel:	1		2	3	4	5	6	7	8
	Channel Gain (dB):	13.98		13.98						
	Channel Resolution (bit):	24-bit		24-bit	24-bit	24-bit	24-bit	24-bit	24-bit	24-bit
	Channel Sample Rate (sps):	256 ksps		256 ksps						
	H-phone FAT Sens @250 Hz (dBV):	-164.12		-219.62						
	H-phone Factory Sens @250 Hz (dBV):									
Results	Cal Start (UTC):	18:54:41		18:57:06						
	Cal Stop (UTC):	18:56:41		18:59:06						
	System Gain @250 Hz (dB re FS/µPa):	-163.50		-218.70						
	H-phone Sens @250 Hz (dB re 1 V/µPa):	-164.42		-219.62	13.06	13.06	13.06	13.06	13.06	13.06
	Digitization Gain (dB re FS/V):	-13.06		-13.06	-13.06	-13.06	-13.06	-13.06	-13.06	-13.06
	MOB/FQT H-phone Sens Check:	OK		OK	Questionable	Questionable	Questionable	Questionable	Questionable	Questionable
	FAT H-phone Sens Check:									
	SysGain Check:	OK		OK	OK	OK	OK	OK	OK	OK

[redacted]

NOTES:
2-1 Voltage splitter cable HEC-662

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CALIBRATION LOG

Doc# 00191

				Calibration Type	MOB
Recorder Type:	AMAR G4	Board/Recorder S/N:	806	Unit S/N:	624

Date YYYY-MM-DD	Cal performed by	location		
2021-08-17	S. Fenton	Dartmouth Office		
Project #	Project Name	Project Site (link)	PM	Alternate PM
P001631-001	2021 Energy Island Denmark SSV	https://jascoweb.jasco.com/Projec	Federica Pace	N/A

Rec Firmware Ver.	Cal Model	Cal Kit #	Cal S/N	Air Temp (°C)	Recorder Temp (°C)
2.4.9	42AC	16	364724	23.4	23.4
Amb Pressure Source	Amb Press Source S/N	Ambient Press (hPA)	Calibration file(s) path:		
Lab Baro	160754626	1015	\\iso-dmfs02\Products\AMAR\mobilizations\EnergyIslandDenmarkSS		

Conditions	H-phone Model:	M36-V35-900		M36-V0-900						
	H-phone S/N:	G000307		D000760						
	Paired HEC S/N:	HEC-427		HEC-266						
	Channel:	1		2	3	4	5	6	7	8
	Channel Gain (dB):	13.98		13.98						
	Channel Resolution (bit):	24-bit		24-bit	24-bit	24-bit	24-bit	24-bit	24-bit	24-bit
	Channel Sample Rate (sps):	256 ksps		256 ksps						
	H-phone FAT Sens @250 Hz (dBV):	-163.92		-200.74						
	H-phone Factory Sens @250 Hz (dBV):									
Results	Cal Start (UTC):	14:41:29		14:44:45						
	Cal Stop (UTC):	14:43:29		14:46:45						
	System Gain @250 Hz (dB re FS/µPa):	-163.30		-199.50						
	H-phone Sens @250 Hz (dB re 1 V/µPa):	-164.22		-200.42	13.06	13.06	13.06	13.06	13.06	13.06
	Digitization Gain (dB re FS/V):	-13.06		-13.06	-13.06	-13.06	-13.06	-13.06	-13.06	-13.06
	MOB/FQT H-phone Sens Check:	OK		OK	Questionable	Questionable	Questionable	Questionable	Questionable	Questionable
	FAT H-phone Sens Check:									
	SysGain Check:	OK		OK	OK	OK	OK	OK	OK	OK

[redacted]

NOTES:
2-1 voltage splitter cable HEC-660

B.2. On-board Calibrations

Each AMAR was calibrated before deployment and upon retrieval (battery life permitting) with a pistonphone type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S; Figure B-1). The pistonphone calibrator produces a constant tone at 250 Hz at a fixed distance from the hydrophone sensor in an airtight space with known volume. The recorded level of the reference tone on the AMAR yields the system gain for the AMAR and hydrophone. To determine absolute sound pressure levels, this gain was applied during data analysis. Typical calibration variance using this method is less than 0.7 dB absolute pressure.

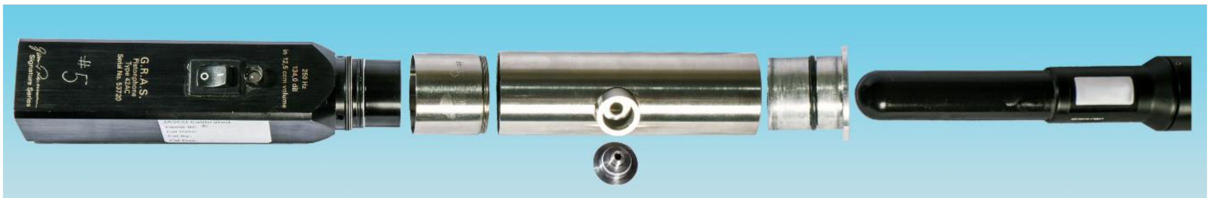

Figure B-1. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M36 hydrophone.

B.2.1. Station A: Deployment and Retrieval Logs

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AMAR Mooring Deployment Log

AcRelease Codes (record again to confirm)		Station	AMAR S/N
NA	NA	A	621

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	Fugro Pioneer	Rob, Calder, Misha, Vicky, Eduardino, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC: +2	Weather, sea state, drift bearing, etc.		

Equipment ID

AMAR S/N	IP Address	Battery Pack(s) S/N: Ch 22 V:	Ch 23 V:
621	192.168.88.5		

	Beacon	H-phone Chan 1	H-phone Chan 2
Model:		M36-V35-90	M36-V00-901
S/N:		G000311	G000462
Verified by:	Inits:	Inits:	Inits:

	AcRel 1	AcRel 2
Model:	N/A	N/A
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		
Verified by:	Inits:	Inits:

Record all dates and times in UTC.

Start

Rec Start yyyy-mm-dd	Rec Start Time (UTC)	Sync Event Time
2021-Sep-18	05:03:53	"

Calibration

* AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-16	10	42AC	43119
*Amb Pressure (hPa)	Pressure Sensor used (incl. S/N)		
1008.9	Ships Sensor		

	H-phone Chan 1	H-phone Chan 2
Tone Start (UTC):	Streaming	"
Tone Stop (UTC):	Streaming	"
CAL_GUI Rev. #:	46	"
² Deployment System Gain (dB re 1 µPa):	-164.0	-218.7
² Mobilization Sys Gain (dB re 1 µPa):	-163.4	-218.7
[+] Peak SPL clipping threshold (dB re 1 µPa):		
[–] Peak SPL clipping threshold (dB re 1 µPa):		

² Difference in Sys Gain between deployment and the mobilization should be < 0.75 dB.

Deployment

Deploy Date (UTC)	Water Depth	Units
2021-Sep-18	33.485	m
GPS S/N(s): DZ GPS	+ Ship Draft or n/a: 0	
	= Net Water Depth: 33.485	

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Proposed:	N/A	Multiple	Multiple		N/A
Controlled Drop Start:	07:35:30			019	N/A
Free Drop/ On Bottom:	07:37:40	56 32' 58.54" N	6 16' 13.00" E	020	N/A
Grapple Weight Drop:	07:49:28	56 32' 58. 61" N	6 16" 2.02" E	021	N/A

Note: while waypoints are provided, the lat and lon are from the ships Survey GPS/ sidescan run, and should be taken as the correct locations. On bottom (Easting northing) locations are: 332203.717 6270586.105, with reference 32N-EE21. confirm hydrophone one y+y, see video.

All required deck checks and deployment steps complete:

Note locations for multiple hydrophones here

All fields complete, as verified by (Inits):

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AMAR Mooring Retrieval Log

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Please return if found.

Confirmed Release Code(s)		Station	AMAR S/N
NA	NA	A	621

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	location	Vessel	Captain, Crew
RM CR	Denmark	*Fugro Pioneer*	Rob, Calder, Misha, Vicky, Eduardino, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC: +2	Weather, sea state, drift bearing, etc.: dark, 1.5m to 2 m lot of heave.		

Deployment

Record Start Date	Record Start Time	Deploy Date	Net Water Depth
2021-Sep-18	05:03:53	2021-Sep-18	33.485 m

	AcRel 1	AcRel 2
S/N:	NA	NA
RELEASE Code:		
Enable Code:		
Disable Code:		

	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Controlled Drop Start:			019	N/A
Free Drop/ On Bottom:	56 32' 58.54" N	6 16' 13.00" E	020	N/A
Grapple Weight Drop:	56 32' 58. 61" N	6 16" 2.02" E	021	N/A

Retrieval

Retrieve Date (UTC)	GPS S/N(s)
9/20/2021	DZ gps

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Release Code Sent:	"	"	"	"	"
Surfaced/End of Data:	04:16:45				
On deck:	04:40:17				

Calibration

*AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-20	10	42AC	43119

*Amb Pressure (hPa)	Ambient Pressure Source (incl. S/N)
1023.2	Ships sensor

	H-phone 1	H-phone 2
Tone Start (UTC):	Streaming	"
Tone Stop (UTC):	Streaming	"
CAL_GUI Rev. #:	46	"
²Retrieval System Gain (dB re 1 µPa):	-163.3	-218.3
²Mobilization System Gain (dB re 1 µPa):	-163.4	-218.7

² Difference in Sys Gain between retrieval and the mobilization should be < 1.0 dB. Retrieval cal required for M8 series hydrophones or as required by project.

Stop Time

² Actual stop time (UTC). ³ Stop time according to the AMAR clock.

Sync Event Time	²Record Stop, UTC	³Record Stop, AMAR
	04:49:05	"

Eqpmnt ID

AMAR S/N
621
Inits:

	H-phone Chan 1	H-phone Chan 2
Model:	M36-V35-900	M36-V00-901
S/N:	G000311	G000462
Verified by:	Inits:	Inits:

All fields complete, as verified by (Inits):

AMAR stopped, green dummy plug installed, pressure equalized, and PRV reset, as verified by (Inits):

B.2.2. Station B: Deployment and Retrieval Logs

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AMAR Mooring Deployment Log

AcRelease Codes (record again to confirm)		Station	AMAR S/N
NA	NA	B	623

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	Fugro Pioneer	Rob, Calder, Misha, Vicky, Eduardino, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC	Weather, sea state, drift bearing, etc.		
+2			

Equipment ID

AMAR S/N	IP Address	Battery Pack(s) S/N: Ch 22 V:	Ch 23 V:
623	192.168.99.5		

	Beacon	H-phone Chan 1	H-phone Chan 2
Model:		M36-V35-90	M36-V00-901
S/N:		G000306	G000461
Verified by:	Inits:	Inits:	Inits:

	AcRel 1	AcRel 2
Model:	N/A	N/A
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		
Verified by:	Inits:	Inits:

Start

Record all dates and times in UTC.

Rec Start yyyy-mm-dd	Rec Start Time (UTC)	Sync Event Time
2021-Sep-18	05:04:31	"

Calibration

* AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-16	10	42AC	43119
*Amb Pressure (hPa)	Pressure Sensor used (incl. S/N)		
1008.9	Ships Sensor		

	H-phone Chan 1	H-phone Chan 2
Tone Start (UTC):	Stream	"
Tone Stop (UTC):	Stream	"
CAL_GUI Rev. #	46	"
² Deployment System Gain (dB re 1 µPa):	-163.8	-218.8
² Mobilization Sys Gain (dB re 1 µPa):	-163.5	-218.7
[+] Peak SPL clipping threshold (dB re 1 µPa):		
[–] Peak SPL clipping threshold (dB re 1 µPa):		

² Difference in Sys Gain between deployment and the mobilization should be < 0.75 dB.

Deployment

Deploy Date (UTC)	Water Depth	Units
2021-Sep-18	32.99	m
GPS S/N(s)	+ Ship Draft or n/a	
DZ GPS	= Net Water Depth	
	32.99	

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Proposed:	N/A	Multiple	Multiple		N/A
Controlled Drop Start:	07:02:37			15	
Free Drop/ On Bottom:	07:04:30	56 32' 59.13" N	6 16' 18.8" E	16/17	
Grapple Weight Drop:	07:10:39	56 33' 0.29" N	6 16' 16.31" E	18	

Note: while gps points are provided the lat lons are from the ships survey gps, and are to be considered more correct. On bottom easting northing (32N-EE21) 332302.101 6270599.642. confirm phones on y+y see video.

All required deck checks and deployment steps complete:

Note locations for multiple hydrophones here

All fields complete, as verified by (Inits):

JASCO APPLIED SCIENCES

AMAR Mooring Retrieval Log

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Please return if found.

Confirmed Release Code(s)		Station	AMAR S/N
NA	NA	B	623

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	location	Vessel	Captain, Crew
RM CR	Denmark	*Fugro Pioneer*	Rob, Calder, Misha, Vicky, Eduardino, Malcolm, Vincenzo, Georgio, Eugenio

Local Time re UTC: +2

Weather, sea state, drift bearing, etc.: 2.1 m sig, 3.3m max 23kn breeze

Deployment

Record Start Date	Record Start Time	Deploy Date	Net Water Depth
2021-Sep-18	05:04:31	2021-Sep-18	32.99 m

	AcRel 1	AcRel 2
S/N:	NA	NA
RELEASE Code:		
Enable Code:		
Disable Code:		

	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Controlled Drop Start:			15	
Free Drop/ On Bottom:	56 32' 59.13" N	6 16' 18.8" E	16/17	
Grapple Weight Drop:	56 33' 0.29" N	6 16' 16.31" E	18	

Retrieval

Retrieve Date (UTC)	GPS S/N(s)
9/19/2021	DZ-GPS

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Release Code Sent:	"	"	"	"	"
Surfaced/End of Data:	06:32:20				
On deck:	06:47:36				

Calibration

*AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-19	10	42AC	43119

*Amb Pressure (hPa)	Ambient Pressure Source (incl. S/N)
1018.9	Ships Sensor

	H-phone 1	H-phone 2
Tone Start (UTC):	streaming	"
Tone Stop (UTC):	streaming	"
CAL_GUI Rev. #:	46	"
²Retrieval System Gain (dB re 1 µPa):	-163.3	-219.4
²Mobilization System Gain (dB re 1 µPa):	-163.5	-218.7

²Difference in Sys Gain between retrieval and the mobilization should be < 1.0 dB.
Retrieval cal required for M8 series hydrophones or as required by project.

Stop Time

²Actual stop time (UTC). ³Stop time according to the AMAR clock.

Sync Event Time	²Record Stop, UTC	³Record Stop, AMAR
	06:59:30	

Eqpmnt ID

AMAR S/N
623
Inits:

	H-phone Chan 1	H-phone Chan 2
Model:	M36-V35-900	M36-V00-901
S/N:	G000306	G000461
Verified by:	Inits:	Inits:

confirmed recording on retreival

All fields complete, as verified by (Inits):

AMAR stopped, green dummy plug installed, pressure equalized, and PRV reset, as verified by (Inits):

B.2.3. Station C: Deployment and Retrieval Logs

JASCO APPLIED SCIENCES

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AMAR Mooring Deployment Log

AcRelease Codes (record again to confirm)		Station	AMAR S/N
NA	NA	C	623

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns
JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	Fugro Pioneer	Calder Rob,
Local Time re UTC	Weather, sea state, drift bearing, etc.	2.1m sig 3.5m max 23kn wind	
+2			

Equipment ID

AMAR S/N	IP Address	Battery Pack(s) S/N: Ch 22 V:	Ch 23 V:
623	192.168.88.5		

	Beacon	H-phone Chan 1	H-phone Chan 2
Model:		M36-V35-90	M36-V00-901
S/N:		G000306	G000461
Verified by:	Inits:	Inits:	Inits:

	AcRel 1	AcRel 2
Model:	N/A	N/A
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		
Verified by:	Inits:	Inits:

Record all dates and times in UTC.

Start

Rec Start yyyy-mm-dd	Rec Start Time (UTC)	Sync Event Time
2021-Sep-19	07:32:53	

Calibration

* AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-19	10	42AC	43119
*Amb Pressure (hPa)	Pressure Sensor used (incl. S/N)		
1018.9	Ships sensor		

	H-phone Chan 1	H-phone Chan 2
Tone Start (UTC):	Streaming	
Tone Stop (UTC):	Streaming	
CAL_GUI Rev. #:	46	
² Deployment System Gain (dB re 1 µPa):	-163.3	-219.4
² Mobilization Sys Gain (dB re 1 µPa):	-163.5	-218.7
[+] Peak SPL clipping threshold (dB re 1 µPa):		
[-] Peak SPL clipping threshold (dB re 1 µPa):		

² Difference in Sys Gain between deployment and the mobilization should be < 0.75 dB.

Deployment

Deploy Date (UTC)	Water Depth	Units
2021-Sep-19	32.726	m
GPS S/N(s)	+ Ship Draft or n/a	
	0	
	= Net Water Depth	
DZ GPS	32.726	

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Proposed:	N/A	Multiple	Multiple		N/A
Controlled Drop Start:					
Free Drop/ On Bottom:	"	56 33' 1.04" N	6 16' 43.55" E	"	"
Grapple Weight Drop:	"	56 33' 0.59" N	6 16' 46.36" E	"	"

locations are provided by ship survey gps, on bottom sidescan locations are 32N-EE21 easting northing: 332714.607 6270648.711. confirm hydrophone on y+y.

All required deck checks and deployment steps complete:

Note locations for multiple hydrophones here

All fields complete, as verified by (Inits):

JASCO APPLIED SCIENCES

AMAR Mooring Retrieval Log

www.jasco.com Toll free: +1.866.825.2466
Please return if found.

Confirmed Release Code(s)		Station	AMAR S/N
NA	NA	C	623

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	location	Vessel	Captain, Crew
RM CR	Denmark	*Fugro Pioneer*	Rob, Calder, Misha, Vicky, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC: +2	Weather, sea state, drift bearing, etc.: 1.5 2m waves		

Deployment

Record Start Date	Record Start Time	Deploy Date	Net Water Depth
2021-Sep-19	07:32:53	2021-Sep-19	32.726 m

	AcRel 1	AcRel 2
S/N:	NA	NA
RELEASE Code:		
Enable Code:		
Disable Code:		

	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Controlled Drop Start:	"			
Free Drop/ On Bottom:	56 33' 1.04" N	6 16' 43.55" E	"	"
Grapple Weight Drop:	56 33' 0.59" N	6 16' 46.36" E	"	"

Retrieval

Retrieve Date (UTC)	GPS S/N(s)
9/20/2021	DZ GPS

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Release Code Sent:	"	"	"	"	"
Surfaced/End of Data:	05:13:32				
On deck:	05:25:27				

Calibration

*AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-20	10	42AC	43119
*Amb Pressure (hPa)	Ambient Pressure Source (incl. S/N)		
1028.2	Ships sensor		

	H-phone 1	H-phone 2
Tone Start (UTC):		
Tone Stop (UTC):		
CAL_GUI Rev. #:		
[2] Retrieval System Gain (dB re 1 µPa):	-163.7	-219.2
[2] Mobilization System Gain (dB re 1 µPa):	-163.5	-218.7

[2] Difference in Sys Gain between retrieval and the mobilization should be < 1.0 dB.
Retrieval cal required for M8 series hydrophones or as required by project.

Stop Time

[2] Actual stop time (UTC). [3] Stop time according to the AMAR clock.

Sync Event Time	[2] Record Stop, UTC	[3] Record Stop, AMAR
	05:51:56	

Eqpmnt ID

AMAR S/N
623
Inits:

	H-phone Chan 1	H-phone Chan 2
Model:	M36-V35-900	M36-V00-901
S/N:	G000306	G000461
Verified by:	Inits:	Inits:

Flasher SN V06-18 (Yellow Tape) not working

All fields complete, as verified by (Inits):

AMAR stopped, green dummy plug installed, pressure equalized, and PRV reset, as verified by (Inits):

B.2.4. Station D: Deployment and Retrieval Logs

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AMAR Mooring Deployment Log

AcRelease Codes (record again to confirm)		Station	AMAR S/N
NA	NA	D	624

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	Fugro Pioneer	Rob, Calder, Misha, Vicky, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC	Weather, sea state, drift bearing, etc.		
+2			

Equipment ID

AMAR S/N	IP Address	Battery Pack(s) S/N: Ch 22 V:	Ch 23 V:
624	192.168.88.5		

	Beacon	H-phone Chan 1	H-phone Chan 2
Model:		M36-V35-90	M36-V00-901
S/N:		G000307	D000760
Verified by:	Inits:	Inits:	Inits:

	AcRel 1	AcRel 2
Model:	N/A	N/A
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		
Verified by:	Inits:	Inits:

Record all dates and times in UTC.

Start

Rec Start yyyy-mm-dd	Rec Start Time (UTC)	Sync Event Time
2021-Sep-18	05:05:08	

Calibration

* AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-16	10	42AC	43119
*Amb Pressure (hPa)	Pressure Sensor used (incl. S/N)		
1008.9	Ships Sensor		

	H-phone Chan 1	H-phone Chan 2
Tone Start (UTC):	Streaming	"
Tone Stop (UTC):	Streaming	"
CAL_GUI Rev. #:	46	"
² Deployment System Gain (dB re 1 µPa):	-163.6	-200.0
² Mobilization Sys Gain (dB re 1 µPa):	-163.6	-199.5
[+] Peak SPL clipping threshold (dB re 1 µPa):		
[–] Peak SPL clipping threshold (dB re 1 µPa):		

² Difference in Sys Gain between deployment and the mobilization should be < 0.75 dB.

Deployment

Deploy Date (UTC)	Water Depth	Units
2021-Sep-18	31.878	m
GPS S/N(s)	+ Ship Draft or n/a	
DZ GPS	0	
	= Net Water Depth	
	31.878	

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Proposed:	N/A	Multiple	Multiple		N/A
Controlled Drop Start:	06:29:31	"	"	011	"
Free Drop/ On Bottom:	06:31:13	56 33' 2.58" N	6 16' 56.35" E	12/13	"
Grapple Weight Drop:	06:37:10	56 33' 3.51" N	6 16' 54.06" E	14	"

while waypoint number are provided, the lat and lon are from the ships gps and sidescan, and should be taken as the correct on. On bottom sidescan location are 32N-EE21 easting northing: 332952.533 6270678.967, confirm recording on deployent y+y

All required deck checks and deployment steps complete:

Note locations for multiple hydrophones here

All fields complete, as verified by (Inits):

JASCO APPLIED SCIENCES

AMAR Mooring Retrieval Log

www.jasco.com Toll free: +1.866.825.2466
Please return if found.

Confirmed Release Code(s)		Station	AMAR S/N
NA	NA	D	624

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	*Fugro Pioneer*	Rob, Calder, Misha, Vicky, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC: +2	Weather, sea state, drift bearing, etc.: 2.1m sig, 3.3m max 23kn breeze		

Deployment

Record Start Date	Record Start Time	Deploy Date	Net Water Depth
2021-Sep-18	05:05:08	2021-Sep-18	31.878 m

	AcRel 1	AcRel 2
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		

	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Controlled Drop Start:	"	"	011	"
Free Drop/ On Bottom:	56 33' 2.58" N	6 16' 56.35" E	12/13	"
Grapple Weight Drop:	56 33' 3.51" N	6 16' 54.06" E	14	"

Retrieval

Retrieve Date (UTC)	GPS S/N(s)
9/19/2021	DZ gps

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Release Code Sent:	"	"	"	"	"
Surfaced/End of Data:	05:45:04				
On deck:	05:57:52				

Calibration

*AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-19	10	42AC	43119
*Amb Pressure (hPa)	Ambient Pressure Source (incl. S/N)		
1018.9	Ships Sensor		

	H-phone 1	H-phone 2
Tone Start (UTC):	Streaming	"
Tone Stop (UTC):	Streaming	"
CAL_GUI Rev. #:	46	46
[1] Retrieval System Gain (dB re 1 µPa):	-163.7	-199.9
[1] Mobilization System Gain (dB re 1 µPa):	-163.6	-199.5

[1] Difference in Sys Gain between retrieval and the mobilization should be < 1.0 dB. Retrieval cal required for M8 series hydrophones or as required by project.

Stop Time

[2] Actual stop time (UTC). [3] Stop time according to the AMAR clock.

Sync Event Time	[2] Record Stop, UTC	[3] Record Stop, AMAR
	06:03:05	"

Eqpmnt ID

AMAR S/N
624
Inits:

	H-phone Chan 1	H-phone Chan 2
Model:	M36-V35-900	M36-V00-901
S/N:	G000307	D000760
Verified by:	Inits:	Inits:

confirmed recording on retreival, see vids.

All fields complete, as verified by (Inits):

AMAR stopped, green dummy plug installed, pressure equalized, and PRV reset, as verified by (Inits):

B.2.5. Station E: Deployment and Retrieval Logs

JASCO APPLIED SCIENCES

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AMAR Mooring Retrieval Log

Confirmed Release Code(s)		Station	AMAR S/N
NA	NA	E	624

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	*Fugro Pioneer*	Rob, Calder, Misha, Vicky, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC: +2	Weather, sea state, drift bearing, etc.		

Deployment

Record Start Date	Record Start Time	Deploy Date	Net Water Depth
2021-Sep-19	06:54:11	2021-Sep-19	32.449 m

	AcRel 1	AcRel 2
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		

	Lat (d° mm.mmm' N/S)	Lon (d° mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Controlled Drop Start:	"	"	"	"
Free Drop/ On Bottom:	56 33' 9.09" N	6 18' 8.97" E	"	"
Grapple Weight Drop:	56 33' 8.76" N	6 18' 12.27" E	"	"

Retrieval

Retrieve Date (UTC)	GPS S/N(s)
9/20/2021	DZ GPS

	Time (UTC)	Lat (d° mm.mmm' N/S)	Lon (d° mm.mmm' E/W)	GPS Waypoint	GPS Accuracy(m)
Release Code Sent:	"	"	"	"	"
Surfaced/End of Data:	05:57:02				
On deck:	06:04:40				

Calibration

*AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-20	10	42AC	43119
*Amb Pressure (hPa)	Ambient Pressure Source (incl. S/N)		
1028.2	Ships Sensor		

	H-phone 1	H-phone 2
Tone Start (UTC):	Streaming	"
Tone Stop (UTC):	Streaming	"
CAL_GUI Rev. #:	46	"
²Retrieval System Gain (dB re 1 µPa):	-163.5	-200.2
²Mobilization System Gain (dB re 1 µPa):	-163.6	-199.5

² Difference in Sys Gain between retrieval and the mobilization should be < 1.0 dB.
Retrieval cal required for M8 series hydrophones or as required by project.

Stop Time

² Actual stop time (UTC). ³ Stop time according to the AMAR clock.

Sync Event Time	² Record Stop, UTC	³ Record Stop, AMAR
	06:10:46	

Eqpmnt ID

AMAR S/N	
624	Inits:

	H-phone Chan 1	H-phone Chan 2
Model:	M36-V35-900	M36-V00-901
S/N:	G000307	D000760
Verified by:	Inits:	Inits:

All fields complete, as verified by (Inits):

AMAR stopped, green dummy plug installed, pressure equalized, and PRV reset, as verified by (Inits):

JASCO APPLIED SCIENCES

www.jasco.com Toll free: +1.866.825.2466
Please return if found.

AMAR Mooring Deployment Log

AcRelease Codes (record again to confirm)		Station	AMAR S/N
NA	NA	E	624

General

Project #	Project Name	Project Manager (PM)	Alternate PM
P001631-001	Fugro Energy Island SSC	Federica Pace	Robin Burns

JASCO Team (Inits)	Location	Vessel	Captain, Crew
RM CR	Denmark	Fugro Pioneer	Rob, Calder, Misha, Vicky, Malcolm, Vincenzo, Georgio, Eugenio
Local Time re UTC	Weather, sea state, drift bearing, etc.	2.1m 3.3m waves 23 kn wind	
+2			

Equipment ID

AMAR S/N	IP Address	Battery Pack(s) S/N: Ch 22 V:	Ch 23 V:
624	192.168.88.5		

	Beacon	H-phone Chan 1	H-phone Chan 2
Model:		M36-V35-90	M36-V00-901
S/N:		G000307	D000760
Verified by:	Inits:	Inits:	Inits:

	AcRel 1	AcRel 2
Model:	N/A	N/A
S/N:		
RELEASE Code:		
Enable Code:		
Disable Code:		
Verified by:	Inits:	Inits:

Start

Record all dates and times in UTC.

Rec Start yyyy-mm-dd	Rec Start Time (UTC)	Sync Event Time
2021-Sep-19	06:54:11	

Calibration

* AMBIENT pressure, which is the direct measurement, not barometric pressure.

Cal Date (UTC)	Calibrator Kit #	Calibrator Model	Calibrator S/N
2021-Sep-19	10	42AC	43119
*Amb Pressure (hPa)	Pressure Sensor used (incl. S/N)		
1018.9	Ships Sensor		

	H-phone Chan 1	H-phone Chan 2
Tone Start (UTC):	Stream	"
Tone Stop (UTC):	Stream	"
CAL_GUI Rev. #:	46	"
² Deployment System Gain (dB re 1 µPa):	-163.7	-199.9
² Mobilization Sys Gain (dB re 1 µPa):	-163.6	-199.5
[+] Peak SPL clipping threshold (dB re 1 µPa):		
[–] Peak SPL clipping threshold (dB re 1 µPa):		

² Difference in Sys Gain between deployment and the mobilization should be < 0.75 dB.

Deployment

Deploy Date (UTC)	Water Depth	Units
2021-Sep-19	32.449	m
GPS S/N(s)	+ Ship Draft or n/a	
DZ gps	0	
	= Net Water Depth	
	32.449	

	Time (UTC)	Lat (d°mm.mmm' N/S)	Lon (d°mm.mmm' E/W)	GPS Waypoint	GPS Accuracy (m)
Proposed:	N/A	Multiple	Multiple		N/A
Controlled Drop Start:	"	"	"	"	"
Free Drop/ On Bottom:	"	56 33' 9.09" N	6 18' 8.97" E	"	"
Grapple Weight Drop:	"	56 33' 8.76" N	6 18' 12.27" E	"	"

GPS points are from ship survey gps + sidescan, on bottom location in easting northings 32N-EE21: 334199.553 6270841.325. confirm recording on deployment y+y.

All required deck checks and deployment steps complete:

Note locations for multiple hydrophones here

All fields complete, as verified by (Inits):

B.3. M36 900 Hydrophone

GeoSpectrum Technologies Inc.
Customizing Detection

M36-900

The M36-900 is a wide-band omni-directional hydrophone designed for marine observation. It comes with a pre-amplified output of 0 to 35 dB (selectable on order) with current or voltage signalling.

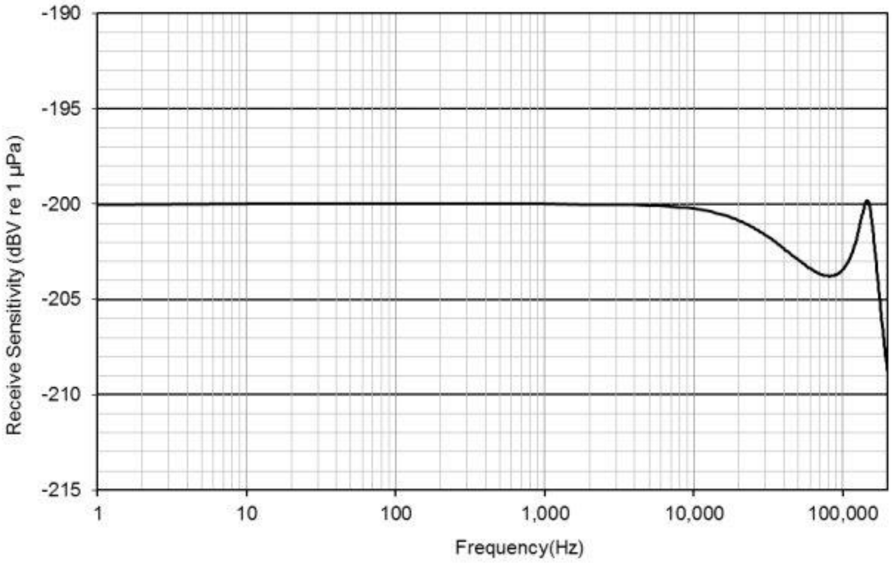
Characteristics	
Nominal Voltage Sensitivity (without preamp)	-200 dBV re 1 µPa @ 20°C
Size	7.8" length, 1.3" max OD
Depth Rating	900m
Storage and Operating Temperatures	-40 to +70°C
Acceleration Sensitivity	<1.5 mbar/g, in air, any axis
Labelling	Calibration parameters, serial number, date
Connector	MCBH-8M
Pre-Amplifier	
Preamp signalling	Current, single ended voltage or, differential voltage (selectable on order)
Gain	0 – 35 dB (selectable on order)
Input Voltage	6.8 VDC nominal 4.5 – 30 VDC operating range
Band Pass	5 Hz HPF, no LPF installed (unless otherwise specified)
IRN	<30 nV/√Hz @10 Hz <4 nV/√Hz @1 kHz
Current Draw	1.3 mA (at 6.8 VDC) 4.2 mA with current signalling preamp

ADDRESS:
10 Akerley Blvd., Unit 19
Dartmouth, NS
Canada B3B 1J4

M36-900-08-17-v4

Phone: 902.406.4111
Fax: 902.435.8987
website: www.geospectrum.ca
e-mail: sales@geospectrum.ca

GeoSpectrum Technologies Inc.
Customizing Detection



M36 Frequency Response (without preamp)

ADDRESS:
10 Akerley Blvd., Unit 19
Dartmouth, NS
Canada B3B 1J4

M36-900-08-17-v4

Phone: 902.406.4111
Fax: 902.435.8987
website: www.geospectrum.ca
e-mail: sales@geospectrum.ca

Appendix C. Acoustic Data Analysis Methods

The data sampled at 256 kHz was processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal vocalizations. This section describes the ambient, vessel, and marine mammal detection algorithms employed (Figure C-1).

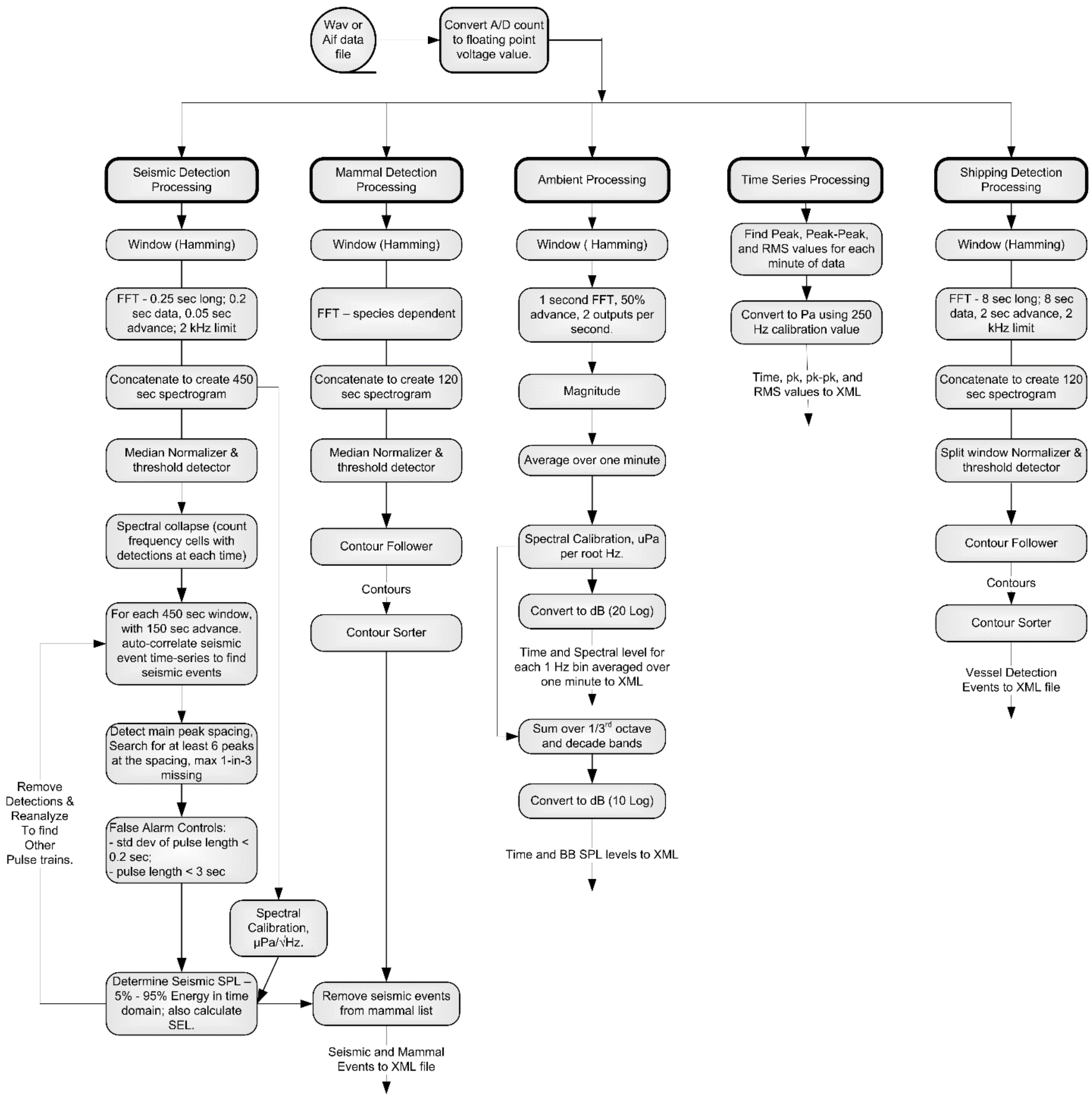


Figure C-1. Major stages of the automated acoustic analysis process performed with JASCO's custom software suite.

C.1. Total Ambient Sound Levels

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially impulsive noise such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on marine life. We provide specific definitions of relevant metrics used in this report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The zero-to-peak pressure level, or peak pressure level (PK or $L_{p,pk}$; dB re 1 μPa), is the decibel level of the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, $\mathrm{p}(\mathrm{t})$:

$$\mathrm{PK} = L_{p,\mathrm{pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} \tag{C-4}$$

PK is often included as criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a noise event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or L_p; dB re 1 μPa) is the decibel level of the mean-square pressure in a stated frequency band over a specified time window (T; s) containing the acoustic event of interest. It is important to note that SPL always refers to an mean square pressure level and therefore not instantaneous pressure:

$$\mathrm{SPL} = L_p = 10\log_{10}\left[\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right] \tag{C-5}$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed duration. Because the window length, *T*, is the divisor, events with similar sound exposure level (SEL), but more spread out in time have a lower SPL.

The sound exposure level (SEL or L_E, dB re 1 μPa^2 s) is a measure related to the acoustic energy contained in one or more acoustic events (N). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T):

$$\mathrm{SEL} = L_E = 10\log_{10}\left[\int_T p^2(t)\,dt \Big/ T_0 p_0^2\right] \tag{C-6}$$

where T_0 is a reference time interval of 1 s. The SEL continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over periods with multiple events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \tag{C-7}$$

To compute the SPL(T_{90}) and SEL of acoustic events in the presence of high levels of background noise, equations C-4 and C-5 are modified to subtract the background noise contribution:

$$\mathrm{SPL}(T_{90}) = L_{p90} = 10\log_{10}\left[\frac{1}{T_{90}}\int_{T_{90}}\left(p^2(t)-\overline{n^2}\right)dt\Big/p_0^2\right] \quad \text{(C-8)}$$

$$L_E = 10\log_{10}\left[\int_{T}\left(p^2(t)-\overline{n^2}\right)dt\Big/T_0p_0^2\right] \quad \text{(C-9)}$$

where $\overline{\mathrm{n}^2}$ is the mean square pressure of the background noise, generally computed by averaging the squared pressure of a temporally proximal segment of the acoustic recording during which acoustic events are absent (e.g., between pulses).

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \quad \text{(C-10)}$$

$$L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458 \quad \text{(C-11)}$$

where the 0.458 dB factor accounts for the 10% of SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $\mathrm{p(t)}$, over the same period of time, T:

$$L_{\mathrm{eq}} = 10\log_{10}\left[\frac{1}{T}\int_{T} p^2(t)\,dt\Big/p_0^2\right] \quad \text{(C–12)}$$

The equations for SPL and the energy-equivalent SPL are numerically identical; conceptually, the difference between the two metrics is that the former is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over times typically of one minute to several hours.

C.2. One-third-octave-band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. These values directly compare to the Wenz curves, which represent typical deep ocean sound levels (Figure 2) (Wenz 1962). This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analysing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into 1/3-octave-bands, which are one tenth of a decade (approximately one-third of an octave) wide. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the *i*th 1/3-octave-band, $\mathrm{f_c(i)}$, is defined as:

$$f_\mathrm{c}(i) = 10^{\frac{i}{10}}\,\mathrm{kHz} \qquad \text{(C-1)}$$

and the low (flo) and high (fhi) frequency limits of the *i*th 1/3-octave-band are defined as:

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_\mathrm{c}(i) \quad \text{and} \quad f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_\mathrm{c}(i) \qquad \text{(C-2)}$$

The 1/3-octave-bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure C-2).

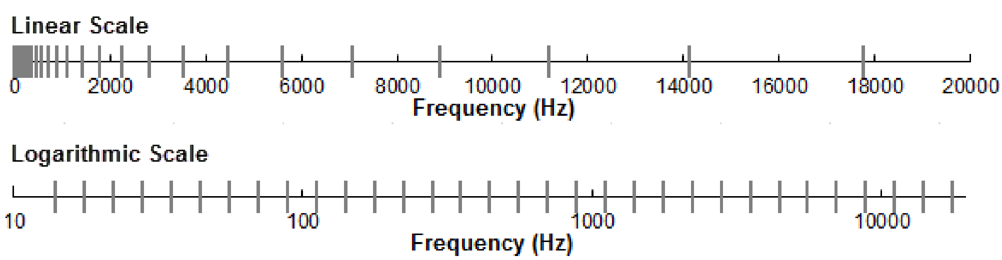


Figure C-2. One-third-octave frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the *i*th band ($\mathrm{L_{p,i}}$) is computed from the spectrum $\mathrm{S(f)}$ between $\mathrm{f_{lo,i}}$ and $\mathrm{f_{hi,i}}$:

$$L_{\mathrm{p},i} = 10\log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\,\mathrm{d}f \;\; \mathrm{dB} \qquad \text{(C-13)}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10} \sum_i 10^{\frac{L_{p,i}}{10}}\,\mathrm{dB} \qquad \text{(C-14)}$$

Figure C-3 shows an example of how the 1/3-octave-band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the 1/3-octave-bands are wider than 1 Hz, the 1/3-octave-band SPL is higher than the spectral levels, especially at higher frequencies. One-third-octave-band analysis is applied to continuous and impulsive noise sources. For impulsive sources, the 1/3-octave-band SEL is typically reported.

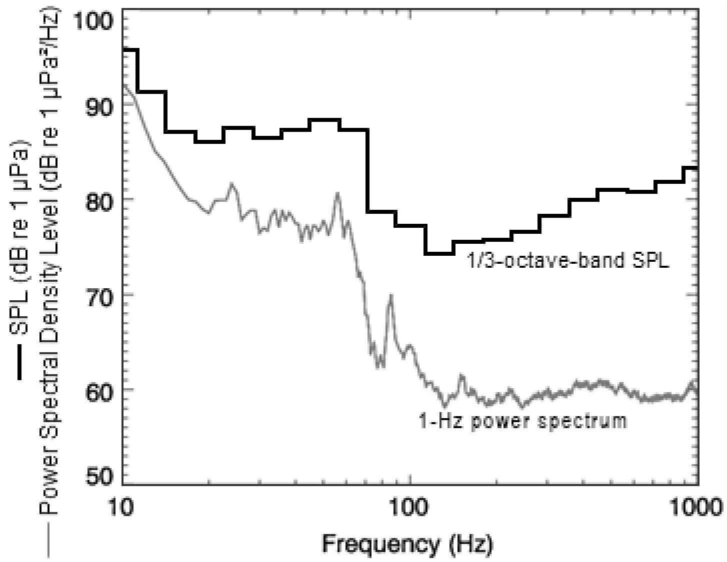


Figure C-3. Sound pressure spectral density levels and the corresponding 1/3-octave-band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

Table C-1. One-third-octave-band frequencies (Hz).

Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2
11	11.2	12.6	14.1
12	14.1	15.8	17.8
13	17.8	20.0	22.4
14	22.4	25.1	28.2
15	28.2	31.6	35.5
16	35.5	39.8	44.7
17	44.7	50.1	56.2
18	56.2	63.1	70.8
19	70.8	79.4	89.1
20	89.1	100.0	112.2
21	112	126	141
22	141	158	178
23	178	200	224
24	224	251	282
25	282	316	355
26	355	398	447
27	447	501	562
28	562	631	708
29	708	794	891

30	891	1000	1122
31	1122	1259	1413
32	1413	1585	1778
33	1778	1995	2239
34	2239	2512	2818
35	2818	3162	3548
36	3548	3981	4467
37	4467	5012	5623
38	5623	6310	7079
39	7079	7943	8913
40	8913	10000	11220
41	11220	12589	14125

Appendix D. Sources Technical Specifications

D.1. Sparker Source

Geophysical Services Offshore

GSO 360 Tip
Sparker Source

GSO BV
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The Netherlands

INTRODUCTION

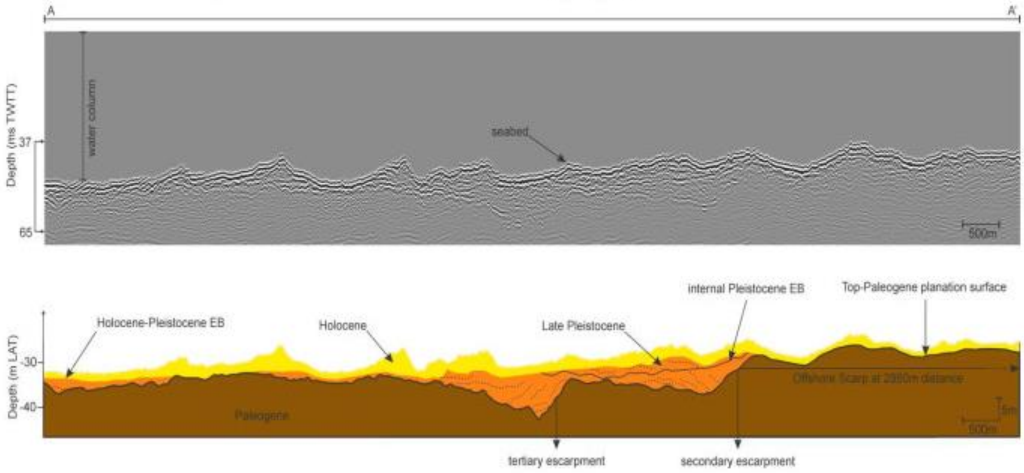
The GSO-360 is a member of the latest generation of GSO sparker energy sources. GSO sparkers are based on proven technology. Our sparkers were developed in-house to support the ever changing requirements of clients who continually seek to acquire better quality data sets and more cost effective acquisition. The GSO sparker range is manufactured and built in The Netherlands and currently consists of the following models: GSO-120FW, GSO-180, GSO-360, GSO-540 and GSO-720.

With the GSO-360 sparker you will be able to acquire very high resolution (<30 cm) seismic profiles of the "shallow" sub bottom strata in water depths up to 1000 m. Depending on the energy level, the geology and water depth, the effective penetration can exceed 200 m below seabed.

The GSO-360 sparker has proven to be a very stable and repeatable energy source. When combined with the GSO 24 element single channel mini streamers, the GSO-360 can be used as a reliable and low maintenance energy source. The same proven characteristics allows the GSO-360 to be used as a very high resolution acoustic source for multi-channel operations for which is has become very successful. The GSO-360 is fast becoming the preferred tool to use by clients predominantly for windfarms and sub-sea engineering surveys that require 2D UHR multi-channel operations.

Complete GSO-360 sparker system with HV tow cable, HV junction box and CSP-N Power Supply.

GSO-360 sparker on the back deck, ready for deployment.



***Example of VHR Single-Channel Seismic Data** (courtesy of RCMG Ghent University)*

The above data set was acquired in 2015 by the Renard Centre of Marine Geology (RCMG), Department of Geology and Soil Science, during a project to compare and evaluate various acoustic seismic sources. The above example depicts two previously undiscovered river terraces found during the survey. The origin of these terraces is likely to be found in the scouring effects of the Rhine and/or Meuse rivers from the Netherlands during sea-level lowering.

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03-2018

Geophysical Services Offshore

GSO 360 Tip Sparker Source

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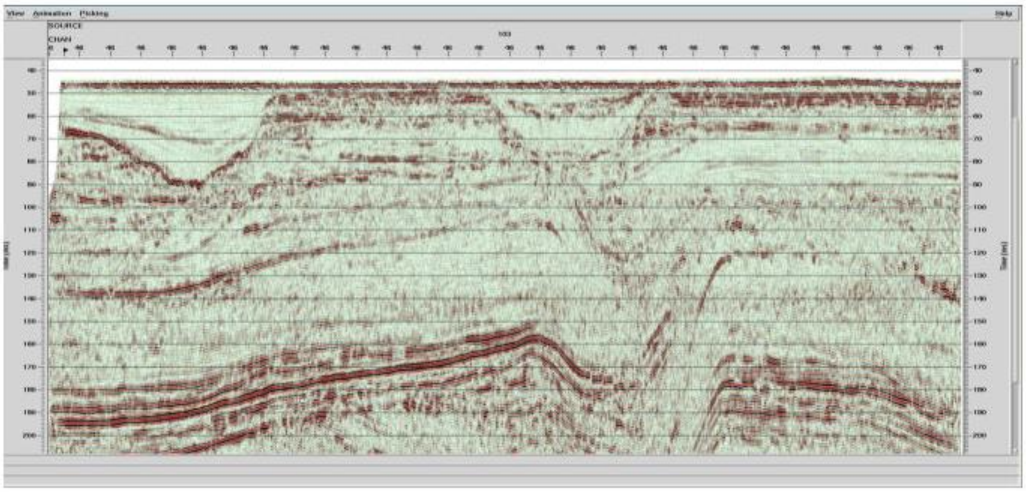
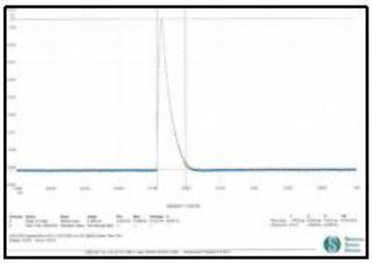


Example Multi-Channel 2D UHR Seismic Data.

The above UHR data set was acquired and processed in 2014 by GSO BV. Data was acquired with a GSO-360 sparker source at an energy setting of a 1000 Joules. The receiver was a 24 channel, 3.125 group interval seismic cable. Full fold data was acquired using a shot point interval of 1.562 metres over the ground. (Location: North Sea).

FEATURES



Negative Polarity Mode

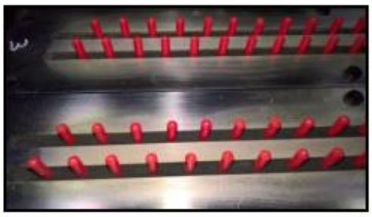
The GSO-360 sparker has been designed for operation with any 3rd party negative polarity power supply. This concept consists of using a NEGATIVE electric pulse, instead of a positive electric pulse.

Note: working with a negative electric pulse is NOT the same thing as reversing the polarity of a conventional power supply, which generates a positive pulse.

Example GSO-360 / 500Joules Electrical pulse test: note the sharp pulse rise giving an average pulse width of 170 µS

Zero Electrode Wear

By working in negative polarity mode the GSO-360 reduces the electrode tip wear to practically zero. Therefore once the GSO-360 has been deployed, data acquisition can continue without the need to retrieve the sparker once or twice a day in order to maintain the tips. This feature, unlike other standard sparker sources, makes the GSO-360 sparker an extremely low maintenance source to operate and saves the client hours on non-productive vessel time.



Enhanced Acoustic Repeatability

Near zero tip wear is essential for the repeatability of the acoustic pulse, which depends largely on a constant, unaltered electrode surface.

These GSO electrodes were fired approximately 4,000,000 times (almost continuously) during a project in 2016. Note the absolute minimum wear to the electrode tips.

GEOPHYSICAL SERVICES OFFSHORE

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GSO 360 Tip Sparker Source

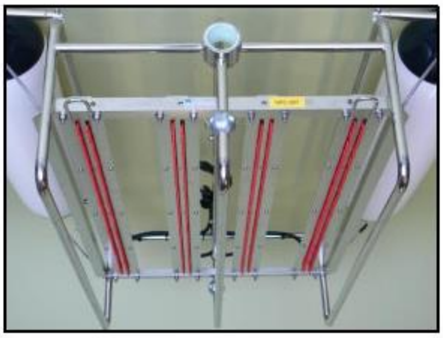
User determined Sparker Parameters

The simple design of the GSO 360-sparker provides the user total control of all the relevant sparker parameters such as depth, amount of Joules/tip and geometry. Electrode configurations can be changed without retrieving the sparker by means of a HV junction box located between the HV tow cable and HV power supply unit.

Depth of the source

The effective depth of the source in the water can be controlled by means of the two floats positioned on out riggers on either side of the sparker frame by adjusting the angle of the riggers. This feature is used to adjust the depth in order to optimise the constructive interference between the primary pulse and surface ghost.

GSO-360 Sparker; front view.



Joules/tip

Four individually connected electrode modules of 90 tips each allows the energy from the HV power supply unit to be distributed evenly over 90, 180, 270 or 360 tips. In addition power settings can be adjusted on the HV power supply unit ranging from 50 to 2400 Joules.

GSO-360 Sparker; view from below.

Electrode Configuration

The electrode modules are evenly spaced in a planar array. This geometry along with the design of the GSO electrode modules enhances the downward projection of the acoustic energy. It also reduces the primary pulse length since all tips are perfectly in phase.

The GSO-360 sparker consists of 4 x 90 tip electrode modules housed in a compact sparker frame and comes with a standard GSO 60m HV tow cable. Other cable lengths are available upon request.

GSO High Voltage Tow Cable

The HV tow cable is specially manufactured for GSO and has a double insulation jacket and an integrated Aramide braid (BS 2000daN). The power is conducted via 4 x 6mm^2 cores (class 6) and a 25 mm^2 braiding (ground referenced). It is designed to have a very low self-inductance in order to preserve the dI/dt pulse output of the negative polarity power supplies. The coaxial design of the GSO HV tow cable also minimises the EMI (electromagnetic magnetic interference) effects.

The final cable build and connector terminations are completed at the GSO workshops in Rotterdam. The High voltage connectors used are universal and therefore the same HV tow cable can be used with different GSO sparker systems, negating the need to carry different HV cables or inline adaptors for different sources. On board it takes less than 2 minutes to change out GSO sparkers.

Universal HV connectors.

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GSO 360 Tip Sparker Source

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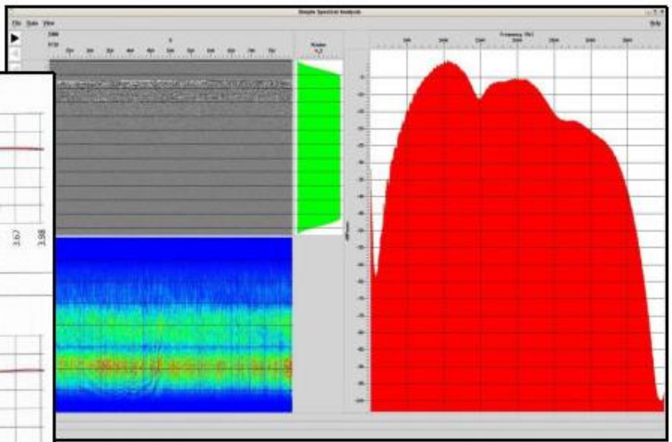
The length of the standard supplied HV cable is 60m, however cables of 40m, 50m or 90m are also available. Other HV tow cable lengths can be built upon request.

High Voltage Power Supply Units

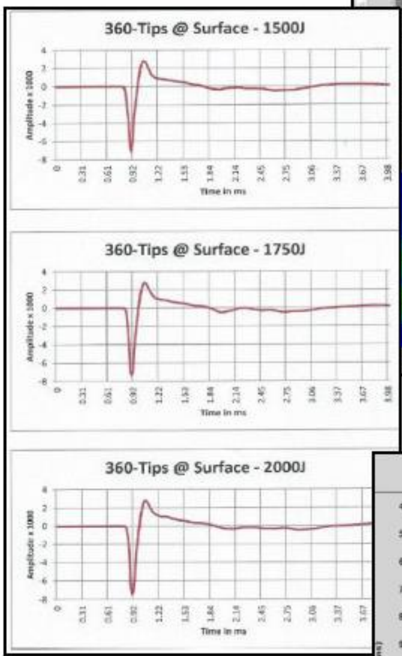
Typically GSO BV supplies the GSO-360 sparker with the Applied Acoustics CSP-N series power supply, however other suitable units are available. The GSO-360 is connected to the PSU via the HV tow cable and junction box. The junction box enables the user to connect/disconnect electrode modules without the need to retrieve the GSO-360 sparker.

Additionally if required a UPS system can be supplied to eliminate possible variations in the mains input power supply. (As shown on top of the Applied Acoustics CSP-N power unit).

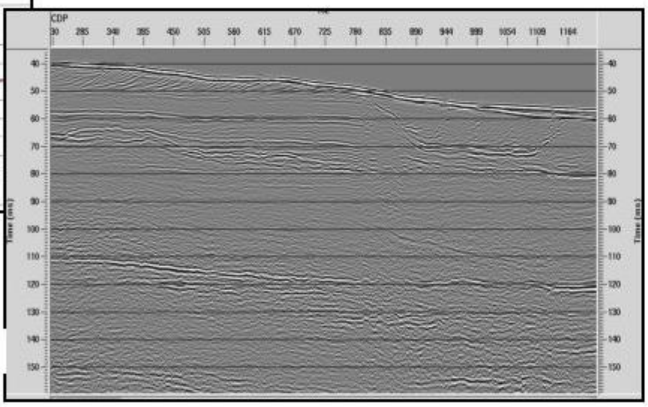
Applied Acoustics CSP-N series HV power supply with UPS unit (on top) and connected HV Junction Box (in front).



Example Spectral Analysis (GSO-360)



Example GSO-360 Pulse Signatures



GSO-360 Data Example

Geophysical Services Offshore

GSO 360 Tip Sparker Source

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SPECIFICATIONS

GSO-360 sparker

Design	:	Marine quality stainless steel (316) Electrically pacified c/w aluminium protection anodes
Dimensions	:	L x W x H = 109 x 75 x 43 cm
Overall Weight	:	46.5 kg
Shipping	:	Standard Euro pallet/plastic container 100 x 120 x 80 cm
Array Depth	:	Adjustable from 20 cm to 50 cm below surface
Array Geometry	:	Planar configuration of 75cm x 100cm for enhanced downward projection of acoustic energy
Number of Tips	:	Number of active Electrode Modules 1-4 corresponding to 90, 180, 270 or 360 tips
Energy Level	:	Recommended max energy per tip in negative polarity mode:- 5.5 Joule/tip (i.e. 2000 Joules)
Standard Configuration	:	4 x 90 tip electrode modules.
Primary Pulse Length	:	Around 0.2 ms
Dominant Frequencies	:	Between 200 - 3000 Hz, depending on the selected energy level & tips

HV Tow Cable

Design	:	Coaxial HV cable, Aramide braid reinforced, double insulated and LOW EM emission
Tested	:	5600 Volts pulsed (100-200 microseconds)
Material/Colour	:	High quality Polyurethane (HFS 100), orange
Outer Diameter	:	30 mm
Bending Radius	:	400 mm
Weight	:	1.10 kg/m
Inner Cores	:	4x6 mm^2 PU insulated
Outer Braiding	:	1x25 mm^2 PU insulated
Strength Member	:	BS=2.5 tons (2000 daN)
Wet Termination	:	4 x single pin HV connectors, each rated for kV pulses of 5 kA, 1 x ground referenced frame connector
Dry Termination	:	5 eye connectors to HV Junction Box

HV Junction Box

Design	:	Heavy duty, custom-made HMPE distribution box for connection of HV cable to negative polarity power supply, allows connection to each electrode module independently.

HV Power Supply Units

Design(Negative Polarity)	:	The preferred option is an Applied Acoustics unit from the CSP-N series. Other Negative Polarity units can be connected. Specifications are available on request

Also available in the GSO sparker range

GSO-180	:	2 x 90 tip electrode modules.
Dimensions		L x W x H = 109 x 57 x 43 cm
Weight	:	35 kg
HV Power Supply	:	100j – 1000j
GSO-540	:	6 x 90 tip electrode modules.
Dimensions		L x W x H = 109 x 75 x 43 cm
Weight	:	60 kg
HV Power Supply	:	100j – 2400j
GSO-120 FW	:	2 x 60 tip electrode modules for use in fresh water
Dimensions		L x W x H = 109 x 57 x 43 cm
Weight	:	35 kg
HV Power Supply	:	100j – 1000j
GSO-720	:	8 x 90 tip electrode modules (available 2018)

Note: Above specifications can be subject to change

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D.2. Sub-bottom Profiler Innomar SES-2000

SES-2000 medium-100

Parametric Sub-bottom Profiler

▶ Performance
- water depth range: 2 – 2,000 m
- penetration: up to 70 m, depending on sediments
- layer resolution: up to 5 cm
- motion compensation: heave, roll
- beam width @ 3 dB: ±1 ° / footprint < 3.5 % of water depth for all frequencies

▶ Transmitter
- primary frequencies: approx. 100 kHz (band 85 – 115 kHz)
- secondary low frequencies: 4, 5, 6, 8, 10, 12, 15 kHz (band 2 – 22 kHz)
- primary source level: > 247 dB//µPa re 1 m
- pulse width: 0.07 – 2 ms
- pulse rate: up to 40/s
- multi-ping mode
- pulse type: CW, Ricker, LFM (chirp)

▶ Acquisition
- primary frequency (echo sounder, bottom track)
- secondary low frequency (sub-bottom data, multi-frequency mode)
- sample rate 96 kHz @ 24 bit

▶ System Components
- transceiver unit 19 inch / 12 U (WHD: 0.52 m x 0.58 m x 0.40 m; 56 kg)
- transducer incl. 30 m cable (WHD: 0.50 m x 0.12 m x 0.50 m; 60 kg)
- system control: internal PC
- KVM remote control

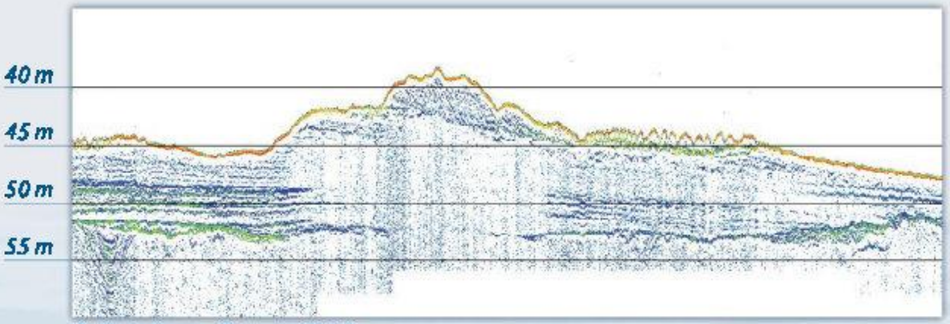
▶ Software
- SESWIN data acquisition software
- SES Convert SEG-Y/XTF data export
- SES NetView remote display
- ISE post-processing software

▶ Power Supply Requirements
- 100 – 240 V AC / 50 – 60 Hz
- power consumption: < 700 W

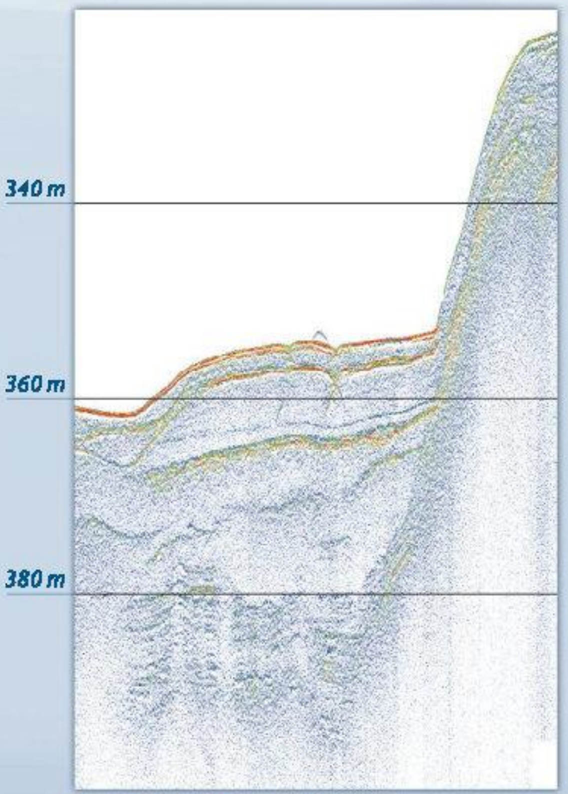
Innomar

www.innomar.com

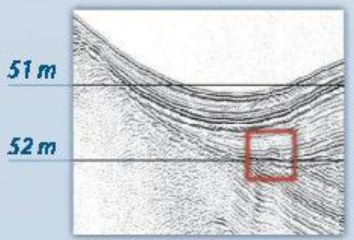
Survey examples of SES-2000 medium-100



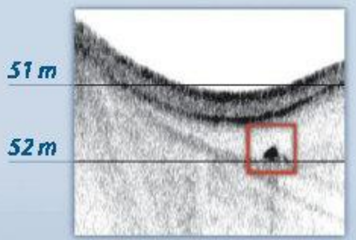
Geological survey (frequency 8 kHz)



Geological survey (frequency 5 kHz)



Cable burial depth survey 15 kHz



... and 100 kHz (cable 8 x 16 cm)

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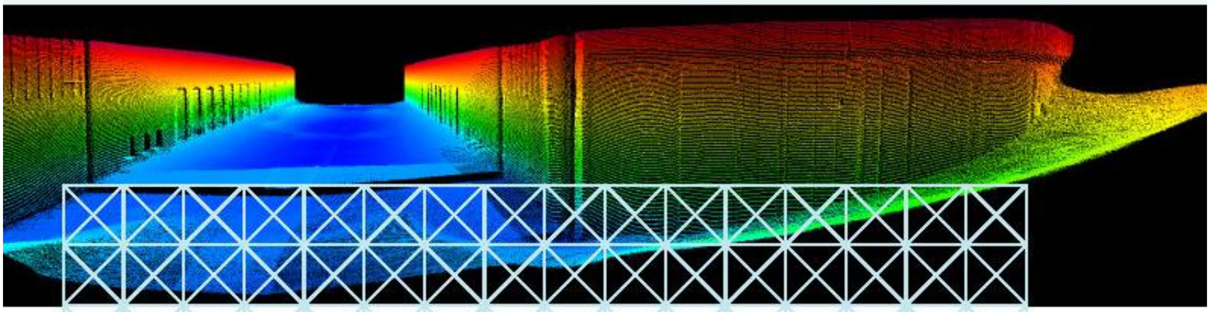
D.3. Multi-Beam Echo Sounder (MBES) Kongsberg EM2040

EM® 2040 MKII

KONGSBERG



MULTIBEAM ECHO SOUNDER

The EM 2040 MKII is a true wide band high resolution shallow water multibeam echo sounder, an ideal tool for any high resolution mapping and inspection application. With this release, Kongsberg Maritime has upgraded the hardware and software to increase the swath and improve the data quality of our EM 2040 series.

Key facts

The system fulfils, and even surpasses, IHO-S44 Exclusive Order and the more stringent LINZ specification.

The EM 2040 was the first 3-sector broadband multibeam echosounder in the market, now available as a 200 - 700 kHz system. The operator can on the fly choose the best operating frequency for the application: 300 kHz for near bottom, 200 kHz for deeper waters and 400 - 700 kHz for very high resolution inspection. 600 kHz wide area high frequency mapping mode offers an unprecedented 100 - 120° swath width. 700 kHz inspection mode provides the highest resolution available contained within a narrow 30° swath.

By alternating between the frequency modes per ping, the system is capable of providing the operator with Multi Frequency Backscatter of up to 5 frequencies in a single pass. The same functionality allows the system to alternate between a full swath mode and a high resolution mode providing full coverage while maintaining ultra high resolution over a target.

Due to the large operating bandwidth, the system has an output sample rate up to 60 kHz. The system can effectively operate with very short pulse lengths, the shortest pulse being 14 microseconds giving a raw range resolution (CT/2) of 10.5 mm.

The angular coverage for the 200 and 300 kHz is up to 170° on slopes and piersides, with coverage up to 8 times water depth on a flat bottom. For a dual transducer system, 220° angular coverage or 10 times the water depth is achieved on a flat bottom.

Components

The EM 2040 MKII is a modular system, fully prepared for upgrading to cater for more demanding applications. The basic system has four units: a transmit transducer, a receive transducer, a processing unit and a hydrographic workstation.

The EM 2040 MKII receiver is 0.5° and is delivered with a 0.25° or 0.5° transmitter(s). The transmit fan is divided into three sectors pinging simultaneously at separate frequencies ensuring a strong and beneficial dampening of multibounce interference.

As an option the EM 2040 MKII can be delivered with dual swath capability, allowing a sufficient sounding density to meet survey coverage standards along track while maintaining a high vessel speed. A single transmitter with dual receiver setup fully exploits the unique angular coverage of our three-sector transmitter for full 220° angular coverage per ping.

The specialised dual transmitter and receiver setup is ideal where mounting requires a large separation of receivers, where mounting the transmitter at the keel is not an option or for ROV pipeline surveying and free span detection. This configuration transmits on a single sector per transmitter with selectable frequency in steps of 10 kHz from 200 to 400 kHz.

The standard depth rating of the EM 2040 MKII transducers is 6000 m, making it ideal for operation on subsea vehicles such as ROVs or AUVs.

443810 /G May 2021

FEATURES

Included Features

- 200-400 kHz wide frequency range
- Seabed image
- Water column display and logging for SIS users
- FM chirp
- Roll, pitch and yaw stabilisation
- Short pulse lengths, large bandwidth
- Transmit and receive nearfield focusing
- Depth rated to 6000 m

Optional features

- Dual swath
- 600 kHz and 700 kHz modes
- EM® MultiFrequency Mode
- Water column display and logging
- Water column phase logging
- Extra detections
- Dual RX
- Dual TX

TECHNICAL SPECIFICATIONS

Frequency range	200 to 700 kHz
Max ping rate	50 Hz
Swath coverage sector	Up to 170° (single receiver) / 220° (dual receiver)
Beam patterns	Equiangular, equidistant high density and ultra high density
No. of beams per ping	512 (Single RX)/1024 (Single RX, Dual Swath)/1600 (Dual RX, Dual Swath)
Roll stabilised beams	± 15°
Pitch stabilised beams	± 10°
Yaw stabilised beams	± 10°

Coverage example for EM 2040 with bottom type rock (BS = - 10 dB), NL = 45 dB, FM enabled

Operating mode	Cold ocean water			Cold fresh water		
EM 2040-04:	**Max depth**	**Max coverage single RX**	**Max coverage dual RX**	**Max depth**	**Max coverage single RX**	**Max coverage dual RX**
200 kHz	635 m	820 m	880 m	1360 m	1880 m	2110 m
300 kHz	480 m	670 m	760 m	740 m	1100 m	1270 m
400 kHz	315 m	410 m	430 m	430 m	570 m	610 m
600 kHz	85 m	130 m	-	115 m	150 m	-
700 kHz	55 m	27 m	-	60 m	30 m	-
EM 2040-07:						
200 kHz	600 m	880 m	930 m	1300 m	1870 m	2000 m
300 kHz	465 m	640 m	725 m	700 m	1050 m	1200 m
400 kHz	300 m	365 m	410 m	375 m	540 m	570 m
600 kHz	65 m	120 m	-	105 m	140 m	-
700 kHz	50 m	25 m	-	55 m	28 m	-

Pulse lenghts

200 kHz		300 kHz		400 kHz	600 kHz	700 kHz
CW	FM	CW	FM	CW	CW	CW
19 to 324 µs	1.5 to 12 ms	19 to 324 µs	1.5 to 6 ms	14 to 108 µs	100 to 410 µs	70 µs

	Beamwidth					Physical dimensions (excluding connectors and mounting arrangements)	
	200 kHz	**300 kHz**	**400 kHz**	**600 kHz**	**700 kHz**	**Dimensions**	**Weight**
TX EM 2040-04	0.7°	0.5°	0.4°	0.25°	0.225°	727 x 142 x 150 mm (LxWxH)	45 kg
TX EM 2040-07	1.5°	1°	0.7°	0.5°	0.45°	407 x 142 x 150 mm (LxWxH)	23 kg
RX	1.5°	1°	0.7°	0.5°	0.45°	407 x 142 x 136 mm (LxWxH)	22 kg
Processing Unit (2U for 19" rack)						482.5 x 424 x 88.6 mm (WxDxH)	10.5 kg
Portable Processing Unit (IP67)						370 x 380 x 101 mm (WxDxH)	10.5 kg

Laptop, Hydrographic Work Station (HWS) and monitor can be delivered on request.

Specifications subject to change without any further notice.
EM® is a registered trademark of Kongsberg Maritime AS in Norway and other countries.
Front page: Curtesy of Port of London.

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KONGSBERG

D.4. Side Scan Sonar (SSS) EdgeTech 4200

EdgeTech

4200 SERIES

SIDE SCAN SONAR SYSTEM

FEATURES

- Optional Multi-Pulse (MP) technology for high speed surveys
- Crisp, high resolution CHIRP images
- Multiple dual simultaneous frequency sets to choose from
- Stainless steel towfish
- Easily integrates to other 3rd party sensors
- Meets IHO & NOAA Survey Specifications

APPLICATIONS

- Cable & Pipeline Surveys
- Geological/Geophysical Surveys
- Mine Countermeasures (MCM)
- Geohazard Surveys
- Channel Clearance
- Search and Recovery
- Archeological Surveys

The 4200 Series is a versatile side scan sonar system that can be configured for almost any survey application from shallow to deep water operations. The 4200 utilizes EdgeTech's Full Spectrum® CHIRP technology to provide crisp, high resolution imagery at ranges up to 50% greater than non-CHIRP systems; thus allowing customers to cover larger areas and save money spent on costly surveys.

One of the unique features of the 4200 is the optional Multi-Pulse (MP) technology, which places two sound pulses in the water rather than one pulse like conventional side scan sonar systems. This allows the 4200 to be towed at speeds of up to 10 knots while still maintaining 100% bottom coverage. In addition, the MP technology will provide twice the resolution when operating at normal tow speeds, thus allowing for better target detection and classification ability. The addition of the optional MP technology provides the operator with two modes of operation; either High Definition Mode (HDM) or High Speed Mode (HSM). This software-selectable mode of operation provides the operator the ability to select the best configuration for the specific job type.

All EdgeTech 4200 systems are comprised of a topside system and a reliable stainless steel towfish. A choice of dual simultaneous frequency sets are available to the user and topside processors come in a choice of configurations from portable to rack mounted units. In addition, an easy-to-use GUI software is supplied with every unit.

For more information please visit EdgeTech.com

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EdgeTech

4200 SERIES

SIDE SCAN SONAR SYSTEM

KEY SPECIFICATIONS

SONAR SPECIFICATIONS	STANDARD	WITH OPTIONAL MP TECHNOLOGY	
Frequency	Choice of either 100/400, 300/600 or 300/900 kHz dual simultaneous		
Operating Range (meters/side)	100 kHz: 500m, 300 kHz: 230m, 400 kHz: 150m, 600 kHz: 120m, 900 kHz: 75m		
Horizontal Beam Width:	100 kHz: 1.5°, 300 kHz: 0.5°, 400 kHz: 0.4°, 600 kHz: 0.26°, 900 kHz: 0.2°	In High Speed Mode: 100 kHz: 1.26°, 300 kHz: 0.54°, 400 kHz: 0.4°, 600 kHz: 0.34°, 900 kHz: 0.3° In High Definition Mode: 100 kHz: 0.64°, 300 kHz: 0.28°, 400 kHz: 0.3°, 600 kHz: 0.26°, 900 kHz: 0.2°	
Resolution Along Track	100 kHz 5 m @ 200 m 300 kHz: 1.3 m @ 150 m 400 kHz: 0.6 m @ 100 m 600 kHz: 0.45 m @ 100 m 900 kHz: 18 cm @ 50 m	High Definition Mode: 100 kHz: 2.5 m @ 200 m 300 kHz: 1.0 m @ 200 m 400 kHz: 0.5 m @ 100 m 600 kHz: 0.45 m @ 100 m 900 kHz: 18 cm @ 50 m	High Speed Mode: 100 kHz: 4.4 m @ 200 m 300 kHz: 1.9 m @ 200 m 400 kHz: 0.7 m @ 100 m 600 kHz: 0.6 m @ 100 m 900 kHz: 26 cm @ 50 m
Resolution Across Track	100 kHz: 8 cm, 300 kHz: 3 cm, 400 kHz: 2 cm, 600 kHz 1.5 cm, 900 kHz: 1 cm		
Vertical Beam Width	50°		
Depression Angle	Tilted down 20°		
TOWFISH	**STAINLESS STEEL**		
Diameter	11.4 cm (4.5 inches)		
Length	125.6 cm (49.5 inches)		
Weight in Air/Saltwater	48 / 36 kg (105 / 80 pounds)		
Depth Rating (Max)	2,000 m		
Standard Sensors	Heading, pitch & roll		
Optional Sensor Port	(1) Serial – RS 232C, 9600 Baud, Bi-directional & 27 VDC		
Options	Pressure Sensor, Magnetometer, Integrated USBL Acoustic Tracking System, Built-in Responder Nose, Depressor, Power Loss Pinger and Custom Sensors		
TOPSIDE PROCESSOR	**4200-P**	**4200**	**701-DL INTERFACE**
Hardware	Portable splash-proof case	19" rack mount computer	19" rack mount interface
Display & Interface	Splash-proof laptop	21" flat panel monitor, keyboard & trackball	Customer-supplied
Power Input	20-36 VDC or 115/230 VAC	115/230 VAC	115/230VAC
Operating System	Windows® XP Pro		
File Format	Native JSF or XTF		
Output	Ethernet		
TOW CABLE			
	Coaxial Kevlar or double-armored up to 6,000 m, winches available		

For more information please visit EdgeTech.com

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D.5. High Precision Acoustic Positioning

HiPAP® Frequency Plan
Information letter

KONGSBERG

HiPAP®, HPR 400 and Cymbal frequency and channels

HPR/HiPAP® Frequency overview
The HiPAP®/HPR 400 transponder channels are as follows:

Tx:	21-24.5kHz	Transponder interrogation	8 frequencies spaced 250Hz
Rx:	27-30.75kHz	Transponder reply	16 frequencies spaces 250Hz
Rx/Tx:	25.0-26.5kHz	Telemetry	7 frequencies spaced 250Hz

Cymbal Frequency overview
Centre frequency 25.6kHz, bandwidth +/-2kHz.
Cymbal uses identical centre frequency for both Tx and Rx, the signals are separated by different codes, BPSK.
Cymbal is utilized by HiPAP® 501/451/351/351P, cNODE® and cPAP® products.

Beam control and impact on interference
HiPAP® uses focused beams directed towards the transponder, regardless of the transponder location relative to the vessel. This beam is +/-5 degrees at 3dB points.
The narrow focused beam can also be used during transponder interrogation after a short initial phase. This is common for both HPR "analogue" frequencies and Cymbal. By this technique, HiPAP® only transmits energy towards the transponder.

Other acoustic positioning systems not having this technology will transmit in all directions, regardless of the transponder position, and spread the energy to transponders not being interrogated.

The narrow focused receiver beam wills also suppress noise and other spurious signals from all other directions then the desired transponder.
These properties are also very important when considering the systems interference capabilities.

Interference
Practical operations on drill rigs have shown that two HiPAP® systems operating simultaneously, one using HiPAP®/ HPR400 "analogue" signals, the other using Cymbal, work with no practical interference problem.

Operating Cymbal positioning simultaneously from two different asynchronous systems will cause occasional acoustic pulse overlapping in the water column. If reception on one system occurs at the same time as the other system transmits, signals may be lost, depending on the distances between the two transducers. This is valid for both wideband systems and traditional narrow band systems.

KM has carried out some trials where both Cymbal and Wideband1 (G5 transponders) where used in a shallow water LBL set up. Both systems operated simultaneously without any significant degradation.

See the next page for the channel and frequency plan.

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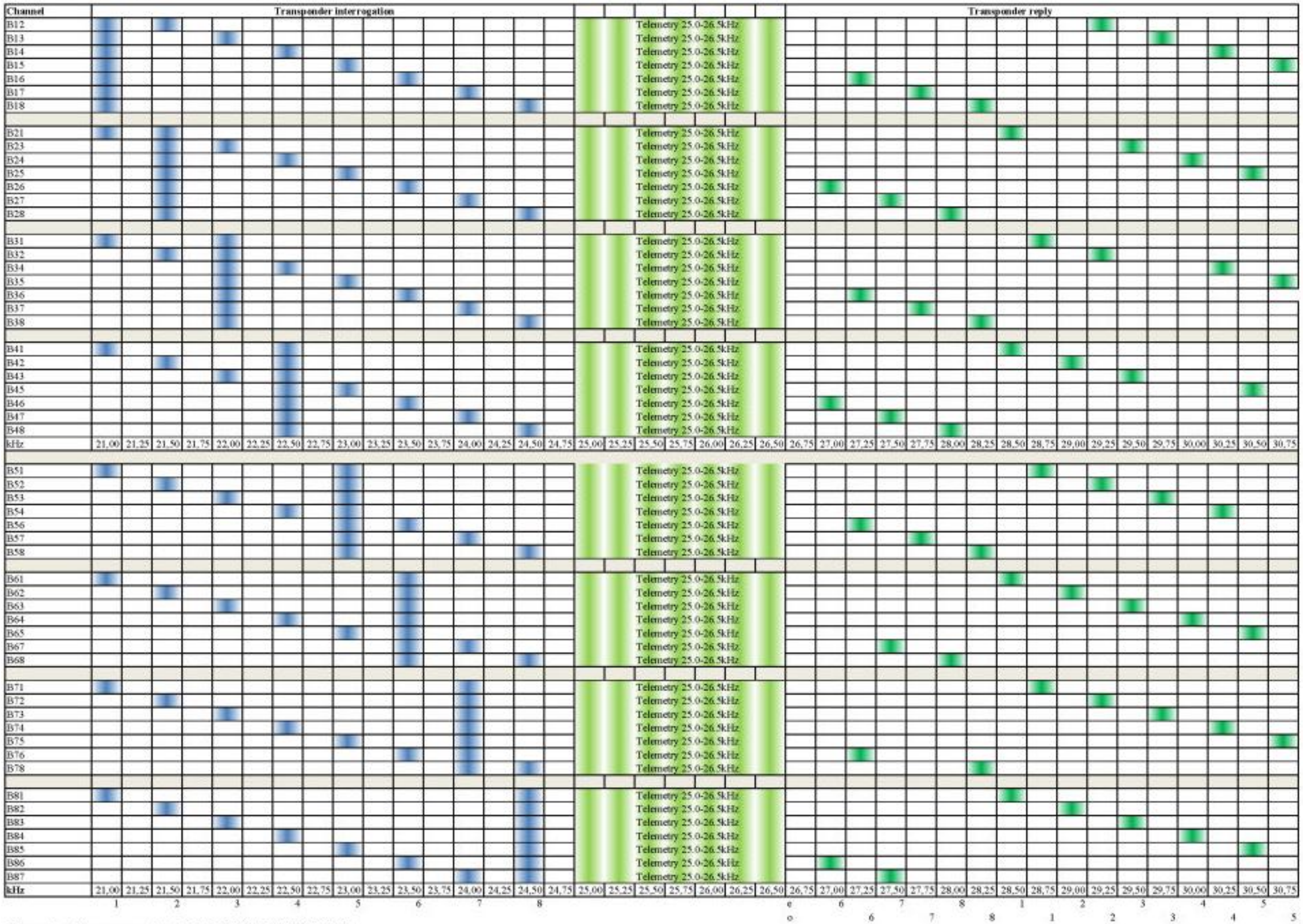
KONGSBERG

Channel and frequency plan for HiPAP 500/501/450/451/350/351/350P/351P and HPR400



Channel and frequency plan for HiPAP 501/451/351/351P

Appendix E. Underwater Acoustics

This section describes in detail the acoustic metrics relevant to this report.

E.1. Acoustic Metrics

Sound is most commonly described using the sound pressure level (SPL) metric. Underwater sound amplitude levels are commonly measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. The mean-square SPL was used to quantify the sounds generated by the source.

SPL (dB re 1 μPa) is the decibel level of the mean square pressure in a stated frequency band over a time window (*T; s*) containing the acoustic event:

$$\mathrm{SPL} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right) \tag{E-1}$$

The SPL is a measure of the effective pressure level over the duration of an acoustic event, such as the emission of one acoustic pulse or sweep. Because the window length, T, is the divisor, events more spread out in time have a lower SPL even though they may have similar total acoustic energy density.

Power spectral density (PSD) level is a description of how the acoustic power is distributed over different frequencies within a spectrum. It is expressed in dB re 1 μPa^2/Hz.

The sound exposure level (SEL, dB re 1 μPa^2 s) is a measure of the total acoustic energy contained in one or more acoustic events. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100}):

$$\mathrm{SEL} = 10\log_{10}\left(\int_{T_{100}} p^2(t)\,dt \Big/ T_0 p_0^2\right) \tag{E-2}$$

where T_0 is a reference time interval of 1 s. The SEL represents the total acoustic energy received at a location during an acoustic event; it measures the total sound energy an organism at that location would be exposed to.

Because the SPL and SEL are both computed from the integral of square pressure, these metrics are related by the following expression, which depends only on the duration of the energy time window T:

$$\mathrm{SPL} = \mathrm{SEL} - 10\log_{10}(T) \tag{E-3}$$

Sound level statistics, namely exceedance percentiles, were used to quantify the distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the level (i.e., PSD level, SPL, or SEL) exceeded by *n*% of the data. L_{99} is the maximum recorded sound level. L_{eq} is the linear arithmetic mean of the sound power, which can be substantially different from the median sound level L_{50}. SPL can also be referred to as L_{eq}, which stands for 'equivalent level'. The two terms are used interchangeably throughout. The median level, rather than the mean, was used to compare the most typical sound levels between AMARs, since the median is less affected by high amplitude outliers (e.g., a crustacean tapping on the hydrophone) than the mean sound level. L_5, the level exceeded by only 5% of the data, represents the highest typical sound levels measured. Sound levels between L_5 and L_{99} are generally from very close passes of vessels, very intense weather events, and other infrequent conditions. L_{95} represents the quietest typical conditions.

E.1. Measurement Terminology

Acoustic energy loss due to propagation from the source to receiver depends on the relative distance of the receiver from the source. The slant range is the direct line separation of source and receiver. The horizontal range is the horizontal component of the slant range as depicted in Figure E-1. The vertical separation between the source and receiver is the water depth minus the source depth and minus the elevation of the hydrophone above the seabed. When the slant range increases to several times the vertical separation, the slant range and horizontal range converge. Slant range is the distance metric used mainly in this report.

Endfire and broadside are the principal directions in the horizontal plane relative to the acoustic source. The endfire direction is along the tow axis (i.e., fore and aft), and the broadside direction is perpendicular to the tow axis (i.e., port and starboard). Seismic airgun arrays are often directional sources, so the received levels in both the broadside and endfire directions were separately assessed.

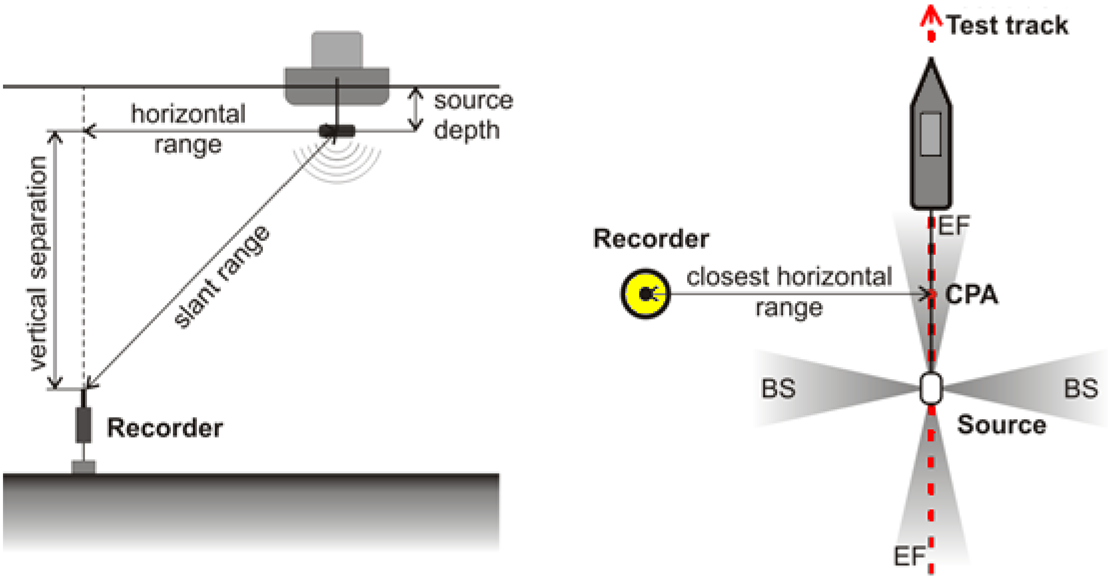


Figure E-1. Typical geometry of sound source characterisation (SSC) measurements and the associated terminology used in this report. BS is broadside, CPA is closest point of approach, and EF is endfire.

Appendix F. Received Levels

Individual amplitude and spectrogram views for each source at CPA for one of the test runs are presented in this Appendix. Figures for other passes are provided as supplementary material to this report; they present comparable features to the ones presented here. Spectrograms are presented for the full frequency scale of monitoring to also display frequency content outside of the main source represented.

F.1. Vessel Only

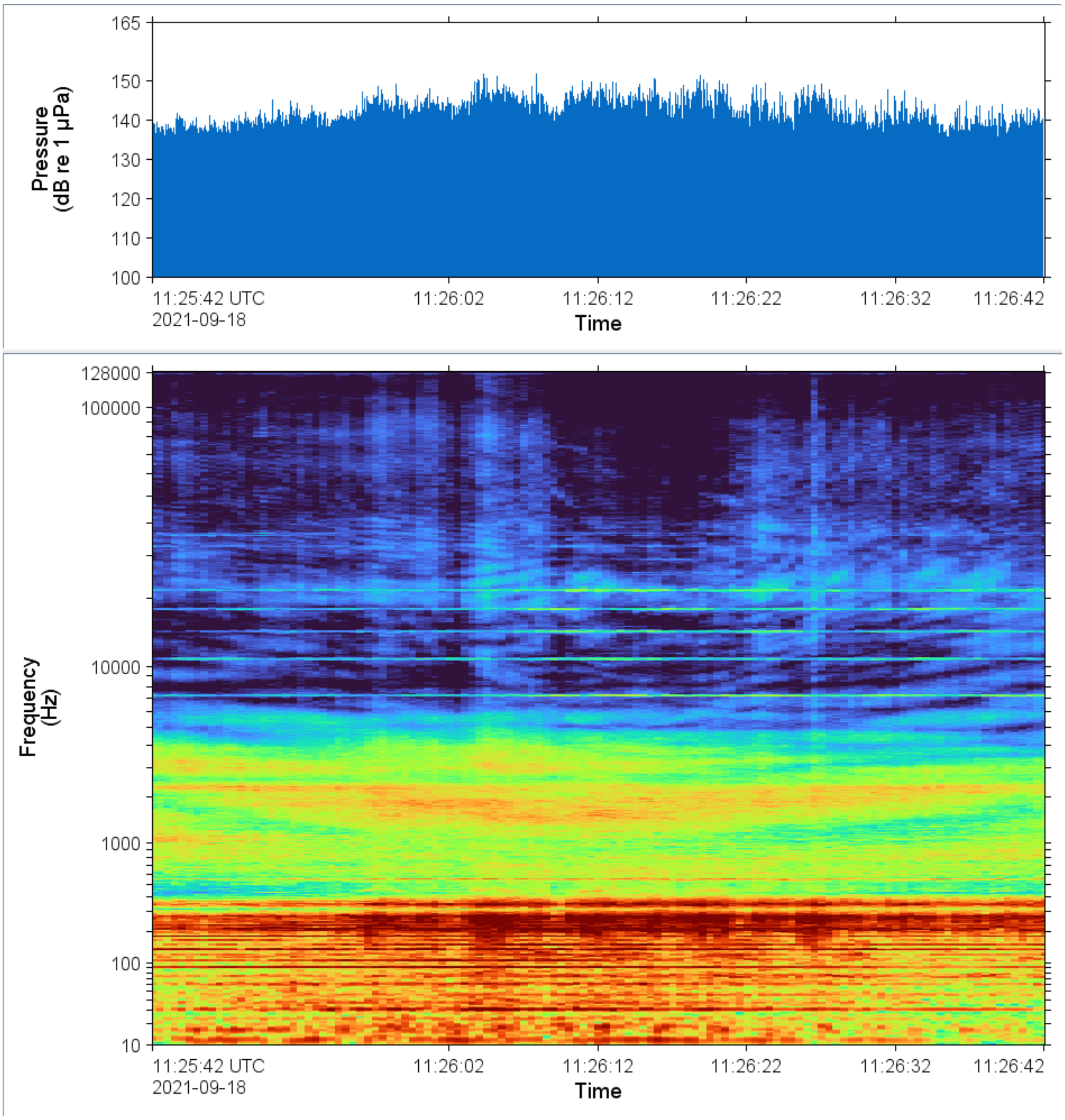


Figure F-1. Station A – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

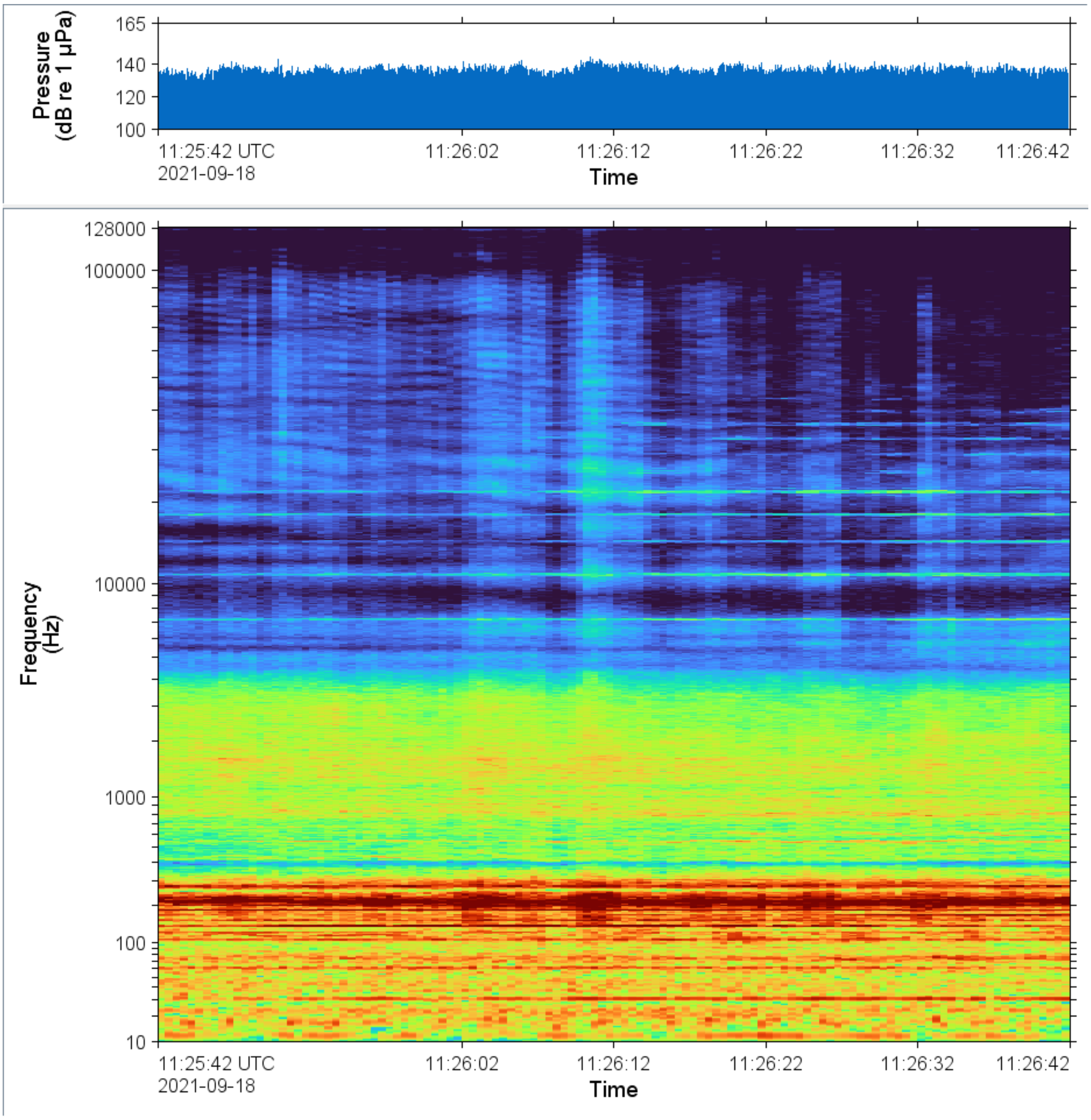


Figure F-2. Station B – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for at 4 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

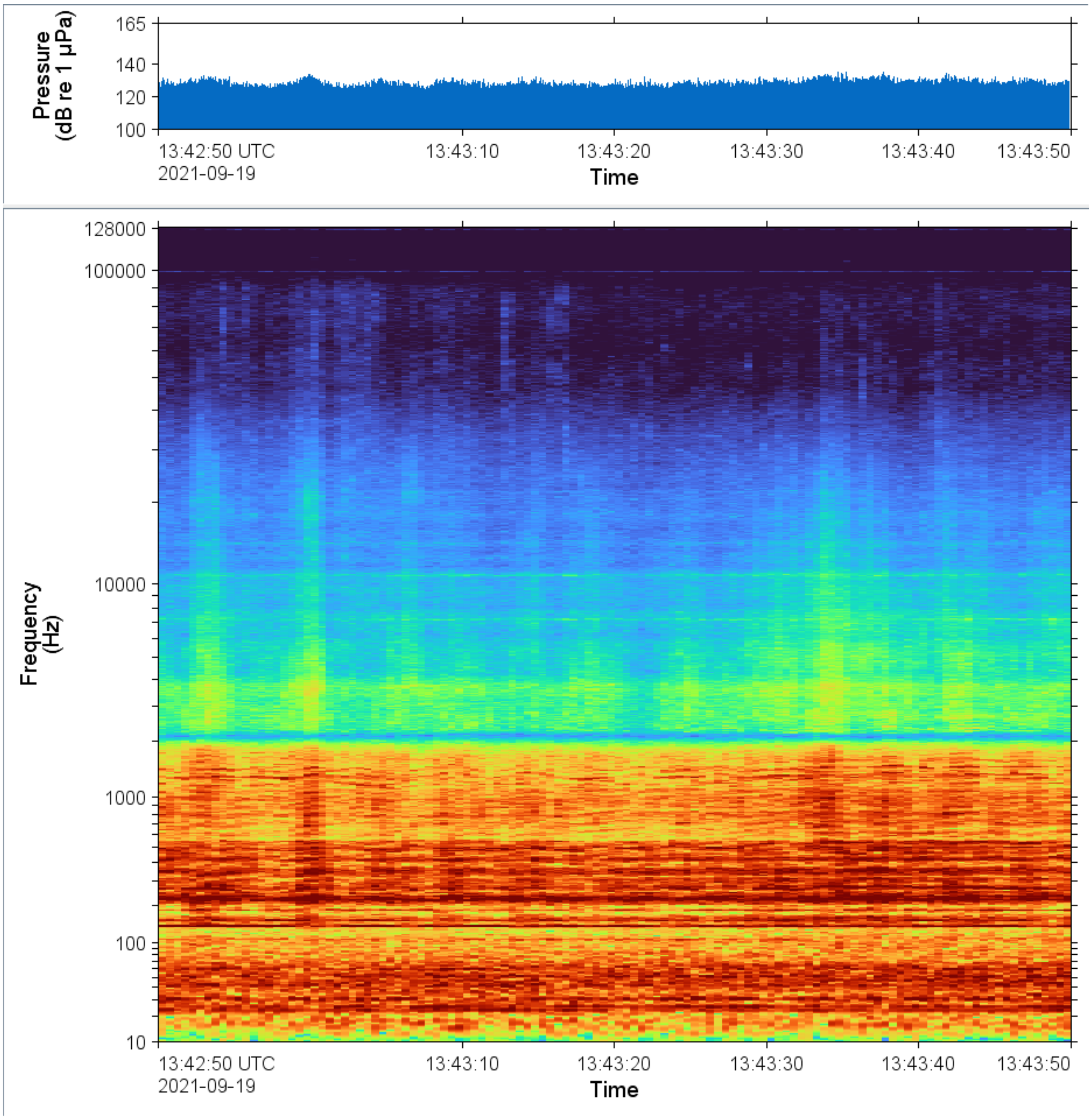


Figure F-3. Station C – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

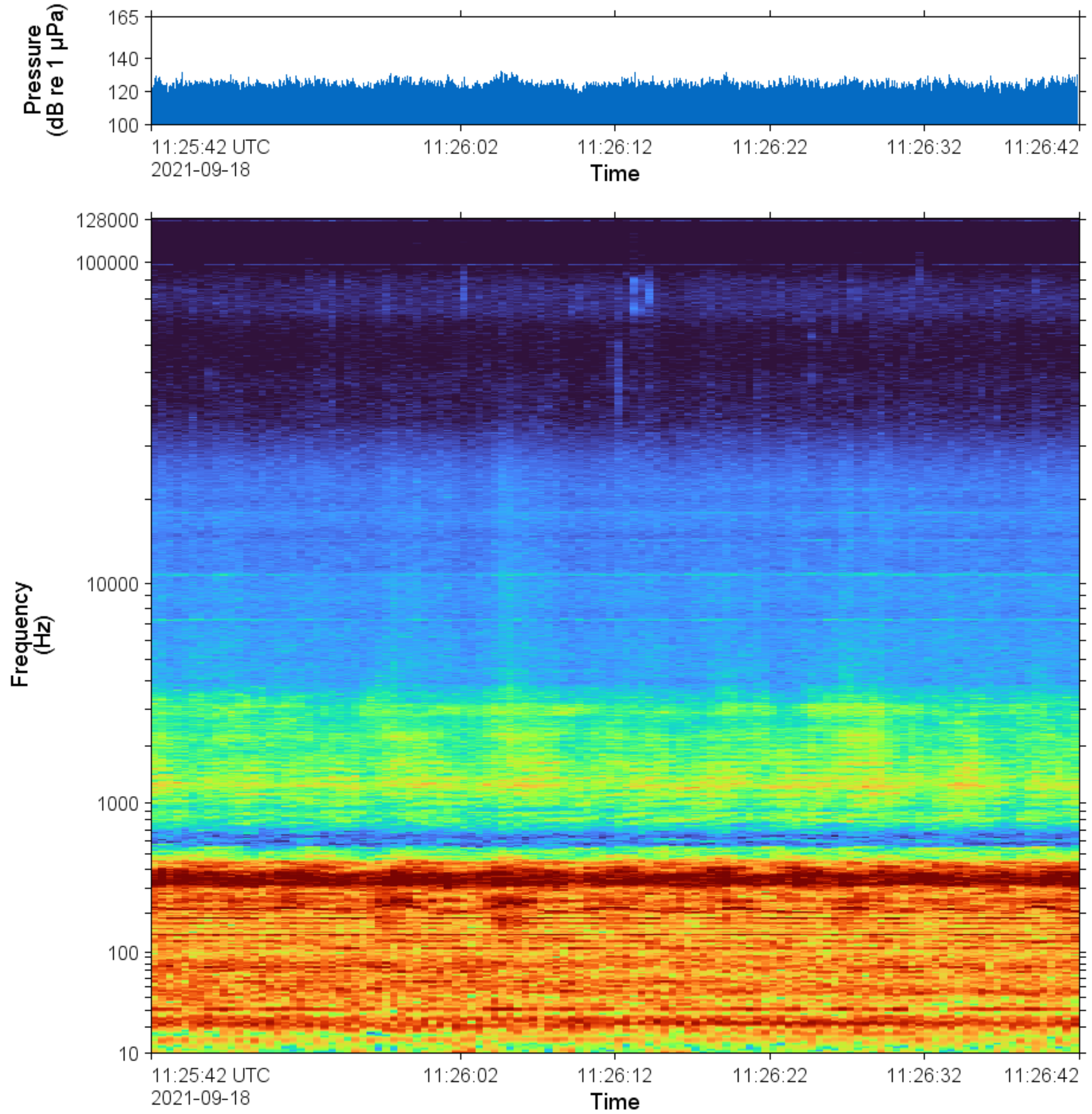


Figure F-4. Station D – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for at 4 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

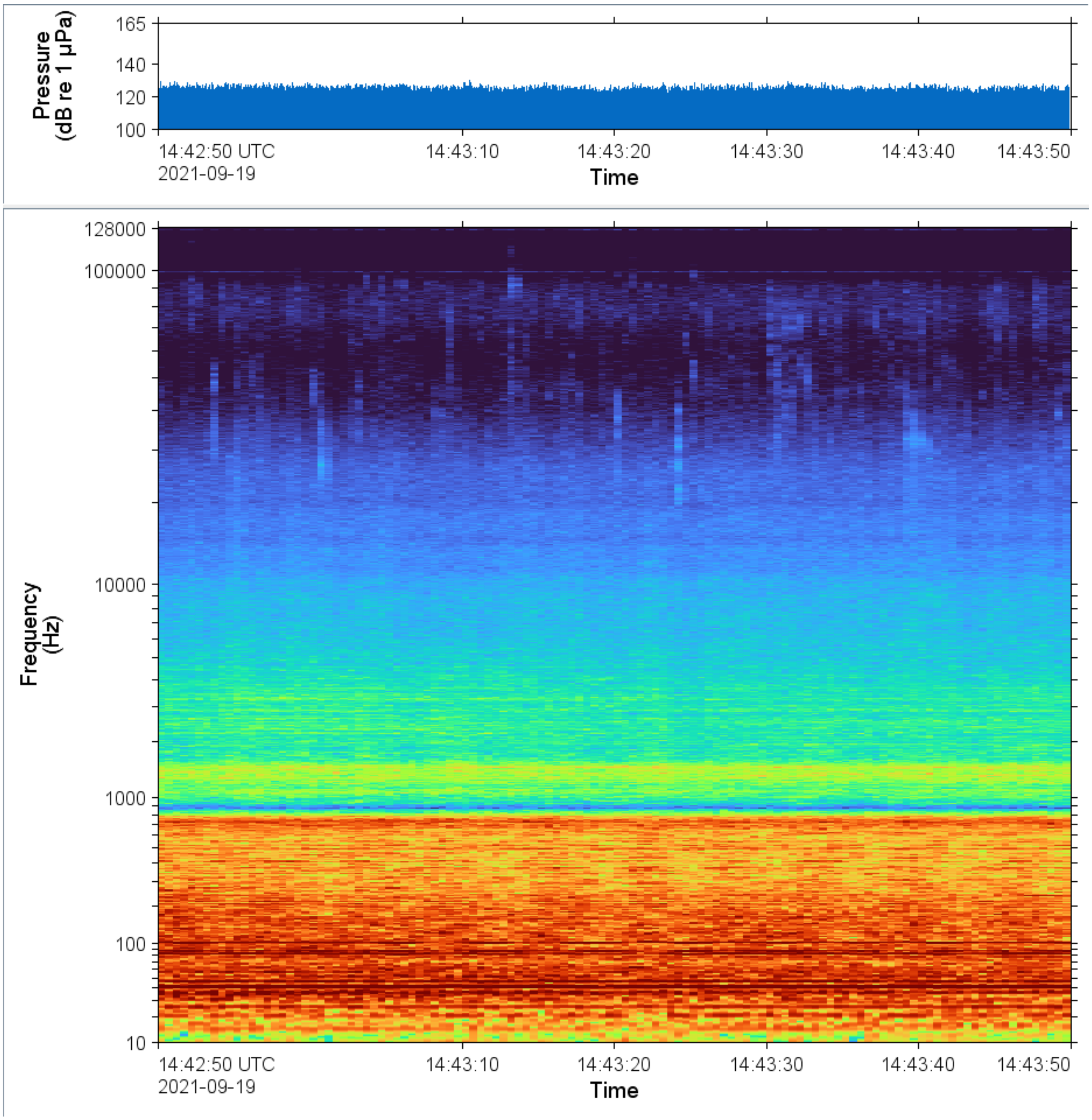


Figure F-5. Station E – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for at 4 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

F.2. Sparker

F.2.1. Main survey line

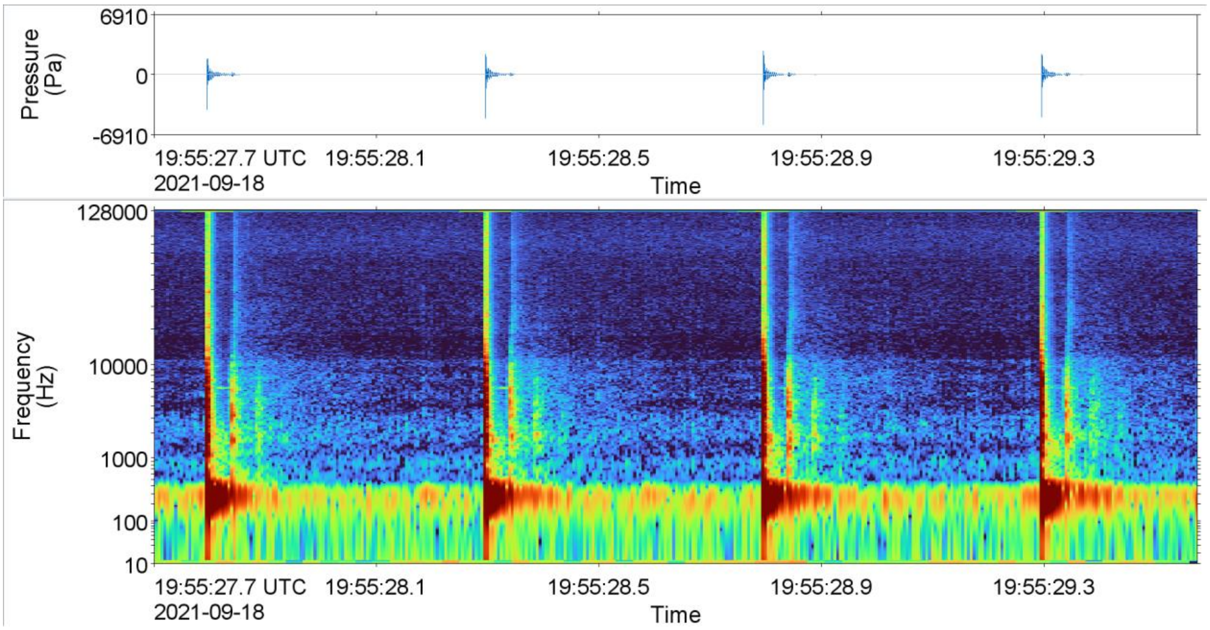


Figure F-6. Station A – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window).

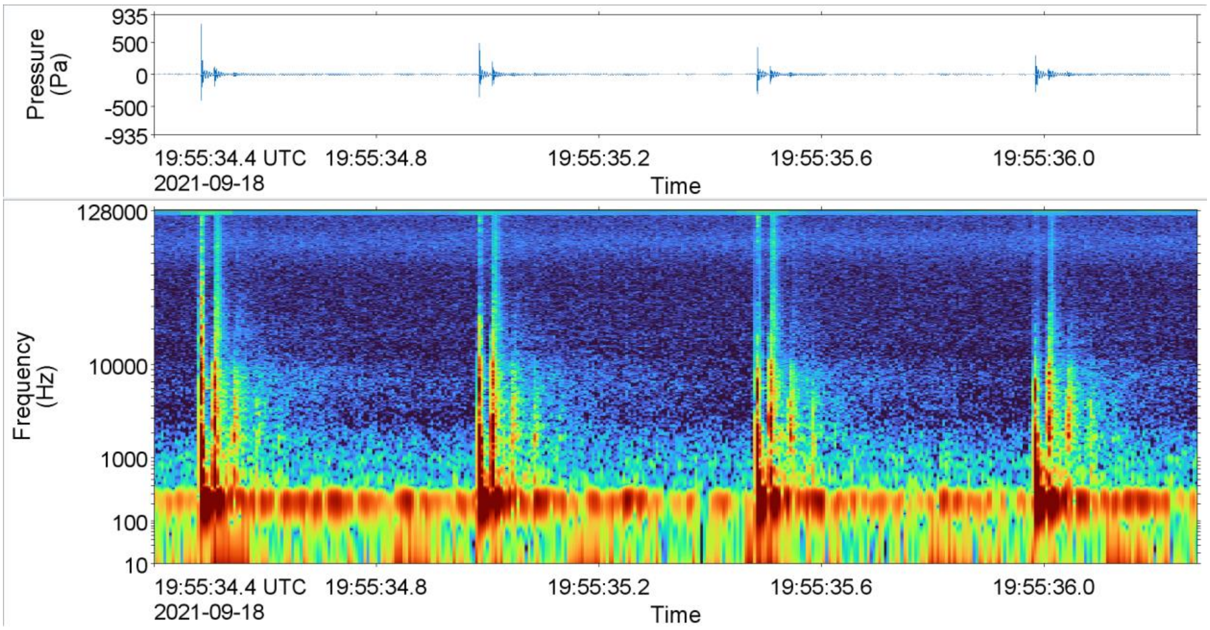


Figure F-7. Station B – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window).

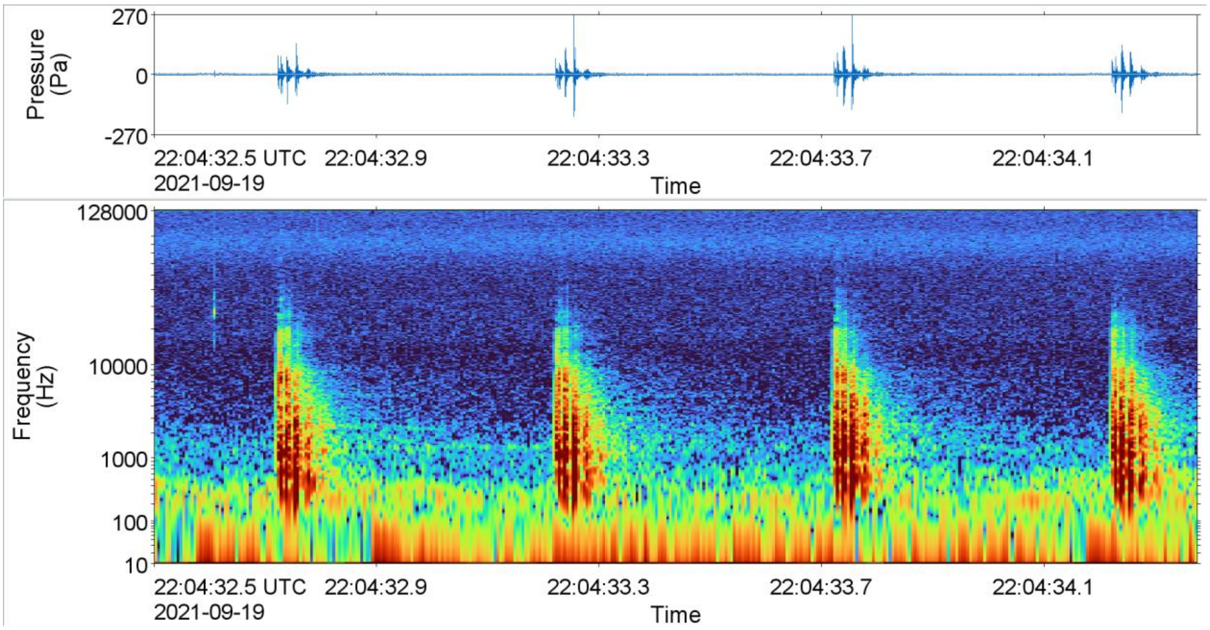


Figure F-8. Station C – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window).

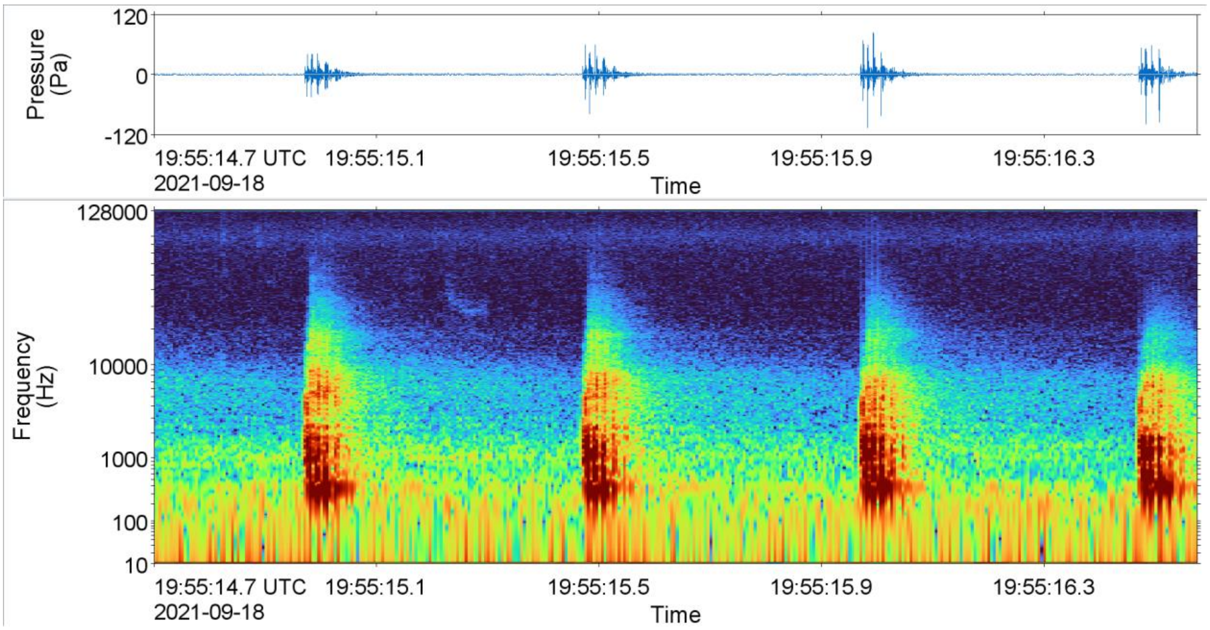


Figure F-9. Station D – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window).

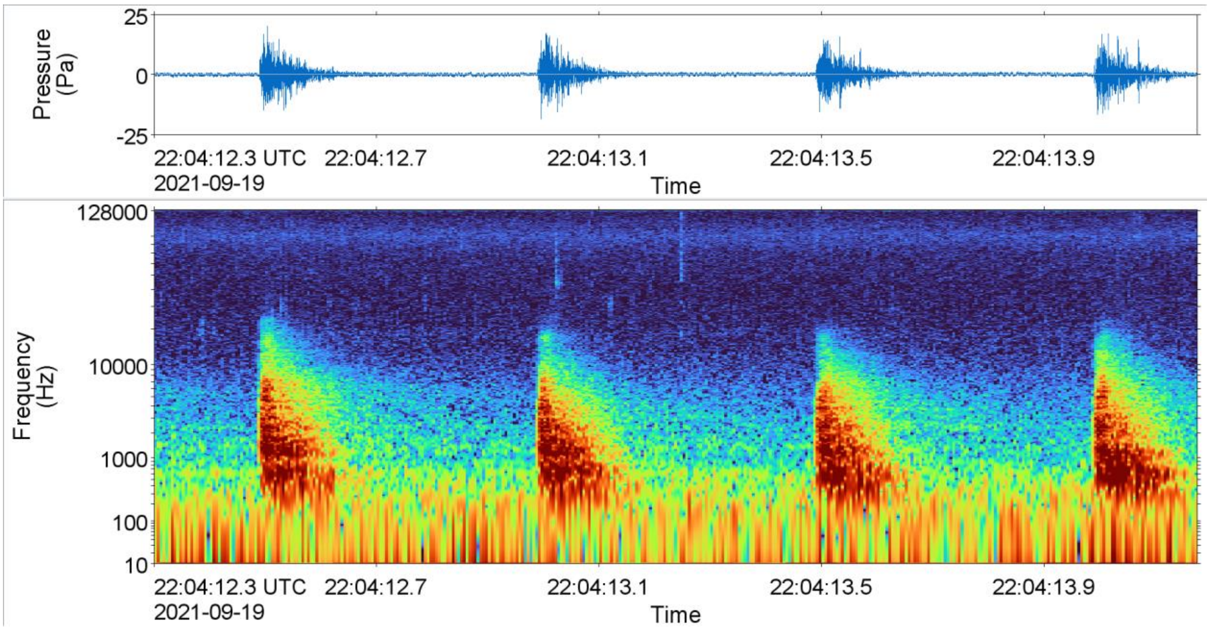


Figure F-10. Station E – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn ((1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window).

F.2.2. 5 km survey line

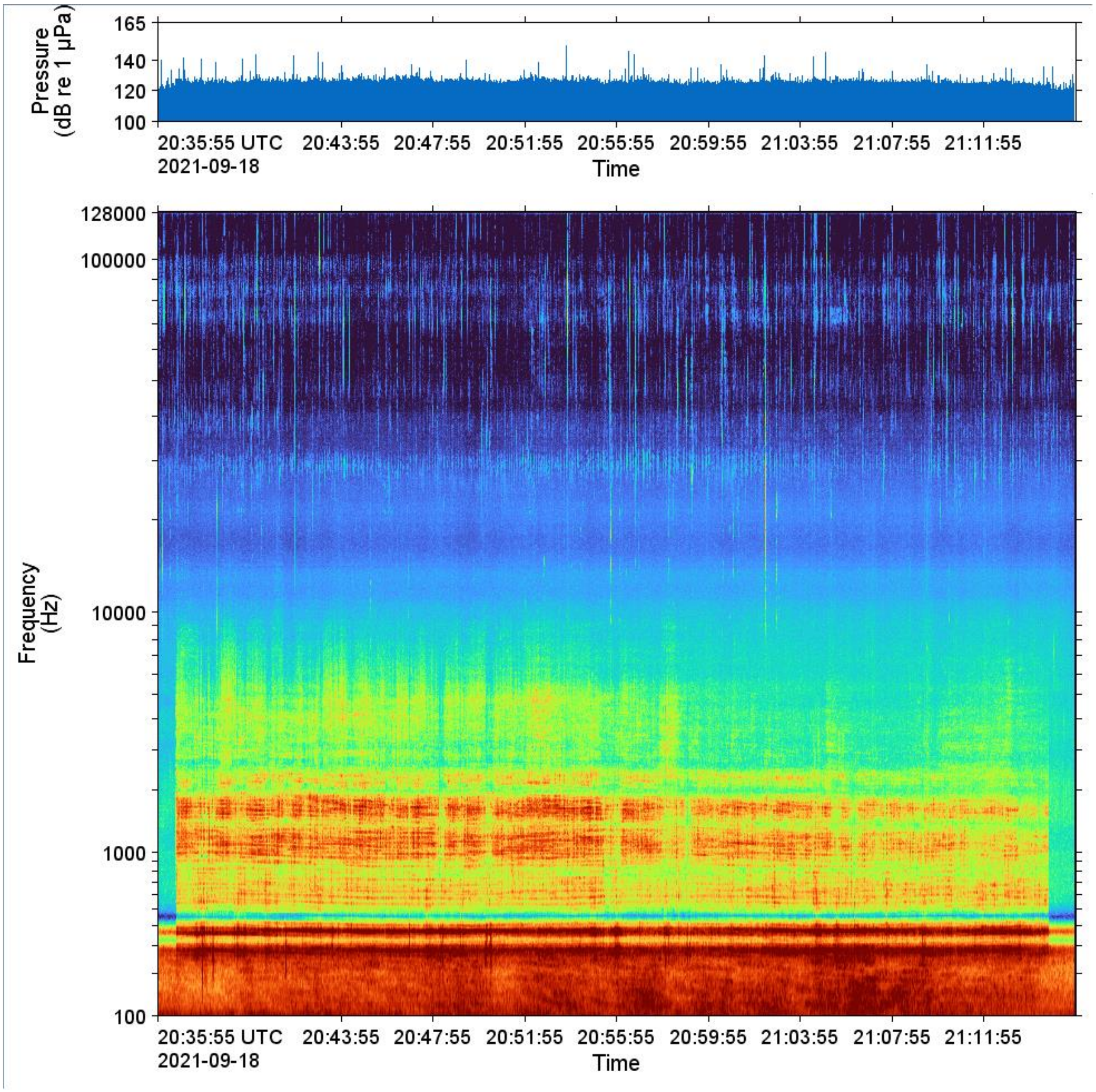


Figure F-11. Station A – 5 km (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window).

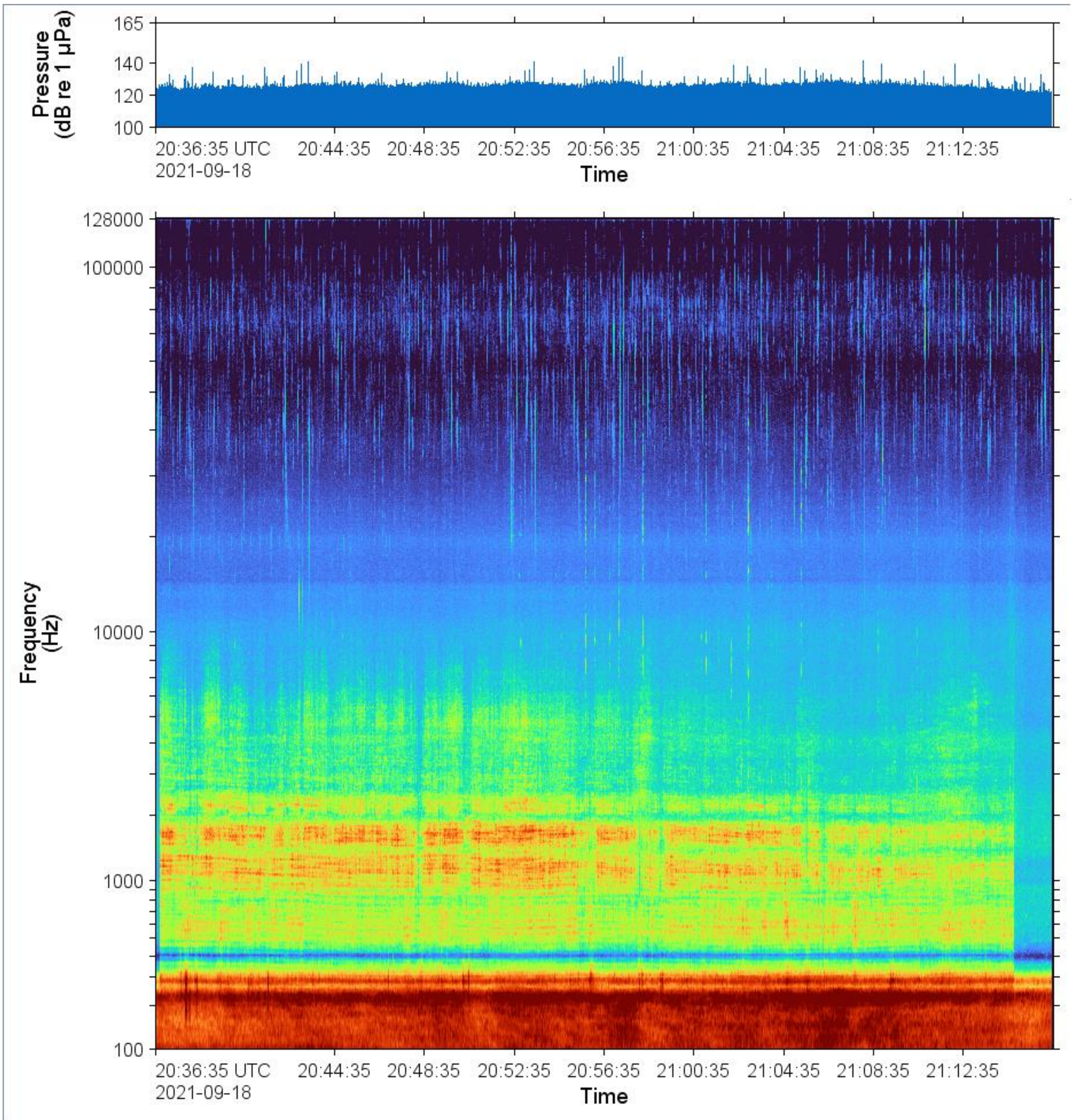


Figure F-12. Station B – 5 km (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window).

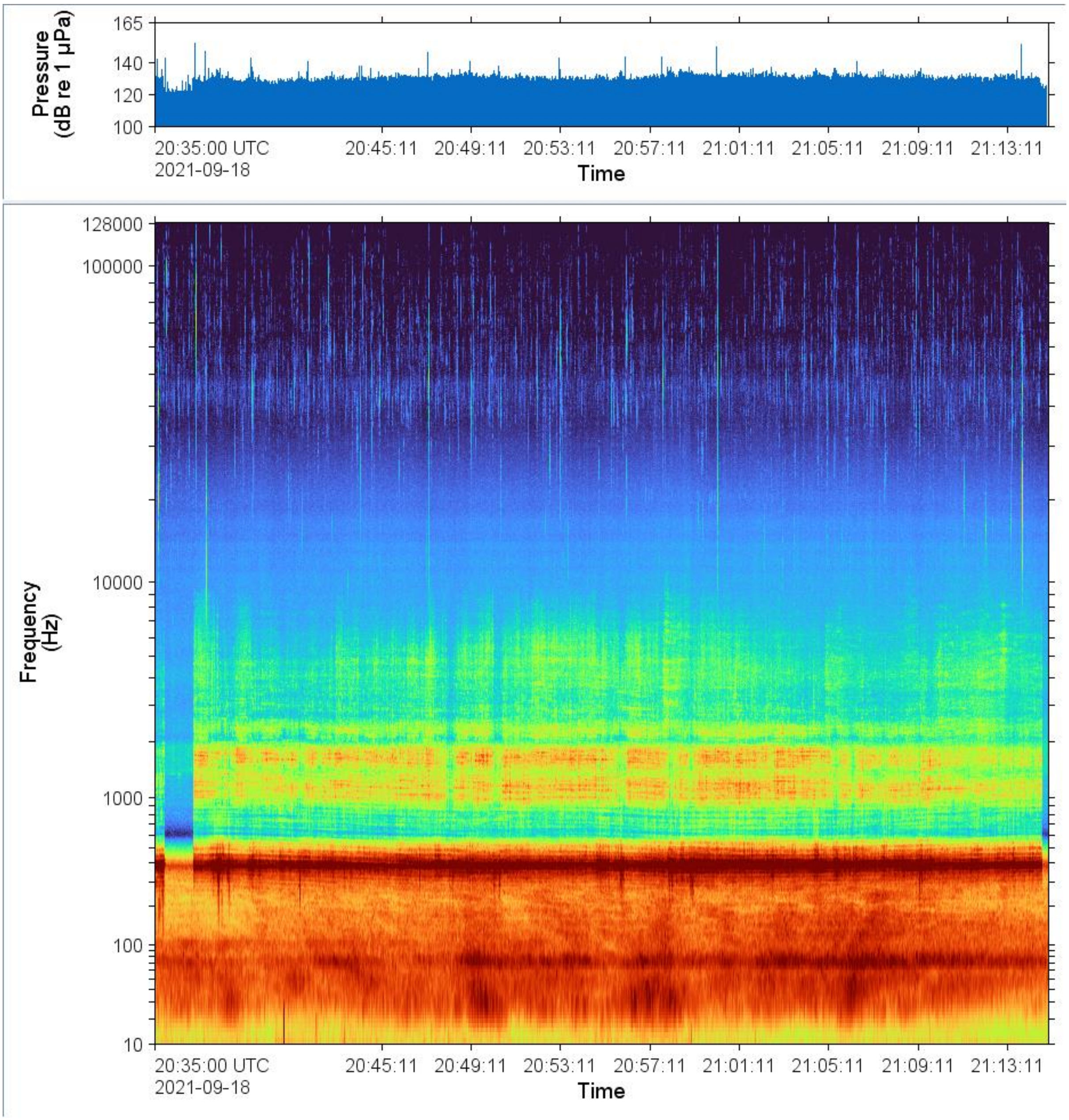


Figure F-13. Station D – 5 km (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window).

F.2.3. 10 km survey line

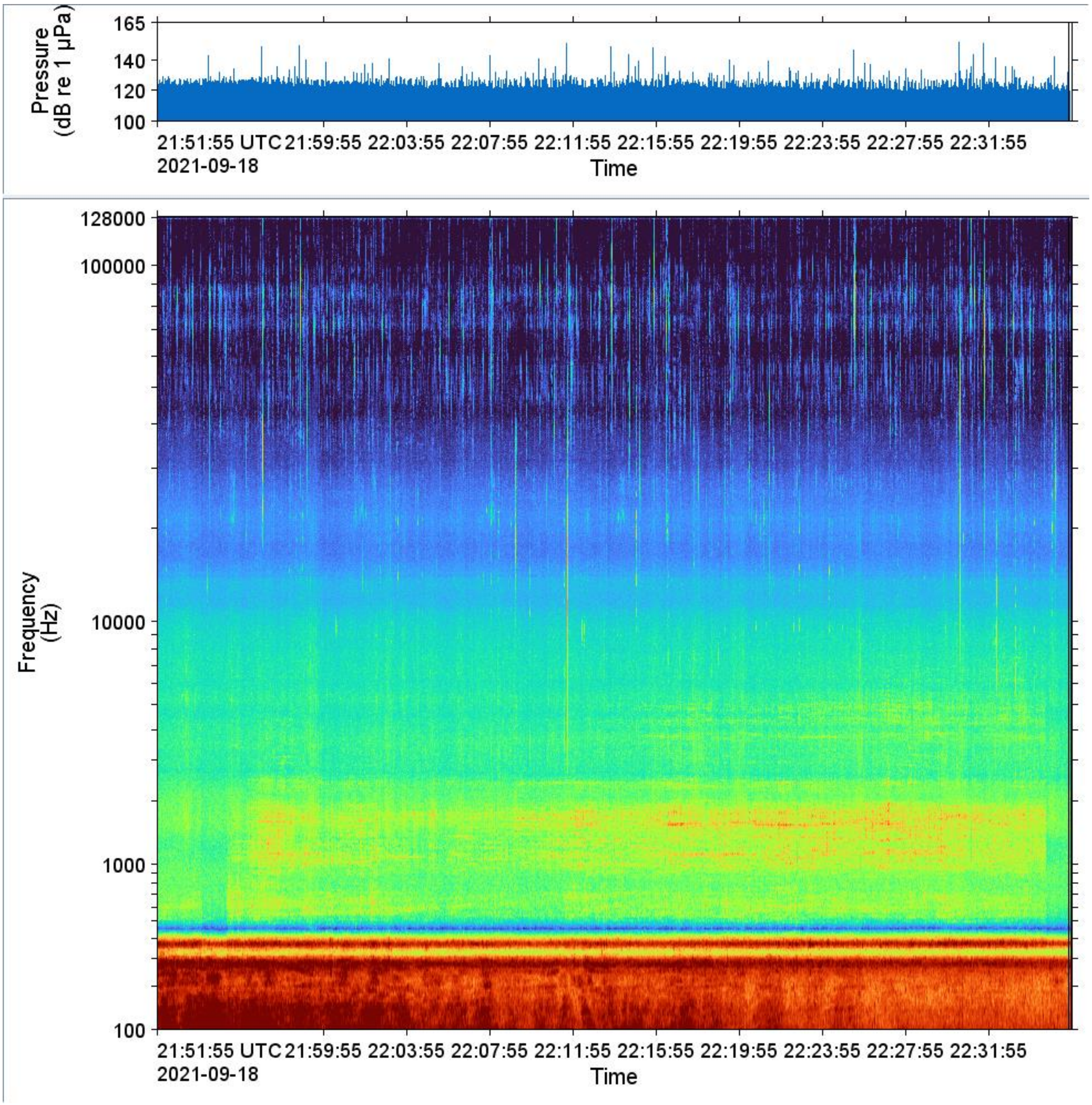


Figure F-14. Station A – 10 km (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window).

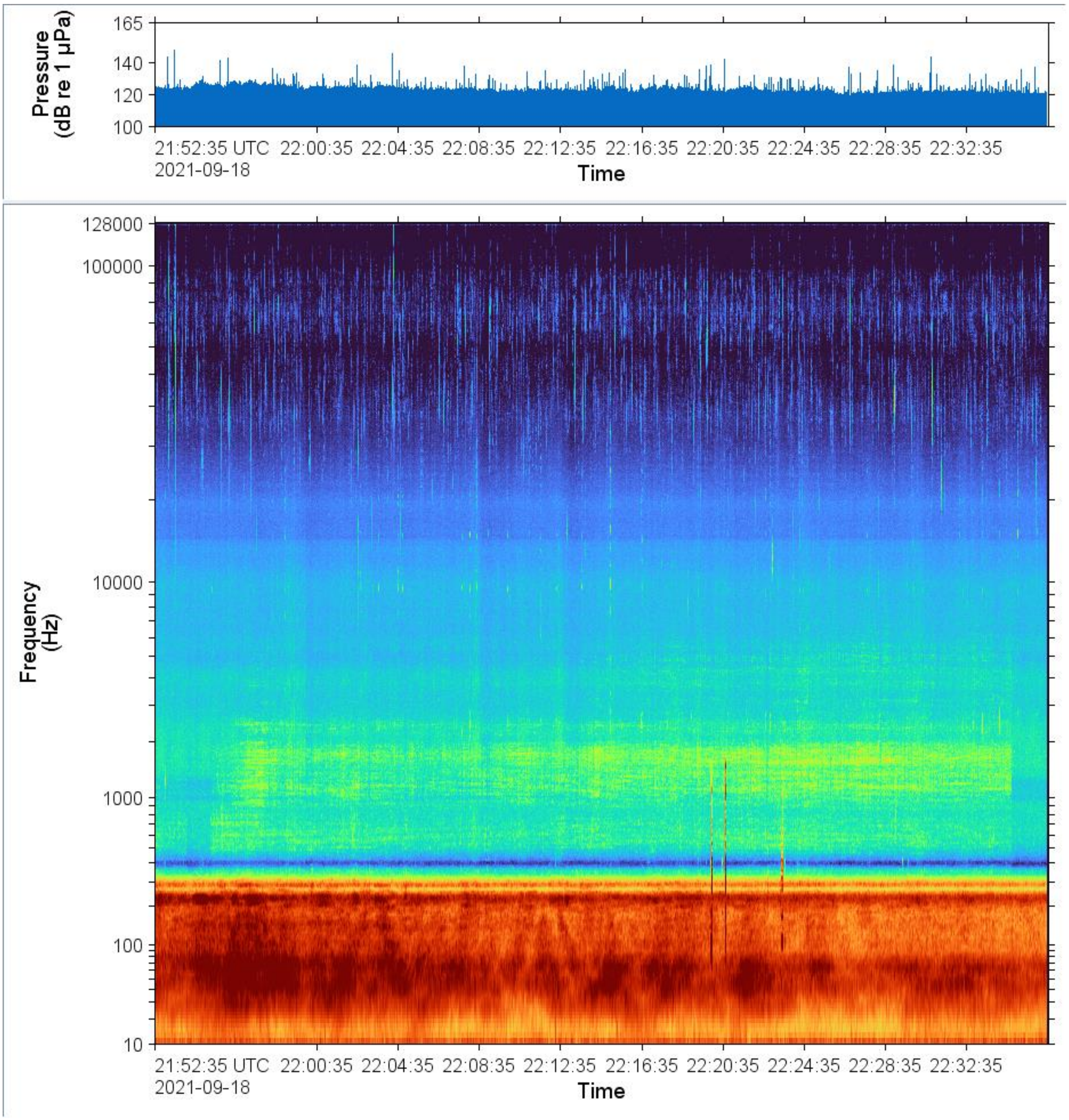


Figure F-15. Station B – 10 km (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window).

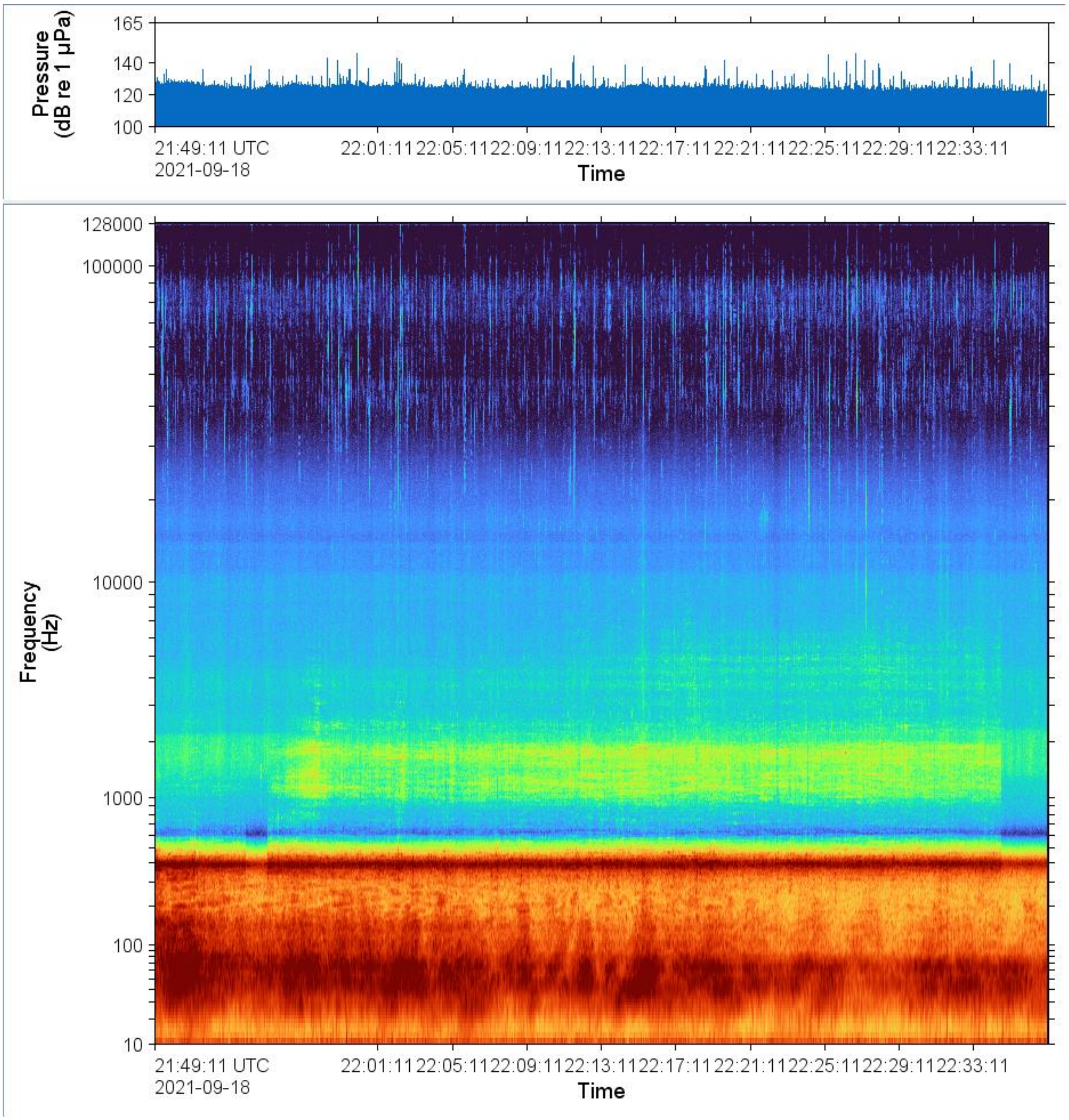


Figure F-16. Station D – 10 km (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window).

F.3. Sub-bottom profiler

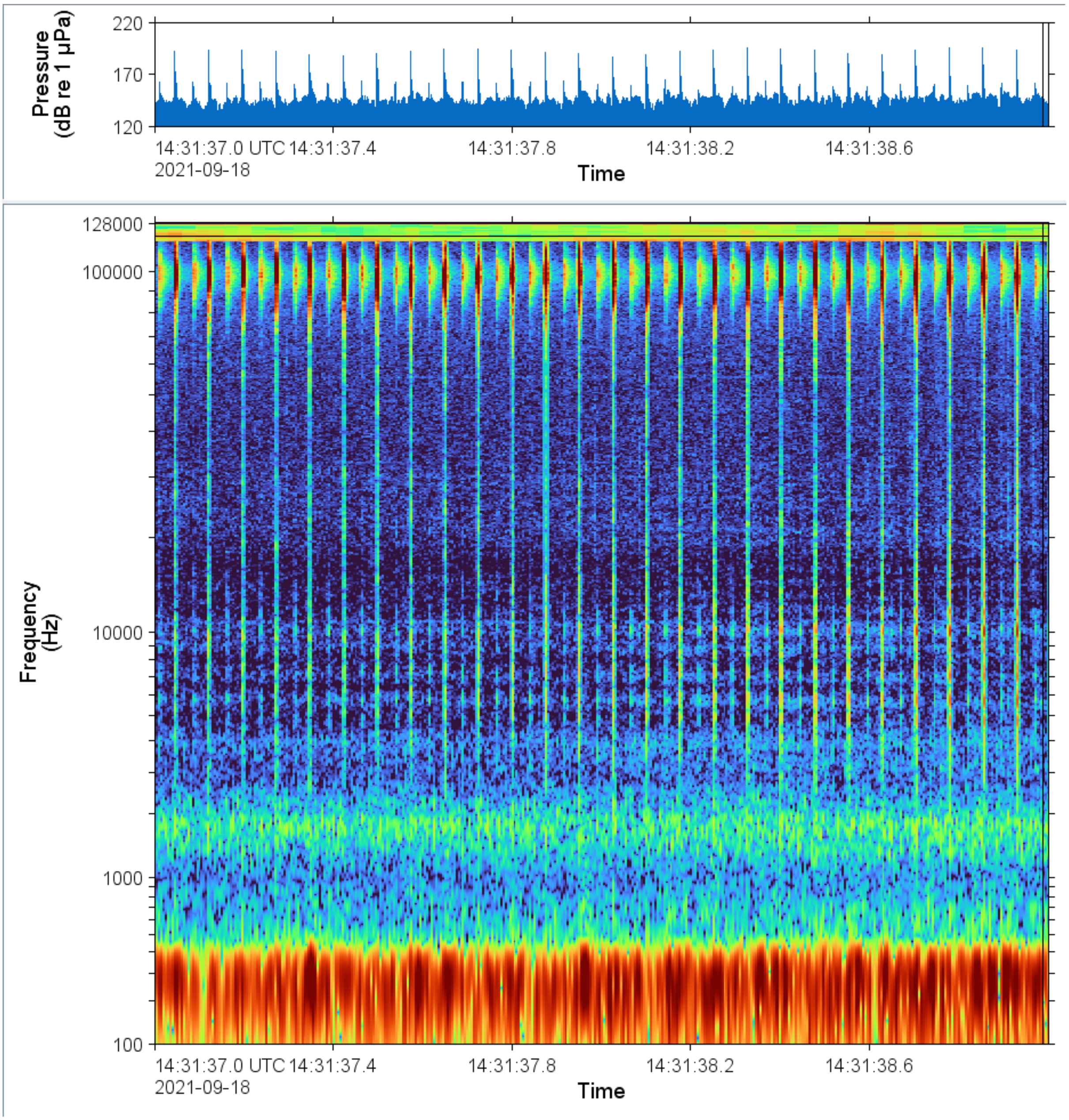


Figure F-17. Station A – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

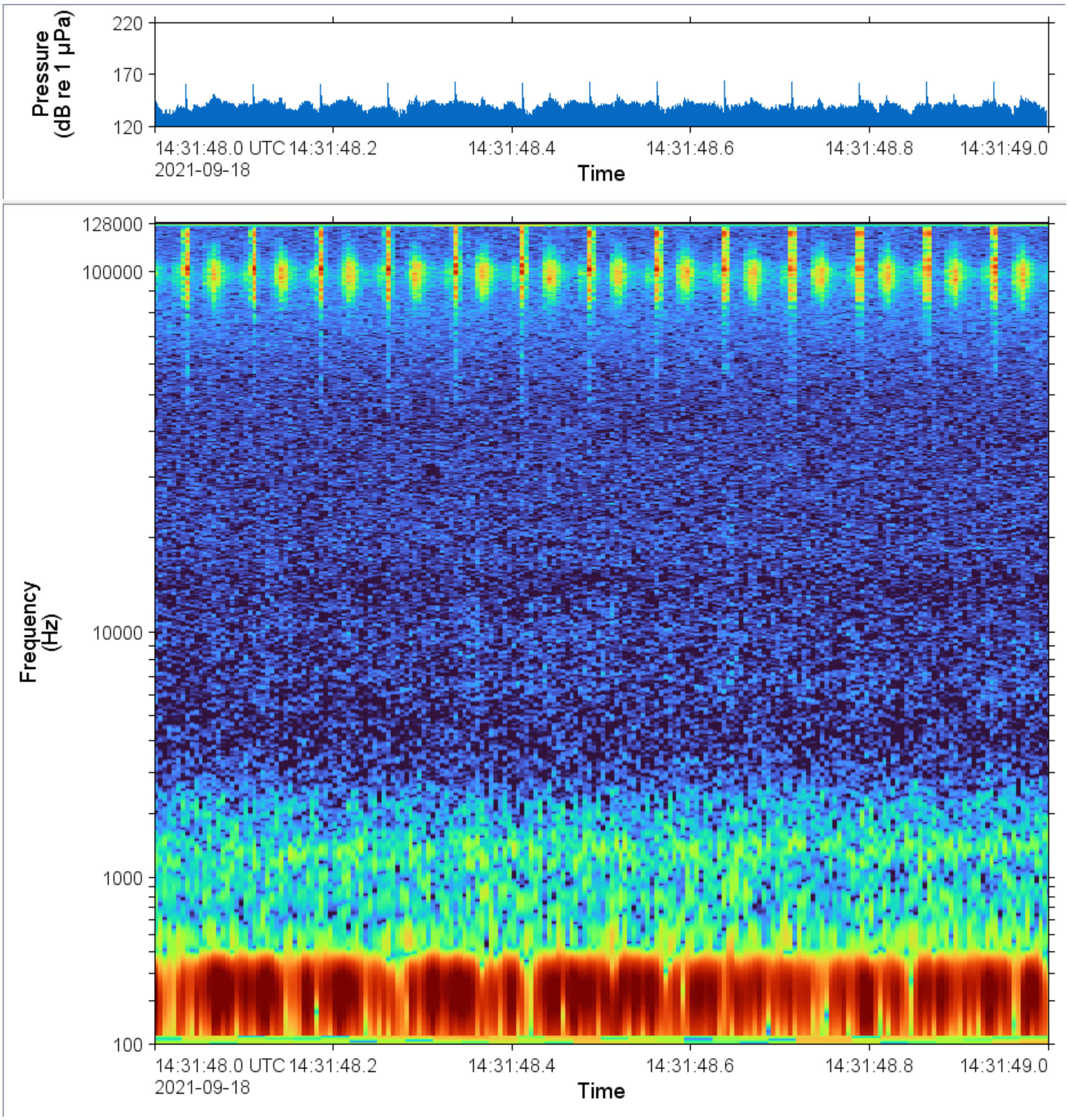


Figure F-18. Station B – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

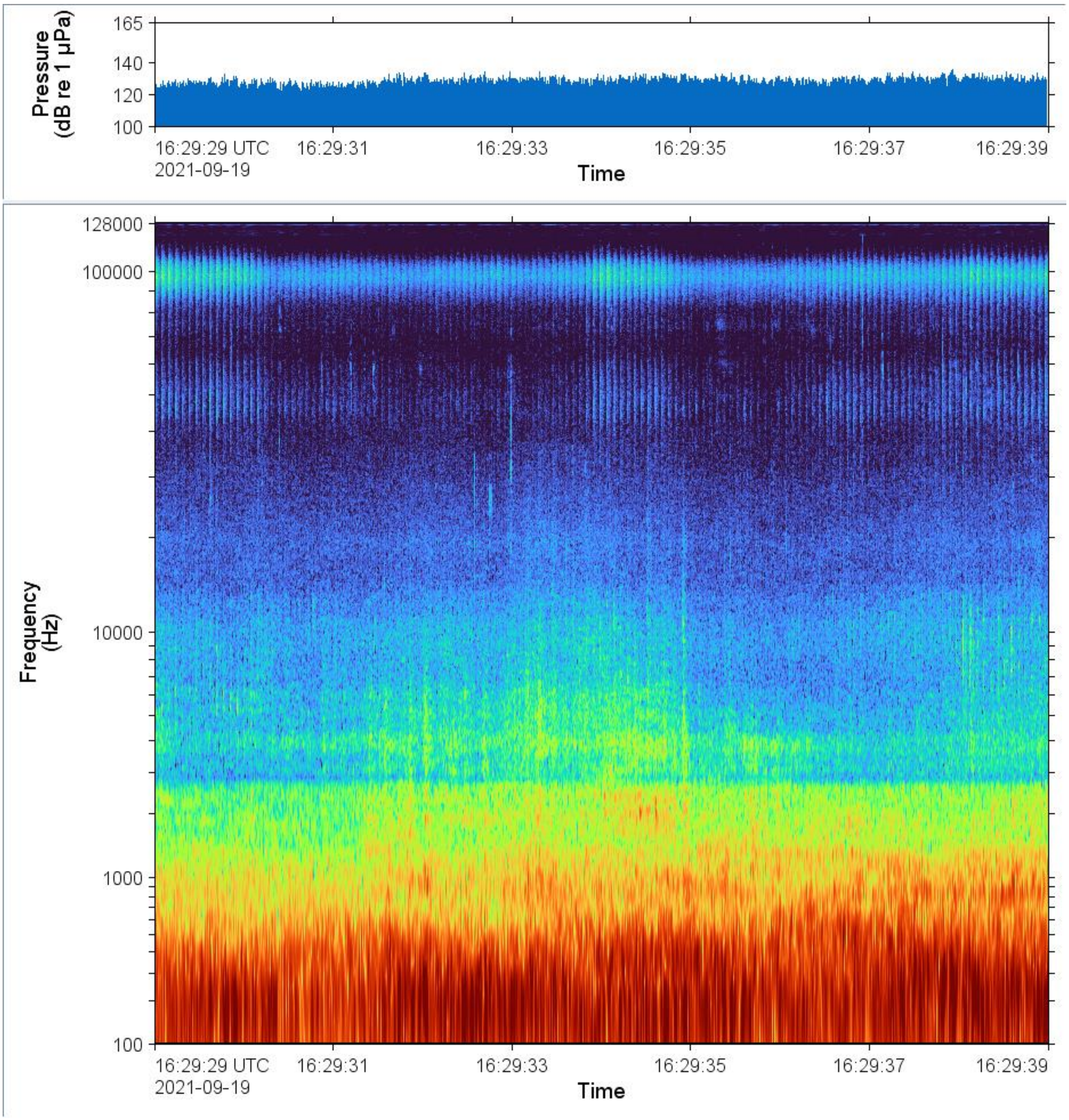


Figure F-19. Station C – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

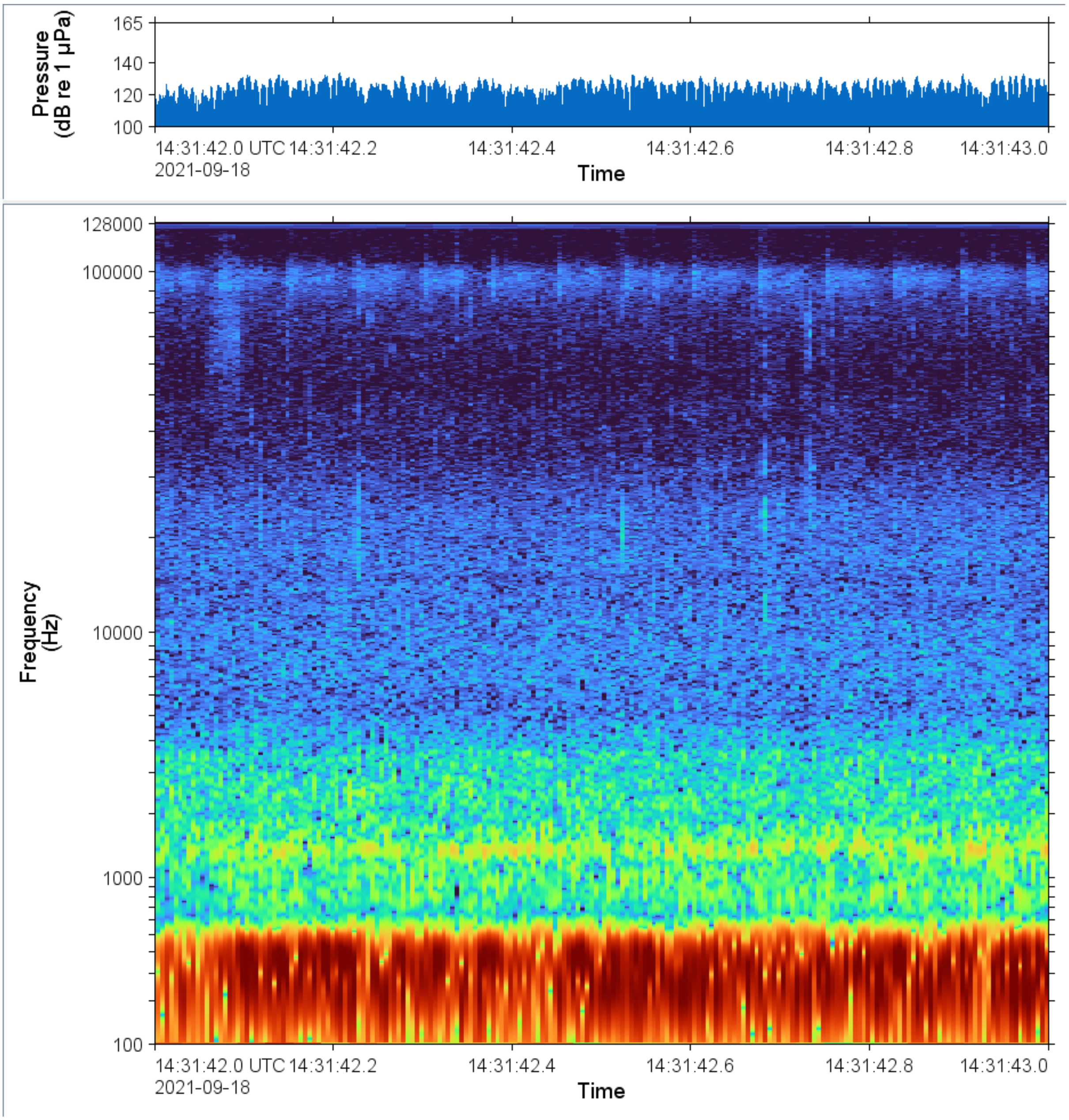


Figure F-20. Station D – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

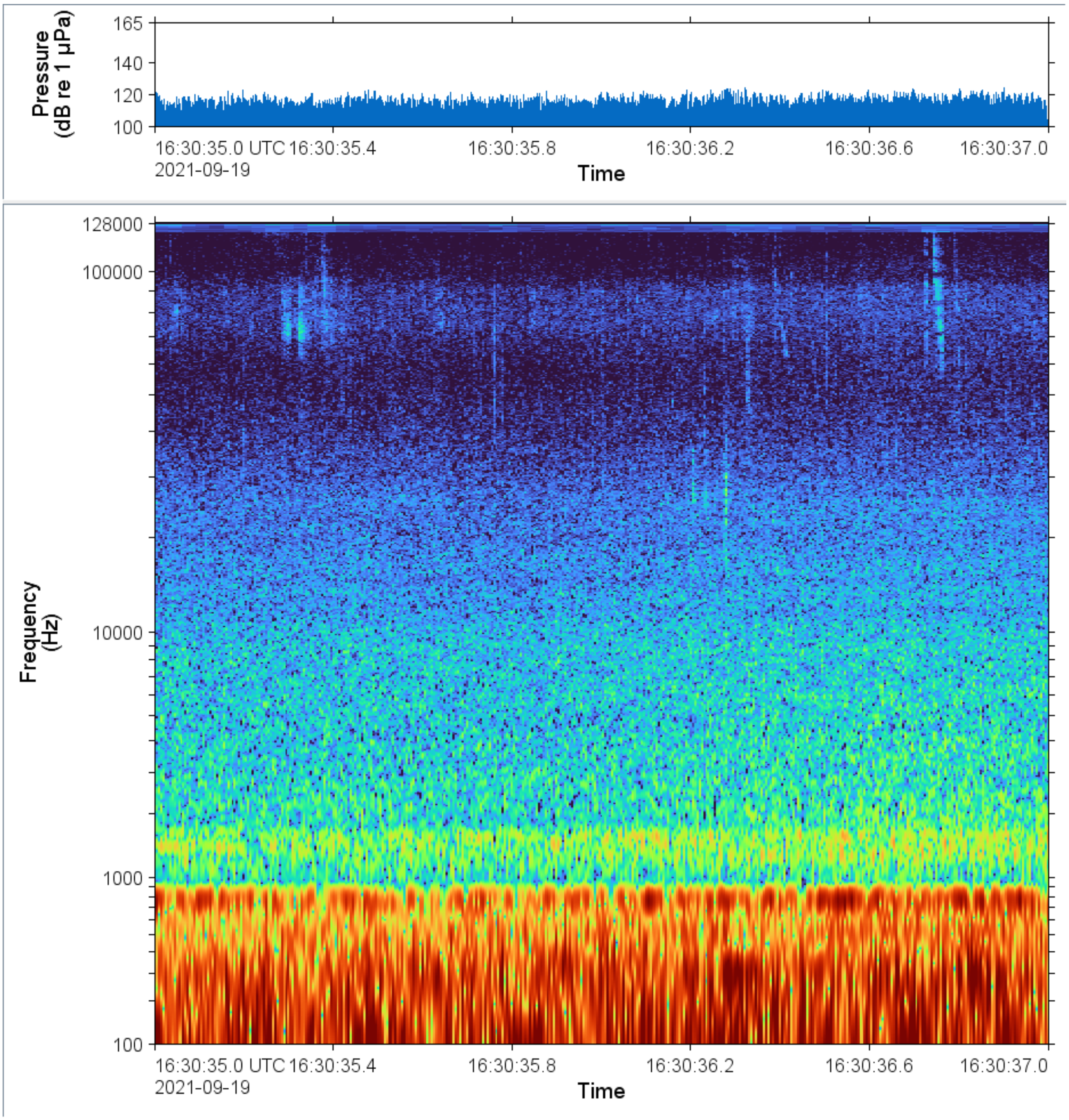


Figure F-21. Station E – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

F.4. Multi-beam echo sounder

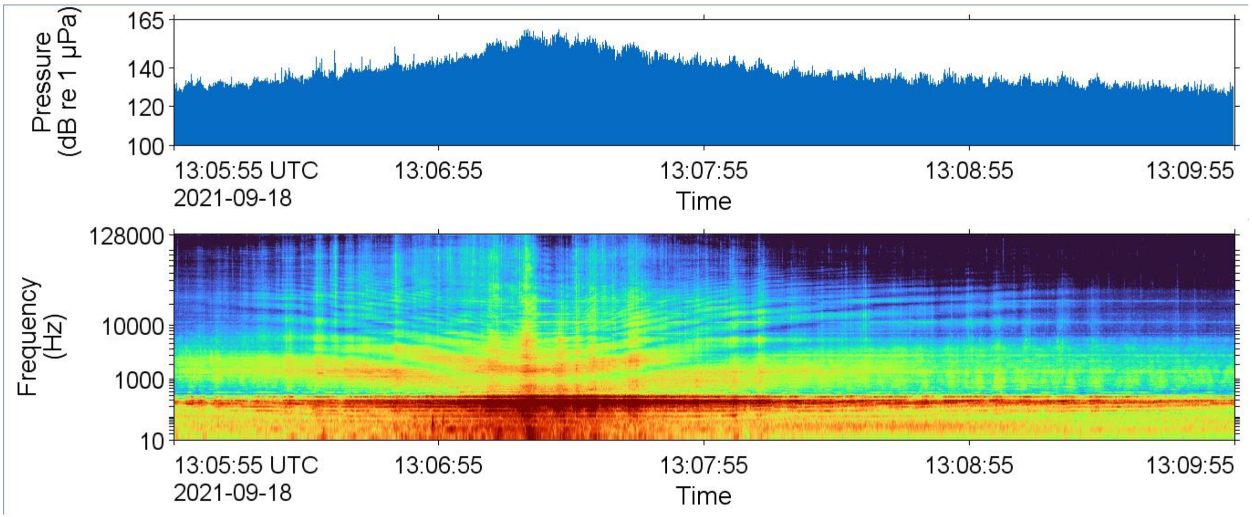


Figure F-22. Station A – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

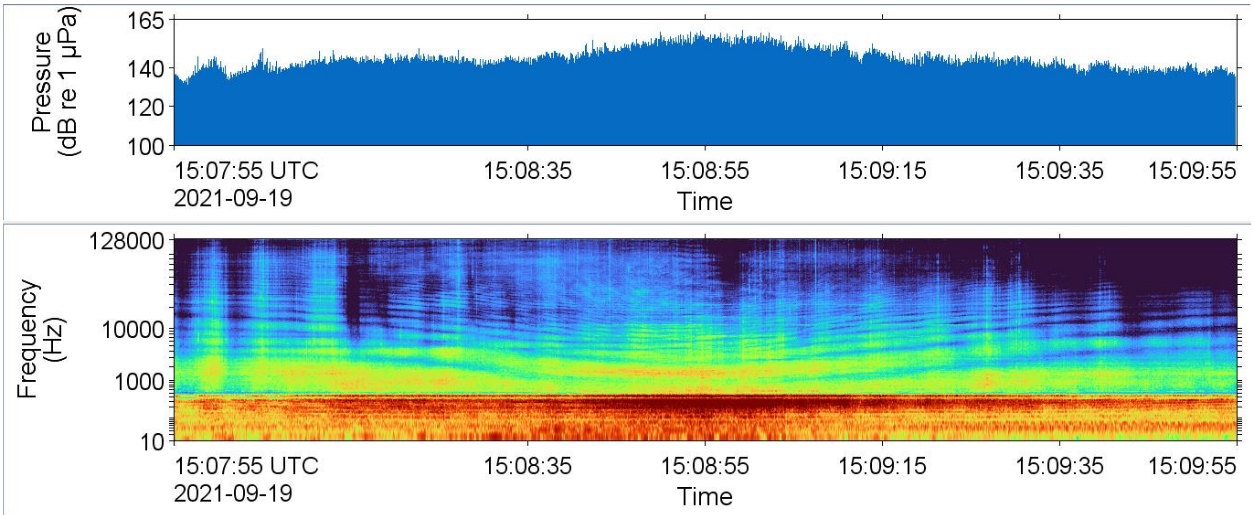


Figure F-23. Station A – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

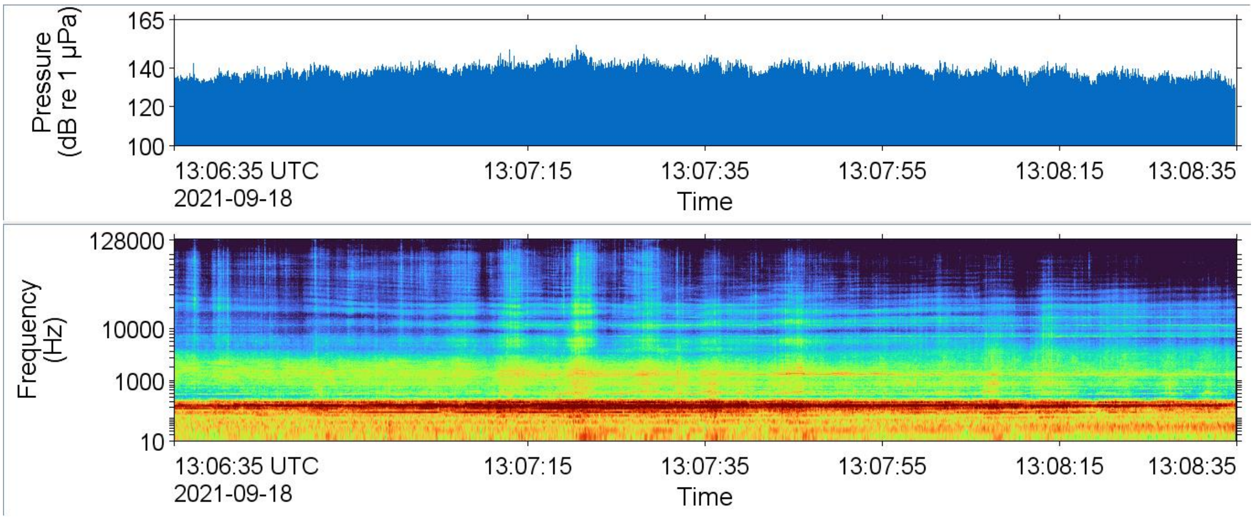


Figure F-24. Station B – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

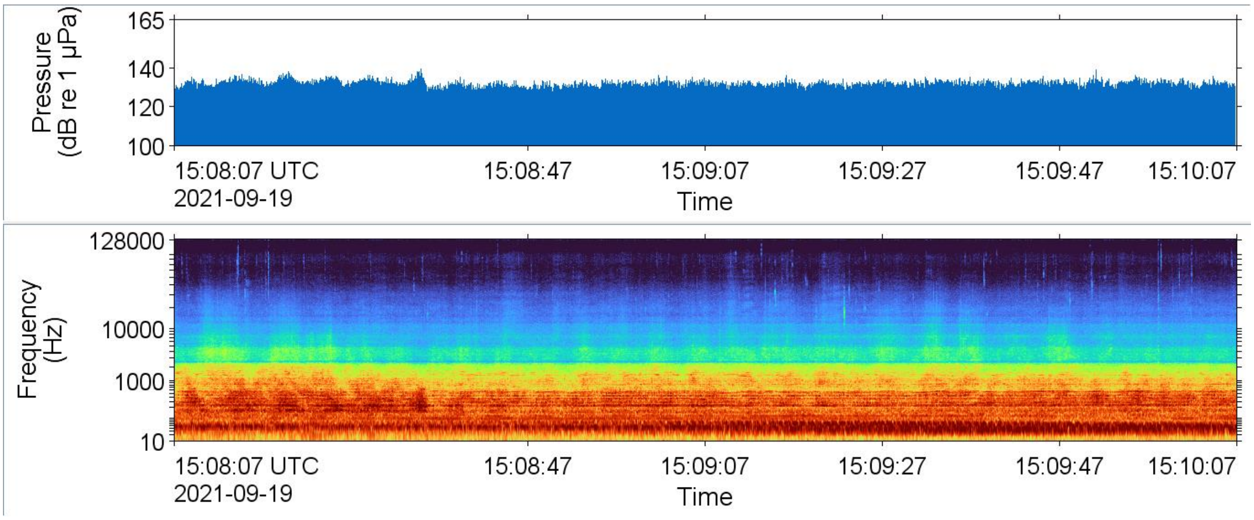


Figure F-25. Station C – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

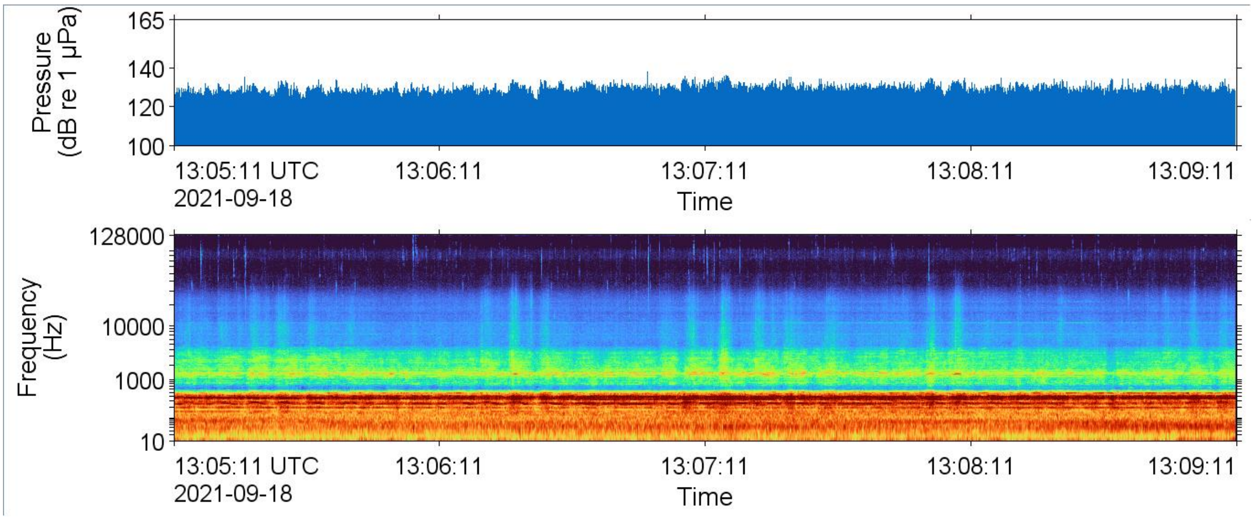


Figure F-26. Station D – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

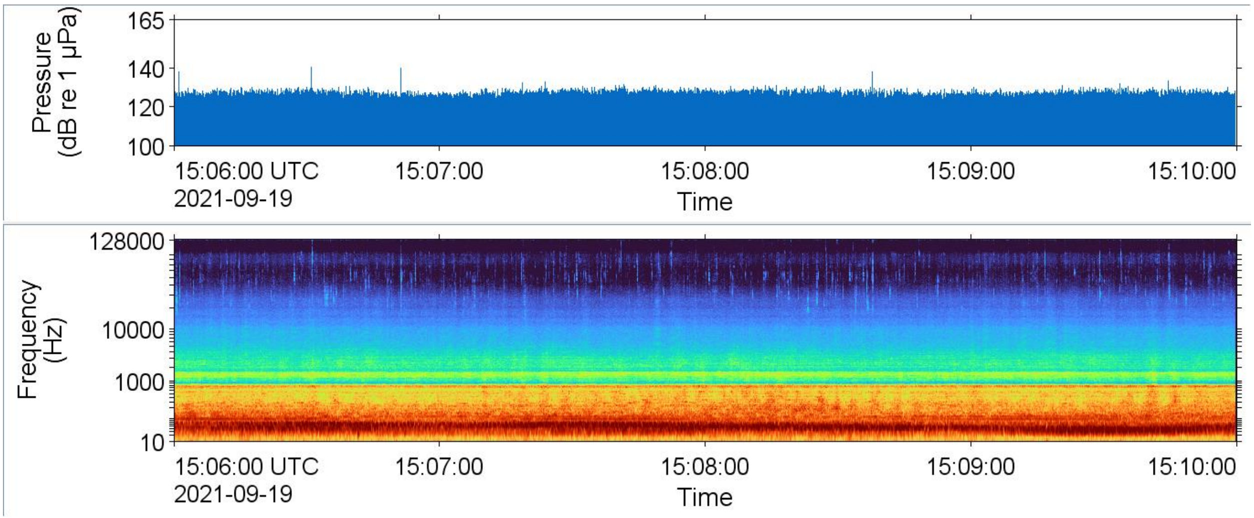


Figure F-27. Station E – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

F.5. Side scan sonar without USBL

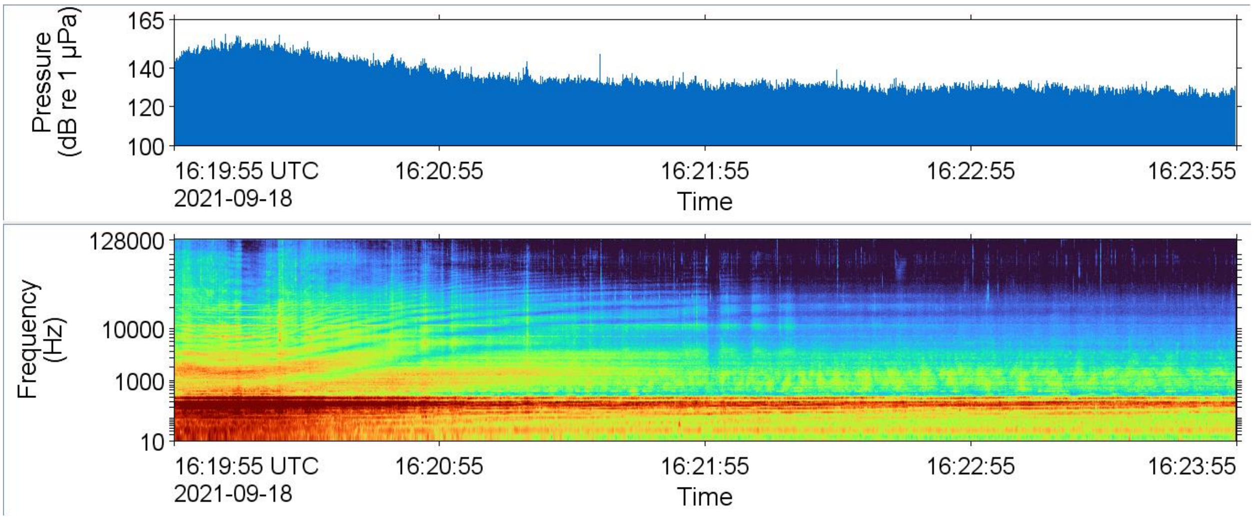


Figure F-28. Station A – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

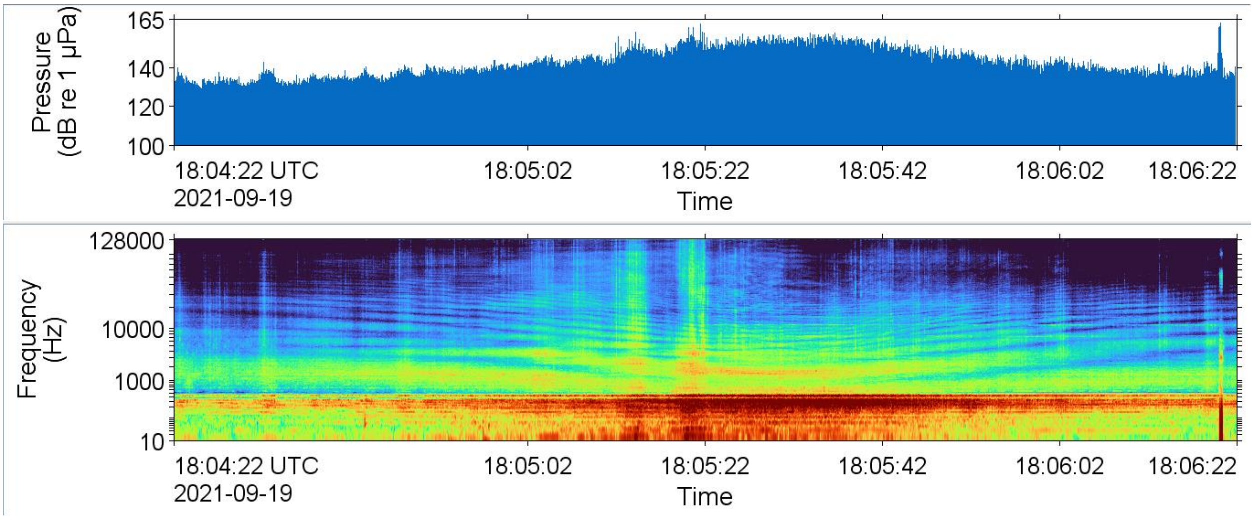


Figure F-29. Station A – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

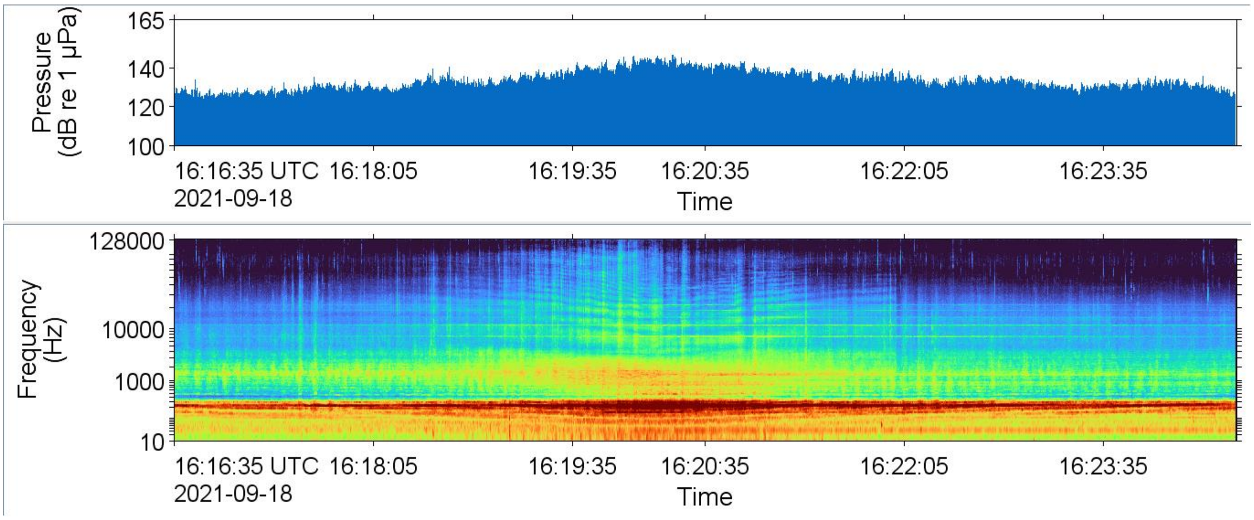


Figure F-30. Station B – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

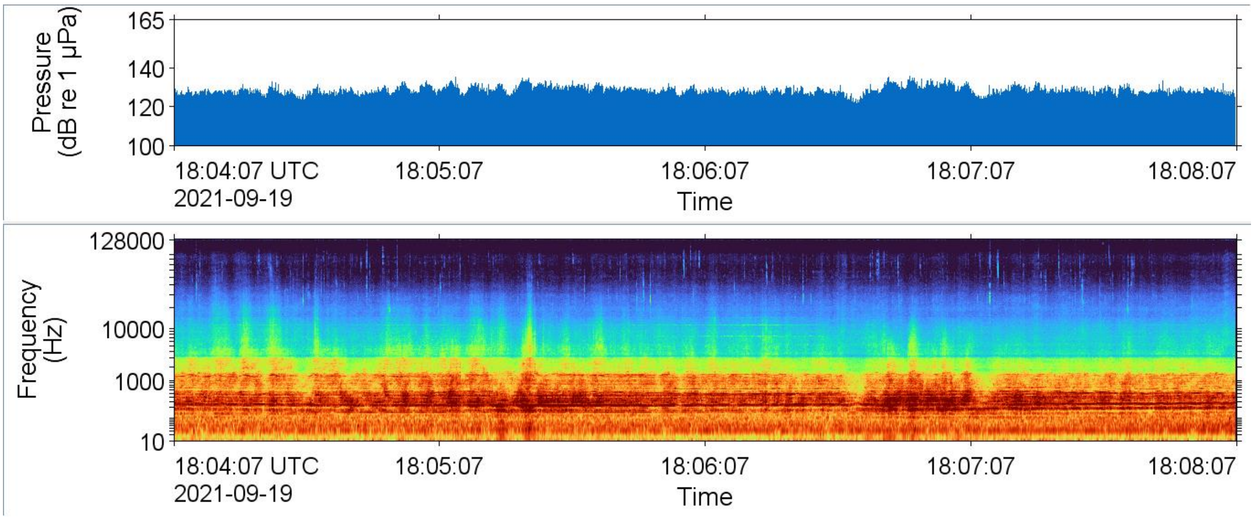


Figure F-31. Station C – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

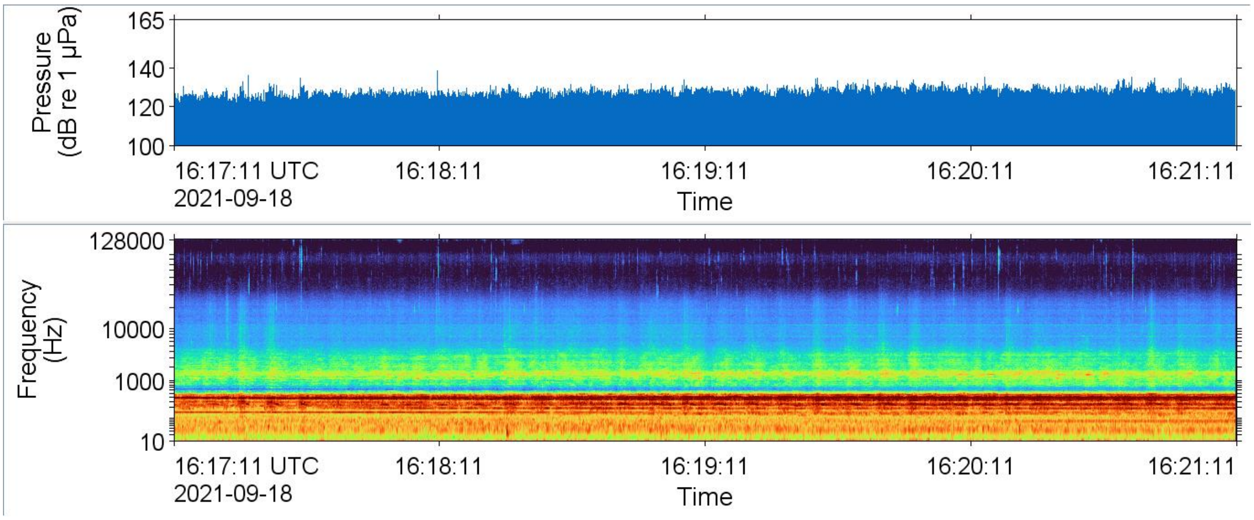


Figure F-32. Station D – Test 1 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

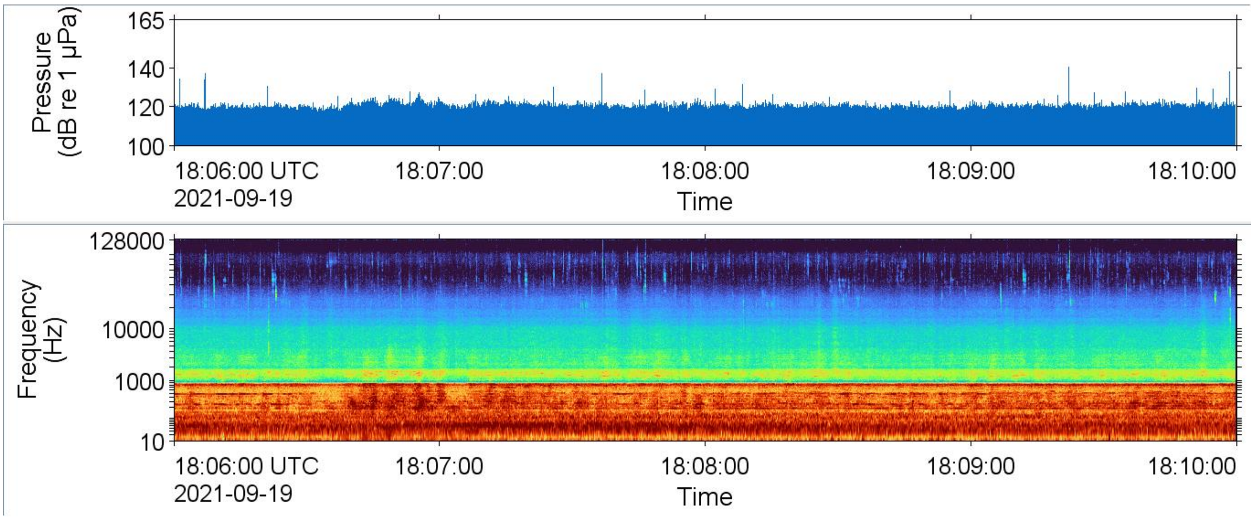


Figure F-33. Station E – Test 2 Pass 1: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time for Test 1 Pass 1 at 4.5 kn (2 Hz frequency resolution, 0.0125 s time window, 0.03 s time step, and Hamming window, normalised across time).

F.6. Side-scan sonar with USBL

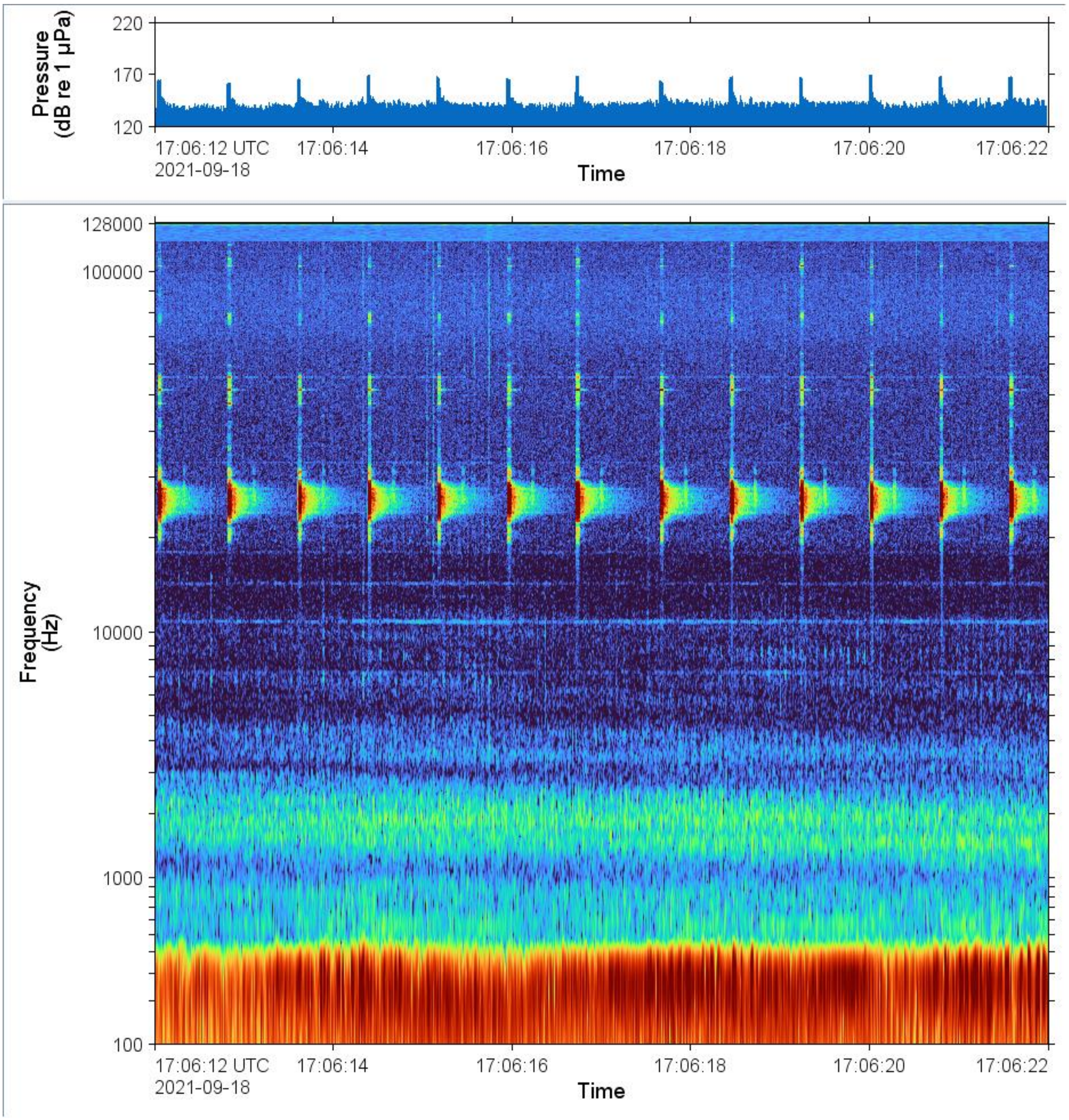


Figure F-34. Station A – Test 1 Pass 2: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window, normalised across time).

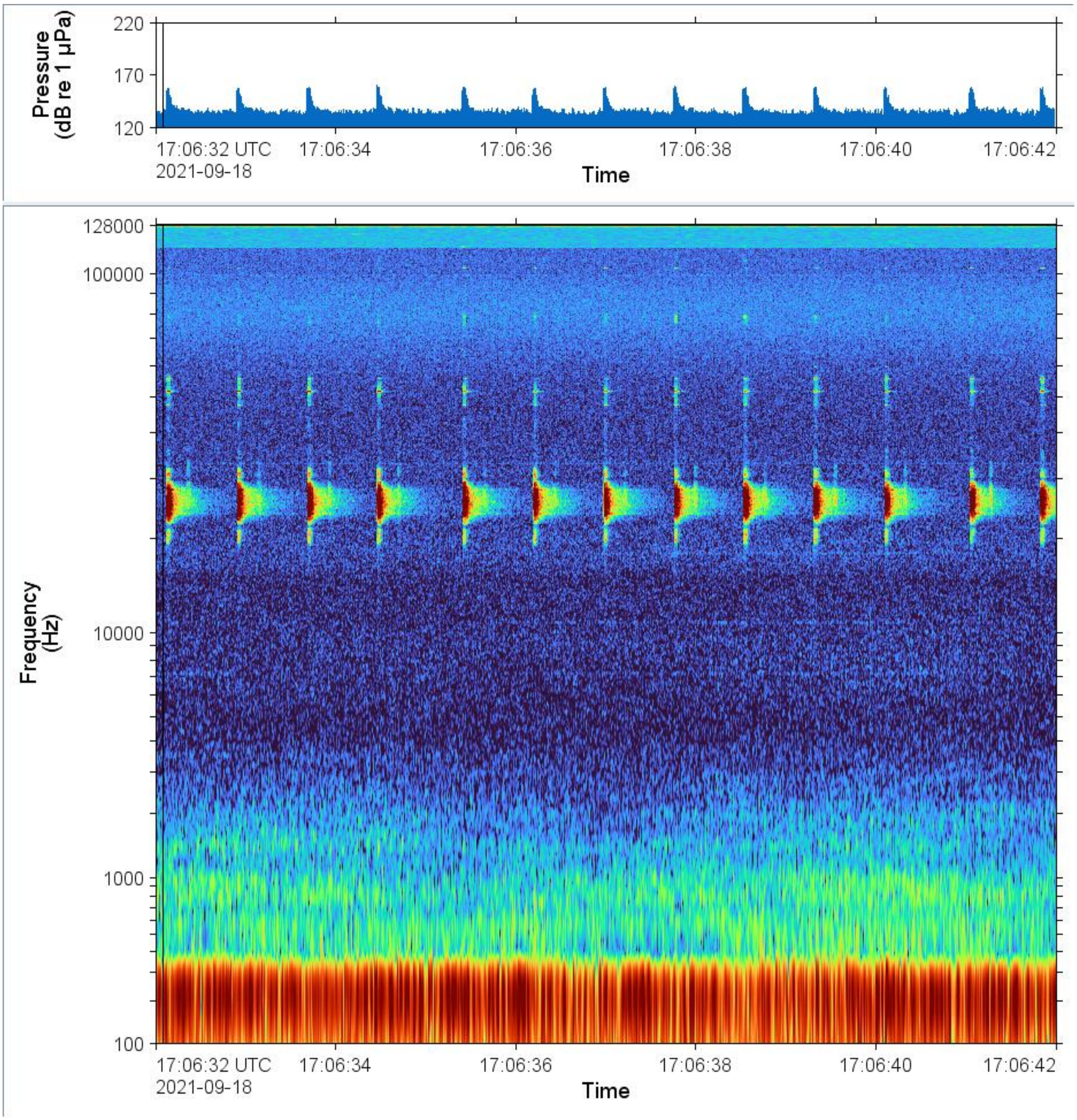


Figure F-35. Station B – Test 1 Pass 2: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window, normalised across time).

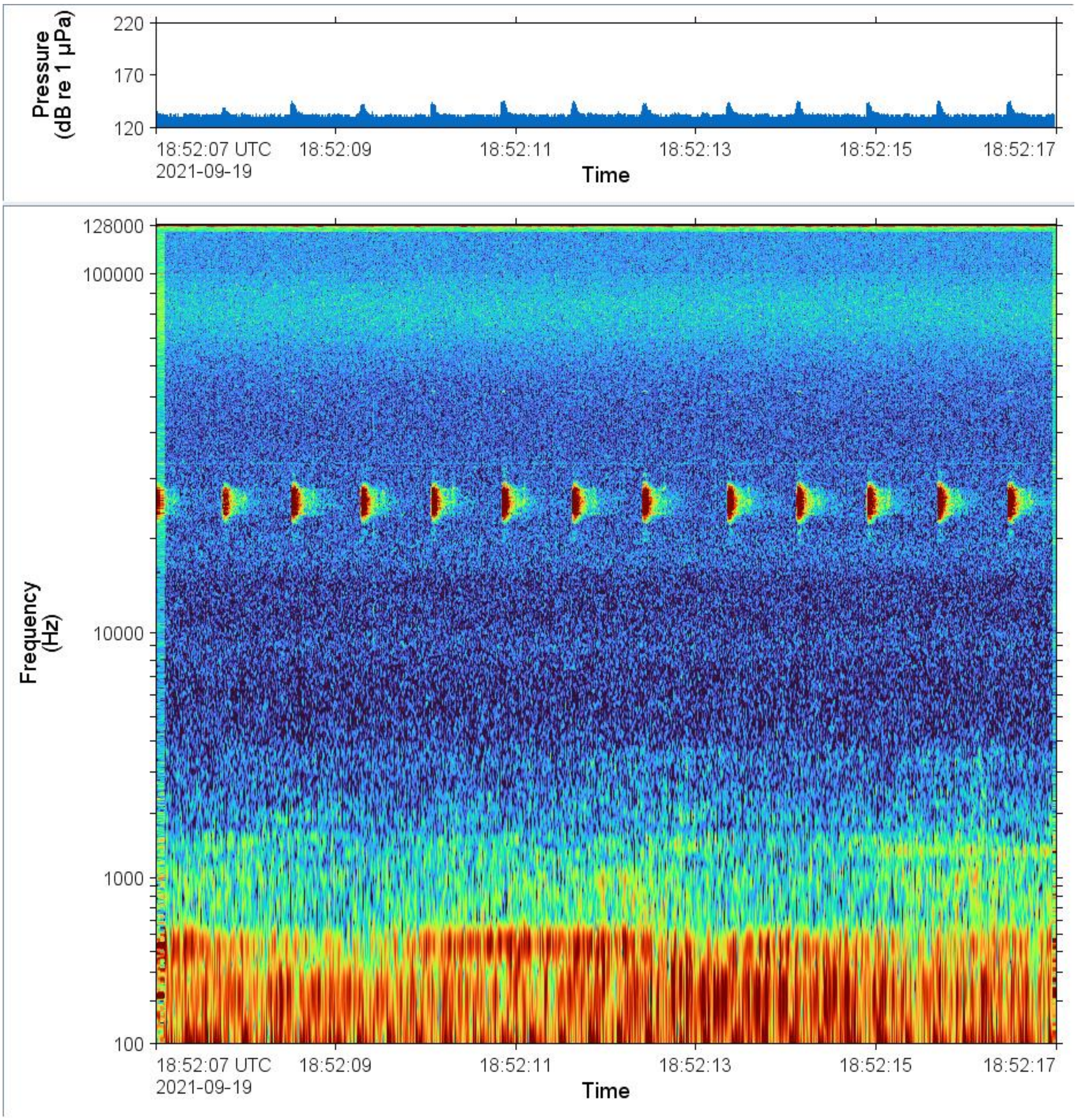


Figure F-36. Station C – Test 2 Pass 2: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window, normalised across time).

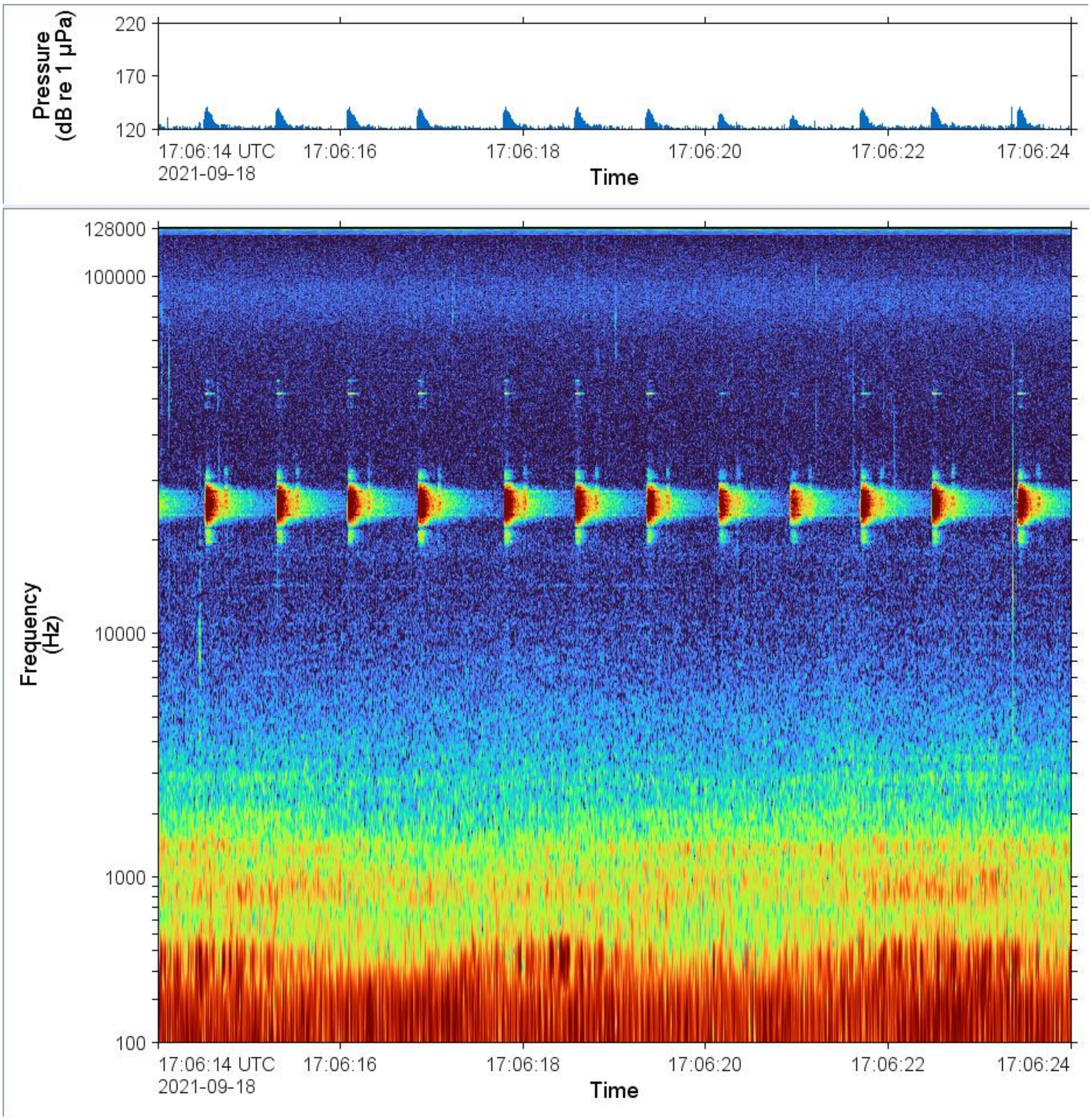


Figure F-37. Station D – Test 1 Pass 2: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window, normalised across time).

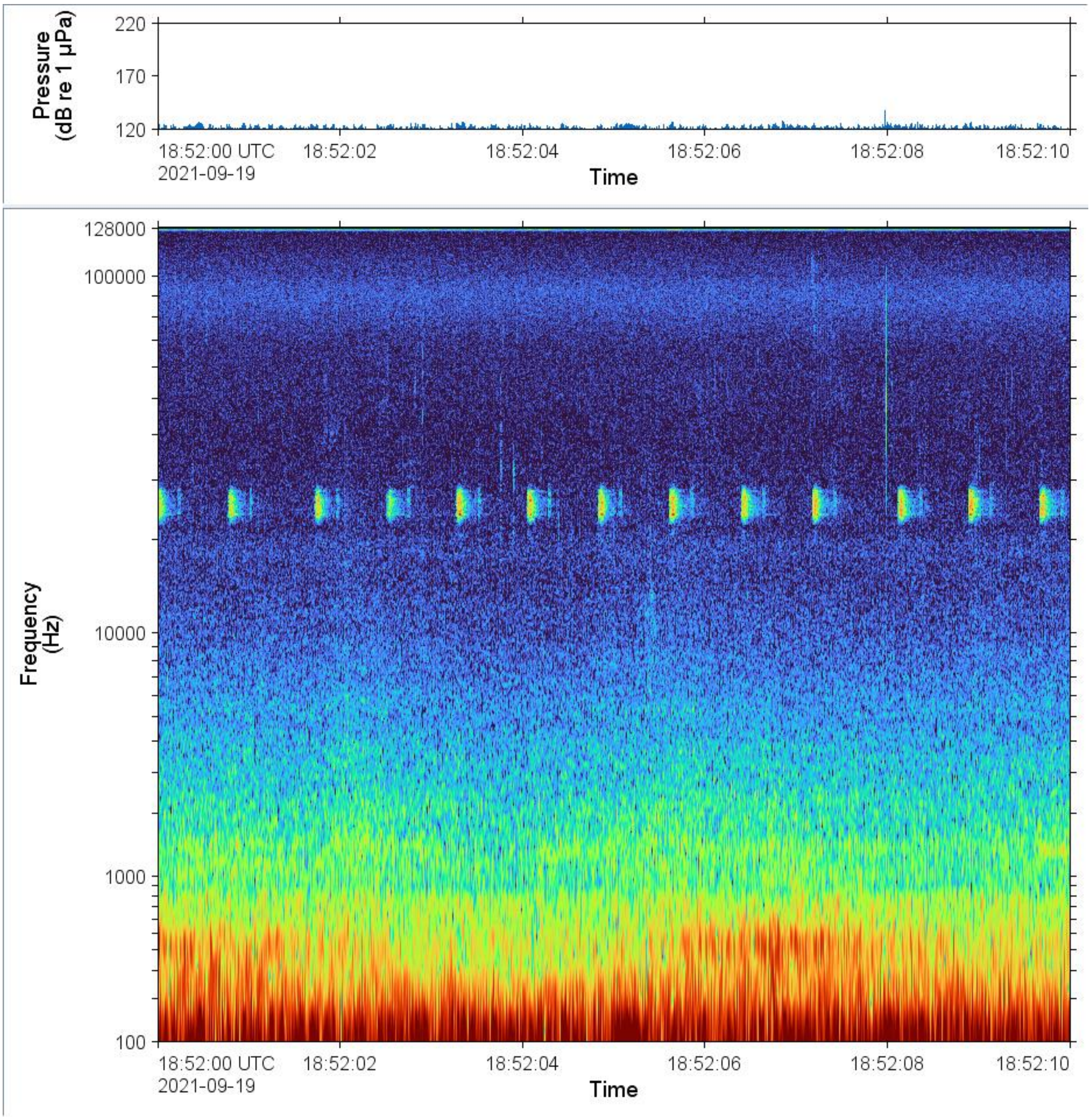


Figure F-38. Station E – Test 2 Pass 2: (Top) Waveform and (bottom) spectrogram of the closest point of approach (CPA) time at 4.5 kn (1 Hz frequency resolution, 0.01 s time window, 0.005 s time step, and Hamming window, normalised across time).