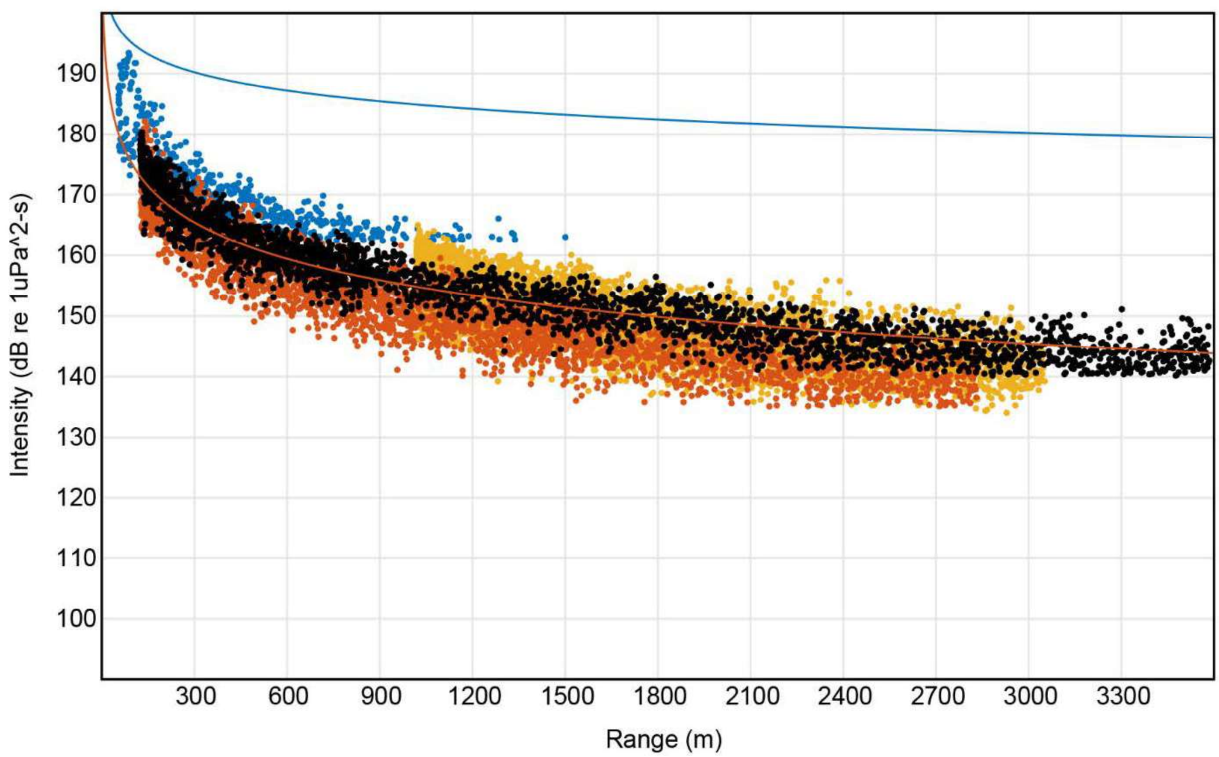
OCS Study
BOEM 2018-052

Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing



US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

BOEM
Bureau of Ocean Energy Management

This Page Intentionally Left Blank

OCS Study
BOEM 2018-052

Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing

September 2018

Authors:
Michele B. Halvorsen and Kevin D. Heaney

Prepared under BOEM Award M15PC00011

Submitted by:
CSA Ocean Sciences Inc.
8502 SW Kansas Avenue
Stuart, Florida 34997
Telephone: 772-219-3000

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

This Page Intentionally Left Blank

DISCLAIMER

Study concept, oversight, and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Contract Number M15PC00011. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2018-052. The report is also available at the National Technical Reports Library at https://ntrl.ntis.gov/NTRL/.

CITATION

Halvorsen MB, Heaney KD. 2018. Propagation characteristics of high-resolution geophysical surveys: open water testing. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. Prepared by CSA Ocean Sciences Inc. OCS Study BOEM 2018-052. 806 p.

ABOUT THE COVER

Cover graphic by Kevin Heaney representing the Mini Sparker, Section 4.28 at Site 3.

ACKNOWLEDGMENTS

We would like to thank Stan Labak for his understanding and encouragement throughout this challenging project as well as critical feedback and review of all reports. Thank you to Patrick Hart and Jeff Martin for rapid engineering responses in the field to address the many technical challenges that arose. Thank you to Patrick Hart and David Foster for critical review, feedback, and supplement of information on the draft which helped to improve the final report. Thanks to Kelly Jones for processing well over 1,300 figures and tracking the many details of this massive report, her reliability, and overall support were greatly appreciated. Thanks to Kayla Hartigan and Stephanie Urquhart for their attention to detail, reliability, and overall support of managing the final report. Thanks to Gerald Reynolds for data management and storage of the 27 TB generated by this project. Thanks to Andrew Heaney and James Murray, of OASIS Inc., for their help in data processing, documentation, and data management.

This Page Intentionally Left Blank

Contents

Contents
(Continued)

Page

Contents (Continued)

Page

Contents
(Continued)

Contents
(Continued)

Page

Contents
(Continued)

Page

Contents
(Continued)

Page

Contents
(Continued)

List of Figures

Page

List of Figures
(Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures
(Continued)

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures
(Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures
(Continued)

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Tables

Page

List of Tables (Continued)

Page

List of Tables (Continued)

Page

List of Tables (Continued)

Page

List of Tables (Continued)

Page

List of Tables (Continued)

Page

List of Tables (Continued)

Page

List of Tables (Continued)

Page

List of Acronyms and Abbreviations

3D	three-dimensional
AA	Applied Acoustics Engineering, Ltd.
BOEM	Bureau of Ocean Energy Management
Boomer	AA 251 Boomer
Bubble Gun	FSI Bubble Gun
Ch	Channel
CPA	closest point of approach
CSA	CSA Ocean Sciences Inc.
dB	decibel
Delta Sparker	Applied Acoustics (AA) Delta Sparker
EK60	Simrad EK60 38 kHz
ET3100	Edgetech 424 Chirp 3100P
ET3200	Edgetech 424 Chirp 3200X
ET4200	Edgetech 4200 side-scan
ET512i	Edgetech 512i
FSI	Falmouth Scientific, Inc.
FSTP	field sampling test plan
GPS	global positioning system
GMT	general mountain time
HASP	health and safety plan
HF	high frequency
HPU	hydraulic power unit
h	hour
HRG	high-resolution geophysical
HSSE	Health, Safety, Security, and Environment
Hz	hertz
Int16	16 bit signed integers
J	joule
kHz	kilohertz
kJ	kilojoule
Klein	Klein 3000 side-scan
km	kilometer
kn	knot
Knudsen	Knudsen 3260 Chirp
LF	low frequency
m	meter
μPa	micropascal
MiniGI-1	Sercel Mini GI (30/30) one airgun
MiniGI-22	Sercel Mini GI (30/30) two airguns
MiniSparker	SIG 2 Mini-sparker
μs	microsecond
ms	millisecond
NMFS	National Marine Fisheries Services
NUWC	Naval Undersea Warfare Center
OASIS	Ocean Acoustical Services and Instrumentation Systems
PRI	pulse repetition interval
QA/QC	quality assurance/quality control
R/V	research vessel
R7111	Reson 7111

List of Acronyms and Abbreviations (Continued)

R7125	Reson 7125
re	relative
RL	received level
rms	root mean square
R/V Sharp	R/V Hugh R. Sharp
S Boom	AA S-Boom 252
s	second
SD	standard deviation
SEL	sound exposure level
SEL_{cum}	cumulative sound exposure level
S1	Site 1
S2	Site 2
S3	Site 3
S4	Site 4
S5	Site 5
SL	source level
$SL_{pk\text{-}pk}$	peak-to-peak source level
SMS	sound monitoring system
SNR	signal-to-noise ratio
SPL_{pk}	peak sound pressure level
SPL_{rms}	root-mean-square sound pressure level
SwathPlus	SEA SWATHPlus Interferometric
TB	terabyte
USGS	U.S. Geological Survey
V	volt
VHF	very high frequency

1 INTRODUCTION

1.1 Background

High-resolution geophysical (HRG) sound sources are integral to a range of commercial, academic, and governmental marine operations supporting marine-based resource sectors, such as energy (e.g., oil and gas, renewable), marine minerals, and infrastructure (e.g., ports, pipelines, cables). Geophysical sources are commonly used during habitat restoration, seafloor mapping, environmental characterization, identification of hazards, and detection of archaeological resources. Geophysical surveys use sound sources that output acoustic signals within frequency bandwidths and amplitudes best suited for the desired survey product. The acoustic signals often are impulsive, tonal, or chirp pulses (short duration signals that sweep through many frequencies). Because of the uncertainty of potential acoustic impacts on marine life from geophysical surveys, regulations require precautionary mitigation strategies.

Regulations treat HRG surveys differently than they do other geophysical (e.g., seismic airgun) surveys because of the often higher frequency (>10 kilohertz [kHz]) signal energy content of many of the sources. The supposition is that higher frequency signals, even at high amplitudes, likely would not propagate far enough for marine species to be negatively affected by received sound levels. However, the lack of scientific evidence prompted the Bureau of Ocean Energy Management (BOEM) to initiate this study. The study was designed to provide high-quality field measurement data from common HRG sources to begin evaluating propagation characteristics to inform potential acoustic impacts on marine life. HRG sources for this study can be grouped into three categories: (1) impulsive signals (e.g., airguns, boomers, and sparkers), which are broadband with most energy at low frequencies; (2) chirp sonars, which are frequency sweeps with most energy at high frequencies; and (3) sonars (e.g., side-scan, multibeam), which are high-frequency tones or chirp signals. Across all sources, operational frequencies range from 20 hertz (Hz) to approximately 900 kHz. These units operate at peak-to-peak source levels (SL_{pk-pk}) ranging from 162 to 240 decibels relative to 1 microPascal meter (dB re 1 μPa m). This SL unit is sometimes written as "dB re 1 μPa at 1 m" (see Note 3 to entry 3.3.2.1 in ISO 18405 [ISO, 2017]); the intended meaning is the same in all three cases (Ainslie, 2010).

1.2 Purpose and Approach

The purpose of this project is to support BOEM's goal of ensuring that acoustic mitigation requirements are scientifically supported, cost effective, practical, and effective at decreasing acoustic impacts, particularly in shallow-water environments where the understanding of acoustic dynamics is limited compared to deep-water environments. The collection of acoustic measurements in shallow-water field environments, along with basic environmental characterizations, fills a critical knowledge gap about acoustic impacts. These data can be used as propagation model inputs to verify and improve predictions about acoustic impacts and shallow-water propagations from these survey sources.

This study focuses on HRG surveys occurring in shallow water (<100 meters [m]) because these water depths represent areas where acoustic propagation is driven by boundary interactions, substrate type, and bathymetry. Accurate acoustic field measurements of HRG sources operating in these depths is considered a key component to validating propagation models to predict received sound exposure levels (SELs) during future Outer Continental Shelf (OCS) activities. These measurements are also valuable to multiple stakeholders who need to understand the various source operations and output characteristics (harmonics and sub-harmonics).

1.3 Project Team

For this project, CSA Ocean Sciences, Inc. (CSA) worked cooperatively with the U.S. Geological Survey (USGS), University of Delaware, Ocean Acoustical Services and Instrumentation Systems (OASIS), Seiche, Ltd. (Seiche), Hydro dB, and Noise Control Engineering (NCE). As prime contractor, CSA was responsible for overall project management, assisted in field sampling plan design, provided field operations staff, and managed compilation of and drafted the final report. The USGS provided the HRG sound sources and operations technicians for the sources. The University of Delaware provided the survey vessel and crew. OASIS assisted with field sampling plan design, analyzed and processed the acoustic data, and prepared portions of the written report. Seiche designed, fabricated, and programmed the acoustic acquisition buoys. Hydro dB provided assistance with field sampling plan design, consultation about technical challenges, and review of the final report. NCE assisted in field sampling plan design and review of the final report.

1.4 Project Objectives

CSA was contracted by BOEM to measure the three-dimensional (3D) sound field produced by 17 commonly used HRG sources and to document the sound propagation from each source in shallow water depths ranging from 10 to 100 m. The study objective was to provide appropriately measured sound fields for the HRG sources to allow better assessment of potential acoustic impacts to marine fauna. The Naval Undersea Warfare Center (NUWC) near-field study (Crocker and Fratantonio, 2016) was reviewed and incorporated into the field study design because it provided controlled, experimental measurements of the sources to be measured in the field study.

The in-field acoustic measurements were critical to the analysis and reporting of HRG received sound levels at the various test sites. Furthermore, the data set is necessary to support a future investigation focusing on validating and improving predicative propagation modeling for these HRG sources. The specific objectives of this study were as follows:

- Incorporate the results of the NUWC near-field study (Crocker and Fratantonio, 2016) with the results of the field measurements from this study;
- Prepare a field sampling test plan (FSTP) (CSA, 2016) using the R/V *Hugh R. Sharp* and acoustic recording buoys to capture acoustic characteristics of the sound fields generated by HRG sources during representative operations;
- Develop and execute the FSTP to adequately sample the 3D sound field produced by each HRG source in water depths of 10, 30, and 100 m for two substrate types (hard and soft), and to measure the sound field of each source at frequencies <200 kHz;
- Process and analyze acoustic and supporting operational data to describe the sound fields for and propagation characteristics of the measured HRG sources;
- Archive all acoustic, supporting operational, oceanographic, and meteorological data; and
- Prepare a report that describes the testing procedure, quantifies the measurements, analyzes the resulting acoustic data, compares measurements to NUWC near-field study results, and discusses the significance of measured data.

1.5 Project Description

Overall, the project team designed and executed a field test plan to measure the sound field generated by HRG source signals, analyzed the acoustic data set, and reported the findings. The project team reviewed the final NUWC near-field study (Crocker and Fratantonio, 2016) measurements of HRG sources collected under controlled conditions in a test tank and confined bodies of water. The NUWC results provided important source characteristics necessary to guide the design of the FSTP. Relevant information was extracted from the NUWC results and summarized to obtain the expected SEL, peak sound pressure level (SPL_{pk}), root-mean-square sound pressure level (SPL_{rms}), and beam pattern information from each source for reference.

The project team, in cooperation with BOEM and USGS, identified the specific vessel, HRG sources, dates of field operation, test sites, and substrate types to best implement the acoustic measurement study (see **Section 2.1**). The HRG sources were ranked by BOEM and USGS based on their priorities. The project team developed an FSTP based on the identified logistics, data needs, and near-field study results of beam patterns and HRG source metrics. The FSTP contained an experimentally robust study design that provided replication of acoustic signal transmission recorded at various distances and adequately sampled the sound fields (in replicate) of each HRG source. The FSTP included the following parameters:

- Measure acoustic signals from up to 17 HRG sources (**Table 1.5-1**);
- Measure sound fields produced by specified operational modes for each HRG source (e.g., frequencies, power levels, pulse lengths, deployment configurations);
- Document the operational modes and deployment conditions of HRG equipment;
- Test the HRG sources in three nominal operational water depths of approximately 10, 30, and 100 m;
- Test the HRG sources in areas containing different sediments types, specifically, a strong reflector (sand) and a weak reflector (mud/silt);
- Report received HRG acoustic signal metrics of SPL_{pk}, SPL_{rms}, and SEL values as a function of range and bearing;
- Measure received levels (RLs) produced by each HRG source down to 100 dB (SPL_{rms}), to ambient or a near-ambient conditions, or out to 4 kilometers (km) from the source;
- Measure up, down, and cross-slope propagation configurations;
- Collect supporting oceanographic, meteorological, and environmental data;
- Document the location of all source and receiver positions during measurements;
- Document pertinent ship self-noise data; and
- Record ambient sound conditions.

Table 1.5-1. HRG sources tested during this project, their primary use, the source category, and signal type produced by the source.

Source	Source Category	Signal type
Seafloor Mapping		
Edgetech 4200	Side-scan Sonar	Chirp
Klein 3000	Side-scan Sonar	Tone Burst
Reson 7111	Multibeam Echosounder	Tone Burst
Reson 7125	Multibeam Echosounder	Tone Burst
Simrad EK60 38 kHz	Multibeam Echosounder	Tone Burst
SEA SWATHPlus	Interferometric Sonar	Tone Burst
Subbottom Profiling		
Applied Acoustics Delta Sparker	Seismic source	Impulse
Applied Acoustics 251 Boomer	Seismic source	Impulse
Applied Acoustics 252 S-Boom	Seismic source	Impulse
Falmouth Scientific Inc. Bubble Gun	Seismic source	Impulse
Sercel Mini GI (30/30)	Seismic source	Impulse
Sercel Mini GI (30/30)	Seismic source	Impulse
SIG 2 Mini Sparker	Seismic source	Impulse
Edgetech 512i	Subbottom Profiler	Chirp
Edgetech 424 3100P	Subbottom Profiler	Chirp
Edgetech 424 3200XS	Subbottom Profiler	Chirp
Knudsen 3260	Subbottom Profiler	Chirp

HRG = high-resolution geophysical.

The field survey team consisted of personnel from CSA, Seiche, USGS, and the crew of the R/V *Hugh R. Sharp*. Field measurements were executed as outlined in the FSTP in cooperation with BOEM and USGS Chief Scientists. The CSA survey team arrived in Lewes, Delaware on 26 June 2016, met the R/V *Hugh R. Sharp* on 27 June 2016, and immediately commenced mobilization activities. Mobilization was completed on 28 June 2016, and with all personnel on board, the R/V *Hugh R. Sharp* commenced transit to Site 4. At each test site, an array of acoustic recorders was deployed, the HRG sources were operated, and acoustic data were recorded and stored (see **Section 2.0**). Field measurements were conducted in two consecutive cruise legs to allow re-fueling and source equipment changes. Leg 1 occurred from 29 June to 7 July 2016; and leg 2 occurred from 8 to 14 July 2016. Field operations took place 24 hours per day for all 17 days of the survey. Demobilization of the vessel occurred on 15 July 2016.

Collected acoustic data were analyzed (**Section 3.0**) by Dr. Kevin Heaney of OASIS to (1) characterize sources' acoustic parameters, including source level, spectrum, pulse lengths, and beam patterns; and (2) characterize the 3D sound field, including received level (i.e., SPL_{pk}, SPL_{rms}, and SEL), and signal spreading in time and frequency. The near-source measurements were compared to the NUWC test tank report measurements. The measured metrics from each HRG source were reported relative to the study site, substrate type, and relative water depth.

The project's final task involved preparing this report addressing the study goals. The acoustical terminology used in this report is compliant with ISO 18405 Underwater Acoustics–Terminology (ISO, 2017).

2 PROJECT METHODOLOGIES

2.1 Field Survey Design

At each of the five sites (**Section 2.1**), the same general field design was used, with some slight differences in hydrophone configurations. The FSTP detailed the methodology needed to acoustically measure HRG source signals to determine propagation characteristics of each source in an open-water environment (CSA, 2016). However, some parameters described in the FSTP were modified to adjust for field conditions and technical challenges encountered as a result of significant design-related failures with the acoustic measurement buoys (**Section 2.5.1.1, 2.6.3.1** and **Appendix B**). Eight acoustic recording buoys were mobilized; six were to be used in the acoustic field array and two were to be spares on board the R/V *Hugh R. Sharp*.

To accurately measure a 3D sound field produced by HRG sources in the presence of a given seafloor type, an acoustic field array consisting of acoustic acquisition buoys was deployed in the geometry shown in **Figures 2.1-1** and **2.1-2**. Originally, the array was composed of six acoustic recording buoys to be deployed at each test site (Figure 2.1-1). Four recording buoys (D, B, E, and F) were arranged in a line perpendicular to the source track approximately 0; 100; 1,000; and 4,000 m from the center of the source track (**Figure 2.1-1**). Relative to the line of four buoy positions (D, B, E, F), two buoys were deployed 100 m perpendicular to the source track, with one (A) positioned 2 km before the source track, and the other (C) positioned 2 km after the source track (**Figure 2.1-1**). **Figure 2.1-2** provides an underwater side view of the four recording buoy positions (D, B, E, F) for the three water depths tested.

The number of hydrophone pairs on each buoy varied depending on the water depth. The pairing of hydrophones consisted of a high-sensitivity (HS) and a low-sensitivity (LS) hydrophone to encompass the broad dynamic range of HRG signals. For buoy positions A, B, E, and F at Site 1 (S1) and Site 2 (S2), each buoy was equipped with a single pair of hydrophones; for Site 3 (S3) and Site 4 (S4), each buoy was equipped with two pairs of hydrophones; and for Site 5 (S5), each buoy was equipped with three pairs of hydrophones (**Figure 2.1-2**). At all sites, buoy position D was unique in that it had two components, a subsurface tripod mount (**Appendix B**, Section 3.2) and a surface buoy. The subsurface tripod mount was moored to the seafloor to provide a fixed single hydrophone position 1.5 m above seafloor, directly beneath the vessel track (**Figure 2.1-1**). The surface buoy provided surface access to the acoustic data at a distance of approximately 30 m from the vessel track (**Figure 2.1-1**). The locations of the acoustic buoys were marked using the R/V *Hugh R. Sharp's* global positioning system (GPS). The location of each source was calculated using the vessel's GPS position and the x, y, z offset of the source relative to the GPS antenna provided by USGS. By using the known position of the source combined with each buoy's deployed position, the acoustic metrics (**Section 1.5**) were calculated for sound impulses.

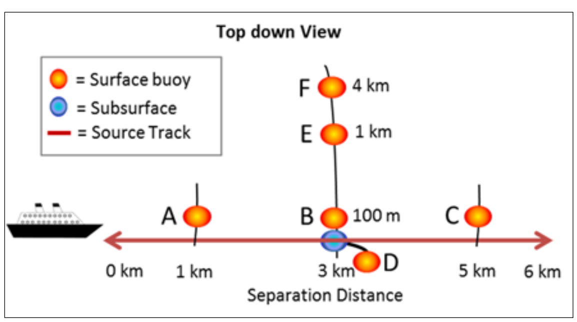


Figure 2.1-1. Design of the original acoustic field array; top-down view.
Position D had a (blue) subsurface, seafloor-mounted hydrophone beneath the vessel track, and a surface buoy moored approximately 30 m from the vessel track. The line of four buoys is marked in distance from the center (3-km mark) of the track line at 0; 100; 1,000; and 4,000 m.

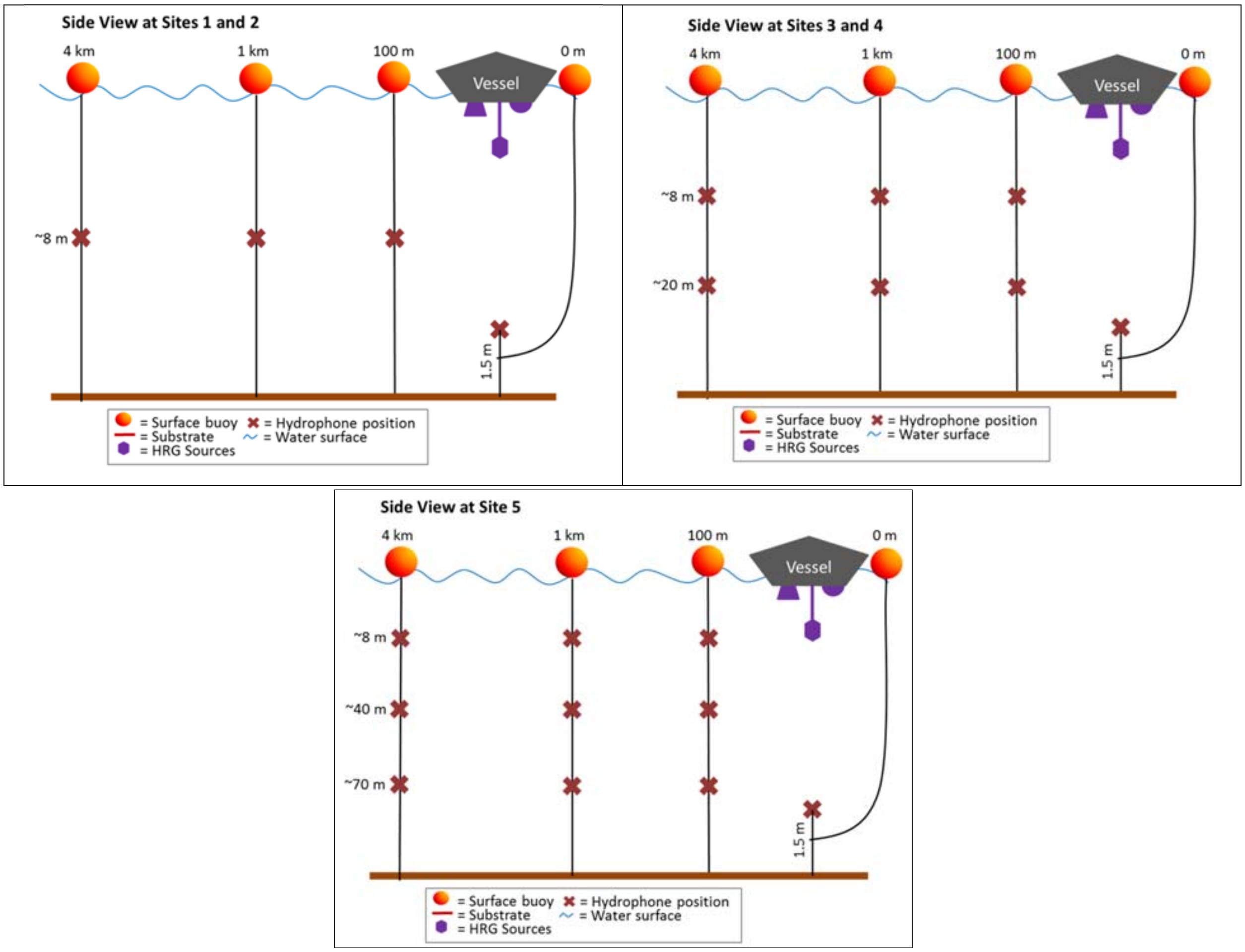


Figure 2.1-2. Illustration of the array layout (side view) at the three tested water depths. Top left: Sites 1 and 2 at 10 m; top right: Sites 3 and 4 at 30 m; bottom: Site 5 at 100 m. Note that buoy D was located directly beneath the vessel track, 1.5 m above the seafloor, and the surface buoy (provided access to the recorded data) was moored approximately 30 m from the track vessel. The approximate hydrophone depths are along the left side of each image.

At each test site, the vessel made a single transit through the field array to record ambient noise and vessel-contributed noise (a control transit). During the control transit, the vessel moved at approximately 3 knots (kn) with all non-essential onboard equipment in quiet mode; no HRG sources were operating. For source measurements, the HRG sources were organized into operational pairings; two sources operated in alternation. For each HRG source, the source vessel transited the approximately 5-km track line (called a Run) through the field array (**Figure 2.1-1**) at approximately 3 kn to reduce masking of the HRG signals by vessel noise during all testing operations. Each HRG source was operated to transmit signals of a typical duration, followed by a 1-second pause, then trigger the other source to transmit, followed by a 1-second pause, and so on. Approximately one transmission every second provided a single source pulse repetition interval (PRI) of 2 seconds, or 3-m spatial sampling, which provided approximately 1,935 signal pings through the 5-km range. The airgun sources, however, had a PRI of 20 to 40 seconds, providing approximately 97 signal pings through the approximately 5-km range. For high-frequency sources (e.g., Klein 3000, Resons) only one source was deployed, and the PRI was 0.4 or 0.5 seconds, respectively. The longer PRI was intended to allow HRG signals to dissipate from the area and provide clearer separation of the recorded HRG signals. At the completion of each Run, the HRG sources were set to new operational modes (e.g., frequencies, power levels, pulse lengths, deployment configurations) or swapped out for different HRG sources. After the HRG sources were measured at one test site (single depth, single bottom type), the field array was recovered in its entirety and relocated to the next test site.

2.2 Test Sites and Substrate Type

Five test sites were selected (**Figure 2.2-1**), and the characteristics for each site are listed in **Table 2-2.1**. Sites were selected for the sediment composition and the relatively flat bathymetry, with little slope for approximately 2 km radius around each test location.

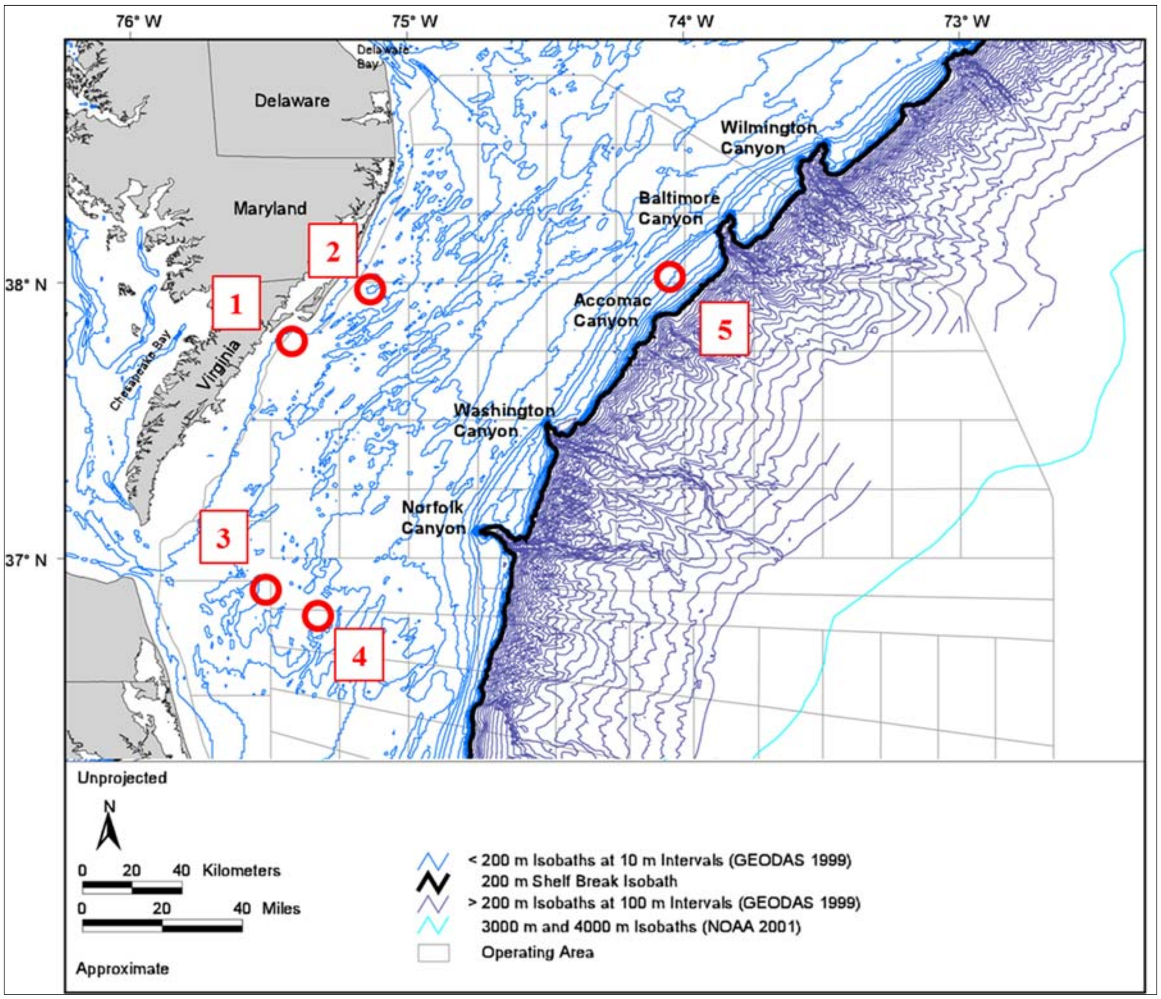


Figure 2-2.1. Map along the U.S. Atlantic coast showing the approximate location of the five test sites, indicated by the red circles and identified by site number.

Table 2.2-1. Test site characteristics.

	Site 1	Site 2	Site 3	Site 4	Site 5
Position	37.811110 N 075.424490 W	37.983515 N 075.133575 W	36.920100 N 075.428100 W	36.880215 N 075.274760 W	38.0 N 074.1 W
Water Depth	10 m	10 m	30 m	30 m	100 m
Substrate Type	Mud	Sand	Mud	Sand	Sandy-Silt

The order of testing was based on the most efficient use of transit time. However, technical challenges arose (**Section 2.5.1.1** and **Appendix B**), thus sites were visited more than once to ensure quality acoustic recordings of the HRG sound signals (**Table 2.2-2**).

Table 2.2-2. Chronological order of site sampling for HRG sources, and testing dates.

Location	2016 Testing Dates	
	Start	End
S4	29 June	1 July
S3	2 July	3 July
S4	4 July	4 July
S2	5 July	6 July
S1	6 July	7 July
Port	7 July	8 July
S5	9 July	11 July
S3	12 July	13 July
S2	13 July	14 July
Port	14 July	15 July

HRG = high-resolution geophysical; S = site; Port = Port Lewes, Delaware.
Testing date ranges include deployment and recovery of the acoustic field array.

2.2.1 Substrate Types

Seafloor composition influences how acoustic signals travel through the environment. A source signal travels many pathways (multipaths) before arriving at a specific receiver site. The multipaths include the direct path through the water as well as single and multiple reflections off the seafloor and sea surface. **Table 2.2-1** notes the substrate type at the five test sites: two in 10 m of water with mud (S1) and sand (S2) substrate; two in 30 m of water with mud (S3) and sand (S4) substrate; and one in 100 m of water with a silty-sand (S5) substrate. Mud is considered a soft sediment that attenuates acoustic signals and decreases the angular reflections back into the water column. Sand is considered a hard sediment that does not attenuate acoustic signals or strip away reflections, thereby increasing the complexity of the received signal.

2.3 Vessel Operation and Survey Team

The R/V *Hugh R. Sharp* (**Figure 2.3-1**) was chartered for this study by USGS and BOEM and was an integral factor for proper field operations and interfacing with the entire shipboard team. The R/V *Hugh R. Sharp*'s home port for this project was Lewes, Delaware.

Figure 2.3-1. R/V *Hugh R. Sharp*.
Photo source: *University of Delaware Messenger*.

The survey team consisted of 28 personnel from various companies, agencies, and organizations. The organizational structure, including roles and companies of the survey personnel, is provided in Table 2.3-1.

Table 2.3-1. Survey team on board the R/V *Hugh R. Sharp* during the Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing study.

Company/Agency	Name	Position	Survey Leg
CSA	Jeff Martin	Project Field Manager	Legs 1 and 2
	Terry Stevens	Deck Operations	
	Gray Lawson	Deck Operations	
R/V *Hugh R. Sharp*	J. Warrington	Vessel Captain	Legs 1 and 2
	E. Falgowski	First Mate	Leg 1
	A. Wyrick	Chief Engineer	
	J. Masten	Engineer	
	P. Nixon	Cook	
	K. Fairbarn	Deckhand	
	T. Thomas	Deckhand	Legs 1 and 2
	C. Bogen	First Mate	Leg 2
	T. North	Chief Engineer	
	C. Lynch	Engineer	
	T.R. Marshall	Deckhand	
	P. Gomez	Cook	
USGS	Patrick Hart	Co-Principal Investigator	Legs 1 and 2
	David Foster	Co-Principal Investigator	Legs 1 and 2
	Bill Danforth	Marine Electronics Engineer	Legs 1 and 2
	Emile Bergeron		Leg 1
	Alex Nichols		Legs 1 and 2
	Chuck Worley		Leg 1
	Tom O'Brien		Legs 1 and 2
	Dal Ferro	Engineering Technician	Leg 2
	Dan Powers	Engineering Technician	Leg 2
BOEM	Stanley Labak	BOEM Representative	Leg 1
Seiche	Lorenzo Scala	Recording Buoy Technician	Legs 1 and 2
	Kaya Marks	Recording Buoy Technician	Legs 1 and 2
	Chris Pierpoint		Leg 2

BOEM = Bureau of Ocean Energy Management; CSA = CSA Ocean Sciences Inc.; USGS = U.S. Geological Survey; Seiche = Seiche Ltd.

2.4 HRG Sources

The 17 HRG sources are listed in **Table 2.4-1**, and include the name of the source used throughout the report, the number of operational modes tested, and the operation status at each test site. The active HRG sound sources used during field operations were supplied and operated by the USGS. There were up to three deployments at each site; the dates of testing are provided in **Table 2.4-2**. Each HRG source was tested in more than one operational mode (combinations of signal level, frequencies, signal length, and deployment configurations).

Table 2.4-1. HRG sound sources tested during this study.

HRG Sound Source	Abbreviated Name	# of Modes Tested	Site 1 10 m Mud	Site 2 10 m Sand	Site 3 30 m Mud	Site 4 30 m Sand	Site 5 100 m Sandy-Silt
Applied Acoustics (AA) Delta Sparker	Delta Sparker	2	No	No	Yes	Yes	Yes
AA252 S-Boom	S Boom	2	Yes	Yes	Yes	Yes	Yes
AA251 Boomer (single plate)	Boomer	2	Yes	Yes	Yes	Yes	Yes
Falmouth Scientific, Inc. (FSI) Bubble Gun (dual plate)	Bubble Gun	2	Yes	Yes	Yes	Yes	No
Edgetech (ET) 4200 side-scan	ET4200	2	Yes	Yes	Yes	Yes	No
Edgetech 424 Chirp 3100P side-scan; topside	ET424 3100P	2	Yes	Yes	Yes	Yes	No
Edgetech 424 Chirp 3200XS side-scan; topside	ET242 3200XS	2	Yes	Yes	Yes	Yes	No
Edgetech 512i side-scan	ET512i	3	Yes	Yes	Yes	Yes	Yes
Sercel Mini GI (30/30); one airgun	MiniGI-1	4	No	No	Yes	Yes	Yes
Sercel Mini GI (30/30); two airguns	MiniGI-2	1	No	No	Yes	Yes	Yes
Klein 3000 side-scan	Klein	2	Yes	Yes	Yes	Yes	No
Knudsen 3260 Chirp (Sharp) side-scan	Knudsen 3260	2	Yes	Yes	Yes	Yes	Yes
Reson (R) 7111 multibeam echosounder	R7111	2	No	No	Yes	Yes	Yes
Reson 7125 (Sharp) multibeam echosounder	R7125	2	Yes	Yes	Yes	Yes	Yes
SIG 2 Mini Sparker	Mini Sparker	2	Yes	Yes	Yes	Yes	Yes
Simrad EK60 38 kHz multibeam echosounder	EK60	3	No	Yes	Yes	Yes	Yes
SEA SWATHPlus –interferometric sonar	SwathPlus	4	Yes	Yes	Yes	Yes	No

HRG = high-resolution geophysical; Sharp = sources that were hull-mounted on the R/V *Hugh R. Sharp*; No = sound source was not tested; Yes = sound source was tested.
Survey dates: 28 June to 15 July 2016.

Table 2.4-2. HRG deployment dates for sound sources tested during this study.

HRG Sound Source Deployment	Site 1 10 m Mud	Site 2 10 m Sand	Site 3 30 m Mud	Site 4 30 m Sand	Site 5 100 m Sandy-Silt
Dates of Deployment #1	6–7 July	5–6 July	2 July	29–30 June	9–10 July
Dates of Deployment #2	--	13–14 July	3 July	30 June–1 July	10–11 July
Dates of Deployment #3	--	--	12–13 July	4 July	11 July

-- = not applicable; HRG = high-resolution geophysical.

2.5 Acoustic Sampling Equipment

Acoustic recording buoys, designed and manufactured by a subcontractor, were used to digitally record HRG output signals. The PAMGuard software, installed on both micro-computers in each buoy, controlled the incoming digital hydrophone signal, and read and logged the analog National Marine Electronics Association's position string received from the GPS antenna. The PAMGuard software originally was programmed to combine the signals from hydrophone pairs, and each signal pair was time-stamped and recorded as a .wav file onto a USB data storage device. Each .wav file contained 512 megabytes (MB) of recorded data and up to three channels of data. GPS data were logged to a Structured Query Language (SQL) database and stored on a USB data storage device that logged buoy position every 0.1 seconds.

Following the reconfiguration of the recording buoys, a single micro-computer was installed in each buoy with PAMGuard software was reprogrammed to recorded the data streams from up to three hydrophones on a buoy. The hydrophone signals were paired, time-stamped, and recorded as a multi-channel .wav file onto a USB data storage device. Each .wav file contained 512 MB of recorded data and up to three channels of data. Early during testing, the USB connectors for the GPS antenna became corroded due to water intrusion in the Pelican™ Case; consequently, S4 (the first site tested) had buoy GPS data, as well as intermittent buoy GPS data at S3 and S5, while S1 and S2 had no GPS data.

Each buoy consisted of a control box, a float, and acoustic acquisition cylinder (**Figure 2.5-1**) that was integrated with a vertical array of hydrophones (hydrophones not shown in figure). Each control box (Pelican™ Case) housed a GPS antenna, USB data storage, and battery. The acoustic acquisition cylinder housed two data acquisition (DAQ) cards, two micro-computers, and connectors to the control box and the hydrophone cables. The hydrophone cables hung vertically below the buoy's acoustic acquisition cylinder. The acoustic recorders archived received HRG signals from the hydrophones. The digital recorders were programmed to record continuously with a sampling rate of 500 kHz to digitize the acoustic signal above Nyquist, which allows for analysis of frequencies up to 250 kHz. The GPS receivers were designed to accurately record the buoy position and time-stamp the recorded acoustic data; however, as noted in the previous paragraph, the GPS receivers only functioned at S4, S3, and S5.

Figure 2.5-1. Photo of an acoustic data acquisition buoy.
From left to right, hydrophone cable connector (black), acoustic acquisition cylinder (thin yellow cylinder), float (thick disc), control box (Pelican™ Case), GPS antenna (mounted to Pelican™ Case lid; not visible), radar reflector (silver cylinder), and safety strobe light at far right attached to end of pole. Photo courtesy of CSA Ocean Sciences, Inc.

The buoys were small enough to be safely deployed and recovered from the back deck of the R/V *Hugh R. Sharp* in conditions up to sea state 5. The acoustic buoys were serviced approximately every 12 to 14 hours, which included data recovery, battery replacement, and any other attention needed. The buoys were equipped with a radar reflector and strobe light for visual and radar location during nighttime hours. The array of buoys was held in position by a series of floats and anchor weights. Temperature sensors were attached to the vertical cable on one buoy near each set of hydrophones to monitor for internal wave phenomenon.

The recording hydrophones were omnidirectional and had a frequency range from 10 Hz to 250 kHz, with a voltage sensitivity of 28.2 microvolts (μV)/count. Two hydrophone sensitivities were used: LS around -165 dB re 1 volts (V)/μPa and HS around -185 dB re 1 V/μPa because the signal levels were expected to have a broad dynamic range, meaning levels could be up to 240 dB re 1 μPa at the nearest hydrophones and as low as 100 dB re 1 μPa at the farthest hydrophones.

One to three hydrophone pairs (a pair consisted of one HS and one LS hydrophone) were suspended below each buoy and placed at specific water depths (**Figure 2.1-2**) to capture the signals produced by the HRG sources as well as ambient noise. These hydrophones were built for purpose, constructed and calibrated to meet the project requirements. The appropriate combination of paired hydrophones was determined for each sensing position based on water depth and distance from the source.

2.5.1 Data Collection Parameters

The project was a continuous, 17-day field survey conducting multiple test combinations (HRG source, operational mode, water depth, and seafloor type). The acoustic signal time-series for each source pairing over sand, mud, and silty-sand substrates were recorded. The acoustic recordings were of sufficient bandwidth (10 Hz to 250 kHz), sampling rate (500 kHz), and sensitivity to enable the computation of several metrics for signal transmissions: SPL_{pk}, SEL, and SPL_{rms}. Recording the source transit through the acoustic field array (called a Run) resulted in adequate data to provide measurements for each HRG source.

Factors that impacted the schedule and number of HRG source measurements included the time it took to transit between test sites, deployment and retrieval of the acoustic field array and HRG sources (particularly in bad weather and strong currents), slow transit speed of the vessel during measurements, and a return trip to shore for refueling. Unexpected technical challenges with the acoustic acquisition buoys arose including water intrusion, hardware failures, and software issues, which also delayed the schedule (see **Section 2.5.1.1, 2.6.3.1,** and **Appendix B**).

2.5.1.1 Chronology of Issues Encountered

This section provides a chronological summary of the issues encountered and the solutions that were applied to acquire as complete a data set as possible. There are references to the buoy positions of the acoustic field array, which changed slightly from site to site. See **Section 2.5-2** for detailed illustrations of the field array layout at each site, **Appendix C** for detailed listing of data gaps at each site, and **Appendix B**, Section 4.2 for photographic documentation of field activities and challenges.

Site 4

During the first field deployment, at site 4, the field array (six acoustic buoys) was deployed, HRG source runs were conducted, and acoustic buoys were serviced. During servicing and quality assurance/quality control (QA/QC), acoustic data gaps were discovered due to the technical issues with the buoys that delayed completion of buoy servicing and caused position C to be removed from the acoustic field array (**Figure 2.5.2-5**). Water was found inside most of the control boxes, which caused the acquisition system to fail to recognize the DAQ cards and produced errors with the graphics driver. Buoy servicing was completed and another set of HRG source runs was performed at Site 4. During buoy recovery, data gaps were discovered again, but this time the issue seemed to be with the electronics of the USB hub in the Pelican™ Case, which caused issues such as interrupting the recording software and stopping GPS functionality.

Solutions

In transit to S3, the buoys were reconfigured; the USB hubs, one of the two micro-computers, and one of the two DAQ cards were removed to address the electronic issues with the USB hubs. Each micro-computer and DAQ card set was reconfigured to record from either the HS or the LS hydrophone (in the original configuration, buoys recorded from both hydrophone sensitivities). Four acoustic buoys were reconfigured to record from LS hydrophones, and two acoustic buoys were reconfigured to record from HS hydrophones. The other two buoys were reconfigured; one to record from LS hydrophones only and the other to record from HS hydrophones only. These reconfigurations allowed for a modified field array layout, which included a pairing of buoys at some positions depending on the number of functional buoys available.

Site 3

Eight reconfigured buoys were deployed following the modified field array positioning (**Figure 2.5.2-4**). Positions A, B, and E had a pair of acoustic buoys where one buoy recorded HS hydrophones, and the other recorded LS hydrophones. The operational HRG source runs were performed, buoys were serviced, and three buoys recorded acoustic data, two of which were full data sets.

Several control boxes had varying degrees of water intrusion during this deployment; three acoustic buoys needed repairs to return functionality.

At S3, five repaired buoys were redeployed at positions A, B, D, E, and F, and the operational HRG source runs were performed. The five buoys were recovered, and three buoys recorded acoustic data.

Solutions

The control boxes were inspected for potential points of water intrusion and subsequently were disassembled and sealed with marine caulk to create a waterproof seal. Component parts were replaced with onboard spares.

Site 4

The vessel transited back to S4 to re-survey and filled in missing acoustic data. A six-hour weather event caused delays at S4. Five buoys were deployed (**Figure 2.5.2-5**), and HRG source runs were performed to fill data gaps. The position D buoy was tangled and dragged by the ET4200 tow-fish. This buoy was recovered, the control box was replaced, and it was redeployed. Upon completion of the HRG source runs, the buoys were recovered; three buoys collected acoustic data, while two did not due to water intrusion into the control box, which short-circuited the USB data storage device.

During transit to S2, the position D acoustic data from the second trip to S4 were inspected; it was discovered that the data files had not recorded any signals. It was determined that an error occurred when the systems were reconfigured to one micro-computer and DAQ card. This buoy had one LS hydrophone wired to Channel 1 (Ch1); however, the DAQ card was not set to record on Ch1, so the buoy did not record any signals. The error was fixed. The control boxes of several buoys continued to experience water intrusion. The control boxes were being submerged because of wave action and insufficient positive buoyancy.

Site 2

Upon arrival at S2, five acoustic buoys were deployed (**Figure 2.5.2-3**) and the HRG source runs were performed. The five buoys were recovered, and three had recorded acoustic data. It was determined that the two buoys that did not collect data had corrosion on the USB connectors inside the control box. The corrosion occurred as a result of earlier water intrusion, which prevented the USB data storage device from maintaining a secure electrical connection to the buoy's micro-computer.

Solutions

During testing at S2, a local fishing vessel delivered recording buoy supplies to the R/V *Hugh R. Sharp* (**Appendix B**, Section 4.2), including additional mooring hardware, electronic supplies, new cables, software, and replacement connectors for the control boxes. Three non-functional buoys were repaired and rebuilt with the new supplies.

During transit to S1, all buoys that were deployed at S2 and one other were repaired and rebuilt with the new supplies. As part of the rebuild plan, a software update was provided to upload onto the buoy micro-computers, but the software failed to install. Two of the replacement buoy connectors were incorrectly wired and subsequently rebuilt in the field.

A total of six buoys were repaired and two required further repair. A modified mooring design was developed to counteract the insufficient buoyancy and prevent the control boxes from submerging. The modified mooring design used Norwegian floats attached to the mooring line; the buoys attached to the floats by a 10-m tailing line (**Appendix B**, Section 4.2).

Site 1

Six repaired buoys were deployed at positions A, B, D, $E_{1,2}$, and F (**Figure 2.5.2-3**) using the modified mooring design and Norwegian floats, and the HRG source runs were performed. The control boxes for all buoys were dry. Three buoys contained complete data sets, and one buoy collected a partial data set. The two buoys that did not collect acoustic data and the one that collected a partial data set experienced software failures. The PAMGuard software that controlled the data recording stopped functioning for an undetermined reason.

The R/V *Hugh R. Sharp* returned to port, completing Leg 1.

Solutions

Buoy repairs and solutions were applied during transit and while in port. In port, a second shipment of supplies was delivered to further remedy buoy deficiencies. The electronics needed attention and many connectors were replaced. Leg 2 began with seven functional acoustic buoy systems.

Site 5

Seven buoys were deployed at positions A, $B_{1,2}$, D, $E_{1,2}$, and F (**Figure 2.5.2-6**), the HRG source runs were performed, and the buoys were recovered. Six of the seven buoys contained data, and all control boxes were dry. The PAMGuard software, which controlled data recording, was not functioning properly (froze shortly after deployment) in the buoy that did not collect data.

The seven buoys were redeployed in the same layout, the HRG source runs were performed, and the buoys were recovered. Six of the seven buoys collected data, and all control boxes were dry. The PAMGuard software, which controlled data recording, was not functioning properly (froze shortly after deployment) in the buoy that did not collect data. It was decided that this buoy would not be deployed for the third HRG run.

Six buoys were redeployed at positions A, B, D, and $E_{1,2}$, and the HRG source runs were performed. During recovery of the buoys, some were found to be submerged due to a strong current; however, all collected data.

Solutions

During transit to S3 repairs were made to non-functional buoys.

Site 3

Deployed seven buoys at positions A, $B_{1,2}$, D, $E_{1,2}$, and F, and the HRG source runs were performed. The buoys were recovered, and six of the seven buoys collected data. The PAMGuard software was not functioning properly in the buoy that did not collect data.

Site 2

Transited to S2; deployed seven buoys at positions A, $B_{1,2}$, D, $E_{1,2}$, and F; and performed the HRG source runs. The buoys were recovered and all seven buoys collected full data sets.

The R/V *Hugh R. Sharp* returned to port on 14 July 2016, completing Leg 2.

Equipment deficiencies of the acoustic measurement buoys included failed GPS, non-seaworthy electronic housing components, and software issues founded in an unstable program that would intermittently turned off. These deficiencies resulted in a data set that was less comprehensive or consistent than originally planned. However, the original design included redundancy of hydrophones and recording sites to enable coverage for these types of technical challenges. The modified acoustic array allowed for the same acoustic coverage but without the safety net of redundancy. Overall, a rich data set was collected from the HRG sources at each site.

2.5.2 Buoy Orientation: Deployment History

The original field array of buoys was organized such that the vessel track drove past three perpendicular lines of acoustic recording buoys, as shown in **Figure 2.5.2-1** (left panel). This image also illustrates each buoy's positional identification by letters (A through F) as well as identification of the buoys (5 to 12). Following the second deployment at S4, the field array was minimized by eliminating Position C, as shown in the right panel of **Figure 2.5.2-1**, in response to issues that arose with the acoustic recording buoys (**Section 2.5.1.1**).

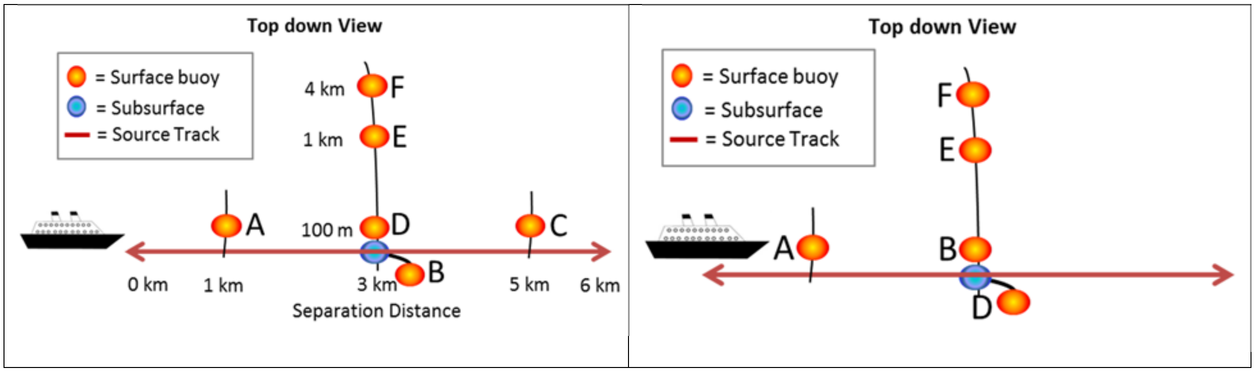


Figure 2.5.2-1. Top down views of the field array.
Top-down view of the original field array (left) with buoy position identification (labels A through F), distances along the source track, and perpendicular buoy distances from center of source track line. Modified field array (right); position C was removed, and all buoy distances remained the same.

Some test sites were sampled more than once because of significant issues with the recording equipment. Re-sampling at the sites is noted by the chronological deployment labels, i.e., deployment 1 (D1), deployment 2 (D2), and deployment 3 (D3). **Figures 2.5.2-2** to **2.5.2-6** provide the field array layout used at each site for each deployment. When a buoy position is listed with subscripts (e.g., $E_{1,2}$), it indicates that two acoustic buoys (individually identifiable by a number in the orange circle) were deployed at the same approximate position (see **Appendix B**, Section 5.0).

Site 1 Deployment History 1

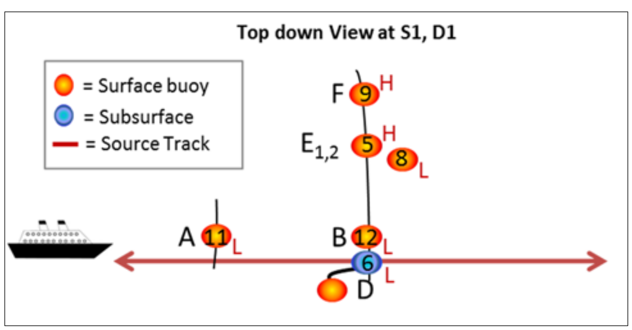


Figure 2.5.2-2. Site 1, deployment 1, 6 to 7 July.
Number inside buoy indicates buoy number; H = high sensitivity; L = low sensitivity; Letters A through F = buoy position; $\text{Letter}_{1,2}$ = two buoys deployed at the same approximate position. Number inside buoy is the buoy identifier.

Site 2 Deployment History 1 and 2

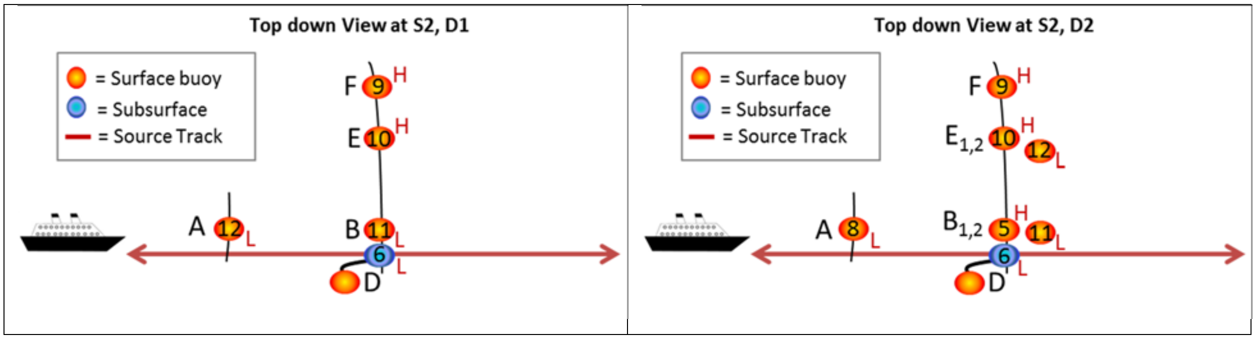


Figure 2.5.2-3. Site 2, deployment 1 (left), 5 to 6 July; deployment 2 (right), 13 to 14 July. Number inside buoy indicates buoy number; H = high sensitivity; L = low sensitivity; Letters A through F = buoy position; Letter$_{1,2}$ = two buoys deployed at the same approximate position. Number inside buoy is the buoy identifier.

Site 3 Deployment History 1, 2, and 3

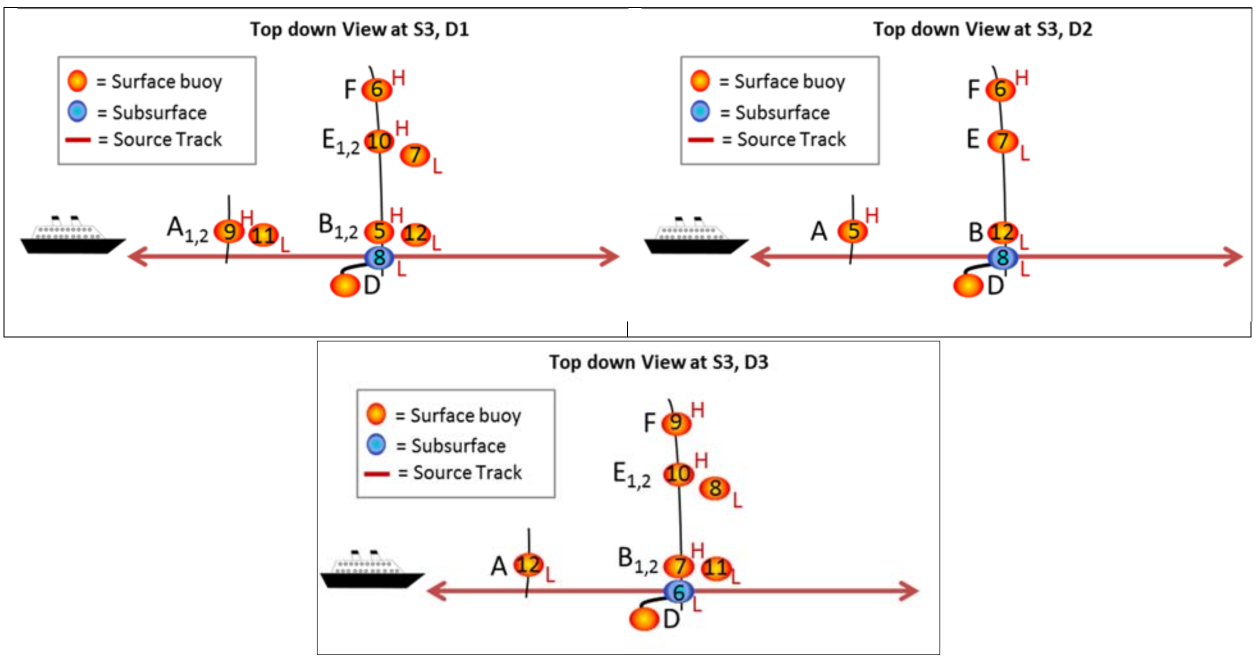


Figure 2.5.2-4. Site 3, deployment 1 (top left), 2 July; deployment 2 (top right), 3 July; deployment 3 (bottom), 12 to 13 July. Number inside buoy indicates buoy number; H = high sensitivity; L = low sensitivity; Letters A through F = buoy position; Letter$_{1,2}$ = two buoys deployed at the same approximate position. Number inside buoy is the buoy identifier.

Site 4 Deployment History 1, 2, and 3

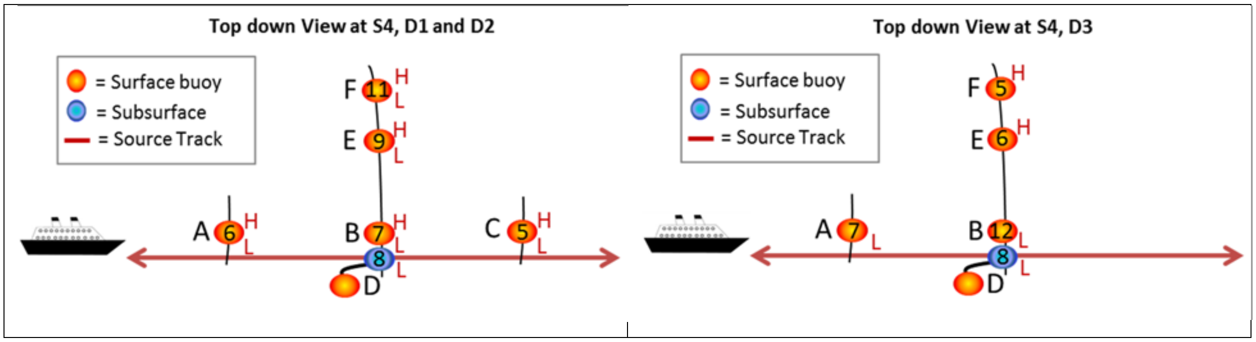


Figure 2.5.2-5. Site 4, deployment 1 (left), 29 to 30 June; deployment 2 (left), 30 June to 1 July; deployment 3 (right), 4 July.
Number inside buoy indicates buoy number; H = high sensitivity; L = low sensitivity; Letters A through F = buoy position; Letter$_{1,2}$ = two buoys deployed at the same approximate position. Number inside buoy is the buoy identifier.

Site 5 Deployment History 1, 2, and 3

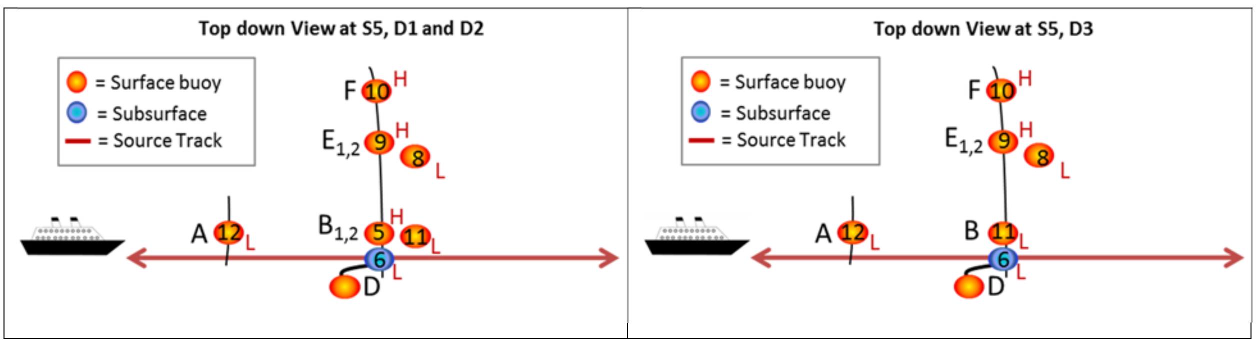


Figure 2.5.2-6. Site 5, deployment 1 (left), 9 to 10 July; deployment 2 (left), 10 to 11 July; deployment 3 (right), 11 July.
Number inside buoy indicates buoy number; H = high sensitivity; L = low sensitivity; Letters A through F = buoy position; Letter$_{1,2}$ = two buoys deployed at the same approximate position. Number inside buoy is the buoy identifier.

2.6 Acoustic Analysis Methodology

2.6.1 Data Conversion

The 500-kHz sampled acoustic data files (.wav) were converted to binary OASIS format (.ts), which contained the acoustic data, signal start time, and sample rate of the acoustic file. For each buoy and deployment, the .ts files were concatenated to generate a single 500-kHz sample file. The data were processed in two passes. An initial quality check using a 0 to 25 kHz baseband spectrogram of a single 6- to 8-minute file, collected from approximately halfway through the run duration, permitted an initial investigation of the acoustic data quality (e.g., identifying if a file was dominated by clipping or strum noise, and if there was sufficient dynamic range).

2.6.2 Trimming and Basebanding

A set of UNIX shells (scripts) were written to process each recording through the sites, runs, sources per run, and buoys. Start of line (SOL) referred to the start of the acoustic buoy deployment, and end of line (EOL) referred to retrieval of the final acoustic buoy. The SOL and EOL times for each run were extracted manually from the USGS experiment log. For each source run, the closest point of approach (CPA) was determined from the navigation data. The data for the closest hydrophone (position D) were used to evaluate the spectral content of each source. For deployments with two sources operating in alternation, each individual source had to be isolated. The upper and lower limits of the frequency content of each source were estimated by plotting the spectra and computing the peak level as a function of upper and lower bound. The narrowest band within 1 dB of the total energy was chosen. Basebanding was performed to make the subsequent processing focus on a single source's energy, thus increasing the efficiency of processing data that were sampled at 500 kHz. Furthermore, the bandwidth of the sources ranged from 10 Hz to 250 kHz. The results of this band check procedure are shown for each source in **Section 4.0**. The data were trimmed (a selection of times associated with each run) and basebanded to encapsulate the acoustic energy of the source.

2.6.3 Calibration

Audio files were generated at sea using PAMGuard, passing the data through a DAQ card. The data were stored in 16-bit signed integer (int16) counts, which range from -32767 to +32767. The dynamic range of the recording system was set to 20 V peak-to-peak, or ±10 V. The conversion from integer values to volts is:

Count sensitivity = (1 / 32767 counts) (10 V)

To convert from counts to volts in dB required a scaling factor of -70.3 dB.

Except where specifically stated, the other gains on the PAMGuard system were set to 0 dB (1.0).

The sensitivity was taken from the corresponding data recorded in the Seiche hydrophone logs for each deployed hydrophone, either in HS or LS mode. The hydrophone sensitivities were frequency dependent, and the sources were characterized by their main frequency components:

- low-frequency: 5 kHz;
- mid-frequency: 20 kHz;
- high-frequency: 100 kHz; or
- very high-frequency: 200 kHz.

For the LS hydrophones (H1), sensitivity was on the order of -165 dB re 1 V/µPa. For the HS hydrophones (H2), sensitivity was approximately -185 dB re 1 V/µPa. In addition to the sensitivity, a 10-dB gain/attenuation was placed within the hardware to manage the sensitivity from the hydrophones.

In the .wav file, the conversion from counts to dB was approximately 95 and 115 dB re 1 µPa for LS and HS hydrophones, respectively.

2.6.3.1 Calibration Issues

During the processing of the data, there was considerable ambiguity about a 10-dB gain by the hardware. In some instances there was a 10-dB offset between co-located hydrophones on the same buoy, as well as paired buoys for a single position. Due to an abundance of technical issues in the field, recording system sensitivity errors were not consistently tracked and documented, including errors in gain levels, occurrence of gain failures, and occurrence of improper connections between hydrophones and gains. The lack of documentation did not allow for the determination of offset specifics. Therefore, a minimum set of calibration corrections was chosen to produce the most consistent received level results across multiple buoys, receptions, and runs. A buoy calibration correction was made only once per hydrophone, buoy, or site if required.

2.6.4 Ping Arrivals and Intensity Percentiles

For each frequency band, isolated signals were separated into individual pings for subsequent processing. An example of the separation into pings without taking propagation range into account is shown in **Figure 2.6-1**. The identified source pings are shown in **Figure 2.6-1** for Knudsen signals, in a fast-time (i.e., signal arrival) versus Run time (i.e., ping number) plot. Note the wavy effect (e.g., at 11 minutes) of the ship motion on the arrival time as well as the multipath arrival (three curves) from the acoustic signal interacting with the seafloor.

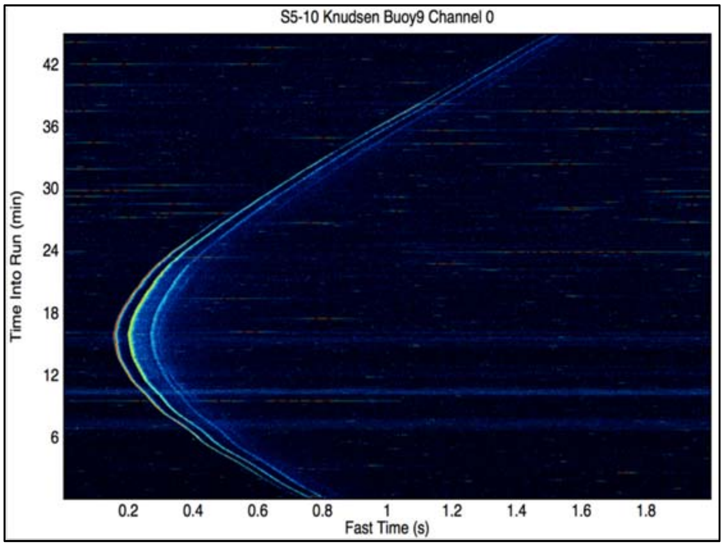


Figure 2.6-1. Knudsen 3260 fast-time (signal arrival)/run time (ping number) arrival signals at S5, Run10, Buoy9, Ch0.
The three curves each represent a different pathway of arrival.

In order to isolate the signals and limit the amount of non-signal noise contribution to the SEL computation, received signals were time-aligned. The HYPACK log files provided trigger times for each HRG source and the GPS location of the ship for every source transmission. The source position was computed using the offset ranges between the vessel GPS antenna and the source for each trigger time estimated buoy position was derived from buoy deployment/recovery positions. From the ship and buoy navigation information, the source-to-buoy range and acoustic travel time were computed (using 1,510 $m \cdot s^{-1}$ as the nominal speed of sound). Signal arrival at the buoy within ±0.5 seconds of a PRI was extracted for every trigger time. This aligned the signals (to the extent that the navigation and clock timing of the acoustic files were correct). Each time-aligned acoustic record was trimmed to the shortest period of time that included all of the received energy for the source of interest. The resulting window contained the isolated signal and permitted a very short record for every ping, which was processed to estimate the acoustic metrics.

The acoustic metrics included the SPL_{pk}, the 5 to 95 percent SPL_{rms}, and SEL; the acoustical terms follow the ISO standard (ISO, 2017). For each ping, the received power level was sorted and the relevant percentiles of the arriving signal were stored. In particular, the 5th, 25th, 50th, 75th, 95th, and 100th percentile per ping were stored. This provided an estimate of the maximum sound pressure arrival and the noise (observable within the dynamic range of the hydrophone). An example of a percentile plot is shown in **Figure 2.6-2** for a high frequency Reson 7111 (R7111) ping. This plot provides rapid diagnosis of the hydrophone health and the signal-to-noise (SNR) ratio. Of note is the 20 dB gap between the 95th percentile (purple) and the 5th percentile (black), which is an expected distribution of valid acoustic ambient noise. The small increase in the lowest percentiles (5 and 25 percent) are due to the passage of the ship raising the background noise, and not due to the source. Some recordings had no signal at all, which would be evident from a nearly constant percentile curve across a run.

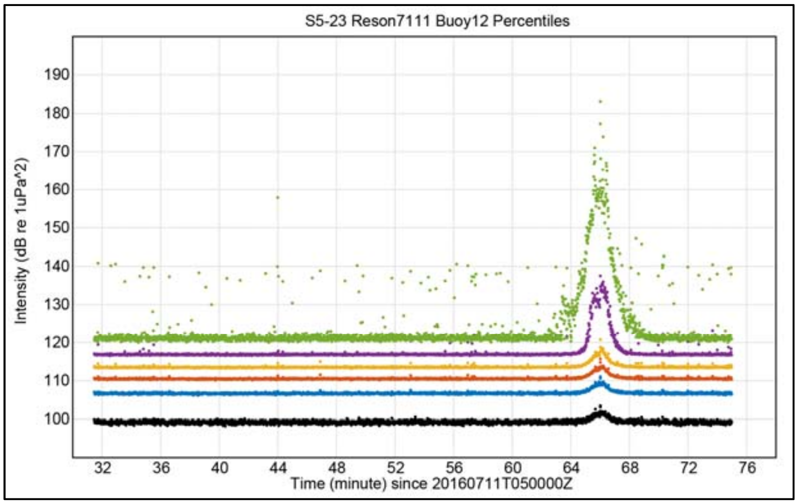


Figure 2.6-2. Reson 7111 received signals in percentiles at Site 5, Run23, Buoy12.
Legend: Percentiles, 5th (black) 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

2.6.5 Peak Pressure Arrivals

The peak pressure is defined as the maximum pressure recorded for a particular trimmed, basebanded data record associated with a single source transmission. The peak is the 100th percentile data point that comes out of percentile processing. The SPL_{pk} is the result of coherent multipath propagation and can be very different in the ocean environment than in a laboratory test. The peak calculation is least sensitive to noise because it does not integrate the signal over time. **Figure 2.6-3** shows the peak arrival power for a Reson 7111 as an example.

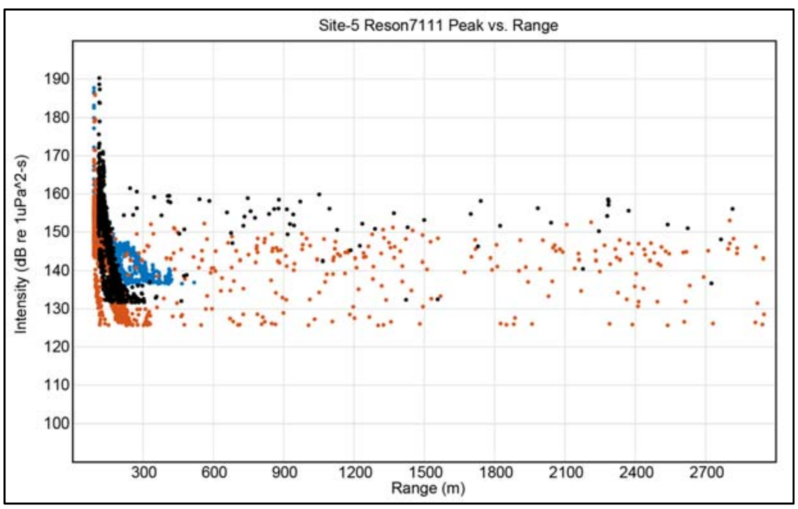


Figure 2.6-3. Reson 7111 SPL_{pk} received signals at Site 5.
Legend: Positions A = black; B = red; D = blue.

2.6.6 Signal Energy Level and Sound Pressure Level

Three metrics, SEL, SPL_{rms}, and SPL_{pk} metrics are represented in the same figure (**Figure 2.6-4**) to show a relative comparison of the levels. The SEL is the total energy within the signal arrival, which is the integral of power over the band (multiplied by the PRI time window). This metric includes signal plus noise, so it may be biased when the SNR is not high. The SPL_{rms} metric is an integration of the power from the time periods containing 5 to 95 percent of the total power divided by the associated time window. An example of the SEL, SPL_{rms}, and SPL_{pk} for the Knudsen 3260 are displayed in the **Figure 2.6-4**.

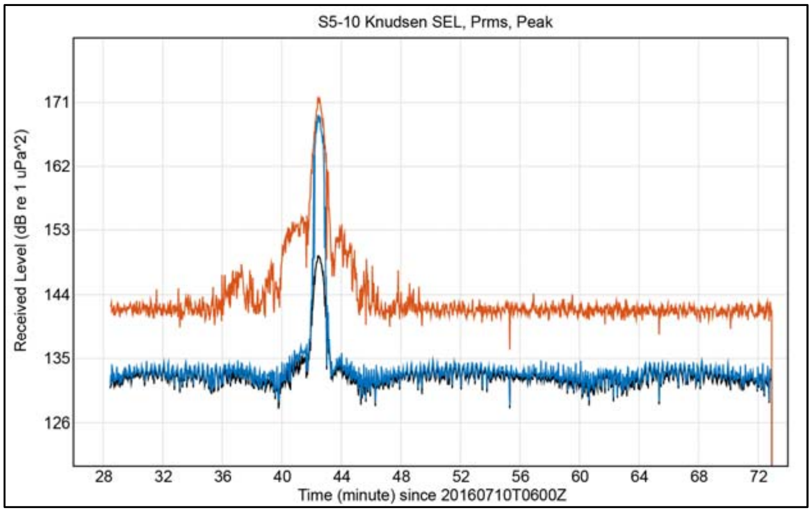


Figure 2.6-4. Knudsen 3260 received signals at S5, Run10, Buoy11.
SPL_{pk} (red), SEL (black), and SPL_{rms} (blue).

2.6.7 Estimated Source Level

To measure the consistency of the observations, the source level (SPL_{pk}, SEL, SPL_{rms}) for each sound source was estimated at each site, and input into a table for comparison with the source levels observed by NUWC (Crocker and Fratantonio, 2016). The first step was to compare the received SL_{pk} versus range that included spherical and cylindrical spreading curves (e.g., **Figure 4.3.3-2,** bottom left). At each site, a decision was made as to which acoustic spreading law was more closely followed: spherical spreading [20 $\log_{10}$ (*range*)] or cylindrical spreading [10 $\log_{10}$ (*range*)]. The highest amplitude signal reception, which was usually on position D at CPA, was used to estimate the source level by taking the log of the estimated range and multiplying by the most applicable spreading law [10 (cylindrical) or 20 (spherical)]. This process was repeated for the SEL and SPL_{rms} metrics. It is worth noting that this approach to calculate estimated source levels is sensitive to the chosen spreading law and the distance between the source and receiver, particularly at close ranges. This helps explain discrepancies between the source levels reported by this study and those reported in the NUWC report (Crocker and Fratantonio, 2016). The source levels reported by this study should not be used for data analysis or impact assessments, as they were calculated to provide a verification of the received levels.

This page left intentionally blank

3 RESULTS: FIELD ARRAY SUMMARY

This section describes the geographic position of the acoustic buoys that collected data, the range coverage of each buoy position, and the bearing of the HRG signals to each buoy for each test site and deployment. The geographic positions of the buoys in the acoustic field array are presented by the latitude/longitude of the buoys and of the source track. **Section 2.5.2** provides details on the orientation of the five buoy positions (A through F) for each deployment. During most deployments, each position was represented by one buoy; however, two buoys occasionally were deployed to capture the dynamic range of HRG signals. The range and bearing to buoys that recorded acoustic data are presented relative to time of the source traveling along the track. Each buoy position covers a certain range, depending on the distance from the source; when buoys did not collect acoustic data, a gap appeared in the range coverage.

Only buoys that captured acoustic data are discussed herein. Each position of the field array was filled by a buoy (or two), each buoy was identified by a number (Buoy5 to Buoy12) and had a hydrophone with a specific sensitivity (HS or LS), and each hydrophone was identified by a four-digit number (e.g., #6159) to identify the specific hydrophone sensitivity value. Exceptions include S4 deployments 1 and 2, where single buoys had both HS and LS hydrophones. S1 and S2 had one hydrophone per buoy, S3 and S4 had two hydrophones per buoy, and S5 had three hydrophones per buoy.

Table 3.0-1 details the deployment variables at each site, the buoy position within the field array, the buoy identification number, and a binary representation of data status (red = buoy deployed, but no acoustic data recorded; green = buoy deployed, acoustic data recorded). All site deployments represented the modified field-array configuration, except for S4 deployment 1, which represented the original array configuration (**Section 2.4.2** for details).

Table 3.0-1. Compilation of HRG data acquisition status identified by buoy number and buoy position for each site.

	Buoy Position in the Acoustic Field Array									
	A-HS	A-LS	B-HS	B-LS	C-HS	C-LS	D-LS	E-HS	E-LS	F-HS
Site 1										
Deployment 1		11		12			6	5	8	9
Site 2										
Deployment 1	12			11			6	10		9
Deployment 2	8		5	11			6	10	12	9
Site 3										
Deployment 1	9	11	5	12			8	10	7	6
Deployment 2		5		12			8		7	6
Deployment 3	12		7	11			6	10	8	9
Site 4										
Deployment 1	6	6	7	7	5	5	8	9	9	11
Deployment 2	6	6	7	7			8	9	9	11
Deployment 3		7		12			8	6		5
Site 5										
Deployment 1		12	5	11			6	9	8	10
Deployment 2		12	5	11			6	9	8	10
Deployment 3		12		11			6	9	8	10

HRG = high-resolution geophysical; HS = high-sensitivity hydrophone; LS = low-sensitivity hydrophone.
Green = buoy deployed, acoustic data recorded; red = buoy deployed, but no data recorded; gray = no buoy deployed; numbers (5-12) inside cells = buoy number.
Note: D-HS and F-LS hydrophones were not included during any testing.

3.1 Site 1: Mud, 10 m Depth

3.1.1 S1 Deployment 1

Navigation and Buoy Position

A single deployment of five measurement buoys was conducted at S1 (**Table 3.0-1**) from 2133 Greenwich Mean Time (GMT) on 6 July through 1700 GMT on 7 July (**Figure 2.5-2**). Four buoys collected acoustic data at three positions, leaving two positions empty. The source track was oriented east-west. Acoustic data were collected at positions D (Buoy6, LS, #6159), $E_{1,2}$ (Buoy5, HS, #6150; Buoy8, LS, #6153), and F (Buoy9, HS, #6155) (**Figure 3.1-1**). Positions A and B were not represented.

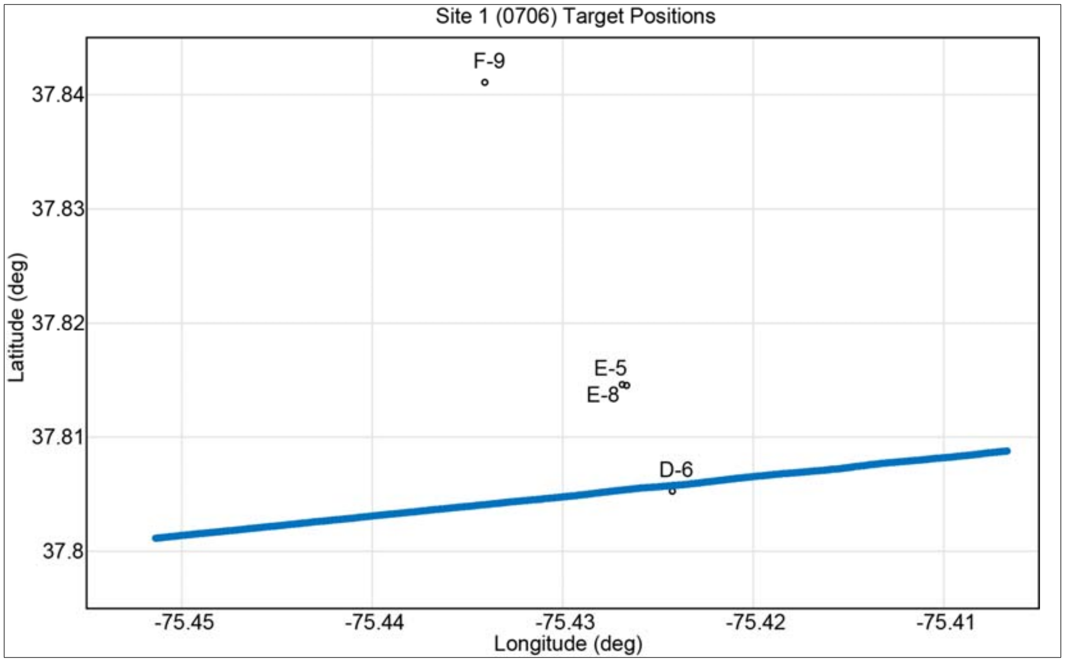


Figure 3.1-1. Site1 (S1), deployment 1, geographic buoy positions relative to the source track. Positions D (Buoy6), $E_{1,2}$ (Buoy5,8), and F (Buoy9) as well as the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, thus bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

The three positions that captured acoustic data were in a perpendicular line to the source track; they shared a CPA as the source passed over position D. The range coverage was sampled from 60 to 2,600 m at the two closest positions (D and E), and from 4,000 to 4,700 m at position F (**Figure 3.1-2**). The distances between 2,600 and 4,000 m were not sampled with this geometry.

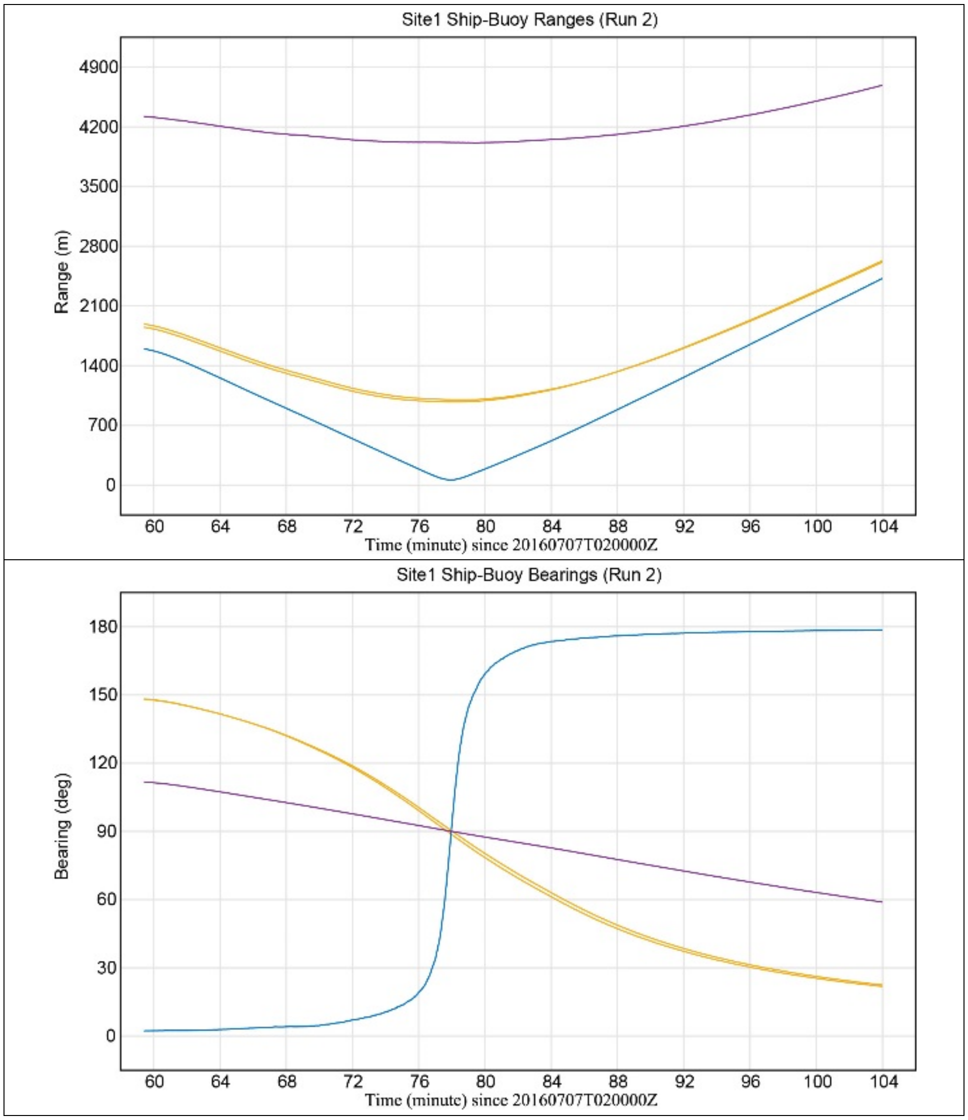


Figure 3.1-2. Site1 (S1), range coverage and bearing.
Top: Source to buoy range relative to time for Run2. Bottom: Bearing of source to buoy relative to time along the source track. Legend: Position, D (Buoy6) = blue; $E_{1,2}$ (Buoy5, Buoy8) = yellow; F (Buoy9) = purple.

3.2 Site 2: Sand, 10 m Depth

3.2.1 S2 Deployment 1

Navigation and Buoy Position

Deployment 1 at S2 included five measurement buoys and occurred from 1200 GMT on 5 July through 1100 GMT on 6 July (**Figure 2.5-3**). Three buoys collected acoustic data at three positions, leaving two positions empty. The source track was oriented northeast-southwest. Acoustic data were collected at positions B (Buoy11, LS, #6151), D (Buoy6, LS, #6159), and F (Buoy9, HS, #6155) (**Figure 3.2-1**). Positions A and E were not represented.

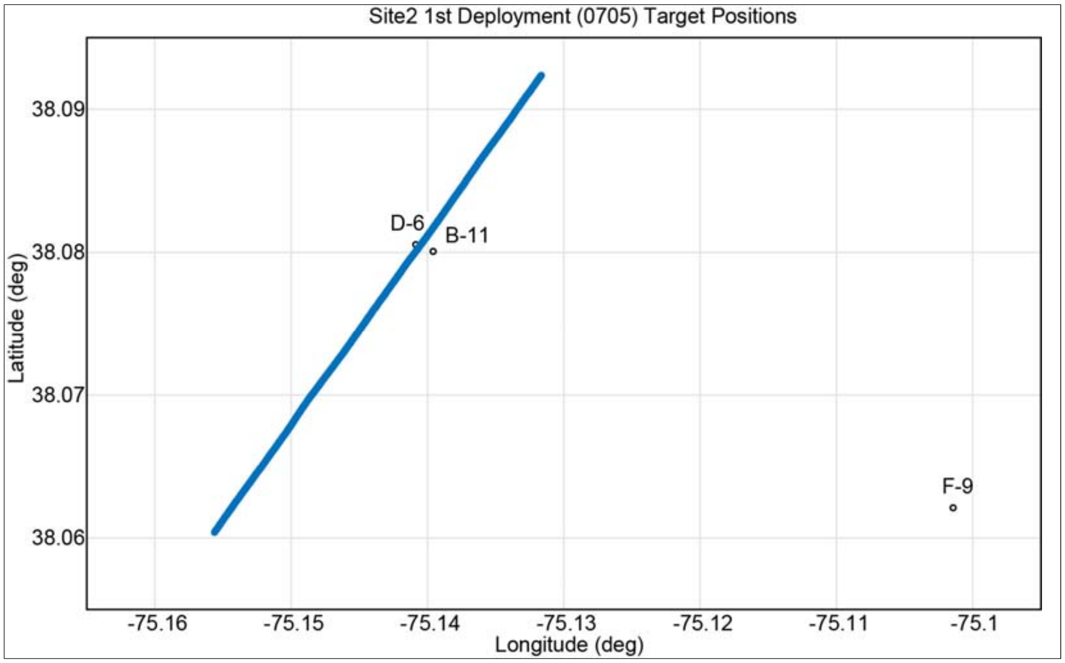


Figure 3.2-1. Site2 (S2), deployment 1, geographic buoy positions.
Positions B (Buoy11), D (Buoy6), and F (Buoy9) as well as the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, thus bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

The three positions that captured acoustic data were in a perpendicular line to the source track; thus, they shared a CPA as the source passed over position D (**Figure 3.2-1**). The range coverage was sampled from 0 to 2,700 m at the closest two positions (B and D), and from 4,000 to 4,700 m at position F (**Figure 3.2-2**). The distances between 2,700 and 4,000 m were not sampled with this geometry.

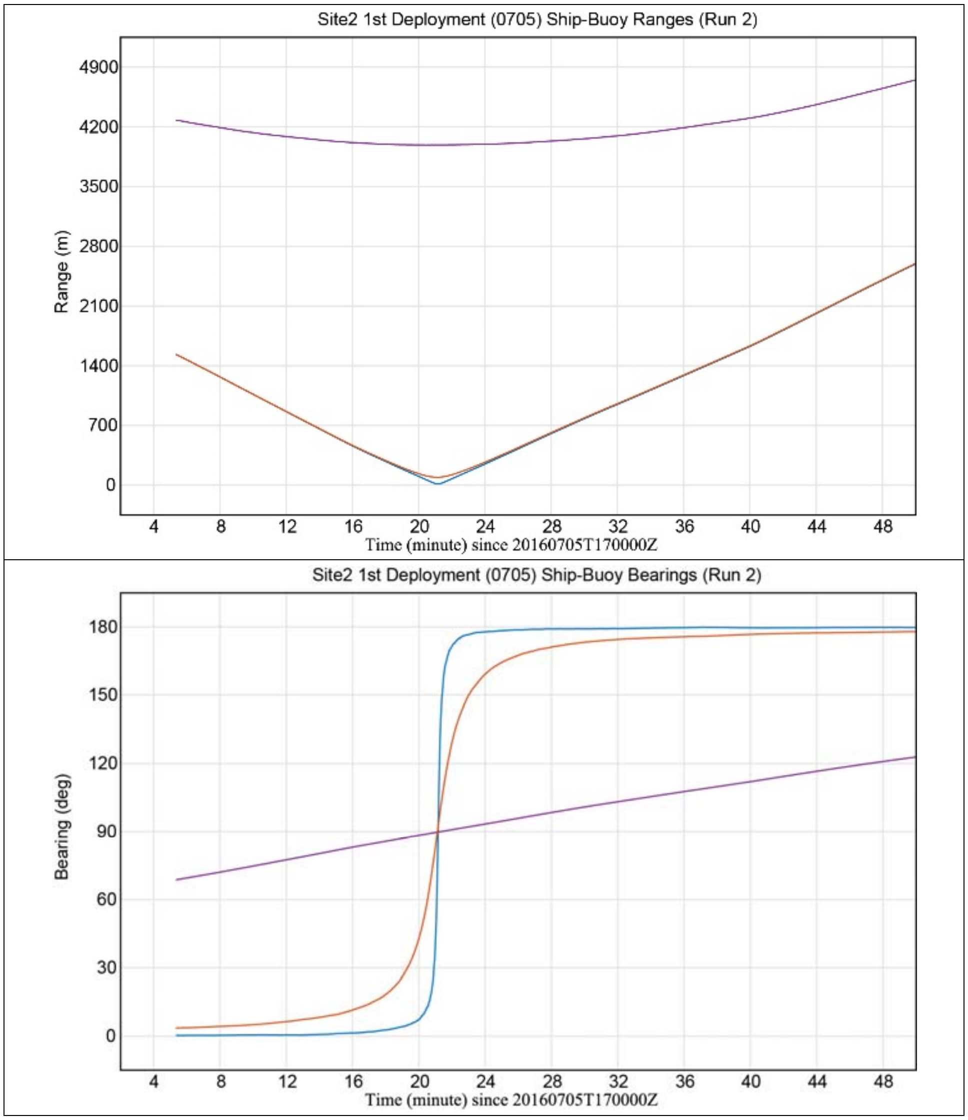


Figure 3.2-2. Site2 (S2), deployment 1, range coverage and bearing.
Top: Source to buoy range relative to time for Run2. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, B (Buoy11) = red; D (Buoy6) = blue; F (Buoy9) = purple.

3.2.2 S2 Deployment 2

Navigation and Buoy Position

Deployment 2 at S2 included seven measurement buoys and occurred from approximately 2100 GMT on 13 July through 1600 GMT on 14 July (**Figure 2.5-3**). Four buoys collected acoustic data at three positions, leaving two positions empty. The source track was oriented northeast-southwest. Acoustic data were collected at positions $B_{1,2}$ (Buoy5, HS, #6156; Buoy11, LS, #6155;), E (Buoy10, HS, #6150), and F (Buoy9, HS, #6155) (**Figure 3.2-3**). Positions A and D were not represented.

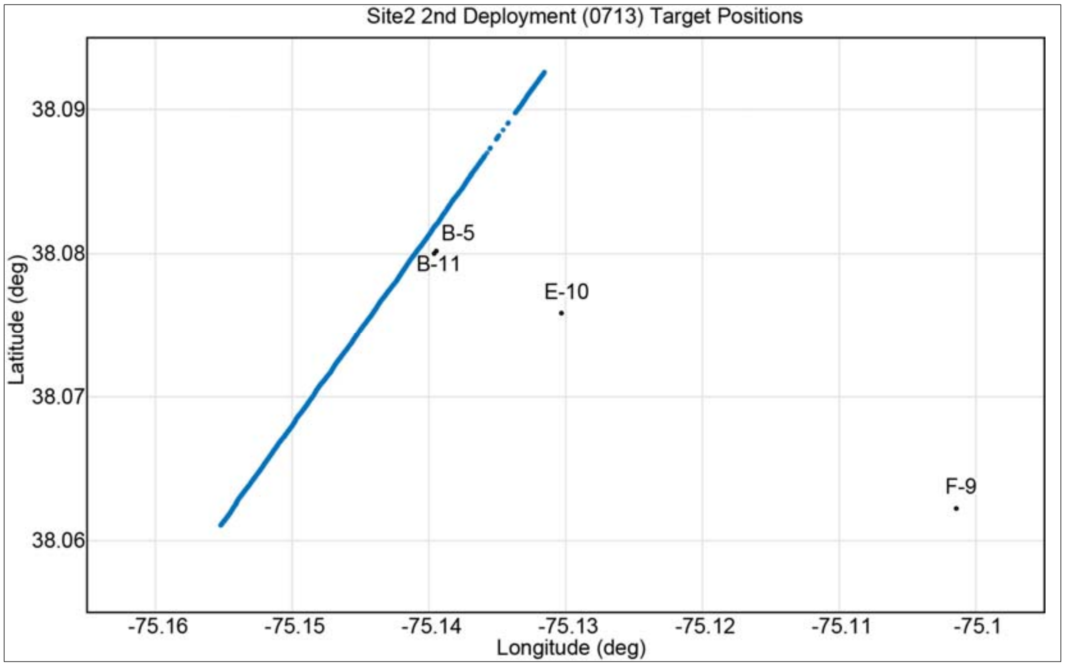


Figure 3.2-3. Site2 (S2), deployment 2, geographic buoy positions.
Positions $B_{1,2}$ (Buoy5,11), E (Buoy10), and F (Buoy9) and the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

The three positions that captured acoustic data were in a perpendicular line to the source track; thus, they shared a CPA as the source passed over position D (note: D did not capture acoustic data). The range coverage was sampled from 30 to 2,600 m at the closest position (B), from 1,000 to 2,700 m at position E, and from 4,000 to 4,700 m at position F (**Figure 3.2-4**). The distances between 2,700 and 4,000 m were not sampled with this geometry.

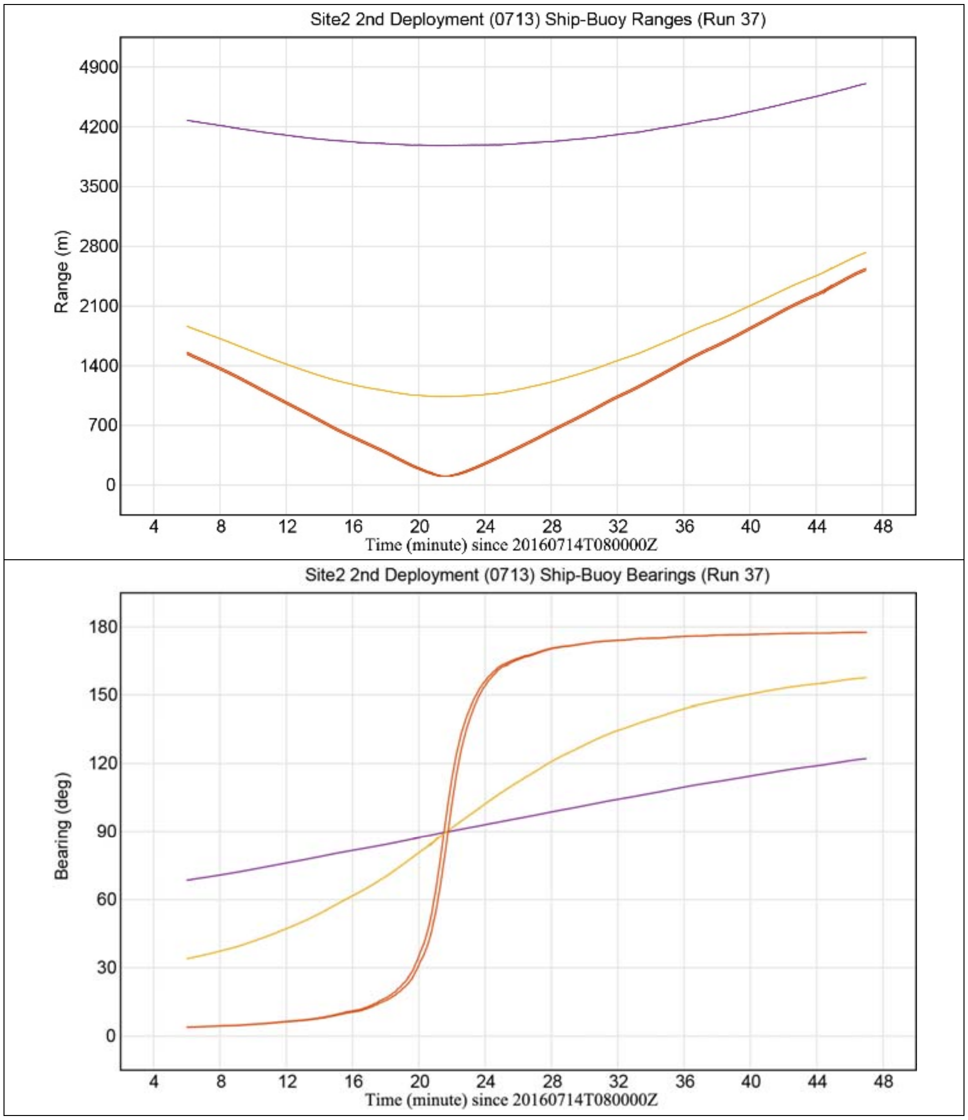


Figure 3.2-4. Site2 (S2), deployment 2, range coverage and bearing.
Top: Source to buoy range relative to time for Run37. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, $B_{1,2}$ (Buoy5,11) = red; E (Buoy10) = yellow; F (Buoy9) = purple.

3.3 Site 3: Mud, 30 m Depth

3.3.1 S3 Deployment 1

Navigation and Buoy Position

Deployment 1 at S3 included eight measurement buoys and occurred from 0400 through 2200 GMT on 2 July (**Figure 2.5-4**). Three buoys collected acoustic data at two positions. The source track was oriented north-south. Three buoys each had two hydrophones (represented by dual hydrophone numbers). Acoustic data were collected at positions $B_{1,2}$ (Buoy5, HS #6149/#6153; Buoy12, LS, #6154/#6148) and E (Buoy7, LS, #6150/#6147) (**Figure 3.3-1**). Positions not represented were A, D, and F.

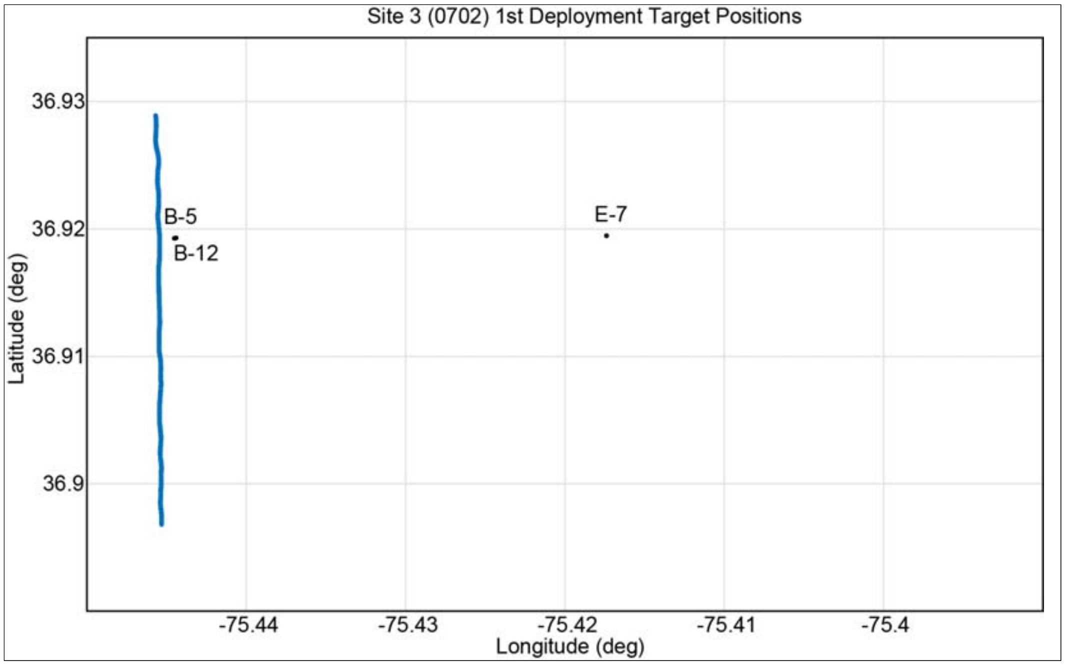


Figure 3.3-1. Site3 (S3), deployment 1, geographic buoy positions.
Positions $B_{1,2}$ (Buoy5,12), and E (Buoy7), as well as the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

Two positions collected acoustic data, providing complete range sampling. The range coverage was sampled from 30 to 3,600 m at positions B and E (**Figure 3.3-2**).

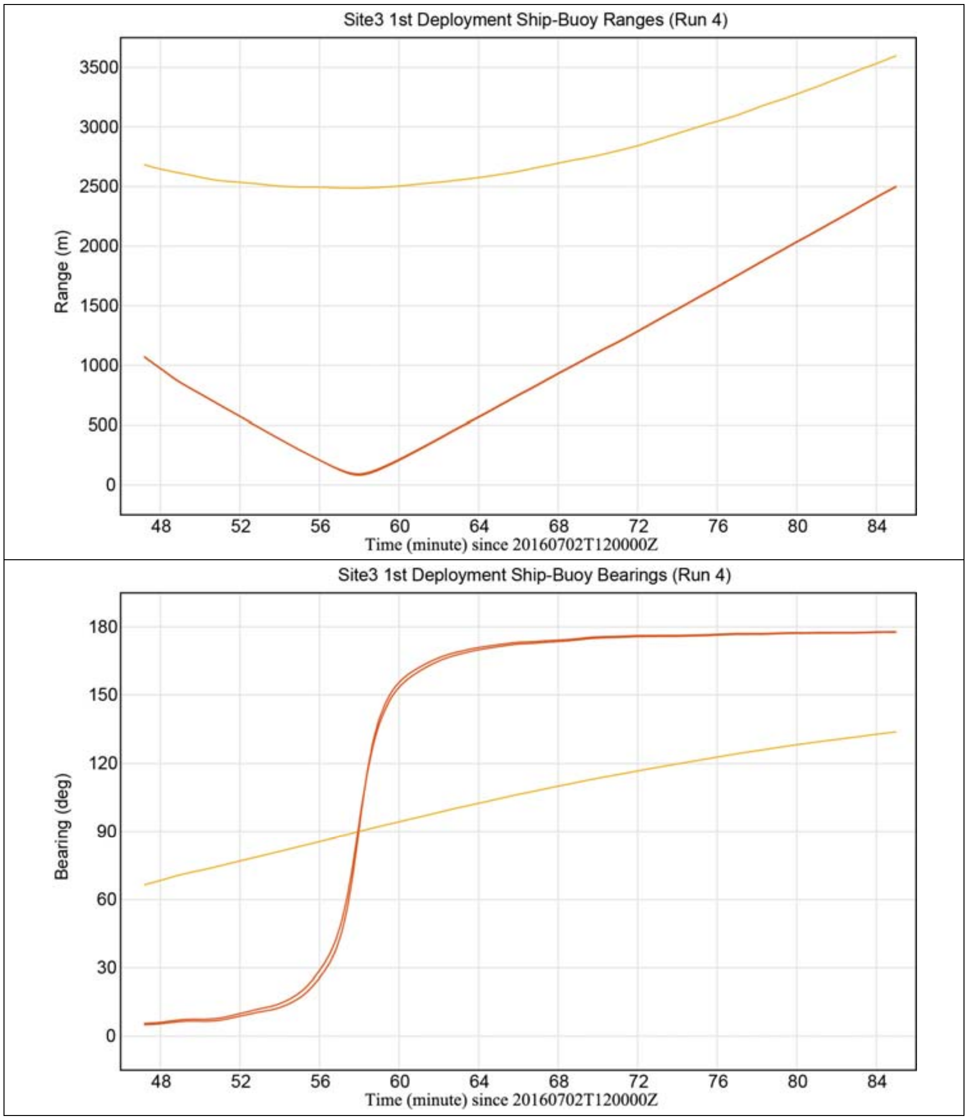


Figure 3.3-2. Site3 (S3), deployment 1 range coverage and bearing.
Top: Source to buoy range relative to time for Run4. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, $B_{1,2}$ (Buoy5,12) = red; and E (Buoy7) = yellow.

3.3.2 S3 Deployment 2

Navigation and Buoy Position

Deployment 2 at S3 included five measurement buoys and occurred from 0000 through 1400 GMT on 3 July (**Figure 2.5-4**). Three buoys collected acoustic data at three positions, leaving two position empty. The source track was oriented north-south. Three buoys each had two hydrophones (represented by dual hydrophone numbers). Acoustic data were recorded at positions A (Buoy5, LS, #6155/#6144), B (Buoy12, LS, #6154/#6148), and F (Buoy6, HS, #6145/#6151) (**Figure 3.3-3**). Positions D and E were not represented.

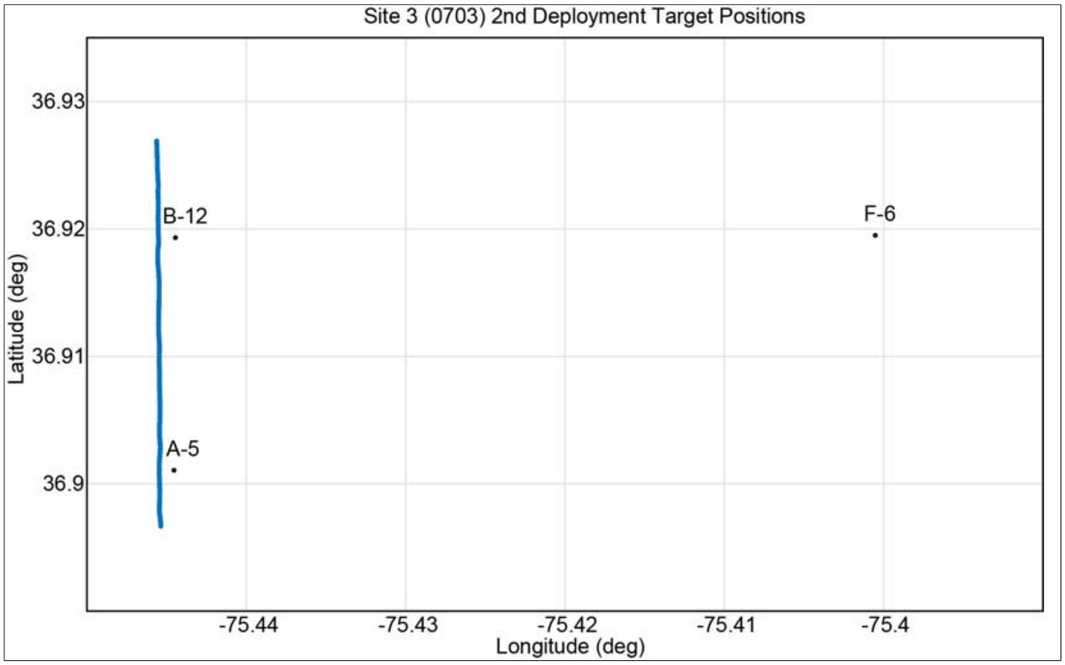


Figure 3.3-3. Site3 (S3), deployment 2, geographic buoy positions.
Positions A (Buoy5), B (Buoy12), and F (Buoy6) as well as the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

The three positions that captured acoustic data were A, B, and F as the source passed over position D (note: D did not capture acoustic data). The range coverage was sampled from 30 to 2,800 m at the two closest positions (A and B), and from 4,000 to 4,700 m at position F. The distances between 2,800 and 4,000 m were not sampled with this geometry (**Figure 3.3-4**).

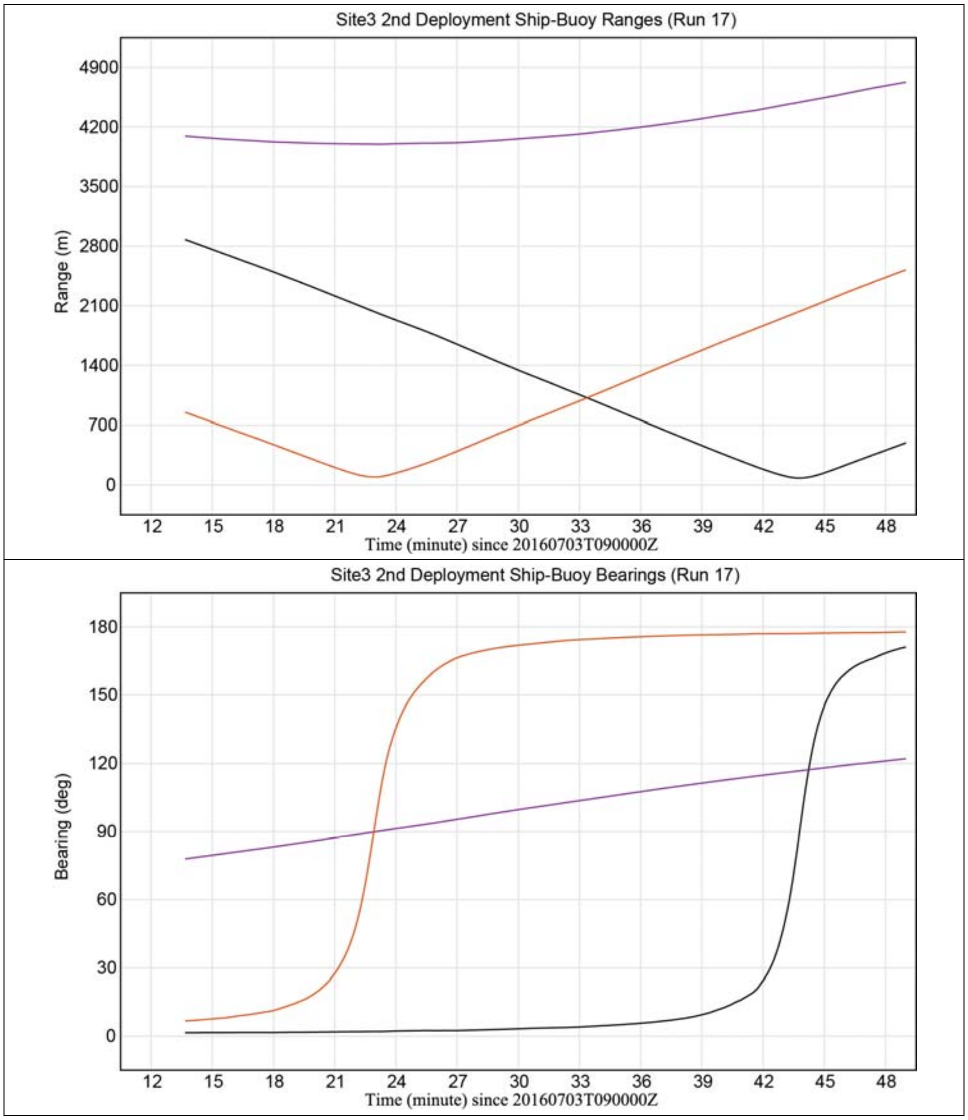


Figure 3.3-4. Site3 (S3), deployment 2, range coverage and bearing.
Top: Source to buoy range relative to time for Run17. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy5) = black; B (Buoy12) = red; and F (Buoy6) = purple.

3.3.3 S3 Deployment 3

Navigation and Buoy Position

Deployment 3 at S3 included seven measurement buoys and occurred from 1200 GMT on 12 July through 2100 GMT on 13 July (**Figure 2.5-4**). Six buoys collected acoustic data at five positions. The source track was oriented north-south. Five buoys each had two hydrophones (represented by dual hydrophone numbers). Acoustic data were recorded at positions A (Buoy12, HS, #6151/#6148), B (Buoy11, LS, #6155/#6145), D (Buoy6, LS, #6158), $E_{1,2}$ (Buoy10, HS, #6150/#6149; Buoy8, LS, #6153/#6147), and F (Buoy9, HS, #6151/#6148) (**Figure 3.3-5**).

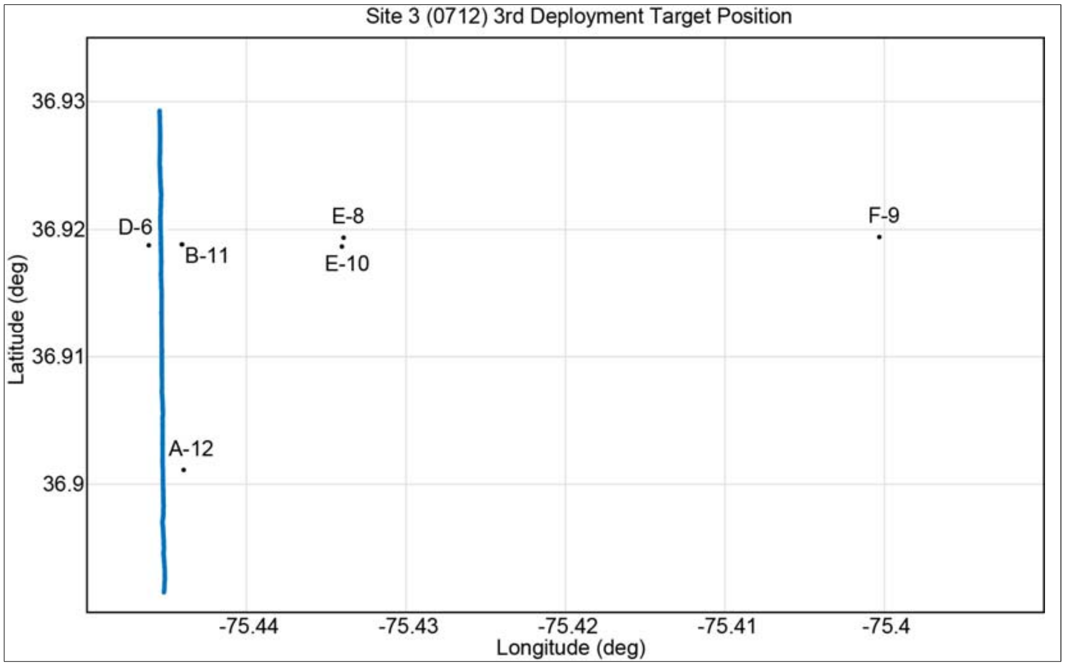


Figure 3.3-5. Site3 (S3), deployment 3, geographic buoy positions.
Positions A (Buoy12), B (Buoy11), D (Buoy6), $E_{1,2}$ (Buoy8,10), and F (Buoy9) and the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, thus bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

All five positions captured acoustic data. The range coverage was sampled by multiple buoys from the CPA to 3,200 m at positions A, B, D, and E, and from 4,000 to 5,000 m at position F. The distances between 3,200 and 4,000 m were not sampled with this geometry (**Figure 3.3-6**).

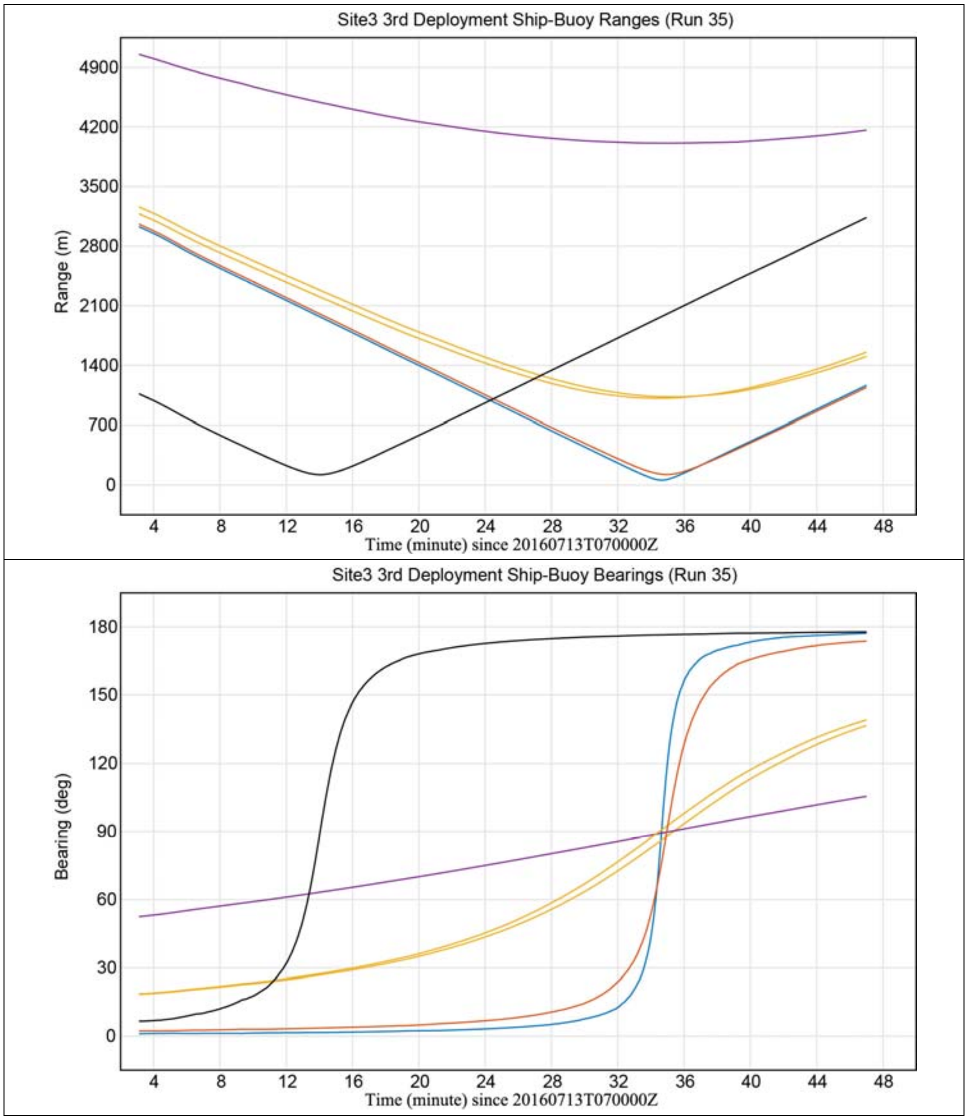


Figure 3.3-6. Site3 (S3), deployment 3, range coverage and bearing.
Top: Source to buoy range relative to time for Run35. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy12) = black; B (Buoy11) = red; D (Buoy6) = blue; $E_{1,2}$ (Buoy8,10) = yellow; and F (Buoy9) = purple.

3.4 Site 4: Sand, 30 m Depth

3.4.1 S4 Deployment 1

Navigation and Buoy Position

Deployment 1 at S4 included six measurement buoys, and occurred from 0300 through 1600 GMT on 30 June (**Figure 2.5-5**). Six buoys collected acoustic data at six positions (note, position C was included); however, data from positions A (LS), E (HS), and C were corrupt, leaving three positions empty. The source track was oriented northeast-southwest. Two buoys each had two hydrophones (represented by dual hydrophone numbers). Acoustic data were collected at positions A (Buoy6, HS, #6150/#6147), B (Buoy 7, HS/LS, #6151/#6145), C (Buoy 5, HS, #6155/#61454), D (Buoy8, LS, #6159), E (Buoy9, LS, #6153/#6149), and F (Buoy11, HS, #6152/#6146) (**Figure 3.4-1**).

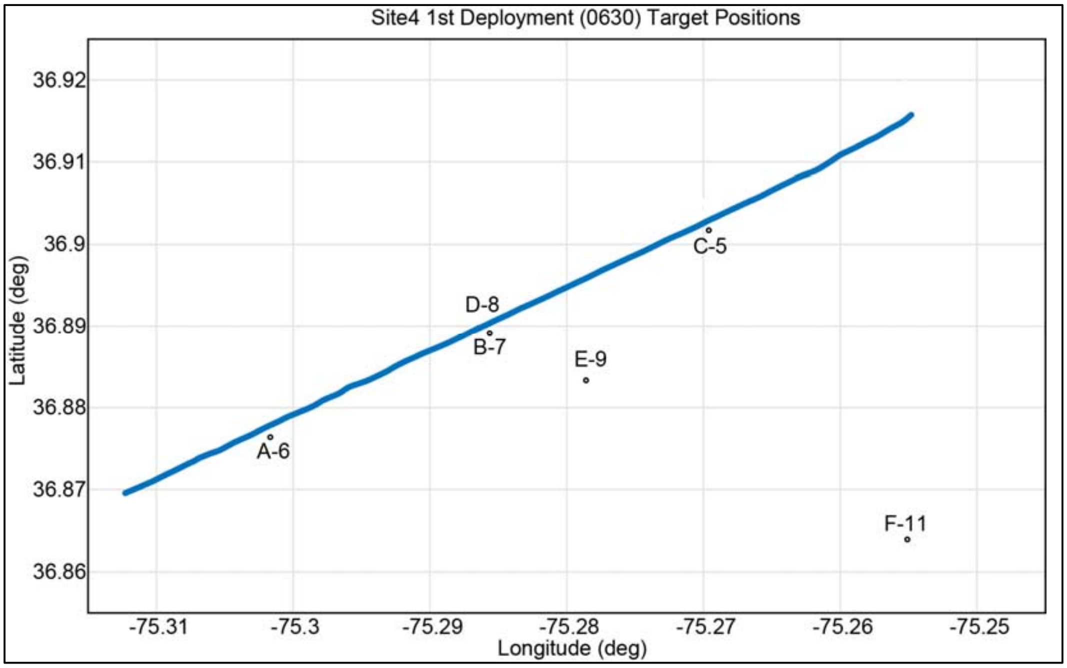


Figure 3.4-1. Site4 (S4), deployment 1, geographic buoy positions.
Positions A (Buoy6), B (Buoy7), C (Buoy5), D (Buoy8), E (Buoy9), and F (Buoy11)and the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

Four positions captured acoustic data. The range coverage was sampled by multiple buoys from the CPA to 6,000 m at positions A, B, C, D, E, and F (**Figure 3.4-2**).

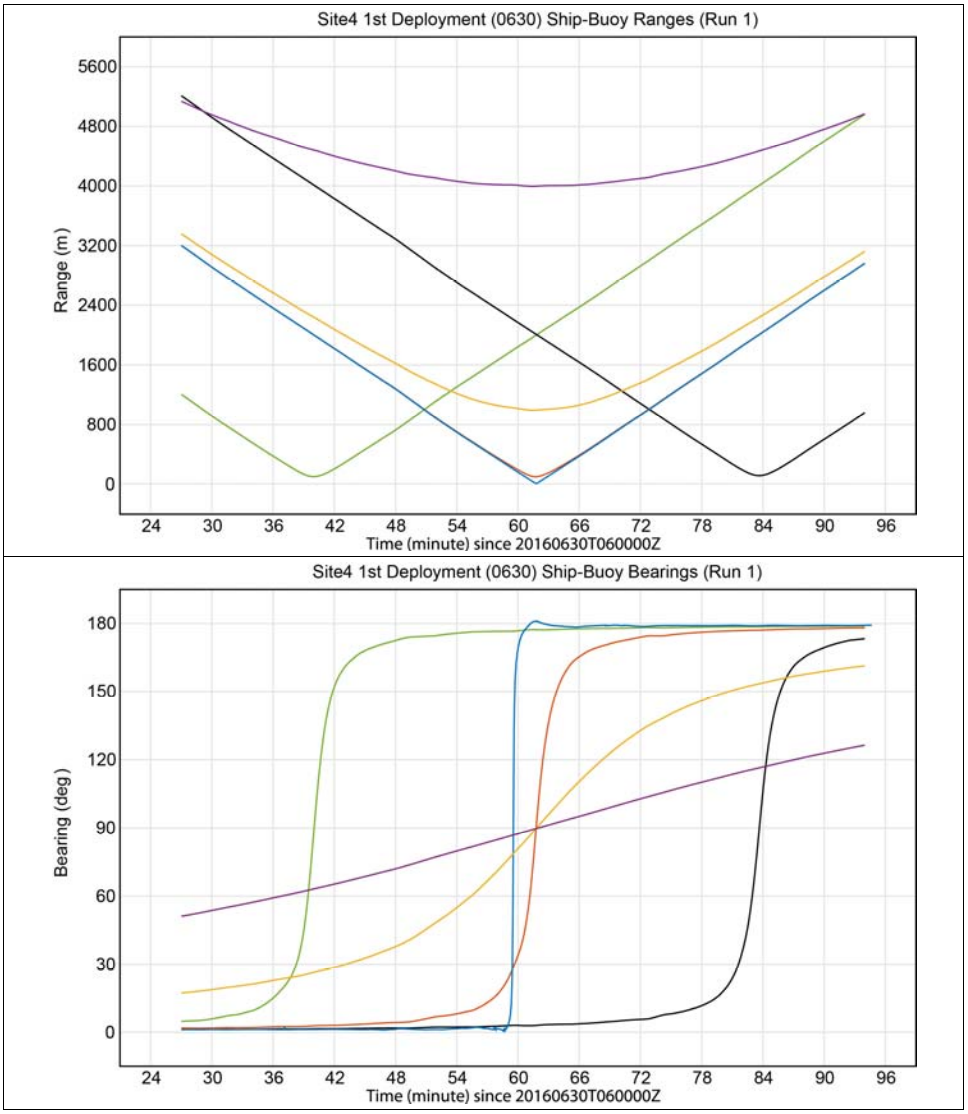


Figure 3.4-2. Site4 (S4), deployment 1, range coverage and bearing.
Top: Source to buoy range relative to time for Run1. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy6) = black; B (Buoy7) = red; C (Buoy5) = green; D (Buoy8) = blue; E (Buoy9) = yellow; and F (Buoy11) = purple.

3.4.2 S4 Deployment 2

Navigation and Buoy Position

Deployment 2 at S4 included five measurement buoys and occurred from 1700 GMT on 30 June through 1630 GMT on 1 July (**Figure 2.5-5**). Four buoys collected acoustic data at four positions, leaving one position empty. The source track was oriented northeast-southwest. The four buoys each had two hydrophones (represented by dual hydrophone numbers). Acoustic data were collected at positions A (Buoy6, HS, #6150/#6147), D (Buoy8, LS, #6159), E (Buoy9, HS #6153/#6149), and F (Buoy11, HS, #6152/#6146) (**Figure 3.4-3**). Position B was not represented.

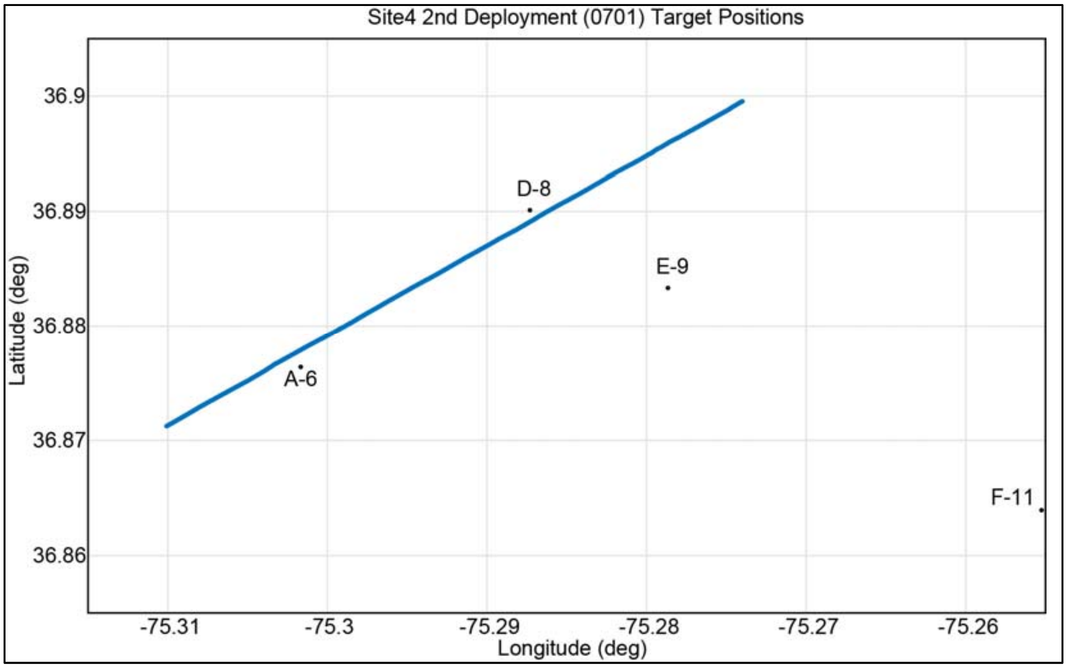


Figure 3.4-3. Site4 (S4), deployment 2, geographic buoy positions.
Positions A (Buoy6), D (Buoy8), E (Buoy9), and F (Buoy11) as well as the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, thus bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

The four positions that captured acoustic data covered ranges from the CPA to 3,500 m at positions A, D, and E; and from 4,000 to 4,900 m at position F. The distances between 3,500 and 4,000 m were not sampled with this geometry (**Figure 3.4-4**).

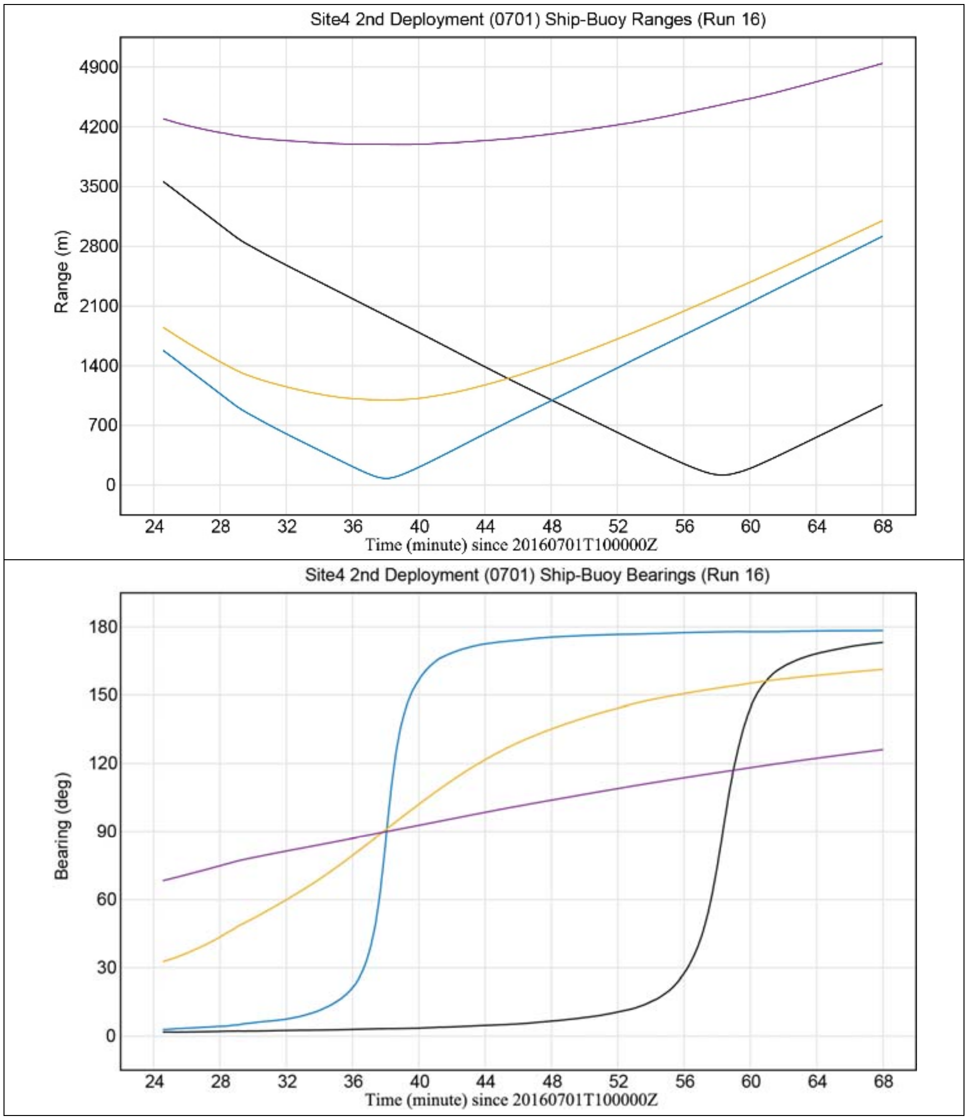


Figure 3.4-4. Site4 (S4), deployment 2, range coverage and bearing.
Top: Source to buoy range relative to time for Run16. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy6) = black; D (Buoy8) = blue; E (Buoy9) = yellow; and F (Buoy11) = purple.

3.4.3 S4 Deployment 3

Navigation and Buoy Position

Deployment 3 at S4 included five measurement buoys and occurred from 0100 GMT on 4 July through 0000 GMT on 5 July (**Figure 2.5-5**). Three buoys collected acoustic data at three positions, leaving two positions empty. The source track was oriented northeast-southwest. Three buoys each had two hydrophones (represented by dual hydrophone numbers). Acoustic data were collected at positions B (Buoy12, LS, #6154/#6148), D (Buoy8, LS, #6159), and F (Buoy5, HS, #6155/#6144) (**Figure 3.4-5**). Positions A and E were not represented.

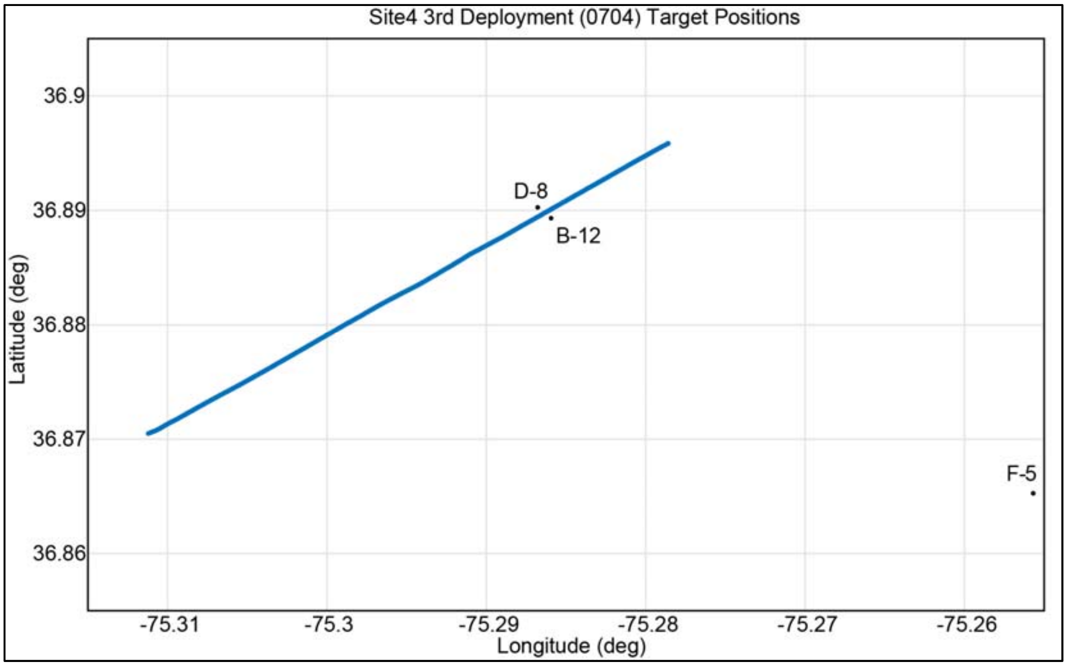


Figure 3.4-5. Site4 (S4), deployment 3, geographic buoy positions.
Positions B (Buoy12), D (Buoy8), and F (Buoy5) and the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

Three positions captured acoustic data. The range coverage was sampled by multiple buoys from the CPA to 3,200 m at positions B and D, and from 3,800 to 4,900 m at position F. The distances between 3,200 and 3,800 m were not sampled with this geometry (**Figure 3.4-6**).

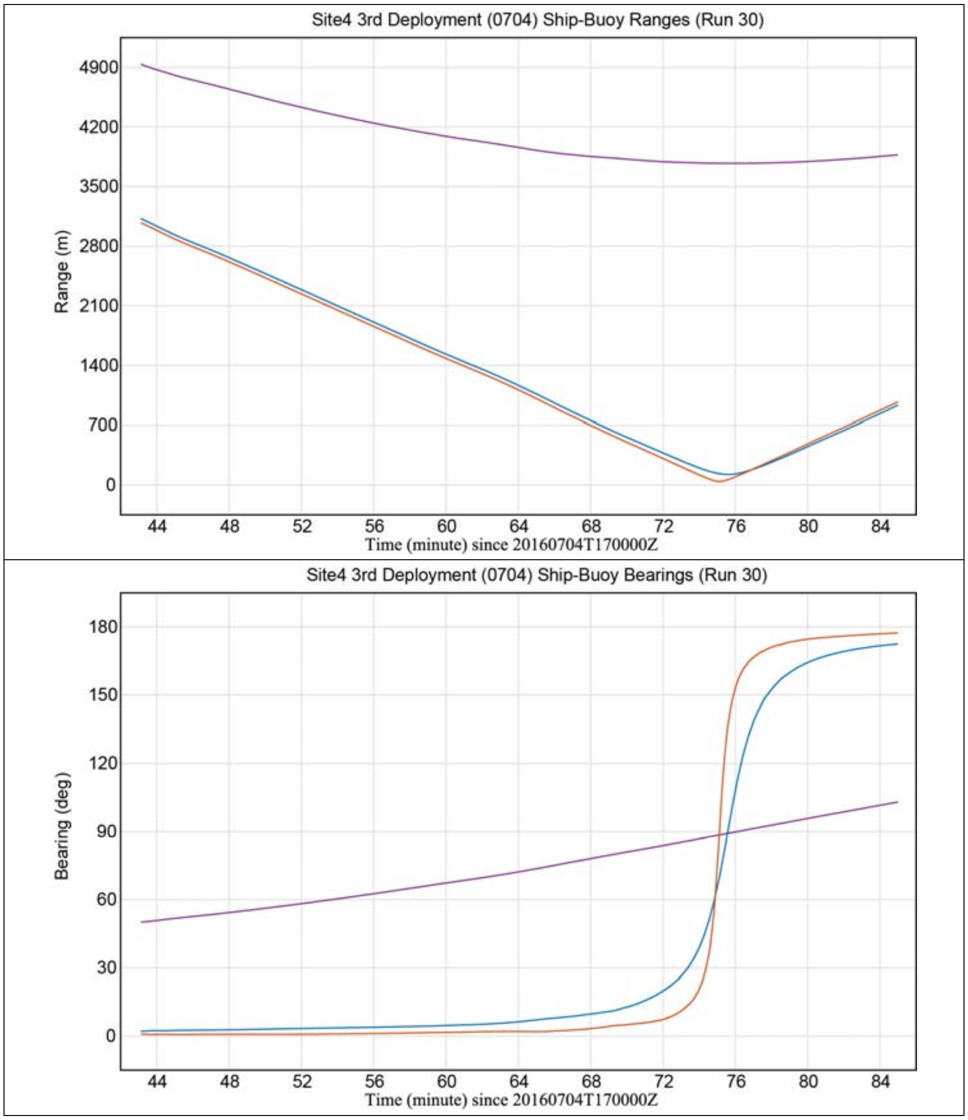


Figure 3.4-6. Site4 (S4), deployment 3, range coverage and bearing.
Top: Source to buoy range relative to time for Run30. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, B (Buoy12) = red; D (Buoy8) = blue; and F (Buoy5) = purple.

3.5 Site 5: Sandy-Silt, 100 m Depth

3.5.1 S5 Deployment 1

Navigation and Buoy Position

Deployment 1 at S5 included seven measurement buoys and occurred from 1400 GMT on 9 July through 1200 GMT on 10 July (**Figure 2.5-6**). Six buoys collected acoustic data at four positions. The source track was oriented northeast-southwest. Five buoys each had three hydrophones (represented by three hydrophone numbers). Acoustic data were collected at positions A (Buoy12, LS, #6151/#6148/#6138), $B_{1,2}$ (Buoy5, HS, #6154/#6144/#6140; Buoy11, LS, #6155/#6145/#6143), D (Buoy6, LS, #6158), and $E_{1,2}$ (Buoy9, HS, #6153/#6147/#6141; Buoy8, LS, #6150/#6149/#6139) (**Figure 3.5-1**). Position F was not represented.

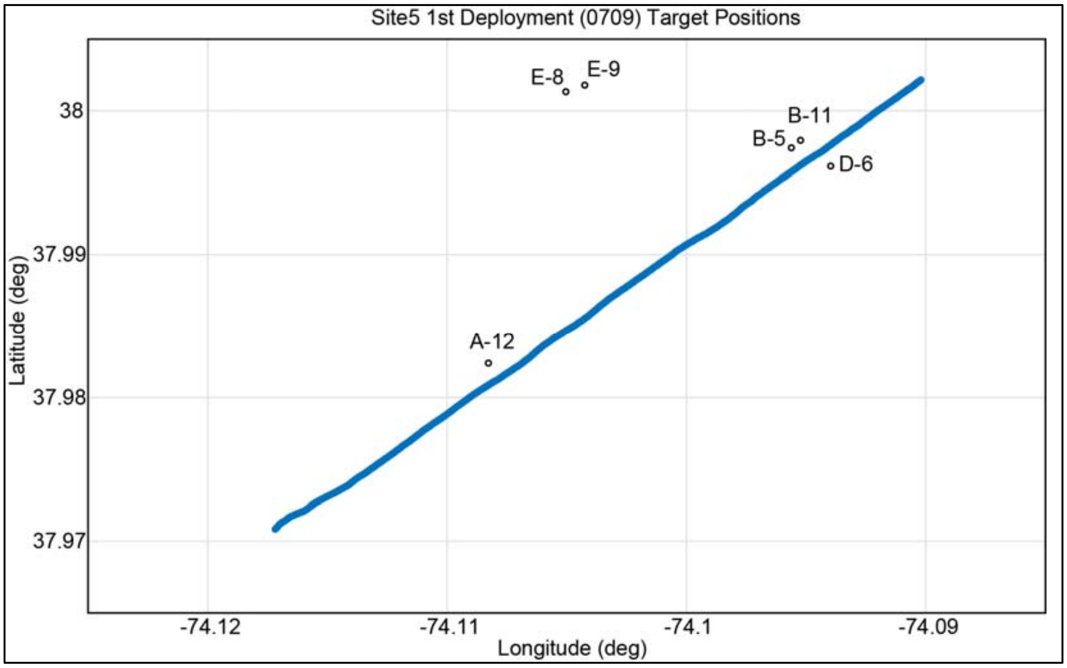


Figure 3.5-1. Site5 (S5), deployment 1, geographic buoy positions.
Positions A (Buoy12), $B_{1,2}$ (Buoy5,11), D (Buoy6), and $E_{1,2}$ (Buoy8,9) and the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

Four positions captured acoustic data. The range coverage was sampled from the CPA to 3,500 m by buoys at positions A, B, D, and E (**Figure 3.5-2**).

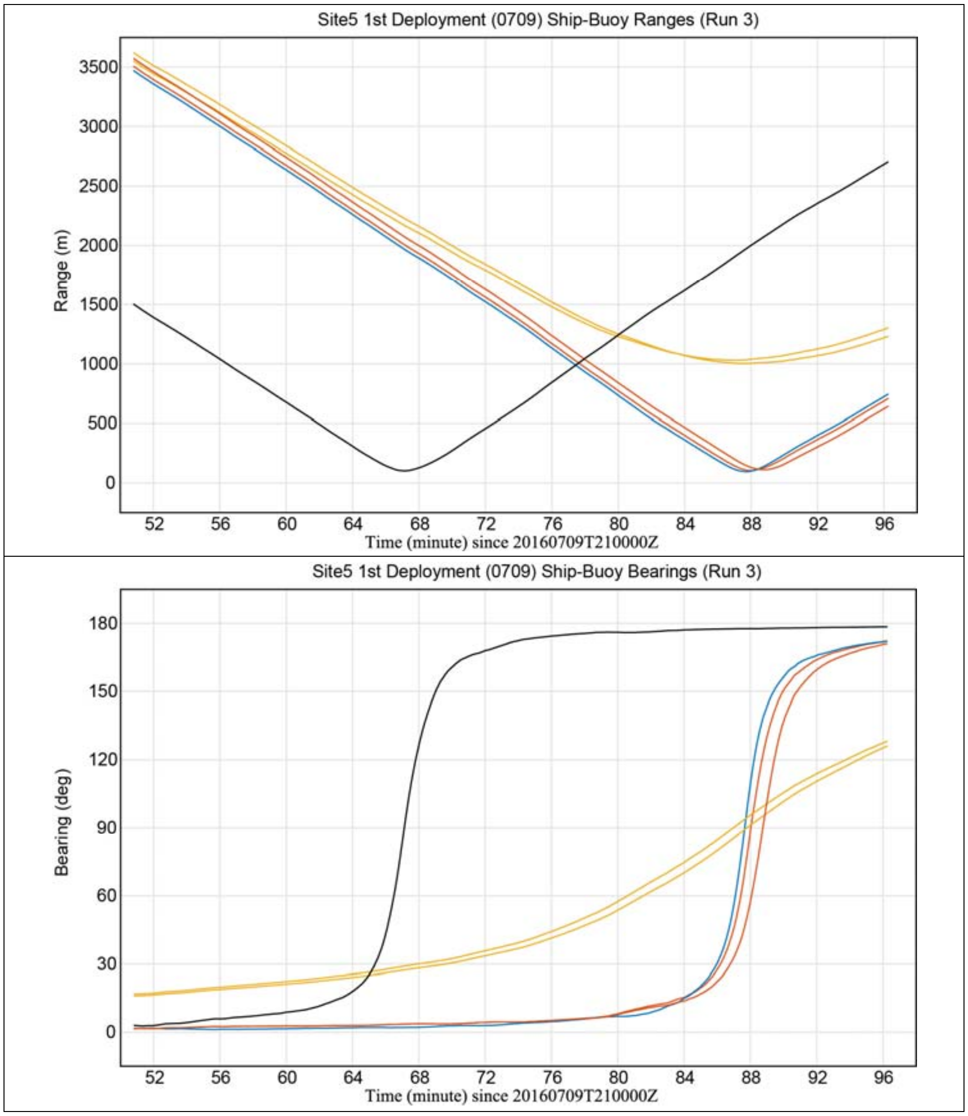


Figure 3.5-2. Site5 (S5), deployment 1, range coverage and bearing.
Top: Source to buoy range relative to time for Run3. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy12) = black; $B_{1,2}$ (Buoy5,11) = red; D (Buoy6) = blue; and $E_{1,2}$ (Buoy8,9) = yellow.

3.5.2 S5 Deployment 2

Navigation and Buoy Position

Deployment 2 at S5 included seven measurement buoys and occurred from 1400 GMT on 10 July through 1600 GMT on 11 July (**Figure 2.5-6**). Six buoys collected acoustic data at five positions. The source track was oriented northeast-southwest. Five buoys each had three hydrophones (represented by three hydrophone numbers). Acoustic data were collected at positions A (Buoy12, LS, #6151/#6148/#6138), B (Buoy11, LS, #6155/#6145/#6143), D (Buoy6, LS, #6158), $E_{1,2}$ (Buoy9, HS, #6153/#6147/#6141; Buoy8, LS, #6150/#6149/#6139), and F (Buoy10, HS, #6152/#6146/#6142) (**Figure 3.5-3**).

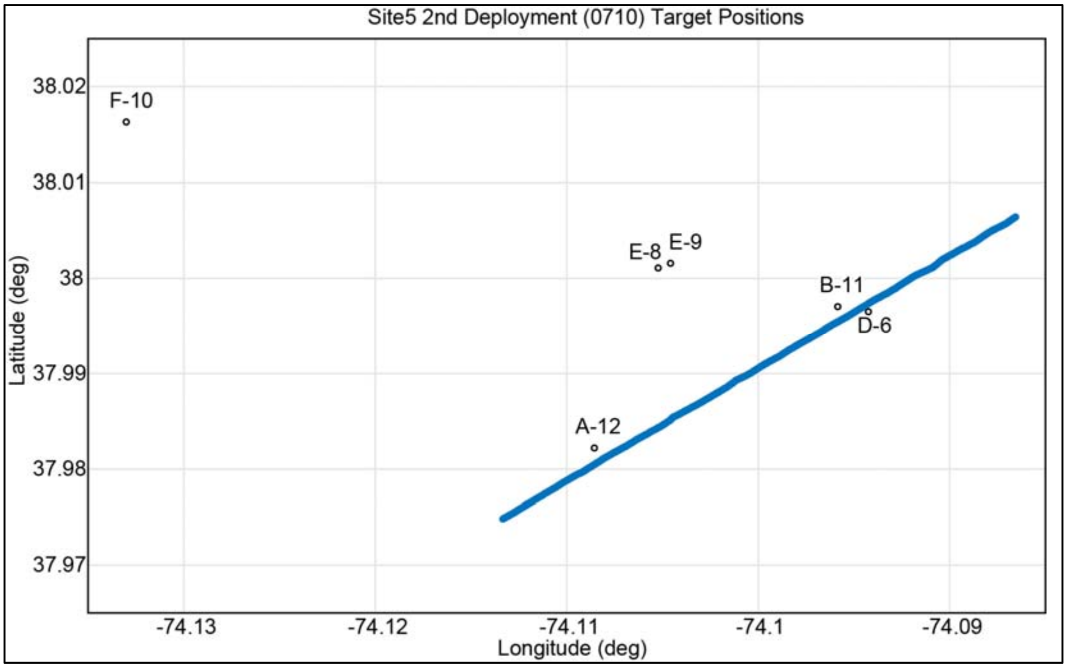


Figure 3.5-3. Site5 (S5), deployment 2, geographic buoy positions.
Positions A (Buoy12), B (Buoy11), D (Buoy6), $E_{1,2}$ (Buoy8,9), and F (Buoy10) as well as the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, thus bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

All five positions captured acoustic data. The range coverage was sampled from the CPA to 3,400 m by buoys at positions A, B, D, and E, and from 4,000 to 4,900 m at position F. The distances between 3,400 and 4,000 m were not sampled with this geometry (**Figure 3.5-4**).

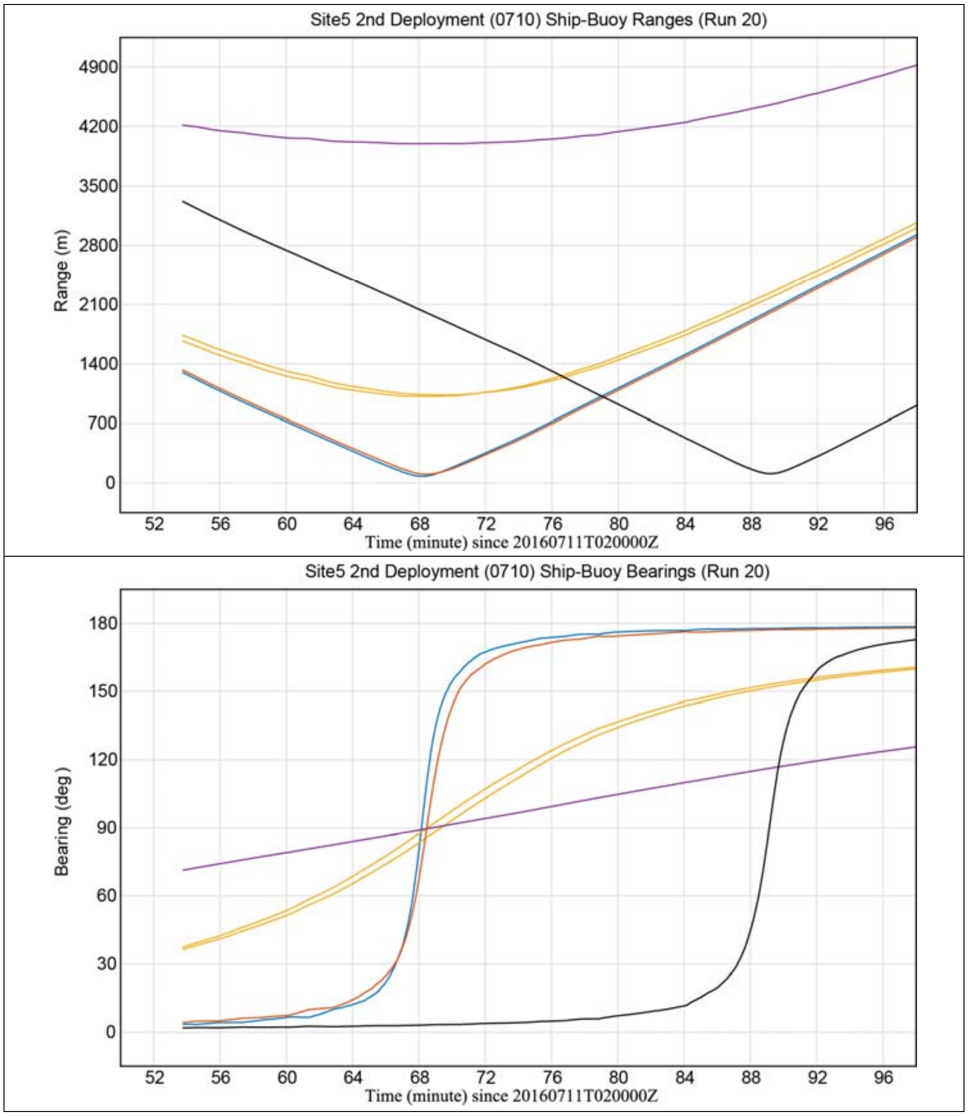


Figure 3.5-4. Site5 (S5), deployment 2, range coverage and bearing.
Top: Source to buoy range relative to time for Run20. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy12) = black; B (Buoy11) = red; D (Buoy6) = blue; $E_{1,2}$ (Buoy8,9) = yellow; and F (Buoy10) = purple.

3.5.3 S5 Deployment 3

Navigation and Buoy Position

Deployment 3 at S5 included six measurement buoys and occurred from 1600 through 2300 GMT on 11 July (**Figure 2.5-6**). Six buoys collected acoustic data at five positions. The source track was oriented northeast-southwest. Five buoys each had three hydrophones (represented by three hydrophone numbers). Acoustic data were collected at positions A (Buoy12, LS, #6151, #6148, #6138), B (Buoy11, LS, #6155/#6145/#6143), D (Buoy6, LS, #6158), $E_{1,2}$ (Buoy9, HS, #6153/#6147/#6141; Buoy8, LS, #6150/#6149/#6139), and F (Buoy10, HS, #6156) (**Figure 3.5-5**).

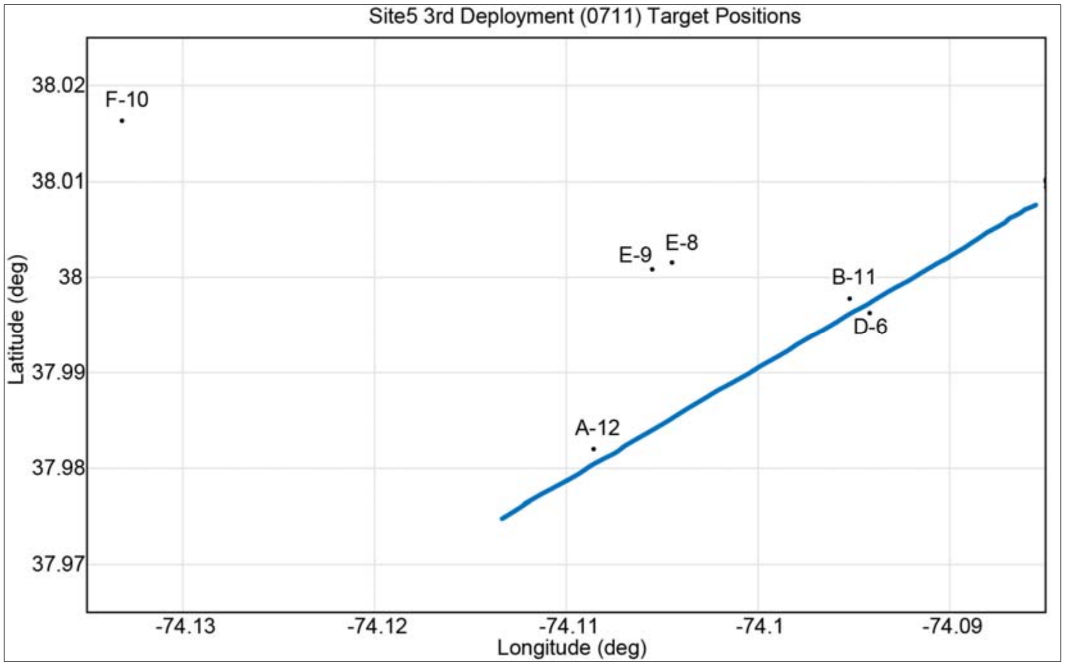


Figure 3.5-5. Site5 (S5), deployment 3, geographic buoy positions.
Positions A (Buoy12), B (Buoy11), D (Buoy6), $E_{1,2}$ (Buoy8,9), and F (Buoy10) and the source track (blue). North is vertical (upward). Note the source went back and forth along the source track. Latitude and longitude are not to scale, so bearings and angles are not properly displayed and are for general orientation only.

Range and Bearing to Buoys

All five positions captured acoustic data. The range coverage was sampled from the CPA to 3,500 m by buoys at positions A, B, D, and E, and from 4,000 to 4,900 m at position F. The distances between 3,500 and 4,000 m were not sampled with this geometry (**Figure 3.5-6**).

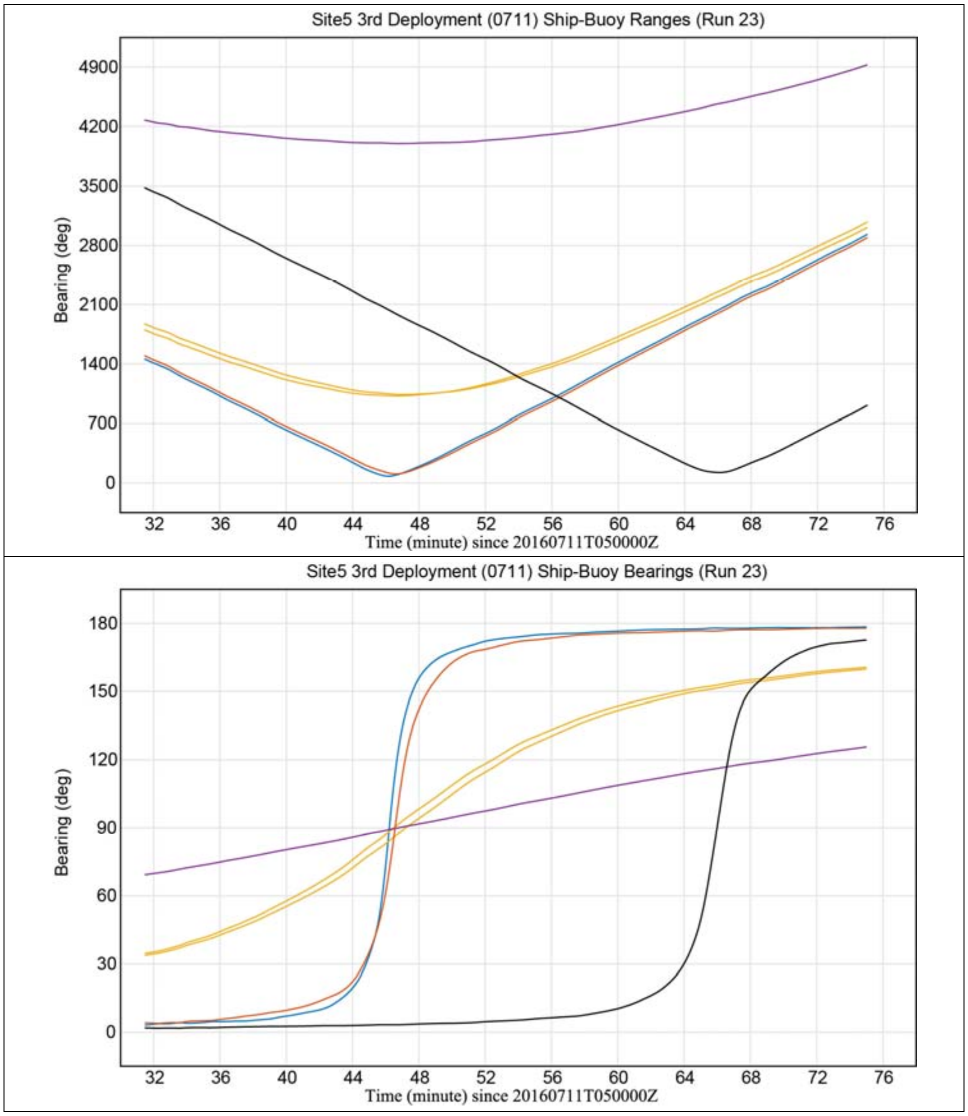


Figure 3.5-6. Site5 (S5), deployment 3, range coverage and bearing.
Top: Source to buoy range relative to time for Run23. Bottom: bearing of source to buoy relative to time along the source track. Legend: Positions, A (Buoy12) = black; B (Buoy11) = red; D (Buoy6) = blue; $E_{1,2}$ (Buoy8,9) = yellow; and F (Buoy10) = purple.

This Page Left Intentionally Blank

4 RESULTS - SOURCES

Each high-resolution geophysical source tested during this survey is discussed in this section. Each source's acoustic signal characteristics are presented at the CPA, including plots of a time-waveform, power spectral density, and spectrum. These data are followed by site-specific acoustics on the received metrics (SPL_{pk}, SEL, and SPL_{rms}), range and bearing plots, and a summary comparing the measured field data with the NUWC data. Difficulties were encountered in the field that affected the data such as buoy positioning and calibration errors (**Section 2.6.3.1**). Dr. Kevin Heaney performed intensive acoustic data processing and analyses, and resolved numerous data discrepancies. Dr. Kevin Heaney addressed errors in calibration and overlapping source signals and buoy navigation, thereby successfully generating viable results.

Many HRG sources radiated sound intensity at harmonics of the transmit frequency, however, none of the measured sources radiated detectable levels of sound at sub-harmonics. In order to evaluate whether harmonics were important with respect to the observed acoustic metrics, the loudest transmission was captured at the CPA and the spectra of this reception was evaluated. Based on the evaluation, lower and upper bounds of the frequency band were selected to be within 1 dB of the full band, as shown in the first table of the Mode 1 chapter for each source. For signals with significant energy in the harmonics, this energy was captured in the results.

The signal processing results for each source operational mode and each site are presented in two figure sets. The first figure set (Percentile Plots) plots the intensity percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}, and 100^{th}) as a function of recording time for a particular set of buoys. The figures provide a rapid quality assessment of the acoustic recording and confirm presence of the source signal. In addition, the figures show when the source signal was observed (or not) and provide a qualitative look at how much the signal increased the local noise field. The first figure set also may show valid acoustic recordings that have no source signal because the source was too far away for effective transmission. A subset of the best representational data are presented in a trio or quad-chart format; only up to four recording positions with acoustic data are presented to show a subset of the large acoustic dataset. The highest percentile reflects the SPL_{pk}, while the lowest percentile plotted is the 5^{th} percentile of the received acoustic intensity. The 5^{th} percentile is not a reflection of the acoustic noise floor because the data were recorded with 16-bit resolution; therefore, the capability of the equipment was insufficient to capture the full dynamic range, which is the maximum received signal level down to the low background noise level; i.e., bottom sound levels were not detectable.

The second figure set (Range Results) shows the range results for all buoys with valid acoustic data. An automated filter was applied to determine when a particular acoustic recording segment contained the source signal. A 30-dB peak to 5 percent ratio filter was applied in most cases. SPL_{pk}, SEL, and SPL_{rms} are plotted as a function of range for each source; SPL_{pk} also is plotted as a function of bearing from the source. The range and bearing were computed using the GPS location of the ship and interpolated between the values of the logged deployment and recovery position, this procedure was used when the buoys GPS failed. Each buoy position is assigned a specific color consistent with the geometry figures in **Section 3.0** (i.e., A = black; B = red; C = green; D = blue; E = yellow; F = purple). Most sources had multiple runs at a single site, and the runs are plotted together in the range results figure set to provide a total representation of the received acoustic level as a function of range. Spherical and cylindrical spreading propagation curves were overlaid onto the received peak versus the range results plot. The propagation curves were generated using the source level as reported by NUWC (Crocker and Fratantonio, 2016), such that the NUWC reported source levels were plugged into the propagation models to generate the curves. When a source was not tested by NUWC, the propagation curves were not plotted. The angle between the source and the receiver is very sensitive to buoy position, meaning when the geometry is unknown or incorrect, the estimation of the bearing is uncertain. A symmetric peak with a center (maximum peak signal) near 90° is expected when buoy navigational position is precisely known.

The received level is a function of the propagation (range) and the source directionality (bearing). The bearing sensitivity was not removed in the results versus range and the range sensitivity was not removed from the results versus bearing. The best approach to account for propagation and source directionality would be to use a propagation model and a directional source, which is beyond the scope of this project.

In describing the acoustic datasets at each site, the term "valid acoustic data" is used to mean that the recorders functioned properly and the collected dataset contains actual acoustic recordings as opposed to non-acoustic noise or a failed buoy recording. Valid acoustic data includes data with signals and/or with acoustic noise. Furthermore, when there are valid acoustic data, it does not mean HRG signals were captured, when signals were captured, it is stated as such.

The final results figure is called a plan view and is defined as a view projected onto a horizontal plane (i.e., top-down view). The plan view illustrates the received levels at each buoy position relative to the moving position of the sound source on the vessel. The plan view displays the spatial two dimensional (2D) pattern of the acoustic propagation, combining acoustic decay with range and horizontal directionality of the source.

4.1 Reson 7125, 200 kHz, 220 dB, 100 Percent Power (Mode 1)

The Reson 7125 multibeam echosounder generates a single, very high-frequency (VHF) signal with a peak frequency of 196 kHz. The operational parameter settings for Mode 1 were a power setting of 220 dB for 100 percent power, and 200 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.1-1** is the selected frequency band (165 to 218 kHz) and SPL_{pk} (208.33 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.1-1. Bandpass determination for the Reson 7125 multibeam echosounder, 200 kHz, 220 dB, 100 percent power at Site 2, Run12.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
100-250	208.52
150-240	208.33
165-218	**208.33**
178-208	204.26

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported below from only one site for simplicity. The Reson 7125, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.1-1**. The first set of peaks at 3 to 6 ms of the time waveform (**Figure 4.1-1,** top panel) is the direct path signal arrival from the Reson 7125 at CPA. The second arrival is likely an indirect reflection from the seafloor. The full spectra (100 to 250 kHz) was used to generate the time series.

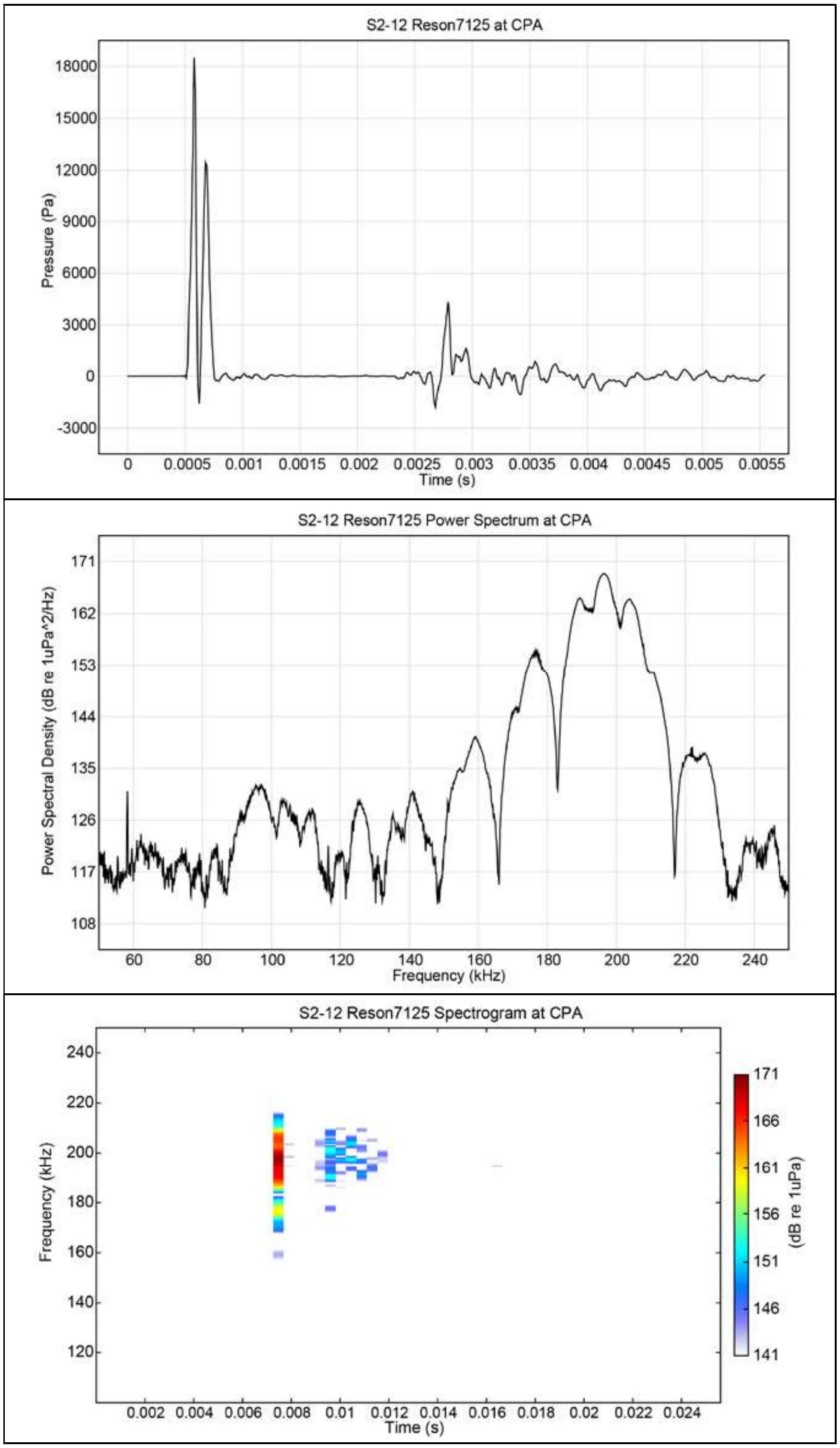


Figure 4.1-1. Reson 7125 measured signal characteristics at closest point of approach (CPA) at Site 2, Run12.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.1.1 Site 1 – Mud, 10 m Depth

At S1, the Reson 7125, Mode 1, had valid acoustic recordings in Run8, only at position D (Buoy6). Positions E (Buoy5 and Buoy8) and F (Buoy9) were too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the three available recordings of the Reson 7125, Mode 1, are shown in **Figure 4.1.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the duration of the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run8, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 196 kHz, the propagation loss was very high and the signal was only observable for a total of 1 minute (30 seconds before and 30 seconds after the CPA).

In **Figure 4.1.1-1**, the top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal because of propagation loss of the VHF signal.

The results panels (**Figure 4.1.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the Reson 7125 at S1, only position D (Buoy6) had any acoustic signal, which is plotted in the graph. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 100 m. The two visible blue tracks (for position D) signify the approach and departure of the source to and from the buoy. The difference could be azimuthal dependence of the source or a small error in the buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.1.1-2**), which shows the received peak level at 102°. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°; as it is at 102°, a small error in the buoy positioning determination is possible.

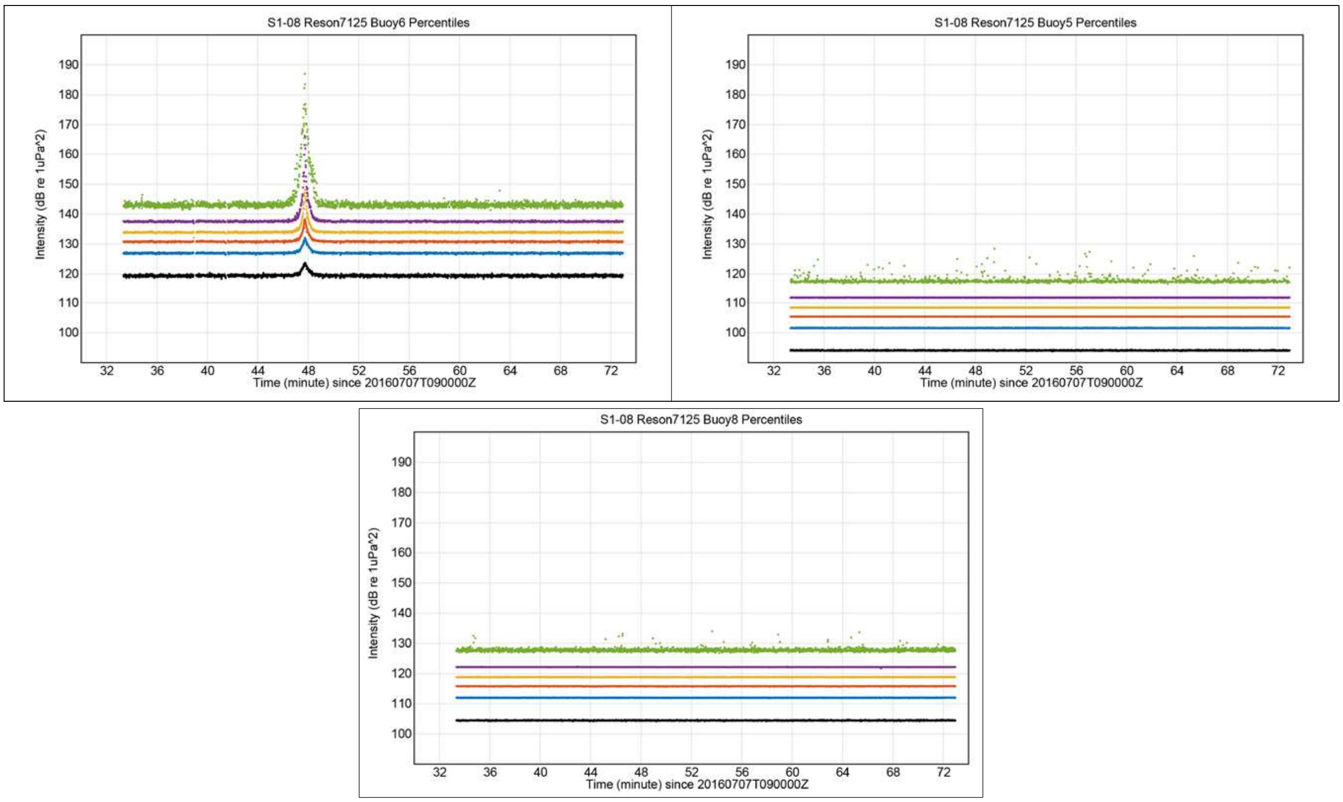


Figure 4.1.1-1. Percentile plots of Reson 7125 signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

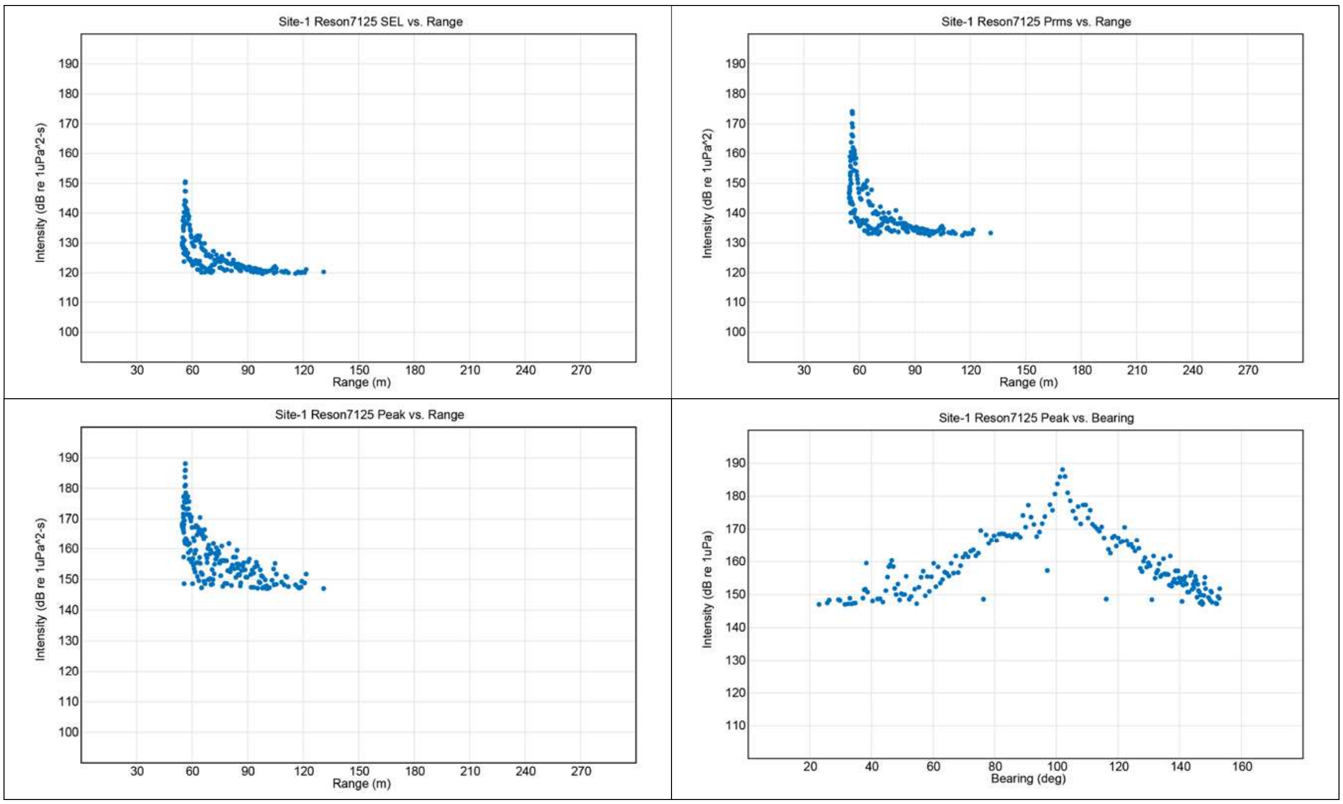


Figure 4.1.1-2. Range results for Reson 7125 signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position D = blue.

The plan view is shown in **Figure 4.1.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 60,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at position D (Buoy6). The gradual rise of the received source level is seen from -80 m to approximately 0 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise at approximately 100 m (y-axis). The CPA of 50 m on the x-axis could be the result of buoy positional errors.

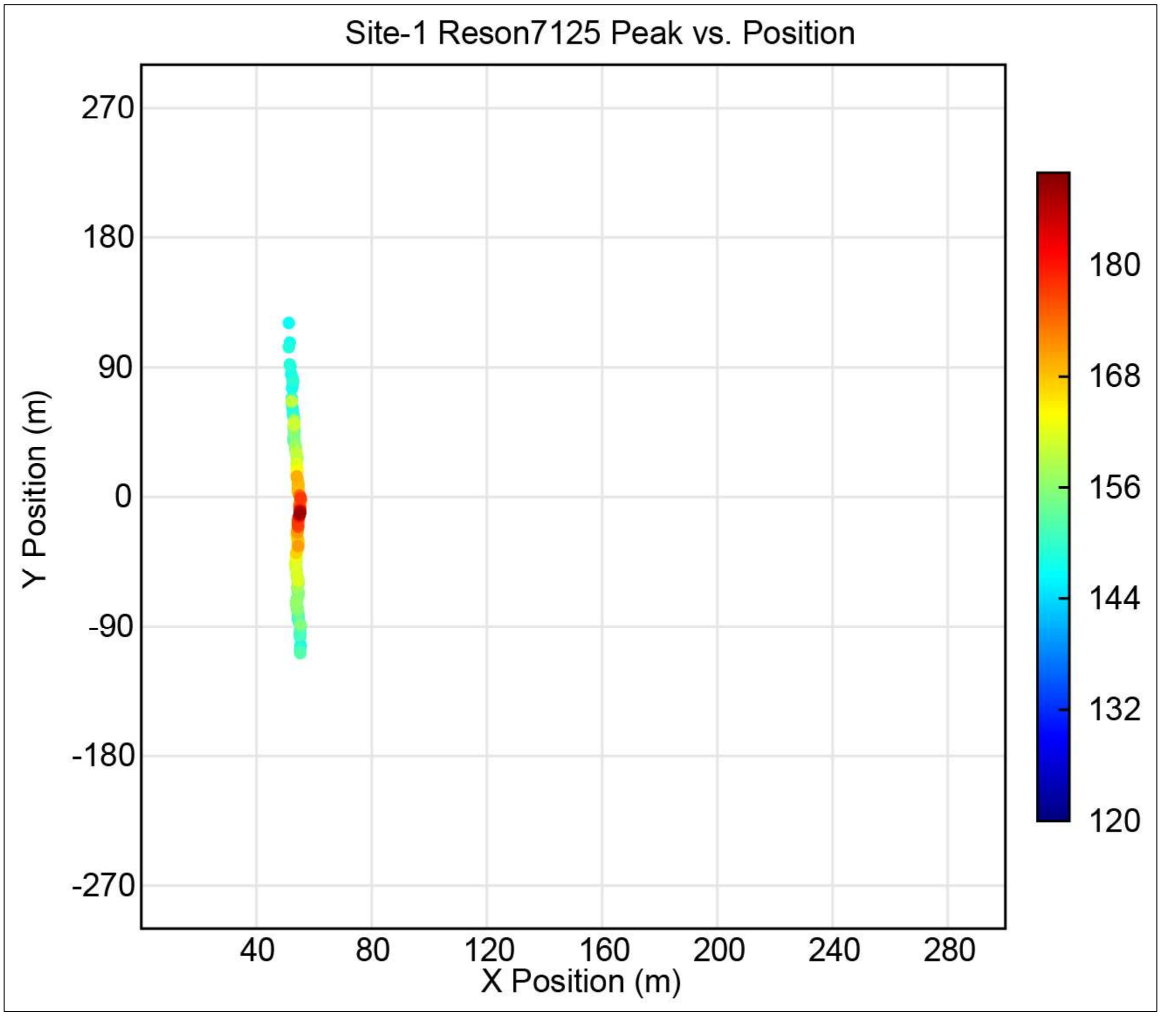


Figure 4.1.1-3. Plan view of received peak level for Reson 7125 at Site 1 for position D (Buoy6).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.1.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] to back propagate the measurement to 1 m.

Table 4.1.1-1. Reson 7125 source levels, Mode 1, at Site 1.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
Reson 7125 Mode 1	200 kHz	100%	220 dB	300 µs	223	209	186
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.1.2 Site 2 – Sand, 10 m Depth

At S2, the Reson 7125, Mode 1, had valid acoustic recordings in Run12 and Run38. For Run12, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run38, position B (Buoy11 and Buoy5) had valid acoustic recordings. Positions E (Buoy10) and F (Buoy9) were too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7125, Mode 1, are shown in **Figure 4.1.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run12, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 196 kHz, the propagation loss was very high and the signal was only observable for a maximum of 2 minutes (60 seconds before and 60 seconds after the CPA).

In **Figure 4.1.2-1**, the top right and bottom panels show the recorded acoustics at positions B and E. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good. However, even with valid acoustic data, there is no evidence of the signal at position E because of propagation loss of the VHF signal.

The results panels (**Figure 4.1.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7125 at S2, only positions D (Buoy6) and B (Buoy11) had acoustic signals, which are plotted in the graph. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 150 m. The conical shape of the position D and position B data points signifies the approach and departure of the source to and from the buoys. All three receptions at position B are close together, showing good calibration and buoy location determination. The difference could be azimuthal dependence of the source or a small error in buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.1.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 145°, indicating an error in buoy positioning. For position B, the received peak level is at approximately 80° and 90°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°; as it is at 145° for position D, an error in the buoy positioning determination is possible.

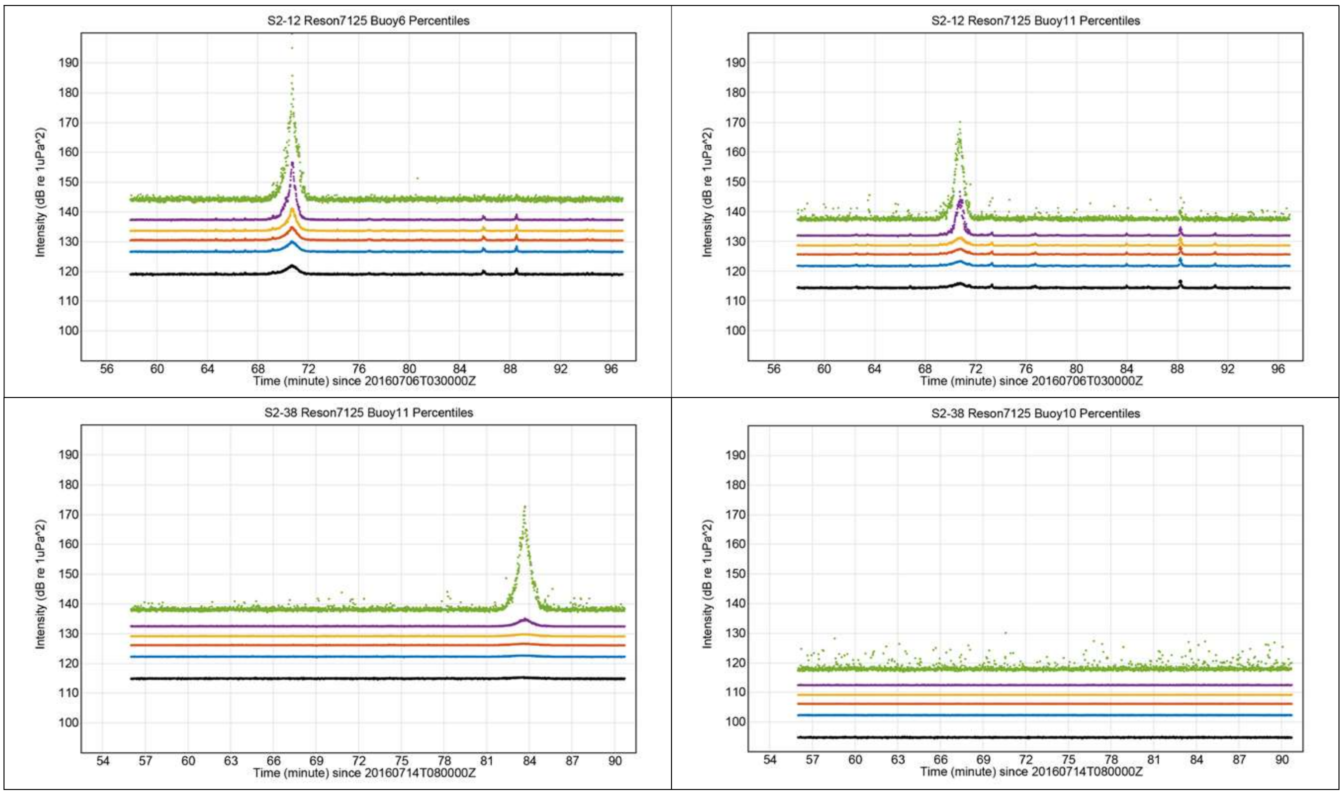


Figure 4.1.2-1. Percentile plots of Reson 7125 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

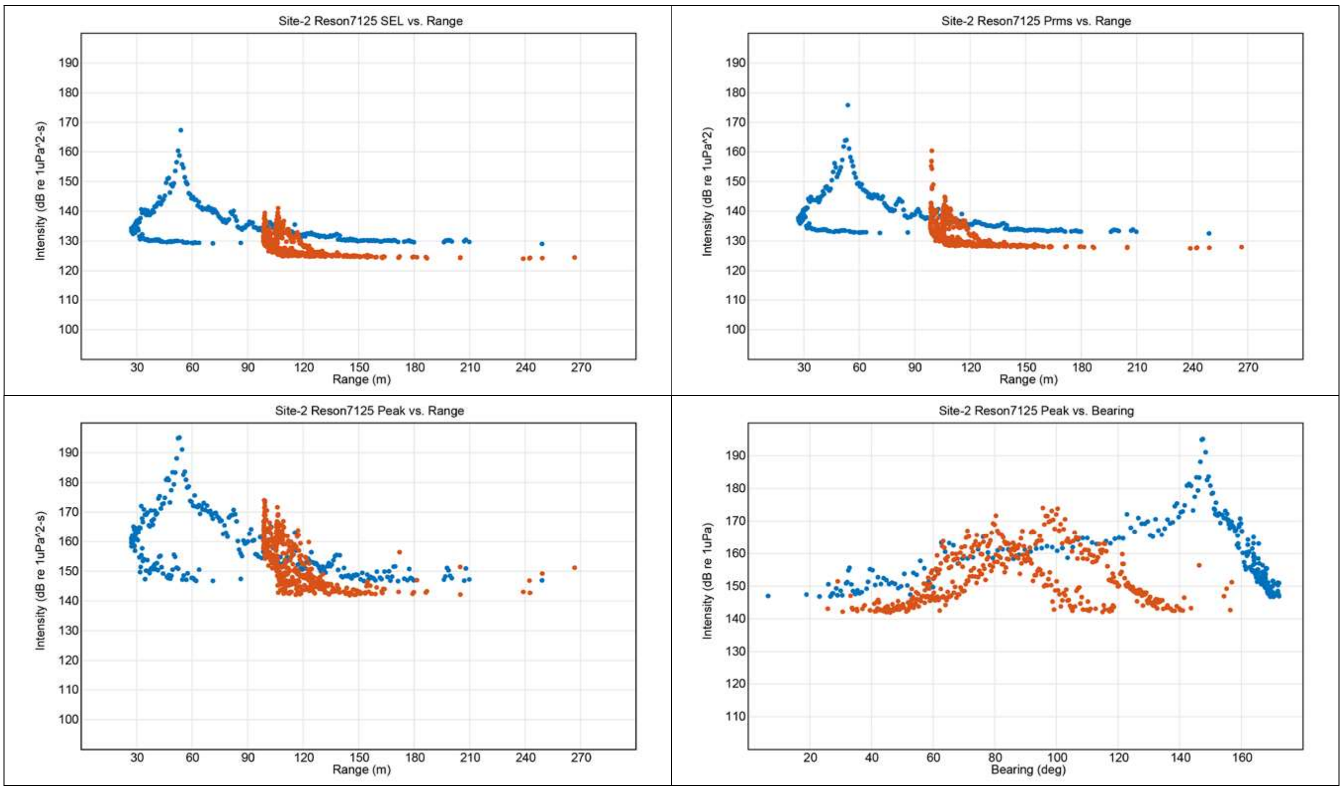


Figure 4.1.2-2. Range results for Reson 7125 signals at Site 2 for positions D (Buoy6) and B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position B = red; position D = blue.

The plan view is shown in **Figure 4.1.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 0,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at position D (Buoy6) and B (Buoy11). The gradual rise of the received source level is seen from -80 m to approximately 0 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise at approximately 100 m (y-axis). The CPA of 50 m on the x-axis could be the result of buoy positional errors.

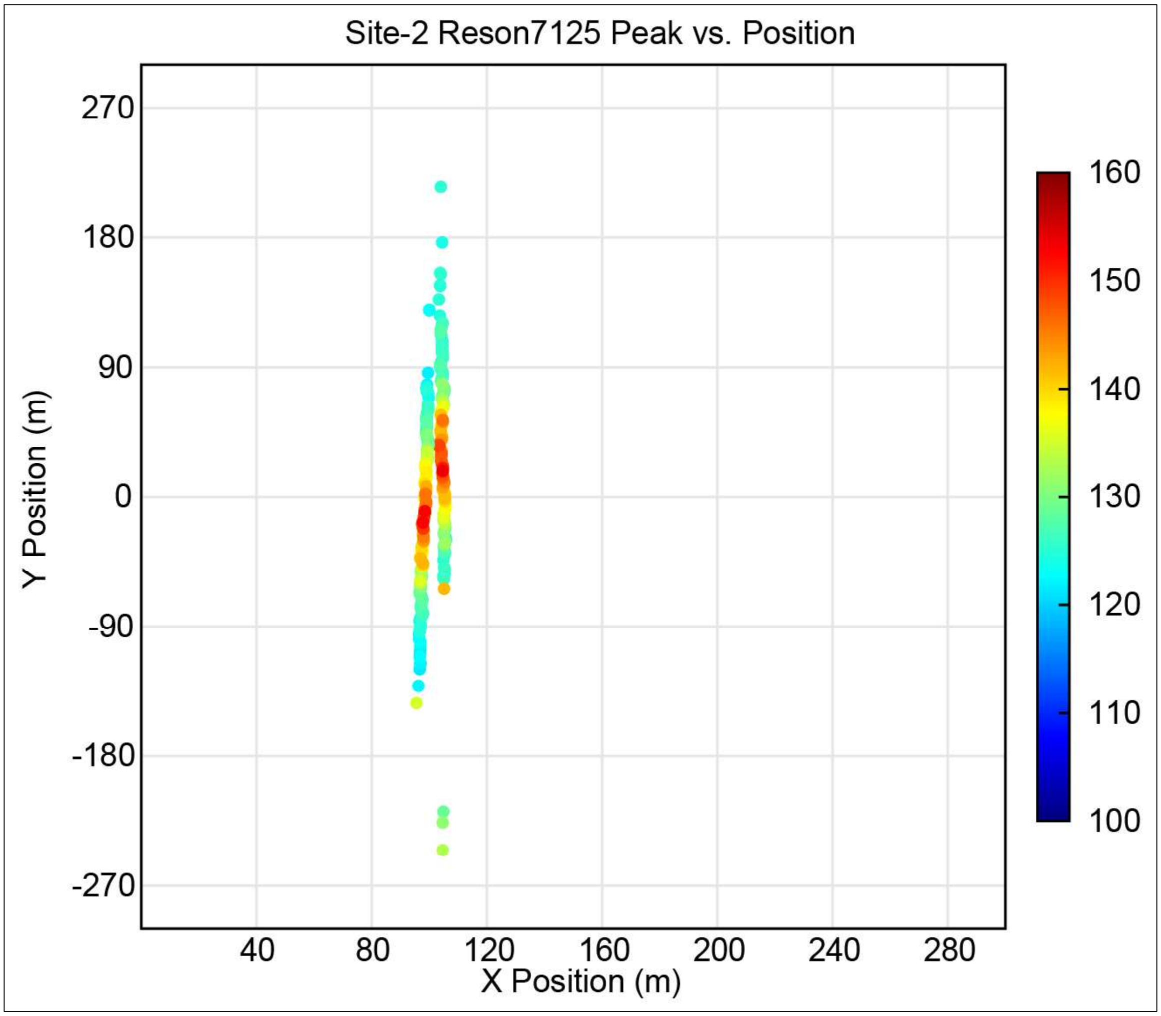


Figure 4.1.2-3. Plan view of received peak level for Reson 7125 at Site 2, showing the results for position D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.1.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] to back propagate the measurement to 1 m.

Table 4.1.2-1. Reson 7125 source levels, Mode 1, at Site 2.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 1	200 kHz	100%	220 dB	300 µs	229	211	203
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.1.3 Site 3 – Mud, 30 m Depth

At S3, the Reson 7125, Mode 1, had valid acoustic recordings for Run34 and Run16. For Run34, positions D (Buoy6), B (Buoy 11) and A (Buoy12) had valid acoustic data and observed signals. For Run16, positions B (Buoy12), and A (Buoy5) had valid acoustic data and observed signals. Positions E and F were too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7125, Mode 1, are shown in **Figure 4.1.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run34, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 196 kHz, propagation loss was very high and the signal was observable for a maximum of 4 minutes (120 seconds before and 120 seconds after the CPA).

In **Figure 4.1.3-1**, four buoys have clear signal arrival. The top left panel shows clear signal at position D (Buoy6), and the top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and B (Buoy12) respectively; note: there is replication of buoy representation because of the multiple deployments. The bottom right panel contains some random noise peaks (floating green dots), which remained through the acoustic processing and are plotted in the results panels.

The results panels (**Figure 4.1.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to collected data. For the Reson 7125 at S3, only positions D (Buoy6), A (Buoy12 and Buoy5 combined), and B (Buoy11, Buoy12, and Buoy12 combined) had acoustic signals, which are plotted in the graph. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 300 m. The conical shape of the position D data points signifies the approach and departure of the source to and from the buoys. All receptions are close together, showing good calibration and buoy position determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 85°, indicating relatively good buoy positioning; for position B at approximately 65°, indicating an error in buoy positioning; and for position A at approximately 100° and 140°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

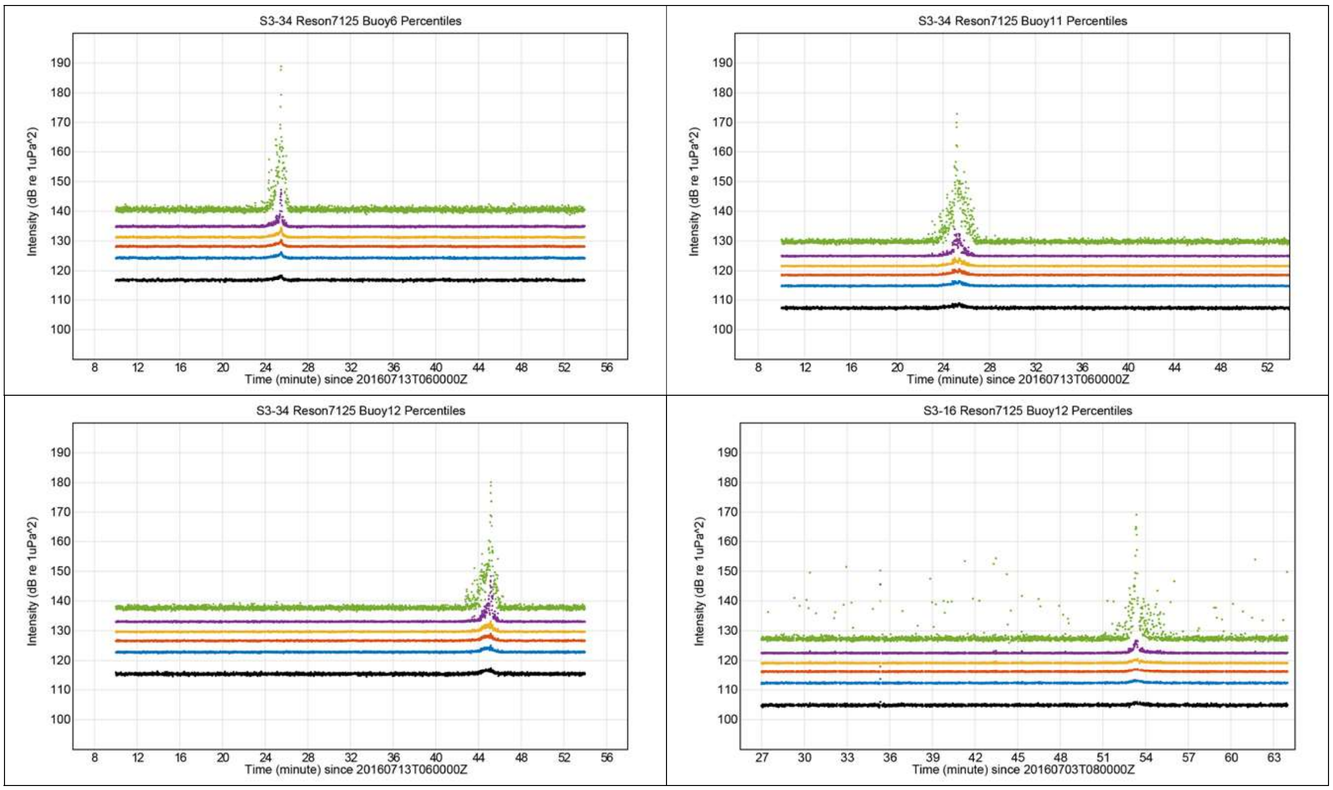


Figure 4.1.3-1. Percentile plots of Reson 7125 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy12); Bottom right: SPL_{pk} arrival at position B (Buoy12). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

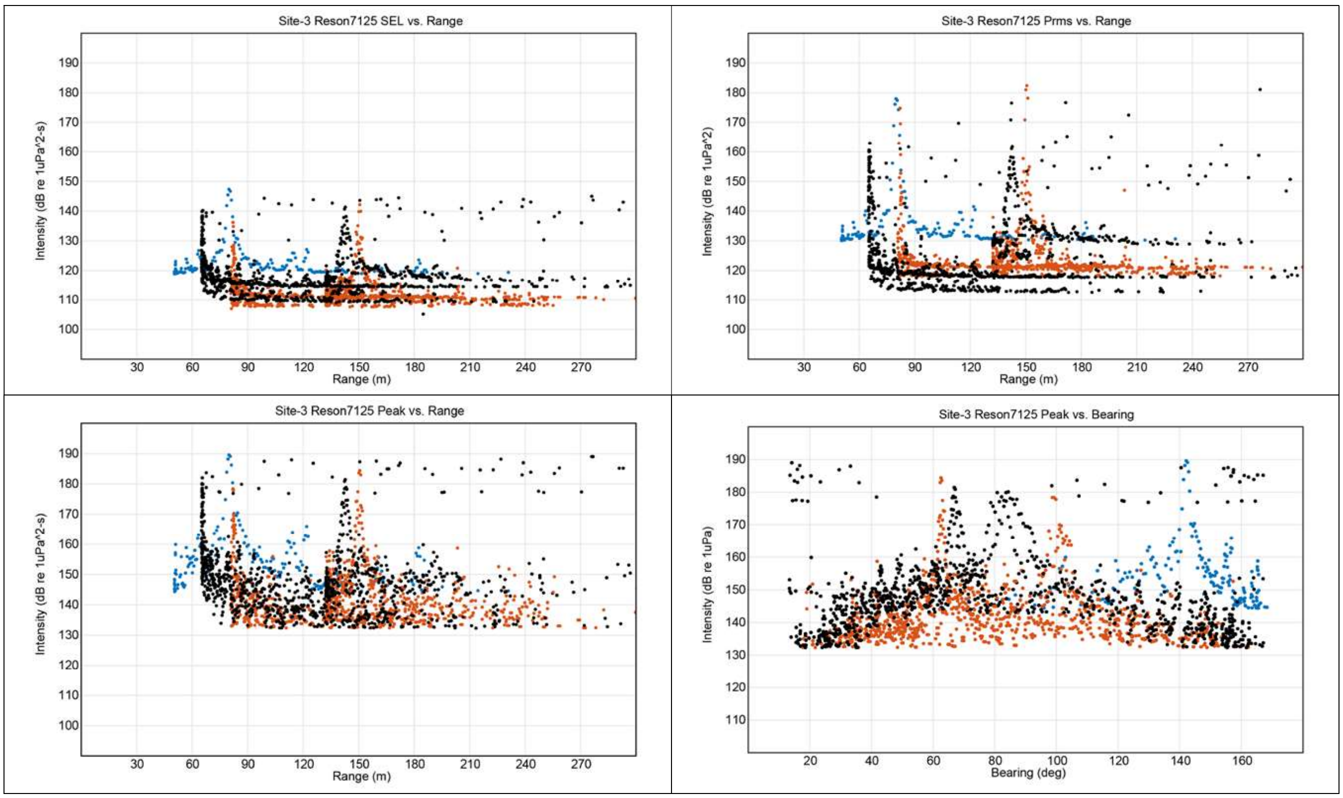


Figure 4.1.3-2. Range results for Reson 7125 combined signals for Run16 and Run34 at Site 3 for positions D (Buoy6), B (Buoy11, Buoy12, and Buoy12 combined), and A (Buoy12 and Buoy5 combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions A = black; B = red; D = blue.

The plan view is shown in **Figure 4.1.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 0,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at position D (Buoy6), B (Buoy12 and 11), and A (Buoy12 and 5). The gradual rise of the received source level is seen from -270 m to approximately 0 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. The CPA of 50 m on the x-axis could be the result of navigation errors.

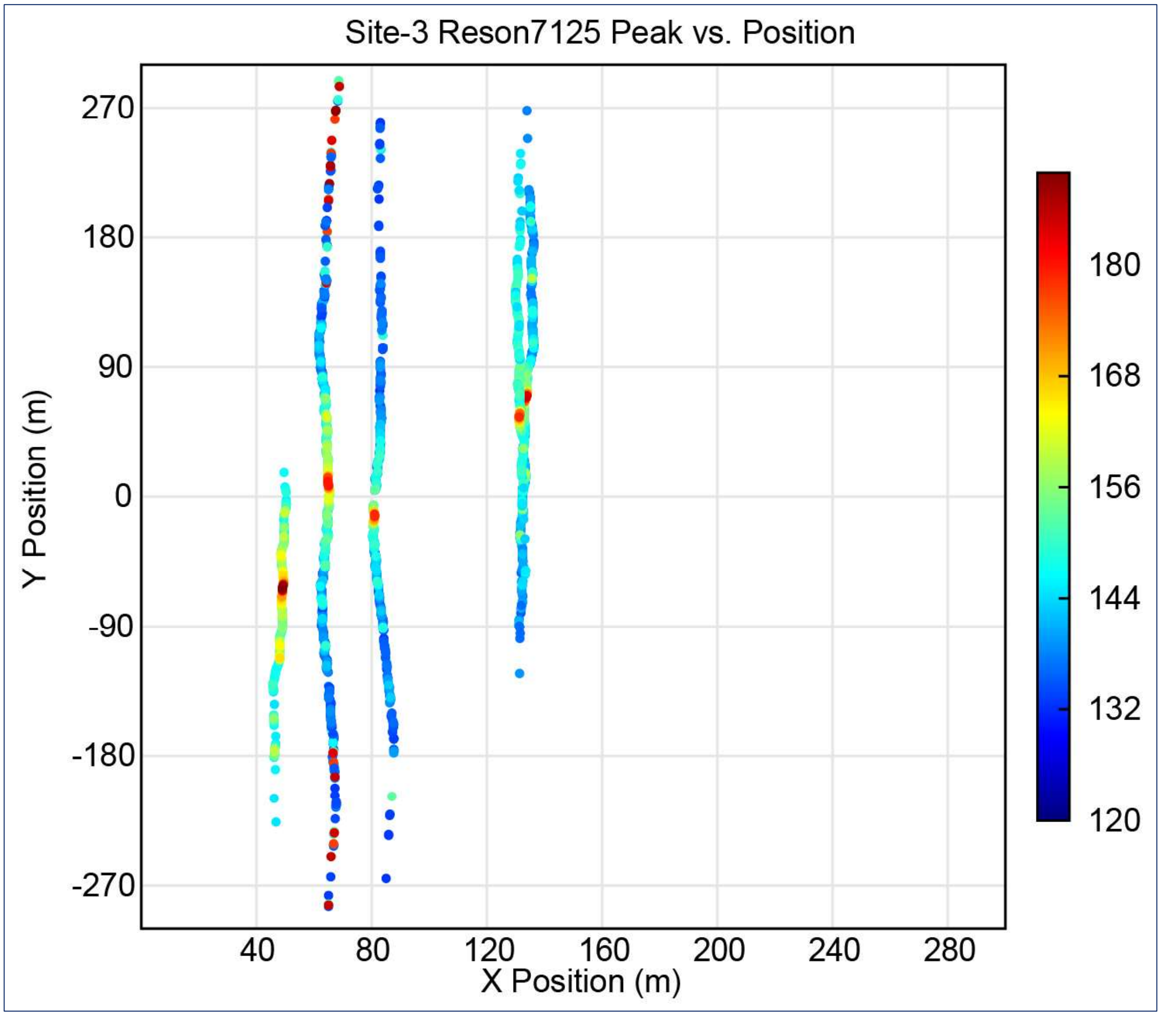


Figure 4.1.3-3. Plan view of received peak level for Reson 7125 at Site 3, showing the results for positions D (Buoy6), B (Buoy12 and 11), and A (Buoy12 and 5).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.1.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] to back propagate the measurement to 1 m.

Table 4.1.3-1. Reson 7125 source levels, Mode 1, at S3.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 1	200 kHz	100%	220 dB	300 µs	228	216	186
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.1.4 Site 4 – Sand, 30 m Depth

At S4, the Reson 7125, Mode 1, had valid acoustic recordings in Run17 and Run31. For Run17, only position E (Buoy9) had valid acoustic data. The data were processed and plotted, but there was no signal due to the large propagation distance for this VHF source. For Run31, positions B (Buoy12) and F (Buoy5) had valid acoustic recordings. Positions E (Buoy9) and F (Buoy5) were too distant to capture the VHF acoustic signal, and position D (Buoy8) did not capture acoustic signals.

Run Summary

The percentiles plots for the available recordings of the Reson 7125, Mode 1, are shown in **Figure 4.1.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run31, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics that lack any signal at positions E (Buoy9) and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good. However, even with valid acoustic data, there is no evidence of the signal at positions E and F because of propagation loss of the VHF signal.

The results panels (**Figure 4.1.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7125 at S4, only position B (Buoy12) had acoustic signal, which is plotted in **Figure 4.1.4-2**. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 150 m. The shape of the position B data points signifies the approach and departure of the source to and from the buoy. All position B receptions are close together, showing good calibration and buoy position determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 100°, indicating relatively good navigational buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

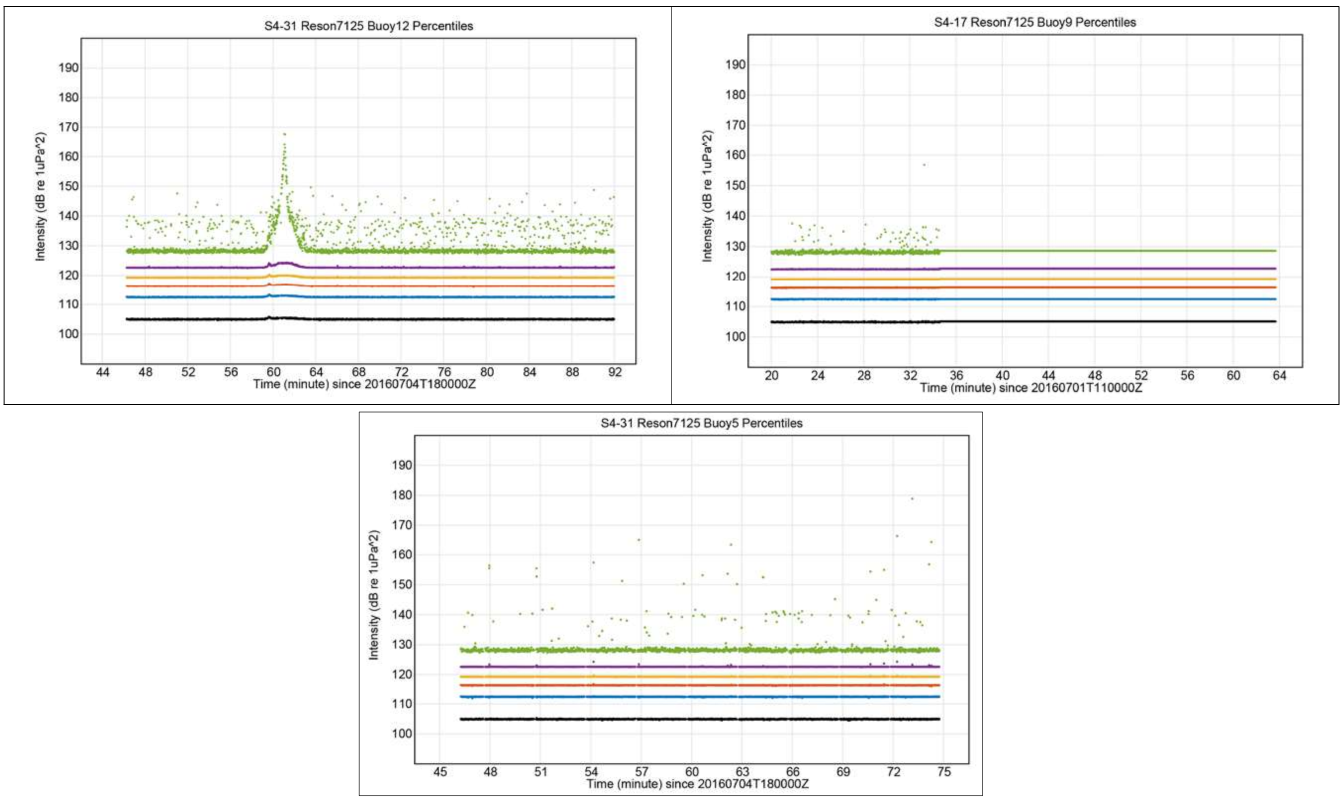


Figure 4.1.4-1. Percentile plots of Reson 7125 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position E (Buoy9); Bottom: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

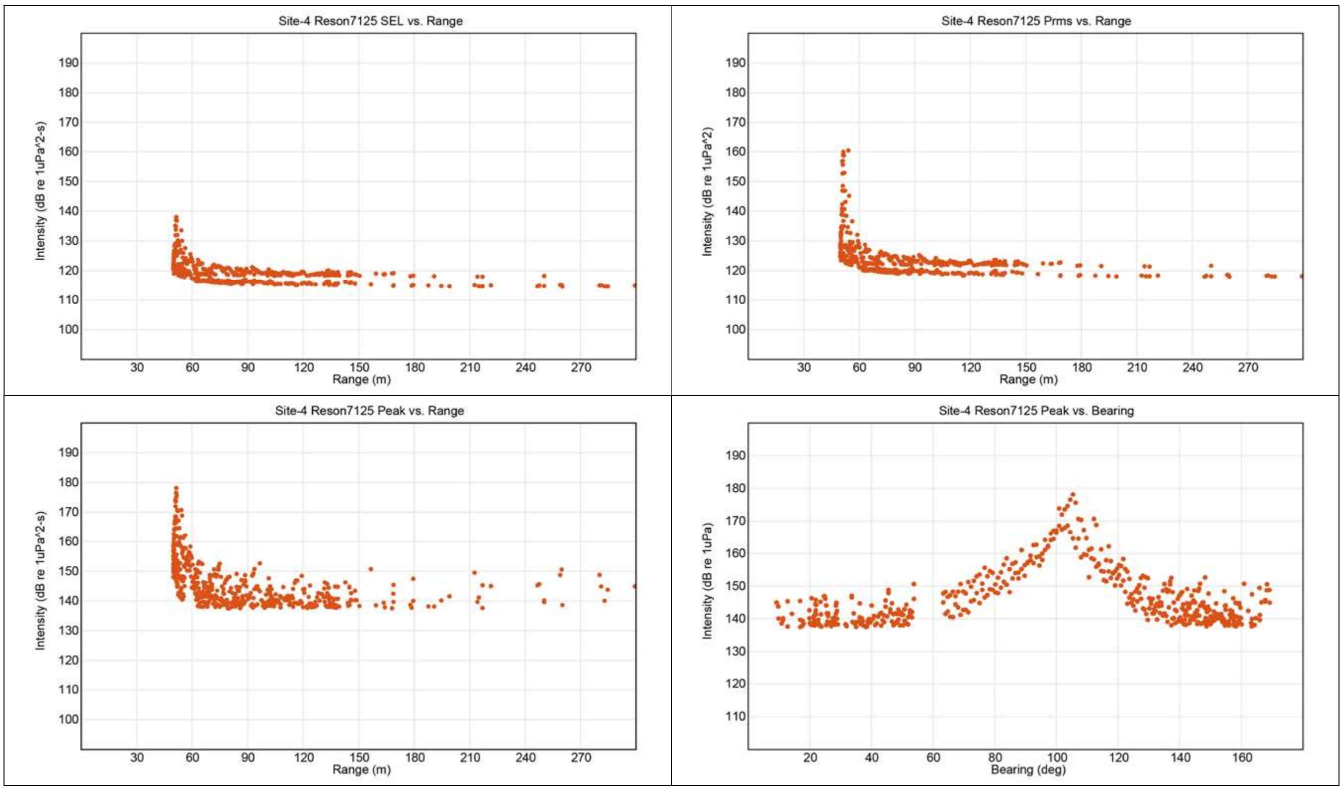


Figure 4.1.4-2. Range results for Reson 7125 signals at Site 4 for position B (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position B = red.

The plan view is shown in **Figure 4.1.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at position B (Buoy12). The gradual rise of the received source level is seen from -270 m to approximately 0 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise at approximately 270 m (y-axis).

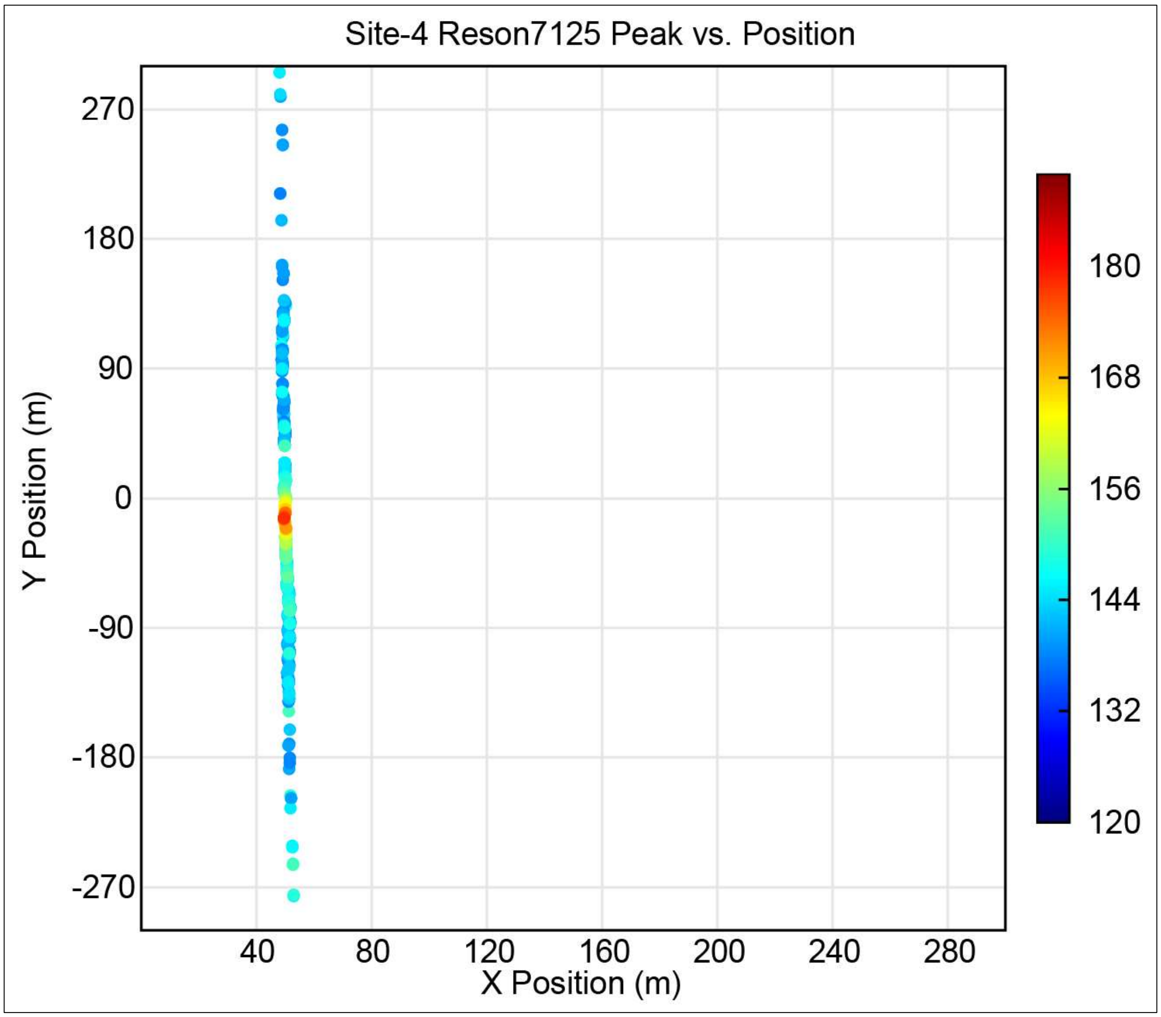


Figure 4.1.4-3. Plan view of received peak level for Reson 7125 at Site 4, showing the results for position B (Buoy12).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.1.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] to back propagate the measurement to 1 m.

Table 4.1.4-1. Reson 7125 source levels, Mode 1, at S4.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 1	200 kHz	100%	220 dB	300 µs	222	194	172
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.1.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Reson 7125, Mode 1, had valid acoustic recordings in Run12 and Run26. For Run12, positions B (Buoy11) and A (Buoy12) had valid acoustic recordings and observed signals. For Run26, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), and A (Buoy12). Positions E (Buoy8 and Buoy9) and F (Buoy10) had valid data but were too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7125, Mode 1, are shown in **Figure 4.1.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run26, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 196 kHz, propagation loss was very high and the signal was only observable for a maximum of 2 minutes (60 seconds before and 60 seconds after the CPA).

The results panels (**Figure 4.1.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7125 at S5, positions D (Buoy6), B (Buoy11 and Buoy11 combined), and A (Buoy12 and Buoy12) had acoustic signals, which are plotted in the graph. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to 300 m. The conical shape of the position D data points signifies the approach and departure of the source to and from the buoys. All three position B receptions are close together, showing good calibration and buoy position determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 90°, indicating good buoy positioning; for position B at approximately 120°, indicating a possible error in buoy positioning; and for position A at approximately 70°, indicating a possible error buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

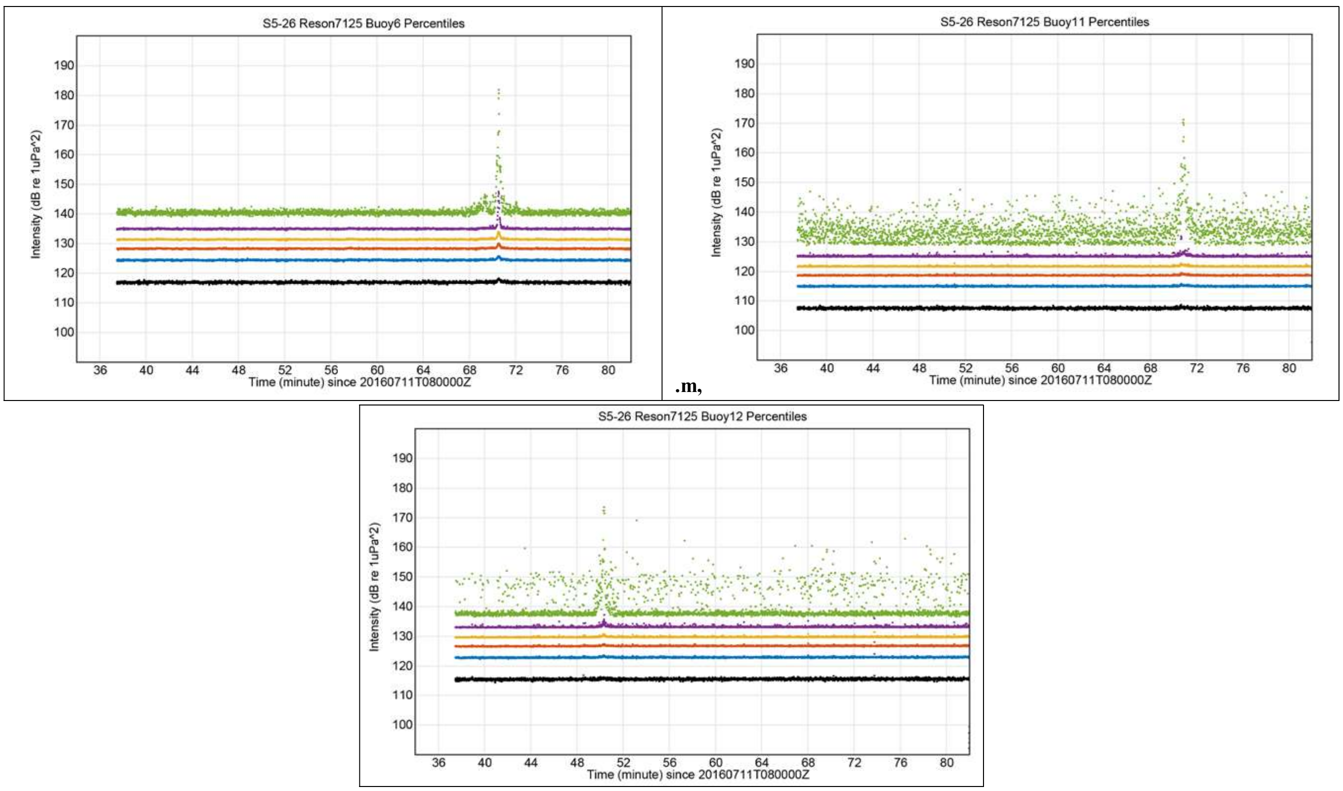


Figure 4.1.5-1. Percentile plots of Reson 7125 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

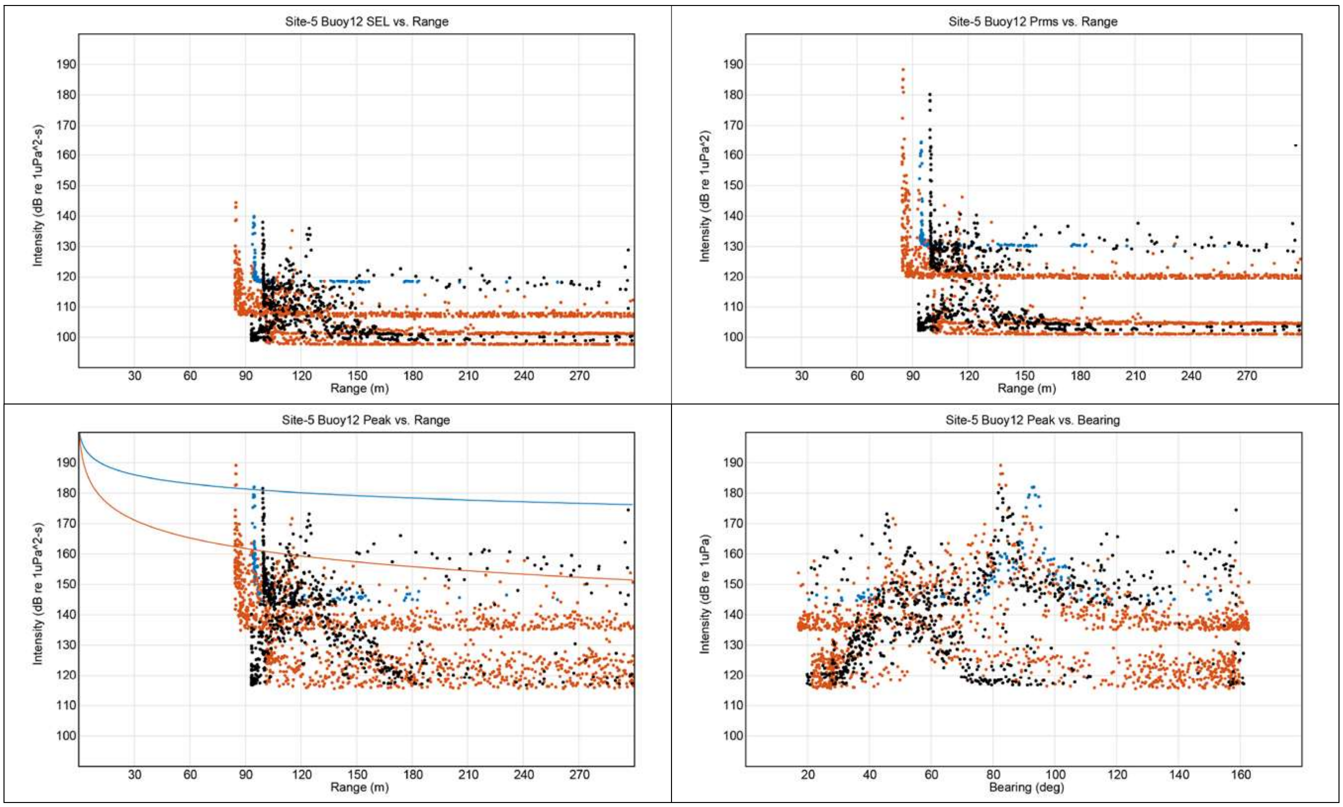


Figure 4.1.5-2. Range results for Reson 7125 signals at Site 5 from Run12 and Run26 for positions D (Buoy6), B (Buoy11 and Buoy11, combined), and A (Buoy12 and Buoy12, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions A = black; B = red; D = blue.

The plan view is shown in **Figure 4.1.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 90,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at position D (Buoy6), B (Buoy11 and Buoy11) and A (Buoy12 and Buoy12). The gradual rise of the received source level is seen as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise.

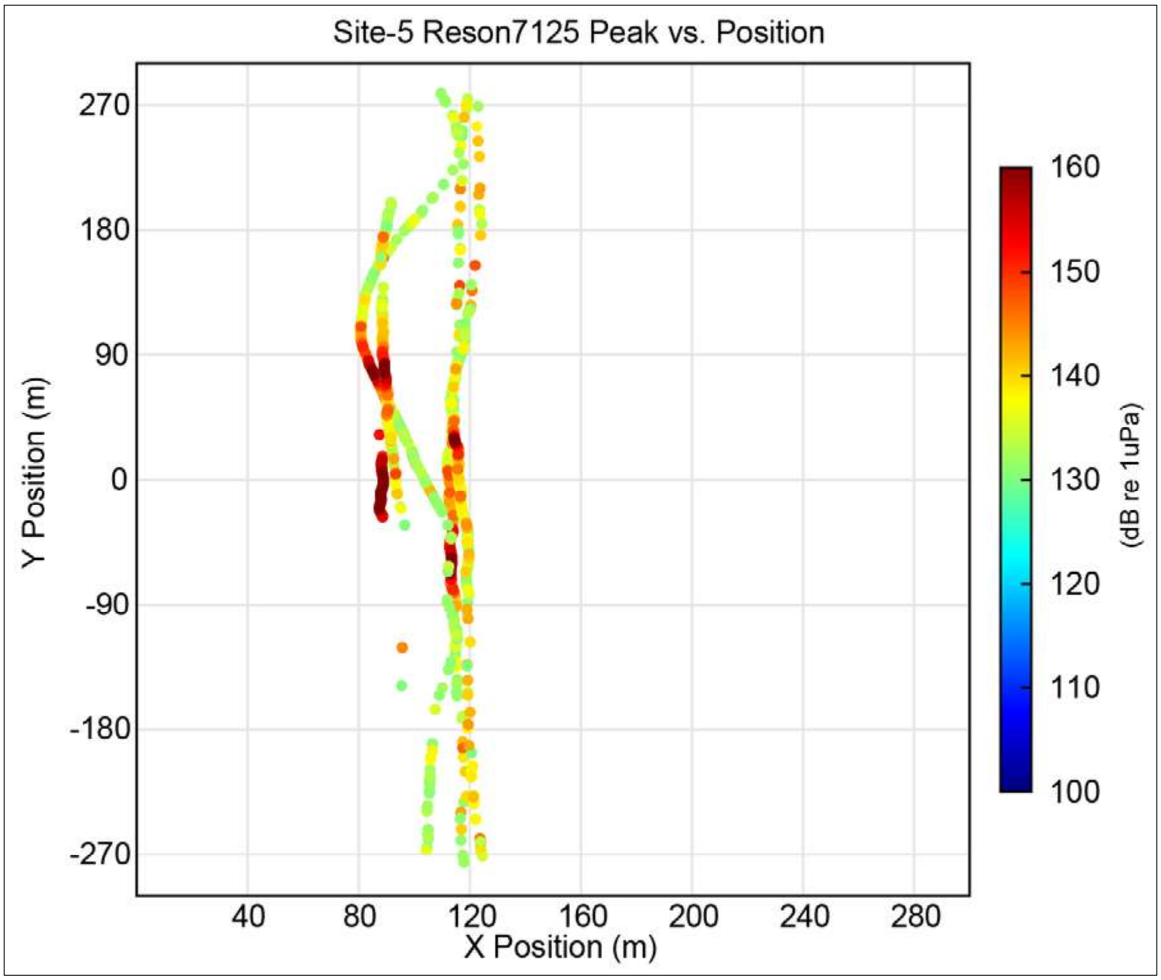


Figure 4.1.5-3. Plan view of received peak level for Reson 7125 at Site 5, showing the results for position D (Buoy6), B (Buoy11 and Buoy11) and A (Buoy12 and Buoy12).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.1.5-1** The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] to back propagate the measurement to 1 m.

Table 4.1.5-1. Reson 7125 source levels, Mode 1, at Site 5.

Source Settings					**Source Level (dB re 1 µPa m)**		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 1	200 kHz	100%	220 dB	300 µs	203	180	165
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.2 Reson 7125, 200 kHz, 190 dB, 50 Percent Power (Mode 2)

The Reson 7125 multibeam echosounder generates a single, very high-frequency (VHF) signal with a peak frequency of 200 kHz. The operational parameter settings for Mode 2 were a power setting of 190 dB for 50 percent power, and 200 kHz output frequency. Overall, the lower power setting and lower decibel level of Mode 2 (relative to Mode 1) produced low-amplitude source signals that were not well captured by the acoustic recording buoys, which resulted in ambiguous results and little information from which to draw conclusions.

4.2.1 Site 1 – Mud, 10 m Depth

At S1, the Reson 7125, Mode 2, had valid acoustic recordings in Run9, only at position D (Buoy6). Position E (Buoy5 and Buoy8) was too distant from the source to capture the VHF acoustic signal at this lower power setting.

Run Summary

The percentile plots for the three available recordings of the Reson 7125, Mode 2, are shown in **Figure 4.2.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run9, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 196 kHz, the propagation loss was very high and the signal was only observable for about four pings. The top left panel shows position D's valid recorded acoustics at the CPA at 1047 UTC. The approximate 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good. However, even with valid acoustic data, there is no evidence of the signal because of the low source power and propagation loss of the VHF signal.

The results panels (**Figure 4.2.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied. For the Reson 7125 at S1, only position D (Buoy6) had any acoustic signal, which is plotted in the graphs. The only points that can be considered valid acoustics are the signals received at 60 m range. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 60 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 2; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level at approximately 65° and 120°. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver.

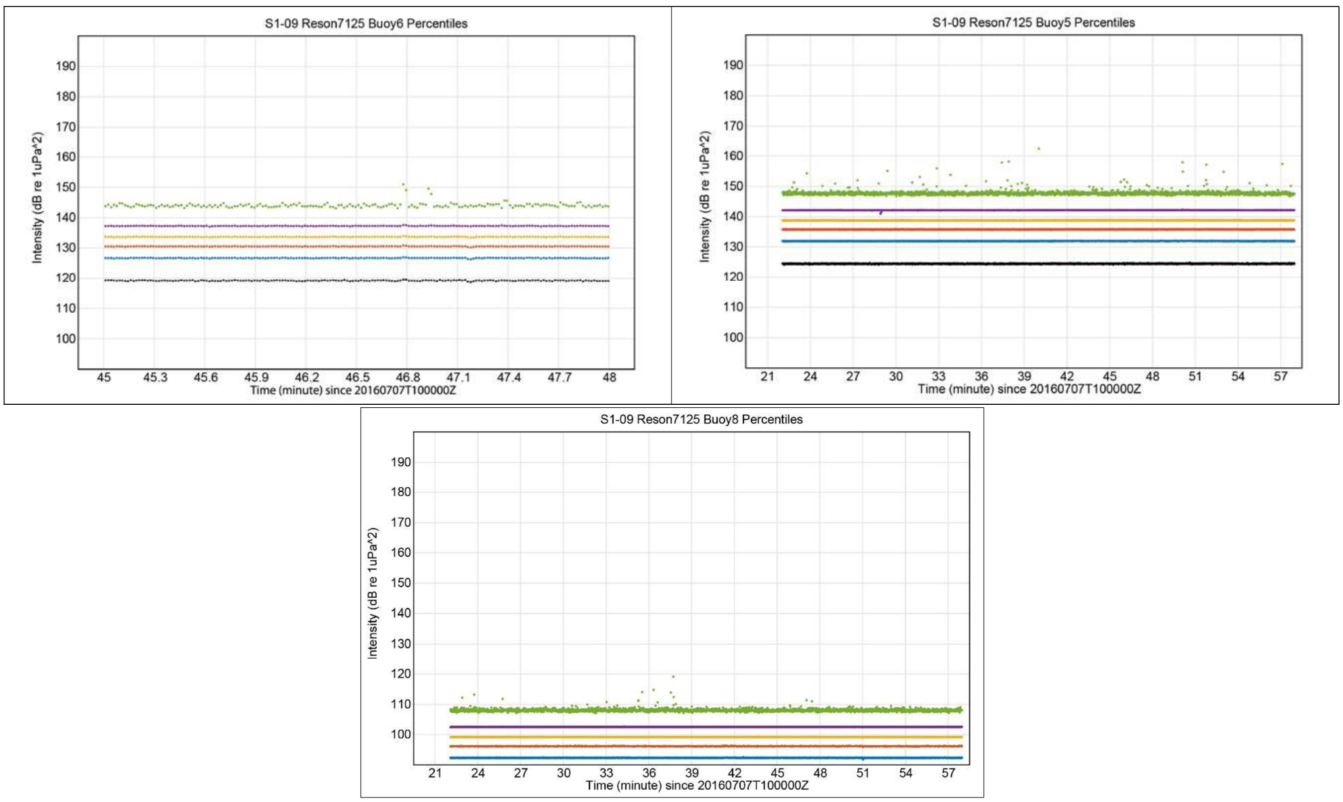


Figure 4.2.1-1. Percentile plots of Reson 7125 signals at Site 1.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: Peak pressure arrival at position E (Buoy5); Bottom: Peak pressure arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

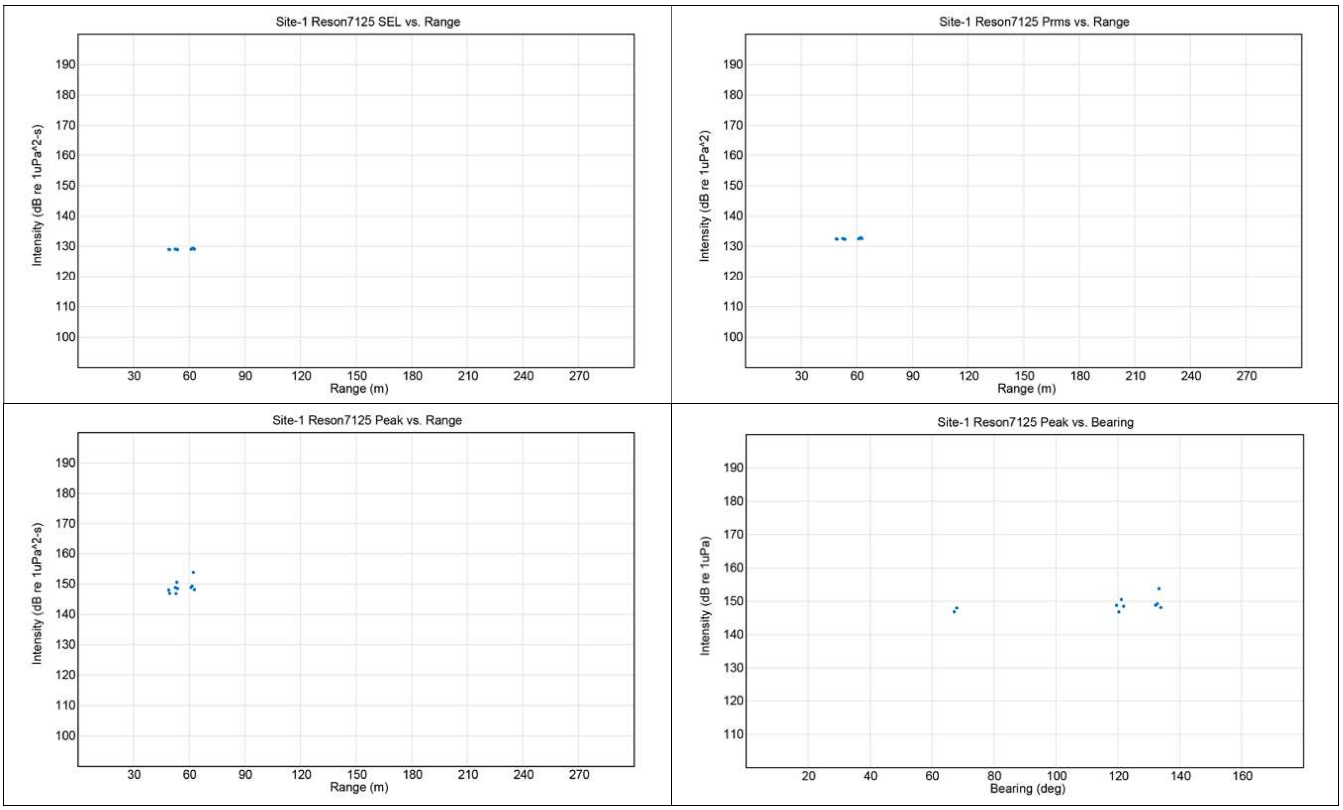


Figure 4.2.1-2. Range results for Reson 7125 signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position D = blue.

The plan view is shown in **Figure 4.2.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -270 to 270-m marks on the y-axis. The CPA is at 45,0 m (x,y). The four pings detected at position D are plotted. The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. However, for Mode 2 at S1, there is not enough information to make such determinations.

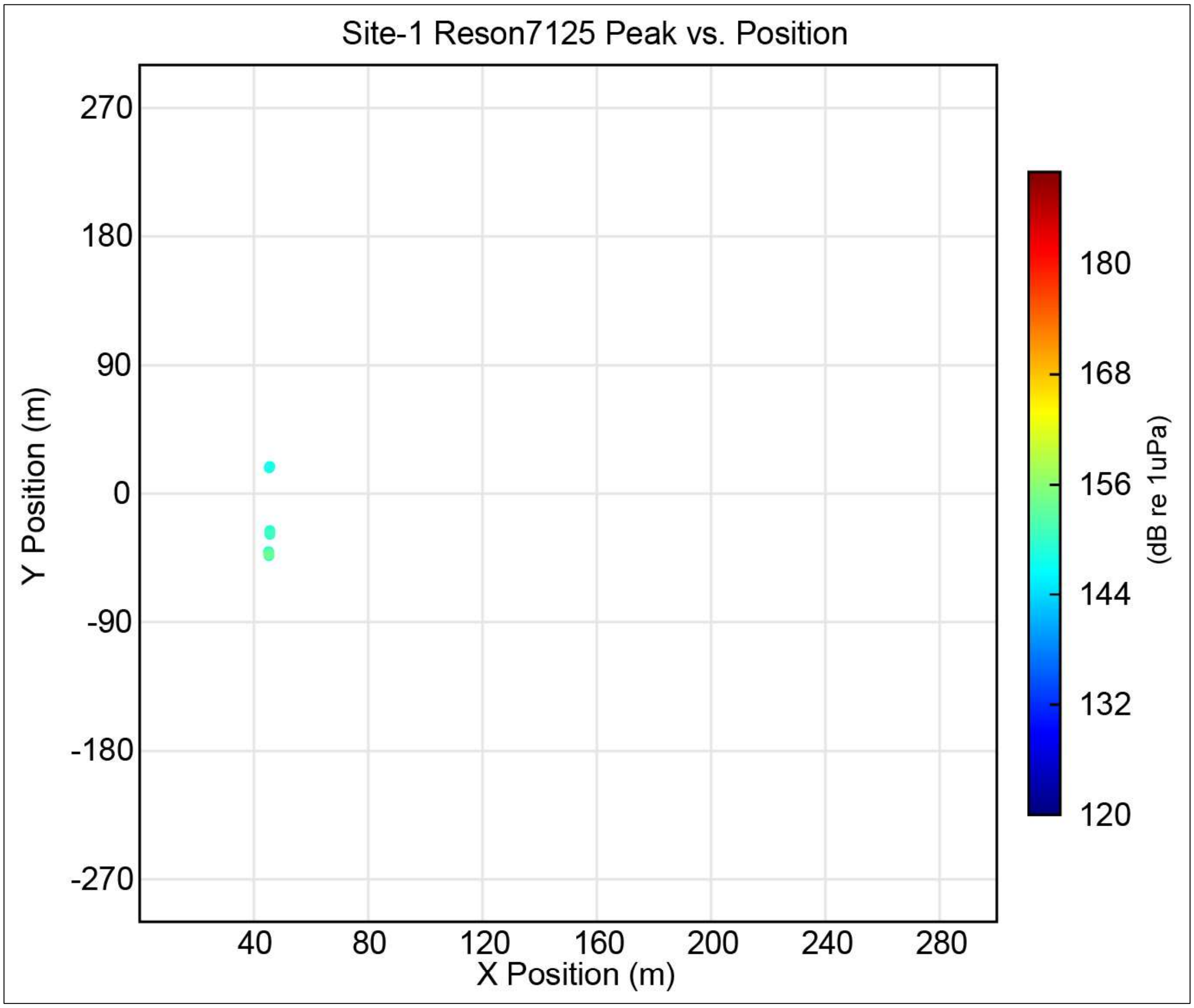


Figure 4.2.1-3. Plan view of received peak level for Reson 7125 at Site 1, showing the results for position D (Buoy6).

Table Source Summary

A summary of source specifications from the field measurement signals would be shown in **Table 4.2.1-1**, but were too weak to be provided.

Table 4.2.1-1. Reson 7125 source levels, Mode 2, at Site 1.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL (dB)	Cycles, Pulse Width	Pk	rms	SEL
Reson 7125 Mode 2	200 kHz	50%	190 dB	300 µs	NA	NA	NA
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.2.2 Site 2 – Sand, 10 m Depth

At S2, the Reson 7125, Mode 2, had valid acoustic recordings in Run13 and Run39. For Run13, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run39, position B (Buoy5 and Buoy11) had valid acoustic recordings. Positions E (Buoy10) and F (Buoy9) had valid acoustic data but were too distant from the source to capture the VHF acoustic signal at this lower power setting.

Run Summary

The percentile plots for the available recordings of the Reson 7125, Mode 2, are shown in **Figure 4.2.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run13, where the received signal is observed. The top left panel shows the recorded acoustics at position D and the other panels show position B. The approximate 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good. In total, four buoys are shown with hints of the signal. A few transmissions were received at positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11). The VHF signal was centered on 196 kHz, the propagation loss was very high, and the signal was only observable for a few pings.

The results panels (**Figure 4.2.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7125 at S2, only positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11, combined) had acoustic data that looked like the source signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 100 m. There are four pings at position D (in blue) and a cluster of pings at position B (in red). The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 2; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.2.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 110°, indicating relatively good buoy positioning. For position B, the received peak level is at approximately 90°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver.

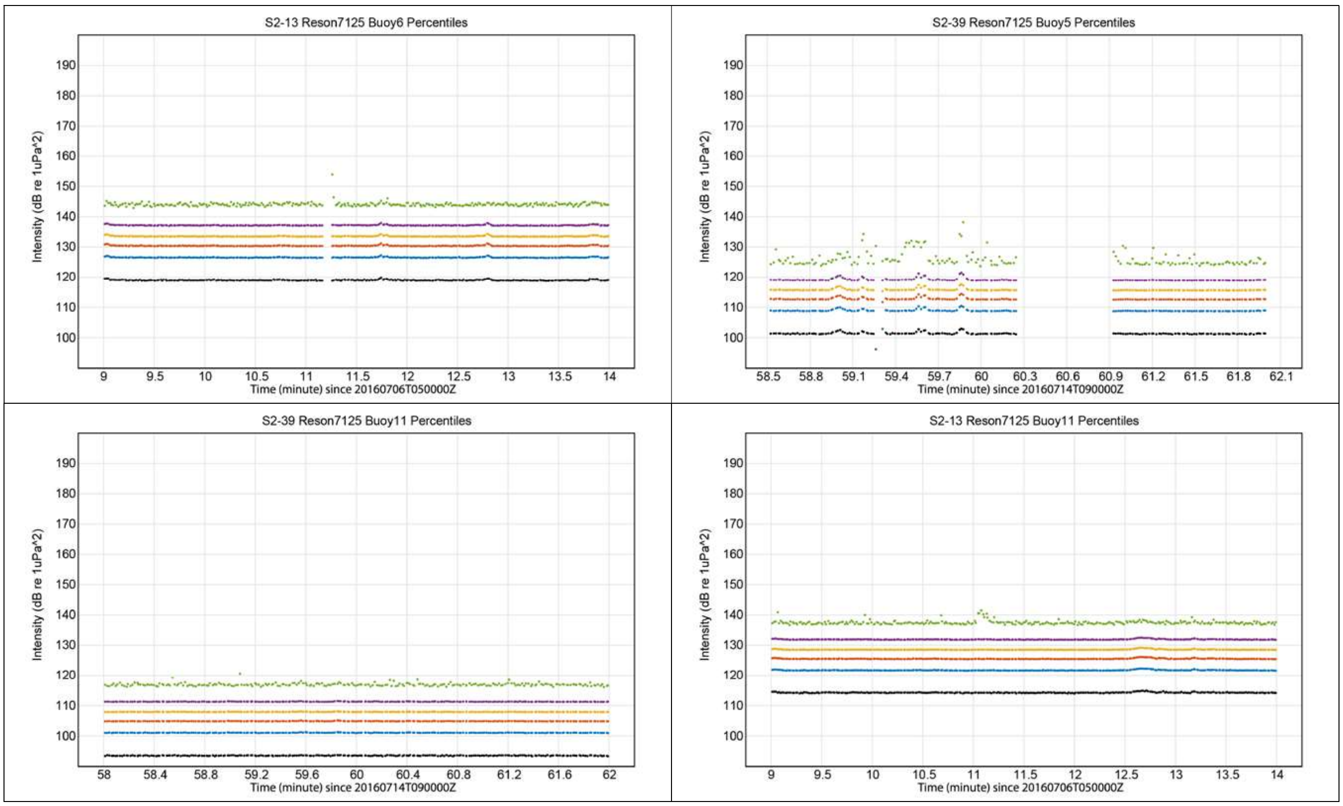


Figure 4.2.2-1. Percentile plots of Reson 7125 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy11). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

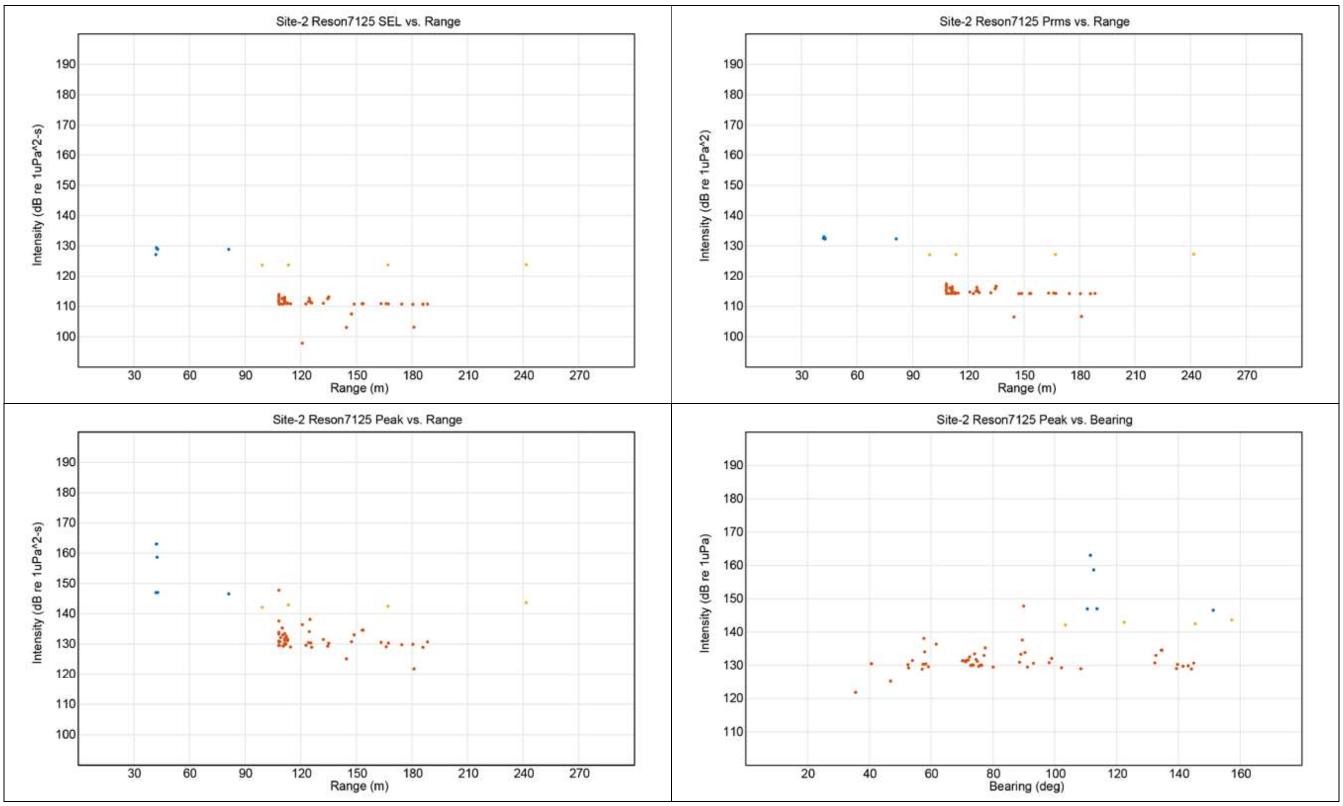


Figure 4.2.2-2. Range results for Reson 7125 signals at Site 2 for positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions B = red; D = blue.

The plan view is shown in **Figure 4.2.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -270 to 270-m marks on the y-axis. The CPA is at 40,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. A few source signals were received at positions D and B. However, the very weak signal accompanied by the presence of noise made the results uninterpretable. The two red dots in the figure are noise peaks that made it through the automated processing stream.

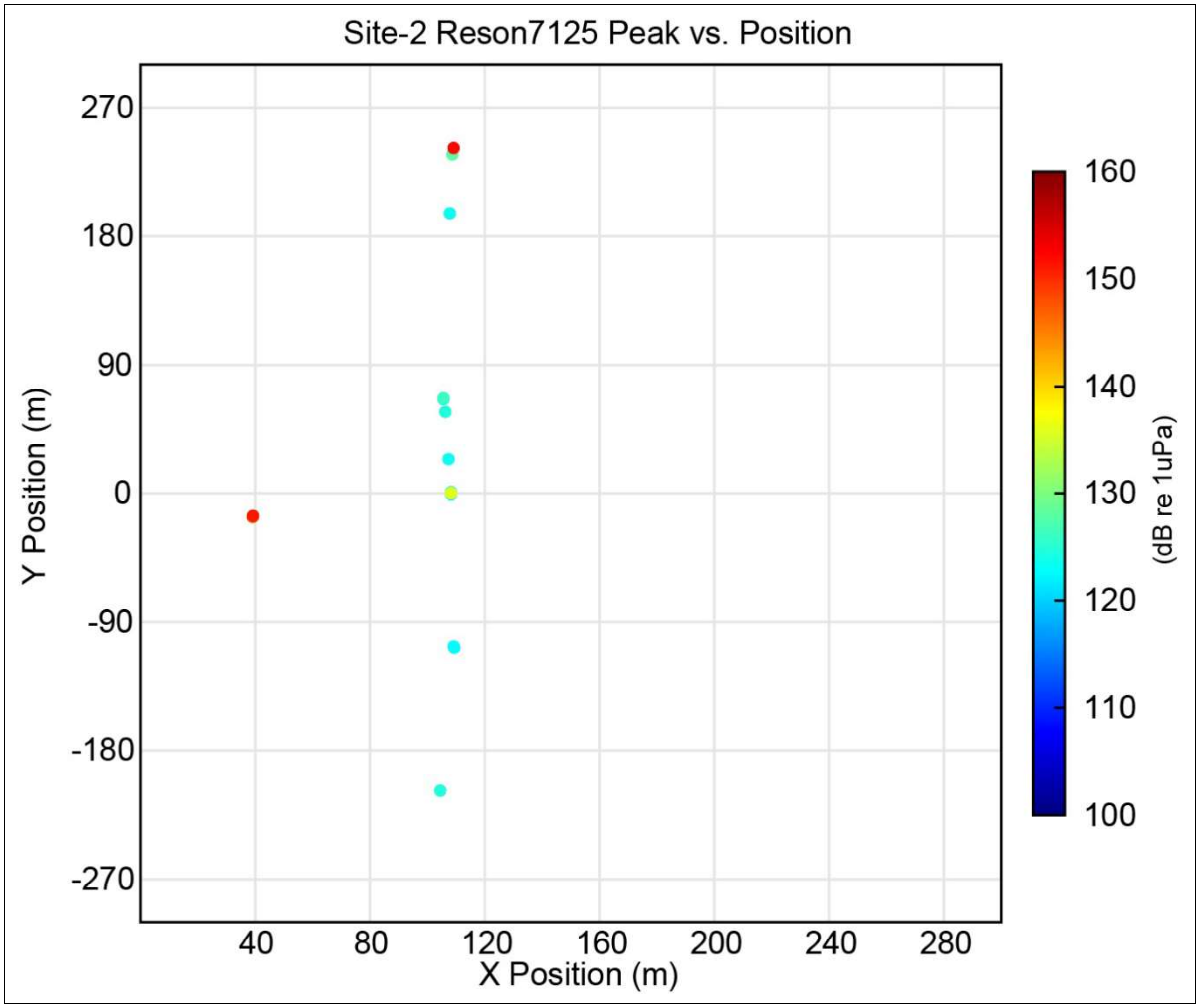


Figure 4.2.2-3. Plan view of received peak level for Reson 7125 at Site 2, showing the results for positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11).

Table Source Summary

A summary of source specifications from the field measurement signals would be shown in **Table 4.2.2-1**, but were too weak to be provided.

Table 4.2.2-1. Reson 7125 source levels, Mode 2, at Site 2.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 2	200 kHz	50%	190 dB	300 µs	NA	NA	NA
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.2.3 Site 3 – Mud, 30 m Depth

At S3, the Reson 7125, Mode 2, had valid acoustic recordings in Run17 and Run35. Run17 had valid acoustic data at positions A (Buoy5), B (Buoy12), and F (Buoy6). For Run35, positions D (Buoy6), A (Buoy12), B (Buoy11), E (Buoy8 and Buoy10), and F (Buoy9) had valid acoustic data. However, only positions D and B had identifiable source signals. For all runs, positions E and F were too distant from the source to capture the VHF acoustic signal at this lower power setting.

Run Summary

The percentile plots for the available recordings of the Reson 7125, Mode 2, are shown in **Figure 4.2.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run35, where the received signal is faintly observed. For this VHF signal centered on 196 kHz, propagation loss was very high and the signal was observable for a few pings. In **Figure 4.2.3-1**, four buoys are shown. The top left panel shows signal at position D (Buoy6), the top right panel show the recorded acoustics at positions B (Buoy11), and the bottom panels show positions A (Buoy12) and E (buoy10) with good acoustic data but no signal is observed.

The results panels (**Figure 4.2.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to collected data. For the Reson 7125 at S3, only positions D (Buoy6) and B (Buoy11) had acoustic data that look like source signals. The top left panel is the SEL versus range, showing received signal energy at ranges from approximately 60 to 130 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 2; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level at approximately 118° for position D and approximately 77° for position B, indicating relatively good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver.

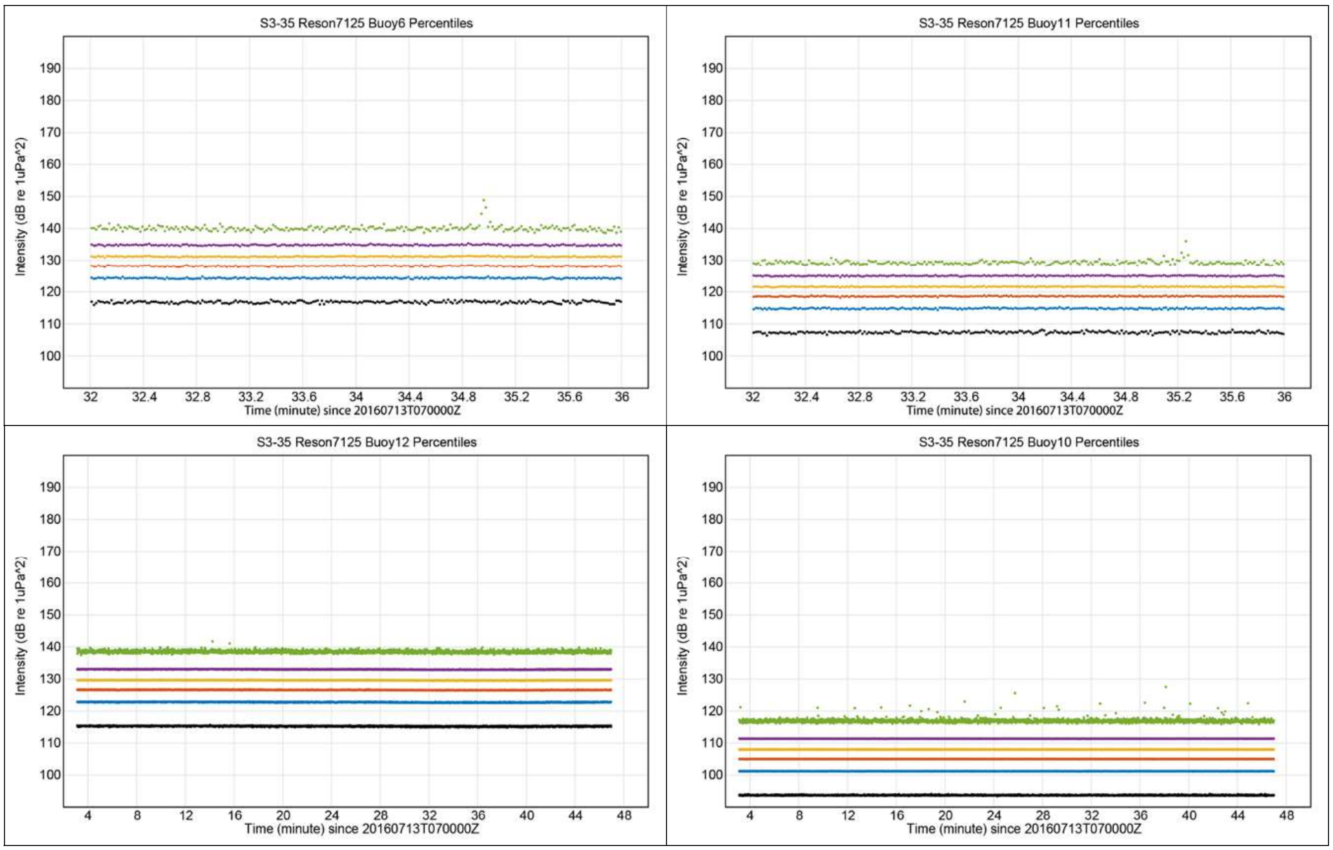


Figure 4.2.3-1. Percentile plots of Reson 7125 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

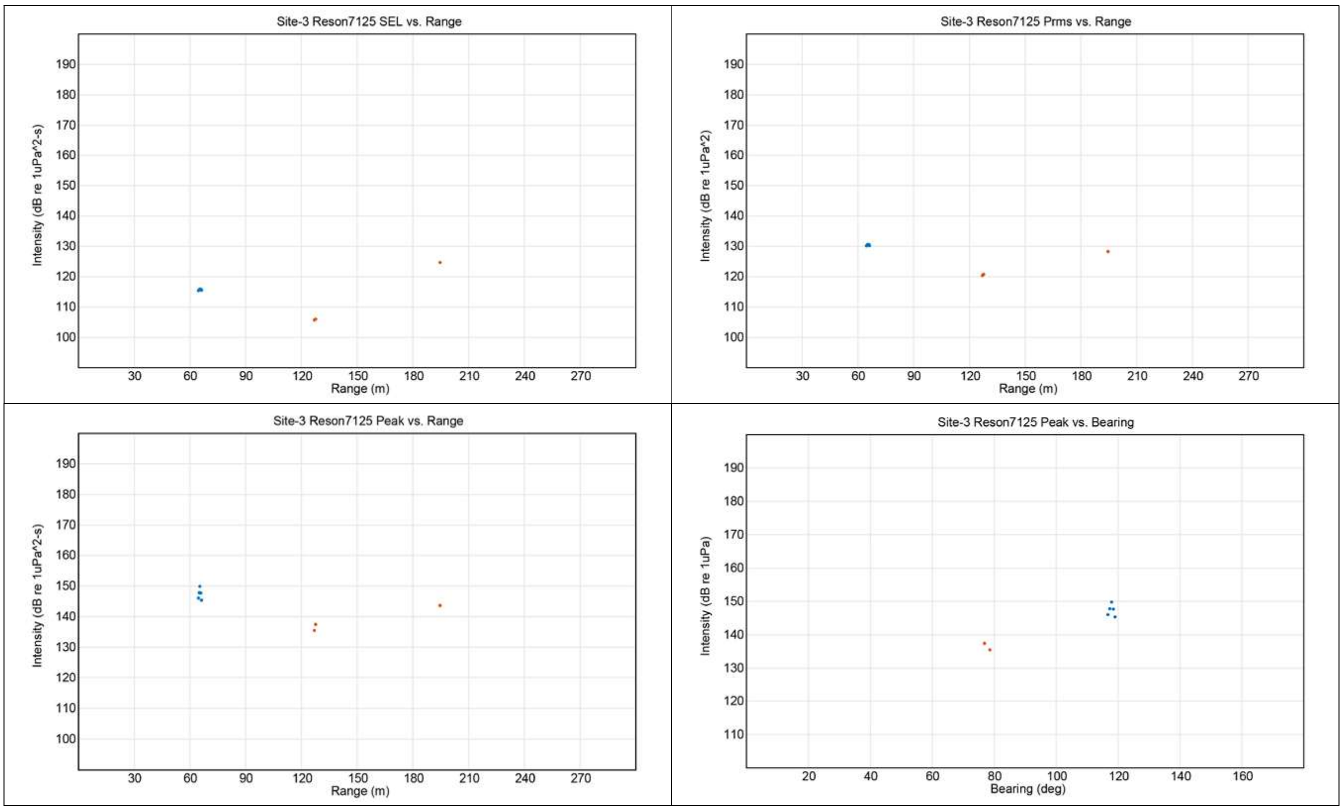


Figure 4.2.3-2. Range results for Reson 7125 signals at Site 3 for positions D (Buoy6) and B (Buoy11) from Run17 and Run35. Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions B = red; D = blue.

The plan view is shown in **Figure 4.2.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -270 to 270-m marks on the y-axis. The CPA is at 60,-40 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). However, for this low power mode at S3, there is not enough information to make such determinations.

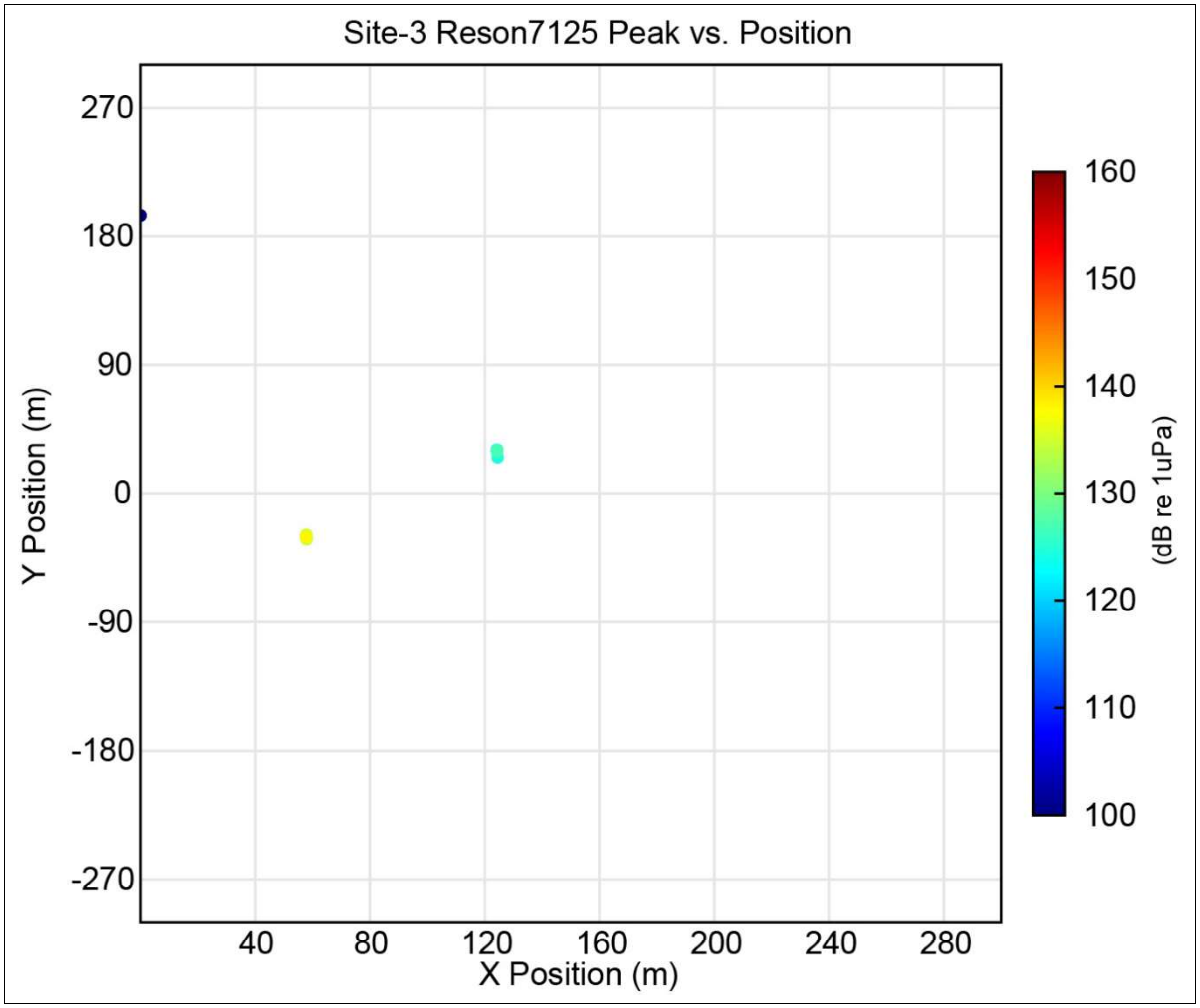


Figure 4.2.3-3. Plan view of received peak level for Reson 7125 at Site 3, showing the results for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the field measurement signals would be shown in **Table 4.2.3-1**, but were too weak to be provided.

Table 4.2.3-1. Reson 7125 source levels, Mode 2, at Site 3.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 2	200 kHz	50%	190 dB	300 µs	NA	NA	NA
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.2.4 Site 4 – Sand, 30 m Depth

At S4, the Reson 7125, Mode 2, had valid acoustic recordings in Run18 and Run32. For Run18, only position E (Buoy9) had valid acoustic data. The data were processed and plotted; however, there was no signal due to the long propagation distance for this VHF low-power source signal. For Run32, position B (Buoy12) had valid acoustic recordings. Overall, there is little evidence of captured source signals at this lower power setting.

Run Summary

The percentiles plots for the available recordings of the Reson 7125, Mode 2, are shown in **Figure 4.2.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The left panel shows position B (Buoy12) for Run32, and the right panel shows position E (Buoy9) for Run18. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good.

The results panels, (**Figure 4.1.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7125 at S4, position B (Buoy12) had acoustic signal, which is plotted in **Figure 4.2.4-2**. The top left panel is the SEL versus range, showing received signal energy at approximately 30 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the Reson 7125, Mode 2; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B.

There were no valid acoustic source signals to provide a plan view figure for the Reson 7125 Mode 2 at S4.

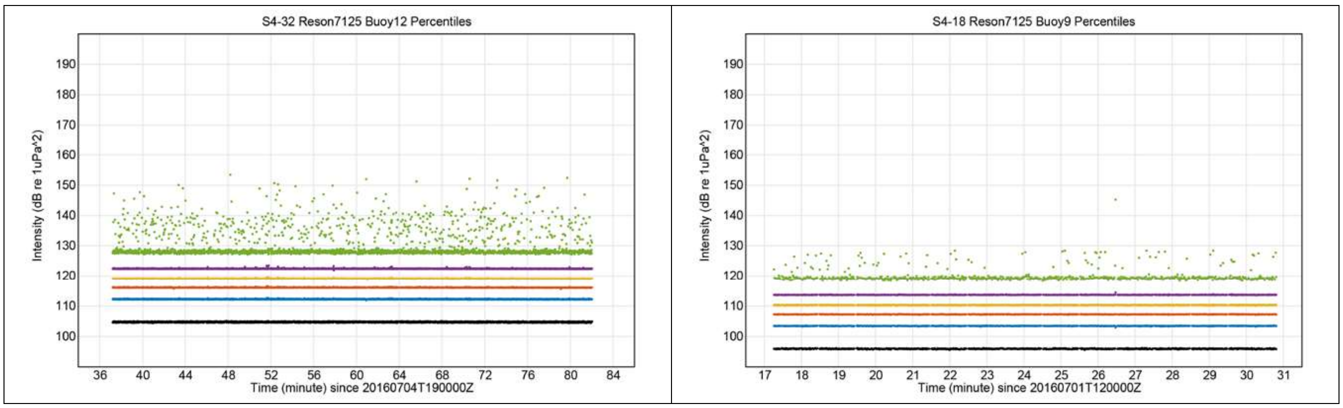


Figure 4.2.4-1. Percentile plots of Reson 7125 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

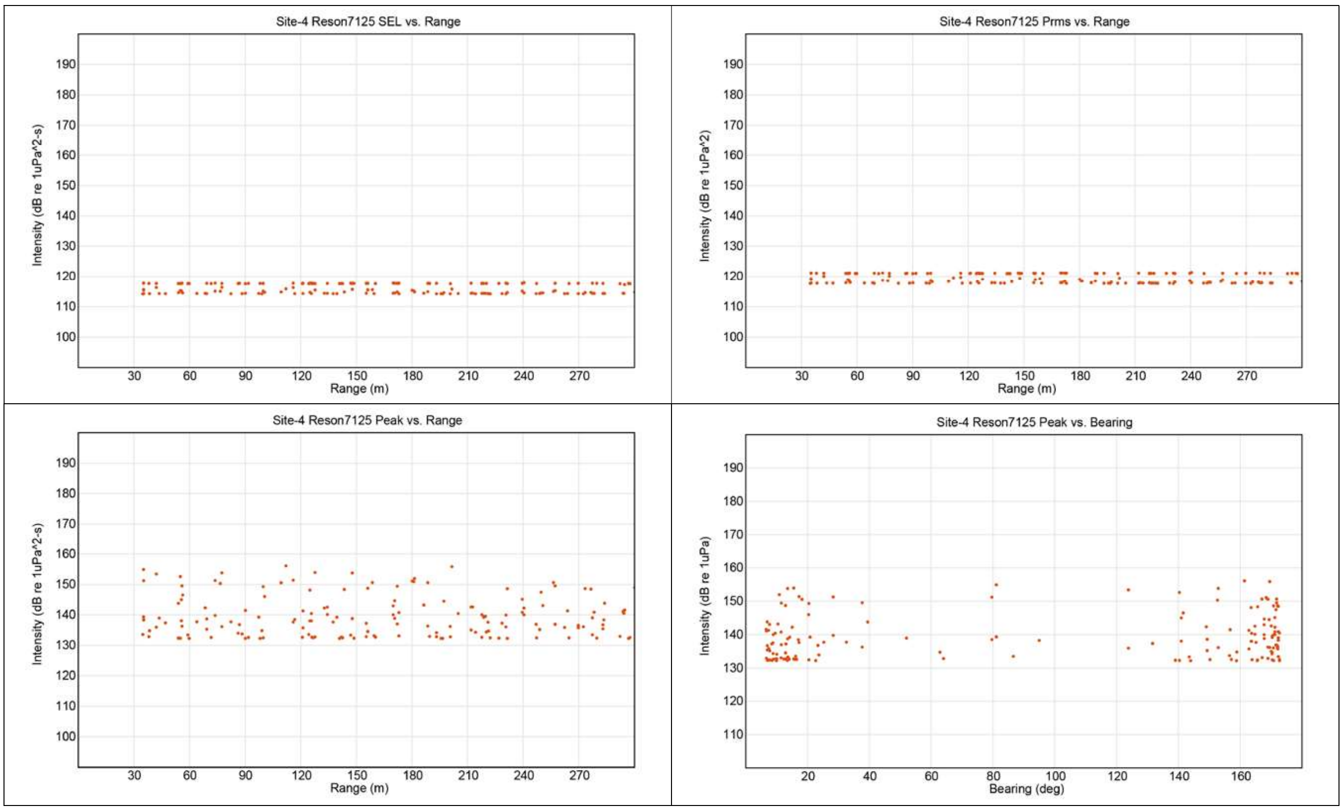


Figure 4.2.4-2. Range results for Reson 7125 signals at Site 4 for position B (Buoy12).
The plotted data are mostly noise, not source signals. Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position B = red.

Table Source Summary

A summary of source specifications from the field measurement signals would be shown in **Table 4.2.4-1**, but were too weak to be provided.

Table 4.2.4-1. Reson 7125 source levels, Mode 2, at Site 4.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 2	200 kHz	50%	190 dB	300 µs	NA	NA	NA
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.2.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Reson 7125, Mode 2, had valid acoustic recordings in Run13 and Run27. For Run13, faint acoustic signals were observed at position A (Buoy12). For Run27, positions D (Buoy6), B (Buoy11), and A (Buoy12) had equivocal acoustic recordings. For Run27, positions E (Buoy8 and Buoy9) and F (Buoy10) were too distant from the source to capture the VHF acoustic signal at this lower power setting.

Run Summary

The percentile plots for the available recordings of the Reson 7125, Mode 2, are shown in **Figure 4.2.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run27, where the received signal is faintly observed. The top right panel and lower panel show position A (Buoy12) for Run13 and Run27, respectively. For this VHF signal centered on 196 kHz, propagation loss was very high.

The results panels (**Figure 4.1.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 23 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7125 at S5, the received acoustic signals did not meet the threshold requirement to be considered source signals. Therefore, the results panels show plotted noise.

There were no valid acoustic source signals to provide a plan view figure for the Reson 7125 Mode 2 at S5.

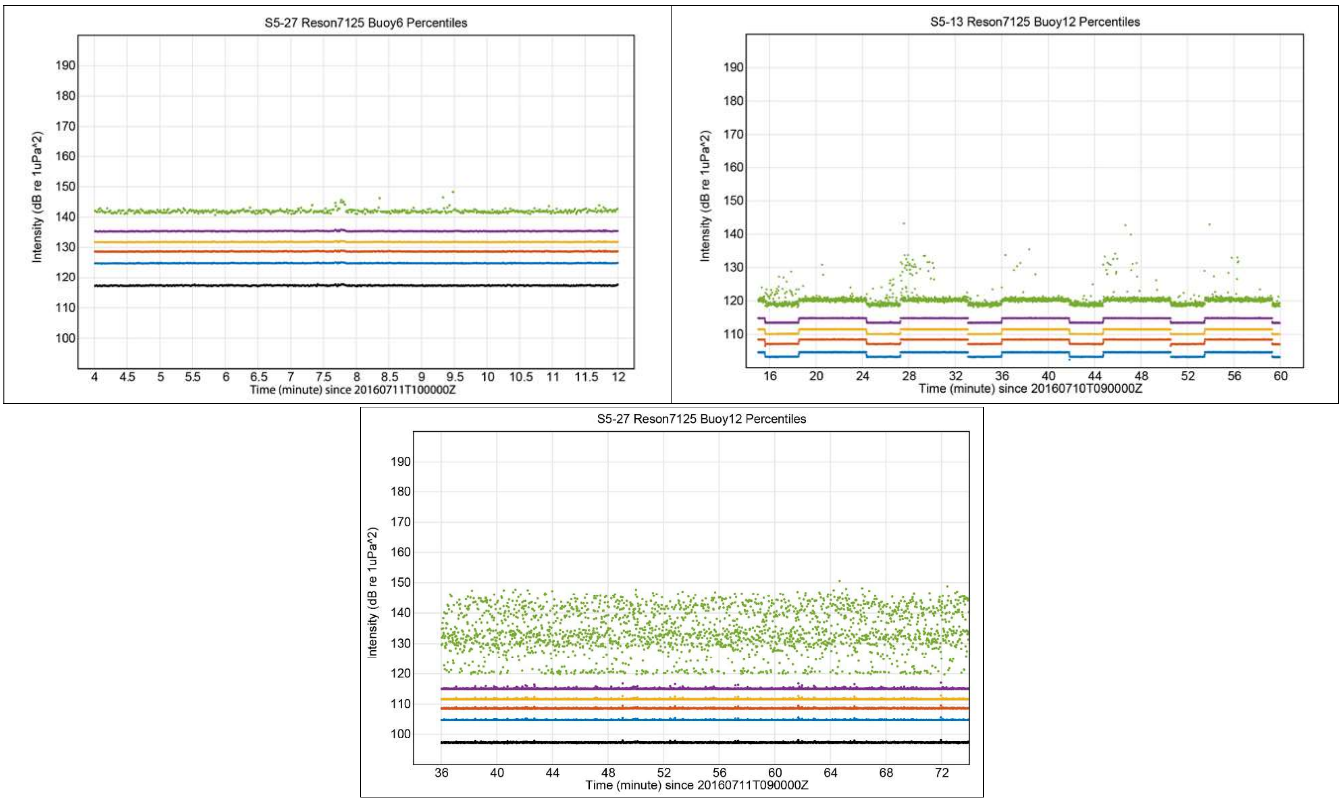


Figure 4.2.5-1. Percentile plots of Reson 7125 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom: SPL_{pk} arrival at position A (Buoy12); Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

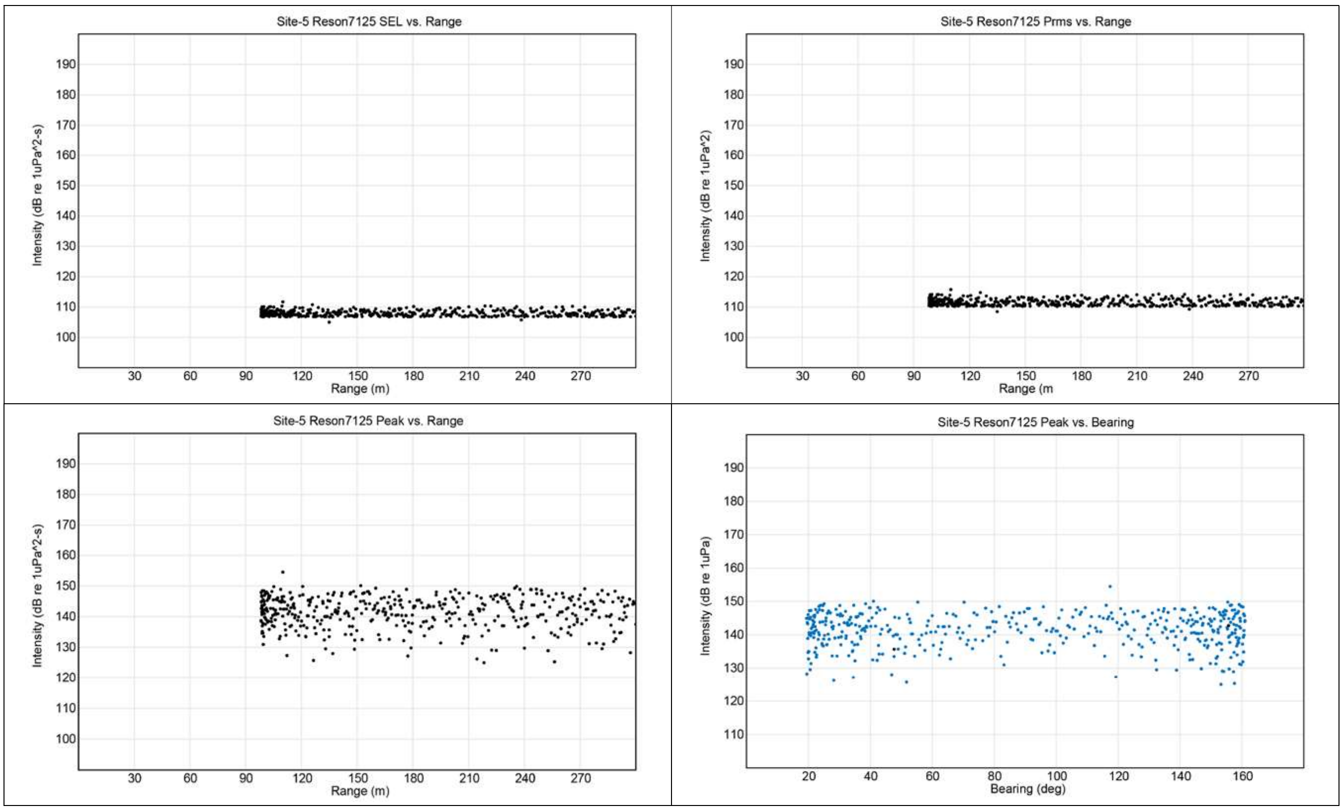


Figure 4.2.5-2. Range results for Reson 7125 signals at Site 5 for positions D (Buoy6), and A (Buoy12) from Run13 and Run27. The plotted data are noise, not source signals. Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions A = black; D =blue.

Table Source Summary

A summary of source specifications from the field measurement signals would be shown in **Table 4.2.5-1**, but were too weak to be provided.

Table 4.2.5-1. Reson 7125 source levels, Mode 2, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL (dB)**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Reson 7125 Mode 2	200 kHz	50%	190 dB	300 µs	NA	NA	NA
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Left Intentionally Blank

4.3 Reson 7111, 100 kHz, 200 dB, 0.17 ms Pulse, 1.5° (Mode 1)

The Reson 7111 multibeam echosounder generates a single, high frequency (HF) signal with a peak frequency of 100 kHz. The operational parameter settings for Mode 1 were a power setting of 200 dB, 0.17-ms pulse length, 1.5° beamwidth, and 100-kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.3-1** is the selected frequency band (90 to 110 kHz) and SPL_{pk} (138 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a quick drop of energy.

Table 4.3-1. Bandpass determination for the Reson 7111 multibeam echosounder, 100 kHz, 200 dB, 0.17 ms pulse, 1.5° at Site 3, Run24.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
50-150	146.35
80-120	140.32
90-110	**138.40**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported below from only one site for simplicity. The Reson 7111, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.3-1**.

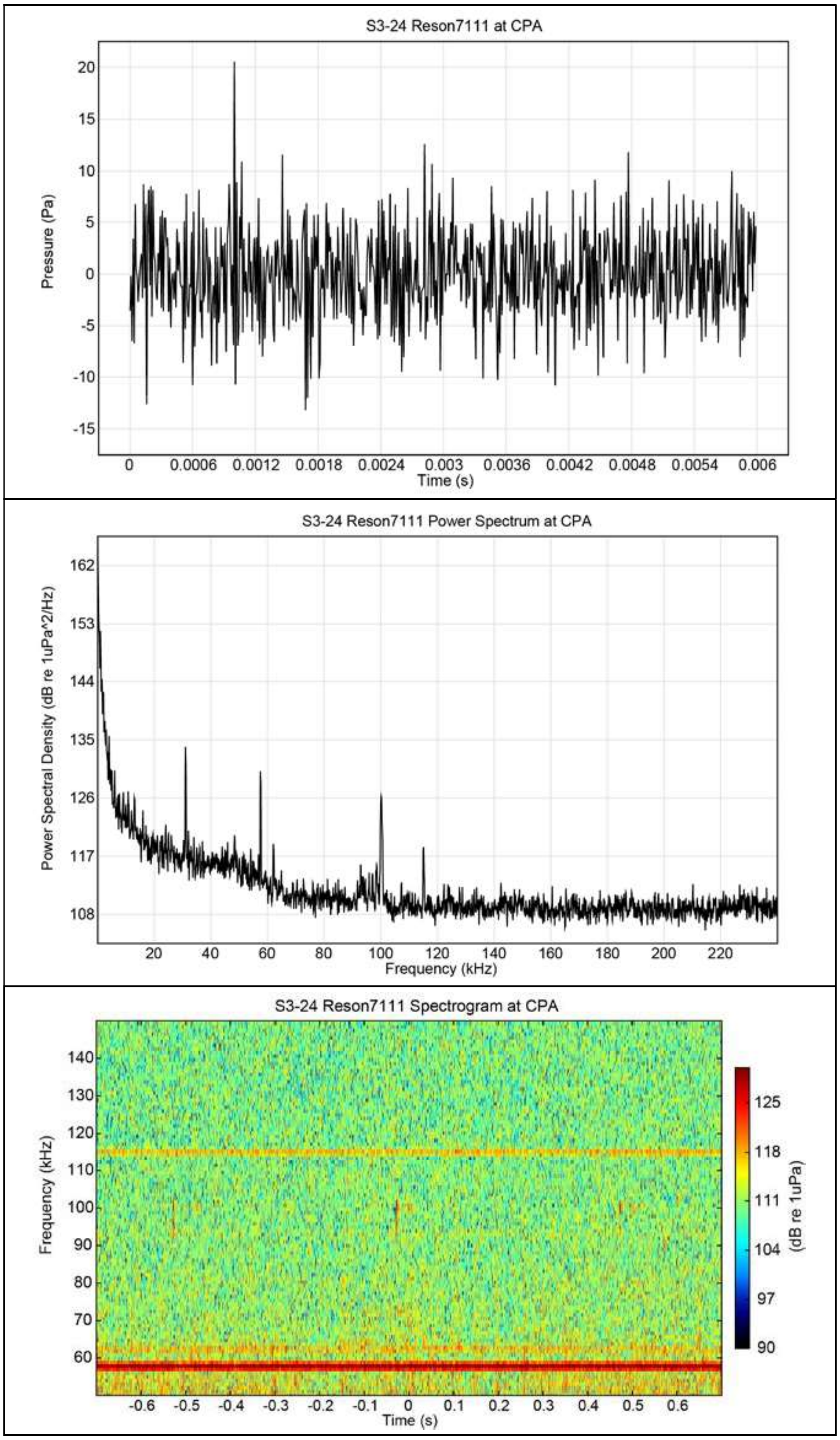


Figure 4.3-1. Reson 7111 measured signal characteristics at the closest point of approach (CPA) at Site 3, Run24.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.3.1 Site 1 – Mud, 10 m Depth

The Reson 7111 (Mode 1) was not deployed at S1.

4.3.2 Site 2 – Sand, 10 m Depth

The Reson 7111 (Mode 1) was not deployed at S2.

4.3.3 Site 3 – Mud, 30 m Depth

At S3, the Reson 7111, Mode 1, had valid acoustic recordings in Run15, Run25, and Run26. For Run15, there were no acoustic recordings of the signal because of recording equipment malfunction. For Run25 and Run26, positions D (Buoy6), B (Buoy11), and A (Buoy12) had valid acoustic data and observed signals. For all runs, positions E and F were too distant from the source to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7111, Mode 1, are shown in **Figure 4.3.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run25, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 100 kHz, propagation loss was very high and the signal was observable for a maximum of 4 minutes (120 seconds before and 120 seconds after the CPA). In **Figure 4.3.3-1**, four buoys have clear signal arrival. The top panels show clear signal at position D (Buoy6) for Run25 and Run26. The bottom panels show the recorded acoustics at positions B (Buoy11) and A (Buoy12).

The results panels (**Figure 4.3.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to collected data. For the Reson 7111 at S3, only positions D (Buoy6), B (Buoy11), and A (Buoy12) had acoustic signals, which are plotted in the graph. The top left panel is the SEL versus range, showing received signal energy at ranges from 65 to 205 m. Multipath propagation is evident from the multiple peaks visible along the range (x-axis). All receptions are close together, showing good calibration and buoy position determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves; spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)] that predict received levels for a 200 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel in **Figure 4.3.3-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position A at approximately 70° and 90°, indicating relatively good buoy positioning; for position B at approximately 60°; and for position D at 130°, indicating a possible position error. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

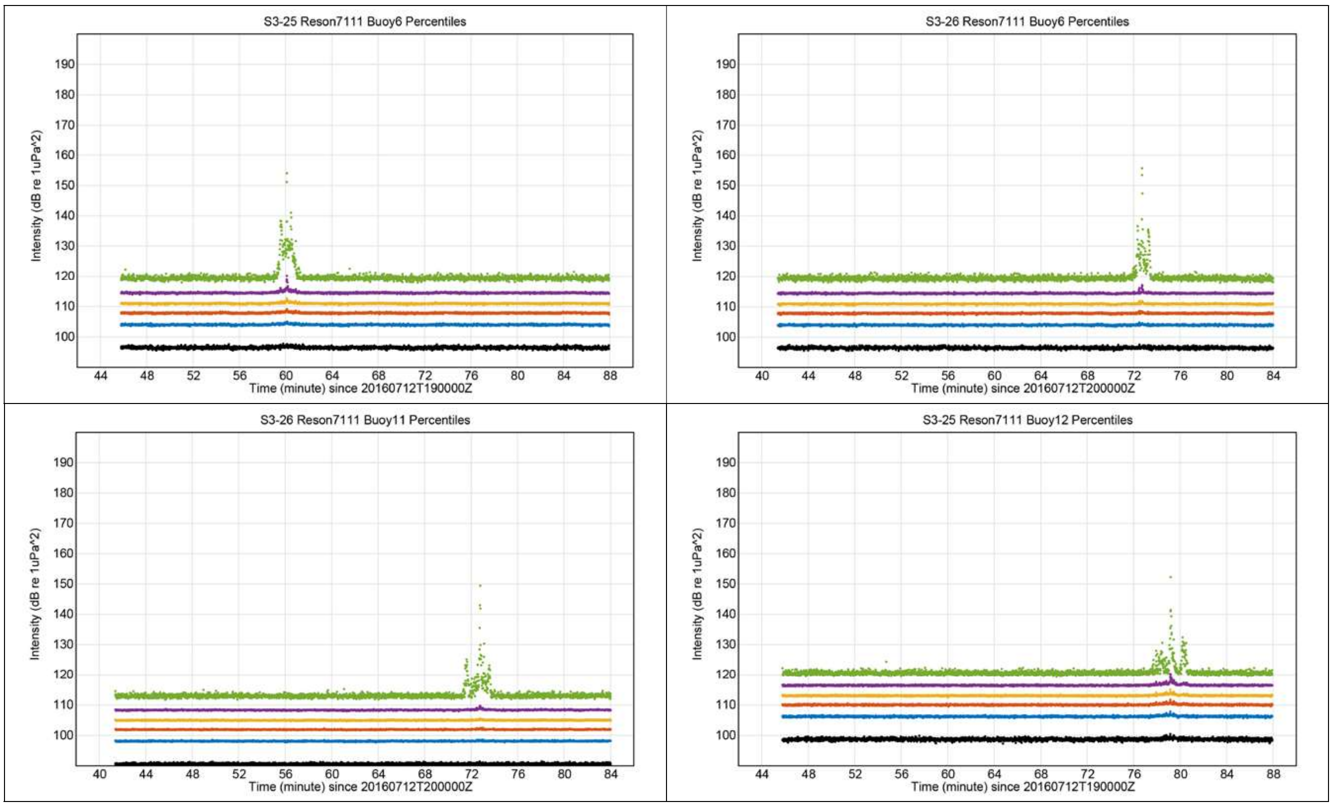


Figure 4.3.3-1. Percentile plots of Reson 7111 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position D (Buoy6); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position A (Buoy12). Legend: percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

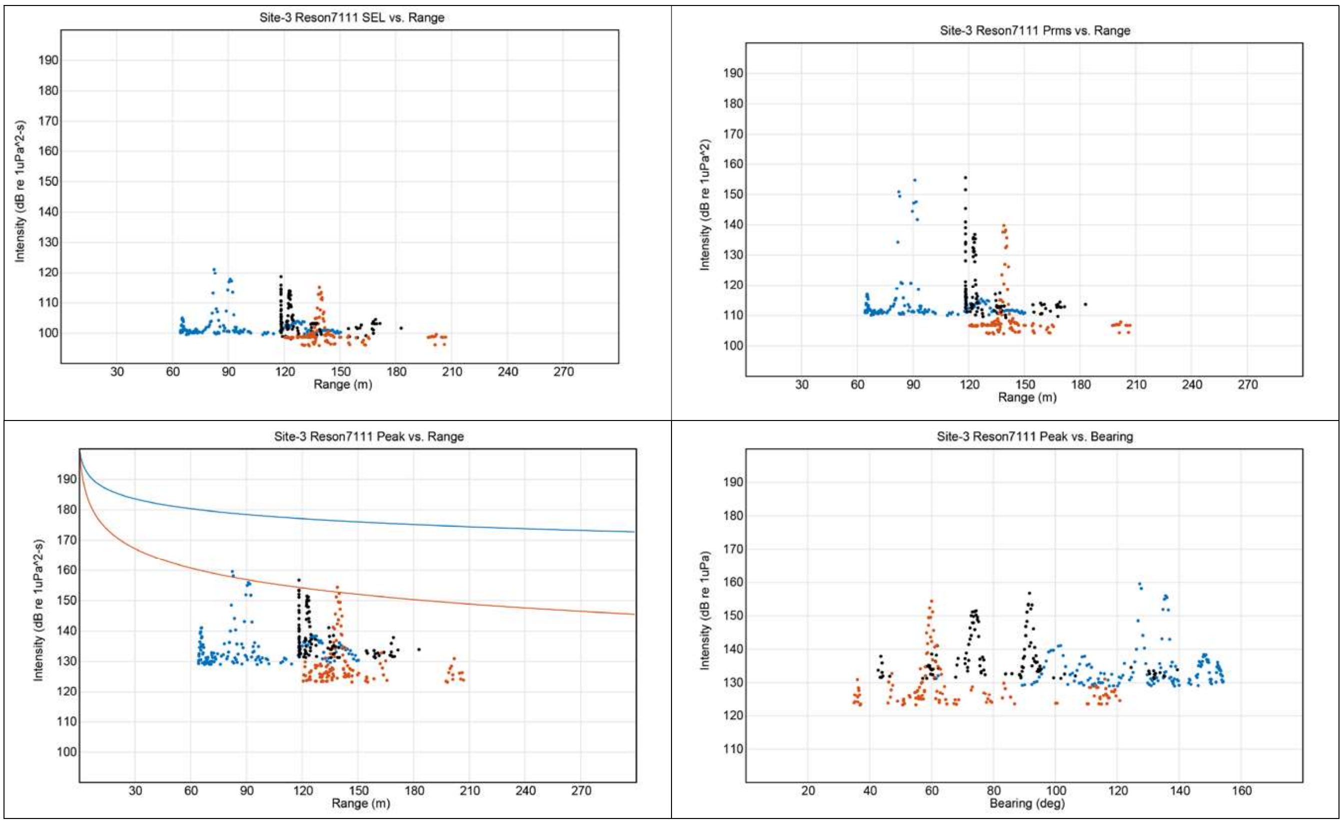


Figure 4.3.3-2. Range results for Reson 7111 combined signals at Site 3 for positions D (Buoy6), B (Buoy11), and A (Buoy12) from Run25 and Run26.

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions A = black; B = red; D = blue.

The plan view is shown in **Figure 4.3.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -270 to 270-m marks on the y-axis. The CPA is at 70,-70 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Recordings at each buoy had strong acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The plan view data indicate an error at position D, where the highest amplitude signal is seen on the y-axis at -70 m, while positions A and B high amplitudes are seen at about 30 m.

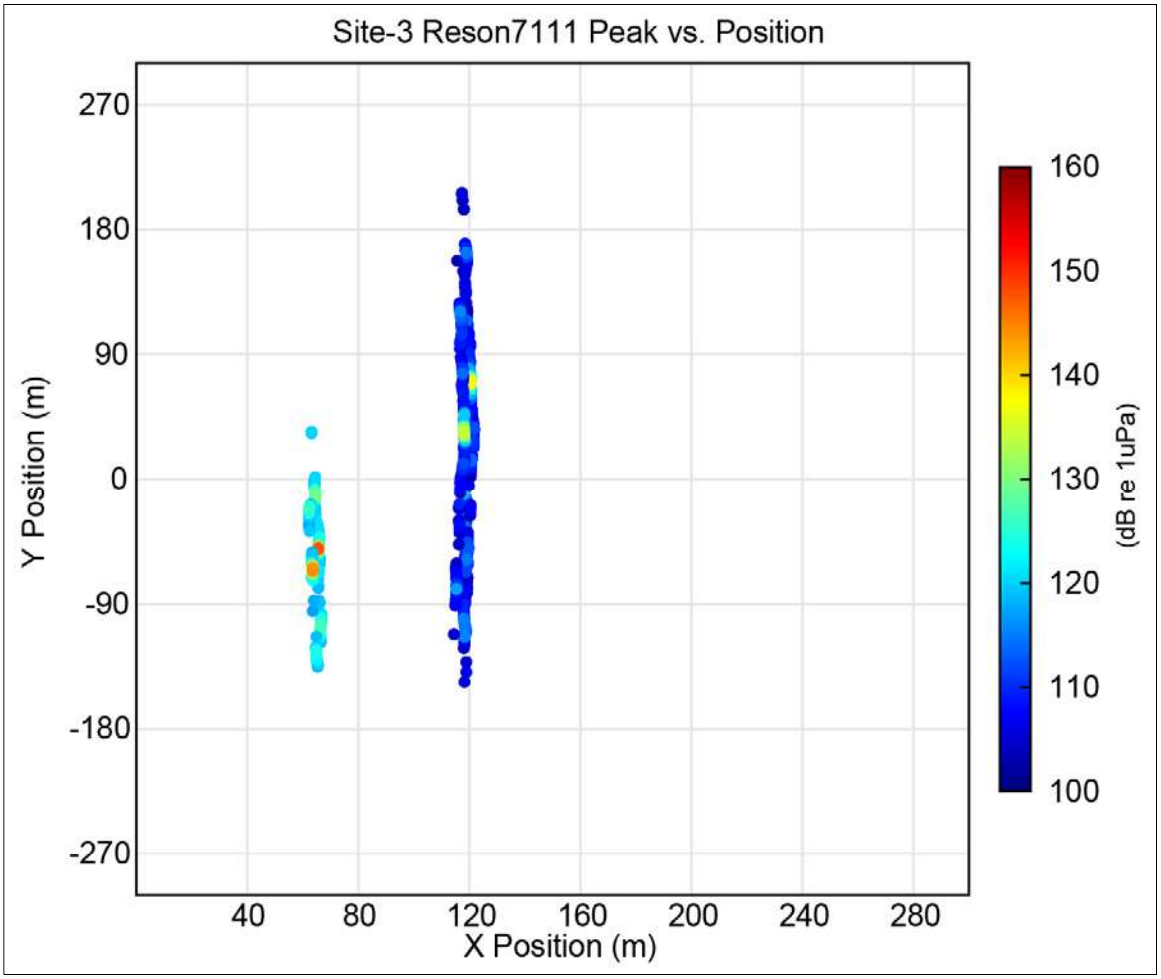


Figure 4.3.3-3. Plan view of received peak level for Reson 7111 at Site 3, showing the results for positions D (Buoy6), B (Buoy11), and A (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the received level field measurement results are provided in **Table 4.3.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.3.3-1. Reson 7111 source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Reson 7111 Mode 1	100 kHz	200 dB	0.17 ms	1.5°	198	193	158
NUWC	100 kHz	200 dB	0.17 ms	1.5°	200	196	158

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.3.4 Site 4 – Sand, 30 m Depth

At S4, the Reson 7111, Mode 1, had valid acoustic recordings during Run5. For Run5, positions A (Buoy6), C (Buoy5), and B (Buoy7) had valid acoustic data. The data were processed and plotted, but there was no source signal due to the large propagation distance for this HF source. Position F (Buoy5) was too distant to capture the HF acoustic signal, and position D (Buoy8) did not capture acoustic signals because of recording equipment malfunction.

Run Summary

The percentile plots for the available recordings of the Reson 7111, Mode 1, are shown in **Figure 4.3.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position A (Buoy6) for Run5, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. There is evidence of multipath propagation as seen by the multiple peaks of the signal versus range. The top right and bottom panels show valid recorded acoustics that lack any signal at positions C (Buoy5) and B (Buoy7, for HS and LS). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good. However, even with valid acoustic data, there is no evidence of the signal at position F because of propagation loss of the HF signal.

The results panels (**Figure 4.3.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7111 at S4, positions A (Buoy6), C (Buoy5), and B (Buoy7) had acoustic signals, which are plotted in **Figure 4.3.4-2**. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 300 m. The rapid fall off with range is indicative of the source directionality. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves; spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)] that predict received levels for a 200 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). For the SPL_{pk}, there is signal from 90 m to approximately 300 m that quickly falls off with range, which shows the propagation at S4 is worse than spherical spreading.

The bottom right results panel in **Figure 4.3.4-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position A at approximately 100°, indicating relatively good navigational buoy position. Position C and B peak amplitudes are around 120°, indicating possible navigation errors. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

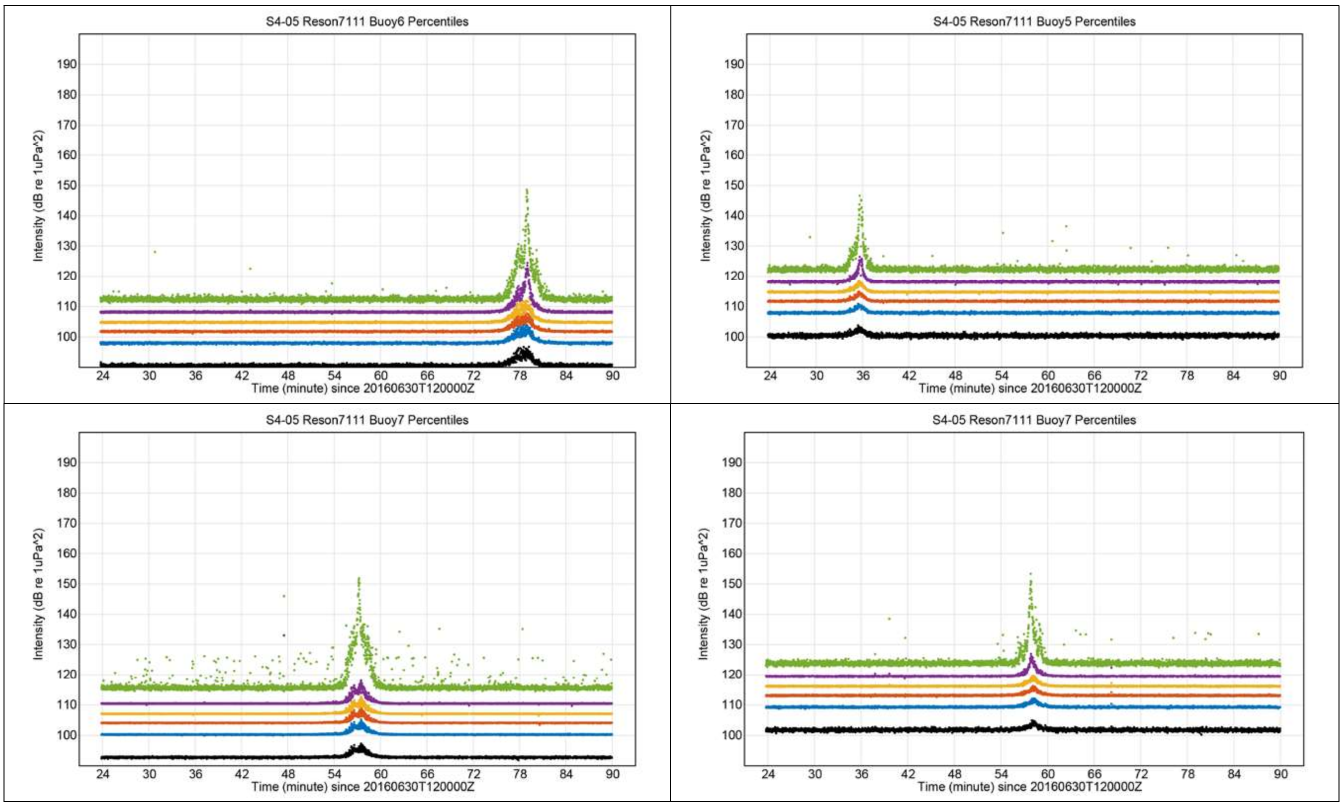


Figure 4.3.4-1. Percentile plots of Reson 7111 signals at Site 4.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position A (Buoy6); Top right: SPL_{pk} arrival at position C (Buoy5); Bottom left: SPL_{pk} arrival at position B (Buoy7, High Sensitivity); Bottom right: SPL_{pk} arrival at position B (Buoy7, Low Sensitivity). Legend: percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

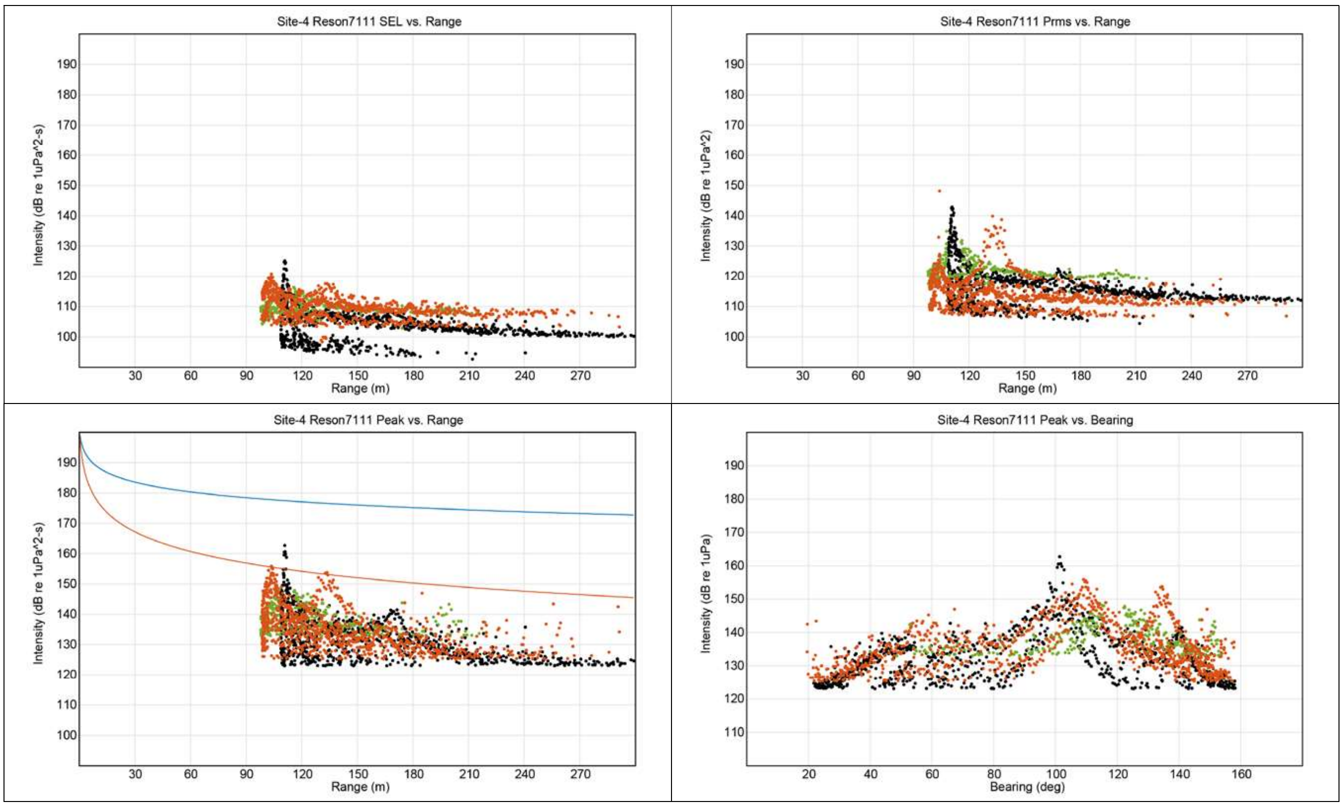


Figure 4.3.4-2. Range results for Reson 7111 signals at Site 4 for positions A (Buoy6), B (Buoy7), and C (Buoy5).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions A = black; B = red; C = green.

The plan view is shown in **Figure 4.3.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -270 to 270-m marks on the y-axis. The CPA is supposed to be at 0,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Recordings at each buoy had strong acoustic peak amplitudes, presumed to be at the CPA, and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The CPA locations are seen on the y-axis at about -45 and -90 m. The buoy with a CPA peak at -90 m is a result of buoy positioning errors.

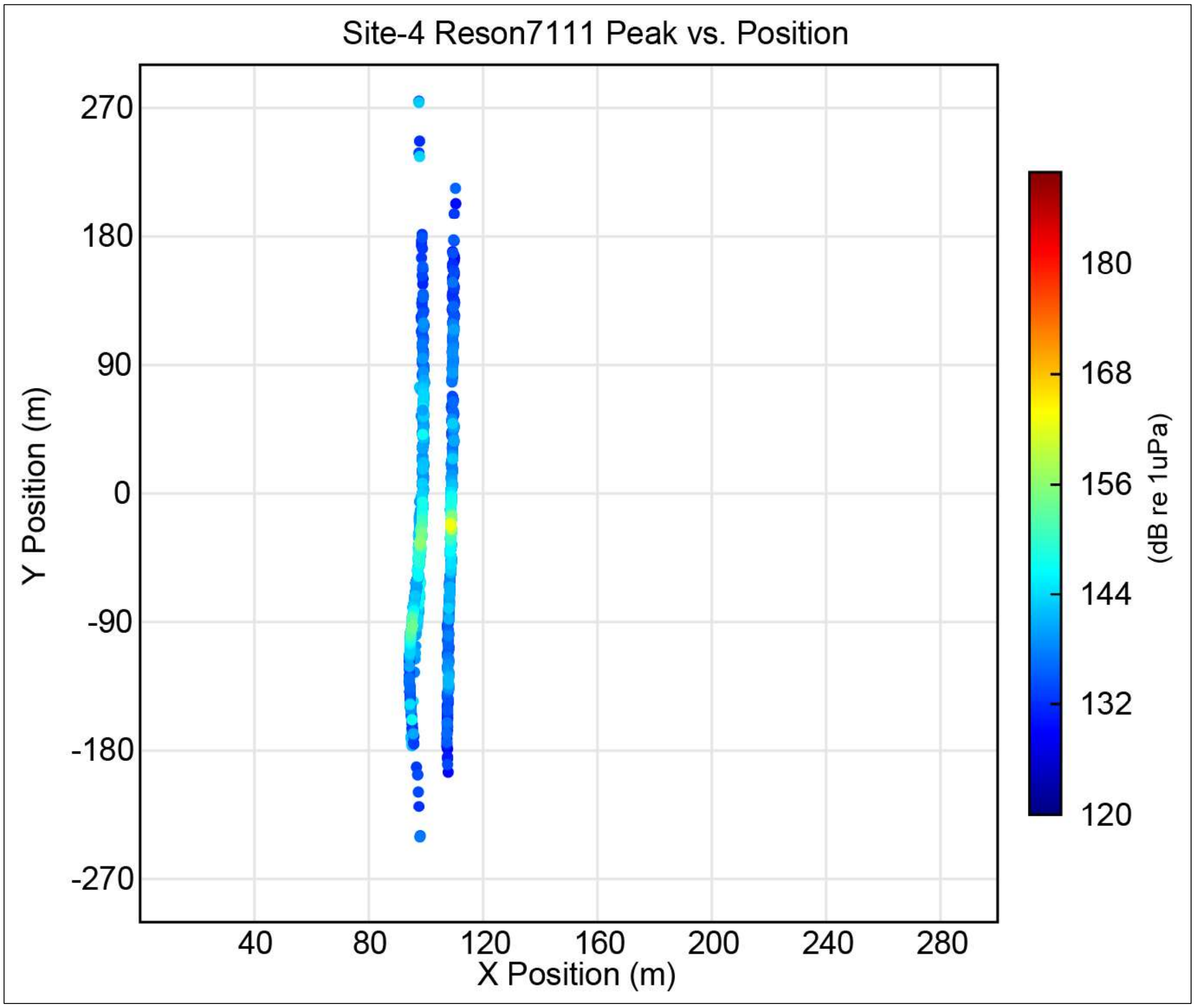


Figure 4.3.4-3. Plan view of received peak level for Reson 7111 at Site 4, showing the results for positions A (Buoy6), B (Buoy7), and C (Buoy5).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the received level field measurement results are provided in **Table 4.3.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.3.4-1. Reson 7111 source levels, Mode 1, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Cycles, Pulse Width	Beam width, Range	Pk	rms	SEL
Reson 7111 Mode 1	100 kHz	200 dB	0.17 ms	1.5°	202	190	165
NUWC	100 kHz	200 dB	0.17 ms	1.5°	200	196	158

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.3.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Reson 7111, Mode 1 was only deployed for Run7 and Run23. For Run7, the data were zeroes, meaning no acoustic data were recorded because of recording equipment malfunction. For Run23, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Positions E and F were too distant from the source to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7111, Mode 1, are shown in **Figure 4.3.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run23, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 100 kHz, propagation loss was high, but the signal was observed for about 12 minutes. There is some evidence of multipath propagation, as seen by multiple peaks along the range.

The results panels (**Figure 4.3.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7111 at S5, positions D (Buoy6), B (Buoy11), and A (Buoy12) had acoustic signals, which are plotted in the graph. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to 400 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves; spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)] that predict received levels for a 200 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The rapid drop off with range is due to the directionality of the source and geometry rather than propagation loss, showing the propagation at this site is better than spherical spreading.

The bottom right results panel in **Figure 4.3.5-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D, A and B near 90°. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

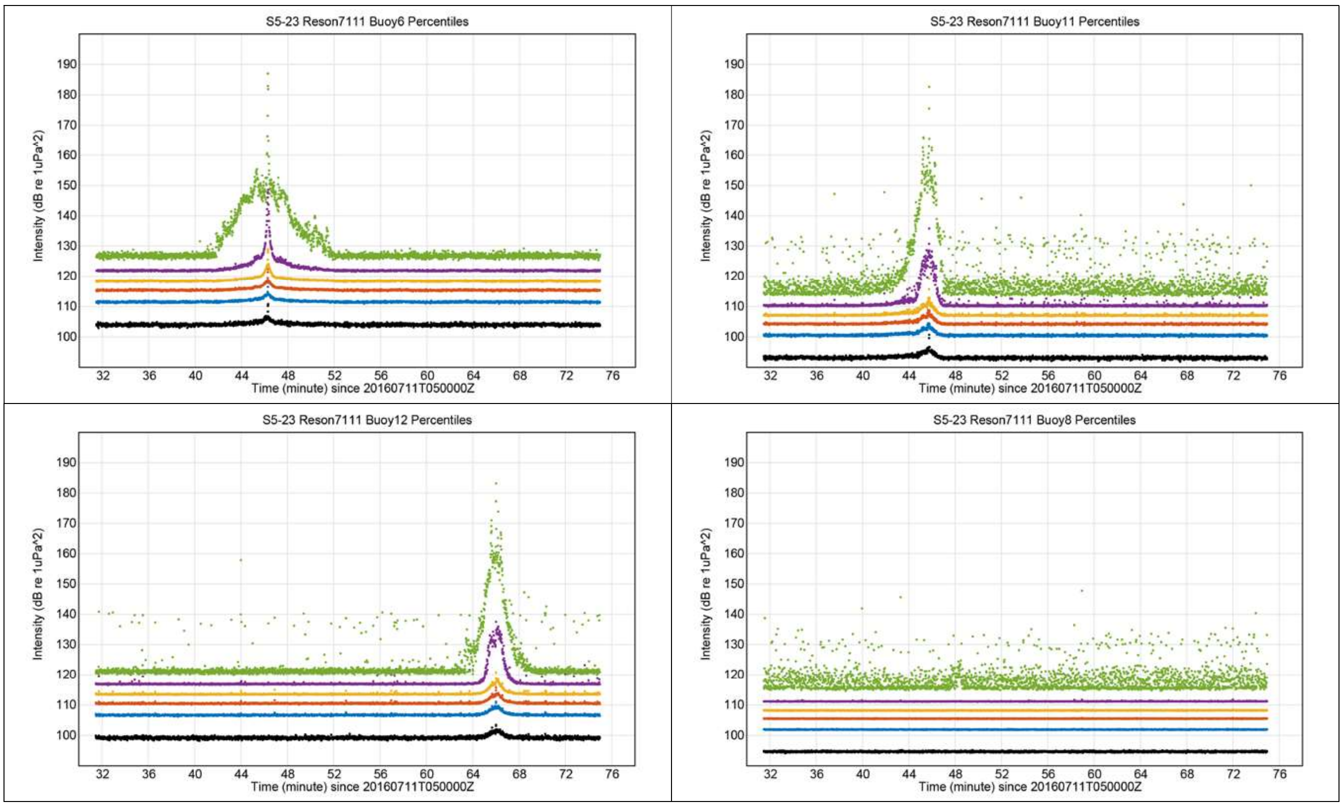


Figure 4.3.5-1. Percentile plots of Reson 7111 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

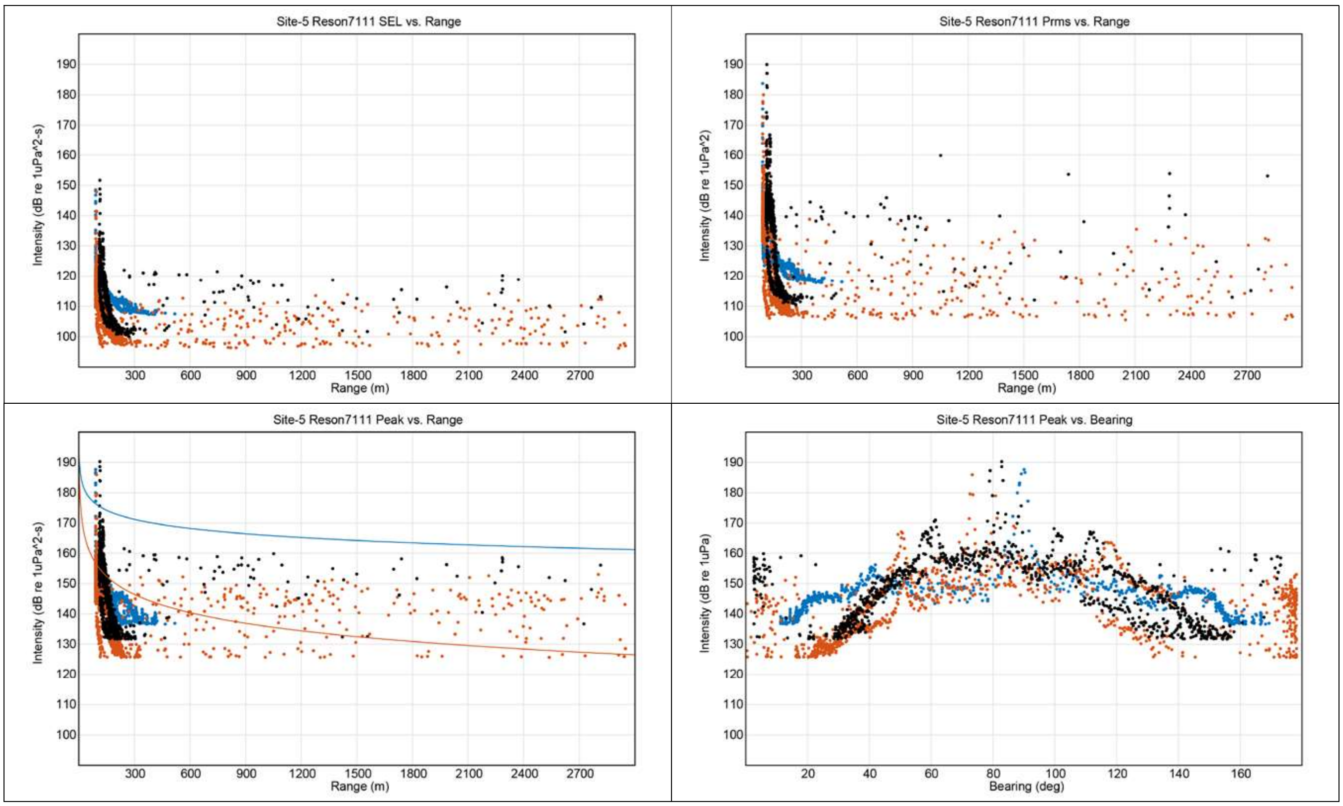


Figure 4.3.5-2. Range results for Reson 7111 signals at Site 5 for positions D (Buoy6), B (Buoy11), and A (Buoy12) from Run23. Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions A = black; B = red; D = blue.

The plan view is shown in **Figure 4.3.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -900 to 900-m marks on the y-axis. The CPA is at 90,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Recordings at each buoy had strong acoustic peak amplitudes, which are presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). Acoustic signals were received at positions D (Buoy6), B (Buoy11), and A (Buoy12).

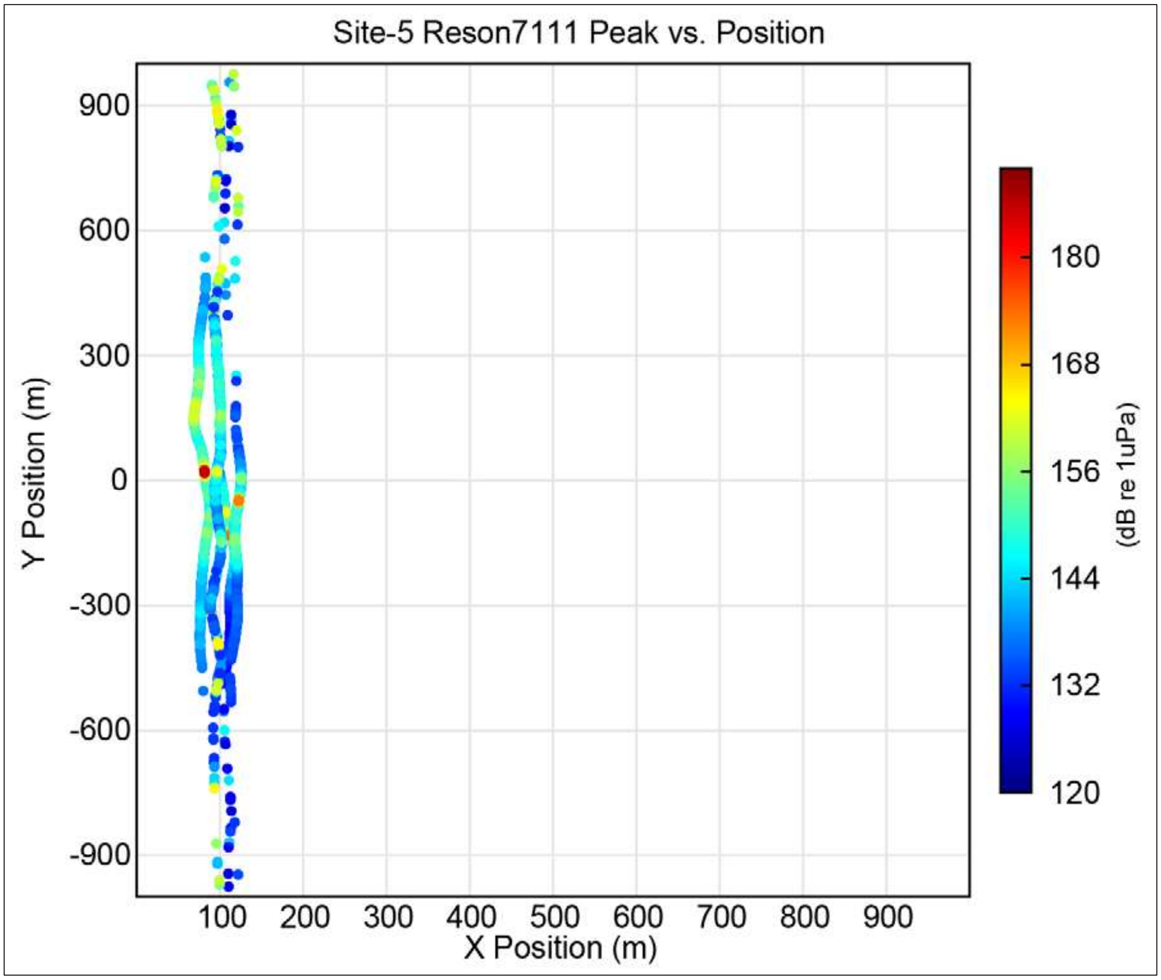


Figure 4.3.5-3. Plan view of received peak level for Reson 7111 at Site 5, showing the results for positions D (Buoy6), B (Buoys 11), and A (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the received level field measurement results are provided in **Table 4.3.5-1.** The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.3.5-1. Reson 7111 source levels, Mode 1, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Cycles, Pulse Width	Beam width, Range	Pk	rms	SEL
Reson 7111 Mode 1	100 kHz	200 dB	0.17 ms	1.5°	200	187	167
NUWC	100 kHz	200 dB	0.17 ms	1.5°	200	196	158

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

This Page Left Intentionally Blank

4.4 Reson 7111, 100 kHz, 200 dB, 0.17-ms Pulse, 3° (Mode 2)

The Reson 7111 multibeam echosounder generates a single, high frequency (HF) signal with a peak frequency of 95 kHz. The operational parameter settings for Mode 2 were a power setting of 200 dB, 0.17-ms pulse length, 3° beamwidth, and 100-kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.4-1** is the selected frequency band (90 to 110 kHz) and SPL_{pk} (128 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a quick drop of energy.

Table 4.4-1. Bandpass determination for the Reson 7111 multibeam echosounder, 100 kHz, 200 dB, 0.17-ms pulse, 3° at Site 3, Run26.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
50-150	130.20
80-120	128.52
90-110	**128.26**
95-105	116.05

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported below from only one site for simplicity. The Reson 7111, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.4-1**.

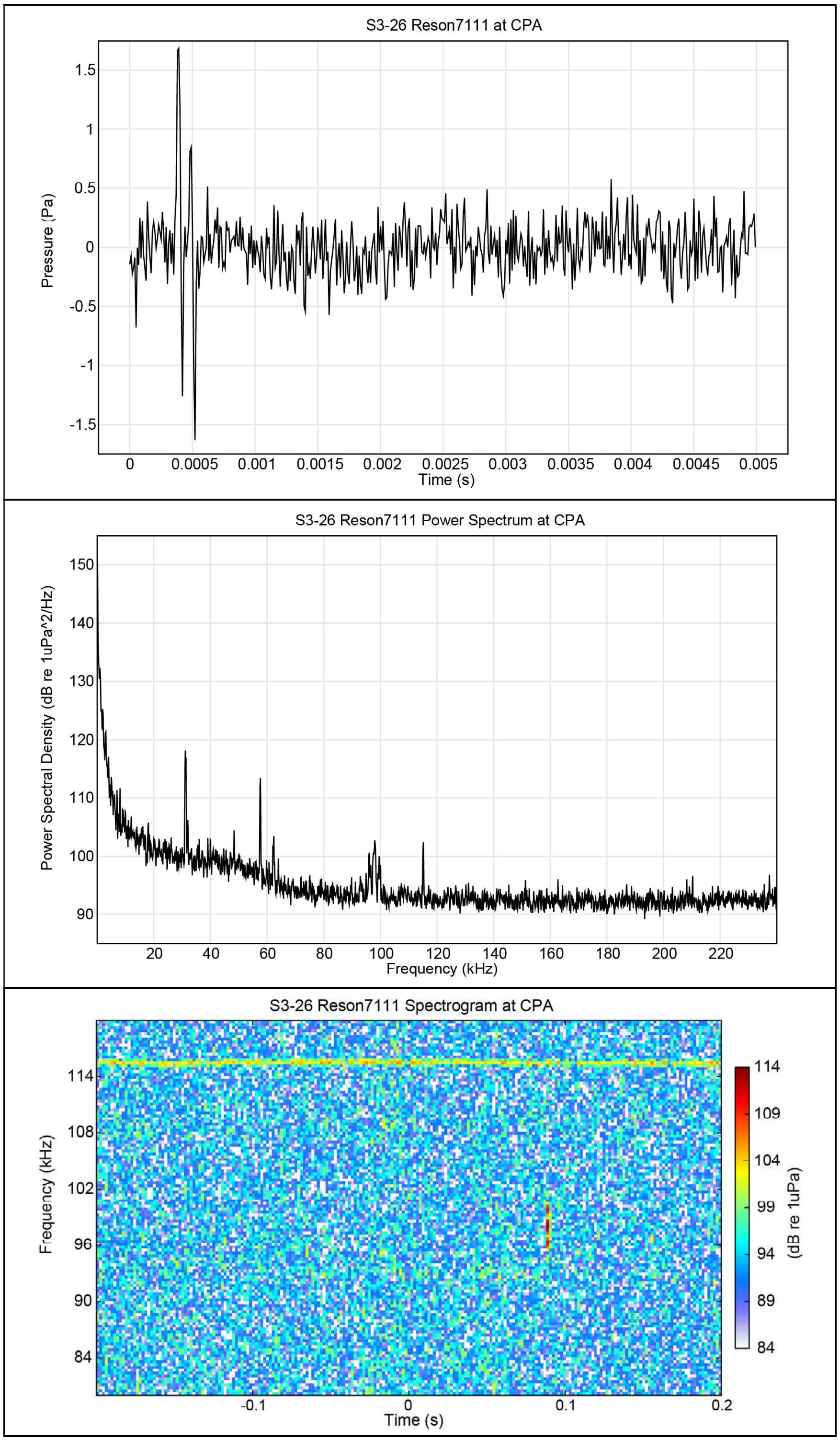


Figure 4.4-1. Reson 7111 measured signal characteristics at the closest point of approach (CPA) at Site 3, Run26.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.4.1 Site 1 – Mud, 10 m Depth

The Reson 7111, Mode 2, was not deployed at S1.

4.4.2 Site 2 – Sand, 10 m Depth

The Reson 7111, Mode 2, was not deployed at S2.

4.4.3 Site 3 – Mud, 30 m Depth

At S3, the Reson 7111, Mode 2, had valid acoustic recordings in Run14 and Run24. For Run14, position B (Buoy12) had valid acoustic data, but the data are not presented due to poor quality. For Run24, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9) had valid acoustic data and observed signals. Positions E and F were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7111, Mode 2, are shown in **Figure 4.4.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run24, where the received signal is observed; the top right panel shows position B (Buoy11); and the bottom panel shows position A (Buoy12). The HF signal is centered on 100 kHz.

The results panels (**Figure 4.4.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to collected data. For the Reson 7111 at S3, positions D (Buoy6), B (Buoy11), and A (Buoy 12) had acoustic data that look like the HF signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 70 to 200 m. Multipath propagation is evident from the multiple peaks visible along the range (x-axis). The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The narrowly defined peak, which has a rapid fall-off with range, is due to the source directionality. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 196 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 140°, indicating a possible error in buoy positioning; for position A at approximately 80°, which is close to expected; and for position B at 60°, indicating possible navigation errors.

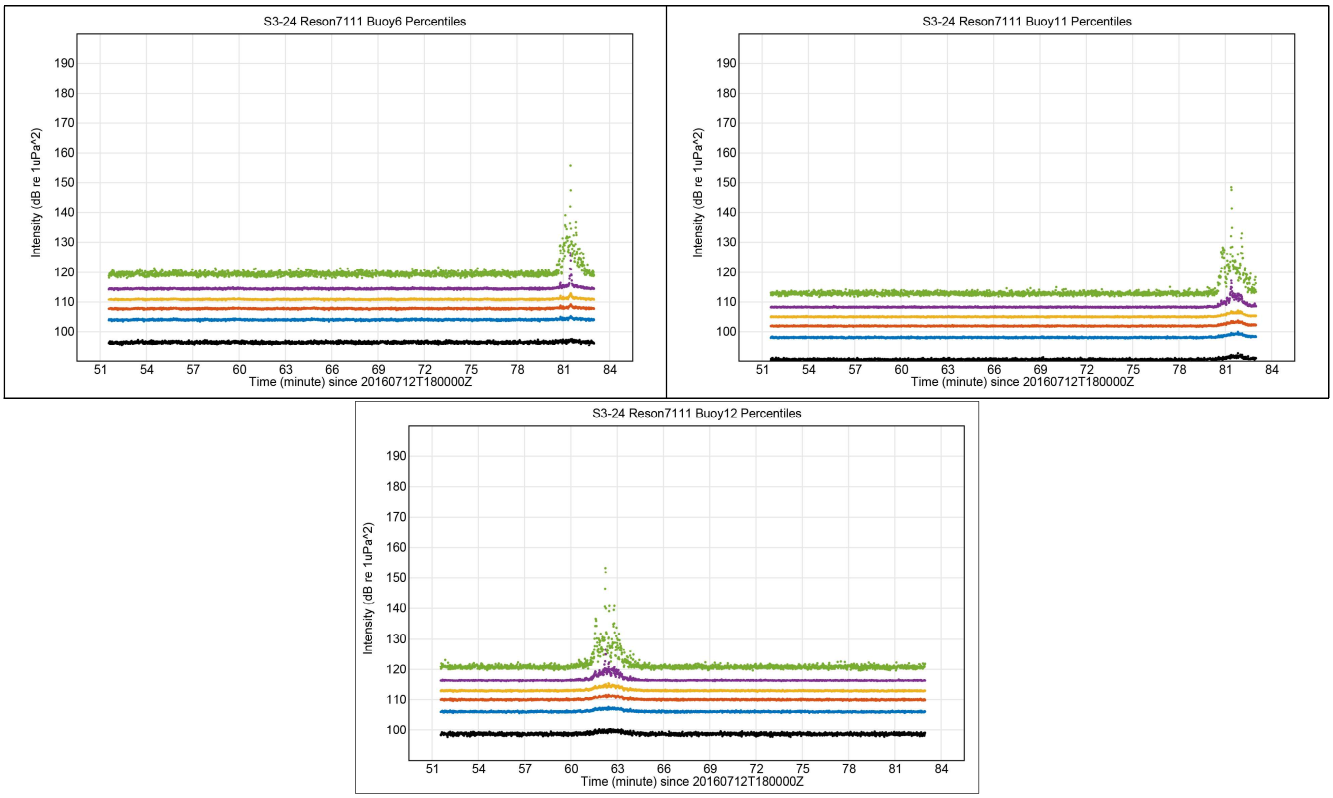


Figure 4.4.3-1. Percentile plots of Reson 7111 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

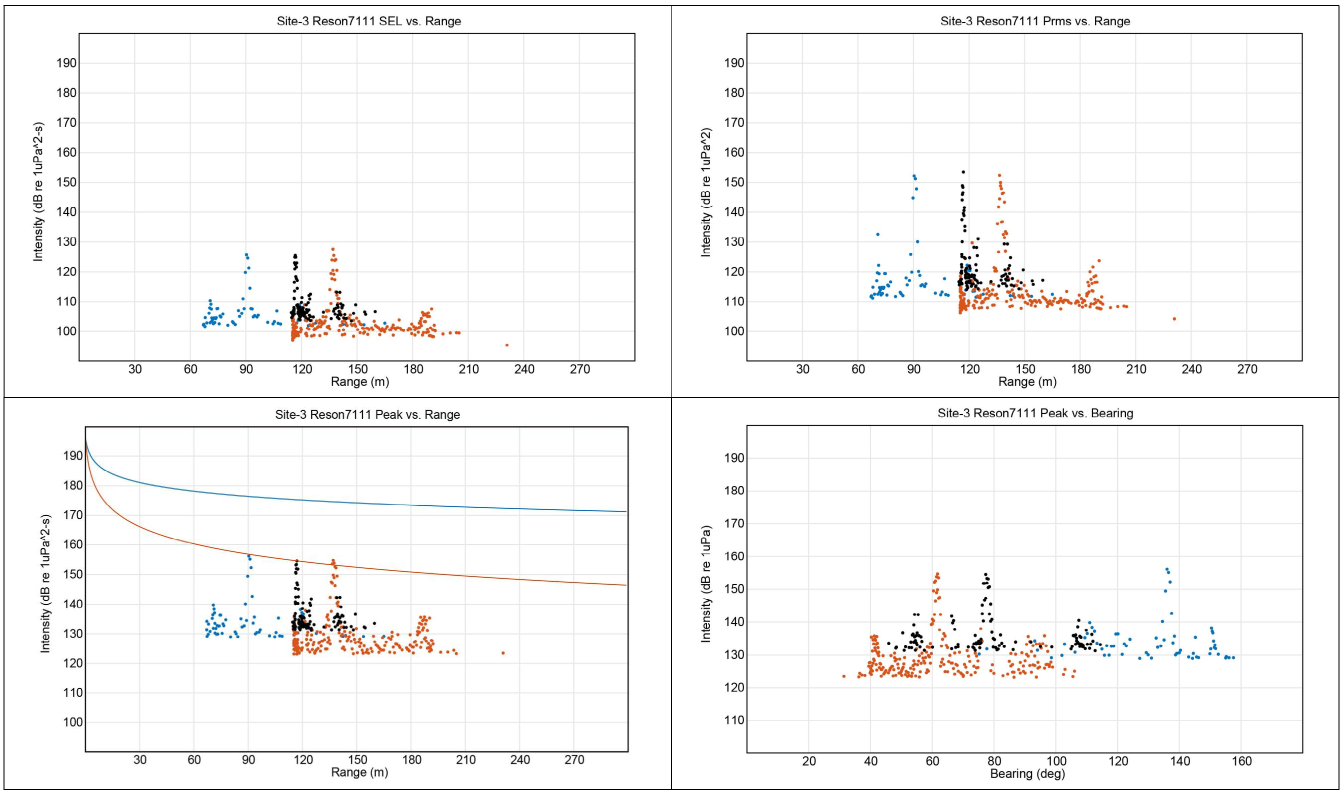


Figure 4.4.3-2. Range results for Reson 7111 combined signals for Run24 at Site 3 for positions D (Buoy6), B (Buoy11), and A (Buoy12). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue.

The plan view is shown in **Figure 4.4.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 60,-80 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at positions D (Buoy6), B (Buoy11), and A (Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen on the y-axis at approximately -80 m, while high amplitudes for positions A and B are seen at about 20 and 70 m.

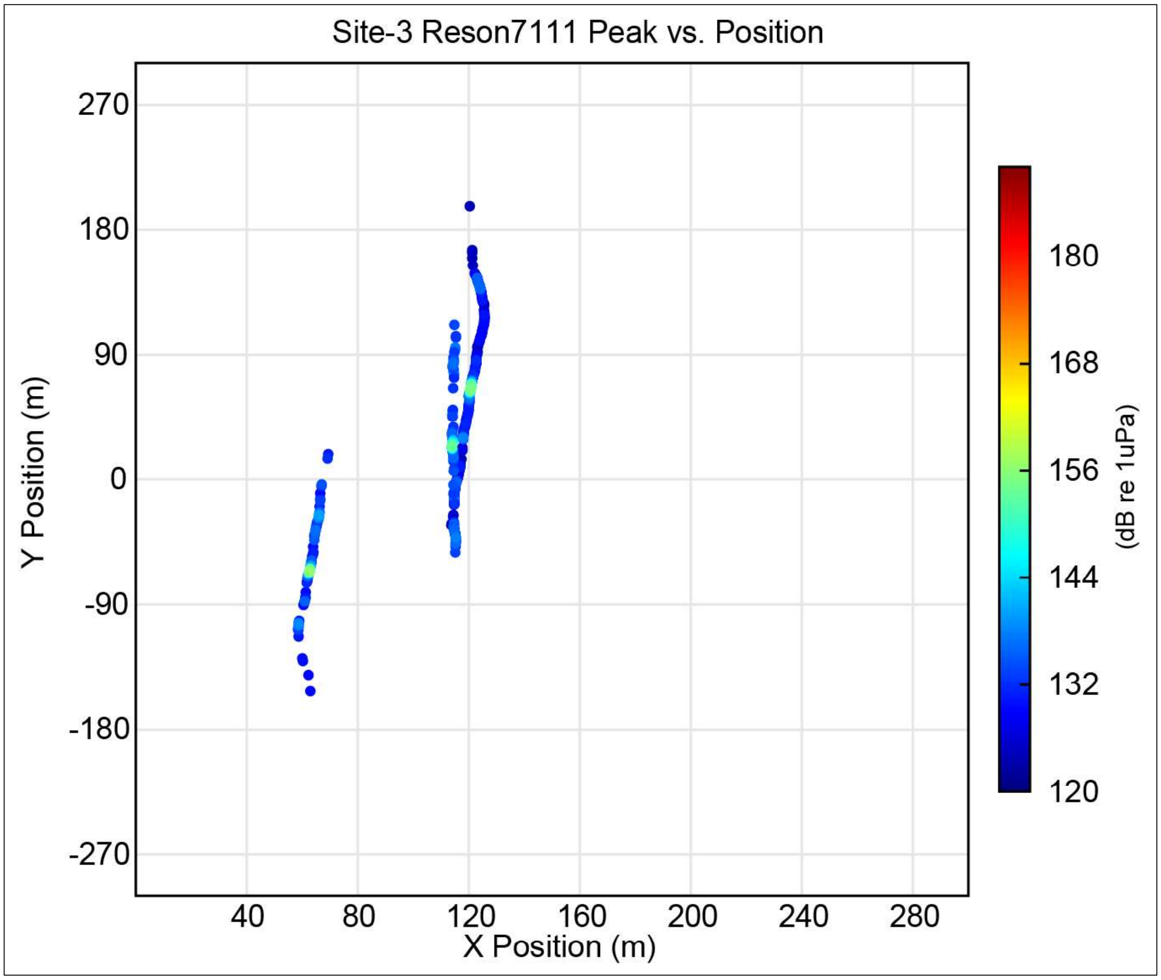


Figure 4.4.3-3. Plan view of received peak level for Reson 7111 at Site 3 for positions D (Buoy6), B (Buoy11), and A (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.4.3-1**. The estimated source levels from the measurements were calculated using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.4.3-1. Reson 7111 source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Reson 7111 Mode 2	100 kHz	200 dB	0.17 ms	3°	196	193	164
NUWC	100 kHz	200 dB	0.17 ms	3°	196	190	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.4.4 Site 4 – Sand, 30 m Depth

At S4, the Reson 7111, Mode 2, had valid acoustic recordings in Run4. For Run4, positions A (Buoy6), B (Buoy7 HS and LS), and C (Buoy5) had valid acoustic recordings. Position D (Buoy8) did not capture acoustic signals, and positions E (Buoy9) and F (Buoy11) were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Reson 7111, Mode 2, are shown in **Figure 4.4.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. In **Figure 4.4.4-1**, the top left panel shows valid recorded acoustics at position C (Buoy5) for Run4. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The top right and lower panels show the signals observed at positions A (Buoy6) and B (Buoy7 HS and LS), respectively.

The results panels (**Figure 4.4.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7111 at S4, positions C (Buoy5), A (Buoy6), and B (Buoy7 HS and LS) had valid acoustic data. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to more than 200 m. The shape of the position B data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed from the 5 percent to 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 196 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position C at approximately 80°, indicating good buoy positioning and for position B at approximately 110°, indicating possible buoy positional errors or processing errors of buoy GPS. The buoy GPS location data was used for all recordings at this site.

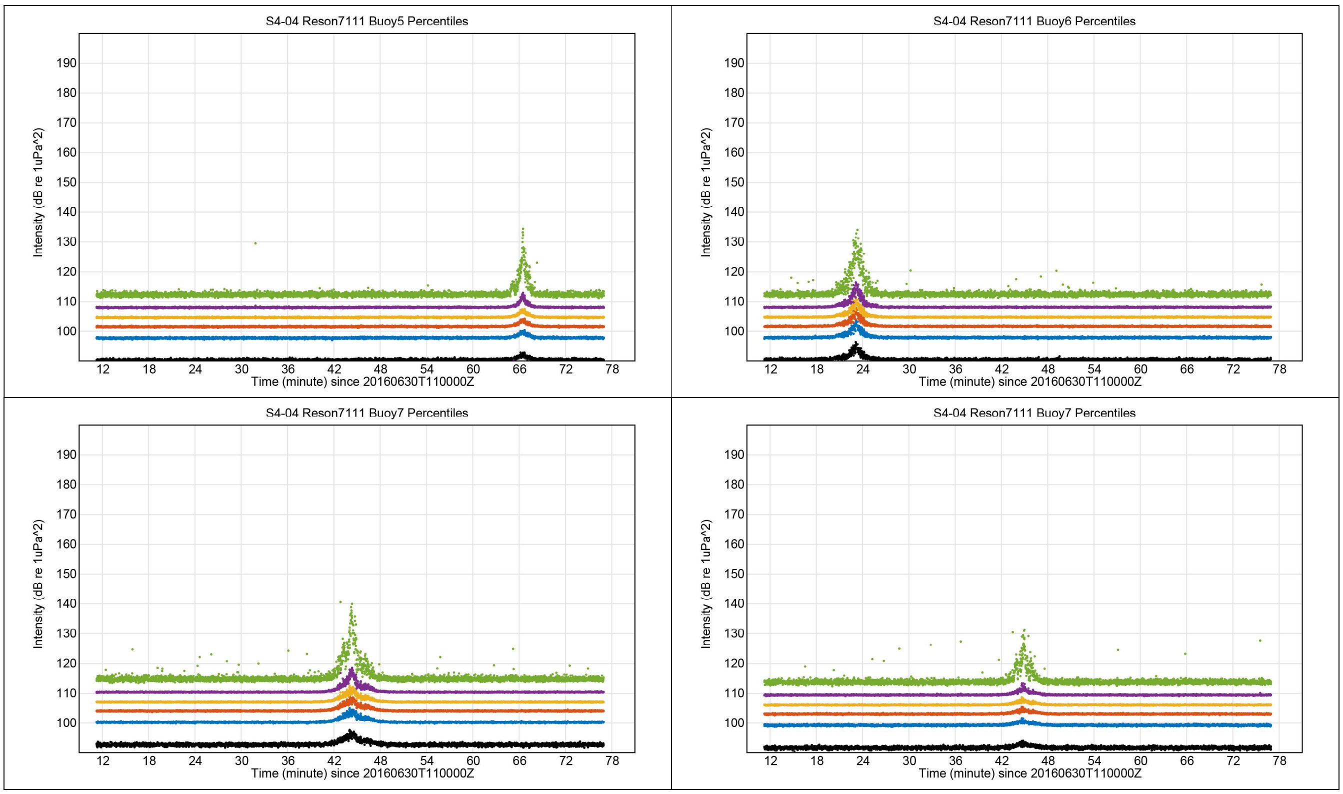


Figure 4.4.4-1. Percentile plots of Reson 7111 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position C (Buoy5); Top right: SPL_{pk} arrival at position A (Buoy6); Bottom left: SPL_{pk} arrival at position B (Buoy7 HS); Bottom right: SPL_{pk} arrival at position B (Buoy7 LS). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

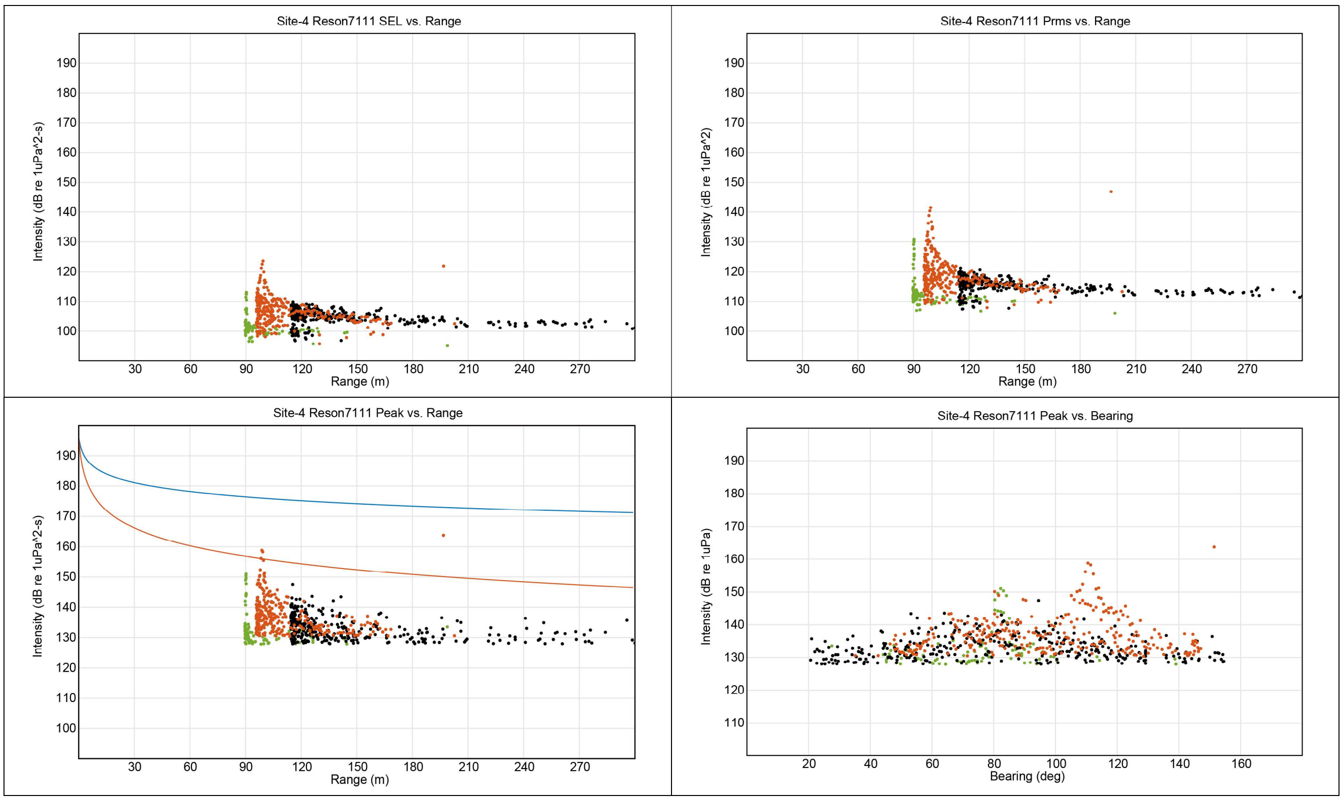


Figure 4.4.4-2. Range results for Reson 7111 signals at Site 4 for position C (Buoy5), A (Buoy6), and B (Buoy7 HS and LS). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; C = green.

The plan view is shown in **Figure 4.4.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 90,-45 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Although these sound levels are lower than other sources, their CPAs are visible. Acoustic signals were received at positions C (Buoy5), B (Buoy7), and A (Buoy6). Recordings at each buoy had acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source).

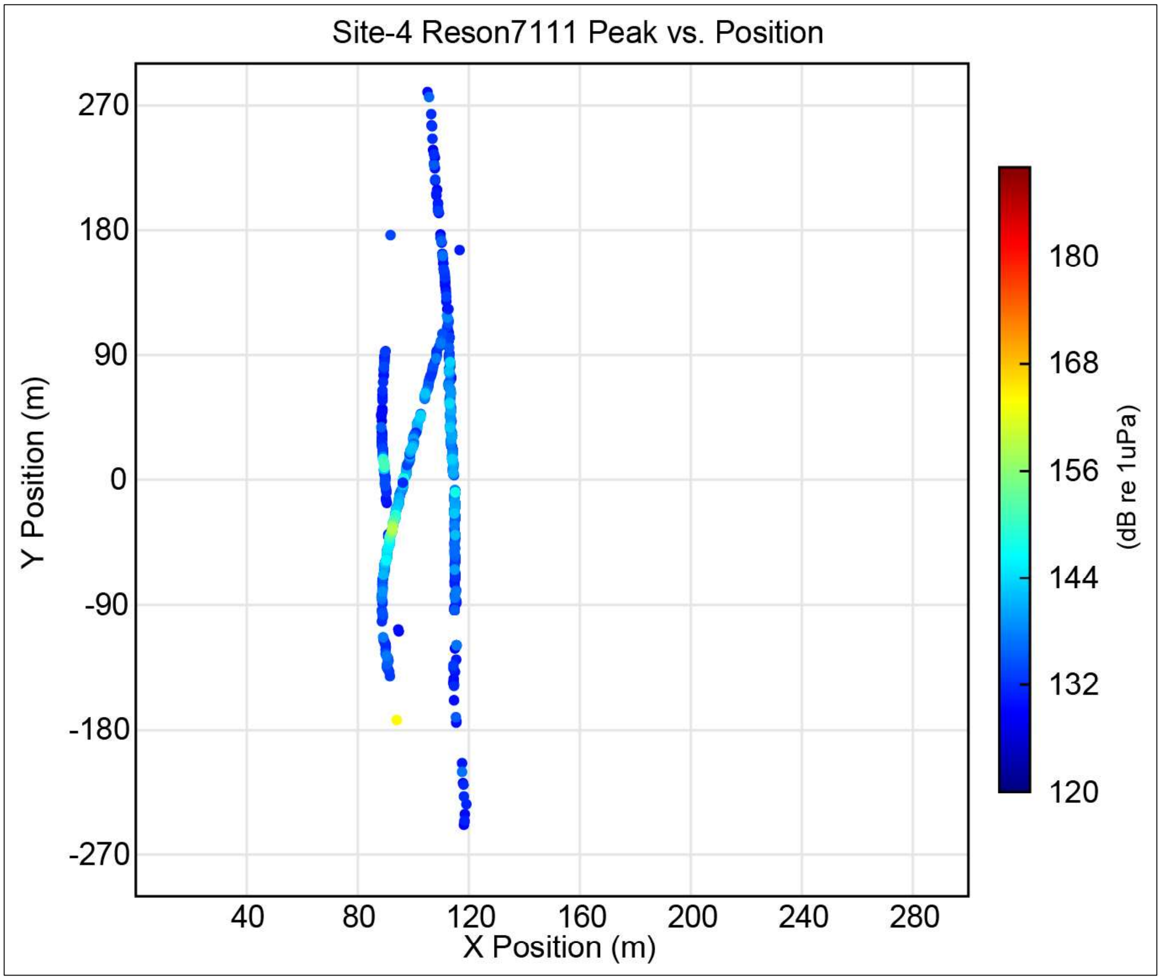


Figure 4.4.4-3. Plan view of received peak level for Reson 7111 at Site 4, showing the results for position C (Buoy5), B (Buoy7), and A (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.4.4-1**. The estimated source levels from the measurements were calculated using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.4.4-1. Reson 7111 source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Cycles, Pulse Width	Beam width, Range	Pk	rms	SEL
Reson 7111 Mode 2	100 kHz	200 dB	0.17 ms	3°	198	182	164
NUWC	100 kHz	200 dB	0.17 ms	3°	196	190	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.4.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Reson 7111, Mode 2, had valid acoustic recordings in Run6 and Run22. For Run6, position A (Buoy12) had valid acoustic recordings. For Run22, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), and A (Buoy12). Positions E (Buoy8 and Buoy9) and F (Buoy10) were too distant to capture the HF acoustic signal.

Run Summary

The S5 receptions differ from the previous sites in that the peak received levels were higher and the signal was observable above the noise for a longer duration. The percentile plots for the available recordings of the Reson 7111, Mode 2, are shown in **Figure 4.4.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT time for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows the recorded acoustics at position D (Buoy6) for Run22, the top right panel shows position B (Buoy11), and the bottom panel shows position A (Buoy12). The approximate 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.4.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Reson 7111 at S5, positions D (Buoy6), B (Buoy11), and A (Buoy12) had valid acoustic data. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to 500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 196 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 100°, position B at approximately 120°, and position A at approximately 70°. With accurate buoy GPS it is not clear why the buoys show what seem to be positional errors.

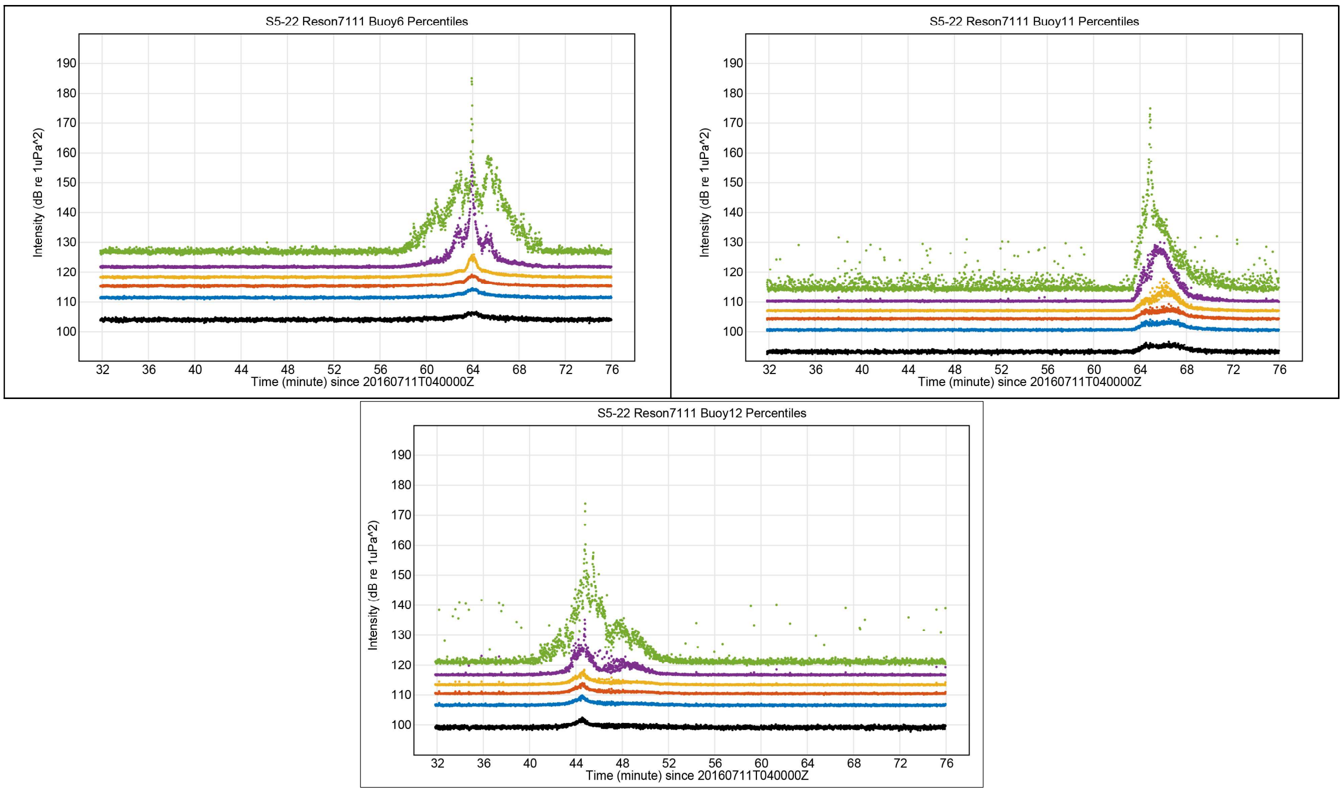


Figure 4.4.5-1. Percentile plots of Reson 7111 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

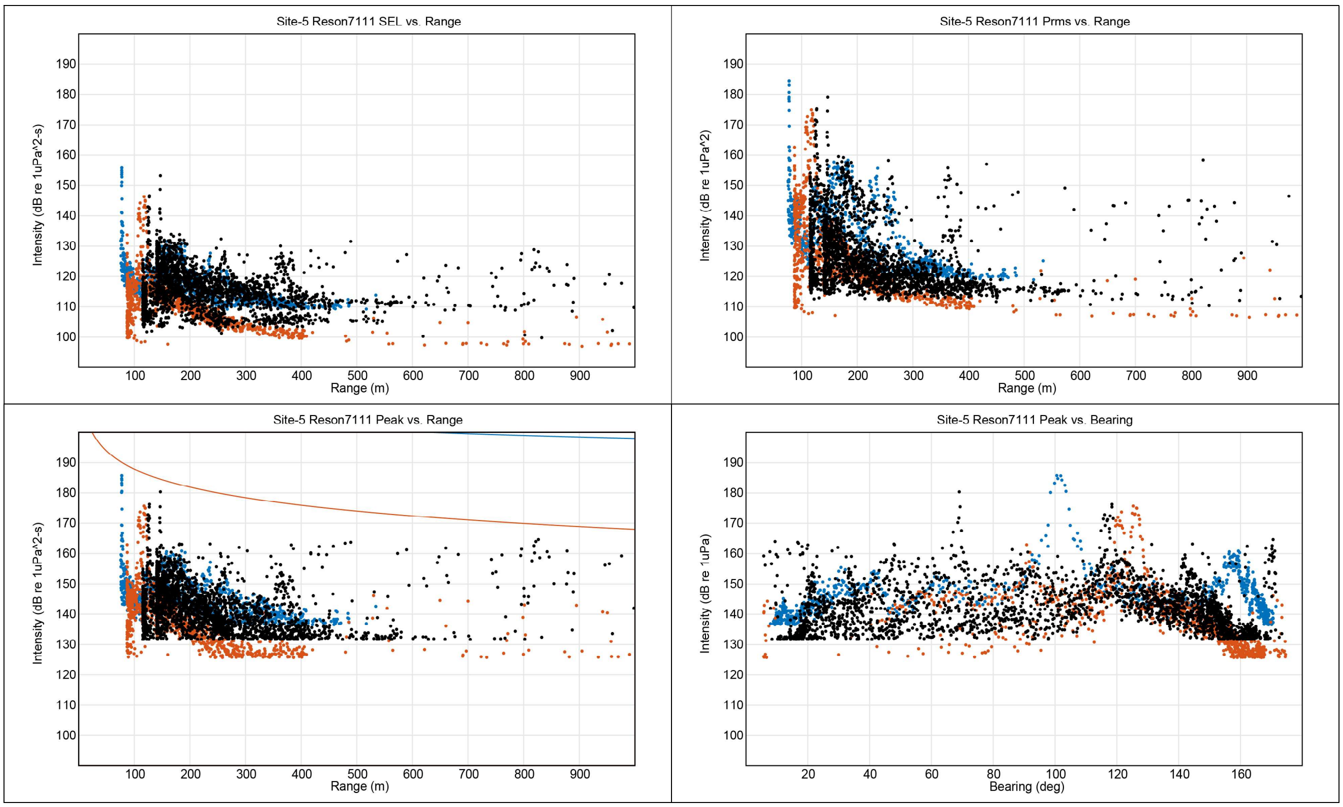


Figure 4.4.5-2. Range results for Reson 7111 signals at Site 5 from Run6 and Run22 for positions D (Buoy6), B (Buoy11), and A (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue.

The plan view is shown in **Figure 4.4.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -500 to 500-m marks on the y-axis. The CPA is at 75,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at positions D (Buoy6), B (Buoy11), and A (Buoy12), and the CPAs are between 0 and -100 m on the y-axis. The gradual rise and fall of the received source level is seen, as well as clear peaks at the CPAs.

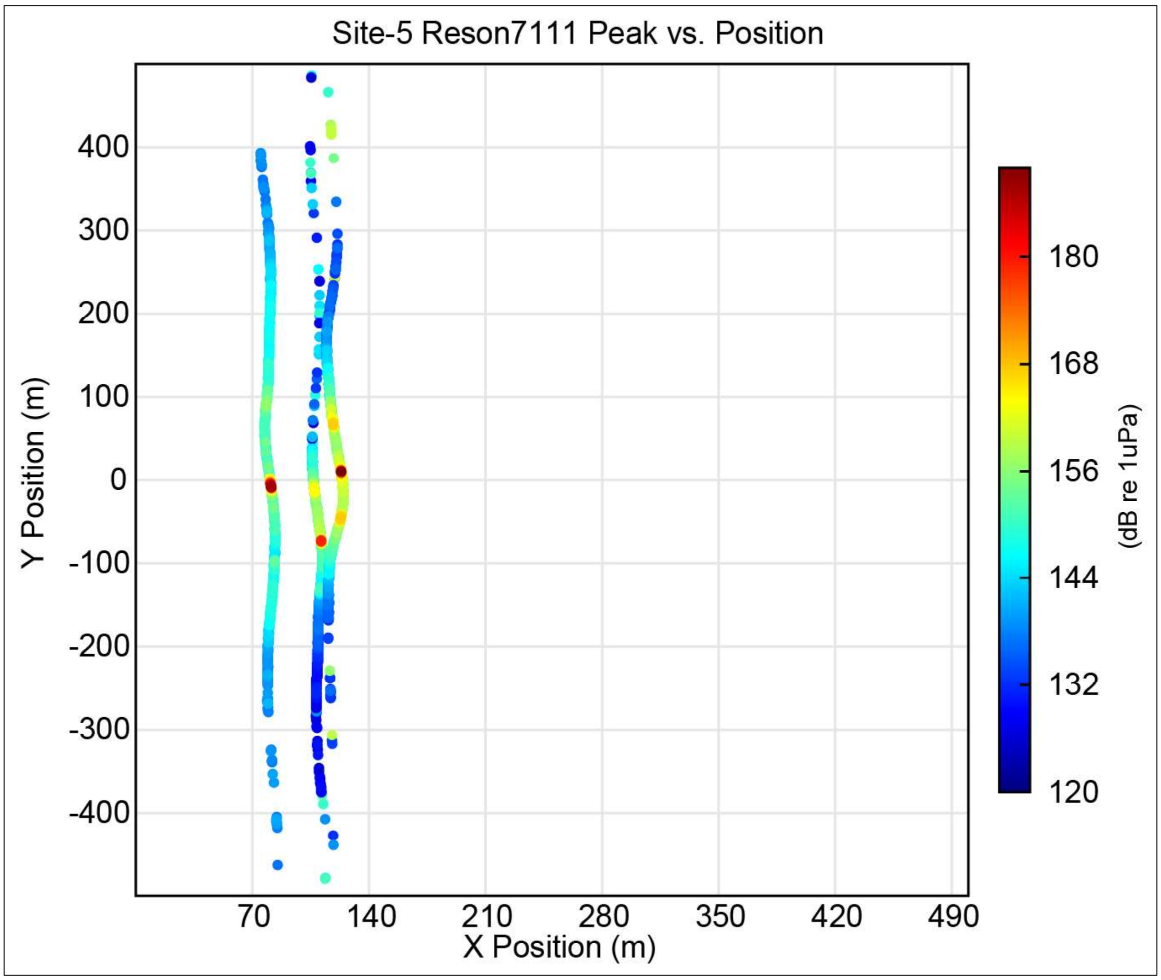


Figure 4.4.5-3. Plan view of received peak level for Reson 7111 at Site 5 for positions D (Buoy6), B (Buoy11), and A (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.4.5-1**. The estimated source levels from the measurements were calculated using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.4.5-1. Reson 7111 source levels, Mode 2, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Reson 7111 Mode 2	100 kHz	200 dB	0.17 ms	3°	197	189	169
NUWC	100 kHz	200 dB	0.17 ms	3°	196	190	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

This Page Left Intentionally Blank

4.5 Klein 3000, 132 kHz, 50-µs Pulse, 400-ms Ping Rate, 400-m Range (Mode 1)

The Klein 3000 multibeam side-scan sonar generates a single high frequency (HF) signal with a peak frequency of 132 kHz. The operational parameter settings for Mode 1 were a 50-µs pulse, 400-ms ping rate, and 400-m range. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.5-1** marks the selected frequency band (85 to 150 kHz) and SPL_{pk} (188 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.5-1. Bandpass determination for the Klein 3000 multibeam side-scan sonar, 132 kHz, 50-µs pulse, 400-ms ping rate, and 400-m range at Site 2, Run14.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
50-150	188.58
85-150	**188.20**
100-140	184.74

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported below from only one site for simplicity. The Klein 3000, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.5-1**.

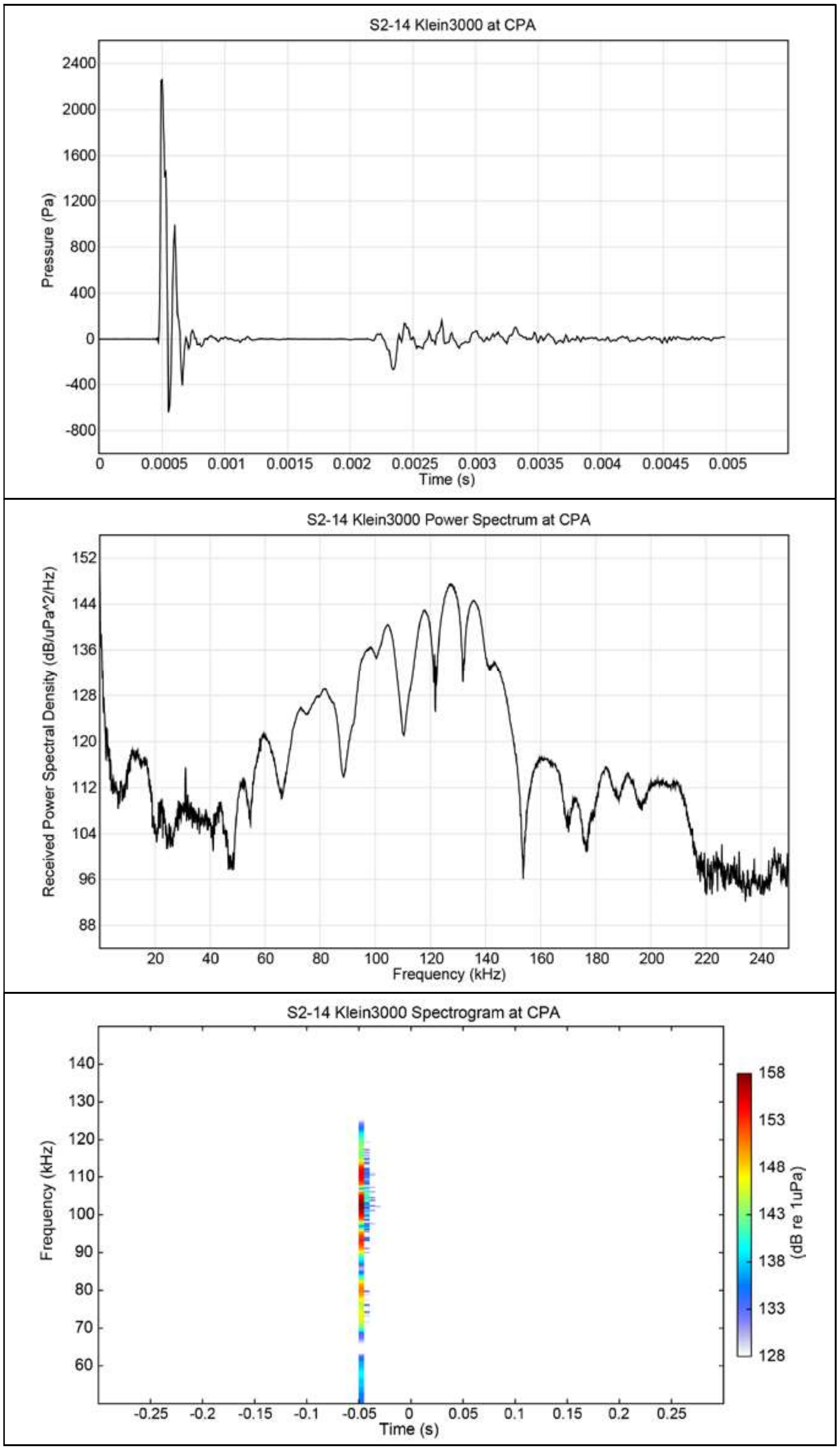


Figure 4.5-1. Klein 3000 measured signal characteristics at closest point of approach (CPA) at Site 2, Run14.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.5.1 Site 1 – Mud, 10 m Depth

At S1, the Klein 3000, Mode 1, had valid acoustic recordings in Run8 at positions D (Buoy6) and E (Buoy5 and Buoy8). However, the signal, due to its high frequency, was only observed at position D. Position F (Buoy9) was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the three available recordings of the Klein 3000, Mode 1, are shown in **Figure 4.5.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run8, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 132 kHz, the propagation loss was very high and the signal was only observable for a total of 2 minutes (60 seconds before and 60 seconds after the CPA).The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.5.1-2**) show the acoustic metrics versus range and bearing for position D (Buoy6) with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the Klein 3000 at S1, only position D (Buoy6) had any acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 120 m. The two visible blue tracks (for position D) signify the approach and departure of the source to and from the buoy. The difference could be azimuthal dependence of the towed source, the source yaw or error in the buoy position relative to the reconstruction of the buoy positioning. The source layback was included in the position computations, but the buoy position was interpolated between the deployment and recovery positions. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes a reference curve: spherical spreading [20 $\log_{10}$ (*range*)], which predicts received levels for a 225 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.5.1-2**), which shows the received peak level at 120°. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

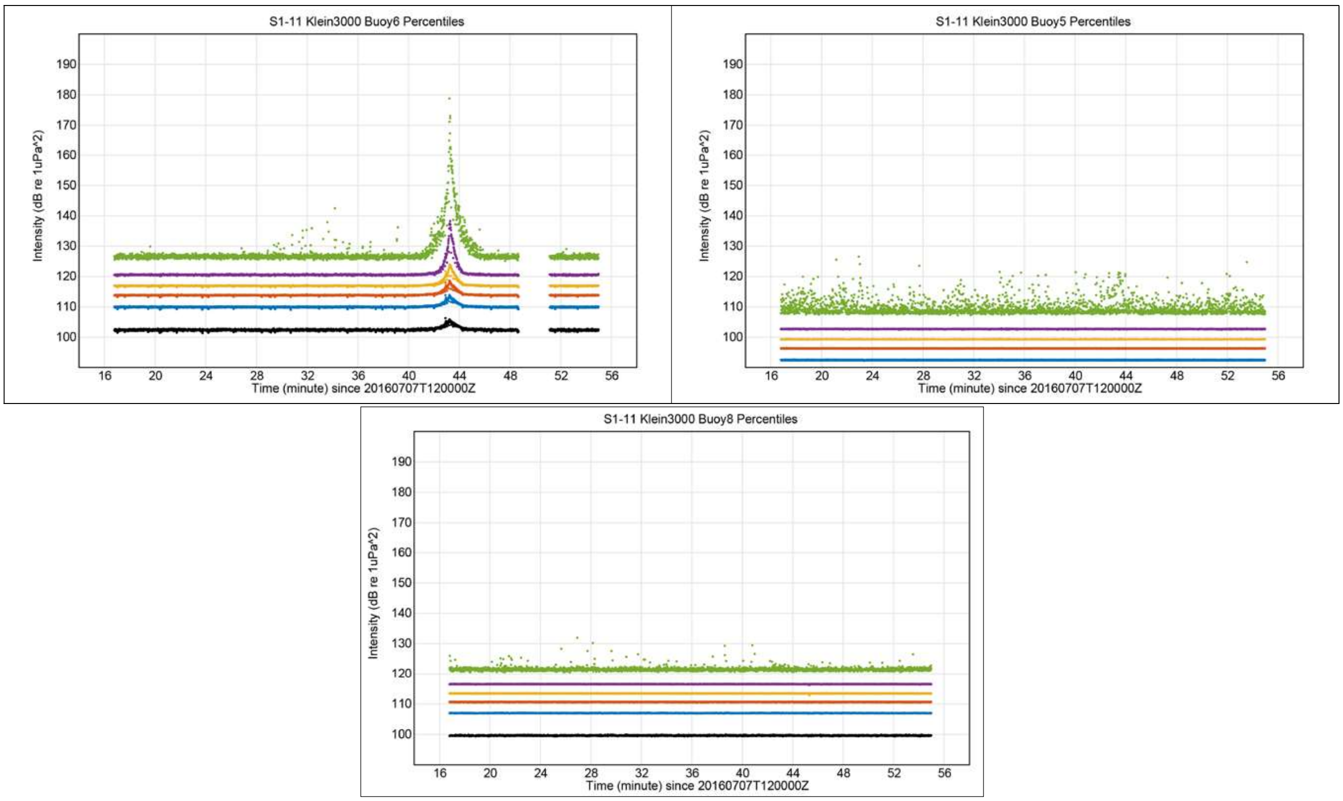


Figure 4.5.1-1. Percentile plots of Klein 3000 signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: Peak pressure arrival at position E (Buoy5); Bottom: Peak pressure arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

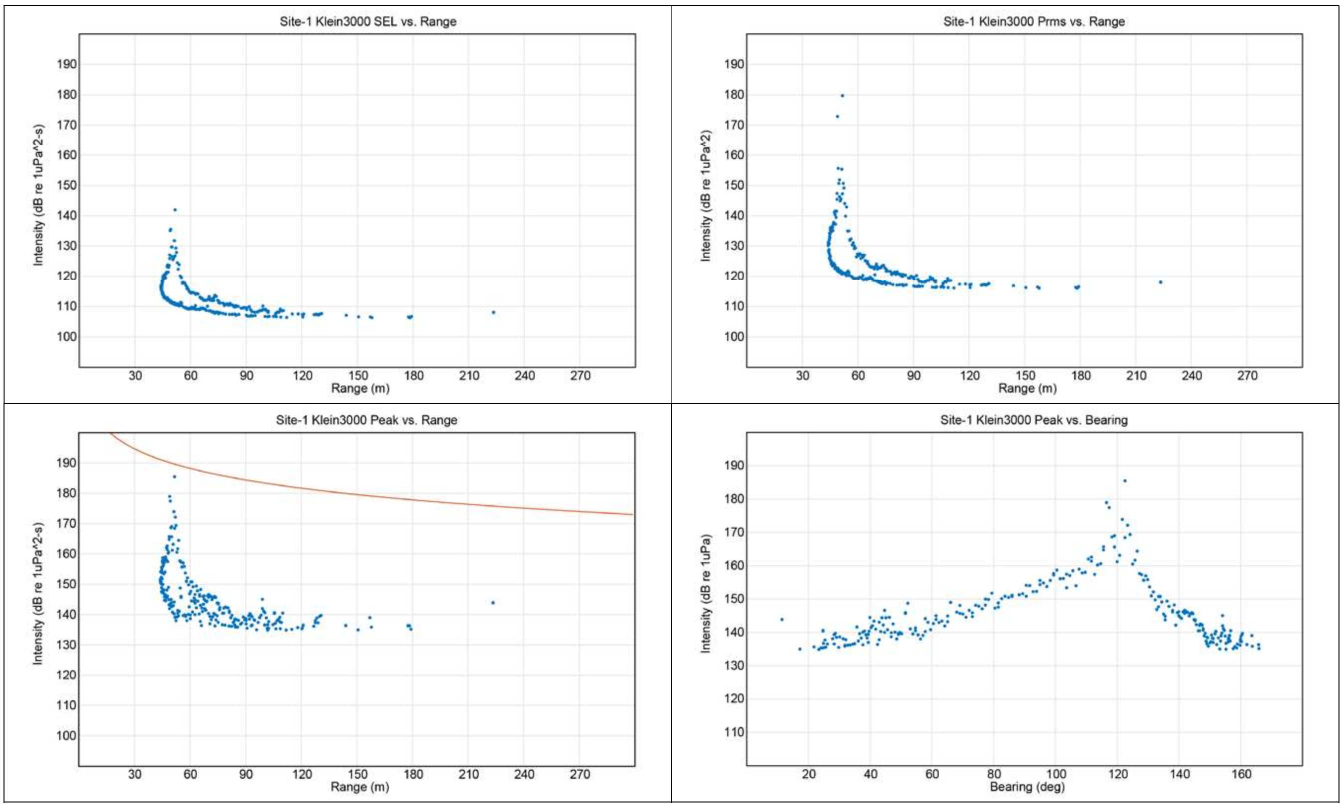


Figure 4.5.1-2. Range results for Klein 3000 signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position, D = blue.

The plan view is shown in **Figure 4.5.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen at approximately -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position D (Buoy6). Recordings at the buoy had strong acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen on the y-axis at approximately -30 m.

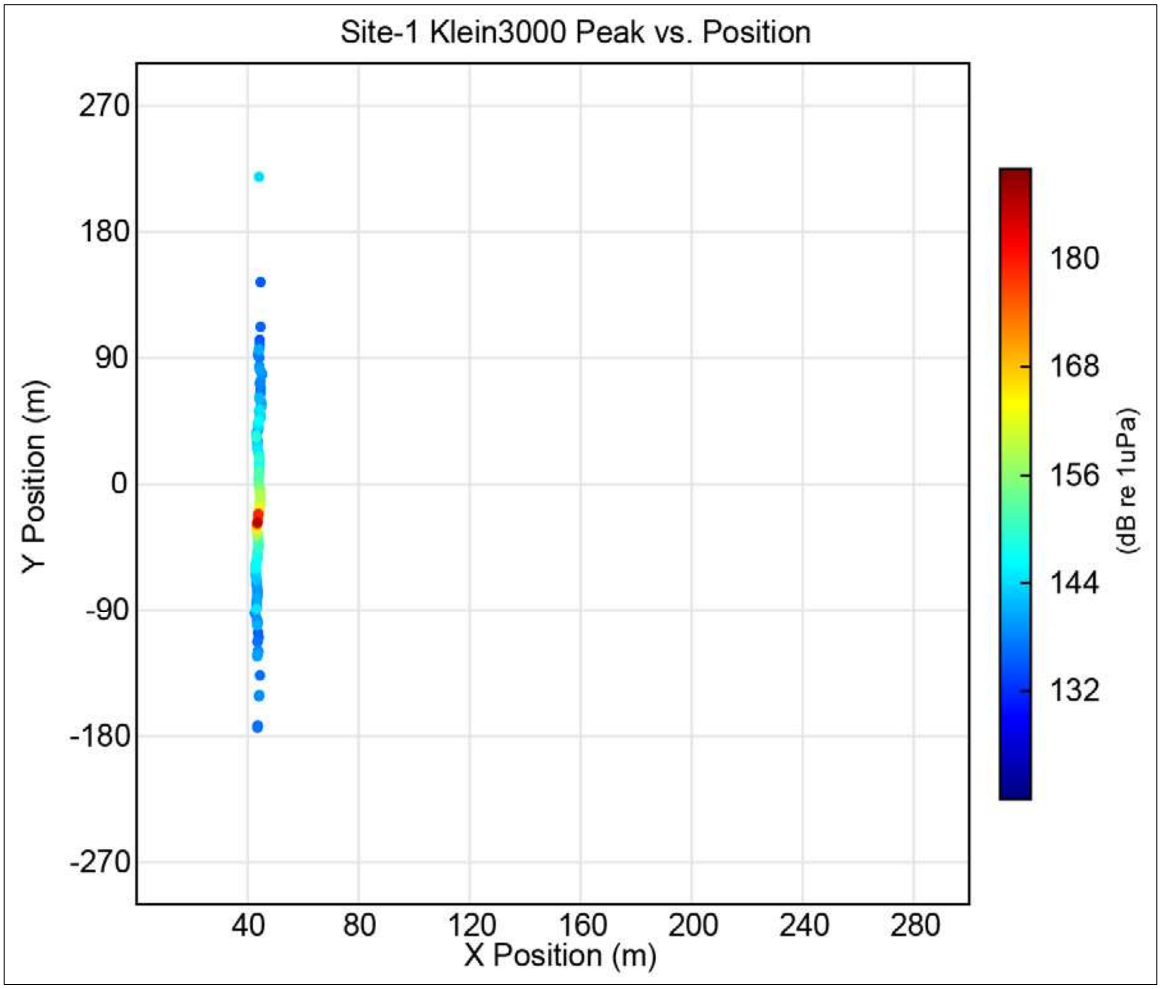


Figure 4.5.1-3. Plan view of received peak level for Klein 3000 at Site 1, showing the results for position D (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.5.1-1.** The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.5.1-1. Klein 3000 source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Klein 3000 Mode 1	132 kHz	NA	50 µs	400-m range	220	214	176
NUWC	132 kHz	NA	50 µs	400-m range	225	220	176

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; µs = microsecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.5.2 Site 2 – Sand, 10 m Depth

At S2, the Klein 3000, Mode 1, had valid acoustic recordings in Run14 and Run40. For Run14, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run40, only position B (Buoy11 and Buoy5) had valid acoustic recordings. For all Runs, positions E (Buoy10) and F (Buoy9) were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Klein 3000, Mode 1, are shown in **Figure 4.5.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run14, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 132 kHz, the propagation loss was very high, and the signal was only observable for a maximum of 2 minutes (60 seconds before and 60 seconds after the CPA). The top right and bottom panels show the recorded acoustics at positions B (Buoy11), B (Buoy11), and B (Buoy5), respectively. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good.

The results panels (**Figure 4.5.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Klein 3000 at S2, positions D (Buoy6) and B (Buoy5 and Buoy11, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 40 to approximately 320 m. For each position, the conical shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 225 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel of **Figure 4.5.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 135°, indicating an error in the buoy positioning. For position B, the received peak level is at approximately 95°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern.

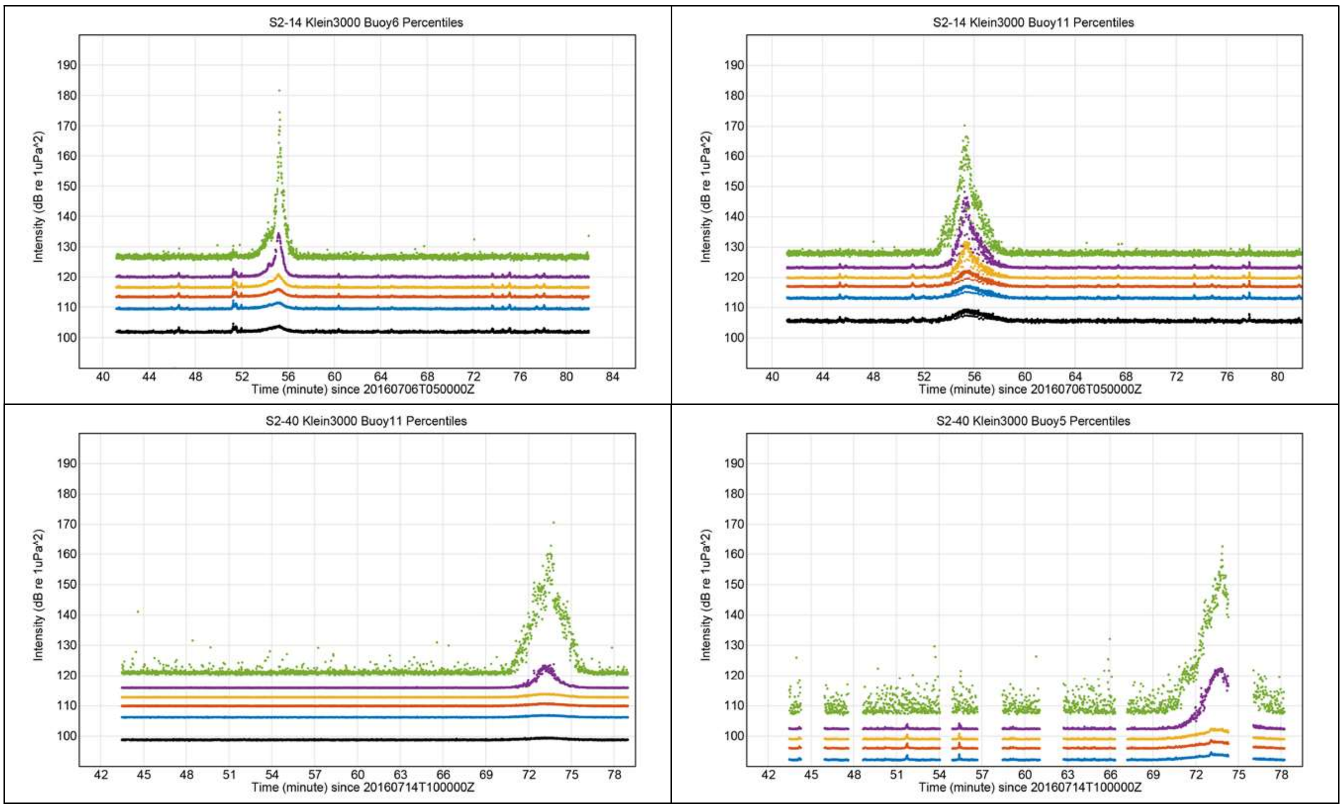


Figure 4.5.2-1. Percentile plots of Klein 3000 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

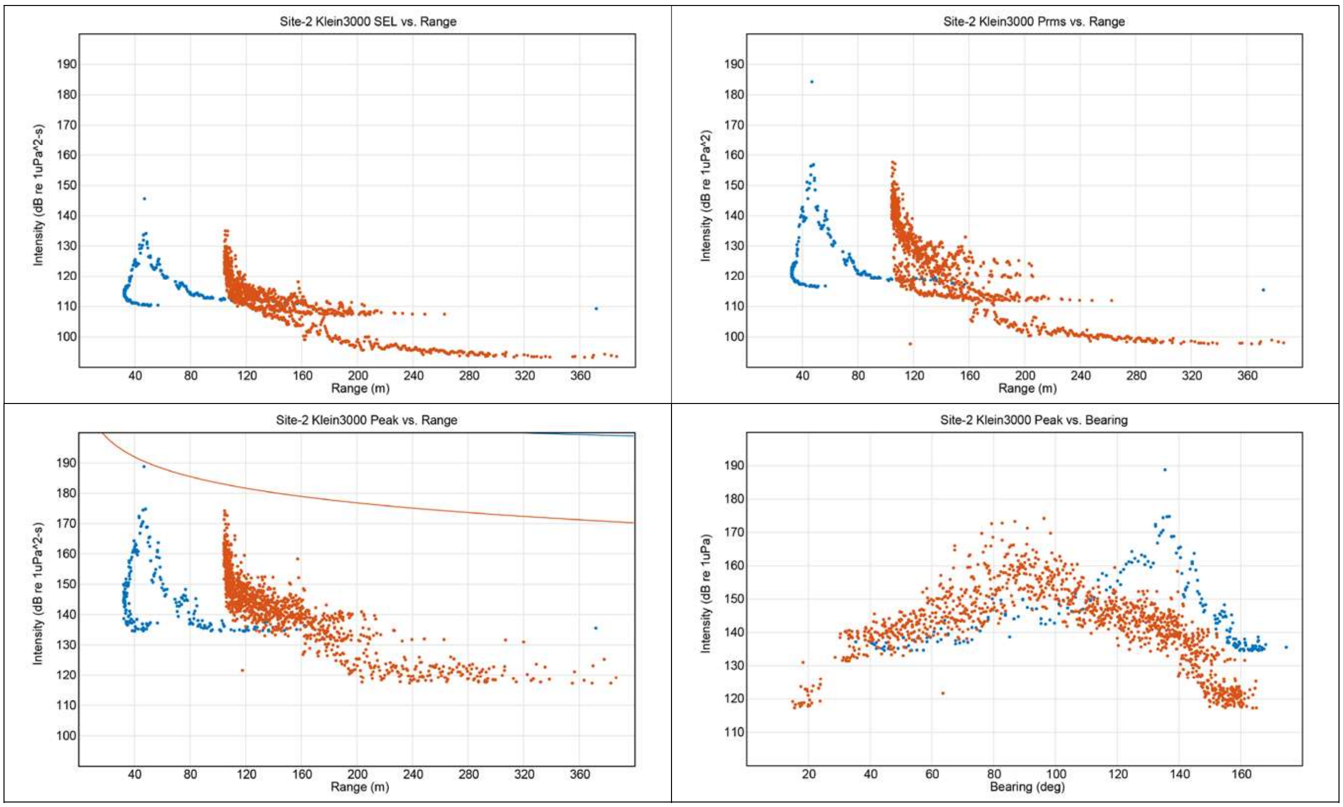


Figure 4.5.2-2. Range results for Klein 3000 signals at Site 2 for positions D (Buoy6) and B (Buoy5 and Buoy11, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.5.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -350 to 350-m marks on the y-axis. The CPA is at 50,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5 and Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen on the y-axis at approximately -30 m, while position B high amplitudes are seen at approximately 0 m.

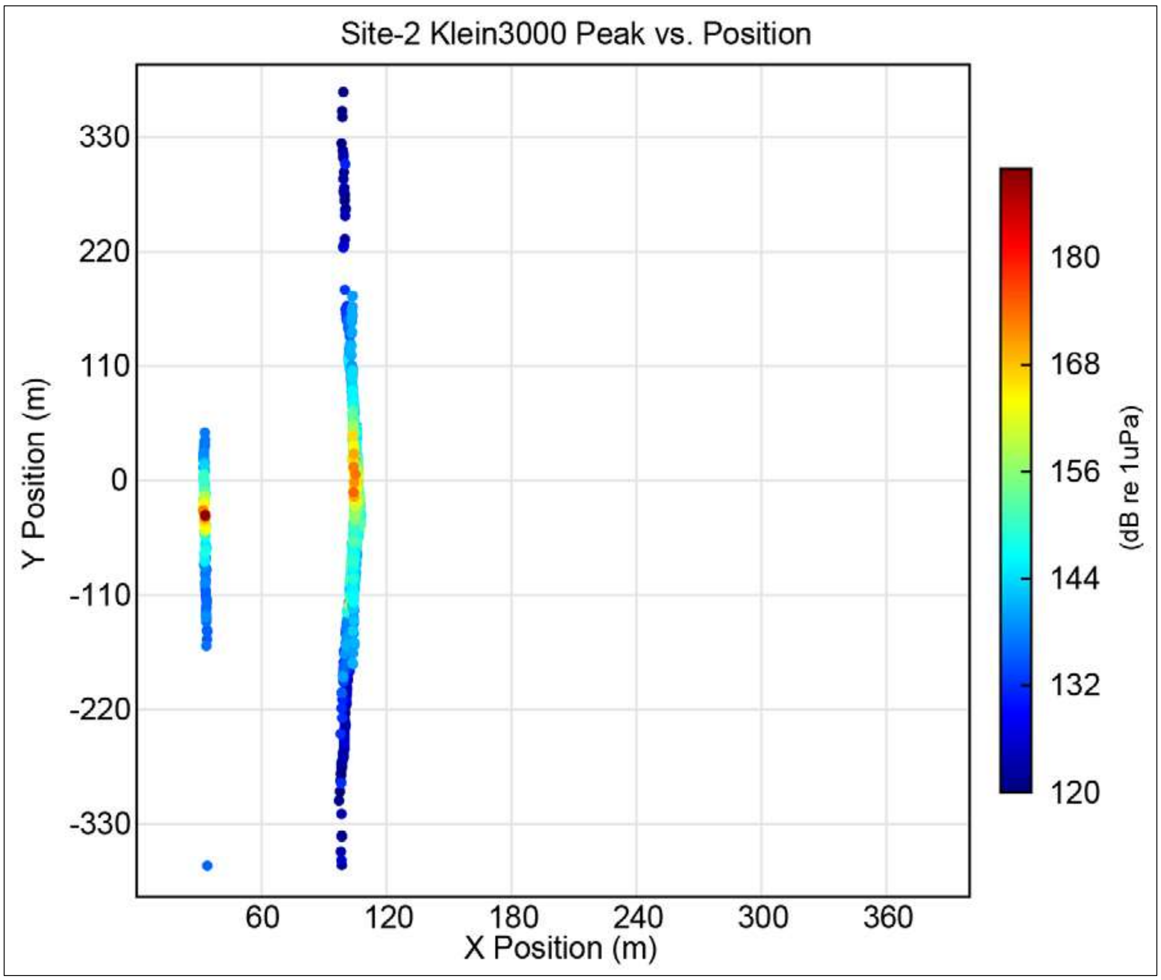


Figure 4.5.2-3. Plan view of received peak level for Klein 3000 at Site 2, showing the results for positions D (Buoy6) and B (Buoy5 and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.5.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.5.2-1. Klein 3000 source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Klein 3000 Mode 1	132 kHz	NA	50 µs	400-m range	223	217	180
NUWC	132 kHz	NA	50 µs	400-m range	225	220	176

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; µs = microsecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.5.3 Site 3 – Mud, 30 m Depth

At S3, the Klein 3000, Mode 1, had valid acoustic recordings in Run18 and Run36. For Run18, positions B (Buoy12), A (Buoy5), and F (Buoy6) had valid acoustic data and observed signals. For Run36, positions D (Buoy6), B (Buoy11), and A (Buoy12) had valid acoustic data and observed signals.

Run Summary

The percentile plots for the available recordings of the Klein 3000, Mode 1, are shown in **Figure 4.5.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run36, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 132 kHz, propagation loss was very high, and the signal was observable for a maximum of 4 minutes (120 seconds before and 120 seconds after the CPA).

In **Figure 4.5.3-1**, buoys with the cleanest signal arrival are plotted. The top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and F (Buoy6). Note there is replication of buoy representation because of the multiple deployments. Position F acoustic signals were accompanied by noise; therefore, it was not included in the results graphs. The bottom right panel contains some random noise peaks around 150 dB (floating green dots), which remained through the acoustic processing and are plotted in the results panels.

The results panels (**Figure 4.5.3-2**) show the acoustic metrics versus range/bearing for six buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the Klein 3000 at S3, only positions D (Buoy6), A (Buoy5 and Buoy12, combined) and B (Buoy11 and Buoy12, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 320 m. For each position, the conical shape of the data points signifies the approach and departure of the source to and from the buoys. Position A (Buoy5) had valid acoustic signals accompanied by noise; therefore, it was not included in the graphs as there were other good receptions versus range for this site. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a

225 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 120°, indicating an error in buoy positioning and for positions A and B at approximately 80°, indicating relatively good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver.

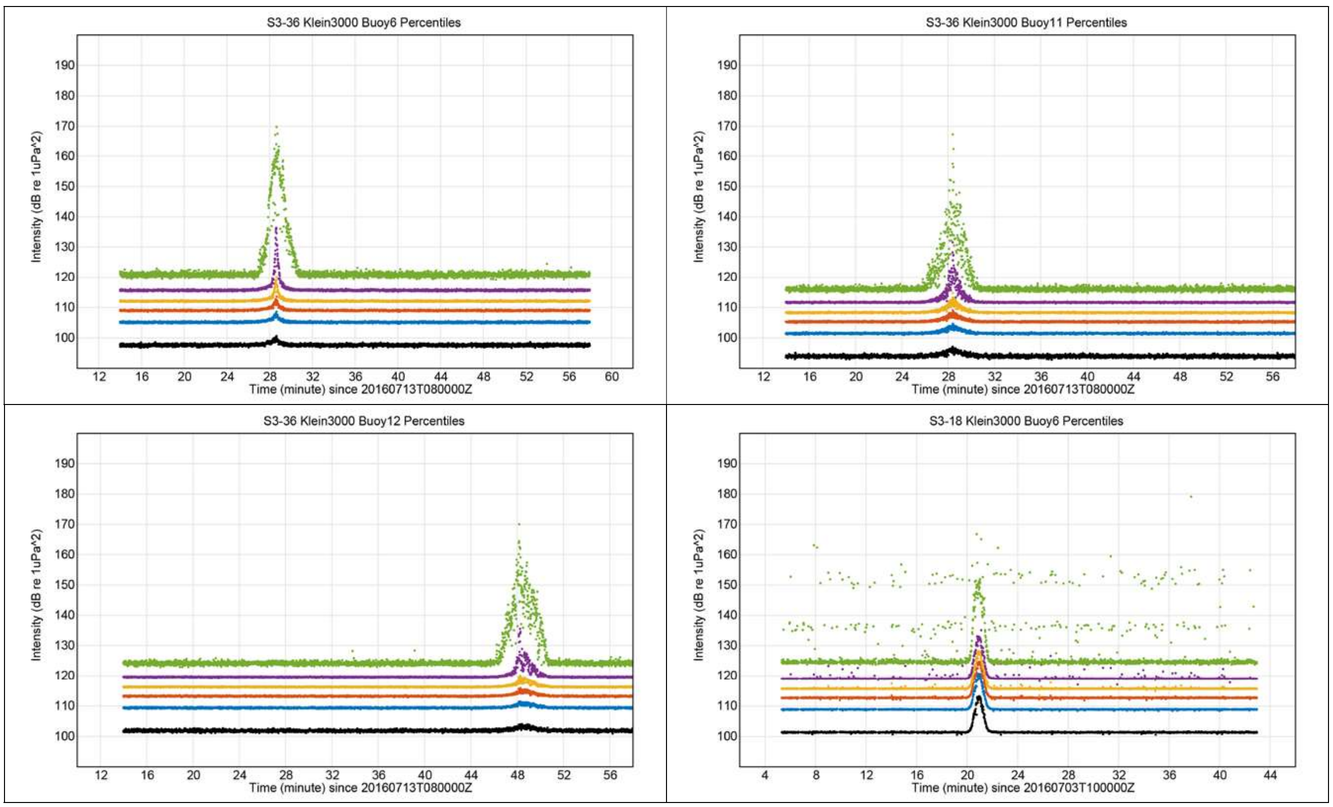


Figure 4.5.3-1. Percentile plots of Klein 3000 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position F (Buoy6). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

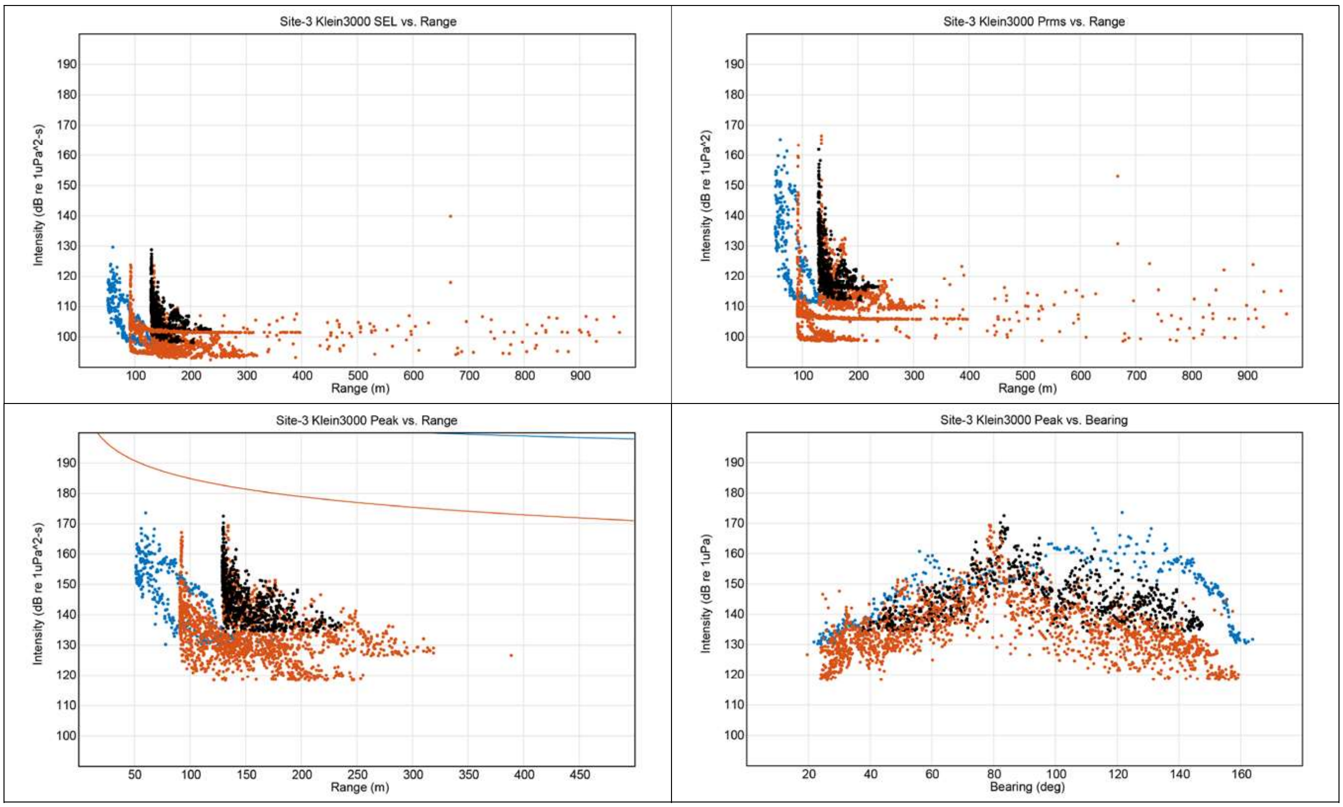


Figure 4.5.3-2. Range results for Klein 3000 combined signals at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy12, combined), and A (Buoy 5 and Buoy12, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue.

The plan view is shown in **Figure 4.5.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 50,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -150 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 and Buoy12), and A (Buoy5 and Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The combination of range and bearing dependence (due to source directionality) is evident, shown in position D's narrow y-axis duration (±100 m) relative to the positions farther from the source (±300 m). The highest amplitude signal for all positions are seen on the y-axis at approximately 0 m.

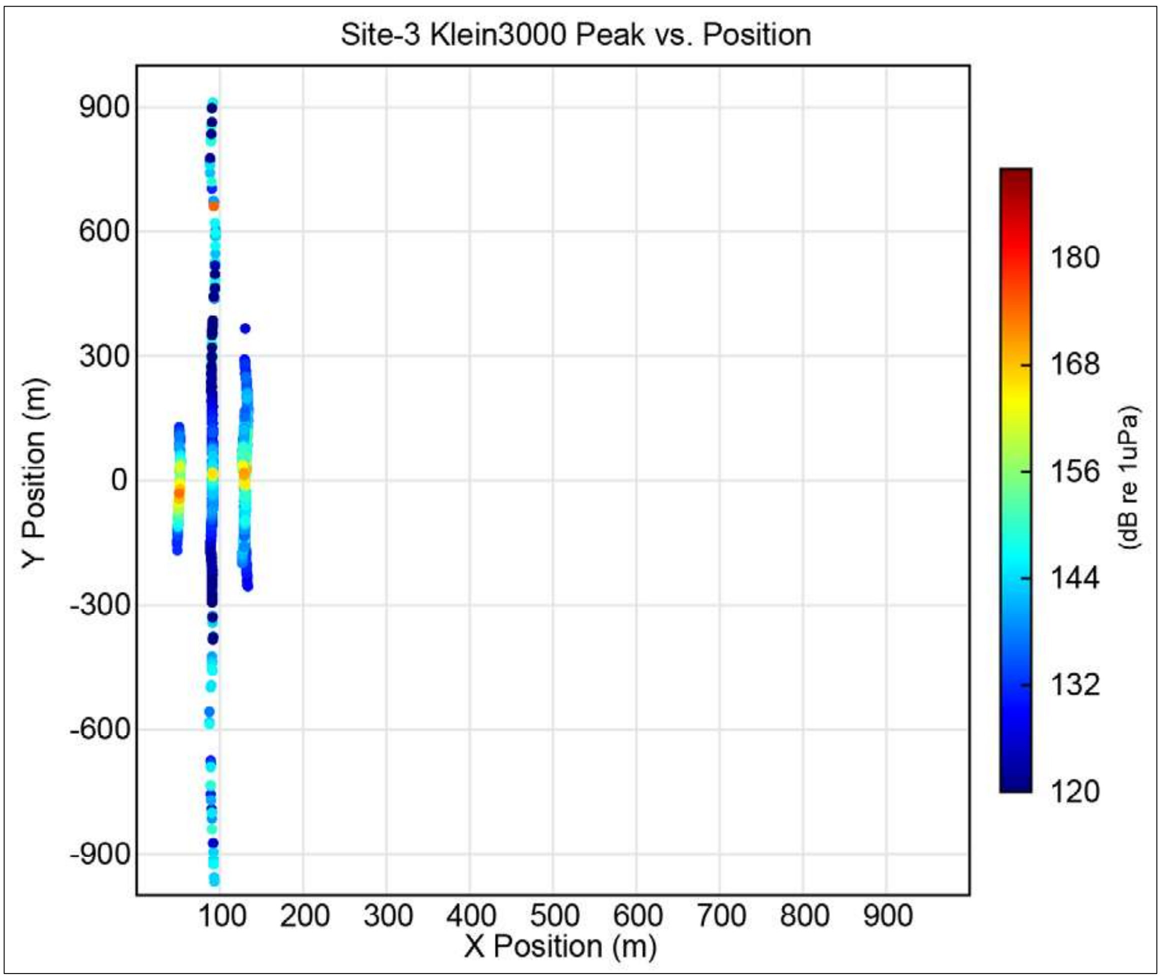


Figure 4.5.3-3. Plan view of received peak level for Klein 3000 at Site 3, showing the results for positions D (Buoy6), B (Buoy11 and Buoy12), and A (Buoy 5 and Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.5.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.5.3-1. Klein 3000 source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Cycles, Pulse Width	Beam width, Range	Pk	rms	SEL
Klein 3000 Mode 1	132 kHz	NA	50 µs	400-m range	210	200	166
NUWC	132 kHz	NA	50 µs	400-m range	225	220	176

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; µs = microsecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.5.4 Site 4 – Sand, 30 m Depth

The Klein 3000, Mode 1, was deployed at S4, Run19; however, none of the acoustic recorders collected data during the Klein 3000's operation.

4.5.5 Site 5 – Sandy-Silt, 100 m Depth

The Klein 3000, Mode 1, was not deployed or operated at S5.

4.6 Klein 3000, 132 kHz, 200-µs Pulse, 400-ms Ping Rate, 200-m Range (Mode 2)

The Klein 3000 multibeam side-scan sonar generates a single high frequency (HF) signal with a peak frequency of 132 kHz. The operational parameter settings for Mode 2 were a 200-µs pulse, 400-ms ping rate, and 200-m range. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.6-1** marks the selected frequency band (85 to 150 kHz) and SPL_{pk} (180 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.6-1. Bandpass determination for the Klein 3000 multibeam side-scan sonar, 132 kHz, 200-µs pulse, 400-ms ping rate, and 200-m range at Site 2, Run15.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
50-240	180.28
50-150	179.59
85-150	**179.58**
100-140	179.05

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported below from only one site for simplicity. The Klein 3000, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.6-1**.

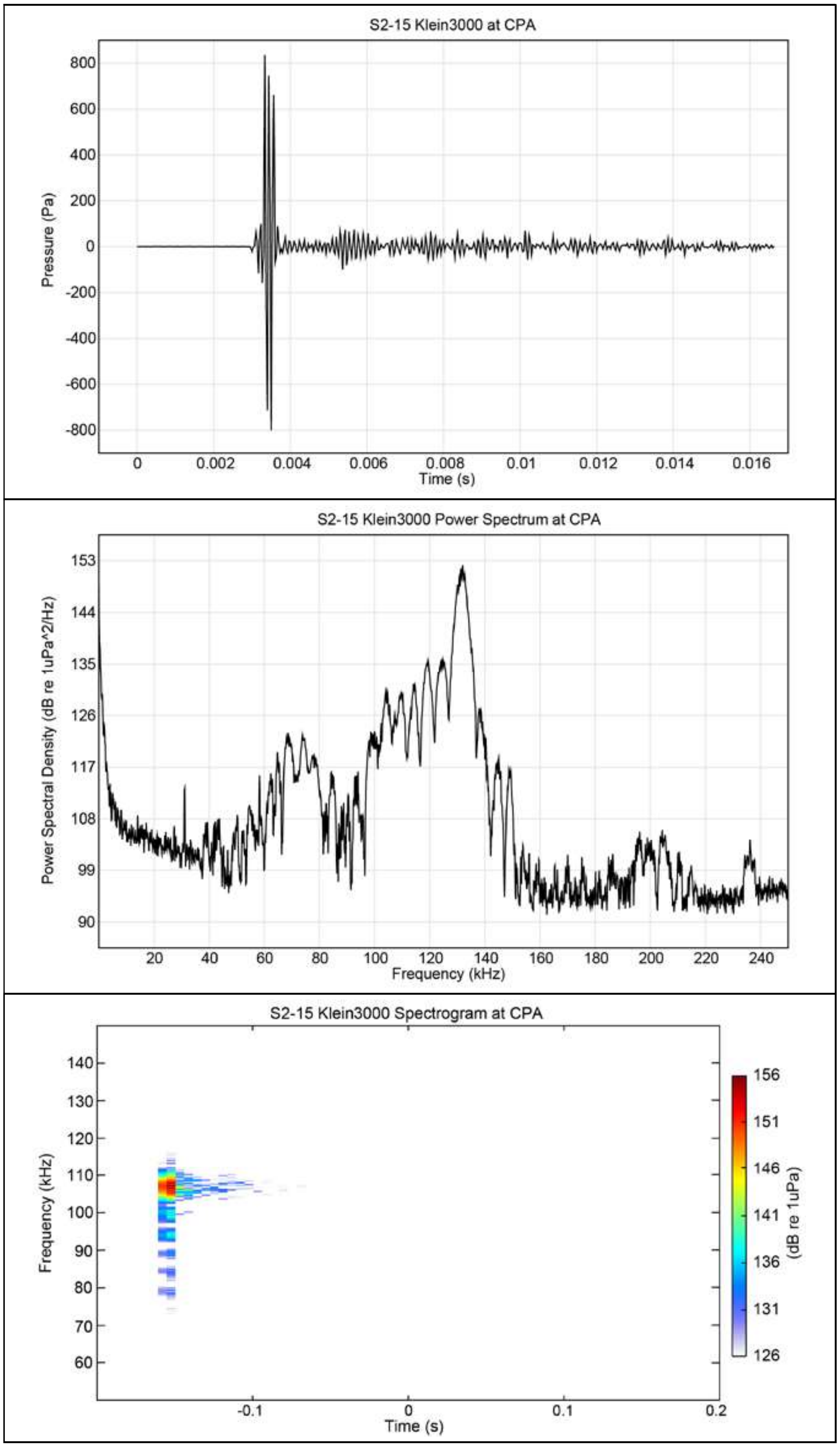


Figure 4.6-1. Klein 3000 measured signal characteristics at closest point of approach (CPA) at Site 2, Run15.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.6.1 Site 1 – Mud, 10 m Depth

At S1, the Klein 3000, Mode 2, had valid acoustic recordings in Run12, at position D (Buoy6). Positions E (Buoy5 and Buoy8) and F (Buoy9) were too distant to capture the HF acoustic signal for this weaker source relative to Mode 1. This source was much weaker than many of the other tested HRG sources, which raises concern as to the actual operational sound level output during testing and if the Klein 3000 was producing the expected 225 dB re 1 μPa SPL_{pk} per NUWC report (Crocker and Fratantonio, 2016).

Run Summary

The percentile plots for the three available recordings of the Klein 3000, Mode 2, are shown in **Figure 4.6.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run12, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustic signals at position E (Buoy5 and Buoy8); however, the signal is weak and barely visible, and therefore it was removed from further analysis. The 25-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.6.1-2**) show the acoustic metrics versus range and bearing for position D (Buoy6) with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the Klein 3000 at S1, only position D (Buoy6) had any acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 90 m. For each position, the conical shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes a reference curve: spherical spreading [20 $\log_{10}$ (*range*)], which predicts received levels for a 225 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.6.1-2**), which shows a received peak level at approximately 70°. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern.

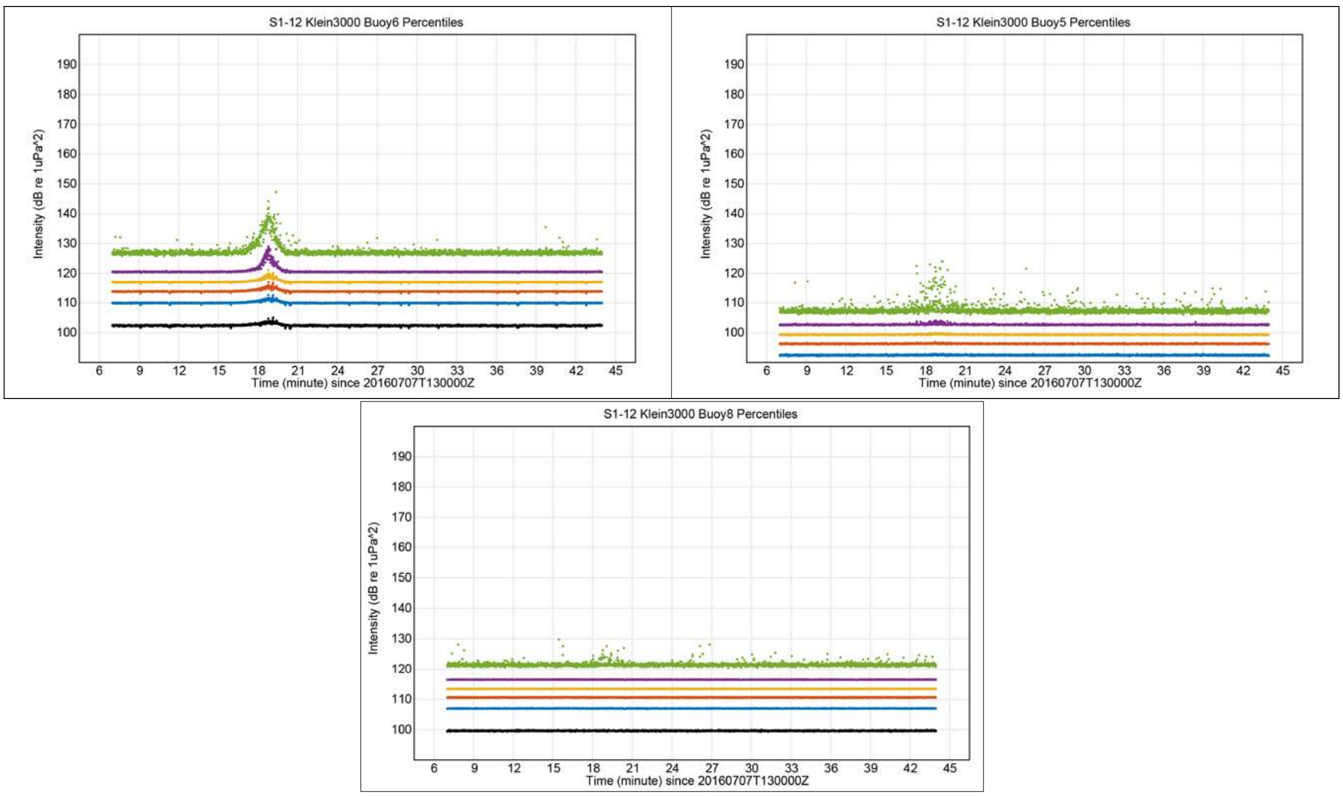


Figure 4.6.1-1. Percentile plots of Klein 3000 signals at Site 1.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

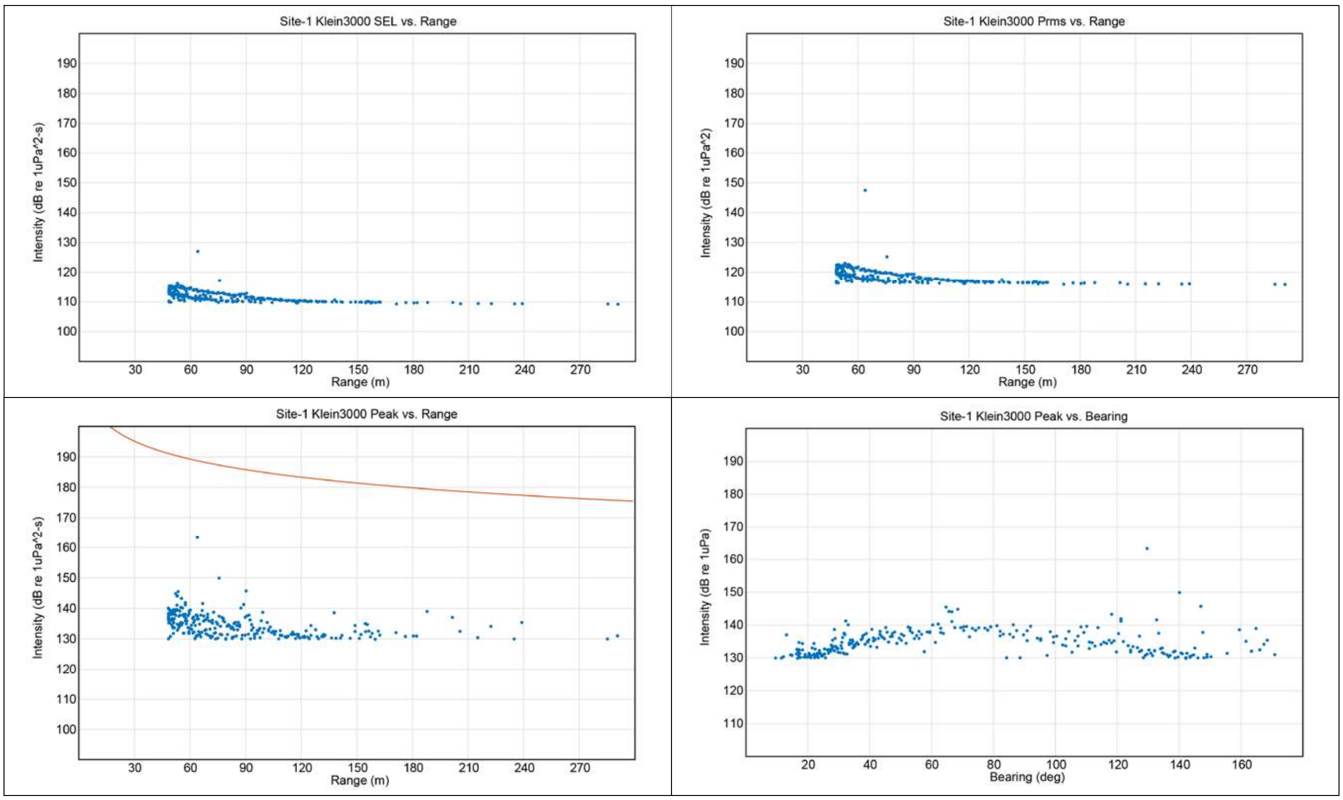


Figure 4.6.1-2. Range results for Klein 3000 signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position, D = blue.

The plan view is shown in **Figure 4.6.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,-45 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -270 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position D (Buoy6), however some of the pings may be noise. Recordings at the buoy had strong acoustic peak amplitudes, which were presumed to be at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen on the y-axis at approximately -45 m.

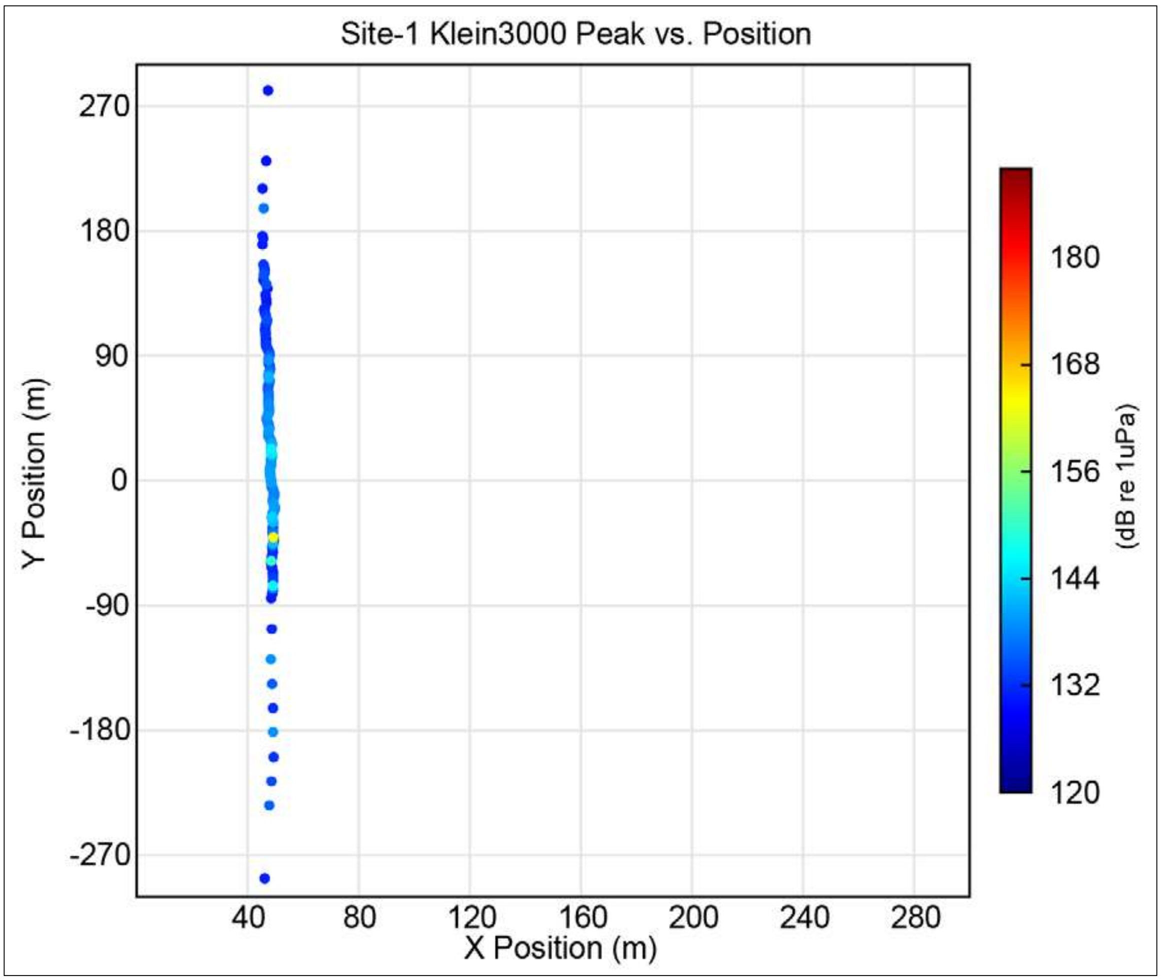


Figure 4.6.1-3. Plan view of received peak level for Klein 3000 at Site 1, showing the results for position D (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.6.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results. The results from this site show a 20-30 dB reduced received level compared to the NUWC test results. With acoustic data from only a single buoy (position D), it was not possible to diagnose the discrepancies between the estimated levels and NUWC measured source levels. Therefore, it is recommended that this data not be used for further analysis.

Table 4.6.1-1. Klein 3000 source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Klein 3000 Mode 2	132 kHz	NA	200 µs	200-m range	200	185	165
NUWC	132 kHz	NA	200 µs	200-m range	225	220	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.6.2 Site 2 – Sand, 10 m Depth

At S2, the Klein 3000, Mode 2, had valid acoustic recordings in Run15 and Run41. For Run15, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run41, position B (Buoy5 and Buoy11) had valid acoustic recordings. For all Runs, positions E (Buoy10) and F (Buoy9) had valid acoustic data but were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Klein 3000, Mode 2, are shown in **Figure 4.6.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run15, where the received signal is observed for 2 minutes (60 seconds before and 60 seconds after the CPA). The top right and bottom panels show the recorded acoustics at position B (Buoy11) and position B (Buoy5 and Buoy11) for Run41. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The gaps in the bottom right panel are the result of intermittent data capture (i.e., loss of data).

The results panels (**Figure 4.6.2-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the Klein 3000 at S2, only positions D (Buoy6) and B (Buoy5 and Buoy11, combined) had valid acoustic signals. The received signals at position B have more energy than those received at position D, which was not expected and may be a result of the directionality of the source. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 250 m. For each position, the conical shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 225 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel of

Figure 4.6.2-2 is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 135°, indicating an error in the buoy positioning. For position B, the received peak level is at approximately 90°, which indicates good buoy positioning.

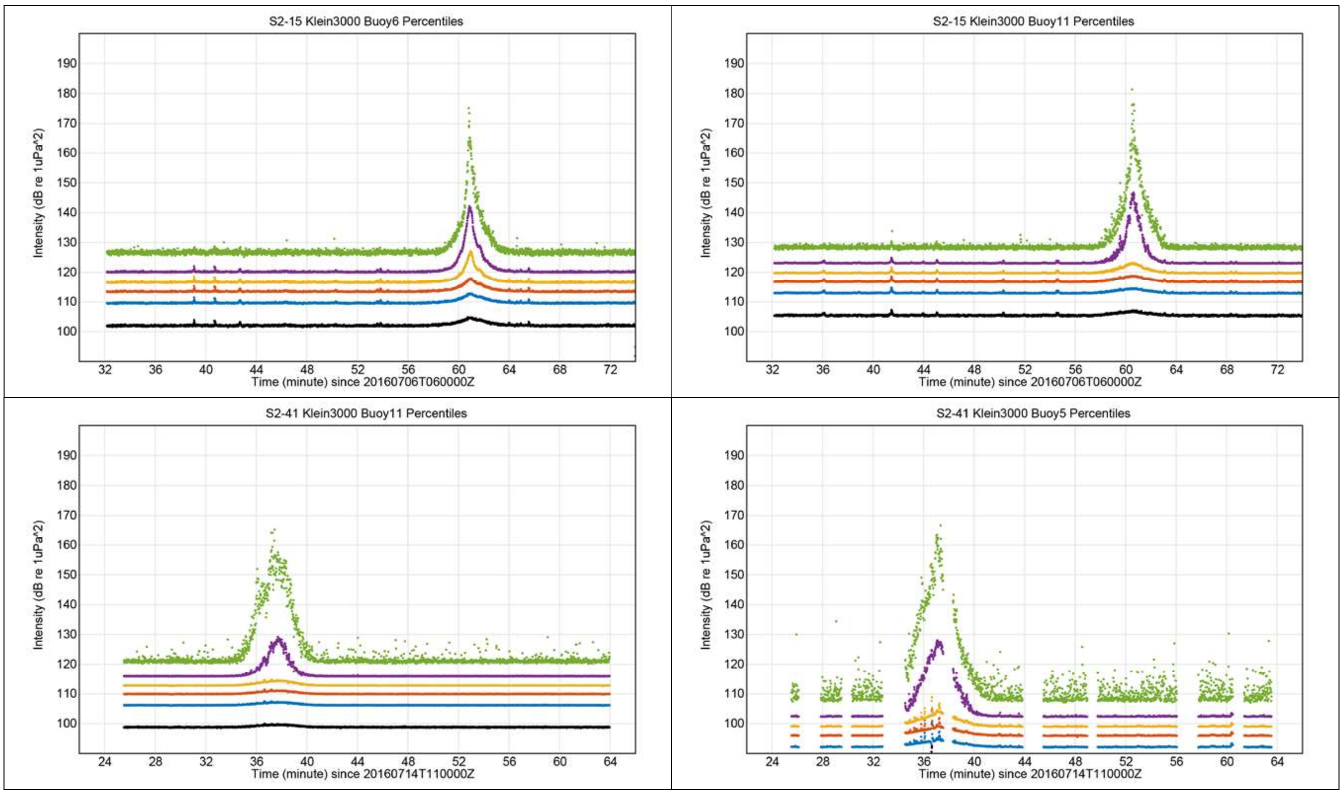


Figure 4.6.2-1. Percentile plots of Klein 3000 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

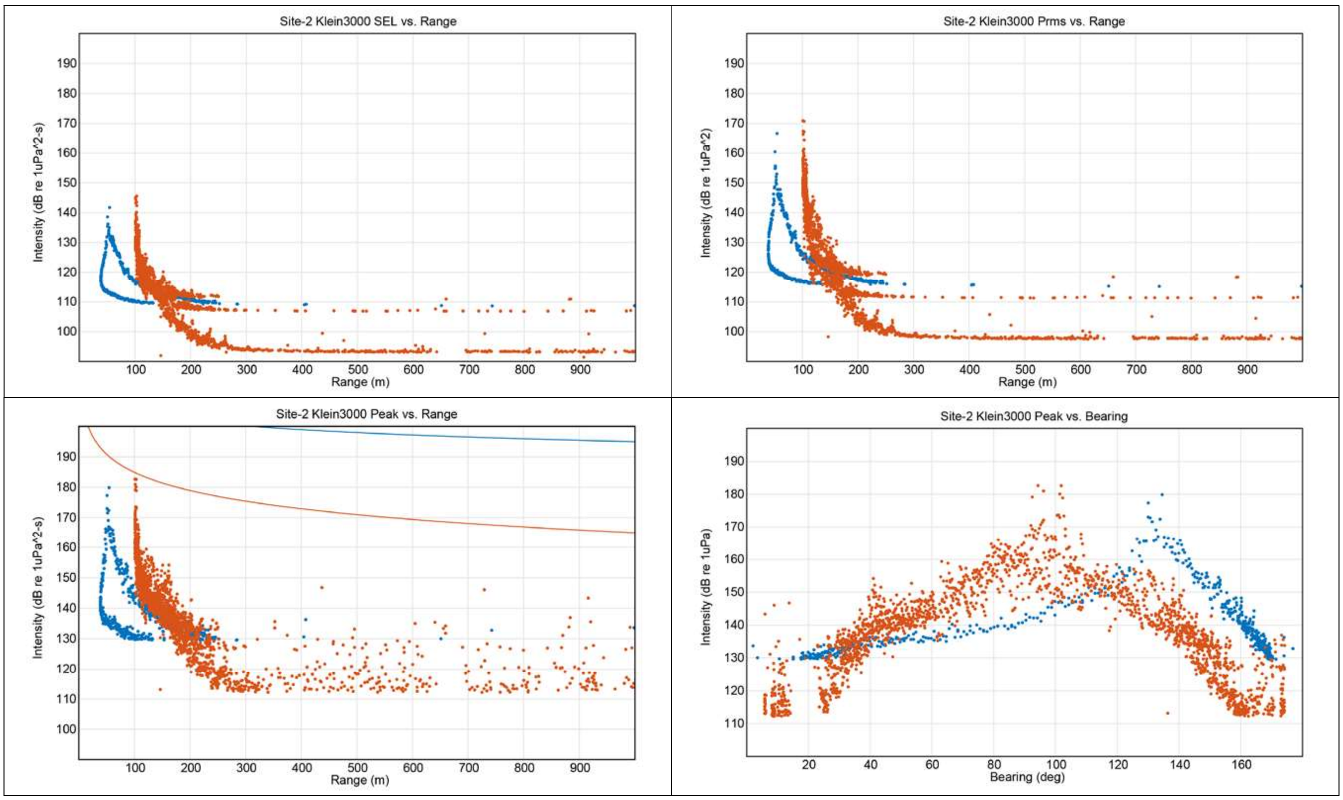


Figure 4.6.2-2. Range results for Klein 3000 signals at Site 2 for positions D (Buoy6) and B (Buoy5 and Buoy11, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.6.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 50,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -300 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5 and Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The CPA is clear as the source passes the receiver, but the observed signal is seen beyond 600 m. The highest amplitude signal for all positions are seen on the y-axis at approximately 0 m.

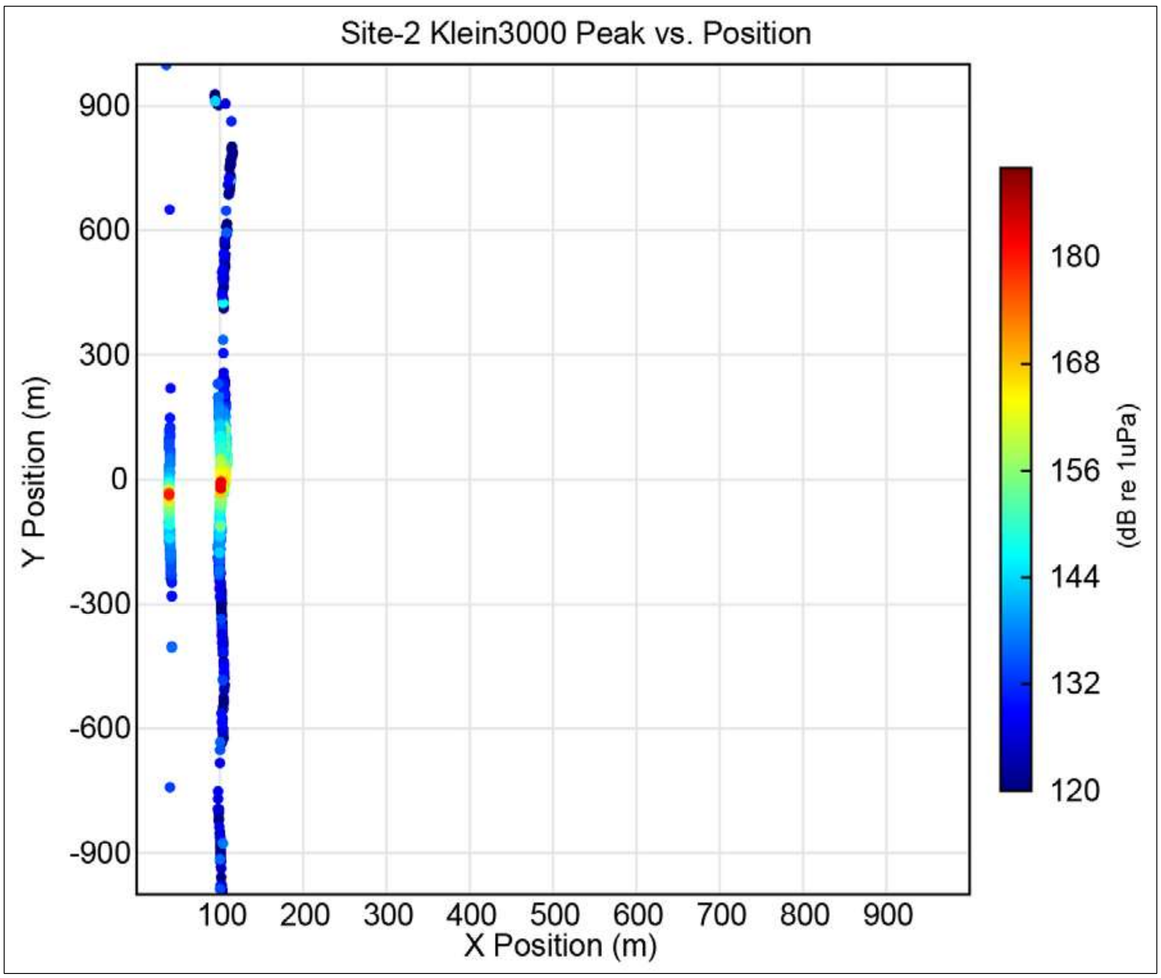


Figure 4.6.2-3. Plan view of received peak level for Klein 3000 at Site 2, showing the results for positions D (Buoy6) and B (Buoy5 and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.6.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.6.2-1. Klein 3000 source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Klein 3000 Mode 2	132 kHz	NA	200 µs	200-m range	225	215	165
NUWC	132 kHz	NA	200 µs	200-m range	225	220	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.6.3 Site 3 – Mud, 30 m Depth

At S3, the Klein 3000, Mode 2, had valid acoustic recordings in Run19 and Run37. For Run19, positions A (Buoy5) and B (Buoy12) had valid acoustic data. For Run37, positions D (Buoy6), B (Buoy11), and A (Buoy12) had valid acoustic data. For all Runs, positions F (Buoy6 and Buoy 9) and E (Buoy8 and Buoy10) had no observed signals because they were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the Klein 3000, Mode 2, are shown in **Figure 4.6.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run37, where the observed received signal is weak, but the signal influences the peak value and the smaller percentiles. For this HF signal centered on 132 kHz, the propagation loss was high and the signal was observable for 4 to 6 minutes. The top right panel shows the recorded acoustics at position B (Buoy11), and the bottom left and right panels show positions A (Buoy12) and B (Buoy12). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are good.

The results panels (**Figure 4.6.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to collected data. For the Klein 3000 at S3, positions D (Buoy6), B (Buoy11 and Buoy12, combined), and A (Buoy5 and Buoy12) had acoustic signals. There were weak acoustic signals at position F, but they are not shown because of a poor signal to noise ratio. Data from position A (Buoy5) also are not shown because it was an extremely noisy recording. The top left panel is the SEL versus range, showing received signal energy from 50 to approximately 300 m. For each position, the conical shape of the data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 225 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The SPL_{pk} plot presents the expected arrival for spherical (red) and cylindrical (blue) spreading. The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D (Buoy6) at approximately 140°, indicating an error in the buoy positioning. For position B, the received peak level is at approximately 80°, and for position A, the received peak level is at approximately 75°; both indicate errors in navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern.

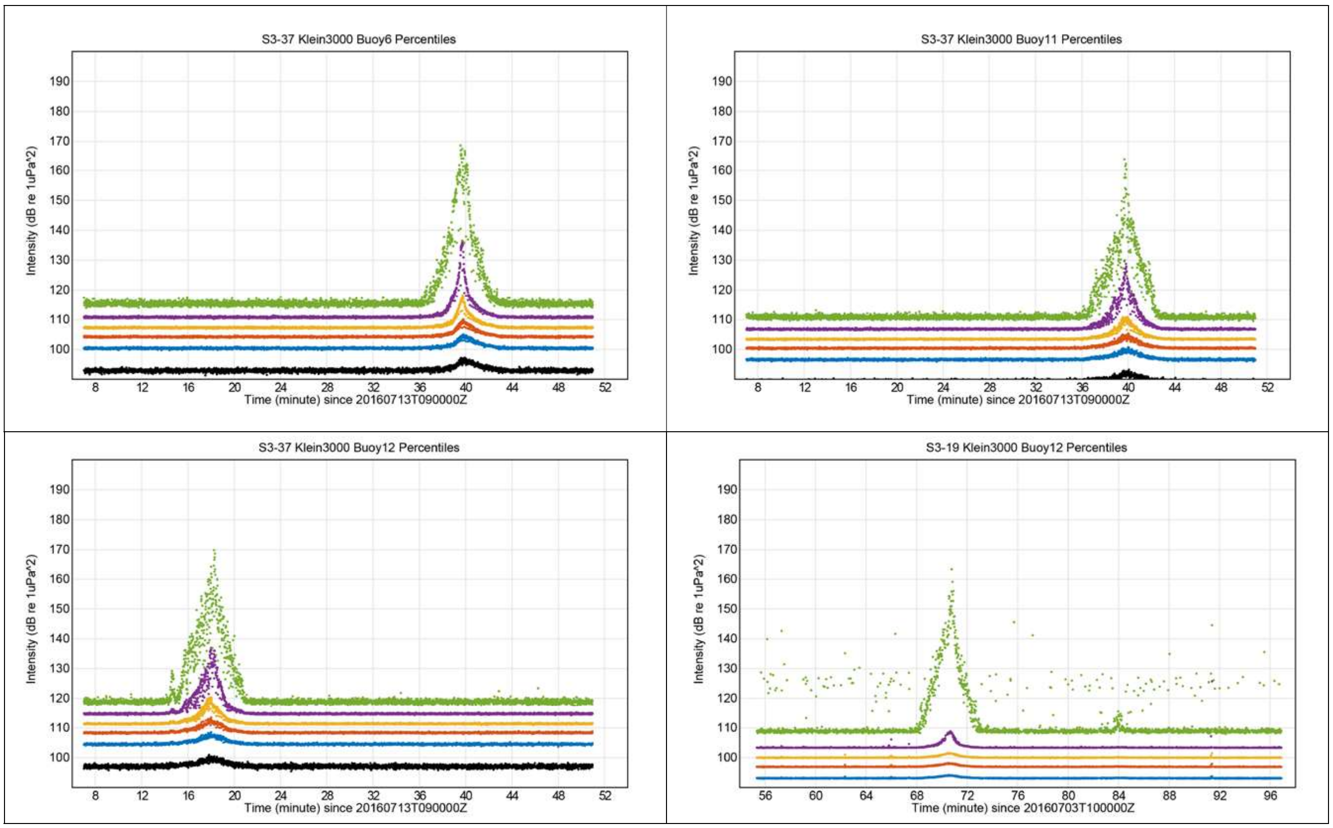


Figure 4.6.3-1. Percentile plots of Klein 3000 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position B (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

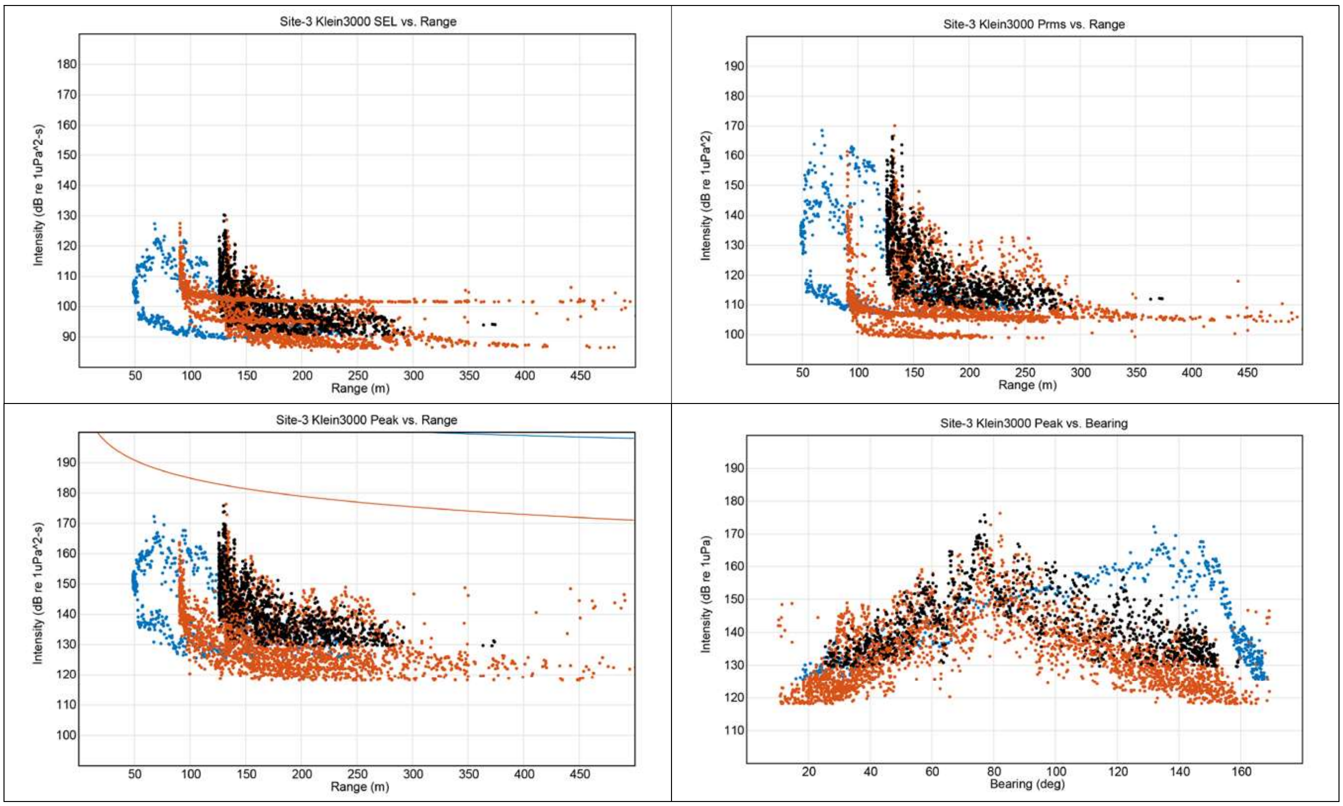


Figure 4.6.3-2. Range results for Klein 3000 combined signals for Run16 and Run34 at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy12, combined), and A (Buoy12).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue.

The plan view is shown in **Figure 4.6.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -500 to 500-m marks on the y-axis. The CPA is at 50,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 and Buoy12), and A (Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen on the y-axis at approximately -50 m, while positions A and B had high amplitudes between approximately 0 and 50 m. The CPAs from 50 to 140 m on the x-axis could be the result of buoy navigational errors.

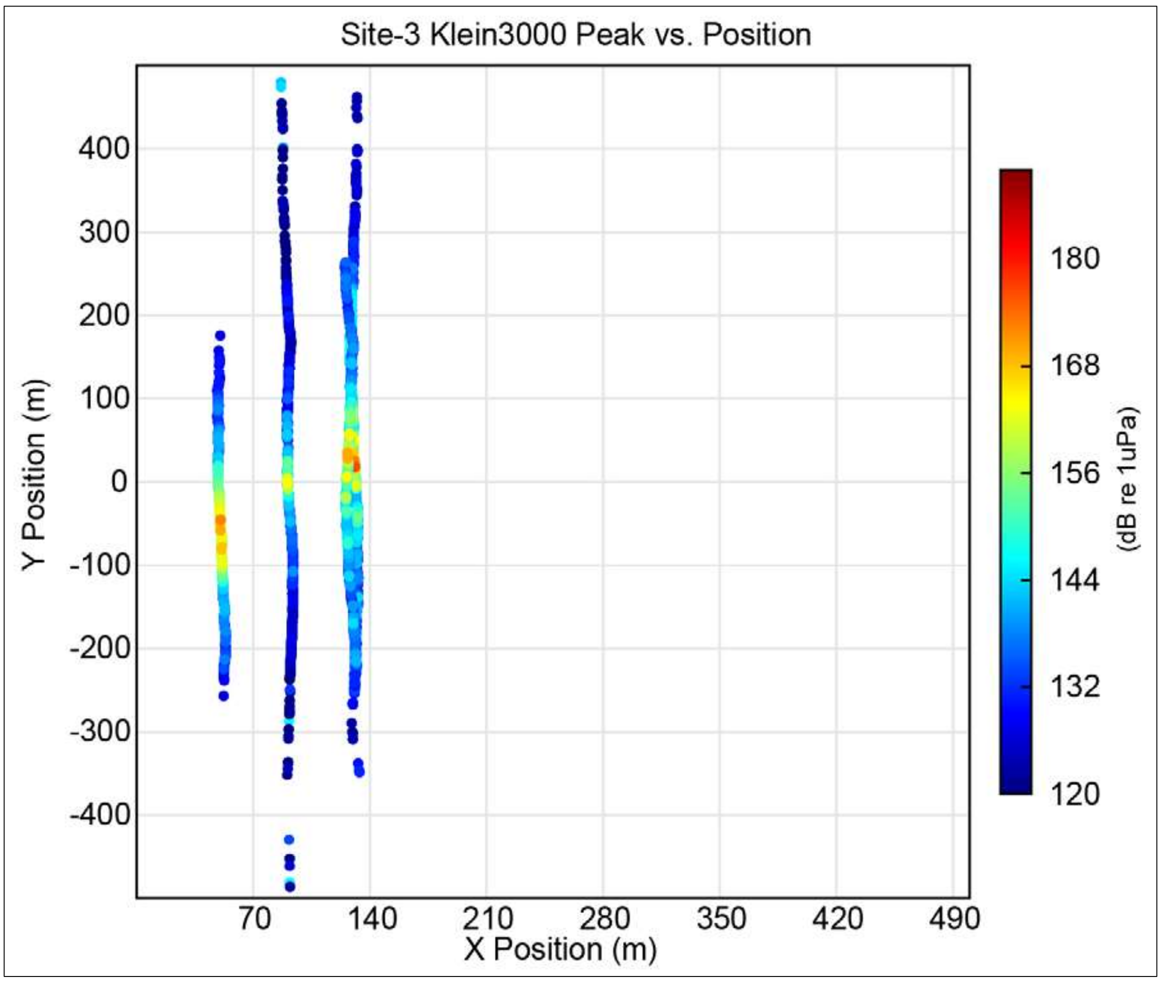


Figure 4.6.3-3. Plan view of received peak level for Klein 3000 at Site 3, showing the results for positions D (Buoy6), B (Buoy11 and Buoy12), and A (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.6.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.6.3-1. Klein 3000 source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					**Source Level (dB re 1 µPa m)**		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
Klein 3000 Mode 2	132 kHz	NA	200 µs	200-m range	218	211	172
NUWC	132 kHz	NA	200 µs	200-m range	225	220	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter;µs = microsecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.6.4 Site 4 – Sand, 30 m Depth

The Klein 3000, Mode 2, was deployed at S4, Run19; however, none of the acoustic recorders collected data during the Klein 3000's operations.

4.6.5 Site 5 – Sandy-Silt, 100 m Depth

The Klein 3000, Mode 2, was not deployed or operated at S5.

This Page Left Intentionally Blank

4.7 Edgetech 4200, 100 kHz, 500-ms Ping Rate, 50-m Range (Mode 1)

The ET4200 side-scan sonar generates a single, high-frequency (HF) signal with a peak frequency of 125 kHz. The operational parameter settings for Mode 1 were a 500-ms ping rate and 50-m range. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.7-1** is the selected frequency band (120 to 130 kHz) and SPL_{pk} (165 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.7-1. Bandpass determination for the ET4200, 100 kHz, 500-ms ping rate, 50-m range at Site 2, Run8.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
100-150	165.51
115-135	165.15
118-132	165.02
120-130	**165.01**

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET4200, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.7-1**.

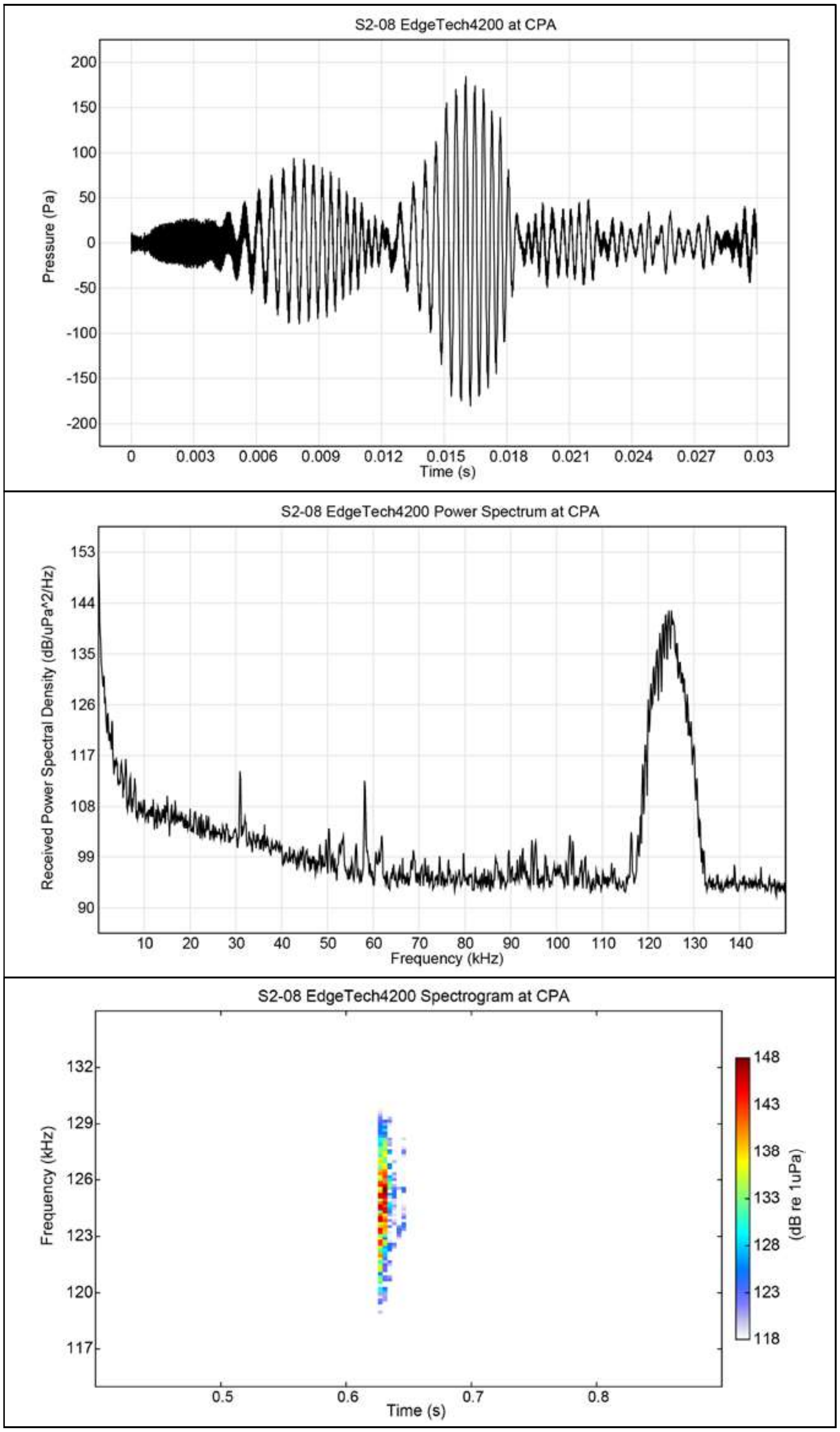


Figure 4.7-1. Edgetech 4200 measured signal characteristics at closest point of approach (CPA) at Site 2, Run8.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.7.1 Site 1 – Mud, 10 m Depth

At S1, the ET4200, Mode 1, had valid acoustic recordings in Run6 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9). However, due to its HF, the signal was only observed at position D. For all Runs, positions E (Buoy5 and Buoy8) and F (Buoy9) were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET4200, Mode 1, are shown in **Figure 4.7.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run6, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 125 kHz, the propagation loss was very high, and the signal was only observable for a total of 1 minute (30 seconds before and 30 seconds after the CPA). The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal because of propagation loss of the HF signal.

The results panels (**Figure 4.7.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the ET4200 at S1, only position D (Buoy6) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 140 m. The two visible blue tracks (for position D) are the approach and departure of the source to and from the buoy. The difference (separation of the tracks) could be azimuthal dependence of the source or a small error in the buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predict received levels for a 206 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.7.1-2**), which shows the received peak level for position D at approximately 110°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

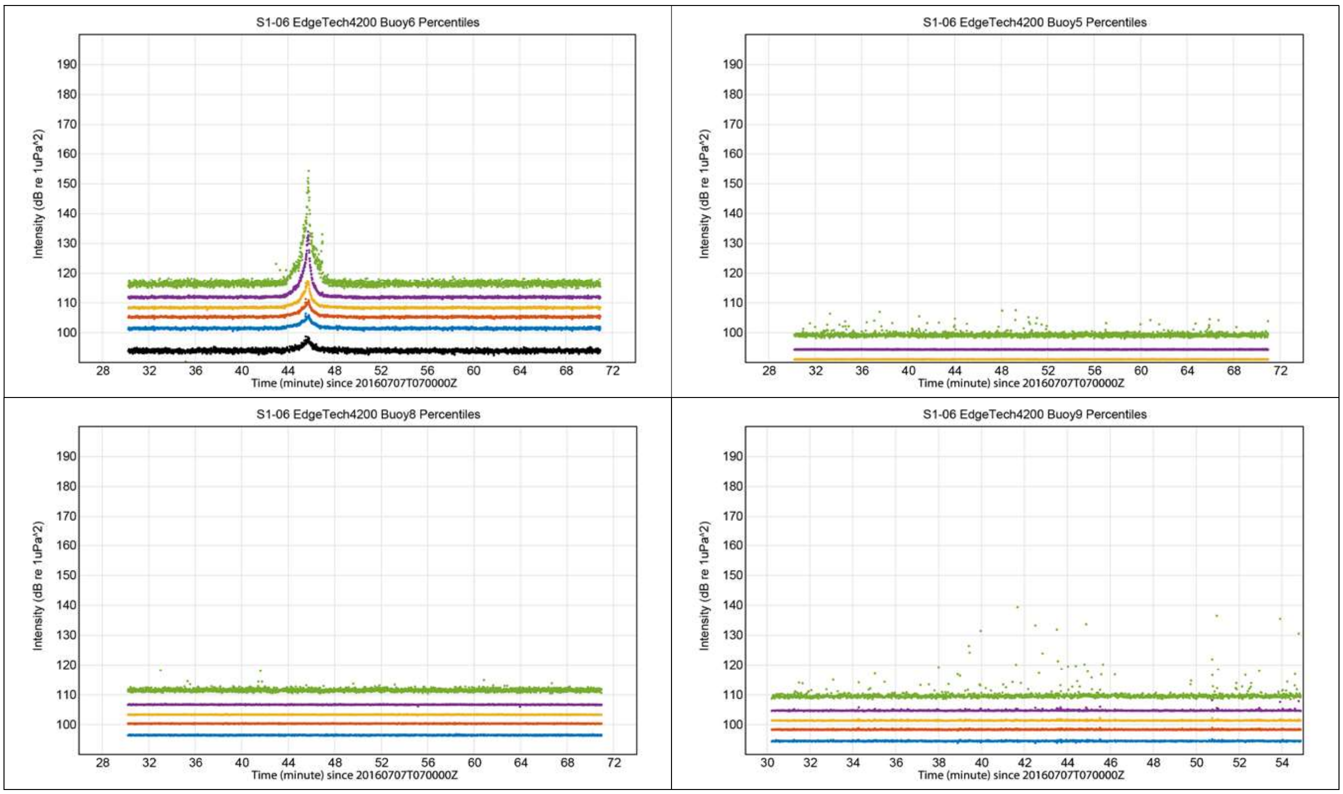


Figure 4.7.1-1. Percentile plots of Edgetech 4200 signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

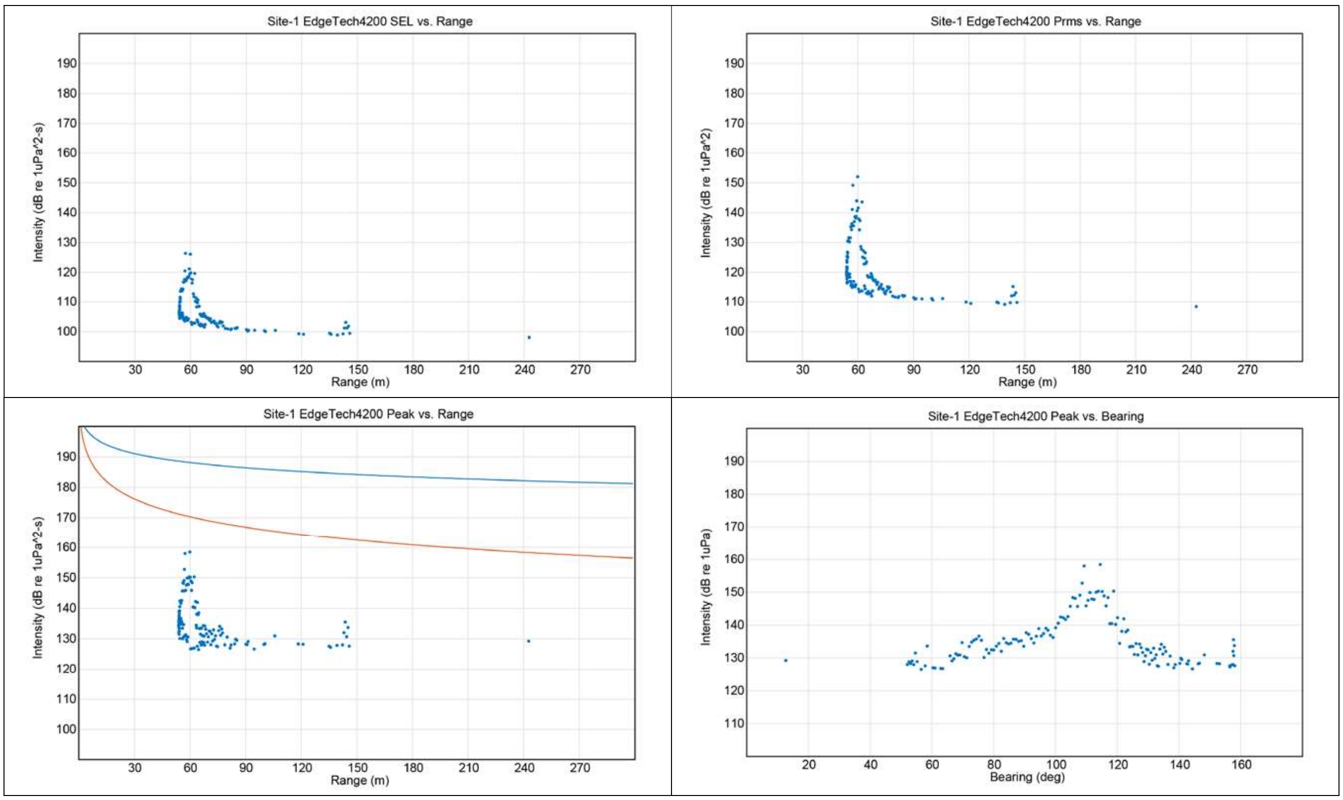


Figure 4.7.1-2. Range results for Edgetech 4200 signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position, D = blue.

The plan view is shown in **Figure 4.7.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -150 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position D (Buoy6). Recordings at the buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately -20 m on the y-axis.

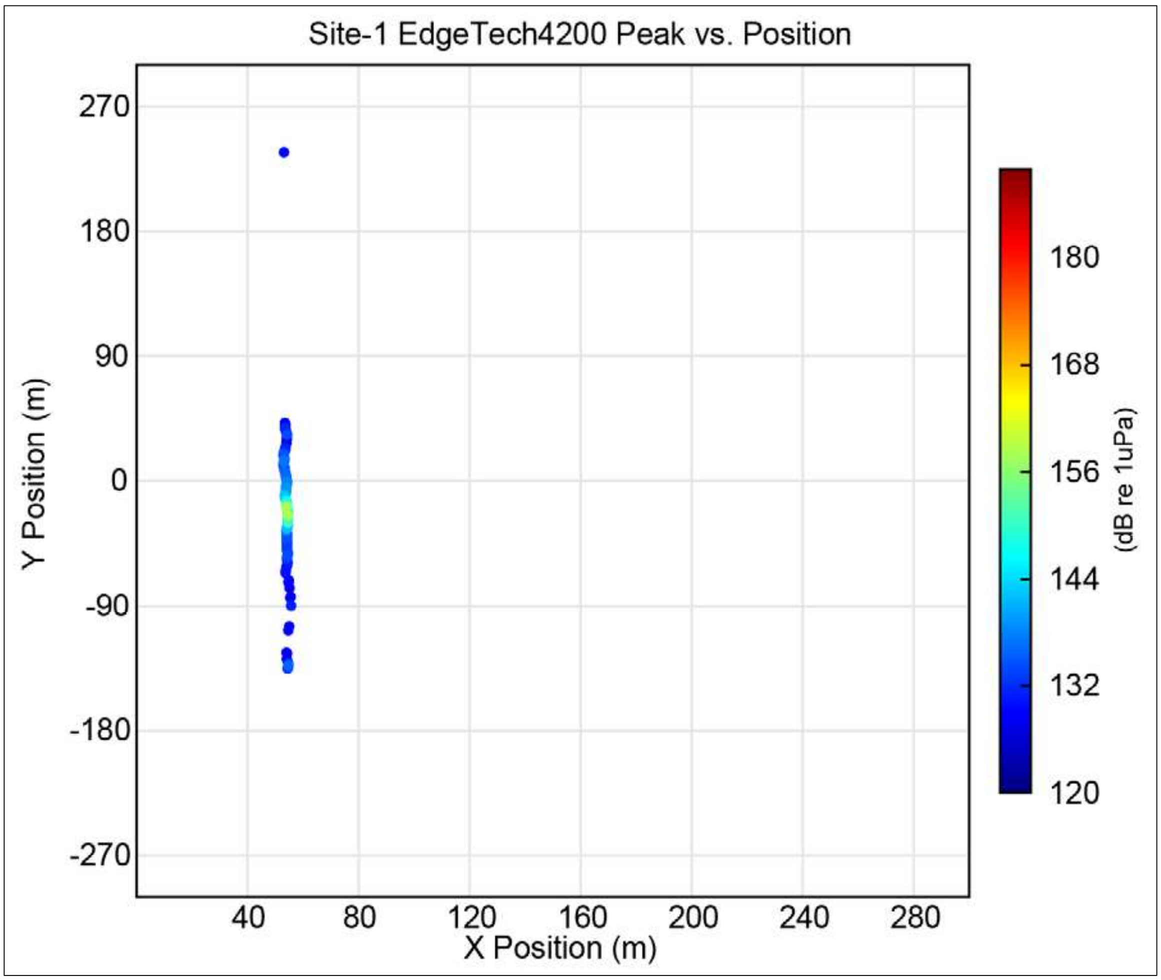


Figure 4.7.1-3. Plan view of received peak level for Edgetech 4200 at Site 1 for position D (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.7.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.7.1-1. ET4200 source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
ET4200 Mode 1	100 kHz	100%	NA	50-m range	196	188	163
NUWC	100 kHz	100%	NA	50-m range	206	201	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m =meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.7.2 Site 2 – Sand, 10 m Depth

At S2, the ET4200, Mode 1, had valid acoustic recordings in Run8 and Run35. For Run8, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run35, position B (Buoy5 and Buoy11) had valid acoustic recordings. For all Runs, positions E (Buoy10) and F (Buoy9) were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET4200, Mode 1, are shown in **Figure 4.7.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel does not show position D (Buoy6) because there was a problem with the trigger file. Instead, the top left panel shows position B (Buoy5) for Run35, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 125 kHz, the propagation loss was very high, and the signal was only observable for a maximum of 2 minutes (60 seconds before and 60 seconds after the CPA). The bottom panel shows the recorded acoustics at position B (Buoy11). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The signal is visible at position B (Buoy5) but not at position B (Buoy11).

The results panels (**Figure 4.7.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied to the collected data. For the ET4200 at S2, only position B (Buoy5) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to approximately 240 m. The conical shape of the position B data points signifies the approach and departure of the source to and from the buoys. All receptions at position B are close together, showing good calibration and buoy location determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 206 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 80°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern.

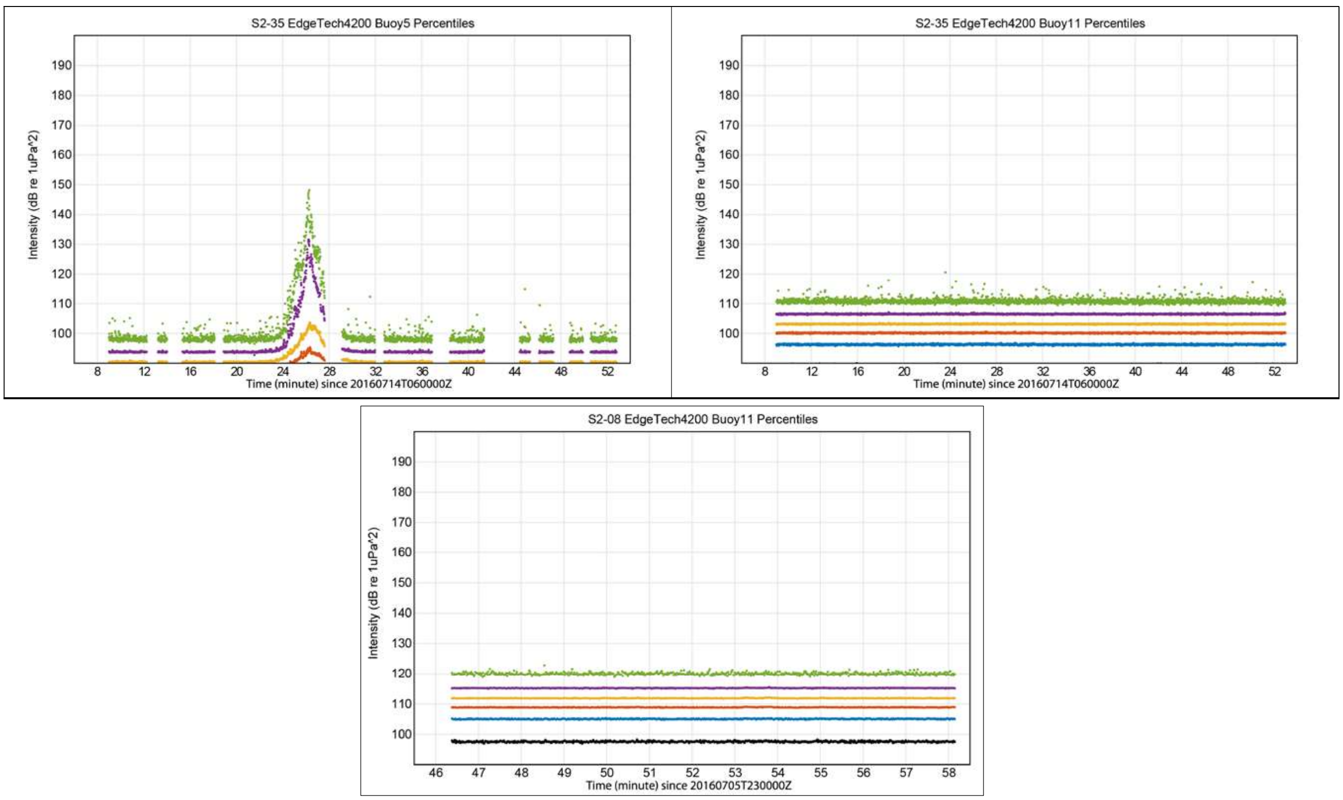


Figure 4.7.2-1. Percentile plots of Edgetech 4200 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy5); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position B (Buoy11). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

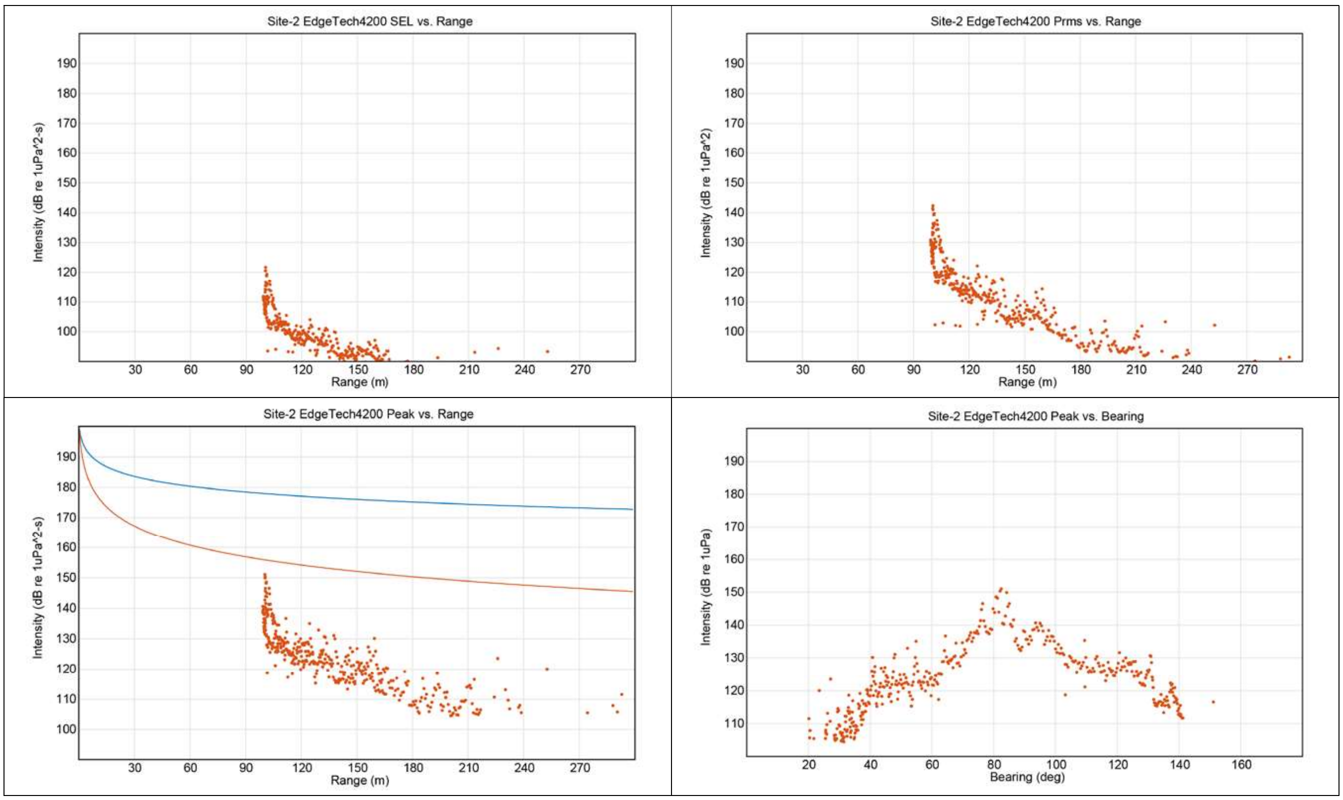


Figure 4.7.2-2. Range results for Edgetech 4200 signals at Site 2 for position B (Buoy5).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.7.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 100,20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -150 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy5). Recordings at the buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position B is seen at approximately 20 m on the y-axis.

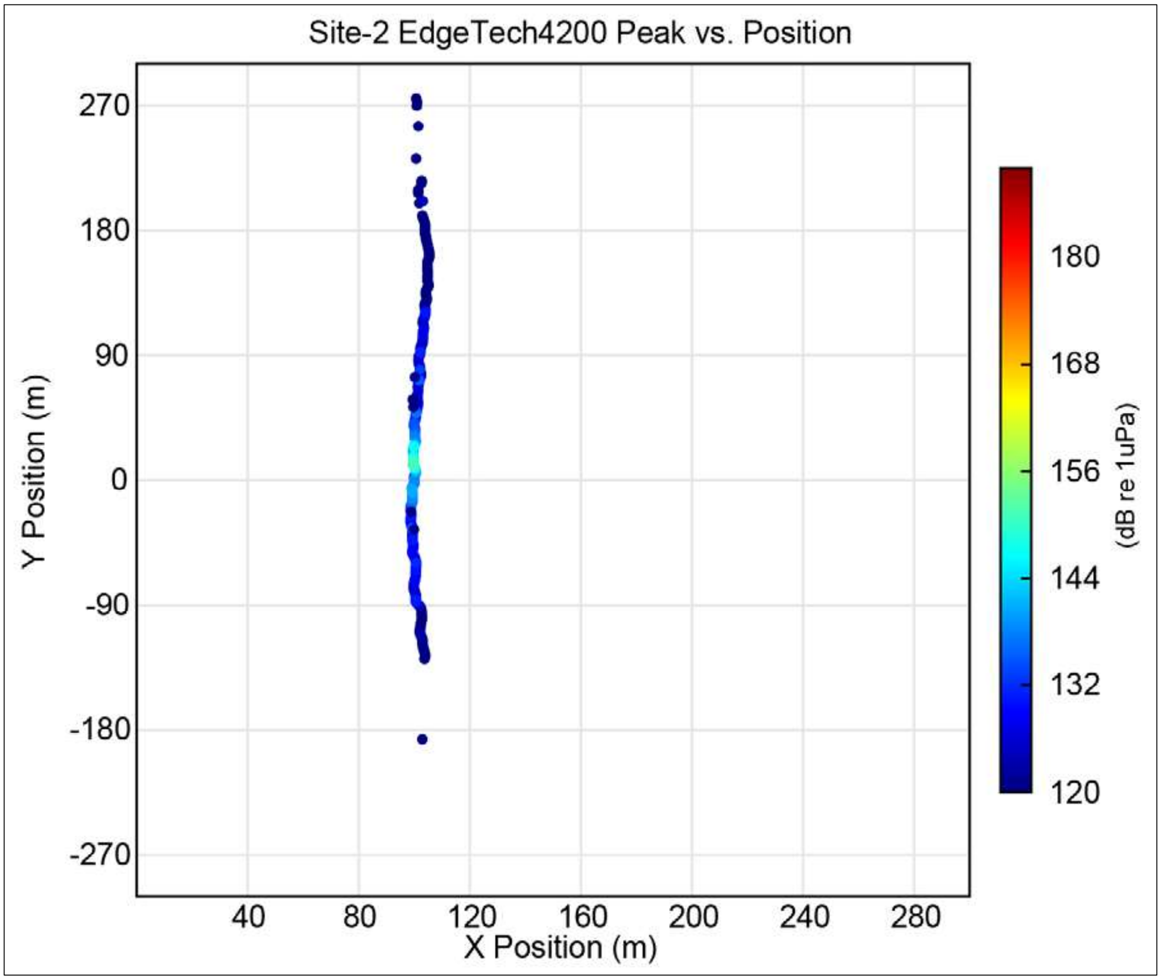


Figure 4.7.2-3. Plan view of received peak level for Edgetech 4200 at Site 2 for position B (Buoy5).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.7.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.7.2-1. ET4200 source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
ET4200 Mode 1	100 kHz	100%	NA	50-m range	192	184	162
NUWC	100 kHz	100%	NA	50-m range	206	201	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.7.3 Site 3 – Mud, 30 m Depth

At S3, the ET4200, Mode 1, had acoustic recordings for Run8 and Run29. The acoustic data for Run8 were problematic in that there was no evidence of valid acoustic data or an observed signal. The Run29 data were corrupted on all buoys. Many of the data had zeros after processing, meaning there were no acoustic data. In addition, several buoys had high levels of noise that masked any potential signals. Signals were observed for Run8 at positions A (Buoy5) and B (Buoy12); however, there were no receptions of sufficient quality to process in order to generate results.

Run Summary

The percentile plots for the available recordings of the ET4200, Mode 1, are shown in **Figure 4.7.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The only data shown are for position A (Buoy5) for Run8; the rest of the data were of insufficient quality to process. The signal is evident, but there is noise and corrupt data. Position B (Buoy12) had calibration issues in the received level that were 20 dB less than the position A (Buoy5) data and had high noise levels. Position D (Buoy8) has valid acoustic recordings, but there was no signal captured; as this buoy is supposed to be nearest to the source, the lack of recorded signal leads to an unidentified error, (e.g., the buoy might have been well outside of its assigned position, the source might not have been working properly).

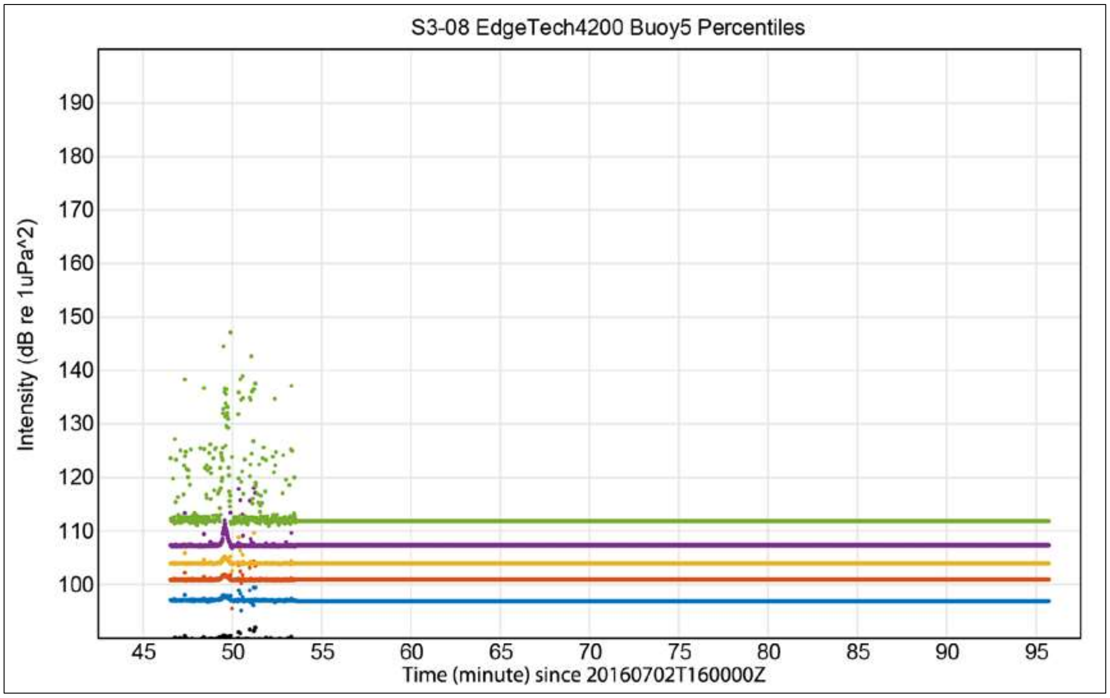


Figure 4.7.3-1. Percentile plots of Edgetech 4200 signals at Site 3.
Buoy percentiles of SPL_{pk} arrival at position A (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

4.7.4 Site 4 – Sand, 30 m Depth

At S4, the ET4200, Mode 1, had acoustic recordings in Run8 and Run24, but there was no evidence of valid acoustic data or an observed signal.

4.7.5 Site 5 – Sandy-Silt, 100 m Depth

The ET4200, Mode 1, was not deployed or operated at S5.

This Page Left Intentionally Blank

4.8 Edgetech 4200, 100 kHz, 500-ms Ping Rate, 100-m Range (Mode 2)

The ET4200 side-scan sonar generates a single, high-frequency (HF) signal with a peak frequency of 125 kHz. The operational parameter settings for Mode 2 were a 500-ms ping rate and 100-m range. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.8-1** is the selected frequency band (118 to 132 kHz) and SPL_{pk} (165 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.8-1. Bandpass determination for the ET4200, 100 kHz, 500-ms ping rate, 100-m range at Site 2, Run9.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
100-150	165.31
115-135	165.13
118-132	**165.09**
120-130	164.94

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET4200, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.8-1**. As seen in the time waveform and power spectral density, the signal is very weak thus not discernable, but it is just noticeable in the spectrogram.

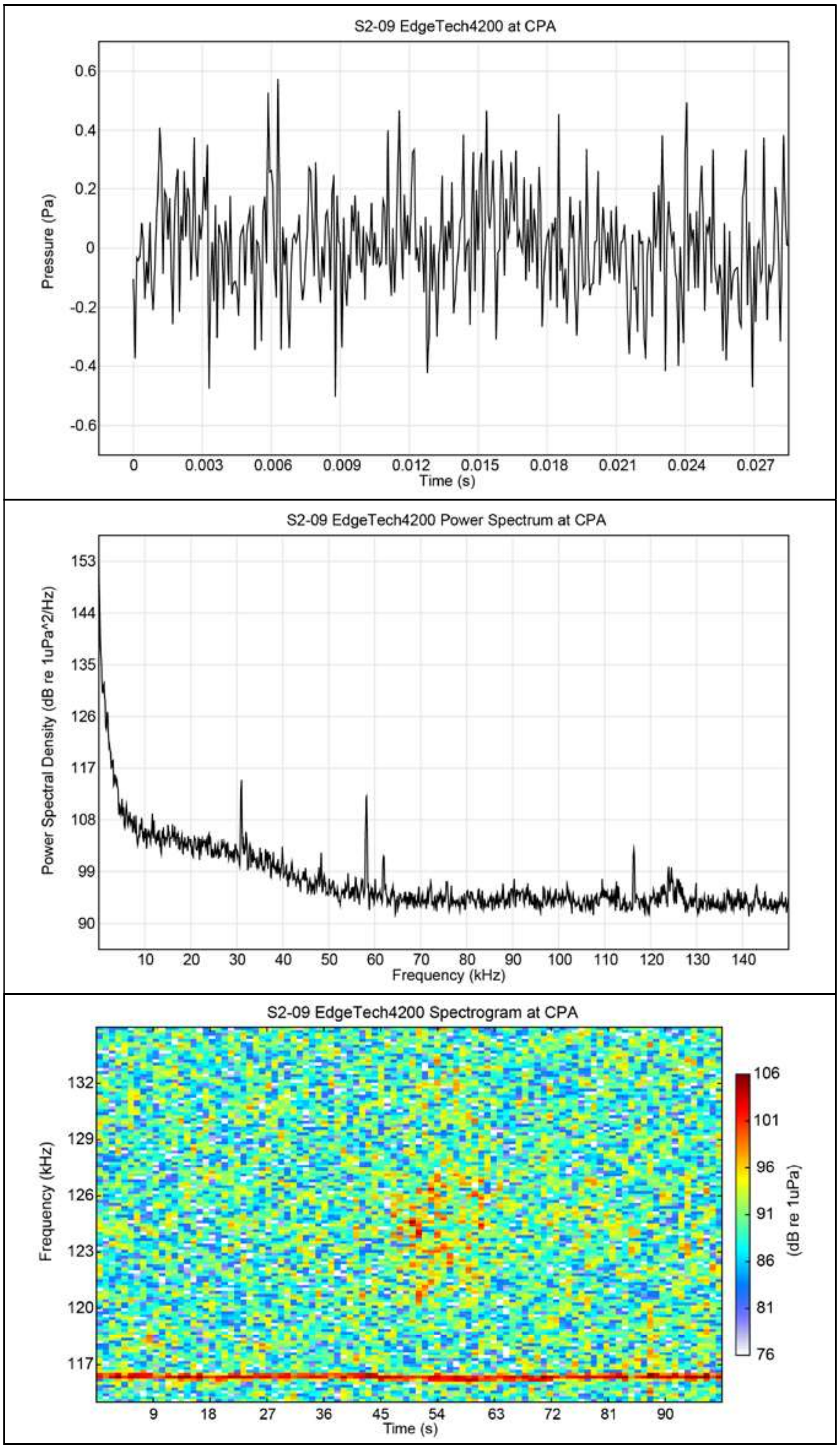


Figure 4.8-1. Edgetech 4200 measured signal characteristics at closest point of approach (CPA) at Site 2, Run9.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.8.1 Site 1 – Mud, 10 m Depth

At S1, the ET4200, Mode 2, had valid acoustic recordings in Run7 at position D (Buoy6). Positions E (Buoy5 and Buoy8) and F (Buoy9) were too distant to capture the HF acoustic signal for this weaker source.

Run Summary

The percentile plots for the three available recordings of the ET4200, Mode 2, are shown in **Figure 4.8.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run7, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 125 kHz, the propagation loss was high, and the signal was only observable for a total of 1 minute (30 seconds before and 30 seconds after the CPA). The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8), but no signal was captured. The acoustic data appear of good quality, but there is no signal observed, likely because of the HF propagation loss. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.8.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied. For the ET4200 at S1, only position D (Buoy6) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 80 m. The two visible blue tracks (for position D) are the approach and departure of the source to and from the buoy. The difference (separation of the tracks) could be azimuthal dependence of the source or error in the buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves; spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predicts received levels for a 206 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.8.1-2**), which shows the received peak level for position D at approximately 115°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

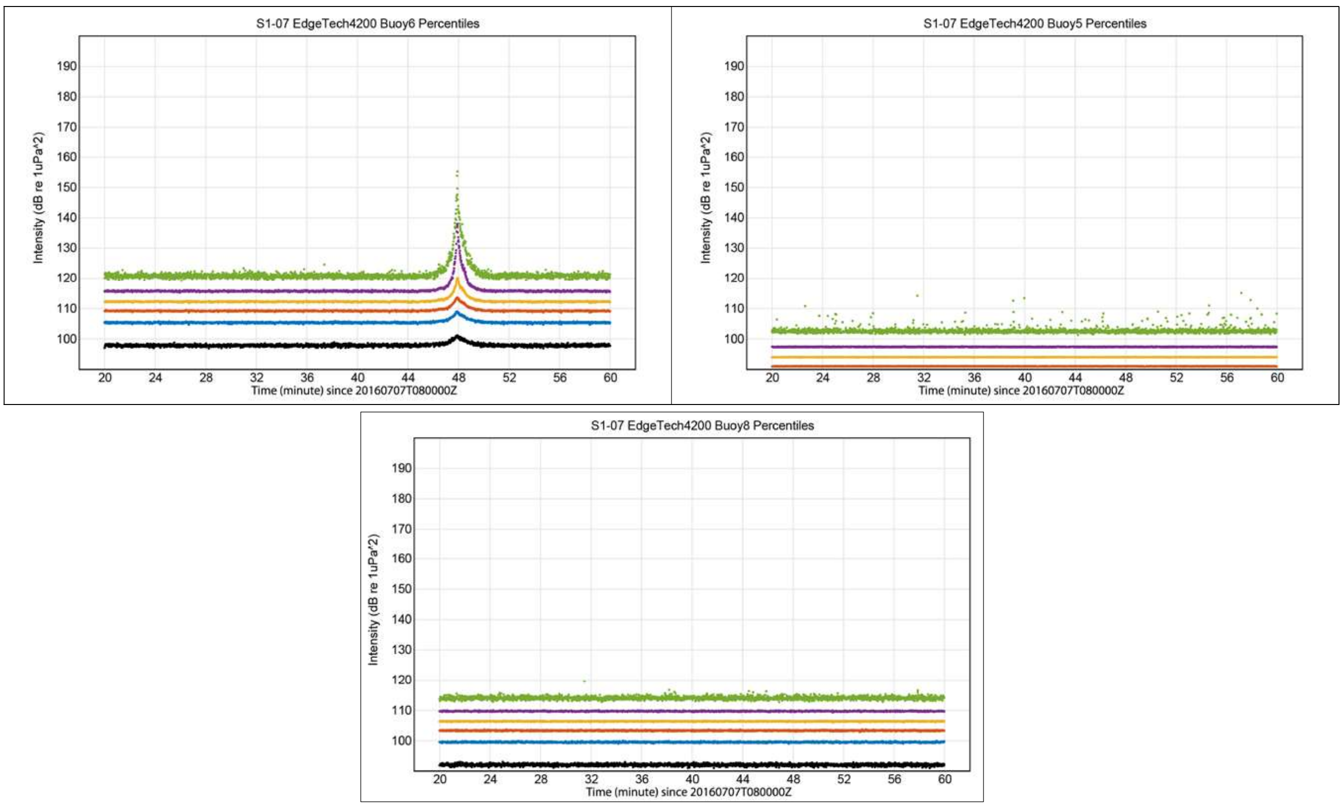


Figure 4.8.1-1. Percentile plots of Edgetech 4200 signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} at position E (Buoy5); Bottom: SPL_{pk} at position E (Buoy8). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

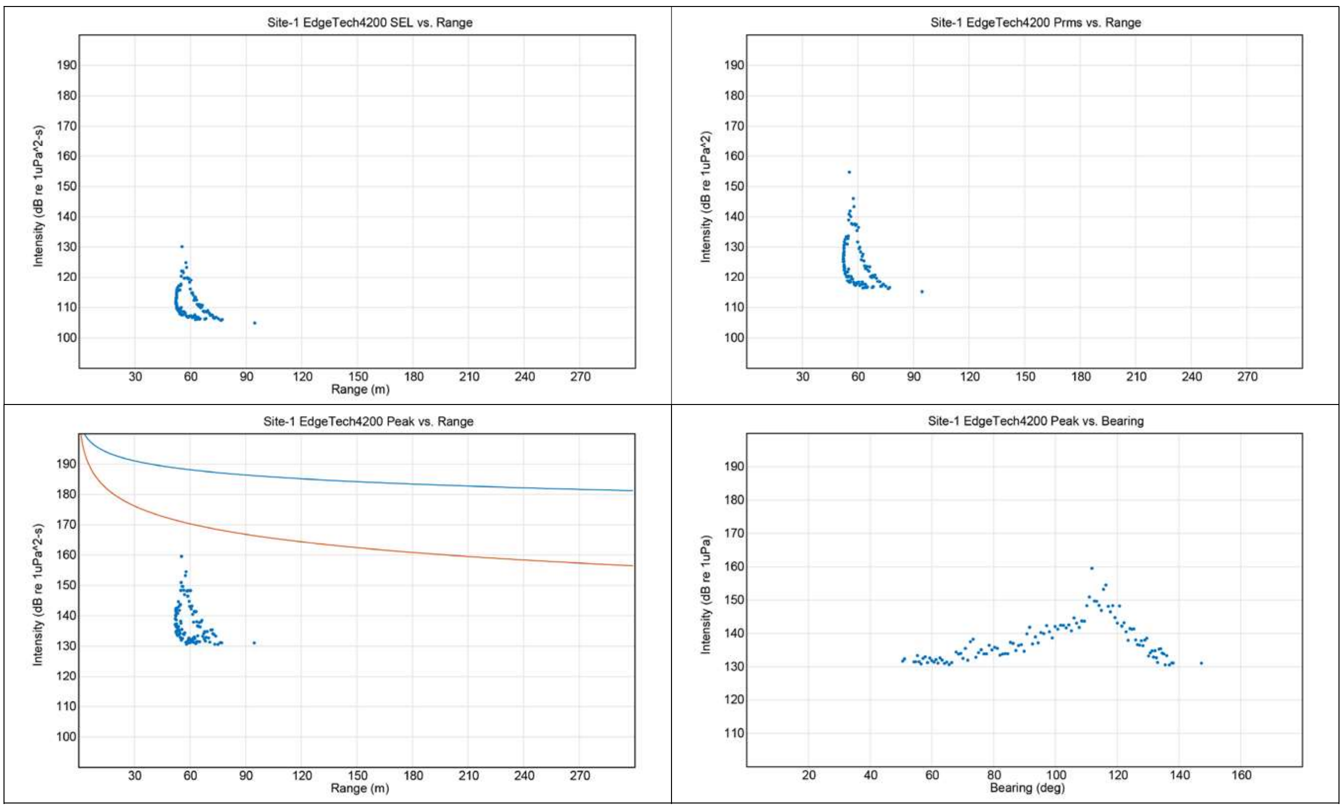


Figure 4.8.1-2. Range results for Edgetech 4200 signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position, D = blue.

The plan view is shown in **Figure 4.8.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA of 50,0 m (x,y) was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position D (Buoy6). Recordings at the buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately -30 m on the y-axis.

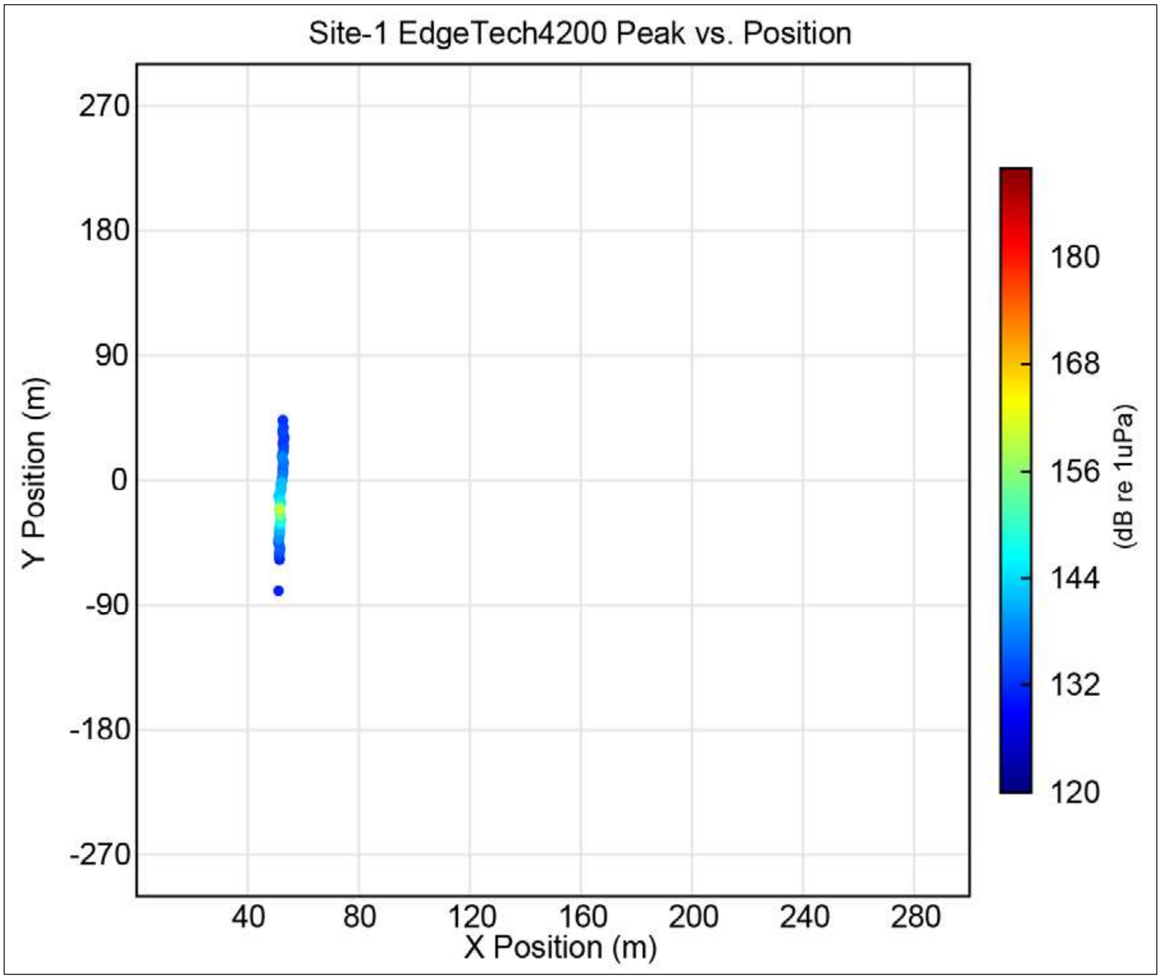


Figure 4.8.1-3. Plan view of received peak level for Edgetech 4200 at Site 1 for position D (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.8.1-1**, Mode 2. The estimated source were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.8.1-1. ET4200 source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
ET4200 Mode 2	100 kHz	100%	NA	100-m range	194	189	164
NUWC	100 kHz	100%	NA	100-m range	206	201	175

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.8.2 Site 2 – Sand, 10 m Depth

At S2, the ET4200, Mode 2, had valid acoustic recordings in Run9 and Run36. For Run9, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run36, position B (Buoy5 and Buoy11) had valid acoustic recordings. For all Runs, positions E (Buoy10) and F (Buoy9) had valid acoustic data but were too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET4200, Mode 2, are shown in **Figure 4.8.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run9, where the received signal is observed and the signal's influence on the peak value as well as on the smaller percentiles. The top right panel shows position B (Buoy5) from Run36. The bottom panel shows position B (Buoy11) and position B (Buoy11) for Run36 and Run9, but no signal is observed in either panel.

The results panels (**Figure 4.8.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied. For the ET4200 at S2, only positions D (Buoy6) and B (Buoy5) had acoustic data that look like signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 20 to approximately 240 m. The conical shape of the data points at positions D and B represents the approach and departure of the source to and from the buoys. The difference could be azimuthal dependence of the source or an error in buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves; spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 206 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.8.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 135°, indicating an error in buoy positioning, and for position B at approximately 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

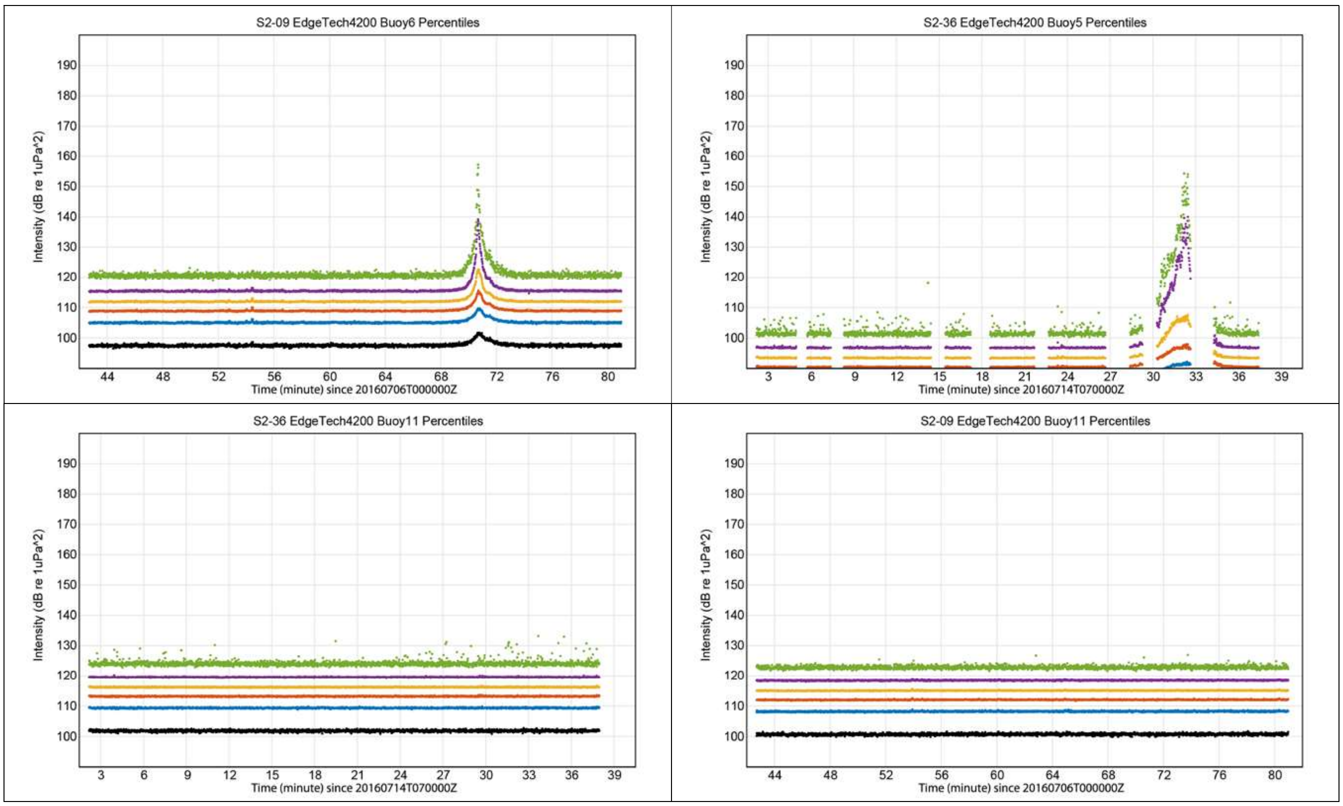


Figure 4.8.2-1. Percentile plots of Edgetech 4200 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy11). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

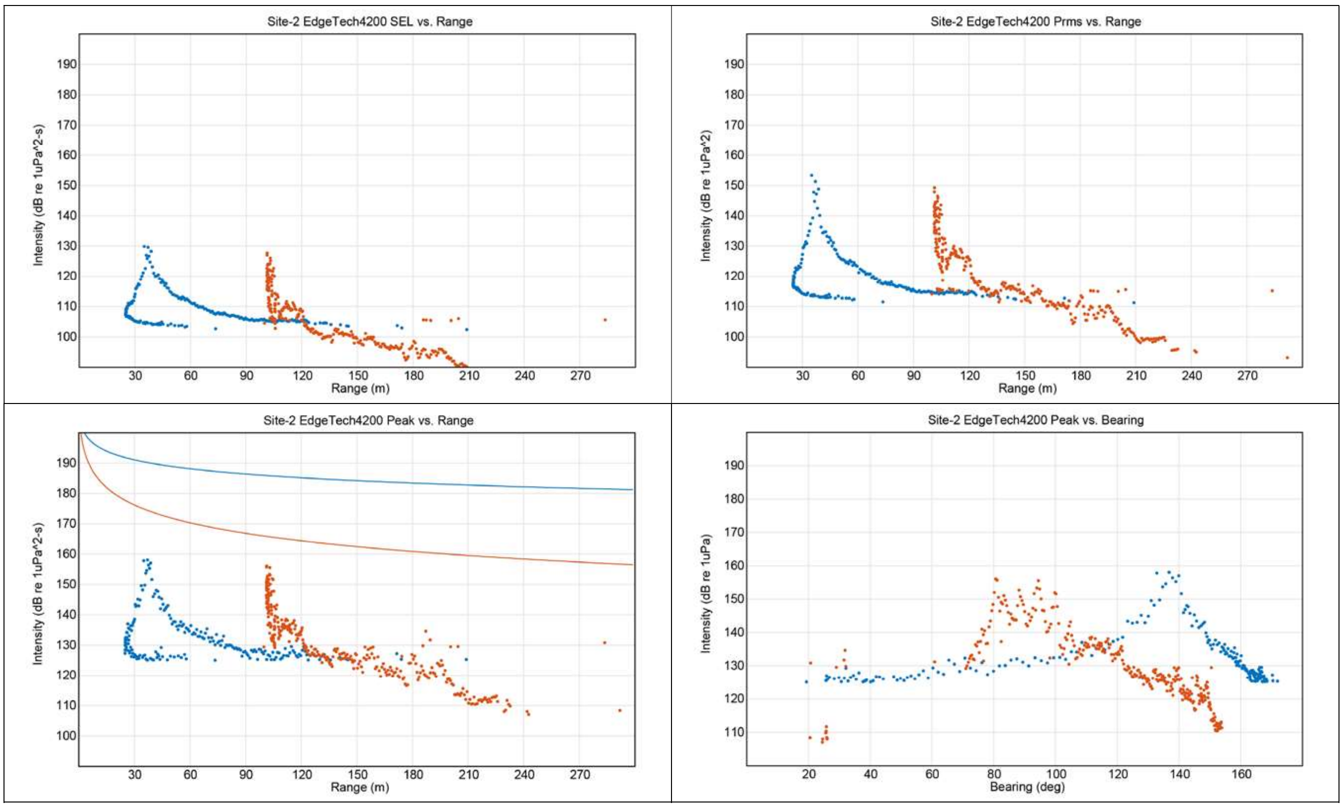


Figure 4.8.2-2. Range results for Edgetech 4200 signals at Site 2 for positions D (Buoy6) and B (Buoy5).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.8.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 30,-40 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is at approximately -40 m seen on the y-axis, while position B had high amplitudes at approximately 0 m.

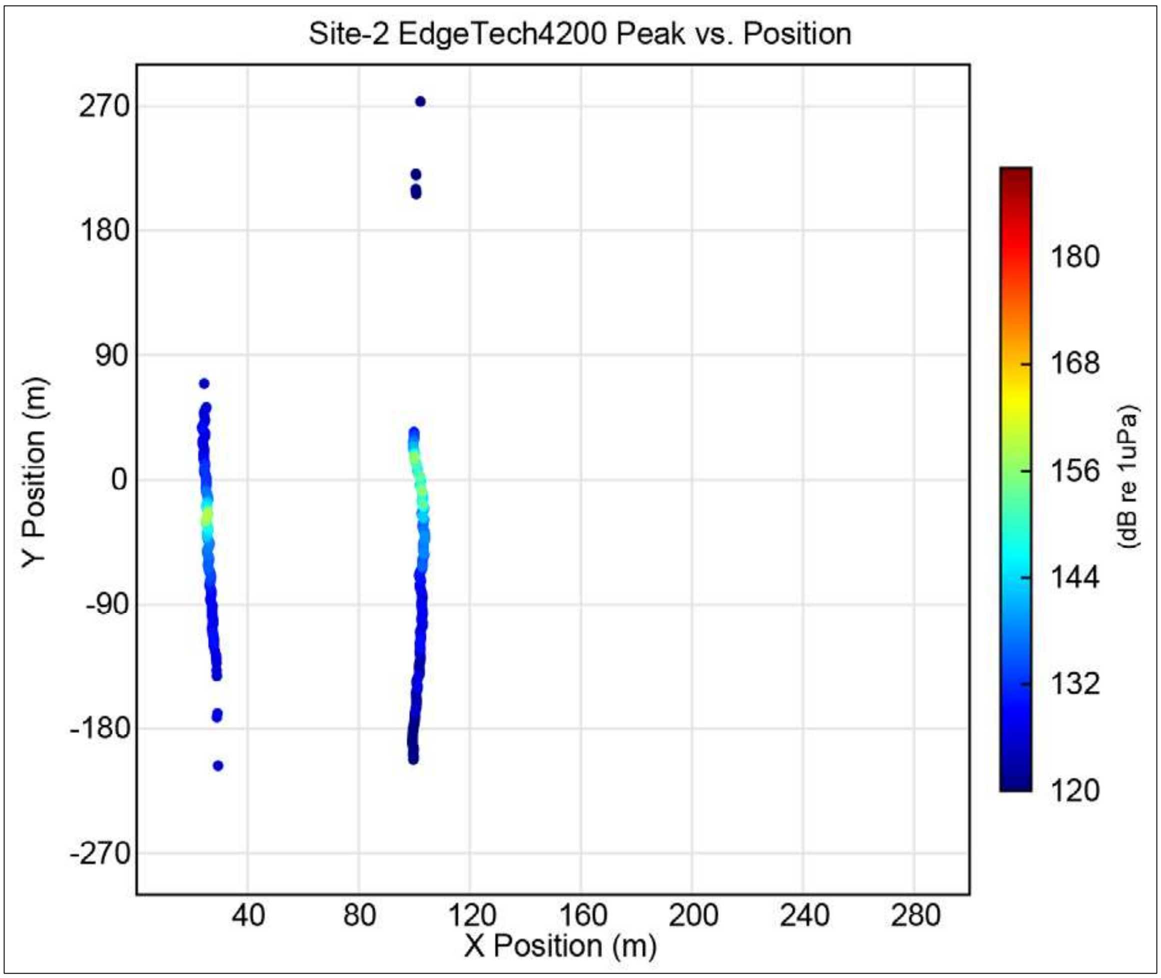


Figure 4.8.2-3. Plan view of received peak level for Edgetech 4200 at Site 2 for positions D (Buoy6) and B (Buoy5).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.8.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.8.2-1. ET4200 source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
ET4200 Mode 2	100 kHz	100%	NA	100-m range	197	190	168
NUWC	100 kHz	100%	NA	100-m range	206	201	175

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.8.3 Site 3 – Mud, 30 m Depth

At S3, the ET4200, Mode 2, had valid acoustic recordings in Run9 at positions D (Buoy6), B (Buoy5 and Buoy12), E (Buoy8 and Buoy10), and F (Buoy9). However, only position B (Buoy5 and Buoy12) had identifiable signals.

Run Summary

The percentile plots for the available recordings of the ET4200, Mode 2, are shown in **Figure 4.8.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The left panel shows position B (Buoy5) for Run9, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The right and left panel show the valid recorded acoustics at position B (Buoy5) and B (Buoy12), respectively.

The results panels (**Figure 4.8.3-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied. For the ET4200 at S3, only positions B (Buoy5 and Buoy12) had acoustic data that look like signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 80 to approximately 300 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves; spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 206 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.8.3-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position B (Buoy5 and Buoy12) has a peak near 90°, which indicates good buoy navigation. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

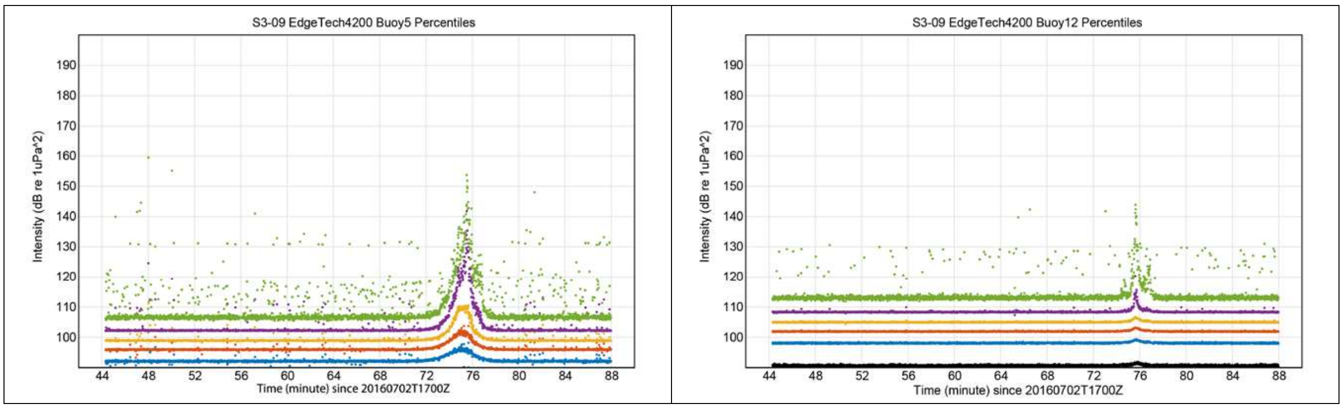


Figure 4.8.3-1. Percentile plots of Edgetech 4200 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy5); Top right: SPL_{pk} arrival at position B (Buoy12). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

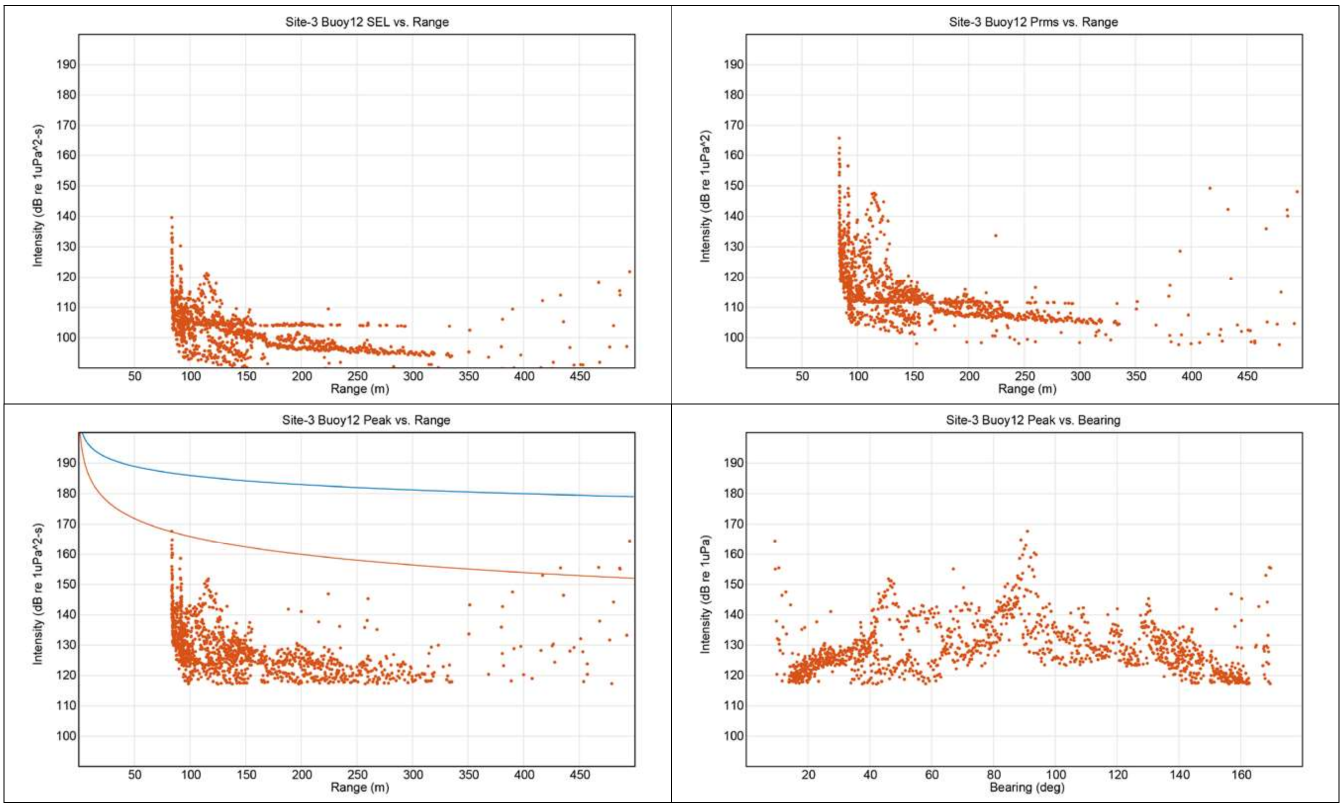


Figure 4.8.3-2. Range results for Edgetech 4200 signals at Site 3 for position B (Buoy5 and Buoy 12, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red.

The plan view is shown in **Figure 4.8.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 83,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -400 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position B was approximately 0 m.

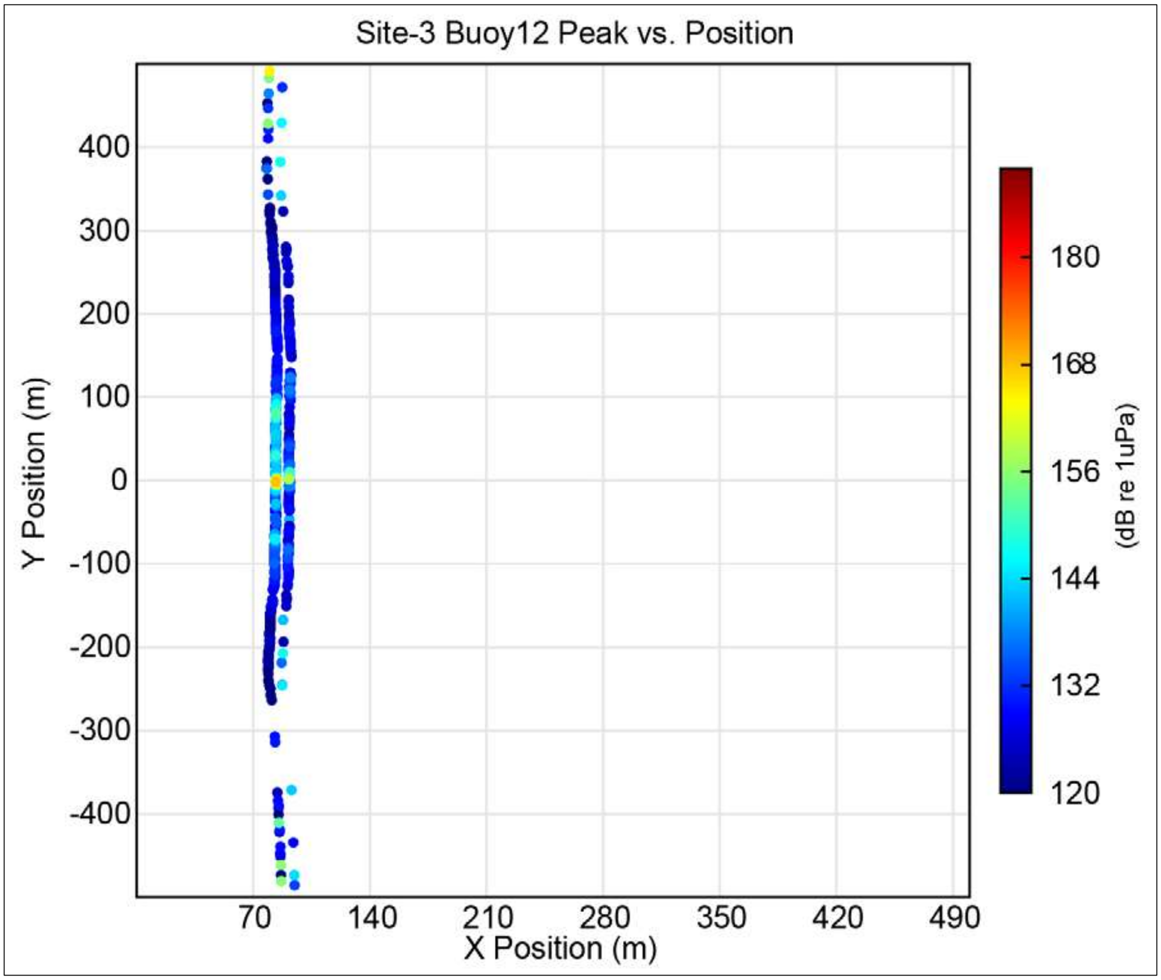


Figure 4.8.3-3. Plan view of received peak level for Edgetech 4200 at Site 3 for positions B (Buoy5 and Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.8.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.8.3-1. ET4200 source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Cycles, Pulse Width**	**Beam width, Range**	**Pk**	**rms**	**SEL**
ET4200 Mode 2	100 kHz	100%	NA	100-m range	187	179	157
NUWC	100 kHz	100%	NA	100-m range	206	201	175

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.8.4 Site 4 – Sand, 30 m Depth

At S4, the ET4200, Mode 2, had acoustic recordings in Run9 and Run23, but there were no meaningful acoustic values. As an example of the types of different recording errors, the percentile plots are provided (**Figure 4.8.4-1**).

Run Summary

The percentile plots for the available recordings of the ET4200, Mode 2, are shown in **Figure 4.8.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy8) for Run23, where the data are invalid. The top right and bottom panels show the invalid data that lack any signal at positions A (Buoy7 and Buoy6) and B (Buoy12). The less than and greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the data are invalid. Given the data are invalid, they were not processed further.

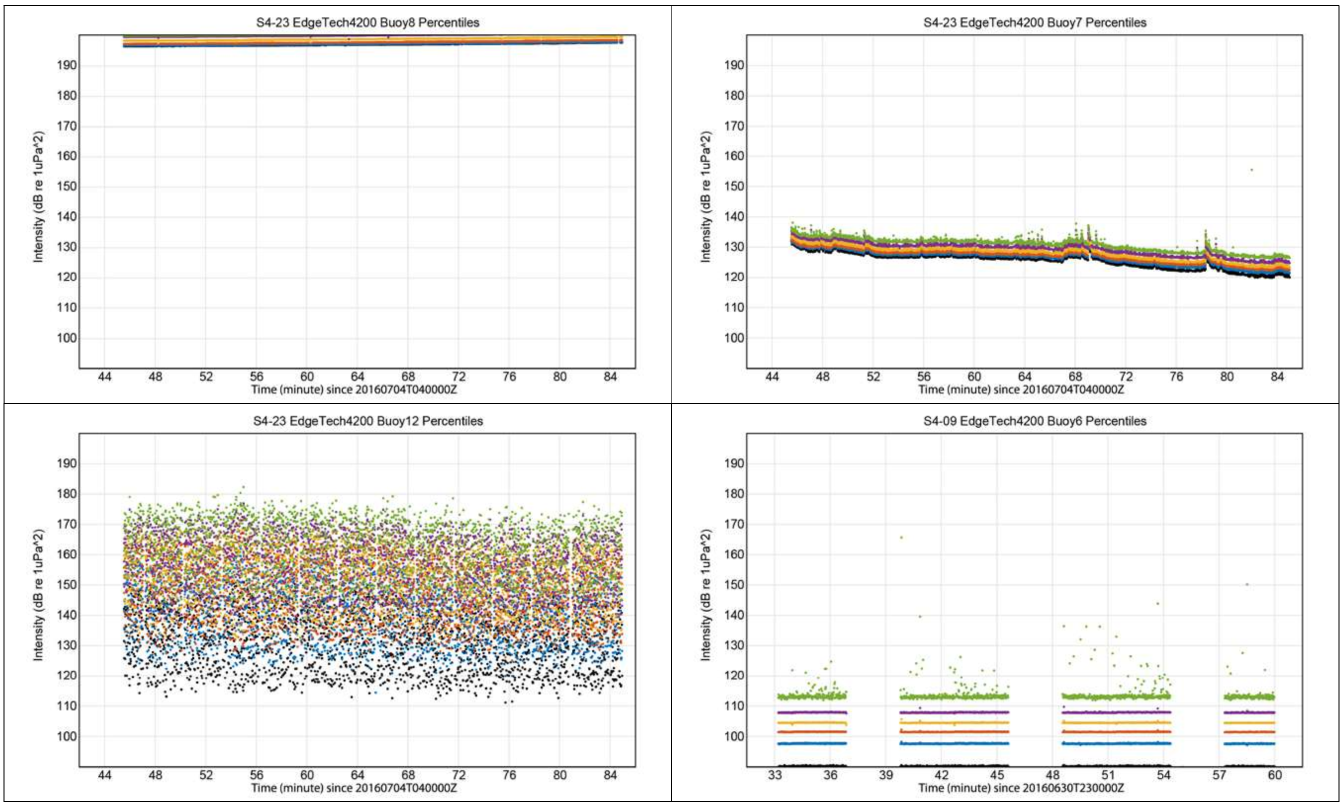


Figure 4.8.4-1. Percentile plots of Edgetech 4200 signals at Site 4.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy8); Top right: SPL_{pk} arrival at position A (Buoy7); Bottom left: SPL_{pk} arrival at position B (Buoy12); Bottom right: SPL_{pk} arrival at position A (Buoy6). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

4.8.5 Site 5 – Sandy-Silt, 100 m Depth

The ET4200, Mode 2, was not deployed or operated at S5.

4.9 SEA SWATHPlus, 234 kHz, 100 Percent Power, 12 Cycles (Mode 1)

The SWATHPlus multibeam echosounder generates a single, very high-frequency (VHF) signal with a peak frequency of 234 kHz. The operational parameter settings for Mode 1 were 100 percent power and 12 cycles. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.9-1** contains the selected frequency band (210 to 250 kHz) and SPL_{pk} (180 dB re 1 µPa) that were applied to the signal for further analysis. The peak results were very sensitive to the frequency band, which was not expected. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.9-1. Bandpass determination for the SWATHPlus, 234 kHz, 100 percent power, 12 cycles at Site 2, Run10.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
210-250	**180.517**
220-250	141.11
224-244	138.9

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The SWATHPlus, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.9-1**. The signal time series, top panel, shows a lower amplitude surface reflection at 0.0032 s (with an extra path length of 6 m to the direct path). The power spectral density plot, middle panel, show peaks at 58 kHz and 115 kHz, which could possibly be sub-harmonics of the 234 kHz source.

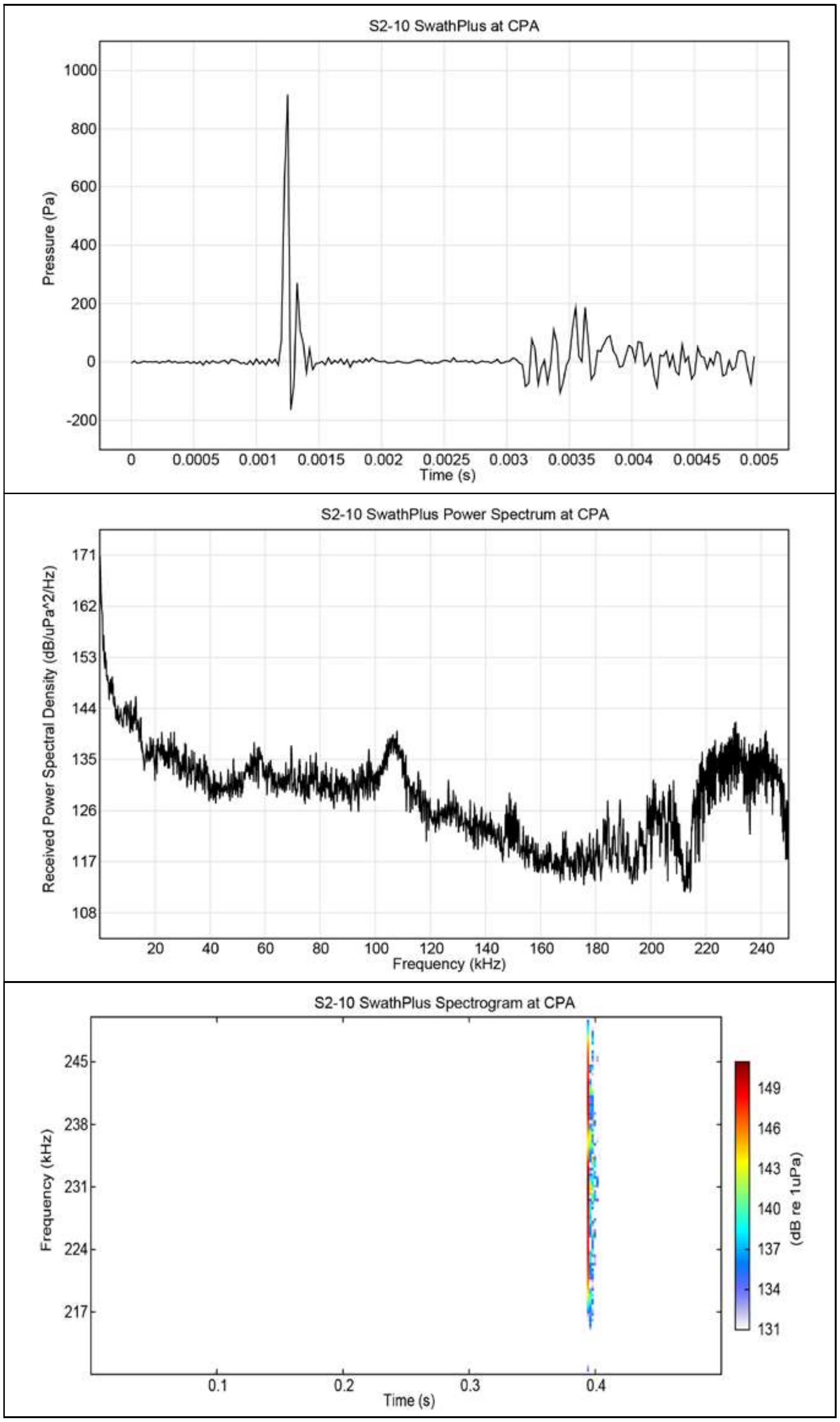


Figure 4.9-1. SWATHPlus measured signal characteristics at closest point of approach (CPA) at Site 2, Run10.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.9.1 Site 1 – Mud, 10 m Depth

At S1, the SWATHPlus, Mode 1, had valid acoustic recordings in Run10 at positions D (Buoy6) and E (Buoy5 and Buoy8). Due to its VHF, the signal was only observed at position D. For all Runs, position E (Buoy5 and Buoy8) was too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for three recordings of the SWATHPlus, Mode 1, are shown in **Figure 4.9.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the duration of the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run10, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 234 kHz, the propagation loss was very high and the signal was only observable for less than 1 minute (30 seconds before and 30 seconds after the CPA). The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at position E because of propagation loss of the VHF signal.

The results panels (**Figure 4.9.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the SWATHPlus at S1, only position D (Buoy6) had an acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 80 m. The two visible blue tracks (for position D) signify the approach and departure of the source to and from the buoy. The difference (separation of tracks) could be azimuthal dependence of the source or a small error in the buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes a reference curve: spherical spreading [$20 \log_{10}$ (*range*)], which predicts received levels for a 225 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The received signals at position D are well below the spherical spreading line, and this is possibly due to the vertical beam pattern of the source.

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.9.1-2**), which shows the received peak level at 115°. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, the figure is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

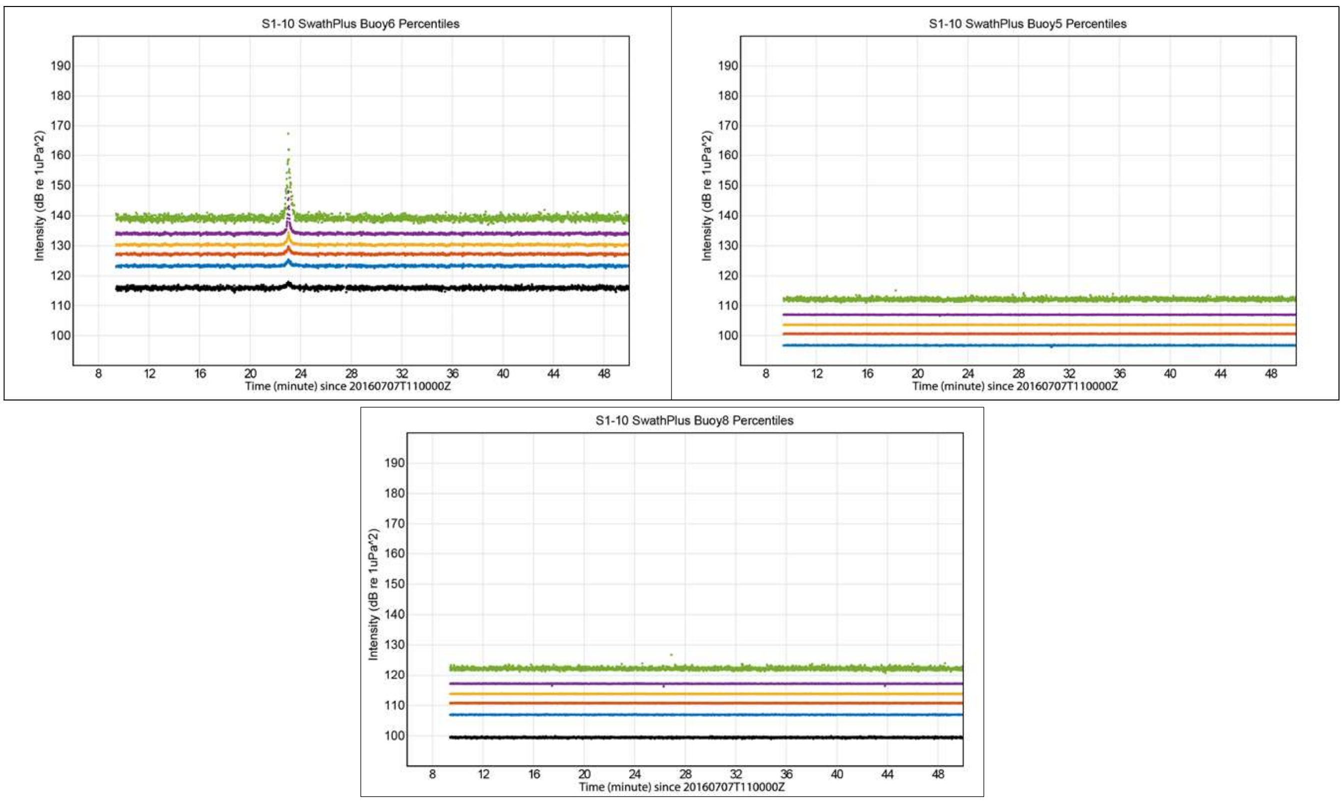


Figure 4.9.1-1. Percentile plots of SWATHPlus signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

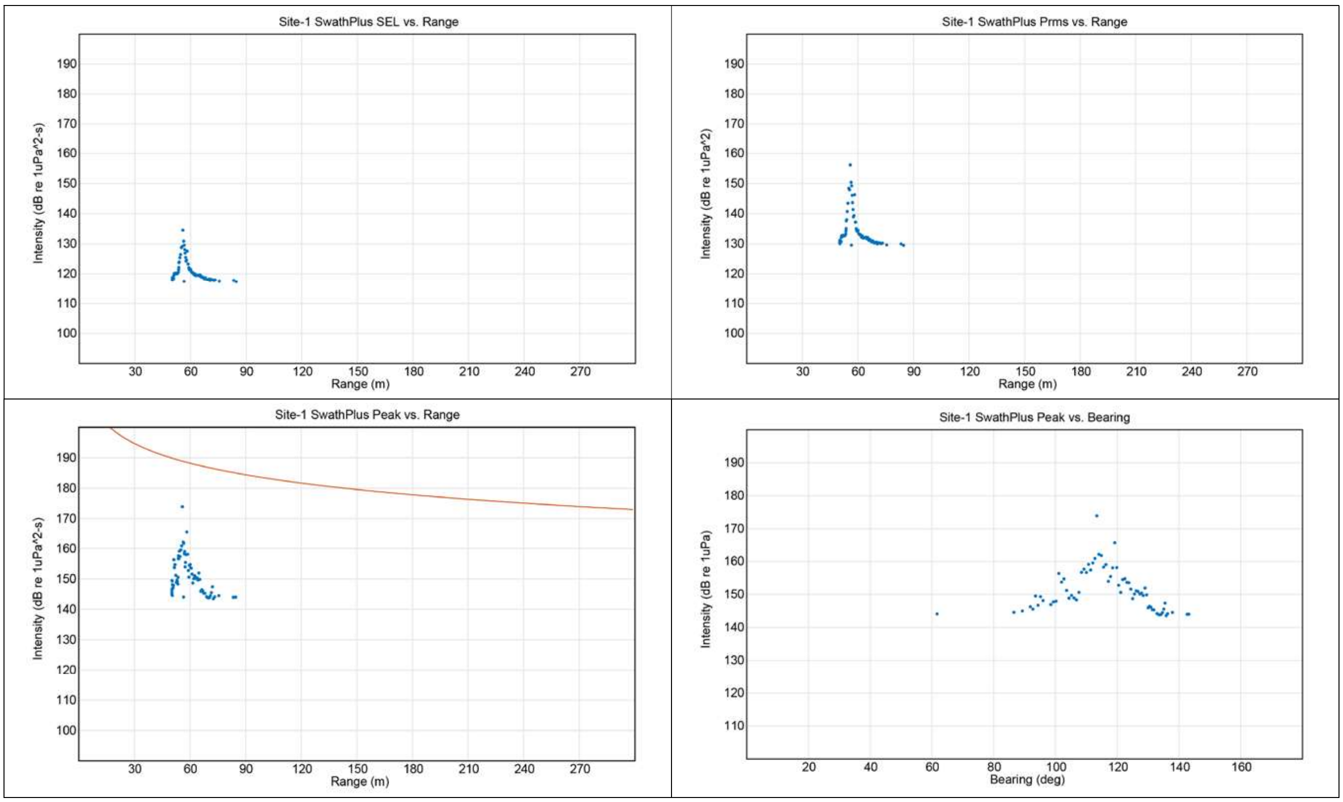


Figure 4.9.1-2. Range results for SWATHPlus signals at Site 1 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the red line is spherical spreading [$20 \log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Position, D = blue.

The plan view is shown in **Figure 4.9.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -80 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position D (Buoy6). Recordings at the buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen on the y-axis at approximately -20 m.

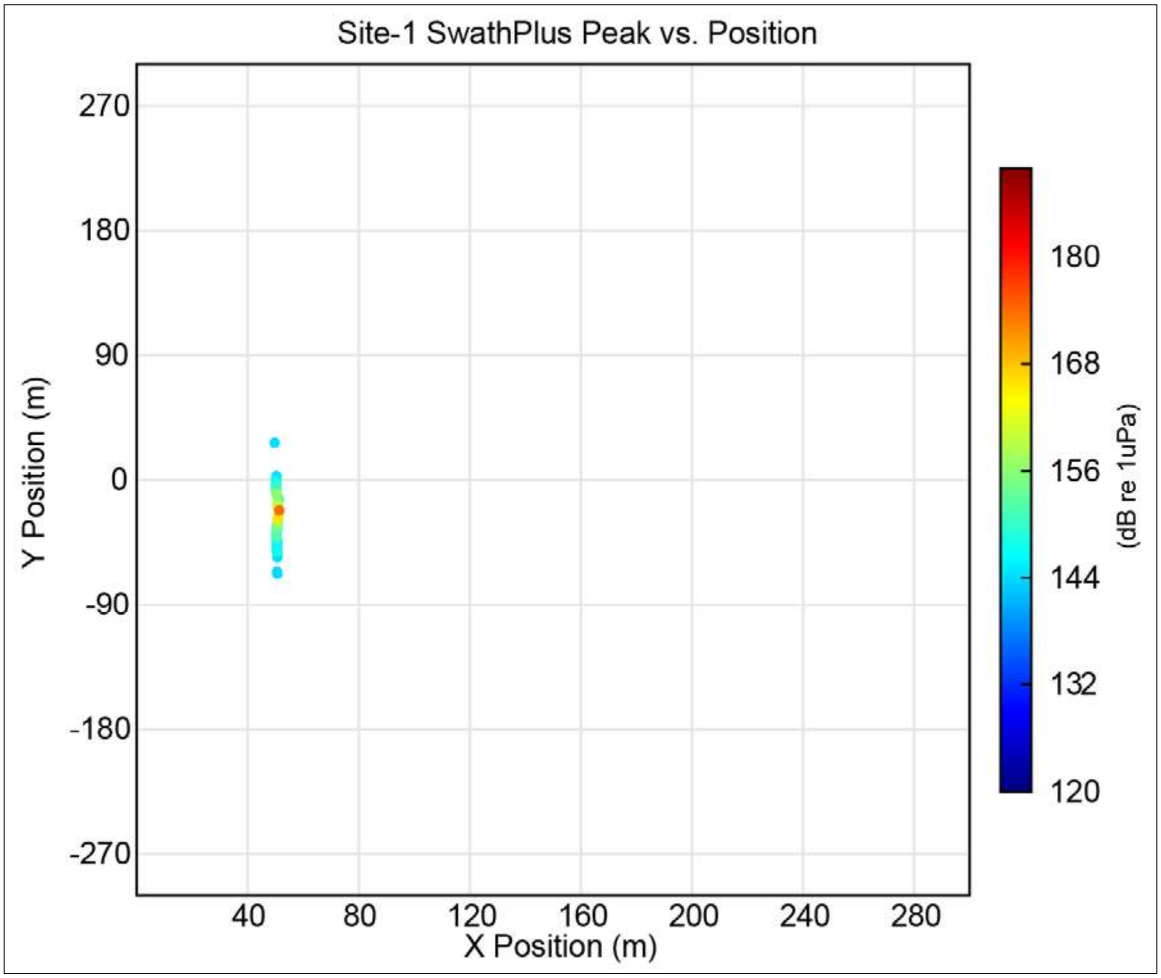


Figure 4.9.1-3. Plan view of received peak level for SWATHPlus at Site 1, showing the results for position D (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.9.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source levels are approximately 20 dB lower than the NUWC report values, and this may be due to the vertical beam pattern of the source.

Table 4.9.1-1. SWATHPlus source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
SWATHPlus Mode 1	234 kHz	100%	NA	12 cycles	209	192	171
NUWC	234 kHz	100%	NA	10 cycles	225	218	174

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.9.2 Site 2 – Sand, 10 m Depth

At S2, the SWATHPlus, Mode 1, had valid acoustic recordings in Run10. Positions D (Buoy6), B (Buoy11), and F (Buoy9) had valid acoustic recordings. However, position F was too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the SWATHPlus, Mode 1, are shown in **Figure 4.9.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run10, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 234 kHz, propagation loss was very high and the signal was only observable for 1 minute (30 seconds before and 30 seconds after the CPA). The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at position F because of propagation loss of the VHF signal.

The results panels (**Figure 4.9.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the SWATHPlus at S2, only positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 30 to 130 m. The shape of the position D and B data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes a reference curve: spherical spreading [20 $\log_{10}$ (*range*)], which predicts received levels for a 225 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.9.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 140°, indicating an error in the buoy positioning. For position B, the received peak level is at approximately 90°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, the figure is a rough estimate of the shape of the beam pattern.

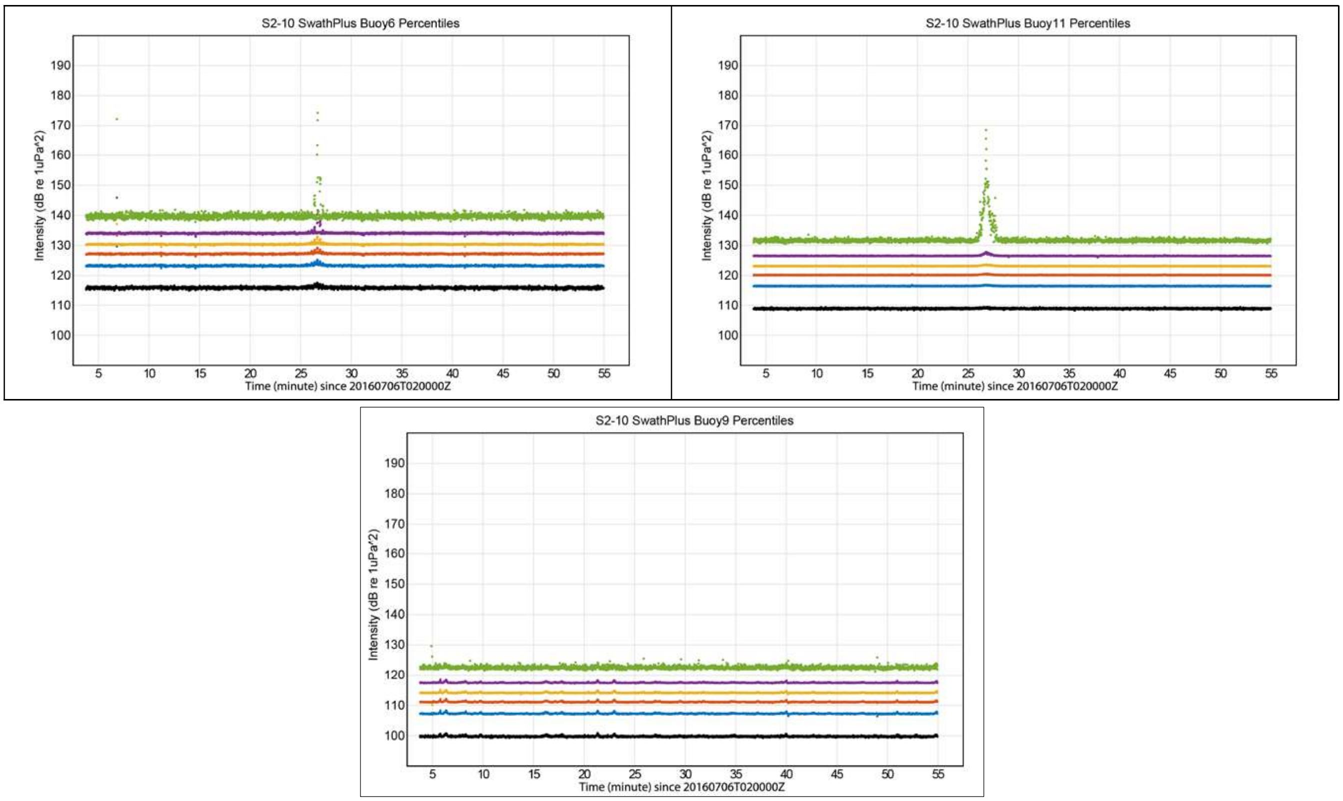


Figure 4.9.2-1. Percentile plots of SWATHPlus signals at Site 2.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

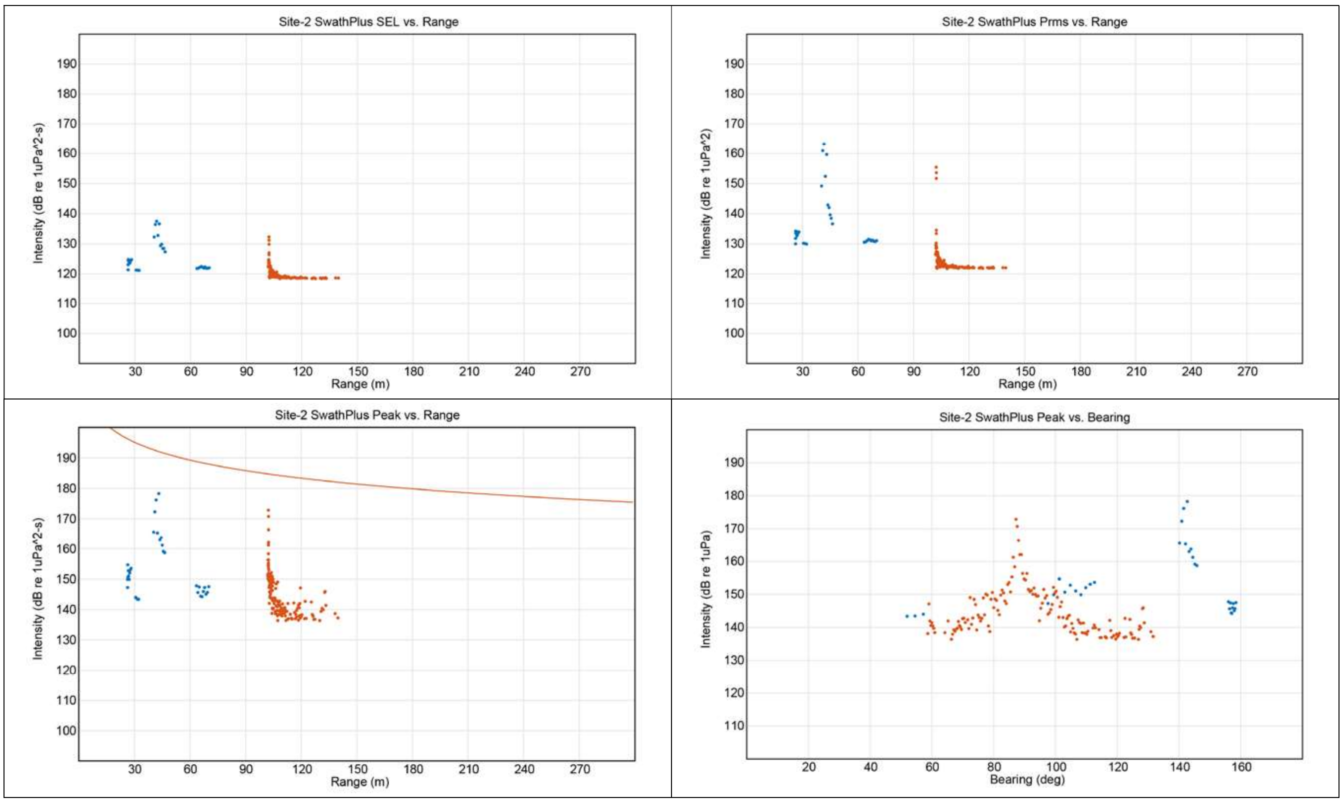


Figure 4.9.2-2. Range results for SWATHPlus signals at Site 2 for positions D (Buoy6) and B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.9.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 30,-45 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -90 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately -45 m on the y-axis, while position B had high amplitudes at approximately 0 m.

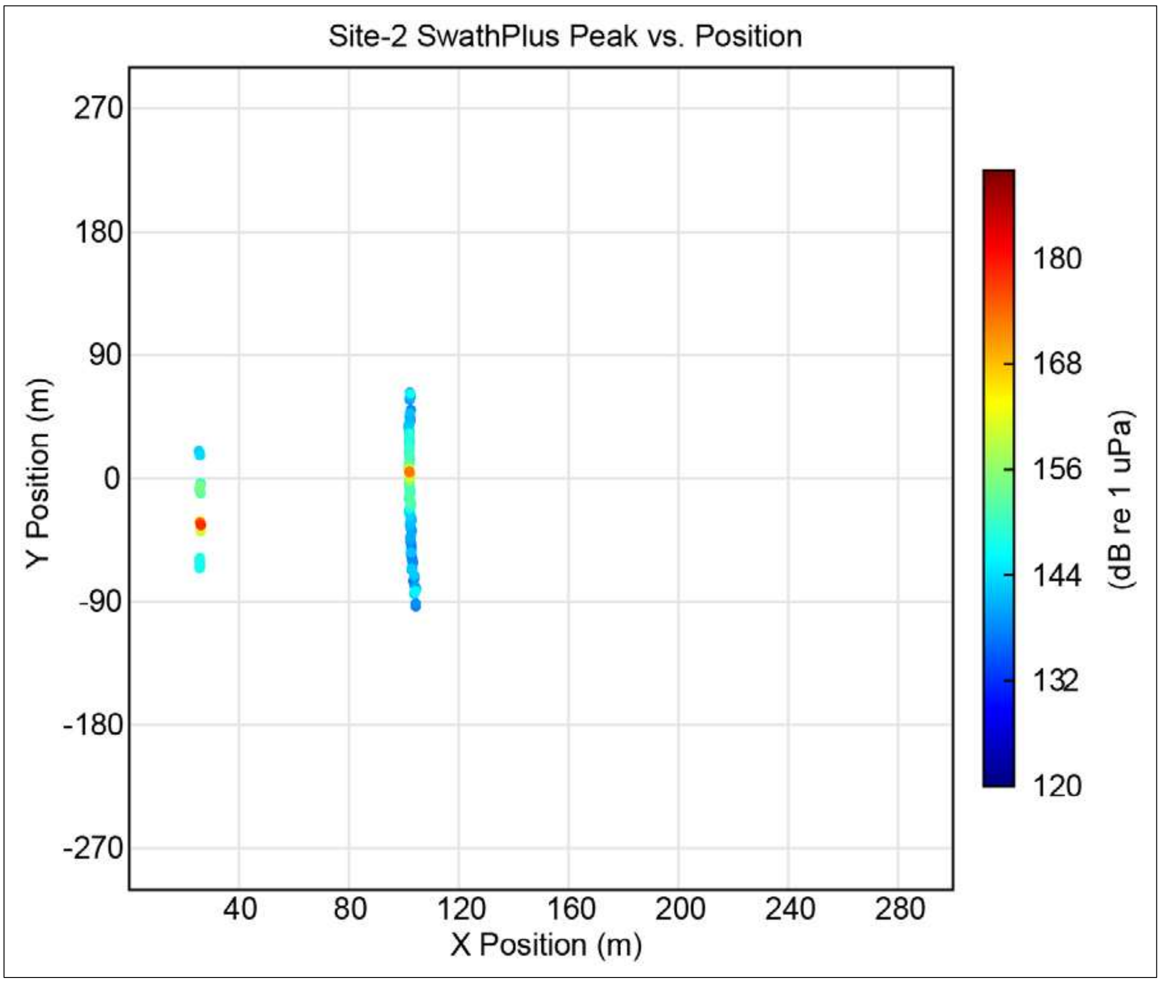


Figure 4.9.2-3. Plan view of received peak level for SWATHPlus at Site 2 for position D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.9.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.9.2-1. SWATHPlus source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
SWATHPlus Mode 1	234 kHz	100%	NA	12 cycles	214	196	178
NUWC	234 kHz	100%	NA	10 cycles	225	218	174

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.9.3 Site 3 – Mud, 30 m Depth

The SWATHPlus, Mode 1, was not deployed or operated at S3.

4.9.4 Site 4 – Sand, 30 m Depth

The SWATHPlus, Mode 1, was not deployed or operated at S4.

4.9.5 Site 5 – Sandy-Silt, 100 m Depth

The SWATHPlus, Mode 1, was not deployed or operated at S5.

4.10 SEA SWATHPlus, 234 kHz, 100 Percent Power, 60 cycles (Mode 2)

The SWATHPlus multibeam echosounder generates a single, very high-frequency (VHF) signal with a peak frequency of 234 kHz. The operational parameter settings for Mode 2 were 100 percent power and 60 cycles. This source configuration was only deployed at S2 during Run11. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.10-1** contains the selected frequency band (225 to 245 kHz) and SPL_{pk} (145 dB re 1 µPa) that were applied to the signal for further analysis. The peak results were very sensitive to the frequency band, which was not expected. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.10-1. Bandpass determination for the SWATHPlus, 234 kHz, 100 percent power, 60 cycles at Site 2, Run11.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
150-250	145.98
210-250	145.91
225-245	**144.84**
228-238	116.10

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The SWATHPlus, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.10-1**.

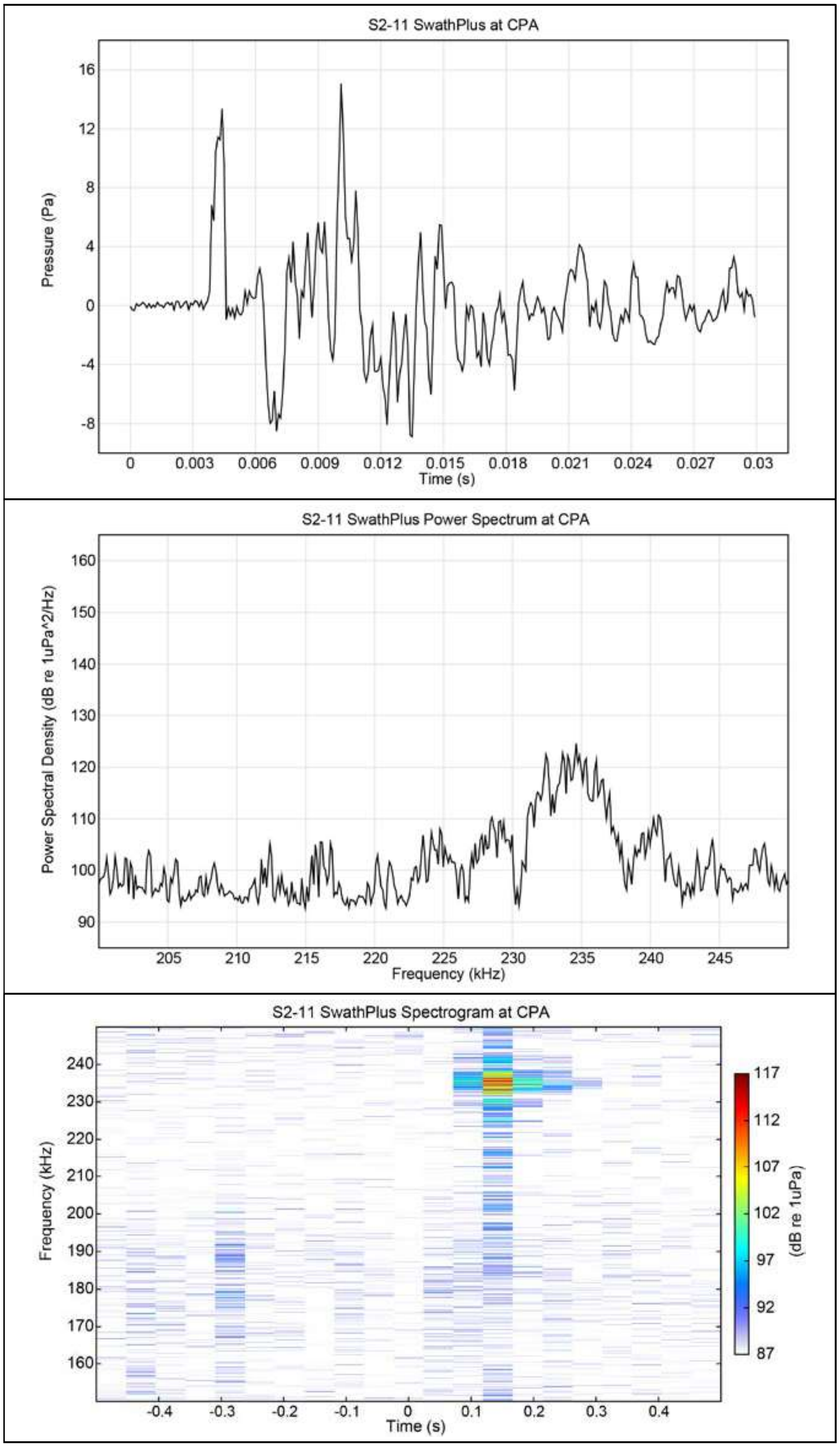


Figure 4.10-1. SWATHPlus measured signal characteristics at closest point of approach (CPA) at Site 2, Run11.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.10.1 Site 1 – Mud, 10 m Depth

The SWATHPlus, Mode 2, was not deployed or operated at S1.

4.10.2 Site 2 – Sand, 10 m Depth

At S2, the SWATHPlus, Mode 2, had valid acoustic recordings in Run11 at positions D (Buoy6), B (Buoy11), and F (Buoy9). However, position F (Buoy9) was too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the SWATHPlus, Mode 2, are shown in **Figure 4.10.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run11, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at position F because of propagation loss of the VHF signal.

The results panels (**Figure 4.10.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the SWATHPlus at S2, only positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 150 m. The conical shape of the position D and position B data points signifies the approach and departure of the source to and from the buoys. The difference (separation of the tracks) could be azimuthal dependence of the source or a small error in the buoy position relative to the reconstruction of the buoy positioning. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predicts received levels for a 223 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.10.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D (Buoy6) at approximately 120°, indicating an error in buoy positioning. For position B, the received peak level is at approximately 90°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

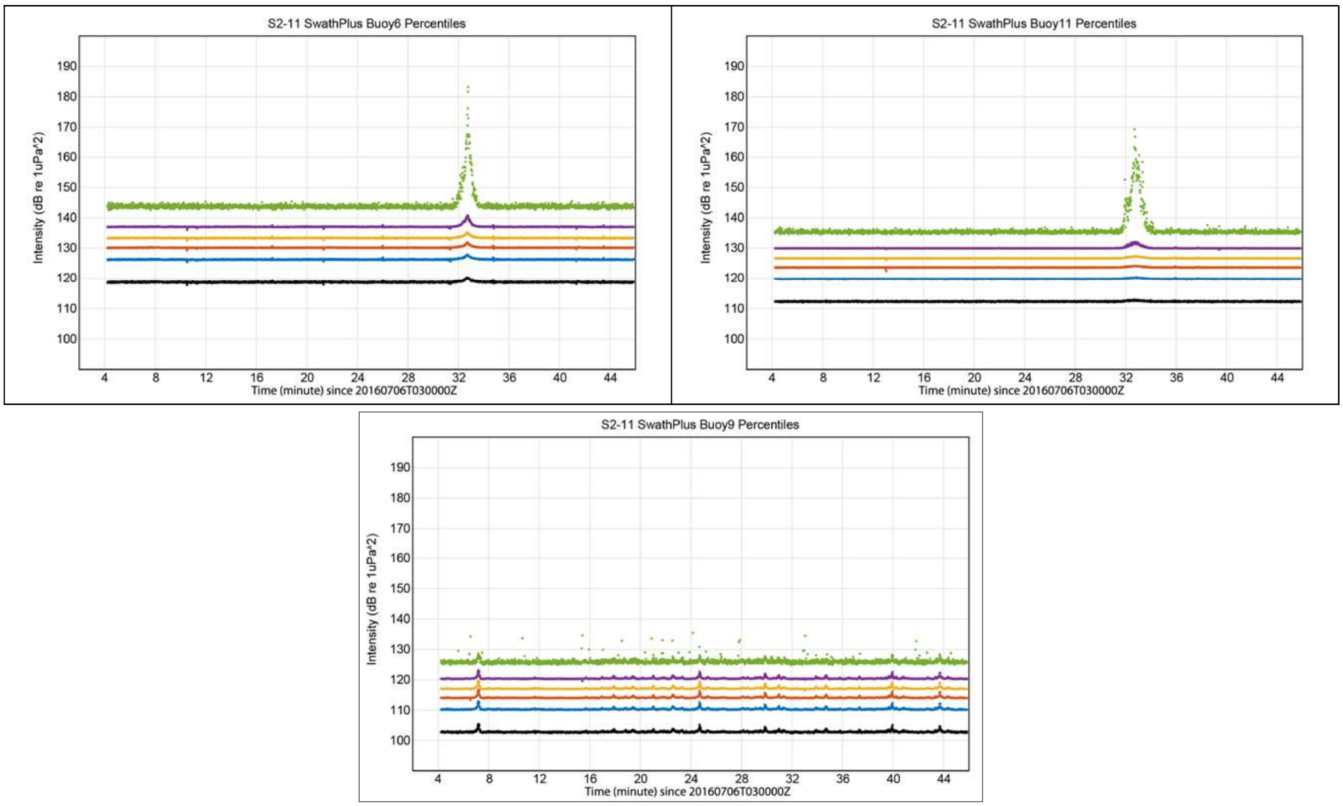


Figure 4.10.2-1. Percentile plots of SWATHPlus signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

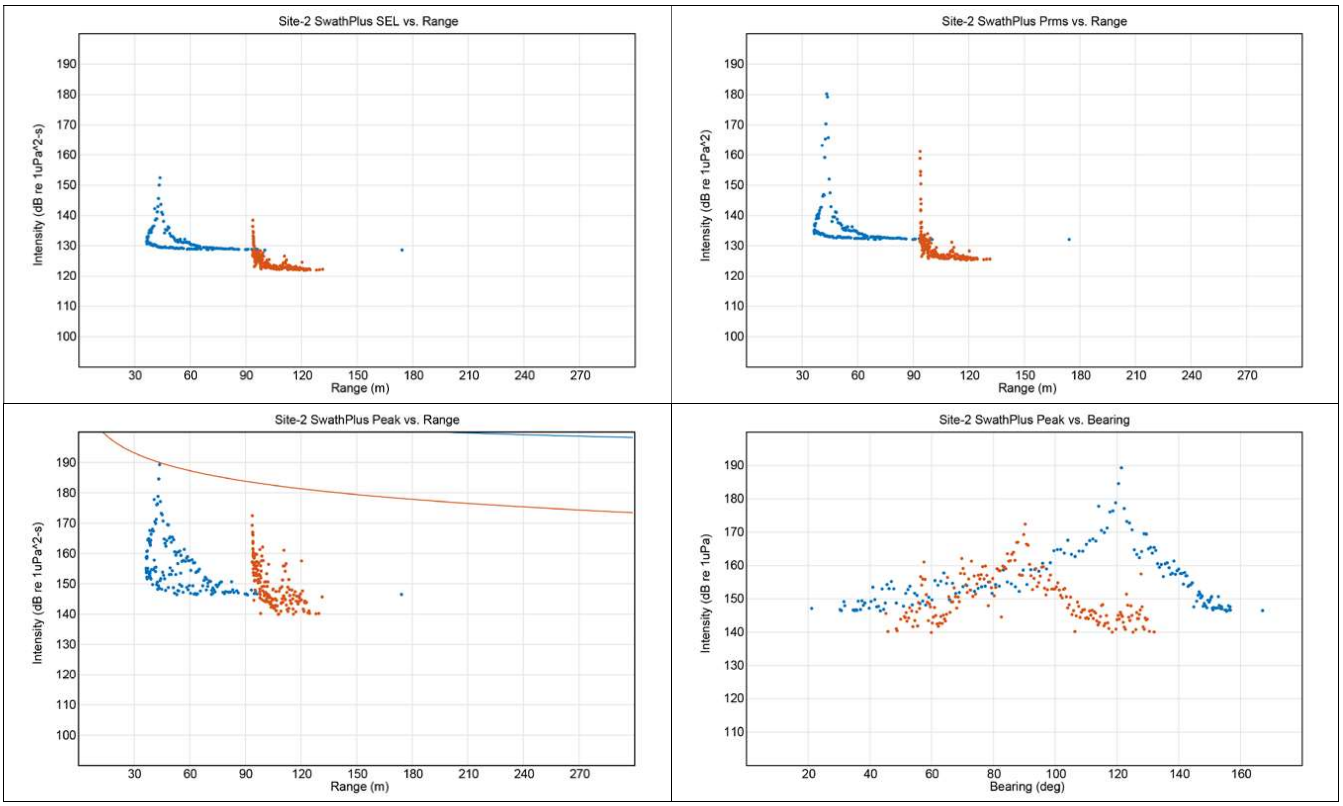


Figure 4.10.2-2. Range results for SWATHPlus signals at Site 2 for positions D (Buoy6) and B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.10.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 40,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -90 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately -20 m on the y-axis, while position B had high amplitudes at approximately 0 m.

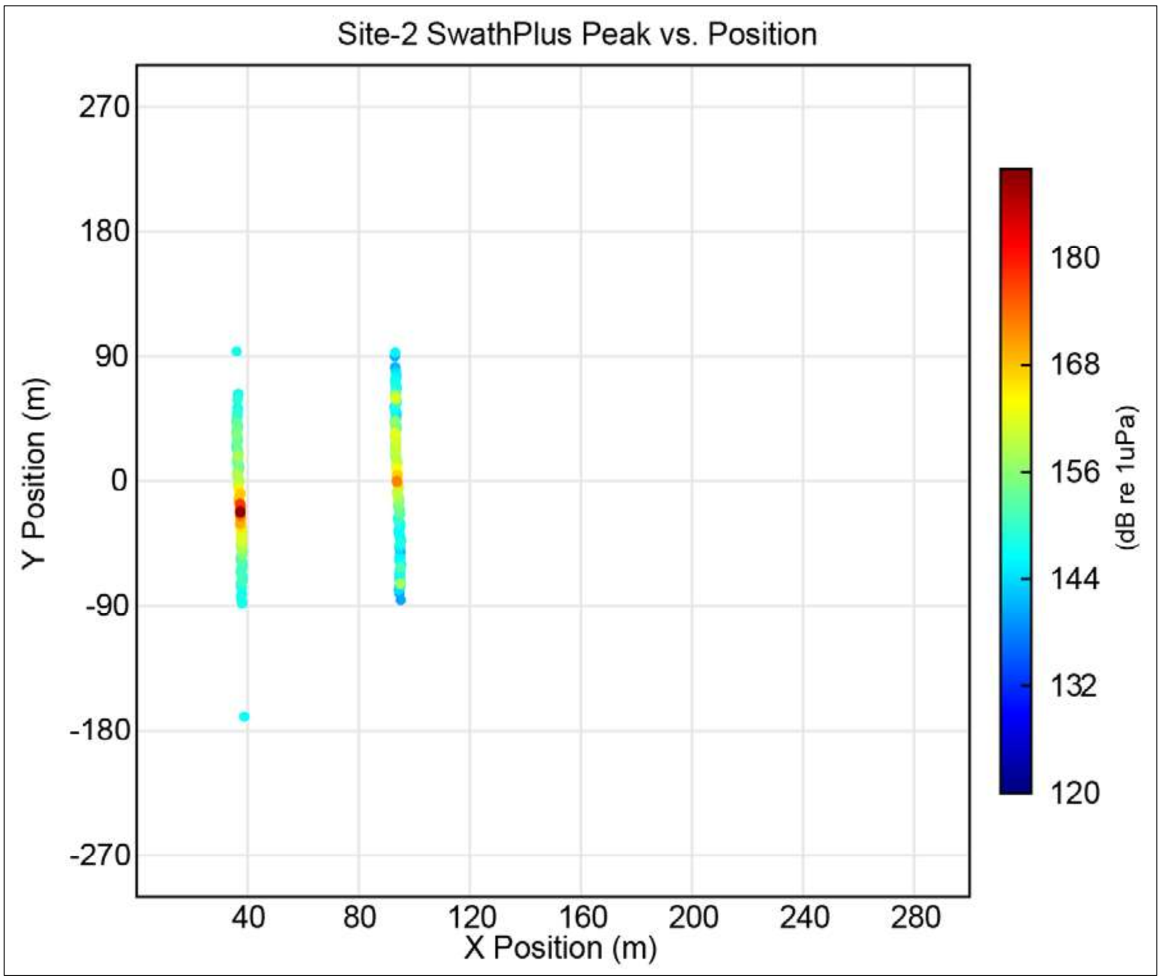


Figure 4.10.2-3. Plan view of received peak level for SWATHPlus at Site 2 for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.10.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.10.2-1. SWATHPlus source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
SWATHPlus Mode 2	234 kHz	100%	NA	60 cycles	206	212	184
NUWC	234 kHz	100%	NA	50 cycles	223	218	180

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.10.3 Site 3 – Mud, 30 m Depth

The SWATHPlus, Mode 2, was not deployed or operated at S3.

4.10.4 Site 4 – Sand, 30 m Depth

The SWATHPlus, Mode 2, was not deployed or operated at S4.

4.10.5 Site 5 – Sandy-Silt, 100 m Depth

The SWATHPlus, Mode 2, was not deployed or operated at S5.

This Page Intentionally Left Blank

4.11 SEA SWATHPlus, 234 kHz, 100 Percent Power, 50 cycles (Mode 3)

The SWATHPlus multibeam echosounder generates a single, very high-frequency (VHF) signal with a peak frequency of 234 kHz. The operational parameter settings for Mode 3 were 100 percent power and 50 cycles. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.11-1** contains the selected frequency band (220 to 240 kHz) and SPL_{pk} (161 dB re 1 µPa) that were applied to the signal for further analysis. The peak results were very sensitive to the frequency band, which was not expected. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.11-1. Bandpass determination for the SWATHPlus, 234 kHz, 100 percent power, 50 cycles at Site 3, Run32.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
150-250	161.36
200-250	160.87
220-240	**160.69**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The SWATHPlus, Mode 3, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.11-1**.

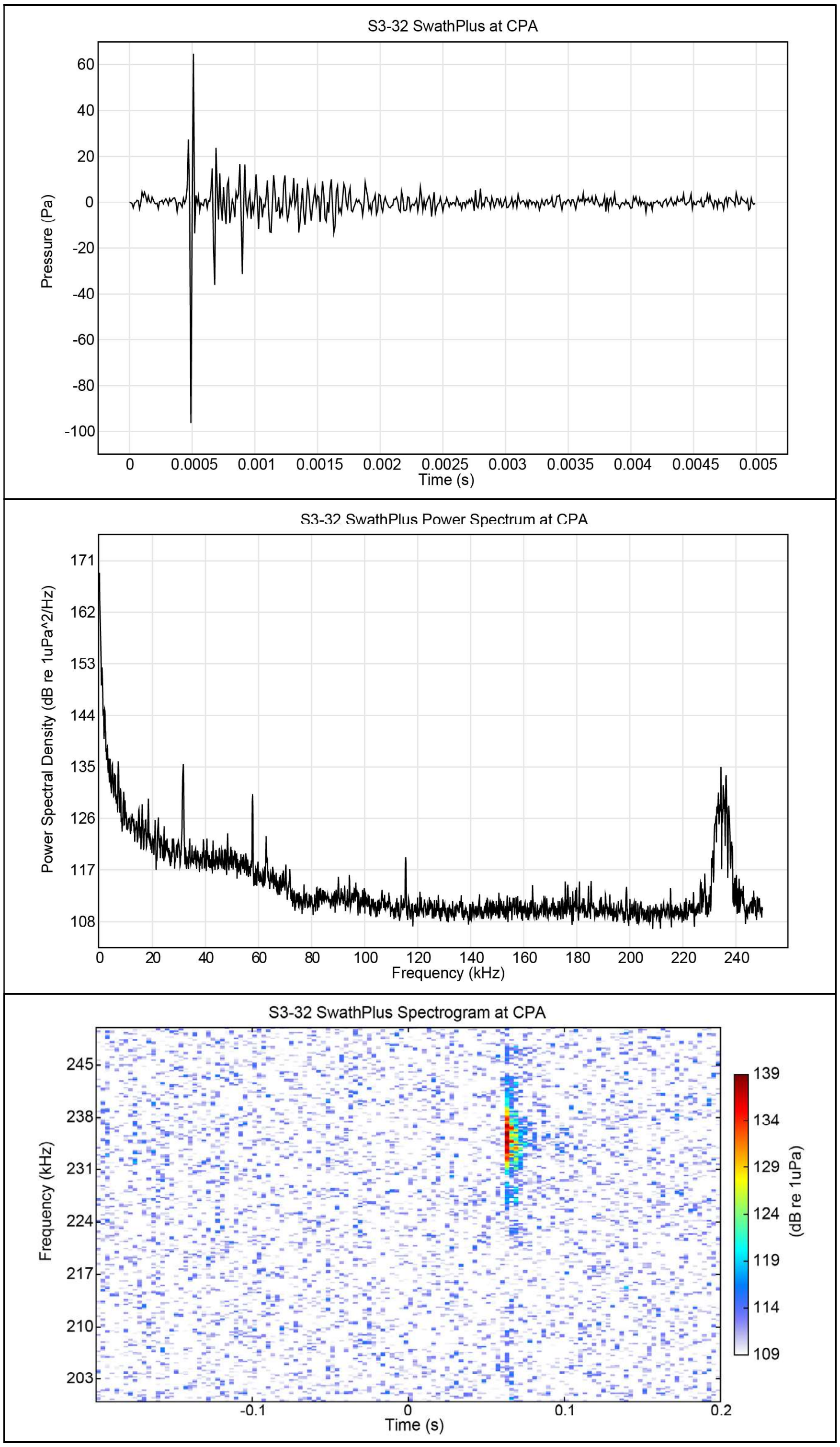


Figure 4.11-1. SWATHPlus measured signal characteristics at closest point of approach (CPA) at Site 3, Run32.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.11.1 Site 1 – Mud, 10 m Depth

The SWATHPlus, Mode 3, was not deployed or operated at S1.

4.11.2 Site 2 – Sand, 10 m Depth

At S2, the SWATHPlus, Mode 3, had valid acoustic recordings in Run37. Positions B (Buoy11) and F (Buoy9) had valid acoustic recordings. However, position F (Buoy9) was too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the SWATHPlus, Mode 3, are shown in **Figure 4.11.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The left panel shows position B (Buoy11) for Run37, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 234 kHz, the propagation loss was very high and the signal was only observable for 1 minute (30 seconds before and 30 seconds after the CPA). The right panel show the recorded acoustics at position F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at position F (Buoy9) because of propagation loss of the VHF signal.

The results panels (**Figure 4.11.2-2**) show the acoustic metrics versus range and bearing for buoys with valid acoustic data. An automated bandpass filter of 30 dB peak to 5 percent ratio was applied to the collected data. For the SWATHPlus at S2, only position B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 110 to approximately 140 m. The conical shape of the position B data points signifies the approach and departure of the source to and from the buoys. All receptions at position B are close together, showing good calibration and buoy location determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes a reference curve: spherical spreading [20 $\log_{10}$ (*range*)], which predicts received levels for a 223 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The received level was well below that expected, possibly due to a calibration error or the source did not have the intended output level.

The bottom right results panel of **Figure 4.11.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position B (Buoy11) at approximately 90°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

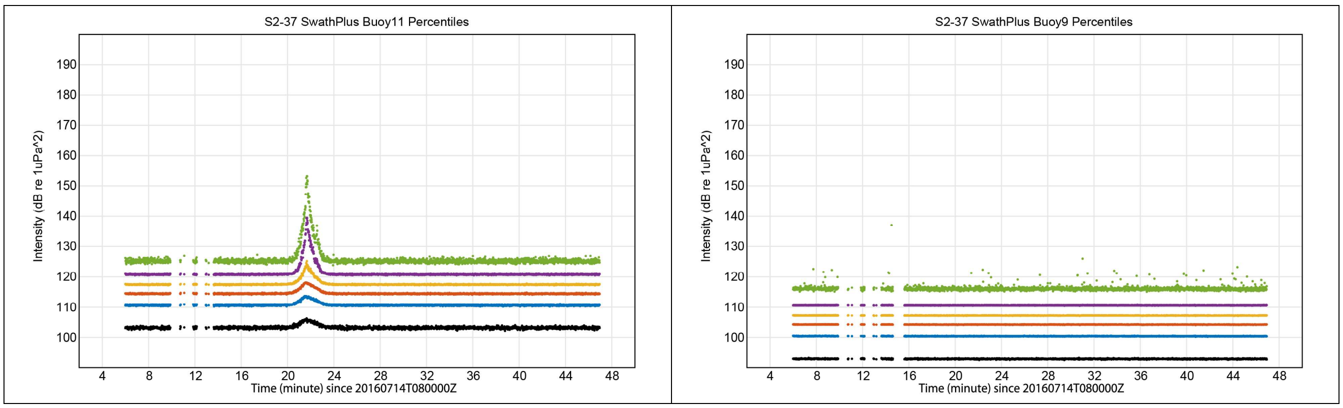


Figure 4.11.2-1. Percentile plots of SWATHPlus signals at Site 2.
Left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy11); Right: SPL_{pk} arrival at position F (Buoy9).
Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

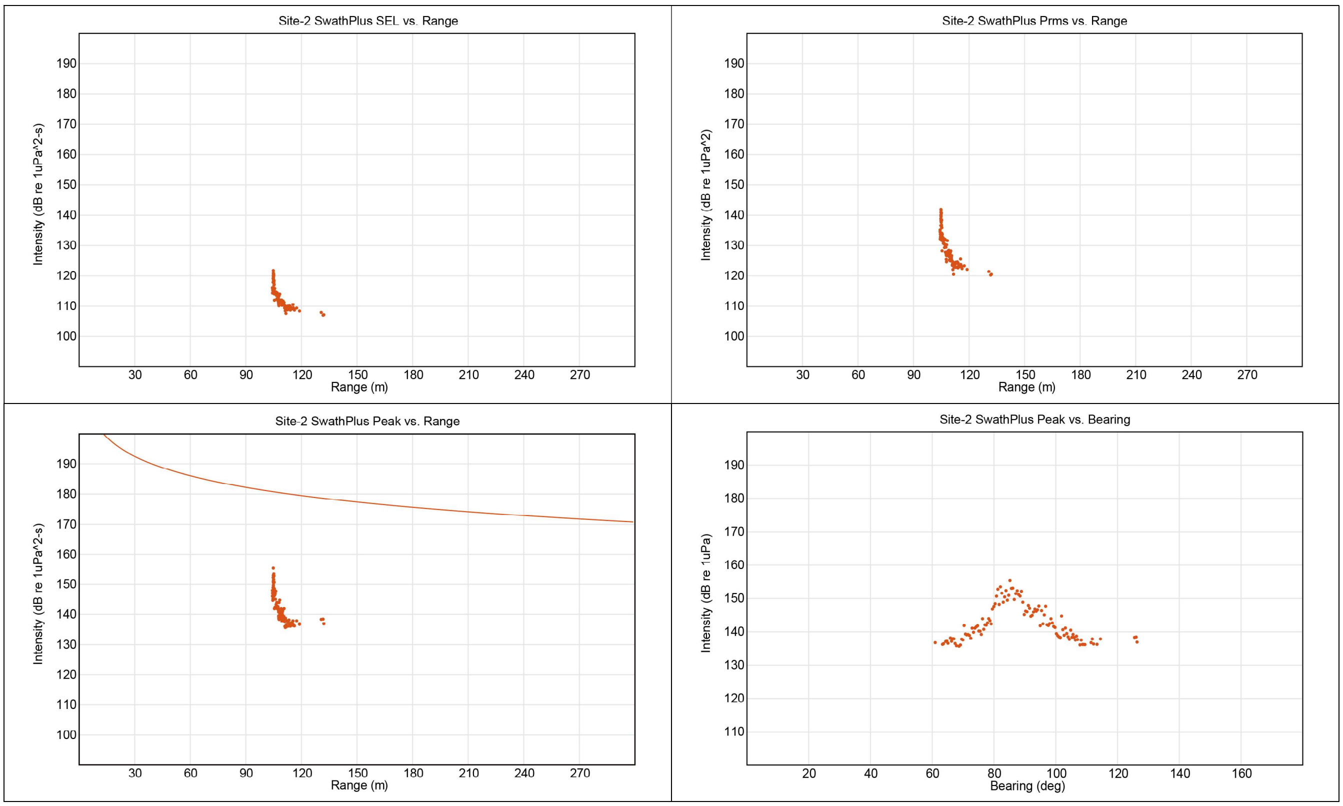


Figure 4.11.2-2. Range results for SWATHPlus signals at Site 2 for position B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.11.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -270 to 270-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level as the CPA was approached, followed by the gradual fall in received source level as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy11). Recordings at the buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position B is seen at approximately 0 m on the y-axis.

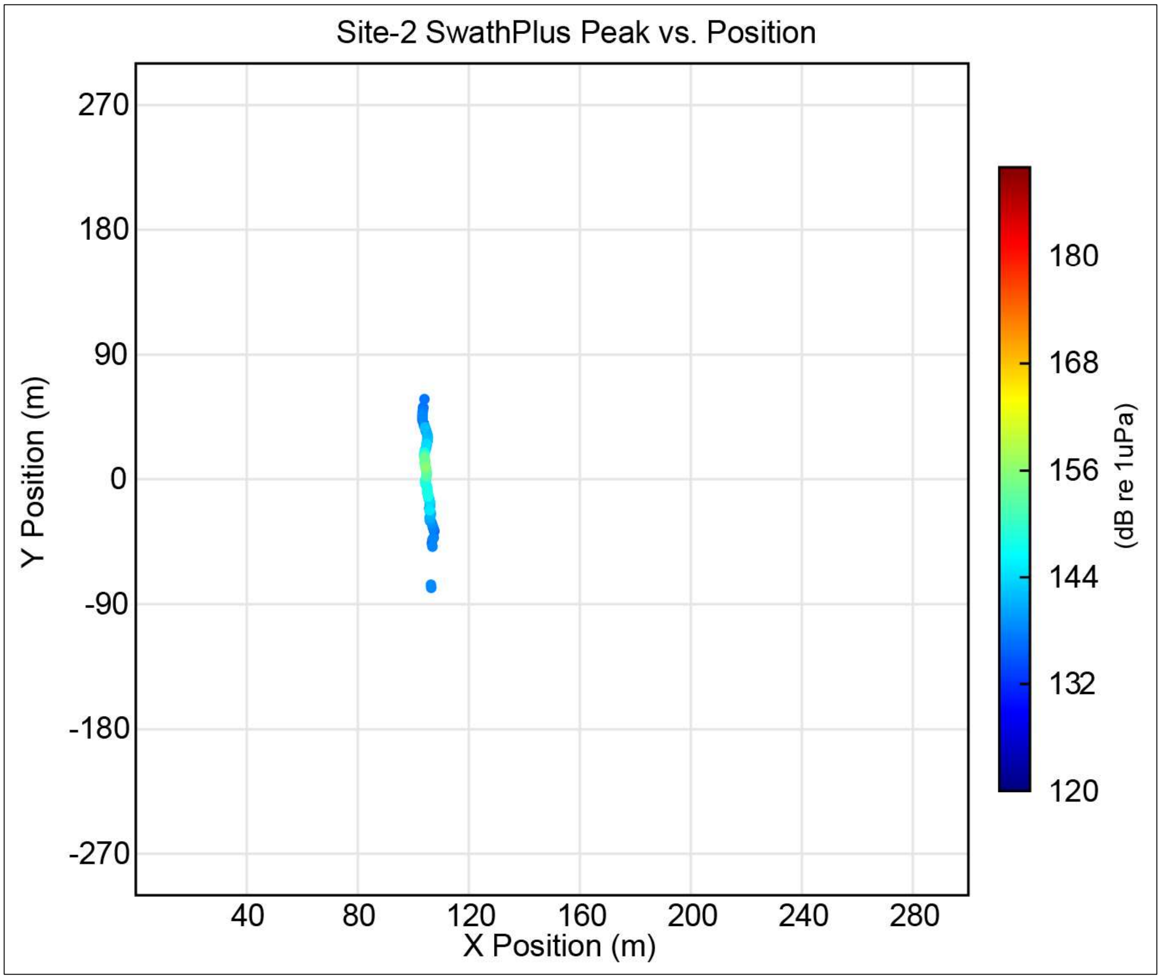


Figure 4.11.2-3. Plan view of received peak level for SWATHPlus at Site 2, showing the results for position B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.11.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.11.2-1. SWATHPlus source levels, Mode 3, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
SWATHPlus Mode 3	234 kHz	100%	NA	50 cycles	199	183	164
NUWC	234 kHz	100%	NA	50 cycles	223	218	180

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.11.3 Site 3 – Mud, 30 m Depth

At S3, the SWATHPlus, Mode 3, had valid acoustic recordings in Run4 and Run32. For Run4, most of the recordings were noise and are not reported on further. For Run32, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the SWATHPlus, Mode 3, are shown in **Figure 4.11.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run32, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 234 kHz, propagation loss was very high and the signal was observable for 1 minute (30 seconds before and 30 seconds after the CPA). The top right and bottom panels show the recorded acoustics at positions B (Buoy11), E (Buoy10), and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.11.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 23 dB peak to 5 percent ratio was applied to collected data. For the SWATHPlus at S3, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9) had acoustic signals. The recorded signals at positions E (Buoy8 and Buoy10) and F (Buoy9) are surprising given that this is a VHF signal, and the signals had a greater than 40 dB SNR. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)] that predict received levels for a 223 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The acoustic signal at position B (Buoy5) is noisy. Signal propagation clearly was better at S3 than S2 for these VHF signals.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 145°, position B at approximately 70°, position A at approximately 80°, position E at approximately 150°, and position F at approximately 125°, indicating errors in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

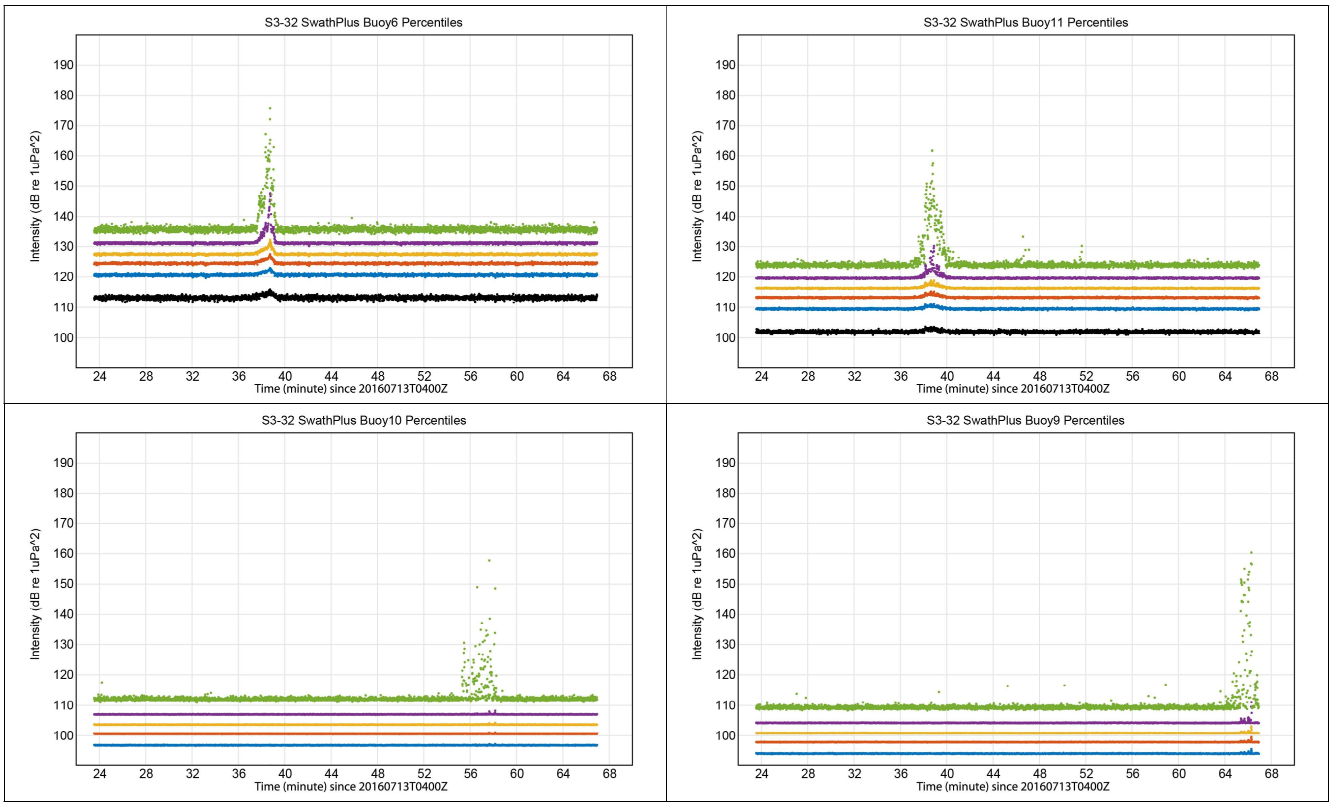


Figure 4.11.3-1. Percentile plots of SWATHPlus signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position E (Buoy10); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

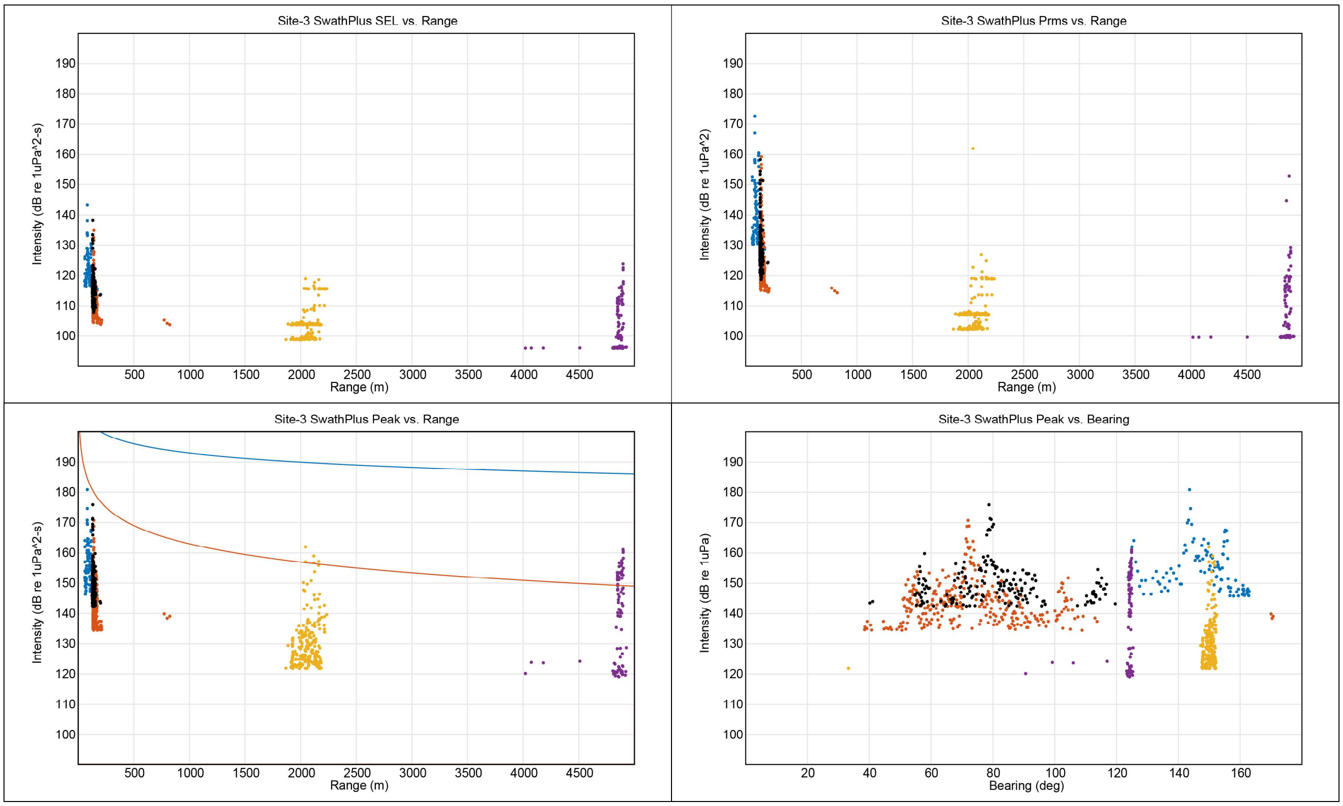


Figure 4.11.3-2. Range results for SWATHPlus combined signals for Run32 at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [$10 \log_{10}$ (*range*)] and the red line is spherical spreading [$20 \log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.11.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). For example, the highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

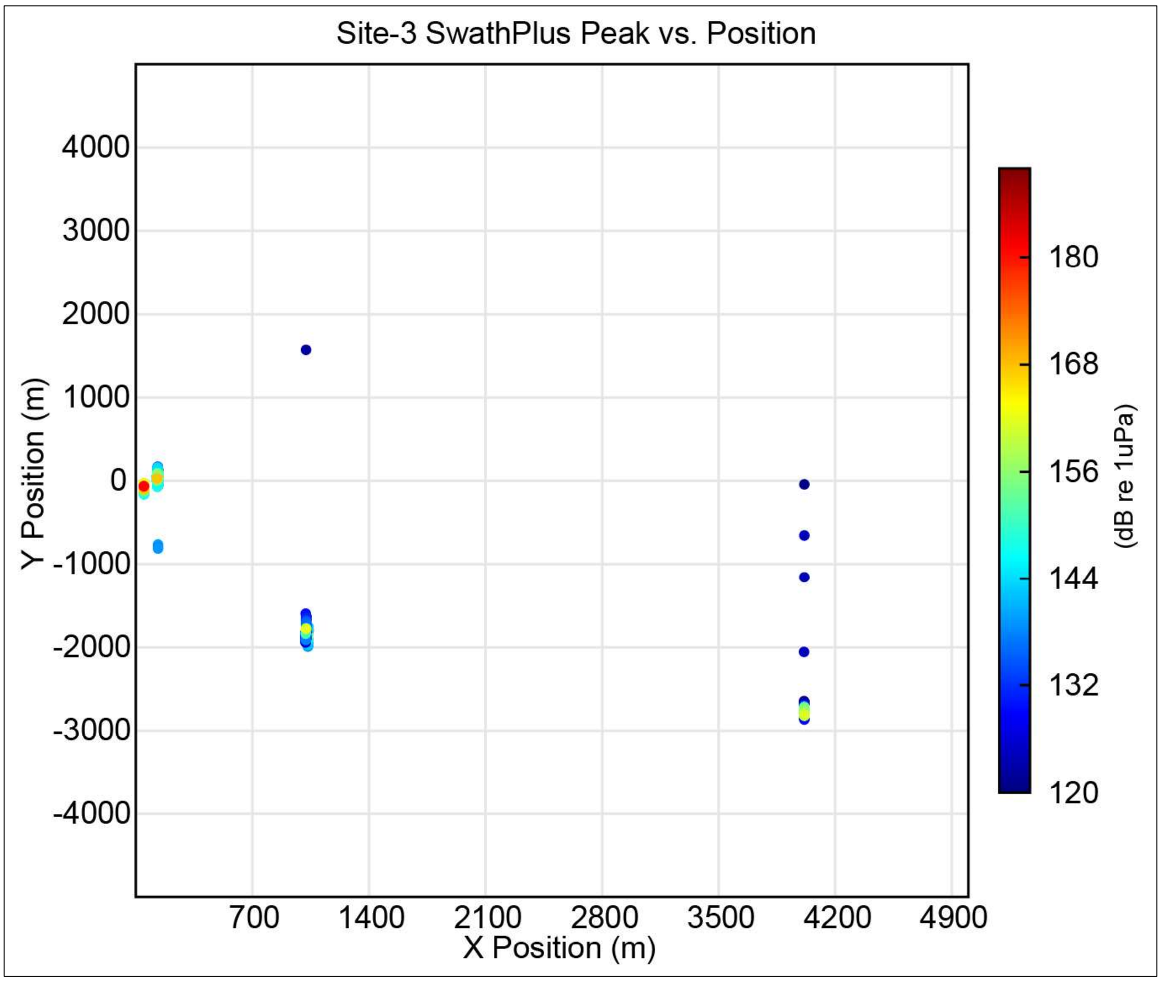


Figure 4.11.3-3. Plan view of received peak level for SWATHPlus at Site 3, showing the results for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.11.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.11.3-1. SWATHPlus source levels, Mode 3, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: Joules, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
SWATHPlus Mode 3	234 kHz	100%	NA	50 cycles	226	195	184
NUWC	234 kHz	100%	NA	50 cycles	223	218	180

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.11.4 Site 4 – Sand, 30 m Depth

At S4, the SWATHPlus, Mode 3, had valid acoustic recordings in Run15 and Run29. For Run15, no positions captured the acoustic signals. For Run29, positions A (Buoy7) and F (Buoy5) had valid acoustic recordings, but after the data were processed and plotted, no acoustic signal was observed.

Run Summary

The percentile plots for the available recordings of the SWATHPlus, Mode 3, are shown in **Figure 4.11.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The left panel shows position A (Buoy7) for Run29, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The right panel shows the acoustic data for position F (Buoy5). Both panels are devoid of acoustic signals.

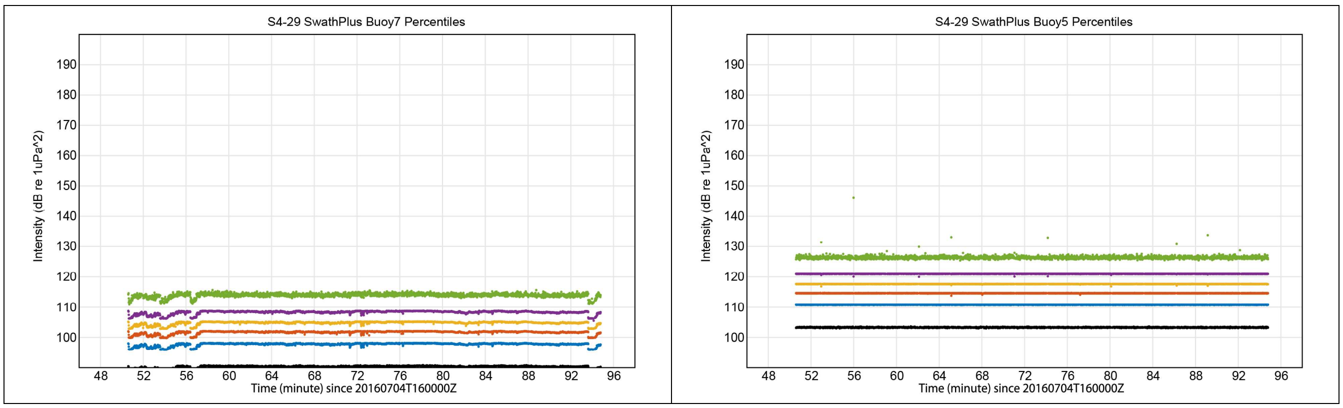


Figure 4.11.4-1. Percentile plots of SWATHPlus signals at Site 4.
Left: Closest buoy percentiles of SPL_{pk} arrival at position A (Buoy7); Right: SPL_{pk} arrival at position F (Buoy5).
Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

4.11.5 Site 5 – Sandy-Silt, 100 m Depth

The SWATHPlus, Mode 3, was not deployed or operated at S5.

4.12 SEA SWATHPlus, 234 kHz, 100 Percent Power, 250 cycles (Mode 4)

The SWATHPlus multibeam echosounder generates a single, very high-frequency (VHF) signal with a peak frequency of 234 kHz. The operational parameter settings for Mode 4 were 100 percent power and 250 cycles. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.12-1** contains the selected frequency band (225 to 245 kHz) and SPL_{pk} (126 dB re 1 µPa) that were applied to the signal for further analysis. The peak results were very sensitive to the frequency band, which was not expected. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.12-1. Bandpass determination for the SWATHPlus, 234 kHz, 100 percent power, 250 cycles at Site 3, Run5.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
210-250	125.93
225-245	**125.70**
228-238	124.82

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The SWATHPlus, Mode 4, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.12-1**.

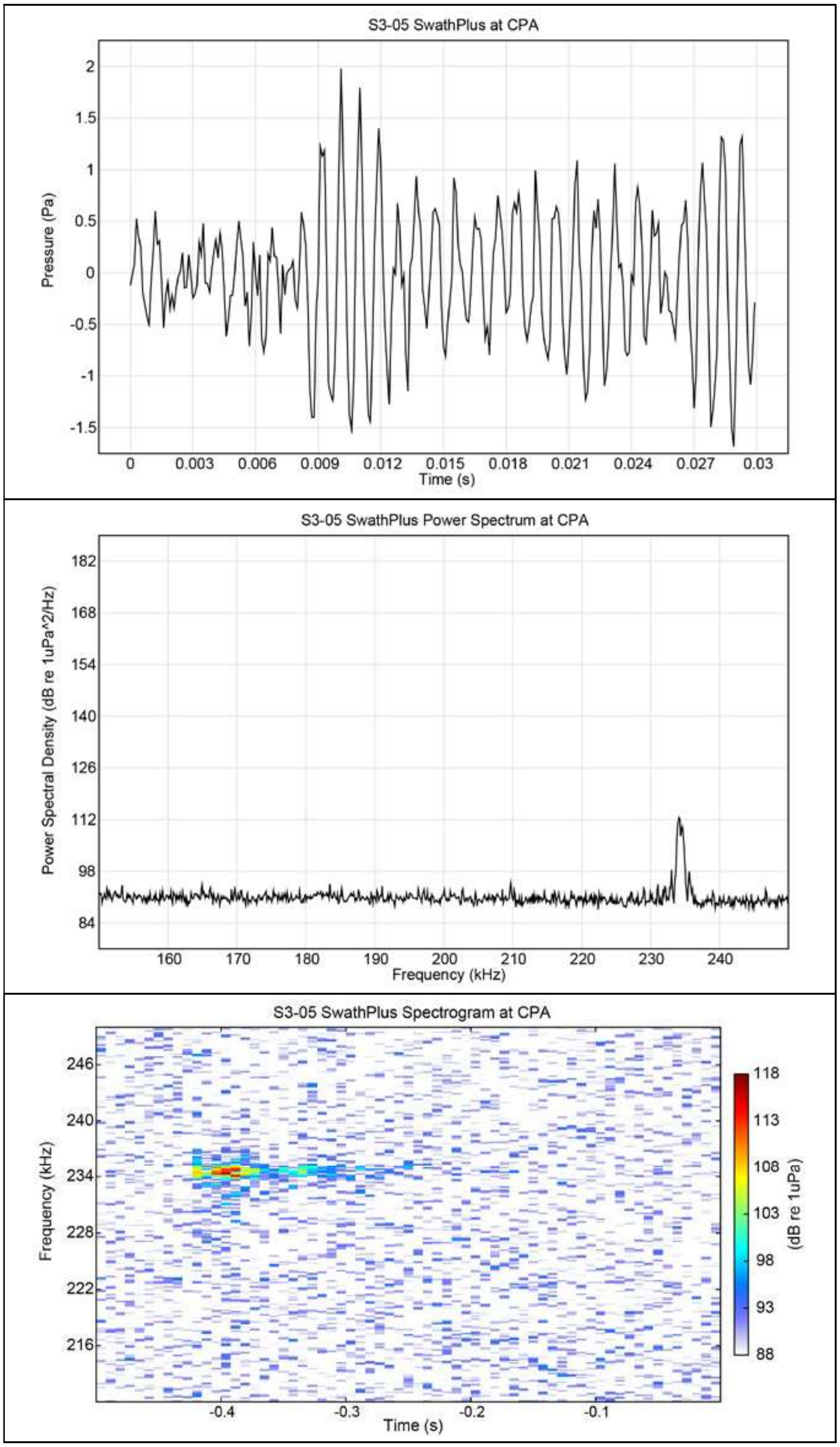


Figure 4.12-1. SWATHPlus measured signal characteristics at closest point of approach (CPA) at Site 3, Run5.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.12.1 Site 1 – Mud, 10 m Depth

The SWATHPlus, Mode 4, was not deployed or operated at S1.

4.12.2 Site 2 – Sand, 10 m Depth

The SWATHPlus, Mode 3, was not deployed or operated at S2.

4.12.3 Site 3 – Mud, 30 m Depth

At S3, the SWATHPlus, Mode 4, had valid acoustic recordings in Run5 and Run33. For Run5, the signal was received at position B (Buoy5), but it is too noisy to include in the analysis. For Run33, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9) had valid acoustic data. Signals from the VHF source were observed at positions D (Buoy6), B (Buoy11), and A (Buoy12). Positions E (Buoy8 and Buoy10) and F (Buoy9) were too distant to capture the VHF acoustic signal.

Run Summary

The percentile plots for the available recordings of the SWATHPlus, Mode 4, are shown in **Figure 4.12.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run33, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this VHF signal centered on 234 kHz, propagation loss was very high and the signal was observable for 2 minutes (60 seconds before and 60 seconds after the CPA). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and A (Buoy12). The signal quality was excellent at short range.

The results panels (**Figure 4.12.3-2**) show the acoustic metrics versus range/bearing for buoys with valid acoustic data. An automated bandpass filter of 23 dB peak to 5 percent ratio was applied to collected data. For the SWATHPlus at S3, positions D (Buoy6), B (Buoy11 and Buoy11), and A (Buoy12 and Buoy12) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 60 to approximately 200 m. The conical shape of the position D (Buoy6) data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 211 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D (Buoy6) at approximately 125°, indicating an error in buoy positioning. For positions B (Buoy11 and Buoy11) and A (Buoy12 and Buoy12), peaks were approximately 80°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

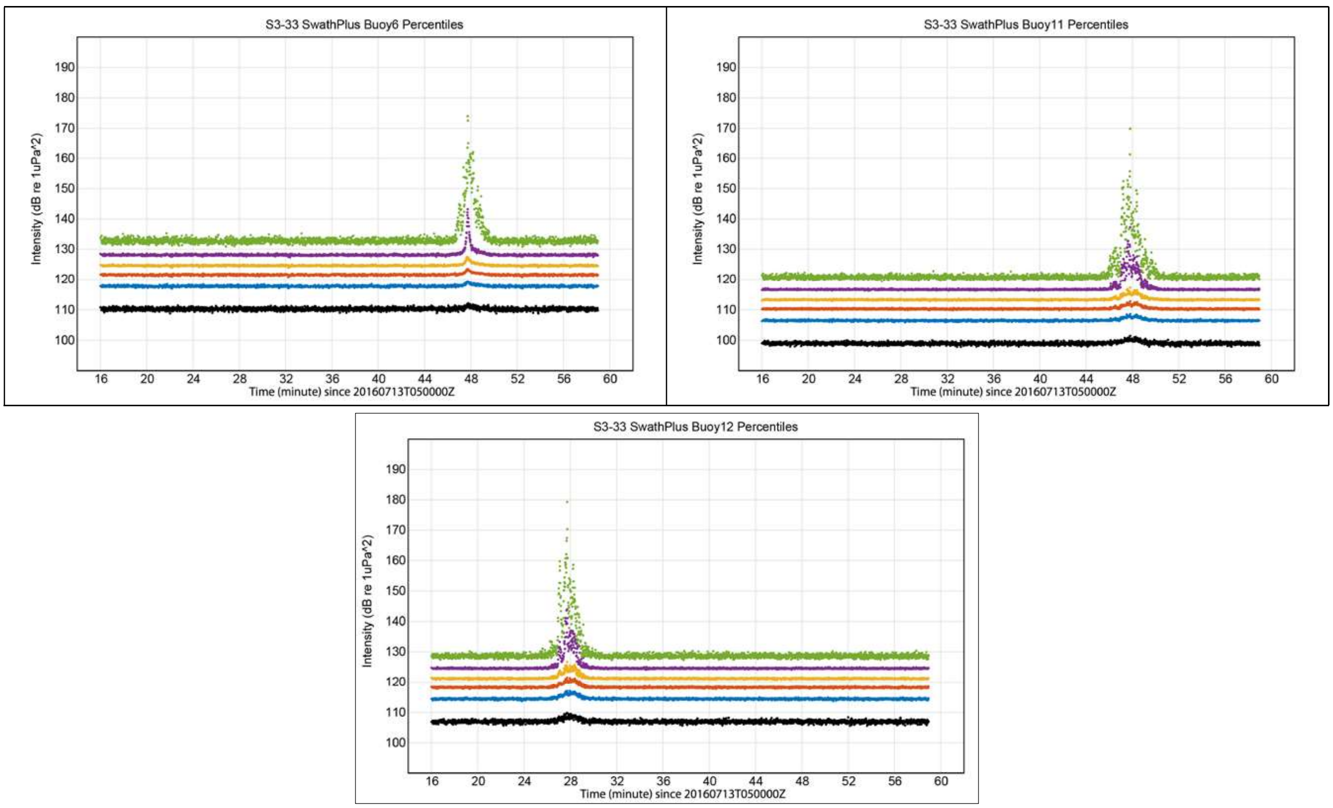


Figure 4.12.3-1. Percentile plots of SWATHPlus signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

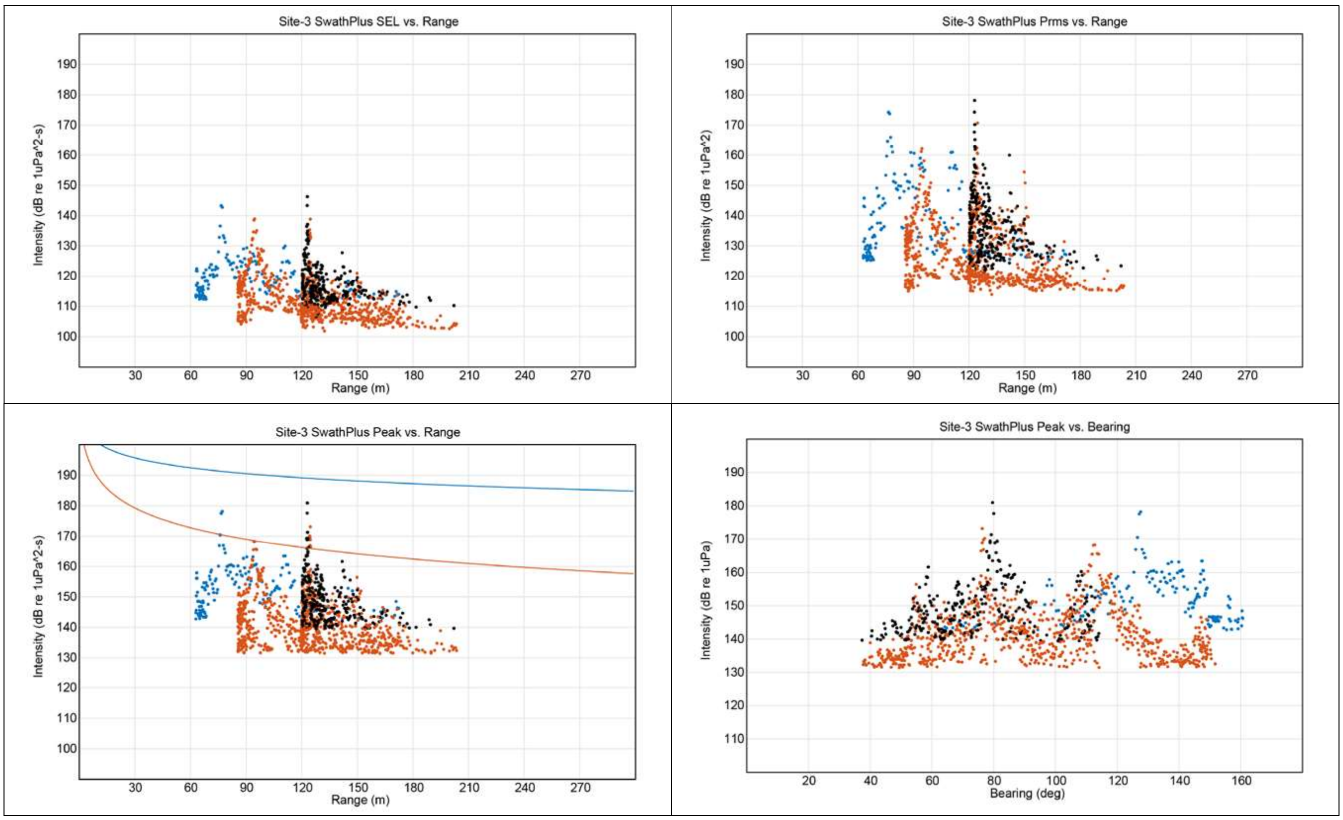


Figure 4.12.3-2. Range results for SWATHPlus combined signals for Run33 at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy11), and A (Buoy12 and Buoy12).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue.

The plan view is shown in **Figure 4.12.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 50,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 and Buoy11), and A (Buoy12 and Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately -45 m on the y-axis, while positions A and B had high amplitudes at approximately -40 and 20 m, respectively.

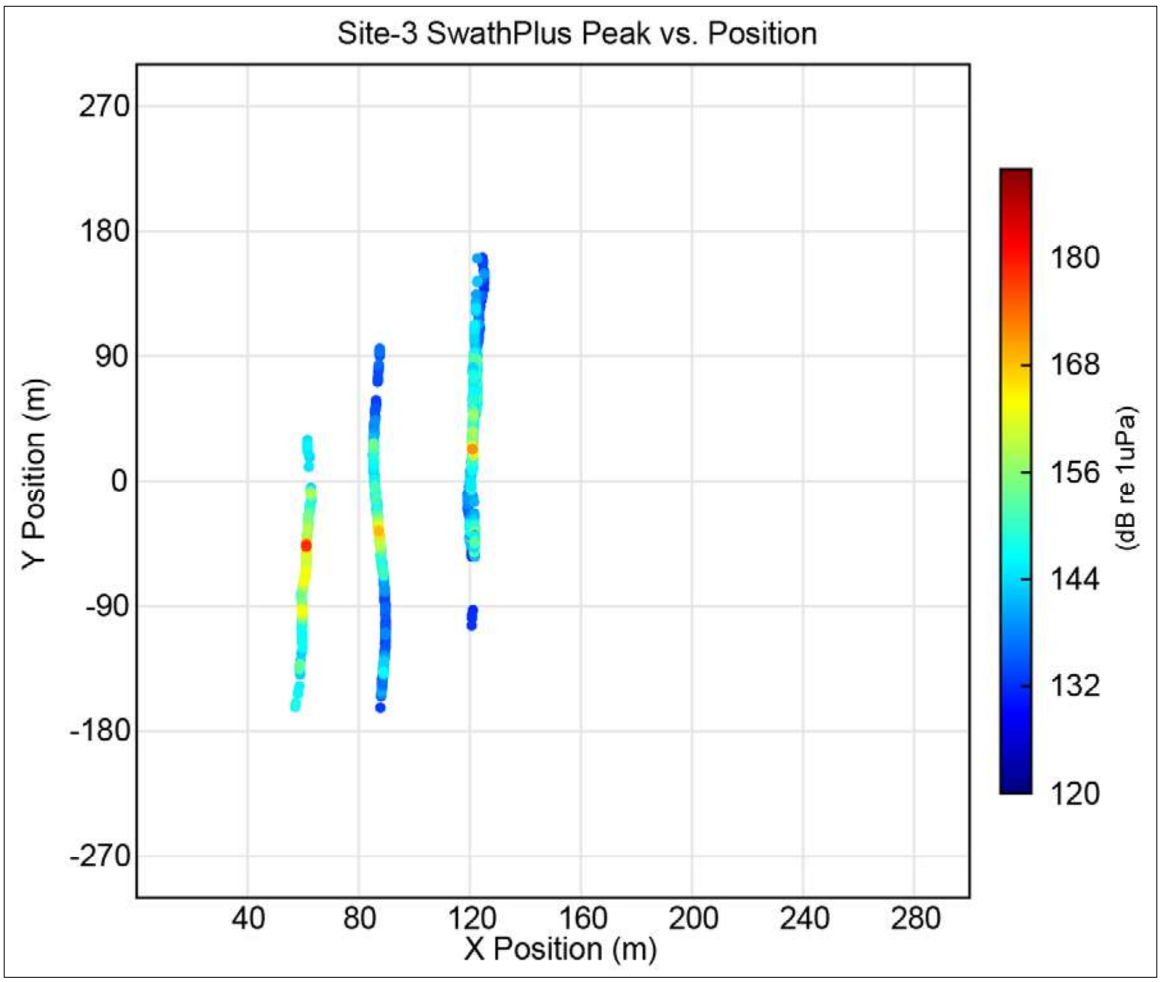


Figure 4.12.3-3. Plan view of received peak level for SWATHPlus at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy11), and A (Buoy 12 and Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.12.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.12.3-1. SWATHPlus source levels, Mode 4, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
SWATHPlus Mode 4	234 kHz	100%	NA	250 cycles	216	203	173
NUWC	234 kHz	100%	NA	250 cycles	211	207	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = sound level.

4.12.4 Site 4 – Sand, 30 m Depth

At S4, the SWATHPlus, Mode 4, had valid acoustic recordings in Run30. For Run30, position B (Buoy12) had valid acoustic recordings and a strong observed signal. Positions A (Buoy7 LS) and F (Buoy5) had valid acoustic recordings, but no signal was observed.

Run Summary

The percentiles plots for the available recordings of the SWATHPlus, Mode 4, are shown in **Figure 4.12.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run30, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recordings, without observed signal, for positions A (Buoy7) and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.12.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the SWATHPlus at S4, only position B (Buoy12) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 45 to approximately 150 m. The shape of the position B (Buoy12) data points signifies the approach and departure of the source to and from the buoy. All position B (Buoy12) receptions are close together, showing good calibration and buoy position determination. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 211 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are two peaks that appear to be invalid.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 90°, indicating good navigational buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver;

thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

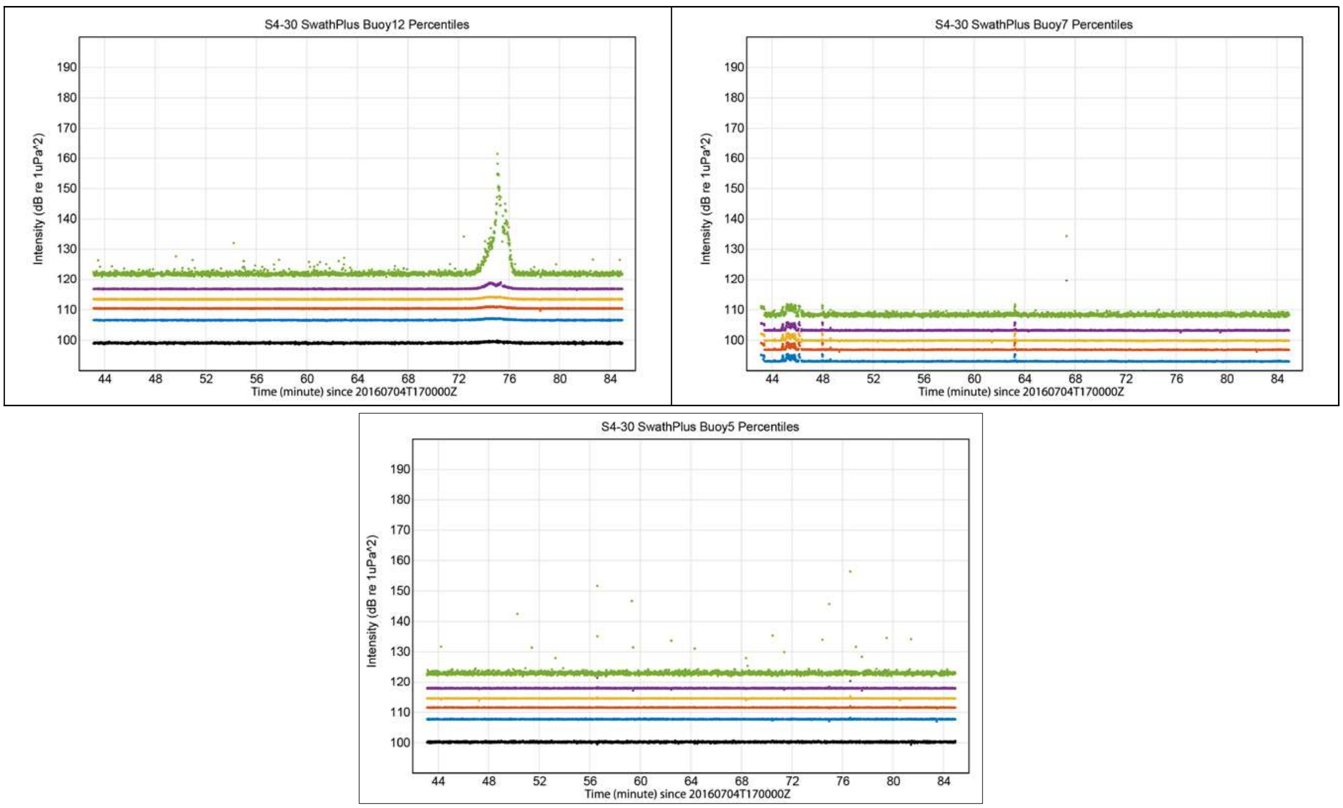


Figure 4.12.4-1. Percentile plots of SWATHPlus signals at Site 4.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy7); Bottom: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

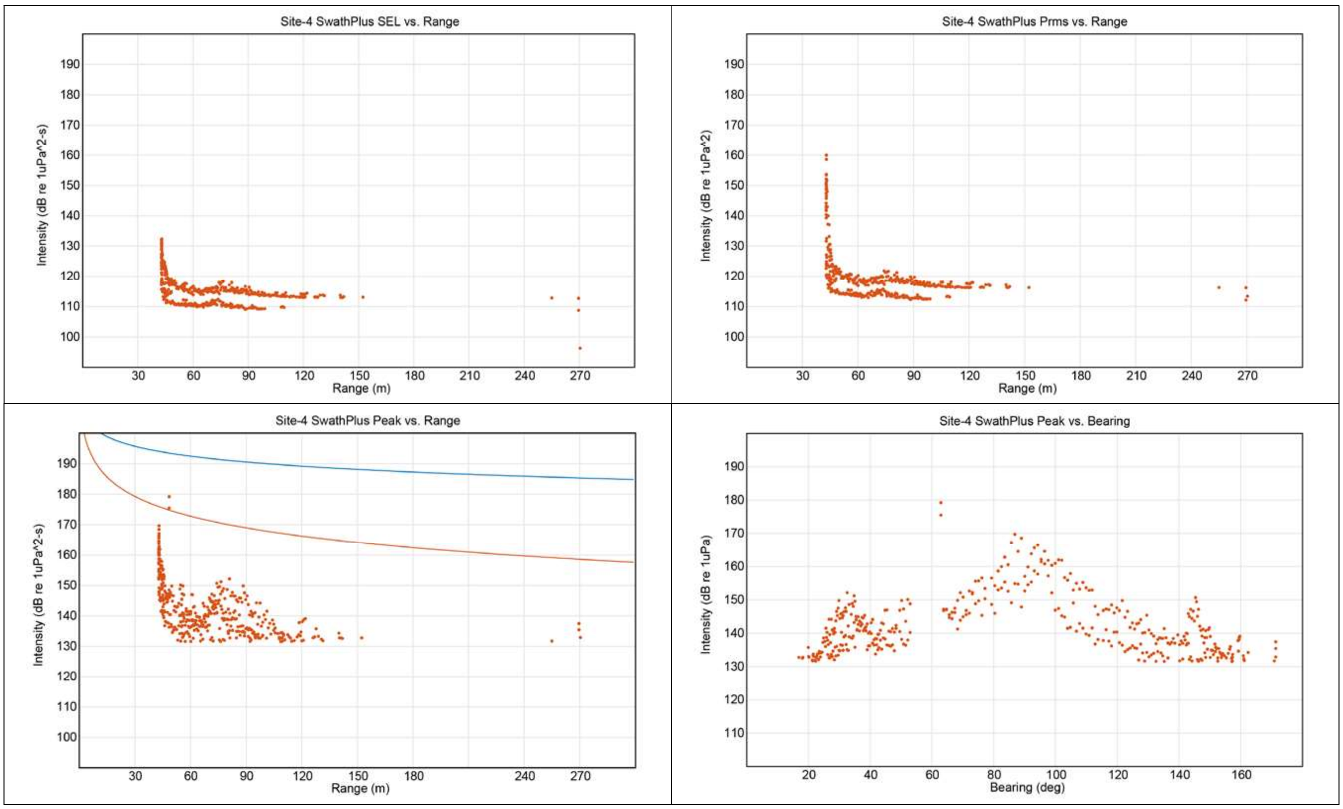


Figure 4.12.4-2. Range results for SWATHPlus signals at Site 4 for position B (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.12.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -280 to 280-m marks on the y-axis. The CPA is at 40,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -130 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy12). Recordings at the buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position B is seen at approximately 10 m on the y-axis.

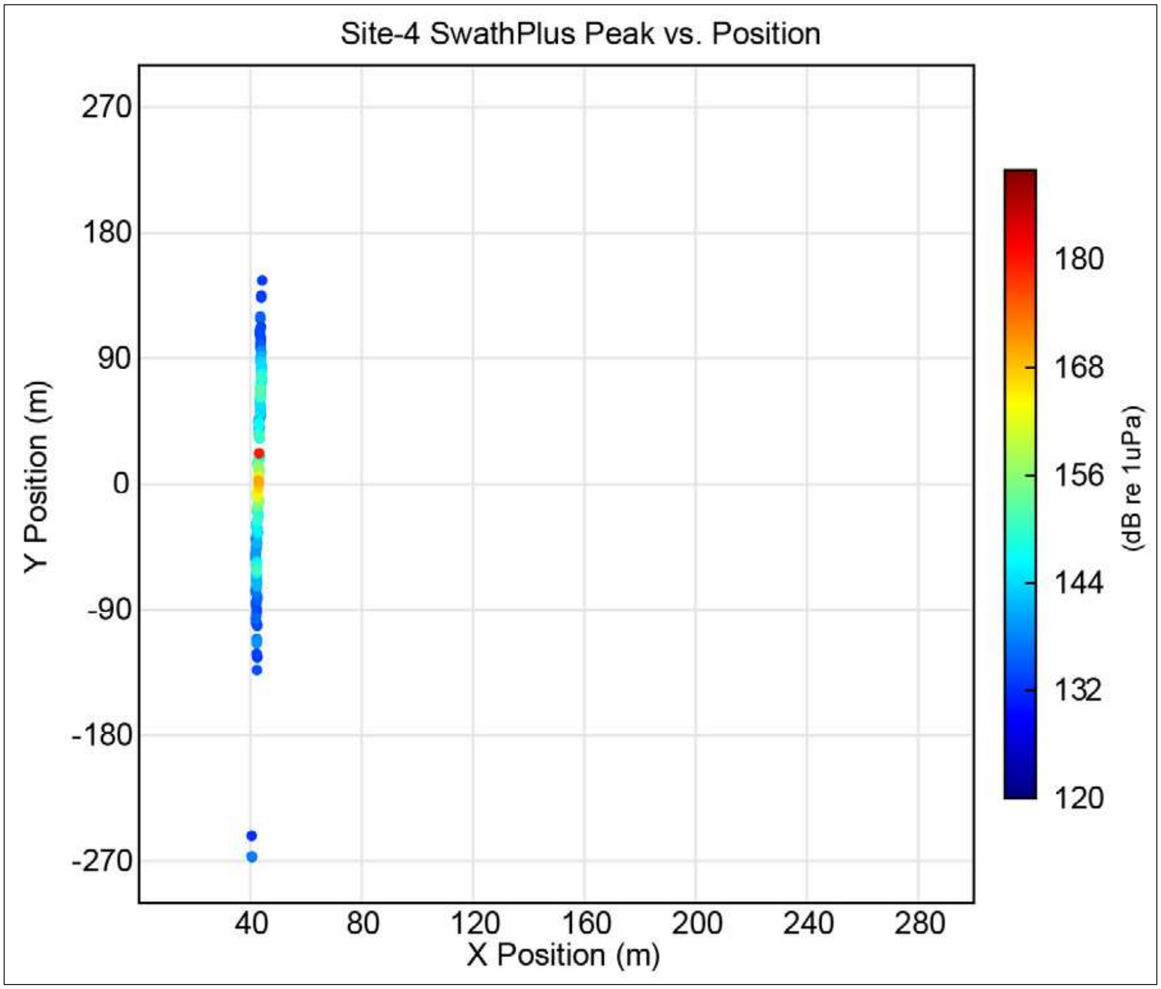


Figure 4.12.4-3. Plan view of received peak level for SWATHPlus at Site 4, showing the results for position B (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.12.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.12.4-1. SWATHPlus source levels, Mode 4, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
SWATHPlus Mode 4	234 kHz	100%	NA	250 cycles	203	193	166
NUWC	234 kHz	100%	NA	250 cycles	211	207	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; ms = millisecond; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.

4.12.5 Site 5 – Sandy-Silt, 100 m Depth

The SWATHPlus, Mode 3, was not deployed or operated at S5.

4.13 Simrad EK60, 38 kHz, 100 Percent Power, 512-µs Pulse, (Mode 1)

The EK60 split-beam echosounder generates a single, high-frequency (HF) signal with a peak frequency of 38 kHz. The operational parameter settings for Mode 1 were 100 percent power, a 512-µs pulse, and a 38-kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.13-1** is the selected frequency band (28 to 48 kHz) and SPL_{pk} (149 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.13-1. Bandpass determination for the EK60 split-beam echosounder, 38 kHz, 100 percent power, 512-µs pulse at Site 3, Run1.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
18-58	149.47
28-48	**149.37**
33-43	148.66

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The EK60, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.13-1**. Described in Chapter 2, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The EK60 was operationally paired in alternation with the ET512i (Chapter 4.20). These pairings were pre-determined to make sure that each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.13-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

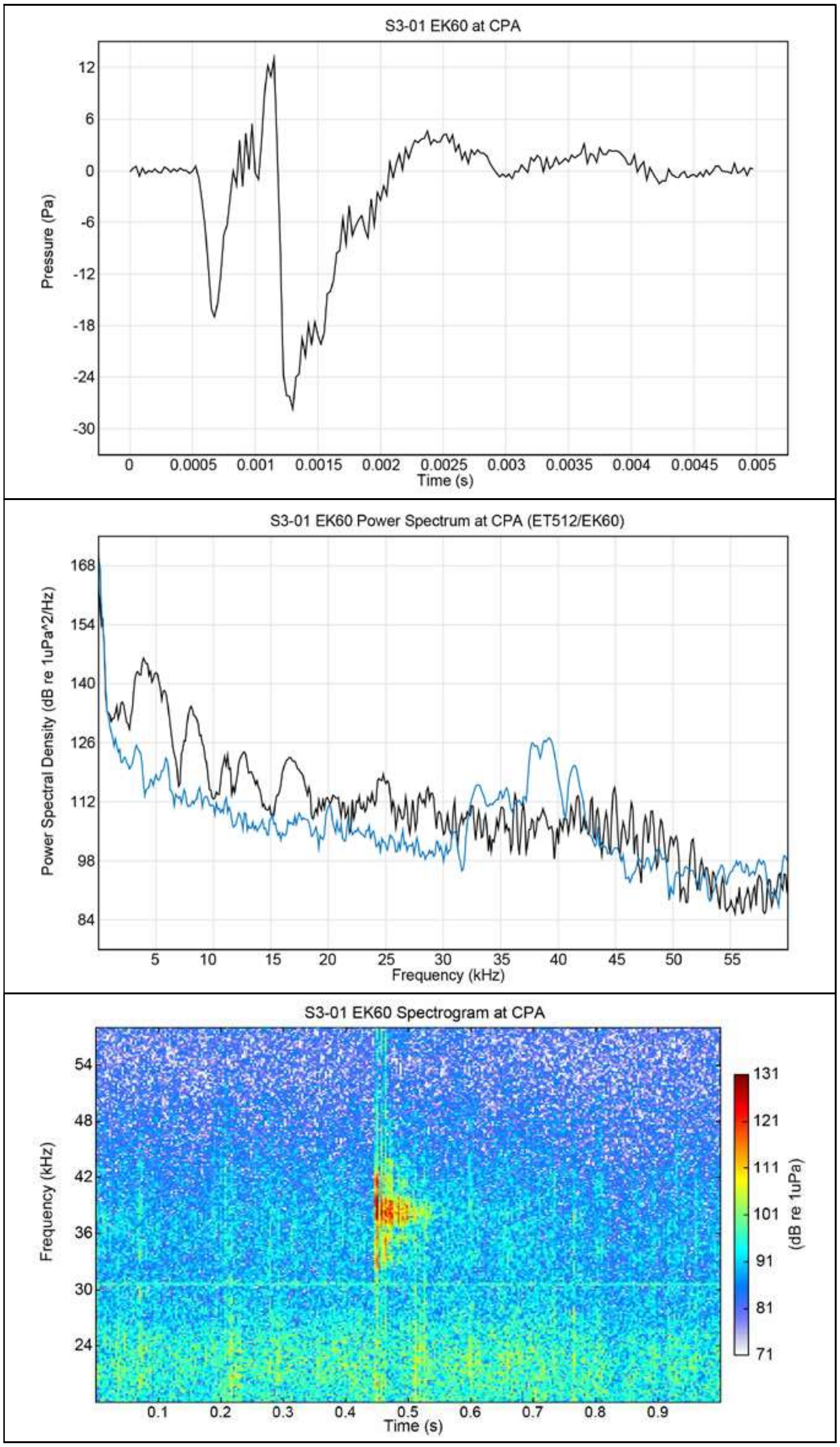


Figure 4.13-1. EK60 measured signal characteristics at closest point of approach (CPA) at Site 3, Run1.

Top: Time-waveform of a signal; Middle: Power spectral density, EK60 =blue, ET512i =black; Bottom: Spectrogram.

4.13.1 Site 1 – Mud, 10 m Depth

The EK60, Mode 1, was not deployed or operated at S1.

4.13.2 Site 2 – Sand, 10 m Depth

The EK60, Mode 1, was not deployed or operated at S2.

4.13.3 Site 3 – Mud, 30 m Depth

At S3, the EK60, Mode 1, had valid acoustic recordings in Run1 and Run21. For Run1, position B (Buoy5 and Buoy12) had valid acoustic data and observed signals. For Run21, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10) had valid acoustic data and observed signals. Position F was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the EK60, Mode 1, are shown in **Figure 4.13.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run21, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. For this HF signal centered on 38 kHz, propagation loss was high, but the signal was observable for 8 minutes (4 minutes before and 4 minuteS after the CPA). The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and A (Buoy12); note: there is replication of buoy representation because of the multiple deployments. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.13.3-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the EK60 at S3, positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy8 and Buoy10, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D (Buoy6) at approximately 120°, indicating an error in buoy positioning. Received peak levels for positions B and A are at approximately 130° and 80°, respectively, indicating errors in buoy positioning, while Position E is at and 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

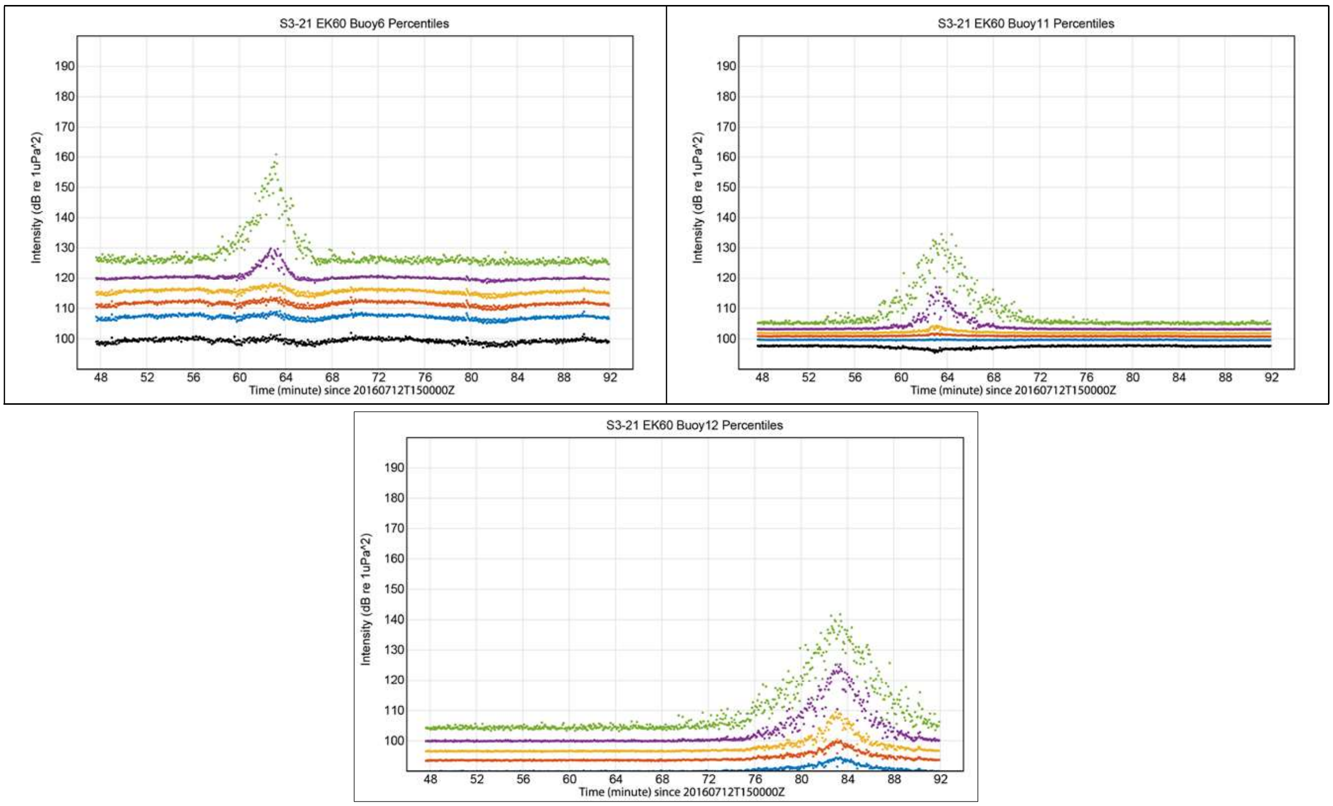


Figure 4.13.3-1. Percentile plots of EK60 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

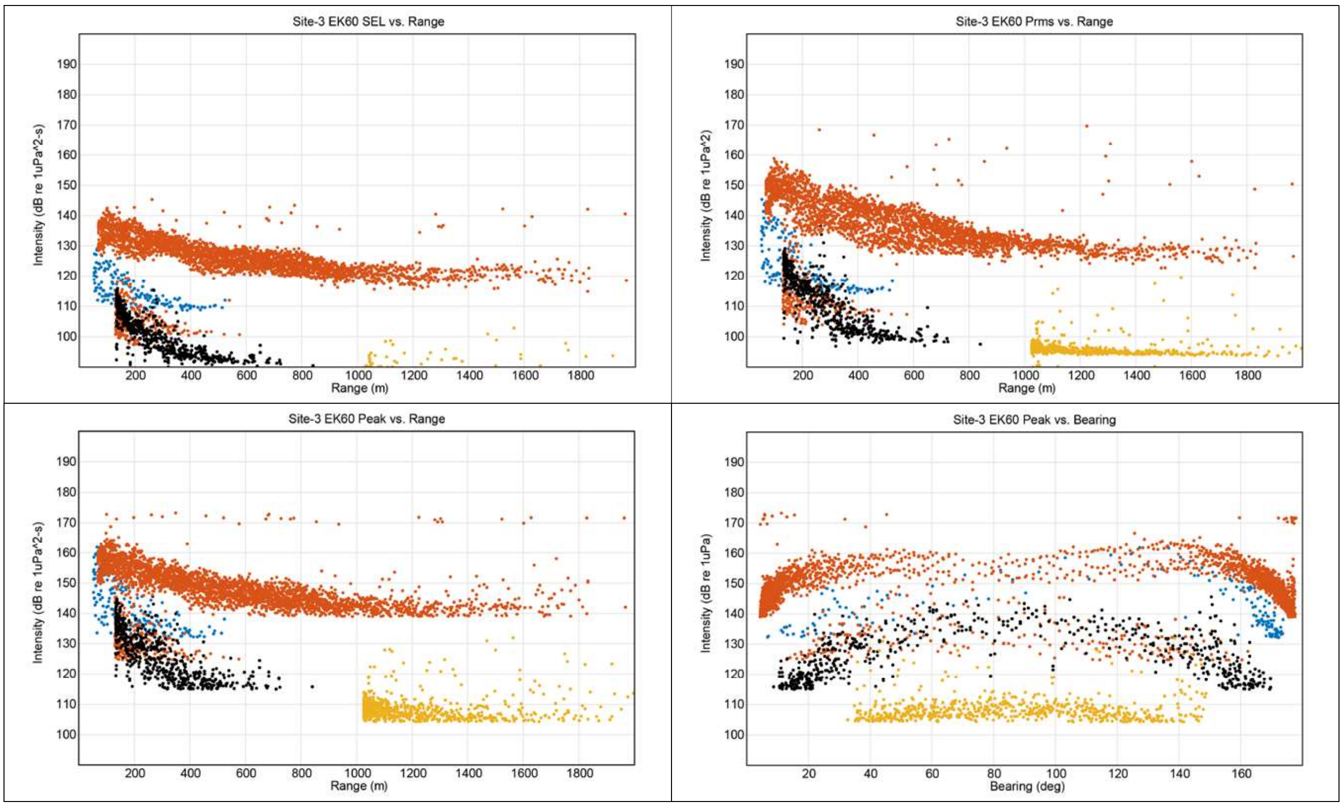


Figure 4.13.3-2. Range results for EK60 combined signals for Run1 and Run21 at Site 3 for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy8 and Buoy10, combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.13.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 80,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,800 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy 5, Buoy11, and Buoy12), A (Buoy12), and E (Buoy8 and Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately -50 m on the y-axis.

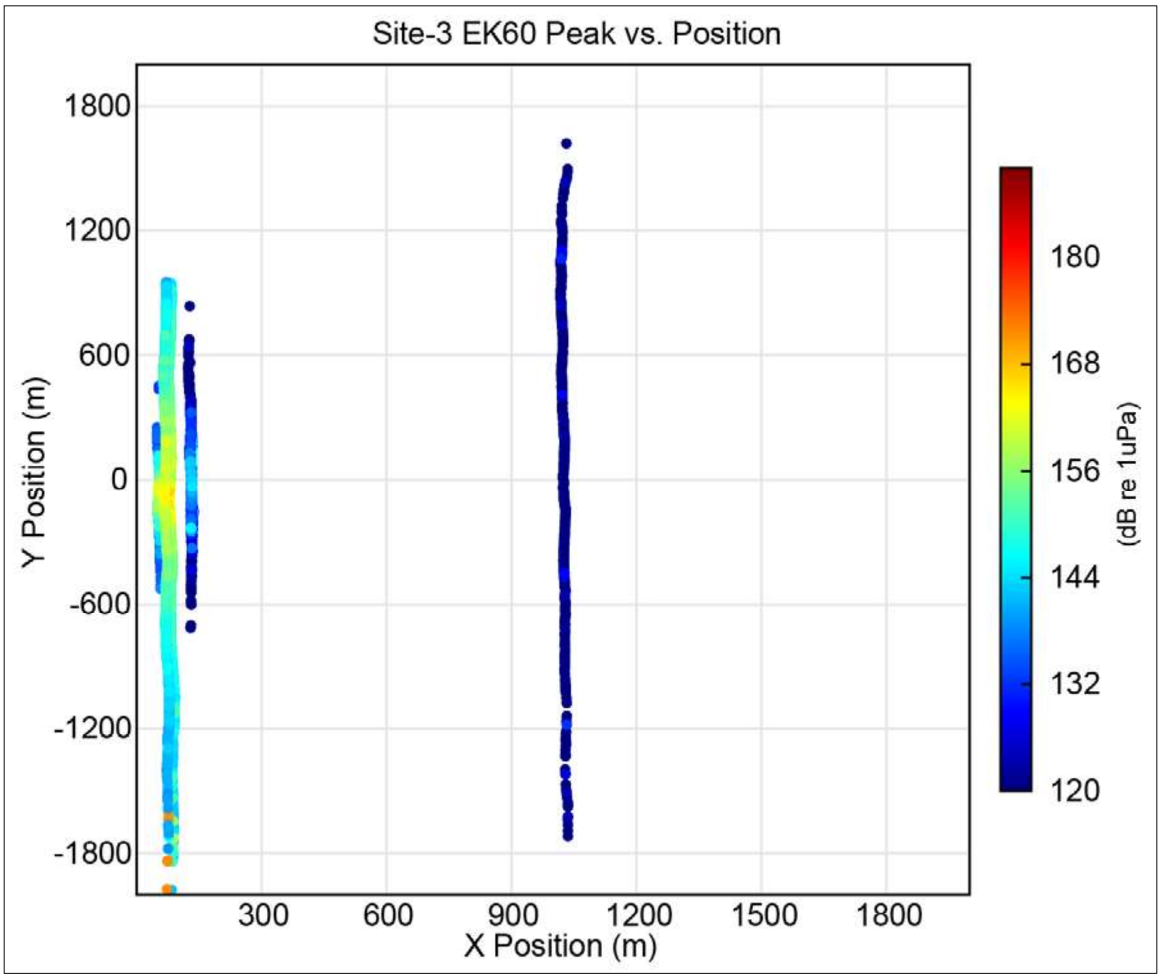


Figure 4.13.3-3. Plan view of received peak level for EK60 at Site 3, showing the results for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12), A (Buoy12), and E (Buoy8 and Buoy10).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.13.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)].

Table 4.13.3-1. EK60 source levels, Mode 1, at Site 3.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 1	38 kHz	100%	NA	512 µs	190	174	158
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.13.4 Site 4 – Sand, 30 m Depth

At S4, the EK60, Mode 1, had valid acoustic recordings in Run1. For Run1, positions B (Buoy7), A (Buoy6), C (Buoy5), and E (Buoy9) had valid acoustic data. Position F was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the EK60, Mode 1, are shown in **Figure 4.13.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy7) for Run1, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics that lack any signal at positions A (Buoy6) and C (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.13.4-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the EK60 at S4, positions B (Buoy7), A (Buoy6), C (Buoy5), and E (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,700 m. The shape of the data points signifies the approach and departure of the source to and from the buoy. There appears to be unresolved calibration issues (**Section 2.6.3.1**) as recordings within a single position show up to a 20 dB gap, for example see position A, B or C. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot; the received peak levels for all positions are not observable. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

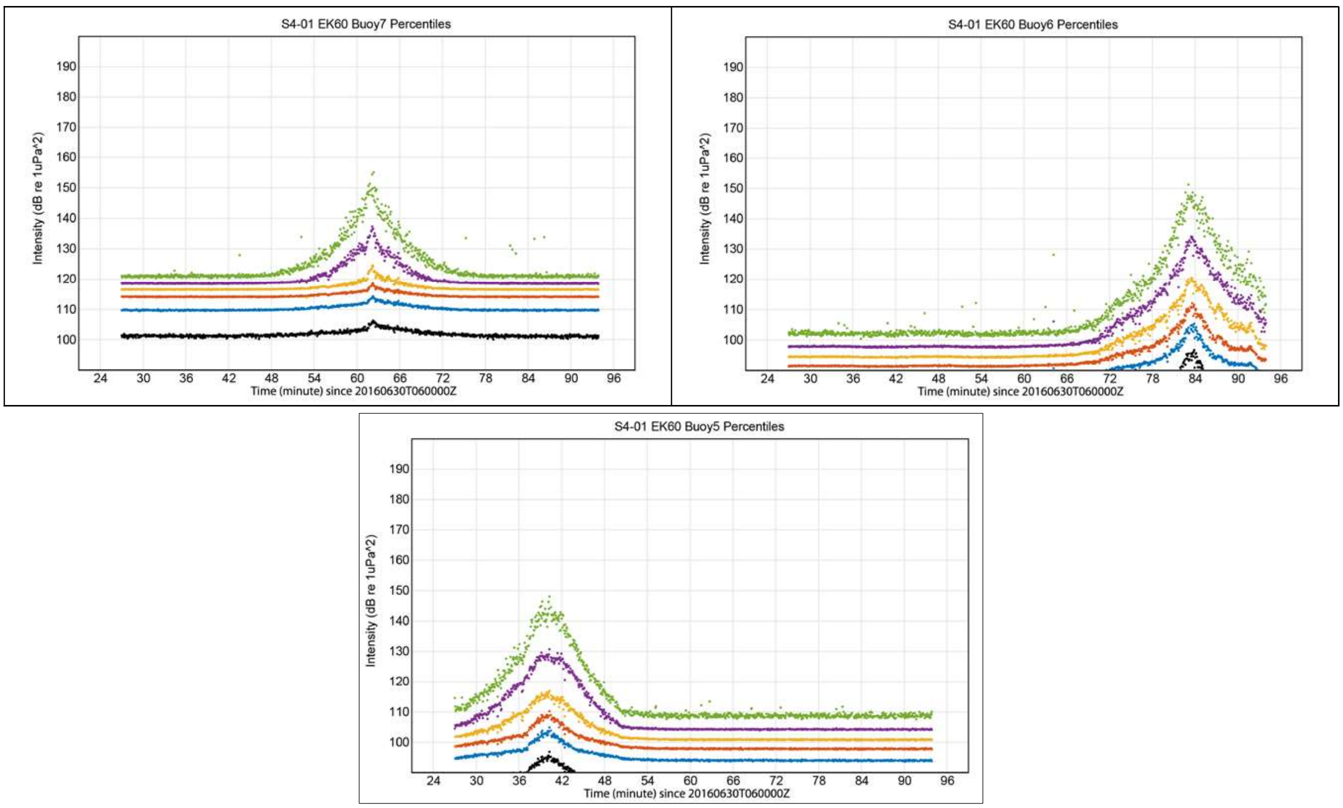


Figure 4.13.4-1. Percentile plots of EK60 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy7); Top right: SPL_{pk} arrival at position A (Buoy6); Bottom left: SPL_{pk} arrival at position C (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

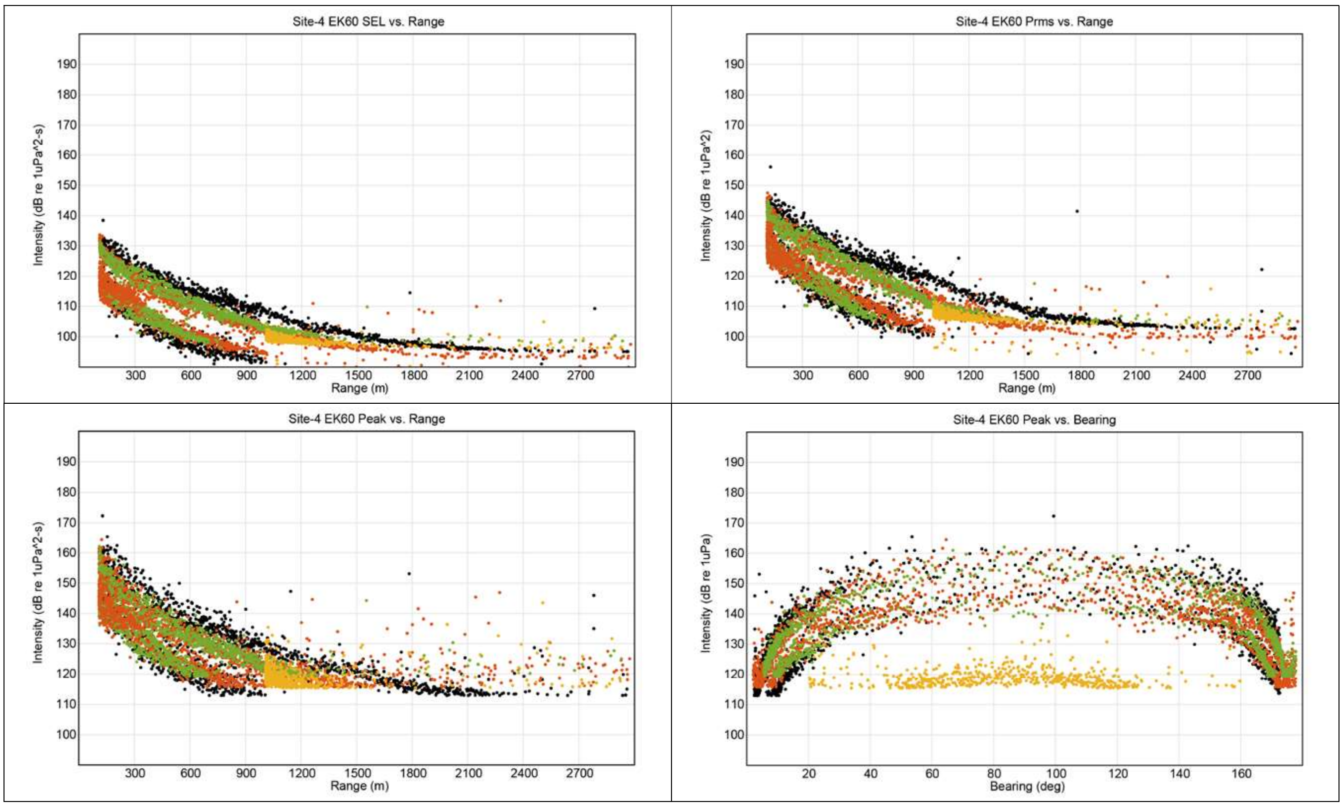


Figure 4.13.4-2. Range results for EK60 signals at Site 4 for positions B (Buoy7), A (Buoy6), C (Buoy5), and E (Buoy9). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; C = green; E = yellow.

The plan view is shown in **Figure 4.13.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 125,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy7), A (Buoy6), C (Buoy5), and E (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

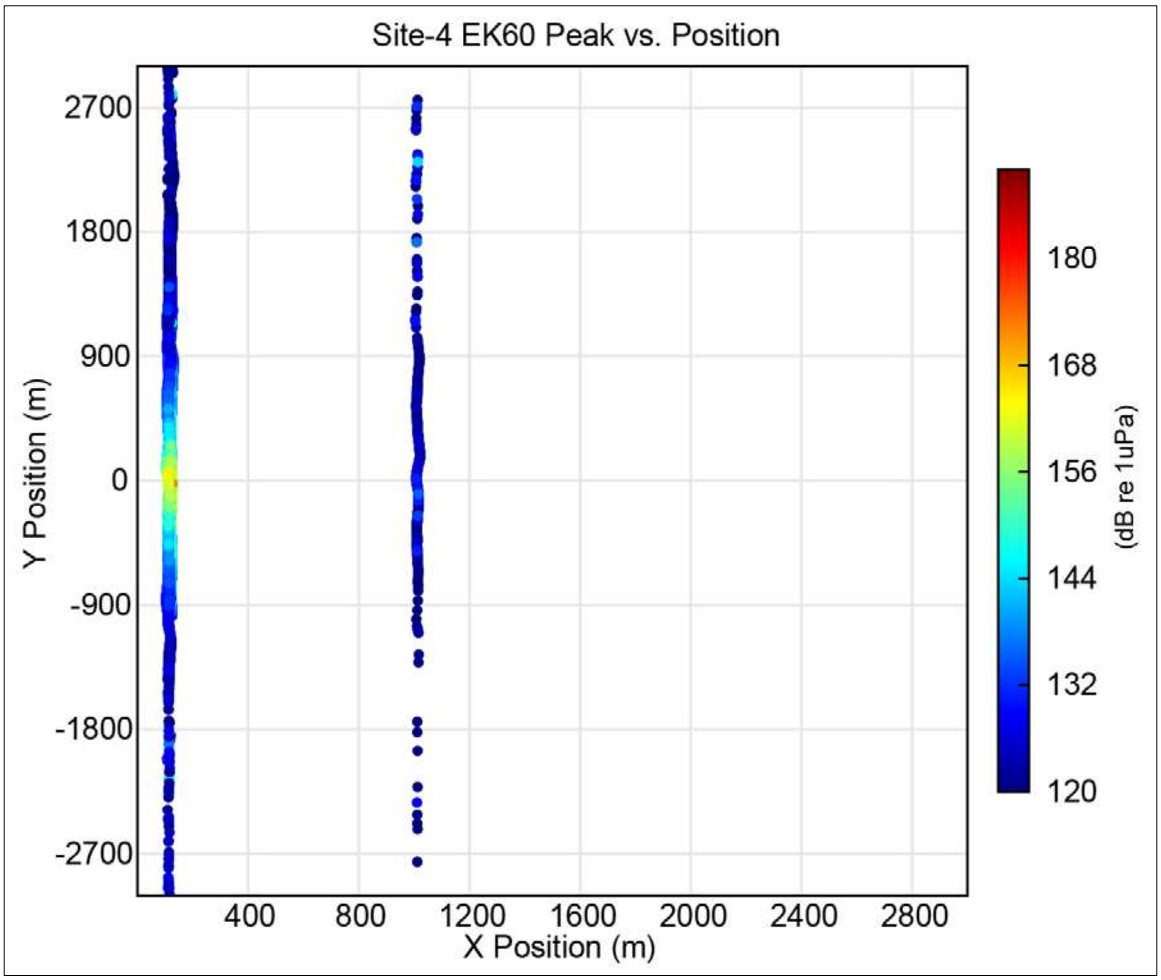


Figure 4.13.4-3. Plan view of received peak level for EK60 at Site 4, showing the results for positions B (Buoy7), A (Buoy6), C (Buoy5), and E (Buoy9).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.13.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)].

Table 4.13.4-1. Measured EK60 source levels, Mode 1, at Site 4.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 1	38 kHz	100%	NA	512 µs	195	179	165
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.13.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the EK60, Mode 1, had valid acoustic recordings in Run8 and Run24. For Run8, positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9) had valid acoustic recordings with barely observable signals. For Run24, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), and A (Buoy12). Position F (Buoy10) was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for recordings of the EK60, Mode 1, are shown in **Figure 4.13.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run8, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11) and A (Buoy12).

The results panels (**Figure 4.13.5-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The source is highly directional, so only the first few pings near broadside are the peak source level. There is a high amount of noise, particularly at position E (Buoy8 and Buoy9, combined). There appears to be unresolved calibration issues (**Section 2.6.3.1**) as recordings within a single position show up to a 20 dB gap, for example see position A, D or E. The conical shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 1; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot; the only observable peaks are for position A (Buoy12) and position D (Buoy6) at approximately 80°, which indicates a possible error in navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

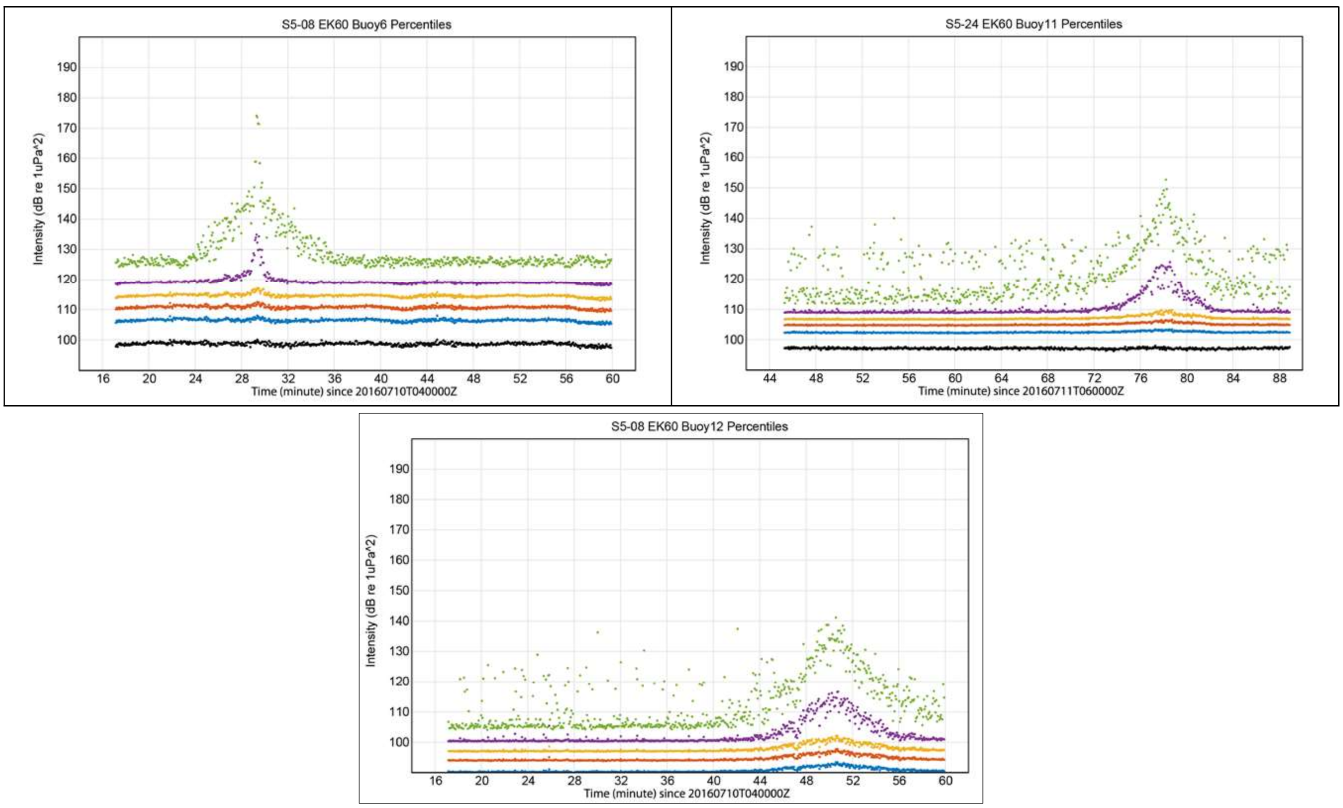


Figure 4.13.5-1. Percentile plots of EK60 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

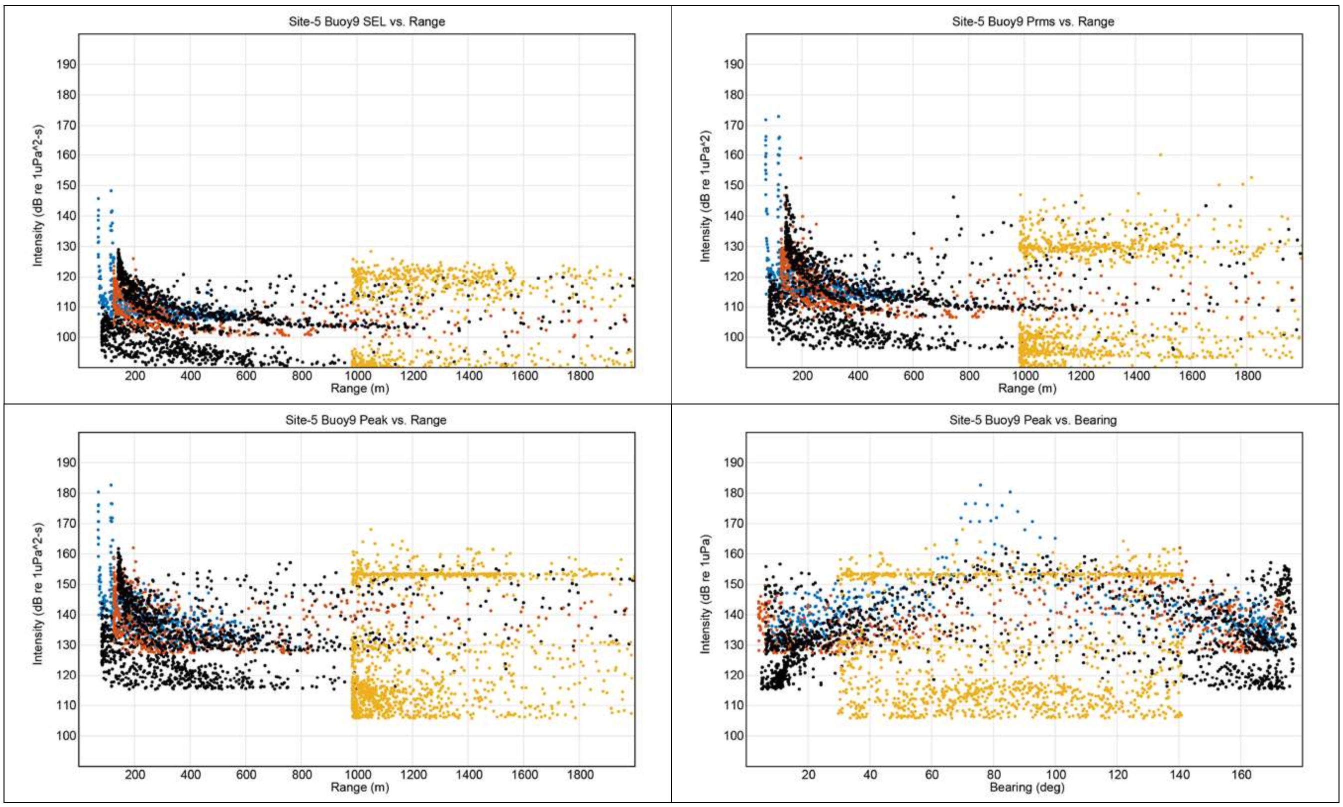


Figure 4.13.5-2. Range results for EK60 signals at Site 5 from Run8 and Run24 for positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy9, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range. Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.13.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 75,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -2,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy9). There are unresolved calibration issues at position E (between Buoy 8 and Buoy 9) (**Section 2.6.3.1**). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

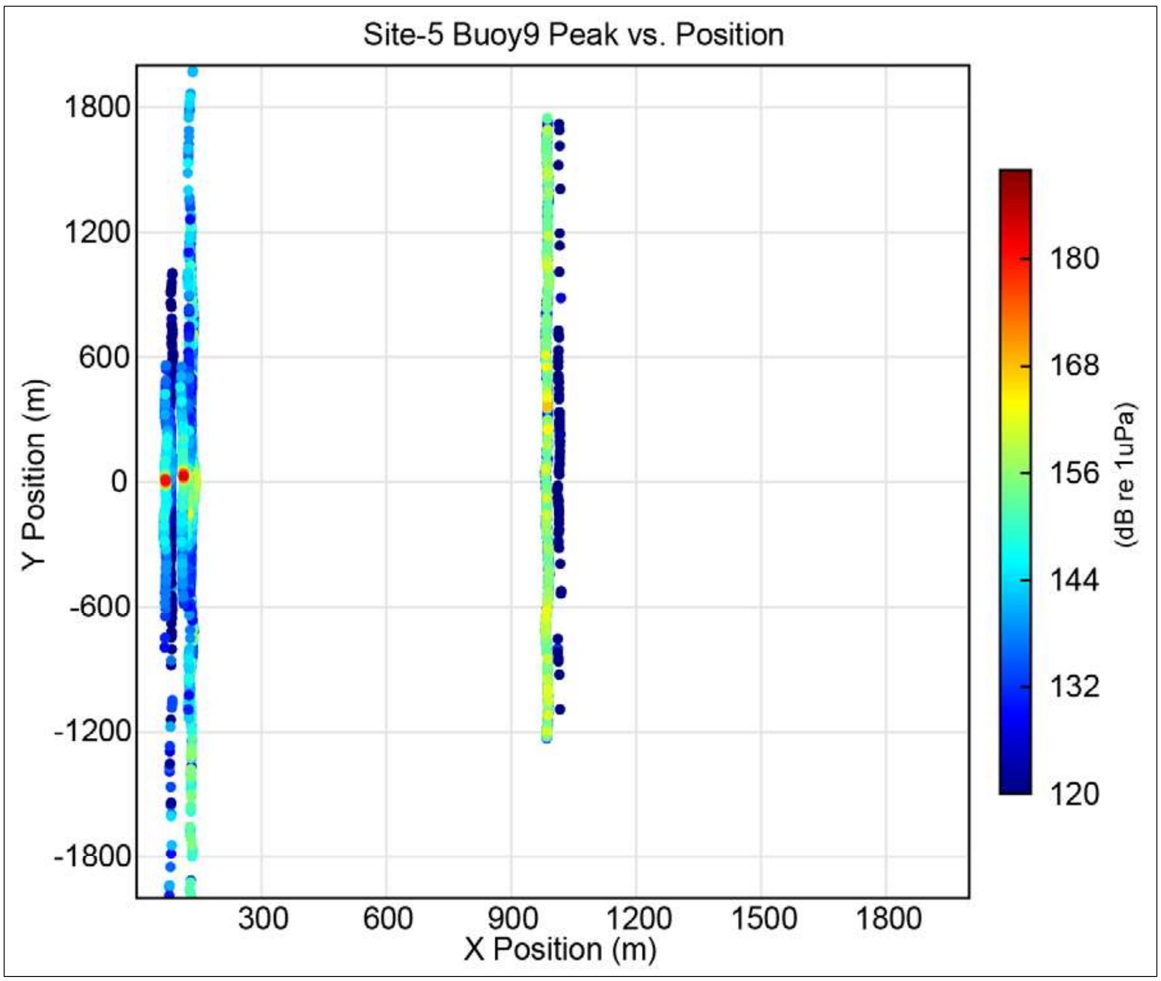


Figure 4.13.5-3. Plan view of received peak level for EK60 at Site 5, showing the results for positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy9).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.13.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)].

Table 4.13.5-1. EK60 source levels, Mode 1, at Site 5.

Source Settings					**Source Level (dB re 1 µPa m)**		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 1	38 kHz	100%	NA	512 µs	198	186	162
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Left Intentionally Blank

4.14 Simrad EK60, 38 kHz, 100 Percent Power, 1,024-µs Pulse (Mode 2)

The EK60 split-beam multibeam echosounder generates a single, high-frequency (HF) signal with a peak frequency of 38 kHz. The operational parameter settings for Mode 2 were 100 percent power, a 1,024-µs pulse, and a 38-kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.14-1** is the selected frequency band (33 to 43 kHz) and SPL_{pk} (146 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.14-1. Bandpass determination for the EK60 split-beam multibeam echosounder, 38 kHz, 100 percent power, 1,024-µs pulse at Site 3, Run3.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
20-100	147.62
18-58	134.76
28-48	128.08
33-43	**146.20**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The EK60, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.14-1**. Described in Chapter 2, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The EK60 was operationally paired in alternation with the ET512i (Chapter 4.20). These pairings were pre-determined to make sure that each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.14-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1s chunks) manually. This approach seemed successful in separating the two sources.

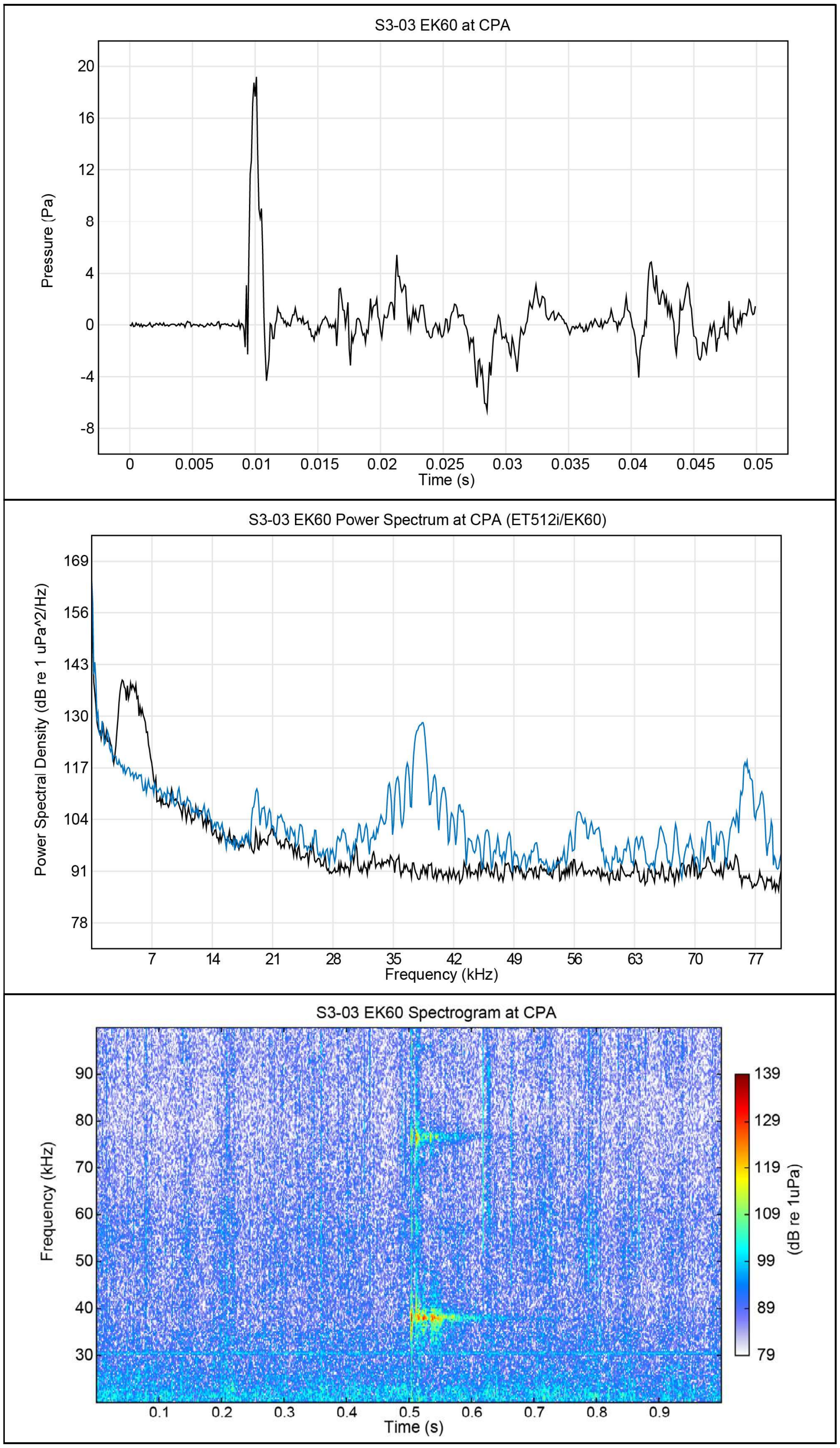


Figure 4.14-1. EK60 measured signal characteristics at closest point of approach (CPA) at Site 3, Run3.
Top: Time-waveform of a signal; Middle: Power spectral density, EK60 =blue, ET512i =black; Bottom: Spectrogram.

4.14.1 Site 1 – Mud, 10 m Depth

The EK60, Mode 2, was not deployed or operated at S1.

4.14.2 Site 2 – Sand, 10 m Depth

The EK60, Mode 2, was not deployed or operated at S2.

4.14.3 Site 3 – Mud, 30 m Depth

At S3, the EK60, Mode 2, had valid acoustic recordings in Run3. For Run3, positions B (Buoy5 and Buoy12) and E (Buoy7) had valid acoustic data. The signal is observed at position B (Buoy5 and Buoy12), but not at position E (Buoy7). Position F was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for recordings of the EK60, Mode 2, are shown in **Figure 4.14.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy12) for Run3, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy5), and E (Buoy7). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.14.3-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the EK60 at S3, position B (Buoy5 and Buoy12) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 2; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, the received peak levels for all positions are not observable. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

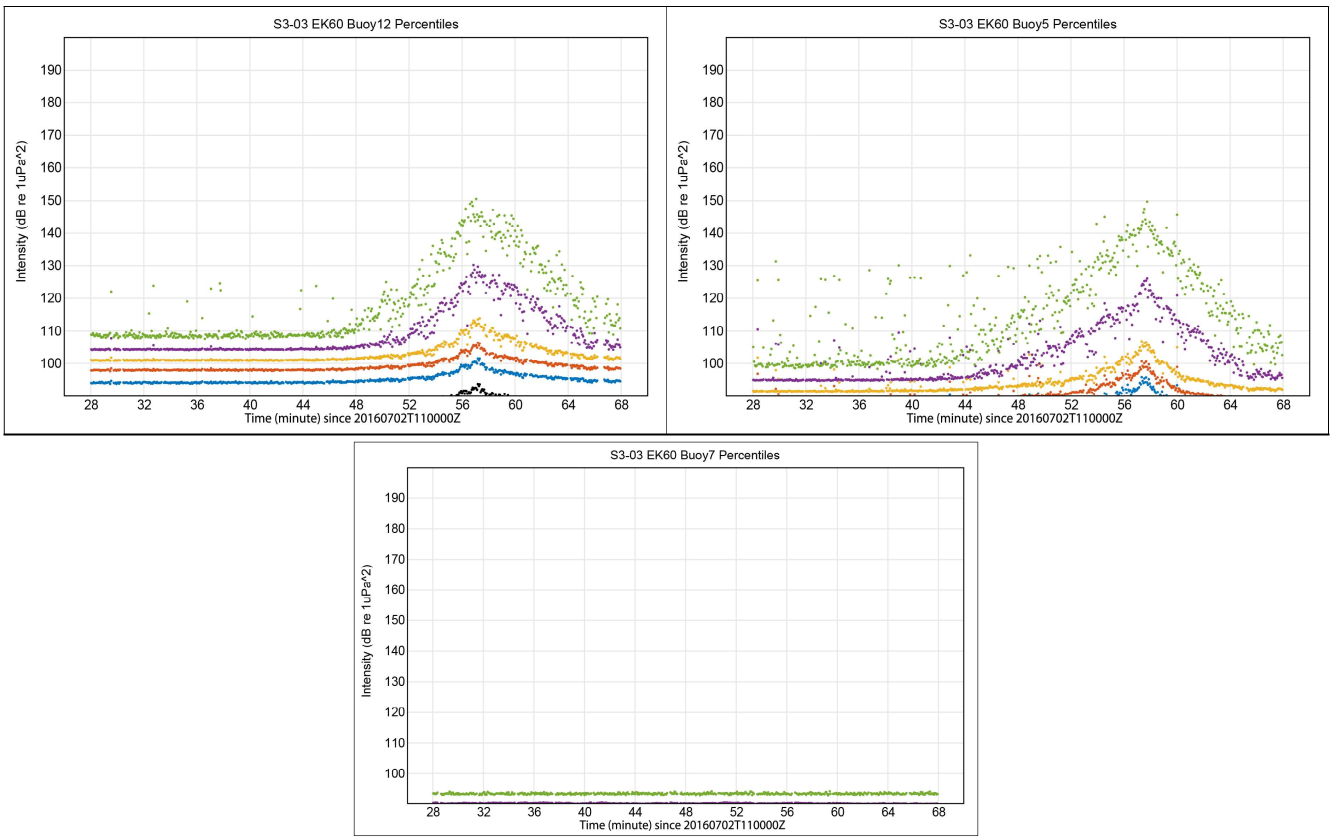


Figure 4.14.3-1. Percentile plots of EK60 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy7). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

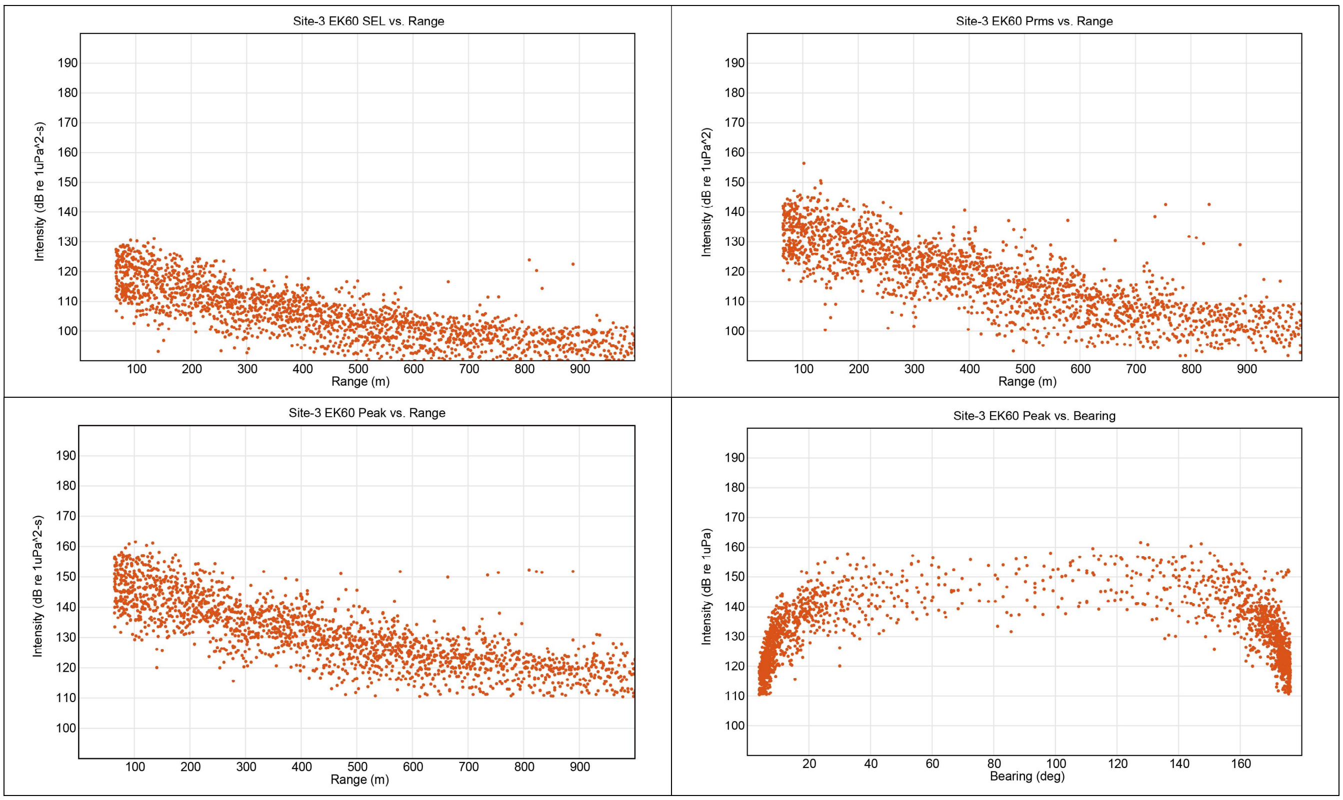


Figure 4.14.3-2. Range results for EK60 combined signals for Run3 at Site 3 for position B (Buoy5 and Buoy12, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.14.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 70,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy5 and Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal at position B is seen at approximately -100 m on the y-axis.

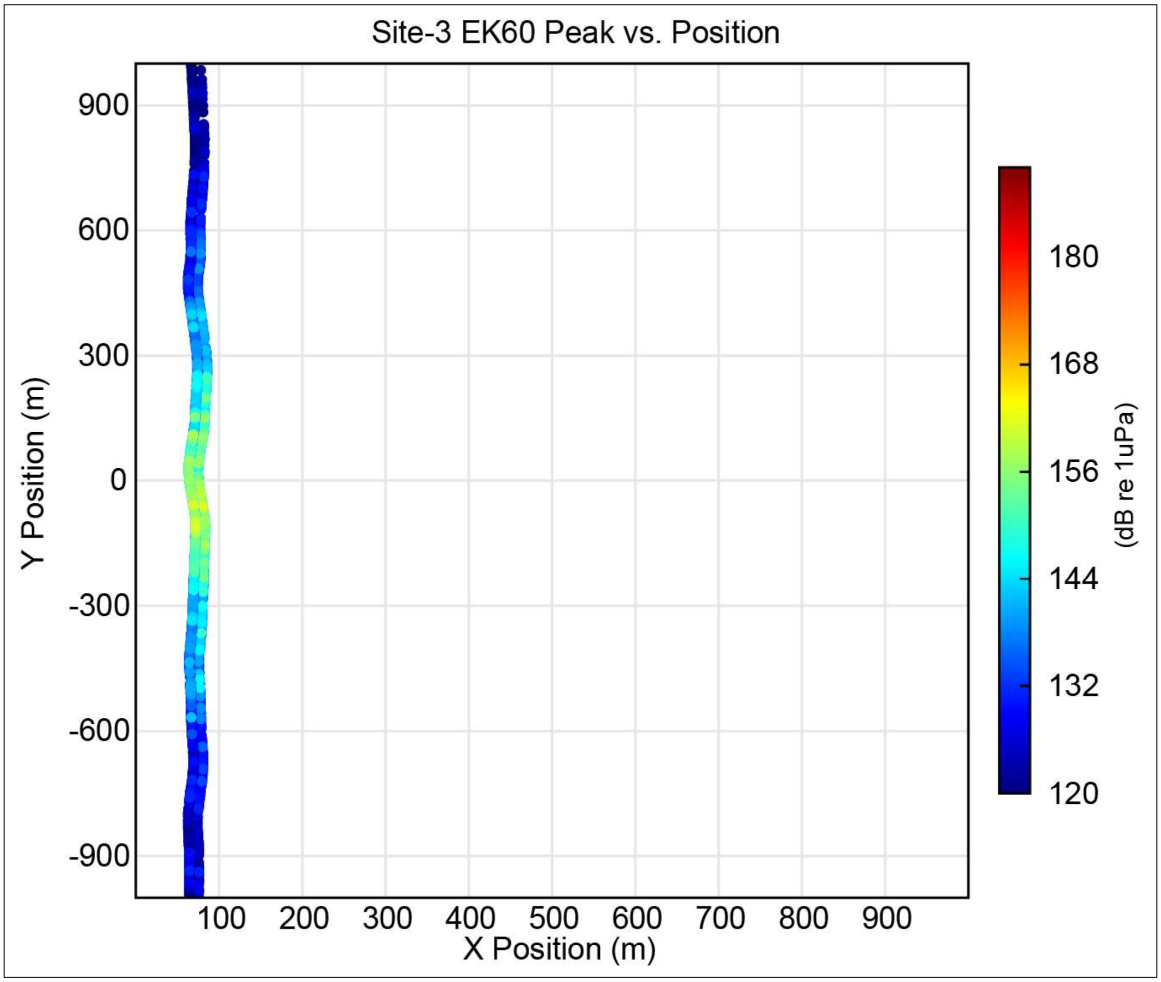


Figure 4.14.3-3. Plan view of received peak level for EK60 at Site 3, showing the results for position B (Buoy5 and Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.14.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)].

Table 4.14.3-1. EK60 source levels, Mode 2, at Site 3.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 2	38 kHz	100%	NA	1024 µs	196	183	165
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.14.4 Site 4 – Sand, 30 m Depth

At S4, the EK60, Mode 2, had valid acoustic recordings in Run3. For Run3, positions B (Buoy7 HS and LS), C (Buoy5), and E (Buoy9) had valid acoustic data. Position F was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the recordings of the EK60, Mode 2, are shown in **Figure 4.14.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT time for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy7 HS) for Run3, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions B (Buoy7 LS), C (Buoy5), and E (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.14.4-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the EK60 at S4, positions B (Buoy7 HS and LS), C (Buoy5), and E (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,800 m. The shape of the data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 2; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for positions B (Buoy7 HS and LS), C (Buoy5), and E (Buoy9) at approximately 90°, indicating good navigational buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

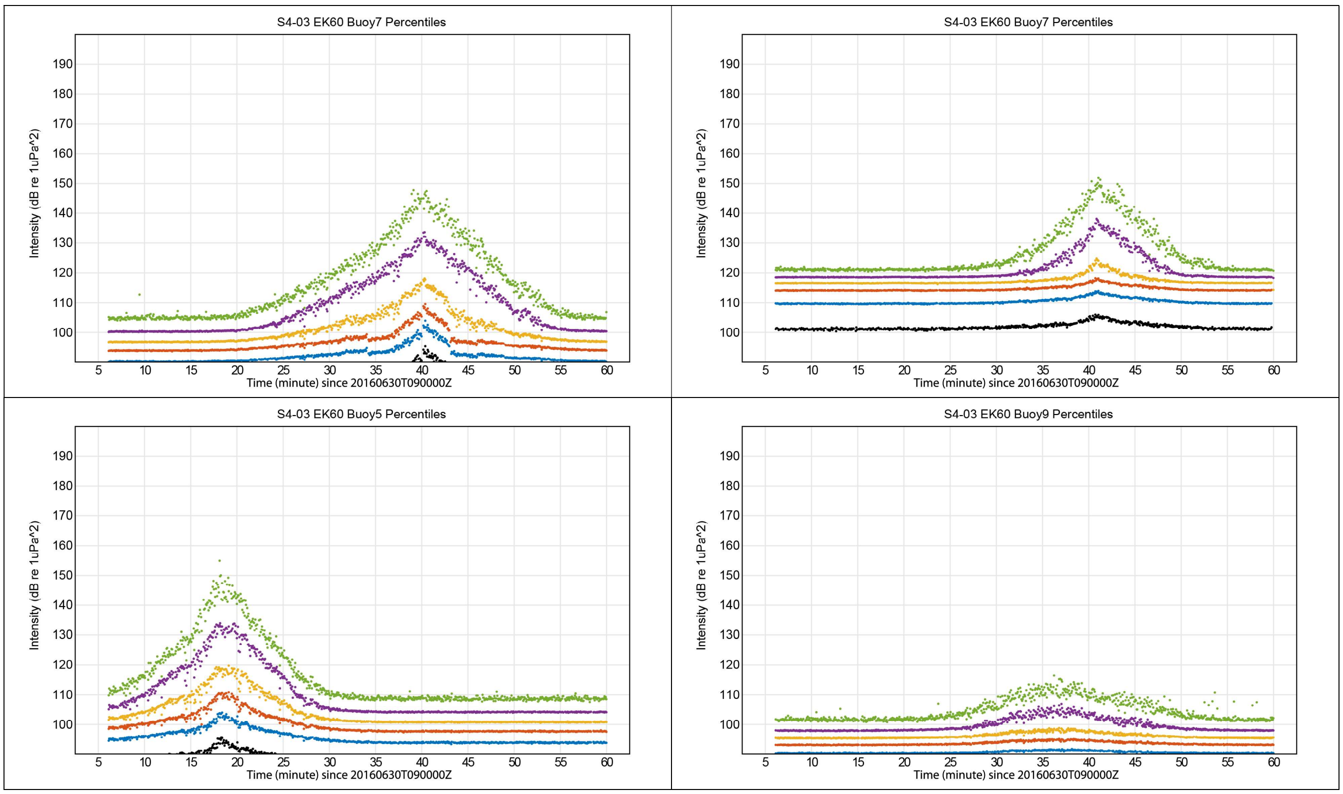


Figure 4.14.4-1. Percentile plots of EK60 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy7, High Sensitivity); Top right: SPL_{pk} arrival at position B (Buoy7, Low Sensitivity); Bottom left: SPL_{pk} arrival at position C (Buoy5); Bottom right: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

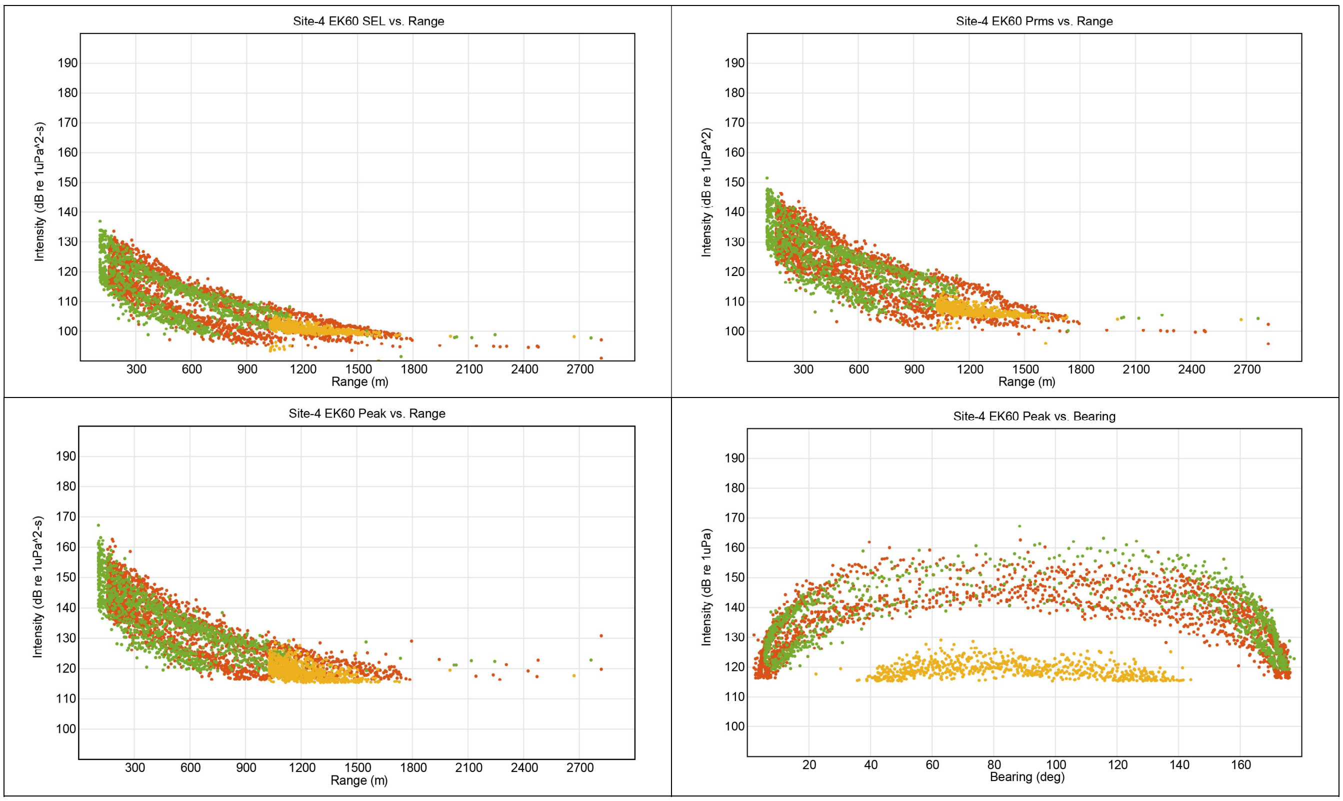


Figure 4.14.4-2. Range results for EK60 signals at Site 4 for positions B (Buoy7, High Sensitivity and Low Sensitivity), C (Buoy5), and E (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions B = red; C = green; E = yellow.

The plan view is shown in **Figure 4.14.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy7 HS and LS), C (Buoy5), and E (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal is seen at approximately 0 m on the y-axis.

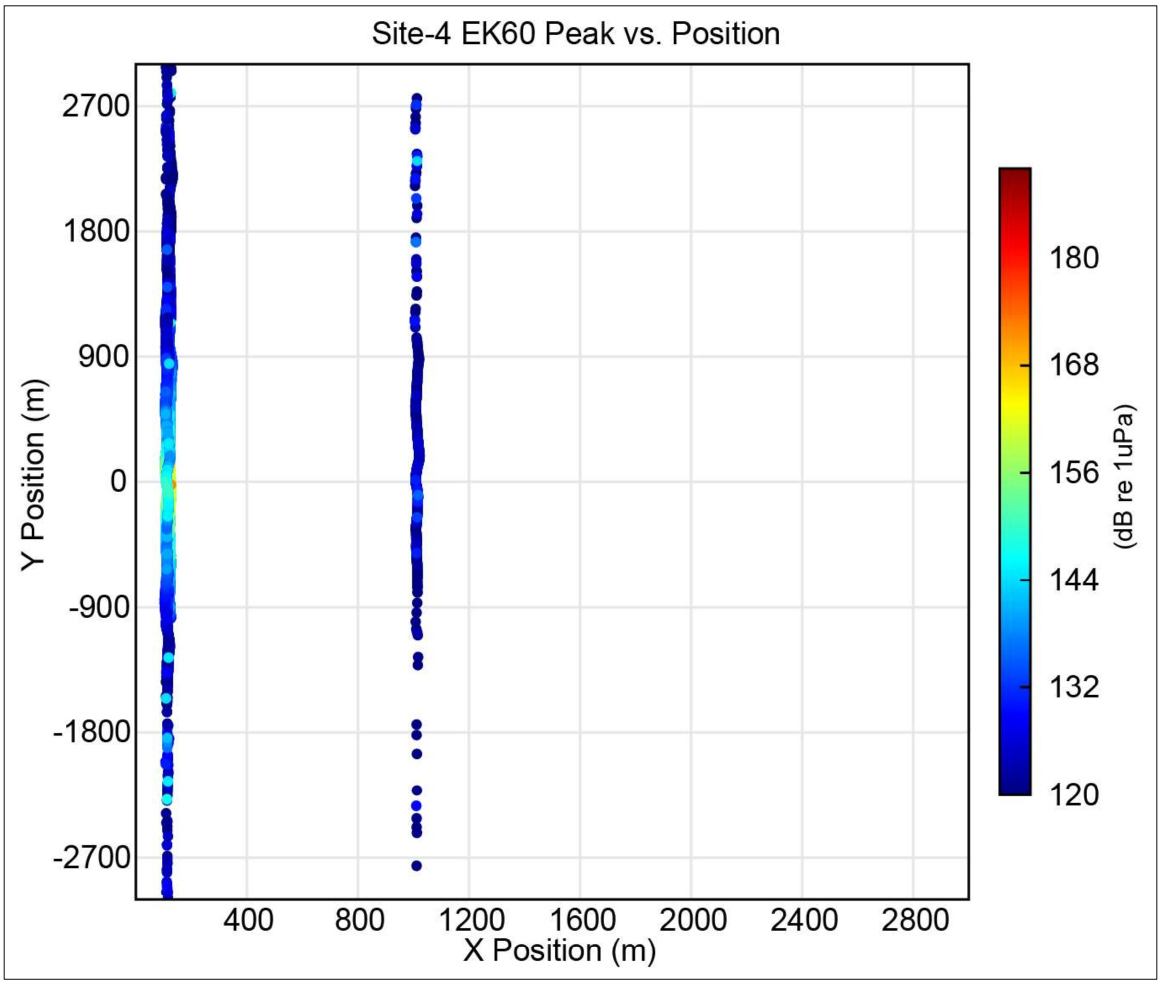


Figure 4.14.4-3. Plan view of received peak level for EK60 at Site 4, showing the results for positions B (Buoy7, High Sensitivity and Low Sensitivity), C (Buoy5), and E (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.14.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)].

Table 4.14.4-1. EK60 source levels, Mode 2, at Site 4.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 2	38 kHz	100%	NA	1024 µs	196	178	166
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.14.5 Site 5 – Sandy-Silt, 100 m Depth

The EK60, Mode 2, was not deployed or operated at S5.

This Page Left Intentionally Blank

4.15 Simrad EK60, 38 kHz, 50 Percent Power, 512-µs Pulse (Mode 3)

The EK60 split-beam multibeam echosounder generates a single, high-frequency (HF) signal with a peak frequency of 38 kHz. The operational parameter settings for Mode 3 were 50 percent power, a 512-µs pulse, and a 38-kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.15-1** is the selected frequency band (28 to 48 kHz) and SPL_{pk} (132 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.15-1. Bandpass determination for the EK60 multibeam echosounder, 38 kHz, 50 percent power, 512-µs pulse at Site 3, Run2.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
18-58	132.17
28-48	**131.95**
33-43	130.27

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The EK60, Mode 3, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.15-1**. Described in Chapter 2, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The EK60 was operationally paired in alternation with the ET512i (Chapter 4.20). These pairings were pre-determined to make sure that each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.15-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1s chunks) manually. This approach seemed successful in separating the two sources.

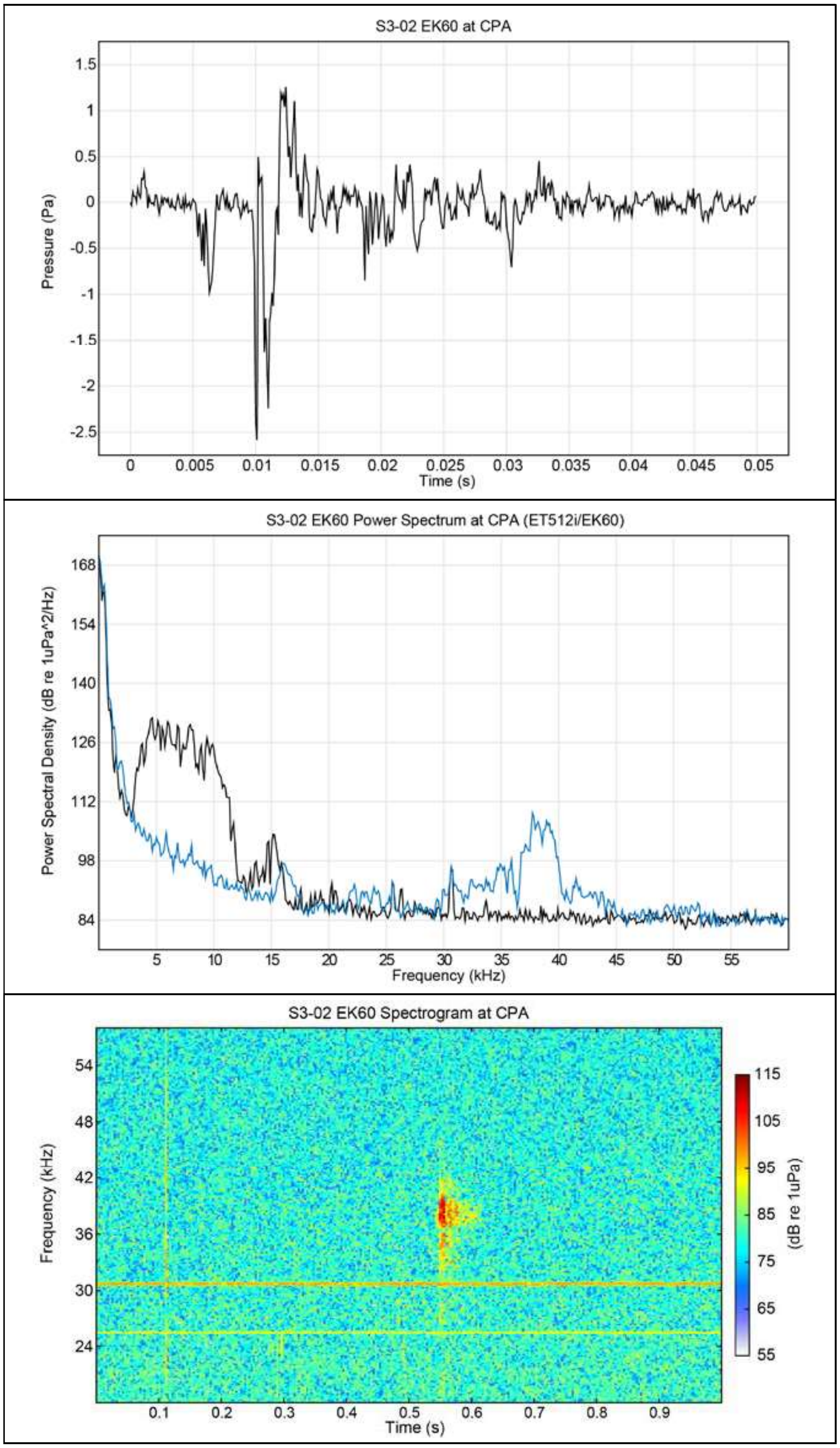


Figure 4.15-1. EK60 measured signal characteristics at closest point of approach (CPA) at Site 3, Run2.
Top: Time-waveform of a signal; Middle: Power spectral density, EK60 = blue, ET512i = black; Bottom: Spectrogram.

4.15.1 Site 1 – Mud, 10 m Depth

The EK60, Mode 3, was not deployed or operated at S1.

4.15.2 Site 2 – Sand, 10 m Depth

The EK60, Mode 3, was not deployed or operated at S2.

4.15.3 Site 3 – Mud, 30 m Depth

At S3, the EK60, Mode 3, had valid acoustic recordings in Run2 and Run22. For Run2, position B (Buoy12) had valid acoustic data and observed signals. For Run22, positions D (Buoy6), B (Buoy11), A (Buoy12), and F (Buoy9) had valid acoustic data and observed signals.

Run Summary

The percentile plots for the available recordings of the EK60, Mode 3, are shown in **Figure 4.15.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run22, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11 and Buoy12) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.15.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the EK60 at S3, positions D (Buoy6), B (Buoy11 and Buoy12, combined), A (Buoy12), and F (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 5,500 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 3; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for all positions at approximately 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

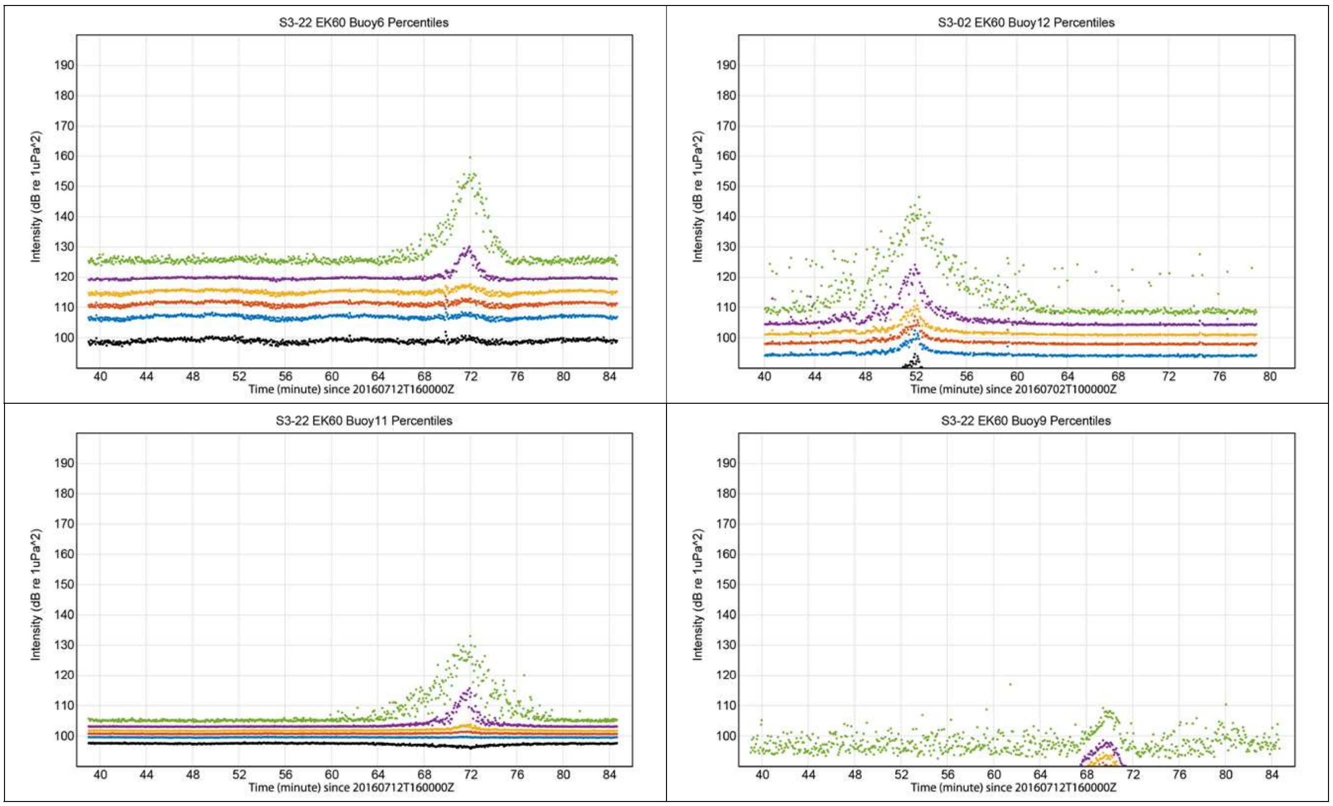


Figure 4.15.3-1. Percentile plots of EK60 signals at Site 3.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy12); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

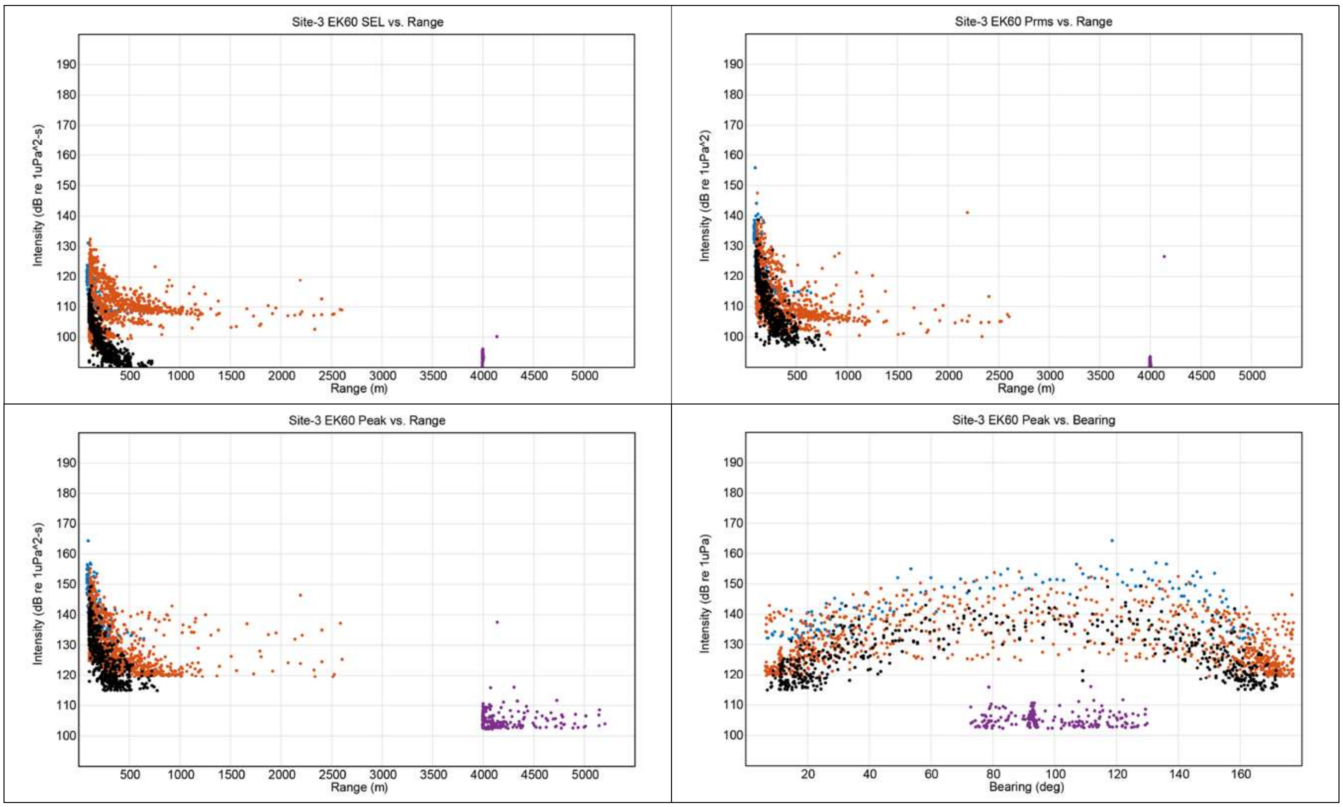


Figure 4.15.3-2. Range results for EK60 combined signals for Run2 and Run22 at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy12), A (Buoy12), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; F = purple.

The plan view is shown in **Figure 4.15.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -6,000 to 6,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 and Buoy12, combined), A (Buoy12), and F (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

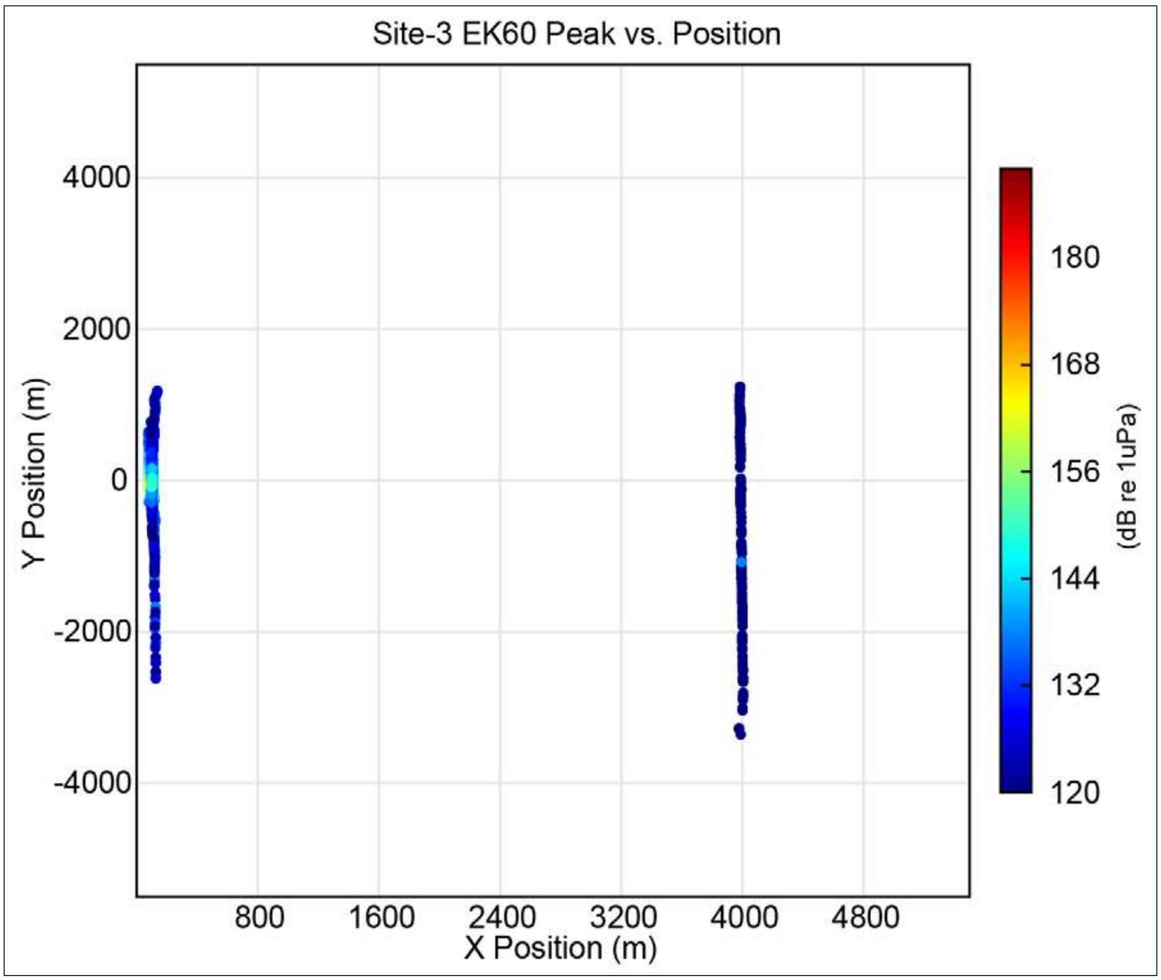


Figure 4.15.3-3. Plan view of received peak level for EK60 at Site 3, showing the results for positions D (Buoy6), B (Buoy11 and Buoy12), A (Buoy12), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.15.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)].

Table 4.15.3-1. EK60 source levels, Mode 3, at Site 3.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 3	38 kHz	50%	NA	512 µs	195	186	170
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.15.4 Site 4 – Sand, 30 m Depth

At S4, the EK60, Mode 3, had valid acoustic recordings in Run2. Positions B (Buoy7 HS and LS), A (Buoy6), C (Buoy5), and E (Buoy9) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the EK60, Mode 3, are shown in **Figure 4.15.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy7 LS) for Run2, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions B (Buoy7 HS), C (Buoy5), and E (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.15.4-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the EK60 at S4, positions B (Buoy7 HS and LS), A (Buoy6), C (Buoy5), and E (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 3; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for all positions at approximately 90°, indicating good navigational buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

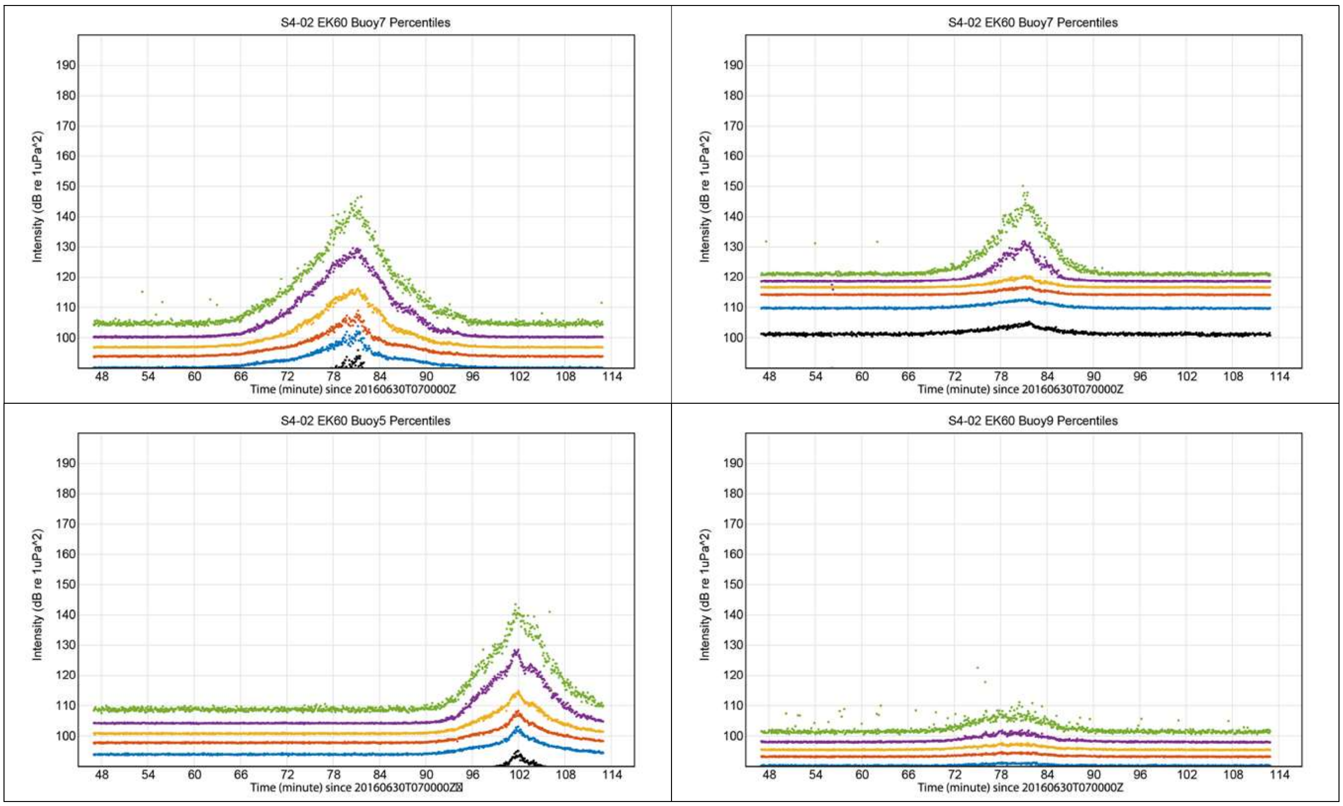


Figure 4.15.4-1. Percentile plots of EK60 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy7, Low Sensitivity); Top right: SPL_{pk} arrival at position B (Buoy7, High Sensitivity); Bottom left: SPL_{pk} arrival at position C (Buoy5); Bottom right: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

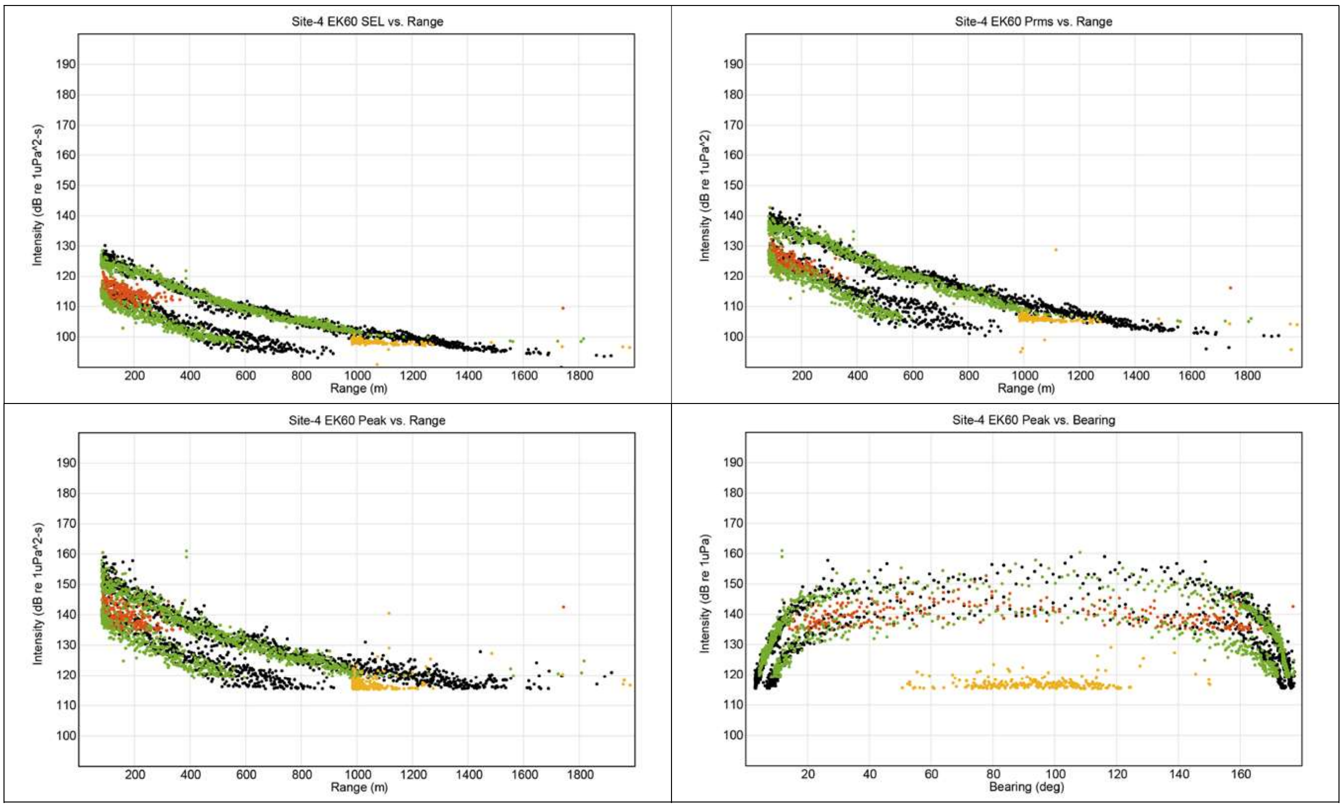


Figure 4.15.4-2. Range results for EK60 signals at Site 4 for positions B (Buoy7, High Sensitivity and Low Sensitivity), A (Buoy6), C (Buoy5), and E (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; C = green; E = yellow.

The plan view is shown in **Figure 4.15.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -800 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy7 HS and LS), A (Buoy6), C (Buoy5), and E (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position B is seen at approximately 0 m on the y-axis.

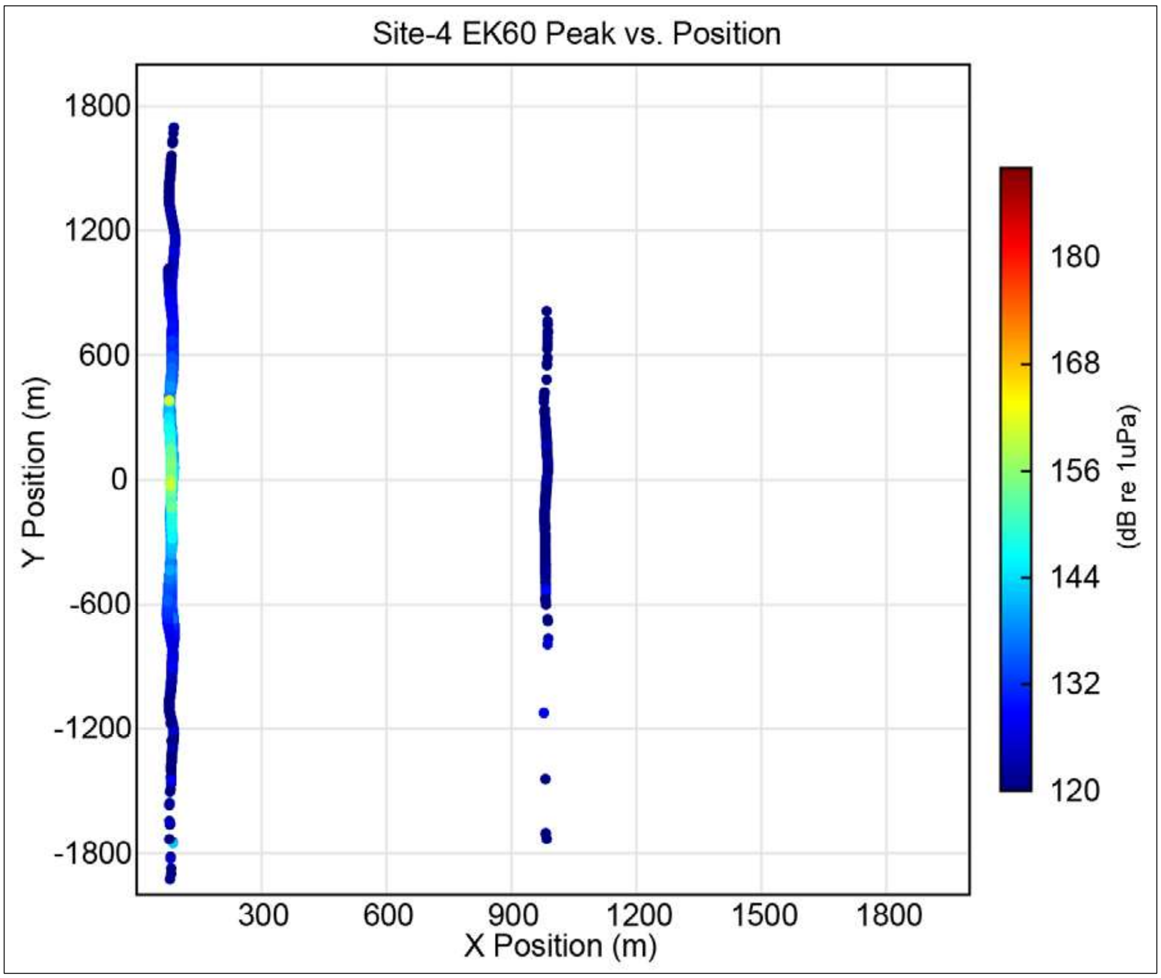


Figure 4.15.4-3. Plan view of received peak level for EK60 at Site 4, showing the results for positions B (Buoy7, High Sensitivity and Low Sensitivity), A (Buoy6), C (Buoy5), and E (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.15.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)].

Table 4.15.4-1. EK60 source levels, Mode 3, at Site 4.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 3	38 kHz	50%	NA	512 µs	196	179	166
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.15.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the EK60, Mode 3, had valid acoustic recordings in Run9 and Run25. For Run9, positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9) had valid acoustic recordings and observed signals. For Run25, positions D (Buoy6), B (Buoy11), and A (Buoy12) had valid acoustic recordings were observed at.

Run Summary

The percentile plots for the available recordings of the EK60, Mode 3, are shown in **Figure 4.15.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run9, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions D (Buoy6), B (Buoy11), and A (Buoy12) for Run25.

The results panels (**Figure 4.15.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the EK60 at S5, positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12 and Buoy12, combined), and E (Buoy8 and Buoy9, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to approximately 3,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range. The NUWC study did not measure the EK60, Mode 3; thus, there is not an available source level to use for plotting reference curves (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 80°, indicating an error in buoy positioning. For all other positions, the received peak level is at approximately 90°, which indicates good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

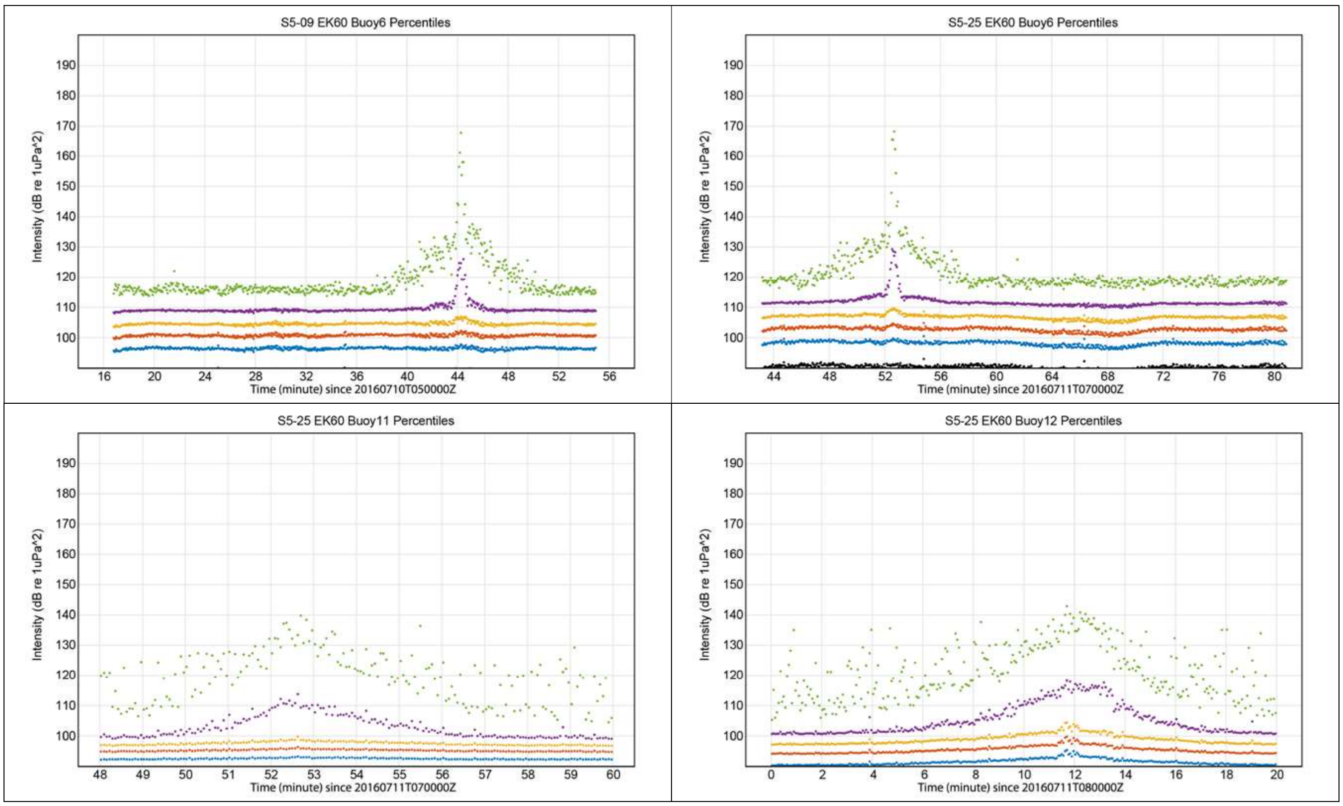


Figure 4.15.5-1. Percentile plots of EK60 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position D (Buoy6); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

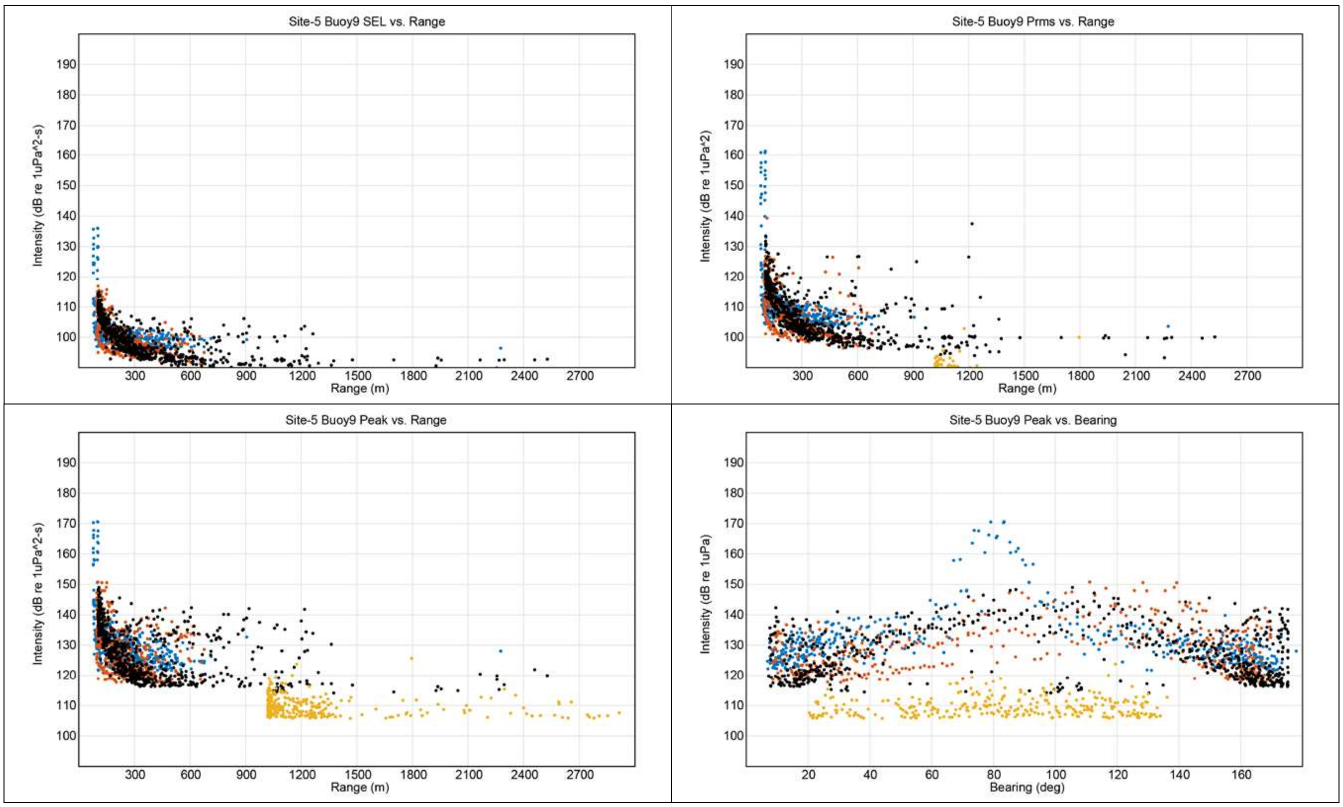


Figure 4.15.5-2. Range results for EK60 signals at Site 5 from Run12 and Run26 for positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12 and Buoy12, combined), and E (Buoy8 and Buoy9, combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.15.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -700 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12 and Buoy12, combined), and E (Buoy8 and Buoy9, combined). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

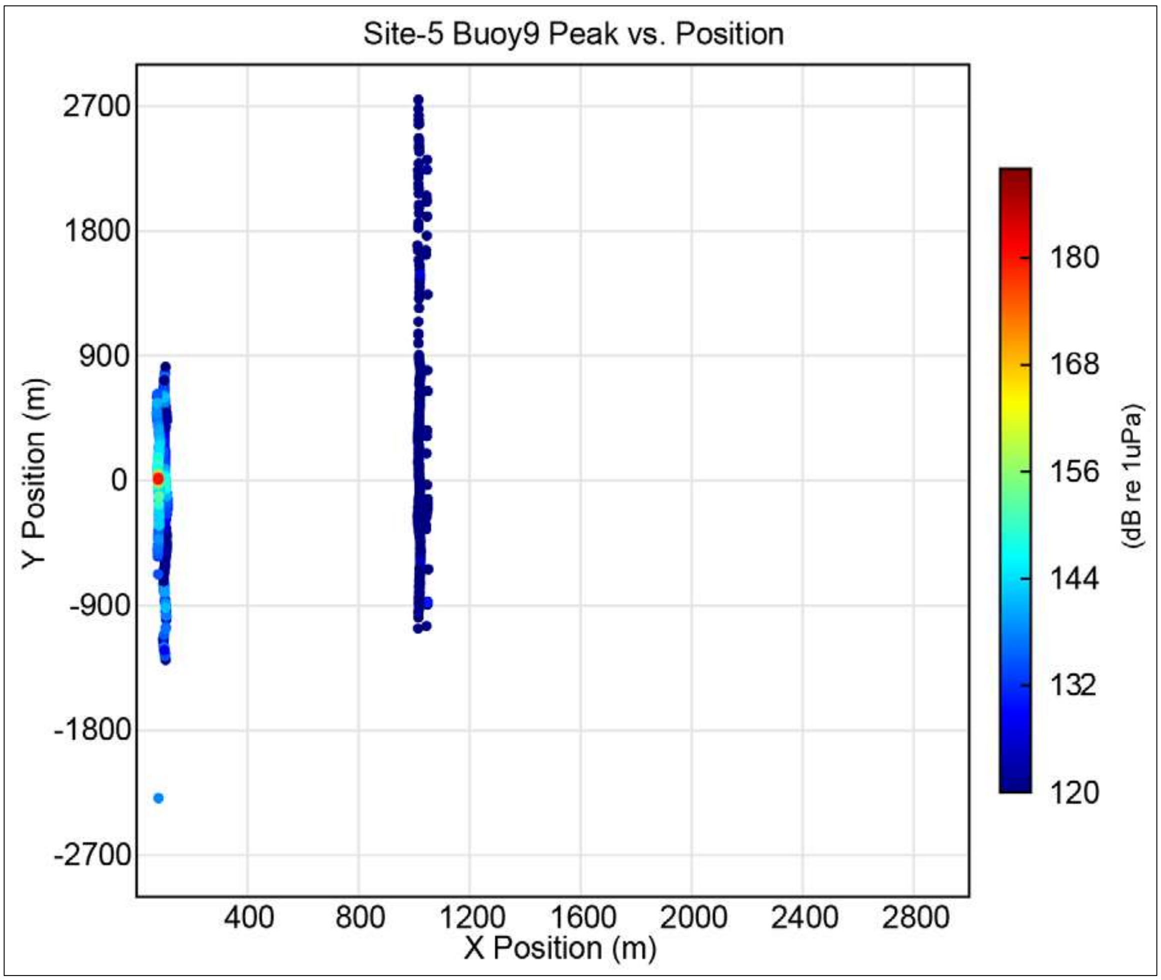


Figure 4.15.5-3. Plan view of received peak level for EK60 at Site 5, showing the results for positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12and Buoy12), and E (Buoy8 and Buoy9 combined).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.15.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)].

Table 4.15.5-1. EK60 source levels, Mode 3, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
EK60 Mode 3	38 kHz	50%	NA	512 µs	192	181	157
NUWC	NA	NA	NA	NA	NM	NM	NM

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; µs = microsecond; NA = not applicable; NM = not measured by NUWC; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.16 Edgetech 424 3100P, 4-24 kHz, 100 Percent Power, 10-ms Pulse (Mode 1)

The ET424 3100P subbottom profiler generates a single, pulse signal with a peak frequency of 13 kHz. The operational parameter settings for Mode 1 were 100 percent power, a 10-ms pulse, and a 4-24 kHz output frequency, using the 3100P topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.16-1** is the selected frequency band (6 to 22 kHz) and SPL_{pk} (159 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.16-1. Bandpass determination for the ET424, 3100P subbottom profiler, 4-24 kHz, 100 percent power, 10-ms pulse at Site 2, Run4.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	159.6
0-100	159.62
1-25	159.57
6-22	**158.99**

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET424 3100P, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.16-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The ET424 was operationally paired in alternation with the S-Boom. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.16-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1s chunks) manually. This approach seemed successful in separating the two sources. The signal time series, as measured at S2 shows a bottom reflection arriving at 0.012 s.

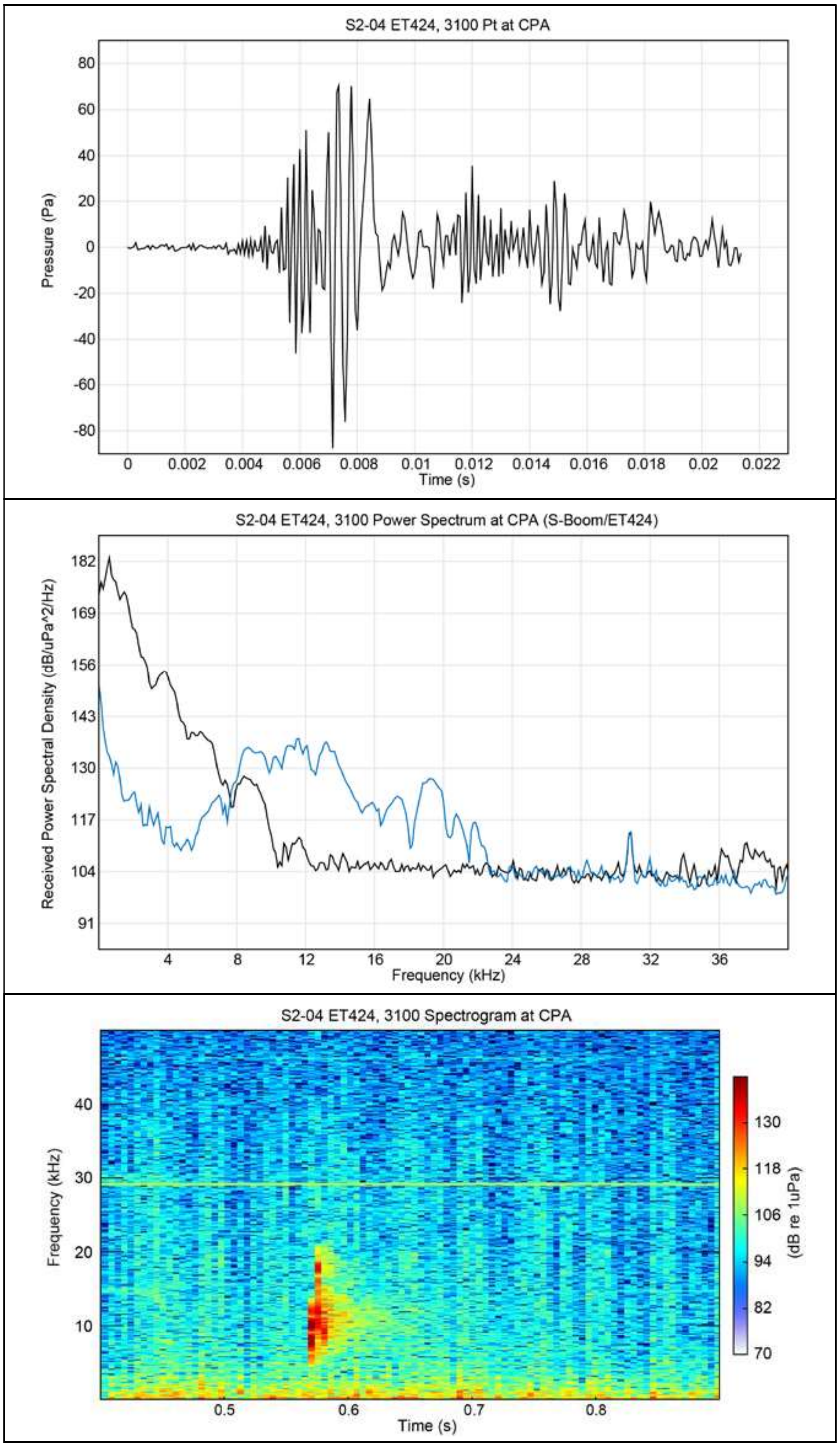


Figure 4.16-1. Edgetech 424 3100P measured signal characteristics at closest point of approach (CPA) at Site 2, Run4.

Top: Time-waveform of a signal; Middle: Power spectral density, ET424 = blue, S-Boom = black; Bottom: Spectrogram.

4.16.1 Site 1 – Mud, 10 m Depth

At S1, the ET424 3100P, Mode 1, had valid acoustic recordings in Run3, at positions D (Buoy6) and E (Buoy5 and Buoy8). Position F (Buoy9) did not capture the HF acoustic signal.

Run Summary

The percentile plots for the three available recordings of the ET424 3100P, Mode 1, are shown in **Figure 4.16.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run3, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.16.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the ET424 3100P at S1, positions D (Buoy6) and E (Buoy5 and Buoy8) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,000 m. The signal arrivals at position D (Buoy6) are high amplitude and show strong source directionality. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predict received levels for a 171 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.16.1-2**), which shows the received peak level for position D at 110° indicating an error in buoy positioning, and for position E at 95°, indicating relatively good buoy positioning. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

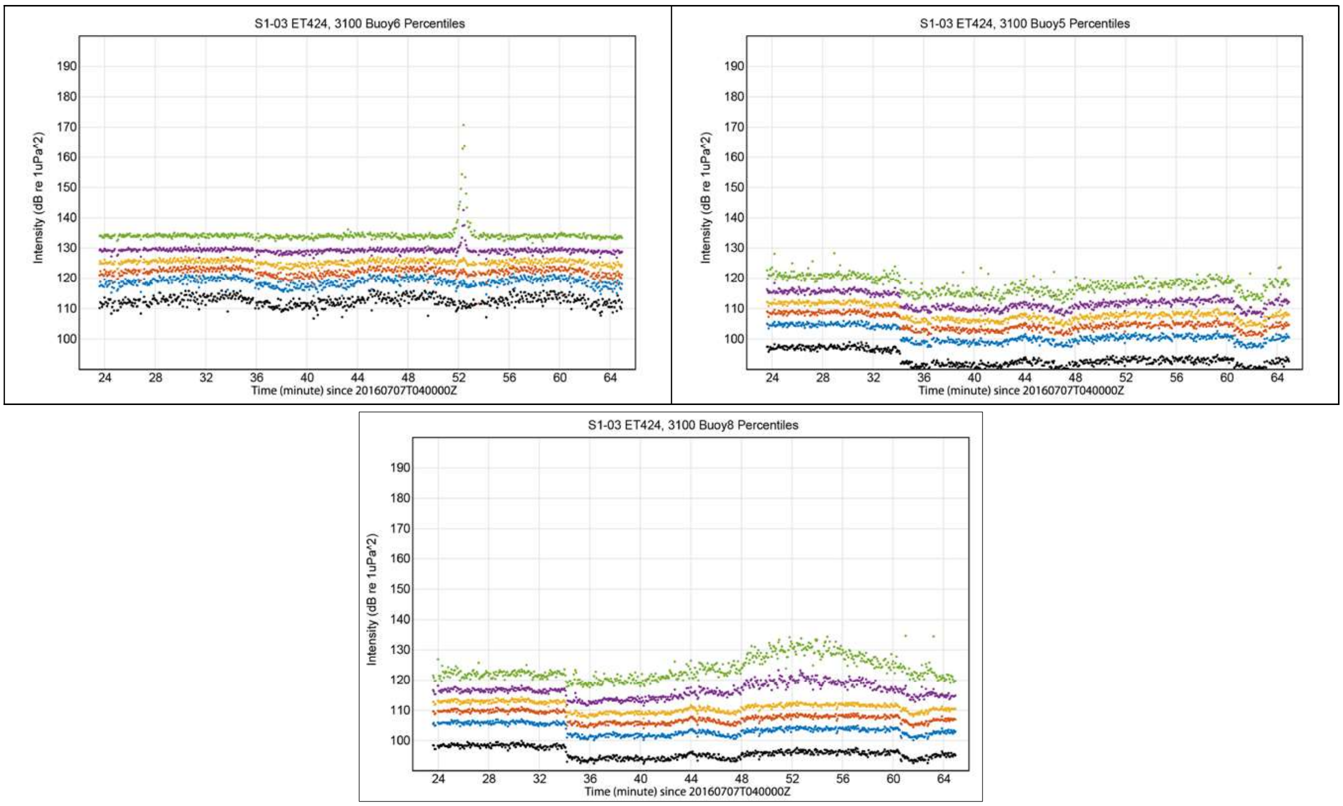


Figure 4.16.1-1. Percentile plots of Edgetech 424 3100P signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

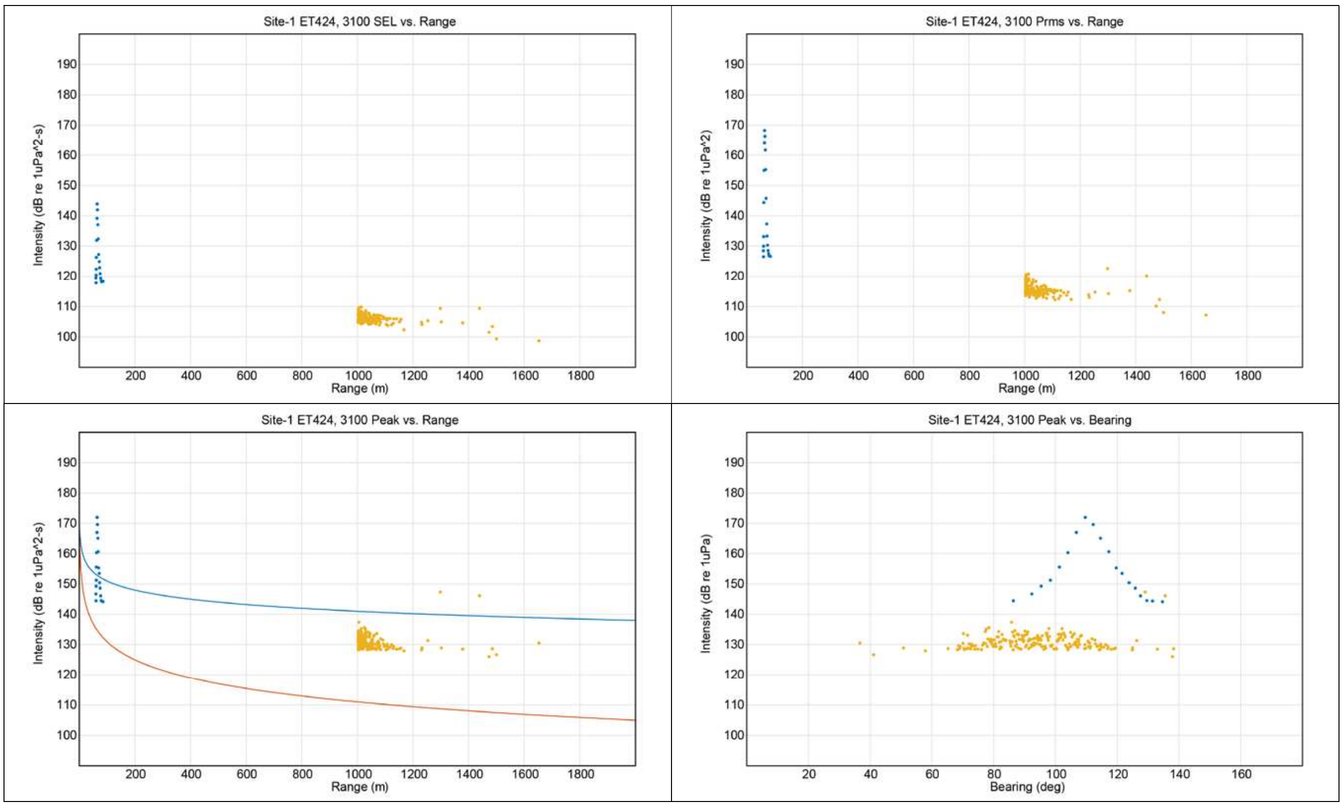


Figure 4.16.1-2. Range results for Edgetech 424 3100P signals at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.16.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8, combined). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

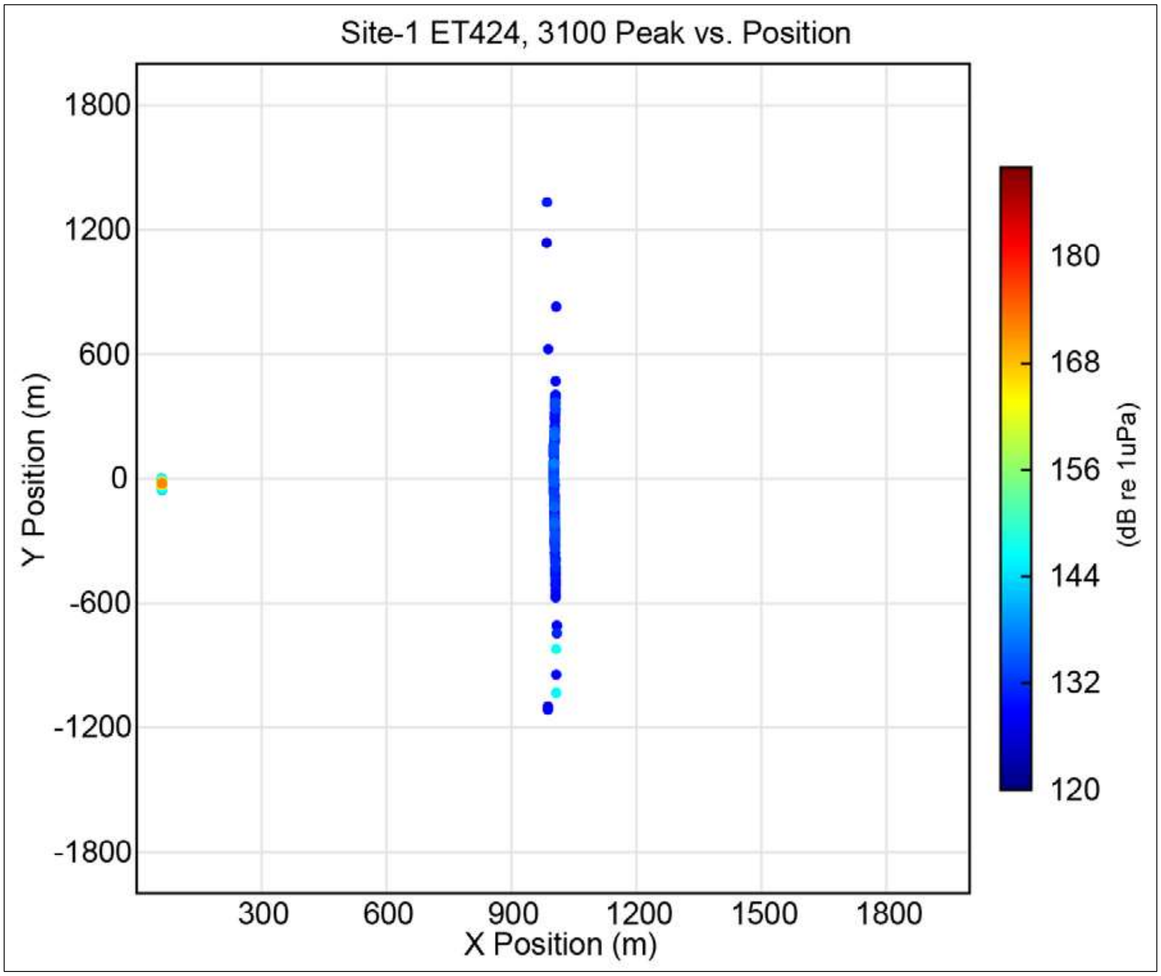


Figure 4.16.1-3. Plan view of received peak level for Edgetech 424 3100P at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.16.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The received levels at buoy position D (Buoy6) are approximately 18 dB higher than levels reported by NUWC, indicating possible calibration errors (**Section 2.6.3.1**), or buoy GPS navigation errors (i.e., the source was closer than realized).

Table 4.16.1-1. ET424, 3100P source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3100P Mode 1	4-24 kHz	100%	NA	10 ms	189	187	164
NUWC	4-24 kHz	100%	NA	10 ms	171	165	141

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.16.2 Site 2 – Sand, 10 m Depth

At S2, the ET424 3100P, Mode 1, had acoustic recordings in Run4, Run5, and Run34. For Run4 and Run5, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings. For Run4 and Run5, positions E (Buoy10) and F (Buoy9) did not capture the HF acoustic signal. For Run34, there is no evidence of the signal.

Run Summary

The percentile plots for the available recordings of the ET424 3100P, Mode 1, are shown in **Figure 4.16.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run4, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions D (Buoy6) for Run5 and B (Buoy11) for Run4. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.16.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3100P at S2, positions D (Buoy6 combined) and B (Buoy11 combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 171 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.16.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 135°, indicating an error in the buoy's positioning. For position B, the received peak level is at approximately 90°, which indicates good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

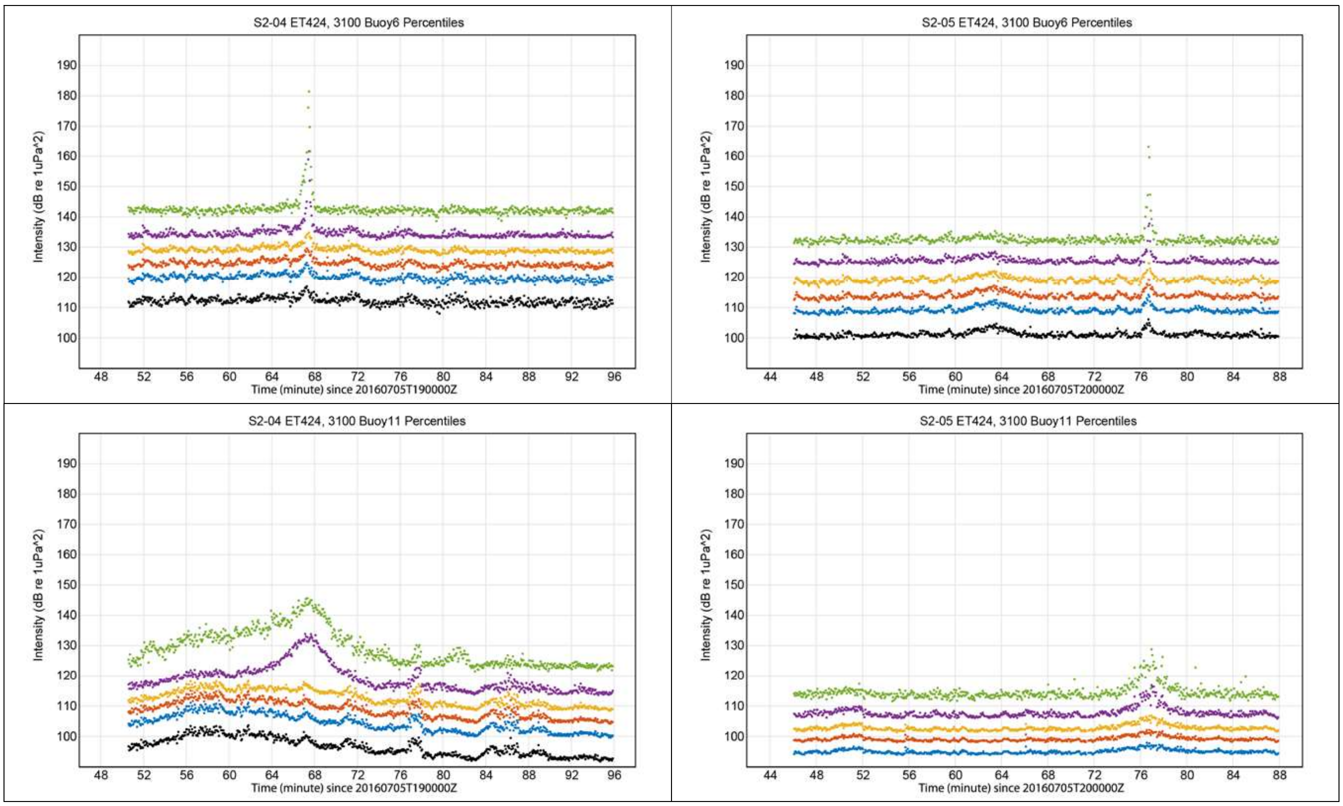


Figure 4.16.2-1. Percentile plots of Edgetech 424 3100P signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position D (Buoy6); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy11). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

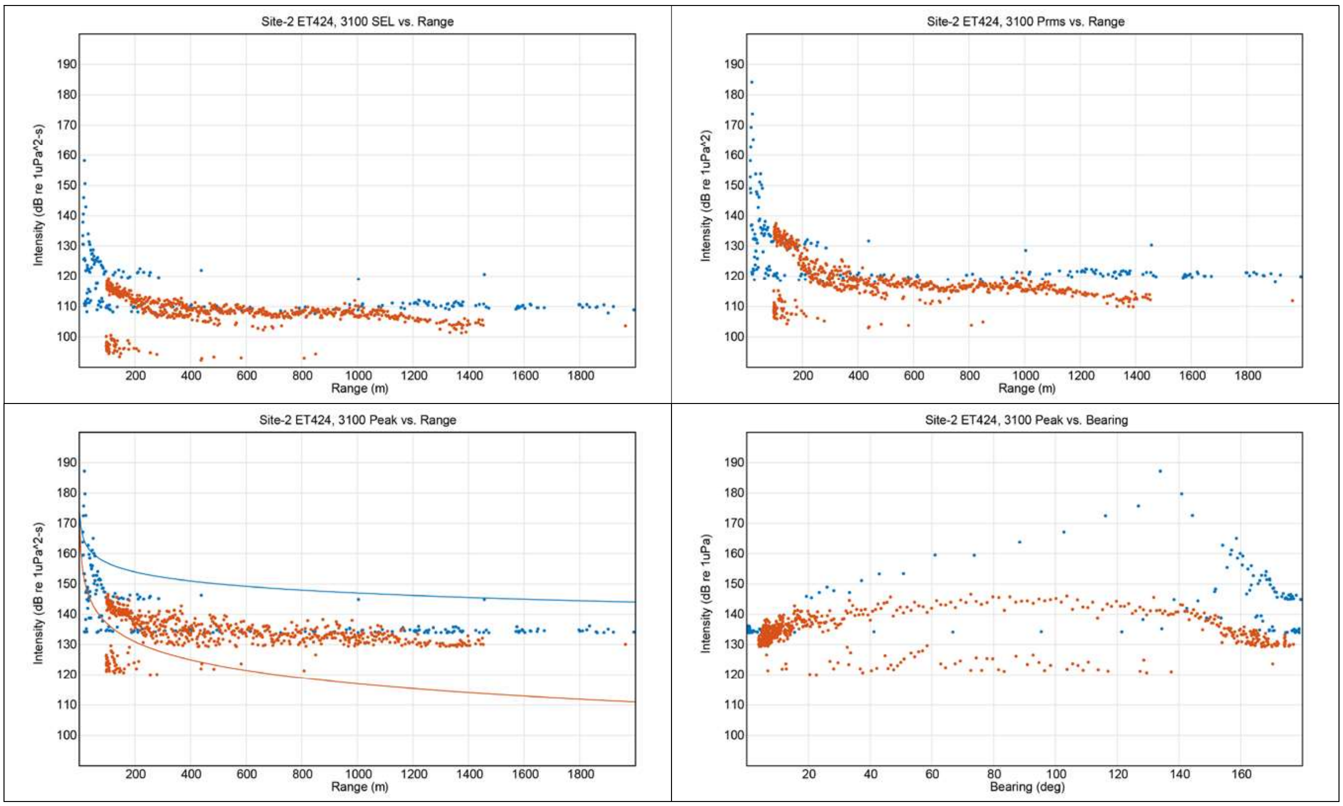


Figure 4.16.2-2. Range results for Edgetech 424 3100P signals at Site 2 for positions D (Buoy6 and Buoy6, combined) and B (Buoy11 and Buoy11, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.16.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 25,-50m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6 and Buoy6, combined) and B (Buoy11 and Buoy11, combined). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

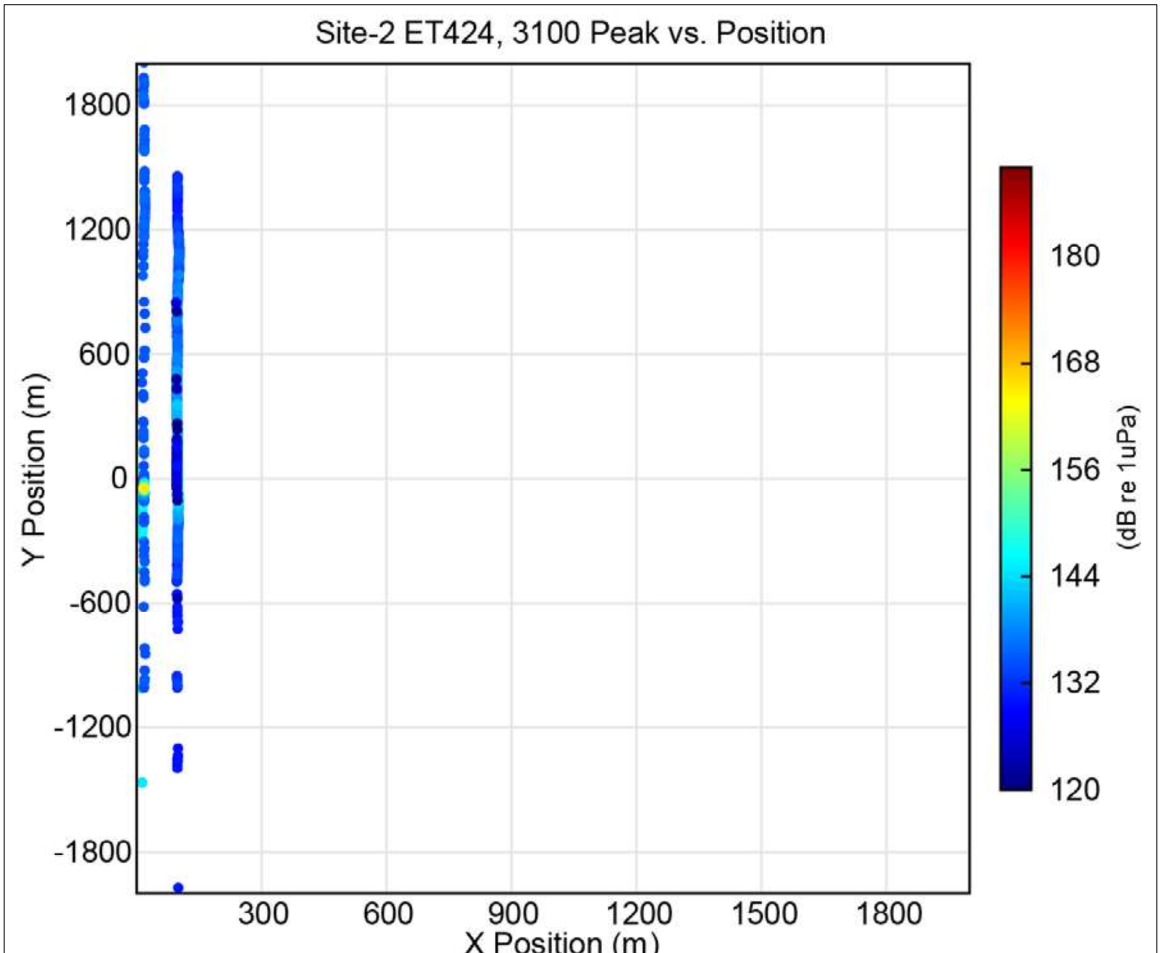


Figure 4.16.2-3. Plan view of received peak level for Edgetech 424 3100P at Site 2 for positions D (Buoy6 and Buoy6) and B (Buoy11 and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.16.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The received levels at position D (Buoy6) are much higher than NUWC reported source levels, indicating a possible calibration issue (**Section 2.6.3.1)**; however, the levels are consistent with levels received by ranging positions. The discrepancy in source levels is an indication of either a serious unresolved calibration issues (**Section 2.6.3.1**) or large buoy navigation errors.

Table 4.16.2-1. ET424, 3100P source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3100P Mode 1	4-24 kHz	100%	NA	10 ms	202	192	173
NUWC	4-24 kHz	100%	NA	10 ms	171	165	141

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.16.3 Site 3 – Mud, 30 m Depth

At S3, the ET424 3100P, Mode 1, had valid acoustic recordings in Run10 and Run30. For Run10, position A (Buoy5) had valid acoustic data and observed signals. For Run30, positions D (Buoy6), B (Buoy11), A (Buoy12) and F (Buoy9) had valid acoustic data and observed signals. Position E (Buoy8 and Buoy10) had valid acoustic data, but signals were not observed.

Run Summary

The percentile plots for the available recordings of the ET424 3100P, Mode 1, are shown in **Figure 4.16.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run30, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and F (Buoy9). The data at position F (Buoy9) are very noisy (i.e., the data have a poor signal to noise ratio). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.16.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the ET424 3100P at S3, positions D (Buoy6), B (Buoy11), A (Buoy5 and Buoy12), and F (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,800 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 171 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The received levels at position F (Buoy9) appears to be approximately 10 dB too high, indicative of an unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 130°, indicating an error in buoy positioning. The peak level of positions A and B are approximately 80°, indicating relatively good buoy positioning, while position F is approximately 115°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

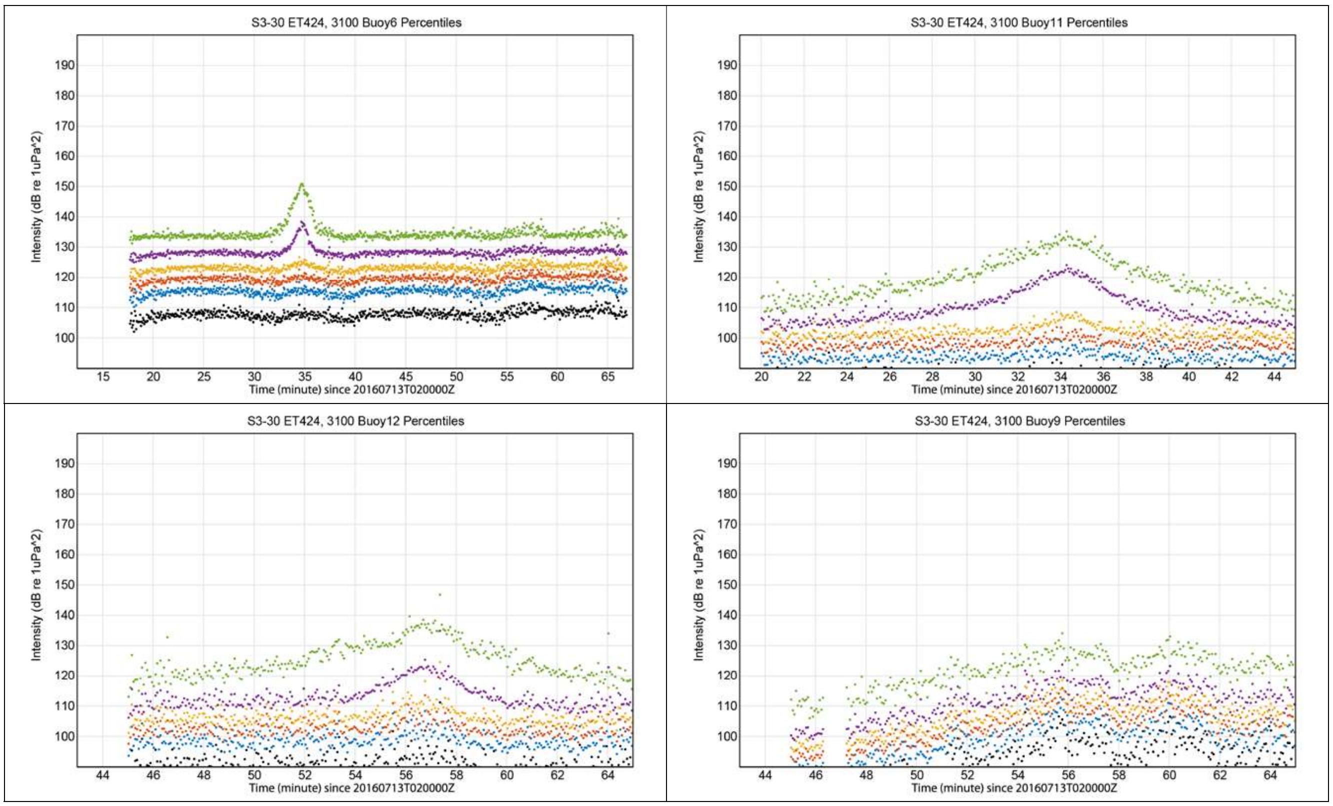


Figure 4.16.3-1. Percentile plots of Edgetech 424 3100P signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

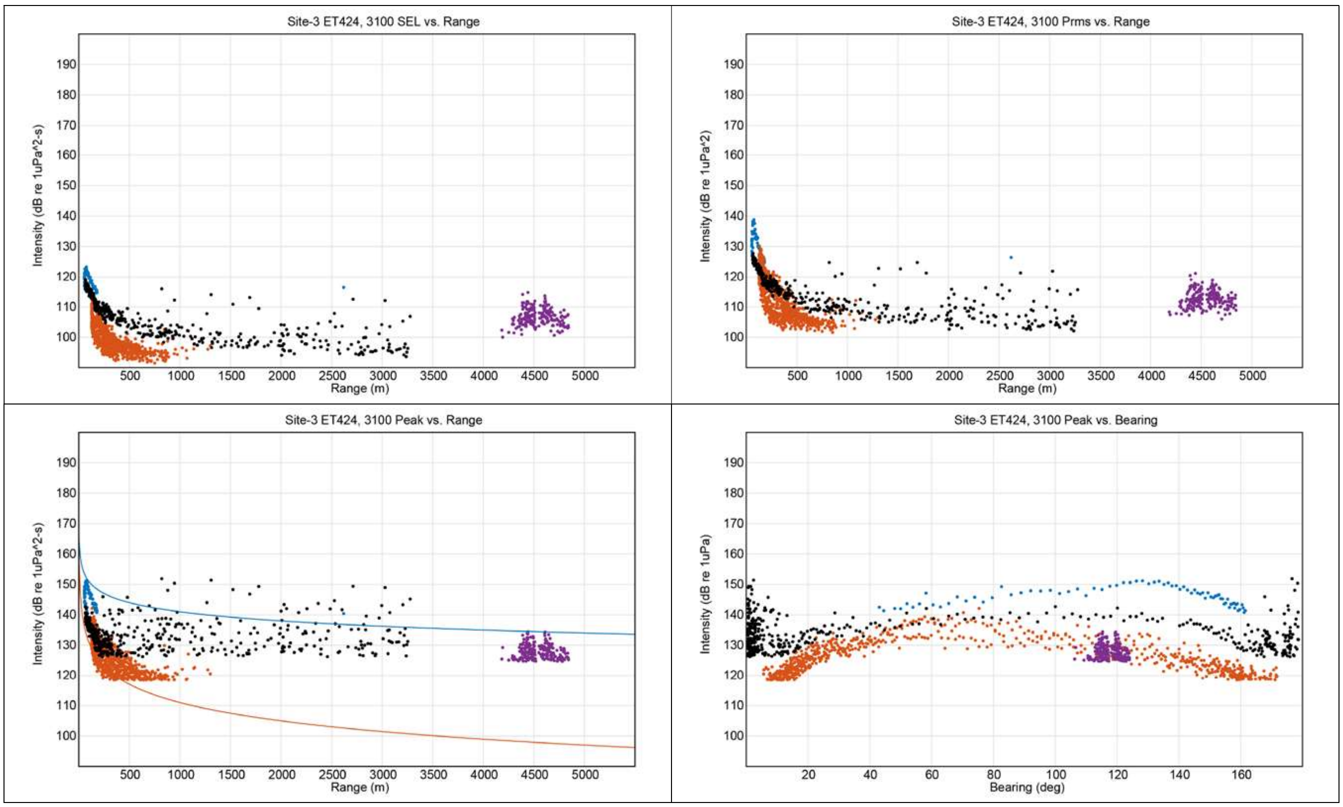


Figure 4.16.3-2. Range results for Edgetech 424 3100P combined signals for Run10 and Run30 at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy5 and Buoy12), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; F = purple.

The plan view is shown in **Figure 4.16.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy5 and Buoy12), and F (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

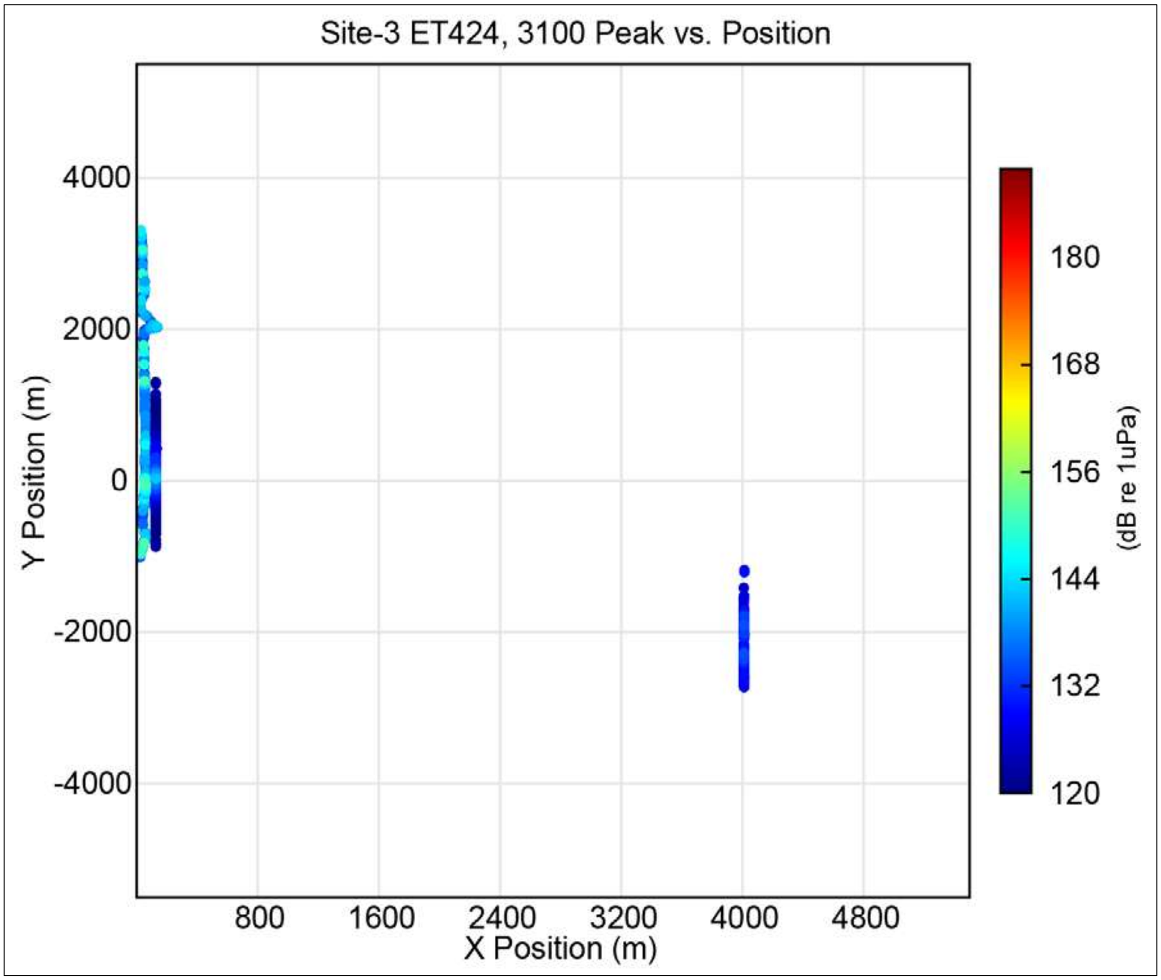


Figure 4.16.3-3. Plan view of received peak level for Edgetech 424 3100P at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy5 and Buoy12), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.16.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.16.3-1. ET424, 3100P source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3100P Mode 1	4-24 kHz	100%	NA	10 ms	170	155	141
NUWC	4-24 kHz	100%	NA	10 ms	171	165	141

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.16.4 Site 4 – Sand, 30 m Depth

At S4, the ET424 3100P, Mode 1, had valid acoustic recordings in Run10, Run11, and Run25. For Run10, positions A (Buoy6), E (Buoy9), and F (Buoy5) had valid acoustic recordings. For Run11, there is no evidence of the signal. For Run25, position B (Buoy12) had valid acoustic data and observed signals.

Run Summary

The percentile plots for the available recordings of the ET424 3100P, Mode 1, are shown in **Figure 4.16.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy12) for Run25, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions A (Buoy6), E (Buoy9), and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.16.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3100P at S4, only position B (Buoy12) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 171 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 80°, indicating relatively good buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

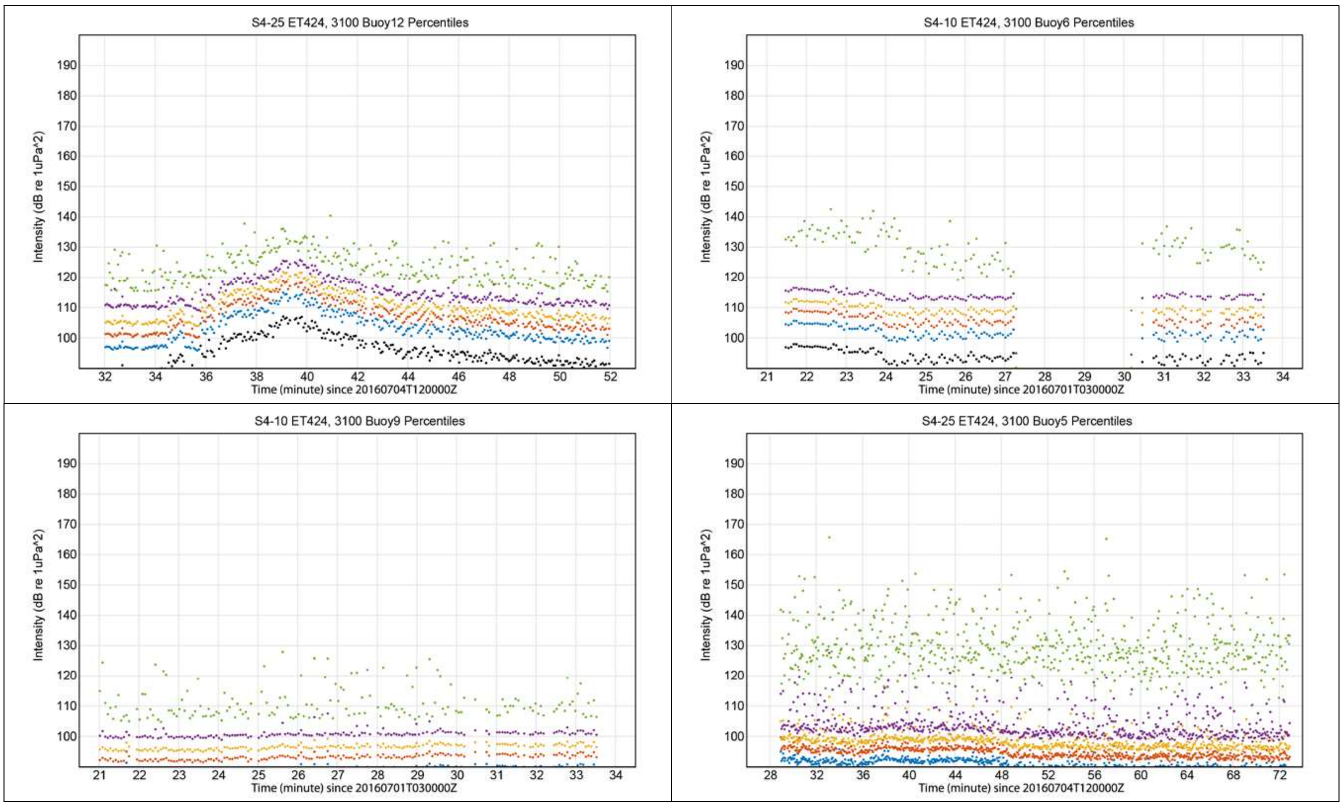


Figure 4.16.4-1. Percentile plots of Edgetech 424 3100P signals at Site 4.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy6); Bottom left: SPL_{pk} arrival at position E (Buoy9); Bottom right: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

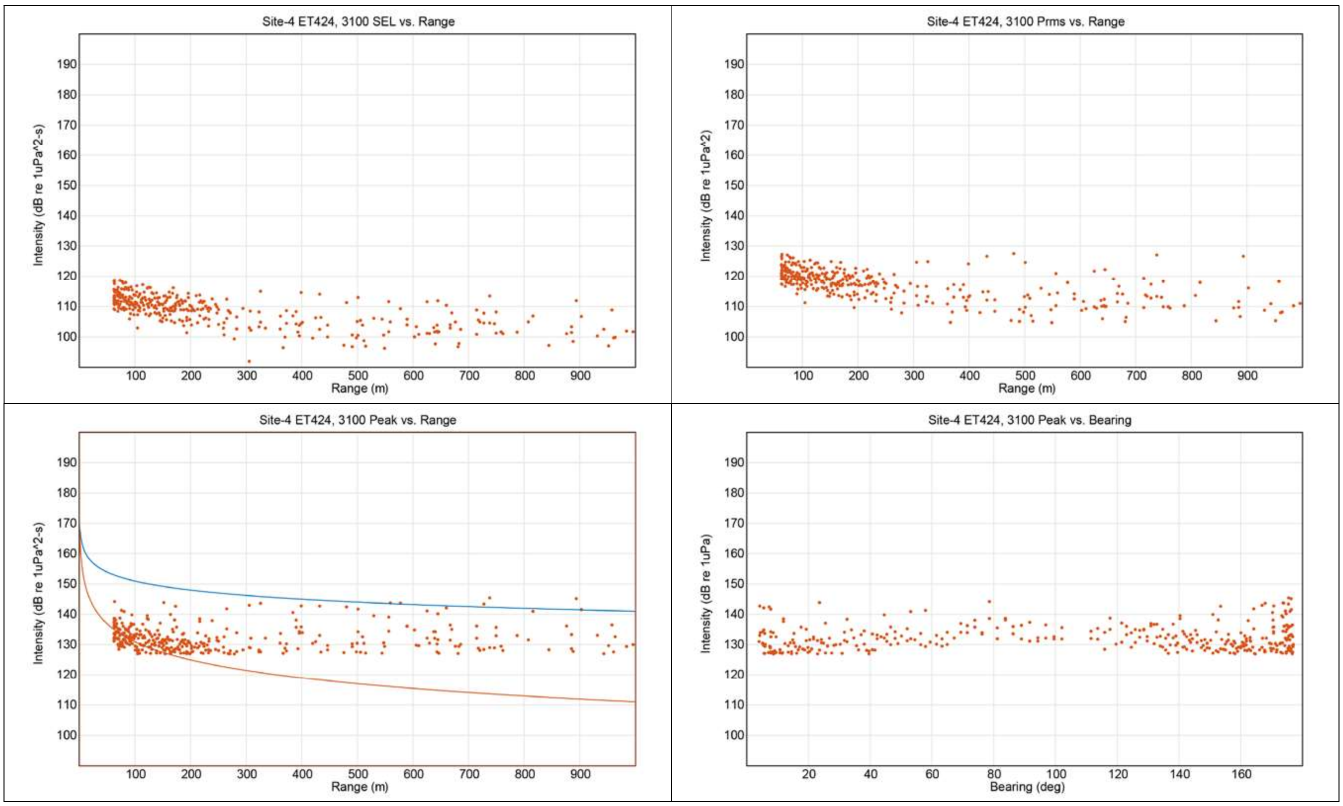


Figure 4.16.4-2. Range results for Edgetech 424 3100P signals at Site 4 for position B (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.16.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy12). Recordings at the buoy had acoustic peak amplitude, presumably at the CPA. The highest amplitude signal for position B is seen at approximately 0 m on the y-axis.

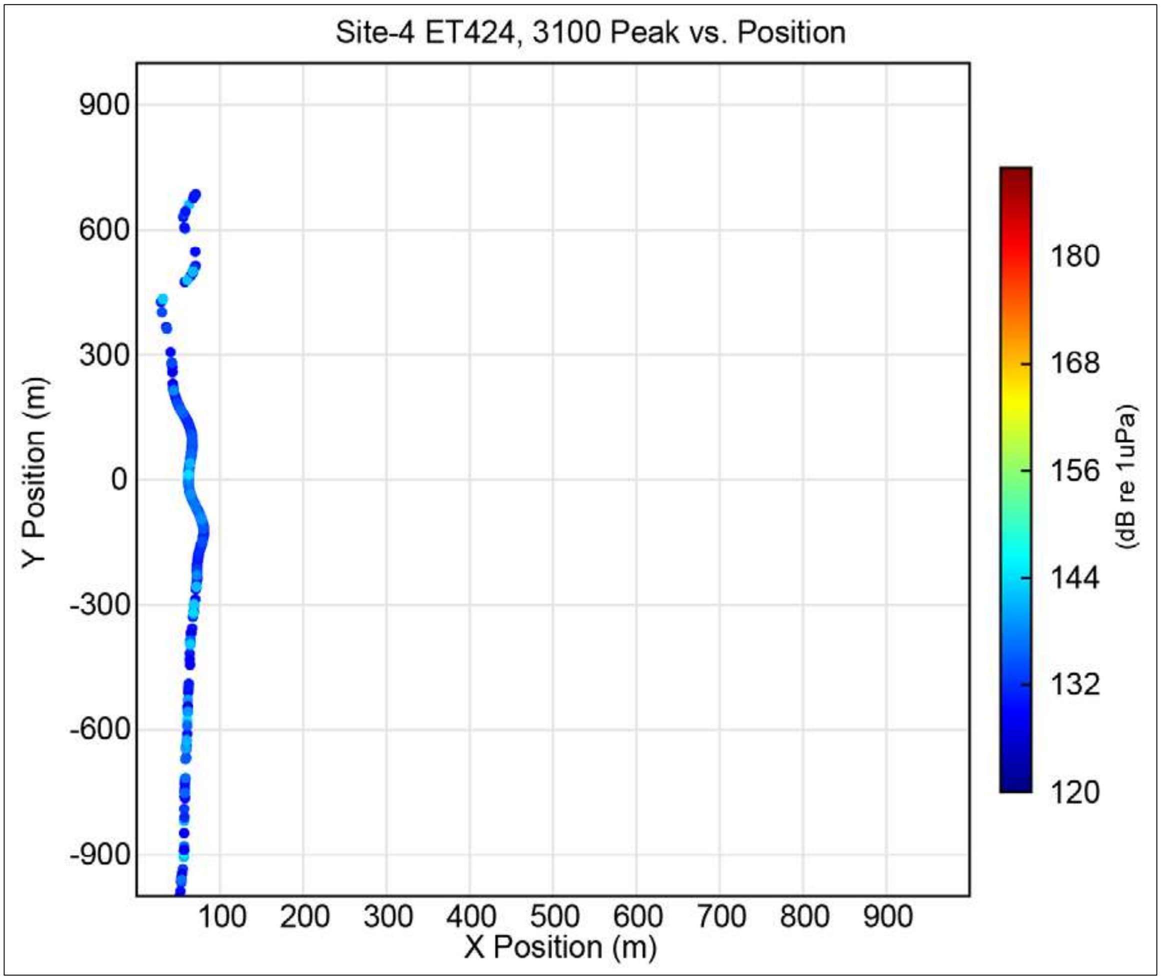


Figure 4.16.4-3. Plan view of received peak level for Edgetech 424 3100P at Site 4 for position B (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.16.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.16.4-1. ET424, 3100P source levels, Mode 1, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3100P Mode 1	4-24 kHz	100%	NA	10 ms	172	156	145
NUWC	4-24 kHz	100%	NA	10 ms	171	165	141

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.16.5 Site 5 – Sandy-Silt, 100 m Depth

The ET424, 3100P, Mode 1, was not deployed or operated at S5.

This Page Left Intentionally Blank

4.17 Edgetech 424 3100P, 4-24 kHz, 100 Percent Power, 1-ms Pulse (Mode 2)

The ET424 3100P subbottom profiler generates a single, pulse signal with a peak frequency of 3 kHz. The operational parameter settings for Mode 2 were 100 percent power, a 1-ms pulse, and a 4-24 kHz output frequency, using the 3100P topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.17-1** is the selected frequency band (0 to 25 kHz) and SPL_{pk} (152 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.17-1. Bandpass determination for the ET424, 3100P subbottom profiler, 4-24 kHz, 100 percent power, 1-ms pulse at S2, Run32.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	151.85
0-100	149.74
0-50	152.46
0-25	**152.25**
0-12	151.73

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET424 3100P, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.17-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The ET424 was operationally paired in alternation with the MiniSparker. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.17-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1s chunks) manually. This approach seemed successful in separating the two sources. The time-series in **Figure 4.17-1** shows the reception of bottom bounce energy.

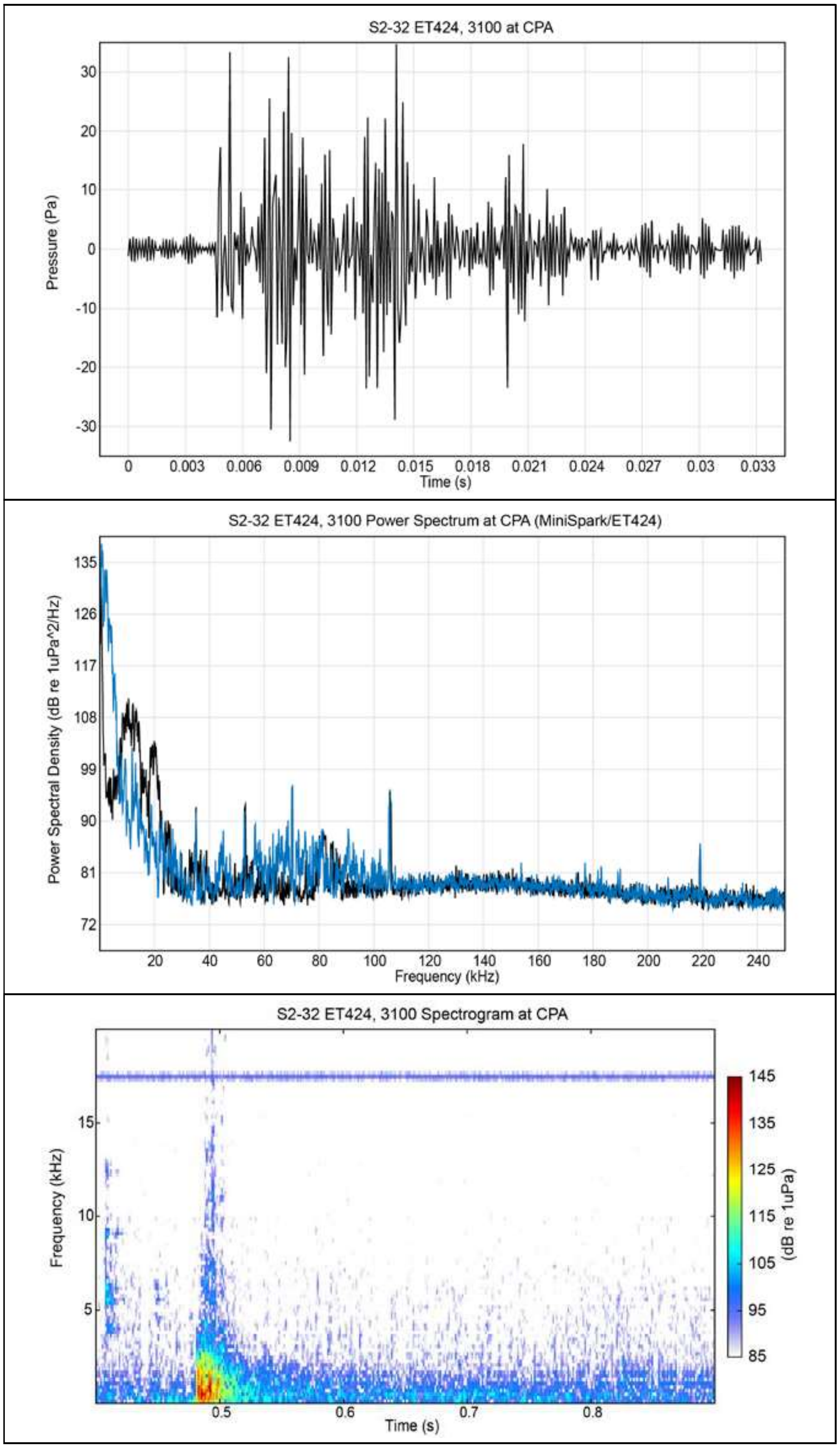


Figure 4.17-1. Edgetech 424 3100P measured signal characteristics at closest point of approach (CPA) at Site 2, Run32.

Top: Time-waveform of a signal; Middle: Power spectral density, ET424 = blue, MiniSparker = black; Bottom: Spectrogram.

4.17.1 Site 1 – Mud, 10 m Depth

The ET424 3100P, Mode 2, was not deployed or operated at S1.

4.17.2 Site 2 – Sand, 10 m Depth

At S2, the ET424 3100P, Mode 2, had valid acoustic recordings in Run32 at positions B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9).

Run Summary

The percentile plots for the available recordings of the ET424 3100P, Mode 2, are shown in **Figure 4.17.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy11) for Run32, where the received signal is faintly observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy5), E (Buoy10), and F (Buoy9). There is faint evidence of the signal, but these results are mostly in-band noise. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.17.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3100P at S2, positions B (Buoy5 and Buoy11 combined) and E (Buoy10) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predict received levels for a 172 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.17.2-2** is the SPL_{pk} versus bearing plot.

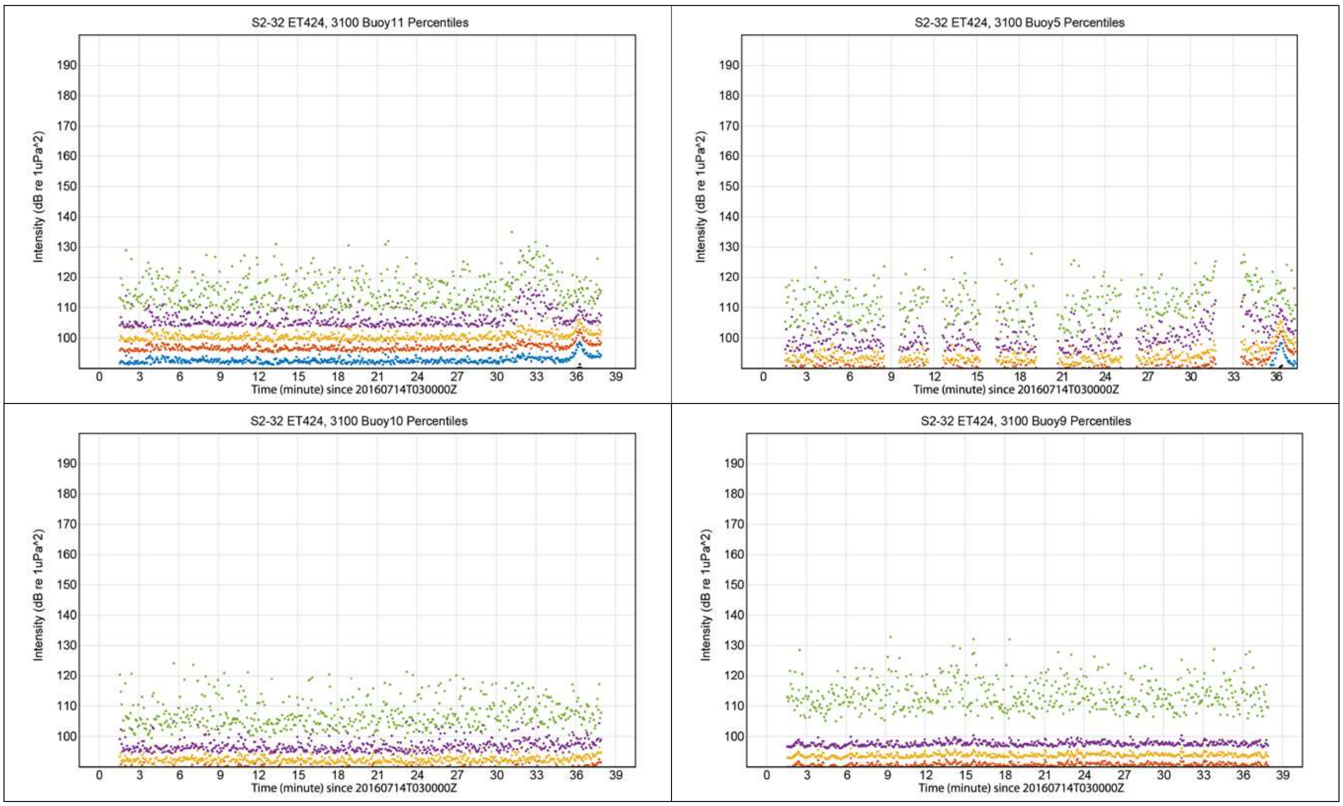


Figure 4.17.2-1. Percentile plots of Edgetech 424 3100P signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy11); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy10); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

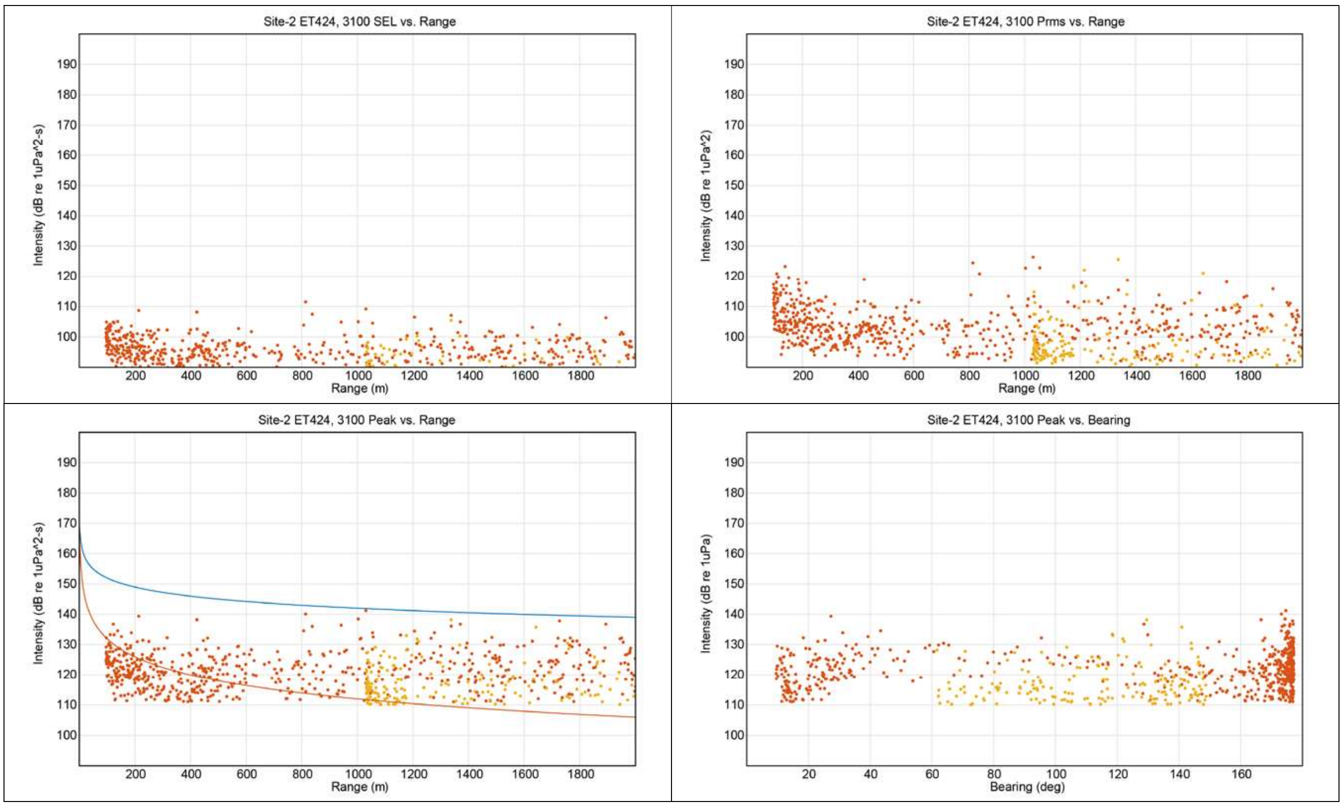


Figure 4.17.2-2. Range results for Edgetech 424 3100P signals at Site 2 for positions B (Buoy5 and Buoy11, combined) and E (Buoy10). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; E = yellow.

The plan view is shown in **Figure 4.17.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at –2,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy5 and Buoy11, combined) and E (Buoy10). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

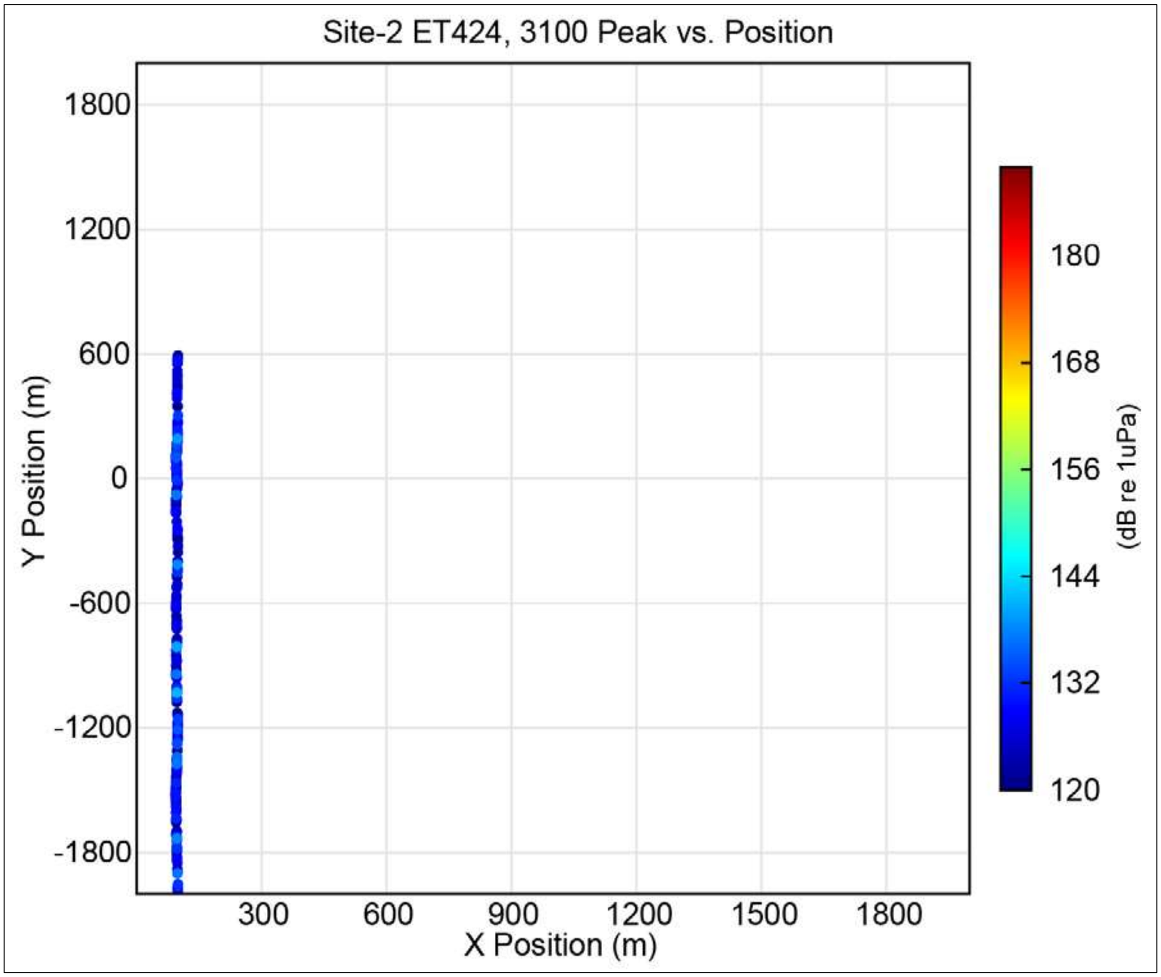


Figure 4.17.2-3. Plan view of received peak level for Edgetech 424 3100P at Site 2, showing the results for positions B (Buoy5 and Buoy11 combined) and E (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.17.2-1**. The estimated source levels were calculated from the measurements at position B (rather than position D) using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.17.2-1. ET424, 3100P source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET424 3100P Mode 2	4-24 kHz	100%	NA	1 ms	173	158	143
NUWC	4-24 kHz	100%	NA	1 ms	172	166	134

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.17.3 Site 3 – Mud, 30 m Depth

At S3, the ET424 3100P, Mode 2, had valid acoustic recordings in Run11 at positions B (Buoy12), A (Buoy5), and F (Buoy6). Position F (Buoy6) was too distant to capture the signal.

Run Summary

The percentile plots for the available recordings of the ET424 3100P, Mode 2, are shown in **Figure 4.17.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position A (Buoy5), where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy12) and F (Buoy6). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.17.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the ET424 3100P at S3, positions B (Buoy12) and A (Buoy5) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 172 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for positions B and A are at approximately 90°. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern.

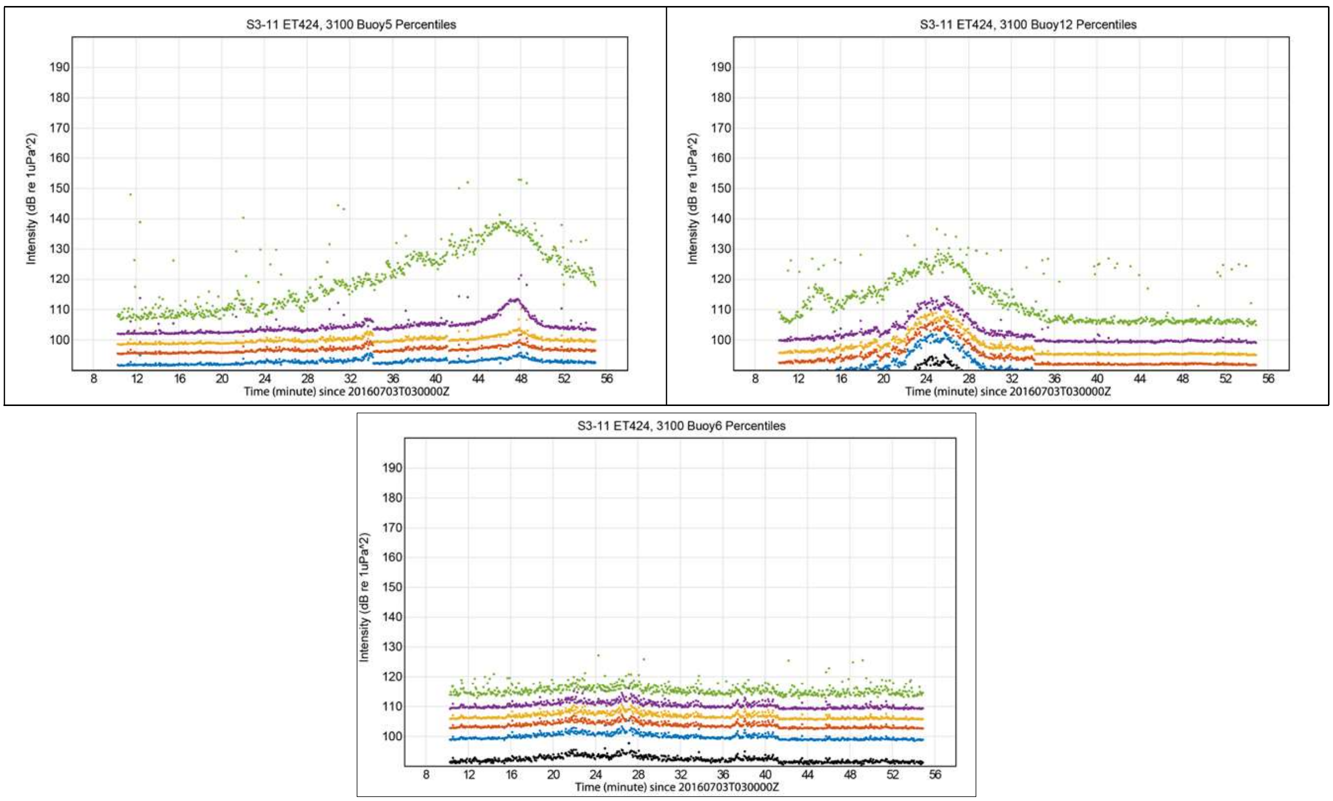


Figure 4.17.3-1. Percentile plots of Edgetech 424 3100P signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position A (Buoy5); Top right: SPL_{pk} arrival at position B (Buoy12); Bottom: SPL_{pk} arrival at position F (Buoy6). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

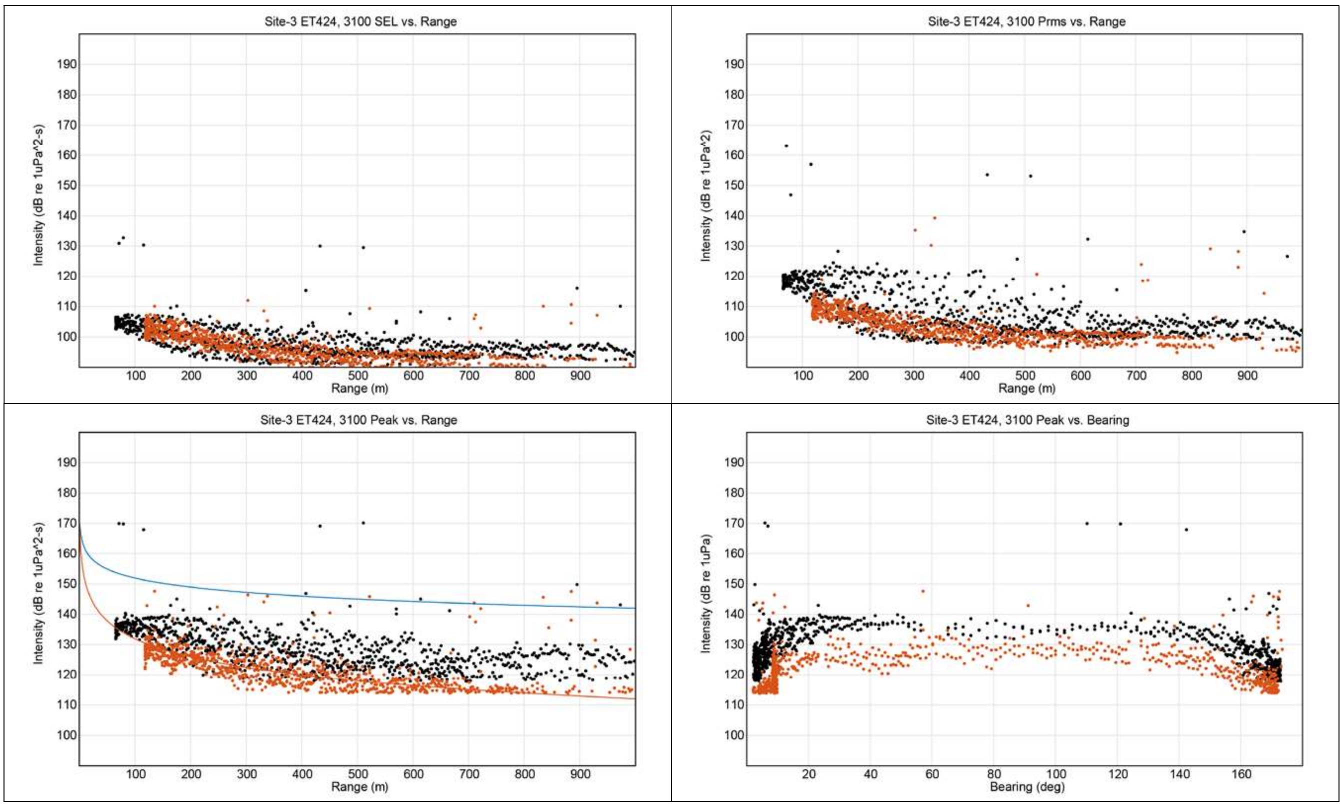


Figure 4.17.3-2. Range results for Edgetech 424 3100P combined signals for Run11 at Site 3 for positions B (Buoy12) and A (Buoy5). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red.

The plan view is shown in **Figure 4.17.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 60,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -700 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy12) and A (Buoy5). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

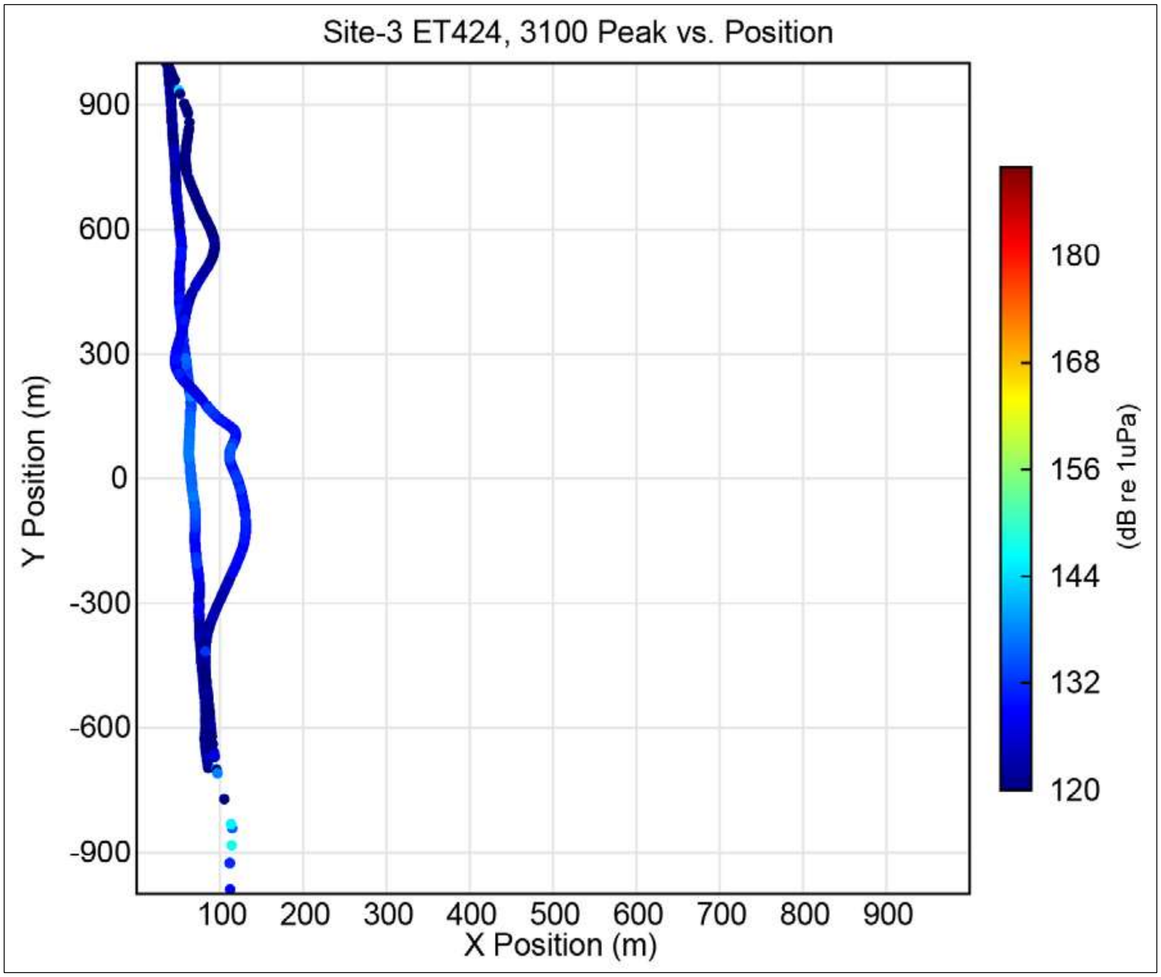


Figure 4.17.3-3. Plan view of received peak level for Edgetech 424 3100P at Site 3 for positions B (Buoy12) and A (Buoy5).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.17.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.17.3-1. ET424, 3100P source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3100P Mode 2	4-24 kHz	100%	NA	1 ms	169	148	134
NUWC	4-24 kHz	100%	NA	1 ms	172	166	134

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.17.4 Site 4 – Sand, 30 m Depth

At S4, the ET424 3100P, Mode 2, had valid acoustic recordings in Run12 and Run26. For Run12, position E (Buoy9) had valid acoustic data. For Run26, position B (Buoy12) had valid acoustic data and signals, while position A (Buoy7) appears to be numerical noise. For all runs, position F was too distant to capture the HF acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET424 3100P, Mode 2, are shown in **Figure 4.17.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run26, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions A (Buoy7) and E (Buoy9), however there were no signals captured at position A. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.17.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3100P at S4, positions B (Buoy12) and E (Buoy9) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 172 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The position E (Buoy9) data is approximately 10 to 20 dB too high, as a result of an unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for positions B and E are at approximately 90°, indicating good navigational buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

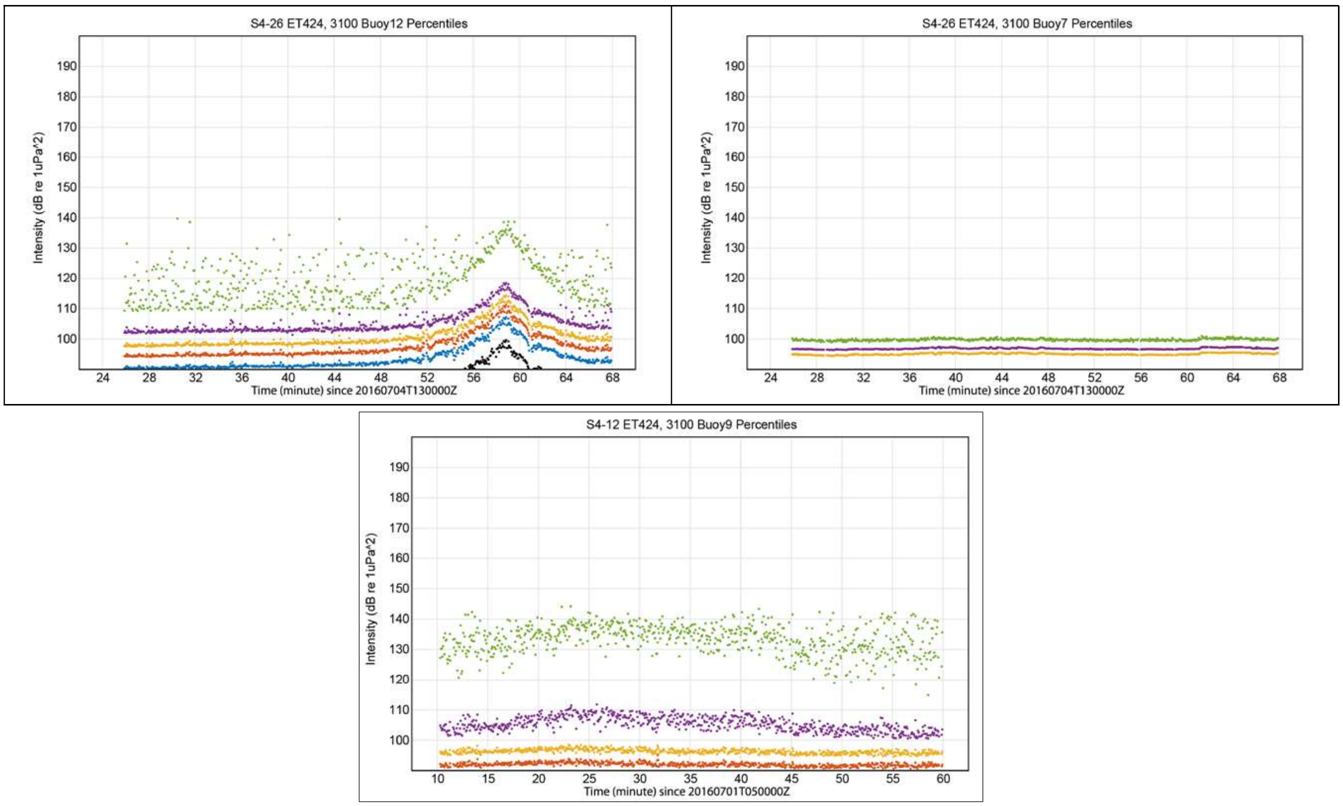


Figure 4.17.4-1. Percentile plots of Edgetech 424 3100P signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy7); Bottom: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

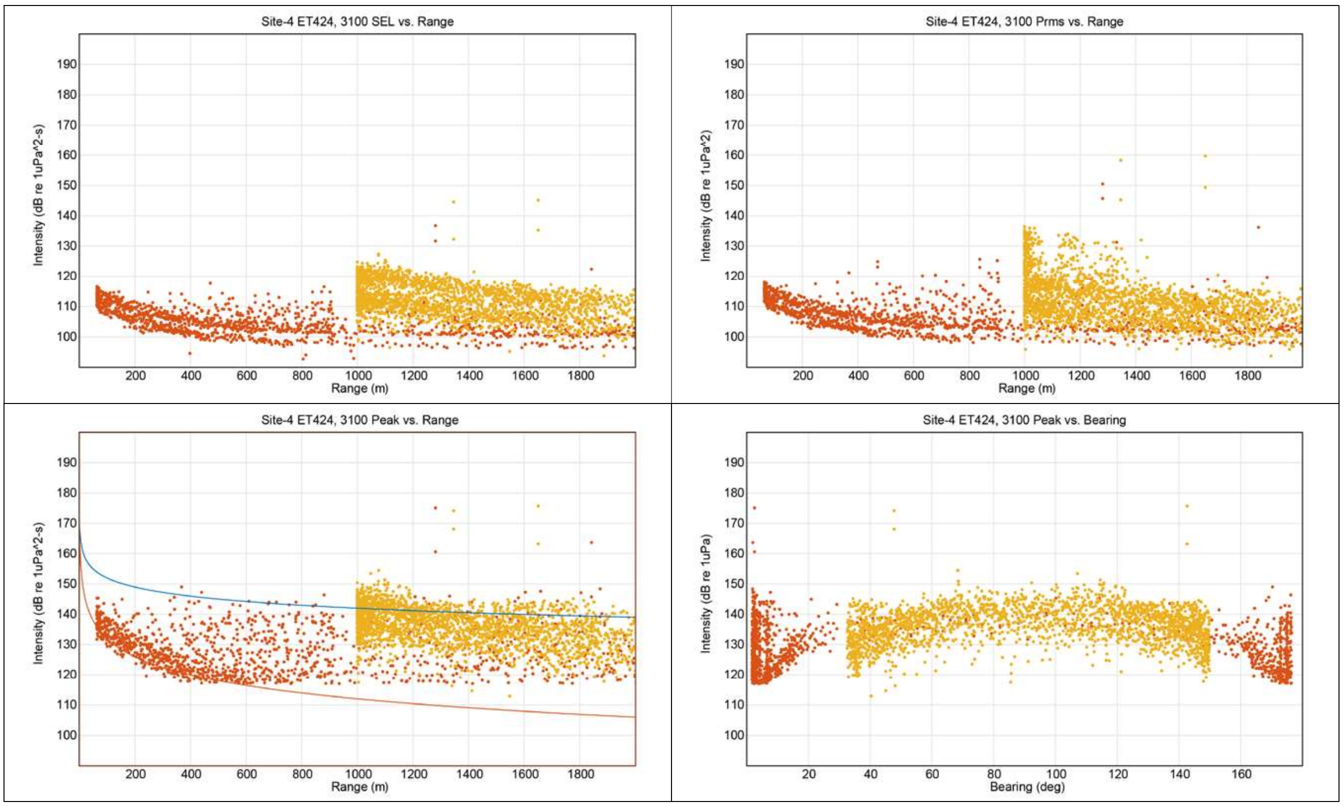


Figure 4.17.4-2. Range results for Edgetech 424 3100P signals at Site 4 for positions B (Buoy12) and E (Buoy9).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; E = yellow.

The plan view is shown in **Figure 4.17.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 75,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -700 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy12) and E (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

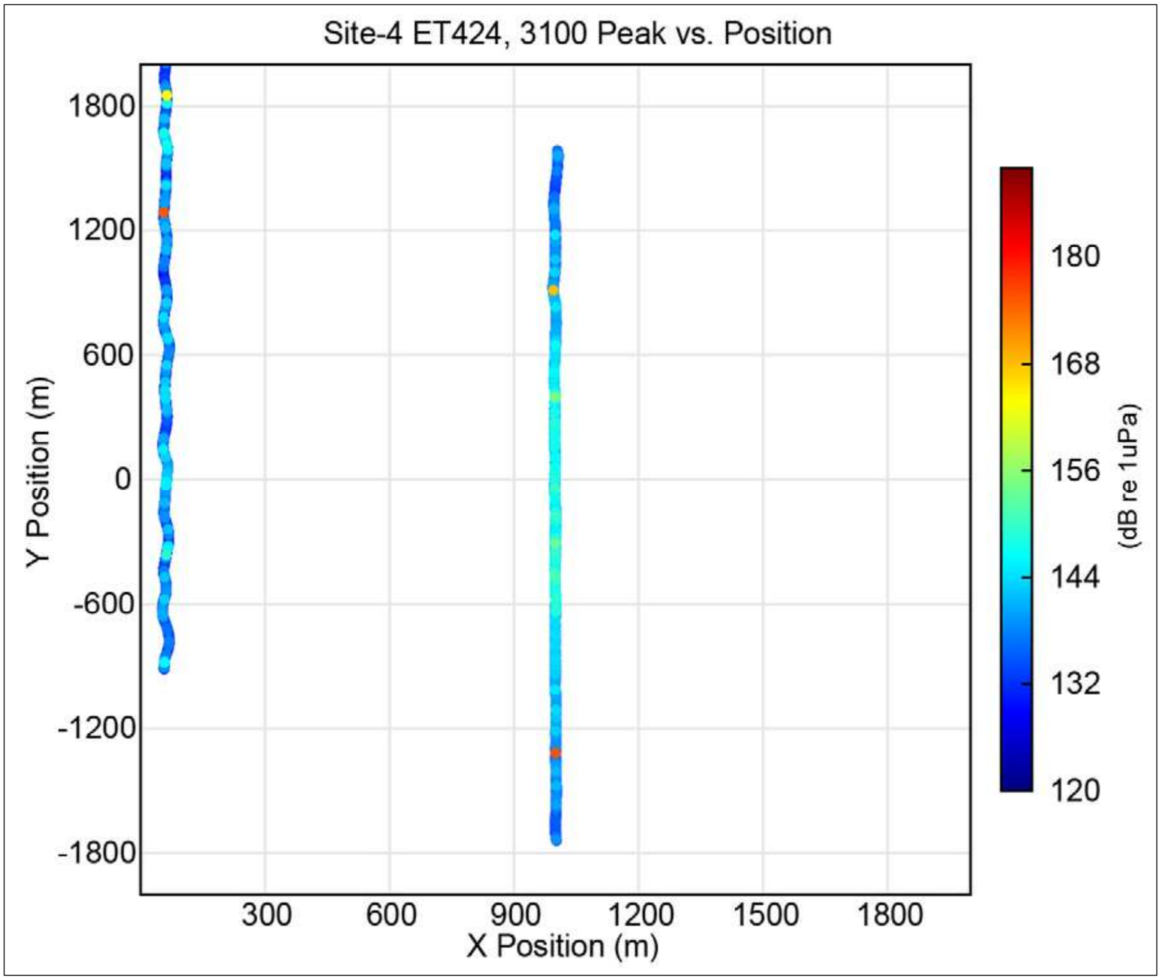


Figure 4.17.4-3. Plan view of received peak level for Edgetech 424 3100P at Site 4 for positions B (Buoy12) and E (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.17.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.17.4-1. ET424, 3100P source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3100P Mode 2	4-24 kHz	100%	NA	1 ms	173	158	145
NUWC	4-24 kHz	100%	NA	1 ms	172	166	134

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.17.5 Site 5 – Sandy-Silt, 100 m Depth

The ET424 3100P, Mode 2, was not deployed or operated at S5.

4.18 Edgetech 424 3200XS, 4-24 kHz, 100 Percent Power, 10-ms Pulse (Mode 1)

The ET424 3200XS subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 13 kHz. The operational parameter settings for Mode 1 were 100 percent power, a 10-ms pulse, and a 4-24 kHz output frequency, using the 3200XS topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.18-1** is the selected frequency band (0 to 25 kHz) and SPL_{pk} (165 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.18-1. Bandpass determination for the ET424 3200XS subbottom profiler, 4-24 kHz, 100 percent power, 10-ms pulse, at Site 2, Run6.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	165.61
0-100	165.91
0-50	165.72
0-25	**165.20**
0-12	163.85

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The ET424 3200XS was operationally paired in alternation with the MiniSparker. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.18-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources. The signal time series, as measured at S2, shows a bottom return arriving at 0.014 s.

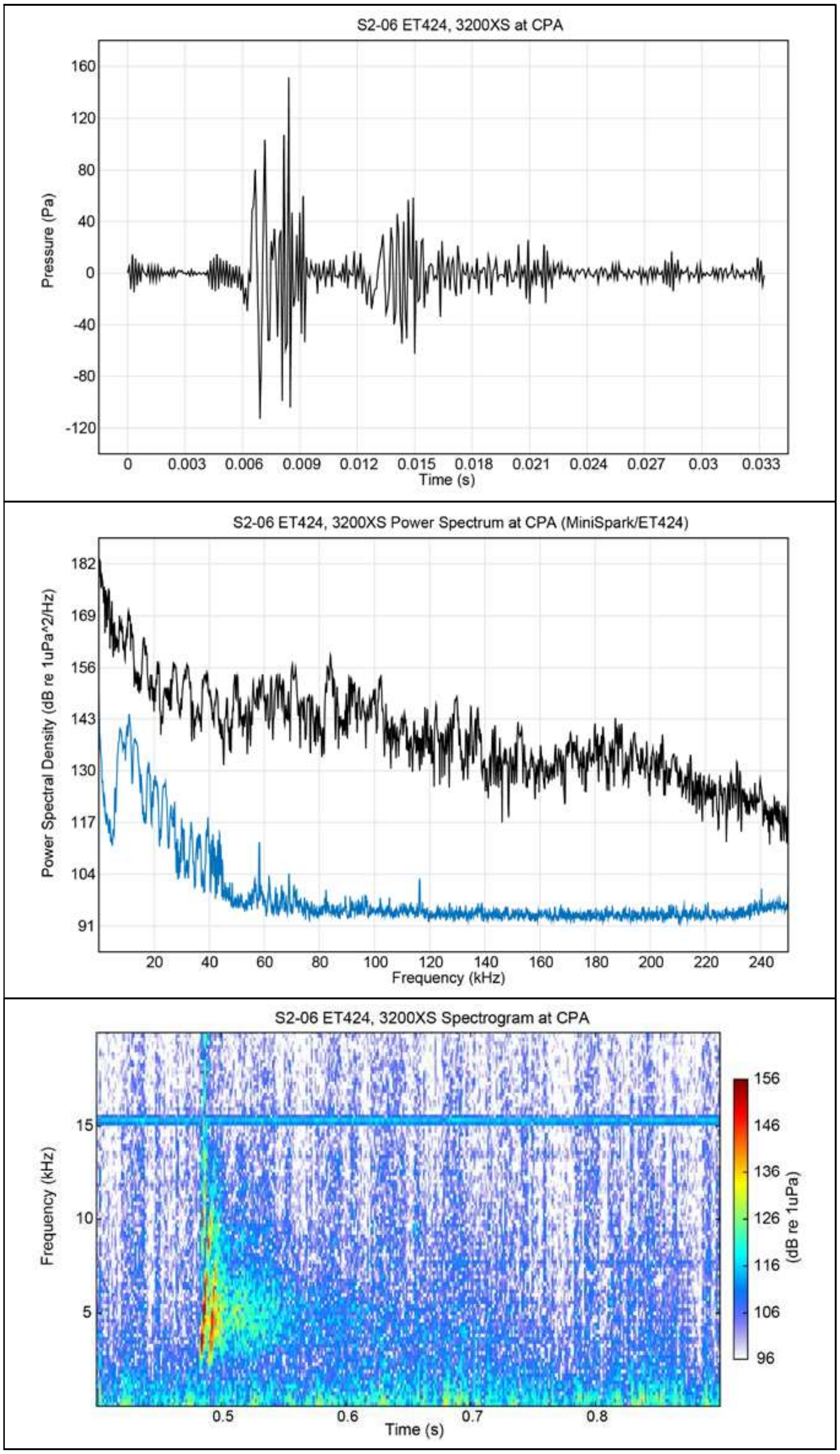


Figure 4.18-1. Edgetech 424 3200XS measured signal characteristics at closest point of approach (CPA) at Site 2, Run6.

Top: Time-waveform of a signal; Middle: Power spectral density, MiniSparker = black, ET424 3200 XS = blue; Bottom: Spectrogram.

4.18.1 Site 1 – Mud, 10 m Depth

At S1, the ET424 3200XS, Mode 1, had valid acoustic recordings in Run4 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the ET424 3200XS, Mode 1, are shown in **Figure 4.18.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run4, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.18.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the ET424 3200XS at S1, positions D (Buoy6) and E (Buoy5 and Buoy8, combined) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. Buoy E is mostly noise, but there is an aggregation of receptions at 1 km that look like signal. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10} (range)$] and cylindrical spreading [$10 \log_{10} (range)$], which predict received levels for a 182 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.18.1-2**), which shows for position D at approximately 110°, indicating a possible error in buoy positioning. For position E, the received peak level is unclear. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For an omnidirectional beam pattern, the center (maximum peak signal) is expected to be at 90°.

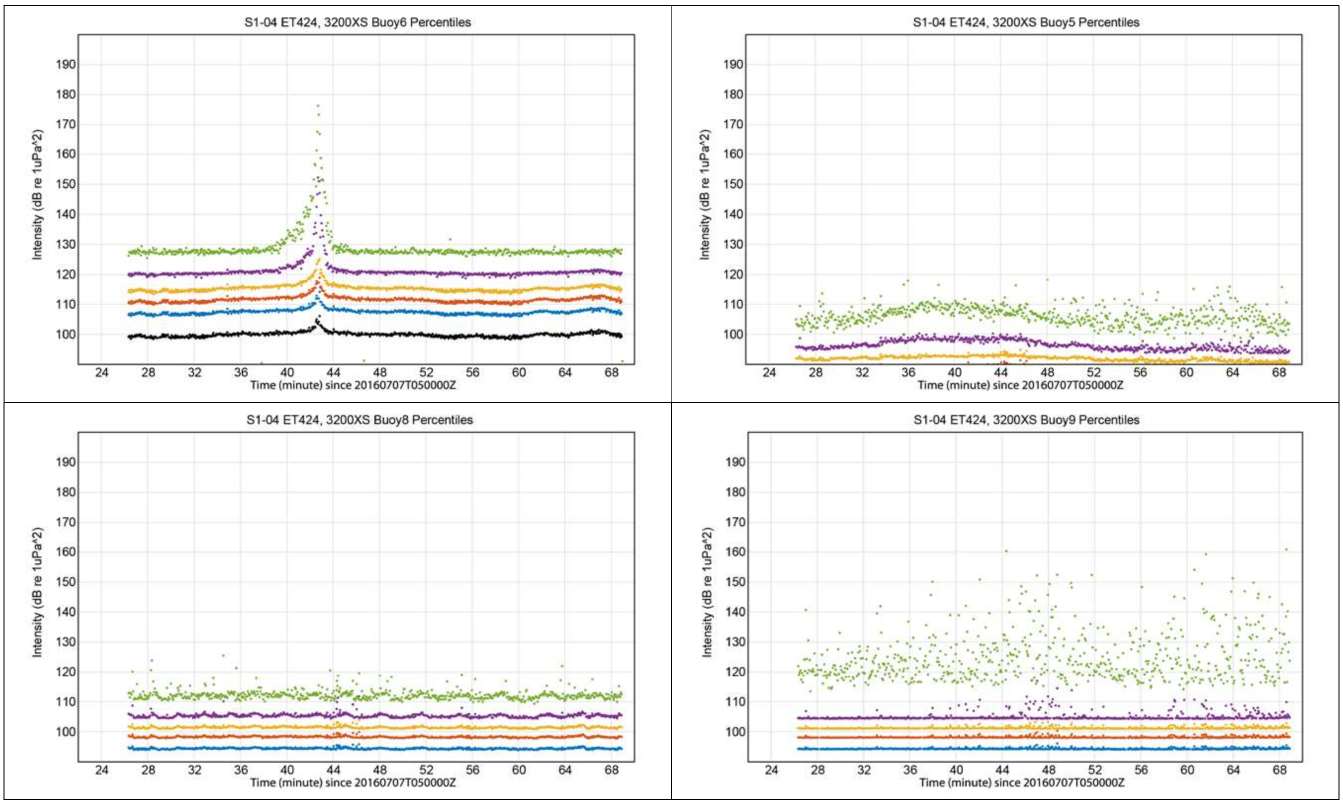


Figure 4.18.1-1. Percentile plots of Edgetech 424 3200XS signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

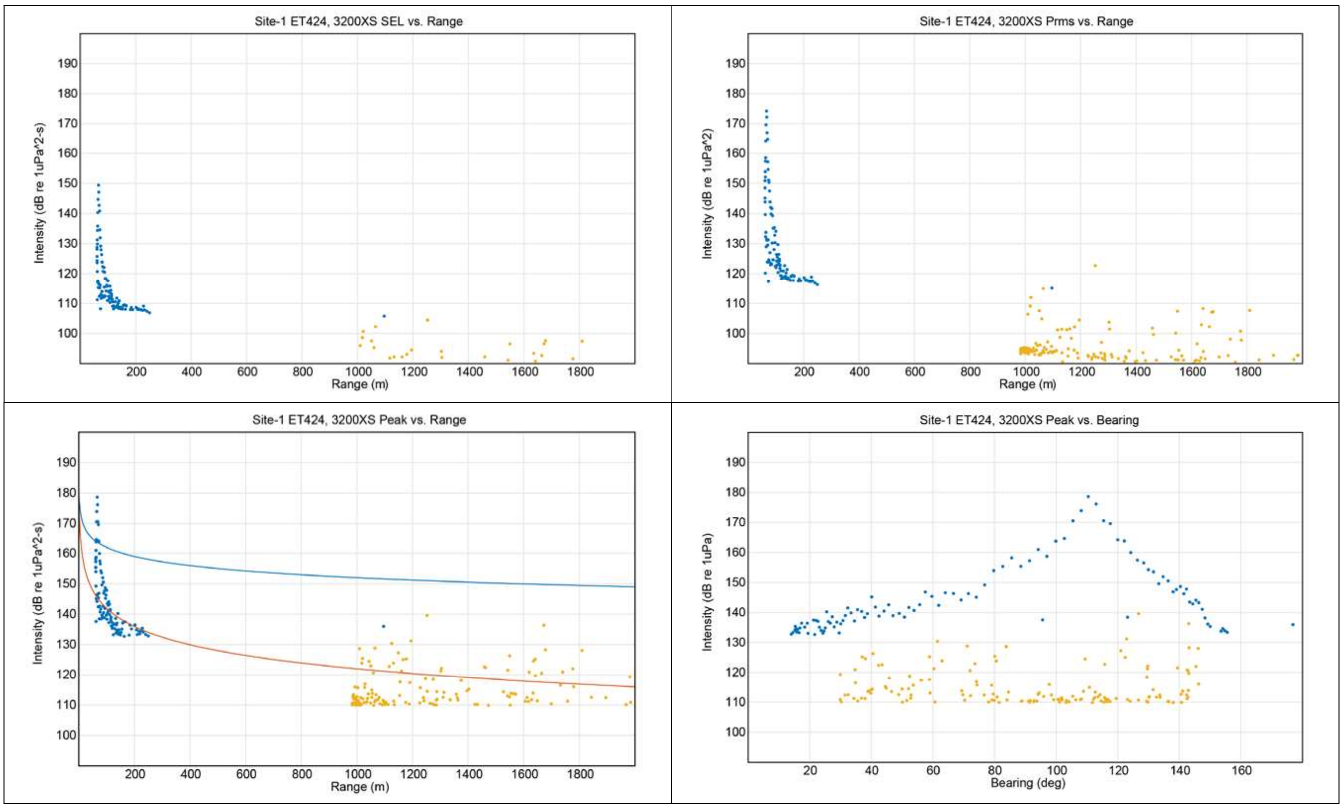


Figure 4.18.1-2. Range results for Edgetech 424 3200XS signals at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.18.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 80,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -50 m on the y-axis.

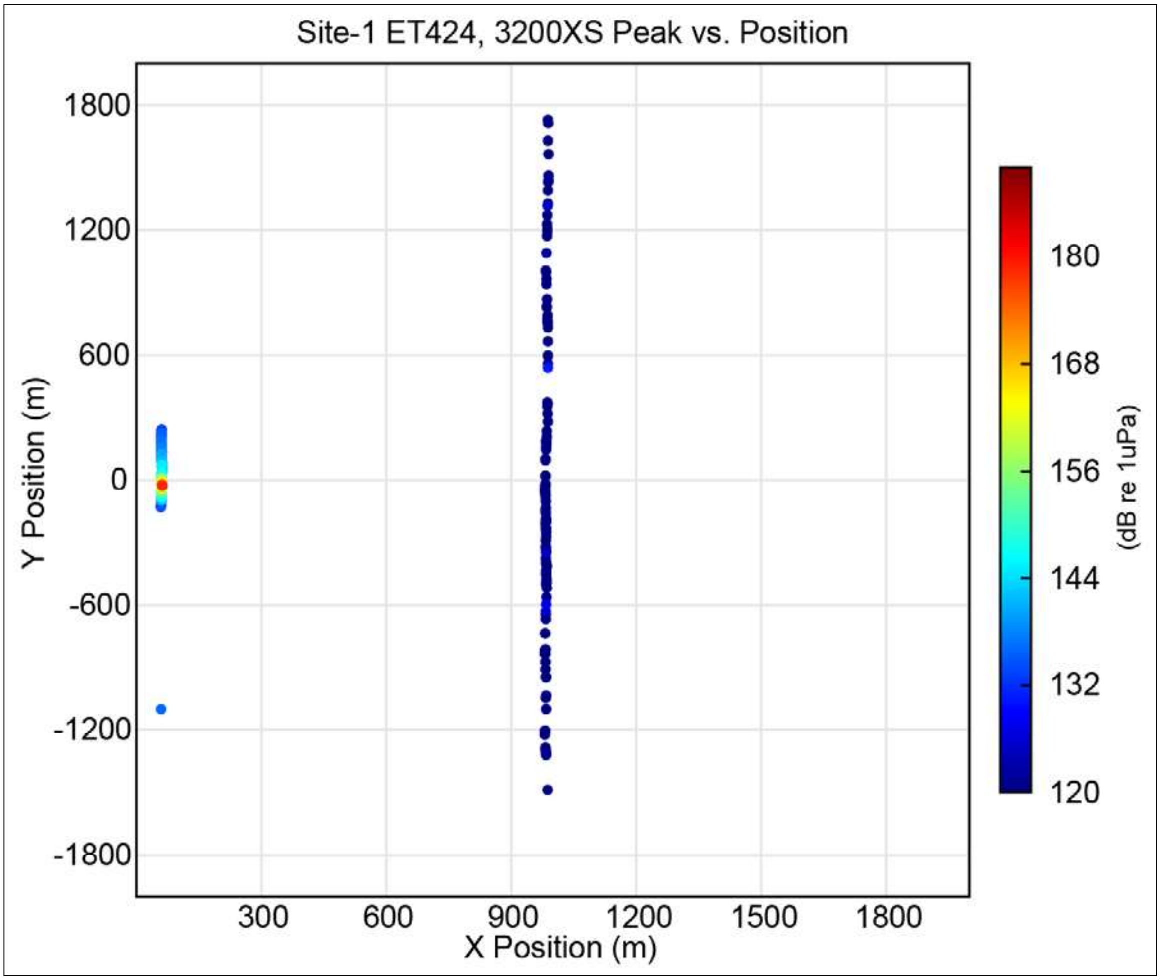


Figure 4.18.1-3. Plan view of received peak level for Edgetech 424 3200XS at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.18.1-1**. The estimated source levels were calculated from the measurements using spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The peak level at the CPA is much higher than expected compared to the NUWC reporting. The estimated source level from position D are approximately 16 dB higher than NUWC reported values, which indicates buoy position errors or unresolved calibration issues (**Section 2.6.3.1**).

Table 4.18.1-1. ET424 3200XS source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3200XS Mode 1	4-24 kHz	100%	NA	10 ms	198	193	169
NUWC	4-24 kHz	100%	NA	10 ms	182	176	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.; SL = source level.

4.18.2 Site 2 – Sand, 10 m Depth

At S2, the ET424 3200XS, Mode 1, had valid acoustic recordings in Run6 and Run33. For Run6, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings. For Run33, positions B (Buoy11) and E (Buoy10) had valid acoustic recordings. For all runs, positions E and F were too distant to capture the acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET424 3200XS, Mode 1, are shown in **Figure 4.18.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run6, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11 and Buoy11, combined) and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at positions E and F because of propagation loss of the signal.

The results panels (**Figure 4.18.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3200 at S2, positions D (Buoy6) and B (Buoy11 and Buoy11, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 182 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.18.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 125°, which indicates that the source traversed directly over the receiver at position D. For position B, the received peak level is at approximately 90°, which indicates good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For an omnidirectional beam pattern, the center (maximum peak signal) is expected to be at 90°.

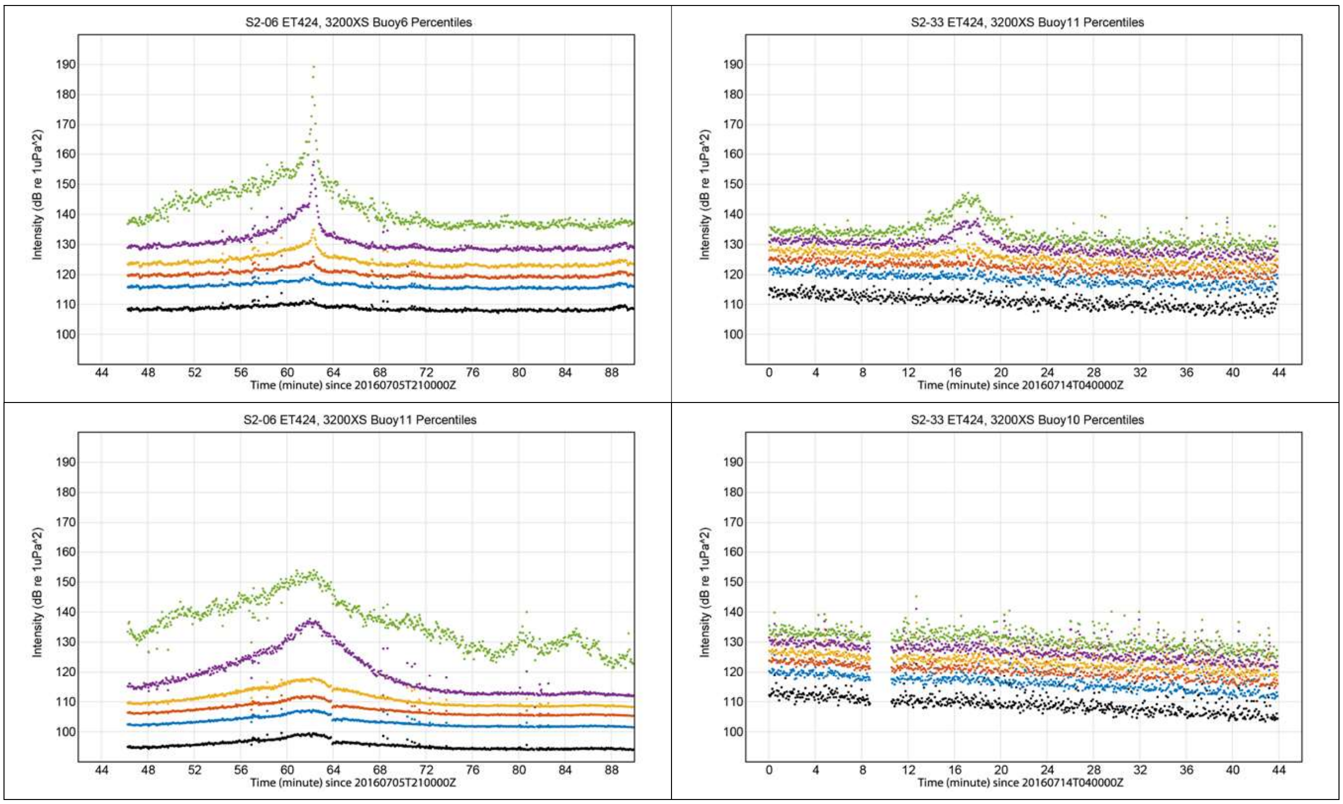


Figure 4.18.2-1. Percentile plots of Edgetech 424 3200XS signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

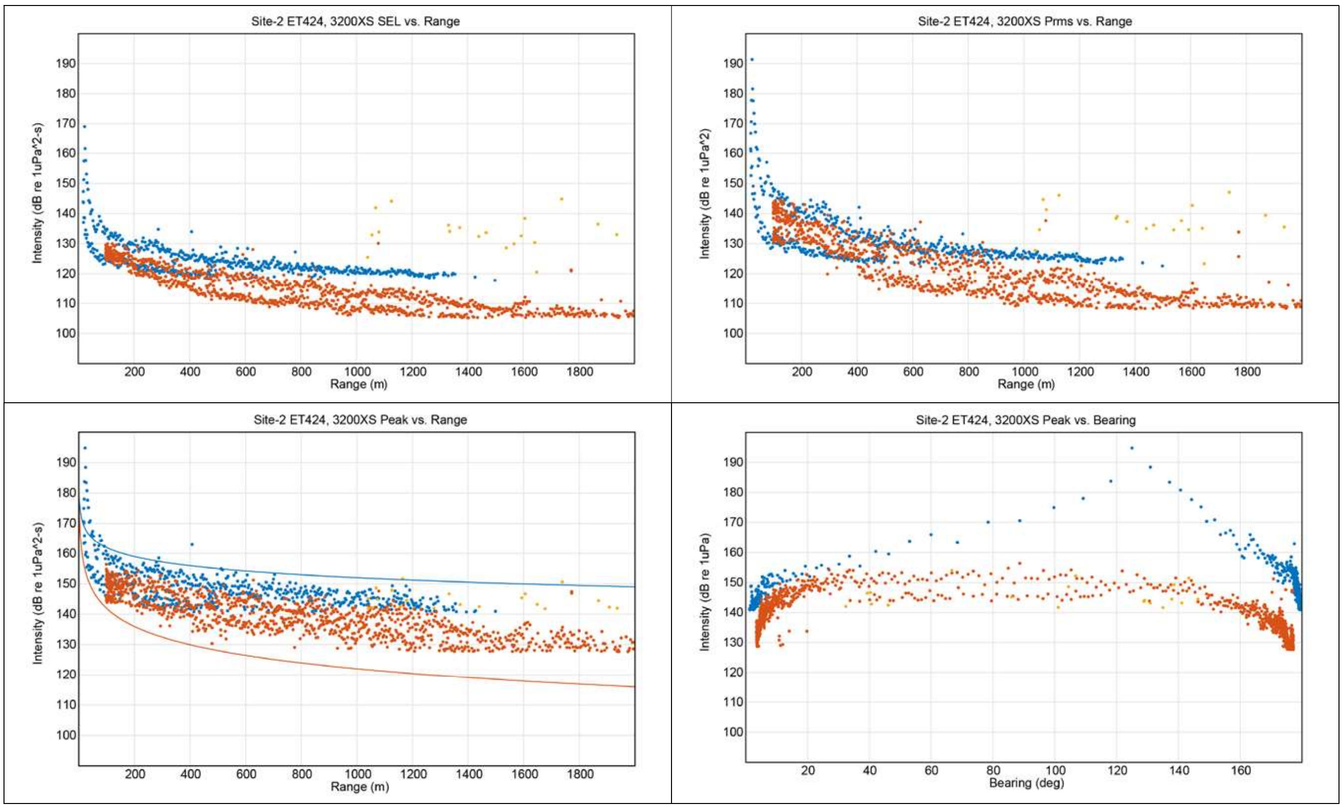


Figure 4.18.2-2. Range results for Edgetech 424 3200XS signals at Site 2 for positions D (Buoy6) and B (Buoy11 and Buoy11, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.18.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 30,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,500 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11 and Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for positions D and B is seen at approximately 0 m on the y-axis.

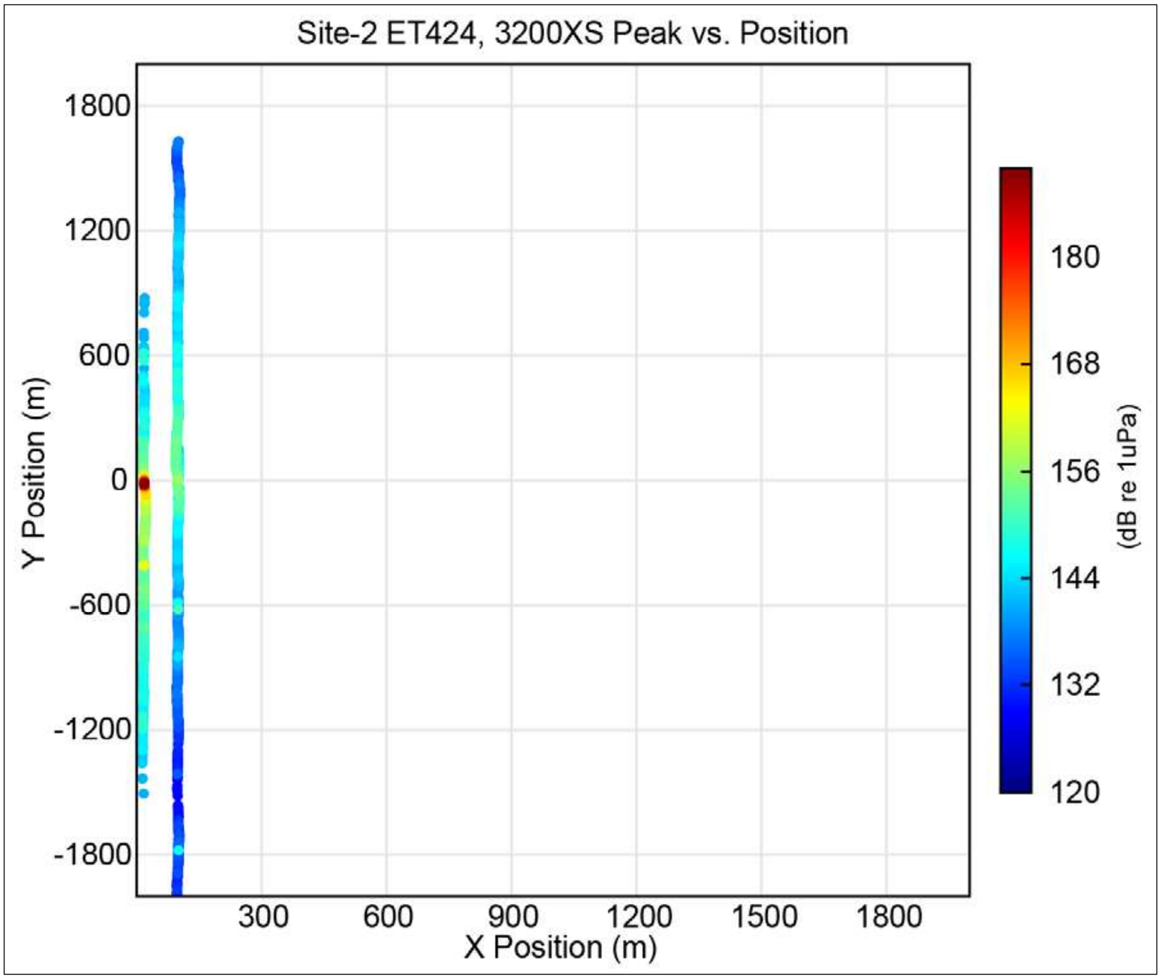


Figure 4.18.2-3. Plan view of received peak level for Edgetech 424 3200XS at Site 2 for positions D (Buoy6) and B (Buoy11 and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.18.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source level from position D are approximately 27 dB higher than NUWC reported values, which is likely a result of a 30 m error in position D.

Table 4.18.2-1. ET424 3200XS source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET424 3200XS Mode 1	4-24 kHz	100%	NA	10 ms	209	204	182
NUWC	4-24 kHz	100%	NA	10 ms	182	176	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.18.3 Site 3 – Mud, 30 m Depth

At S3, the ET424 3200XS, Mode 1, had acoustic recordings in Run12 and Run31. For Run12, there were valid acoustic recordings, but no acoustic signals were captured. For Run31, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10) had valid acoustic data and observed signals. Position F was too distant to capture the acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET424 3200XS, Mode 1, are shown in **Figure 4.18.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run31, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy10). The signal amplitude was not strong, but the data quality is high and the signal was observed on all hydrophones.

The results panels (**Figure 4.18.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the ET424 3200XS at S3, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 182 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 140°, indicating an error in buoy position; for positions A and B at approximately 70°, indicating an error in buoy positioning; and for position E at approximately 120°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

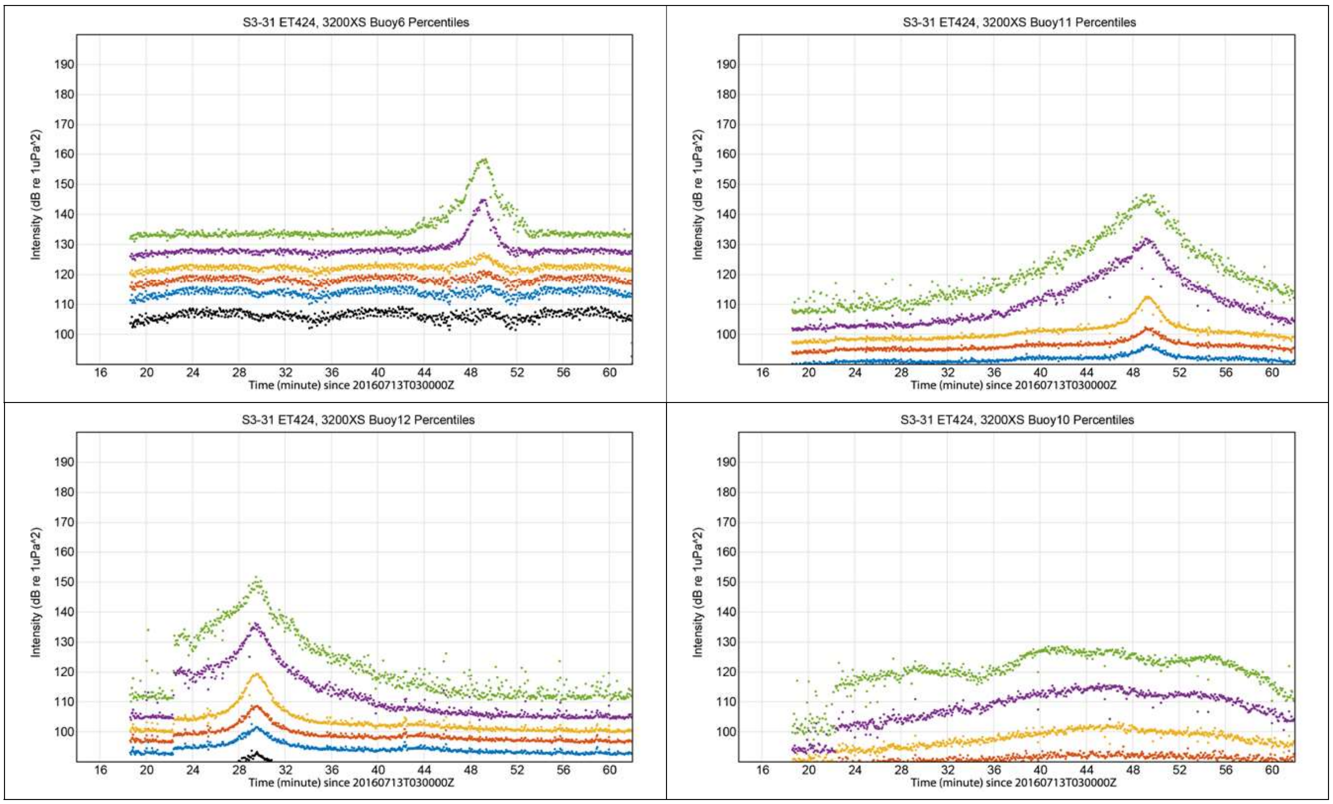


Figure 4.18.3-1. Percentile plots of Edgetech 424 3200XS signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

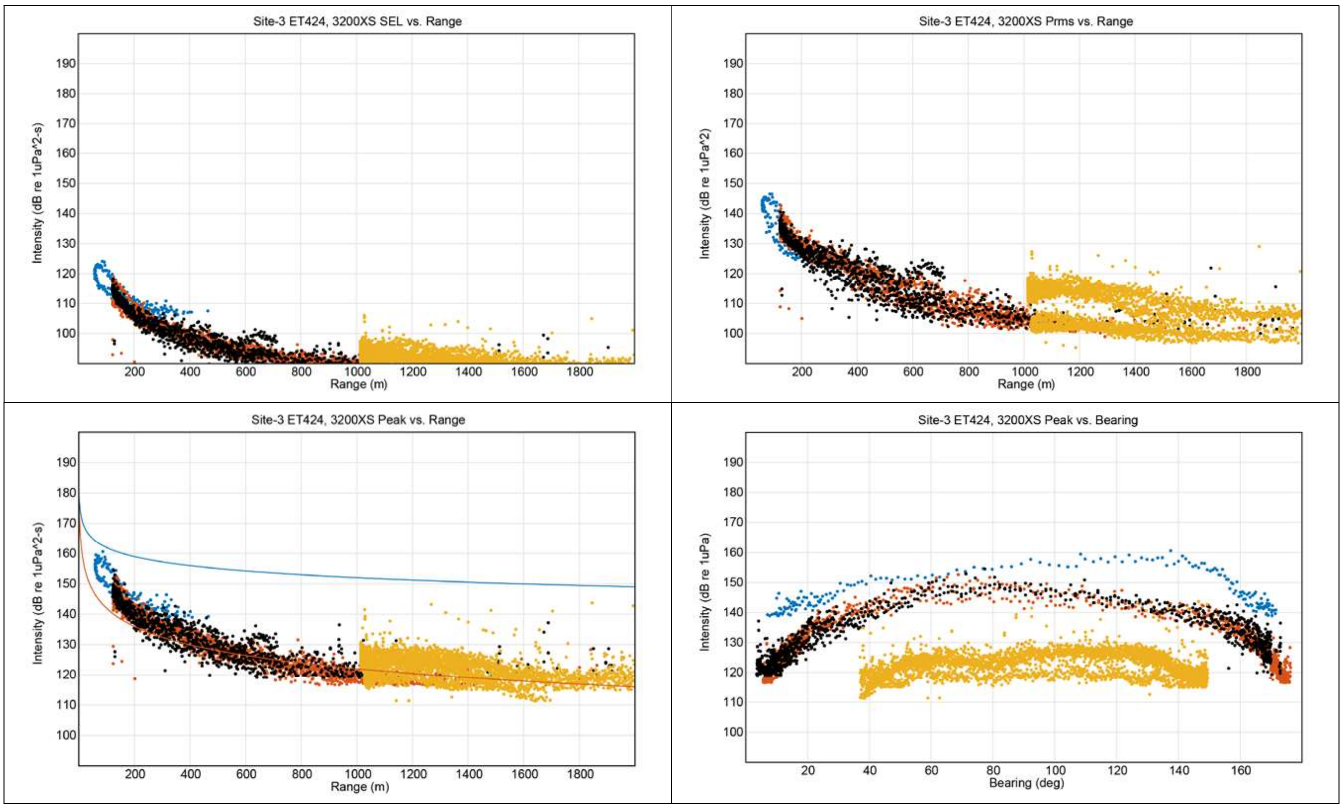


Figure 4.18.3-2. Range results for Edgetech 424 3200XS combined signals for Run31 at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.18.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 80,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -500 m (y-axis) as the CPA approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -20 m on the y-axis, while position B had high amplitudes at approximately 0 m.

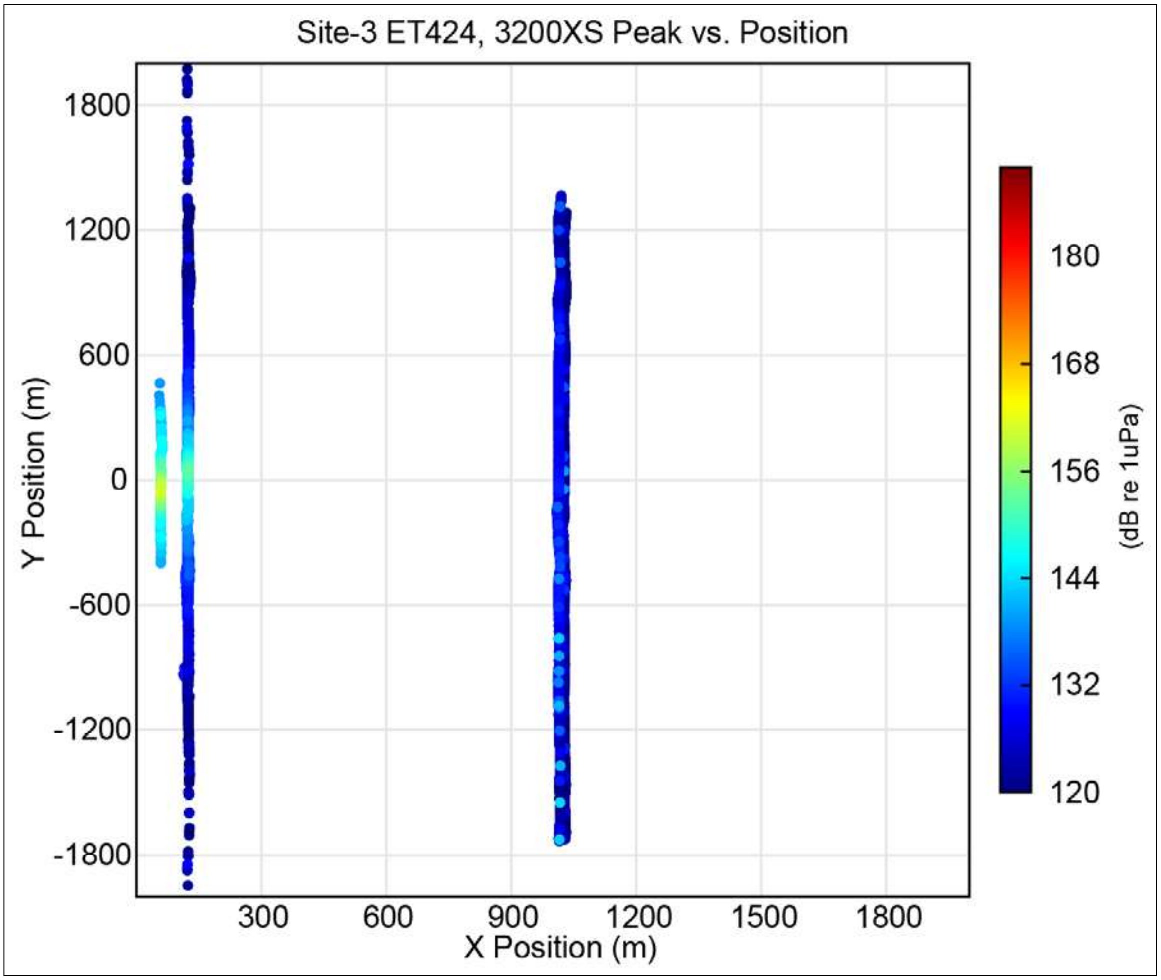


Figure 4.18.3-3. Plan view of received peak level for Edgetech 424 3200XS at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.18.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. At S3, the observed and predicted signal arrival levels for rms and SEL were similar to those reported in the NUWC report.

Table 4.18.3-1. ET424 3200XS source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3200XS Mode 1	4-24 kHz	100%	NA	10 ms	179	165	144
NUWC	4-24 kHz	100%	NA	10 ms	182	176	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level.; SL = source level.

4.18.4 Site 4 – Sand, 30 m Depth

At S4, the ET424 3200XS, Mode 1, had valid acoustic recordings in Run14 and Run28. For Run14, there were valid acoustic recordings, but no acoustic signals were captured. For Run28, positions B (Buoy12), A (Buoy7), and F (Buoy5) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the ET424 3200XS, Mode 1, are shown in **Figure 4.18.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run28, where the signal is weak. The top right and bottom panels show valid recorded acoustics that lack a signal at positions A (Buoy7) and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. There is a faint signal in the rise and fall of the received level versus time for position B (Buoy12).

The results panels (**Figure 4.18.4-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3200XS at S4, only position B (Buoy12) had a weak acoustic signal. For this very weak signal, there is only a faint signal observed, indicated by the aggregation of peaks at 200 m). The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 182 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, shows the received peak level for position B that are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°. Due to the poor data quality at this site, **Figure 4.18.4-2** contains no useful information.

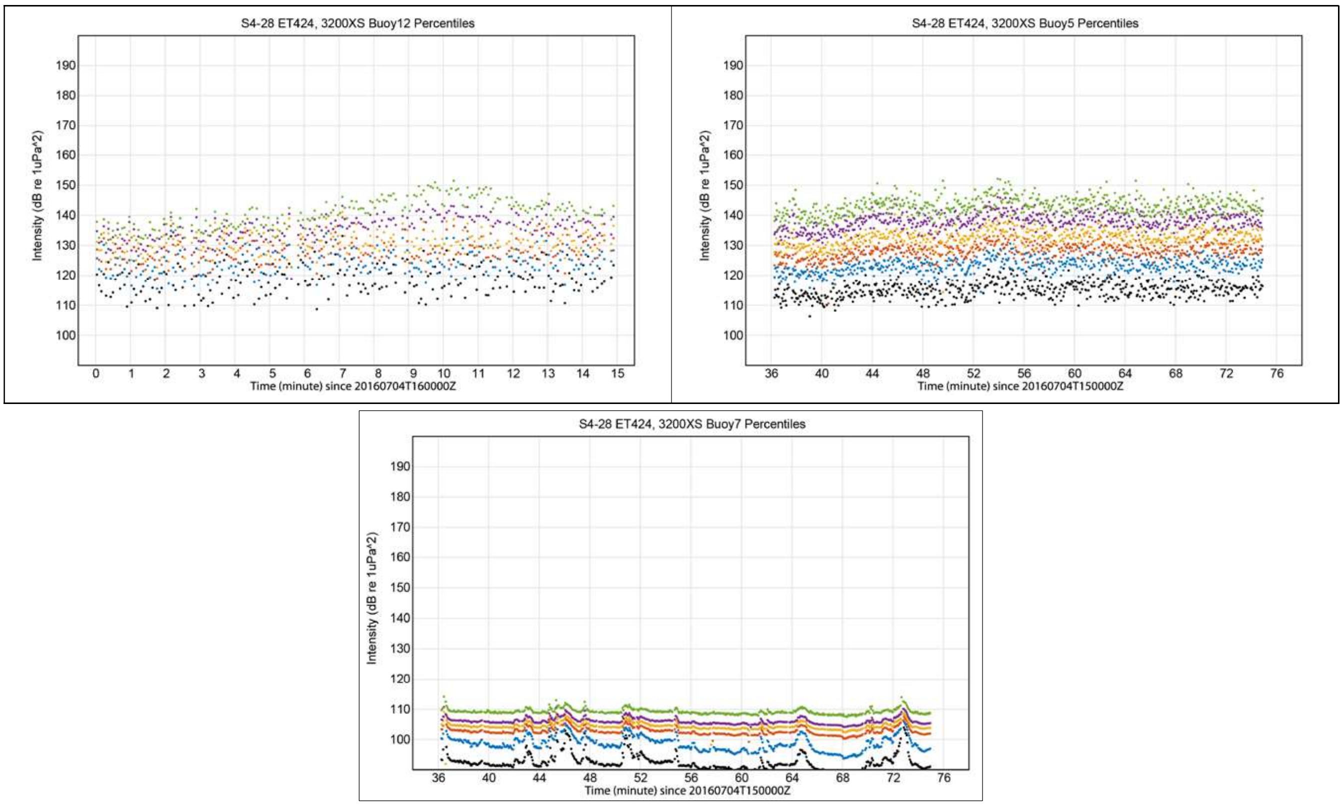


Figure 4.18.4-1. Percentile plots of Edgetech 424 3200XS signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position F (Buoy5); Bottom: SPL_{pk} arrival at position A (Buoy7). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

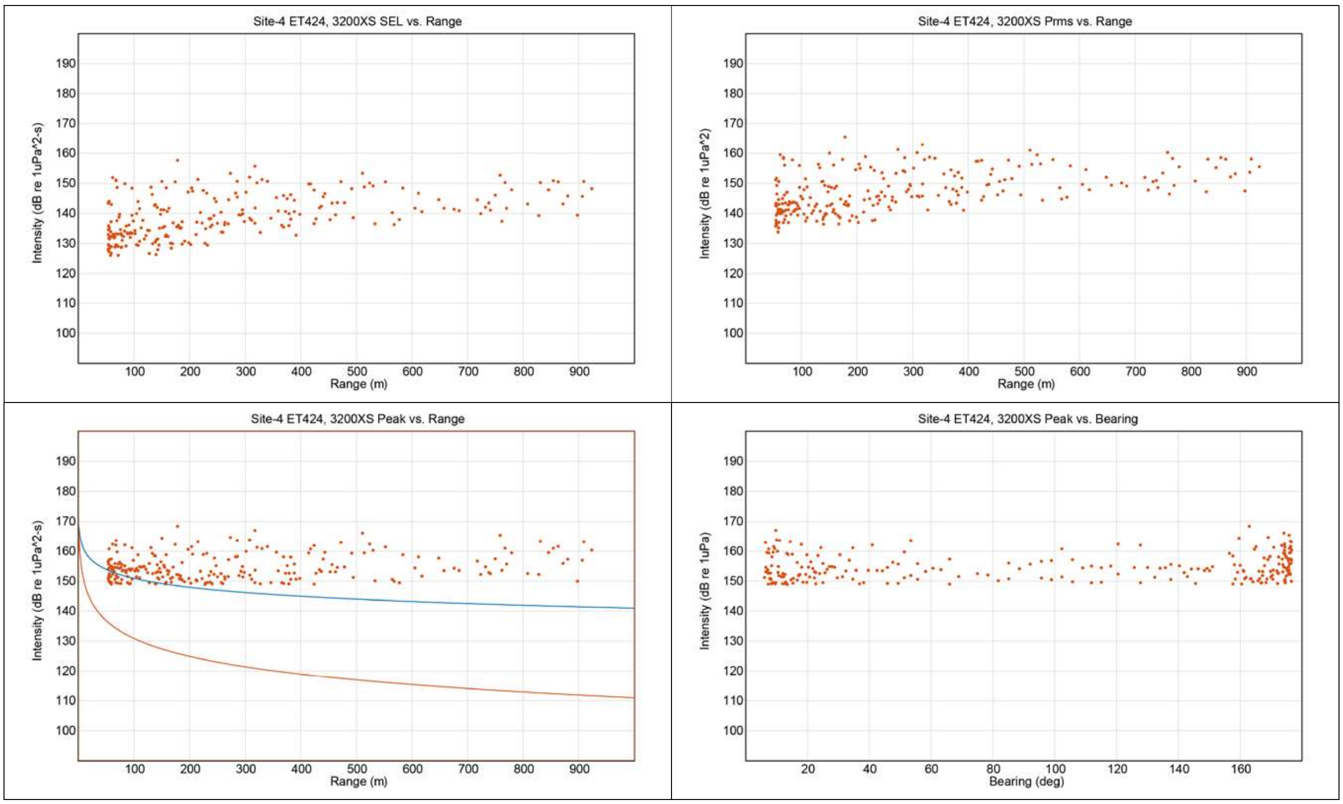


Figure 4.18.4-2. Range results for Edgetech 424 3200XS signals at Site 4 for position B (Buoy12), likely all noise. Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.18.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 50,-150 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Weak acoustic signals were received at position B (Buoy12) and are likely noise. Recordings at the buoy had acoustic peak amplitudes, presumably at the CPA.

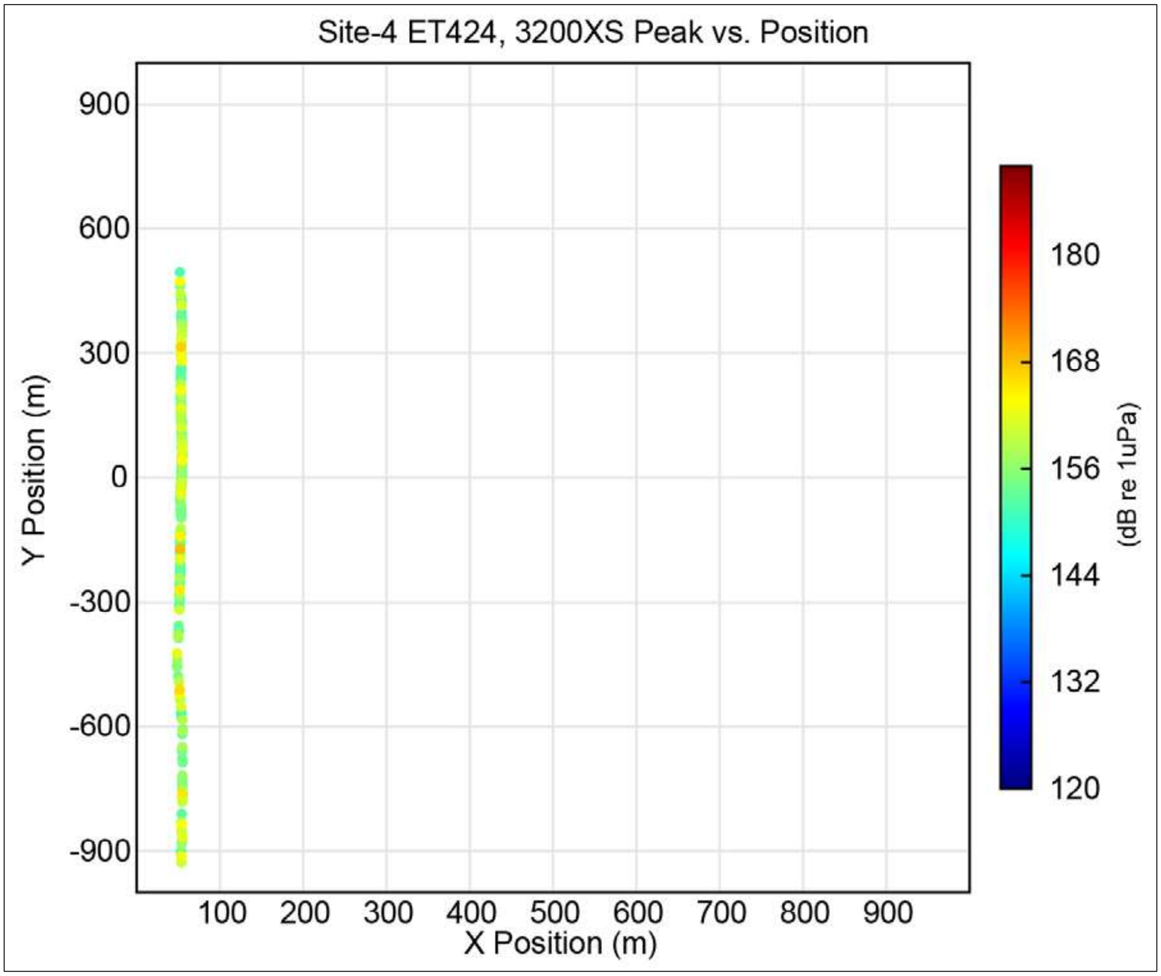


Figure 4.18.4-3. Plan view of received peak level for Edgetech 424 3200XS at Site 4 for position B (Buoy12).

Table Source Summary

For the ET424 3200XS at S4, only position B (Buoy12) had very weak acoustic data. The signal to noise ratio was poor, halting further data analysis. This is likely due to the beam pattern of the source and the lack of data at position D. Therefore, with identification of the source signal so difficult, the Table Source Summary could not be computed for this site.

4.18.5 Site 5 – Sandy-Silt, 100 m Depth

The ET424 3200XS, Mode 1, was not deployed or operated at S5.

This Page Left Intentionally Blank

4.19 Edgetech 424 3200XS, 4-24 kHz, 100 Percent Power, 1-ms Pulse, (Mode 2)

The ET424 3200XS subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 9 kHz. The operational parameter settings for Mode 2 were 100 percent power, a 1-ms pulse, and a 4-24 kHz output frequency, using the 3200XS topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.19-1** is the selected frequency band (5 to 25 kHz) and SPL_{pk} (163 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.19-1. Bandpass determination for the ET424, 3200XS subbottom profiler, 4-24 kHz, 100 percent power, 1-ms pulse at S2, Run7.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
1-200	162.89
1-100	162.78
5-50	162.79
5-25	**162.92**

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET424 3200XS, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.19-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The ET424 was operationally paired in alternation with the MiniSparker. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.19-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1s chunks) manually. This approach seemed successful in separating the two sources.

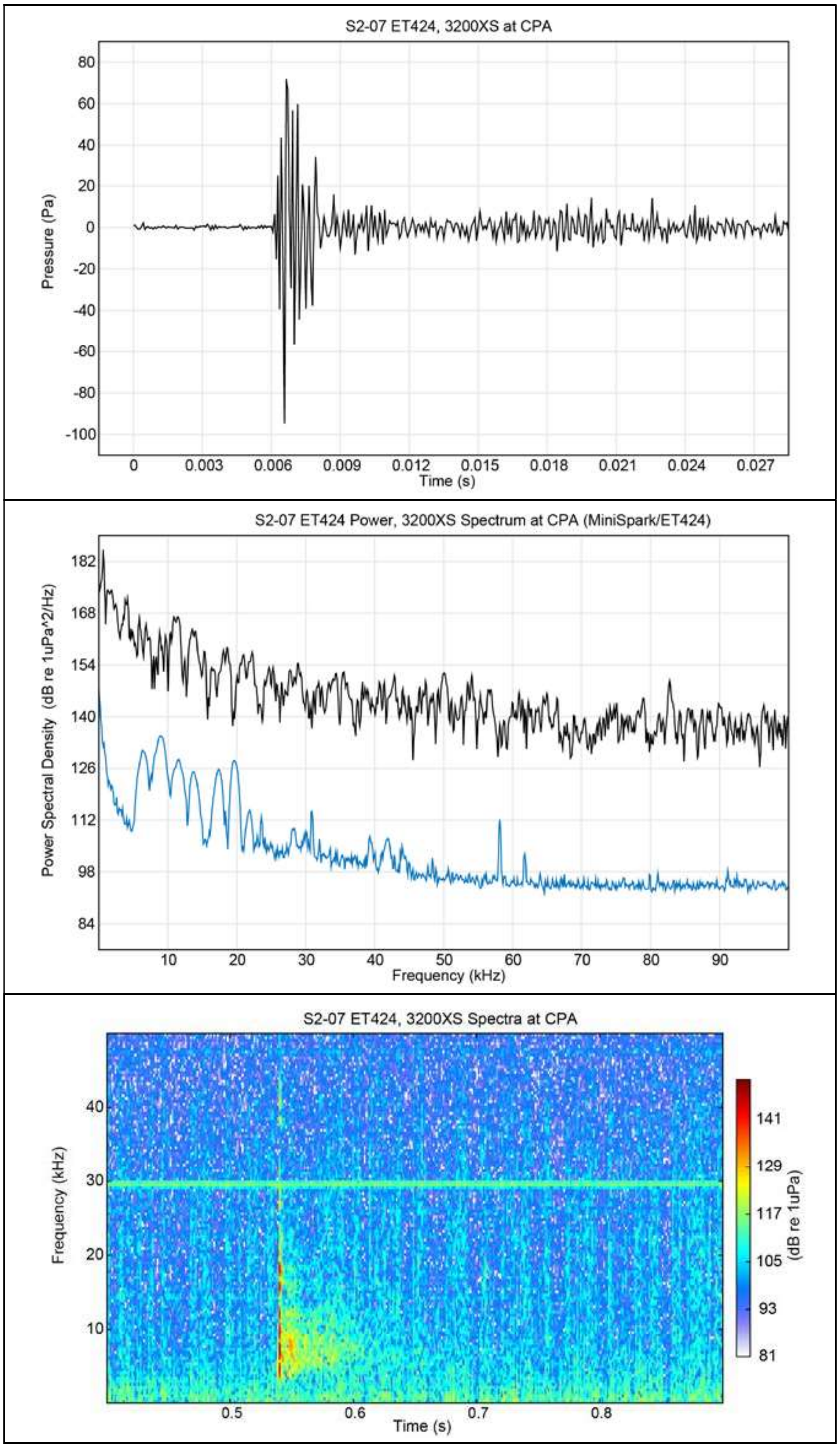


Figure 4.19-1. Edgetech 424 3200XS measured signal characteristics at closest point of approach (CPA) at Site 2, Run7.

Top: Time-waveform of a signal; Middle: Power spectral density, ET424 = blue, MiniSparker = black; Bottom: Spectrogram.

4.19.1 Site 1 – Mud, 10 m Depth

At S1, the ET424 3200XS, Mode 2, had valid acoustic recordings in Run5 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the ET424 3200XS, Mode 2, are shown in **Figure 4.19.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run5, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.19.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the ET424 3200XS at S1, positions D (Buoy6) and E (Buoy5 and Buoy8, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,800 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 182 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). Most of the position E buoy is noise, but there is signal at CPA.

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.19.1-2**), which shows the received peak level for position D at 110°, indicating an error in the buoy positioning. For position E, the received peak level is at approximately 90°, which indicates good buoy positioning. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

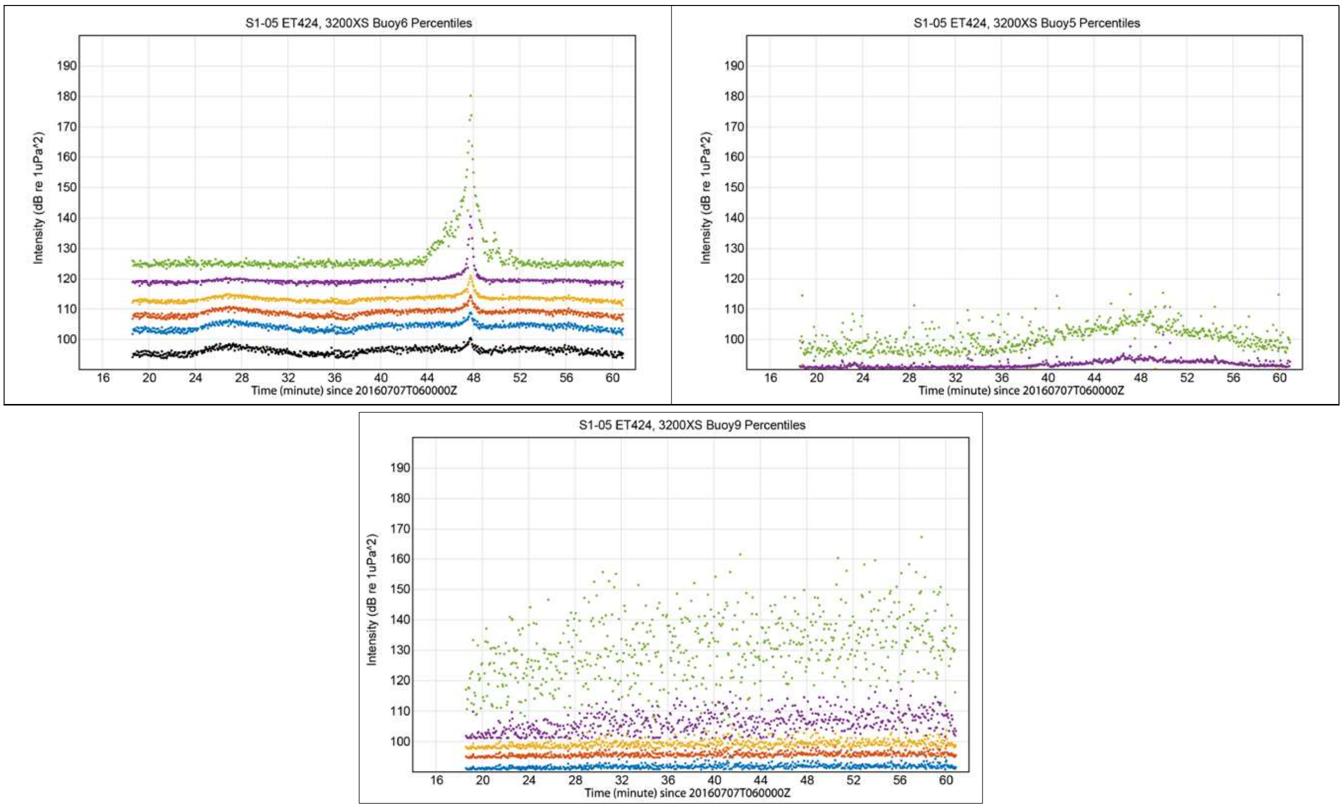


Figure 4.19.1-1. Percentile plots of Edgetech 424 3200XS signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

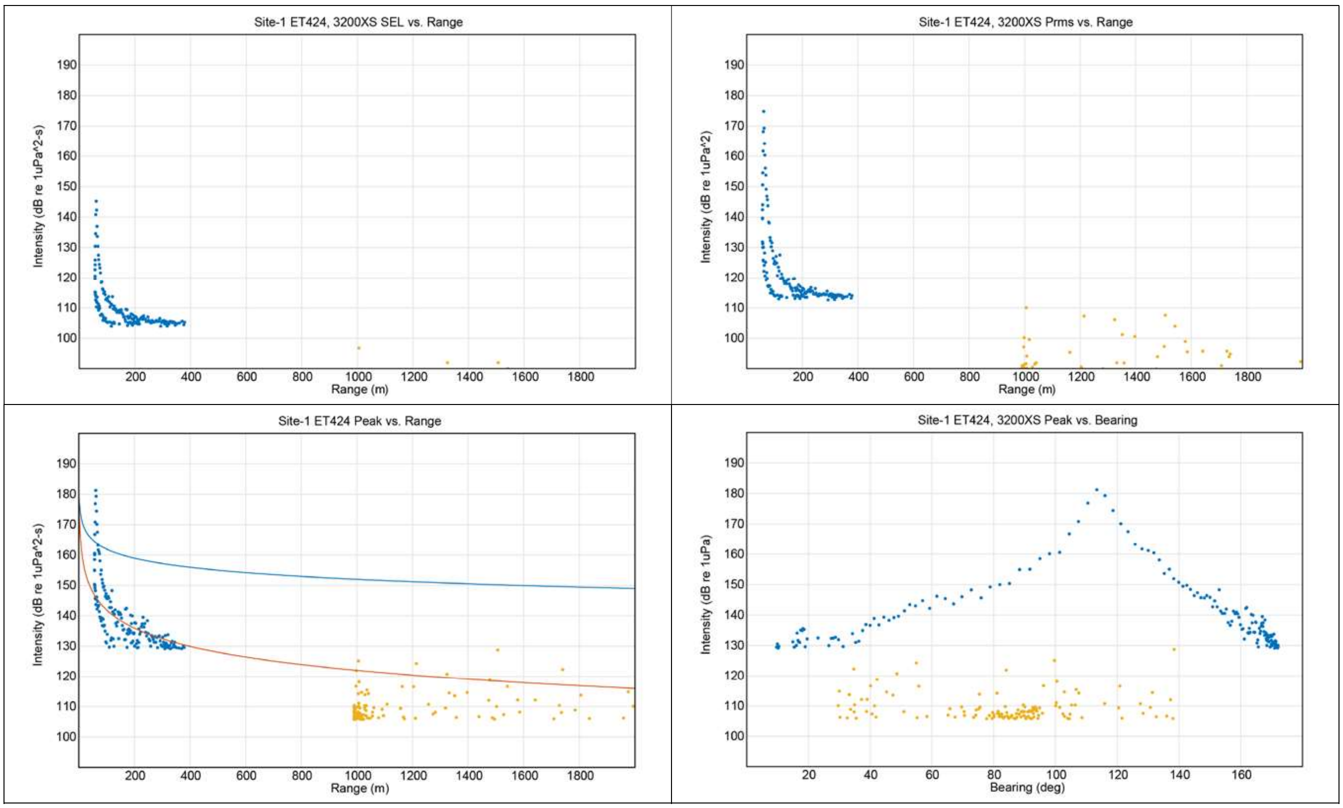


Figure 4.19.1-2. Range results for Edgetech 424 3200XS signals at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.19.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,000 to 2,000-m marks on the y-axis. The CPA is at 55,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -450 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -50 m on the y-axis, while position E had peak amplitudes at approximately -300 m.

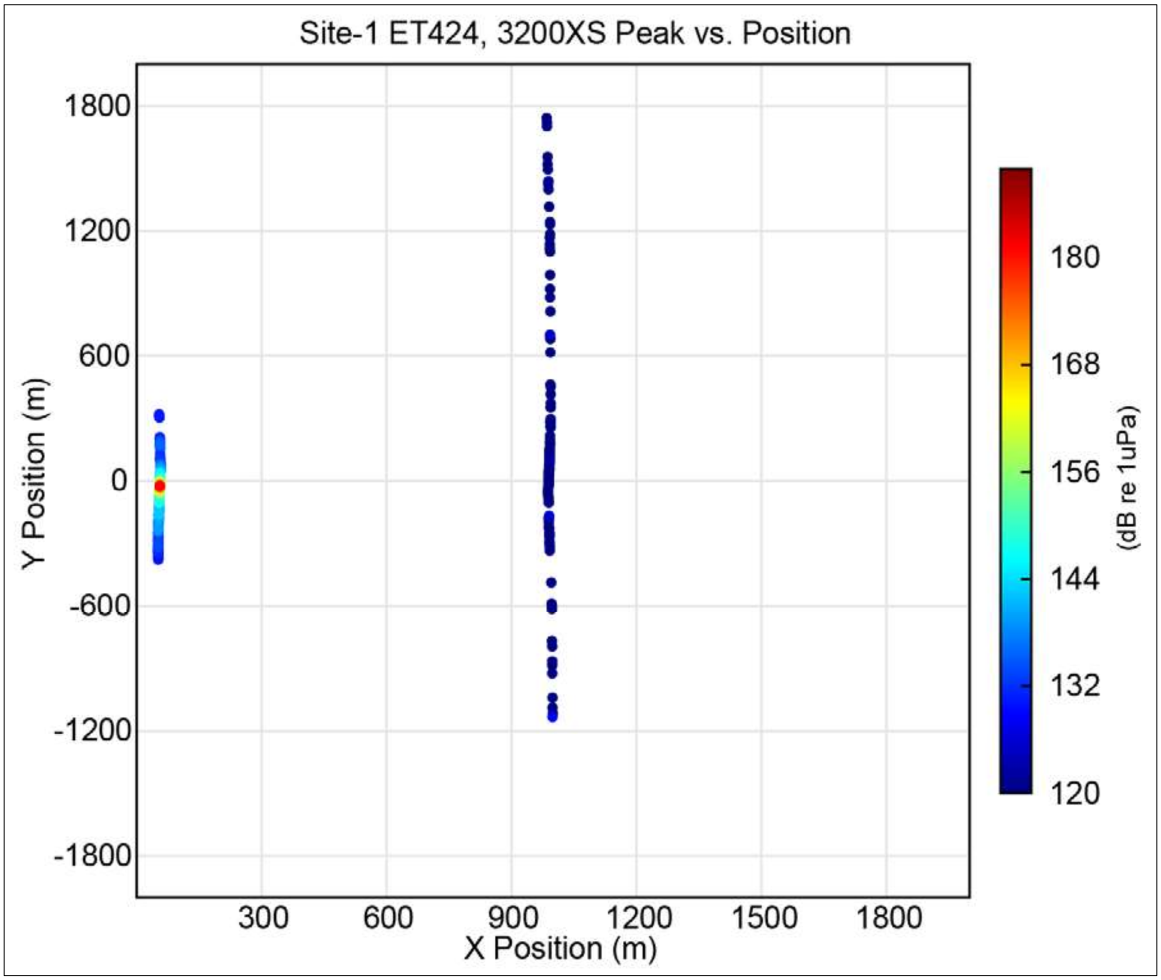


Figure 4.19.1-3. Plan view of received peak level for Edgetech 424 3200XS at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.19.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The peak estimated source level is approximately 17 dB higher than expected compared to the NUWC reporting, which is an indication of a possible 10-m buoy navigation error or unresolved calibration issues (**Section 2.6.3.1**).

Table 4.19.1-1. ET424 3200XS source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3200XS Mode 2	4-24 kHz	100%	NA	1 ms	199	192	163
NUWC	4-24 kHz	100%	NA	5 ms	182	176	152

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.19.2 Site 2 – Sand, 10 m Depth

At S2, the ET424 3200XS, Mode 2, had valid acoustic recordings in Run7 and Run34. For Run7, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings. For Run34, position B (Buoy5 and Buoy11) had valid acoustic recordings. Positions E and F were too distant to capture the acoustic signal.

Run Summary

The percentile plots for the available recordings of the ET424 3200XS, Mode 2, are shown in **Figure 4.19.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run7, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at position B (Buoy5 and Buoy11) for Run7 and Run34. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.19.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3200XS at S2, only positions D (Buoy6) and B (Buoy5 and Buoy11, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 500 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 182 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The double peak in the position B data (Buoy11) (**Figure 4.19.2-2,** top left panel) data is likely due to the passing of an interferer (the first peak) and the source CPA (at time 2308Z). The separation between the 95th percentile and the 100th percentile is indicative of a strong coherent signal.

The bottom right results panel of **Figure 4.19.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 140°, possibly due to the very close range rather than a buoy position error. For position B, the received peak level is at approximately 100°, which indicates relatively good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

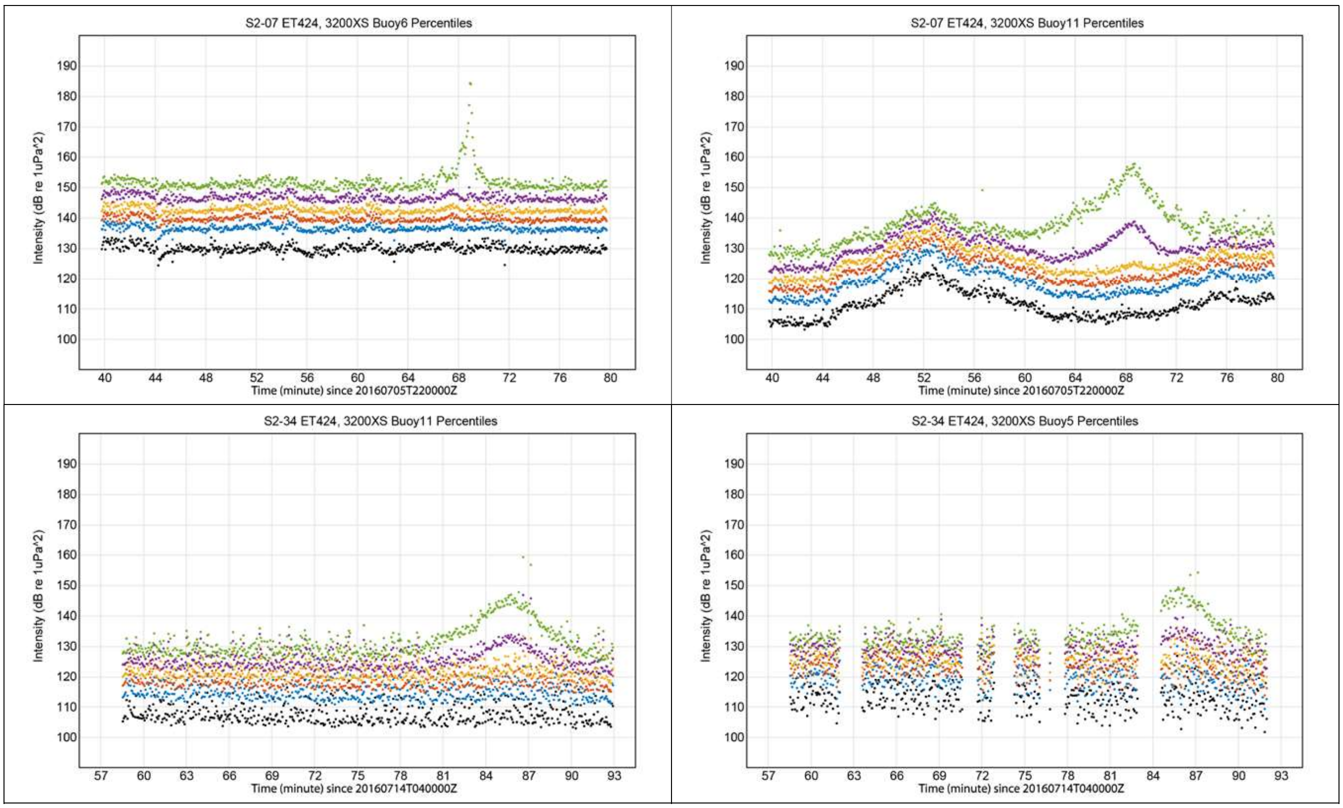


Figure 4.19.2-1. Percentile plots of Edgetech 424 3200XS signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

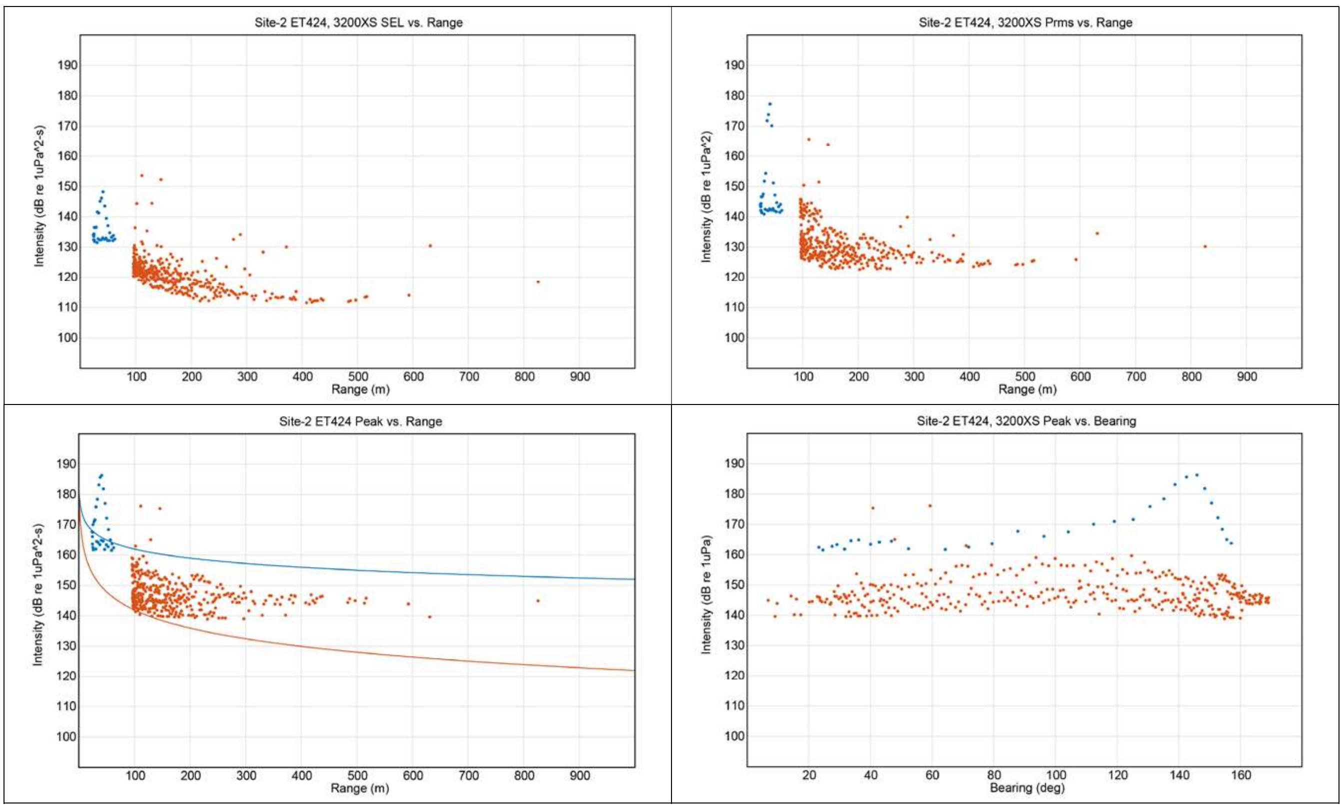


Figure 4.19.2-2. Range results for Edgetech 424 3200XS signals at Site 2 for positions D (Buoy6) and B (Buoy5 and Buoy11, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.19.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 30,-40 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5 and Buoy11). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -40 m on the y-axis, while position B had high amplitudes at approximately 50 m.

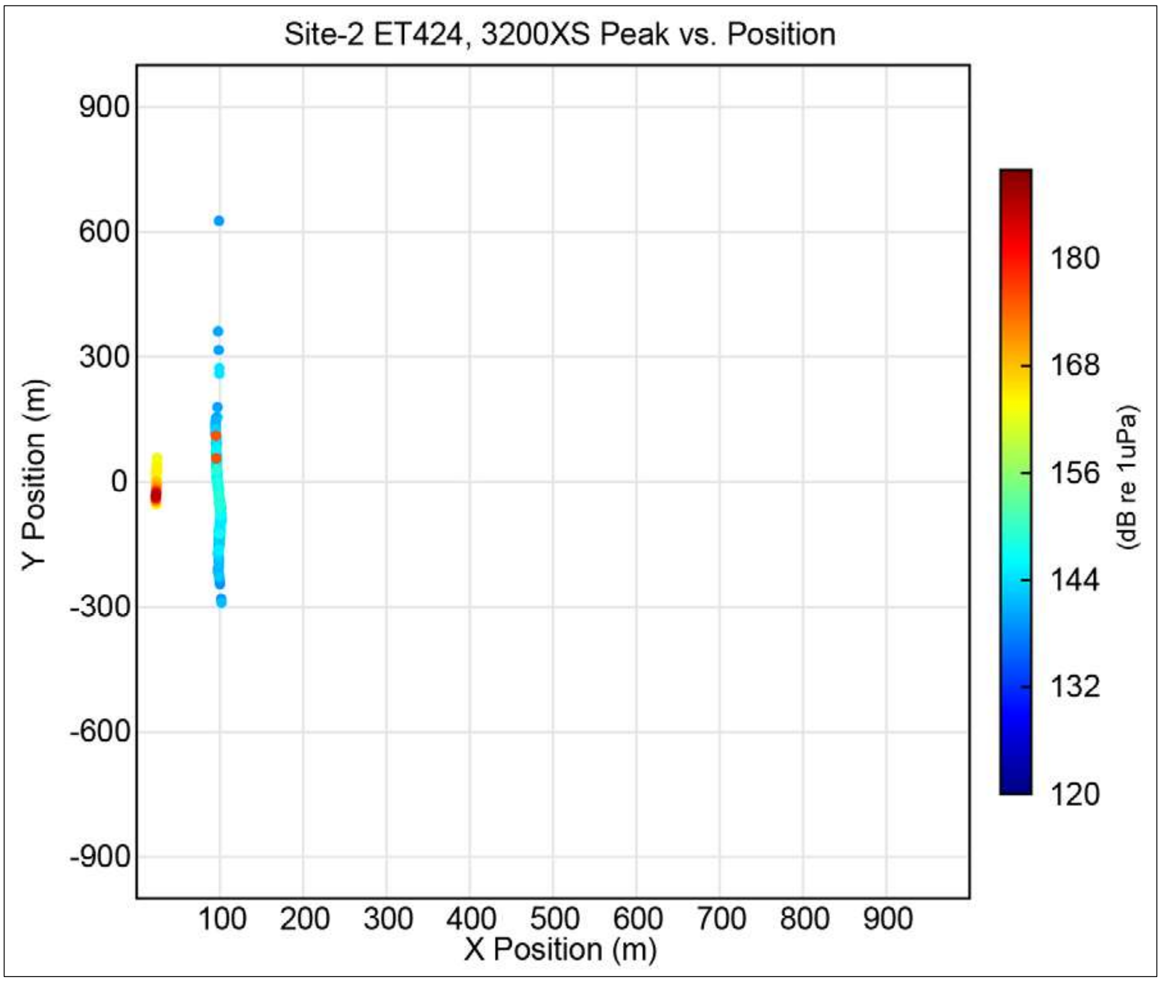


Figure 4.19.2-3. Plan view of received peak level for Edgetech 424 3200XS at Site 2 for positions D (Buoy6) and B (Buoy5 and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.19.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The peak estimated source level is approximately 23 dB higher than expected compared to the NUWC report, which is an indication of a possible 25-m buoy navigation error or unresolved calibration issues (**Section 2.6.3.1**).

Table 4.19.2-1. ET424 3200XS source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3200XS Mode 2	4-24 kHz	100%	NA	1 ms	205	191	165
NUWC	4-24 kHz	100%	NA	5 ms	182	177	149

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.19.3 Site 3 – Mud, 30 m Depth

At S3, the ET424 3200XS, Mode 2, had valid acoustic recordings in Run13 at positions B (Buoy12), A (Buoy5), and F (Buoy6).

Run Summary

The percentile plots for the available recordings of the ET424 3200XS, Mode 2, are shown in **Figure 4.19.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position A (Buoy5) for Run13, where a weak signal reception is observed. The top right and bottom panels show the recorded acoustics at positions B (Buoy12) and F (Buoy6). At positions B and F, the greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the data are not valid. Data at position F are only noise, and data at position B are bad. The weak signal reception at position A does not have sufficient signal to noise ratio to permit further processing. No further data analysis for Mode 2, S3 was conducted.

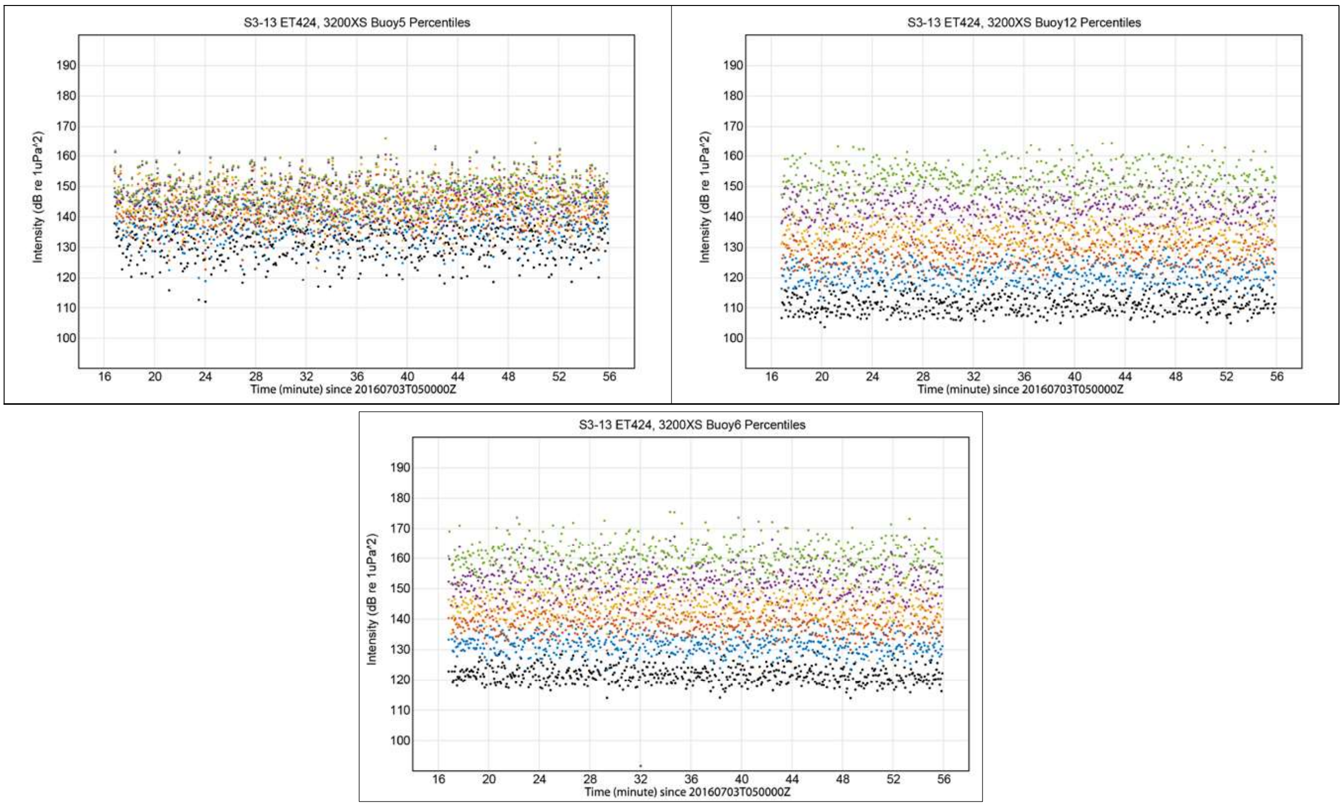


Figure 4.19.3-1. Percentile plots of Edgetech 424 3200XS signals at Site 3; all noise.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position A (Buoy5); Top right: SPL_{pk} arrival at position B (Buoy12); Bottom: SPL_{pk} arrival at position F (Buoy6). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

4.19.4 Site 4 – Sand, 30 m Depth

At S4, the ET424 3200XS, Mode 2, had acoustic recordings in Run13 and Run27. For Run13, there were valid acoustic recordings, but no acoustic signals were captured. For Run27, positions B (Buoy12), A (Buoy7), and F (Buoy5) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the ET424 3200XS, Mode 2, are shown in **Figure 4.19.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy12) for Run27, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions A (Buoy7) and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.19.4-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET424 3200XS at S4, only position B (Buoy12) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 800 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 182 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). Position B (Buoy12) had acoustic signal; position F (Buoy5) only had noise; and position A (Buoy7) had problematic acoustic data.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 110°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

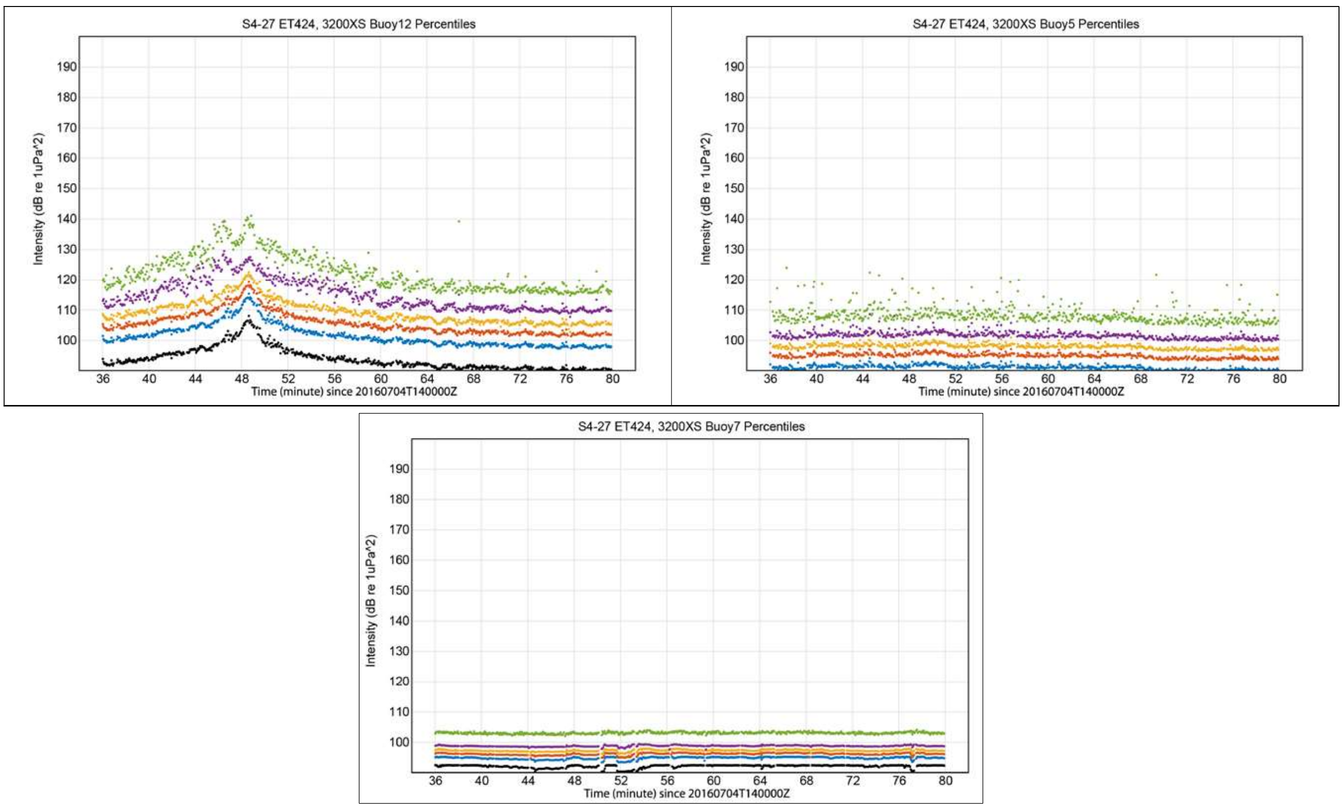


Figure 4.19.4-1. Percentile plots of Edgetech 424 3200XS signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position F (Buoy5); Bottom: SPL_{pk} arrival at position A (Buoy7). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

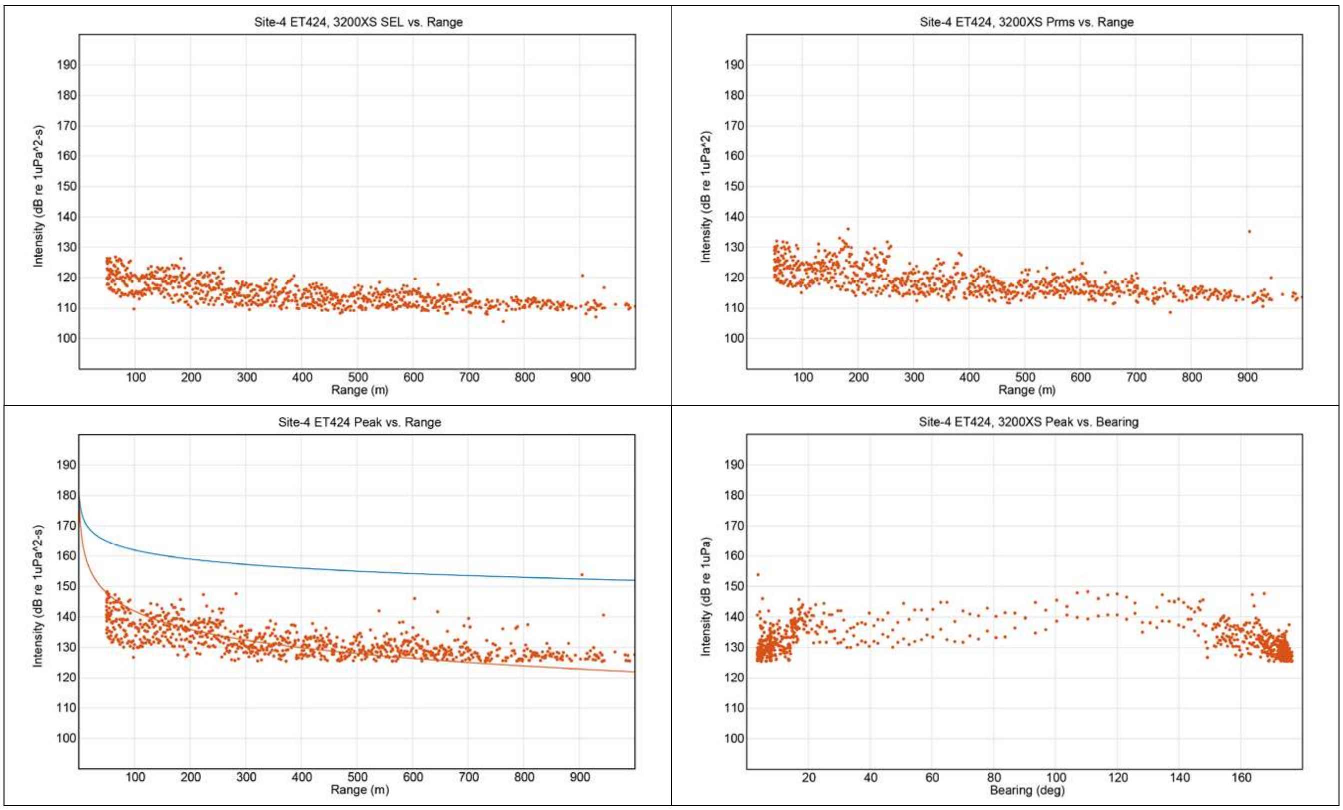


Figure 4.19.4-2. Range results for Edgetech 424 3200XS signals at Site 4 for position B (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.19.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 50,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy12). Recordings at the buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position B is seen at approximately -30 m on the y-axis.

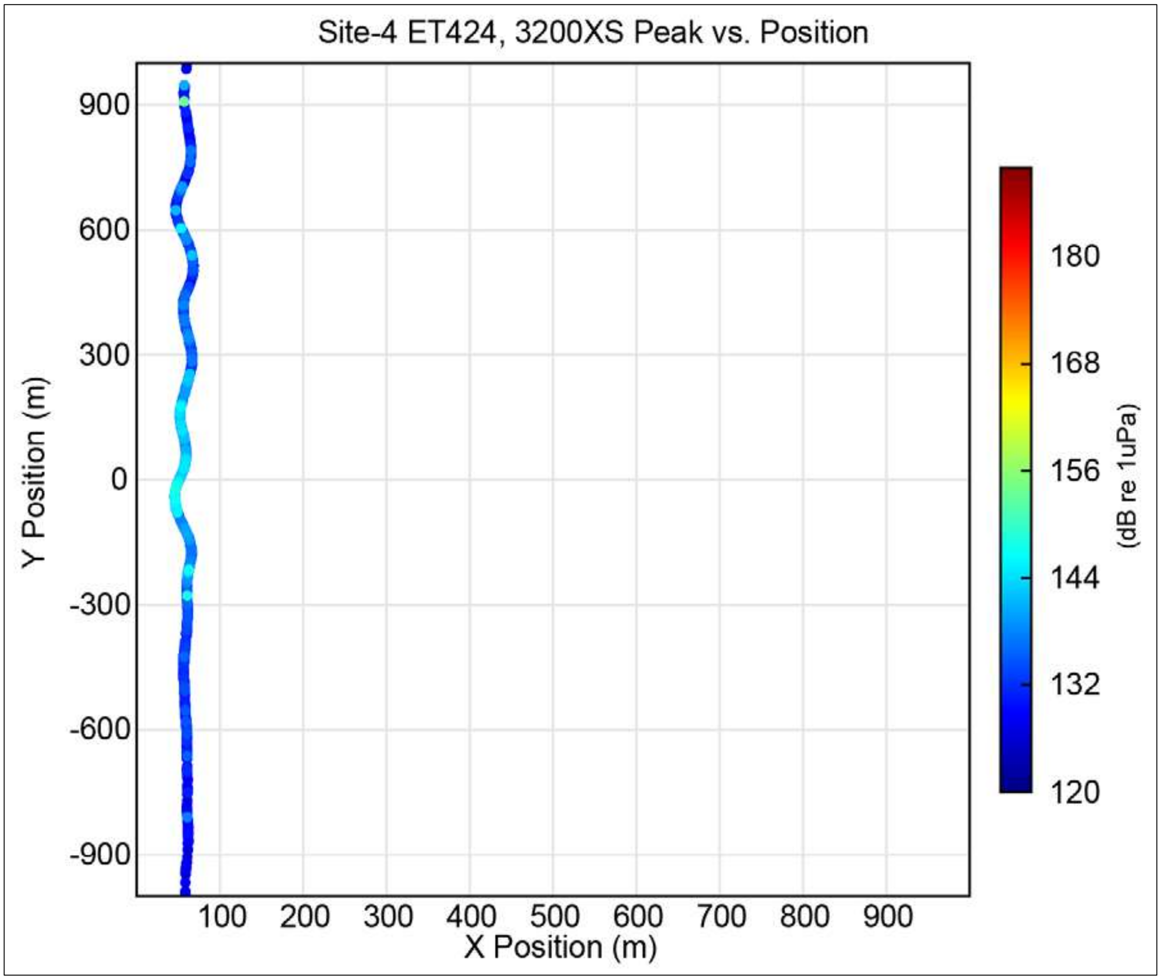


Figure 4.19.4-3. Plan view of received peak level for Edgetech 424 3200XS at Site 4 for position B (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.19.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.19.4-1. ET424, 3200XS source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET424 3200XS Mode 1	4-24 kHz	100%	NA	1 ms	173	157	144
NUWC	4-24 kHz	100%	NA	5 ms	182	177	149

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.19.5 Site 5 – Sandy-Silt, 100 m Depth

The ET424 3200XS, Mode 2, was not deployed or operated at S5.

4.20 Edgetech 512i, 0.5-7.2 kHz, 100 Percent Power, 30-ms Pulse (Mode 1)

The ET512i subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 4 kHz. The operational parameter settings for Mode 1 were 100 percent power, a 30-ms pulse, and a 0.5-7.2 kHz output frequency, with a 512i topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.20-1** is the selected frequency band (0 to 8 kHz) and SPL_{pk} (174 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.20-1. Bandpass determination for the ET512i subbottom profiler, 100 percent power, 30-ms pulse, and 0.5-7.2 kHz at Site 2, Run1.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-100	173.98
0-50	173.91
0-25	173.87
0-8	**173.89**

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET512i, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.20-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The ET512i was operationally paired in alternation with the Knudsen 3260. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.20-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources. The signal time series, as measured at S2, shows a bottom return for arriving at 0.012 s.

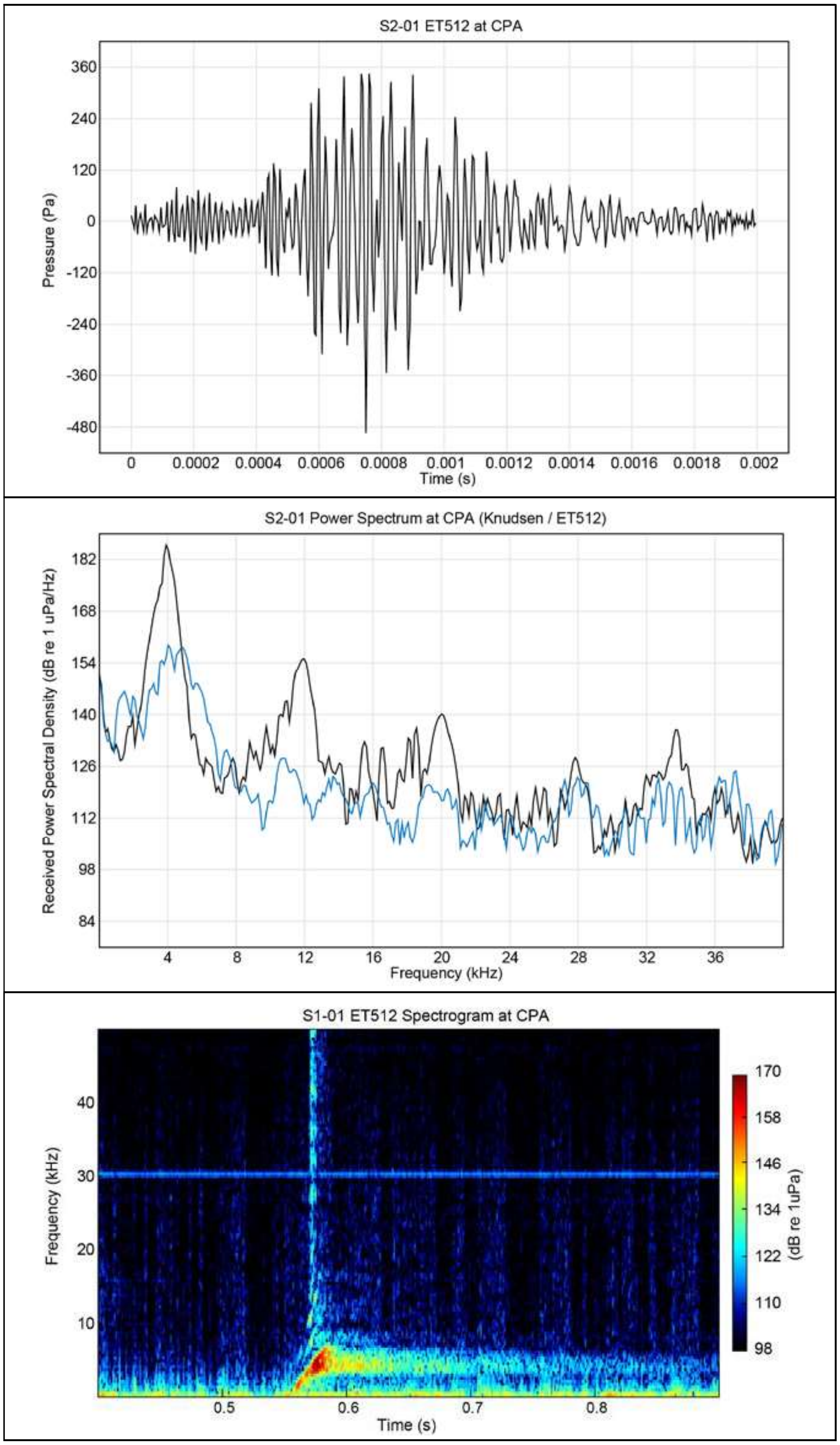


Figure 4.20-1. Edgetech 512i measured signal characteristics at closest point of approach (CPA) at Site 2, Run1.
Top: Time-waveform of a signal; Middle: Power spectral density, ET512i = blue, Knudsen 3260 = black; Bottom: Spectrogram.

4.20.1 Site 1 – Mud, 10 m Depth

At S1, the ET512i, Mode 1, had valid acoustic recordings in Run1 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the ET512i, Mode 1, are shown in **Figure 4.20.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run1, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The data at position F (Buoy9) are likely only noise.

The results panels (**Figure 4.20.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the ET512i at S1, only positions D (Buoy6) and E (Buoy5 and Buoy8) had any acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,100 m. The shape of the data points signifies the approach and departure of the source to and from the buoy. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.20.1-2**), which shows the received peak level for position D at approximately 130°, indicating an error in the buoy positioning. For position E, the received peak level is at approximately 90°, which indicates good navigational buoy. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

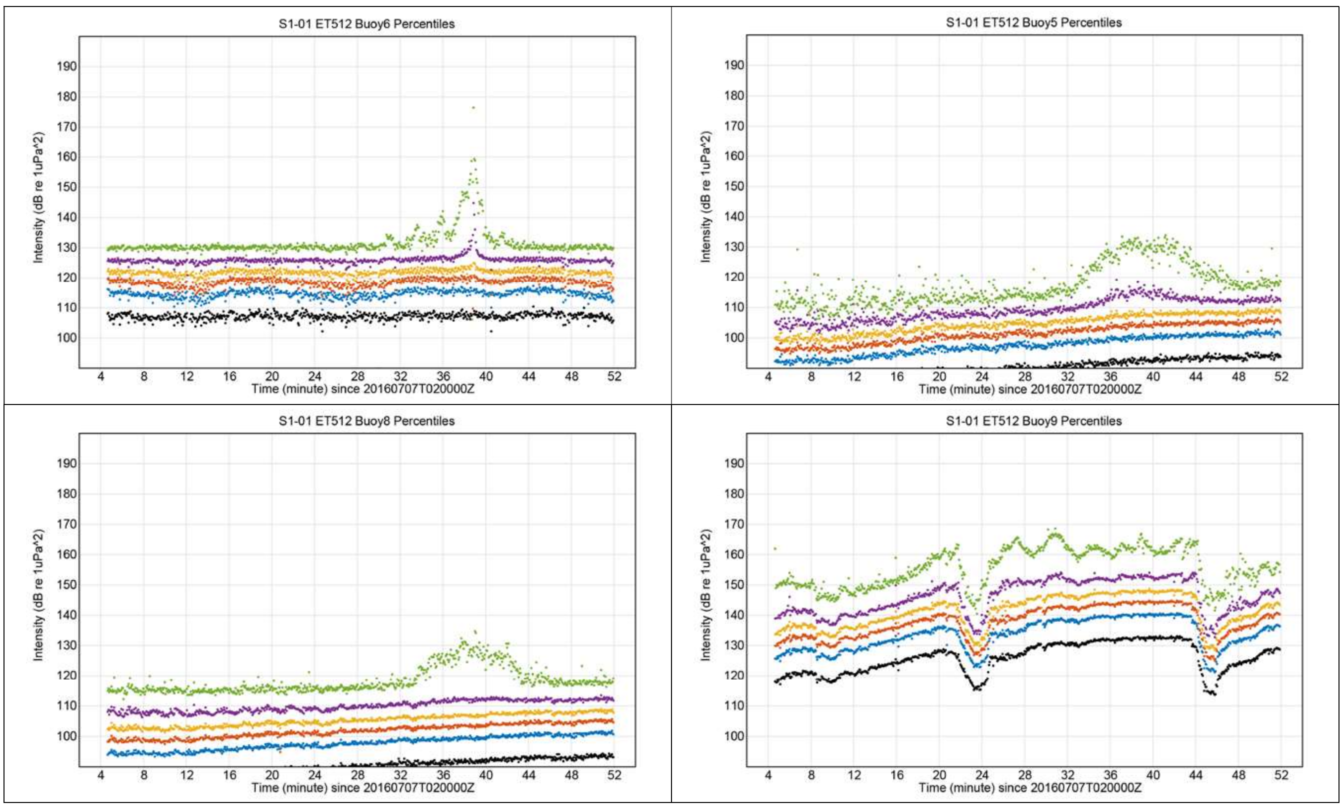


Figure 4.20.1-1. Percentile plots of Edgetech 512i signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

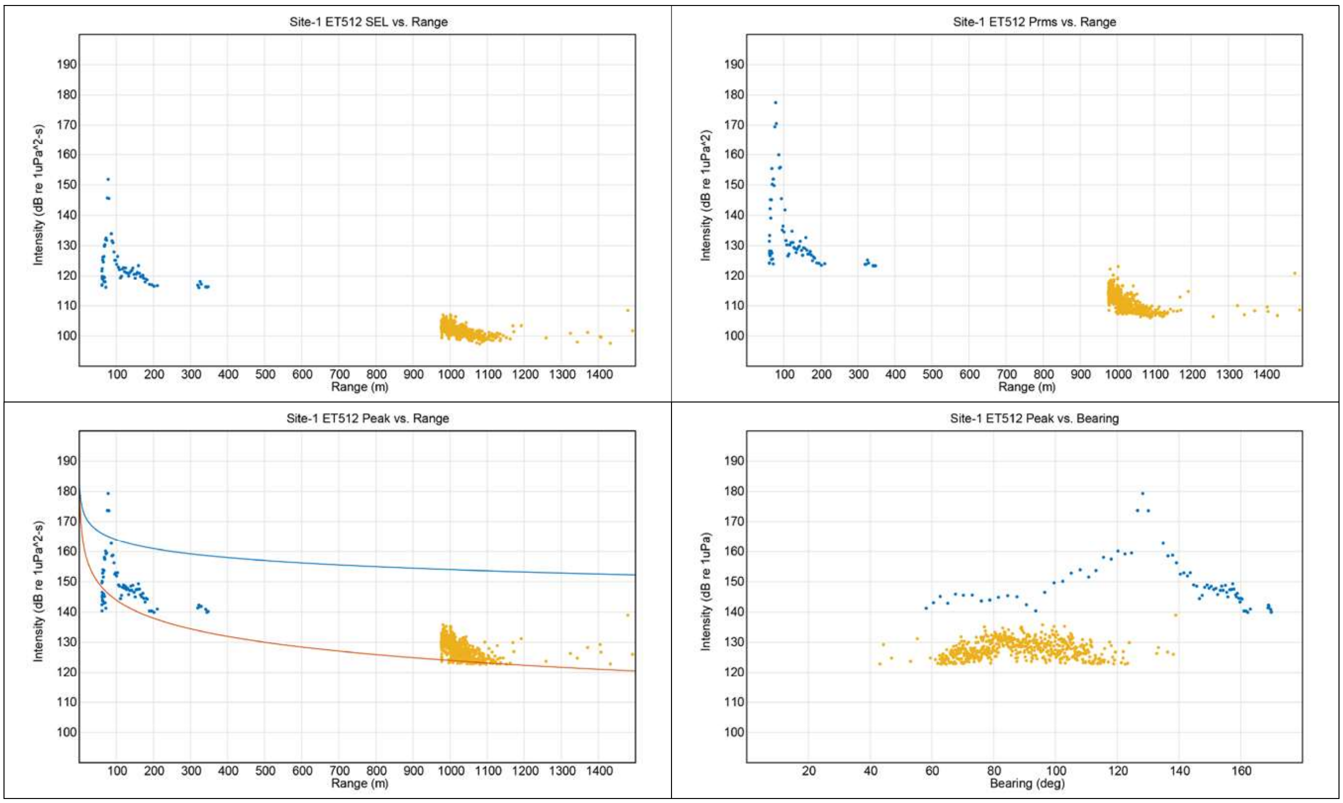


Figure 4.20.1-2. Range results for Edgetech 512i signals at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.20.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,500 to 1,500-m marks on the y-axis. The CPA is at 50,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -300 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -30 m on the y-axis.

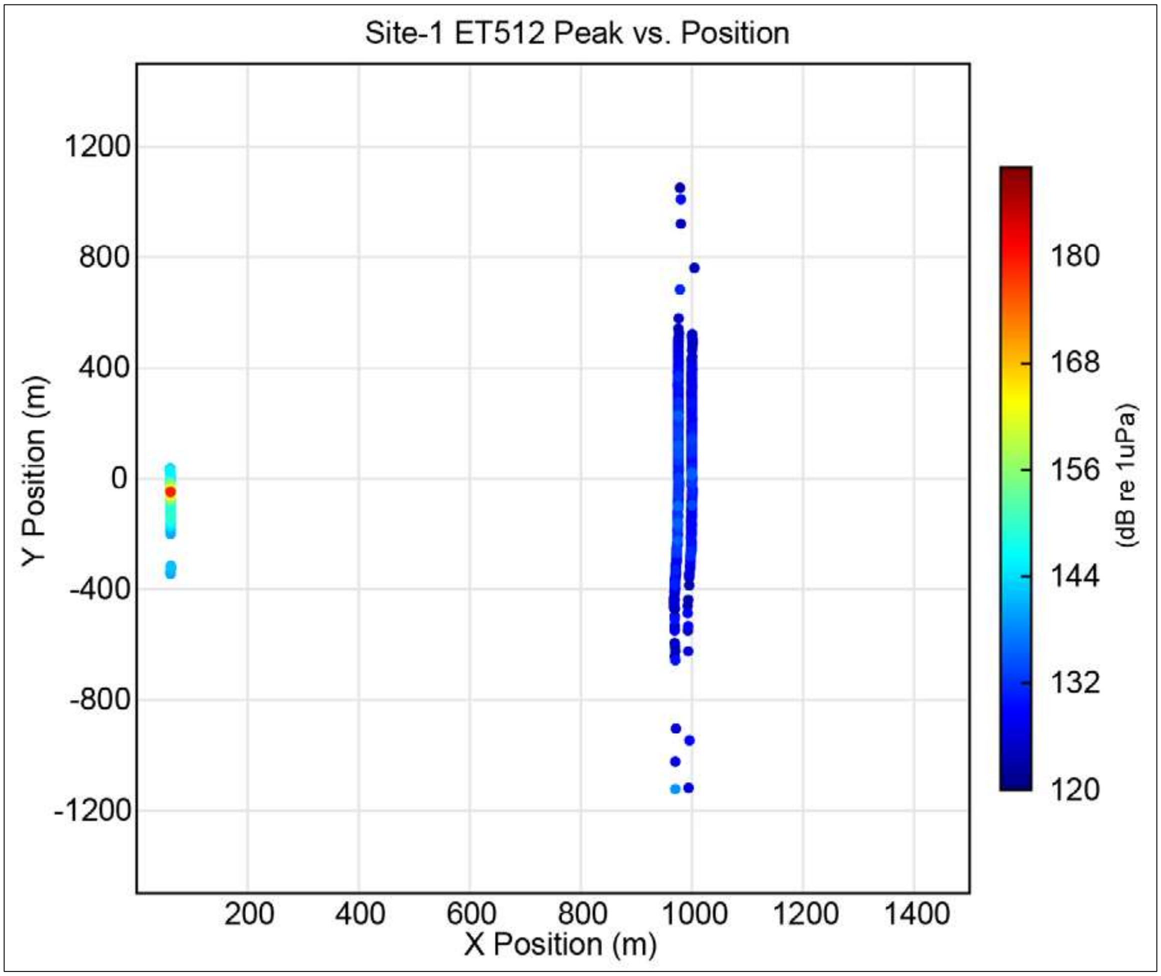


Figure 4.20.1-3. Plan view of received peak level for Edgetech 512i at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.20.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The peak estimated source level is approximately 15 dB higher than expected compared to the NUWC report, which is an indication of a possible 8-m buoy navigation error or unresolved calibration issues (**Section 2.6.3.1**).

Table 4.20.1-1. ET512i source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 1	0.5-7.2 kHz	100%	NA	30 ms	199	197	171
NUWC	0.5-7.2 kHz	100%	NA	30 ms	184	177	157

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.20.2 Site 2 – Sand, 10 m Depth

At S2, the ET512i, Mode 1, had valid acoustic recordings in Run1 and Run29. For Run1, position B (Buoy11) had valid acoustic recordings. For Run29, positions B (Buoy11), E (Buoy10), and F (Buoy9) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 1, are shown in **Figure 4.20.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy11) for Run1, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy10) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.20.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S2, only position B (Buoy11 combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 95 to approximately 1,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.20.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 100°, indicating relatively good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For an omnidirectional beam pattern, the center (maximum peak signal) is expected to be at 90°.

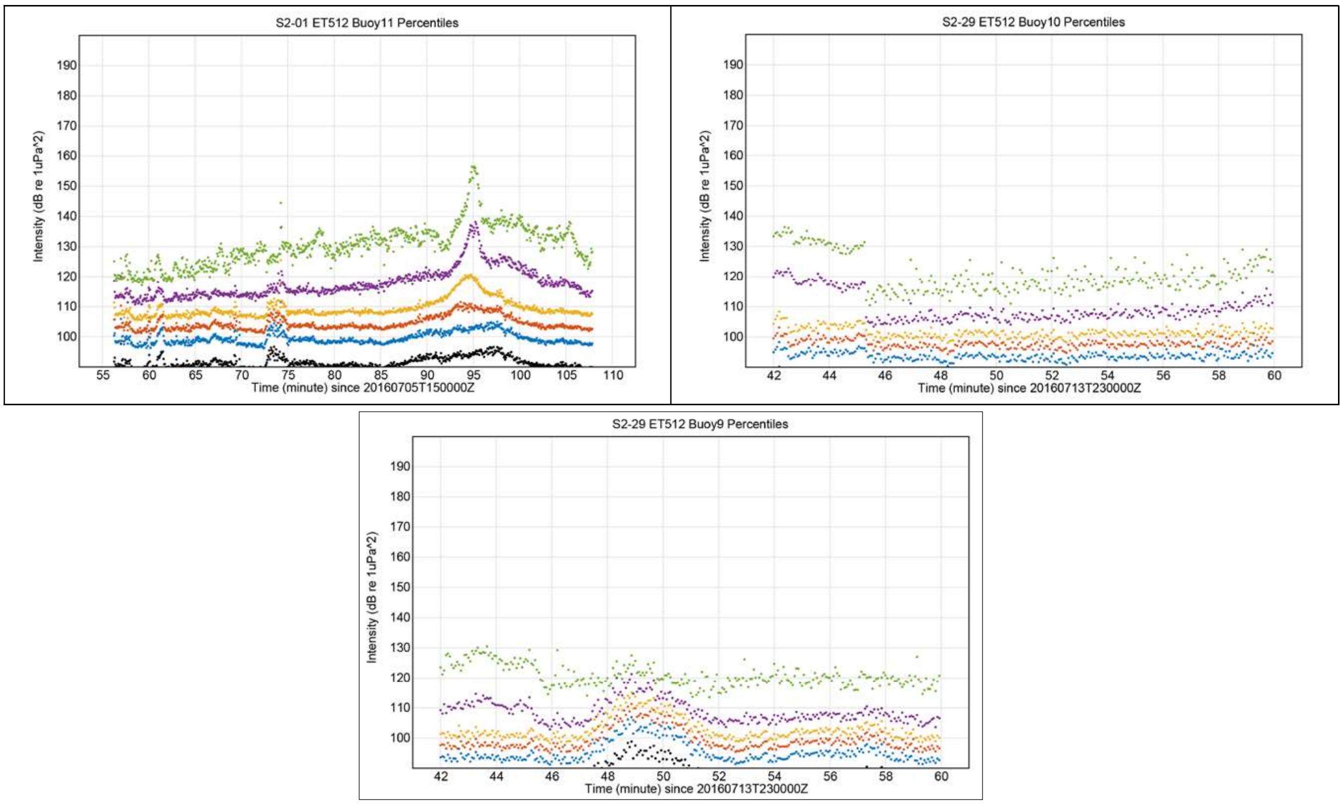


Figure 4.20.2-1. Percentile plots of Edgetech 512i signals at Site 2.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy11); Top right: SPL_{pk} arrival at position E (Buoy10); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

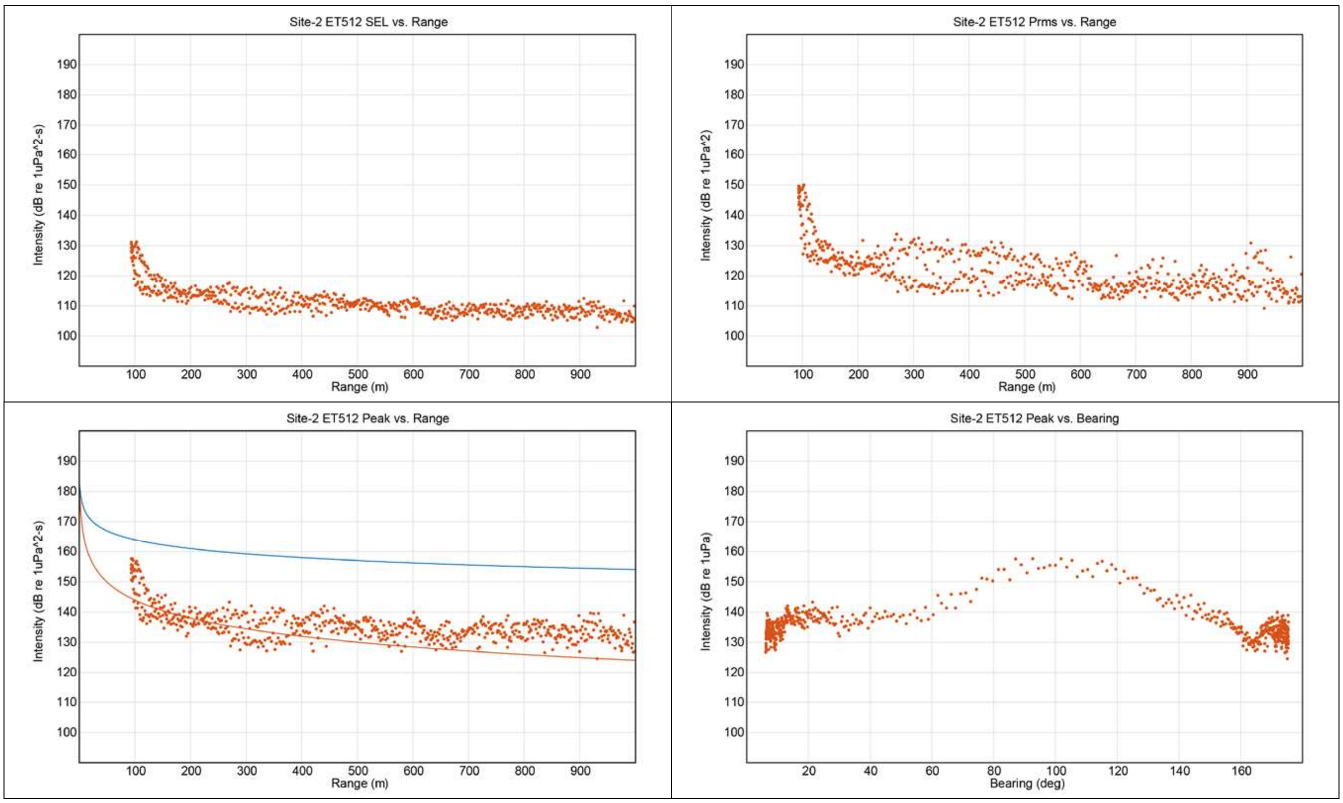


Figure 4.20.2-2. Range results for Edgetech 512i signals at Site 2 for positions B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.20.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy11). Recordings at the buoy had acoustic peak amplitudes, presumably at the CPA

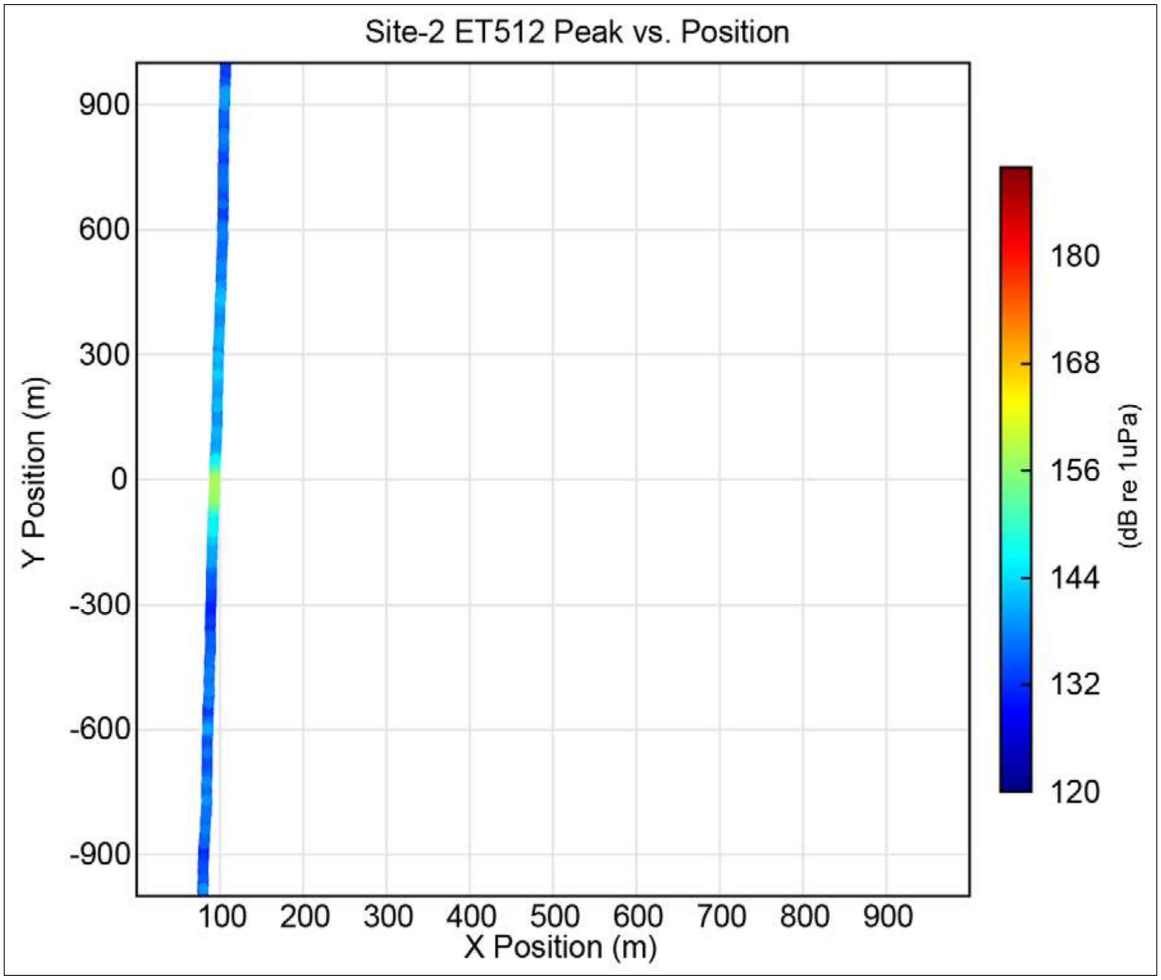


Figure 4.20.2-3. Plan view of received peak level for Edgetech 512i at Site 2 for position B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.20.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.20.2-1. ET512i source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET512i Mode 1	0.5-7.2 kHz	100%	NA	30 ms	188	180	162
NUWC	0.5-7.2 kHz	100%	NA	30 ms	184	177	157

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.20.3 Site 3 – Mud, 30 m Depth

At S3, the ET512i, Mode 1, had valid acoustic recordings in Run1 and Run21. For Run1, position B (Buoy5 and Buoy12) had valid acoustic data and observed signals. For Run21, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10) had valid acoustic data and observed signals.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 1, are shown in **Figure 4.20.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run21, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy10).

The results panels (**Figure 4.20.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the ET512i at S3, positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy 8 and Buoy10, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,300 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There is evidence of about 10 dB of unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, shows the received peak levels for all buoys, which are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

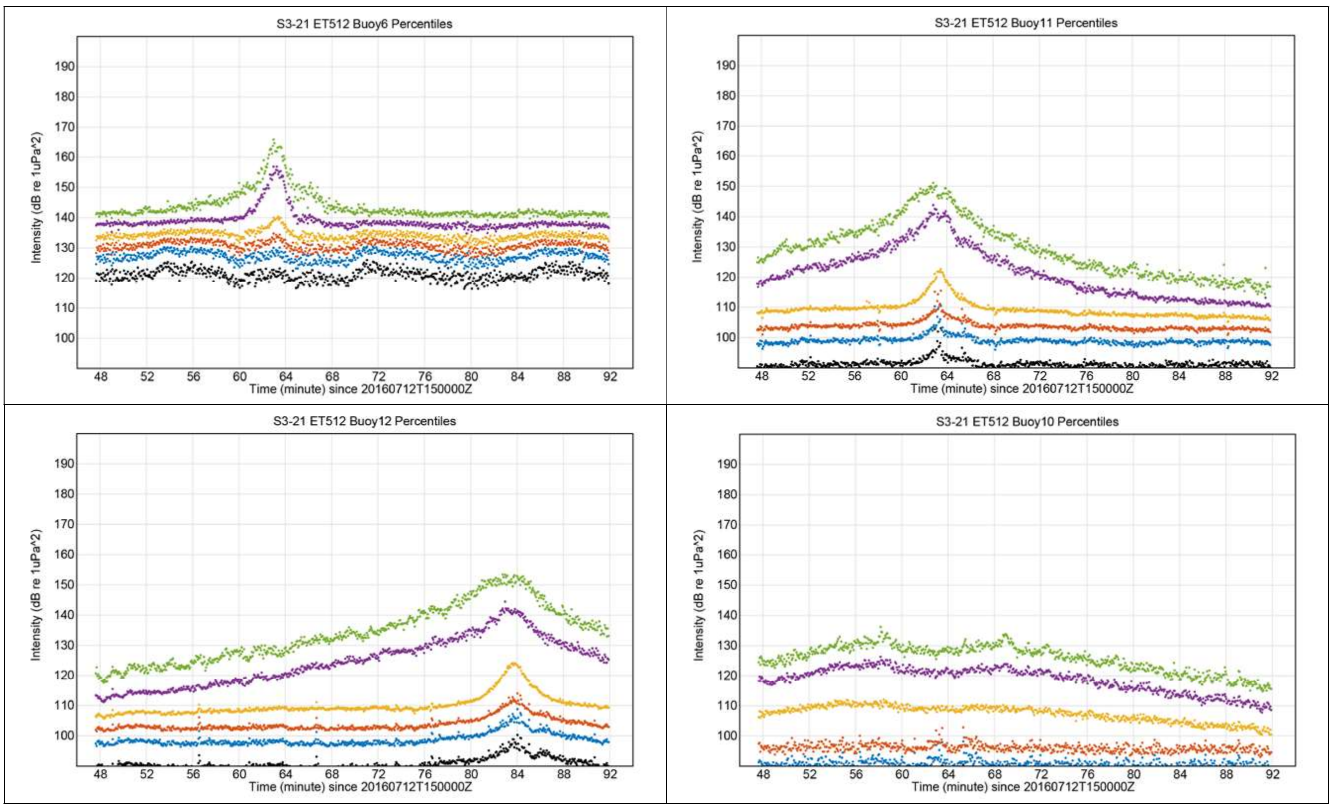


Figure 4.20.3-1. Percentile plots of Edgetech 512i signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

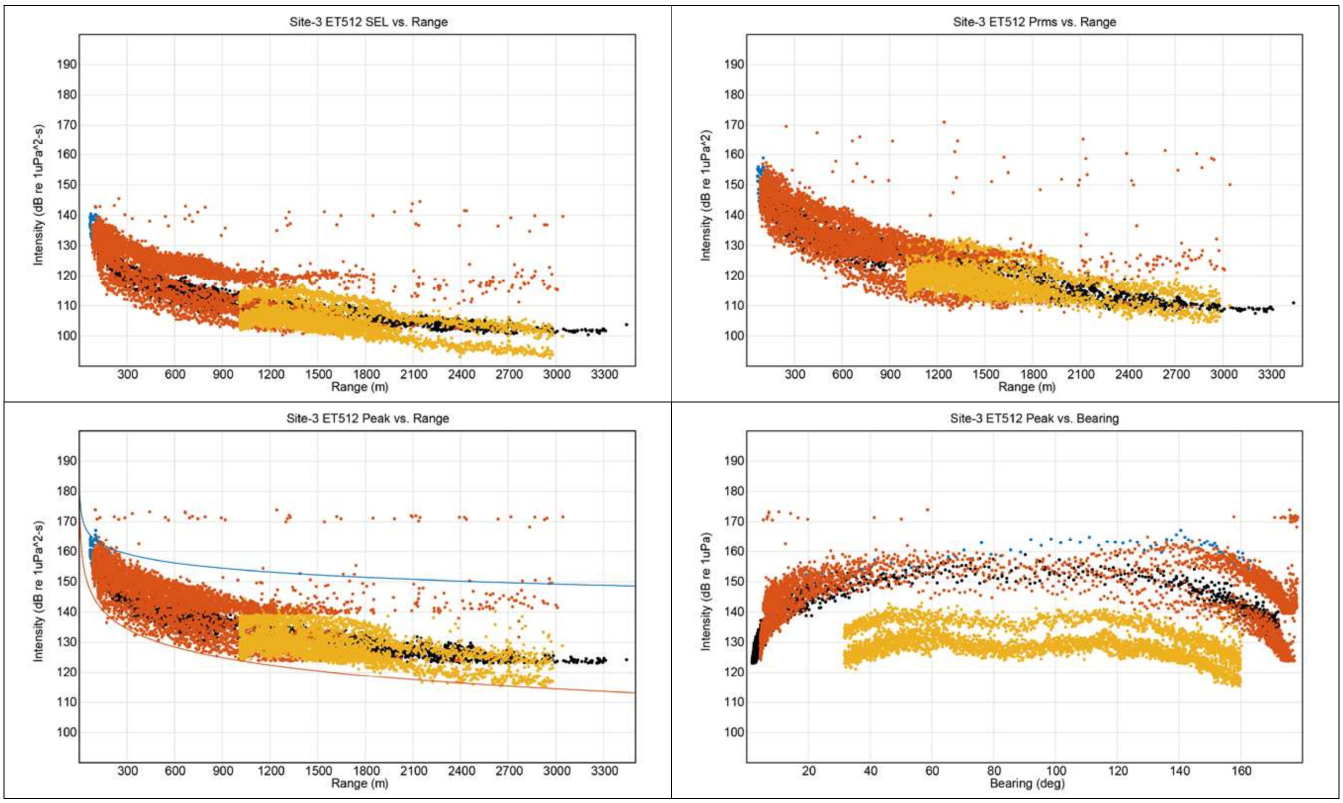


Figure 4.20.3-2. Range results for Edgetech 512i combined signals for Run1 and Run21 at Site 3 for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy8 and Buoy10, combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.20.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,500 to 3,500-m marks on the y-axis. The CPA is at 50,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -200 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy 8 and Buoy10, combined). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -30 m on the y-axis.

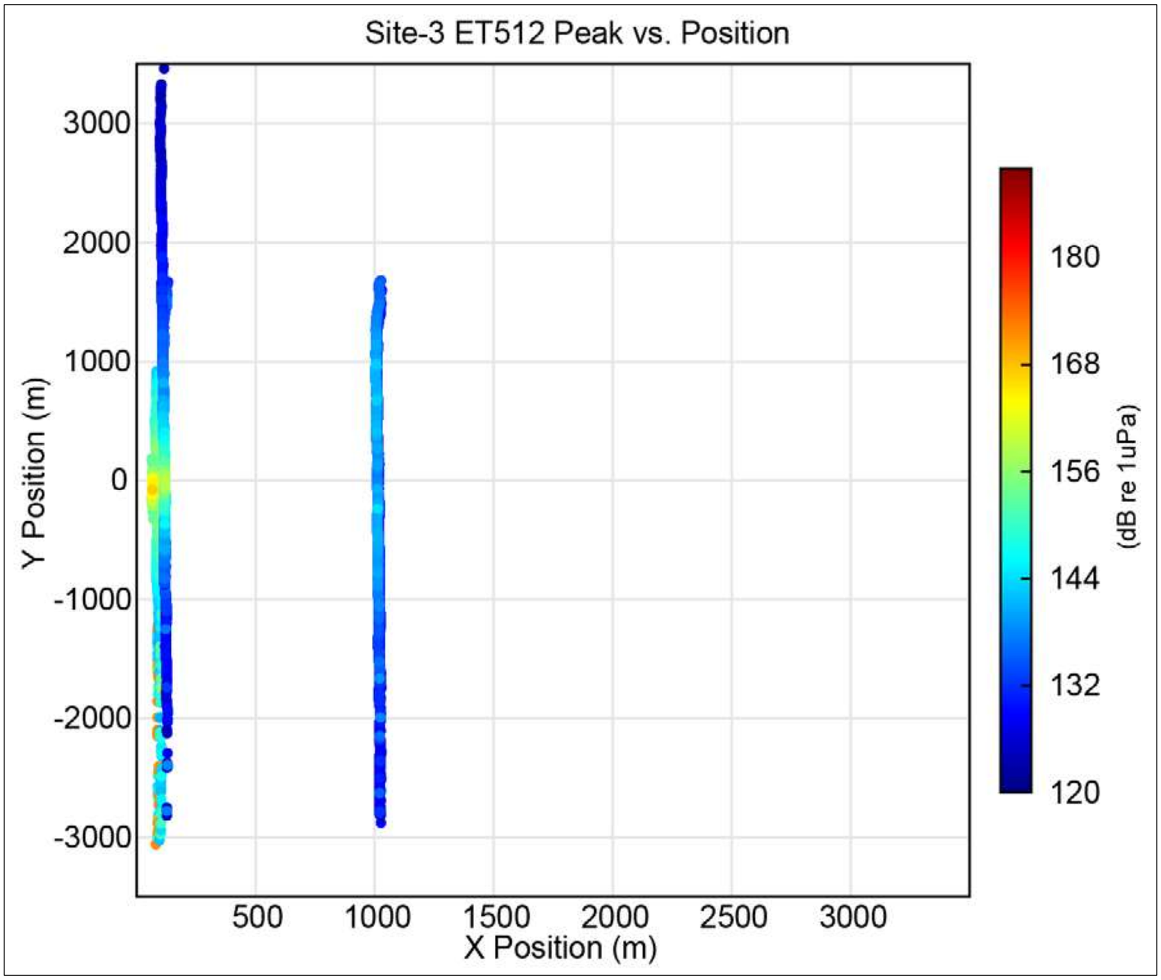


Figure 4.20.3-3. Plan view of received peak level for Edgetech 512i at Site 3 for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12), A (Buoy12), and E (Buoy 8 and Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.20.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.20.3-1. ET512i source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET512i Mode 1	0.5-7.2 kHz	100%	NA	30 ms	187	177	159
NUWC	0.5-7.2 kHz	100%	NA	30 ms	184	177	157

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.20.4 Site 4 – Sand, 30 m Depth

At S4, the ET512i, Mode 1, had valid acoustic recordings in Run1 at positions B (Buoy7 HS and LS), A (Buoy6), C (Buoy5), and E (Buoy9).

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 1, are shown in **Figure 4.20.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy7 HS) for Run1, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions B (Buoy7 LS), A (Buoy6), and C (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.20.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S4, positions B (Buoy7 HS and LS), A (Buoy6), C (Buoy5), and E (Buoy9) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The two distinct groupings of peak pressure levels, specifically for position A, indicate unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, shows the received peak level for all positions, which are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

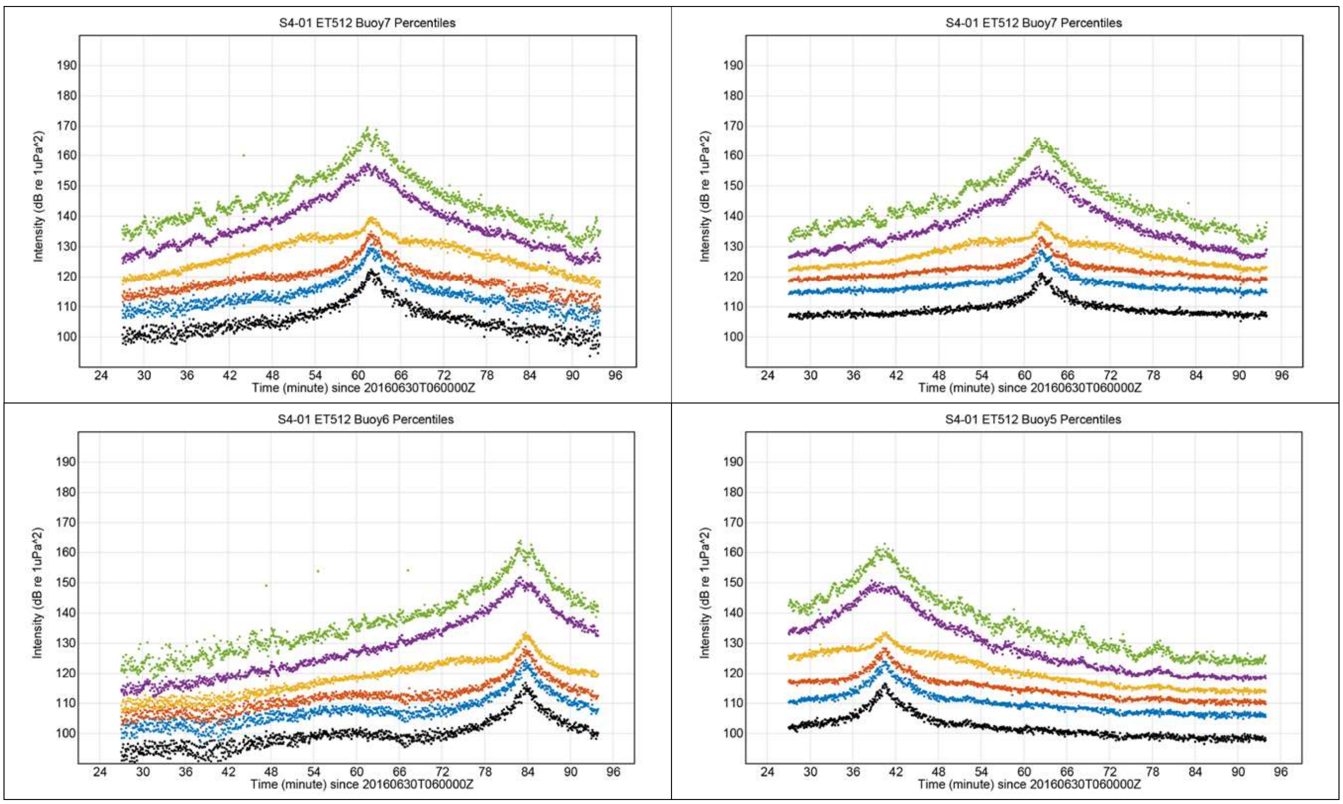


Figure 4.20.4-1. Percentile plots of Edgetech 512i signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy7, High Sensitivity); Top right: SPL_{pk} arrival at position B (Buoy7, Low Sensitivity); Bottom left: SPL_{pk} arrival at position A (Buoy6); Bottom right: SPL_{pk} arrival at position C (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

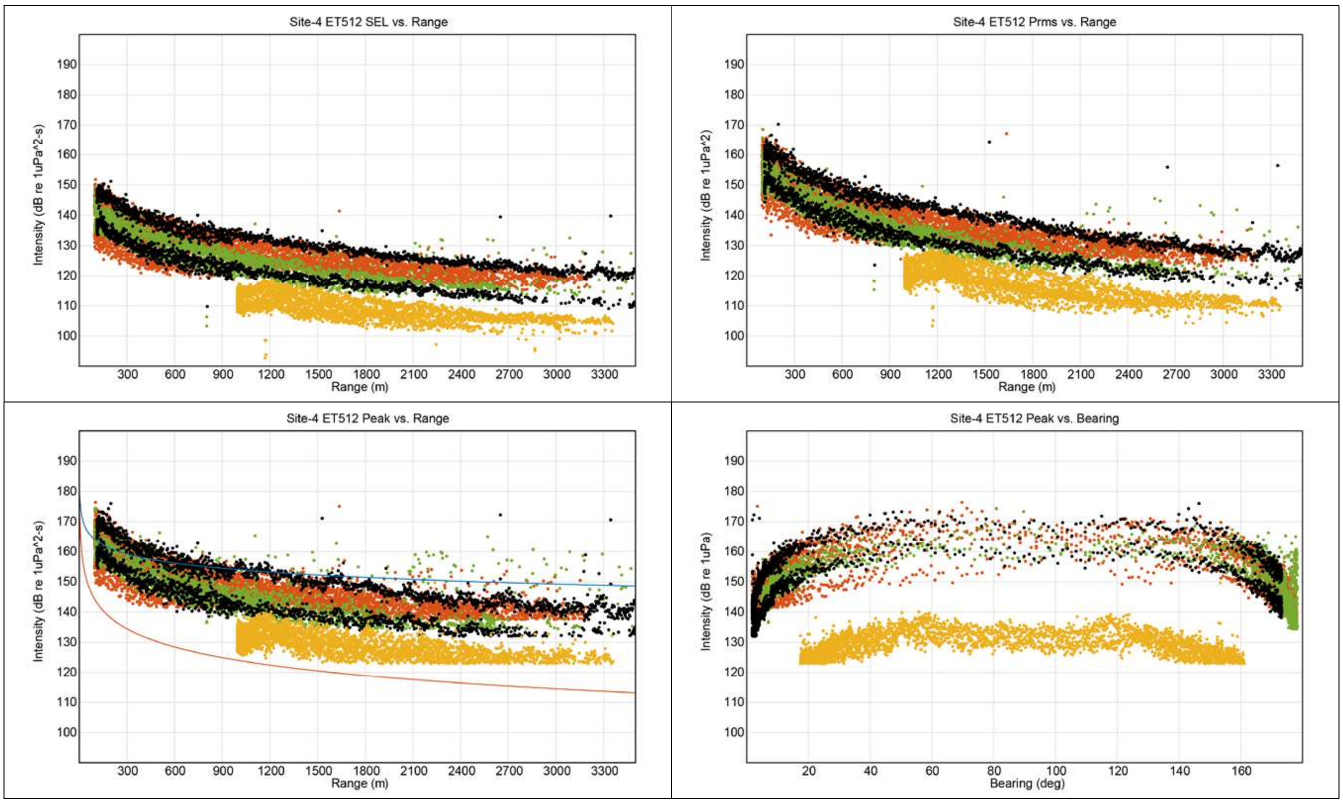


Figure 4.20.4-2. Range results for Edgetech 512i signals at Site 4 for positions B (Buoy7, High Sensitivity, Low Sensitivity), A (Buoy6), C (Buoy5), and E (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; C = green; E = yellow.

The plan view is shown in **Figure 4.20.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,500 to 3,500-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,500 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy7), A (Buoy6), C (Buoy5), and E (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position B is seen at approximately 0 m on the y-axis.

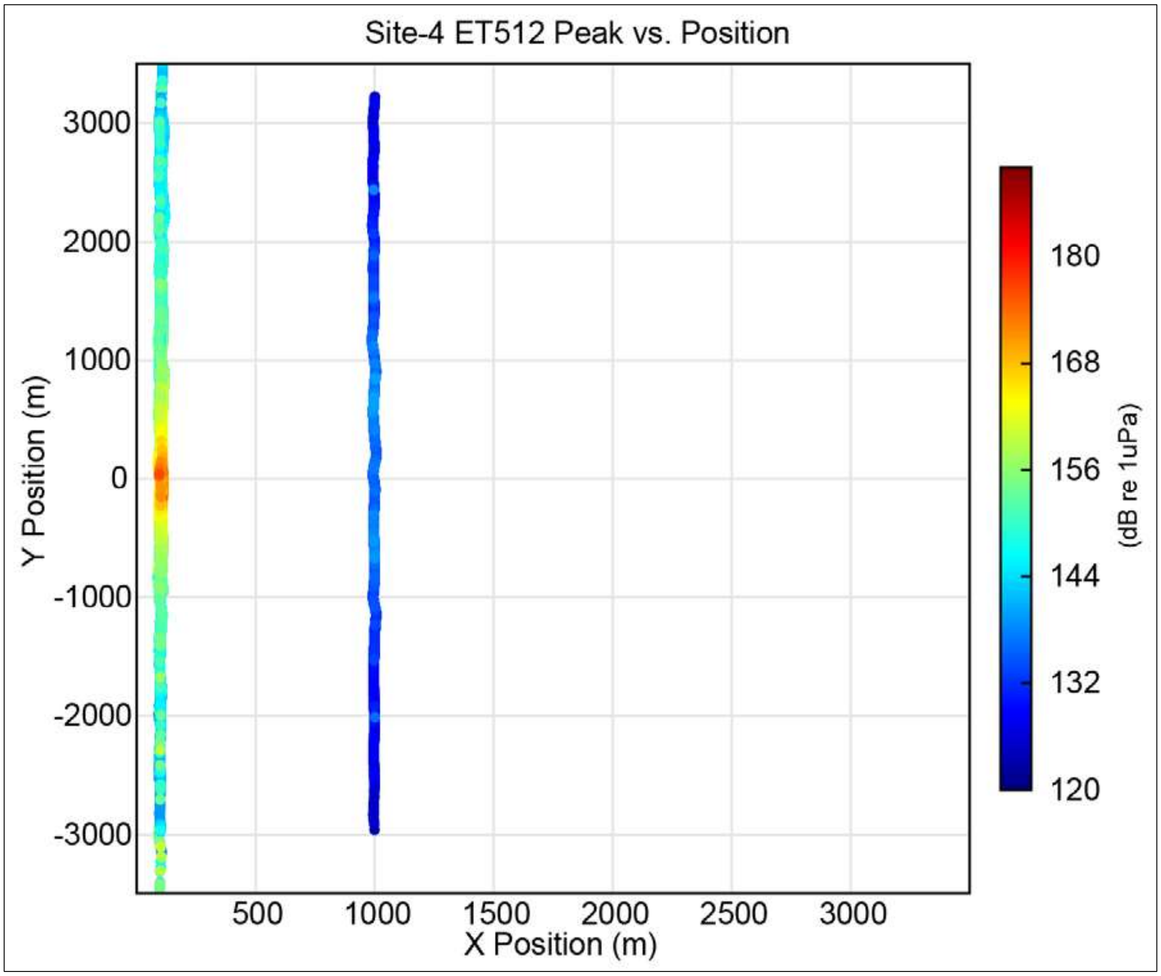


Figure 4.20.4-3. Plan view of received peak level for Edgetech 512i at Site 4 for positions B (Buoy7, High Sensitivity, Low Sensitivity), A (Buoy6), C (Buoy5), and E (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.20.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The values for this table were based on the lower received levels from position A (Buoy6).

Table 4.20.4-1. ET512i source levels, Mode 1, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET512i Mode 1	0.5-7.2 kHz	100%	NA	30 ms	184	175	162
NUWC	0.5-7.2 kHz	100%	NA	30 ms	184	177	157

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.20.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the ET512i, Mode 1, had valid acoustic recordings in Run3 and Run19 at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 1, are shown in **Figure 4.20.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run3, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and F (Buoy10). It is not clear if any of the positions captured the signals of this weak (184 dB re 1µPa) source. Additionally, the S5 environment created a challenging propagation scenario.

The results panels (**Figure 4.20.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S5, positions D (Buoy6) and potentially E (Buoy8 and Buoy9 combined) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 2,200 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There appear to be unresolved calibration errors (**Section 2.6.3.1**) at positions A and B as there is a difference of approximately 20 dB in received levels.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D, A, B, and F near broadside with a slow fall off in angle, which is as expected for good buoy positioning and an omnidirectional source.

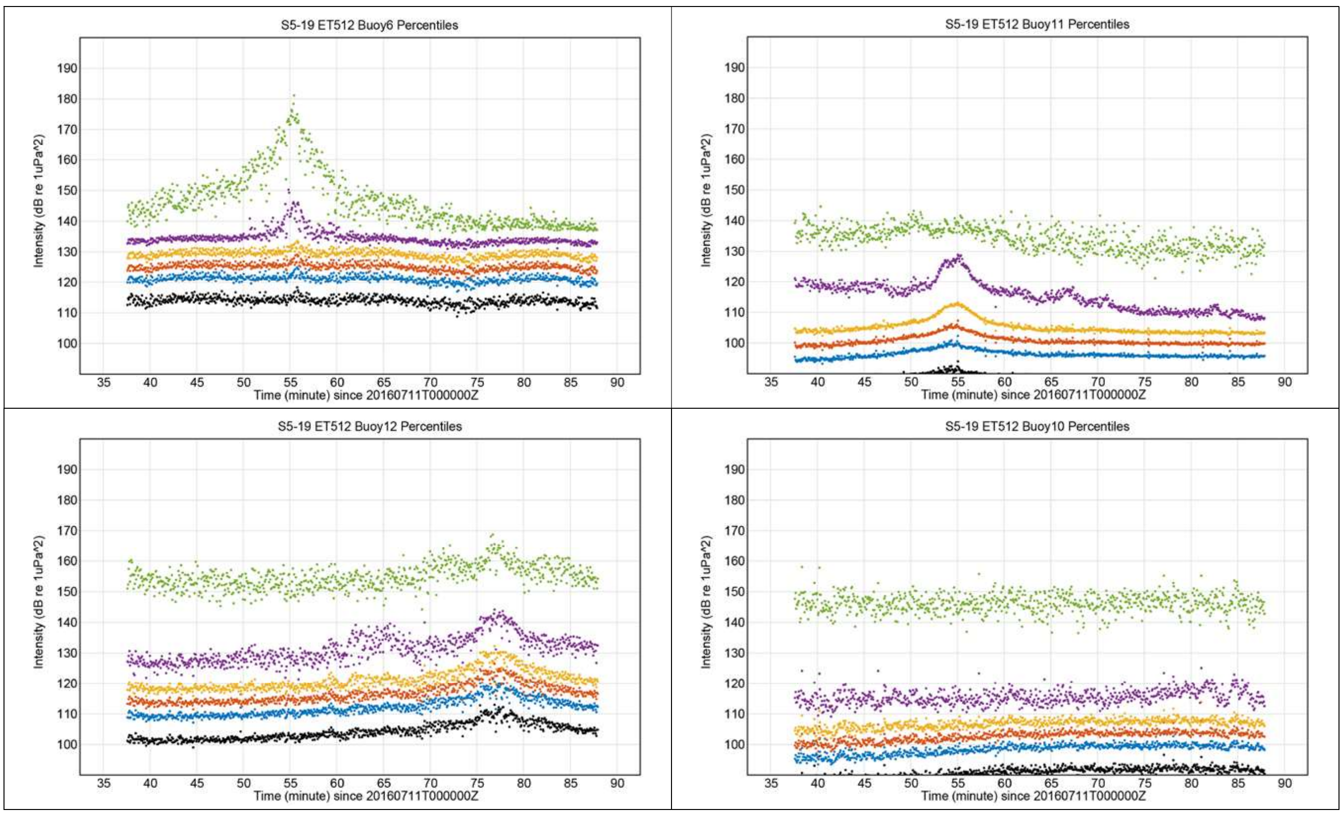


Figure 4.20.5-1. Percentile plots of Edgetech 512i signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position F (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

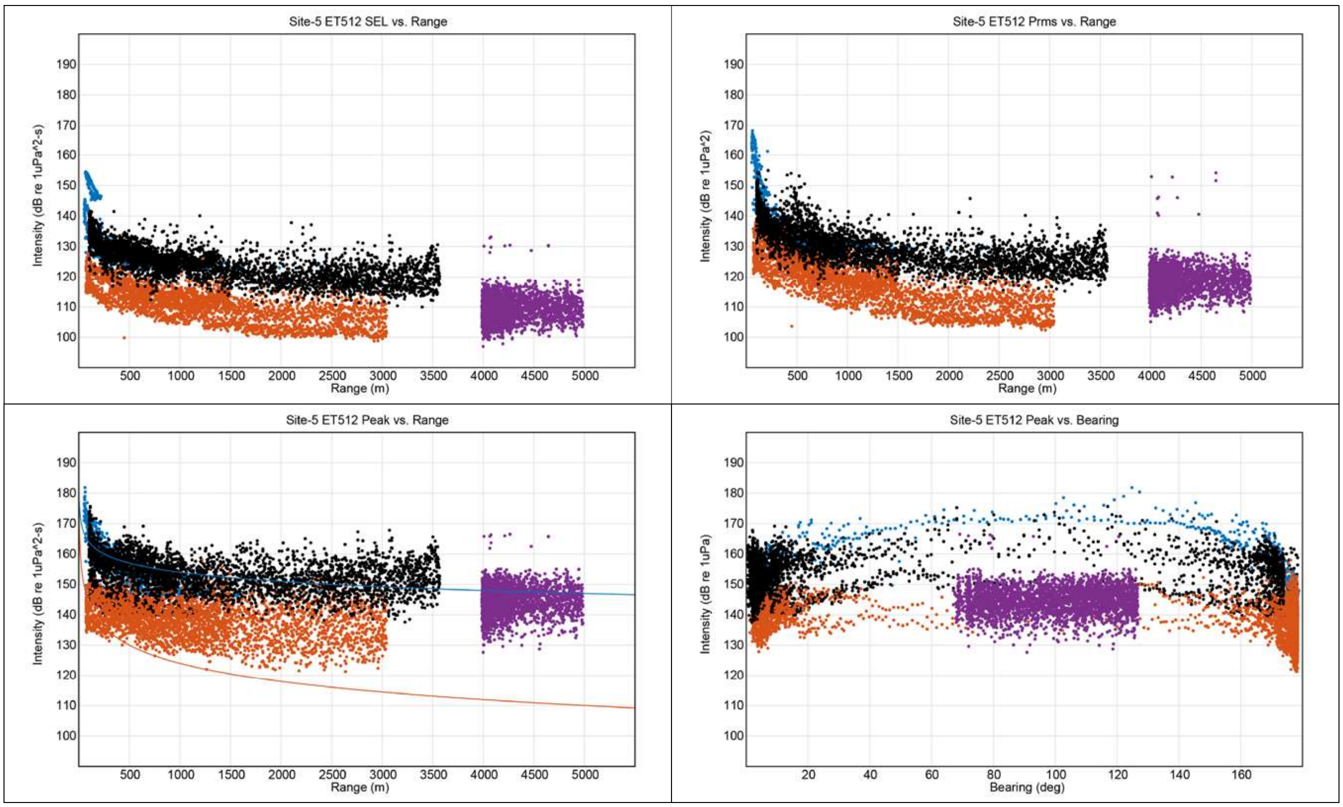


Figure 4.20.5-2. Range results for Edgetech 512i signals at Site 5 from Run4 and Run19 for positions D (Buoy6) and B (Buoy11), A (Buoy12), and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; F = purple.

The plan view is shown in **Figure 4.5.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. It is not clear if these reported peaks are actually received signal.

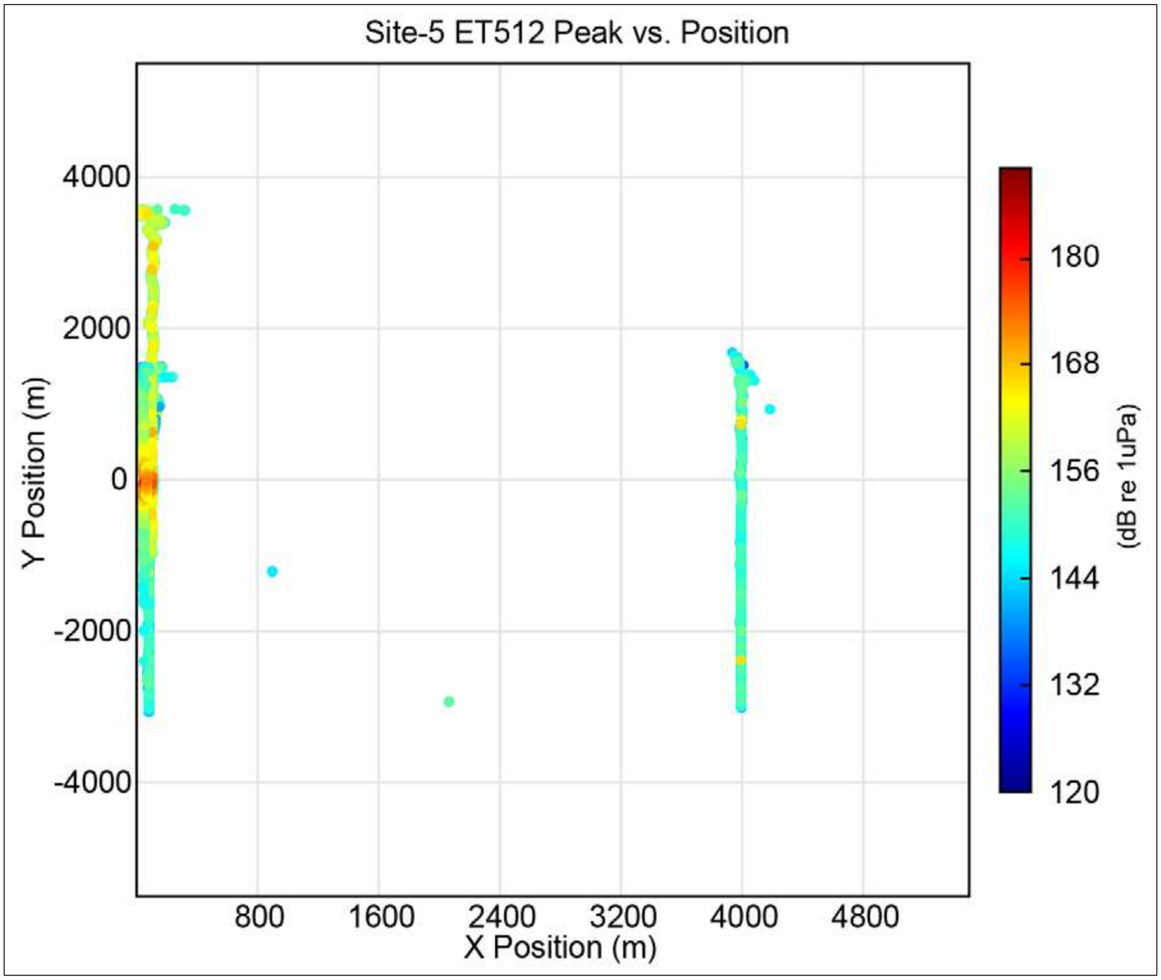


Figure 4.20.5-3. Plan view of received peak level for Edgetech 512i at Site 5 for positions D (Buoy6) and B (Buoy11), A (Buoy12), and F (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.20.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results. The received level fall-off follows a cylindrical spreading law, but it is unclear why the levels are high with the functional buoy GPS and consistency across each receiver, as compared to NUWC reported values.

Table 4.20.5-1. ET512i source levels, Mode 1, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 1	0.5-7.2 kHz	100%	NA	30 ms	189	184	172
NUWC	0.5-7.2 kHz	100%	NA	30 ms	184	177	157

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.21 Edgetech 512i, 2-12 kHz, 100 Percent Power, 20-ms Pulse (Mode 2)

The ET512i subbottom profiler generates a single, low-frequency signal with a peak frequency of 6 kHz. The operational parameter settings for Mode 2 were a 100 percent power, 20-ms pulse, 2 to12 kHz output frequency, with a 512i topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.21-1** is the selected frequency band (1 to 15 kHz) and SPL_{pk} (162 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.21-1. Bandpass determination for the ET512i subbottom profiler, 2-12 kHz, 100 percent power, 20-ms pulse at Site 2, Run2.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
1-200	161.98
1-100	162.02
1-25	161.99
1-15	**161.85**
2-6	130.68

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported below from only one site for simplicity. The ET512i, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.21-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The ET512i was operationally paired in alternation with the Knudsen 3260. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.21-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

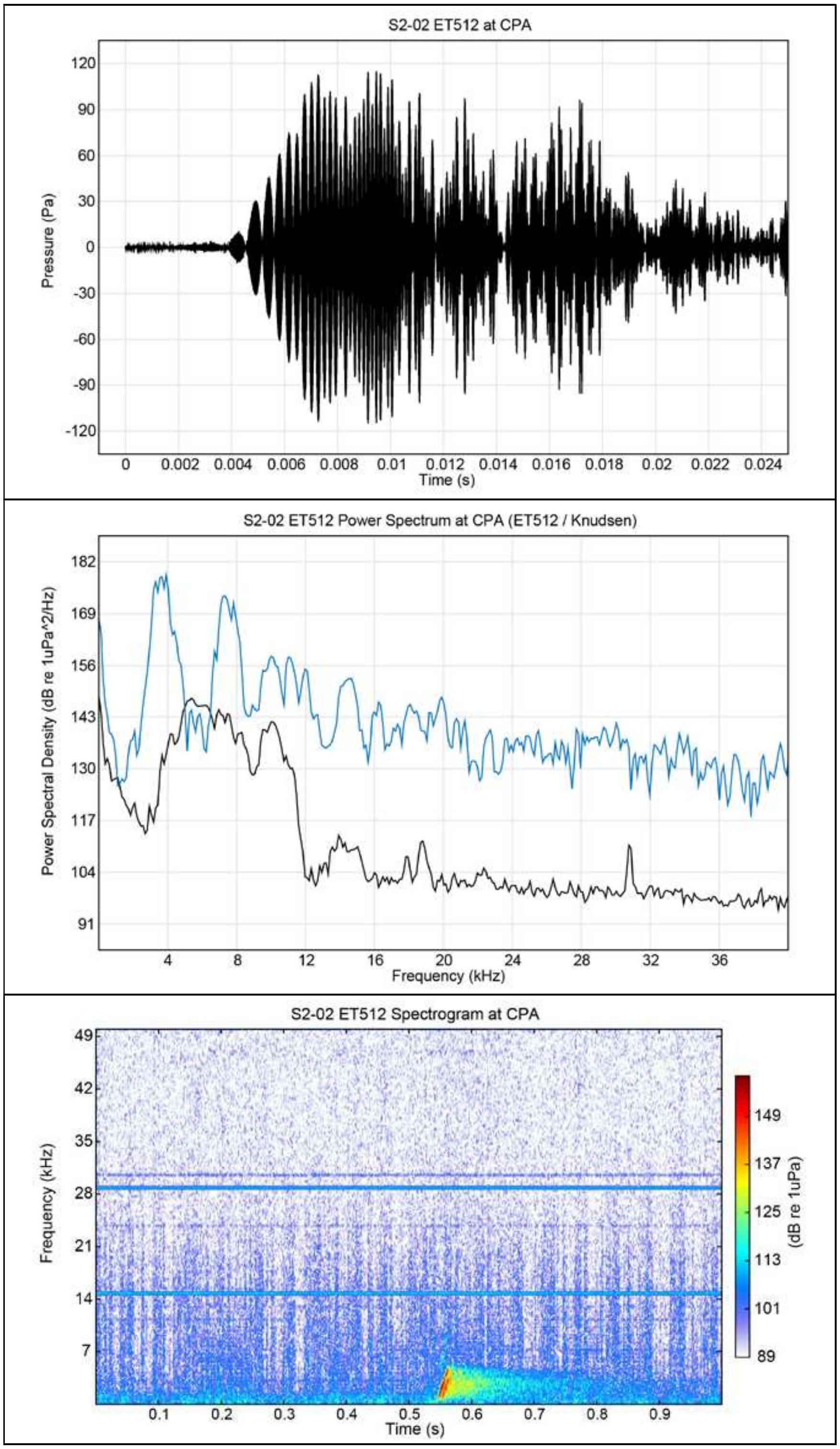


Figure 4.21-1. Edgetech 512i measured signal characteristics at closest point of approach (CPA) at Site 2, Run2.

Top: Time-waveform of a signal; Middle: Power spectral density, ET512i = black, Knudsen 3260 = blue; Bottom: Spectrogram.

4.21.1 Site 1 – Mud, 10 m Depth

At S1, the ET512i, Mode 2, had valid acoustic recordings in Run2, at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the ET512i, Mode 2, are shown in **Figure 4.21.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run2, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8), and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.21.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the ET512i at S1, positions D (Buoy6) and E (Buoy5 and Buoy8) had any acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,300 m. The shape of data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.21.1-2**), which shows for position D at approximately 110°, indicating an error in the buoy positioning. For position E, the data is mostly noise. These SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

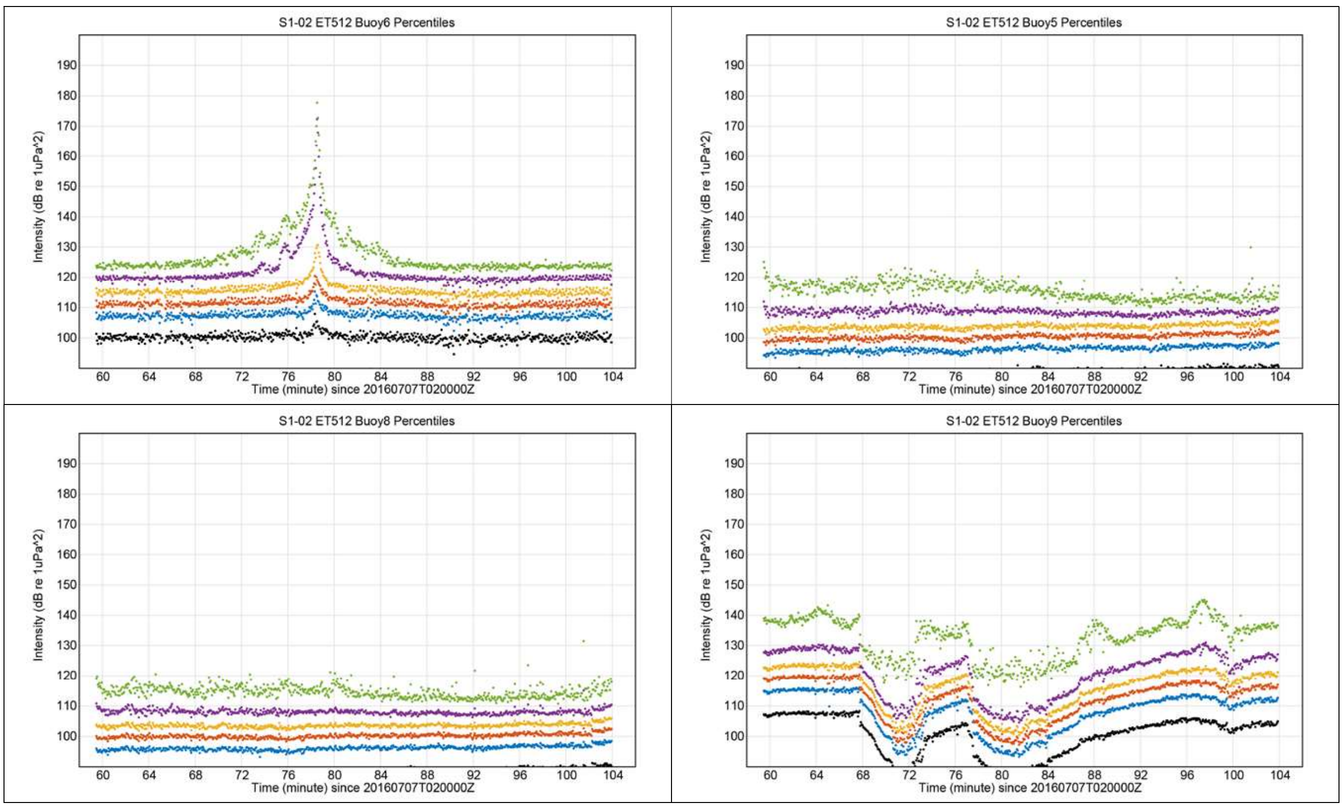


Figure 4.21.1-1. Percentile plots of Edgetech 512i signals at Site 1.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right; SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

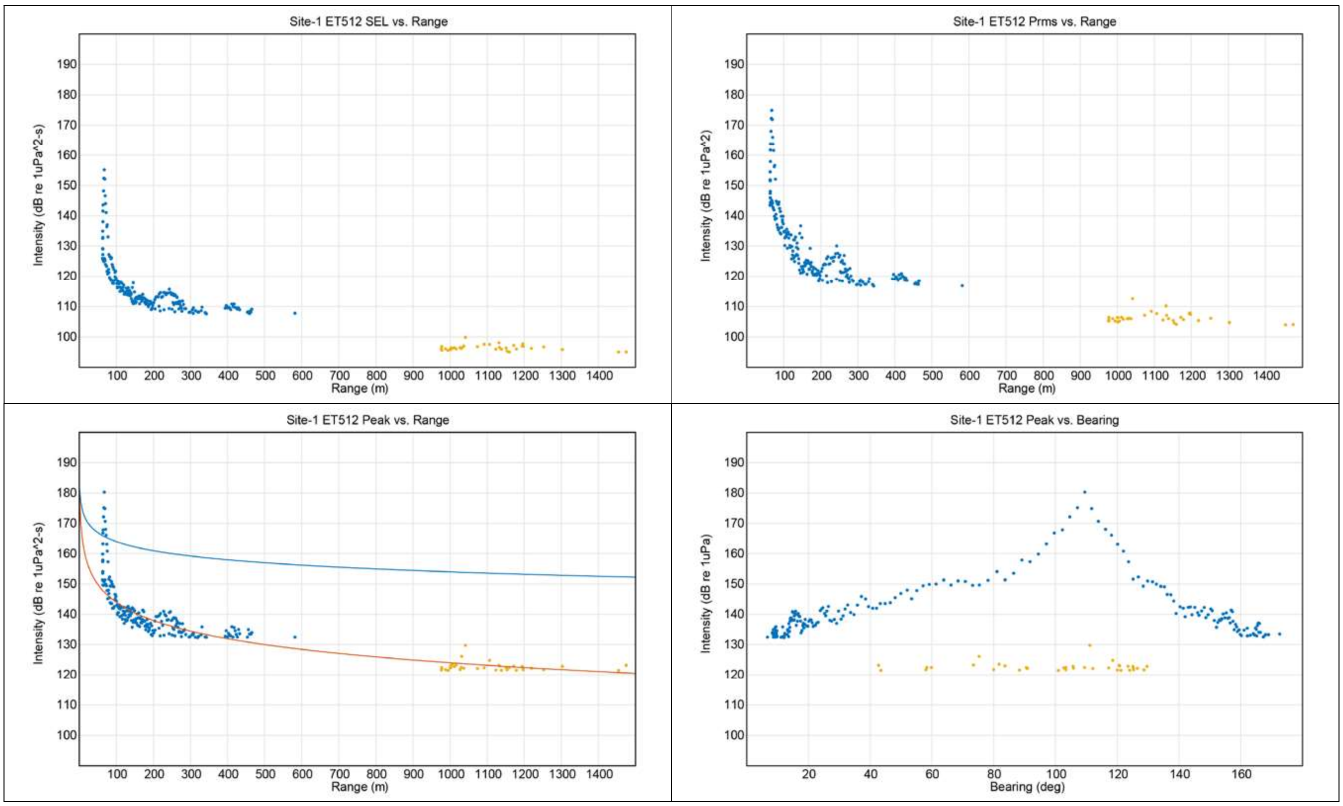


Figure 4.21.1-2. Range results for Edgetech 512i signals at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy9, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.21.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,500 to 1,500-m marks on the y-axis. The CPA is at 50,-25 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -375 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen on the y-axis at approximately -25 m.

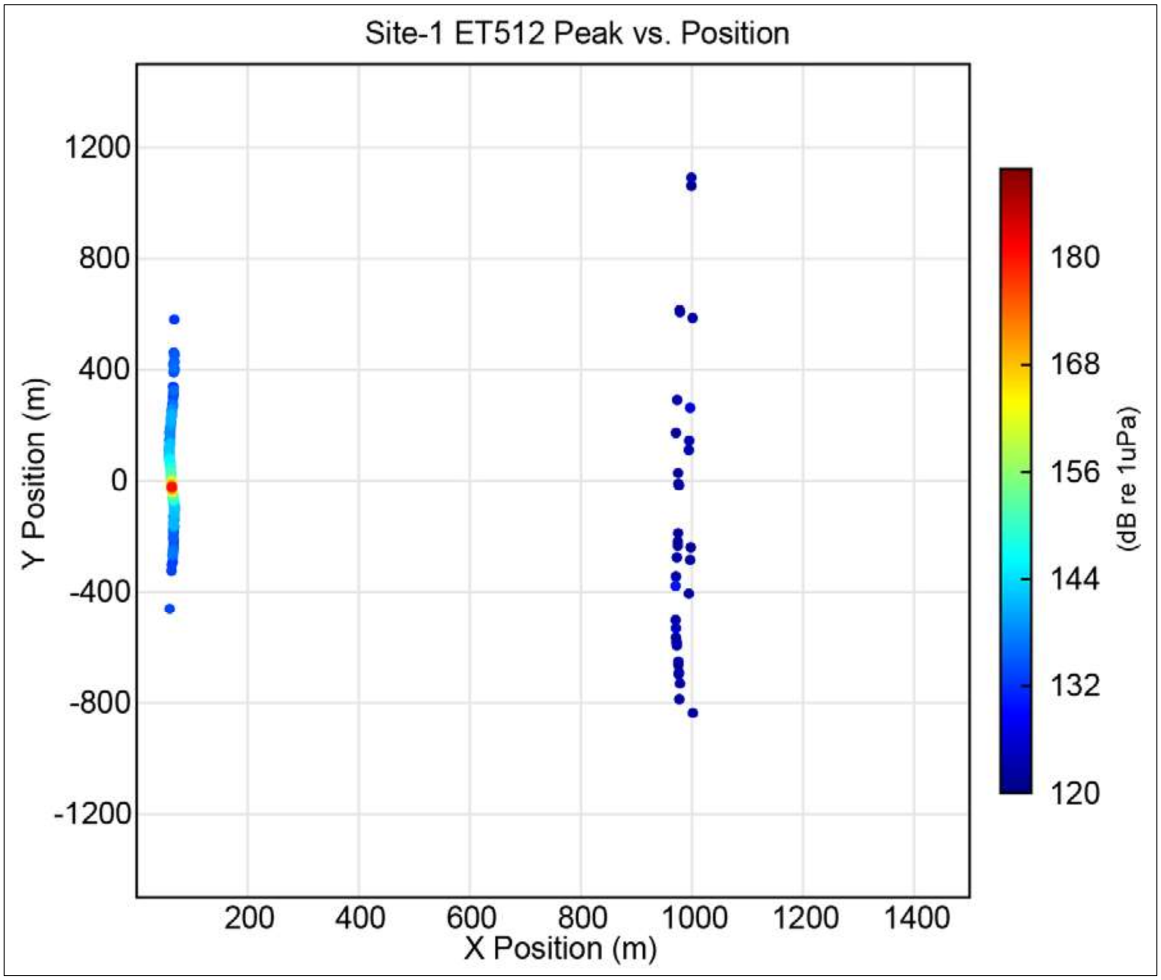


Figure 4.21.1-3. Plan view of received peak level for Edgetech 512i at Site 1, showing the results for positions D (Buoy6) and E (Buoy5 and Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.21.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results. The estimated peak source level at the CPA is approximately 14 dB higher than expected as compared to the NUWC reporting and likely the result of unresolved calibration issues (**Section 2.6.3.1**).

Table 4.21.1-1. ET512i source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 2	2-12 kHz	100%	NA	20 ms	198	192	174
NUWC	2-12 kHz	100%	NA	20 ms	184	179	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.21.2 Site 2 – Sand, 10 m Depth

At S2, the ET512i, Mode 2, had valid acoustic recordings in Run2 and Run30. For Run2, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run30, position B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 2, are shown in **Figure 4.21.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run2, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy5 and Buoy11). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.21.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S1, positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11, combined), E (Buoy10), and F (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.21.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

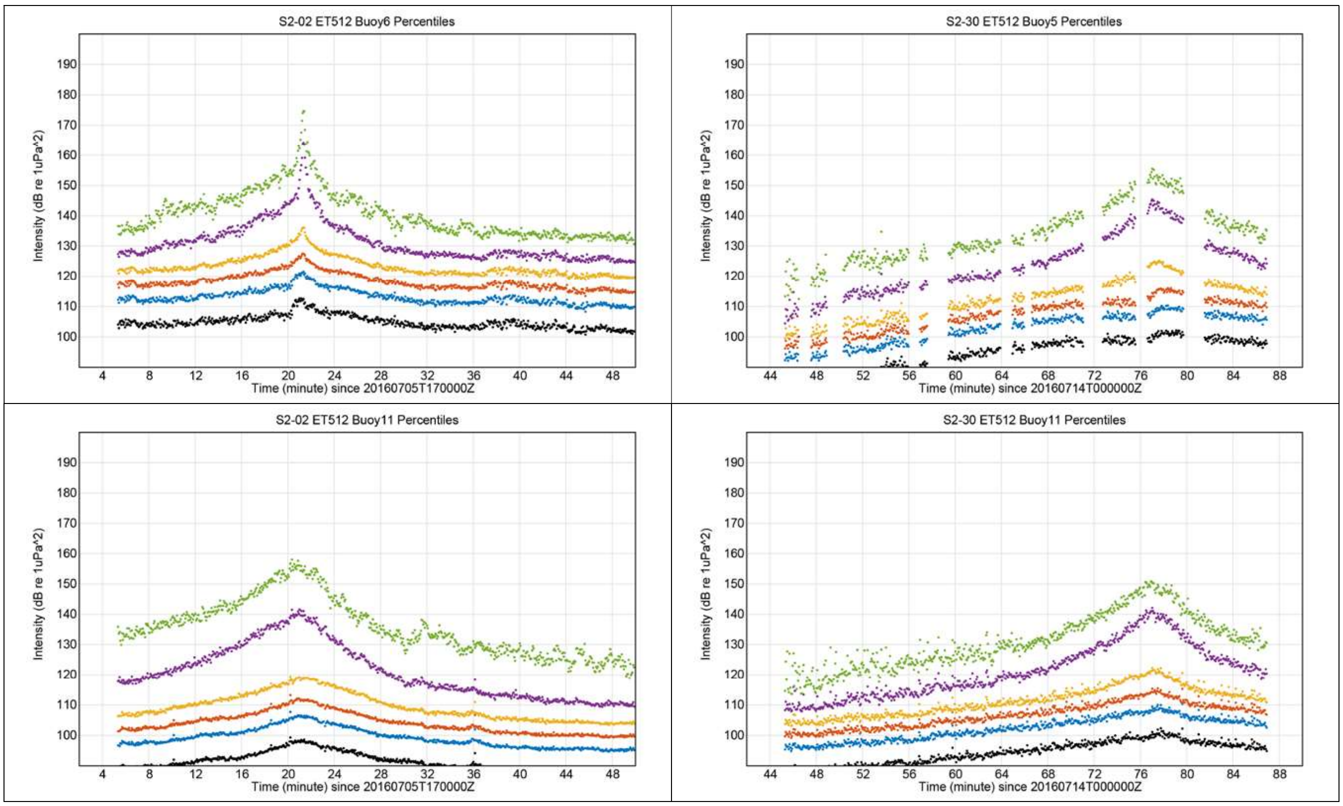


Figure 4.21.2-1. Percentile plots of Edgetech 512i signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy11). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

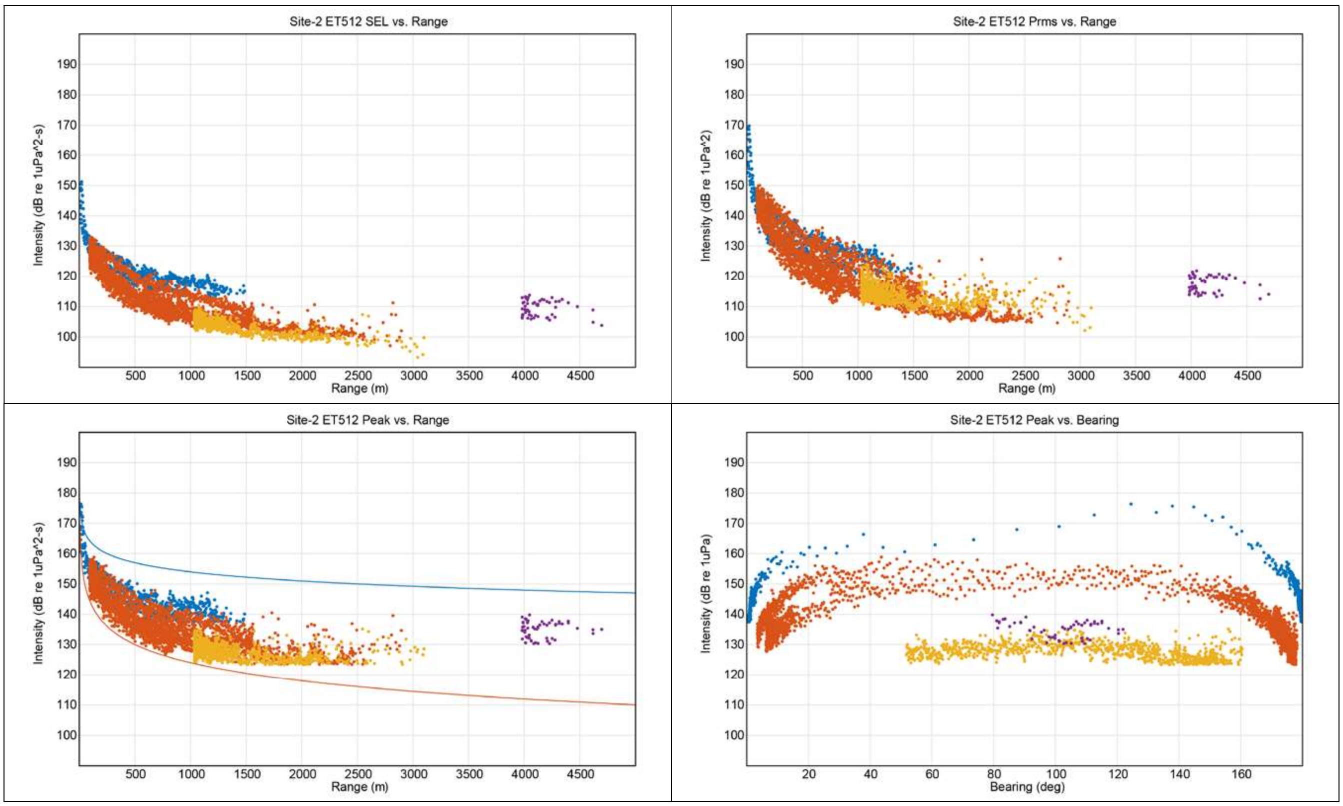


Figure 4.21.2-2. Range results for Edgetech 512i signals at Site 2 for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy11, combined), E (Buoy10), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.21.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 40,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,500 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy5, Buoy11, and Buoy11, combined), E (Buoy10), and F (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen on the y-axis at approximately 0 m.

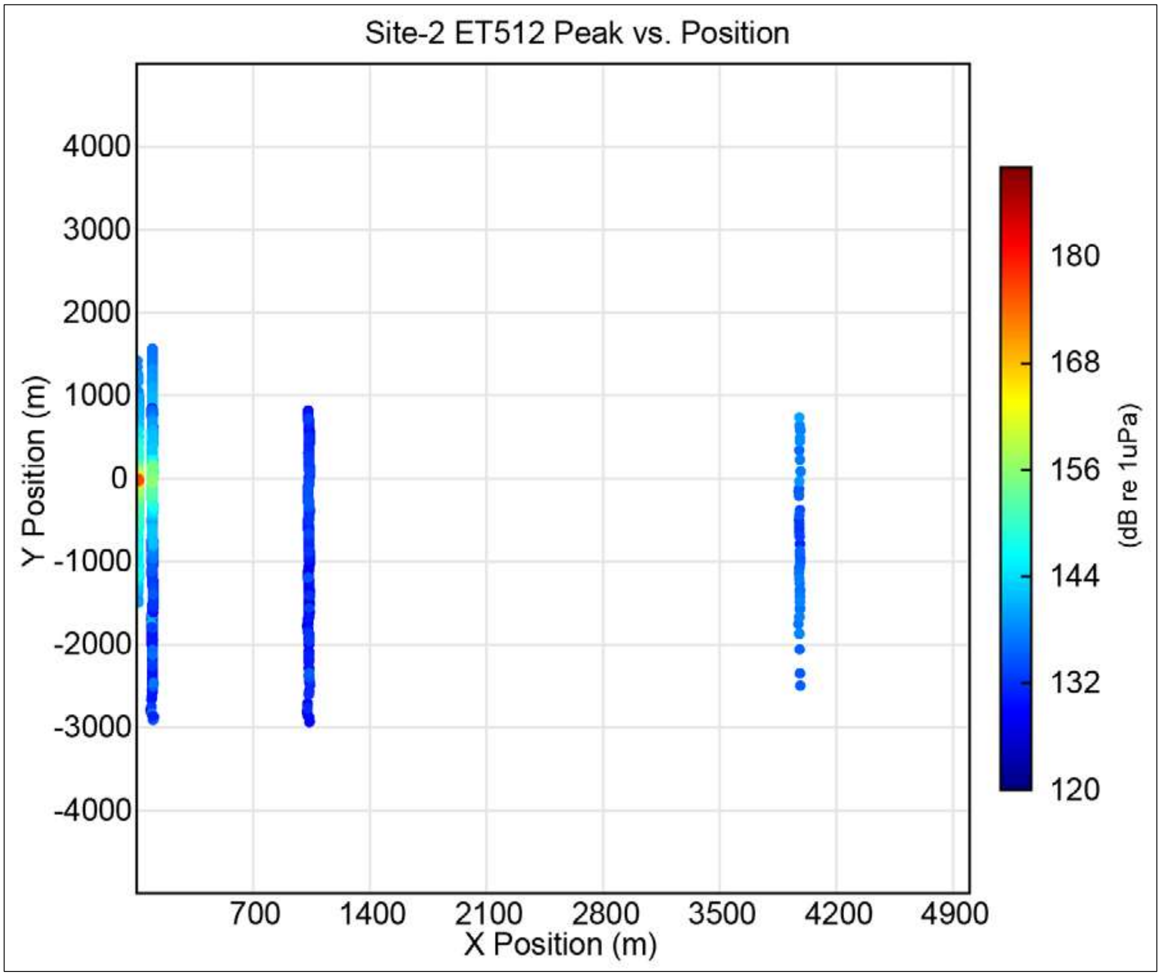


Figure 4.21.2-3. Plan view of received peak level for Edgetech 512i at Site 2, showing the results for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy11), E (Buoy10), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.21.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results. The estimated peak source level at the CPA is approximately 10 dB higher than the NUWC values, and likely the result of either unresolved calibration issues (**Section 2.6.3.1**) or buoy positioning errors.

Table 4.21.2-1. ET512i source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET512i Mode 2	2-12 kHz	100%	NA	20 ms	194	186	168
NUWC	2-12 kHz	100%	NA	20 ms	184	179	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.21.3 Site 3 – Mud, 30 m Depth

At S3, the ET512i, Mode 2, had valid acoustic recordings in Run2 and Run22. For Run2, position B (Buoy5 and Buoy12) had valid acoustic recordings. For Run22, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 2, are shown in **Figure 4.21.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run22, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.21.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the ET512i at S3, positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy8 and Buoy10) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The fact that there are two distinct groupings of peak pressure levels, specifically for position B, indicate unresolved calibration issues.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

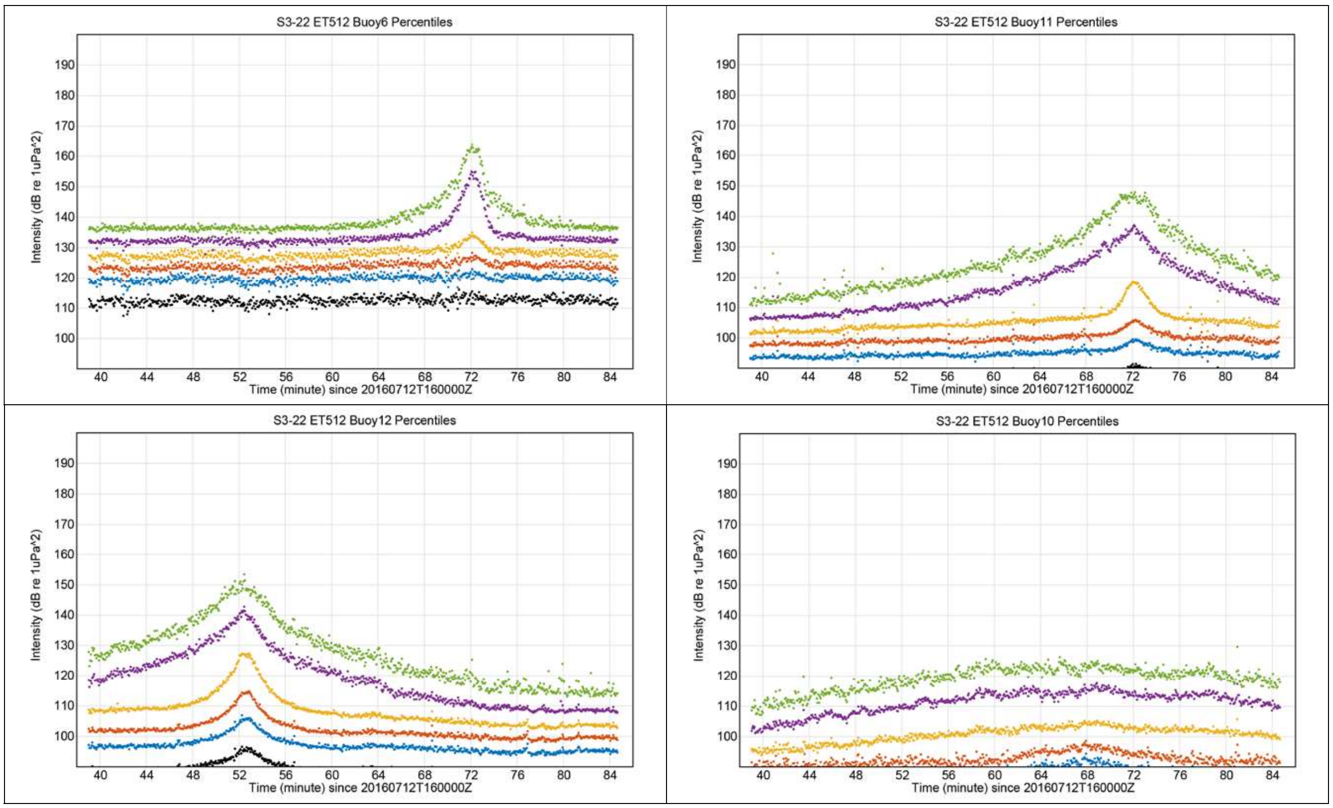


Figure 4.21.3-1. Percentile plots of Edgetech 512i signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

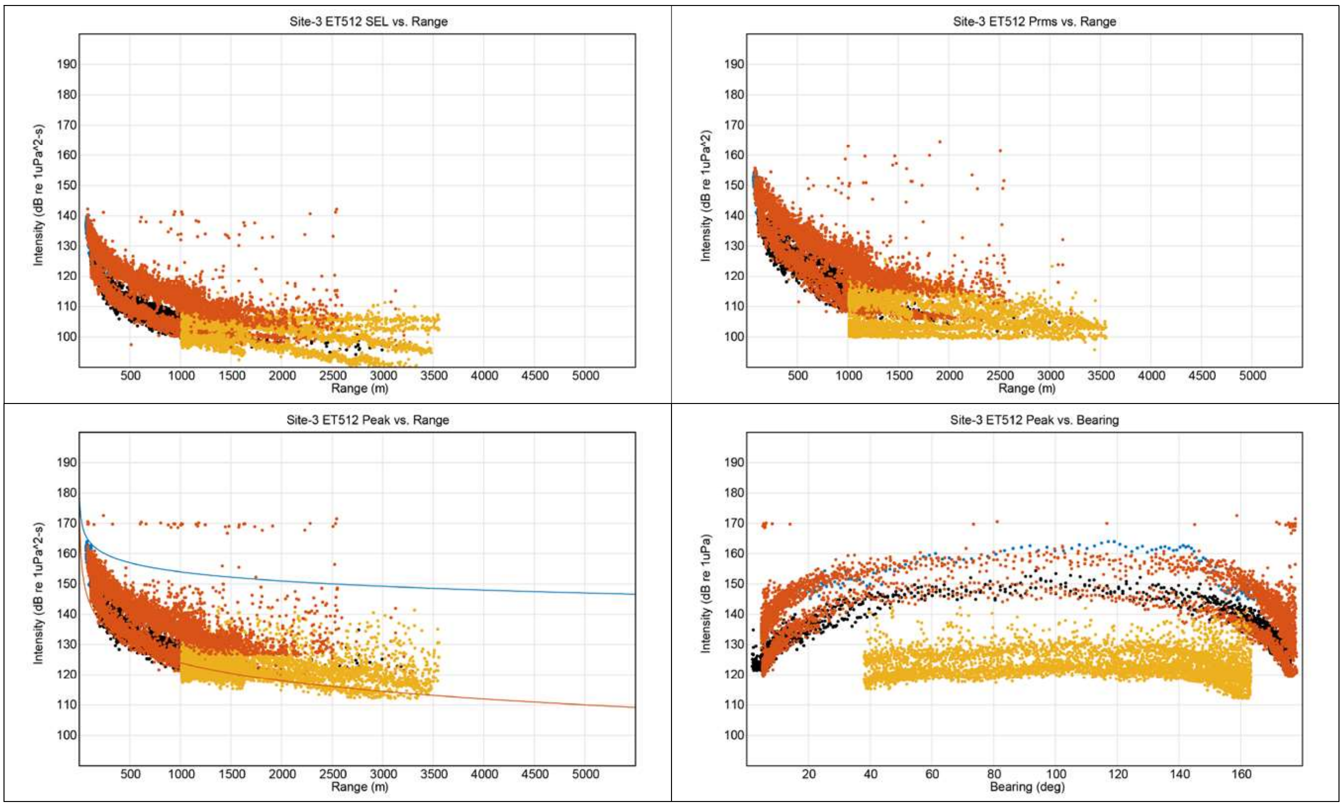


Figure 4.21.3-2. Range results for Edgetech 512i combined signals for Run2 and Run22 at Site 3 for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12, combined), A (Buoy12), and E (Buoy8 and Buoy10, combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.21.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,500 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), A (Buoy12), and B (Buoy5, Buoy11, and Buoy12, combined), and E (Buoy8 and Buoy10, combined). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen on the y-axis at approximately 0 m.

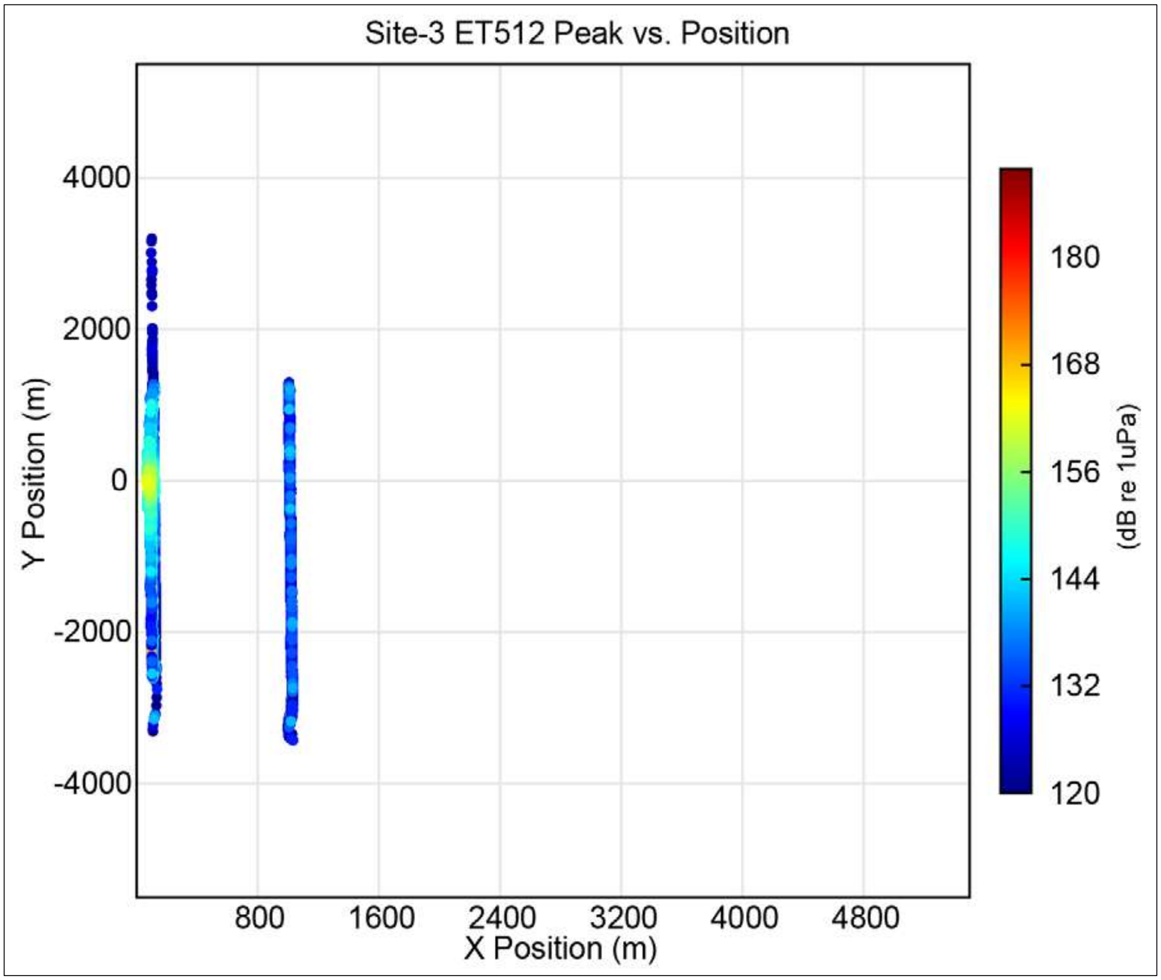


Figure 4.21.3-3. Plan view of received peak level for Edgetech 512i at Site 3, showing the results for positions D (Buoy6), B (Buoy5, Buoy11, and Buoy12), A (Buoy12), and E (Buoy8 and Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.21.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.21.3-1. ET512i source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 2	2-12 kHz	100%	NA	20 ms	184	176	160
NUWC	2-12 kHz	100%	NA	20 ms	184	179	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.21.4 Site 4 – Sand, 30 m Depth

At S4, the ET512i, Mode 2, had valid acoustic recordings in Run2. For Run2, positions B (Buoy7, HS, LS), C (Buoy5), E (Buoy9), and F (Buoy11) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 2, are shown in **Figure 4.21.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position C (Buoy5) for Run2, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at position B (Buoy7, HS, LS) and E (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good.

The results panels (**Figure 4.21.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S4, positions B (Buoy7, HS, LS), C (Buoy5), E (Buoy9), and F (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are two distinct groupings of peak pressure levels for all positions, which indicate unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for all buoys, are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

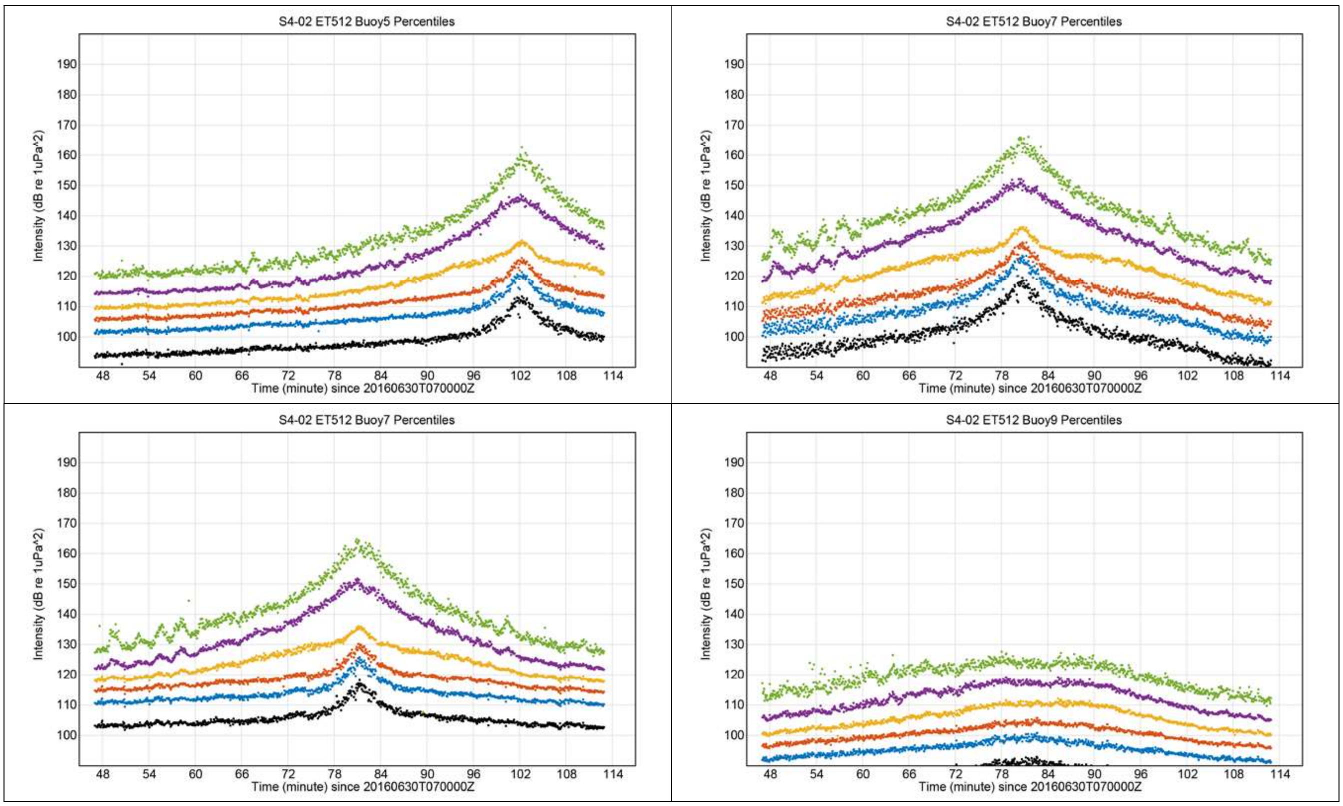


Figure 4.21.4-1. Percentile plots of Edgetech 512i signals at Site 4.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position C (Buoy5); Top right: SPL_{pk} arrival at position B (Buoy7, High Sensitivity); Bottom left: SPL_{pk} arrival at position B (Buoy7, Low Sensitivity); Bottom right: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

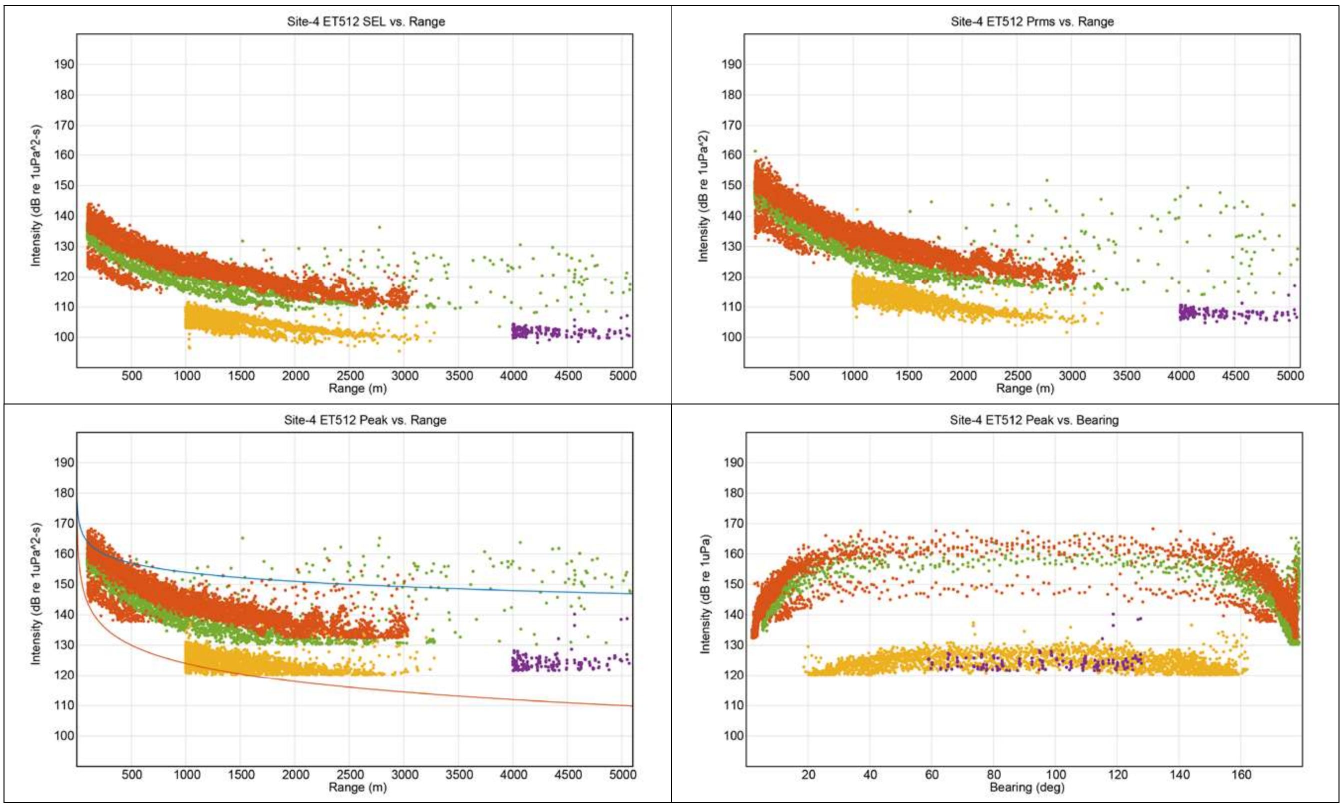


Figure 4.21.4-2. Range results for Edgetech 512i signals at Site 4 for positions B (Buoy7 HS, LS combined), C (Buoy5), E (Buoy9), and F (Buoy11).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; C = green; E = yellow; F = purple.

The plan view is shown in **Figure 4.21.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,500 to 3,500-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -5,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy7, HS, LS), C (Buoy5), E (Buoy9), and F (Buoy11). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position B and C is seen on the y-axis at approximately 0 m.

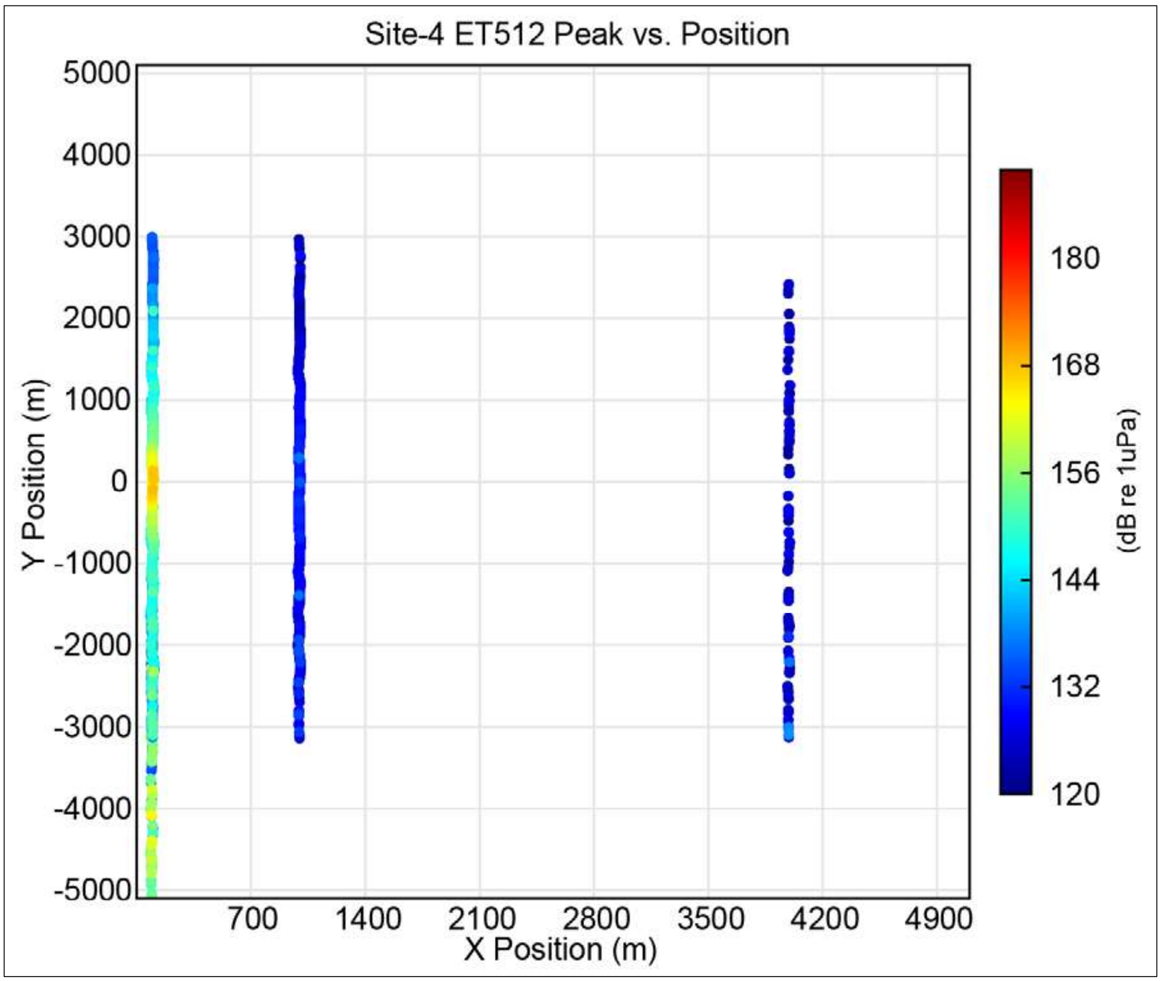


Figure 4.21.4-3. Plan view of received peak level for Edgetech 512i at Site 4, showing the results for positions B (Buoy7 HS, LS), C (Buoy5), E (Buoy9), and F (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.21.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.21.4-1. ET512i source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 2	2-12 kHz	100%	NA	20 ms	188	175	159
NUWC	2-12 kHz	100%	NA	20 ms	184	179	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.21.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the ET512i, Mode 2, had acoustic recordings in Run4 and Run20. For Run4, positions D (Buoy6) and E (Buoy8 and Buoy9) had valid acoustic recordings. For Run20, valid acoustic recordings were observed, but no acoustic signals were captured.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 2, are shown in **Figure 4.21.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run4. The top right and bottom panels show the valid recorded acoustics at position E (Buoy8 and Buoy9. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid. However, it is not clear if any of the positions captured the signals of this weak (184 dB re 1µPa) source. Therefore, due to the lack of observable signals, the data were not processed further for Mode 2 at S5.

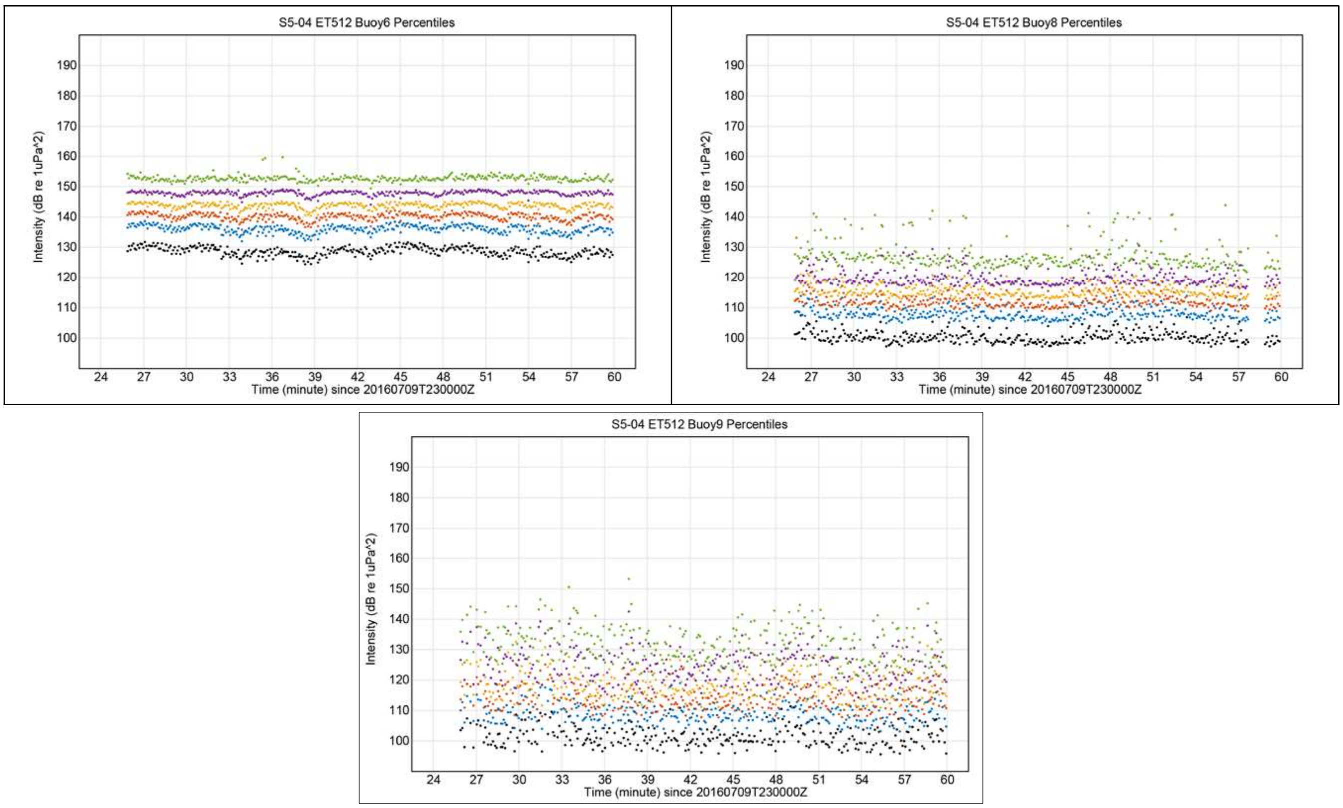


Figure 4.21.5-1. Percentile plots of Edgetech 512i signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy8); Bottom: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

4.22 Edgetech 512i, 0.5-8 kHz, 100 Percent Power, 5-ms Pulse (Mode 3)

The ET512i subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 6 kHz. The operational parameter settings for Mode 3 were a 100 percent power, 5-ms pulse, 0.5-8 kHz output frequency, with a 512i topside processor. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.22-1** is the selected frequency band (1 to 9 kHz) and SPL_{pk} (162 dB re 1 µPa) that were applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.22-1. Bandpass determination for the ET512i subbottom profiler, 0.5-8 kHz, 100 percent power, 5-ms pulse, at Site 2, Run3.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
1-200	162.58
1-100	162.31
1-25	162.02
1-15	161.88
1-9	**161.90**

dB re 1 µPa = decibels relative to one micropascal; ET = Edgetech; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The ET512i, Mode 3, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.22-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Knudsen 3260 was operationally paired in alternation with the ET512i. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.22-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources

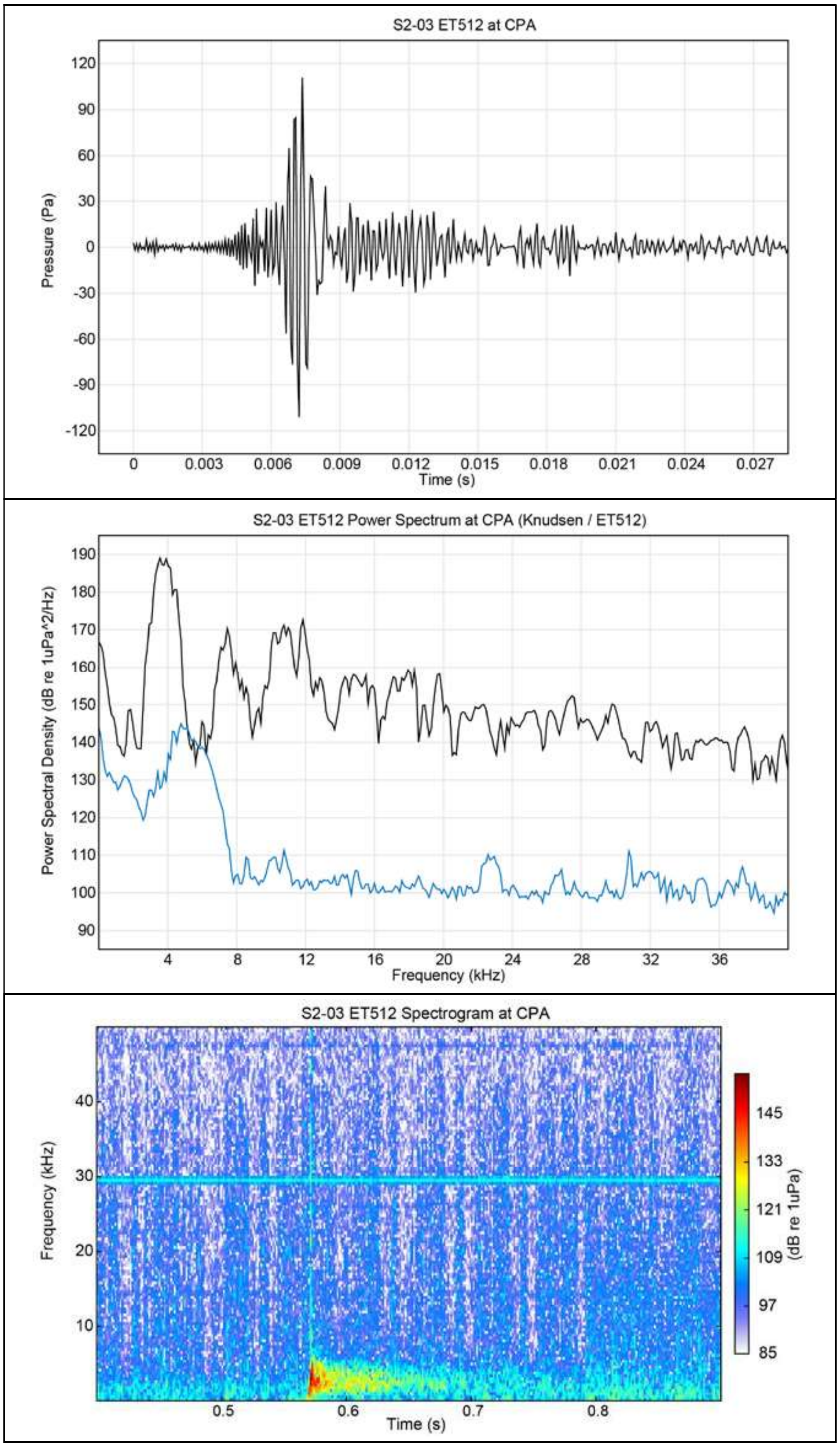


Figure 4.22-1. Edgetech 512i measured signal characteristics at closest point of approach (CPA) at Site 2, Run3.
Top: Time-waveform of a signal; Middle: Power spectral density, Knudsen 3260 = black, ET512i = blue; Bottom: Spectrogram.

4.22.1 Site 1 – Mud, 10 m Depth

The ET512i, Mode 3, was not deployed or operated at S1.

4.22.2 Site 2 – Sand, 10 m Depth

At S2, the ET512i, Mode 3, had valid acoustic recordings in Run3 and Run23. For Run3, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings. For Run23, no positions captured signals.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 3, are shown in **Figure 4.22.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run3, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The right panel shows the valid recorded acoustics at position B (Buoy11). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.22.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S2, positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 10 to approximately 1,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.22.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D (Buoy6), at approximately 150°, which indicates an error in buoy positioning and for position B (Buoy11) at approximately 80°. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

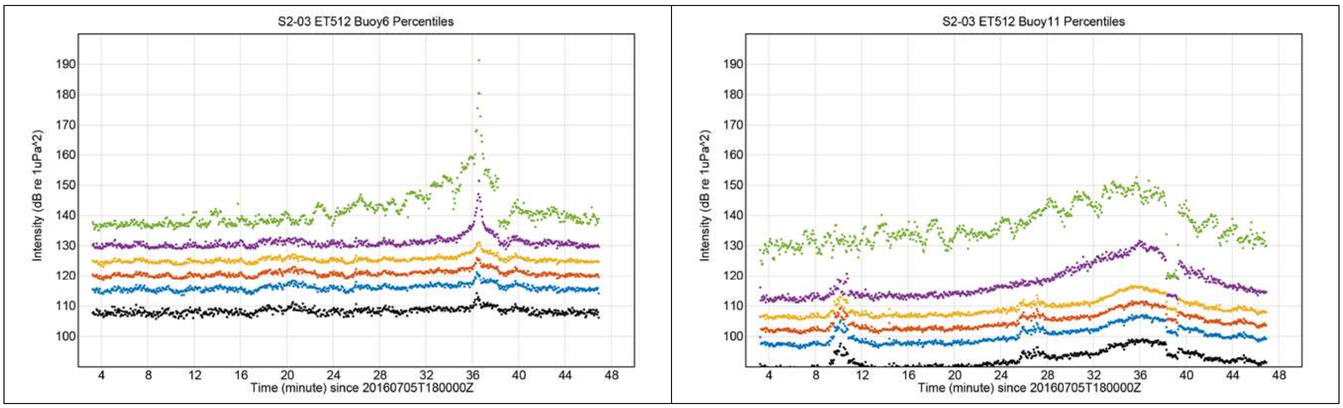


Figure 4.22.2-1. Percentile plots of Edgetech 512i signals at Site 2.
Left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Right: SPL_{pk} arrival at position B (Buoy11).
Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

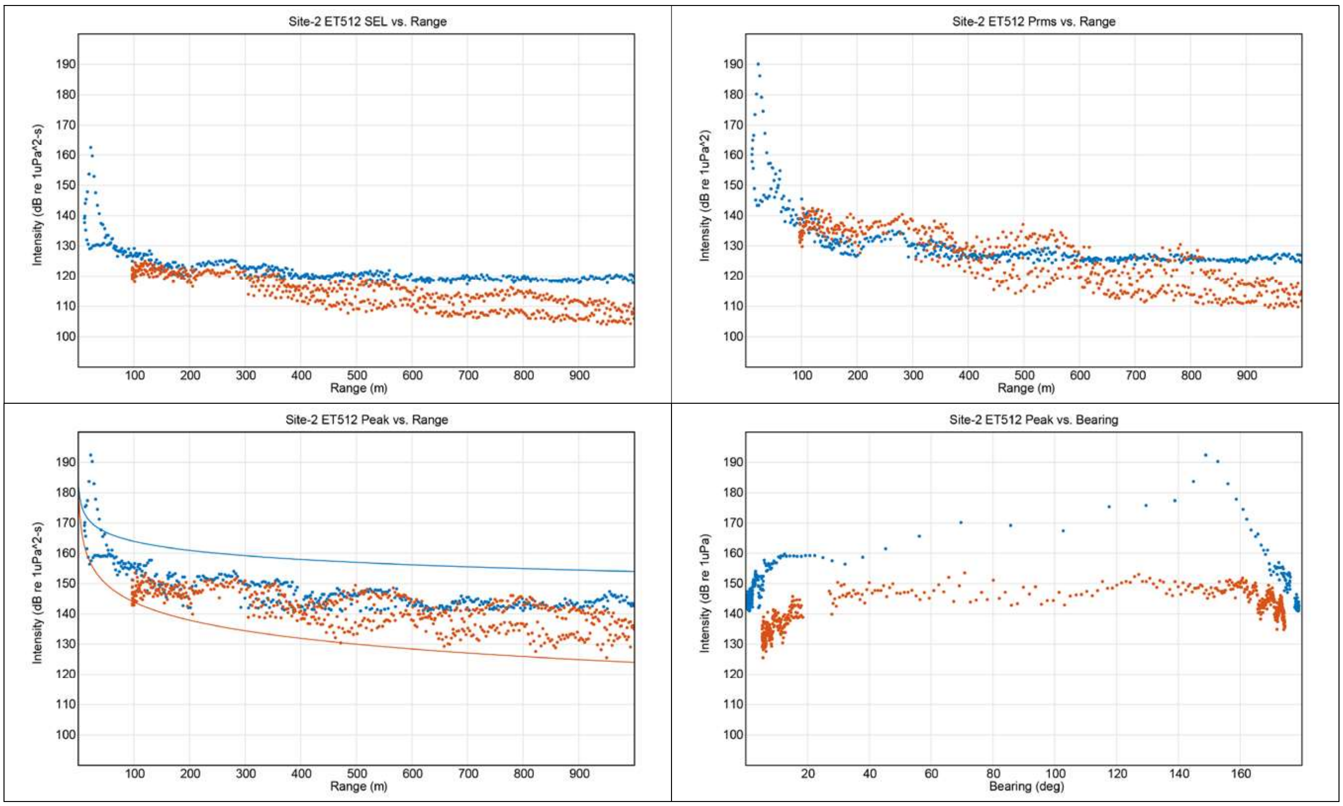


Figure 4.22.2-2. Range results for Edgetech 512i signals at Site 2 for positions D (Buoy6) and B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.22.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 20,-45 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

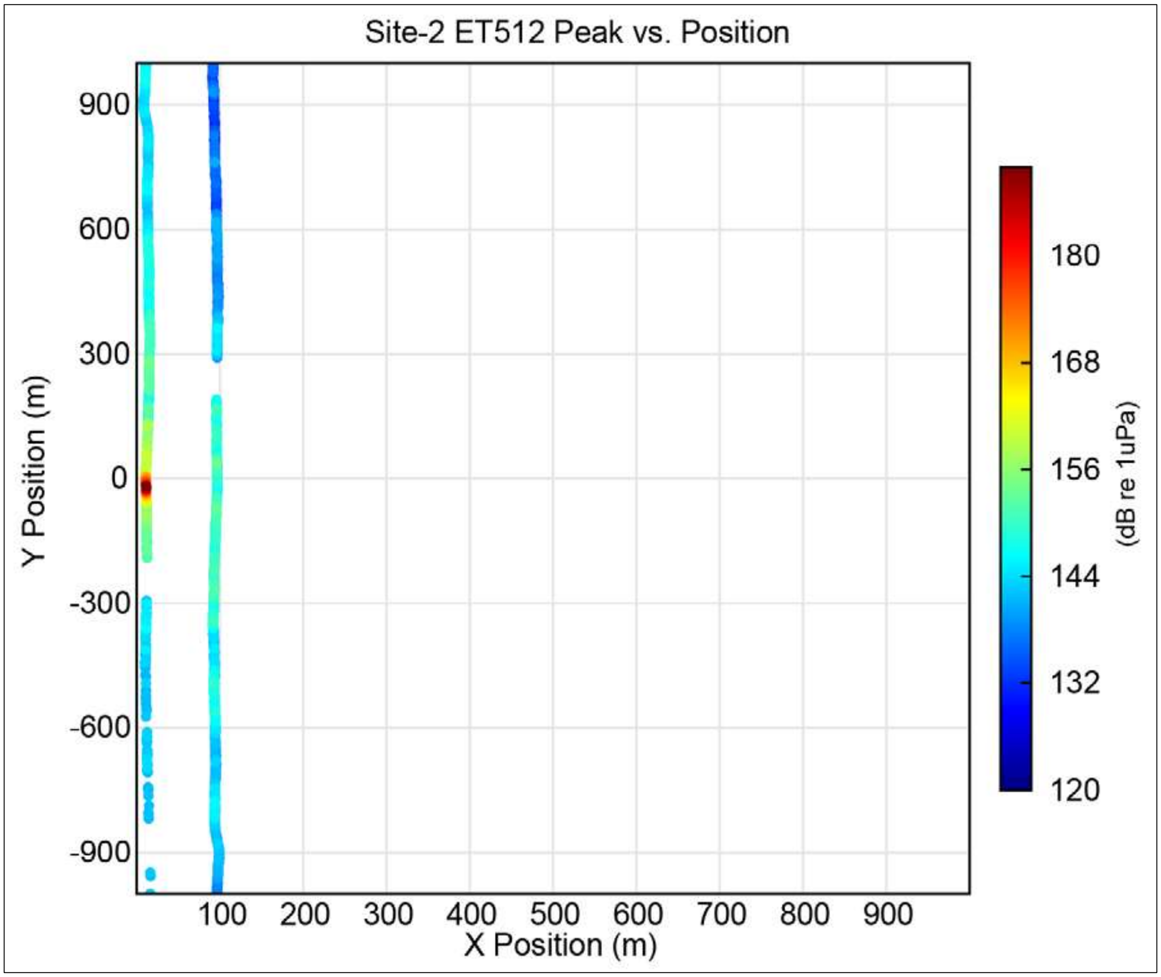


Figure 4.22.2-3. Plan view of received peak level for Edgetech 512i at Site 2, showing the results for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.22.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results. At position D the received levels were higher than expected and are likely an indication of a 10-dB calibration errors (**Section 2.6.3.1**), therefore, the peak received levels at position B were used to estimate the source levels.

Table 4.22.2-1. ET512i, source levels, Mode 3, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 3	0.5-8 kHz	100%	NA	5 ms	178	165	149
NUWC	0.5-8 kHz	100%	NA	5 ms	184	177	150

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.22.3 Site 3 – Mud, 30 m Depth

At S3, the ET512i, Mode 3, had valid acoustic recordings in Run3 and Run22. For Run3, position B (Buoy5 and Buoy12) had valid acoustic data. For Run22, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 3, are shown in **Figure 4.22.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run22, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good.

The results panels (**Figure 4.22.3-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the ET512i at S3, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions that are positionally indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

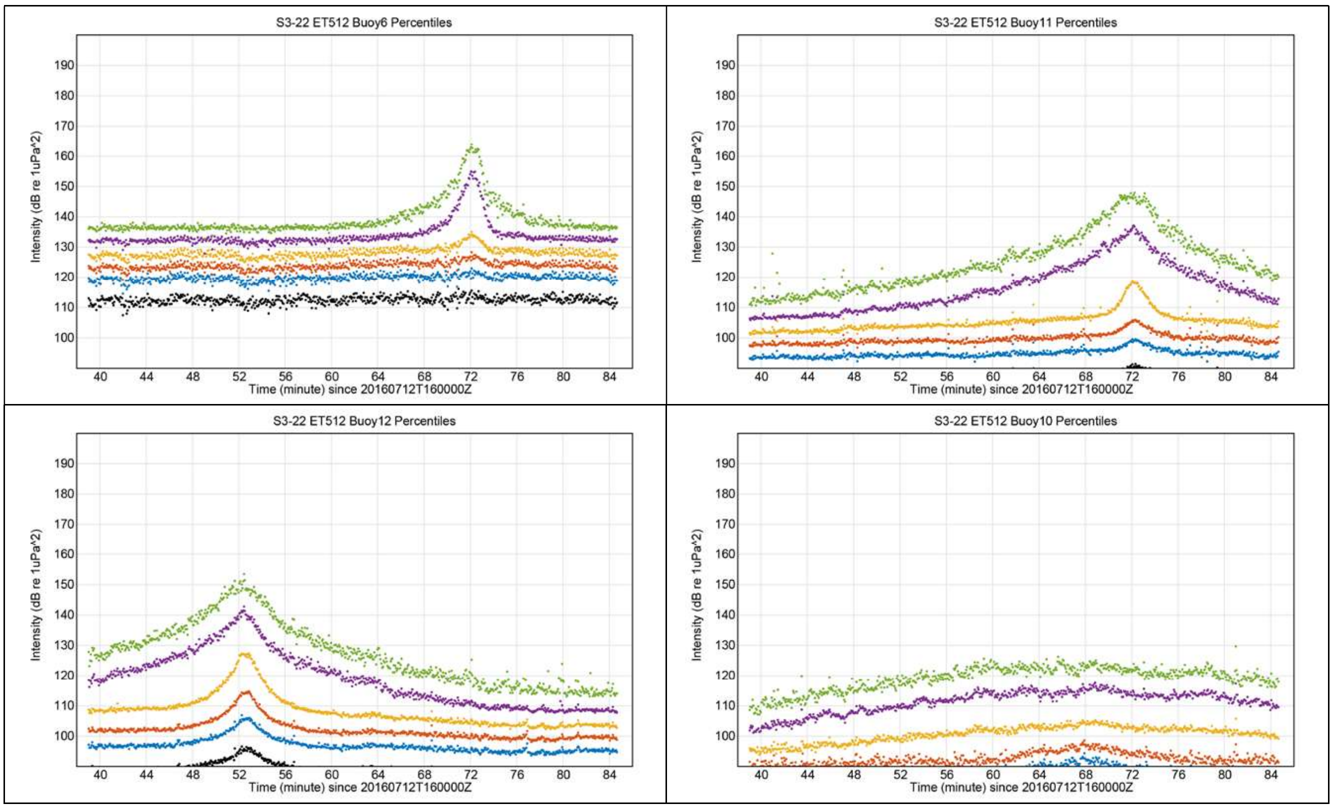


Figure 4.22.3-1. Percentile plots of Edgetech 512i signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

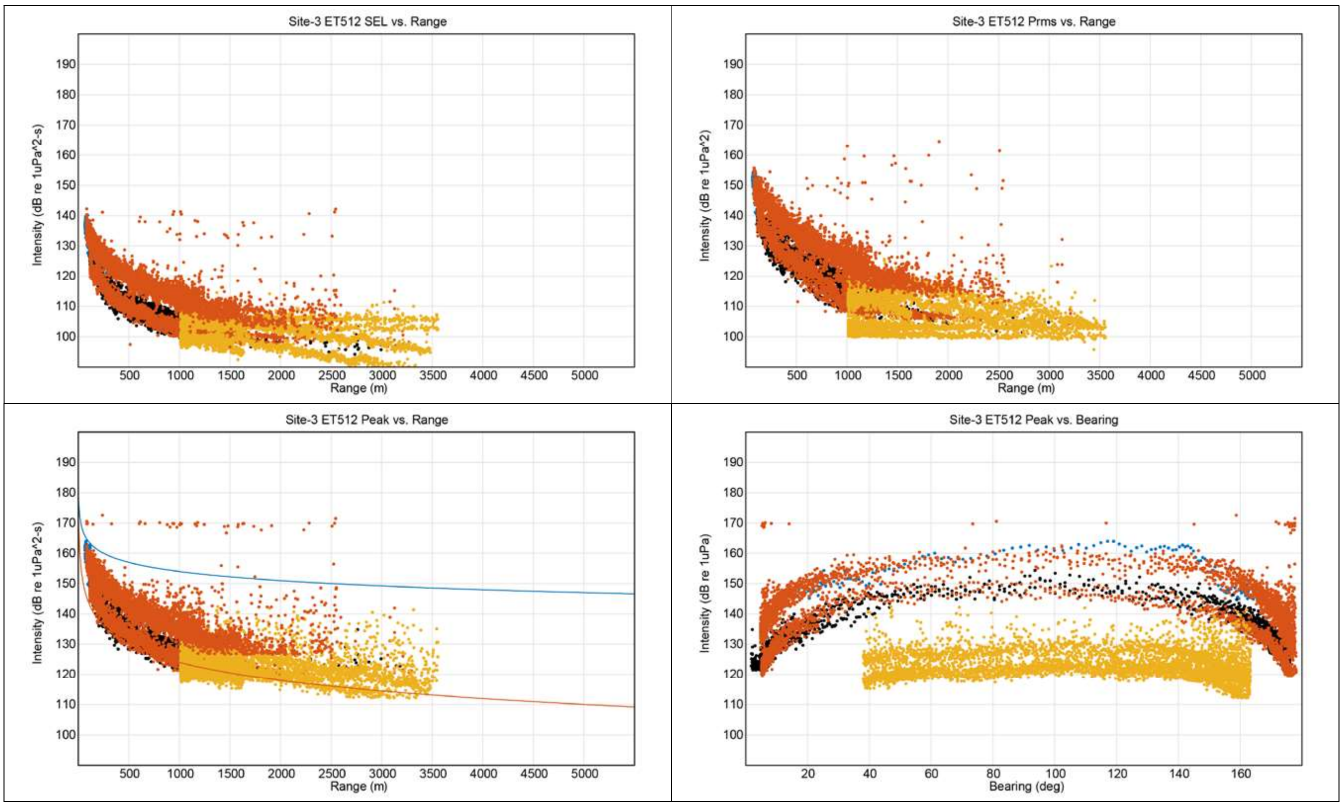


Figure 4.22.3-2. Range results for Edgetech 512i combined signals for Run22 at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.22.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen on the y-axis at approximately 0 m.

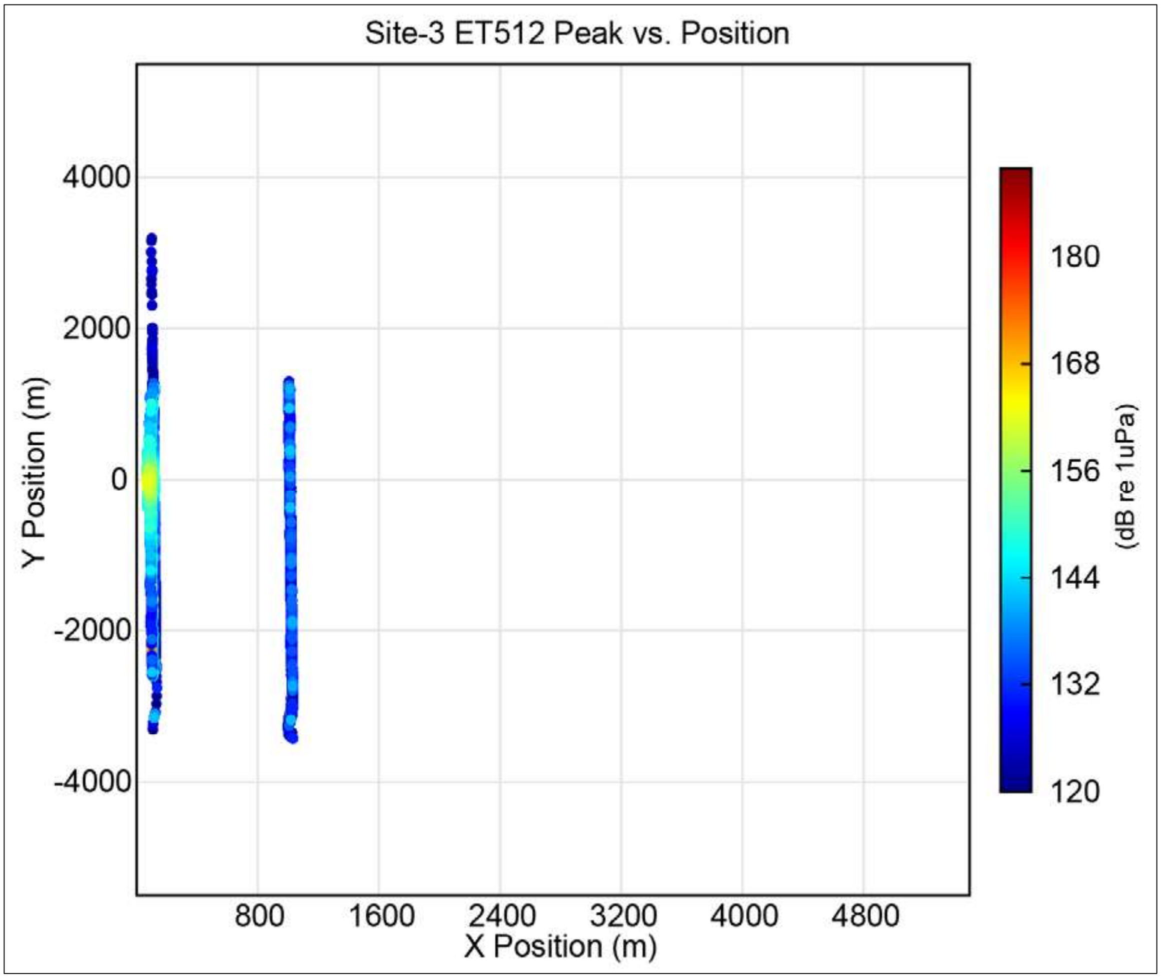


Figure 4.22.3-3. Plan view of received peak level for Edgetech 512i at Site 3, showing the results for positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.22.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.22.3-1. ET512i, source levels, Mode 3, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET512i Mode 3	0.5-8 kHz	100%	NA	5 ms	183	174	159
NUWC	0.5-8 kHz	100%	NA	5 ms	184	177	150

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.22.4 Site 4 – Sand, 30 m Depth

At S4, the ET512i, Mode 3, had valid acoustic recordings in Run3. For Run3, position B (Buoy7 HS, LS), C (Buoy5), E (Buoy9), and F (Buoy11) had valid acoustic data. Position F (Buoy11) did not capture any acoustic signals.

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 3, are shown in **Figure 4.22.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy7 HS) for Run3, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions B (Buoy7 LS), C (Buoy5), and E (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are good.

The results panels (**Figure 4.22.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S4, positions B (Buoy7 HS, LS, combined), C (Buoy5), and E (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,200 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels near 90°, indicating relatively good navigational buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For an omnidirectional source, the center (maximum peak signal) should be at 90°.

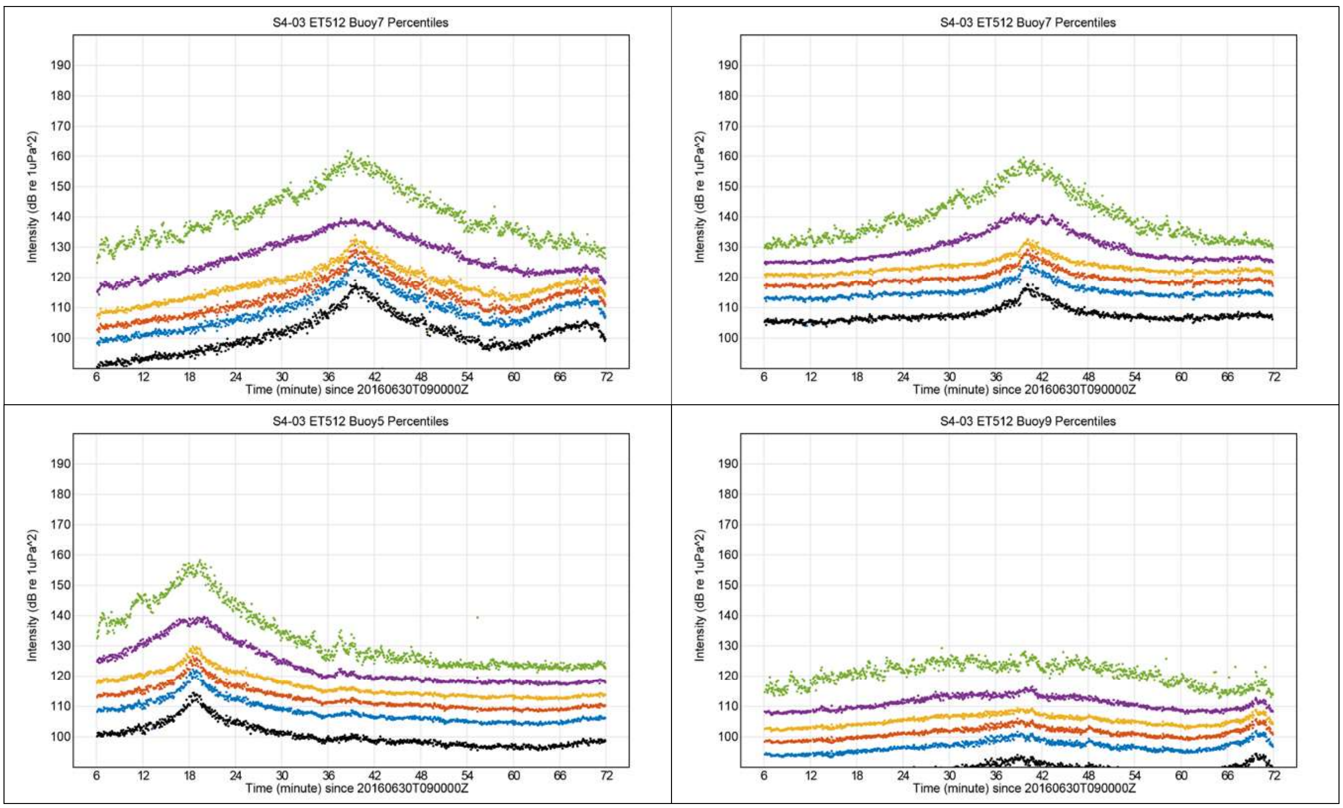


Figure 4.22.4-1. Percentile plots of Edgetech 512i signals at Site 4.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy7, High Sensitivity); Top right: SPL_{pk} arrival at position B (Buoy7, Low Sensitivity); Bottom left: SPL_{pk} arrival at position C (Buoy5); Bottom right: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

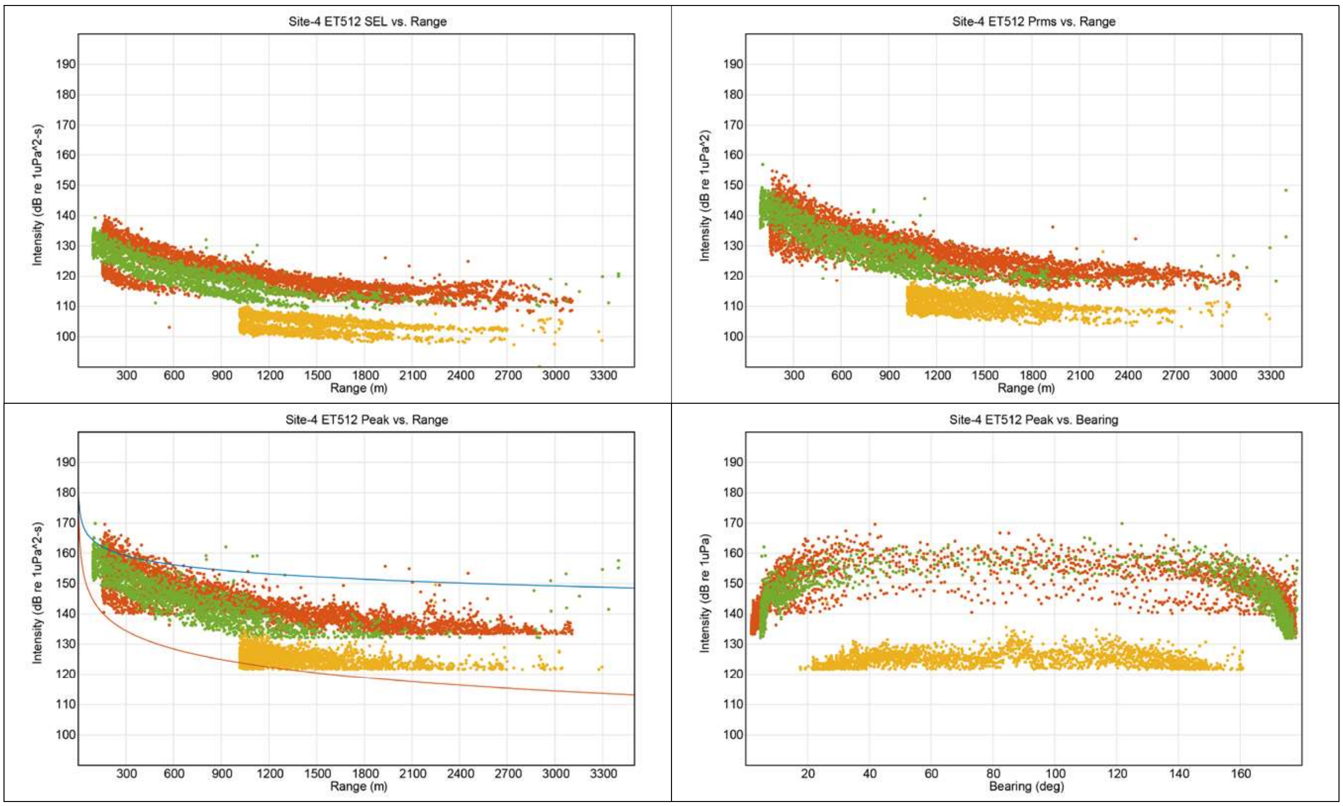


Figure 4.22.4-2. Range results for Edgetech 512i signals at Site 4 for positions B (Buoy7 HS, LS combined), C (Buoy5), E (Buoy9). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; C = green; E = yellow.

The plan view is shown in **Figure 4.22.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,500 to 3,500-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy7 HS, LS), C (Buoy5), and E (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

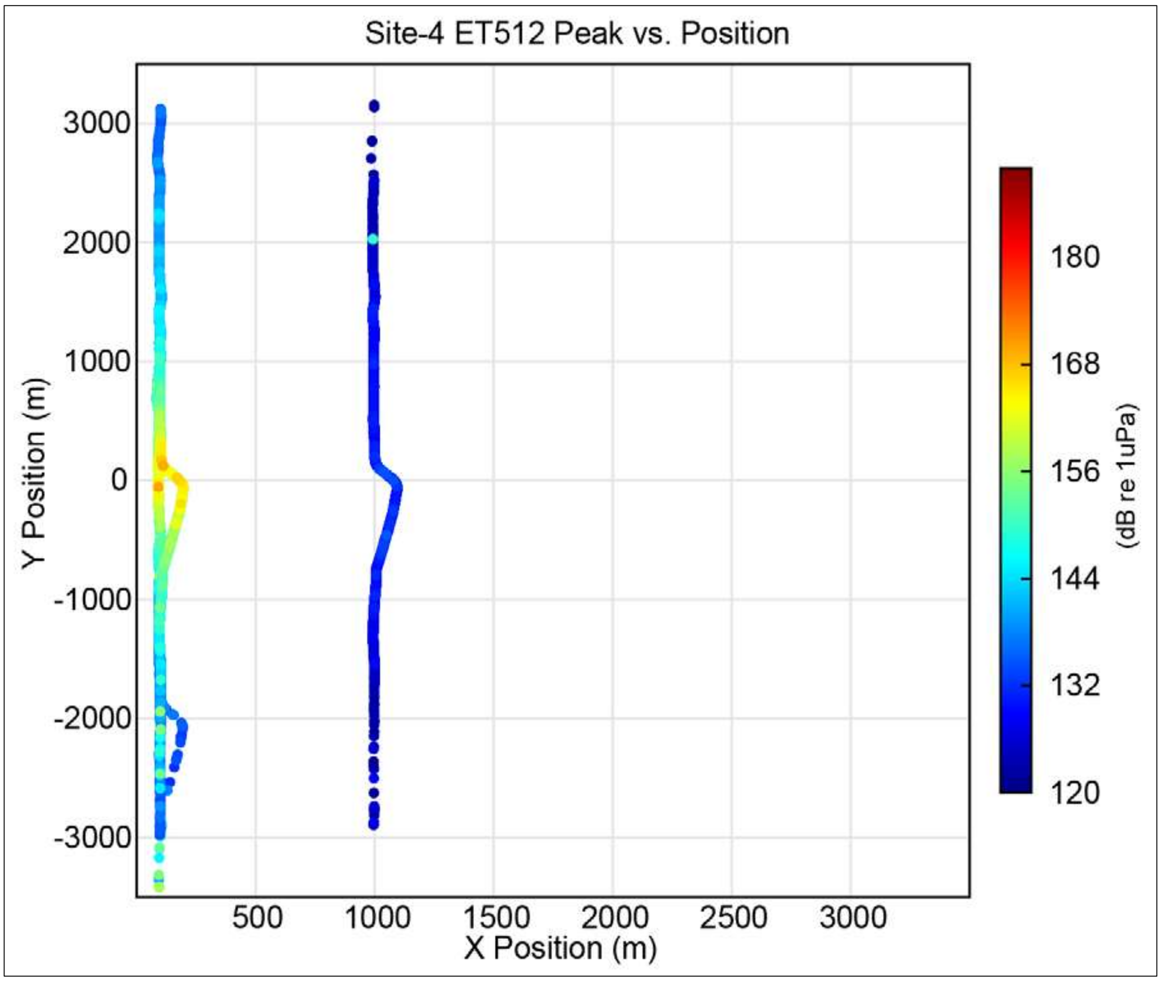


Figure 4.22.4-3. Plan view of received peak level for Edgetech 512i at Site 4, showing the results for positions B (Buoy7 HS, LS), C (Buoy5), E (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.22.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss, [20 $\log_{10}$ (*range*)], for comparison with the NUWC results.

Table 4.22.4-1. ET512i, source levels, Mode 3, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Cycles, Pulse Width	Pk	rms	SEL
ET512i Mode 3	0.5-8 kHz	100%	NA	5 ms	190	175	162
NUWC	0.5-8 kHz	100%	NA	5 ms	184	177	150

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.22.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the ET512i, Mode 3, had valid acoustic recordings in Run5 and Run21. For Run5, position E (Buoy8) had valid acoustic recordings and observed signals. For Run21, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy9), and F (Buoy10).

Run Summary

The percentile plots for the available recordings of the ET512i, Mode 3, are shown in **Figure 4.22.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run21, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position B (Buoy11), A (Buoy12), and E (Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows that the acoustic data are valid.

The results panels (**Figure 4.22.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the ET512i at S5, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 184 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). At position E, there are several distinct groupings of peak pressure levels, which indicate unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot show that all positions have a wide peak near broadside, which is expected with good buoy GPS positioning and an omnidirectional source.

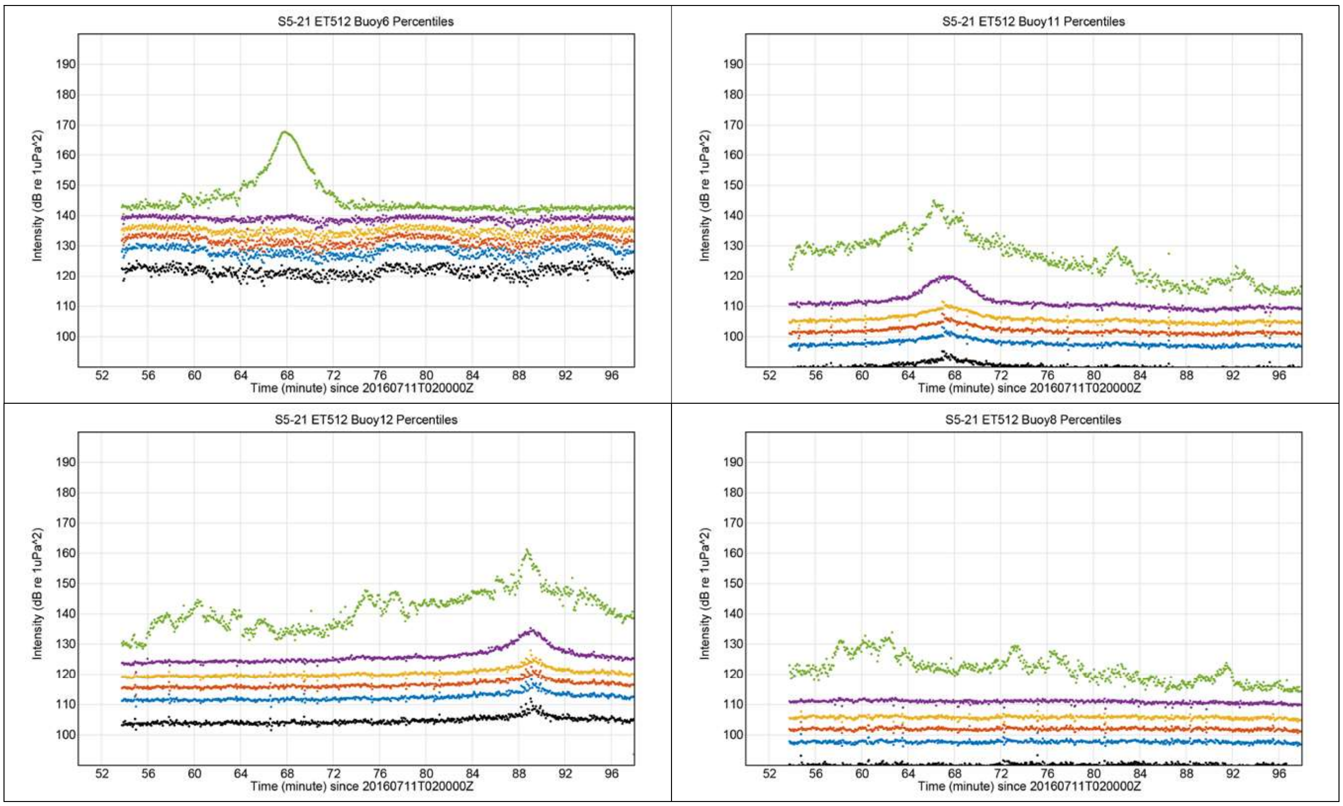


Figure 4.22.5-1. Percentile plots of Edgetech 512i signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

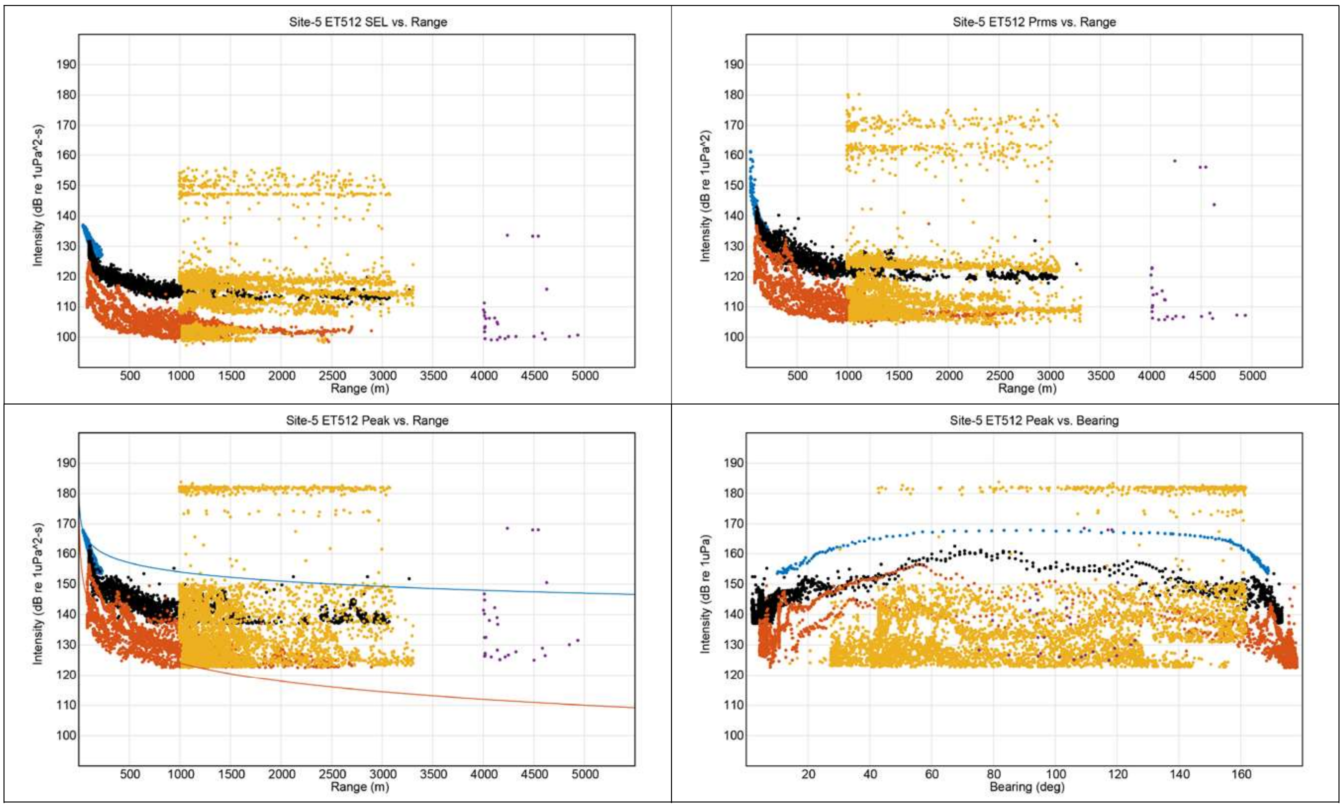


Figure 4.22.5-2. Range results for Edgetech 512i signals at Site 5 from Run5 and Run21 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.22.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 40,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA y) was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen on the y-axis at approximately 0 m.

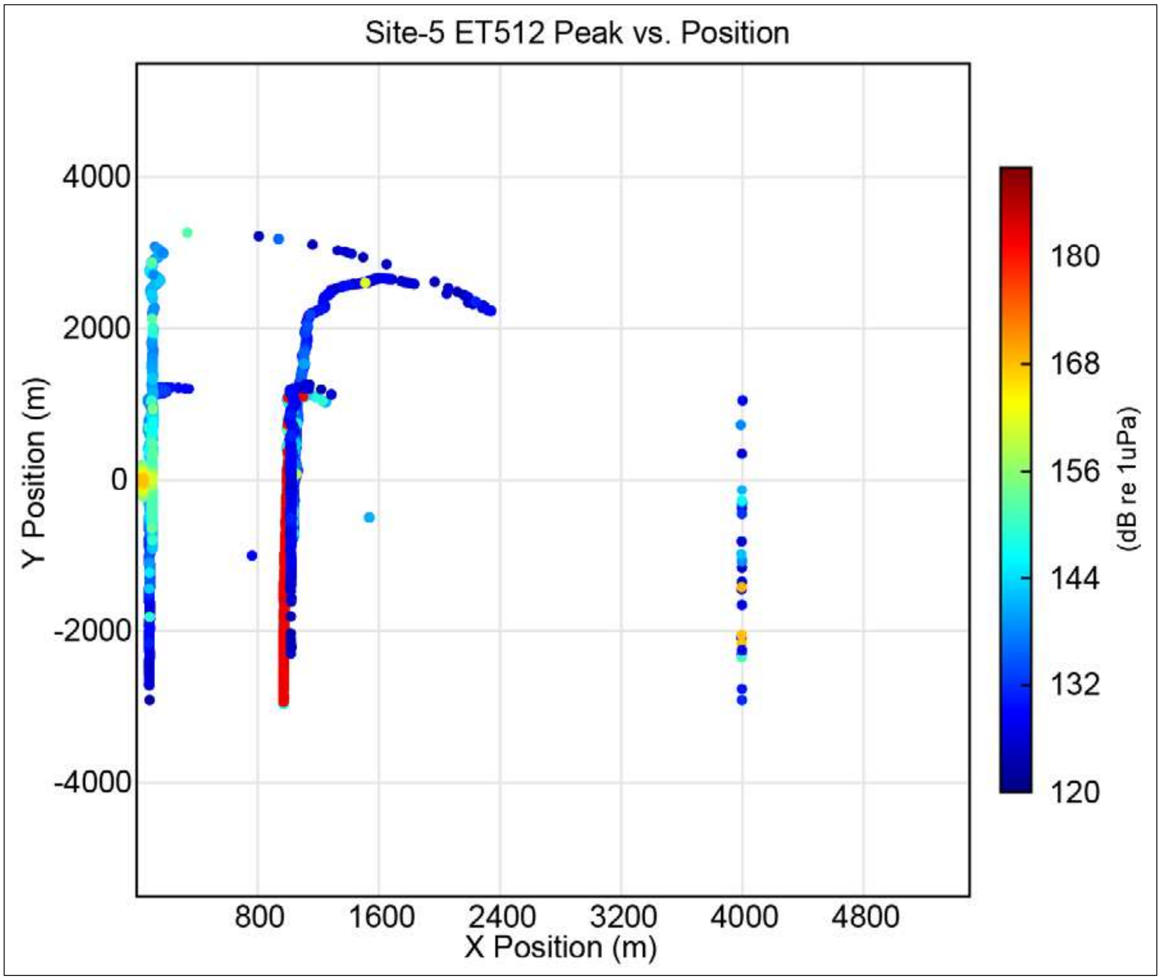


Figure 4.22.5-3. Plan view of received peak level for Edgetech 512i at Site 5, showing the results for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.22.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss, [10 $\log_{10}$ (*range*)], for comparison with the NUWC results. However, the unresolved calibration issues make these results questionable. The fall off beyond 500 m follows cylindrical spreading law, while at ranges less than 500 m the spreading law is unclear.

Table 4.22.5-1. ET512i, source levels, Mode 3, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
ET512i Mode 3	0.5-8 kHz	100%	NA	5 ms	184	168	152
NUWC	0.5-8 kHz	100%	NA	5 ms	184	177	150

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.23 Knudsen 3260, 3.3-5.6 kHz, Power Level-1, 8-ms Pulse, (Mode 1)

The Knudsen 3260 subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 4 kHz. The operational parameter settings for Mode 1 were a power level of 1, an 8-ms pulse, and a 3.3-5.6 kHz output frequency via a 2×2 array (i.e., four transducers). A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The Knudsen 3260 signal had harmonics (3rd and 5th), but they do not add appreciably to the peak level thus were not included in the processing band. The bolded row in **Table 4.23-1** is the selected frequency band (0 to 14 kHz) and SPL_{pk} (195 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.23-1. Bandpass determination for the Knudsen 3260 subbottom profiler, 3.3-5.6 kHz, power level 1, 8-ms Pulse at Site 2, Run1.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0	195.11
0-50	195.12
0-25	195.076
0-14	**195.08**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Knudsen 3260, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.23-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Knudsen 3260 was operationally paired in alternation with the ET512i. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.23-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources. The signal time series, as measured at S2, shows a bottom return arriving at 21 ms.

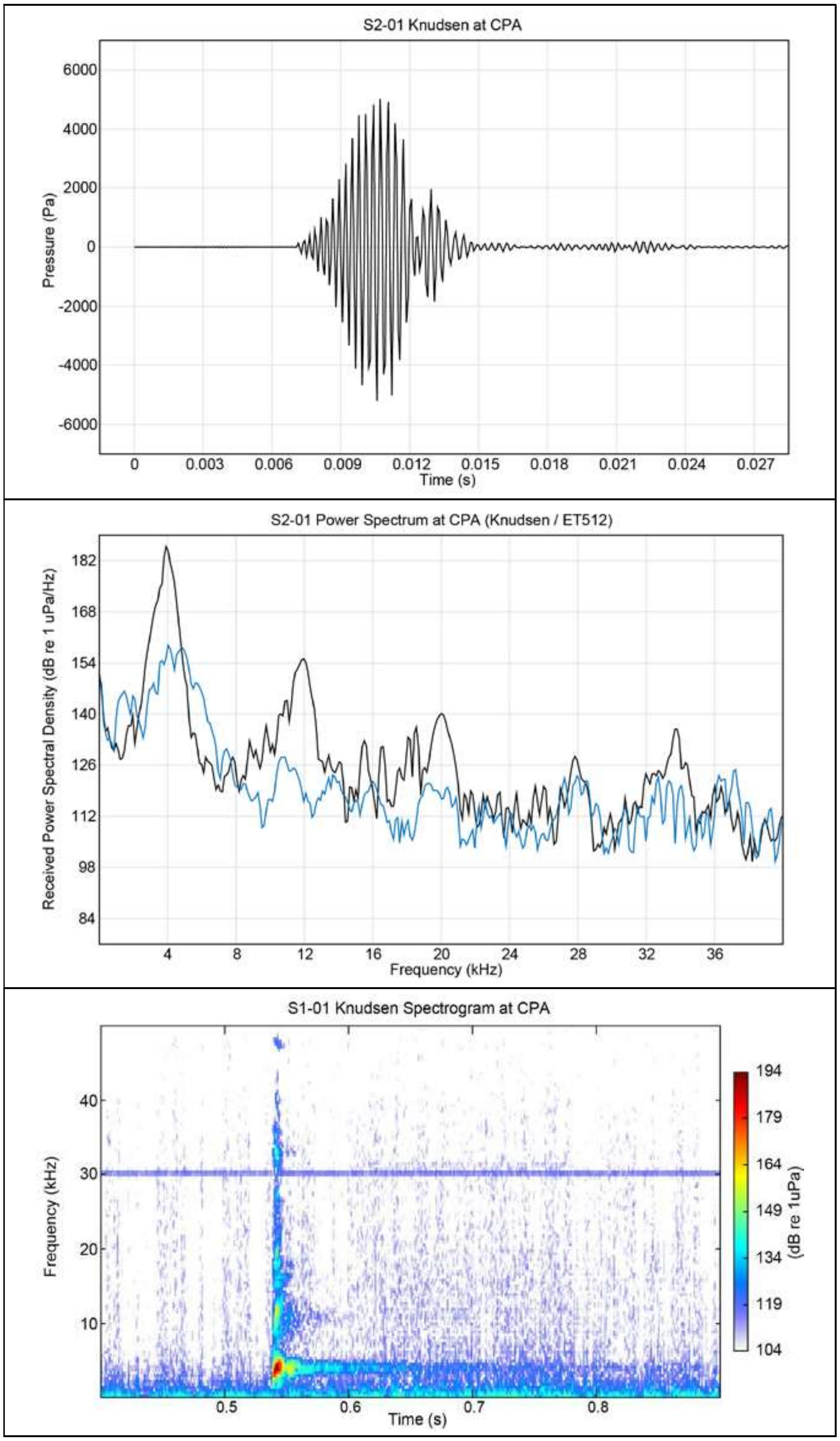


Figure 4.23-1. Knudsen 3260 measured signal characteristics at closest point of approach (CPA) at Site 2, Run1.

Top: Time-waveform of a signal; Middle: Power spectral density, Knudsen 3260 = black, ET512i = blue; Bottom: Spectrogram.

4.23.1 Site 1 – Mud, 10 m Depth

At S1, the Knudsen 3260, Mode 1, had valid acoustic recordings in Run1 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the Knudsen 3260, Mode 1, are shown in **Figure 4.23.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run1, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). The reception at position F (Buoy9) could be signal. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.23.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the Knudsen 3260 at S1, positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 log10 (*range*)]. The reference curves predict received levels for a 210 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 207 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). The resonance pattern in Buoy D (**Figure 4.23.1-2** top right panel) is an indication of the beam-pattern of the 2×2 Knudsen 3260 source array. The signals at position E were a lower amplitude as compared to those at positions D and F, which indicates a calibration issue (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.23.1-2**), which shows the received peak level for position D at 110°; for position E at an indeterminate position; and for position F at approximately 80°, indicating errors in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

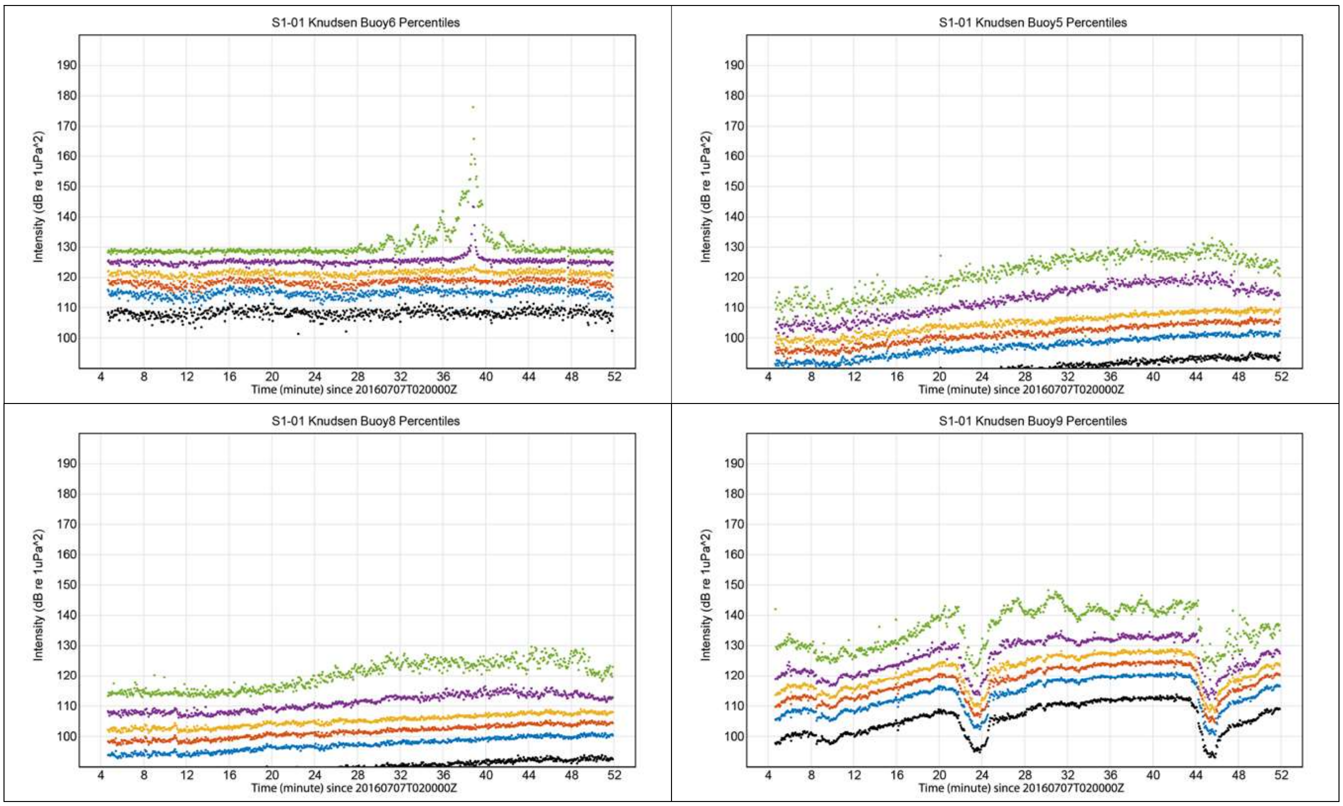


Figure 4.23.1-1. Percentile plots of Knudsen 3260 signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

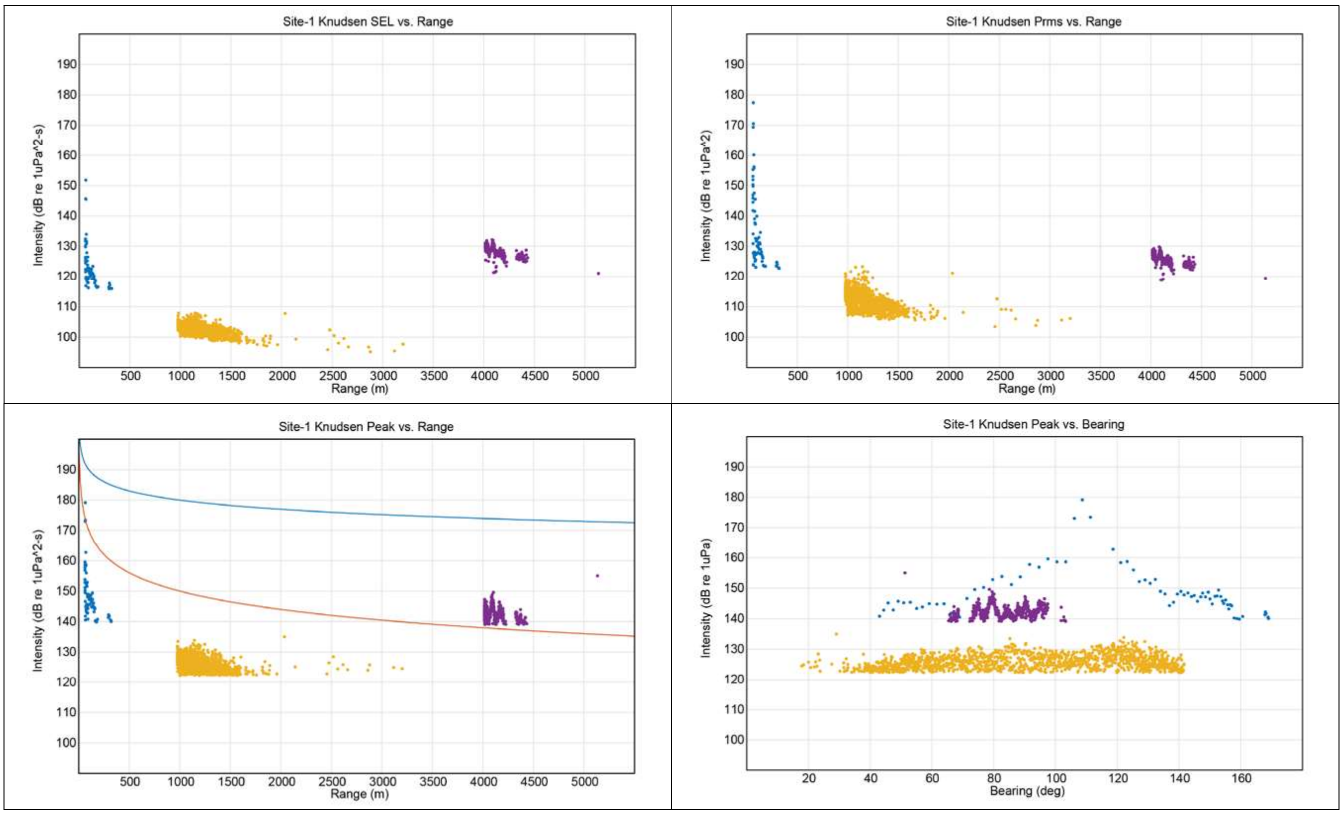


Figure 4.23.1-2. Range results for Knudsen 3260 signals for Run1 at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy8, combined), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.23.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

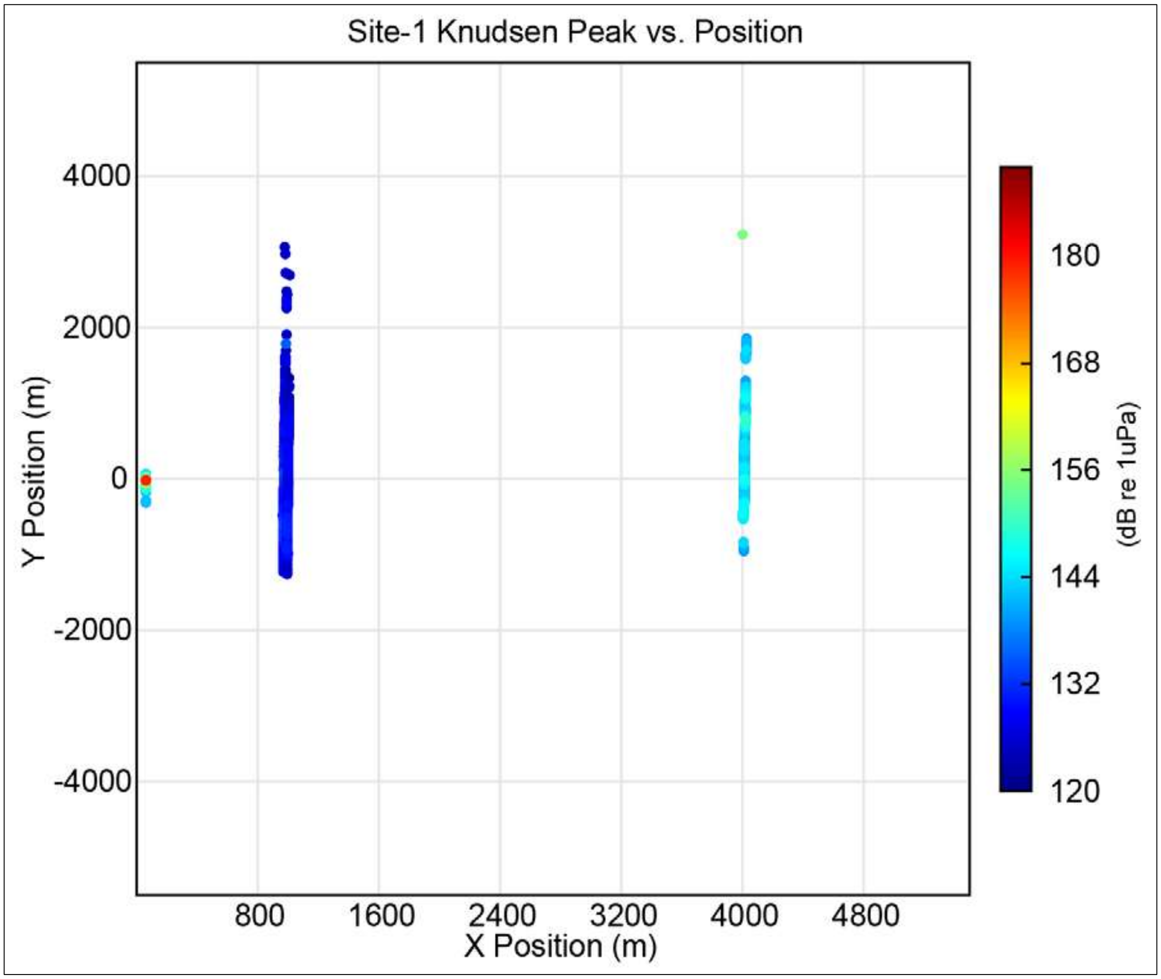


Figure 4.23.1-3. Plan view of received peak level for Knudsen 3260 at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.23.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.23.1-1. Knudsen 3260 source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 1	NA	Level 1	NA	8 ms	204	202	176
NUWC Proxy: Knudsen 3202	NA	Level 1	NA	8 ms	210*	205*	181*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.23.2 Site 2 – Sand, 10 m Depth

At S2, the Knudsen 3260, Mode 1, had valid acoustic recordings in Run1 and Run29. For Run1, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings. For Run29, positions B (Buoy11) and E (Buoy10) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 1, are shown in **Figure 4.23.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run1, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11) and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.23.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 30 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S2, positions D (Buoy6) and B (Buoy11 and Buoy11, combined), and E (Buoy10) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 210 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 207 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.23.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 170°, indicating a large error in buoy positioning. The received peak level for position B is indeterminate, and for position E, it is at approximately 50°, which indicates a large error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

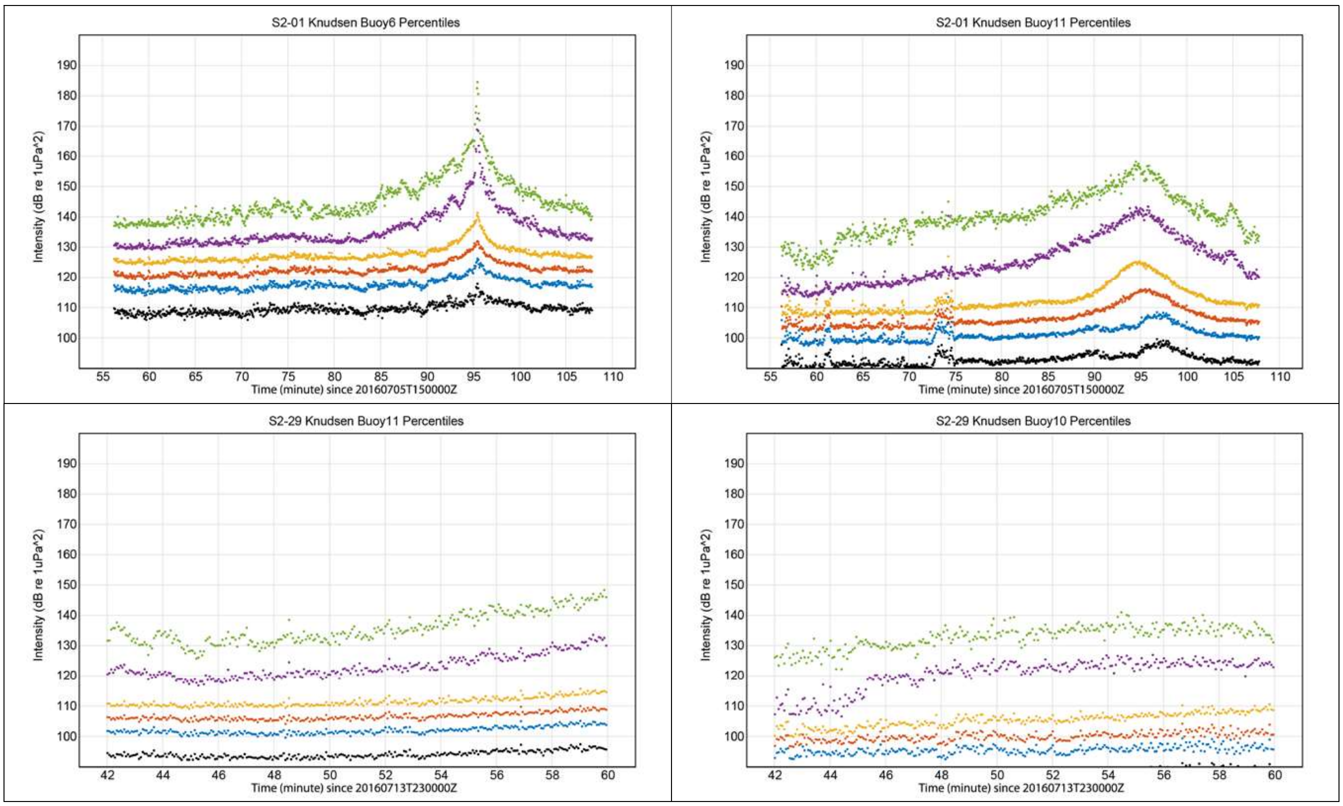


Figure 4.23.2-1. Percentile plots of Knudsen 3260 signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

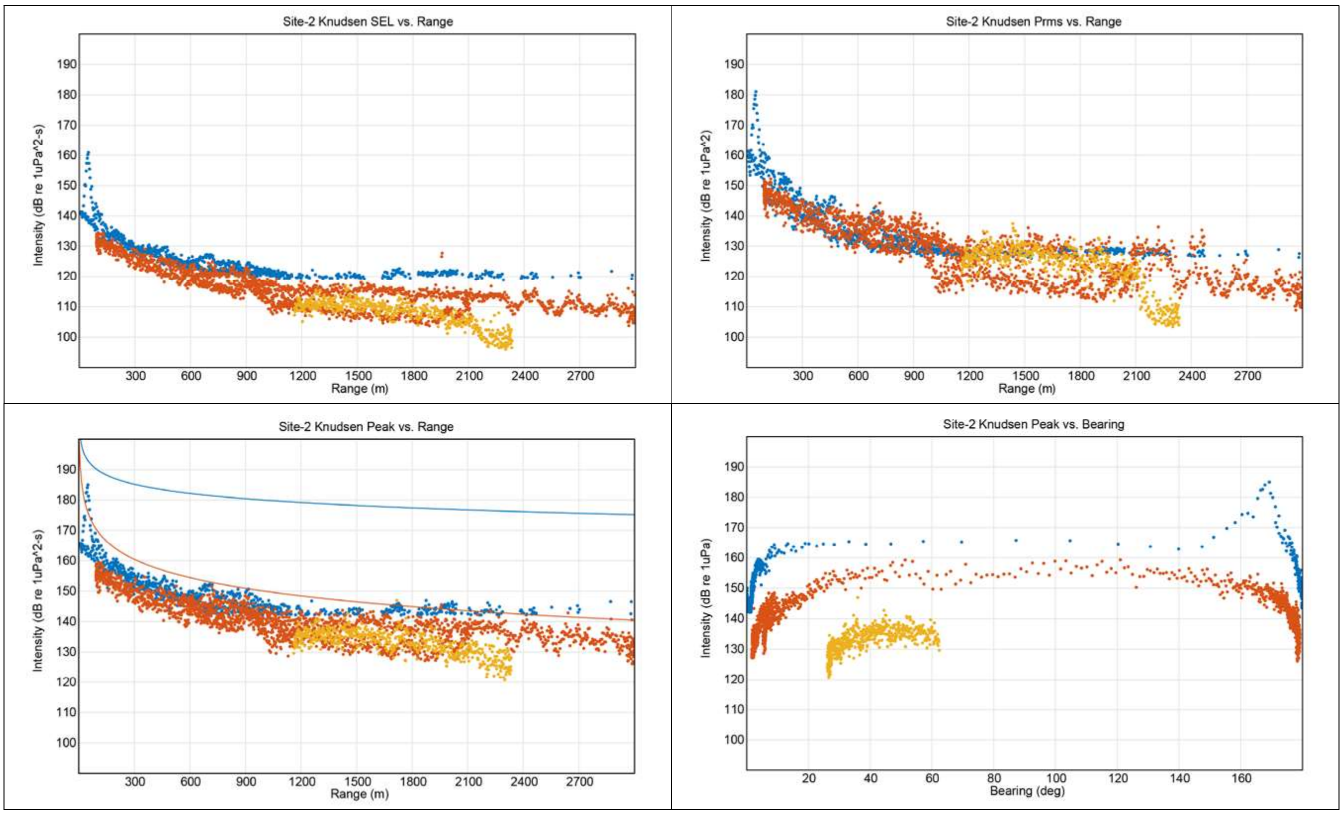


Figure 4.23.2-2. Range results for Knudsen 3260 signals for Run1 and Run29 at Site 2 for positions D (Buoy6), B (Buoy11 and Buoy11, combined), and E (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.23.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 30,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -800 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 combined), and E (Buoy10). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -30 m on the y-axis, while position B had high amplitudes at approximately 0 m.

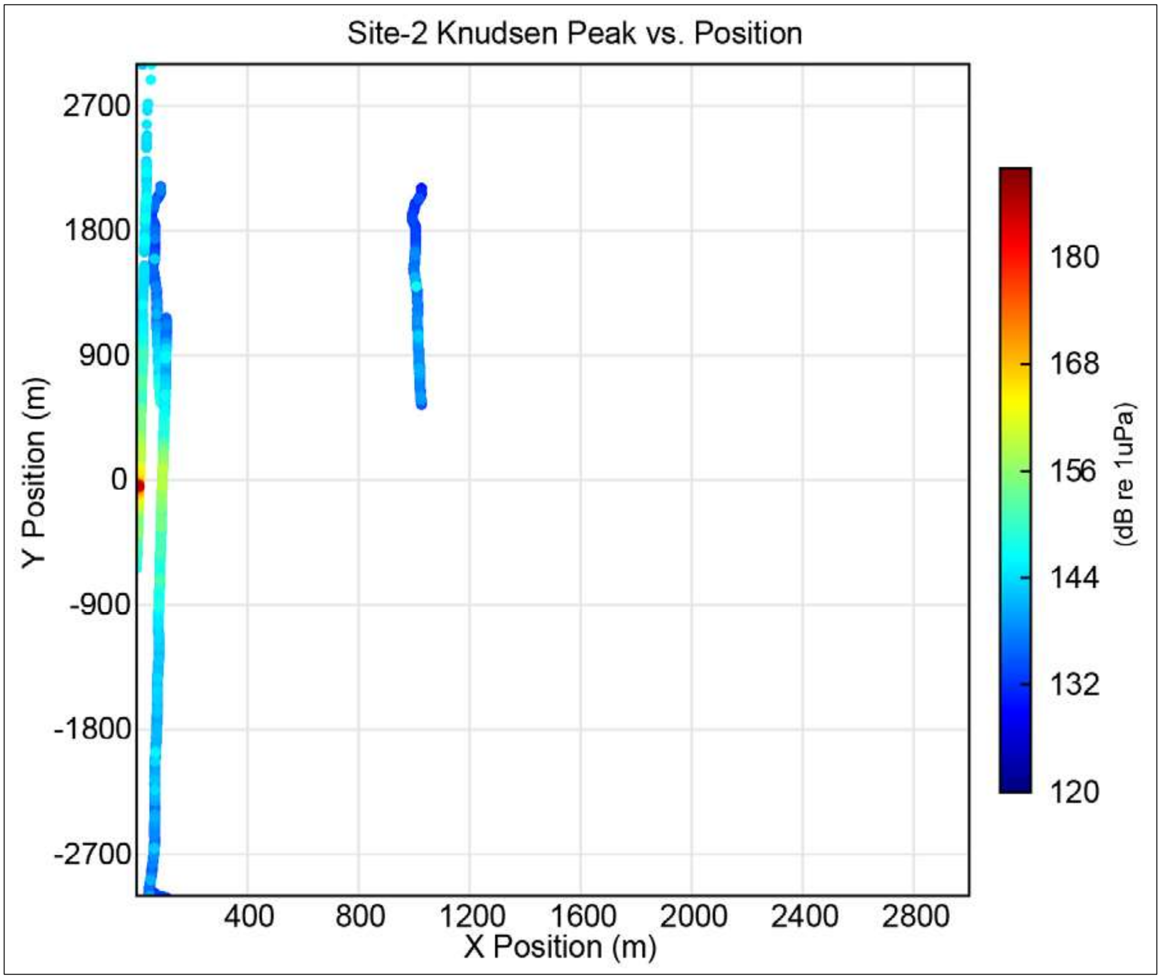


Figure 4.23.2-3. Plan view of received peak level for Knudsen 3260 at Site 2 for positions D (Buoy6), B (Buoy11 and Buoy11), and E (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.23.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.23.2-1. Knudsen 3260 source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 1	NA	Level 1	NA	8 ms	203	201	181
NUWC Proxy: Knudsen 3202	NA	Level 1	NA	8 ms	210*	205*	181*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.23.3 Site 3 – Mud, 30 m Depth

At S3, the Knudsen 3260, Mode 1, had valid acoustic recordings in Run6 and Run27. For Run6, position B (Buoy5 and Buoy12) had valid acoustic recordings. For Run27, positions B (Buoy11), E (Buoy10), and F (Buoy9) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 1, are shown in **Figure 4.23.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy12) for Run6, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy5), E (Buoy10), and F (Buoy9).

The results panels (**Figure 4.23.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the Knudsen 3260 at S3, position B (Buoy5, Buoy11, and Buoy12), E (Buoy10), and F (Buoy9) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,300 m. Peak signals at positions E (Buoy10) and F (Buoy9) were high-quality receptions. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 210 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 207 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). The data gap for position F is a result of a 1-minute corrupted file.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 140°, indicating an error in buoy positioning; for position E at approximately 60°; and for position F at approximately 80°, indicating errors in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

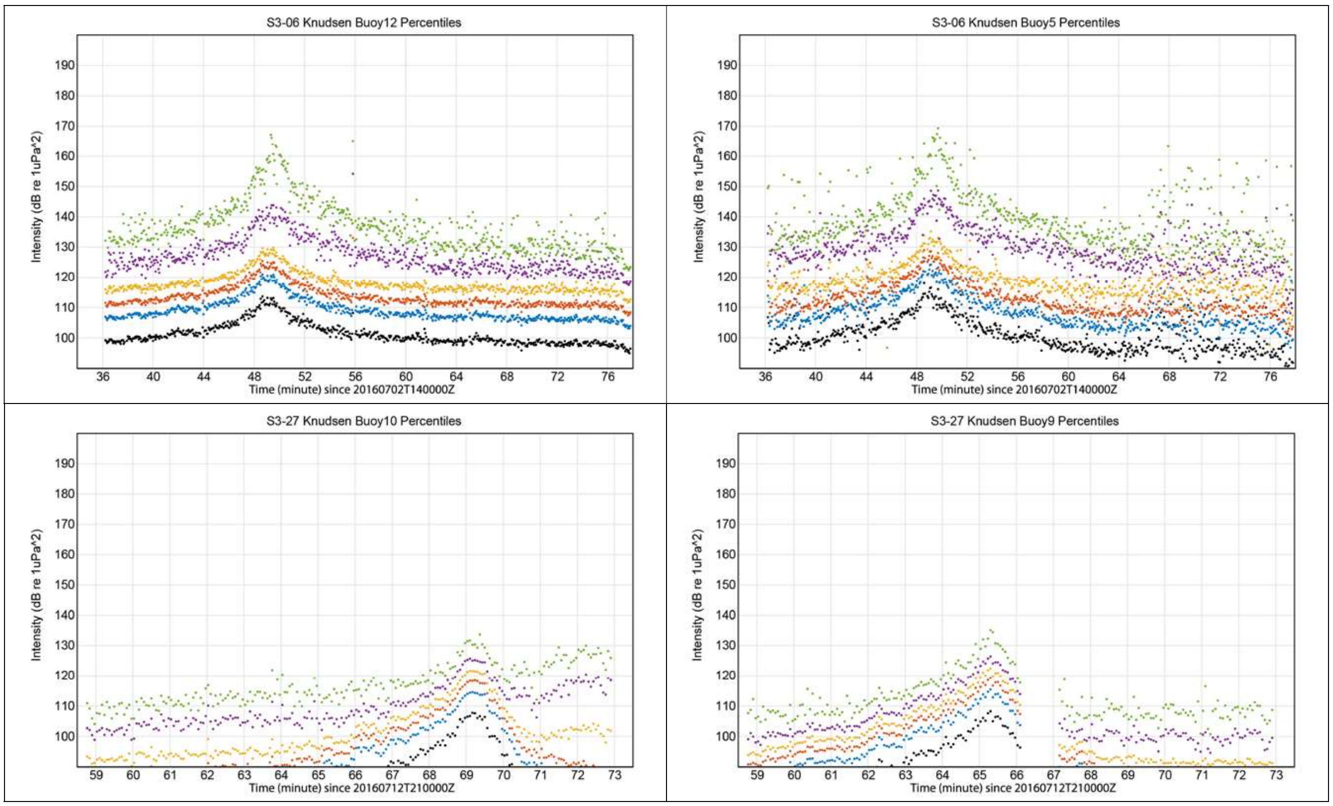


Figure 4.23.3-1. Percentile plots of Knudsen 3260 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy10); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

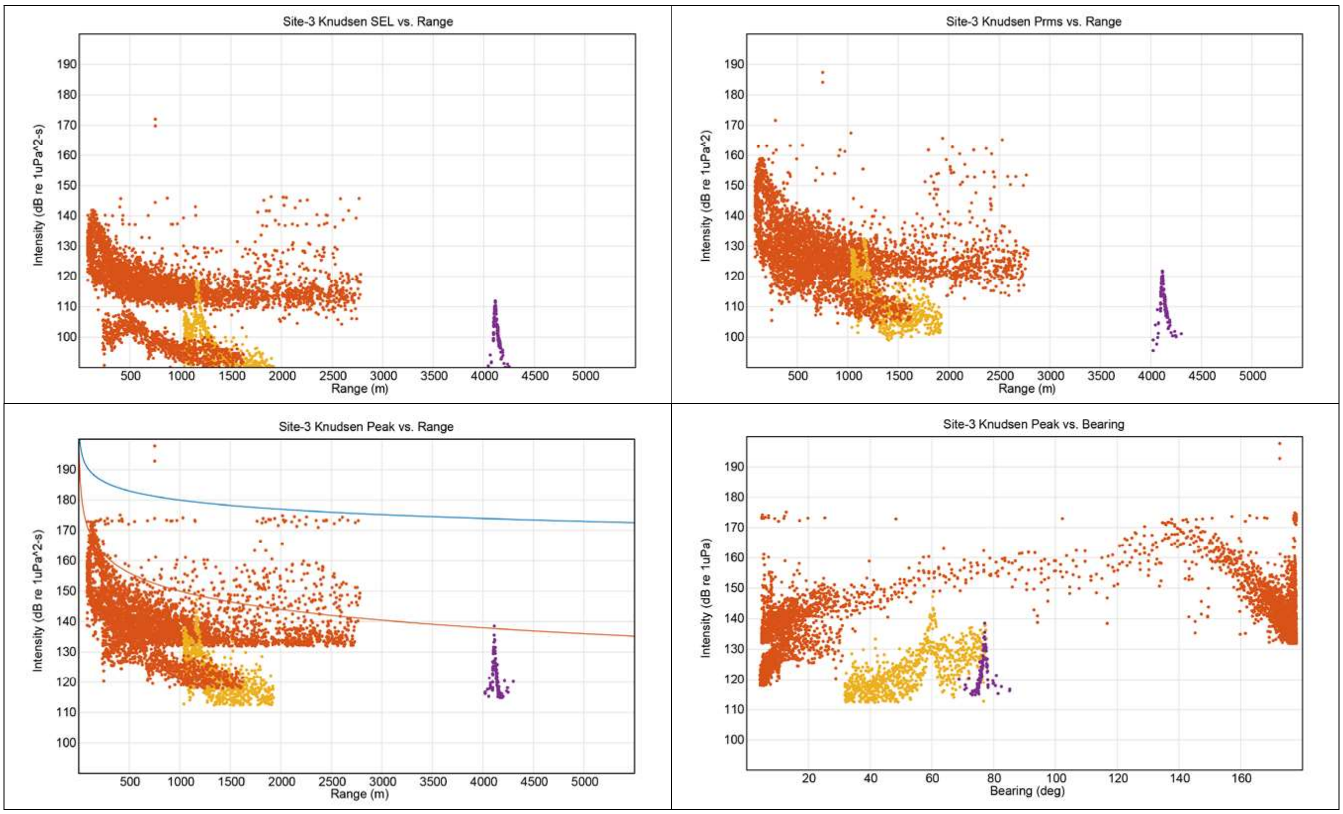


Figure 4.23.3-2. Range results for Knudsen 3260 combined signals for Run6 and Run27 at Site 3 for positions B (Buoy5, Buoy11, and Buoy12, combined), E (Buoy10), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; E = yellow; F = purple.

The plan view is shown in **Figure 4.23.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 75,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy5, Buoy11, and Buoy12), E (Buoy10), and F (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

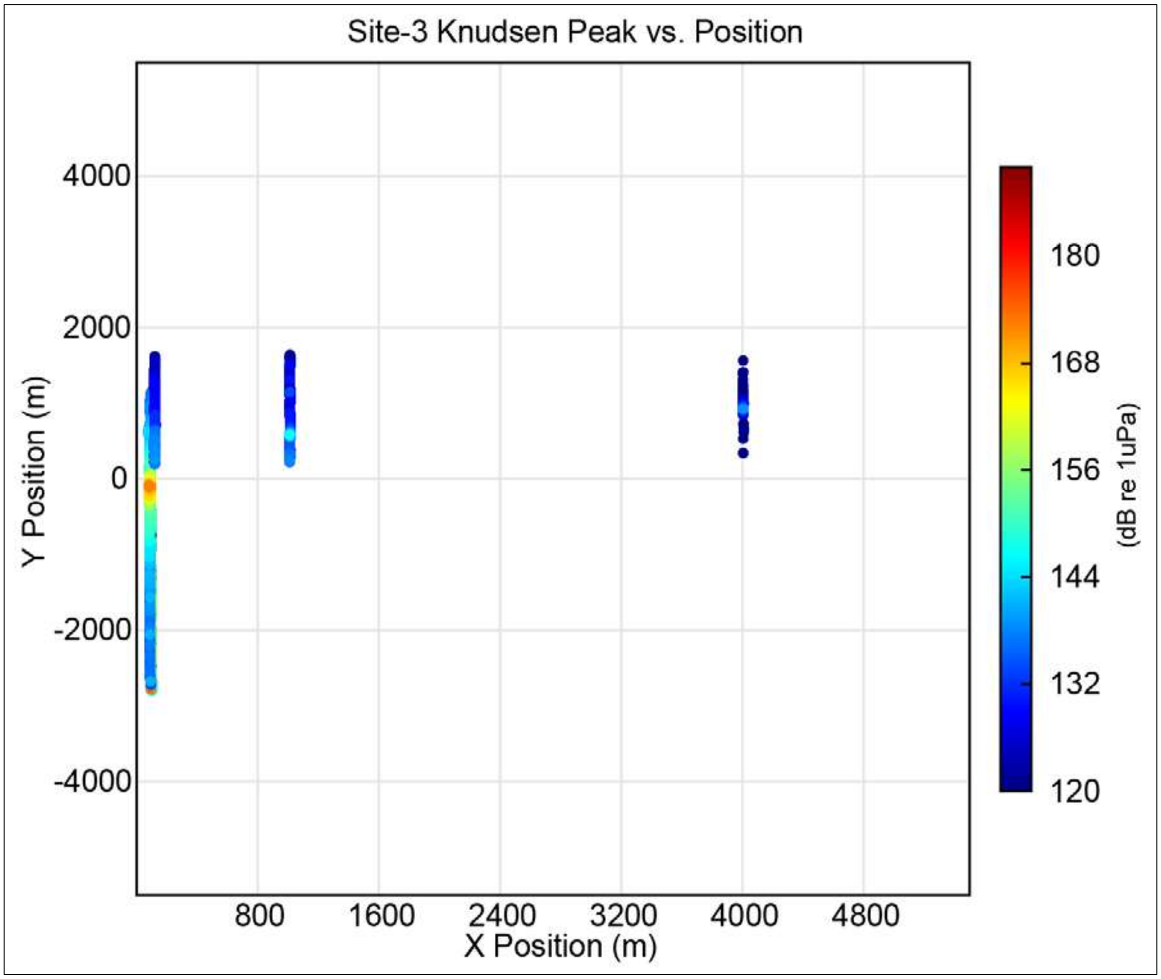


Figure 4.23.3-3. Plan view of received peak level for Knudsen 3260 at Site 3 for positions B (Buoy5, Buoy11, and Buoy12), E (Buoy10), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.23.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.23.3-1. Knudsen 3260 source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 1	NA	Level 1	NA	8 ms	202	188	172
NUWC Proxy: Knudsen 3202	NA	Level 1	NA	8 ms	210*	205*	181*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.23.4 Site 4 – Sand, 30 m Depth

At S4, the Knudsen 3260, Mode 1, had valid acoustic recordings in Run6 and Run21. For Run6, positions D (Buoy8) and A (Buoy6) had valid acoustic data. For Run21, positions B (Buoy12) and F (Buoy5) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 1, are shown in **Figure 4.23.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy8) for Run6, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions B (Buoy12), A (Buoy6), and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.23.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S4, positions D (Buoy8), A (Buoy6), and B (Buoy12) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 3,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 log10 (range)]. The reference curves predict received levels for a 210 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 207 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). The resonance pattern in Buoy D (**Figure 4.23.1-2** top right panel) is an indication of the beam-pattern of the 2×2 Knudsen 3260 source array, which was deployed for this project. There are calibration errors (**Section 2.6.3.1**) at position D as seen in the received levels being approximately 40 dB down compared to the other positions.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for positions D, B, and A at approximately 100°, indicating relatively good navigational buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

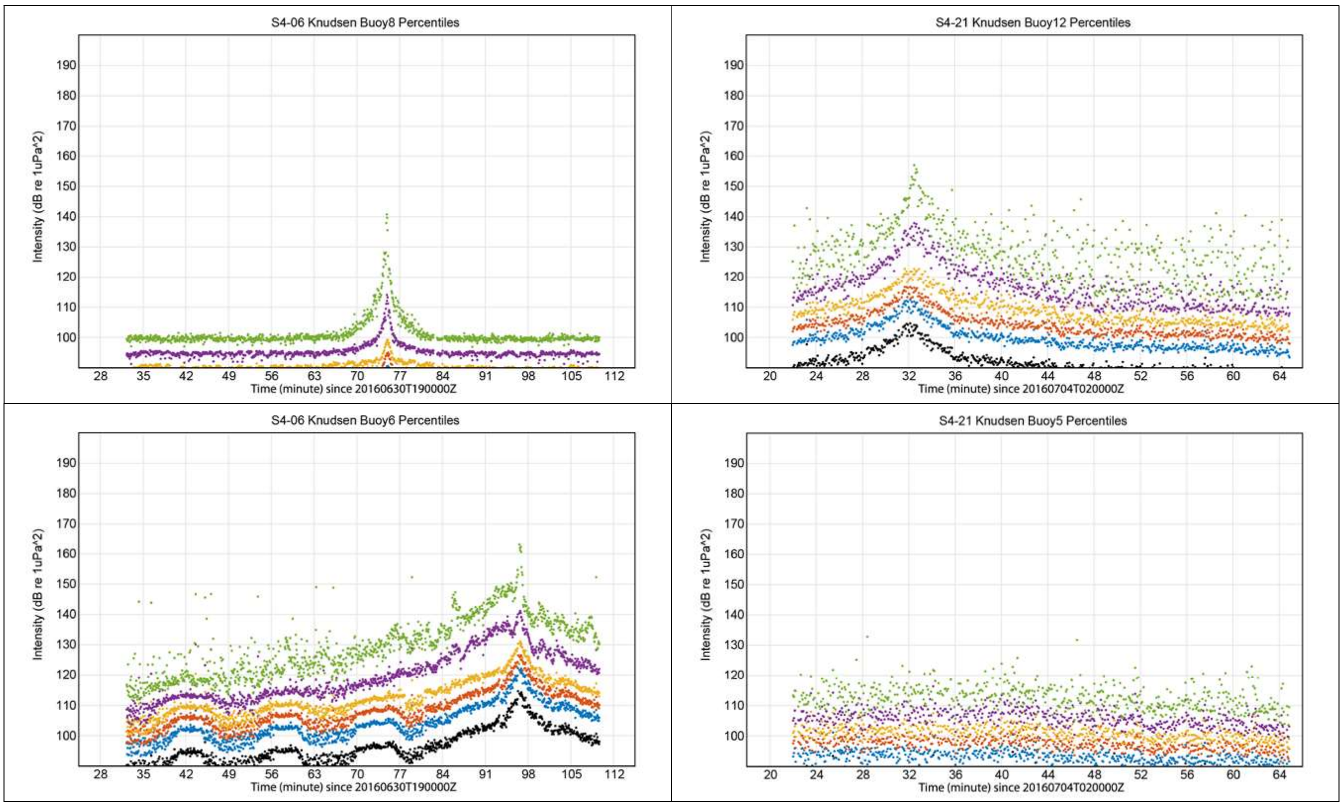


Figure 4.23.4-1. Percentile plots of Knudsen 3260 signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy8); Top right: SPL_{pk} arrival at position B (Buoy12); Bottom left: SPL_{pk} arrival at position A (Buoy6); Bottom right: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

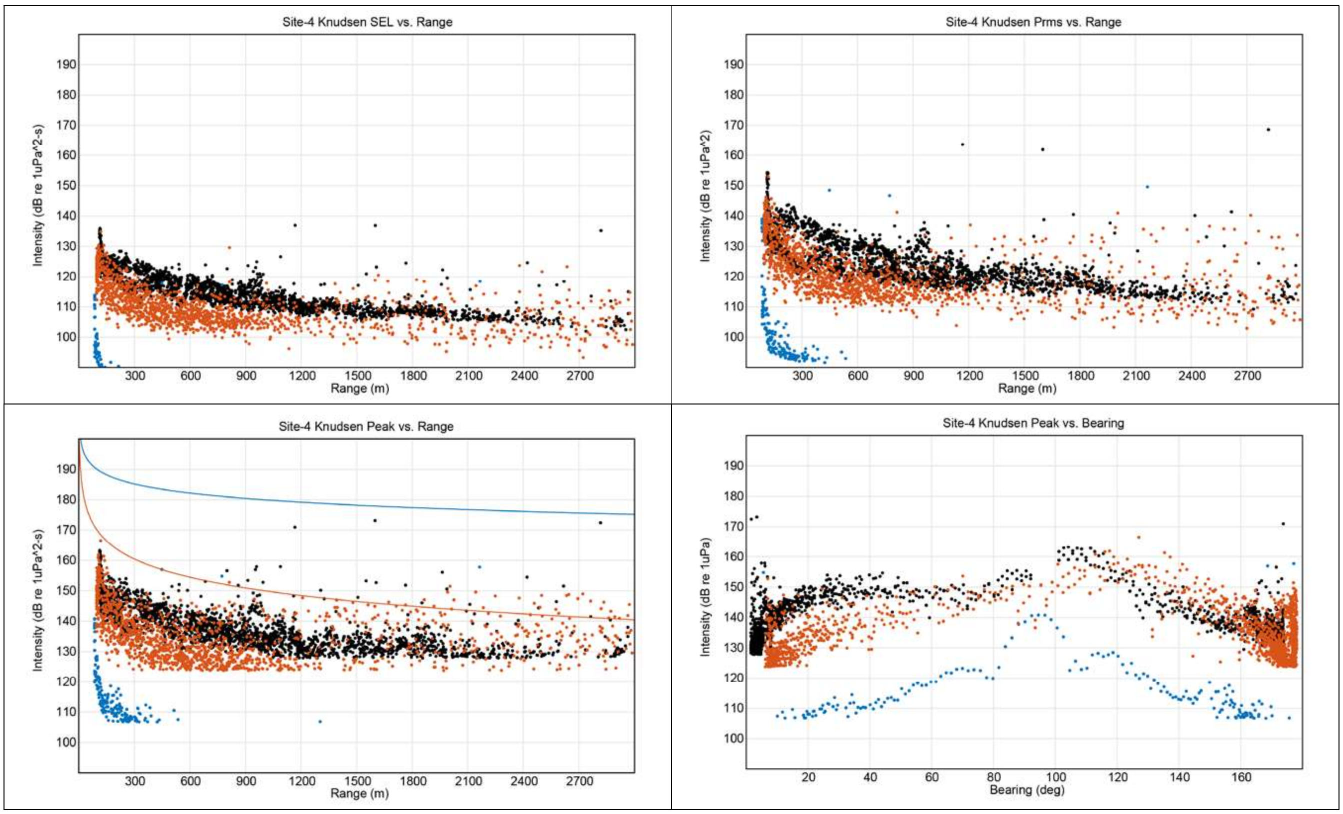


Figure 4.23.4-2. Range results for Knudsen 3260 signals at Site 4 for positions D (Buoy8), B (Buoy12) and A (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red, D=blue.

The plan view is shown in **Figure 4.23.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,200 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy8), B (Buoy12) and A (Buoy6). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

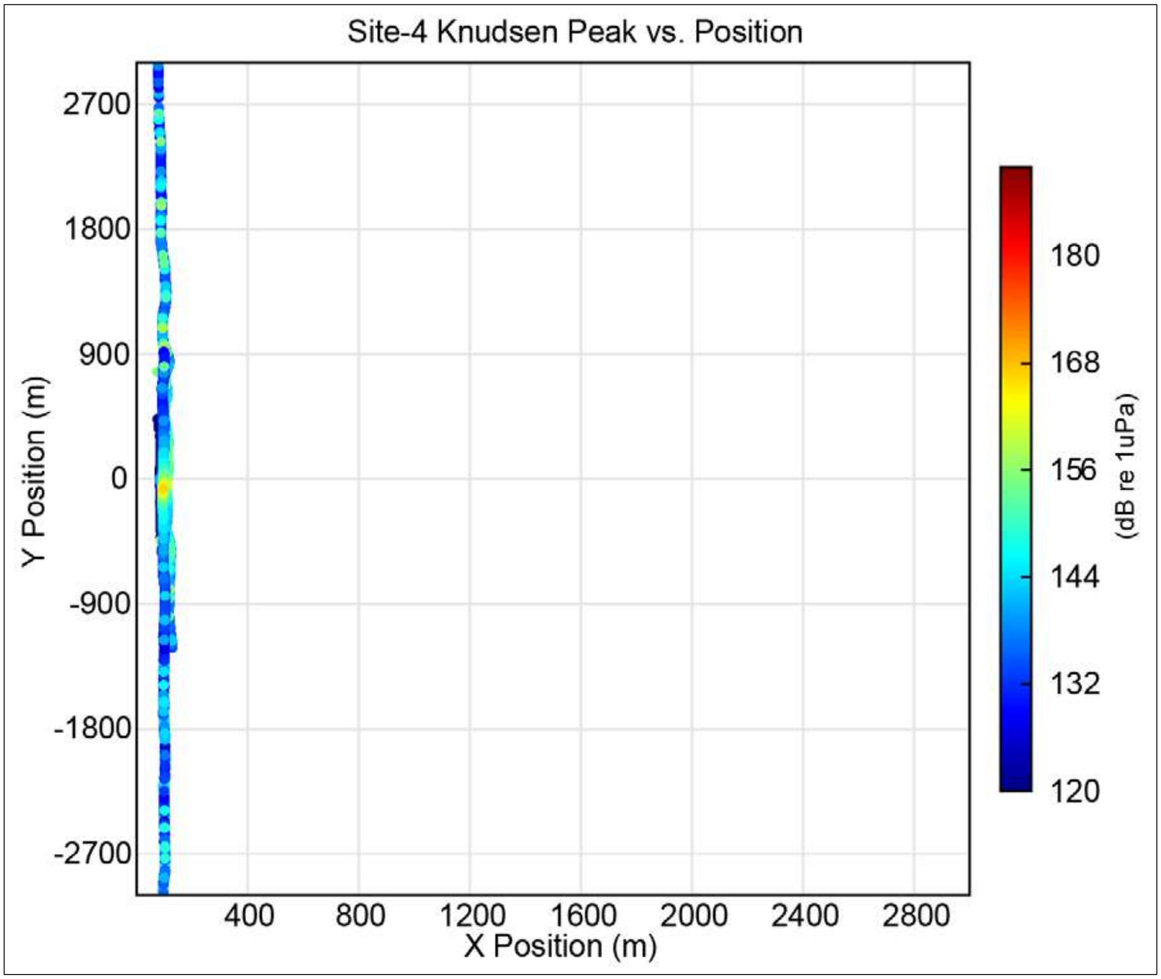


Figure 4.23.4-3. Plan view of received peak level for Knudsen 3260 at Site 4 for positions D (Buoy8), B (Buoy12) and A (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.23.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.23.4-1. Knudsen 3260 source levels, Mode 1, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 1	NA	Level 1	NA	8 ms	204	196	177
NUWC Proxy: Knudsen 3202	NA	Level 1	NA	8 ms	210*	205*	181*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.23.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Knudsen 3260, Mode 1, had valid acoustic recordings in Run10 at positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9).

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 1, are shown in **Figure 4.23.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run10, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions A (Buoy12) and E (Buoy8 and Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.23.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S5, positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 210 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 207 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). The received levels are quite low because of the beamwidth of the source, and only if the source were to pass directly over position D would the levels be close to expected values.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D and A are near 90° with a slow fall off, as expected for buoy GPS navigation and a horizontally omnidirectional source. Note the Knudsen has a significant vertical beam pattern. Buoy E appears to peak around 100°.

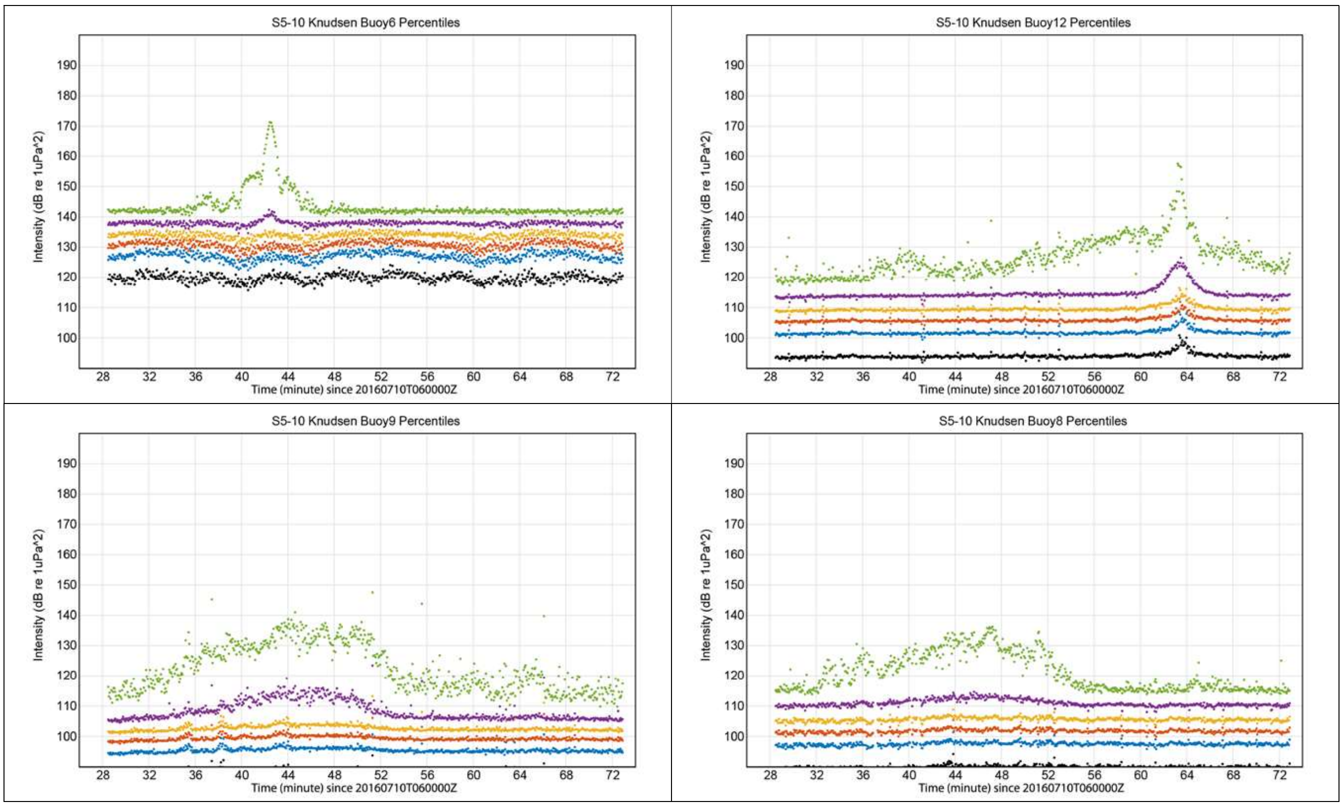


Figure 4.23.5-1. Percentile plots of Knudsen 3260 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom left: SPL_{pk} arrival at position E (Buoy9); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

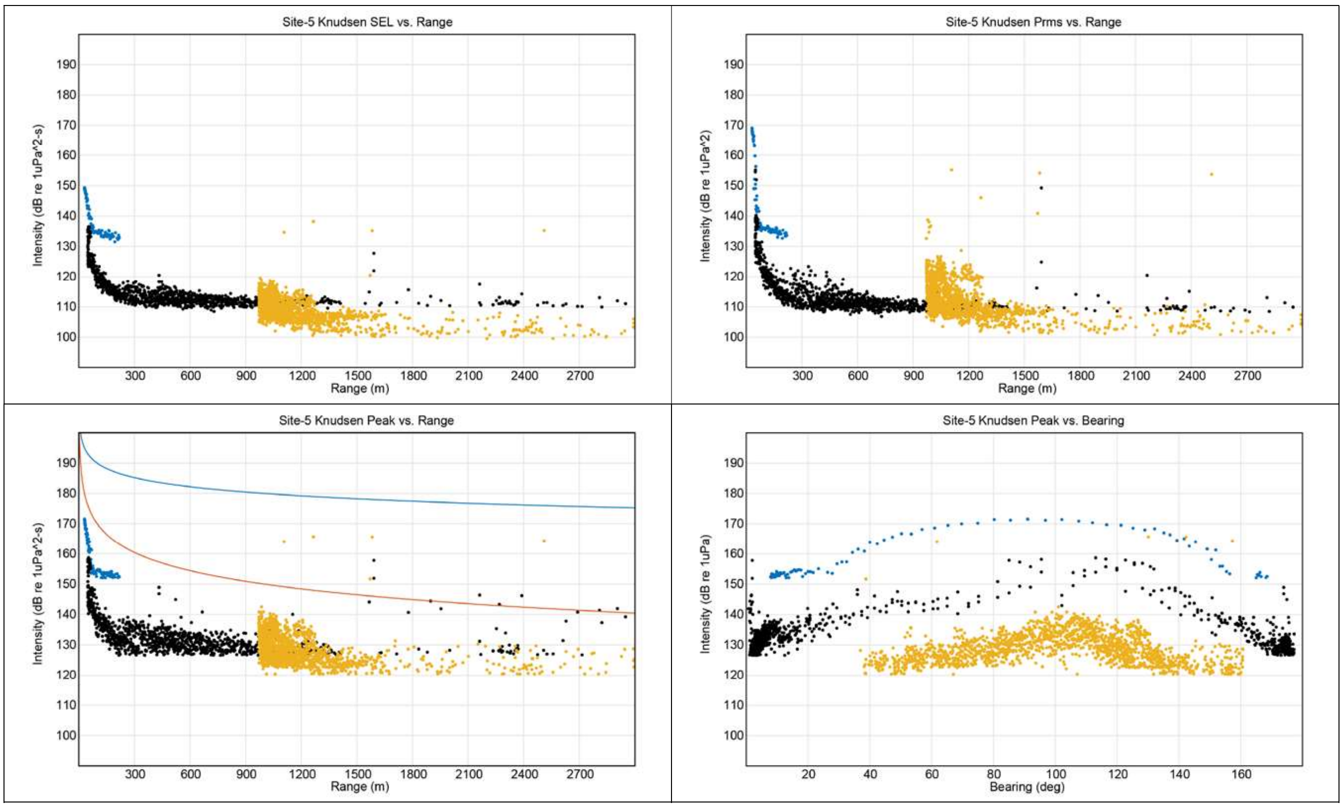


Figure 4.23.5-2. Range results for Knudsen 3260 signals at Site 5 from Run10 for positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [$10 \log_{10}$ (*range*)] and the red line is spherical spreading [$20 \log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue; E = yellow.

The plan view is shown in **Figure 4.23.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 30,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

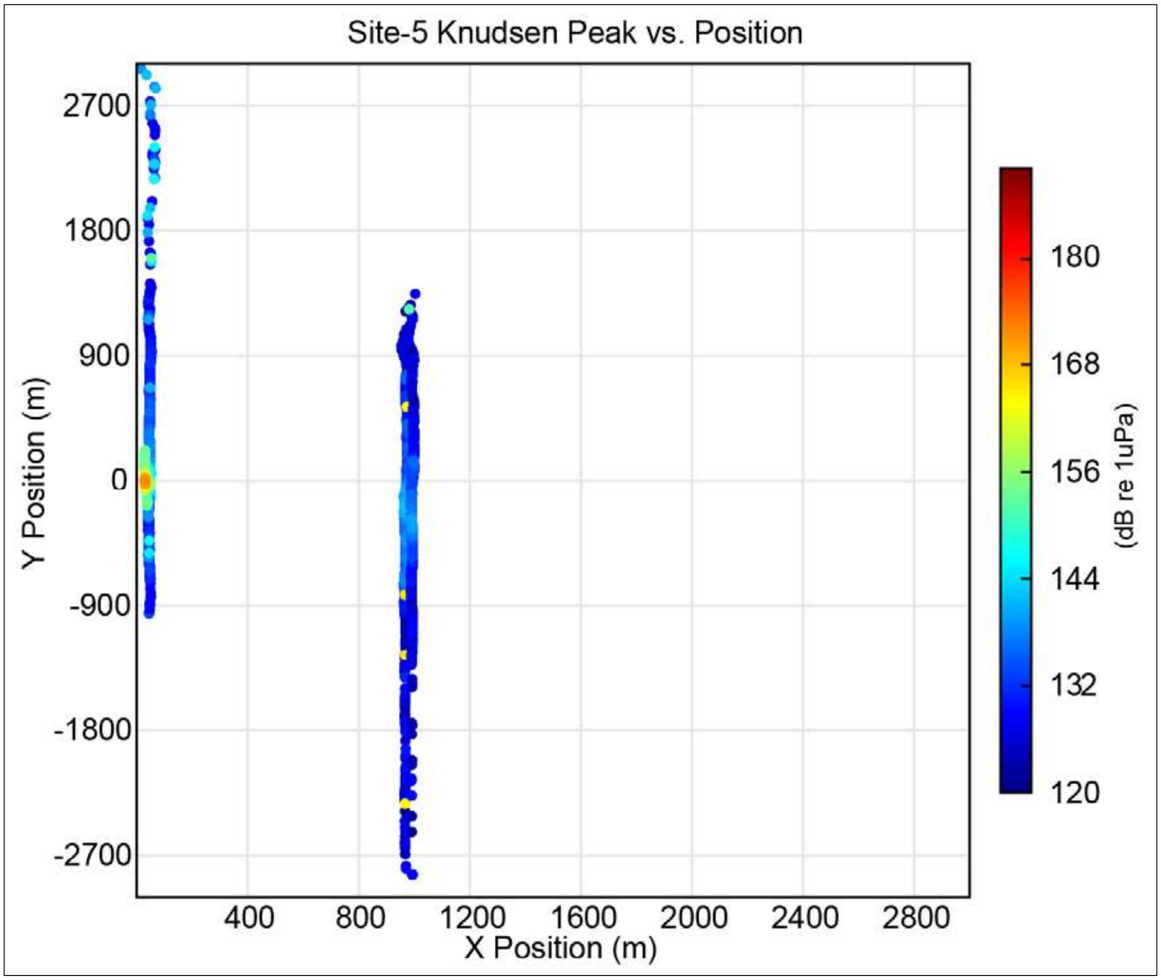


Figure 4.23.5-3. Plan view of received peak level for Knudsen 3260 at Site 5 for positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.23.5-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.23.5-1. Knudsen 3260 source levels, Mode 1, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 1	NA	Level 1	NA	8 ms	201	198	179
NUWC Proxy: Knudsen 3202	NA	Level 1	NA	8 ms	210*	205*	181*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

This Page Intentionally Left Blank

4.24 Knudsen 3260, 3.3-5.6 kHz, Power Level-4, 32-ms Pulse (Mode 2)

The Knudsen 3260 subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 4 kHz. The operational parameter settings for Mode 2 were a power level of 4, a 32-ms pulse, and a 3.3-5.6 kHz output frequency via a 2×2 array (i.e., four transducers). The source level of Mode 2 has a peak of 217 dB re 1 µPa m, meaning it is a high-level source, which made extracting these data signals relatively easy when multiple sources were operated simultaneously. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. There are harmonics for this source, but they are not included in the processing because they are 24 dB down and therefore do not affect the acoustic metrics. The bolded row in **Table 4.24-1** is the selected frequency band (1 to 12 kHz) and SPL_{pk} (168 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.24-1. Bandpass determination for the Knudsen 3260 subbottom profiler, 3.3-5.6 kHz, power level-4, 32-ms Pulse, at Site 2, Run30.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	168.04
0-100	168.05
0-50	167.85
0-25	167.69
1-12	**167.59**
0-8	167.25

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Knudsen 3260, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.24-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Knudsen 3260 was operationally paired in alternation with the ET512i. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.24-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

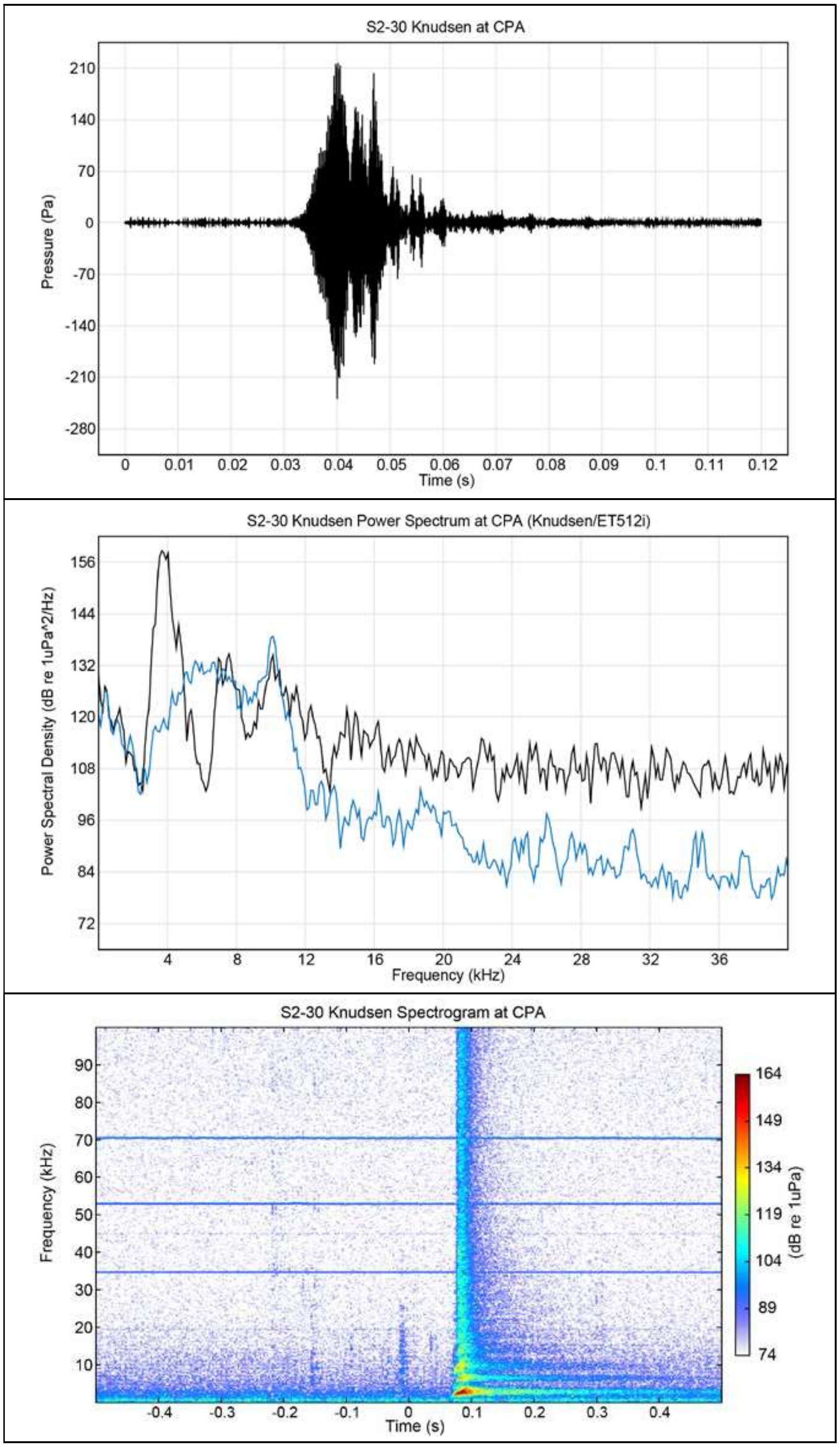


Figure 4.24-1. Knudsen 3260 measured signal characteristics at closest point of approach (CPA) at Site 2, Run30.
Top: Time-waveform of a signal; Middle: Power spectral density, Knudsen 3260 = black, ET512i = blue; Bottom: Spectrogram.

4.24.1 Site 1 – Mud, 10 m Depth

At S1, the Knudsen 3260, Mode 2, had valid acoustic recordings in Run2 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the Knudsen 3260, Mode 2, are shown in **Figure 4.24.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run2, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). The receptions at position F (Buoy9) have a good signal to noise ratio; however, it is unclear if they are signal. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.24.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the Knudsen 3260 at S1, positions D (Buoy6), E (Buoy5 and Buoy8, combined), and F (Buoy9) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,700 m. The shape of the data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)]. The reference curves predict received levels for a 217 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 214 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). The resonance pattern in Buoy D (upper right panel) is an indication of the beam-pattern of the 2×2 source array. The signals at position C were a lower amplitude as compared to those at positions D and F, which indicates a calibration issue.

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.24.1-2**), which shows the received peak level for position D at 110°; for position E at approximately 100°; and position F at approximately 70°, indicating errors in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

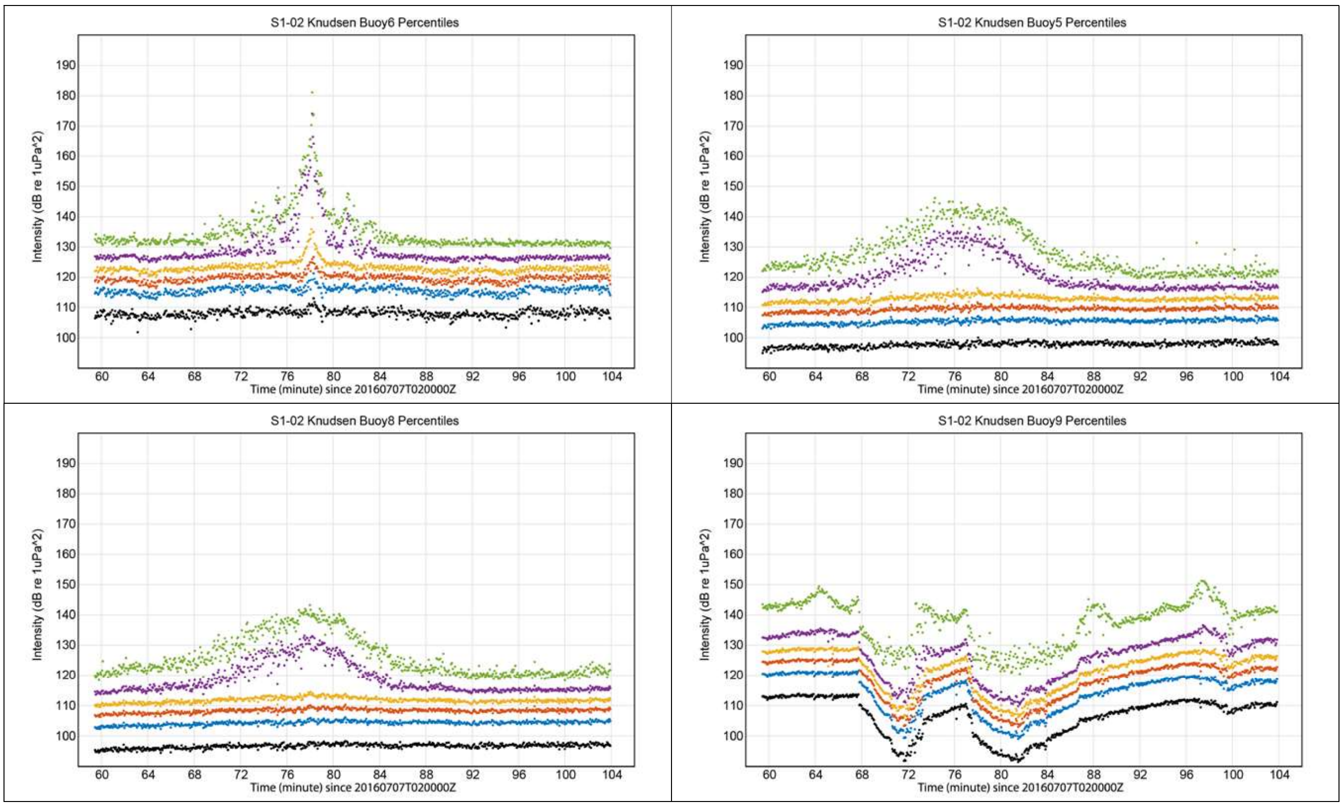


Figure 4.24.1-1. Percentile plots of Knudsen 3260 signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

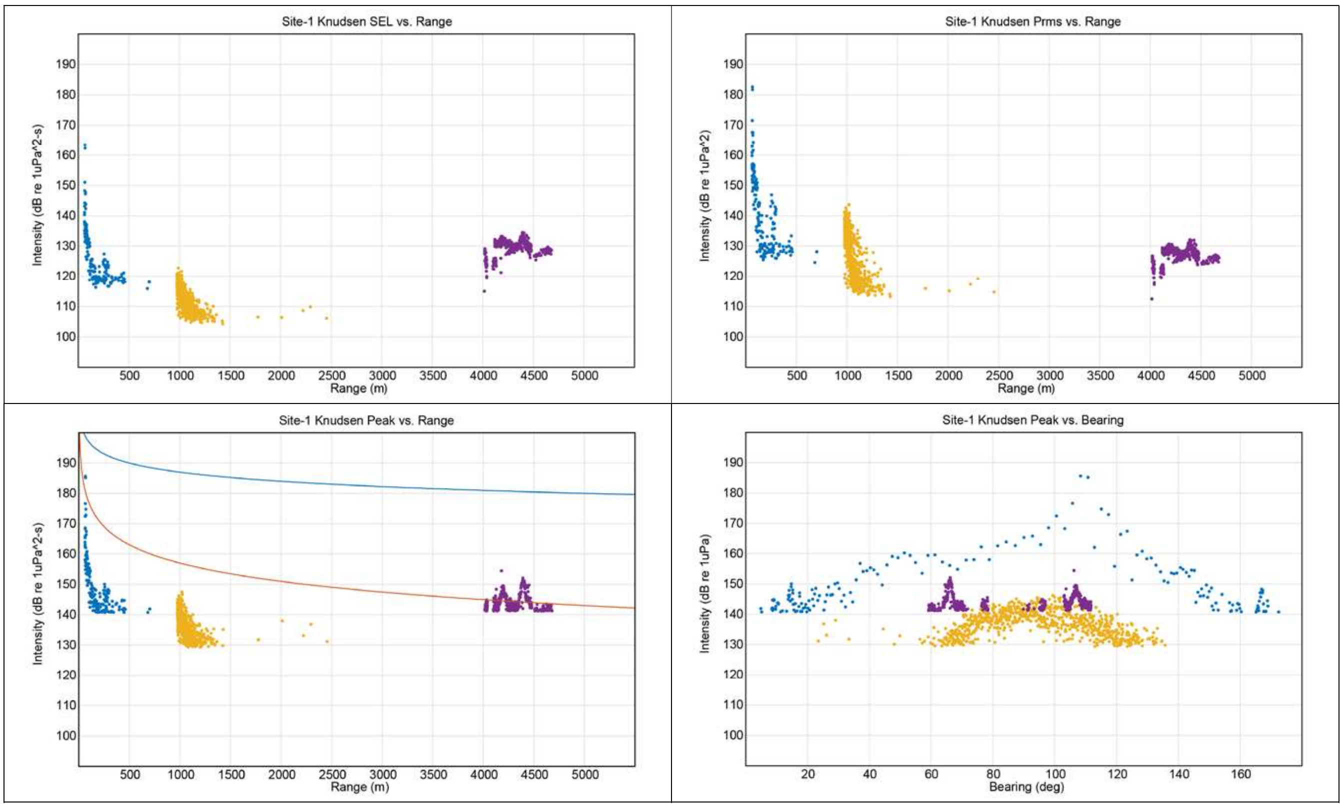


Figure 4.24.1-2. Range results for Knudsen 3260 signals at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy8, combined), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.24.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -200 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

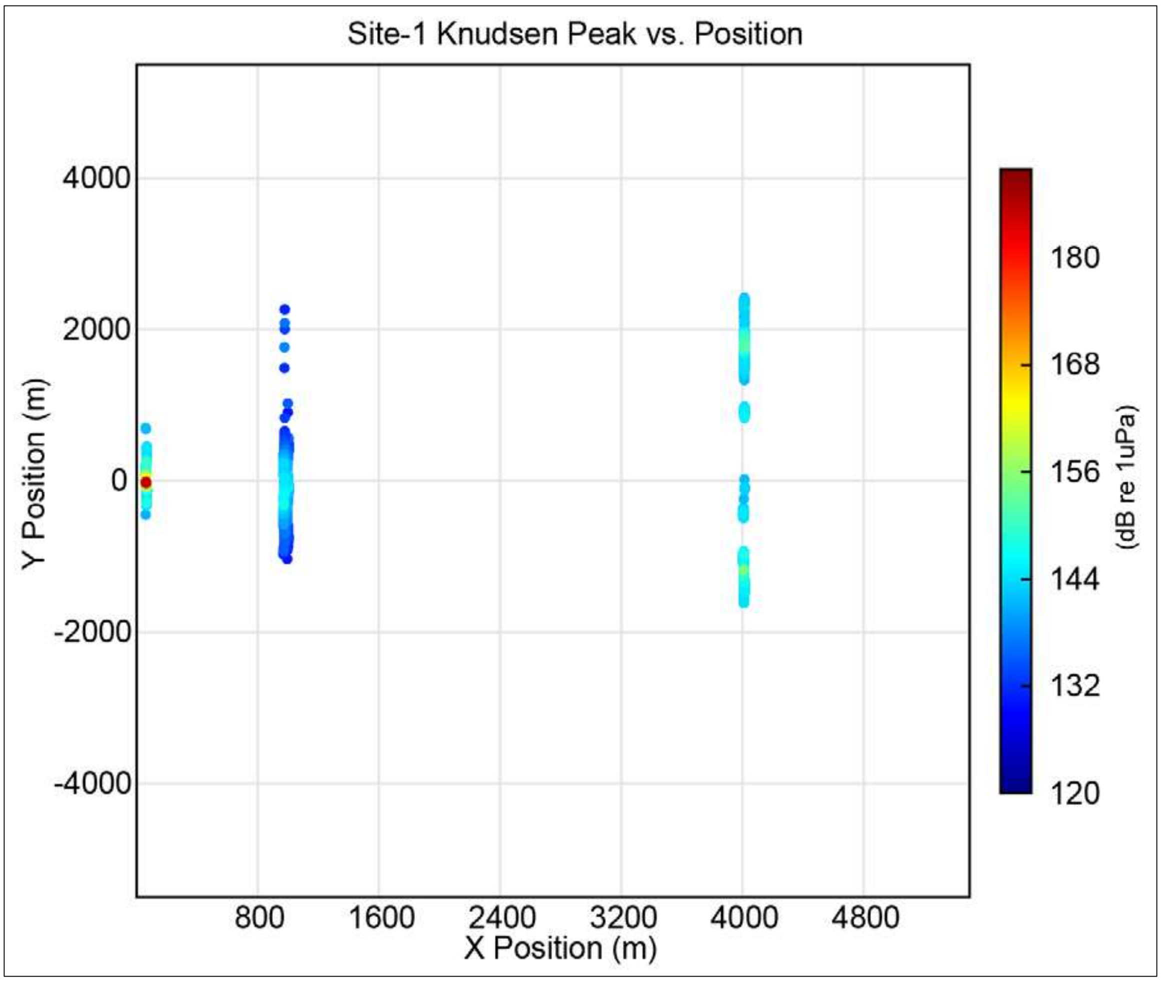


Figure 4.24.1-3. Plan view of received peak level for Knudsen 3260 at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.24.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.24.1-1. Knudsen 3260 source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 2	NA	Level 4	NA	32 ms	213	210	191
NUWC Proxy: Knudsen 3202	NA	Level 4	NA	32 ms	217*	212*	196*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.24.2 Site 2 – Sand, 10 m Depth

At S2, the Knudsen 3260, Mode 2, had valid acoustic recordings in Run2 and Run30. For Run2, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings. For Run30, positions B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 2, are shown in **Figure 4.24.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run2, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11 and Buoy11) and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.24.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S2, positions D (Buoy6), B (Buoy5 and Buoy11, combined), E (Buoy10), and F (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 217 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 214 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.24.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 140°, indicating an error in buoy navigation. For position B, the received peak level is at approximately 70°, indicating an error in buoy navigation, and for positions E and F, received peak levels are approximately 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

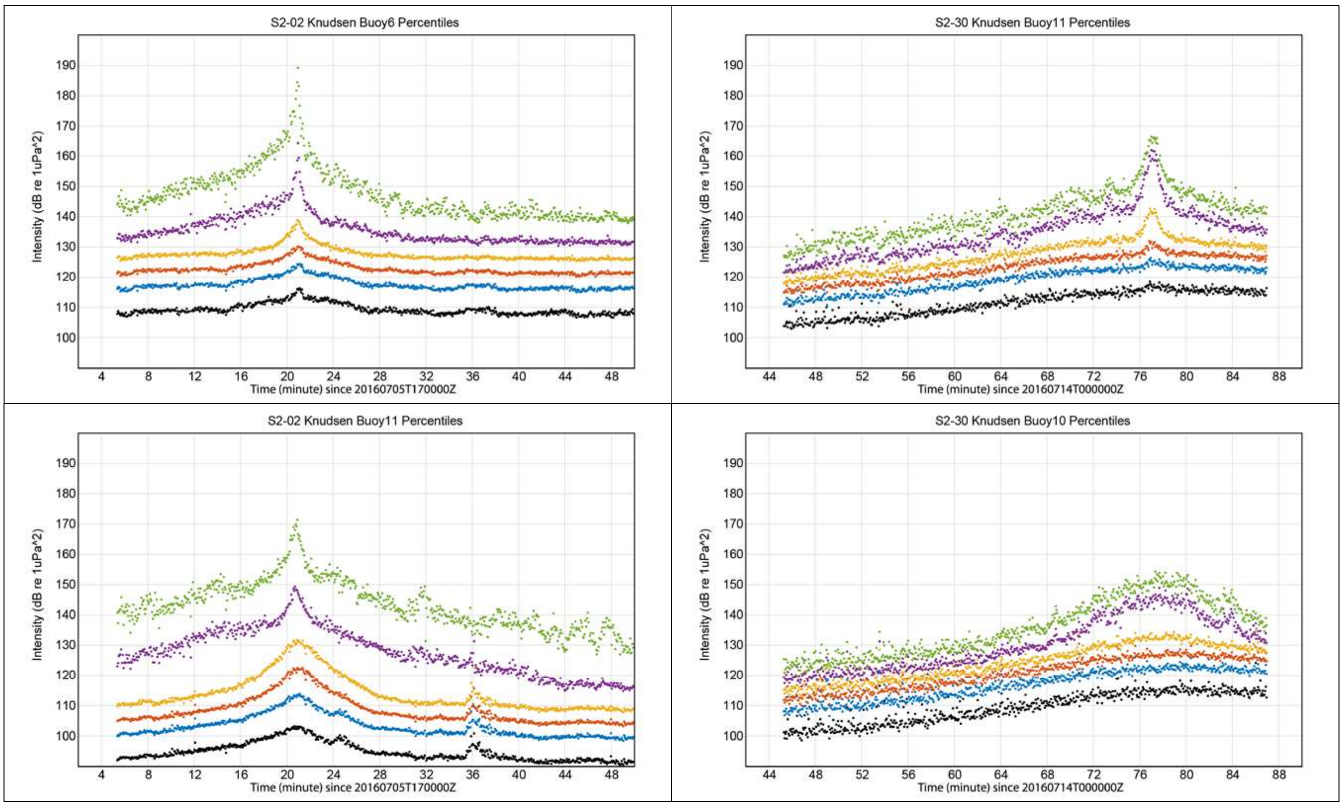


Figure 4.24.2-1. Percentile plots of Knudsen 3260 signals at Site 2.

Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

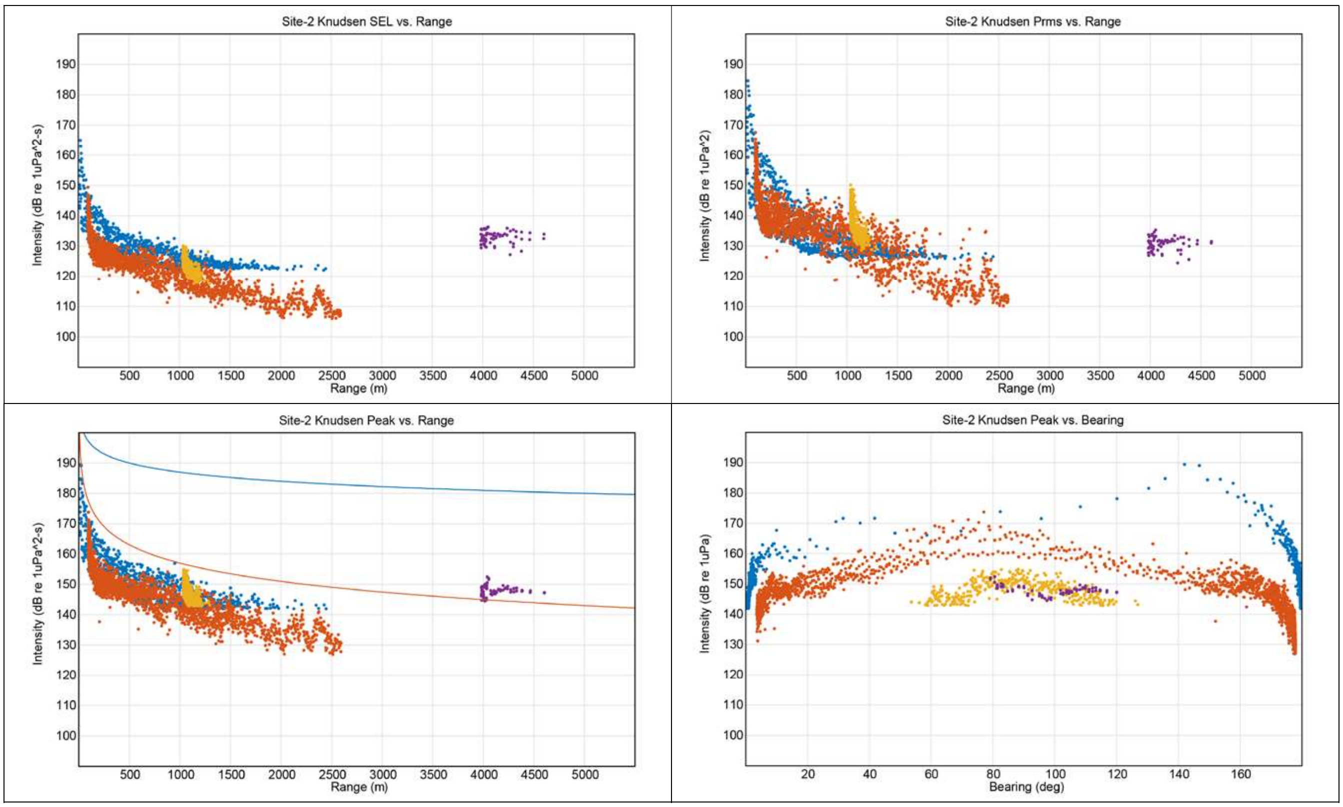


Figure 4.24.2-2. Range results for Knudsen 3260 signals at Site 2 for positions D (Buoy6), B (Buoy5 and Buoy11, combined), E (Buoy10), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.24.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 40,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1500 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

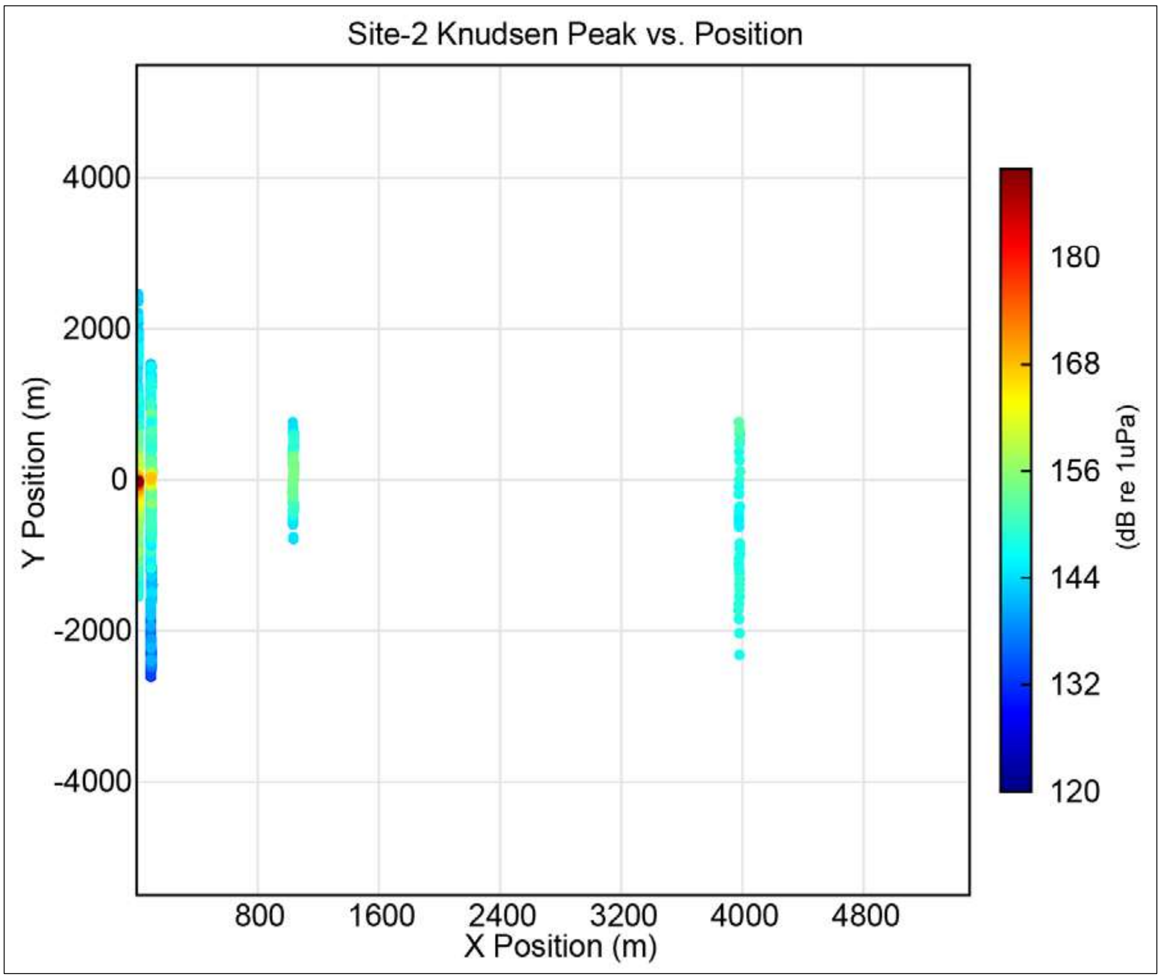


Figure 4.24.2-3. Plan view of received peak level for Knudsen 3260 at Site 2 for positions D (Buoy6), B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.24.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.24.2-1. Knudsen 3260 source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 2	NA	Level 4	NA	32 ms	214	211	191
NUWC Proxy: Knudsen 3202	NA	Level 4	NA	32 ms	217*	212*	196*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J= joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.24.3 Site 3 – Mud, 30 m Depth

The Knudsen 3260, Mode 2, was not deployed or operated at S3.

4.24.4 Site 4 – Sand, 30 m Depth

The Knudsen 3260, Mode 2, was not deployed or operated at S4.

4.24.5 Site 5 – Sandy-Silt, 100 m Depth

The Knudsen 3260, Mode 2, was not deployed or operated at S5.

4.25 Knudsen 3260, 3.3-5.6 kHz, Power Level-4, 64-ms Pulse (Mode 3)

The Knudsen 3260 subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 4 kHz. The operational parameter settings for Mode 3 were a power level of 4, a 64-ms pulse, and a 3.3-5.6 kHz output frequency via a 2×2 array (i.e., four transducers). A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.25-1** is the selected frequency band (1 to 15 kHz) and SPL_{pk} (195 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy. The Knudsen does exhibit resonances, which were 25 dB down from the main-lobe and did not affect the acoustic metrics.

Table 4.25-1. Bandpass determination for the Knudsen 3260 subbottom profiler, 3.3-5.6 kHz, power level-4, 64-ms Pulse, at Site 2, Run3.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
1-200	196.08
1-100	195.82
1-25	195.40
1-15	**194.99**
1-9	193.77

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Knudsen 3260, Mode 3, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.25-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Knudsen 3260 was operationally paired in alternation with the ET512i. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.25-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

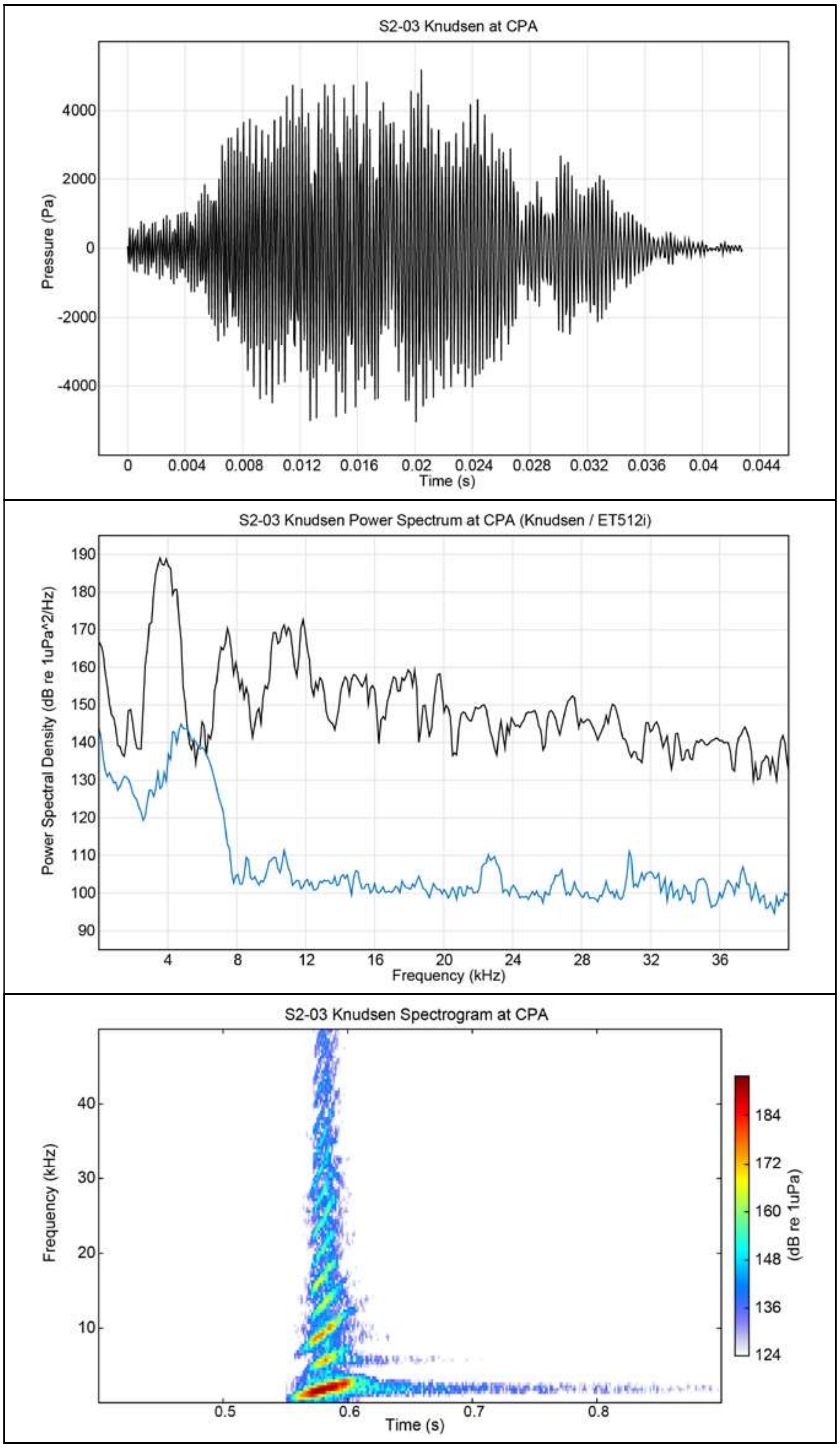


Figure 4.25-1. Knudsen 3260 measured signal characteristics at closest point of approach (CPA) at Site 2, Run3.
Top: Time-waveform of a signal; Middle: Power spectral density, Knudsen 3260 = black, ET512i = blue; Bottom: Spectrogram.

4.25.1 Site 1 – Mud, 10 m Depth

The Knudsen 3260, Mode 3, was not deployed or operated at S1.

4.25.2 Site 2 – Sand, 10 m Depth

At S2, the Knudsen 3260, Mode 3, had valid acoustic recordings in Run3 at positions D (Buoy6) and B (Buoy11).

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 3, are shown in **Figure 4.25.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The left panel shows position D (Buoy6) for Run3, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The right panel shows the valid recorded acoustics at positions B (Buoy11). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.25.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S2, positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 217 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 214 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). Also note that NUWC did not measure a 64-ms pulse width, thus their 32-ms pulse width mode was used.

The bottom right results panel of **Figure 4.25.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 160°, indicating an error in the buoy positioning. For position B, the received peak level is indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

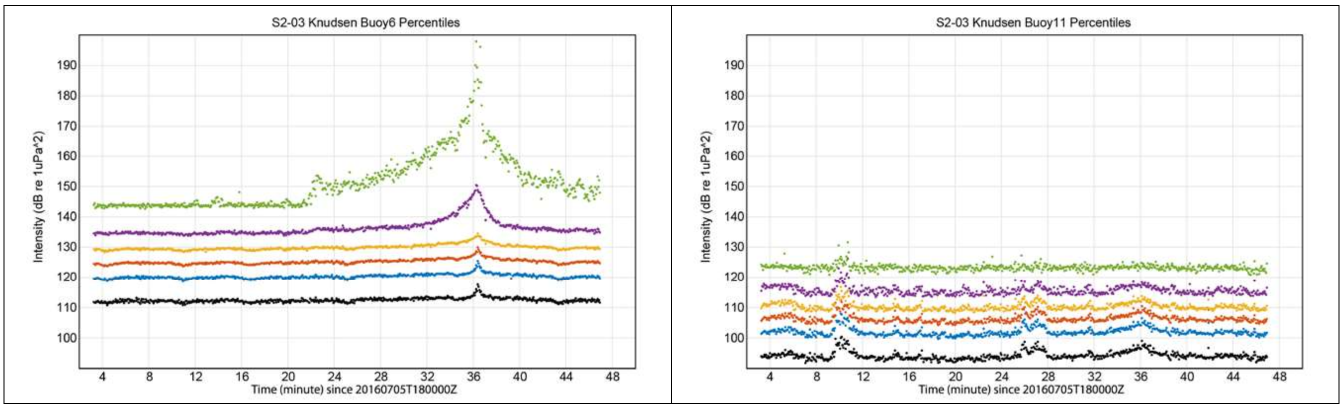


Figure 4.25.2-1. Percentile plots of Knudsen 3260 signals at Site 2.
Left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Right: SPL_{pk} arrival at position B (Buoy11).
Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

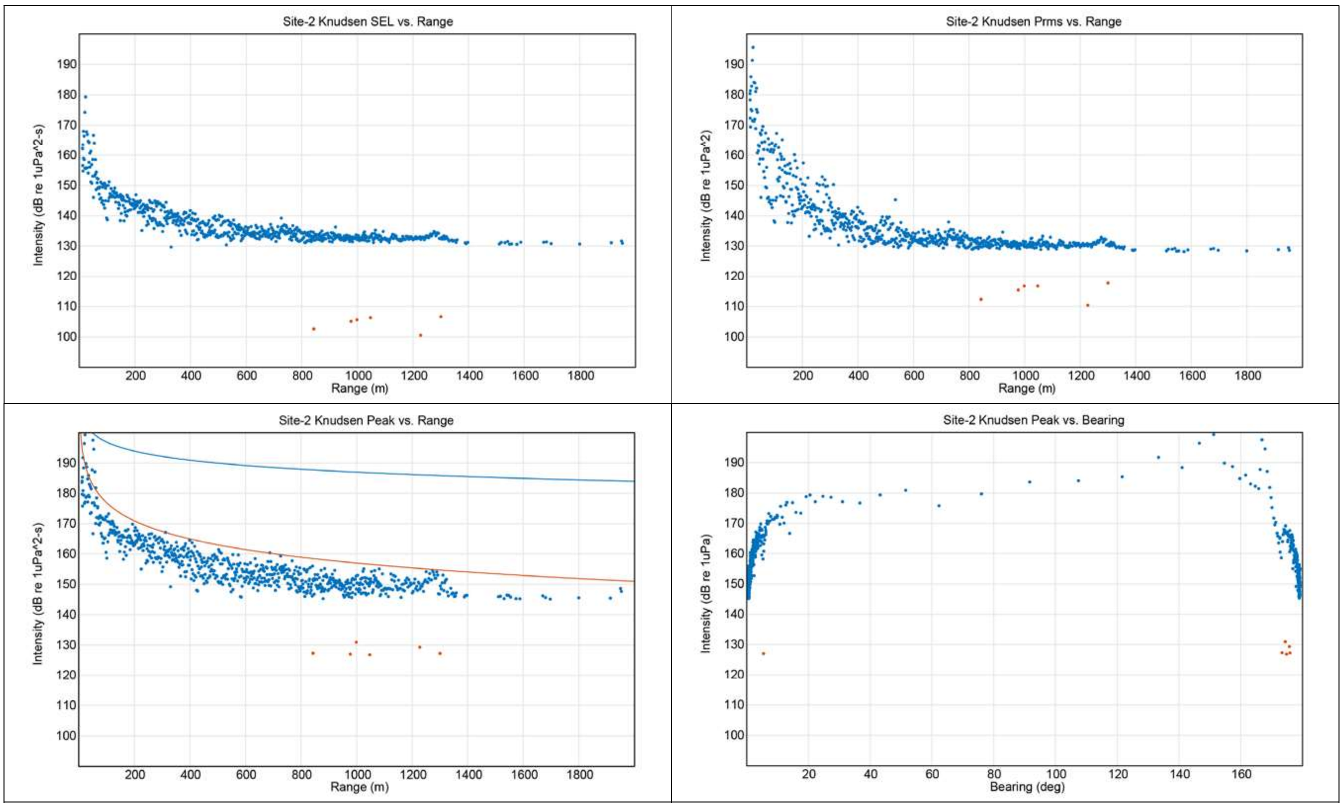


Figure 4.25.2-2. Range results for Knudsen 3260 signals at Site 2 for Run3 for positions D (Buoy6) and B (Buoy11). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.25.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,900 to 1,900-m marks on the y-axis. The CPA is at 25,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,200 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

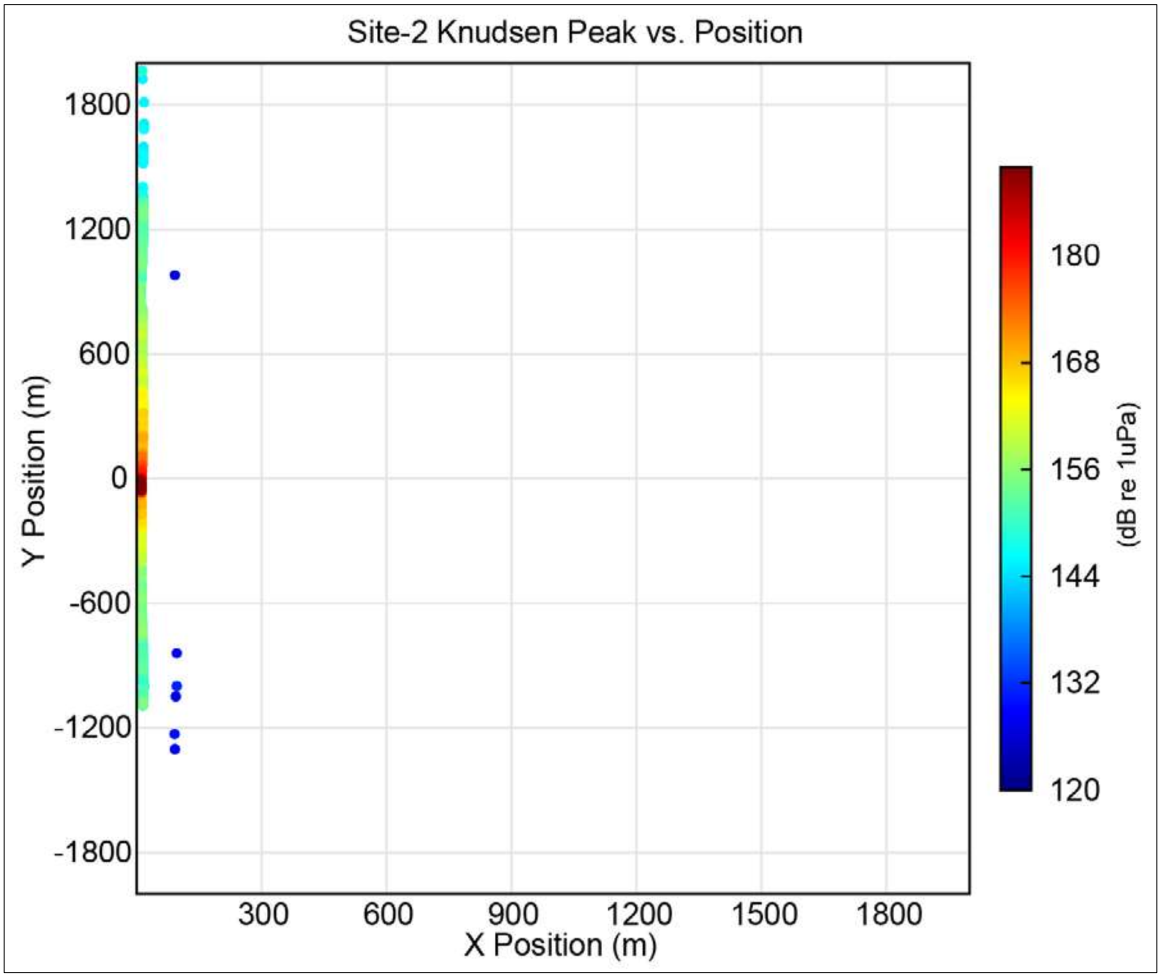


Figure 4.25.2-3. Plan view of received peak level for Knudsen 3260 at Site 2 for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.25.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.25.2-1. Knudsen 3260 source levels, Mode 3, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 3	NA	Level 4	NA	64 ms	211	205	190
NUWC Proxy: Knudsen 3202	NA	Level 4	NA	32 ms	217*	212*	196*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2x2 transducer array.

4.25.3 Site 3 – Mud, 30 m Depth

At S3, the Knudsen 3260, Mode 3, had valid acoustic recordings in Run7 and Run28. For Run7, positions B (Buoy12) and A (Buoy5) had valid acoustic data and observed signals. For Run28, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy10), and F (Buoy9) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 3, are shown in **Figure 4.25.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run28, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11 and Buoy12) and A (Buoy12).

The results panels (**Figure 4.25.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the Knudsen 3260 at S3, positions D (Buoy6), B (Buoy11 and Buoy12, combined), A (Buoy5 and Buoy12, combined), E (Buoy8 and Buoy10, combined), and F (Buoy5) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,500 m. The two distinct groupings of peak pressure levels, specifically for positions B and E, indicate calibration issues. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 217 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2x1 transducer with a peak SL of 214 dB re 1 µPa m. In order to account for the 2x2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). Also note that NUWC did not measure a 64-ms pulse width, thus their 32-ms pulse width mode was used.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D and B at approximately 110°, indicating errors in buoy positioning, and for positions A, E, and F at approximately 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

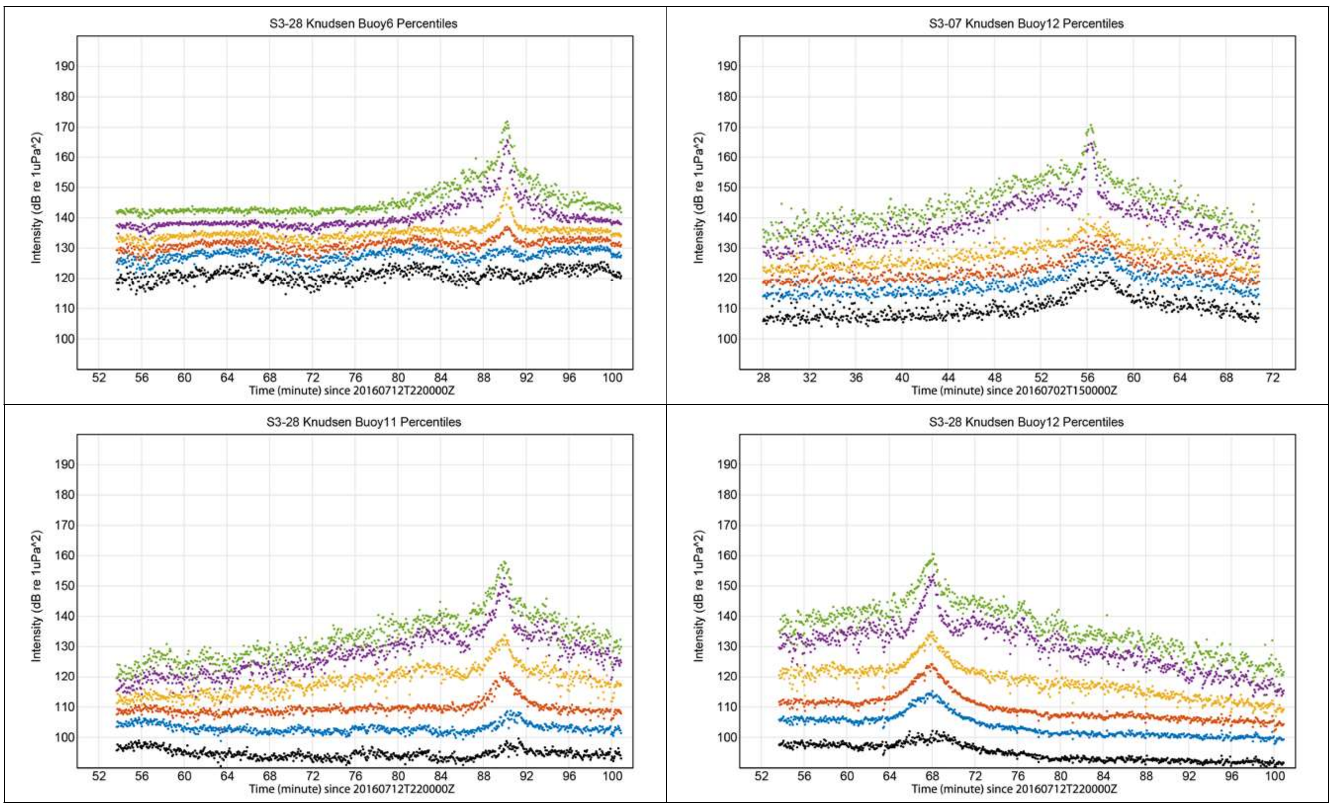


Figure 4.25.3-1. Percentile plots of Knudsen 3260 signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy12); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

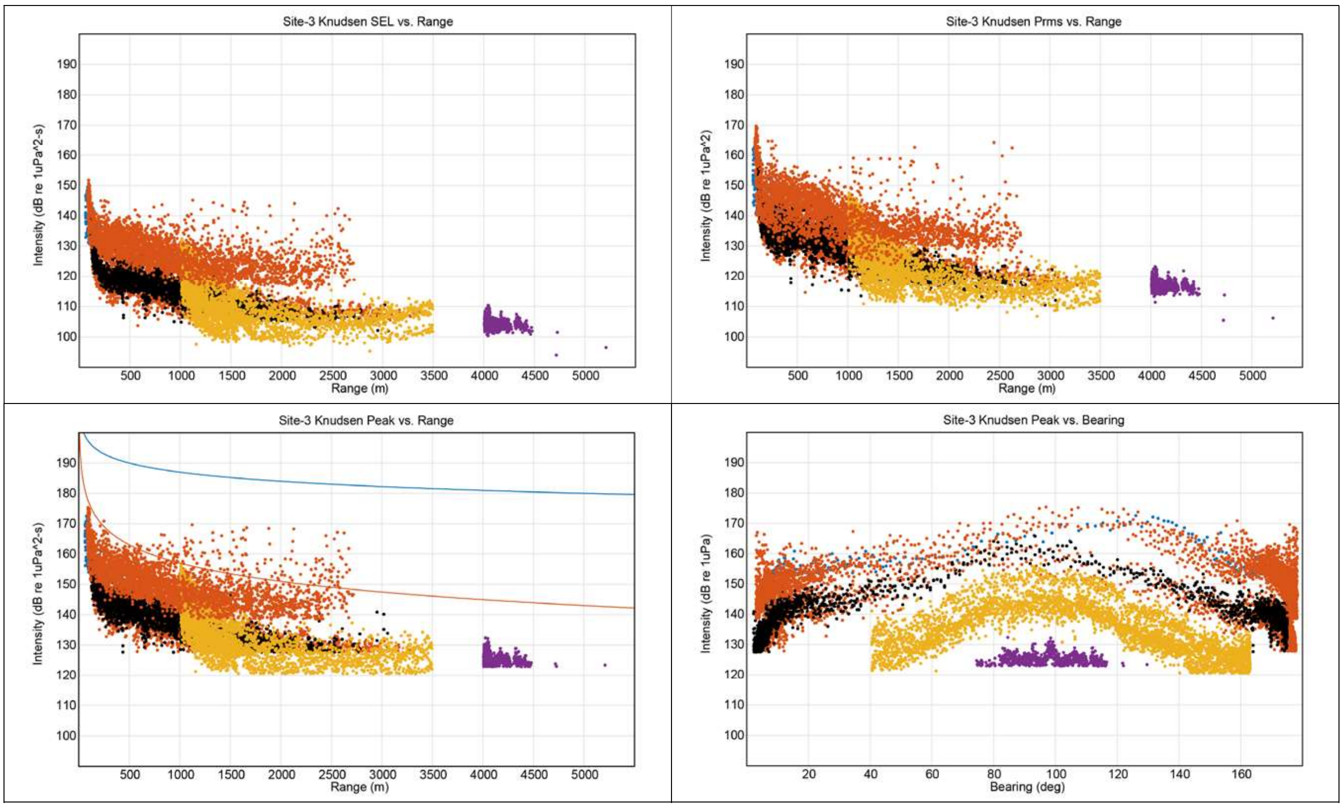


Figure 4.25.3-2. Range results for Knudsen 3260 combined signals for Run7 and Run28 at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy12, combined), A (Buoy5 and Buoy12, combined), E (Buoy8 and Buoy10, combined), and F (Buoy5).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.
Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.25.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,500 to 5,500-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 and Buoy12 combined), A (Buoy5 and Buoy12 combined), E (Buoy8 and Buoy10 combined), and F (Buoy5). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

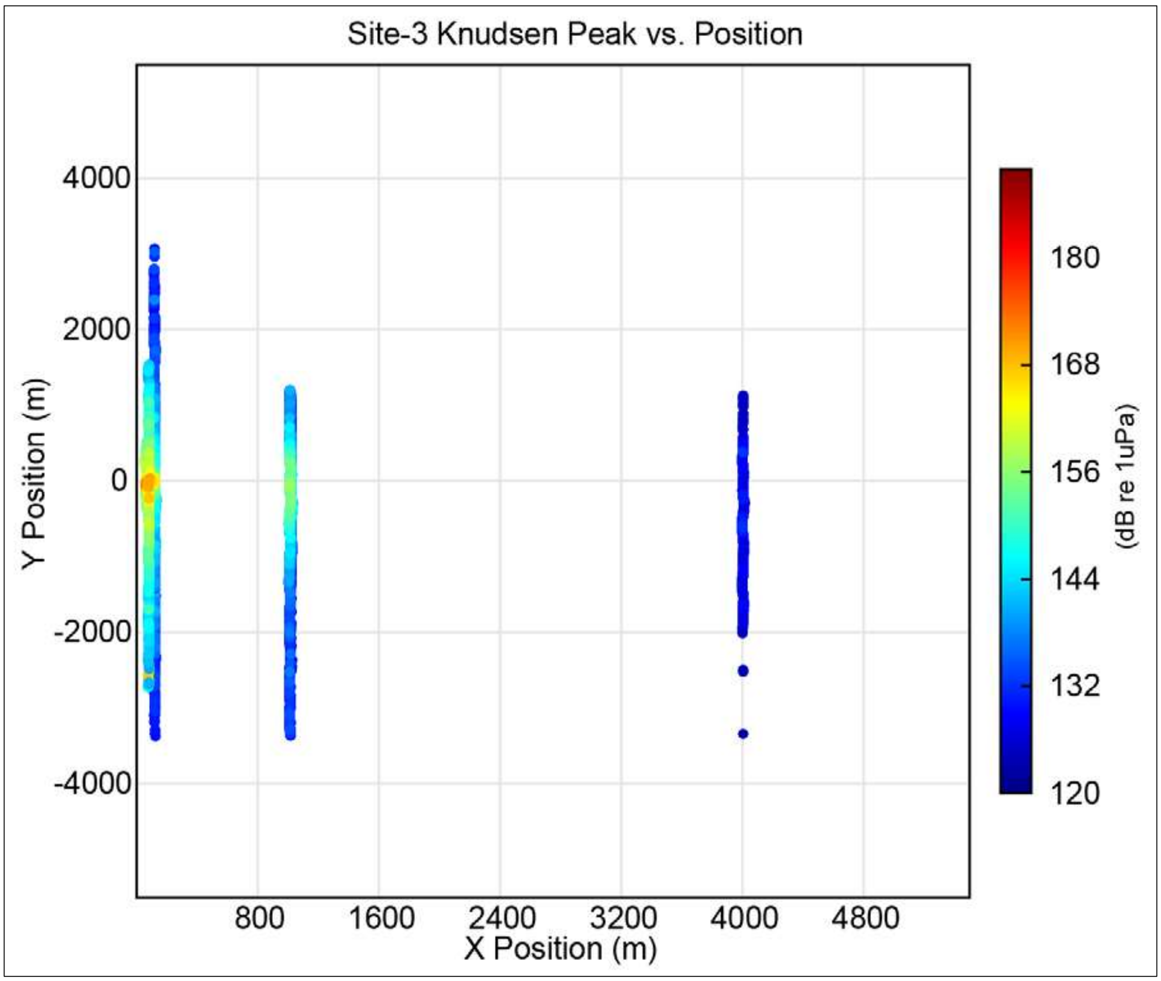


Figure 4.25.3-3. Plan view of received peak level for Knudsen 3260 at Site 3 for position D (Buoy6), B (Buoy11 and Buoy12, combined), A (Buoy5 and Buoy12, combined), E (Buoy8 and Buoy10, combined), and F (Buoy5).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.25.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.25.3-1. Knudsen 3260 source levels, Mode 3, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 3	NA	Level 4	NA	64 ms	215	210	192
NUWC Proxy: Knudsen 3202	NA	Level 4	NA	32 ms	217*	212*	196*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.25.4 Site 4 – Sand, 30 m Depth

At S4, the Knudsen 3260, Mode 3, had valid acoustic recordings in Run7 and Run22. For Run7, positions D (Buoy8) and A (Buoy6) had valid acoustic data. For Run22, there were valid acoustic data, but no signals were captured.

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 3, are shown in **Figure 4.25.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The left panel shows position D (Buoy8) for Run7, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The right panel shows valid recorded acoustics at position A (Buoy6). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.25.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S4, only positions D (Buoy8) and A (Buoy6) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 217 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 214 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). Also note that NUWC did not measure a 64-ms pulse width, thus their 32-ms pulse width mode was used. There are calibration errors (**Section 2.6.3.1**), seen at position D as seen in the received levels being approximately 20 dB down compared to the other positions, seen at position A in the two distinct groupings of peak pressure levels.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 90°, indicating good buoy position; and received peak level for position A at approximately 75°, indicating an error in buoy position. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

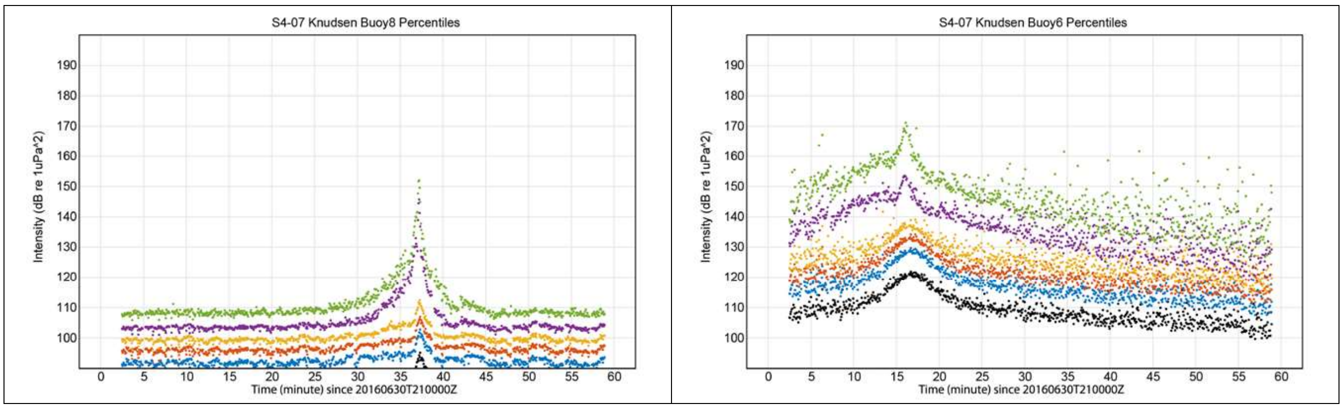


Figure 4.25.4-1. Percentile plots of Knudsen 3260 signals at Site 4.
Left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy8); Right: SPL_{pk} arrival at position A (Buoy6).
Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

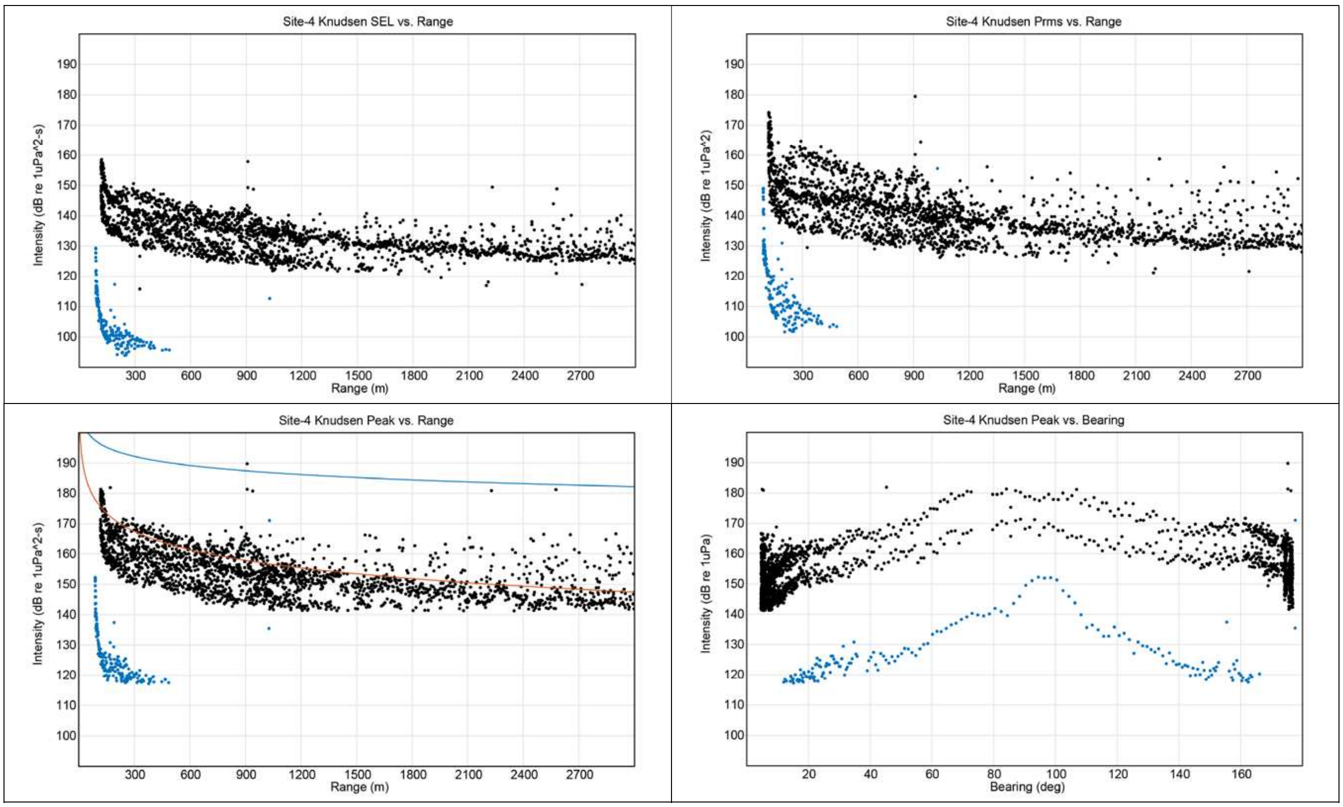


Figure 4.25.4-2. Range results for Knudsen 3260 signals at Site 4 from Run7 for positions D (Buoy8) and A (Buoy6). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue.

The plan view is shown in **Figure 4.25.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 150,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -200 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy8) and A (Buoy6). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis. Position D has unresolved calibration issues.

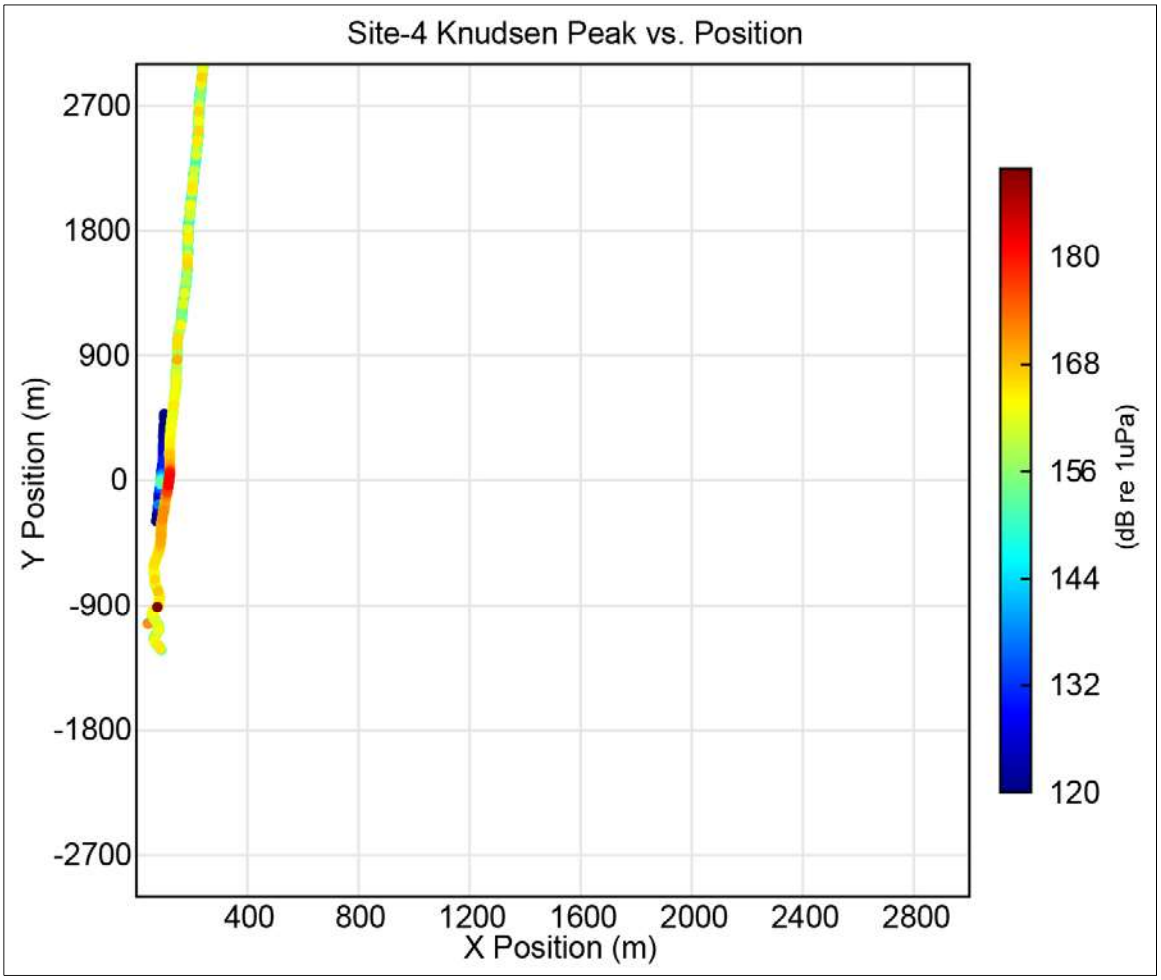


Figure 4.25.4-3. Plan view of received peak level for Knudsen 3260 at Site 4 for positions D (Buoy8) and A (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.25.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.25.4-1. Knudsen 3260 source levels, Mode 3, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 3	NA	Level 4	NA	64 ms	213	205	191
NUWC Proxy: Knudsen 3202	NA	Level 4	NA	32 ms	217*	212*	196*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.25.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Knudsen 3260, Mode 3, had valid acoustic recordings in Run11 and Run21. For Run11, positions D (Buoy6), A (Buoy12), and E (Buoy8) had valid acoustic recordings and observed signals. For Run21, valid acoustic recordings were observed at positions D (Buoy6) and B (Buoy11).

Run Summary

The percentile plots for the available recordings of the Knudsen 3260, Mode 3, are shown in **Figure 4.25.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run11, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recording acoustics at positions D (Buoy6), A (Buoy12), and E (Buoy8).

The results panels (**Figure 4.25.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Knudsen 3260 at S5, positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12), and E (Buoy8) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)]. The reference curves predict received levels for a 217 dB re 1 µPa m, which is based on a NUWC measured Knudsen 3202, using a 2×1 transducer with a peak SL of 214 dB re 1 µPa m. In order to account for the 2×2 transducers used in this study, 3 dB were added to the NUWC measured SL, which provided a proxy for the Knudsen 3260 (Crocker and Fratantonio, 2016). Also note that NUWC did not measure a 64-ms pulse width, thus their 32-ms pulse width mode was used.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level of for all positions at approximately 80°, which is off the expected broadside, based on the buoy GPS navigation. This positioning is unlikely a buoy navigation error, but could be a possible out-of-plane propagation effect or could be due to a slight cant of the source mounted on the sled. Note the source is strongly directional in the vertical, but not in the horizontal. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

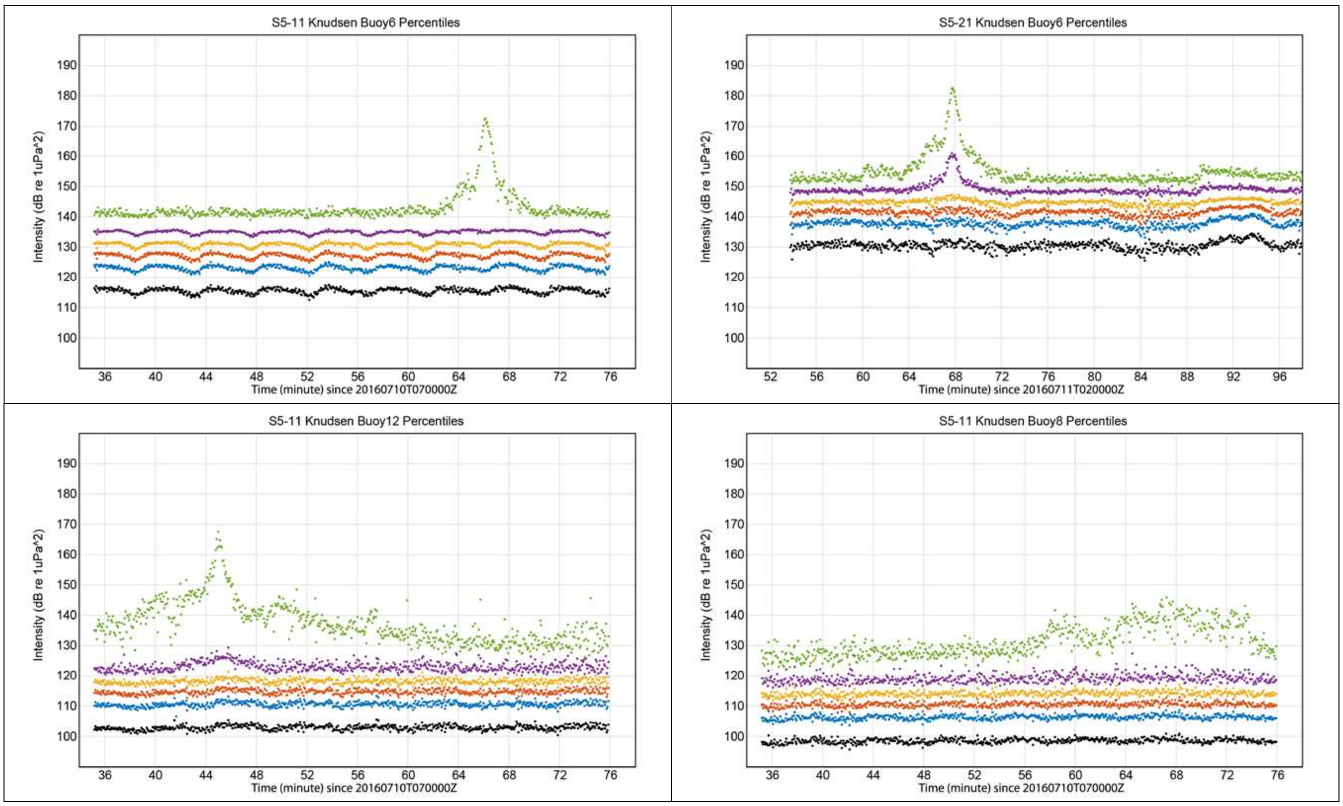


Figure 4.25.5-1. Percentile plots of Knudsen 3260 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position D (Buoy6); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

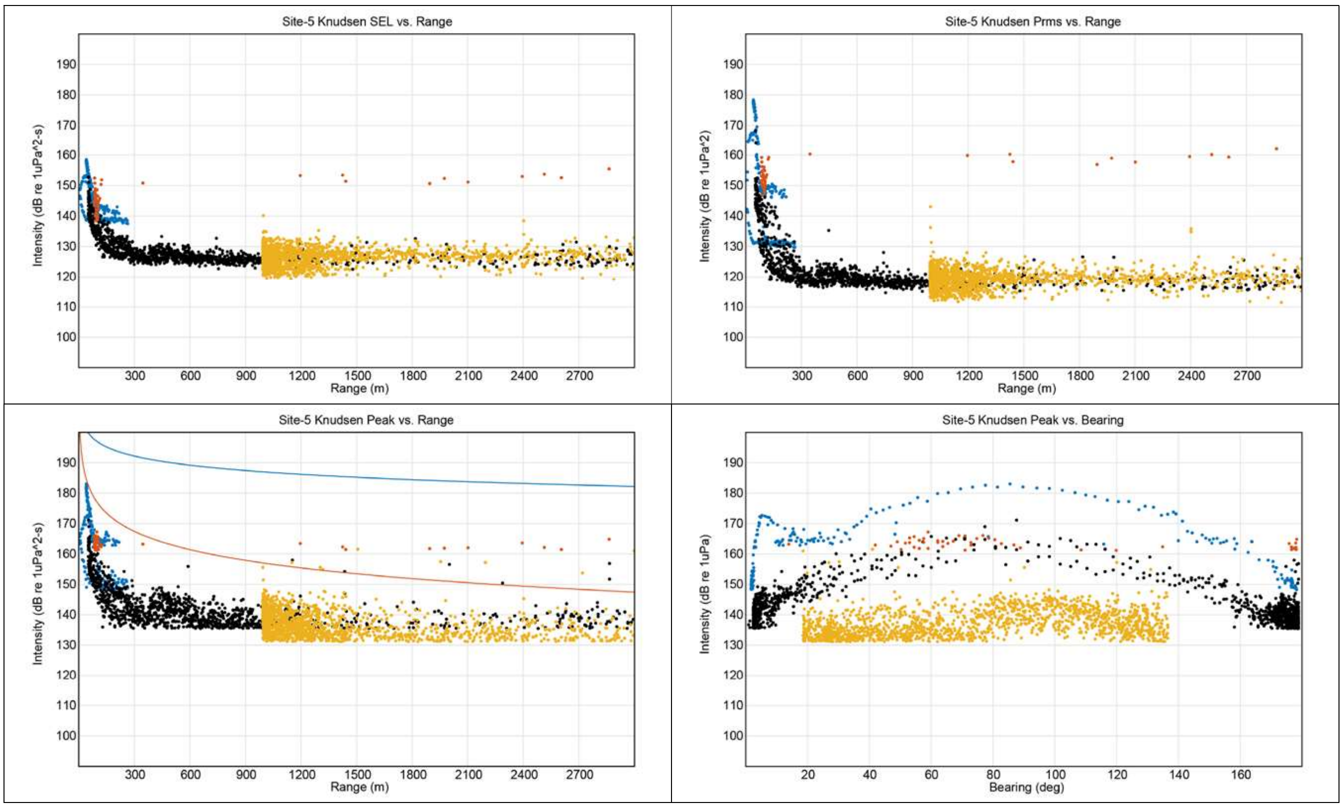


Figure 4.25.5-2. Range results for Knudsen 3260 signals at Site 5 from Run11 and Run21 for positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12), and E (Buoy8).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.25.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,800 to 2,800-m marks on the y-axis. The CPA is at 71,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

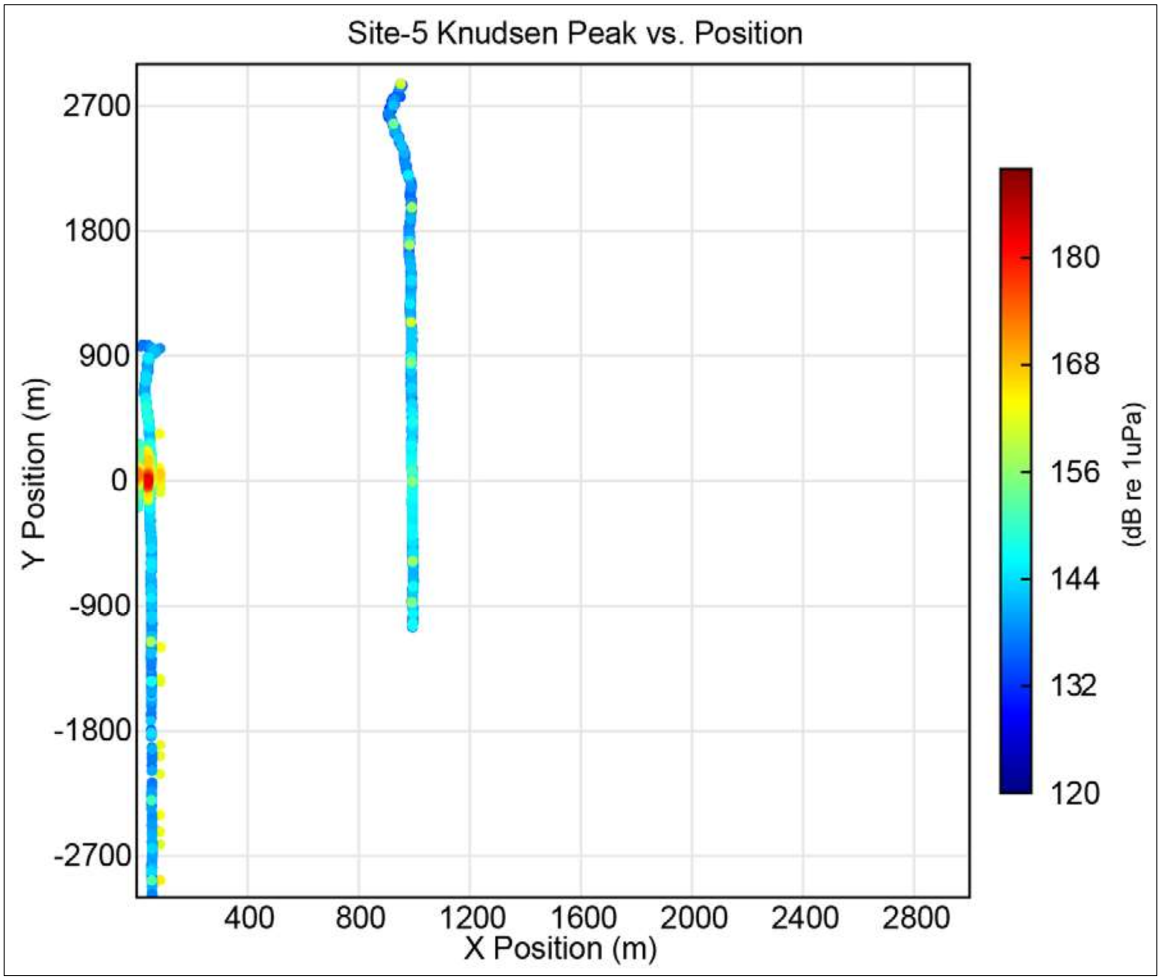


Figure 4.25.5-3. Plan view of received peak level for Knudsen 3260 at Site 5 for positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.25.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.25.5-1. Knudsen 3260 source levels, Mode 3, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Cycles, Pulse Width**	**Pk**	**rms**	**SEL**
Knudsen 3260 Mode 3	NA	Level 4	NA	64 ms	215	211	192
NUWC Proxy: Knudsen 3202	NA	Level 4	NA	32 ms	217*	212*	196*

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; ms = millisecond; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 3 dB were added to the SL to account for the Knudsen 3260 2×2 transducer array.

4.26 Applied Acoustics 252 S-Boom, 0.1-5 kHz, 1 kJ, Low Power, Three Plates (Mode 1)

The Applied Acoustics 252 S-Boom generates a single, low-frequency (LF) signal with a peak frequency of 1 kHz. The operational parameter settings for Mode 1 were 1 kJ, low power, three plates, and 0.1 to 5 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.26-1** is the selected frequency band (0 to 12 kHz) and SPL_{pk} (196 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.26-1. Bandpass determination for the Applied Acoustics 252 S-Boom, 0.1-5 kHz, 1 kilojoule, low power, and three plates at Site 2, Run4.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-220	196.17
0-100	196.25
0-22	196.21
0-12	**196.192**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The 252 S-Boom, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.26-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The S-Boom was operationally paired in alternation with the ET424. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.26-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

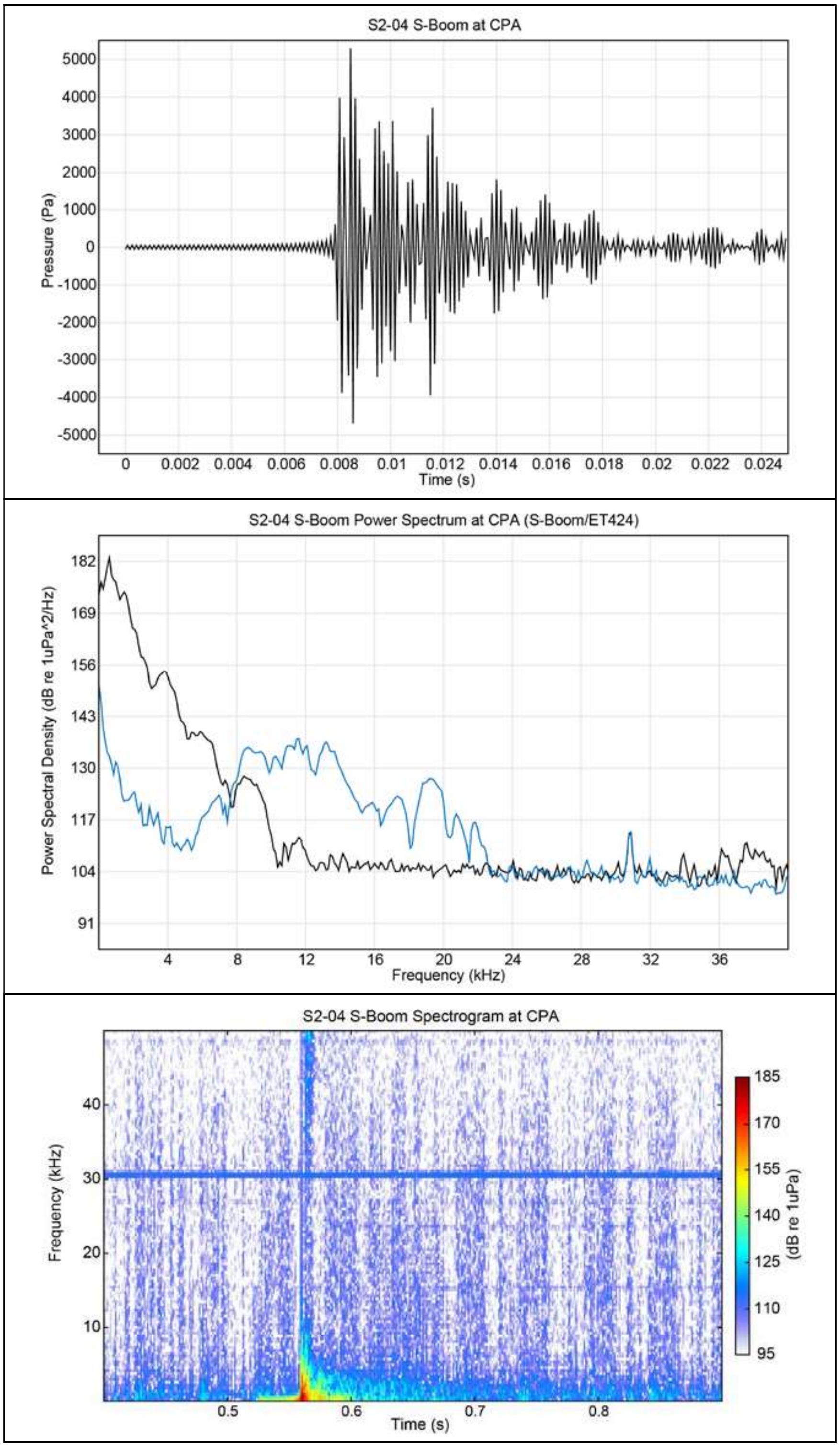


Figure 4.26-1. Applied Acoustics 252 S-Boom, 1 kilojoule low power, measured signal characteristics at closest point of approach (CPA) at Site 2, Run4.
Top: Time-waveform of a signal; Middle: Power spectral density, S-Boom = black, ET424 = blue; Bottom: Spectrogram.

4.26.1 Site 1 – Mud, 10 m Depth

At S1, the 252 S-Boom, Mode 1, had valid acoustic recordings in Run4 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the 252 S-Boom, Mode 1, are shown in **Figure 4.26.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run4, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.26.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the 252 S-Boom at S1, positions D (Buoy6), E (Buoy5 and Buoy8, combined), and F (Buoy9) had acoustic signal. The received levels are low at position E and possibly at position F, which are likely due to unresolved calibration issues (**Section 2.6.3.1**). The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 208 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). Position E had lower received levels relative to other positions, which is likely the result of a calibration error.

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.26.1-2**), which shows the received peak level for position D at approximately 115° indicating an error in buoy positioning. Positions E and F, which were at a greater distance and less sensitive to bearing, show peaks near 90°, indicating good buoy positioning.

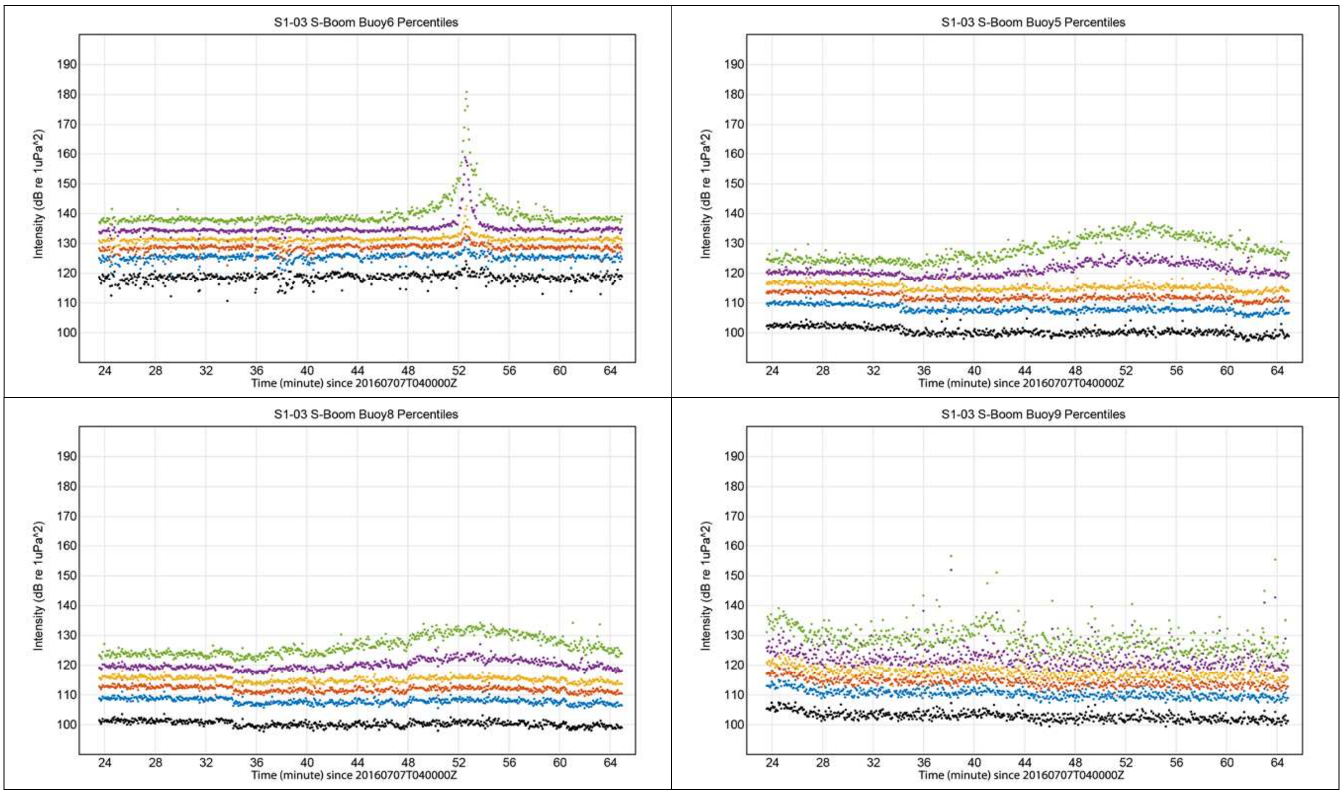


Figure 4.26.1-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

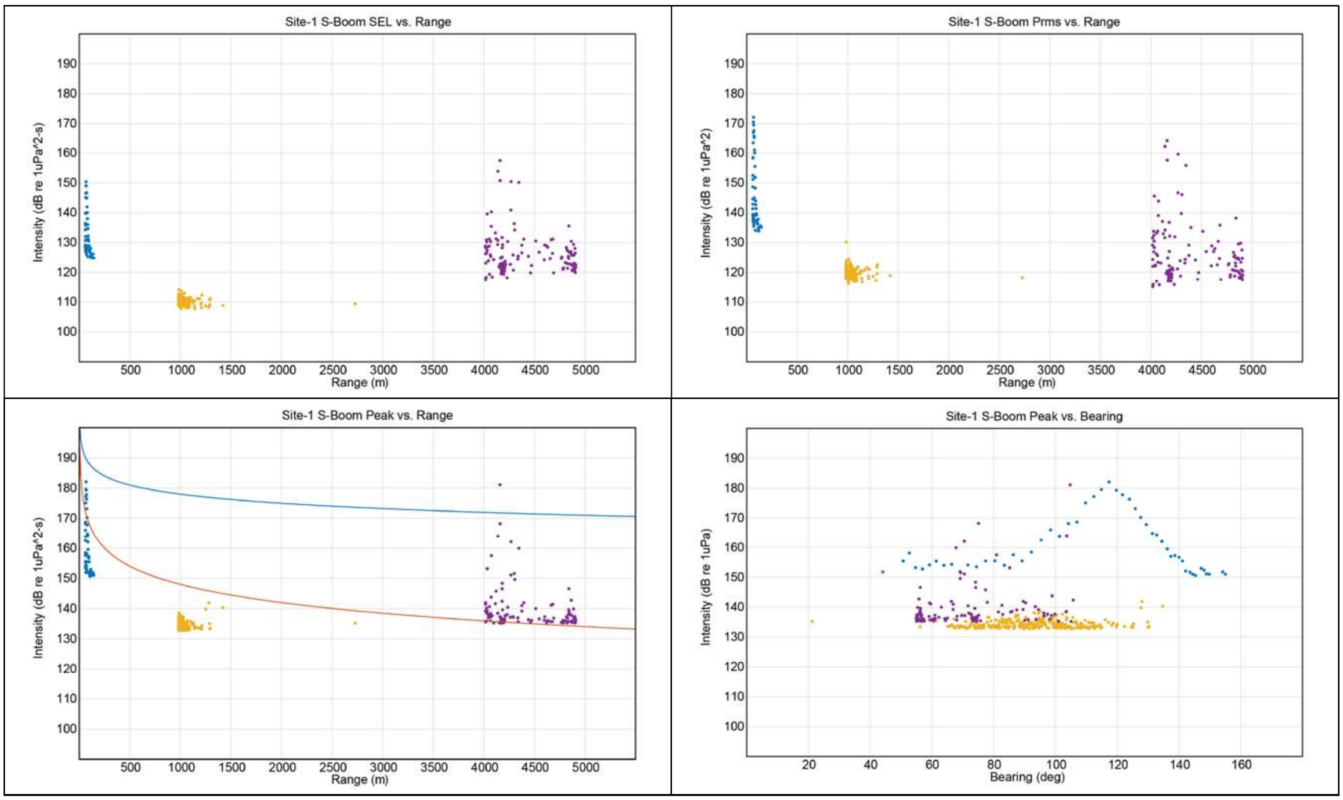


Figure 4.26.1-2. Range results for Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy8, combined), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.26.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

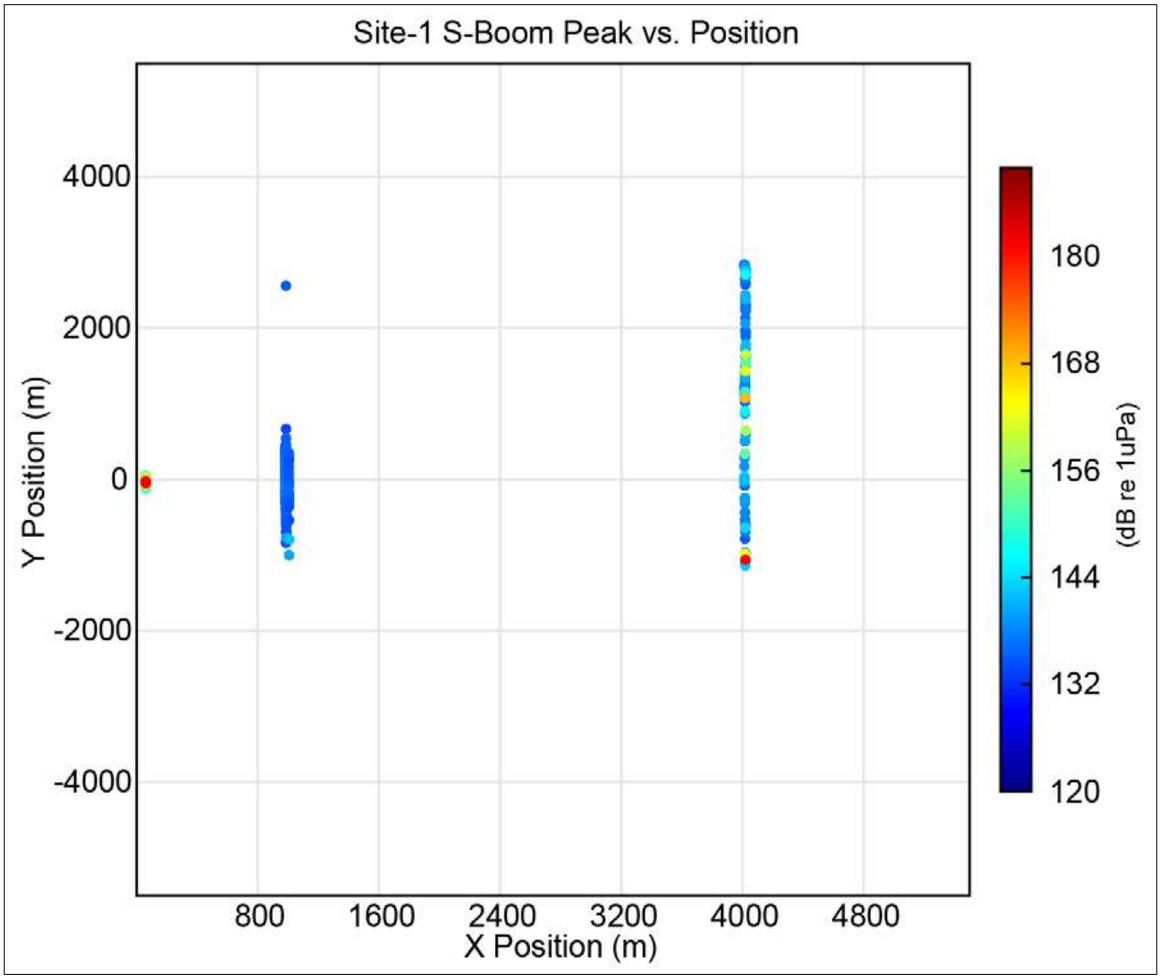


Figure 4.26.1-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 1 kilojoule low power, at Site 1 for positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.26.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.26.1-1. Applied Acoustics 252 S-Boom source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
252 S-Boom Mode 1	0.1-5	1,000 J	Low Power	3 Plates	207	197	176
NUWC	0.1-5	1,000 J	Low Power	3 Plates	208	202	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.26.2 Site 2 – Sand, 10 m Depth

At S2, the 252 S-Boom, Mode 1, had valid acoustic recordings in Run4 and Run31. For Run4, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run31, position B (Buoy5 and Buoy11) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 1, are shown in **Figure 4.26.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run4, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position B (Buoy5 and Buoy11). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.26.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 252 S-Boom at S2, positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11, combined) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 210 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The shape of the data points signifies the approach and departure of the source to and from the buoys. The rapid fall-off with range shows the source directionality and high propagation loss of this signal at S2. The large asymmetry of the position D data indicates a navigation error. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 208 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.26.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 150°, indicating an error in buoy positioning. For position E, the received peak level is at approximately 90°, which indicates good navigational buoy positioning.

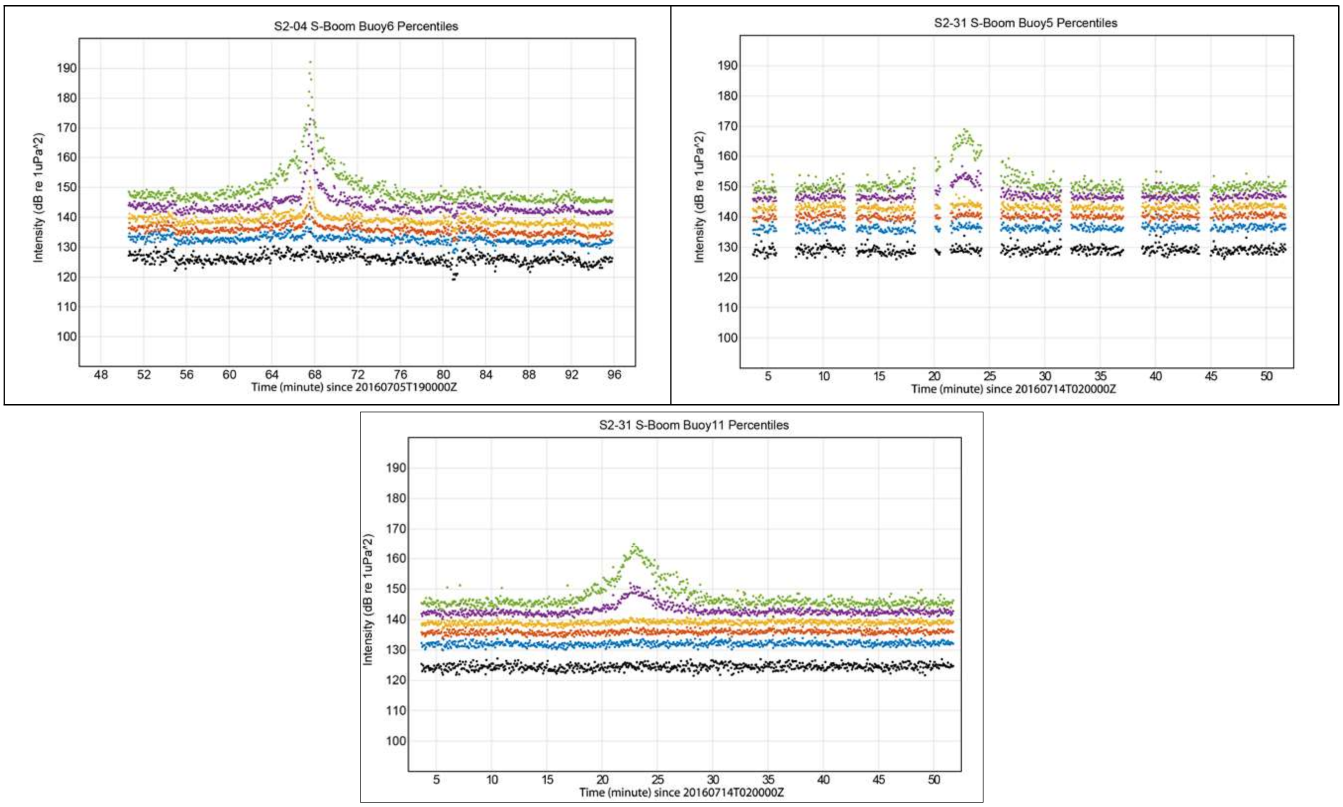


Figure 4.26.2-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom: SPL_{pk} arrival at position B (Buoy11). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

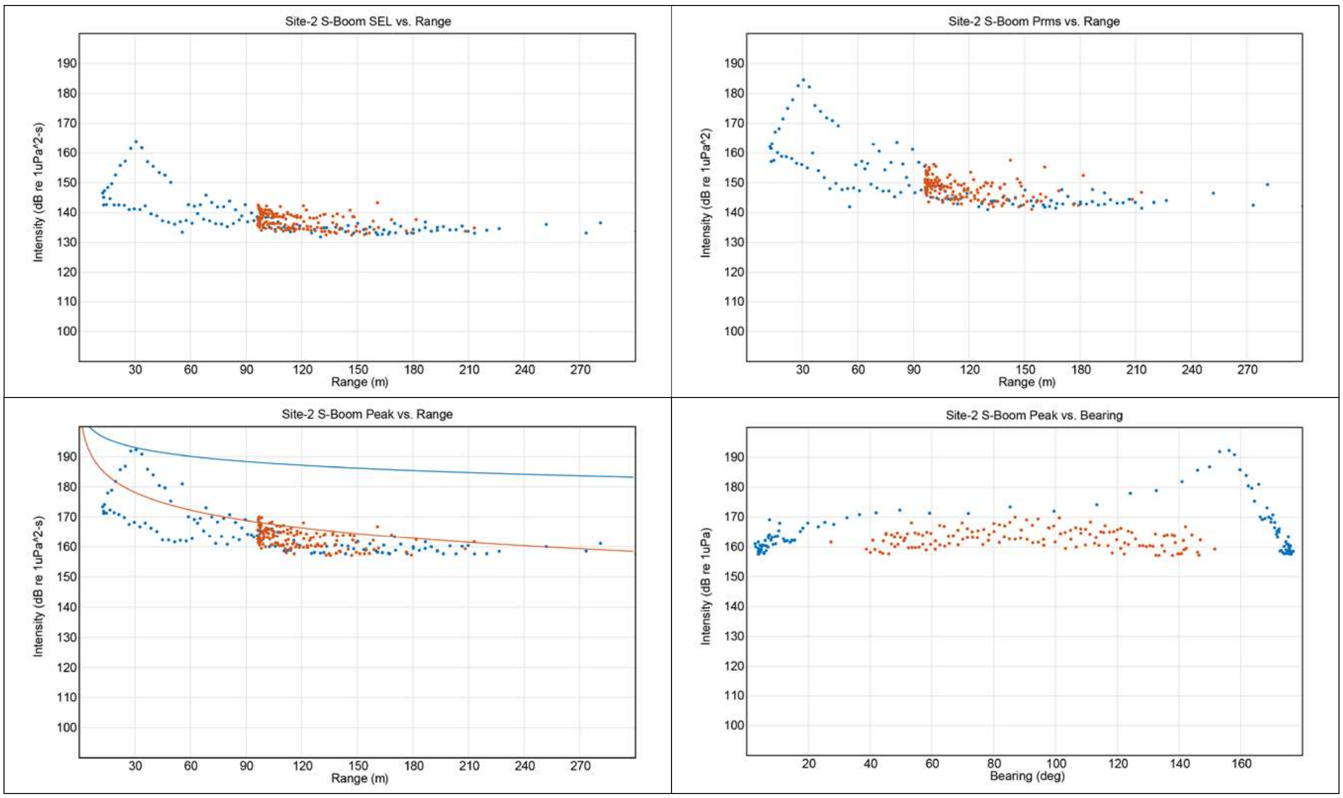


Figure 4.26.2-2. Range results for Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 2 for positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.26.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -300 to 300-m marks on the y-axis. The CPA is at 15,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -230 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -30 m on the y-axis.

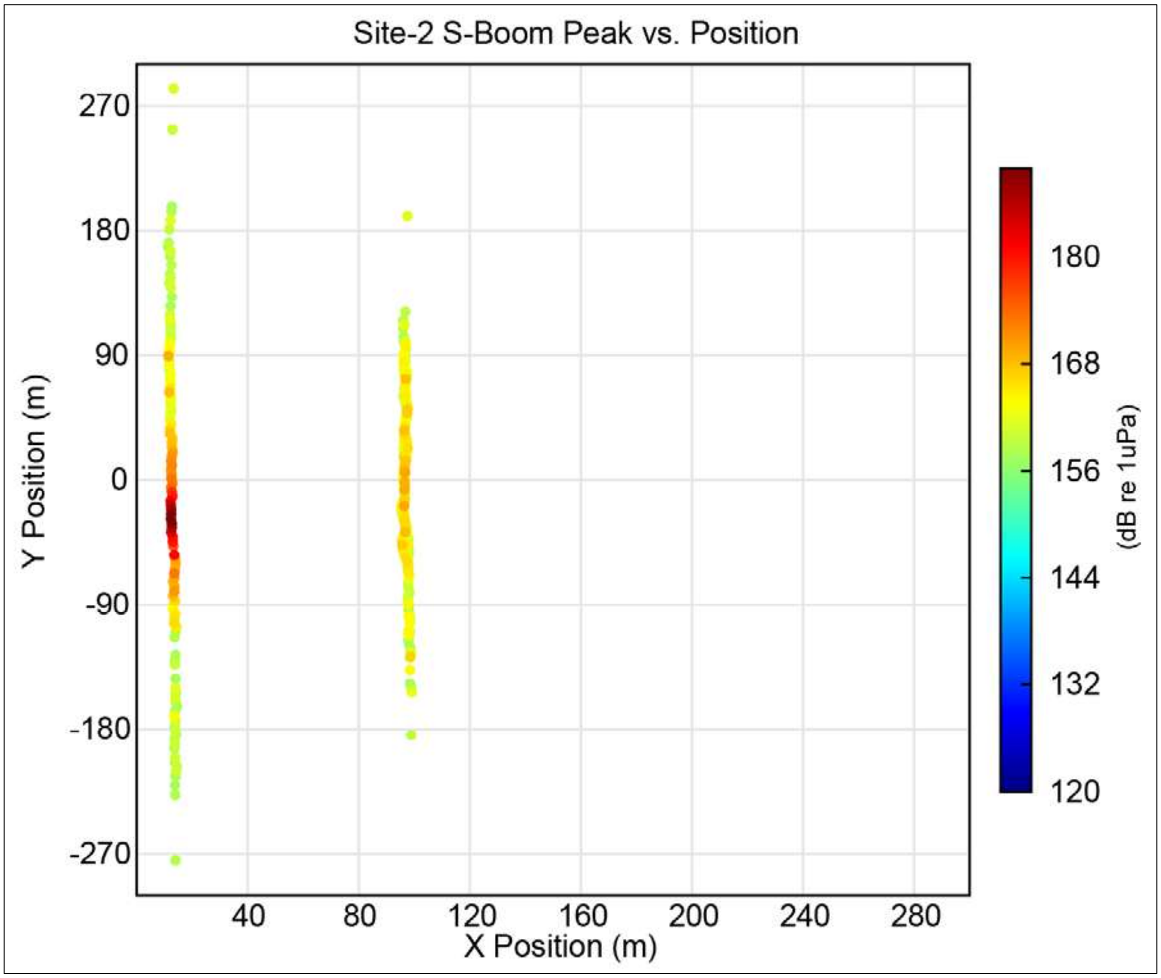


Figure 4.26.2-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 1 kilojoule low power, at Site 2 for positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.26.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results

Table 4.26.2-1. Applied Acoustics 252 S-Boom source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
252 S-Boom Mode 1	0.1-5	1,000 J	Low Power	3 Plates	207	198	176
NUWC	0.1-5	1,000 J	Low Power	3 Plates	208	202	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.26.3 Site 3 – Mud, 30 m Depth

At S3, the 252 S-Boom, Mode 1, had valid acoustic recordings in Run6 and Run27. For Run6, position B (Buoy5 and Buoy12) had valid acoustic recordings. For Run27, position E (Buoy10) had acoustic recordings.

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 1, are shown in **Figure 4.26.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run6, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position B (Buoy5). Position E (Buoy10) from Run27 is shown in the bottom right panel, and the shape of the data and the sound levels are incorrect; therefore, the data were not processed further in this analysis. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.26.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the 252 S-Boom at S3, position B (Buoy5 and Buoy12, combined) and position E (Buoy10) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to 2,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 208 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 120°, indicating an error in buoy positioning.

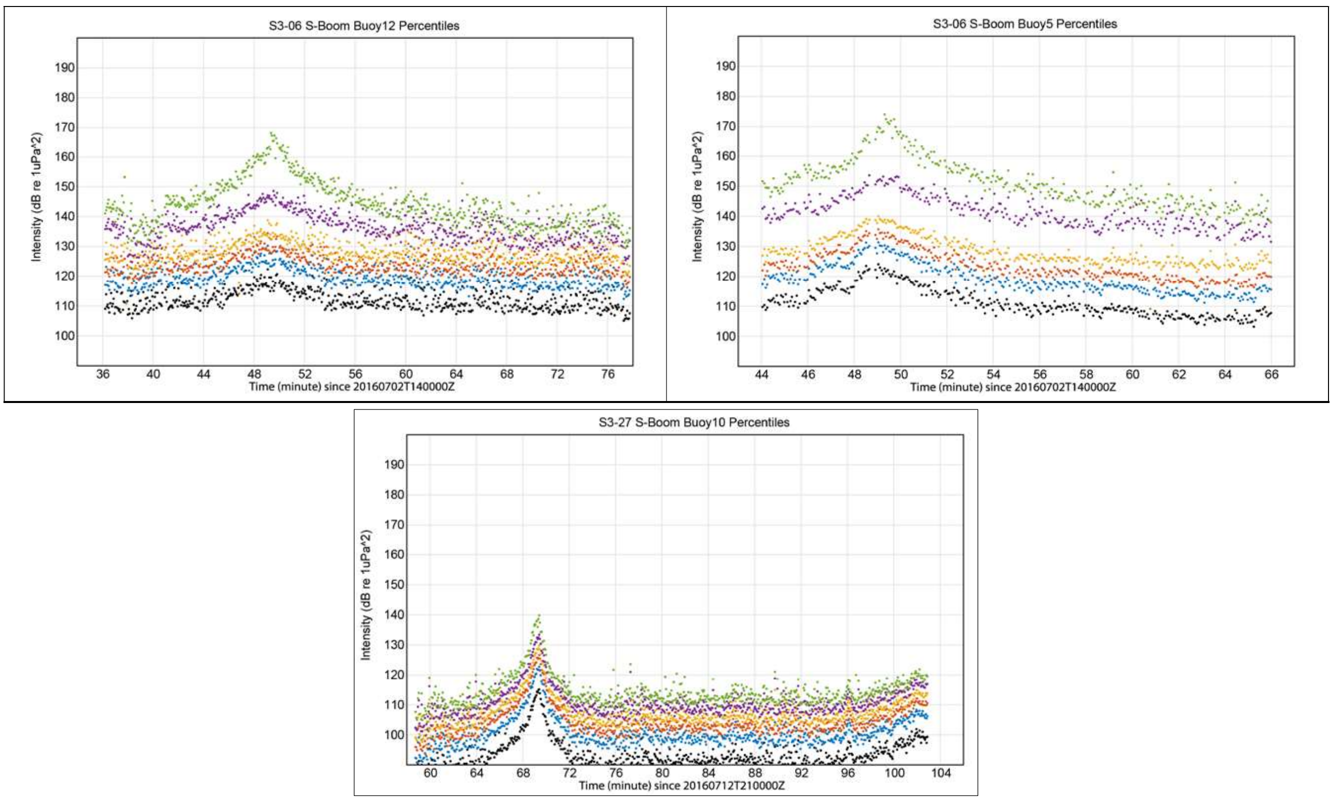


Figure 4.26.3-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

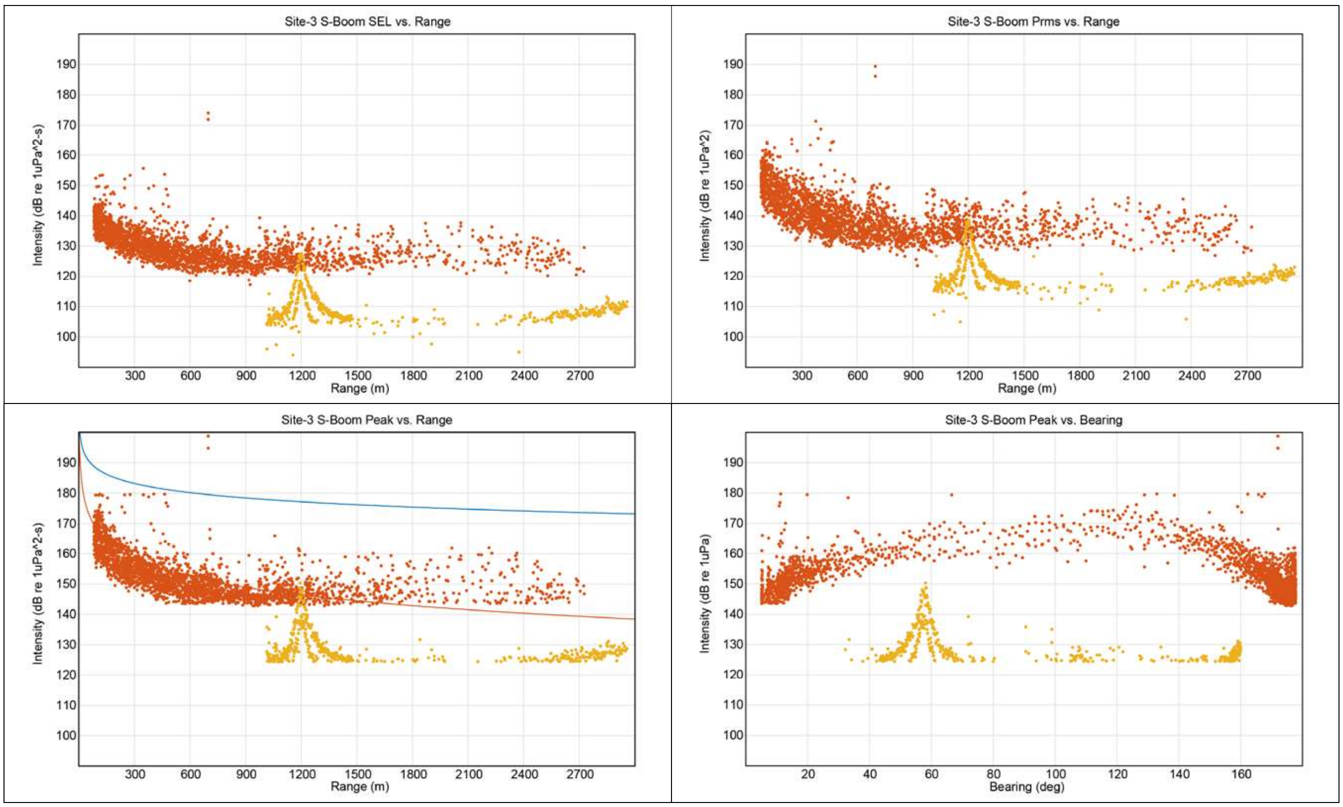


Figure 4.26.3-2. Range results for Applied Acoustics 252 S-Boom combined signals, 1 kilojoule low power, for Run6 and Run27 at Site 3 for positions B (Buoy5 and Buoy12, combined) and E (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, B = red; E = yellow.

The plan view is shown in **Figure 4.26.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -2,700 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy5 and Buoy12) and E (Buoy10). Recordings at the buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position B is seen at approximately -30 m on the y-axis.

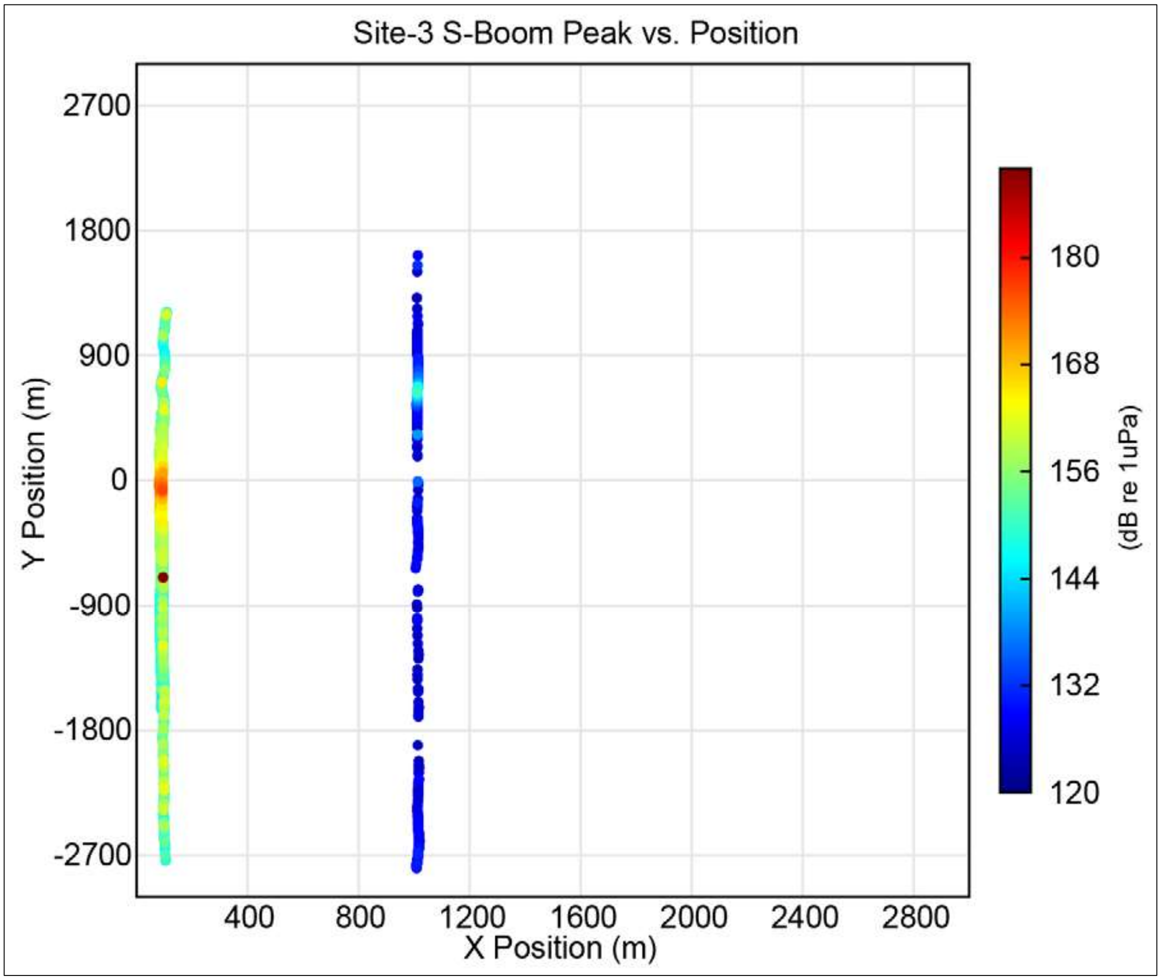


Figure 4.26.3-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 1 kilojoule low power, at Site 3 for position B (Buoy5 and Buoy12) and E (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.26.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.26.3-1. Applied Acoustics 252 S-Boom source levels, Mode 1, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
252 S-Boom Mode 1	0.1-5	1,000 J	Low Power	3 Plates	207	192	174
NUWC	0.1-5	1,000 J	Low Power	3 Plates	208	202	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.26.4 Site 4 – Sand, 30 m Depth

At S4, the 252 S-Boom, Mode 1, had valid acoustic recordings in Run6 and Run21. For Run6, positions D (Buoy8) and A (Buoy6) had valid acoustic data with signals observed. For Run21, positions B (Buoy12) and A (Buoy7) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 1, are shown in **Figure 4.26.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy8) for Run6, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The levels for this recording are low and presumed incorrect. The top right and bottom panels show valid recorded acoustics at positions B (Buoy12), A (Buoy6), and A (Buoy7). The received signal is observed at position A (Buoy6). However, positions B (Buoy12) and A (Buoy7) did not capture any acoustic signals; these data are shown for completeness. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.26.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 252 S-Boom at S4, positions D (Buoy8) and A (Buoy6) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 900 m. There are calibration errors (**Section 2.6.3.1**) at position D as seen in the received levels being approximately 40 dB down compared to the other positions. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 208 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 100° and for position A at approximately 110°, indicating errors in buoy positioning.

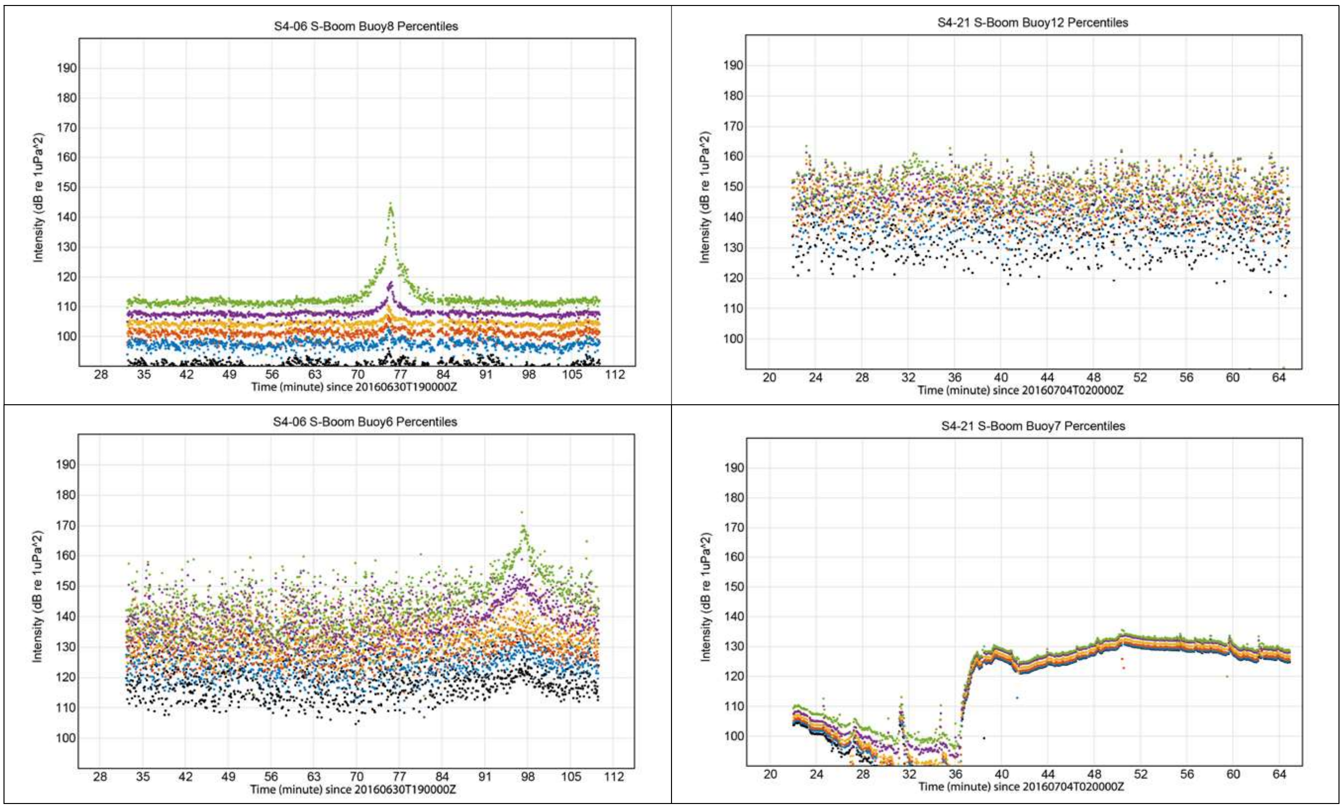


Figure 4.26.4-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy8); Top right: SPL_{pk} arrival at position B (Buoy12); Bottom left: SPL_{pk} arrival at position A (Buoy6); Bottom right: SPL_{pk} arrival at position A (Buoy7). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

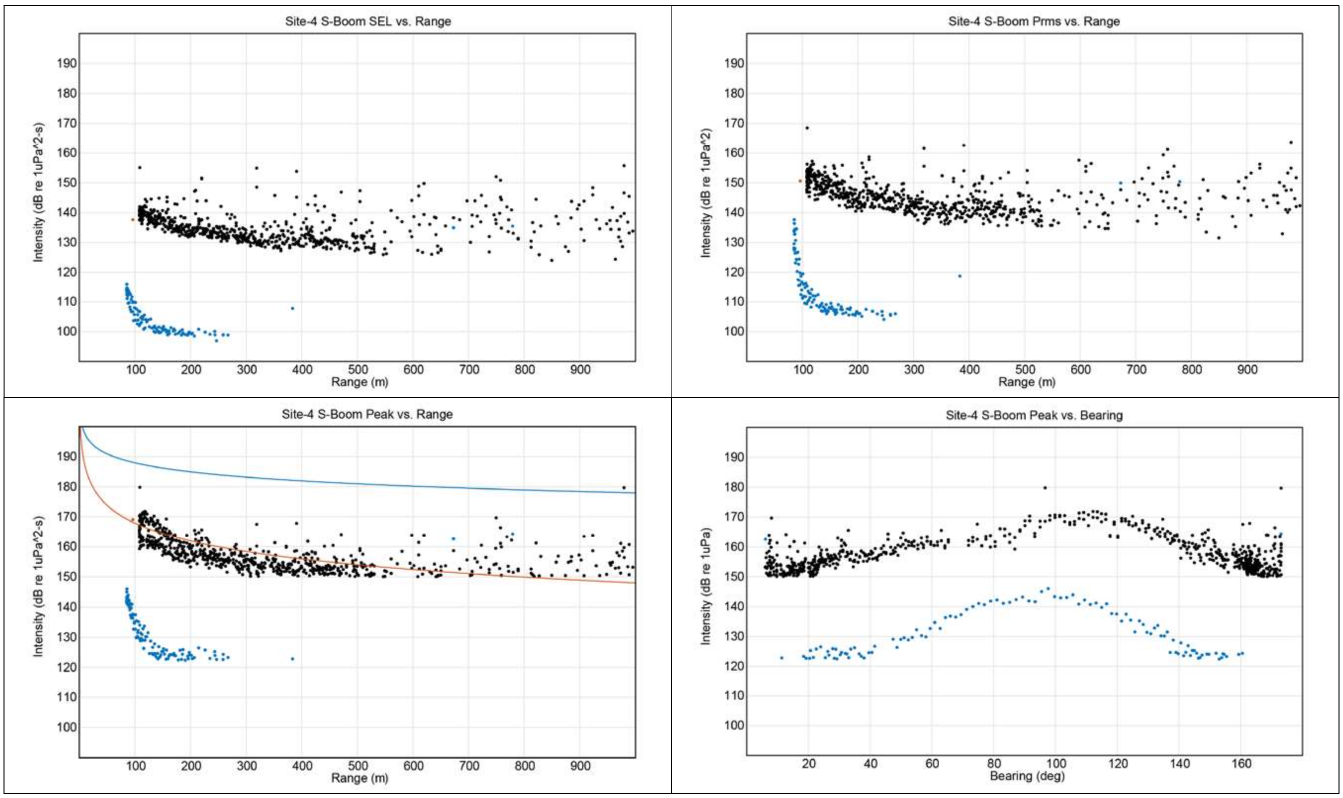


Figure 4.26.4-2. Range results for Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 4 for positions D (Buoy8) and A (Buoy6).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue.

The plan view is shown in **Figure 4.26.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 80,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -280 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy8) and A (Buoy6). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -30 m on the y-axis, while position A had high amplitudes at approximately -50 m.

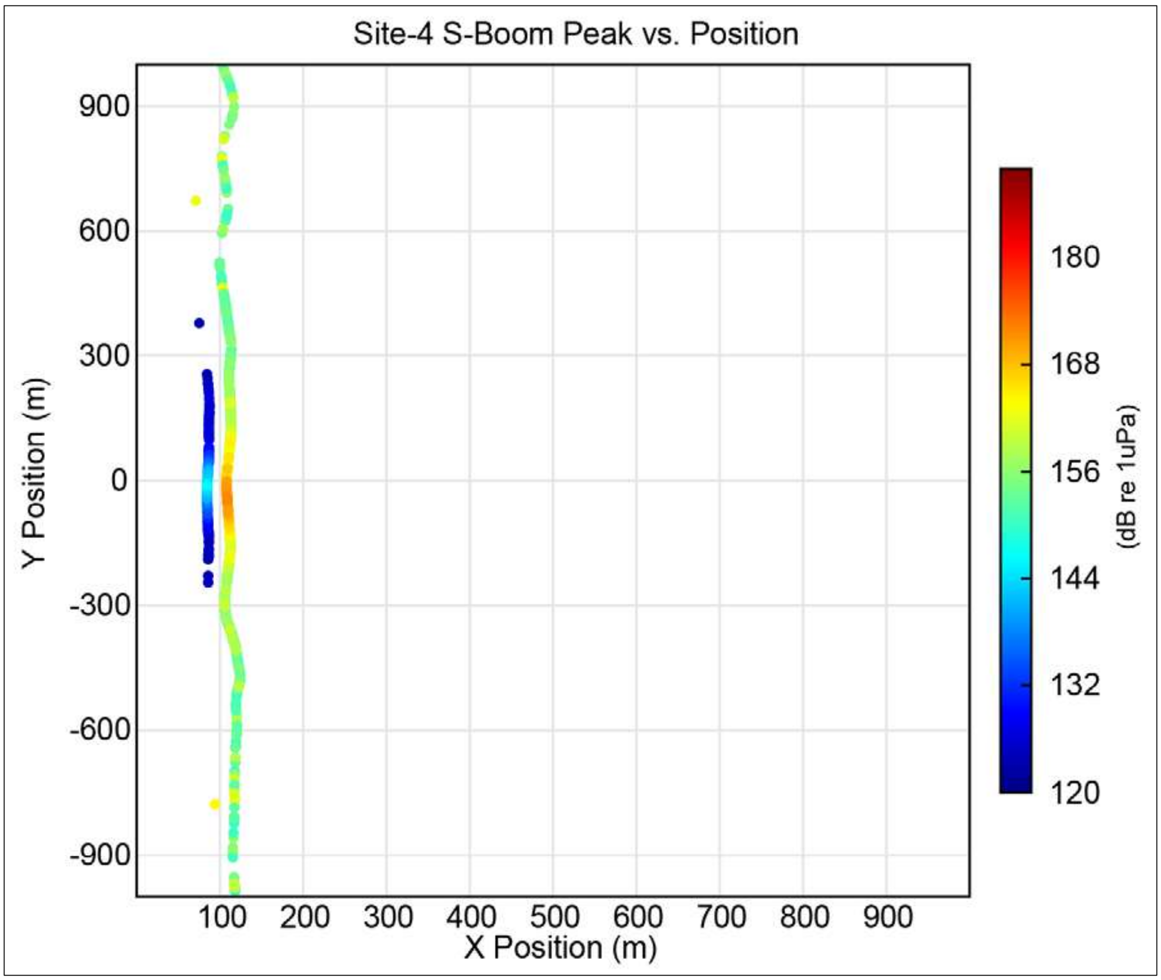


Figure 4.26.4-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 1 kilojoule low power, at Site 4 for positions D (Buoy8) and A (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.26.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.26.4-1. Applied Acoustics 252 S-Boom source levels, Mode 1, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
252 S-Boom Mode 1	0.1-5	1,000 J	Low Power	3 Plates	213	197	185
NUWC	0.1-5	1,000 J	Low Power	3 Plates	208	202	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.26.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the 252 S-Boom, Mode 1, had valid acoustic recordings in Run8and Run25. For Run8, positions D (Buoy6), A (Buoy12), and E (Buoy8) had valid acoustic recordings. For Run25, valid acoustic recordings were observed at positions A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 1, are shown in **Figure 4.26.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run8, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position A (Buoy12), E (Buoy8), and F (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.26.5-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 252 S-Boom at S5, positions D (Buoy6), A (Buoy12 and Buoy12, combined), E (Buoy8, Buoy8, and Buoy9, combined), and F (Buoy10) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 5,000 m. There is some spread associated with calibration uncertainty. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 208 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D, A, E, and F at approximately 120°, which is off the expected broadside based on the buoy GPS navigation, and could be due to the orientation of the source on the sled or to 3-dimensional propagation effects.

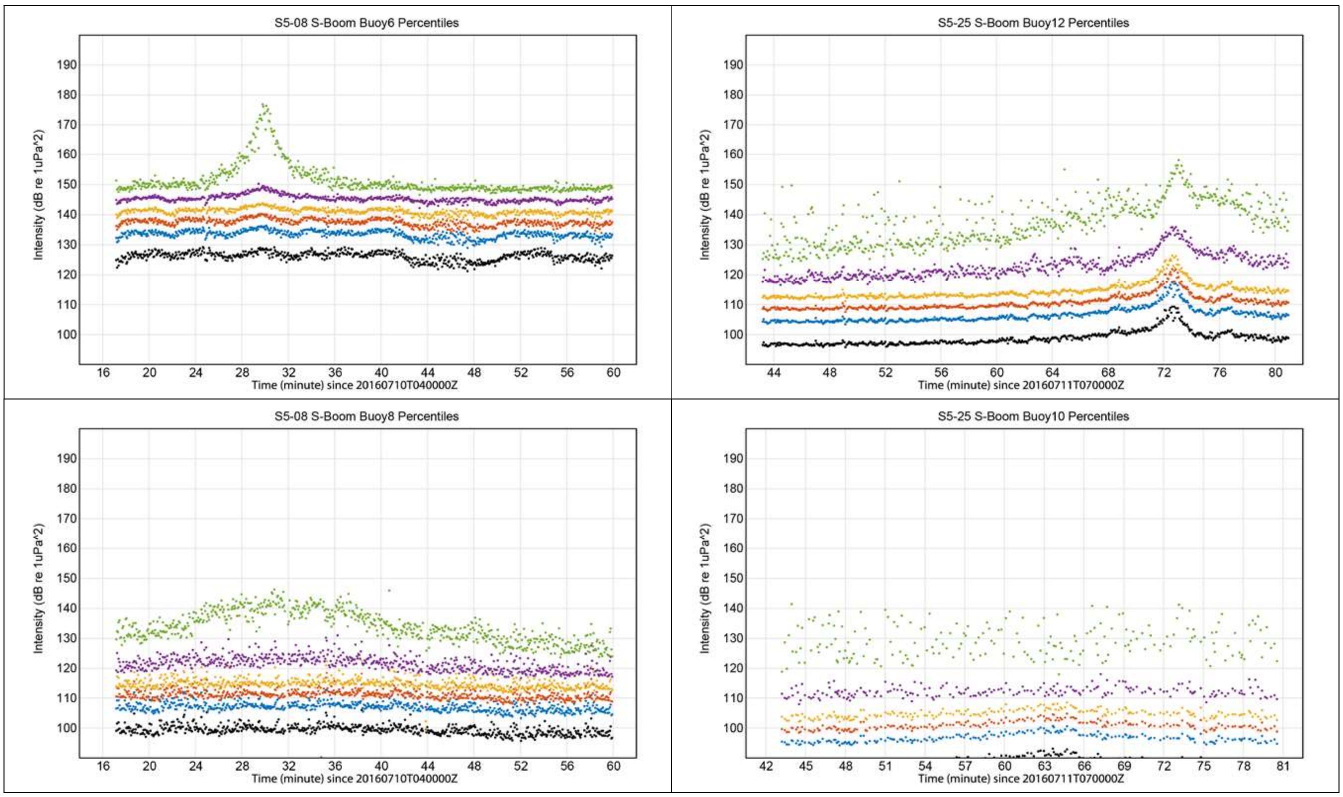


Figure 4.26.5-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

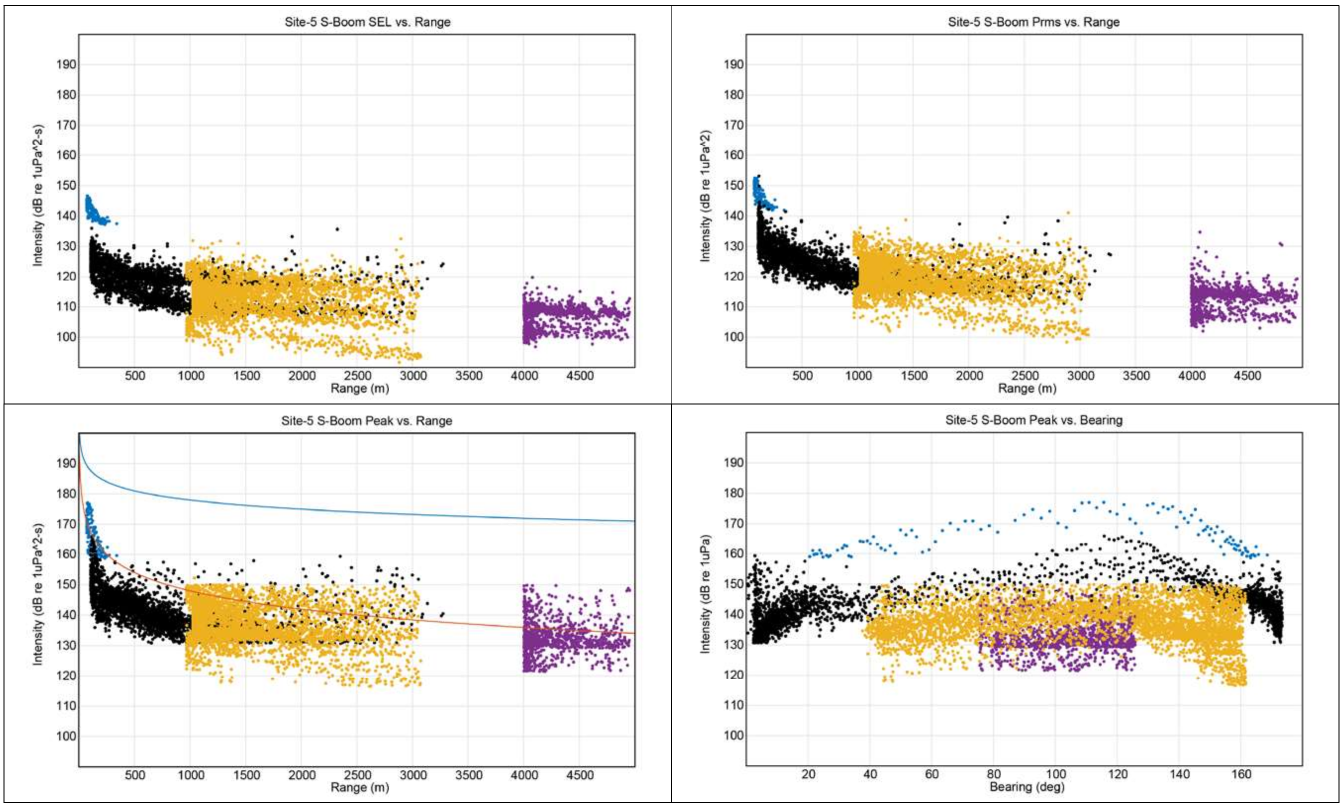


Figure 4.26.5-2. Range results for Applied Acoustics 252 S-Boom signals, 1 kilojoule low power, at Site 5 from Run12 and Run26 for positions D (Buoy6), A (Buoy12 and Buoy12, combined), E (Buoy8, Buoy8, and Buoy9, combined), and F (Buoy10). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.26.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 71,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. The fall off with range is rapid due to the vertical beam pattern of the source. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), A (Buoy12 and Buoy12), E (Buoy8, Buoy8, and Buoy9), and F (Buoy10). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

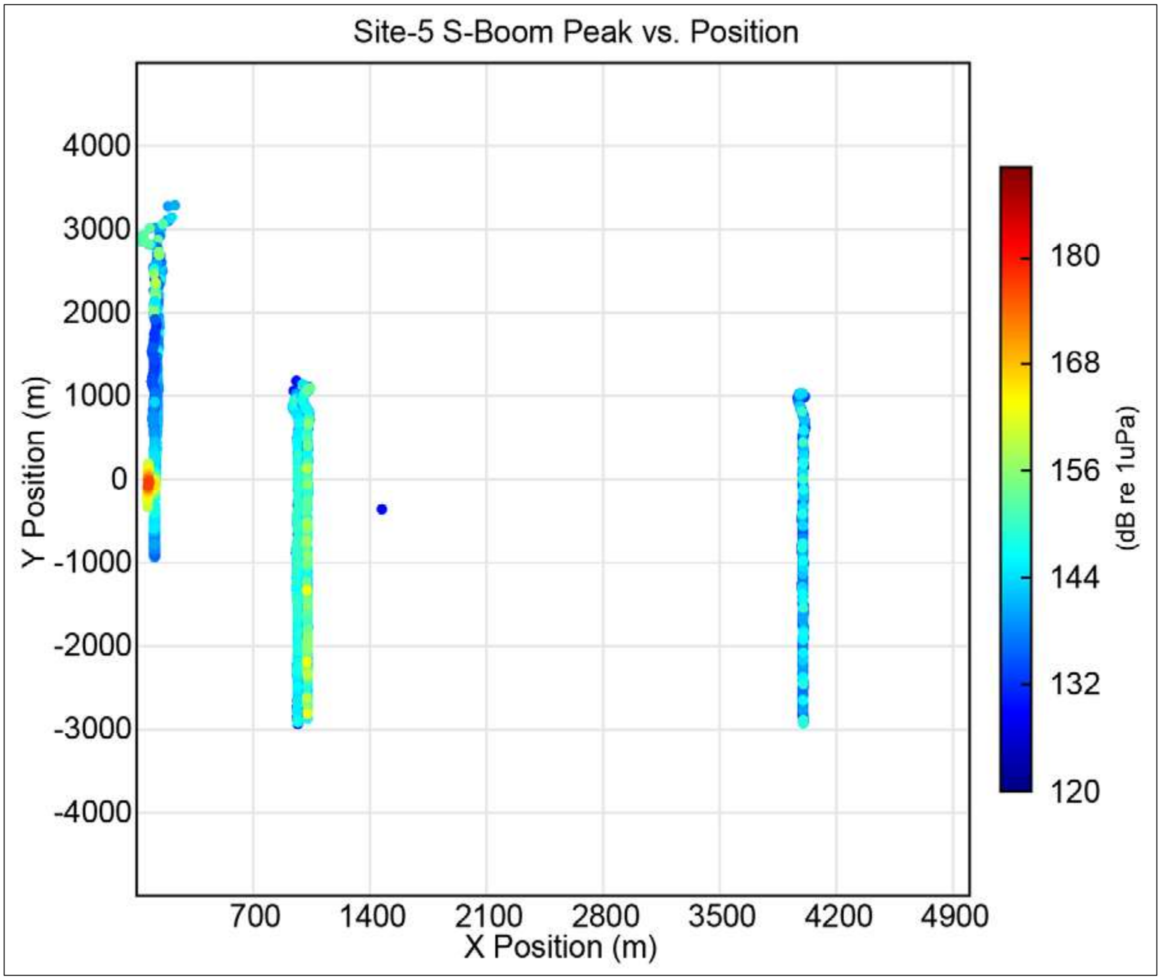


Figure 4.26.5-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 1 kilojoule low power, at Site 5 for positions D (Buoy6), A (Buoy12 and Buoy12), E (Buoy8, Buoy8, and Buoy9), and F (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.26.5-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.26.5-1. Applied Acoustics 252 S-Boom source levels, Mode 1, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
252 S-Boom Mode 1	0.1-5	1,000 J	Low Power	3 Plates	214	190	182
NUWC	0.1-5	1,000 J	Low Power	3 Plates	208	202	171

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Left Intentionally Blank

4.27 Applied Acoustics 252 S-Boom, 0.1-5 kHz, 200 J, Low Power, Single Plate (Mode 2)

The Applied Acoustics 252 S-Boom generates a single, low-frequency signal with a peak frequency of 1 kHz. The operational parameter settings for Mode 2 were a power setting of 200 J, low power, single plate, and 0.1-5 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.27-1** is the selected frequency band (0 to 12 kHz) and SPL_{pk} (196 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.27-1. Bandpass determination for the Applied Acoustics 252 S-Boom, 0.1-5 kHz, 200 Joules, low power, single plate at Site 2, Run4.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-220	196.25
0-100	188.21
0-25	196.49
0-12	**196.14**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The 252 S-Boom, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.27-1.** As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The S-Boom was operationally paired in alternation with the ET424. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of Figure **4.27-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

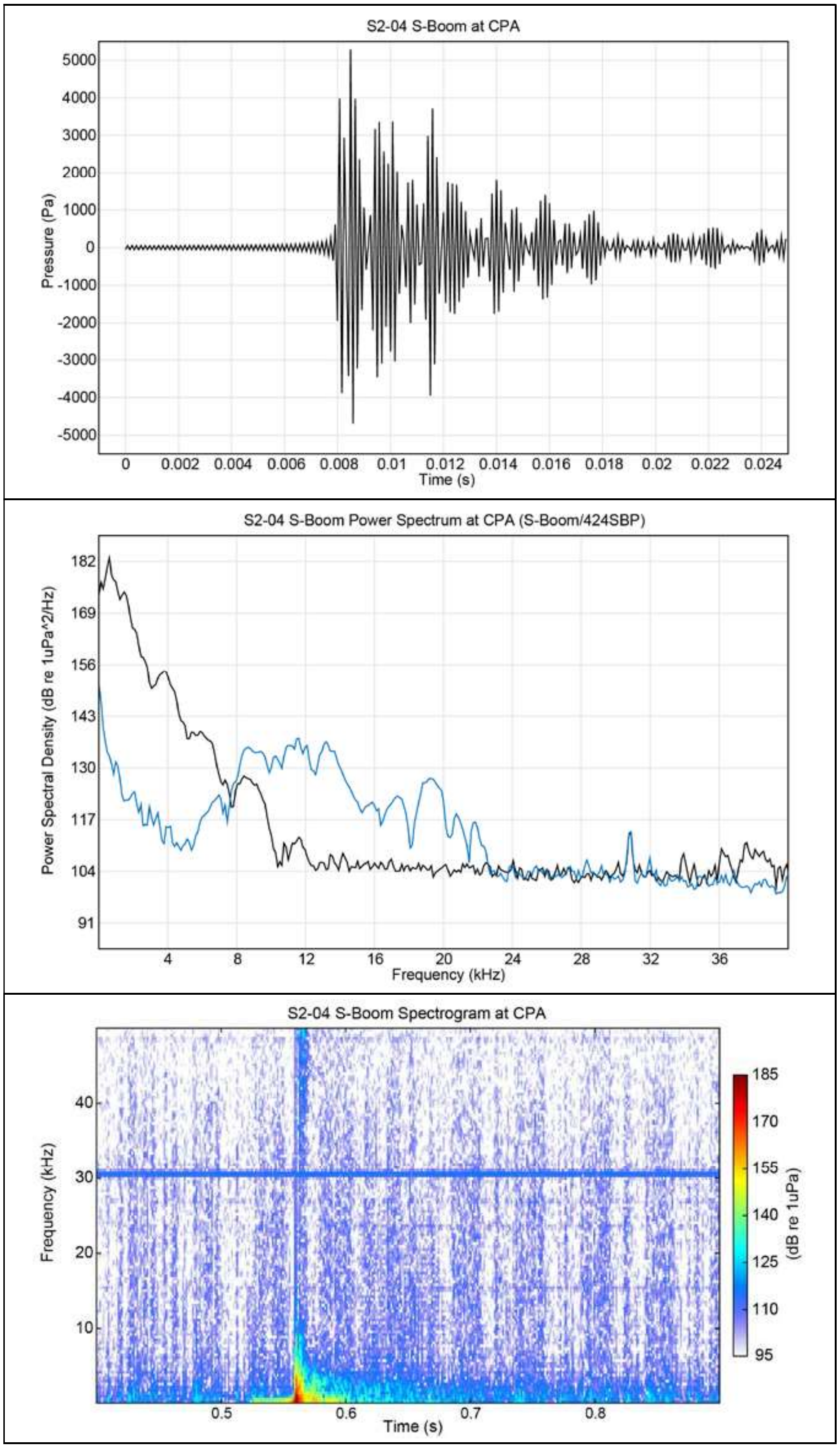


Figure 4.27-1. Applied Acoustics 252 S-Boom, 200 Joules, low power, measured signal characteristics at closest point of approach (CPA) at Site 2, Run4.
Top: Time-waveform of a signal; Middle: Power spectral density, S-Boom = black, ET424 = blue; Bottom: Spectrogram.

4.27.1 Site 1 – Mud, 10 m Depth

The S-Boom, Mode 2, was not deployed or operated at S1.

4.27.2 Site 2 – Sand, 10 m Depth

At S2, the S-Boom, Mode 2, had valid acoustic recordings in Run5 and Run32. For Run5, positions D (Buoy6) and B (Buoy11) had valid acoustic recordings; for Run32, position B (Buoy5 and Buoy11) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 2, are shown in **Figure 4.27.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run5, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position B (Buoy5, Buoy11, and Buoy11). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.27.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 252 S-Boom at S2, positions D (Buoy6) and B (Buoy5, Buoy11, Buoy11, combined) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 201 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.27.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D and B at approximately 130°, indicating errors in buoy positioning.

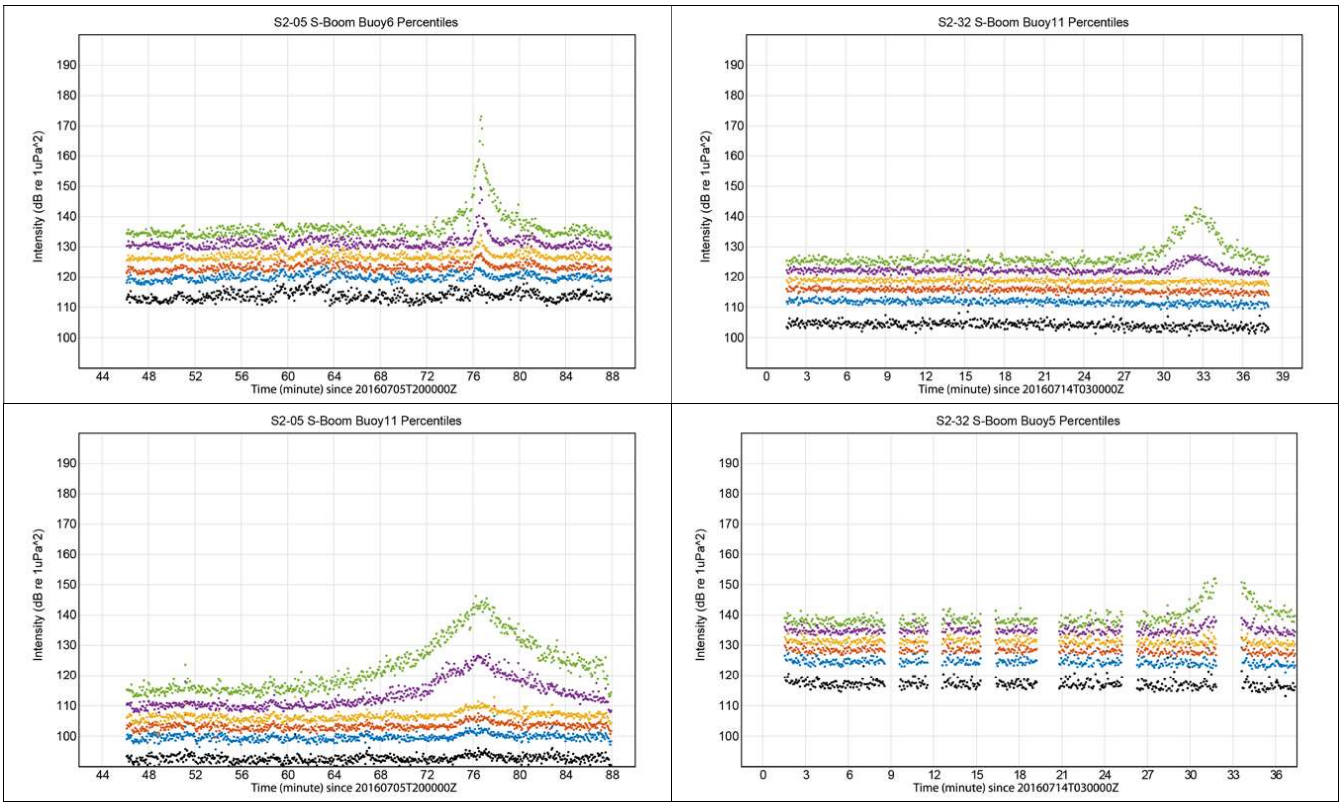


Figure 4.27.2-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy11); Bottom right: SPL_{pk} arrival at position B (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

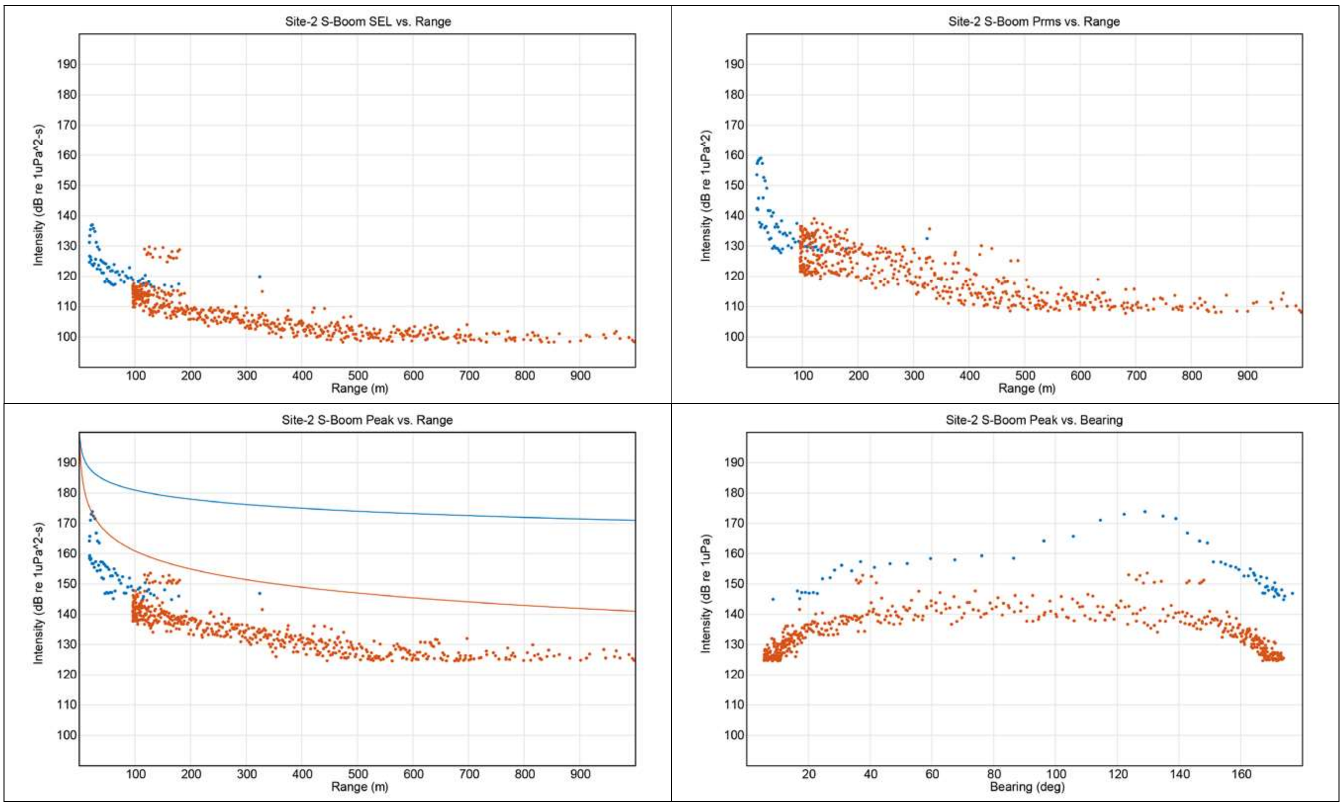


Figure 4.27.2-2. Range results for Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 2 for positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [$10 \log_{10}$ (*range*)] and the red line is spherical spreading [$20 \log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.27.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 20,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -150 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis, while position B had high amplitudes at approximately 0 m.

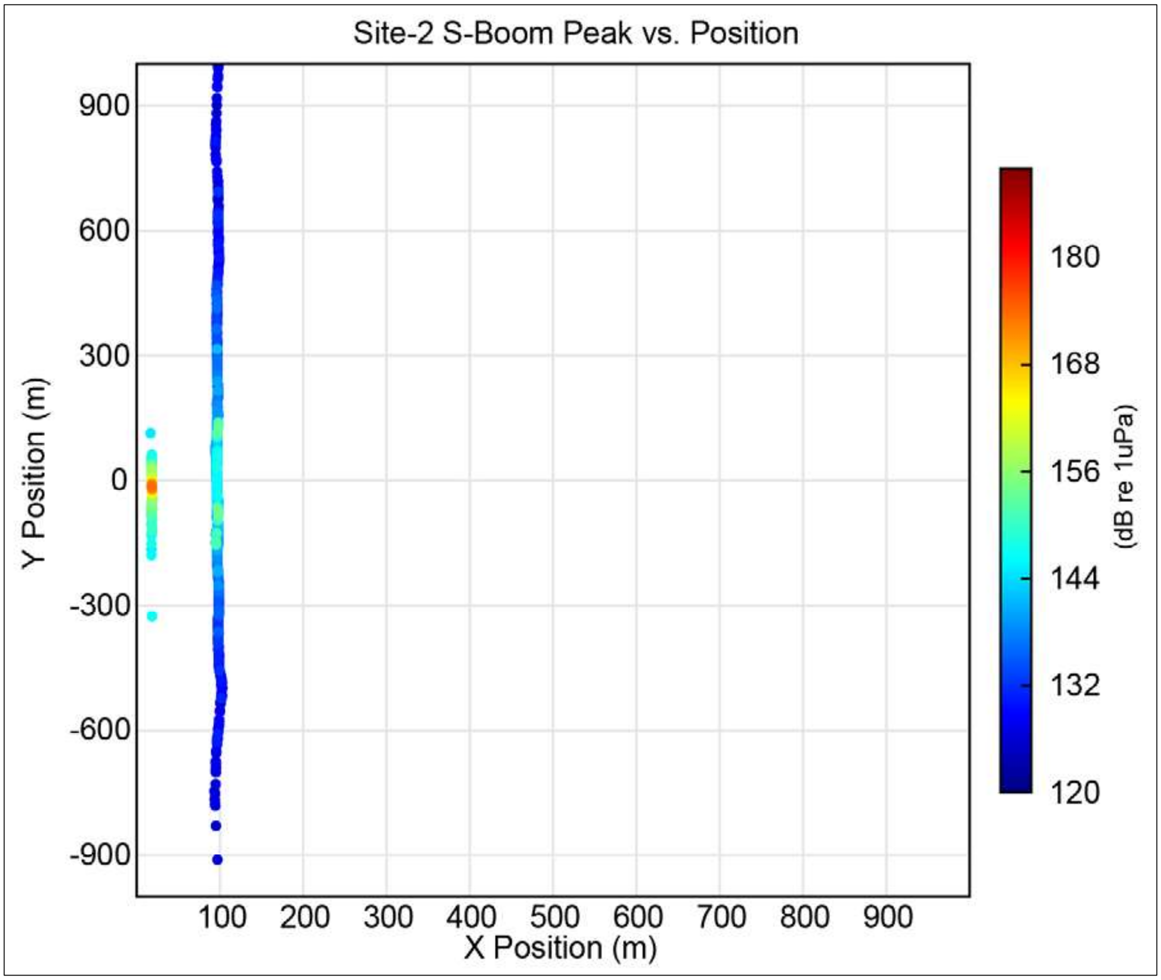


Figure 4.27.2-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 200 Joules, low power, at Site 2 for positions D (Buoy6) and B (Buoy5, Buoy11, and Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.27.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.27.2-1. Applied Acoustics 252 S-Boom source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
252 S-Boom Mode 2	0.1-5	200 J	Low Power	1 Plate	203	188	167
NUWC	0.1-5	200 J	Low Power	1 Plate	201	191	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.27.3 Site 3 – Mud, 30 m Depth

At S3, the 252 S-Boom, Mode 2, had valid acoustic recordings in Run7 and Run28. For Run7, position B (Buoy12) had valid acoustic data. For Run28, positions D (Buoy6), B (Buoy11), and A (Buoy12) had valid acoustic data.

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 2, are shown in **Figure 4.27.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run28, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11 and Buoy12), and A (Buoy12). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.27.3-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the 252 S-Boom at S3, positions D (Buoy6), B (Buoy11 and Buoy12, combined), and A (Buoy12) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 201 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are several distinct groupings of peak pressure levels, specifically for position B, indicating calibration issues.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D, B, and A at approximately 90°, indicating good buoy positioning.

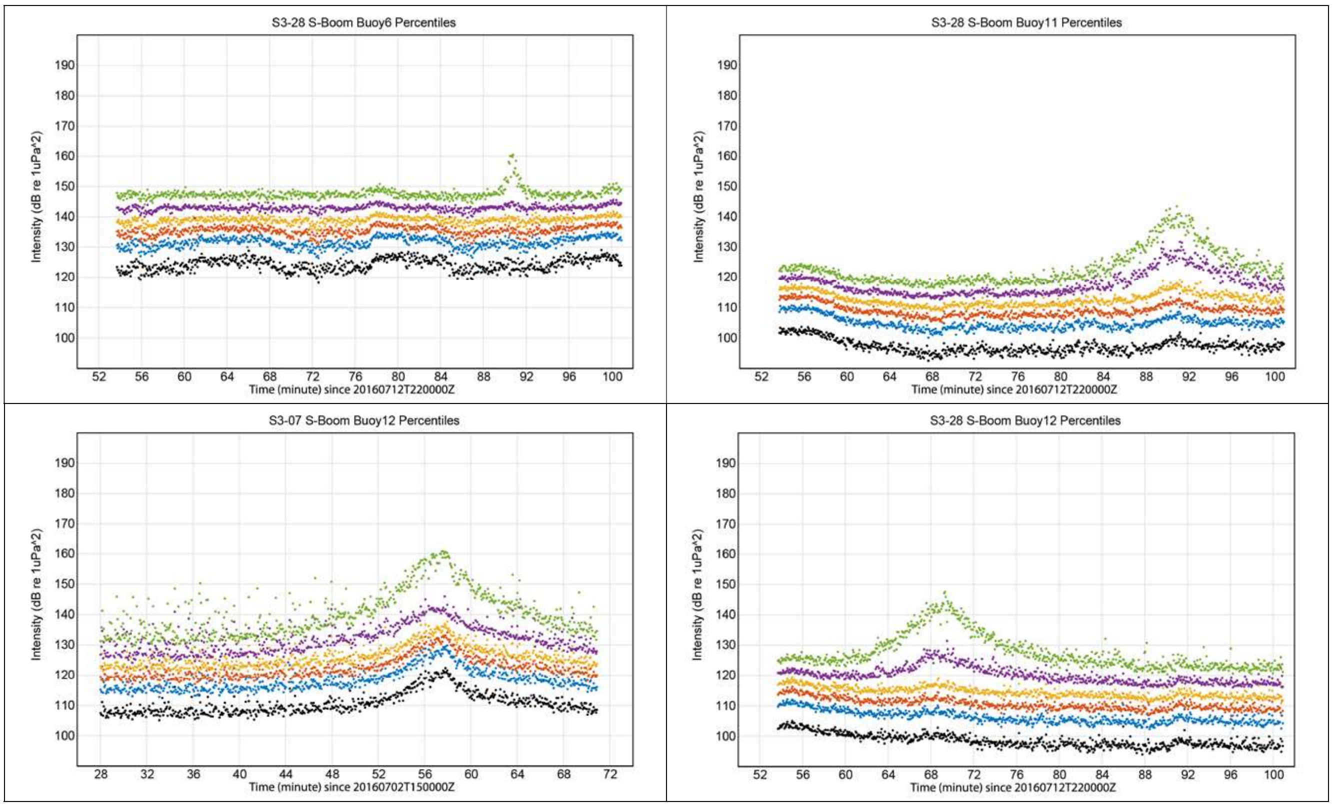


Figure 4.27.3-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position B (Buoy12); Bottom right: SPL_{pk} arrival at position A (Buoy12). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

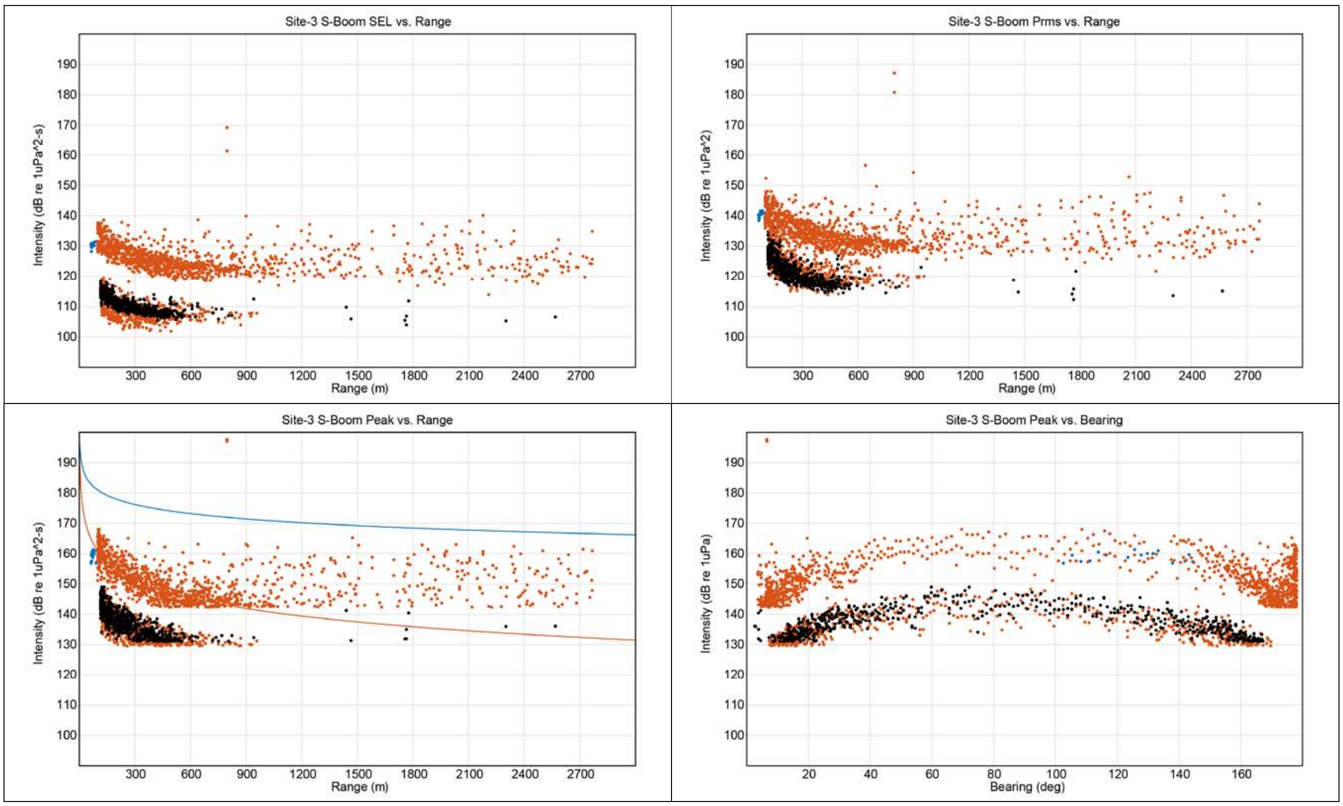


Figure 4.27.3-2. Range results for Applied Acoustics 252 S-Boom combined signals, 200 Joules, low power, for Run7 and Run28 at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy12, combined), and A (Buoy12).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue.

The plan view is shown in **Figure 4.27.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -2,700 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11 and Buoy12), and A (Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

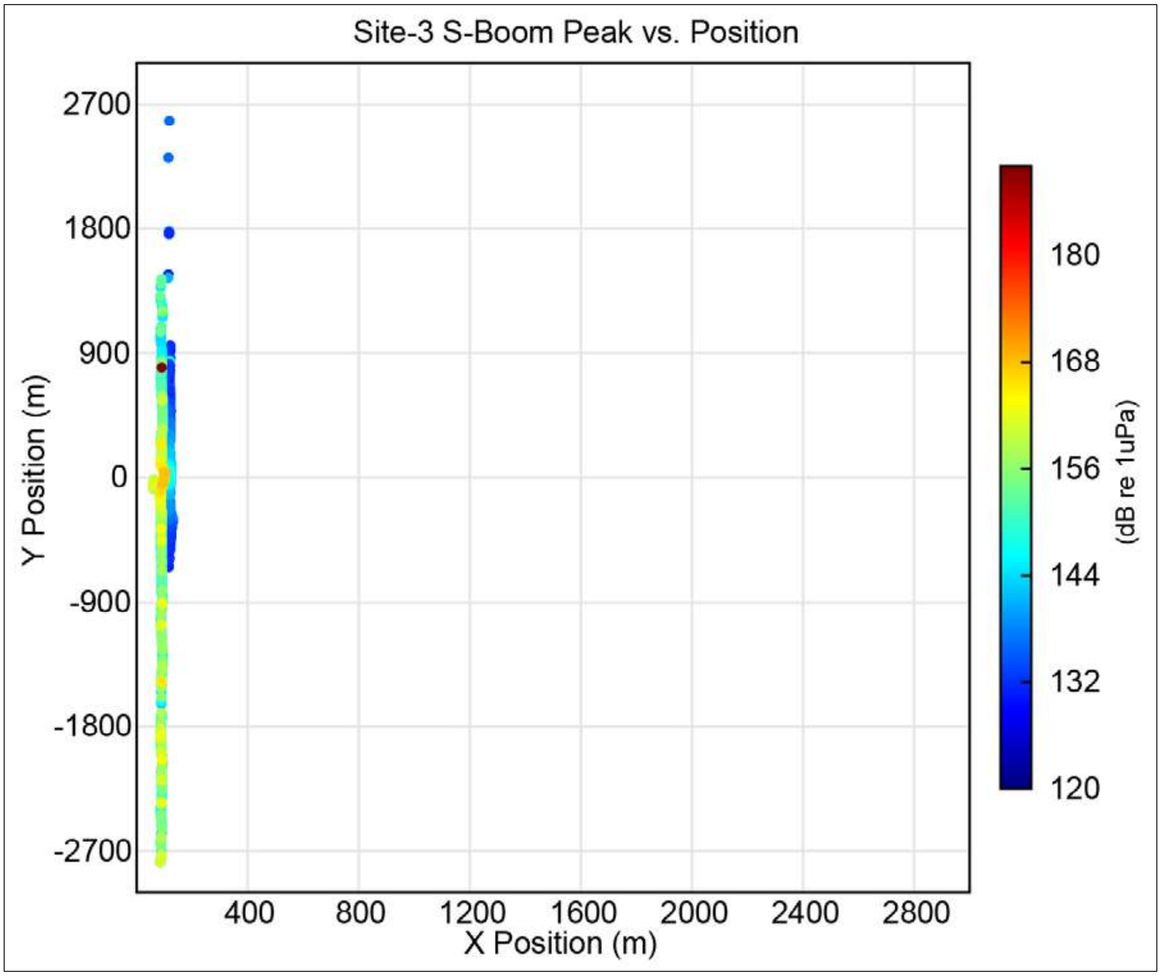


Figure 4.27.3-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 200 Joules, low power, at Site 3 for positions D (Buoy6), B (Buoy11 and Buoy12), and A (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.27.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.27.3-1. Applied Acoustics 252 S-Boom source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
252 S-Boom Mode 2	0.1-5	200 J	Low Power	1 Plate	200	182	169
NUWC	0.1-5	200 J	Low Power	1 Plate	201	191	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.27.4 Site 4 – Sand, 30 m Depth

At S4, the 252 S-Boom, Mode 2, had valid acoustic recordings in Run7 and Run22. For Run7, positions D (Buoy8) and A (Buoy6) had valid acoustic data. For Run22, position F (Buoy5) had acoustic data, but the signal to noise ratio was poor.

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 2, are shown in **Figure 4.27.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy8) for Run7, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The sound levels at position D were low and presumed incorrect. The top right panel shows valid recorded acoustics at position A (Buoy6). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. Position F (Buoy5) is shown in the bottom panel for completeness, these data have noise issues as seen by the greater than 20 dB difference over the signal-floor percentile of 5 percent.

The results panels (**Figure 4.27.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 252 S-Boom at S4, positions D (Buoy6) and A (Buoy6) had acoustic signal, which is plotted in **Figure 4.27.4-2**. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,000 m. The position D (Buoy8) acoustic levels are very low. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 201 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are several distinct groupings of peak pressure levels for positions D and A, indicating unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 65° and for position A at approximately 100°, indicating errors in buoy positioning.

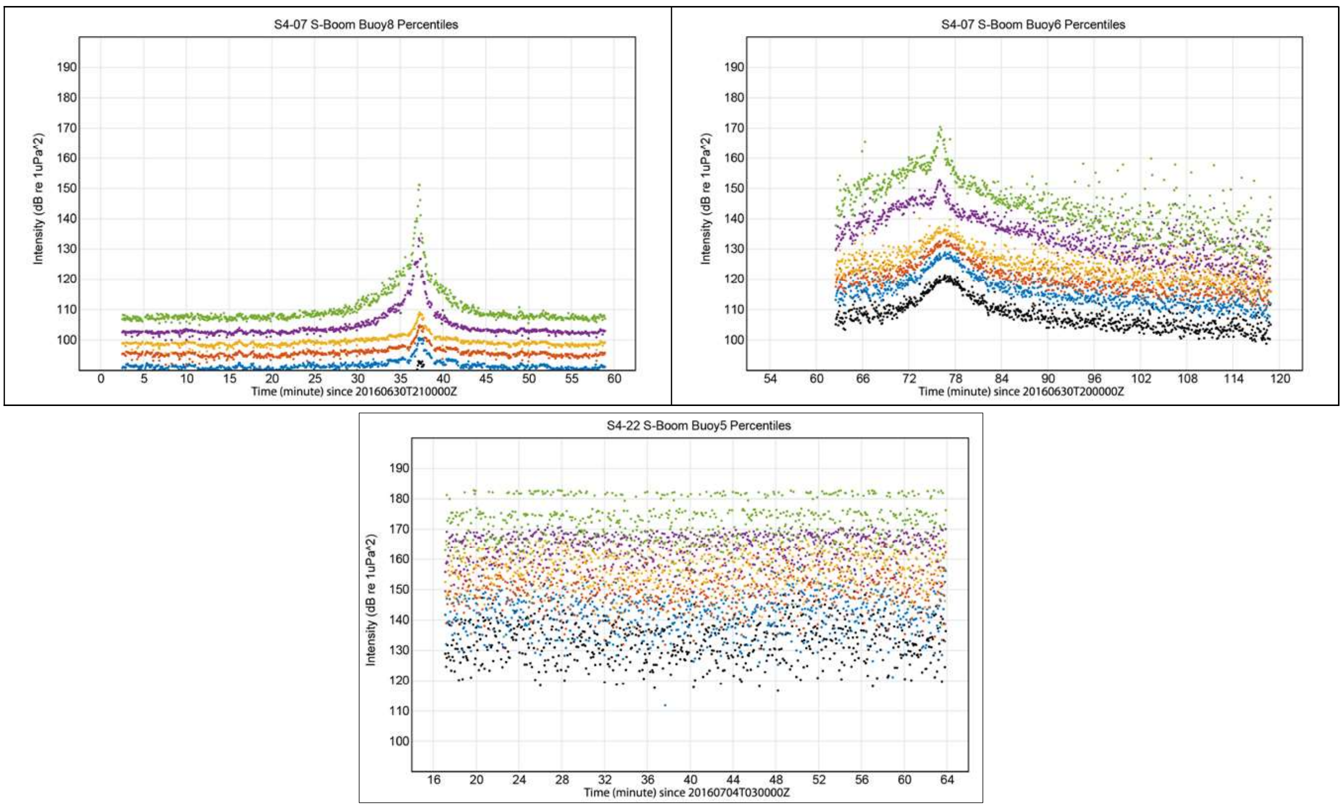


Figure 4.27.4-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy8); Top right: SPL_{pk} arrival at position A (Buoy6); Bottom: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

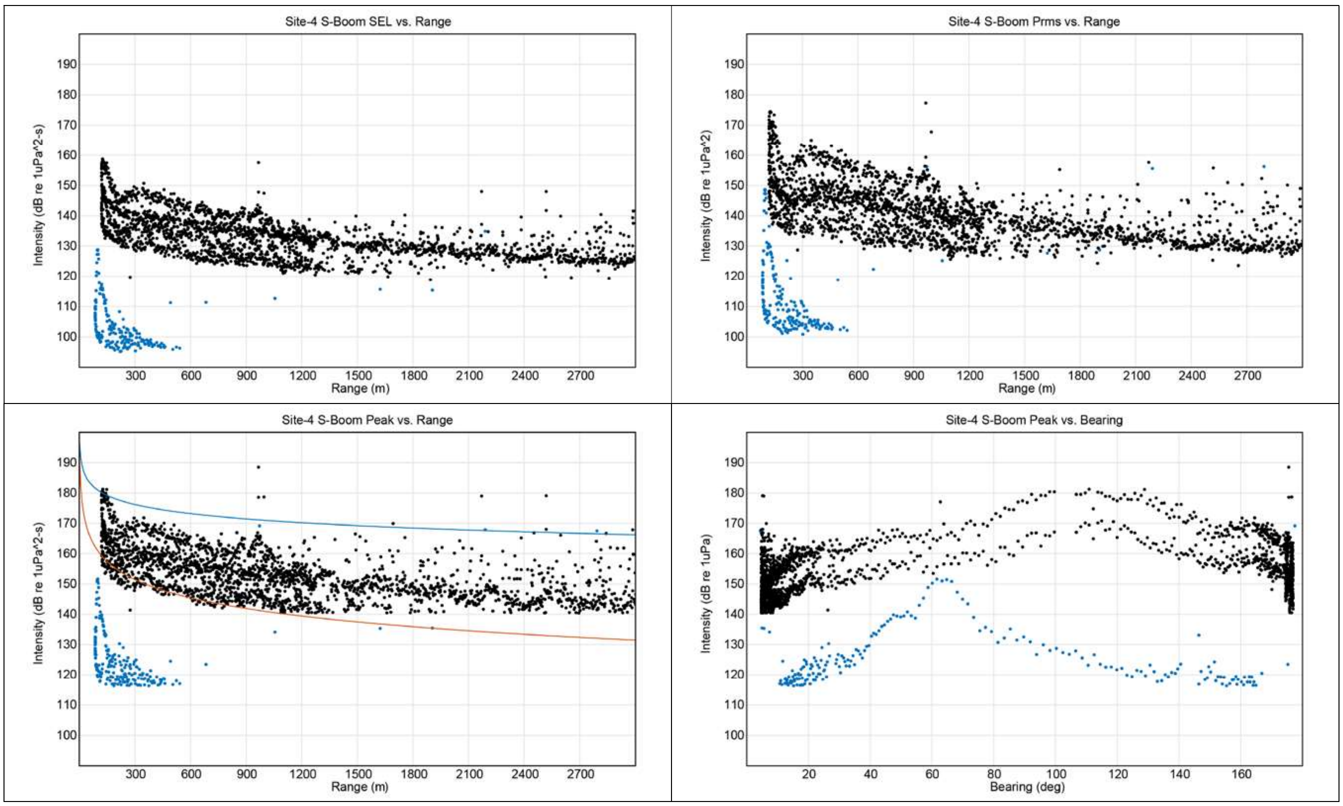


Figure 4.27.4-2. Range results for Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 4 for positions D (Buoy8) and A (Buoy6).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue.

The plan view is shown in **Figure 4.27.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 120,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and A (Buoy6). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

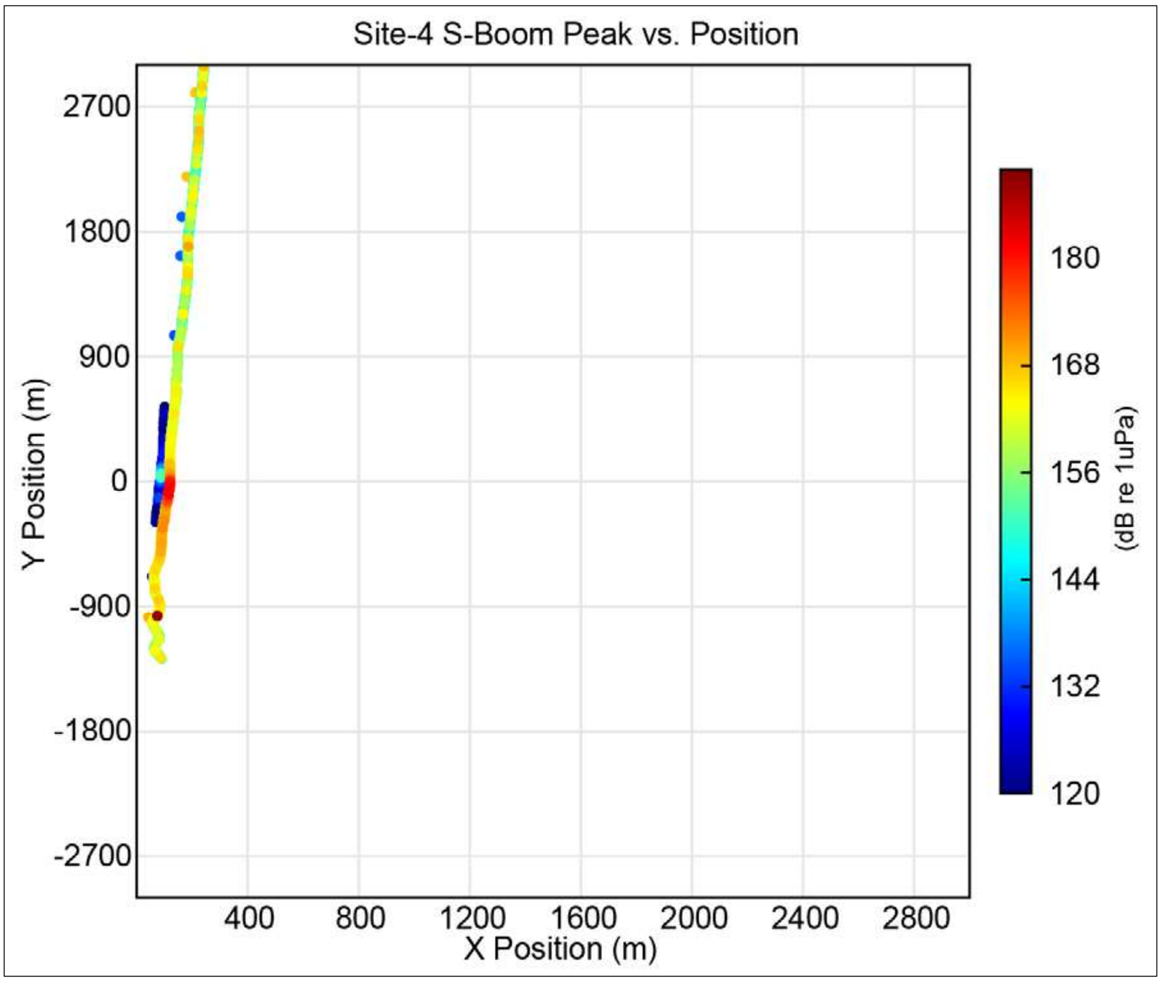


Figure 4.27.4-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 200 Joules, low power, at Site 4 for positions D (Buoy8) and A (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.27.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.27.4-1. Applied Acoustics 252 S-Boom source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
252 S-Boom Mode 2	0.1-5	200 J	Low Power	1 Plate	200	194	174
NUWC	0.1-5	200 J	Low Power	1 Plate	201	191	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.27.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the 252 S-Boom, Mode 2, had valid acoustic recordings in Run9 and Run24. For Run9, positions D (Buoy6), A (Buoy12), and E (Buoy8) had valid acoustic recordings. For Run24, valid acoustic recordings were observed at positions B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Run Summary

The percentile plots for the available recordings of the 252 S-Boom, Mode 2, are shown in **Figure 4.27.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run9, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions A (Buoy12), E (Buoy8), and F (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.27.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 252 S-Boom at S5, positions D (Buoy6), B (Buoy11), A (Buoy12 and Buoy12, combined), E (Buoy8, Buoy8, and Buoy9, combined), and F (Buoy10) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 201 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are several distinct groupings of peak pressure levels at all positions, indicating unresolved calibration issues (**Section 2.6.3.1**).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D, B, A, E, and F at approximately 90°, indicating good buoy positioning.

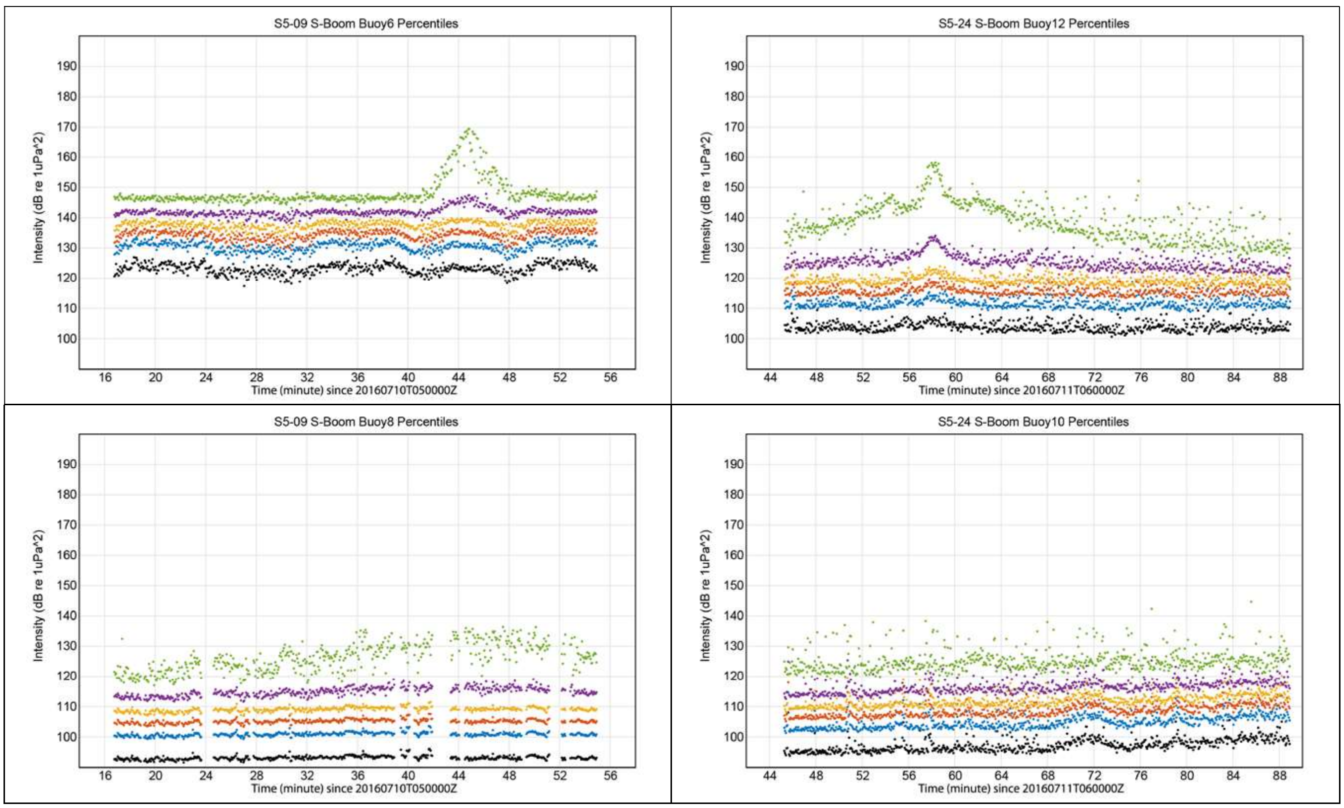


Figure 4.27.5-1. Percentile plots of Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

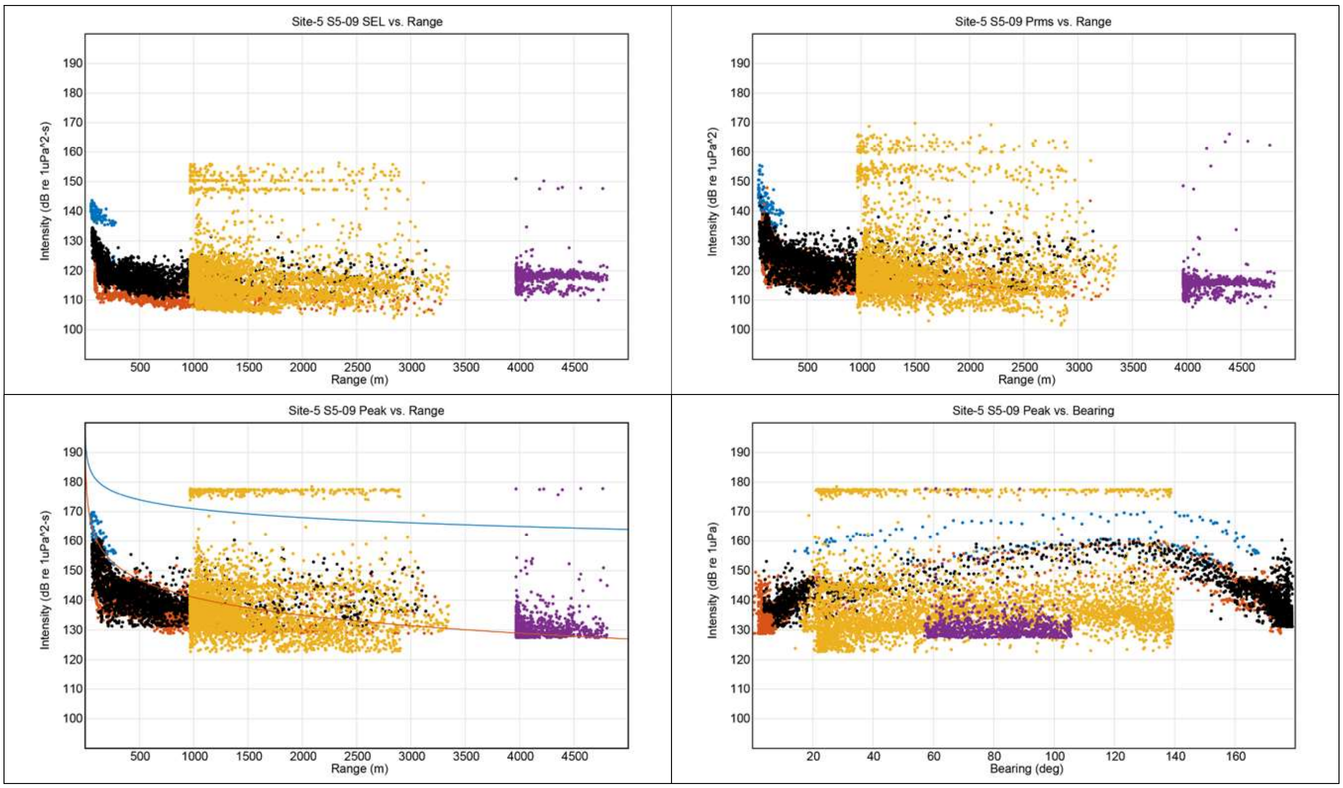


Figure 4.27.5-2. Range results for Applied Acoustics 252 S-Boom signals, 200 Joules, low power, at Site 5 from Run9 and Run24 for positions D (Buoy6), B (Buoy11), A (Buoy12 and Buoy12, combined), E (Buoy8, Buoy8, and Buoy9 combined), and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.27.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 53,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12 and Buoy12), E (Buoy8, Buoy8, and Buoy9), and F (Buoy10).

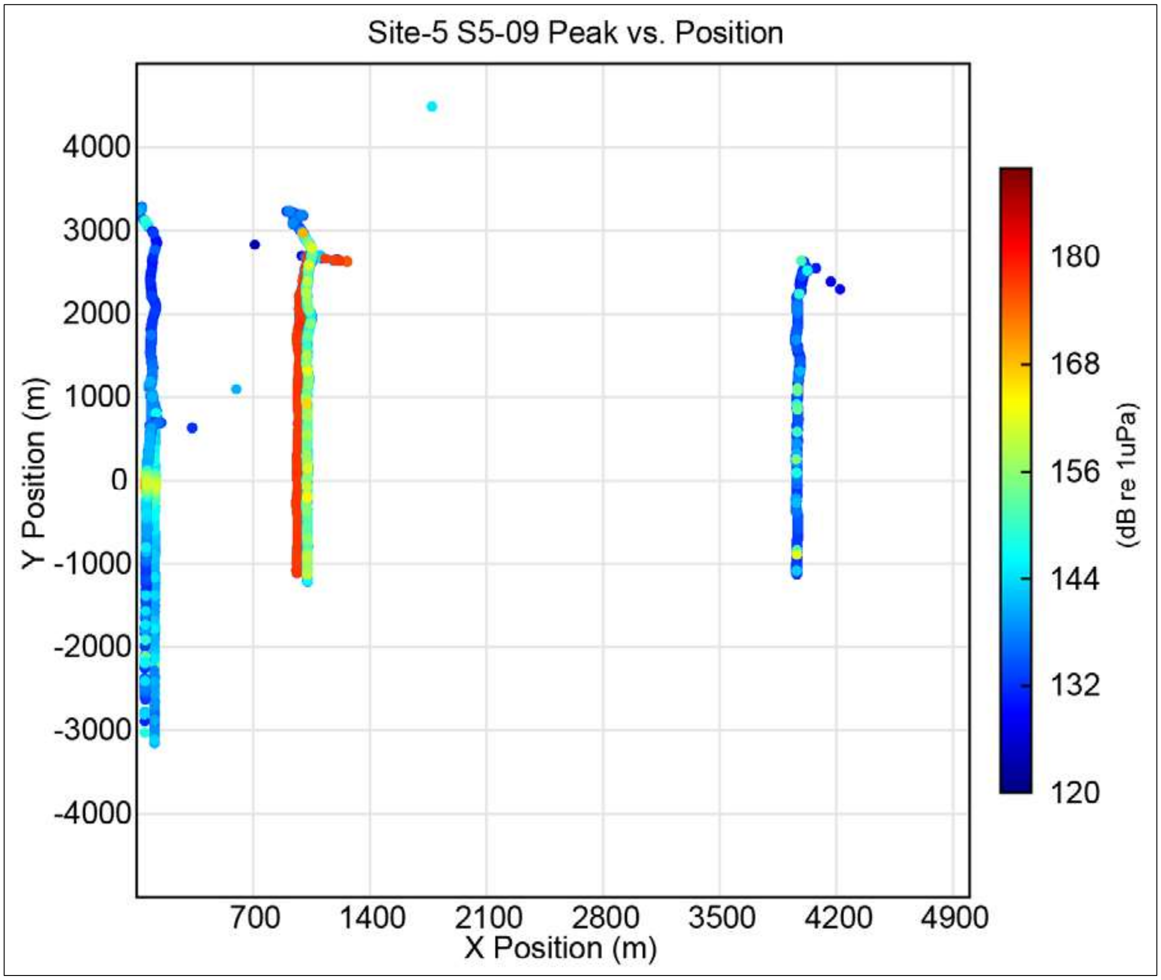


Figure 4.27.5-3. Plan view of received peak level for Applied Acoustics 252 S-Boom, 200 Joules, low power, at Site 5 for positions D (Buoy6), B (Buoy11), A (Buoy12 and Buoy12), E (Buoy8, Buoy8, and Buoy9), and F (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.27.5-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.27.5-1. Applied Acoustics 252 S-Boom source levels, Mode 2, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
252 S-Boom Mode 2	0.1-5	200 J	Low Power	1 Plate	201	179	174
NUWC	0.1-5	200 J	Low Power	1 Plate	201	191	159

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.28 SIG 2 Mini Sparker ELC 820, 700 J, Low Power (Mode 1.0)

The Mini Sparker subbottom profiler generates a single, low-frequency signal with a peak frequency of 1 kHz. The operational parameter settings for Mode 1.0 were a power setting of 700 J on low power. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.28-1** is the selected frequency band (0 to 12 kHz) and SPL_{pk} (201 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

There were two other mode settings which were 700 J high power and 750 J high power. The measured metrics for these two mode settings are presented in the Table source summaries only for each site, as they were not fully processed for this report.

Table 4.28-1. Bandpass determination for the Mini Sparker ELC 820, subbottom profiler, 700 Joules, low power at Site 2, Run6.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	203.99
0-100	202.75
0-50	200.04
0-25	200.95
0-12	**201.42**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Mini Sparker, Mode 1.0, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.28-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. However, the power spectral density (middle panel of **Figure 4.28-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually.

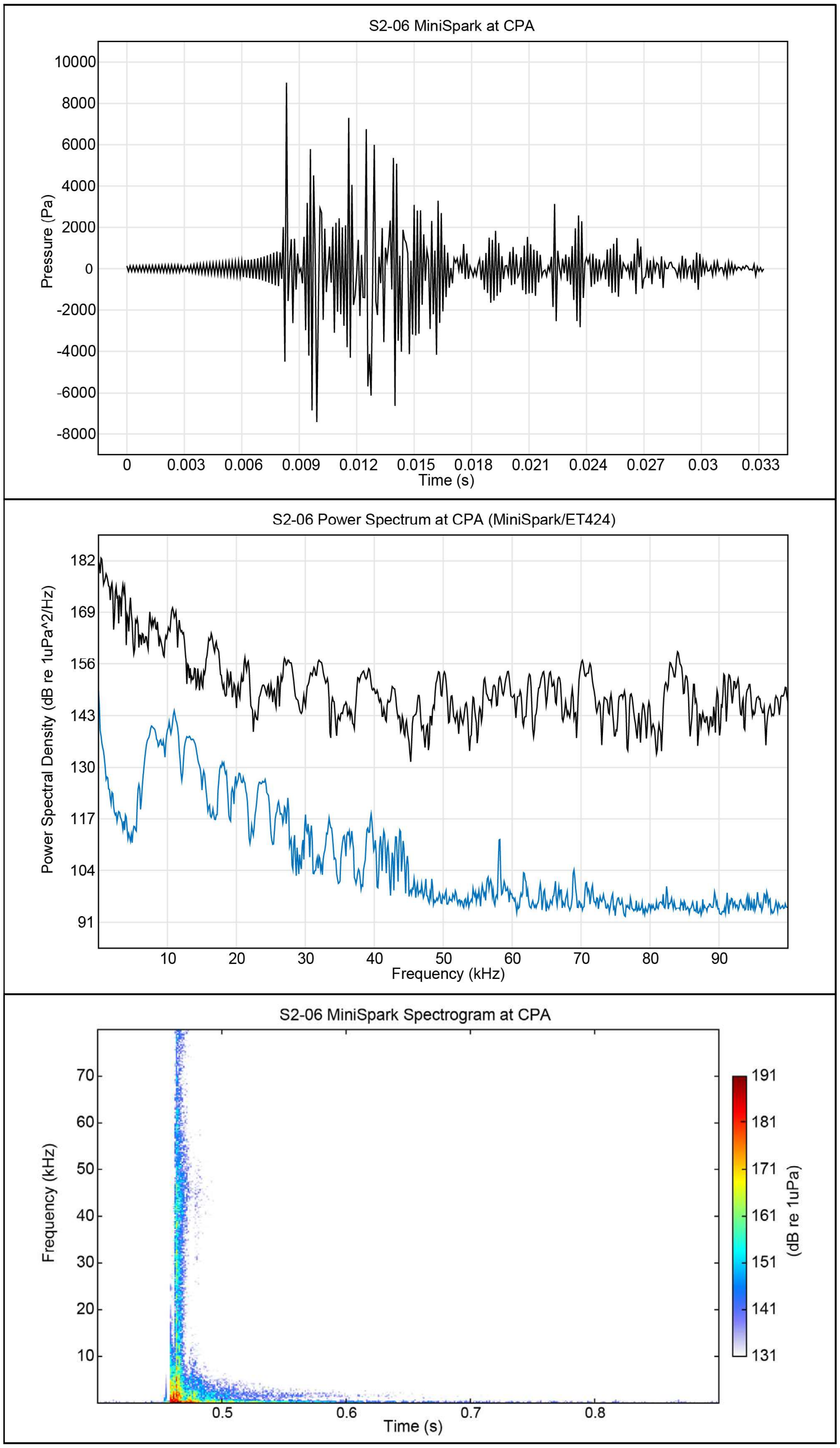


Figure 4.28-1. Mini Sparker, 700 Joules low power, measured signal characteristics at closest point of approach (CPA) at Site 2, Run6.
Top: Time-waveform of a signal; Middle: Power spectral density, Mini Sparker = black, ET424 = blue; Bottom: Spectrogram.

4.28.1 Site 1 – Mud, 10 m Depth

The Mini Sparker, 700 J low power, Mode 1.0, was not deployed or operated at S1. Only a 750 J high power, Mode 1.2, was operated at S1, a full analysis was not completed other than to report the measured metrics, shown in **Table 4.28.1-1**.

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results for 750 J high power (Mode 1.2) are provided in **Table 4.28.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. Please note this is a different operational mode setting that is not comparable across sites or with the 700 J low power, Mode 1.0.

Table 4.28.1-1. Mini Sparker, 750 J high power source levels, Mode 1.2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 1.0	NA	700 J	Low Power	NA	NM	NM	NM
Mini Sparker Mode 1.1	NA	700 J	High Power	NA	NM	NM	NM
Mini Sparker Mode 1.2	NA	750 J	High Power	NA	221	209	191
NUWC	NA	700 J	Low Power	NA	215	206	182
NUWC	NA	700 J	High Power	NA	NM	NM	NM
NUWC	NA	750 J	High Power	NA	214	206	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NM = not measured; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.28.2 Site 2 – Sand, 10 m Depth

At S2, the Mini Sparker 700 J low power, Mode 1.0, had valid acoustic recordings in Run6 at positions D (Buoy6), B (Buoy 5 and Buoy11), E (Buoy10), and F (Buoy9). Position F (Buoy9) did not capture the acoustic signal.

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 1.0, are shown in **Figure 4.28.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run6, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy5), and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.28.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Mini Sparker at S2, only positions D (Buoy6), B (Buoy5 and Buoy11, combined), and E (Buoy10) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 25 to approximately 2,400 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 215 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are several distinct groupings of peak pressure levels, specifically for position B, indicating calibration issues (**Section 2.6.3.1**).

The bottom right results panel of **Figure 4.28.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 130°, indicating an error in buoy positioning. For positions B and E, the received peak levels are at approximately 90°, which indicates good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

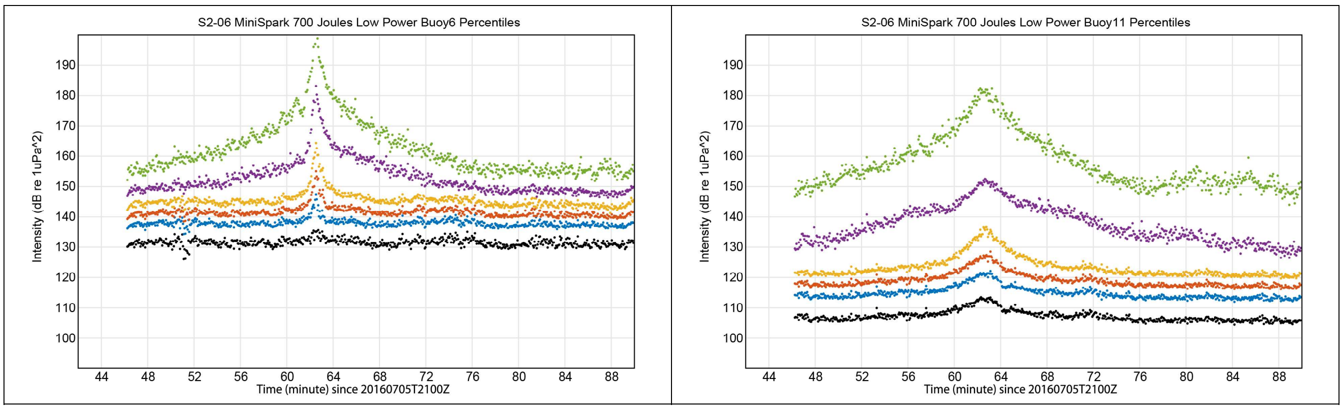


Figure 4.28.2-1. Percentile plots of Mini Sparker, 700 Joules low power, signals at Site 2.
Left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Right: SPL_{pk} arrival at position B (Buoy11).
Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

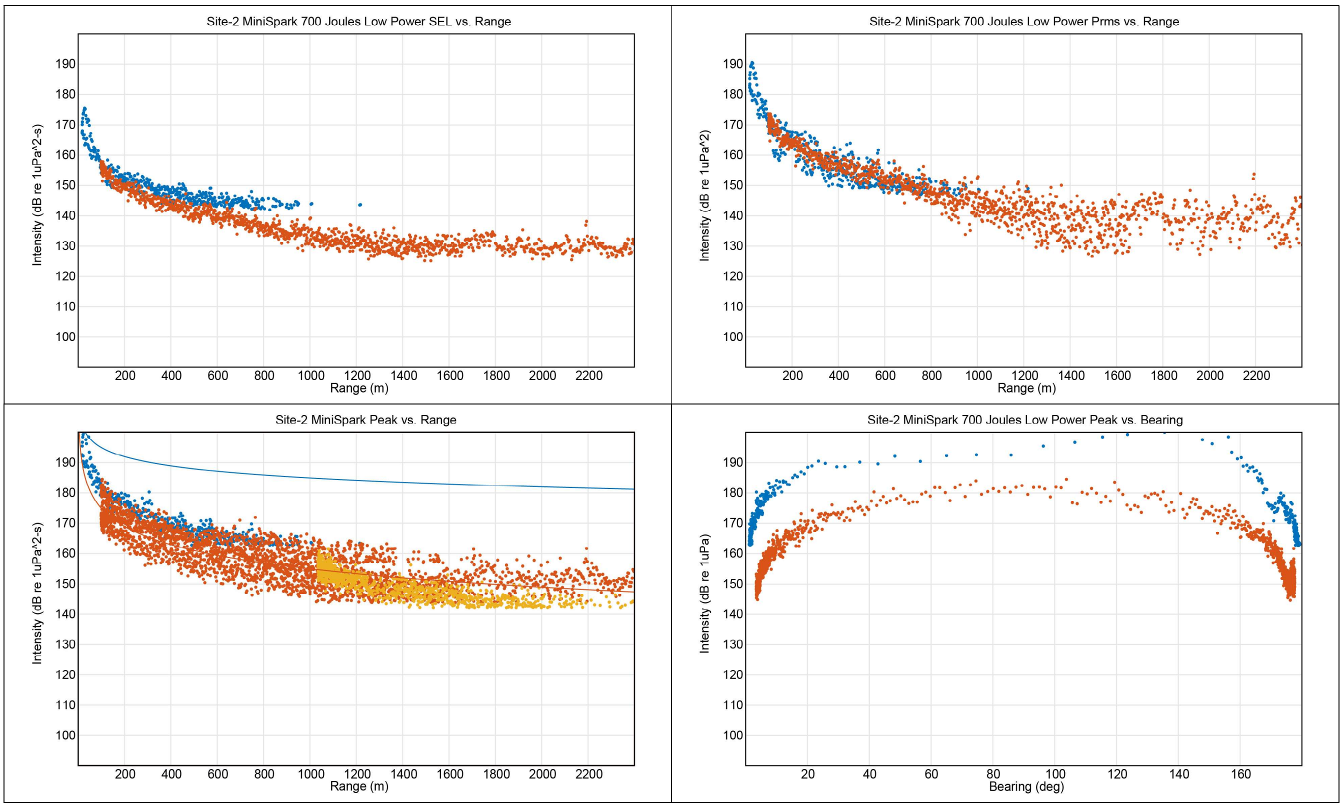


Figure 4.28.2-2. Range results for Mini Sparker, 700 Joules low power, signals at Site 2 for positions D (Buoy6), B (Buoy5 and Buoy11 combined), and E (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.28.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,200 to 2,200-m marks on the y-axis. The CPA is at 25,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -800 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy5 and Buoy11 combined), and E (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signals for positions D and B are seen at approximately 0 m on the y-axis.

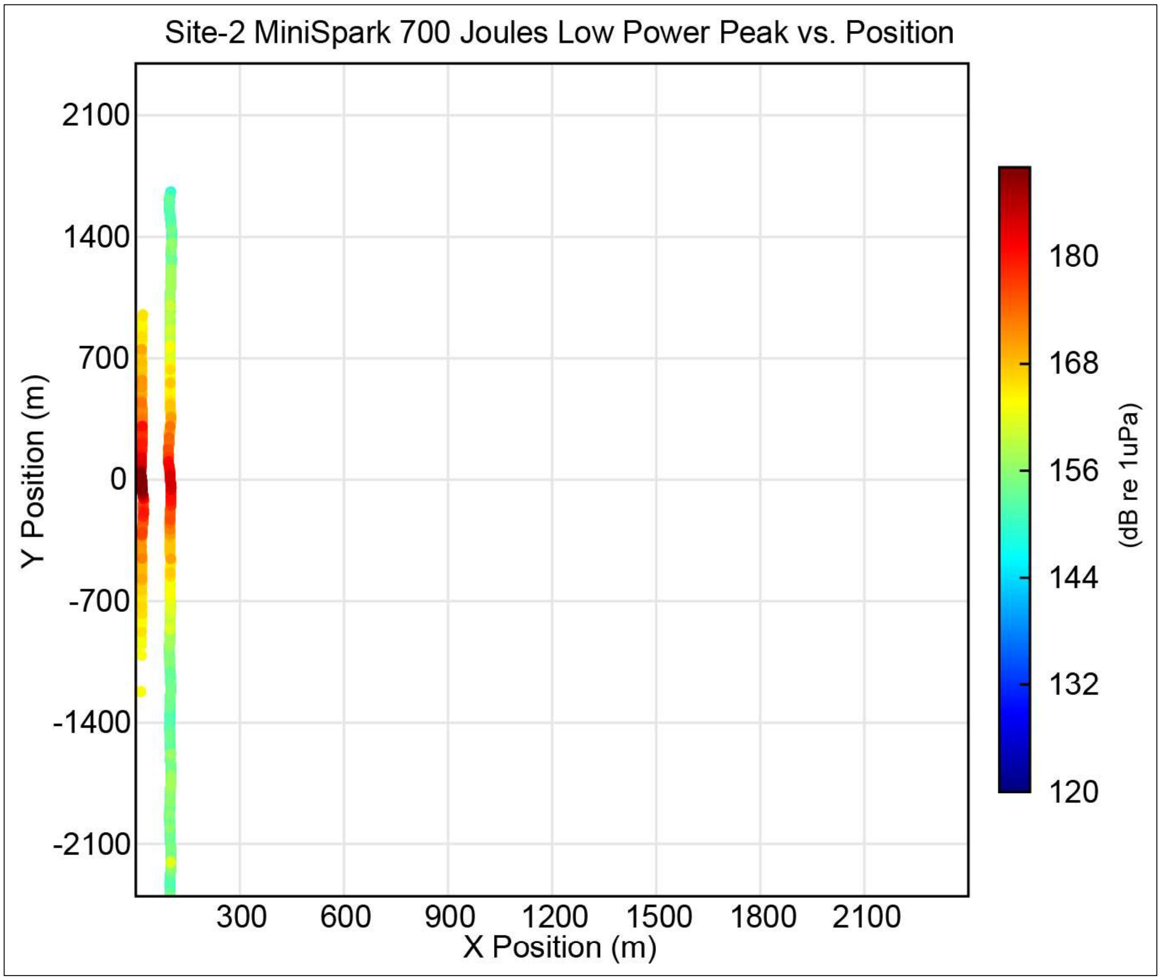


Figure 4.28.2-3. Plan view of received peak level for Mini Sparker, 700 Joules low power, at Site 2 for positions D (Buoy6), B (Buoy5 and Buoy11), and E (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results for 700 J low power (Mode 1.0), 700 J high power (Mode 1.1), and 750 J high power (Mode 1.2) are provided in are provided in **Table 4.28.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.28.2-1. Mini Sparker, 700 J low power, Mode 1.0, 700 J high power, Mode 1.1 and 750 J high power, Mode 1.2, source levels, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
Mini Sparker Mode 1.0	NA	700 J	Low Power	NA	218	204	190
Mini Sparker Mode 1.1	NA	700 J	High Power	NA	217	207	192
Mini Sparker Mode 1.2	NA	750 J	High Power	NA	213	205	176
NUWC	NA	700 J	Low Power	NA	215	206	182
NUWC	NA	700 J	High Power	NA	NM	NM	NM
NUWC	NA	750 J	High Power	NA	214	206	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NM = not measured; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.28.3 Site 3 – Mud, 30 m Depth

At S3, the Mini Sparker, 700 J low power, Mode 1.0, had valid acoustic recordings in Run30. For Run30, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy10) had valid acoustic data and observed signals.

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 1.0, are shown in **Figure 4.28.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run30, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy10). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.28.3-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the Mini Sparker at S3, positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy10) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 3,600 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 215 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 140°, and positions A and B at approximately 60°, indicating errors in buoy positioning. The received peak level for position E is at approximately 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

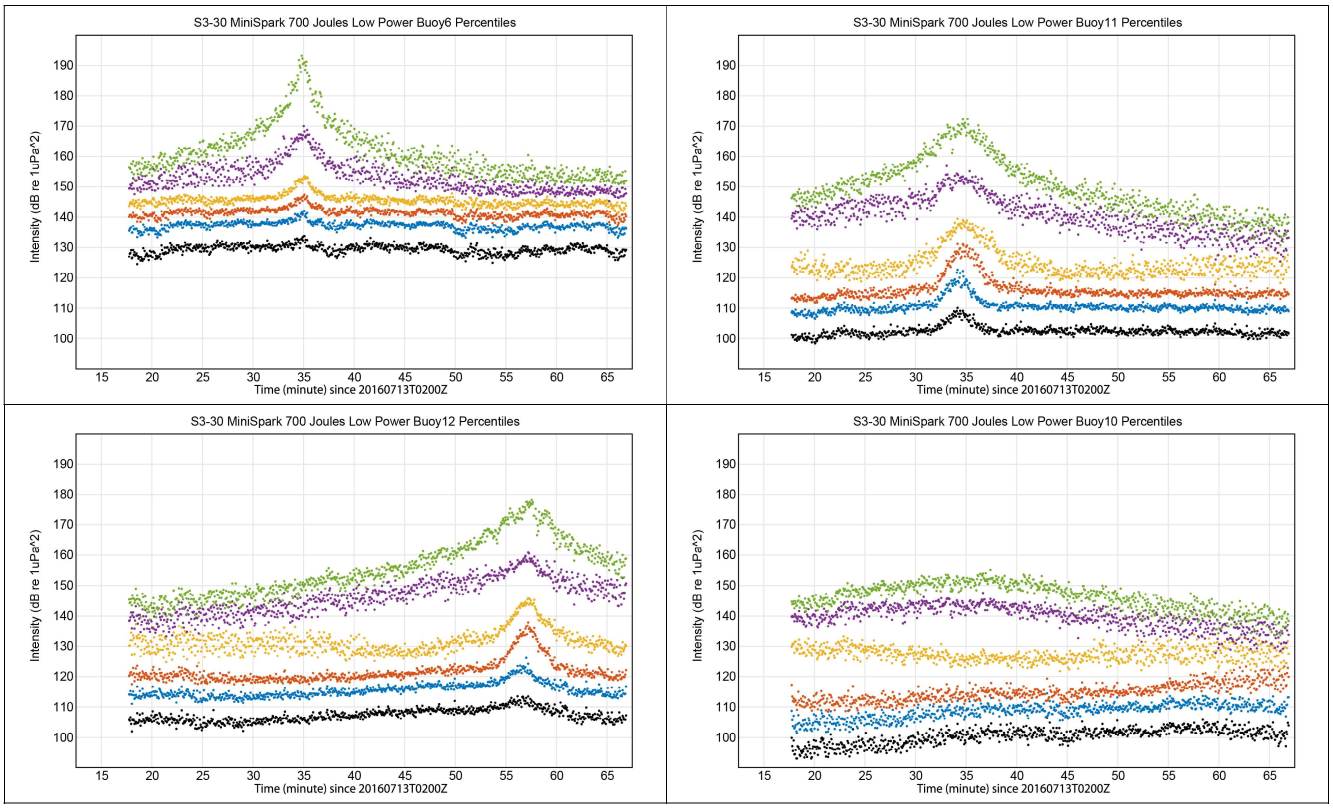


Figure 4.28.3-1. Percentile plots of Mini Sparker, 700 Joules low power, signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

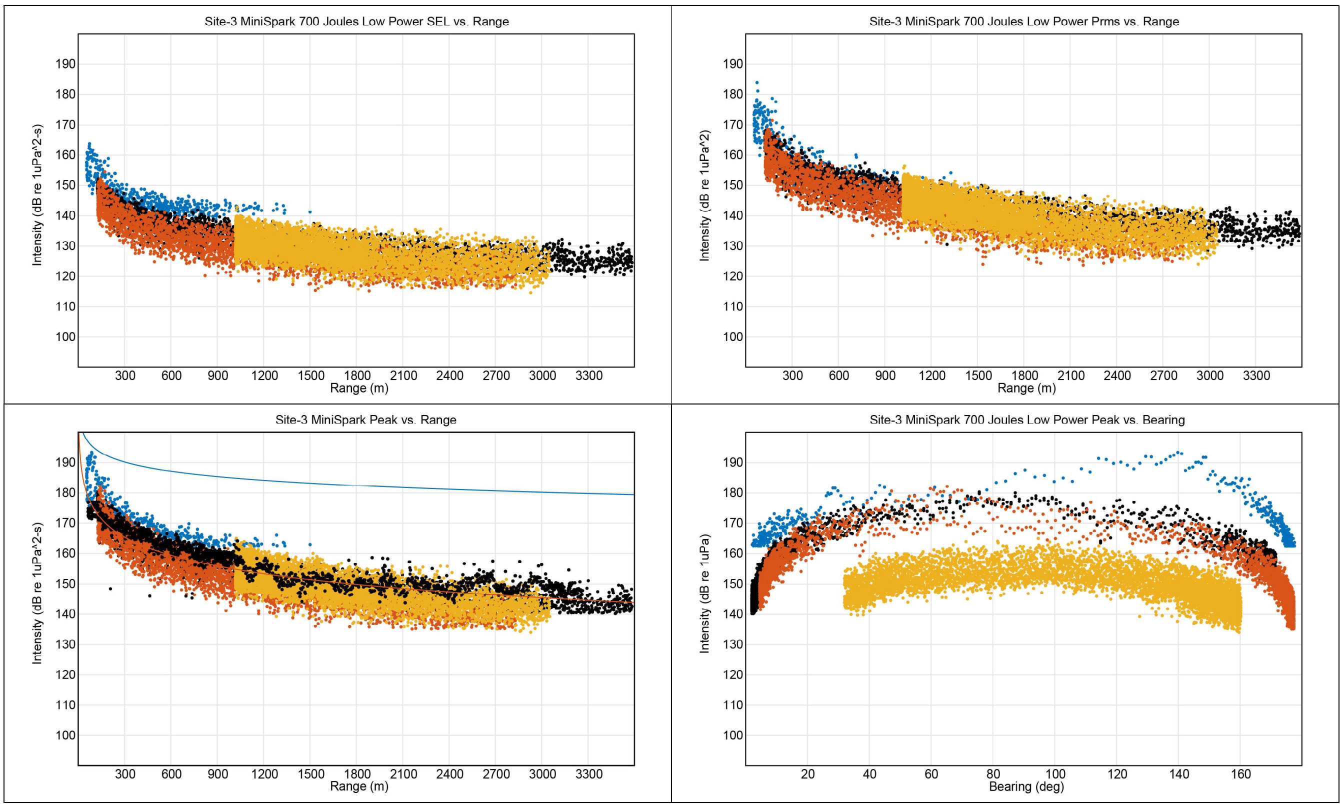


Figure 4.28.3-2. Range results for Mini Sparker, 700 Joules low power, combined signals for Run10 and Run30 at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy5 and Buoy12, combined), and E (Buoy10).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.28.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,500 to 3,500-m marks on the y-axis. The CPA is at 50,-30 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,200 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -30 m on the y-axis, while position B had high amplitudes at approximately 0 m.

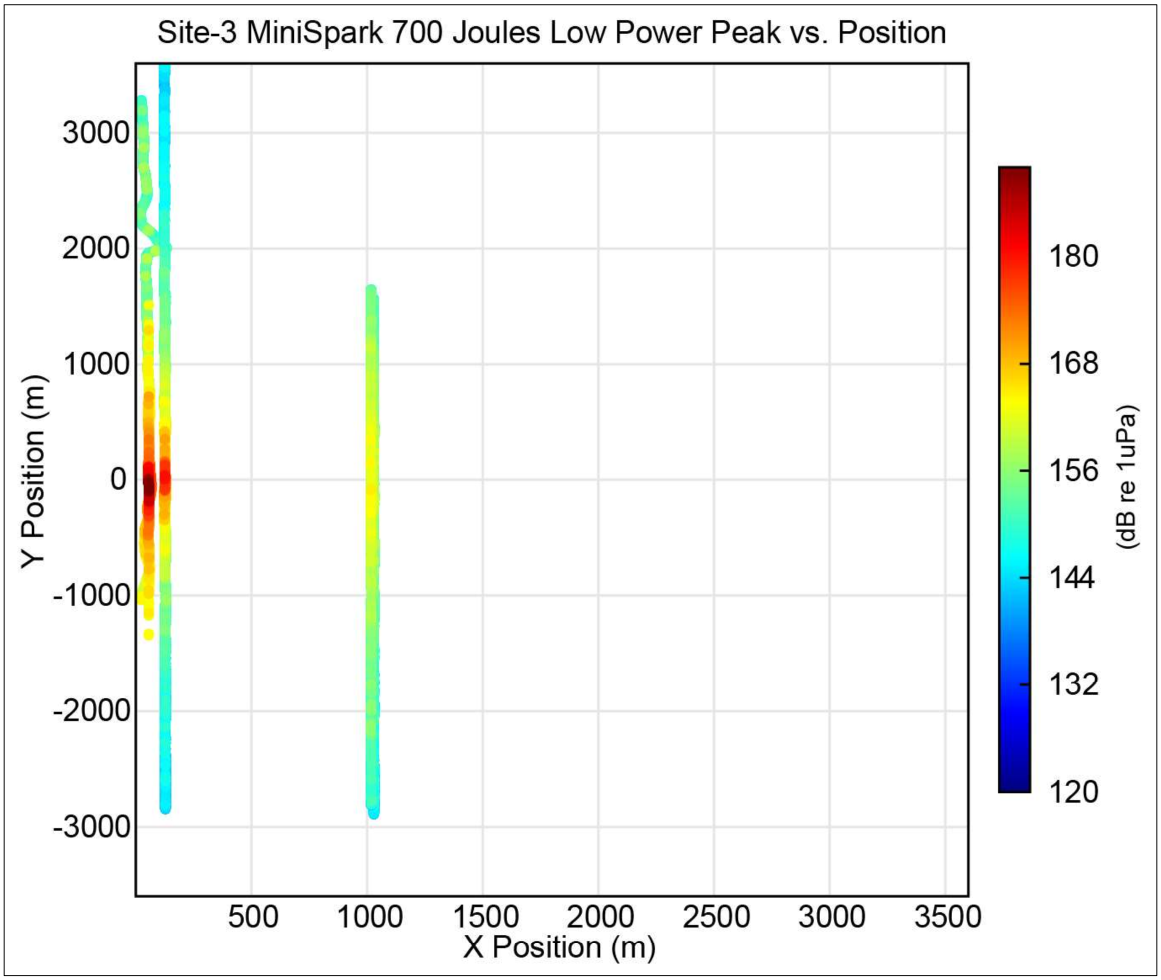


Figure 4.28.3-3. Plan view of received peak level for Mini Sparker, 700 Joules low power, at Site 3 for positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results for 700 J low power (Mode 1.0) and 700 J high power (Mode 1.1) are provided in are provided in in **Table 4.28.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. Please note the 700 Joule high power is a different operational mode setting that is not comparable with the 700 J low power, Mode 1.0.

Table 4.28.3-1. Mini Sparker, 700 J low power, Mode 1.0, and 700 J high power, Mode 1.1, source levels, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 1.0	NA	700 J	Low Power	NA	220	205	191
Mini Sparker Mode 1.1	NA	700 J	High Power	NA	210	197	184
Mini Sparker Mode 1.2	NA	750 J	High Power	NA	NM	NM	NM
NUWC	NA	700 J	Low Power	NA	215	206	182
NUWC	NA	700 J	High Power	NA	NM	NM	NM
NUWC	NA	750 J	High Power	NA	214	206	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NM = not measured; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.28.4 Site 4 – Sand, 30 m Depth

The Mini Sparker, 700 J low power, Mode 1.0, was not deployed or operated at S4. A 700 J high power mode and a 750 J high power mode were operated, and a full analysis was not completed other than to report the measured metrics, shown in **Table 4.28.4-1**.

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results for 700 J high power (Mode 1.1) and 750 J high power (Mode 1.2) are provided in are provided in **Table 4.28.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. Please note these are different operational mode settings that are not comparable with the 700 J low power, Mode 1.0.

Table 4.28.4-1. Mini Sparker, 700 J high power, Mode 1.1 and 750 J high power, Mode 1.2, source levels, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 1.0	NA	700 J	Low Power	NA	NM	NM	NM
Mini Sparker Mode 1.1	NA	700 J	High Power	NA	WS	WS	WS
Mini Sparker Mode 1.2	NA	750 J	High Power	NA	210	186	185
NUWC	NA	700 J	Low Power	NA	215	206	182
NUWC	NA	700 J	High Power	NA	NM	NM	NM
NUWC	NA	750 J	High Power	NA	214	206	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NM = not measured; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level; WS = weak signal.

4.28.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Mini Sparker, 700 J low power, Mode 1.0, had valid acoustic recordings in Run3 and Run19. For Run3, positions D (Buoy6) and E (Buoy8) had valid acoustic recordings and observed signals. For Run19, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8).

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 1.0, are shown in **Figure 4.28.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run19, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.28.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Mini Sparker at S5, positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy8, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to 3,600 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 215 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There is a wide spread over the peak pressure levels for all positions, indicating calibration issues.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D and A at approximately 80° and for position B at approximately 120°, indicating errors in buoy positioning. The received peak level for position E is at approximately 90°, indicating good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°.

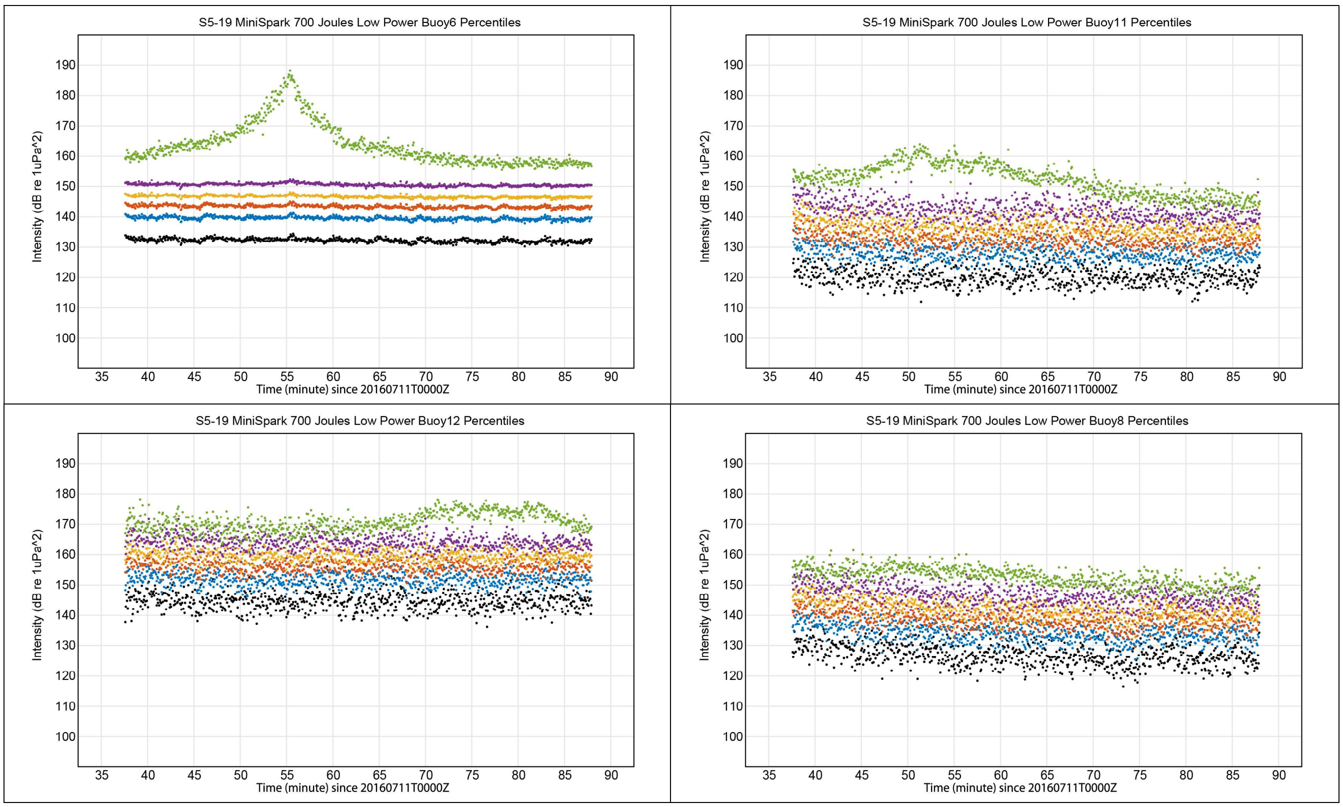


Figure 4.28.5-1. Percentile plots of Mini Sparker, 700 Joules low power, signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

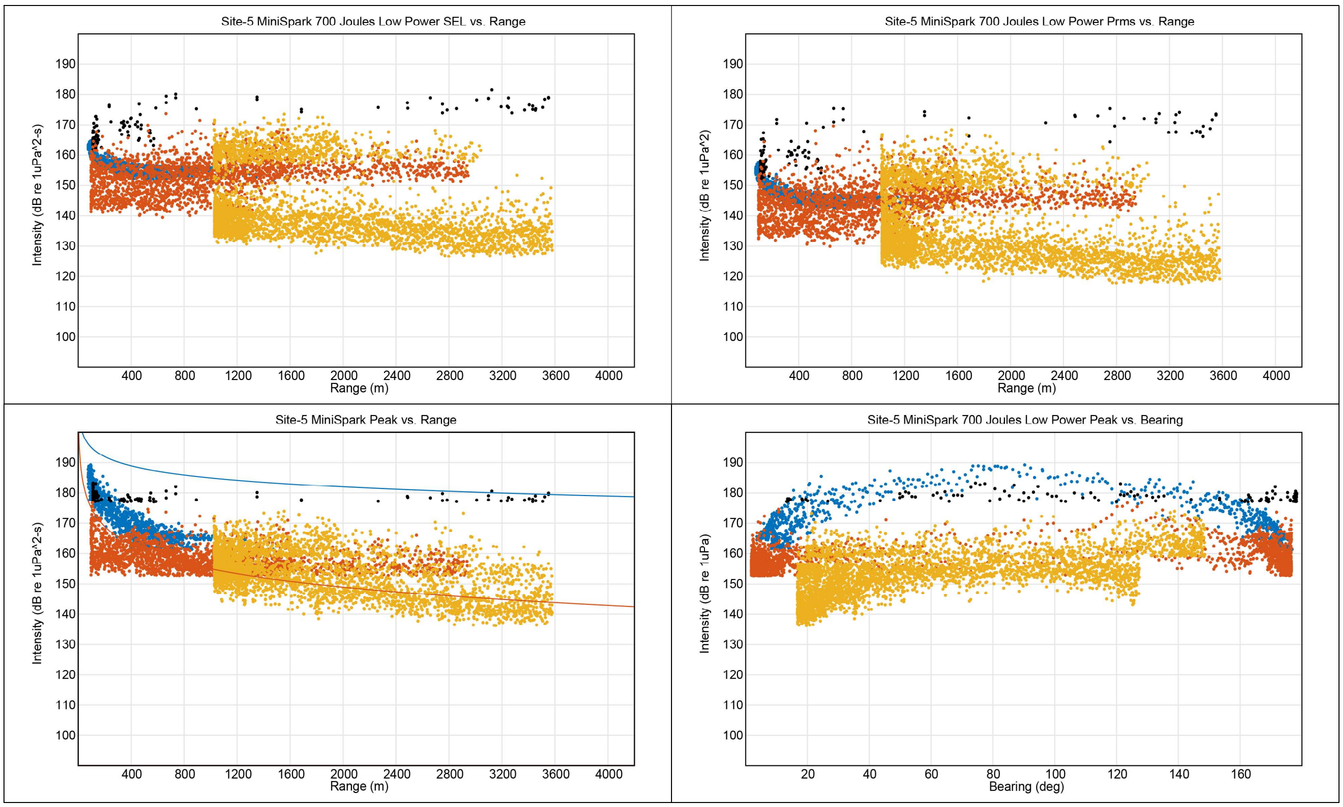


Figure 4.28.5-2. Range results for Mini Sparker, 700 Joules low power, signals at Site 5 from Run3 and Run19 for positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy8, combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.28.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -4,000 to 4,000-m marks on the y-axis. The CPA is at 90,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,600 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy8). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

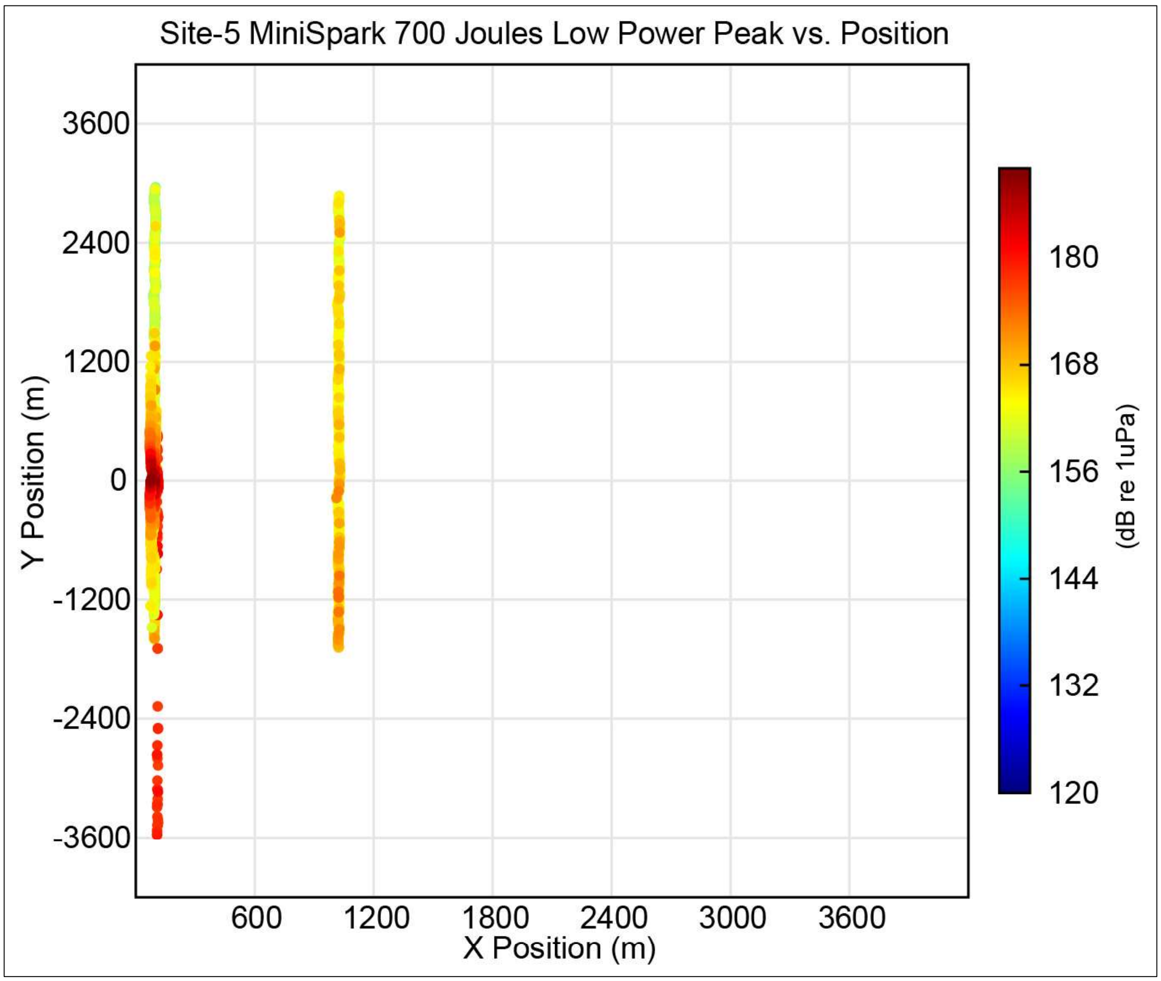


Figure 4.28.5-3. Plan view of received peak level for Mini Sparker, 700 Joules low power, at Site 5 for positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results for 700 J low power (Mode 1.0) are provided in **Table 4.28.5-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results

Table 4.28.5-1. Mini Sparker, 700 J low power, source levels, Mode 1.0, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 1.0	NA	700 J	Low Power	NA	222	192	200
Mini Sparker Mode 1.1	NA	700 J	High Power	NA	NM	NM	NM
Mini Sparker Mode 1.2	NA	750 J	High Power	NA	NM	NM	NM
NUWC	NA	700 J	Low Power	NA	215	206	182
NUWC	NA	700 J	High Power	NA	NM	NM	NM
NUWC	NA	750 J	High Power	NA	214	206	182

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NM = not measured; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.29 SIG 2 Mini Sparker ELC 820, 500 J, High Power (Mode 2)

The Mini Sparker subbottom profiler generates a single, low-frequency (LF) signal with a peak frequency of 1 kHz. The operational parameter settings for Mode 2 were a power setting of 500 J on high power. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.29-1** is the selected frequency band (0 to 25 kHz) and SPL_{pk} (199 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.29-1. Bandpass determination for the Mini Sparker ELC 820, subbottom profiler, 500 Joules high power at Site 2, Run7.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-220	199.18
0-100	198.28
0-50	198.74
0-25	**198.90**
0-12	198.10

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Mini Sparker, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.29-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Mini Sparker was operationally paired in alternation with the ET424. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.29-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

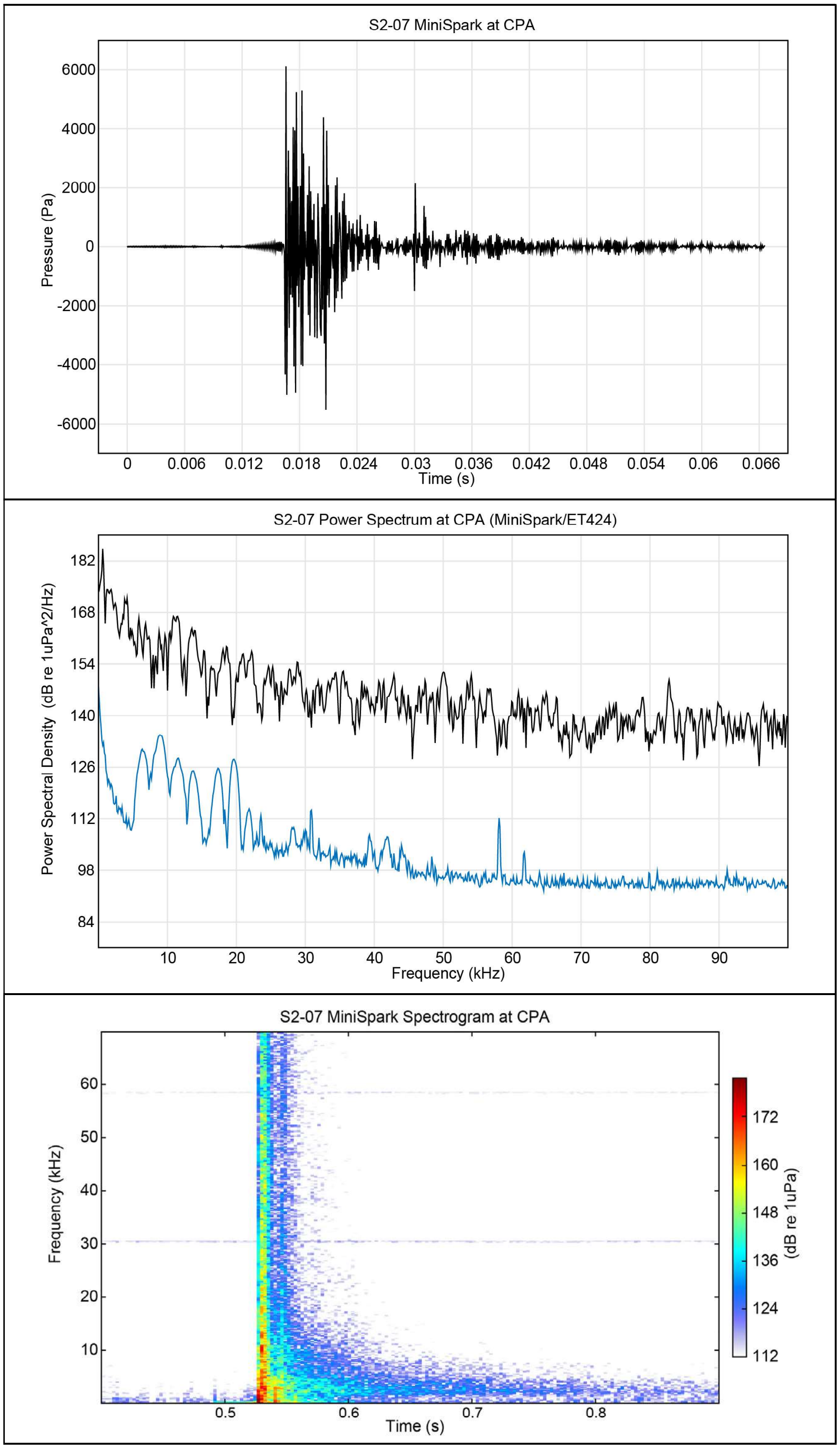


Figure 4.29-1. Mini Sparker, 500 Joules high power, measured signal characteristics at closest point of approach (CPA) at Site 2, Run7.
Top: Time-waveform of a signal; Middle: Power spectral density,
Mini Sparker = black, ET424 = blue; Bottom: Spectrogram.

4.29.1 Site 1 – Mud, 10 m Depth

At S1, the Mini Sparker, 500 J high power, Mode 2, had valid acoustic recordings in Run4 at positions D (Buoy6), E (Buoy5 and Buoy8), and F (Buoy9).

Run Summary

The percentile plots for the three available recordings of the Mini Sparker, Mode 2, are shown in **Figure 4.29.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run4, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions E (Buoy5 and Buoy8) and F (Buoy9). There is no visible signal at position F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.29.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the Mini Sparker at S1, positions D (Buoy6) and E (Buoy5 and Buoy8, combined) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 210 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.29.1-2**), which shows the received peak level for position D at approximately 110° and for position E at approximately 80°, indicating errors in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

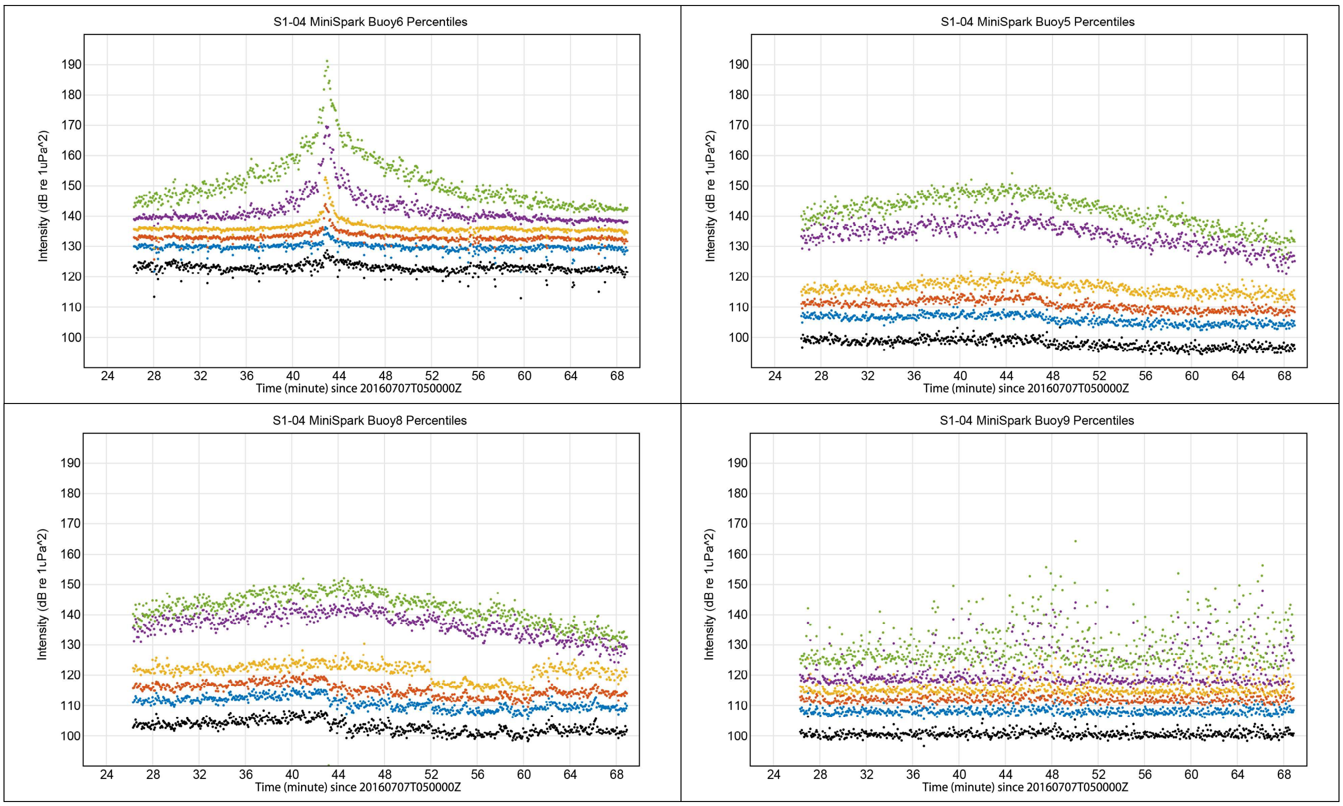


Figure 4.29.1-1. Percentile plots of Mini Sparker signals, 500 Joules high power, at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

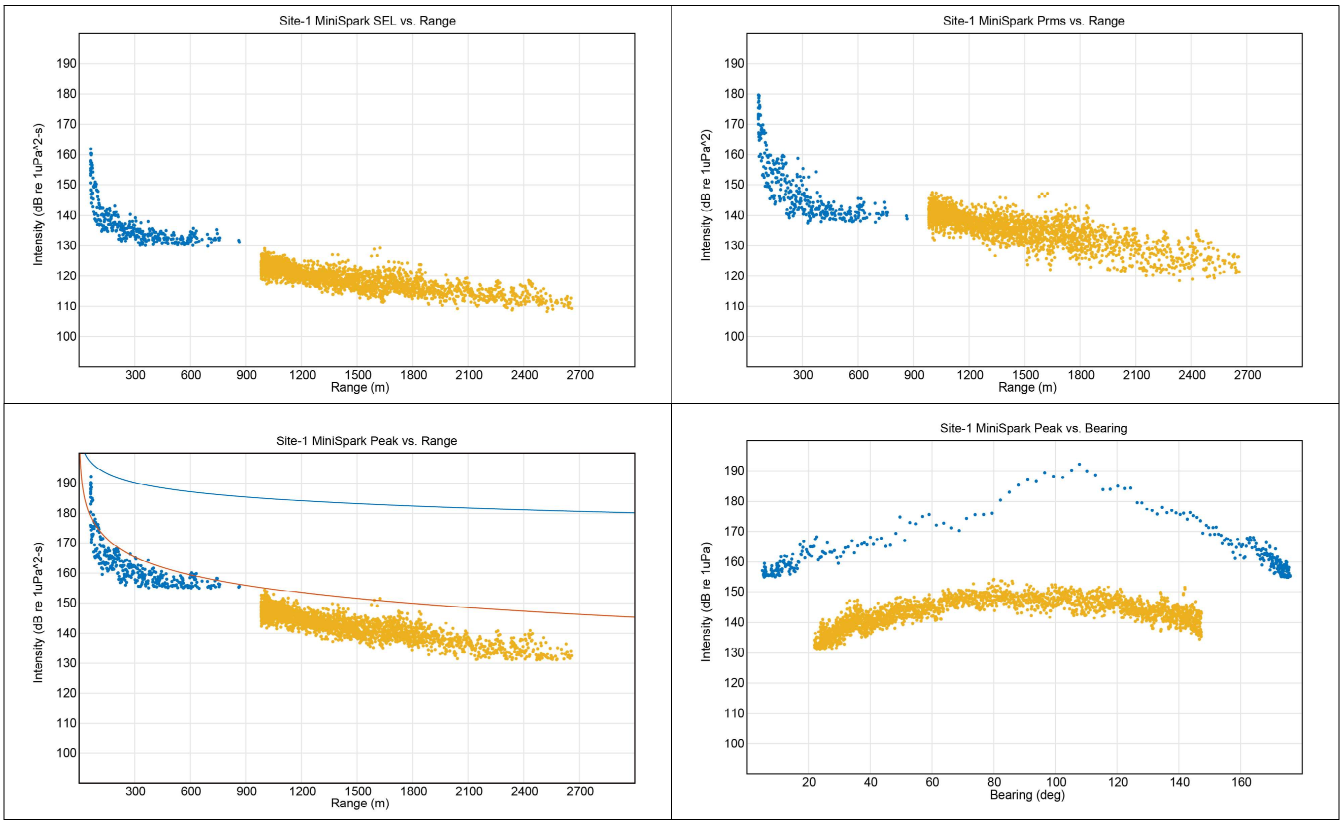


Figure 4.29.1-2. Range results for Mini Sparker signals, 500 Joules high power, at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.29.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,800 to 2,800-m marks on the y-axis. The CPA is at 90,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

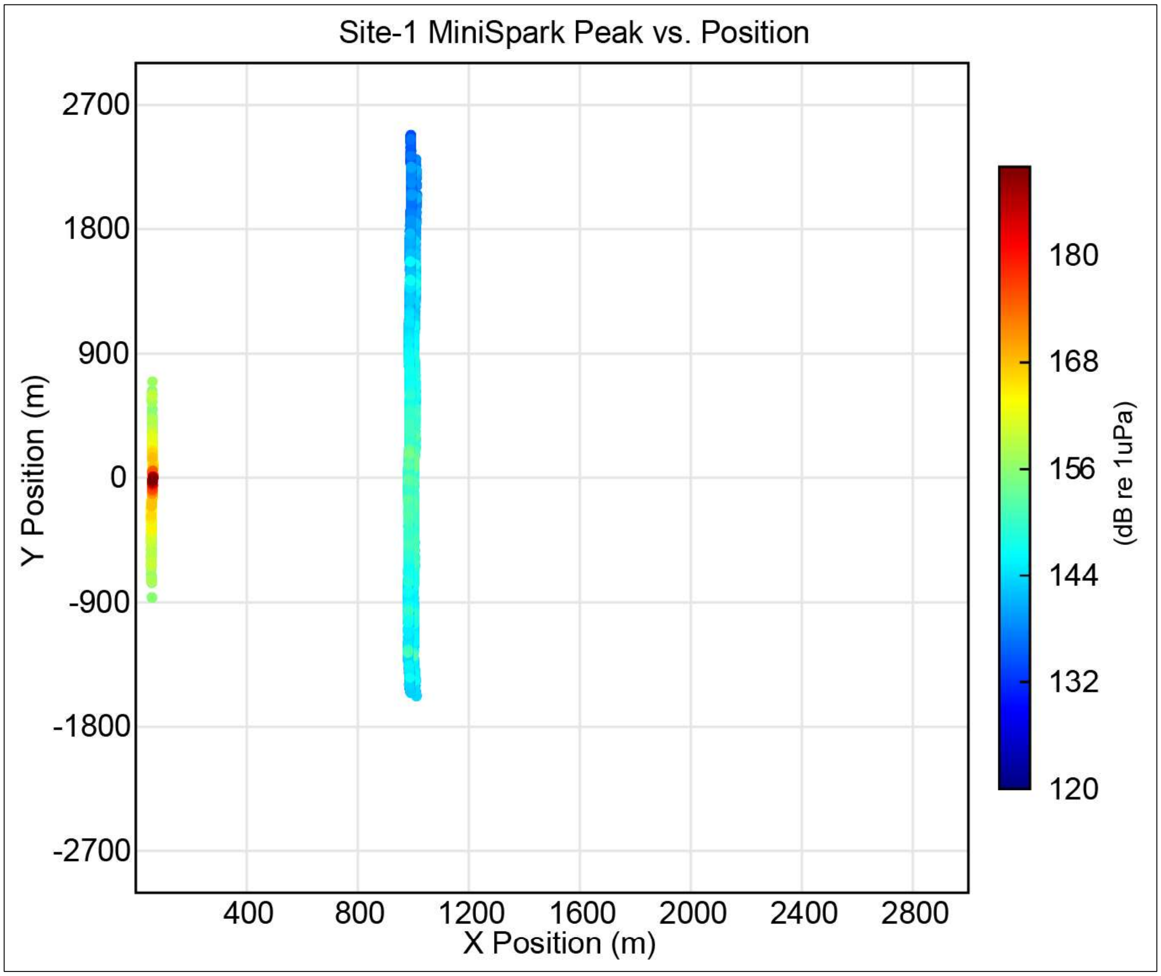


Figure 4.29.1-3. Plan view of received peak level for Mini Sparker, 500 Joules high power, at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.29.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.29.1-1. Mini Sparker, 500 J high power, source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
Mini Sparker Mode 2	NA	500 J	High Power	NA	211	200	181
NUWC	NA	500 J	High Power	NA	210	201	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.29.2 Site 2 – Sand, 10 m Depth

At S2, the Mini Sparker, 500 J high power, Mode 2, had valid acoustic recordings in Run7 and Run34. For Run7, position D (Buoy6) had valid acoustic recordings; for Run34, positions B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9) had valid acoustic recordings.

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 2, are shown in **Figure 4.29.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run7, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics for Run34 at positions B (Buoy11), E (Buoy10), and F (Buoy9). At position F (Buoy9) the signal was weak. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.29.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Mini Sparker at S2, positions D (Buoy6), B (Buoy5 and Buoy11, combined), E (Buoy10), and F (Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 5 to approximately 4,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 210 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.29.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 135° and for positions B and E at approximately 70°, indicating errors in buoy positioning. The received peak level for position F is at indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

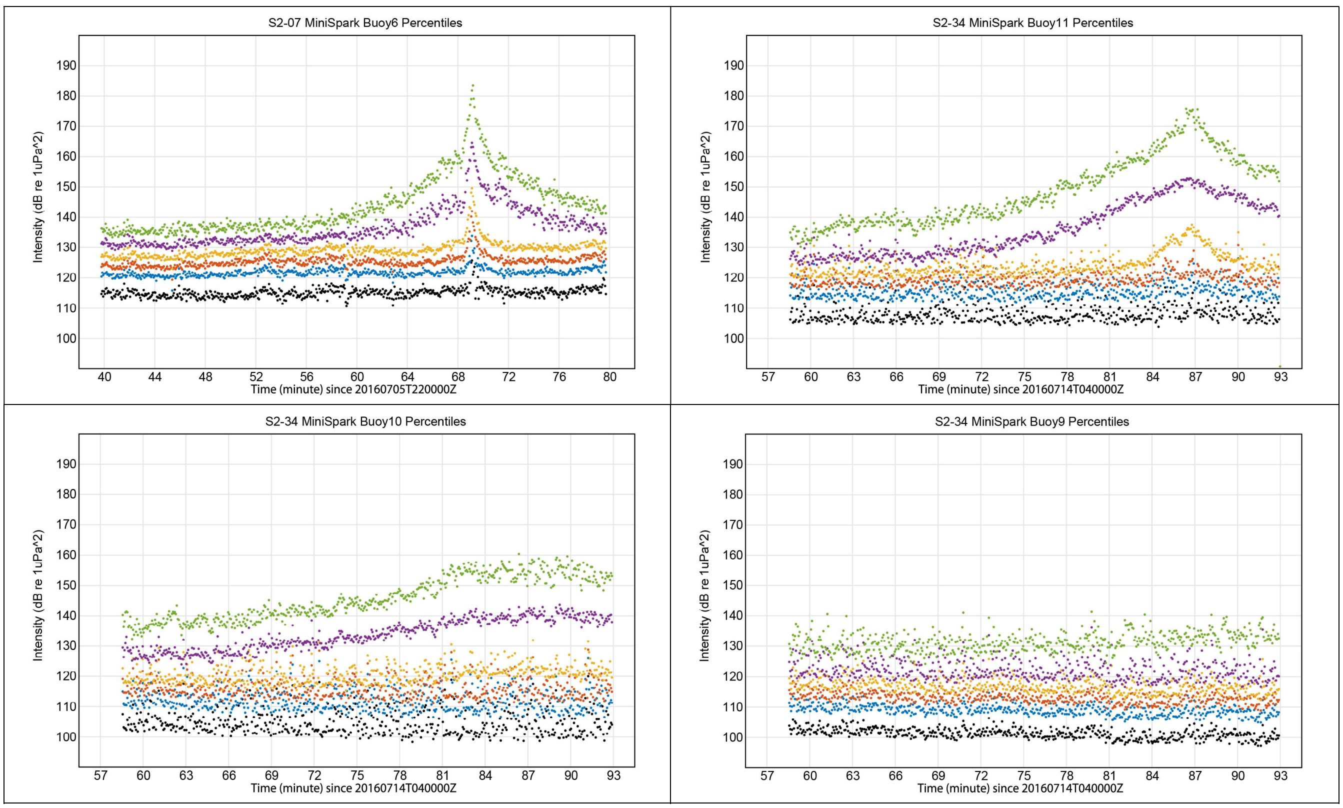


Figure 4.29.2-1. Percentile plots of Mini Sparker signals, 500 Joules high power, at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position E (Buoy10); Bottom right: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

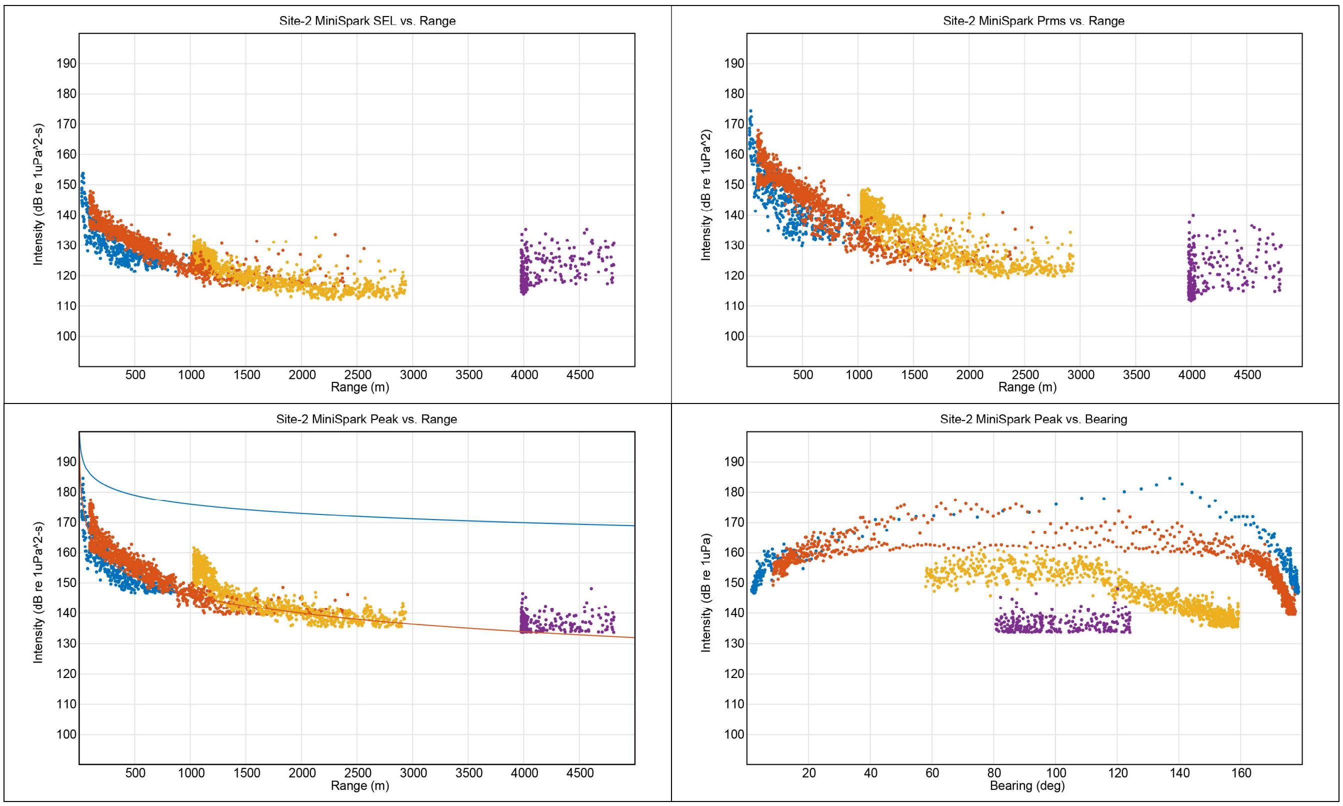


Figure 4.29.2-2. Range results for Mini Sparker signals, 500 Joules high power, at Site 2 for positions D (Buoy6), B (Buoy5 and Buoy11, combined), E (Buoy10), and F (Buoy9).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.29.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

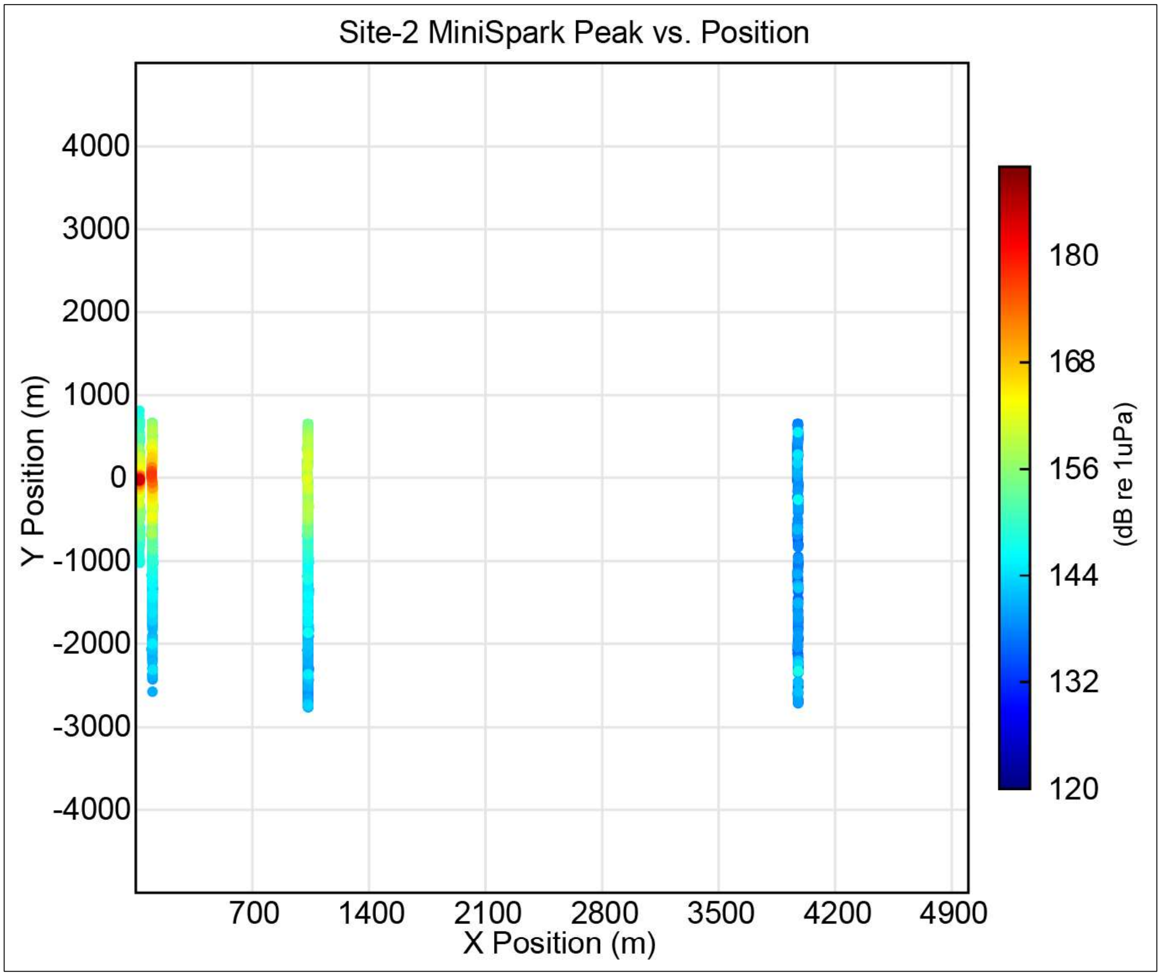


Figure 4.29.2-3. Plan view of received peak level for Mini Sparker, 500 Joules high power, at Site 2 for positions D (Buoy6), B (Buoy5 and Buoy11), E (Buoy10), and F (Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.29.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.29.2-1. Mini Sparker, 500 J high power, source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
Mini Sparker Mode 2	NA	500 J	High Power	NA	210	201	180
NUWC	NA	500 J	High Power	NA	210	201	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.29.3 Site 3 – Mud, 30 m Depth

At S3, the Mini Sparker, 500 J high power, Mode 2, had valid acoustic recordings in Run11 at positions B (Buoy12), A (Buoy5), and F (Buoy6).

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 2, are shown in **Figure 4.29.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run11, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panel show the valid recorded acoustics at positions A (Buoy5) and F (Buoy6). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.29.3-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to collected data. For the Mini Sparker at S3, positions B (Buoy12), A (Buoy5), and F (Buoy6) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 4,800 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 210 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak levels for position B, A, and F at approximately 80° to 100°, indicating relatively good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

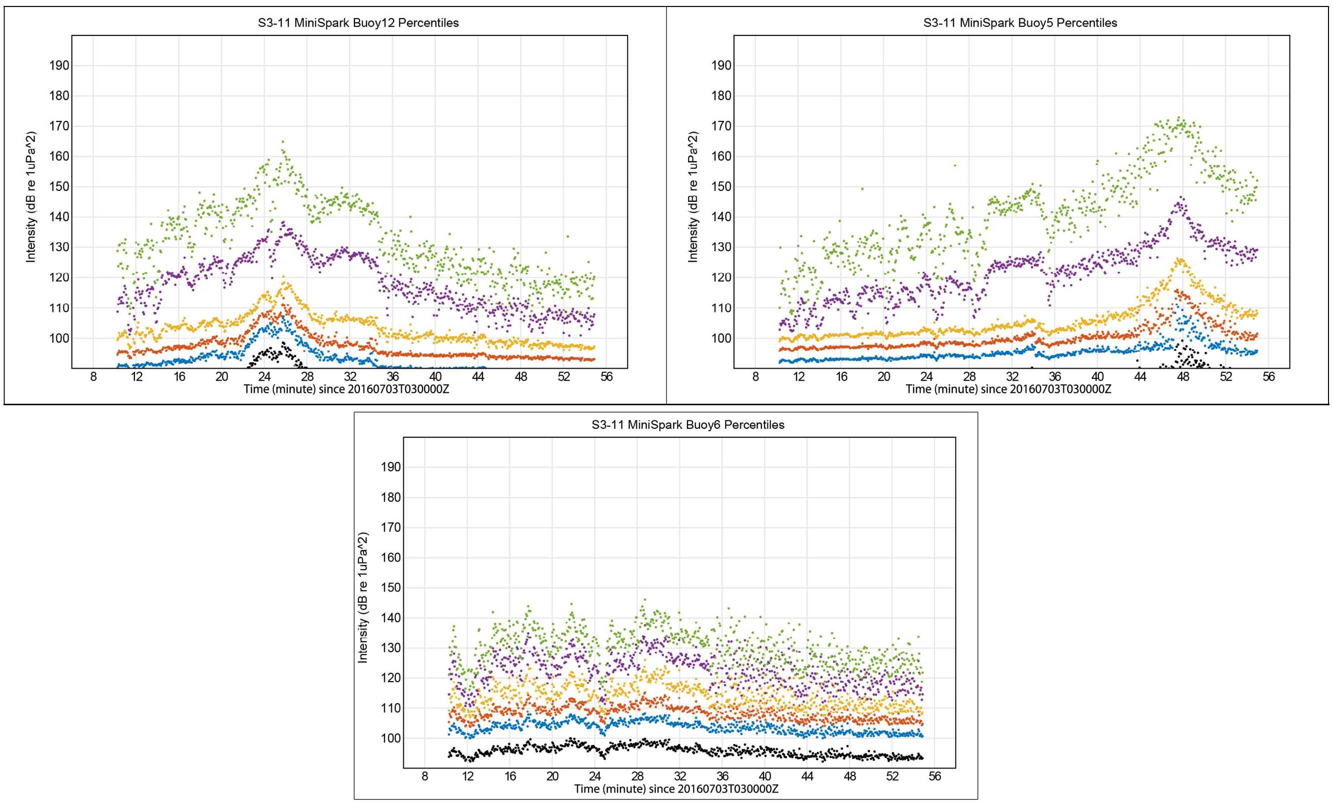


Figure 4.29.3-1. Percentile plots of Mini Sparker signals, 500 Joules high power, at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy5); Bottom: SPL_{pk} arrival at position F (Buoy6). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

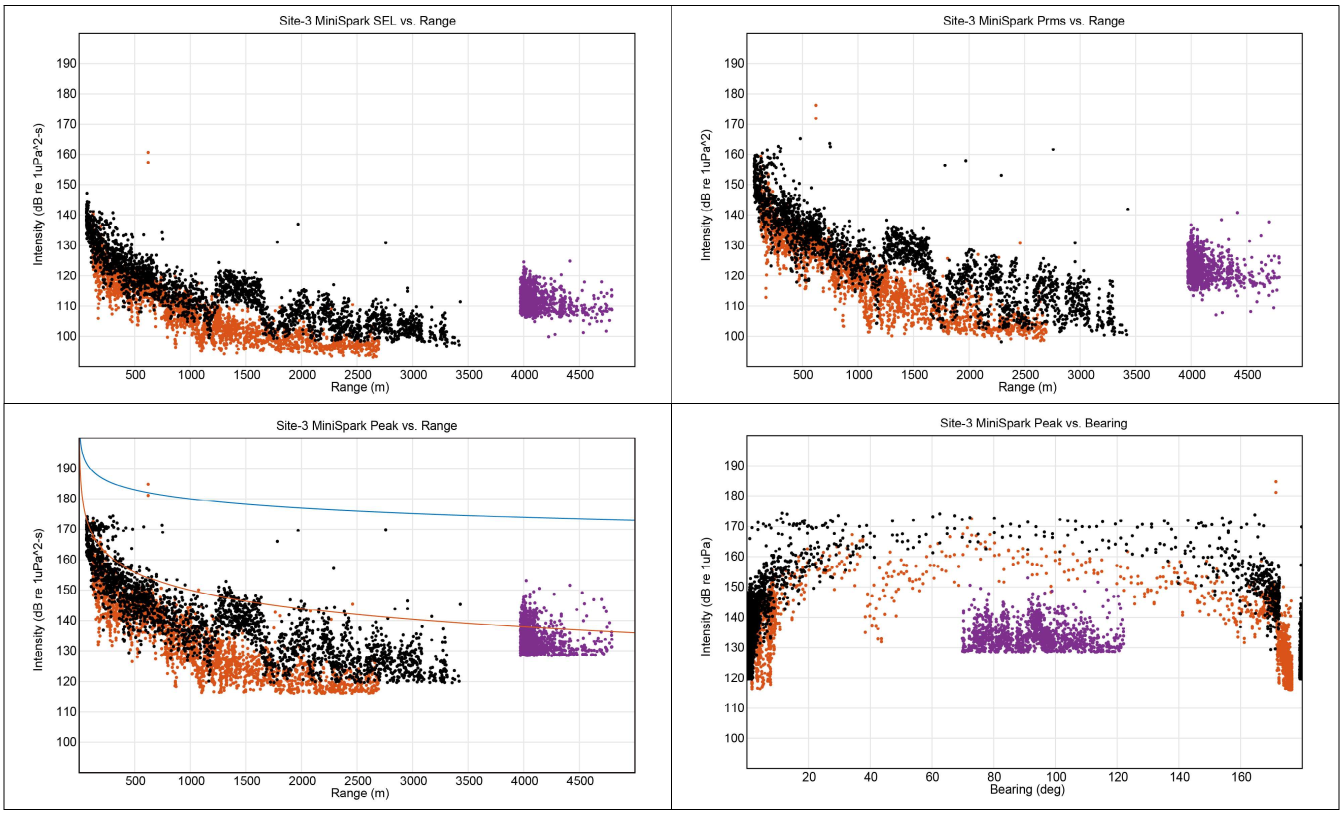


Figure 4.29.3-2. Range results for Mini Sparker combined signals, 500 Joules high power, for Run11 at Site 3 for positions B (Buoy12), A (Buoy5), and F (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; F = purple.

The plan view is shown in **Figure 4.29.3-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -2,500 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions B (Buoy12), A (Buoy5), and F (Buoy6). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position B is seen at approximately 0 m on the y-axis.

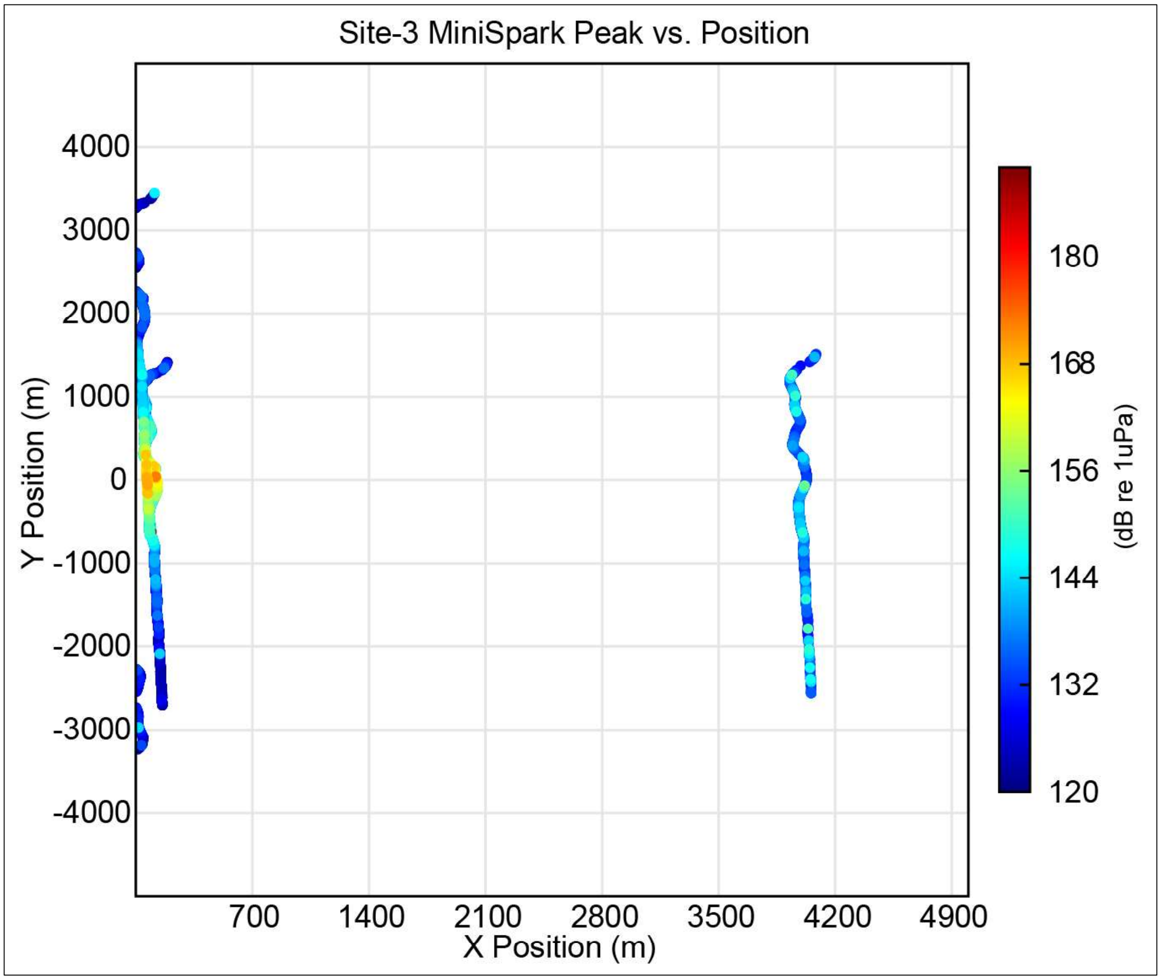


Figure 4.29.3-3. Plan view of received peak level for Mini Sparker, 500 Joules high power, at Site 3 for positions B (Buoy12), A (Buoy5), and F (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.29.3-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.29.3-1. Mini Sparker, 500 J high power, source levels, Mode 2, at Site 3. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 2	NA	500 J	High Power	NA	209	194	182
NUWC	NA	500 J	High Power	NA	210	201	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.29.4 Site 4 – Sand, 30 m Depth

At S4, the Mini Sparker, 500 J high power, Mode 2, had valid acoustic recordings for Run25 at positions B (Buoy12), A (Buoy7), and F (Buoy5).

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 2, are shown in **Figure 4.29.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run25, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the acoustic recordings at positions A (Buoy7), which has bad data, and F (Buoy5), where the signal is not visible. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.29.4-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Mini Sparker at S4, only position B (Buoy12) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 60 to approximately 1,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 210 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B at approximately 100°, indicating an error in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

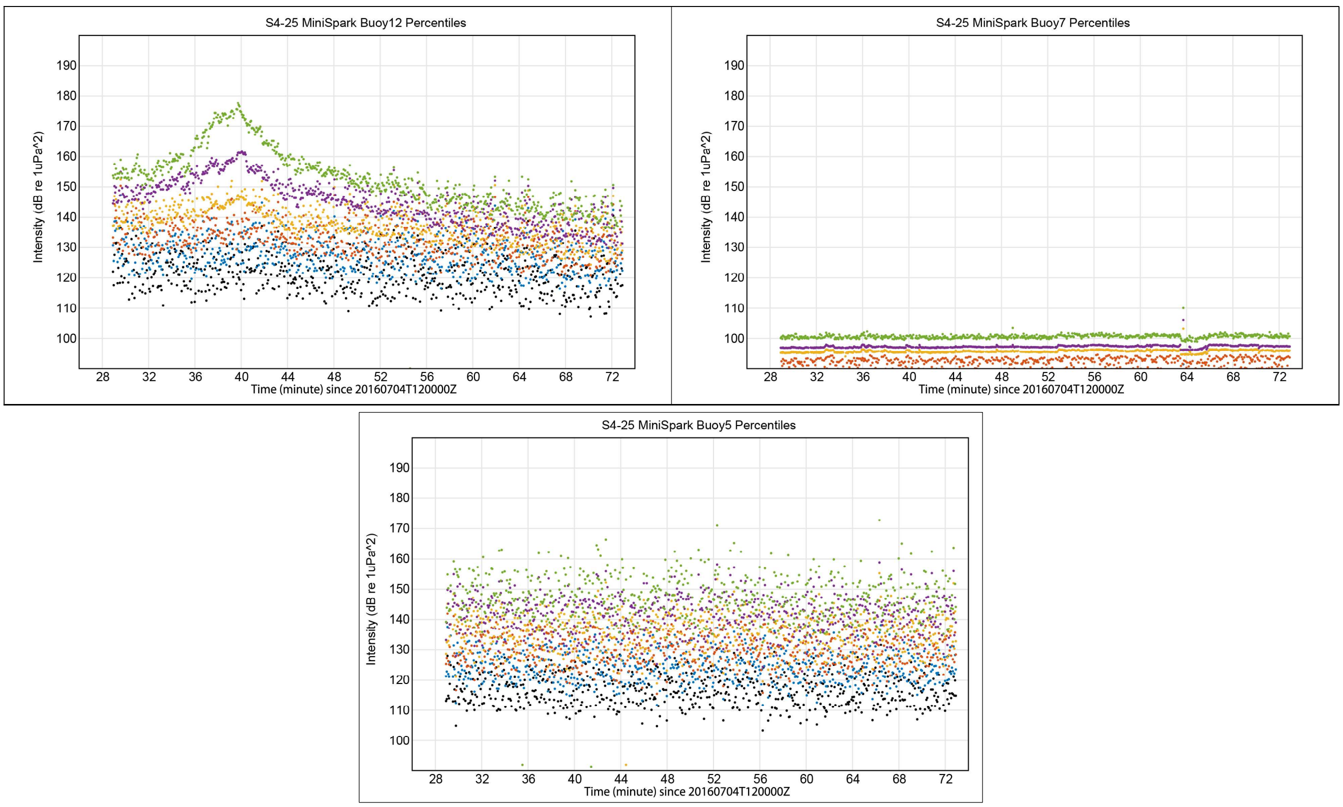


Figure 4.29.4-1. Percentile plots of Mini Sparker signals, 500 Joules high power, at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy7); Bottom: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

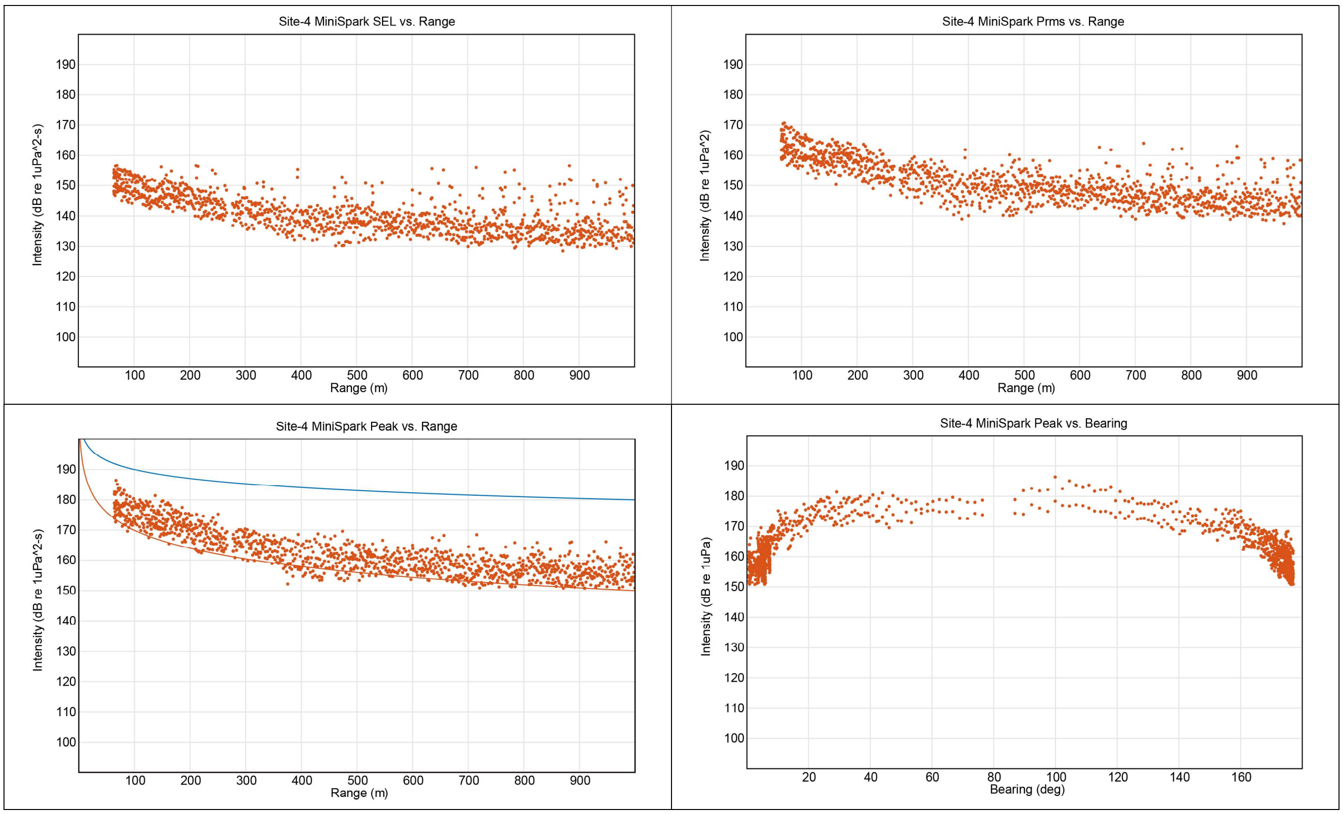


Figure 4.29.4-2. Range results for Mini Sparker signals, 500 Joules high power, at Site 4 for position B (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.29.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position B (Buoy12). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position B is seen at approximately 0 m on the y-axis.

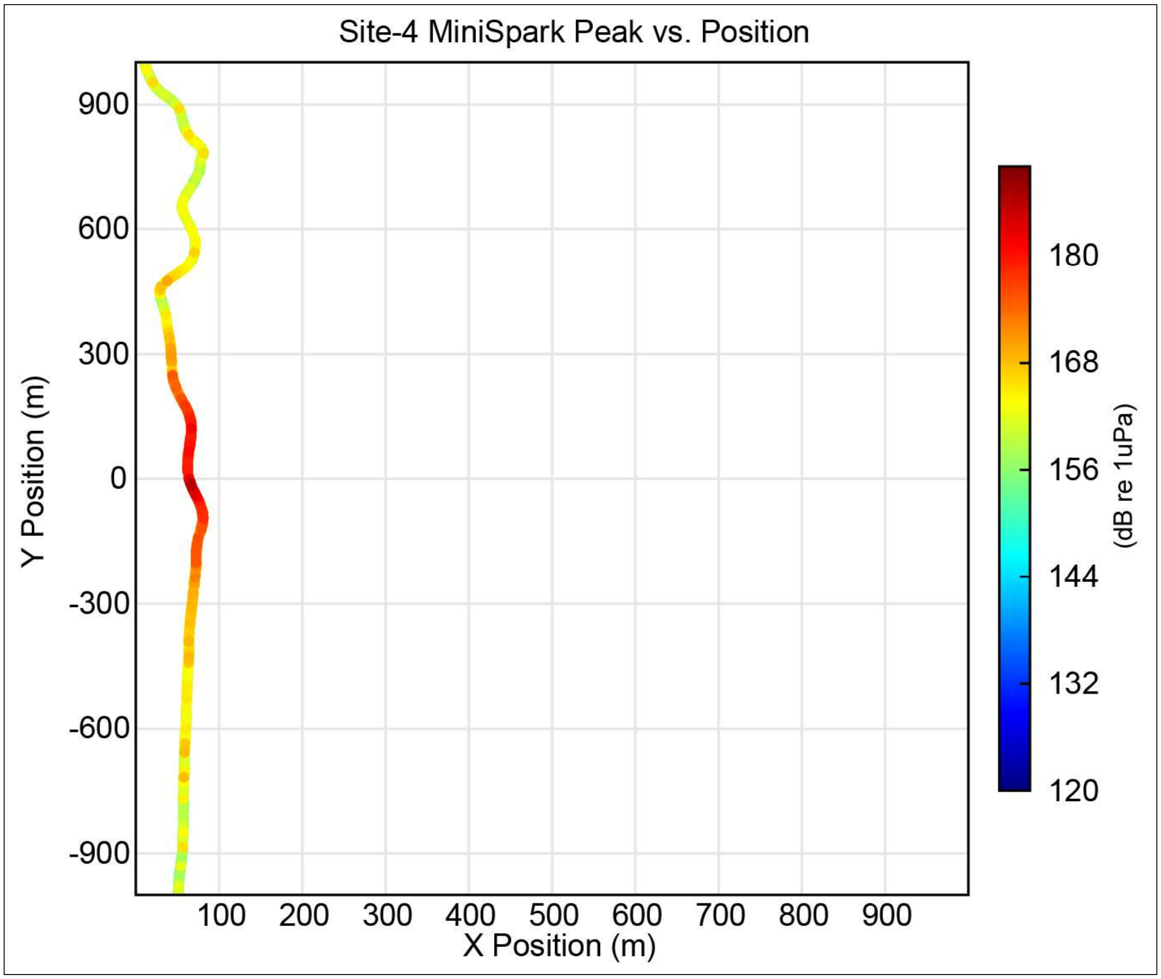


Figure 4.29.4-3. Plan view of received peak level for Mini Sparker, 500 Joules high power, at Site 4 for position B (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.29.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.29.4-1. Mini Sparker, 500 J high power, source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 2	NA	500 J	High Power	NA	211	196	181
NUWC	NA	500 J	High Power	NA	210	201	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.29.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Mini Sparker, 500 J high power, Mode 2, had valid acoustic recordings in Run4 and Run5 at positions D (Buoy6) and E (Buoy8 and Buoy9).

Run Summary

The percentile plots for the available recordings of the Mini Sparker, Mode 2, are shown in **Figure 4.29.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run4, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position E (Buoy8 and Buoy9). The data at position E (Buoy9) had noise spikes, and a filter was applied to remove all received levels above 165 dB re 1 µPa.

The results panels (**Figure 4.29.5-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Mini Sparker at S5, positions D (Buoy6) and E (Buoy8 and Buoy9, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 80 to approximately 3,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 210 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are distinct groupings of peak pressure levels, specifically for position D, indicating calibration issues.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level broadly at 90°, which is expected for buoys with GPS navigation and a symmetric source.

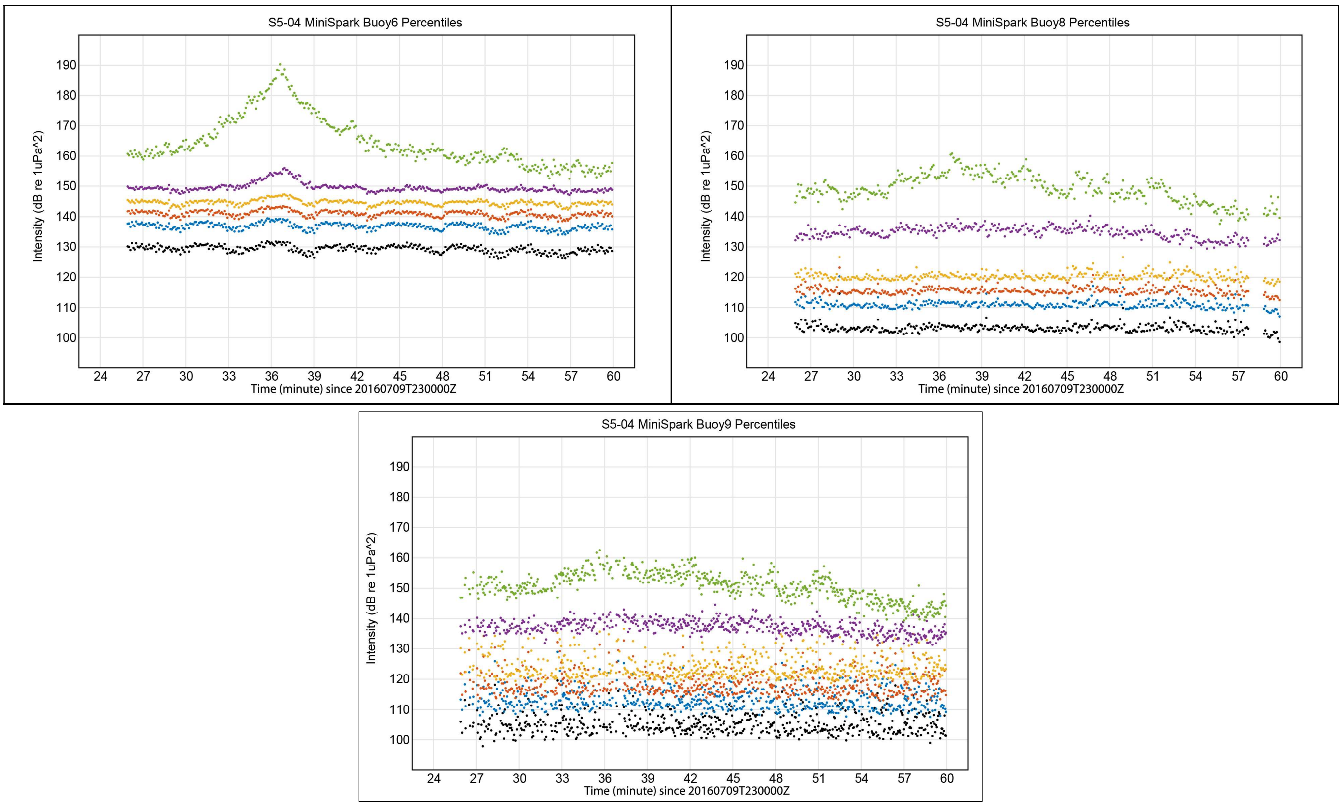


Figure 4.29.5-1. Percentile plots of Mini Sparker signals, 500 Joules high power, at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy8); Bottom: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

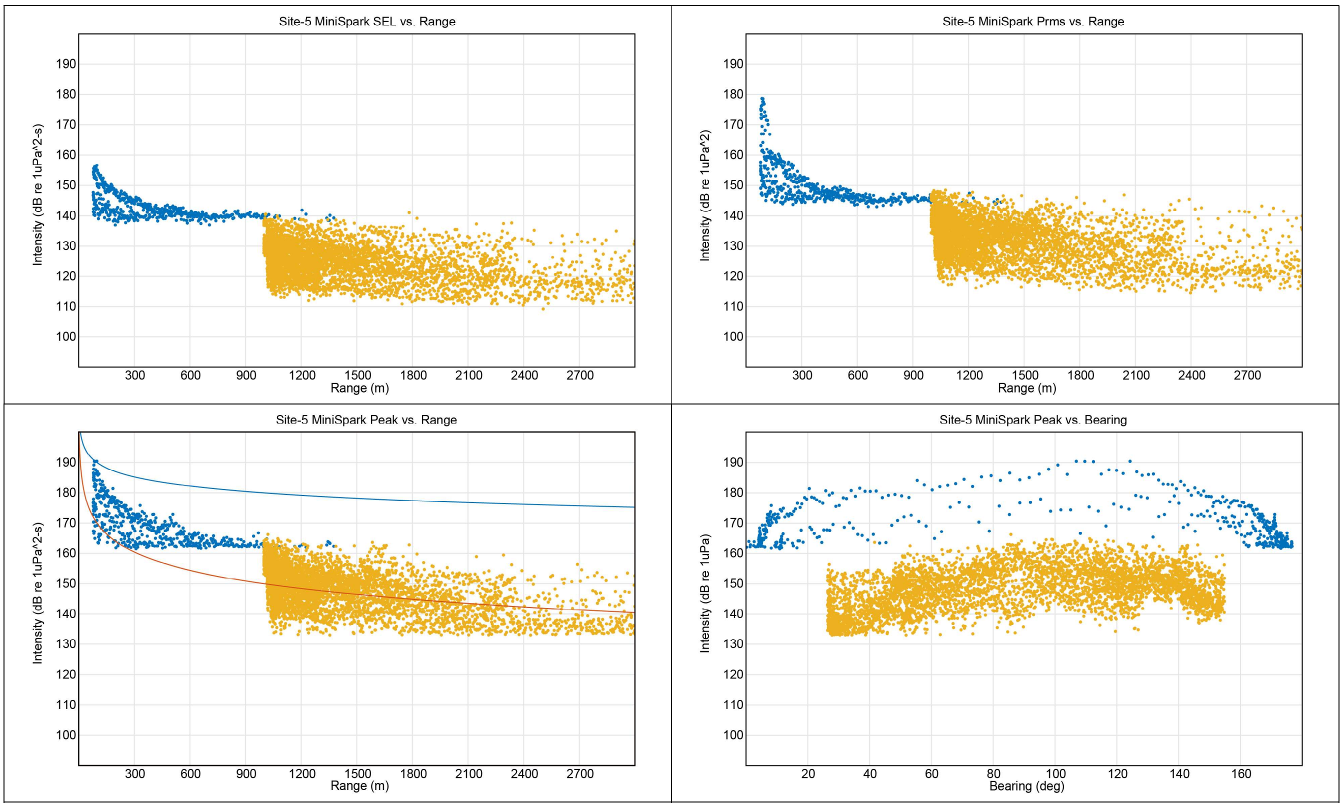


Figure 4.29.5-2. Range results for Mini Sparker signals, 500 Joules high power, at Site 5 from Run4 and Run5 for positions D (Buoy6) and E (Buoy8 and Buoy9, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.29.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -1,3000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and E (Buoy8 and Buoy9). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

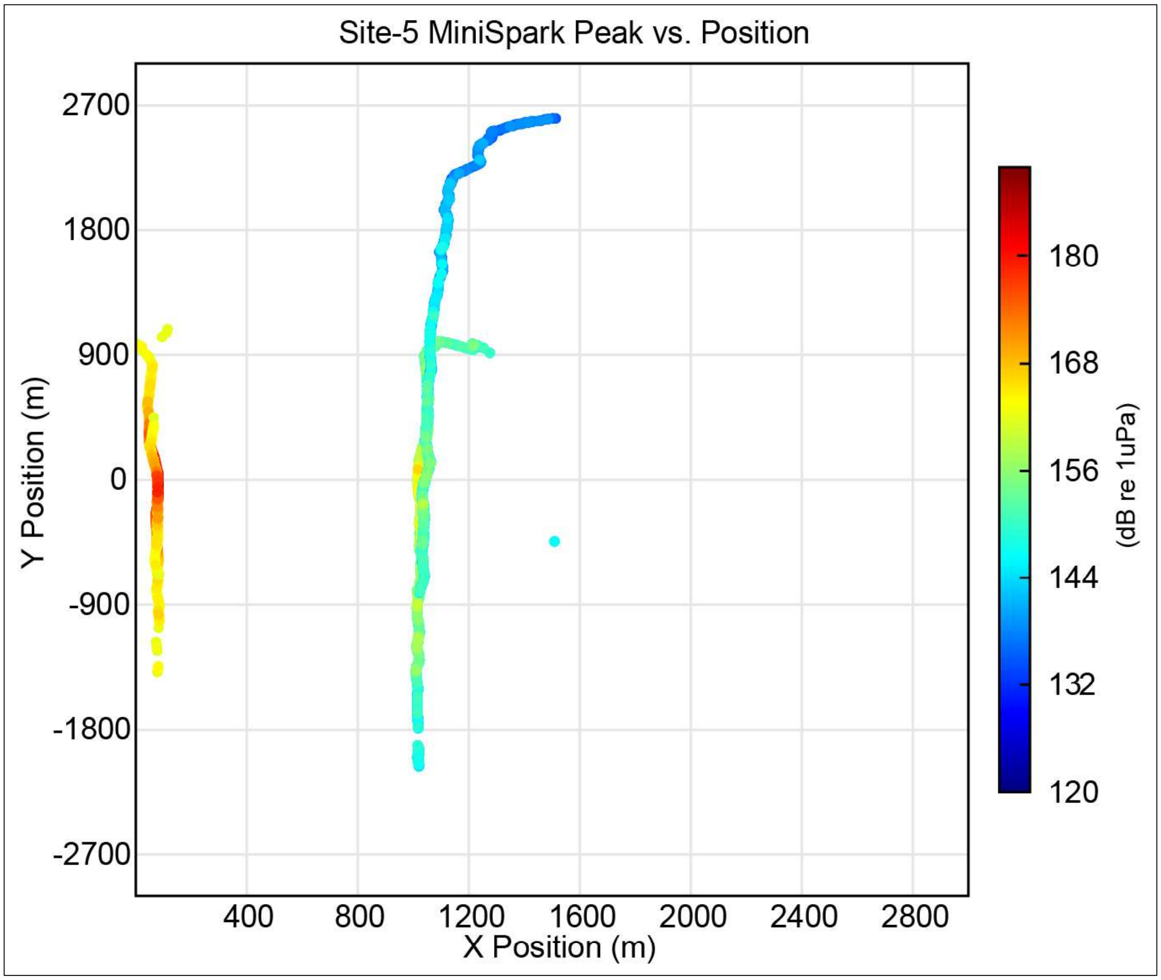


Figure 4.29.5-3. Plan view of received peak level for Mini Sparker, 500 Joules high power, at Site 5 for positions D (Buoy6) and E (Buoy8 and Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.29.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.29.5-1. Mini Sparker, 500 J high power, source levels, Mode 2, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					**Source Level (dB re 1 µPa m)**		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini Sparker Mode 2	NA	500 J	High Power	NA	205	182	173
NUWC	NA	500 J	High Power	NA	210	201	177

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.30 Applied Acoustics 251 Boomer, 0.1-5 kHz, 200 J, Lower Power, Single Plate (Mode 1)

The 251 Boomer acoustic source generates a single, low-frequency broadband signal with significant energy from 10 Hz to 5 kHz. The operational parameter settings for Mode 1 were a single plate, 200 J on lower power, and a 0.1 to 5 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.30-1** is the selected frequency band (0 to 8 kHz) and SPL_{pk} (175 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.30-1. Bandpass determination for the 251 Boomer, single plate, 200 Joules, lower power, 0.1-5 kHz, at Site 2, Run26.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	174.97
0-50	174.93
0-25	174.74
0-8	**174.97**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The 251 Boomer, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.30-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The 251 Boomer was operationally paired in alternation with the Bubble Gun. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.30-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

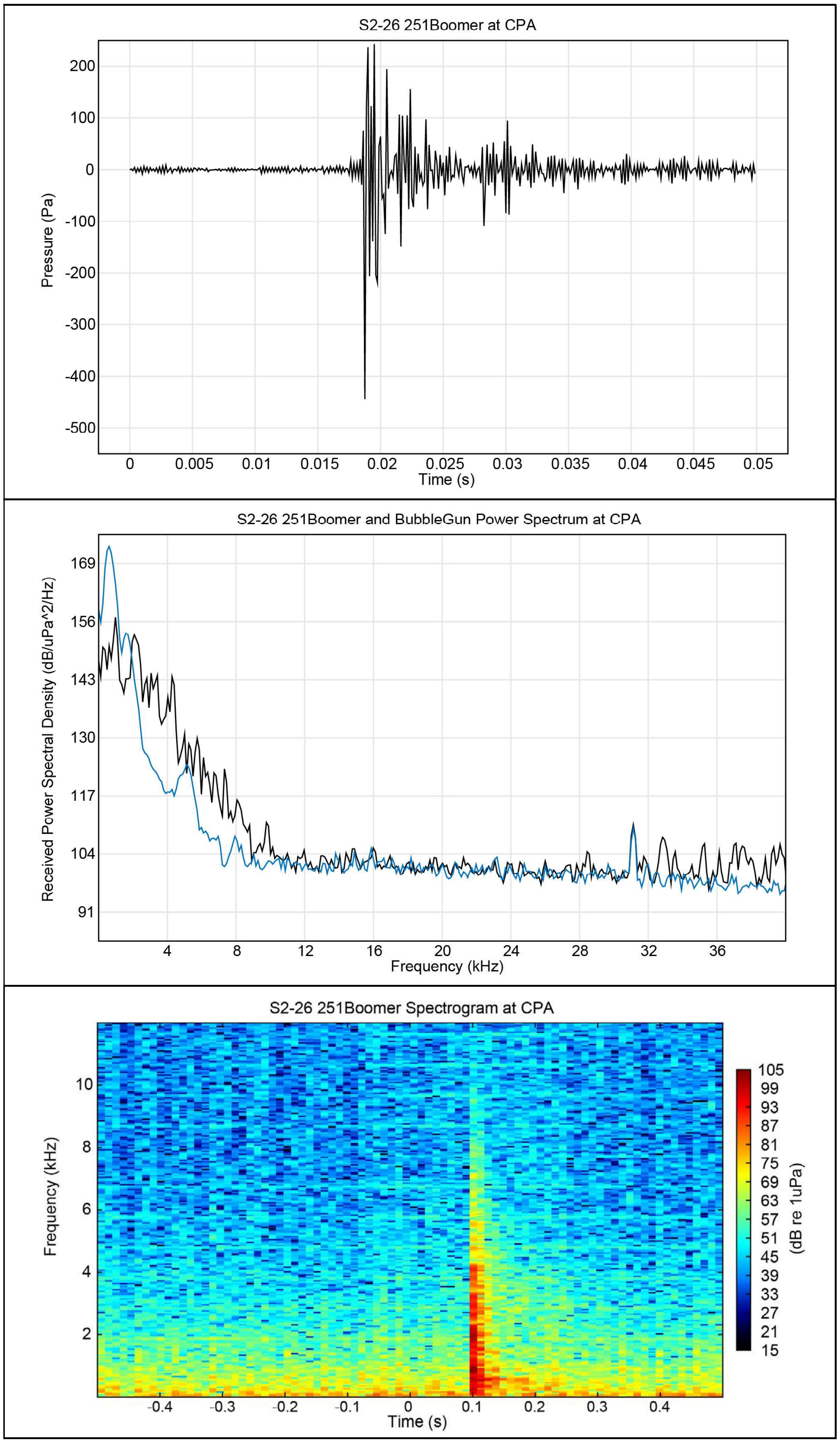


Figure 4.30-1. 251 Boomer, 200 Joules low power, measured signal characteristics at closest point of approach (CPA) at Site 2, Run26.

Top: Time-waveform of a signal; Middle: Power spectral density, 251 Boomer = black, Bubble Gun = blue; Bottom: Spectrogram.

4.30.1 Site 1 – Mud, 10 m Depth

At S1, the 251 Boomer, Mode 1, had valid acoustic recordings in Run13 at positions D (Buoy6) and E (Buoy5 and Buoy8).

Run Summary

The percentile plots for the three available recordings of the 251 Boomer, Mode 1, are shown in **Figure 4.30.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run13, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. For this directional source, the signal was only observable for a total of 4 minutes (2 minutes before and 2 minutes after the CPA). The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8). The 25-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.30.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied. For the 251 Boomer at S1, positions D (Buoy6) and E (Buoy5 and Buoy8, combined) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 1,500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 206 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The position E (Buoy5 and Buoy8, combined) results appear to be at least 10 dB lower than expected.

The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.30.1-2**), which shows the received peak level for position D at approximately 120° and for position B at approximately 100°, indicating errors in buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

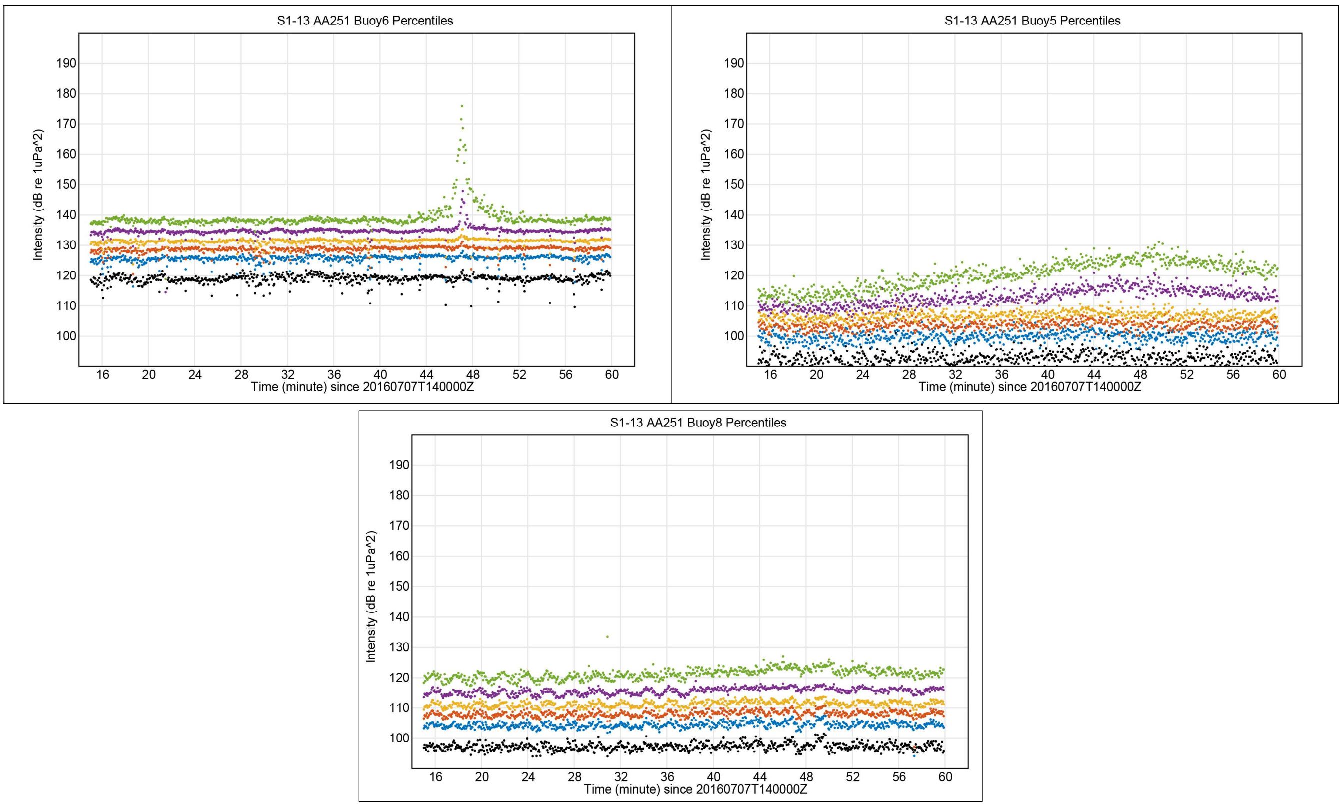


Figure 4.30.1-1. Percentile plots of 251 Boomer signals, 200 Joules low power, at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

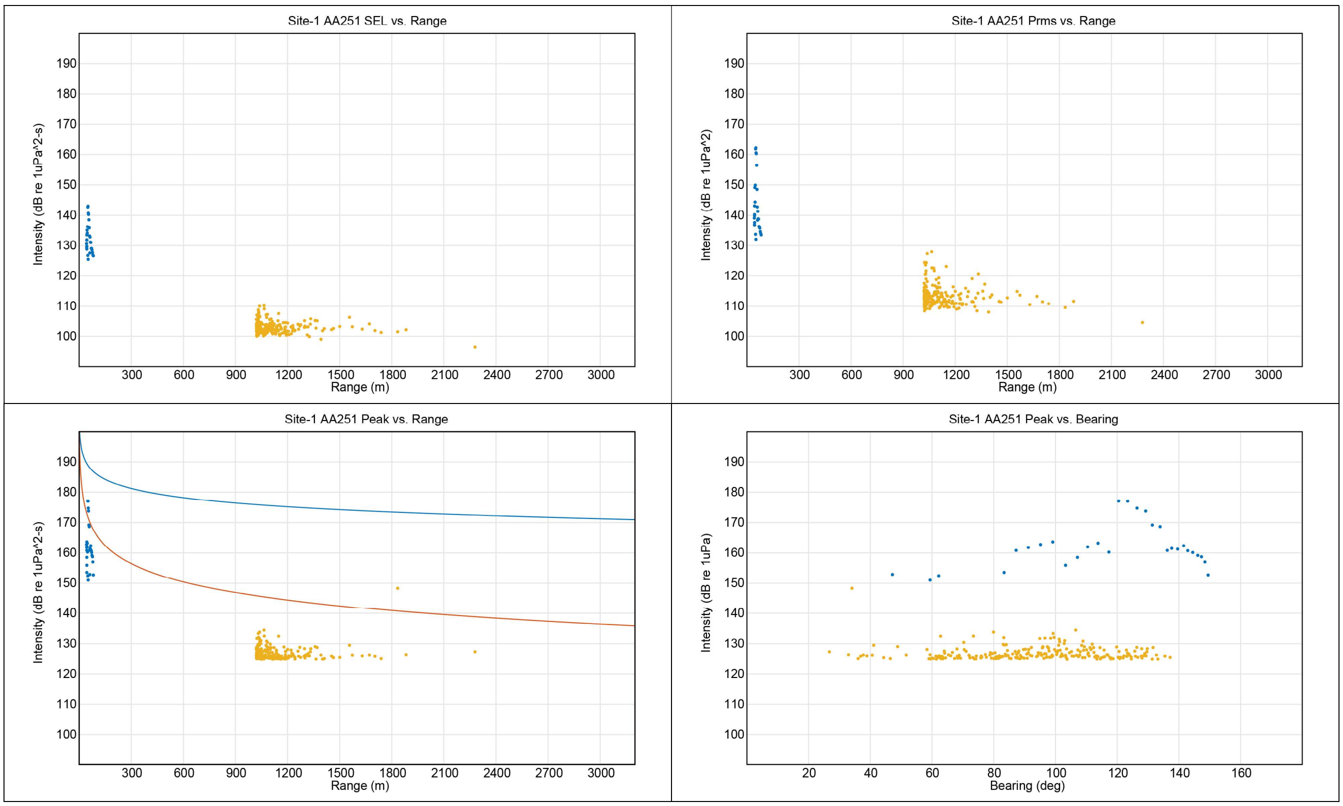


Figure 4.30.1-2. Range results for 251 Boomer signals, 200 Joules low power, at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.30.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA is at 50,-10 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position E is seen at approximately 0 m on the y-axis.

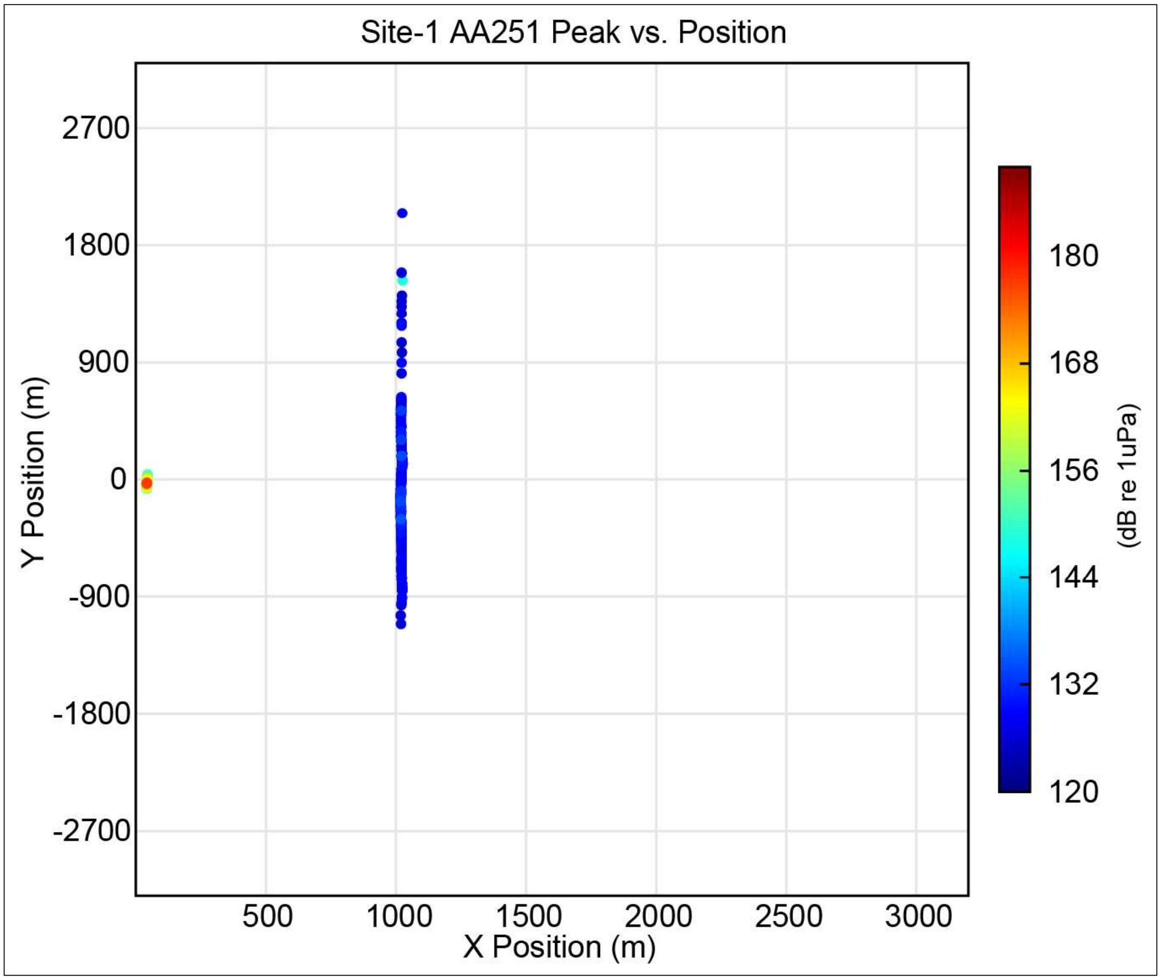


Figure 4.30.1-3. Plan view of received peak level for 251 Boomer, 200 Joules low power, at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.30.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.30.1-1. 251 Boomer, 200 Joules low power, source levels, Mode 1, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
251 Boomer Mode 1	NA	200 J	Low Power	NA	210	197	178
NUWC	NA	200 J	Low Power	NA	206	198	167

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.30.2 Site 2 – Sand, 10 m Depth

At S2, the 251 Boomer, Mode 1, had valid acoustic recordings in Run26 at positions D (Buoy6), B (Buoy11), and F (Buoy9).

Run Summary

The percentile plots for the available recordings of the 251 Boomer, Mode 1, are shown in **Figure 4.30.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run26, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The signal is visible at position B (Buoy11) but not at position F (Buoy9).

The results panels (**Figure 4.30.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 251 Boomer at S2, positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 30 to approximately 800 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 206 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.30.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 120° indicating errors in buoy positioning. For position B the peak is at approximately 80°. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°which corresponds to the CPA.

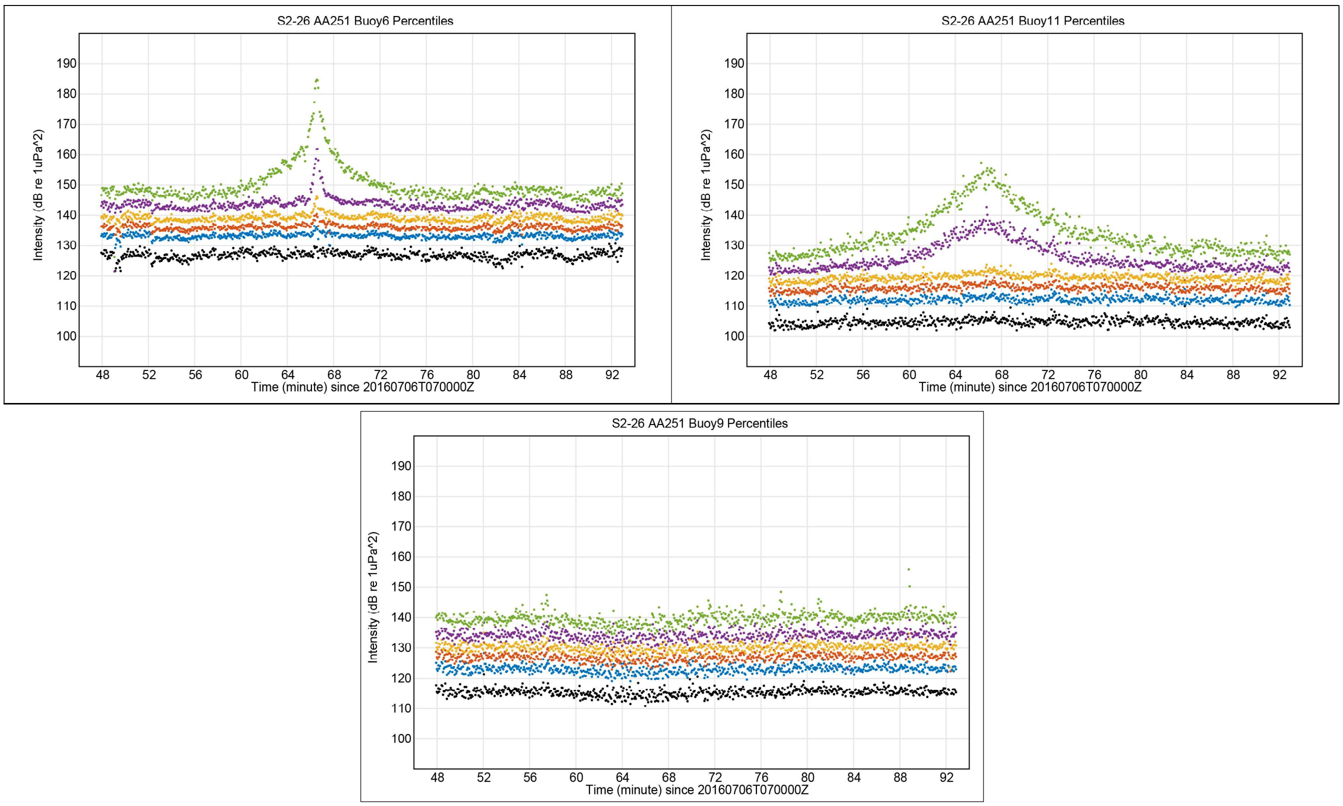


Figure 4.30.2-1. Percentile plots of 251 Boomer signals, 200 Joules low power, at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

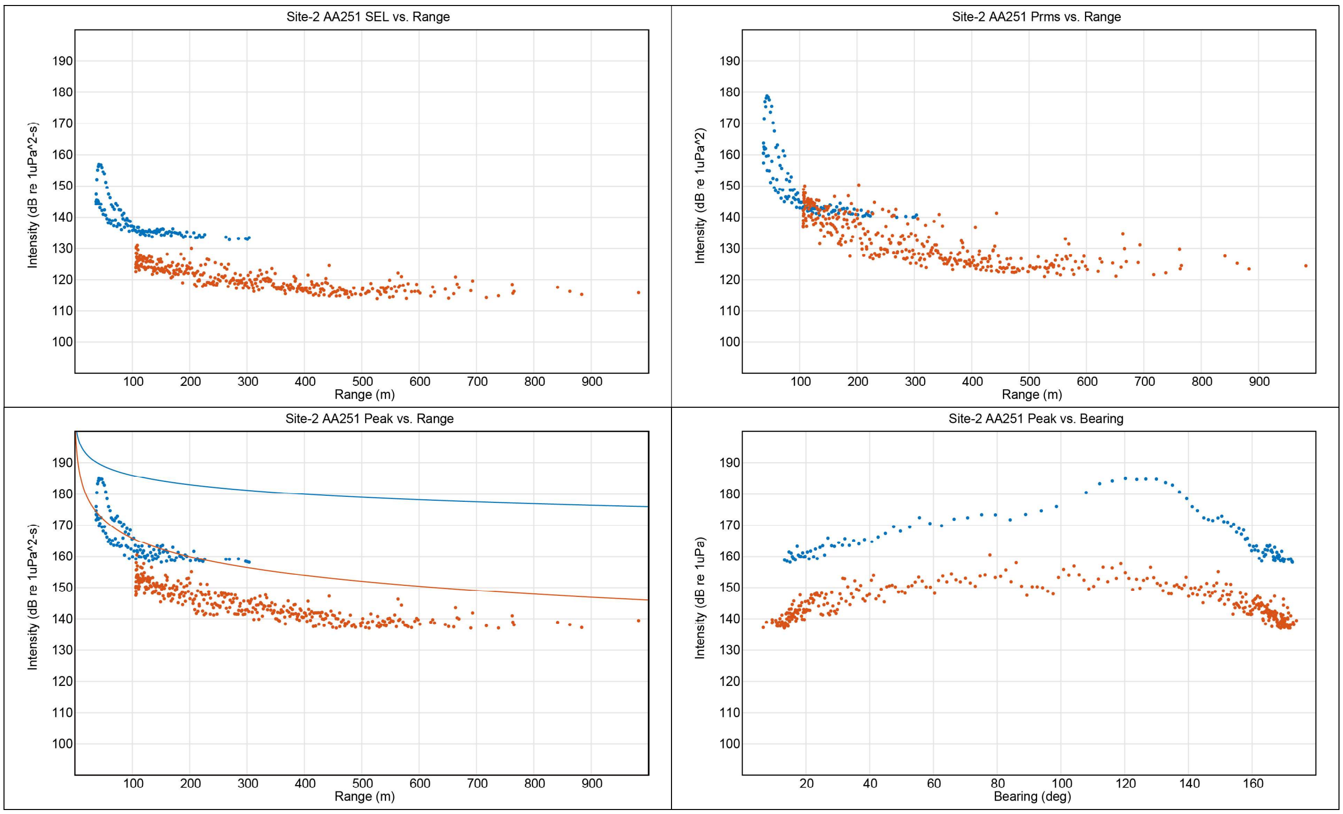


Figure 4.30.2-2. Range results for 251 Boomer signals, 200 Joules low power, at Site 2 for positions D (Buoy6) and B (Buoy11). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.30.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 35,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -300 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -20 m on the y-axis, while position B had high amplitudes at approximately 0 m.

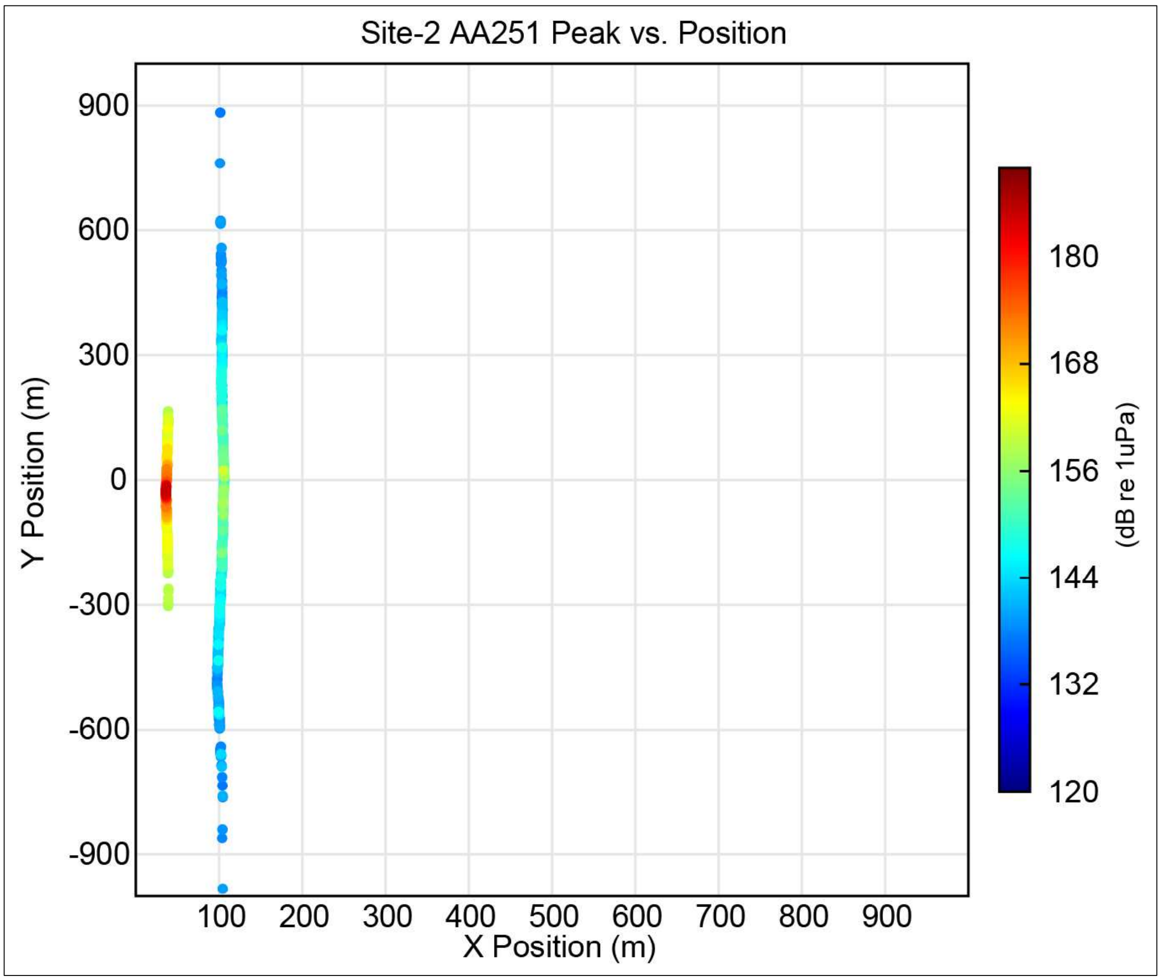


Figure 4.30.2-3. Plan view of received peak level for 251 Boomer, 200 Joules low power, at Site 2 for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.30.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.30.2-1. 251 Boomer, 200 Joules low power, source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
251 Boomer Mode 1	NA	200 J	Low Power	NA	201	194	173
NUWC	NA	200 J	Low Power	NA	206	198	167

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.30.3 Site 3 – Mud, 30 m Depth

The 251 Boomer, Mode 1, was not deployed or operated at S3.

4.30.4 Site 4 – Sand, 30 m Depth

The 251 Boomer, Mode 1, was not deployed or operated at S4.

4.30.5 Site 5 – Sandy-Silt, 100 m Depth

The 251 Boomer, Mode 1, was not deployed or operated at S5.

This Page Intentionally Left Blank

4.31 Applied Acoustics 251 Boomer, 0.1-5 kHz, 100 J, Lower Power, Single Plate (Mode 2)

The 251 Boomer acoustic source generates a single, low-frequency signal with a peak frequency between 10 Hz and 5 kHz. The operational parameter settings for Mode 2 were a single plate, 100 J on lower power, and a 0.1 to 5 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.31-1** is the selected frequency band (0 to 25 kHz) and SPL_{pk} (185 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.31-1. Bandpass determination for the 251 Boomer, 0.1-5 kHz, 100 Joules, lower power, single plate, at Site 2, Run27.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-200	179.49
0-50	183.85
0-25	**184.66**
1-15	184.22
0-8	183.80
0-4	148.40

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The 251 Boomer, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.31-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The 251 Boomer was operationally paired in alternation with the Bubble Gun. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.31-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

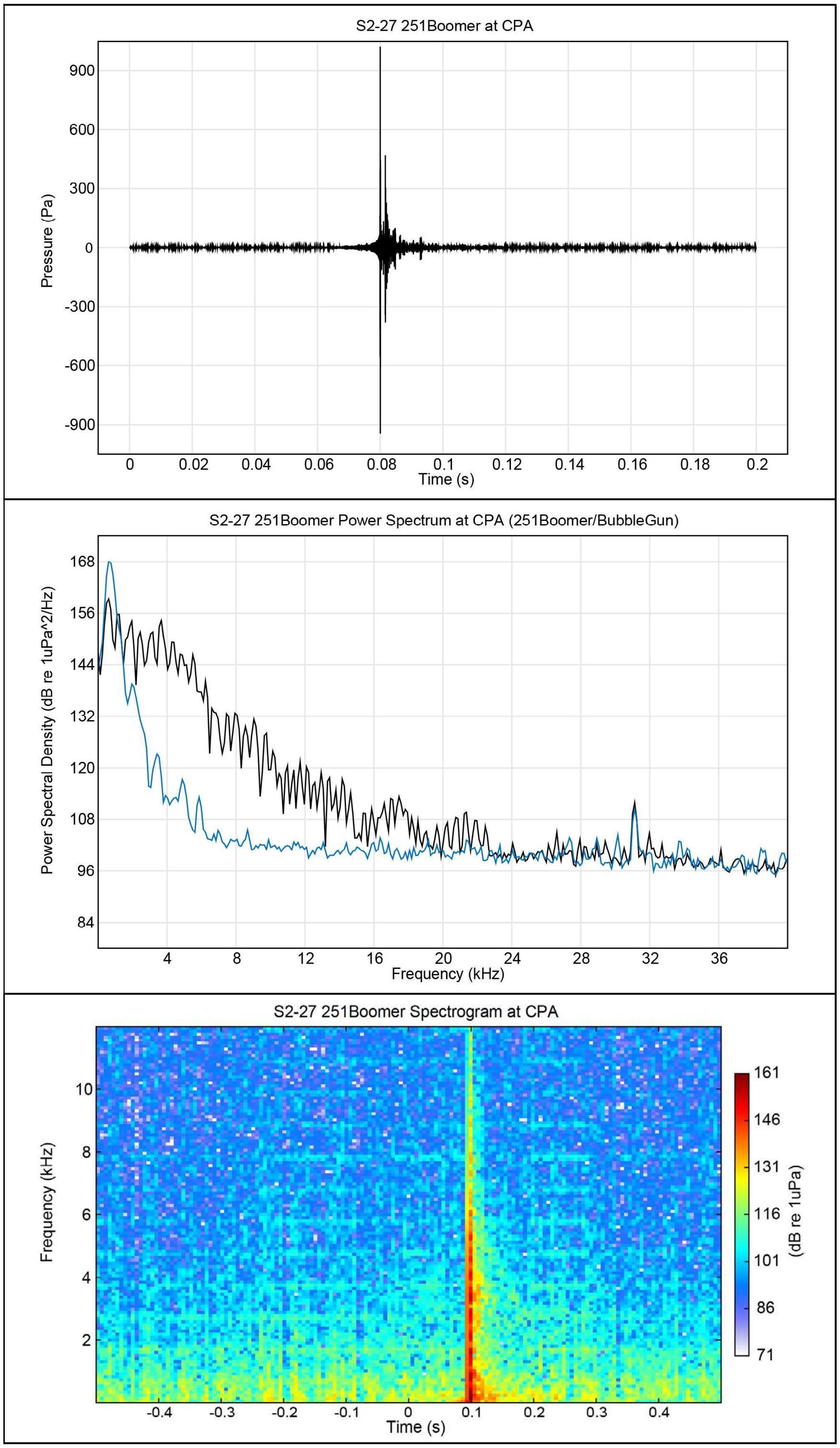


Figure 4.31-1. 251 Boomer, 100 Joules low power, measured signal characteristics at closest point of approach (CPA) at Site 2, Run27.
Top: Time-waveform of a signal; Middle: Power spectral density, 251 Boomer = black, Bubble Gun = blue; Bottom: Spectrogram.

4.31.1 Site 1 – Mud, 10 m Depth

The 251 Boomer, Mode 2, was not deployed or operated at S1.

4.31.2 Site 2 – Sand, 10 m Depth

At S2, the 251 Boomer, Mode 2, had valid acoustic recordings in Run27 at positions D (Buoy6), B (Buoy11), and F (Buoy9).

Run Summary

The percentile plots for the available recordings of the 251 Boomer, Mode 2, are shown in **Figure 4.31.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run27, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and F (Buoy9). Position F (Buoy9) was too distant for signals to be observed. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.31.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the 251 Boomer at S2, positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 800 m. The conical shape of the position D data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predict received levels for a 201 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.31.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 130°, indicating an error in buoy positioning. Note that for close sources, a small position error can lead to a large bearing error. For position B, the received peak level is indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

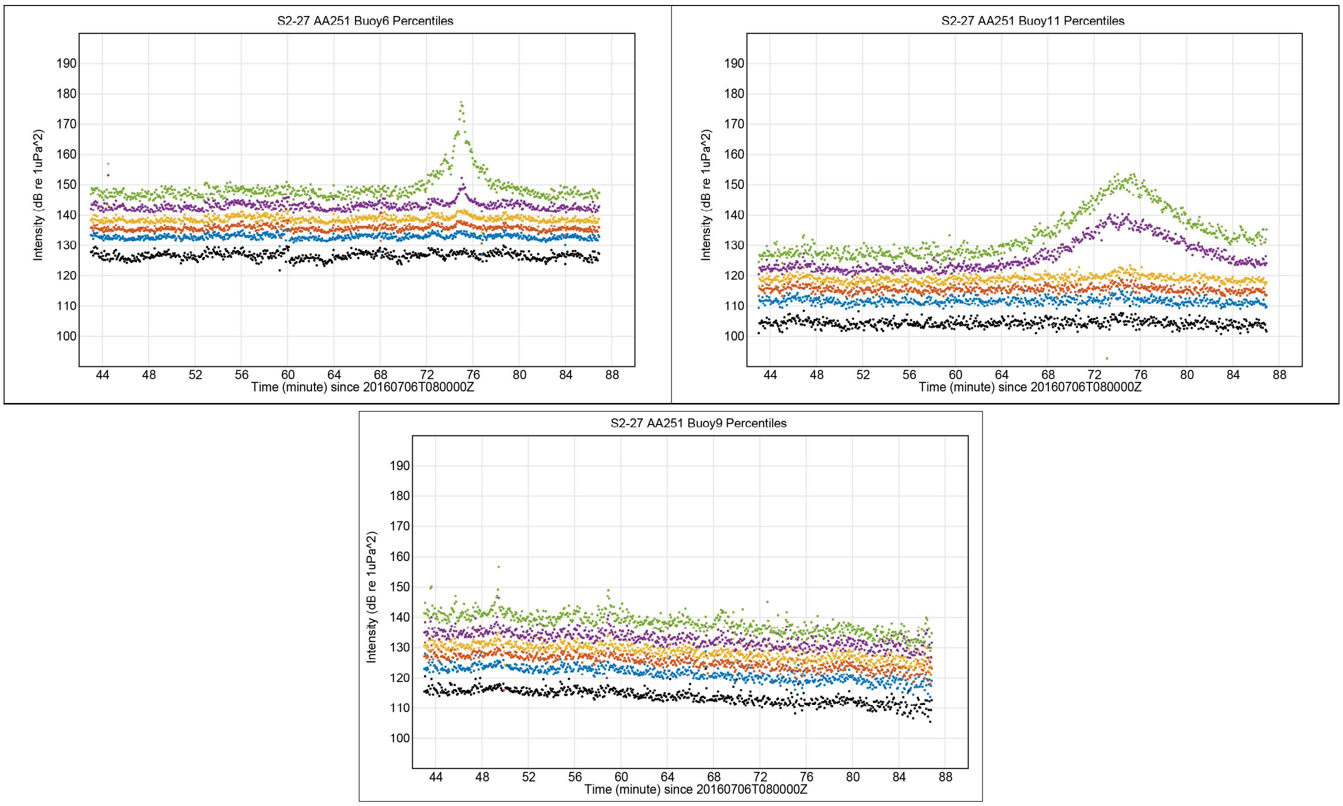


Figure 4.31.2-1. Percentile plots of 251 Boomer signals, 100 Joules low power, at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

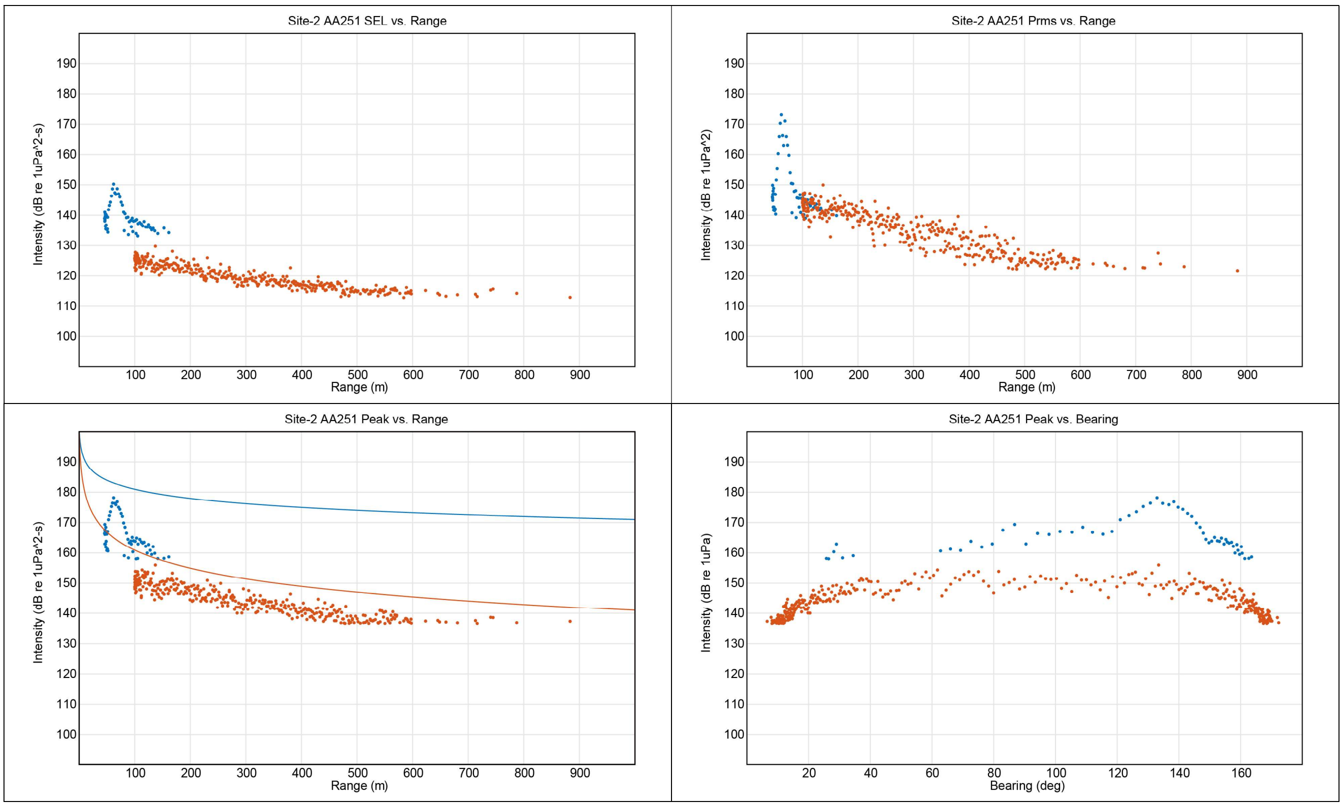


Figure 4.31.2-2. Range results for 251 Boomer signals, 100 Joules low power, at Site 2 for positions D (Buoy6) and B (Buoy11). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.31.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 40,-50 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -180 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -50 m on the y-axis

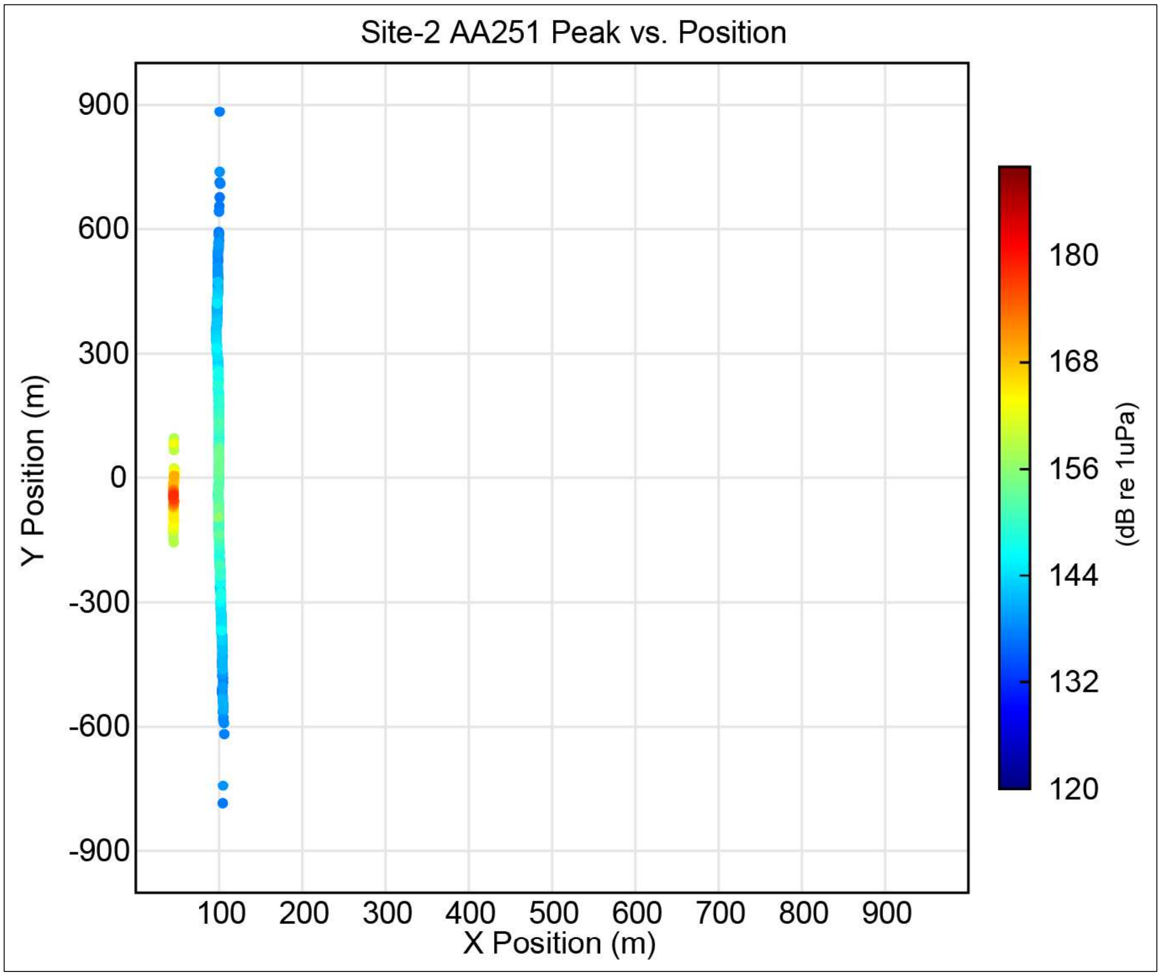


Figure 4.31.2-3. Plan view of received peak level for 251 Boomer, 100 Joules low power, at Site 2 for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.31.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.31.2-1. 251 Boomer, 100 Joules low power, source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
251 Boomer Mode 2	NA	100 J	Low Power	NA	196	191	168
NUWC	NA	100 J	Low Power	NA	201	191	160

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.31.3 Site 3 – Mud, 30 m Depth

The 251 Boomer, Mode 2, was not deployed or operated at S3.

4.31.4 Site 4 – Sand, 30 m Depth

The 251 Boomer, Mode 2, was not deployed or operated at S4.

4.31.5 Site 5 – Sandy-Silt, 100 m Depth

The 251 Boomer, Mode 2, was not deployed or operated at S5.

This Page Intentionally Left Blank

4.32 FSI Bubble Gun, 0.1-2 kHz, Dual Plate (Mode 1)

The Bubble Gun acoustic source generates a single, low-frequency (LF) signal with a peak frequency between 500 Hz and 1 kHz. The operational parameter settings for Mode 1 were a dual plate and 0.1 to 2 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.32-1** is the selected frequency band (0 to 8 kHz) and SPL_{pk} (185 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.32-1. Bandpass determination for the Bubble Gun acoustic source, 0.1-2 kHz, and dual plate at Site 2, Run26.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-100	185.0
0-50	185.0
0-25	184.95
0-8	**184.85**

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Bubble Gun, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.32-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Bubble Gun was operationally paired in alternation with the 251 Boomer. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of Figure **4.32-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

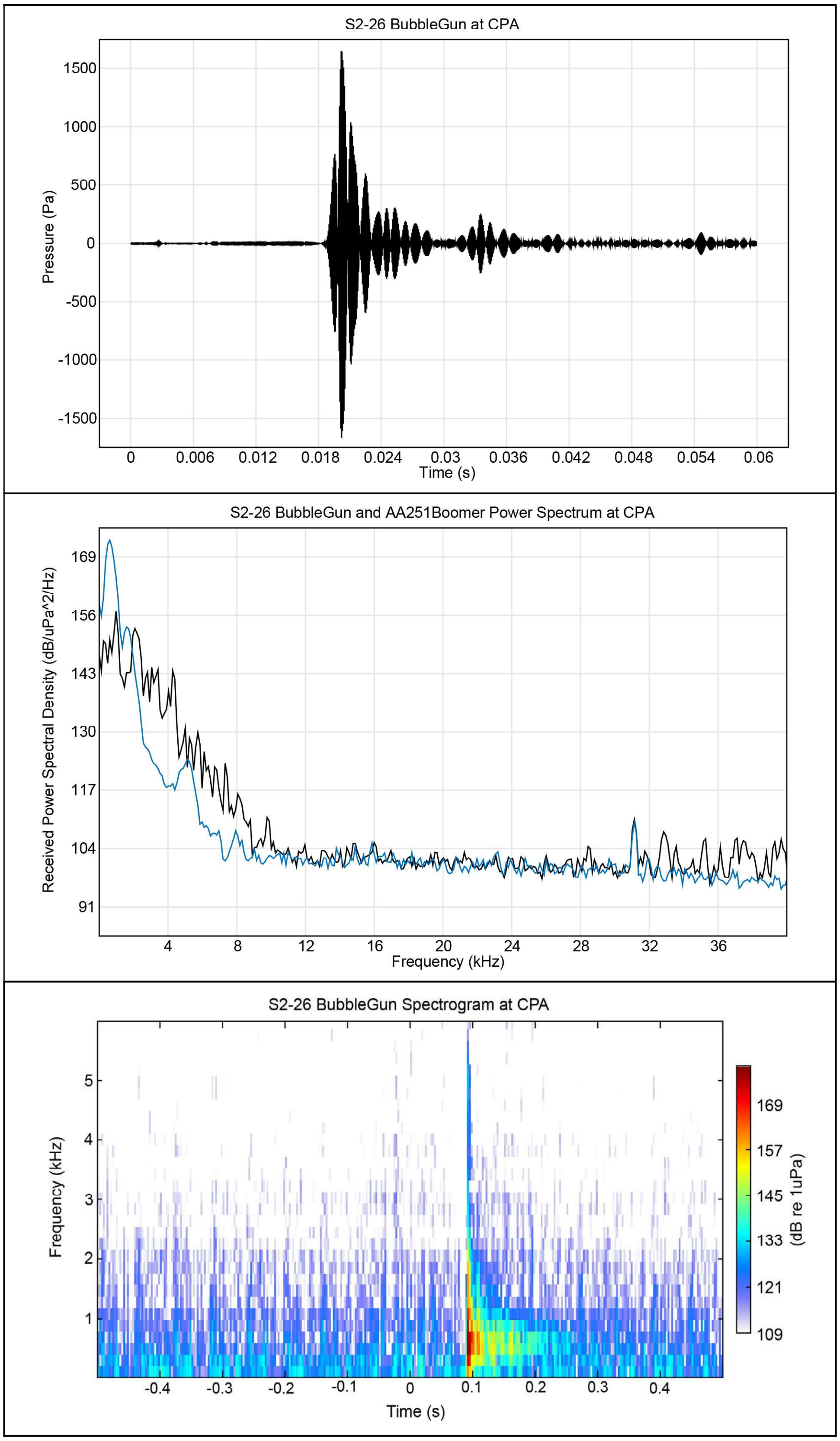


Figure 4.32-1. Bubble Gun measured signal characteristics at closest point of approach (CPA) at Site 2, Run26.
Top: Time-waveform of a signal; Middle: Power spectral density, AA251 Boomer = black, Bubble Gun = blue; Bottom: Spectrogram.

4.32.1 Site 1 – Mud, 10 m Depth

The Bubble Gun, Mode 1, was not deployed or operated at S1.

4.32.2 Site 2 – Sand, 10 m Depth

At S2, the Bubble Gun, Mode 1, had valid acoustic recordings in Run26 at positions D (Buoy6), B (Buoy11), and F (Buoy9).

Run Summary

The percentile plots for the available recordings of the Bubble Gun, Mode 1, are shown in **Figure 4.32.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run26, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at position F because of propagation loss of the signal.

The results panels (**Figure 4.32.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Bubble Gun at S2, positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 950 m. The conical shape of the position D data points signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 204 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016), however, the source levels for the dual plate configuration were from a malfunctioning system with plates that did not trigger simultaneously, so their reported values could be around 3 dB lower than expected.

The bottom right results panel of **Figure 4.32.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D (Buoy6) at approximately 130°, indicating an error in buoy positioning. For position B, the received peak level is at approximately 90°, which indicates good buoy positioning. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) is expected to be at 90°.

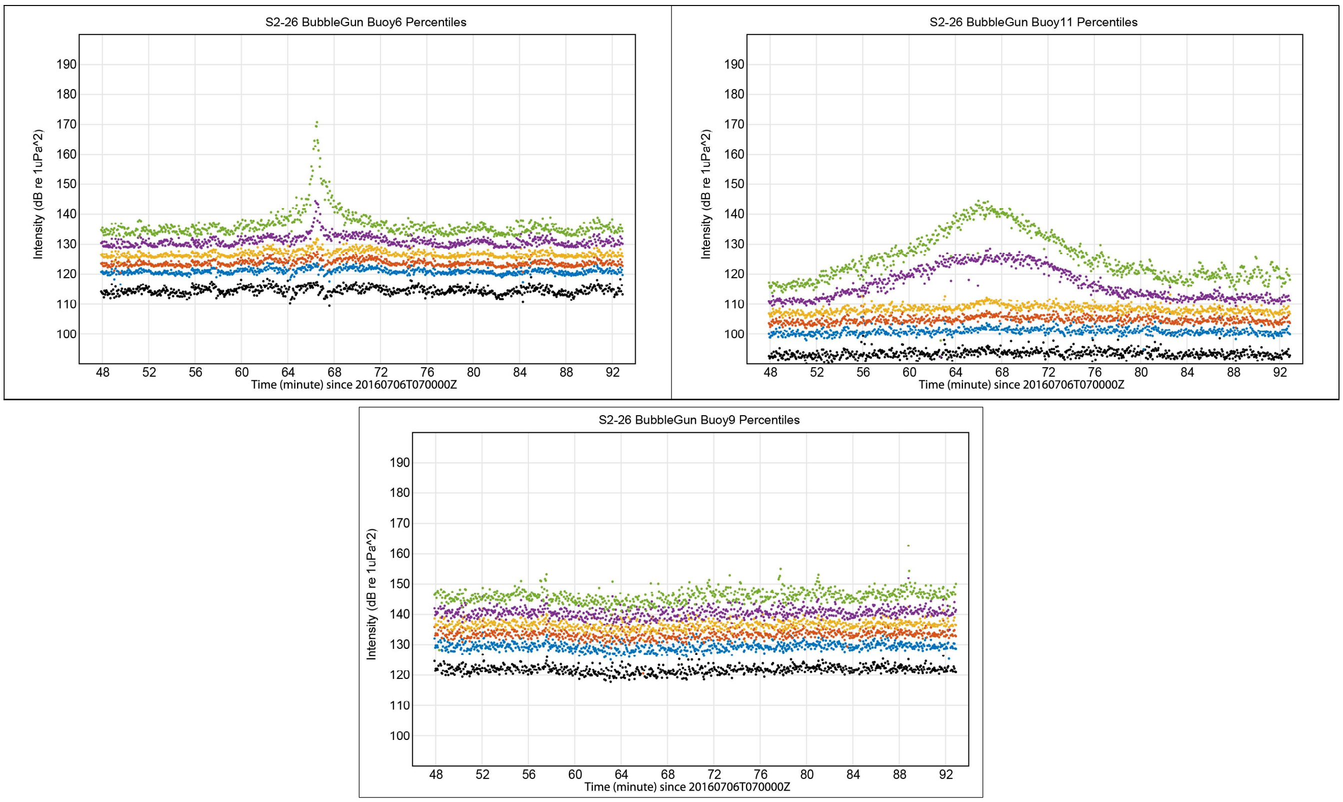


Figure 4.32.2-1. Percentile plots of Bubble Gun signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

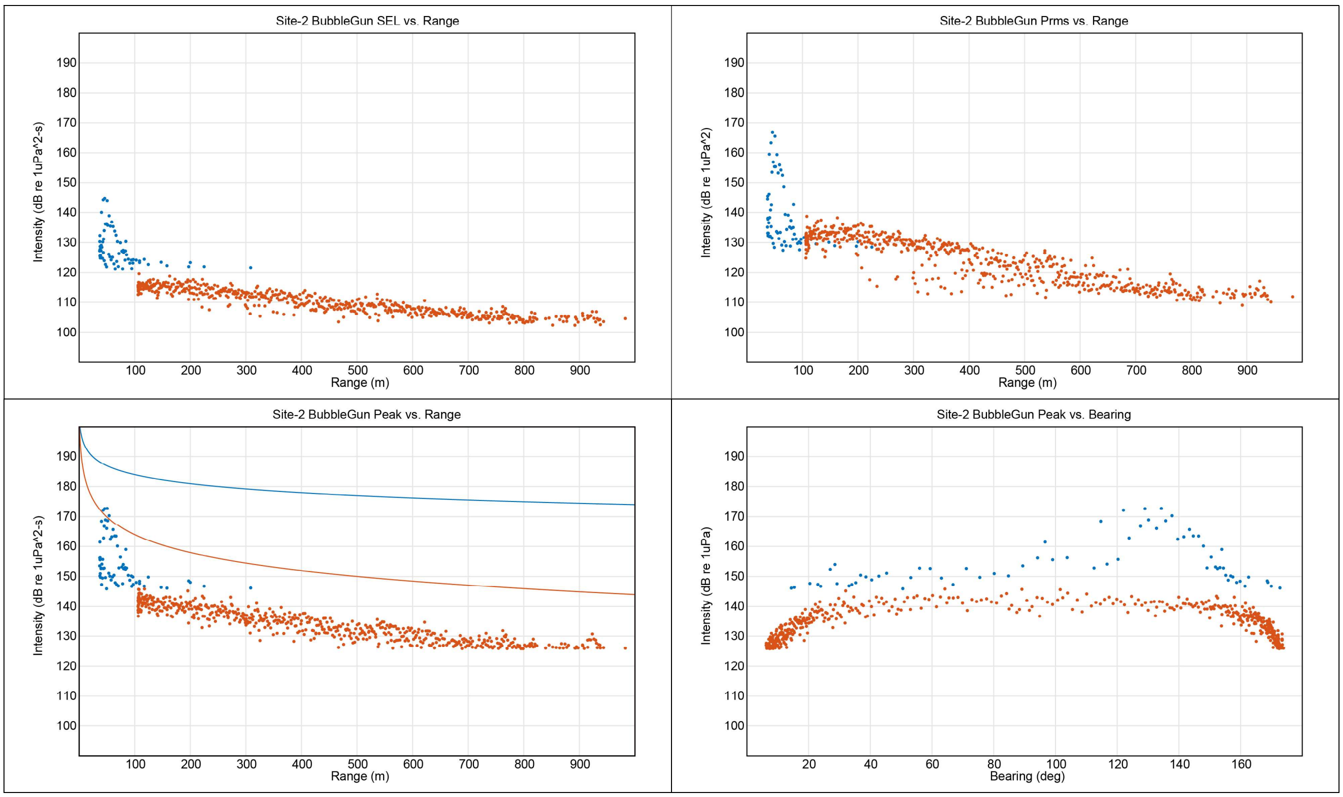


Figure 4.32.2-2. Range results for Bubble Gun signals at Site 2 for positions D (Buoy6) and B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.32.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 40,-60 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -300 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately -60 m on the y-axis, while position B had high amplitudes at approximately 0 m.

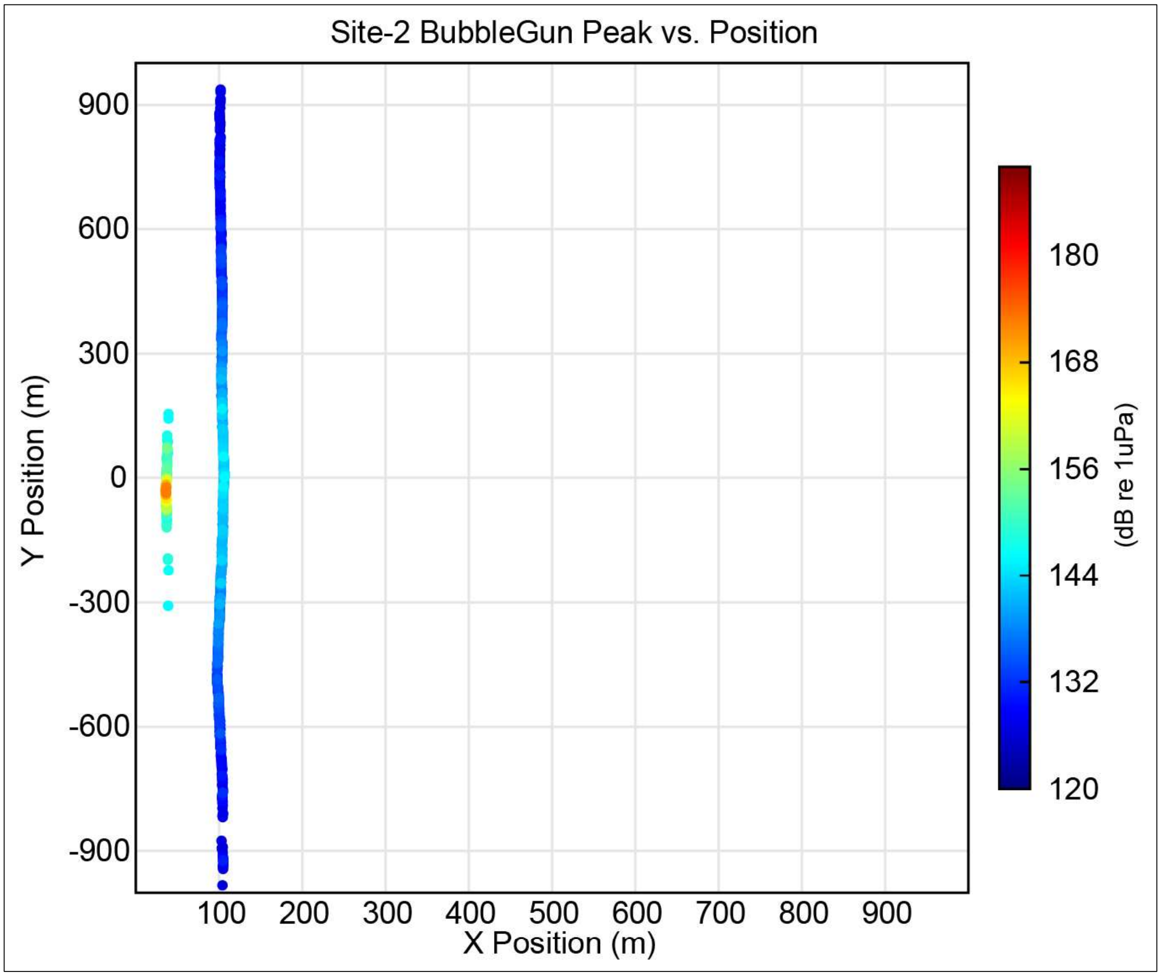


Figure 4.32.2-3. Plan view of received peak level for Bubble Gun at Site 2 for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.32.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The values reported by NUWC for the dual plate configuration were from a malfunctioning system with plates that did not trigger simultaneously, so these could be 3 dB lower than expected.

Table 4.32.2-1. Bubble Gun source levels, Mode 1, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Bubble Gun Mode 1	NA	NA	NA	2 Plates	206	199	177
NUWC	NA	NA	NA	2 Plates	204*	198*	173*

Bubble Gun = FSI Bubble Gun; dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = values reported by NUWC for the dual plate configuration were from a malfunctioning system with plates that did not trigger simultaneously, so these could be 3 dB low.

4.32.3 Site 3 – Mud, 30 m Depth

At S3, the Bubble Gun, Mode 1, had valid acoustic recordings in Run12 at positions B (Buoy12), A (Buoy5), and F (Buoy6).

Run Summary

The percentile plots for the available recordings of the Bubble Gun, Mode 1, are shown in **Figure 4.32.3-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position B (Buoy12) for Run12. The top right and bottom panels show the recorded acoustics at positions A (Buoy5) and F (Buoy6). However, for unknown reasons, all recordings had no discernable signals, and therefore were not analyzed further.

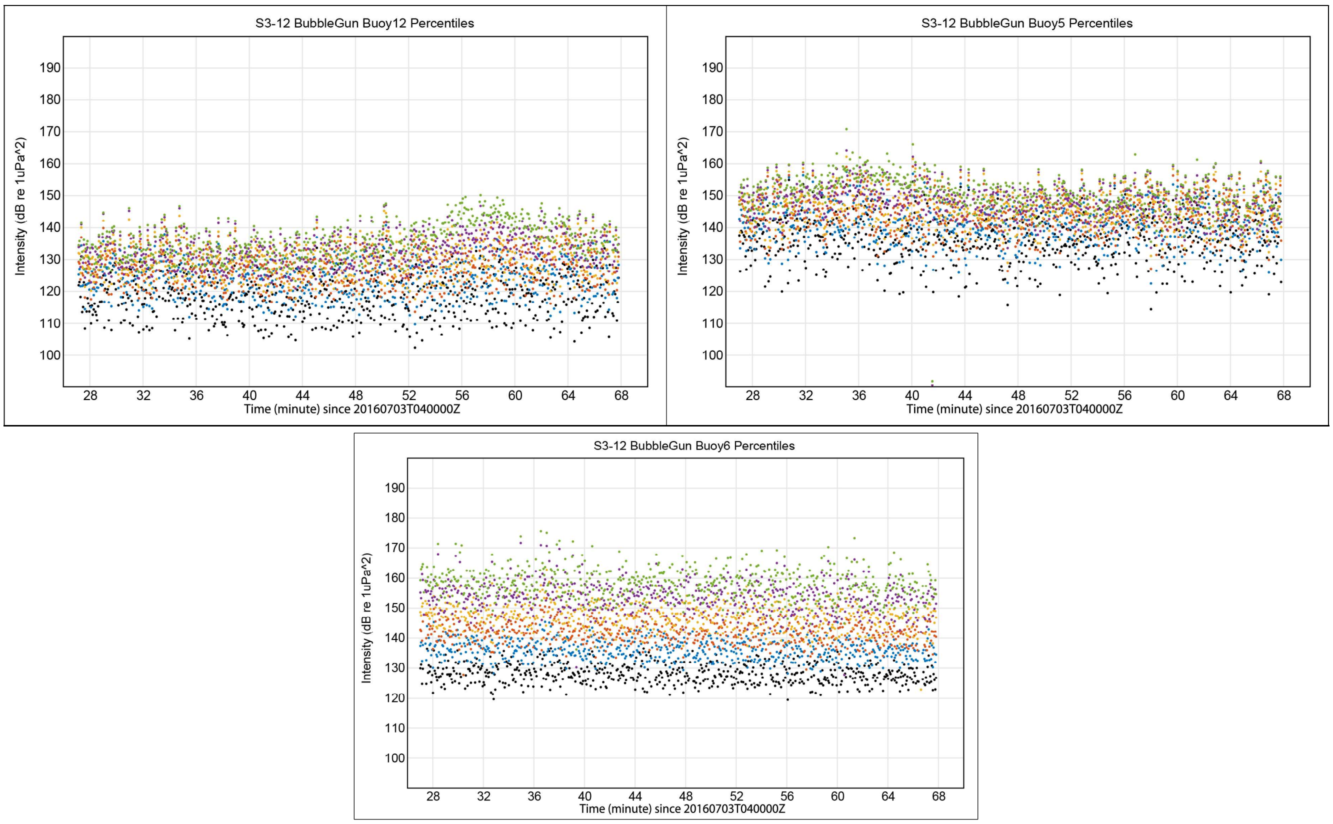


Figure 4.32.3-1. Percentile plots of Bubble Gun signals at Site 3.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy5); Bottom: SPL_{pk} arrival at position F (Buoy6). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

4.32.4 Site 4 – Sand, 30 m Depth

At S4, the Bubble Gun, Mode 1, was towed during Run13 and Run27; however, recordings with valid acoustic data and signals were not obtained.

4.32.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Bubble Gun, Mode 1, had valid acoustic recordings in Run10 at positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9).

Run Summary

The percentile plots for the available recordings of the Bubble Gun, Mode 1, are shown in **Figure 4.32.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run10, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions A (Buoy12) and E (Buoy8 and Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.32.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Bubble Gun at S5, positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9, combined) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 90 to approximately 3,000 m. The conical shape of the data points at positions D and A signifies the approach and departure of the source to and from the buoys. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 204 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D and position A near broadside (90°) which is expected for functioning buoy GPS navigation and an omnidirectional source.

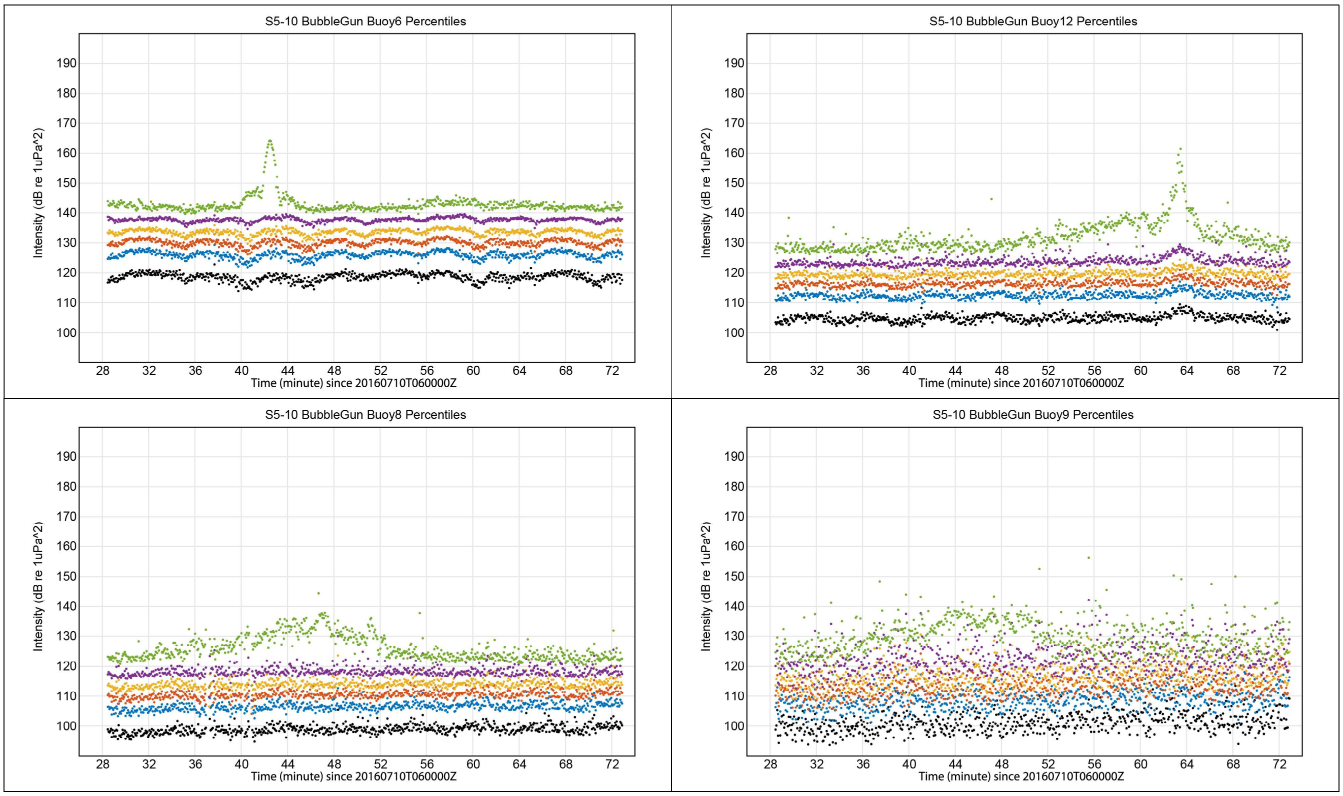


Figure 4.32.5-1. Percentile plots of Bubble Gun signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position E (Buoy9). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

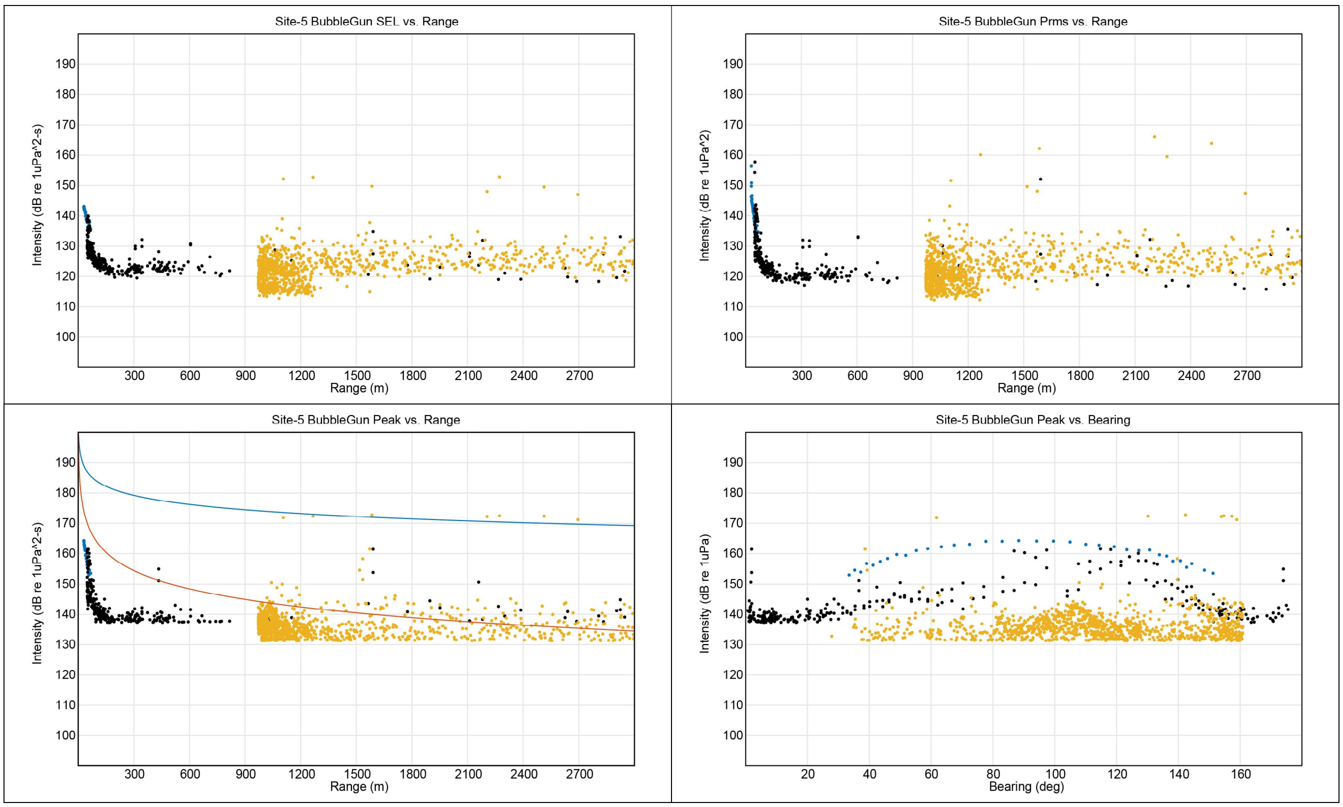


Figure 4.32.5-2. Range results for Bubble Gun signals at Site 5 Run10 for positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9, combined).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.
Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue; E = yellow.

The plan view is shown in **Figure 4.32.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -3,000 to 3,000-m marks on the y-axis. The CPA at 80,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -900 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9).

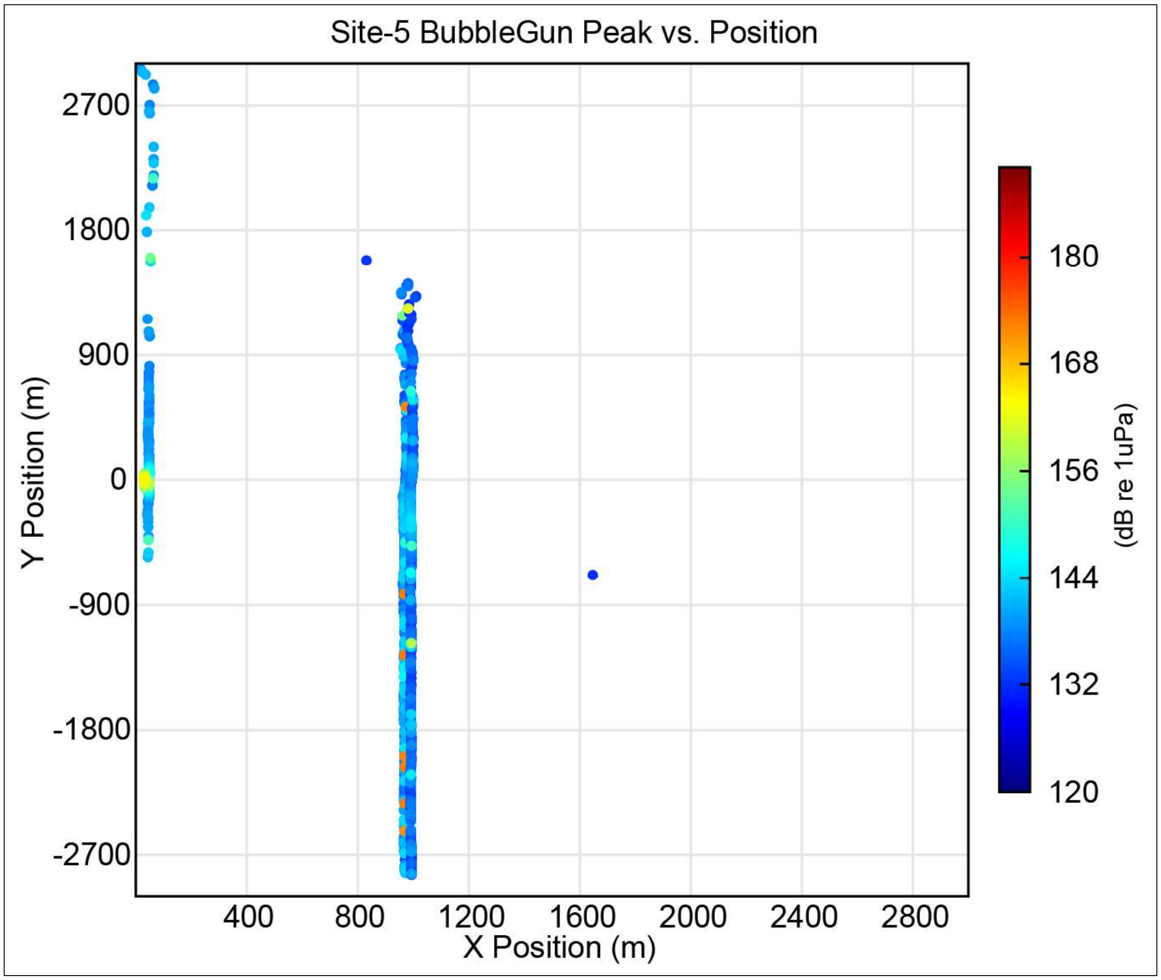


Figure 4.32.5-3. Plan view of received peak level for Bubble Gun at Site 5 for positions D (Buoy6), A (Buoy12), and E (Buoy8 and Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.32.5-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results. The values reported by NUWC for the dual plate configuration were from a malfunctioning system with plates that did not trigger simultaneously, so these could be 3 dB lower than expected.

Table 4.32.5-1. Bubble Gun source levels, Mode 1, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Bubble Gun Mode 1	NA	NA	NA	2 Plates	203	196	182
NUWC	NA	NA	NA	2 Plates	204*	198*	173*

Bubble Gun = FSI Bubble Gun; dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = values reported by NUWC for the dual plate configuration were from a malfunctioning system with plates that did not trigger simultaneously, so these could be 3 dB low.

This Page Intentionally Left Blank

4.33 FSI Bubble Gun, 0.1-2 kHz, Single Plate (Mode 2)

The Bubble Gun acoustic source generates a single, low-frequency signal with a peak frequency between 500 Hz and 1 kHz that rapidly drops off by 6 kHz. The operational parameter settings for Mode 2 were a single plate and 0.1-2 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.33-1** is the selected frequency band (0 to 8 kHz) and SPL_{pk} (182 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.33-1. Bandpass determination for the Bubble Gun acoustic source, 0.1-2 kHz, and single plate at Site 2, Run27.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-25	181.80
1-15	182.12
0-8	**182.04**
0-4	148.29

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Bubble Gun, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.33-1**. As described in **Chapter 2**, most of the HRG sources were organized into operational pairings; two sources operated in alternation. The Bubble Gun was operationally paired in alternation with the 251 Boomer. The pairings were pre-determined to ensure each source's frequency band did not overlap. However, the power spectral density (middle panel of **Figure 4.33-1**) shows the overlap of the frequencies. The signals were separated in time, usually with the sources alternating every second (with a 2 s pulse repetition interval for each source). Without GPS timing on the receivers this meant that the signals had to be separated (by 1 s chunks) manually. This approach seemed successful in separating the two sources.

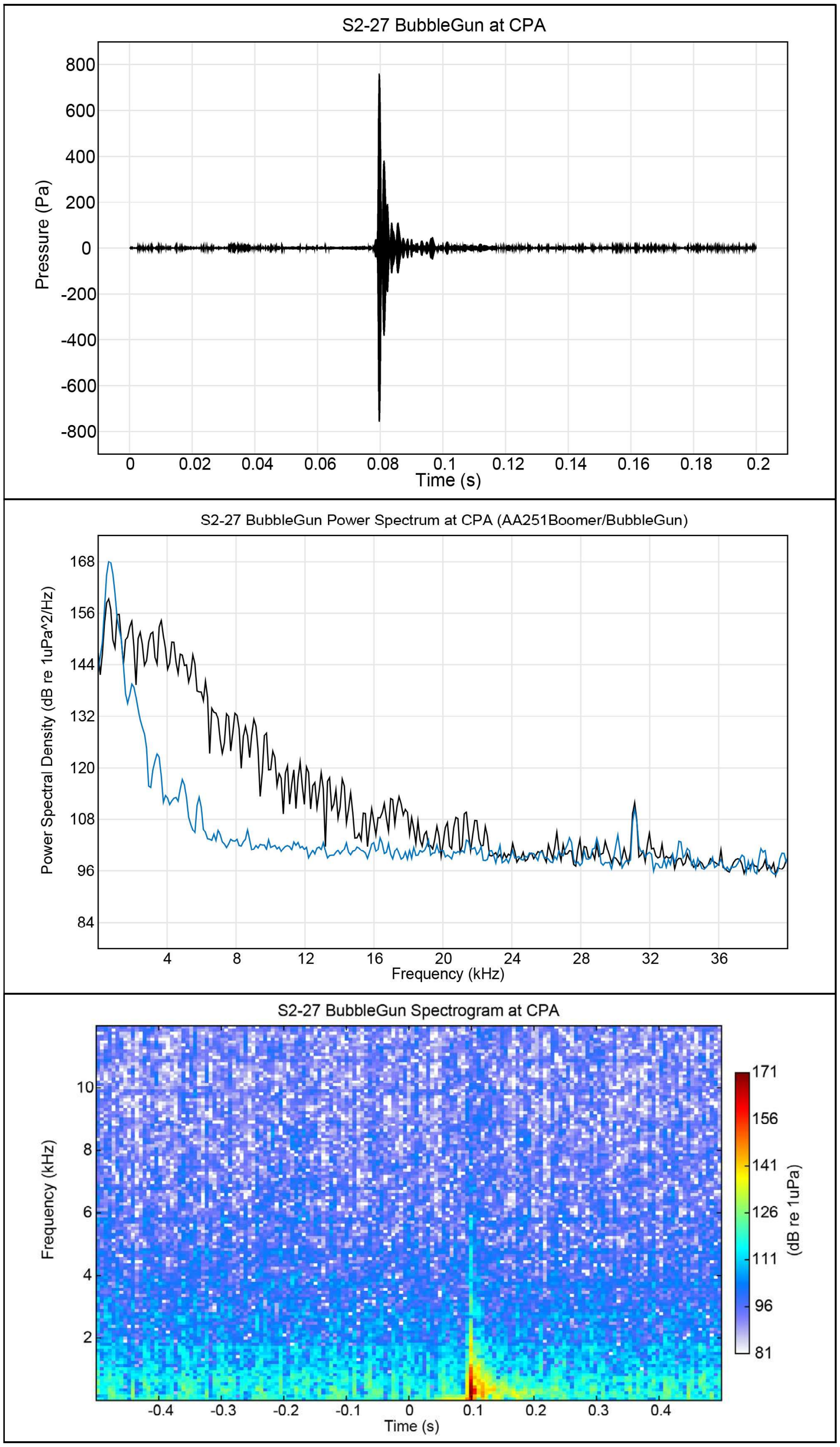


Figure 4.33-1. Bubble Gun measured signal characteristics at closest point of approach (CPA) at Site 2, Run27.

Top: Time-waveform of a signal; Middle: Power spectral density, 251 Boomer = black, Bubble Gun = blue; Bottom: Spectrogram.

4.33.1 Site 1 – Mud, 10 m Depth

At S1, the Bubble Gun, Mode 2, had valid acoustic recordings in Run13 at positions D (Buoy6) and E (Buoy5 and Buoy8).

Run Summary

The percentile plots for the three available recordings of the Bubble Gun, Mode 2, are shown in **Figure 4.33.1-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run13, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position E (Buoy5 and Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid.

The results panels (**Figure 4.33.1-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 20 dB peak to 5 percent ratio was applied. For the Bubble Gun at S1, positions D (Buoy6) and E (Buoy5 and Buoy8) had acoustic signal. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 203 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). There are calibration errors (**Section 2.6.3.1**) at position E as seen in the received levels being approximately 40 dB down compared to the other buoys. The bottom right results panel is the SPL_{pk} versus bearing plot (**Figure 4.33.1-2**).

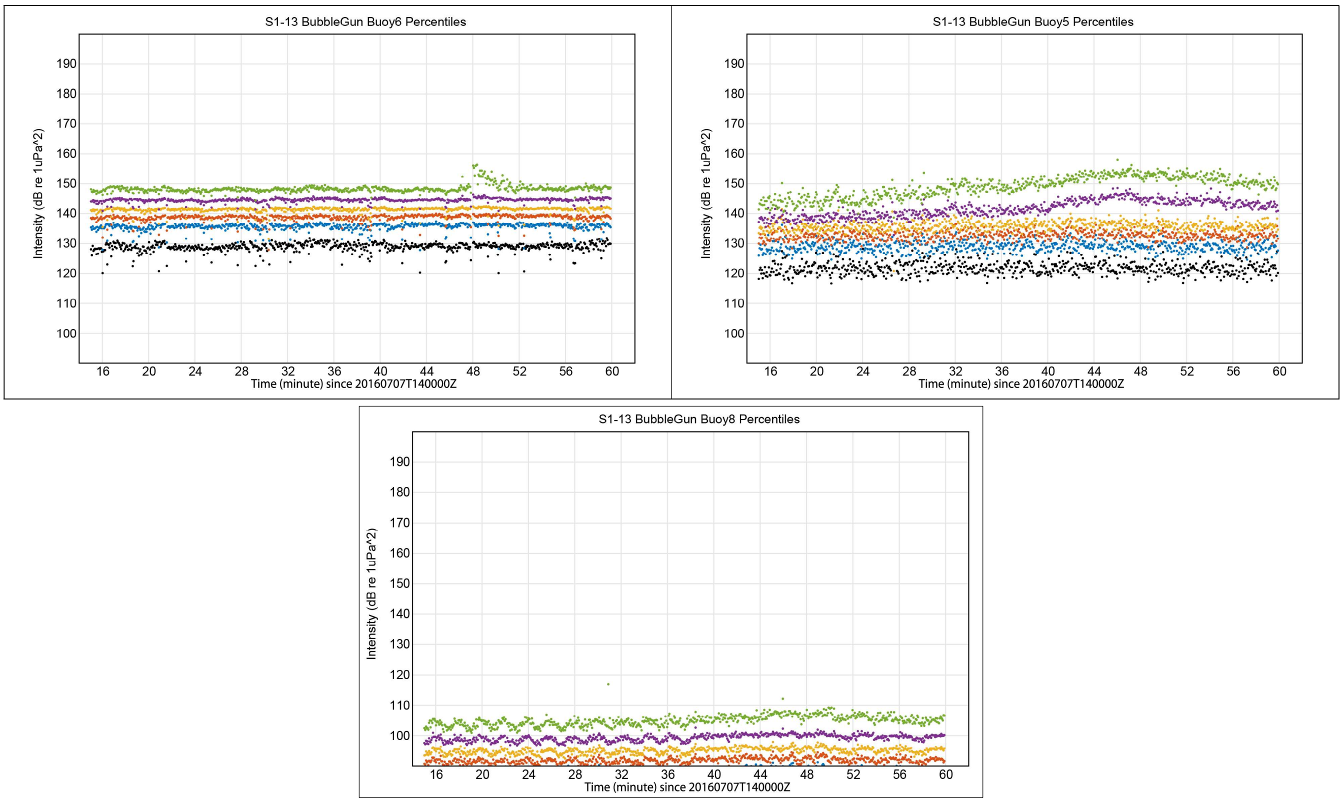


Figure 4.33.1-1. Percentile plots of Bubble Gun signals at Site 1.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position E (Buoy5); Bottom: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

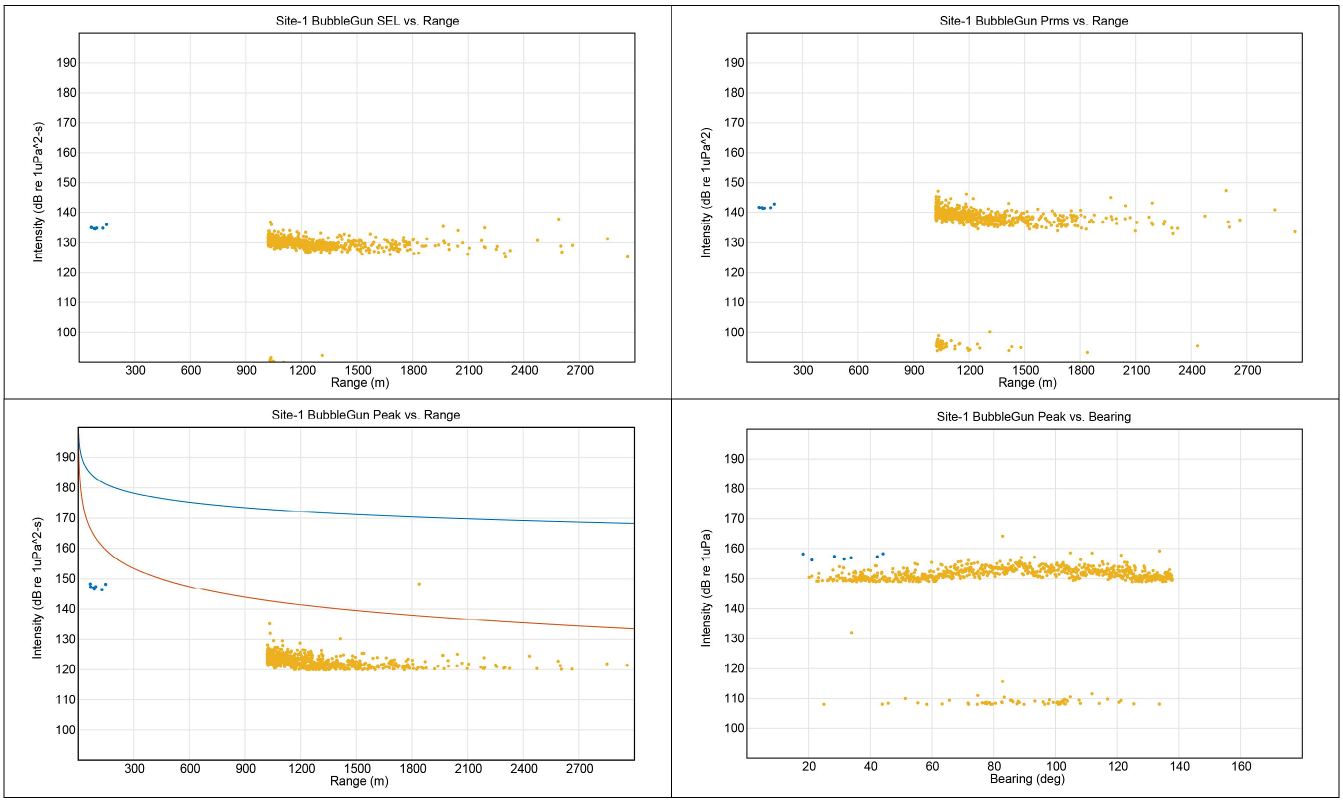


Figure 4.33.1-2. Range results for Bubble Gun signals at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8, combined). Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing plot. Legend: Positions, D = blue; E = yellow.

The plan view is shown in **Figure 4.33.1-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,800 to 2,800-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at positions D (Buoy6) and E (Buoy5 and Buoy8). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

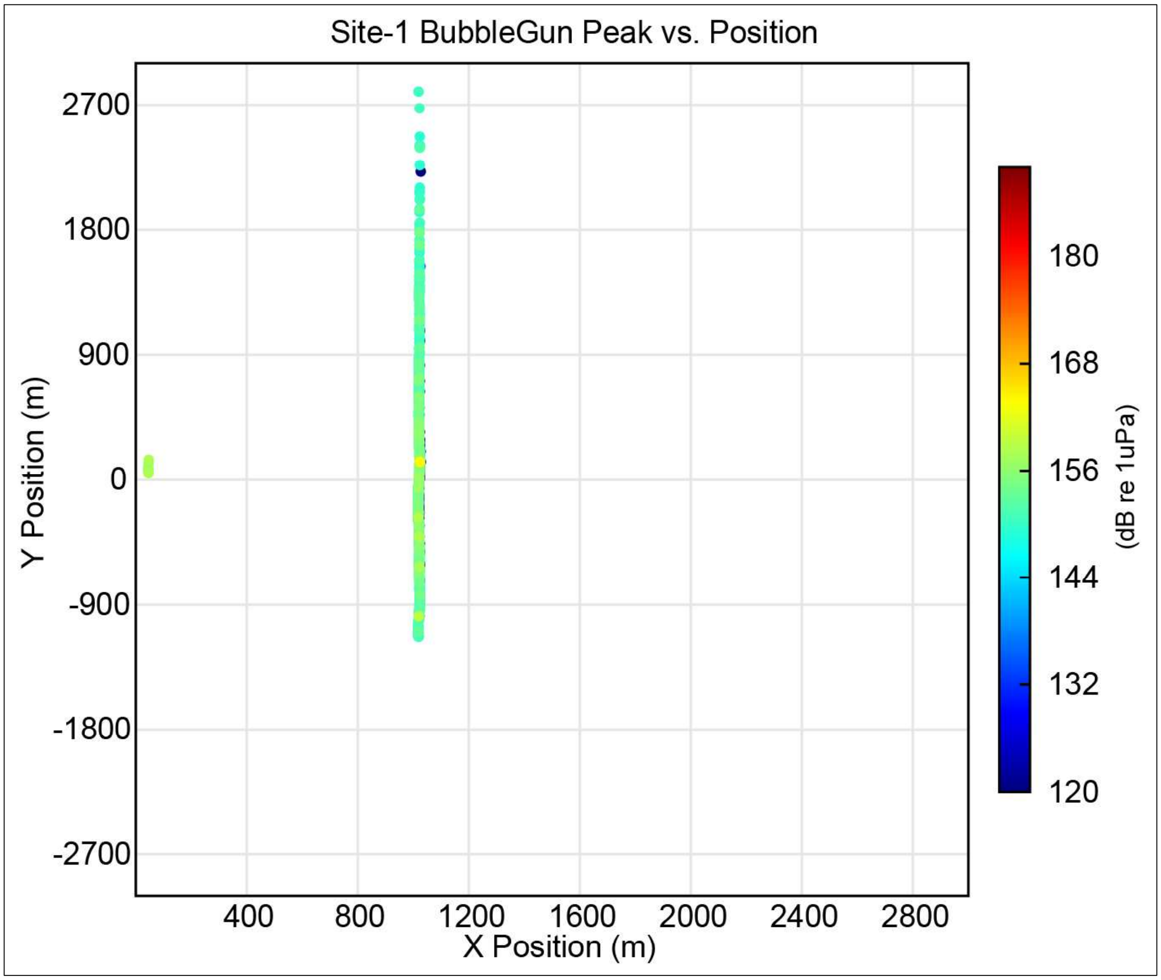


Figure 4.33.1-3. Plan view of received peak level for Bubble Gun at Site 1 for positions D (Buoy6) and E (Buoy5 and Buoy8).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.33.1-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.33.1-1. Bubble Gun, source levels, Mode 2, at Site 1. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Bubble Gun Mode 2	NA	NA	NA	1 Plate	203	182	175
NUWC	NA	NA	NA	1 Plate	203	196	170

Bubble Gun = FSI Bubble Gun; dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.33.2 Site 2 – Sand, 10 m Depth

At S2, the Bubble Gun, Mode 2, had valid acoustic recordings in Run27 at positions D (Buoy6), B (Buoy11), and F (Buoy9).

Run Summary

The percentile plots for the available recordings of the Bubble Gun, Mode 2, are shown in **Figure 4.33.2-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run27, where the received signal is observed, and the signal's influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the recorded acoustics at positions B (Buoy11) and F (Buoy9). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, there is no evidence of the signal at position F (Buoy9).

The results panels (**Figure 4.33.2-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Bubble Gun at S2, only positions D (Buoy6) and B (Buoy11) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 2,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 203 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel of **Figure 4.33.2-2** is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately 130° indicating errors in buoy positioning, although for short source-receiver ranges, small errors in position can lead to large errors in bearing. For position B the peak was at approximately 80°.

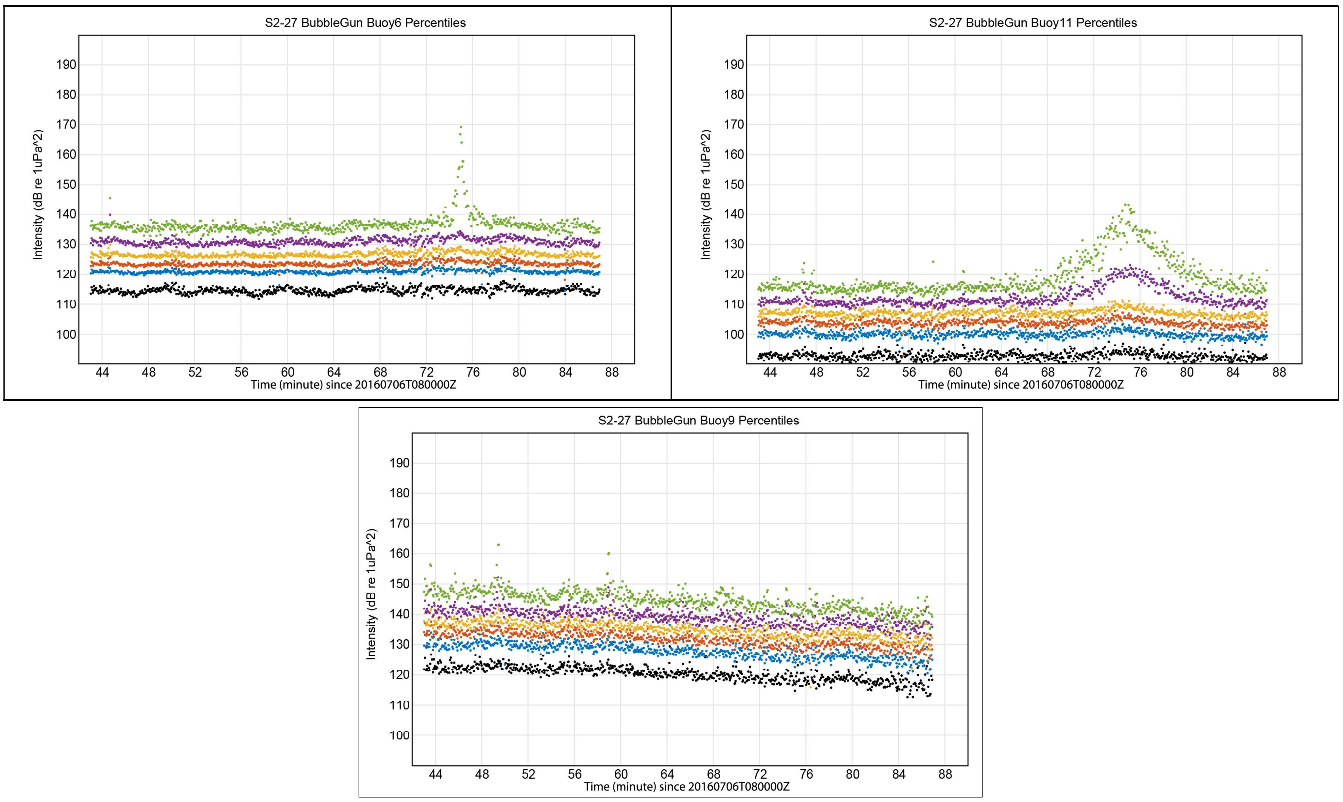


Figure 4.33.2-1. Percentile plots of Bubble Gun signals at Site 2.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom: SPL_{pk} arrival at position F (Buoy9). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

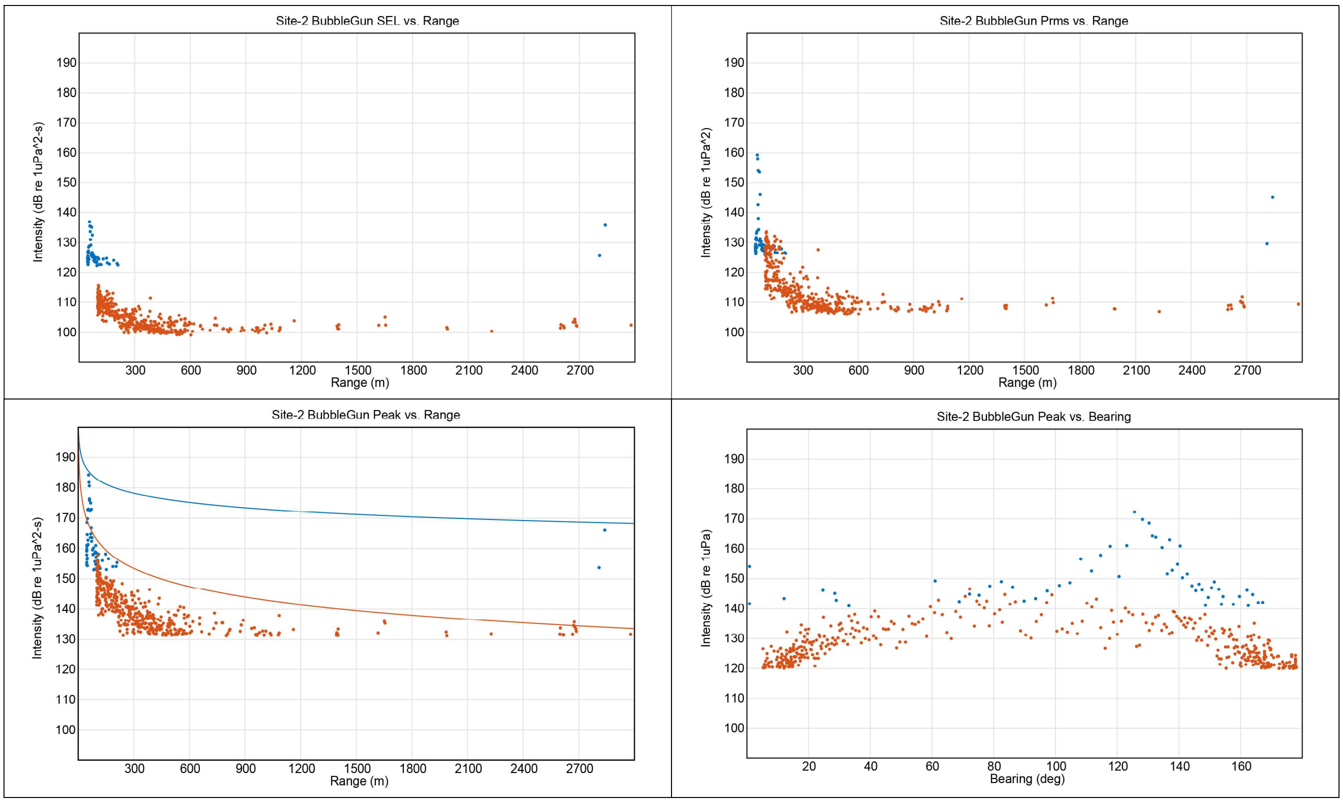


Figure 4.33.2-2. Range results for Bubble Gun signals at Site 2 for positions D (Buoy6) and B (Buoy11).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, B = red; D = blue.

The plan view is shown in **Figure 4.33.2-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -2,800 to 2,800-m marks on the y-axis. The CPA is at 50,-20 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -100 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6) and B (Buoy11). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

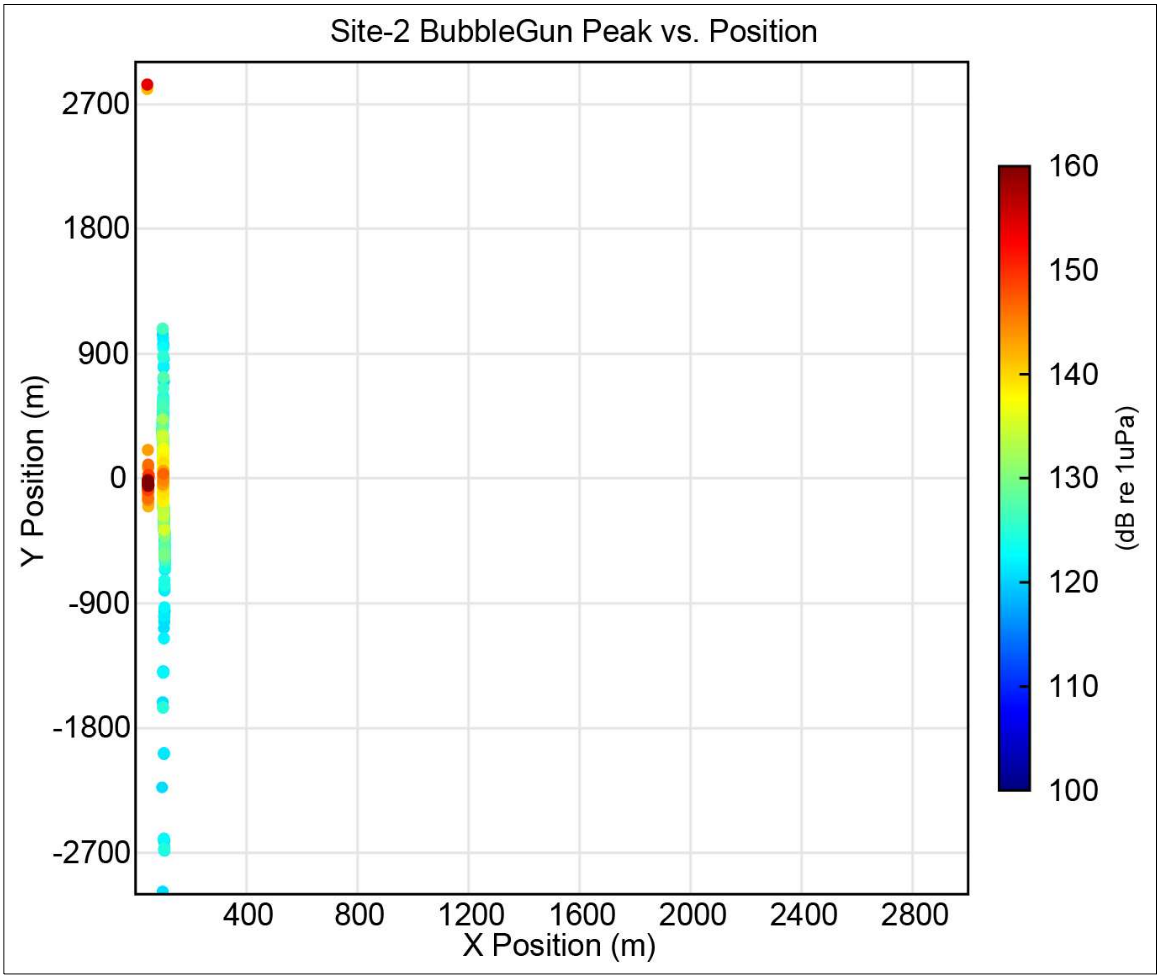


Figure 4.33.2-3. Plan view of received peak level for Bubble Gun at Site 2 for positions D (Buoy6) and B (Buoy11).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.33.2-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.33.2-1. Bubble Gun, source levels, Mode 2, at Site 2. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Bubble Gun Mode 2	NA	NA	NA	1 Plate	205	193	171
NUWC	NA	NA	NA	1 Plate	203	196	170

Bubble Gun = FSI Bubble Gun; dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.33.3 Site 3 – Mud, 30 m Depth

At S3, the Bubble Gun, Mode 2, was towed for Run13, but there were no valid recorded acoustic data or signals.

4.33.4 Site 4 – Sand, 30 m Depth

At S4, the Bubble Gun, Mode 2, had valid acoustic recordings in Run28 at positions B (Buoy12), A (Buoy7), and F (Buoy5).

Run Summary

The percentile plots for the available recordings of the Bubble Gun, Mode 2, are shown in **Figure 4.33.4-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position B (Buoy12) for Run28, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show valid recorded acoustics that lack any signal at positions A (Buoy7) and F (Buoy5). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. However, even with valid acoustic data, there is no evidence of the signal at position F (Buoy5) because of propagation loss. At position A (Buoy7), the acoustic data were bad.

The results panels (**Figure 4.33.4-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Bubble Gun at S4, position B (Buoy12) had acoustic signal with a poor signal to noise ratio. The top left panel is the SEL versus range, showing received signal energy at ranges from 50 to approximately 500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 203 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The SNR for this source is poor, only the cluster of peaks at the closest range are considered signal, which made it difficult to estimate source levels.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position B is indeterminate. The SPL_{pk} versus bearing data were not adjusted for the range changes as the source approached and departed the receiver; thus, it is a rough estimate of the shape of the beam pattern. For a symmetric beam pattern, the center (maximum peak signal) should be at 90°. The distribution of peaks with bearing is a result of very noisy data.

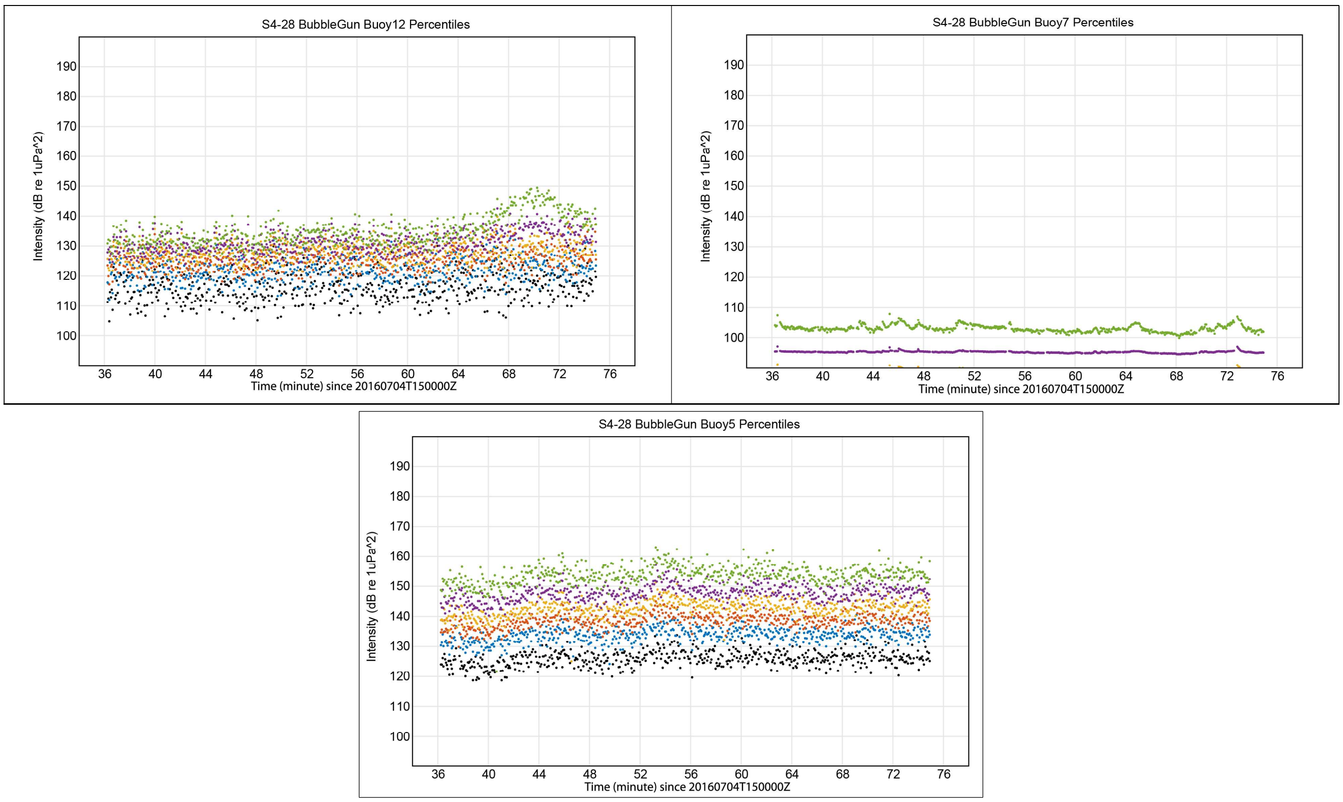


Figure 4.33.4-1. Percentile plots of Bubble Gun signals at Site 4.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position B (Buoy12); Top right: SPL_{pk} arrival at position A (Buoy7); Bottom: SPL_{pk} arrival at position F (Buoy5). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

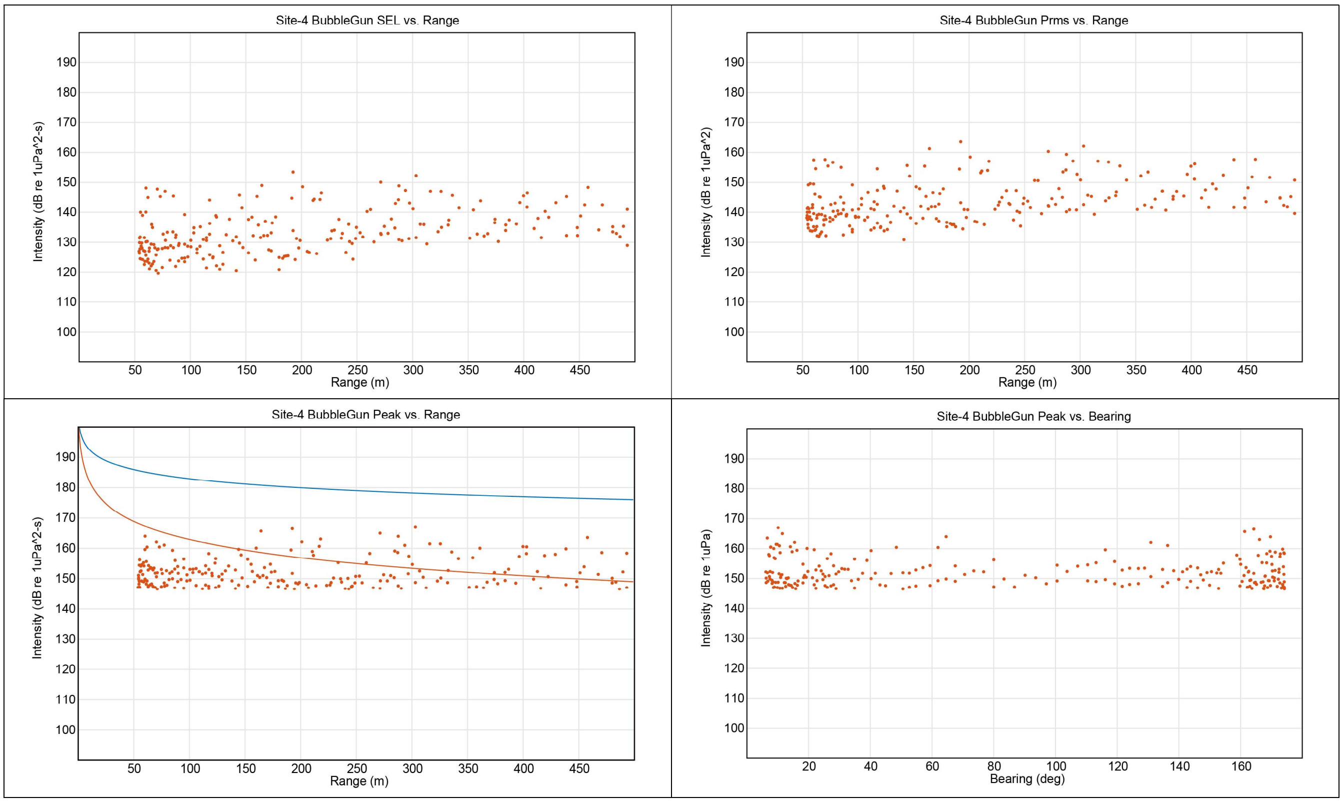


Figure 4.33.4-2. Range results for Bubble Gun signals at Site 4 for position B (Buoy12).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, B = red.

The plan view is shown in **Figure 4.33.4-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -500 to 500-m marks on the y-axis. The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at position B (Buoy12). Recordings at the buoy had acoustic peak amplitudes, presumably at the CPA and when the receiver was in the main beam of the source signal (i.e., broadside to the source). However, there is only minimal indication of the observed signal at CPA.

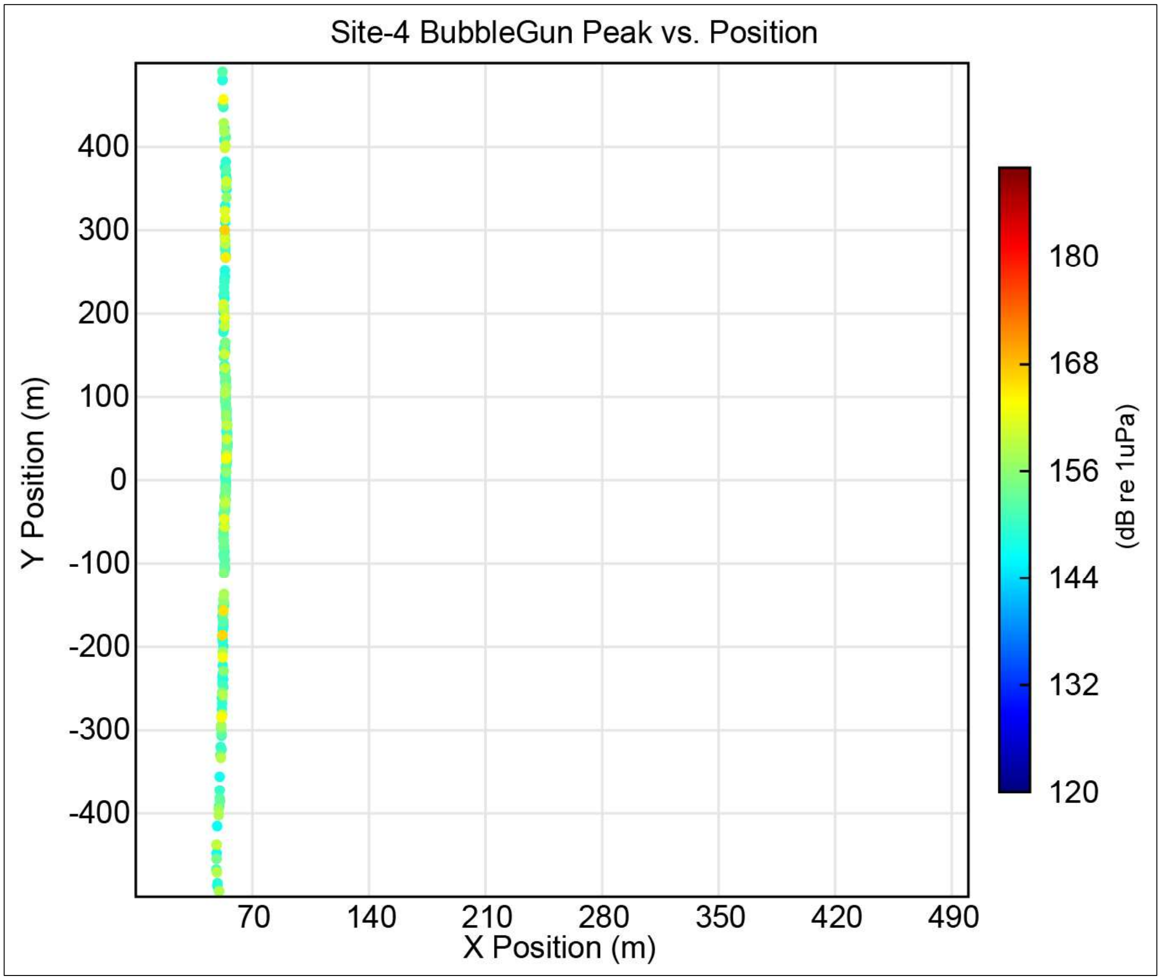


Figure 4.33.4-3. Plan view of received peak level for Bubble Gun at Site 4 for position B (Buoy12).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.33.4-1**. The estimated source levels were calculated from the measurements using a spherical spreading loss [20 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.33.4-1. Bubble Gun, source levels, Mode 2, at Site 4. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Bubble Gun Mode 2	NA	NA	NA	1 Plate	199	187	175
NUWC	NA	NA	NA	1 Plate	203	196	170

Bubble Gun = FSI Bubble Gun; dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.33.5 Site 5 – Sandy-Silt, 100 m Depth

The Bubble Gun, Mode 2, was not deployed or operated at S5 because of technical source issues.

4.34 Sercel Mini GI (30/30), Dual Airguns, No Insert, 30-, 26-, and 24-Second Shot Rates (Mode 1)

The MiniGI-2, Mode 1, airgun source generates a low-frequency signal with a peak frequency below 500 Hz. The operational parameter settings for Mode 1 were two airguns with no insert, and 30-, 26-, and 24-second shot rates and were analyzed and reported together. The bandwidth used for processing was 0 to 4 kHz. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.34-1** is the selected frequency band (0 to 4 kHz) and SPL_{pk} (180 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.34-1. Bandpass determination for the MiniGI-2 acoustic source, dual airguns, no insert, 30-, 26-, and 24-second shot rates, at Site 5, Run17.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	166.24
0-20	175.46
0-12	180.18
0-8	176.20
0-4	**180.20**
0-2	138.53

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The MiniGI-2, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.34-1**.

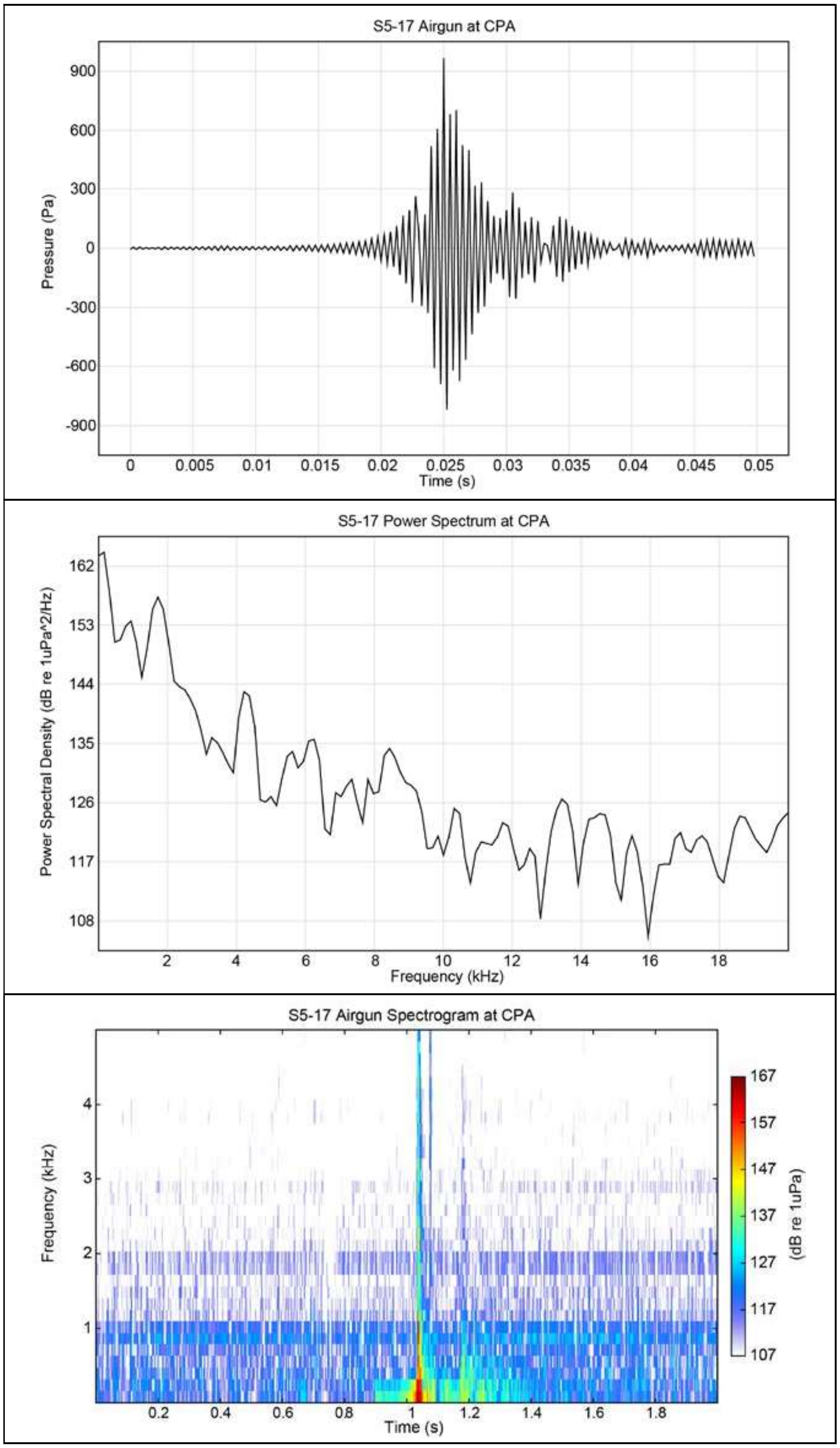


Figure 4.34-1. MiniGI-2 measured signal characteristics at closest point of approach (CPA) at Site 5, Run17.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.34.1 Site 1 – Mud, 10 m Depth

The MiniGI-2, Mode 1, was not deployed or operated at S1.

4.34.2 Site 2 – Sand, 10 m Depth

The MiniGI-2, Mode 1, was not deployed or operated at S2.

4.34.3 Site 3 – Mud, 30 m Depth

The MiniGI-2, Mode 1, was not deployed or operated at S3.

4.34.4 Site 4 – Sand, 30 m Depth

The MiniGI-2, Mode 1, was not deployed or operated at S4.

4.34.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the MiniGI-2, Mode 1, had valid acoustic recordings in Run17 and Run30. For Run17, valid acoustic recordings were observed at positions D (Buoy6), B (Buoy11), A (Buoy12), and E (Buoy8). For Run30, positions D (Buoy6), E (Buoy8), and F (Buoy10) had valid acoustic recordings. The source also was towed during Run14 and Run29, but there were no useful acoustic recordings due to buoy failure.

Run Summary

The percentile plots for the available recordings of the MiniGI2, Mode 1, are shown in **Figure 4.34.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run17, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position B (Buoy11), E (Buoy8) and F (Buoy10). For this LF signal centered below 500 Hz, propagation loss was low and the signal was observable for the duration of the run at all positions. The greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. For the shortest-range positions (D, B, and A) the data have signal-to-noise received levels around 180 dB re 1 µ Pa and the signal-to-noise ratios were more than 60 dB.

The results panels (**Figure 4.34.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 23 dB peak to 5 percent ratio was applied to the collected data. For the MiniGI-2 at S5, positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy8), and F (Buoy10) had strong acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The received signal is quite consistent across buoys, though there are possible calibration errors (**Section 2.6.3.1**) at position F (Buoy10) which has received levels approximately 10 dB lower when compared to the other positions. For the SPL_{rms} metric only, the Buoy D reception falls well below the other sensors, which is likely not a calibration issue but a propagation or a signal to noise issue because of the method used to compute rms. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 235 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). For all positions, there is close agreement with range (i.e., the data are tight). Several of the hydrophones at the same position demonstrate a consistent 3- to 5-dB offset, which likely is due to the depth dependence of the acoustic field rather than a calibration error.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions at approximately 90°, which is expected for GPS navigation and omnidirectional sources.

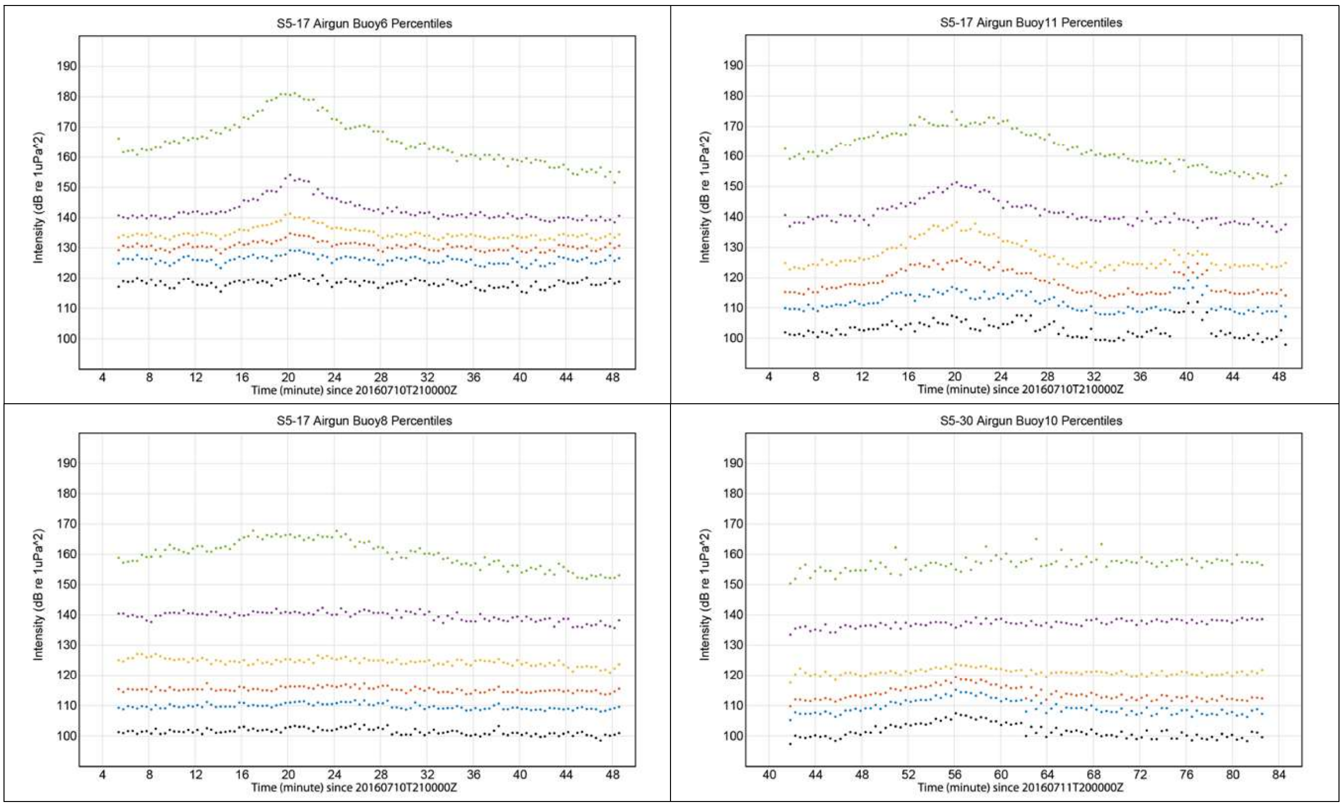


Figure 4.34.5-1. Percentile plots of MiniGI-2 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

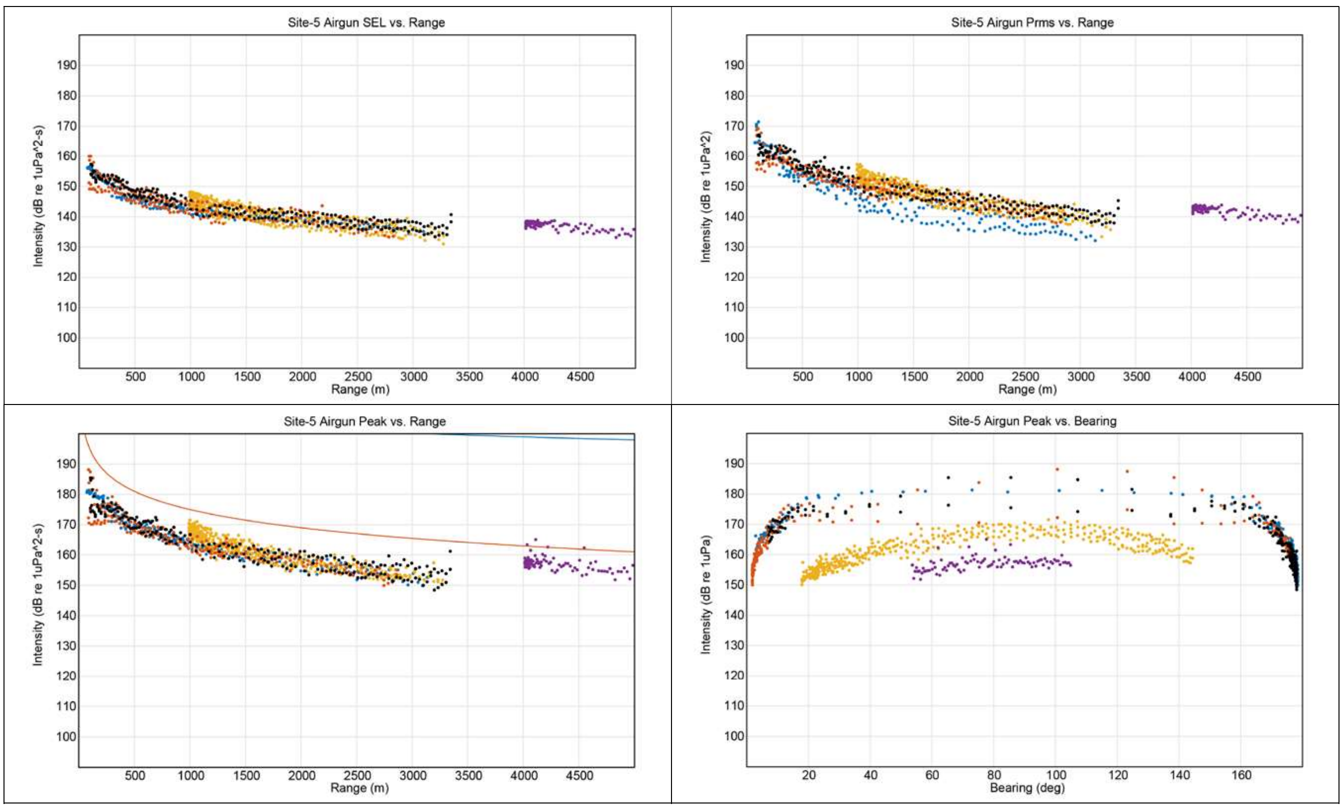


Figure 4.34.5-2. Range results for MiniGI-2 signals at Site 5 from Run17 and Run30 for positions D (Buoy6 and Buoy6, combined), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy8, combined), and F (Buoy10).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [$10 \log_{10}$ (*range*)] and the red line is spherical spreading [$20 \log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.34.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -4,500 to 4,500-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy8), and F (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

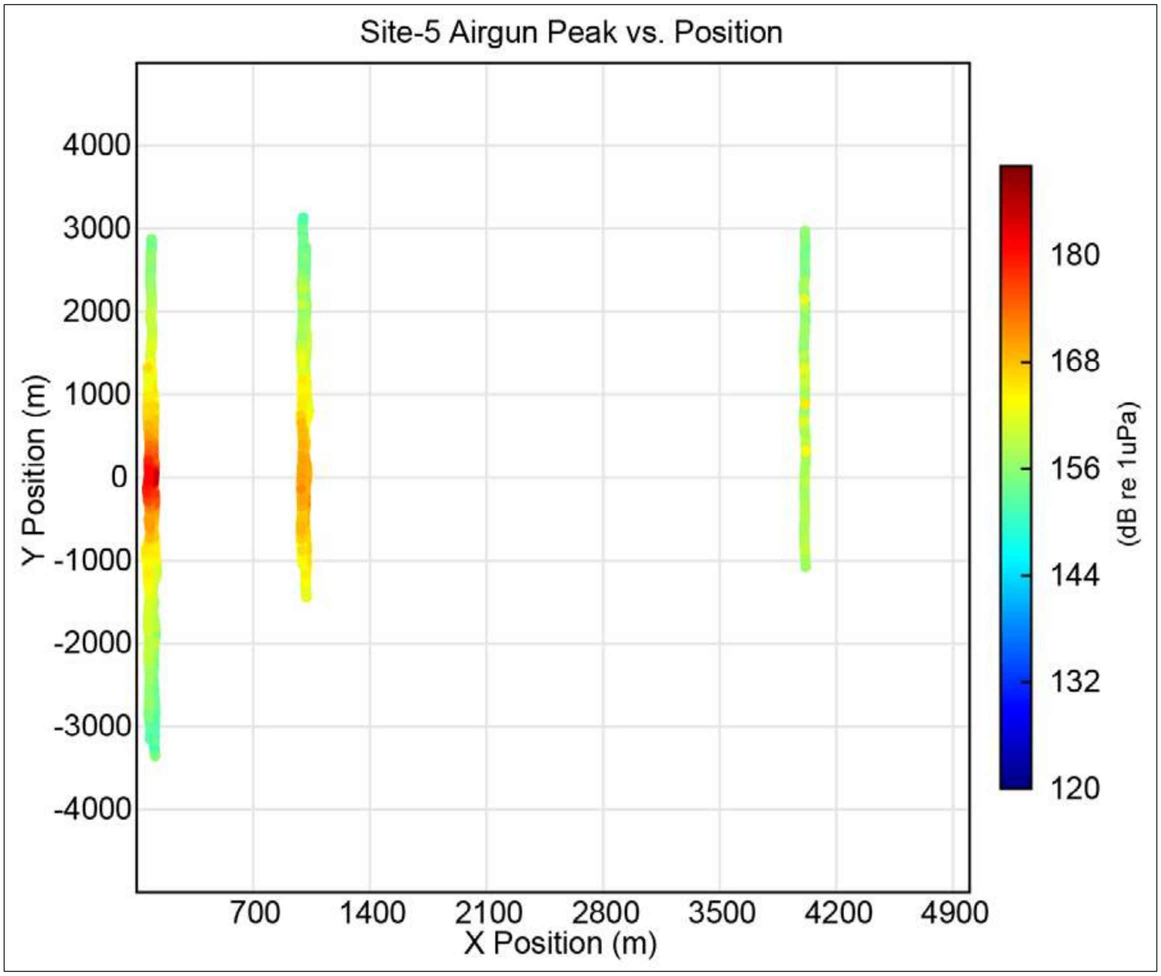


Figure 4.34.5-3. Plan view of received peak level for MiniGI-2 at Site 5 for positions D (Buoy6 and Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy8), and F (Buoy10).

Table Source Summary

A summary of expected source specifications and the field measurement results are provided in **Table 4.34.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source levels are about 10 dB too low when compared to the NUWC report values. This difference is not due to buoy position errors because many distant buoys which are insensitive to exact range captured signals. These differences are due to calibration errors (**Section 2.6.3.1**), which are also observed at the position F receptions which appear to be 10 dB higher than the other buoys.

Table 4.34.5-1. MiniGI-2 source levels, Mode 1, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini GI (30/30) Mode 1	NA	NA	NA	2 guns No insert	226	210	198
NUWC	NA	2,500 psi at 3 m depth	NA	2 guns No insert	235	228	206

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; psi = pounds per square inch; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.35 Sercel Mini GI (30/30), Single Airgun#1, No Insert, 24-Second Shot Rate (Mode 2)

The MiniGI-1, Mode 2, airgun source generates a low-frequency signal with a peak frequency below 500 Hz. The operational parameter settings for Mode 2 were a single airgun#1 with no insert, and a 24-second shot rate. The bandwidth used for processing was 0 to 4 kHz. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.35-1** is the selected frequency band (0 to 4 kHz) and SPL_{pk} (178 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.35-1. Bandpass determination for the MiniGI-1 acoustic source, single airgun#1, no insert, and 24-second shot rate, at Site 5, Run15.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	165.58
0-20	174.89
0-12	178.51
0-8	175.06
0-4	**178.41**
0-2	141.25

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The MiniGI-1, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.35-1**.

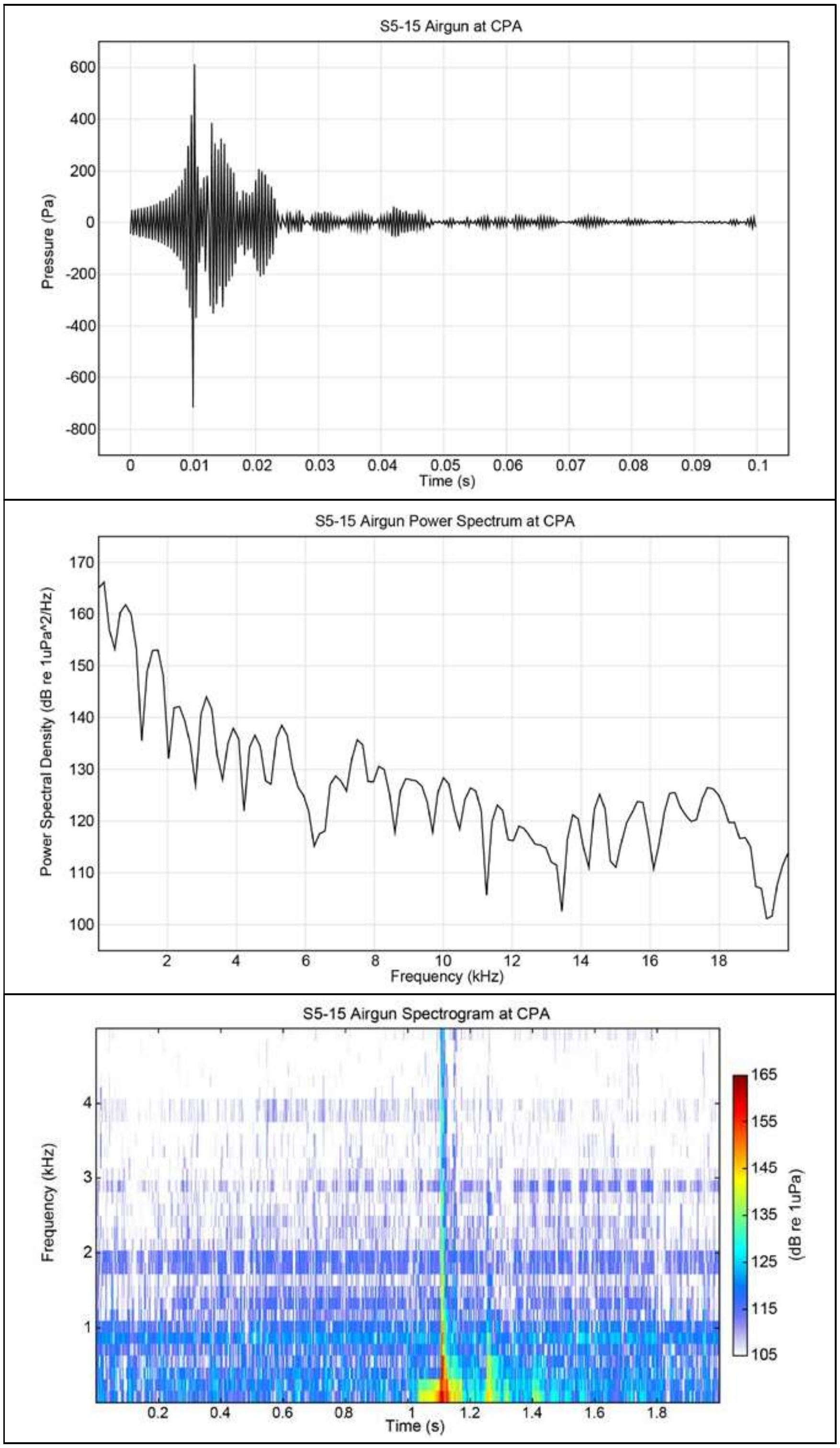


Figure 4.35-1. MiniGI-1 measured signal characteristics at closest point of approach (CPA) at Site 5, Run15.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.35.1 Site 1 – Mud, 10 m Depth

The MiniGI-1, Mode 2, was not deployed or operated at S1.

4.35.2 Site 2 – Sand, 10 m Depth

The MiniGI-1, Mode 2, was not deployed or operated at S2.

4.35.3 Site 3 – Mud, 30 m Depth

The MiniGI-1, Mode 2, was not deployed or operated at S3.

4.35.4 Site 4 – Sand, 30 m Depth

The MiniGI-1, Mode 2, was not deployed or operated at S4.

4.35.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the MiniGI-1, Mode 2, had valid acoustic recordings in Run15 at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Noise issues, due to strumming and other low-frequency sound were a problem at positions E (Buoy9) and F (Buoy10), but the noisy data were filtered to extract the signals. For this source, the signal was received on all hydrophones.

Run Summary

The percentile plots for the available recordings of the MiniGI-1, Mode 2, are shown in **Figure 4.35.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run15, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at position B (Buoy11), A (Buoy12), and E (Buoy8). The greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. For this LF signal centered below 500 Hz, propagation loss was low, and the signal was observable for the duration of the run at all positions. For the shortest-range positions (D, B, and A), the data have signal-to-noise received levels around 180 dB re 1 µ Pa, and the signal-to-noise ratios were more than 60 dB.

The results panels (**Figure 4.35.5-2**) show the acoustic metrics versus range and bearing for all buoys with valid acoustic data. An automated bandpass filter of 23 dB peak to 5 percent ratio was applied to the collected data. For the MiniGI-1, Mode 2, at S5, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10) had strong acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to approximately 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 228 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). For all positions, there is close agreement with range (i.e., the data are tight). Several of the hydrophones at the same position demonstrate a consistent 3- to 5-dB offset, which likely is due to the depth dependence of the acoustic field rather than a calibration error.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions at approximately 90°, as expected for an omnidirectional source.

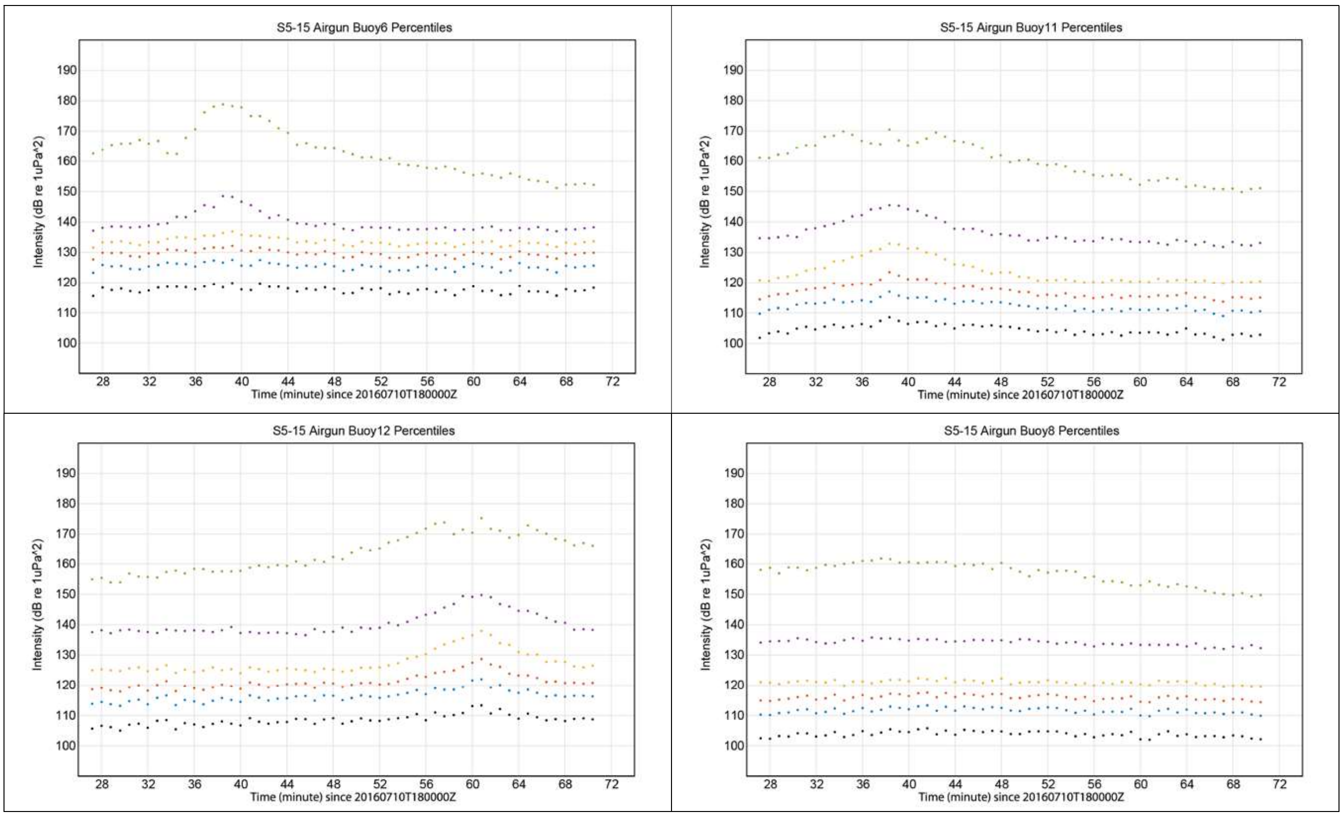


Figure 4.35.5-1. Percentile plots of MiniGI-1 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

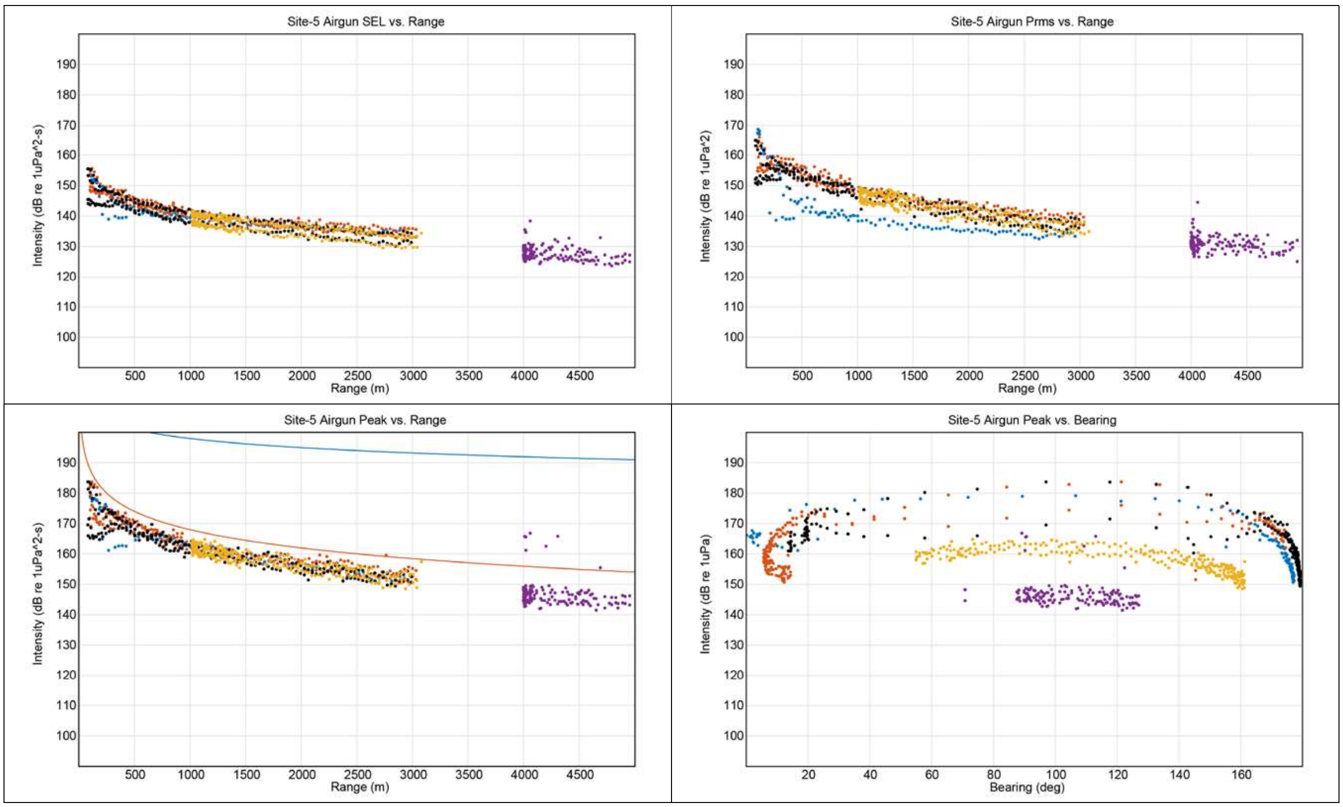


Figure 4.35.5-2. Range results for MiniGI-1 signals at Site 5 from Run15 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9, combined) and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.35.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 100,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

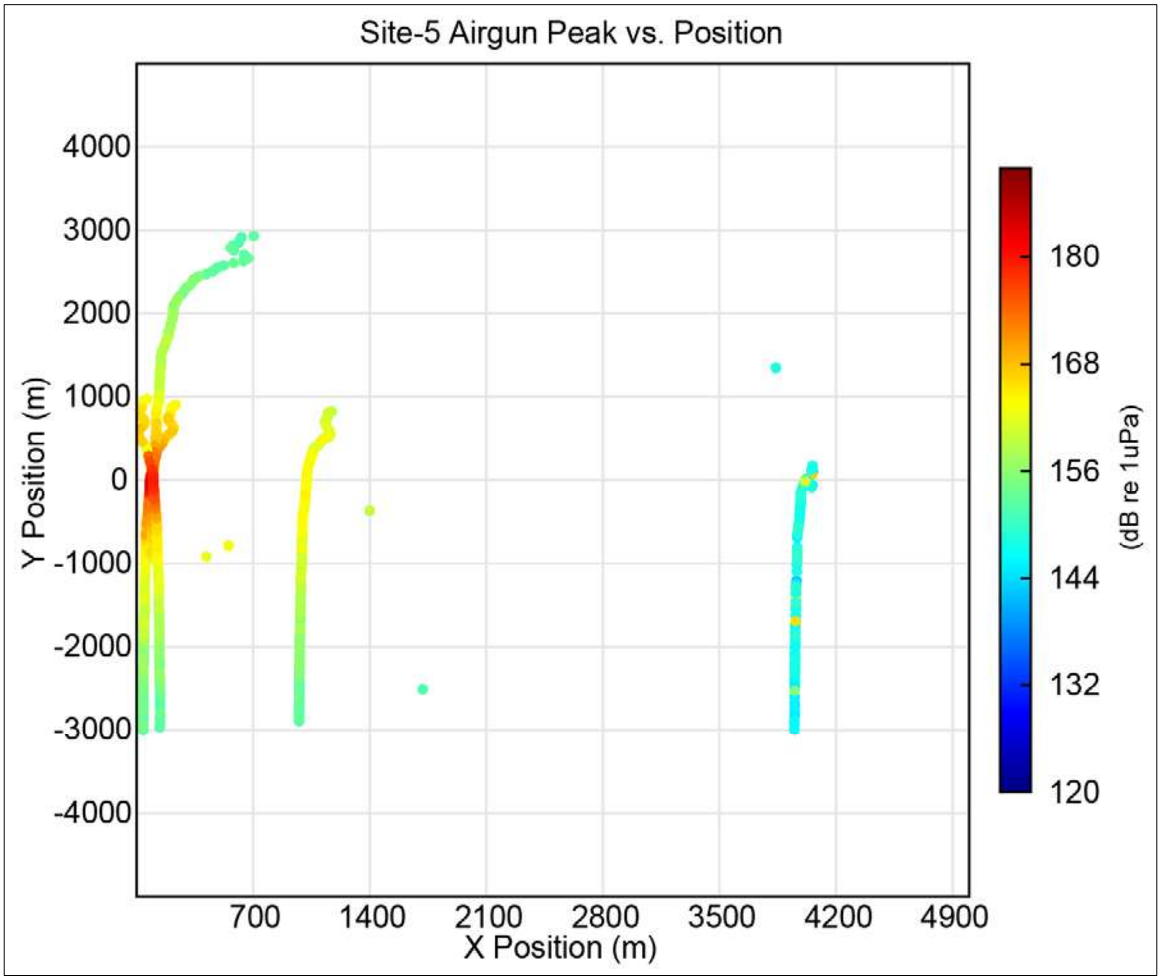


Figure 4.35.5-3. Plan view of received peak level for MiniGI-1 at Site 5 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Table Source Summary

A summary of expected source specifications and the field measurement results are provided in **Table 4.35.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source levels are about 10 dB too low when compared to the NUWC report values. This difference is not due to buoy position errors because many distant buoys which are insensitive to exact range captured signals. These differences are due to unresolved calibration errors (**Section 2.6.3.**1).

Table 4.35.5-1. MiniGI-1 source levels, Mode 2, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini GI (30/30) Mode 2	NA	NA	NA	1 gun No insert	219	208	193
NUWC	NA	2,500 psi at 3 m depth	NA	1 gun No insert	228	223	199

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; psi = pounds per square inch; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.36 Sercel Mini GI (30/30), Single Airgun#2, No Insert, 24-Second Shot Rate (Mode 3)

The MiniGI-1, Mode 3 airgun source generates a low-frequency signal with a peak frequency below 300 Hz. The operational parameter settings for Mode 3 were a single airgun#2 with no insert, and a 24-second shot rate. The bandwidth used for processing was 0 to 4 kHz. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.36-1** is the selected frequency band (0 to 4 kHz) and SPL_{pk} (166 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.36-1. Bandpass determination for the MiniGI-1 acoustic source, single airgun#2, no insert, and 24-second shot rate, at Site 5, Run16.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	149.03
0-20	163.89
0-12	166.15
0-8	164.19
0-4	**166.13**
0-2	139.68

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The MiniGI-1, Mode 3, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.36-1**.

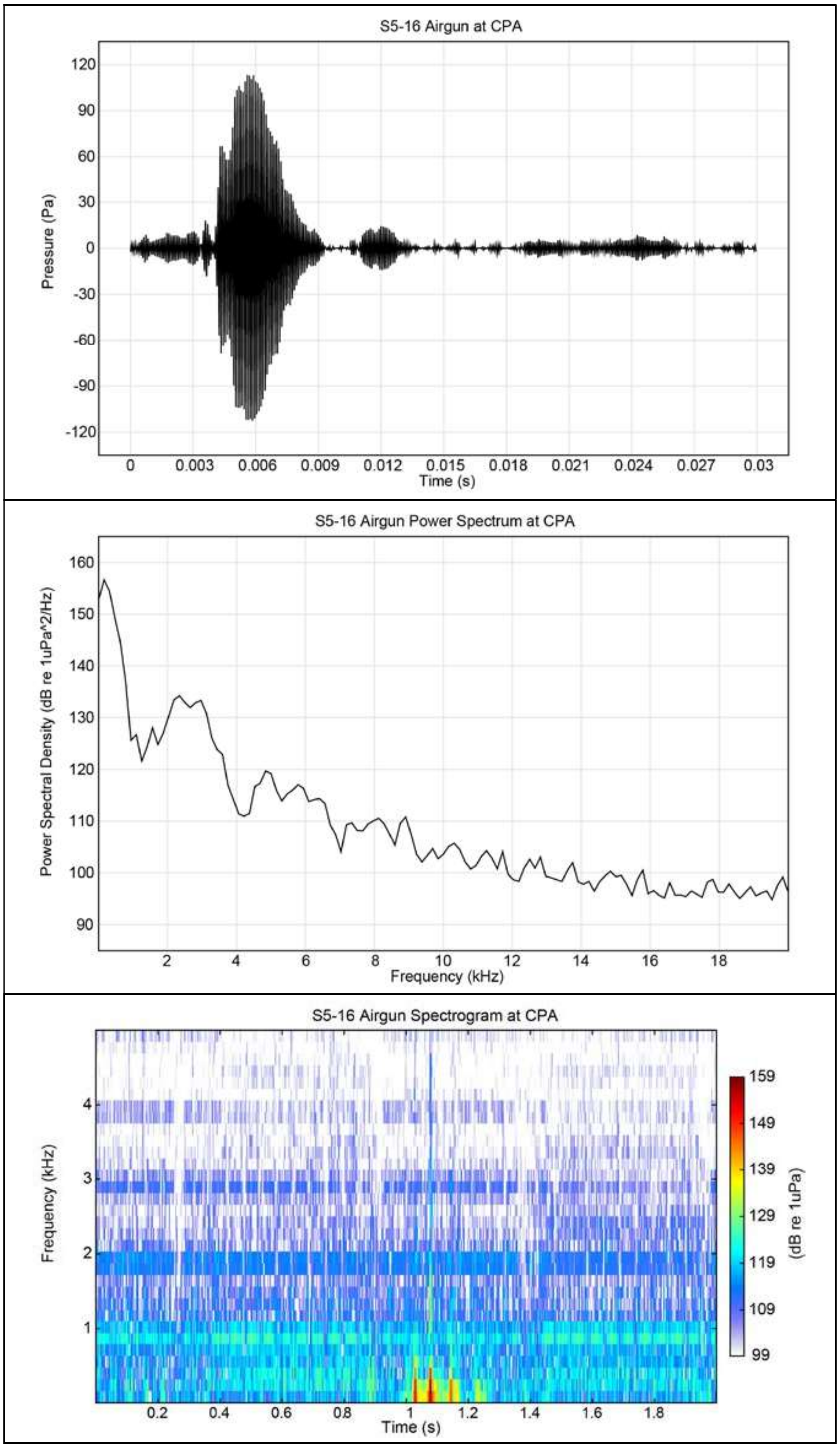


Figure 4.36-1. MiniGI-1 measured signal characteristics at closest point of approach (CPA) at Site 5, Run16.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.36.1 Site 1 – Mud, 10 m Depth

The MiniGI-1, Mode 3, was not deployed or operated at S1.

4.36.2 Site 2 – Sand, 10 m Depth

The MiniGI-1, Mode 3, was not deployed or operated at S2.

4.36.3 Site 3 – Mud, 30 m Depth

The MiniGI-1, Mode 3, was not deployed or operated at S3.

4.36.4 Site 4 – Sand, 30 m Depth

The MiniGI-1, Mode 3, was not deployed or operated at S4.

4.36.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the MiniGI-1, Mode 3, had valid acoustic recordings in Run16 at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Noise issues, due to strumming and other low-frequency sound, were a problem at positions E (Buoy9) and F (Buoy10), but the noisy data were filtered to extract the signals. For this source, the signal was received on all hydrophones.

Run Summary

The percentile plots for the available recordings of the MiniGI-1, Mode 3, are shown in **Figure 4.36.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run16, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy11), A (Buoy12), and E (Buoy8). The greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. For this LF signal centered below 300 Hz, propagation loss was low and the signal was observable for the duration of the run at all positions. For the shortest-range positions (D, B, and A), the data have signal-to-noise received levels around 180 dB re 1 μ Pa, and the signal-to-noise ratios were more than 60 dB.

The results panels (**Figure 4.36.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the MiniGI-1, Mode 3, at S5, positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10) had strong acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to approximately 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. There are unresolved calibration errors (**Section 2.6.3.1**) at position D (Buoy6) as seen in the notably lower received levels for the SPL_{rms} relative to the positions beyond 300 m. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 228 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). For all positions, there is close agreement with range (i.e., the data are tight). Several of the hydrophones at the same position demonstrate a consistent 3- to 5-dB offset, which likely is due to the depth dependence of the acoustic field rather than a calibration error.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions at approximately 90°, which is expected with good buoy GPS navigation and an omnidirectional source.

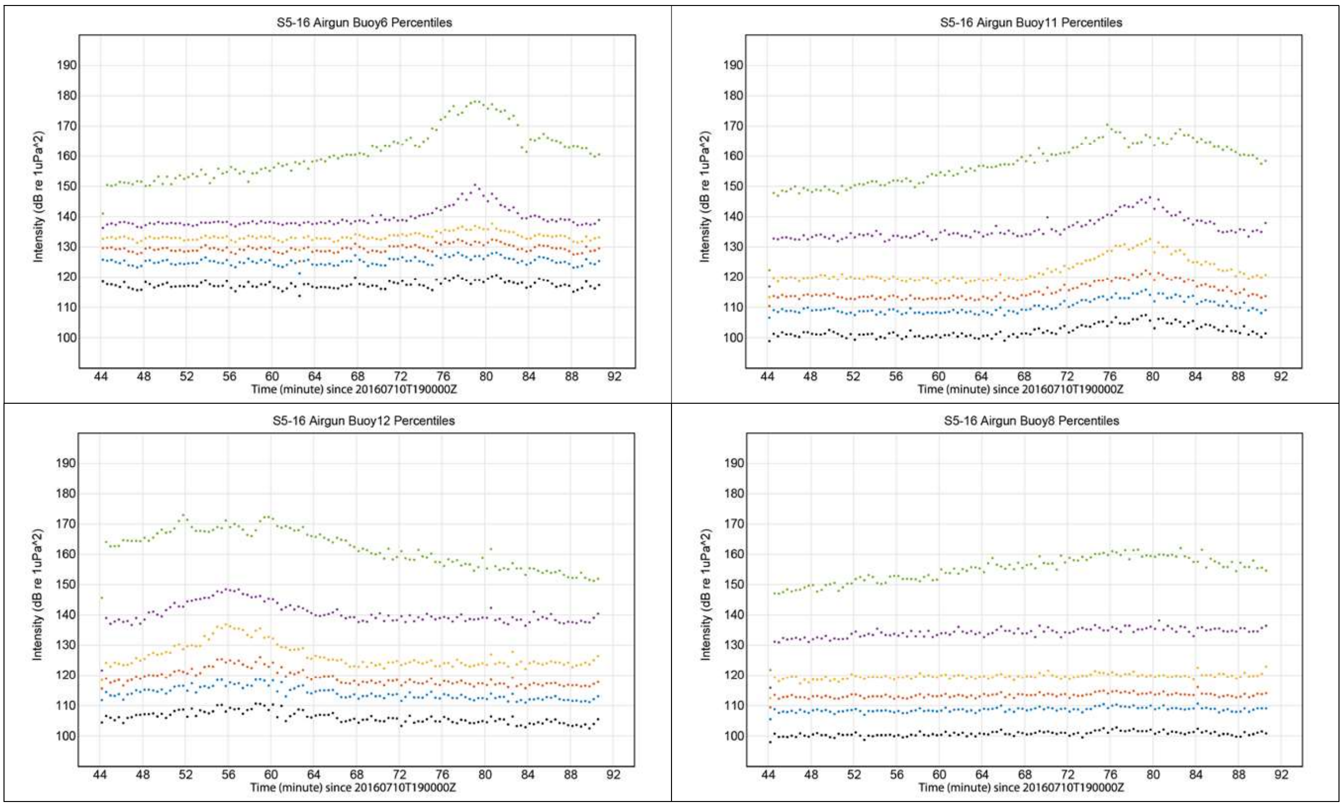


Figure 4.36.5-1. Percentile plots of MiniGI-1 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy11); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

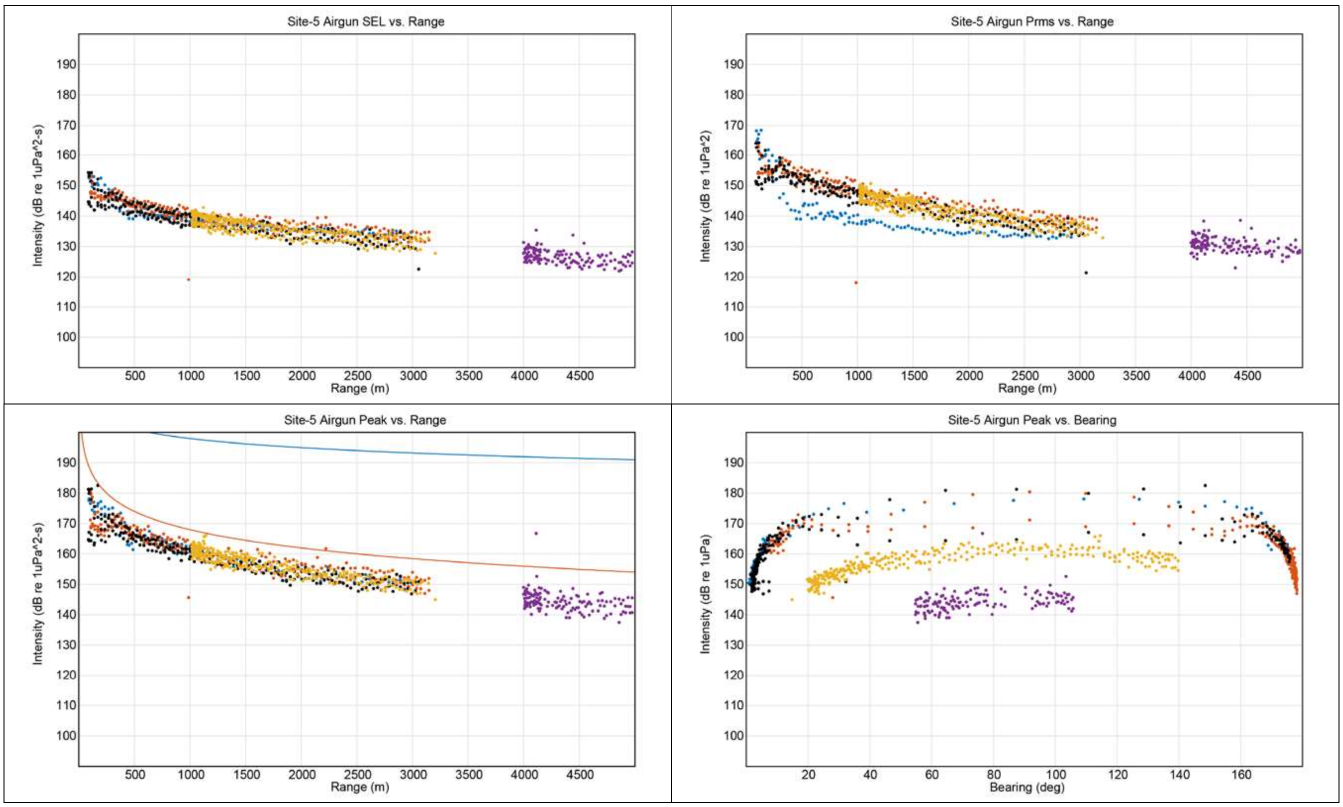


Figure 4.36.5-2. Range results for MiniGI-1 signals at Site 5 from Run16 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.36.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 91,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

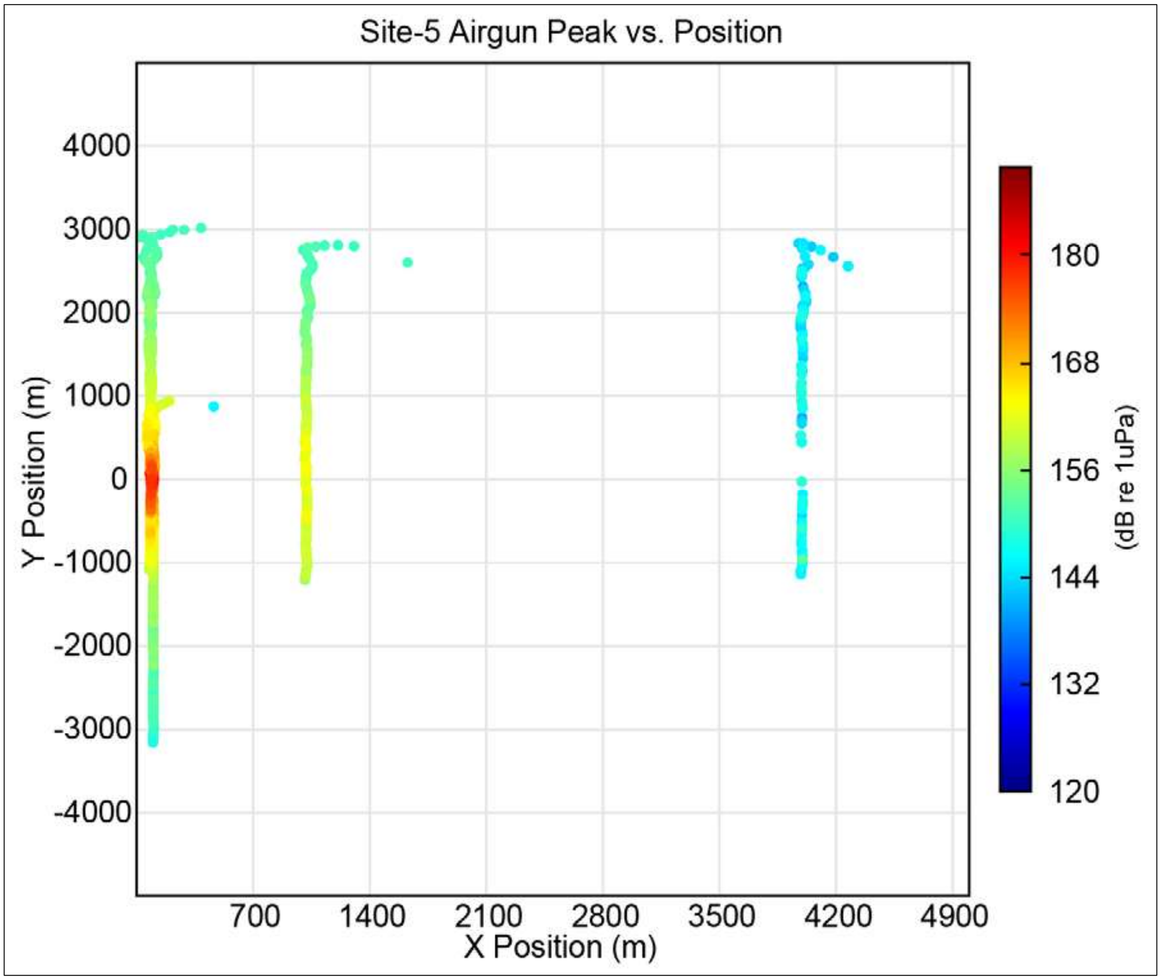


Figure 4.36.5-3. Plan view of received peak level for MiniGI-1 at Site 5 for positions D (Buoy6), B (Buoy11), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.36.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source levels are approximately 12 dB lower than the NUWC report values, and this difference is not due to buoy position errors because many distant buoys, which are insensitive to exact range, captured signals. These differences are due to unresolved calibration errors (**Section 2.6.3.1**).

Table 4.36.5-1. MiniGI-1 source levels, Mode 3, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini GI (30/30) Mode 3	NA	NA	NA	1 gun No insert	216	207	191
NUWC	NA	2,500 psi at 3 m depth	NA	1 gun No insert	228	223	199

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule: kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; psi = pounds per square inch; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.37 Sercel Mini GI (30/30), Single Airgun, 15-in^3 Inserts, 8-second Shot Rate (Mode 4)

The MiniGI-1, Mode 4, airgun source generates a low-frequency signal with a peak frequency below 500 Hz. The operational parameter settings for Mode 4 were a single airgun with 15-in^3 inserts, and an 8-second shot rate. The bandwidth used for processing was 0 to 4 kHz. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.37-1** is the selected frequency band (0 to 4 kHz) and SPL_{pk} (178 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.37-1. Bandpass determination for the MiniGI-1 acoustic source, single airgun, 15-in^3 inserts, 8-second shot rate, at Site 5, Run18.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	165.58
0-20	174.89
0-12	178.51
0-8	175.06
0-4	**178.41**
0-2	141.25

dB re 1 µPa = decibels relative to one micropascal; in^3 = cubic inch; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The MiniGI-1, Mode 4, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.37-1**.

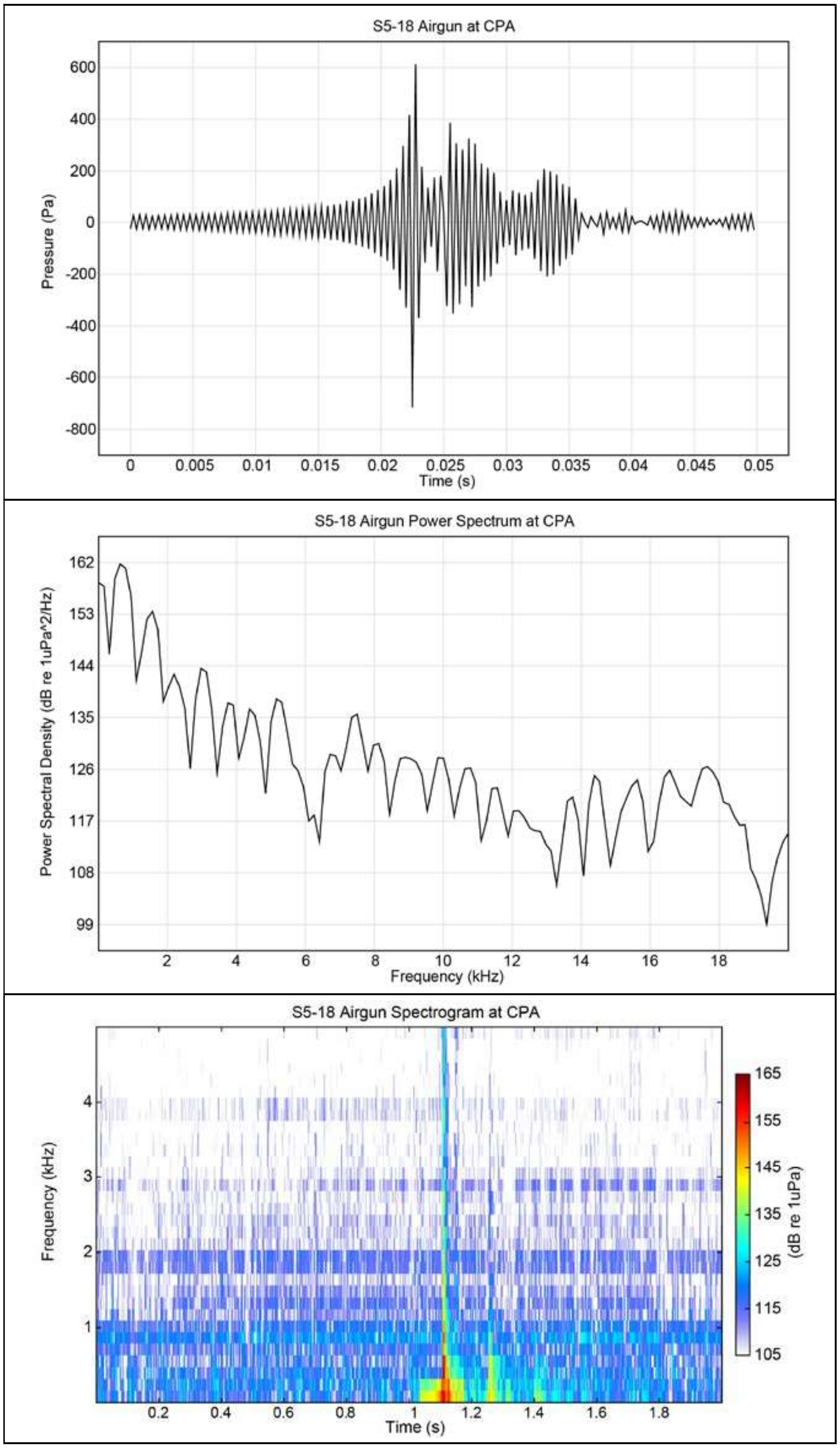


Figure 4.37-1. MiniGI-1 measured signal characteristics at closest point of approach (CPA) at Site 5, Run18.

Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.37.1 Site 1 – Mud, 10 m Depth

The MiniGI-1, Mode 4, was not deployed or operated at S1.

4.37.2 Site 2 – Sand, 10 m Depth

The MiniGI-1, Mode 4, was not deployed or operated at S2.

4.37.3 Site 3 – Mud, 30 m Depth

The MiniGI-1, Mode 4, was not deployed or operated at S3.

4.37.4 Site 4 – Sand, 30 m Depth

The MiniGI-1, Mode 4, was not deployed or operated at S4.

4.37.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the MiniGI-1, Mode 4, had valid acoustic recordings in Run18 at positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Noise issues, due to strumming and other low-frequency sound were a problem at positions E (Buoy9) and F (Buoy10), but the noisy data were filtered to extract the signals.

Run Summary

The percentile plots for the available recordings of the MiniGI-1, Mode 4, are shown in **Figure 4.37.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run18, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions A (Buoy12), E (Buoy8), and F (Buoy10). The greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. For this LF signal centered below 500 Hz, propagation loss was low, and the signal was observable for the duration of the run at all positions. For the shortest-range positions (D, B, and A), the data have signal-to-noise received levels around 180 dB re 1 μPa, and the signal-to-noise ratios were more than 60 dB.

The results panels (**Figure 4.37.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the MiniGI-1, Mode 4, at S5, positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10) had strong acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to approximately 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [$20 \log_{10}$ (*range*)] and cylindrical spreading [$10 \log_{10}$ (*range*)], which predict received levels for a 227 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). For all positions, there is close agreement with range (i.e., the data are tight). Several of the hydrophones at the same position demonstrate a consistent 3- to 5-dB offset, which likely is due to the depth dependence of the acoustic field rather than a calibration error.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions at approximately 90, which is as expected for good buoy GPS navigation and an omnidirectional source.

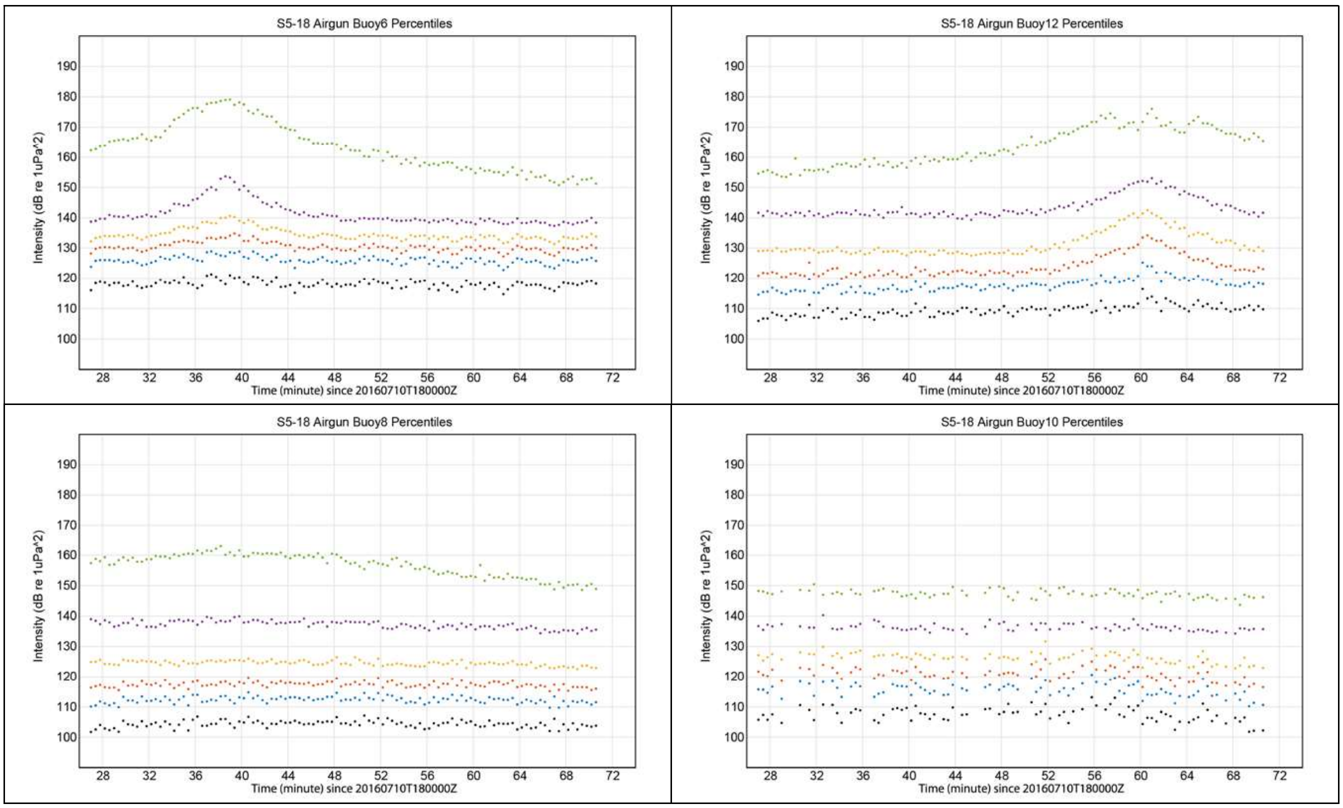


Figure 4.37.5-1. Percentile plots of MiniGI-1 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom left: SPL_{pk} arrival at position E (Buoy8); Bottom right: SPL_{pk} arrival at position F (Buoy10). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

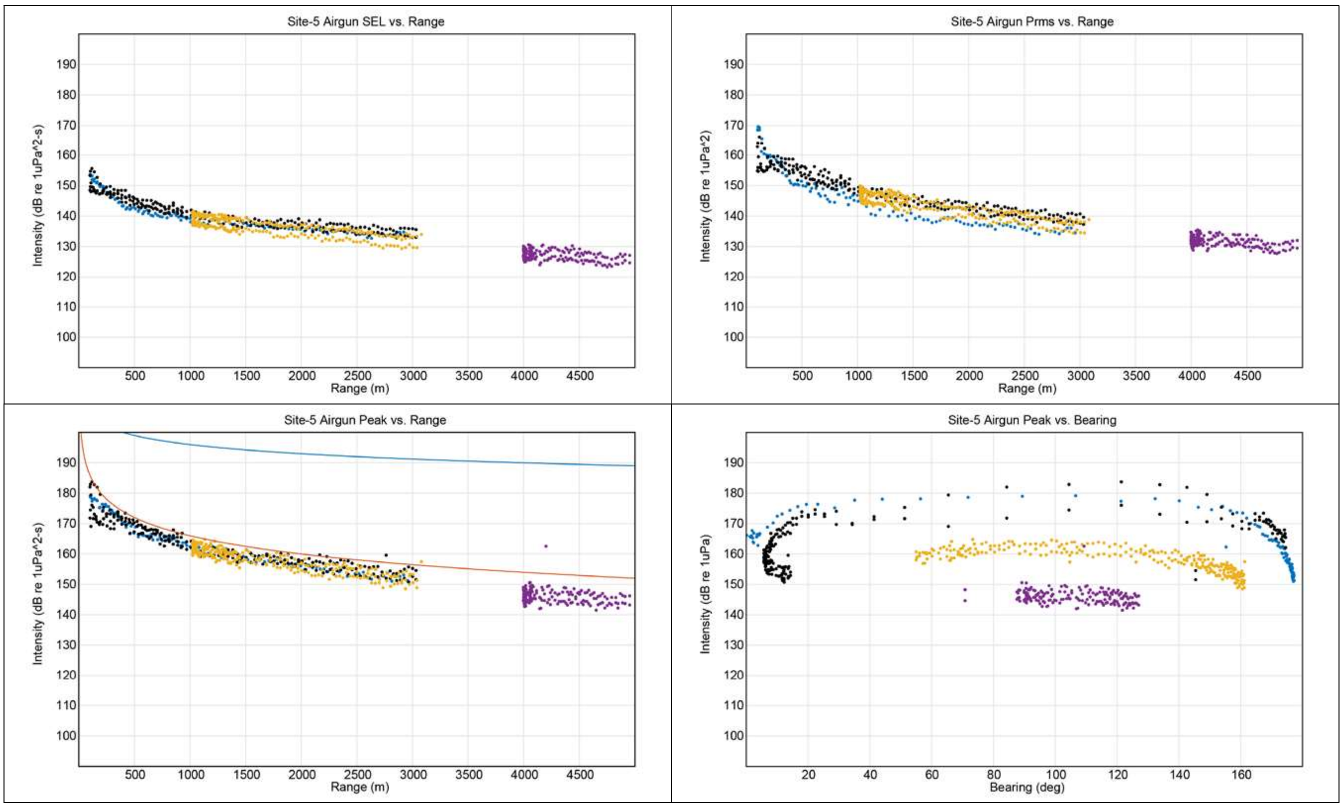


Figure 4.37.5-2. Range results for MiniGI-1 signals at Site 5 from Run18 for positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.37.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

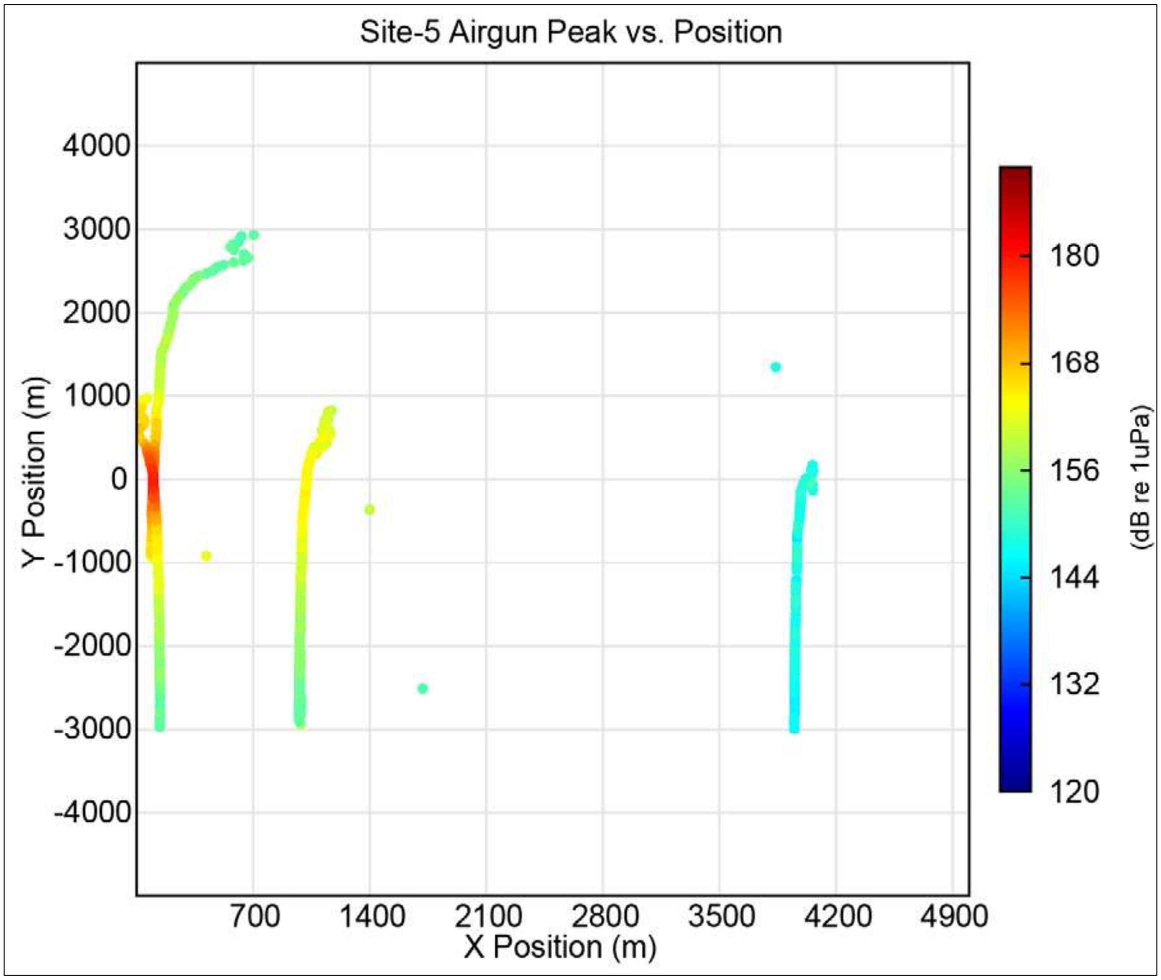


Figure 4.37.5-3. Plan view of received peak level for MiniGI-1 at Site 5 for positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.37.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source levels are about 10 dB lower than the NUWC report values, and this difference is not due to buoy position errors because many distant buoys, which are insensitive to exact range, captured signals. These differences are due to unresolved calibration errors (**Section 2.6.3.1**).

Table 4.37.5-1. MiniGI-1 source levels, Mode 4, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini GI (30/30) Mode 4	NA	NA	NA	1 gun 15-ci insert	216	207	191
NUWC	NA	2,500 psi at 3 m depth	NA	1 gun 15-ci insert	227*	222*	198*

ci = cubic inch; dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule: kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; psi = pounds per square inch; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.
* = 1 dB was removed from this SL to account for the insert because NUWC did not measure the source using these same operational settings.

This Page Intentionally Left Blank

4.38 Sercel Mini GI (30/30), Single Airgun#1, Full 30/30, No Insert, 24-Second Shot Rate (Mode 5)

The MiniGI-1, Mode 5, airgun source generates a low-frequency, high-amplitude signal with a peak frequency below 500 Hz. The operational parameter settings for MiniGI-1, Mode 5 were a single airgun#1 with no insert, full 30/30, and a 24-second shot rate. The bandwidth used for processing was 0 to 4 kHz. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.38-1** is the selected frequency band (0 to 4 kHz) and SPL_{pk} (170 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.38-1. Bandpass determination for the MiniGI-1 acoustic source, single airgun#1, full 30/30, no insert, and 24-second shot rate, at Site 5, Run28.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	155.35
0-20	168.43
0-12	170.02
0-8	168.52
0-4	**170.01**
0-2	149.10

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The MiniGI-2, Mode 5, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.38-1**.

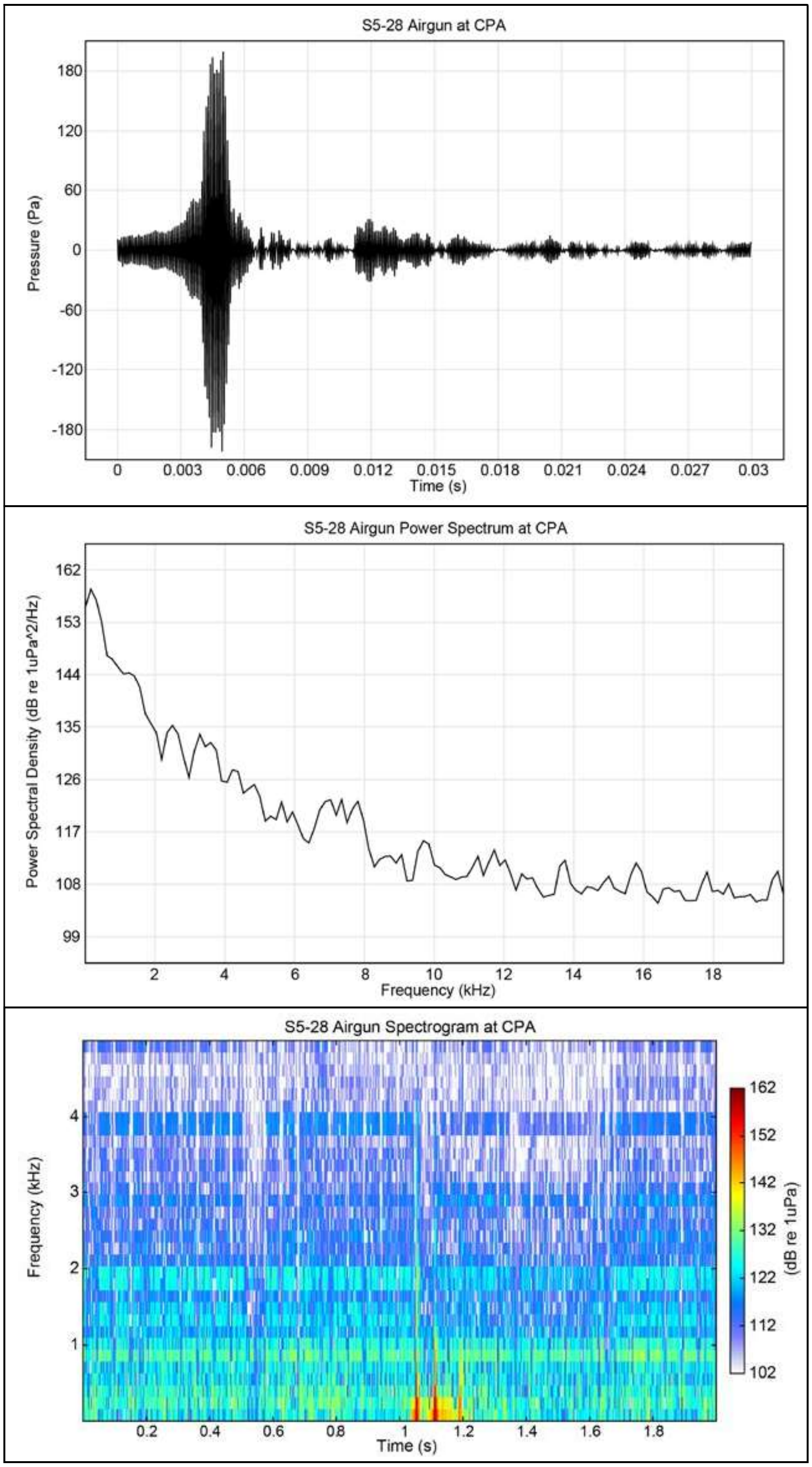


Figure 4.38-1. MiniGI-1 measured signal characteristics at closest point of approach (CPA) at Site 5, Run28.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.38.1 Site 1 – Mud, 10 m Depth

The MiniGI-1, Mode 5, was not deployed or operated at S1.

4.38.2 Site 2 – Sand, 10 m Depth

The MiniGI-1, Mode 5, was not deployed or operated at S2.

4.38.3 Site 3 – Mud, 30 m Depth

The MiniGI-1, Mode 5, was not deployed or operated at S3.

4.38.4 Site 4 – Sand, 30 m Depth

The MiniGI-1, Mode 5, was not deployed or operated at S4.

4.38.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the MiniGI-1, Mode 5, had valid acoustic recordings in Run28 at positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10). Noise issues, due to strumming and other low-frequency sound were a problem at positions E (Buoys9) and F (Buoy10), but the noisy data were filtered to extract the signals.

Run Summary

The percentile plots for the available recordings of the MiniGI-1, Mode 5, are shown in **Figure 4.38.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run28, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions A (Buoy12), E (Buoy9), and F (Buoy10). The greater than 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. For this LF signal centered below 500 Hz, propagation loss was low, and the signal was observable for the duration of the run at all positions. For the shortest-range positions (D, B, and A), the data have signal-to-noise received levels around 180 dB re 1 µPa, and the signal-to-noise ratios were more than 60 dB.

The results panels (**Figure 4.38.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the MiniGI-1 at S5, positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10) had strong acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to 5,000 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The received signal is quite consistent across buoys, though there are possibly calibration errors (**Section 2.6.3.1**) at position F (Buoy10), which has received levels approximately 10 dB lower compared to the other positions. For the SPL_{rms} metric only, position D received levels fall well below the other received levels, this is likely not a calibration issue but a propagation or a signal to noise issue because of the way the rms is computed. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 228 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). For all positions, there is close agreement with range (i.e., the data are tight). Several of the hydrophones at the same position demonstrate a consistent 3- to 5-dB offset, which likely is due to the depth dependence of the acoustic field rather than a calibration error.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for all positions at approximately 90°, which is expected for GPS navigation and omnidirectional sources.

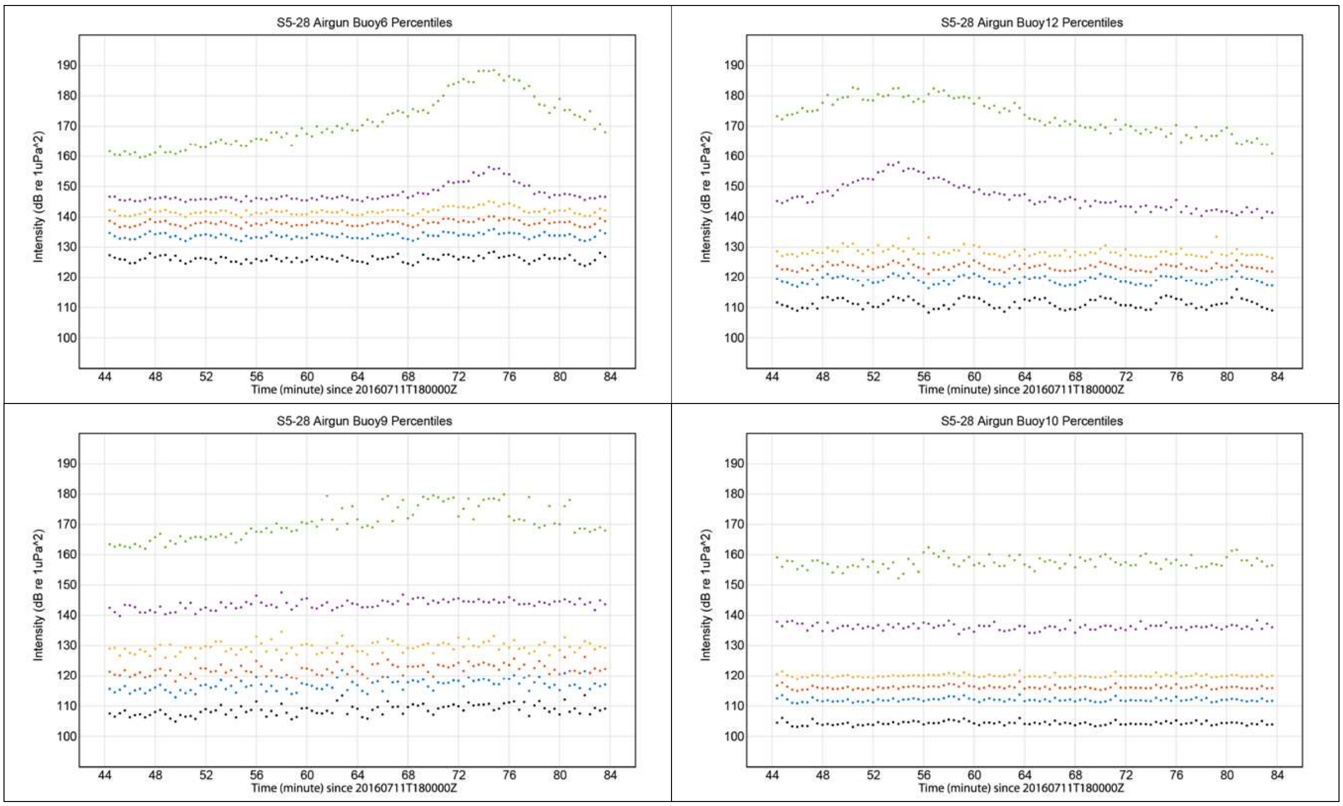


Figure 4.38.5-1. Percentile plots of MiniGI-1 signals at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position A (Buoy12); Bottom left: SPL_{pk} arrival at position E (Buoy9); Bottom right: SPL_{pk} arrival at position F (Buoy10). Legend: Percentiles, 5th (black), 25th (blue), 50th (red), 75th (orange), 95th (purple), and 100th (green).

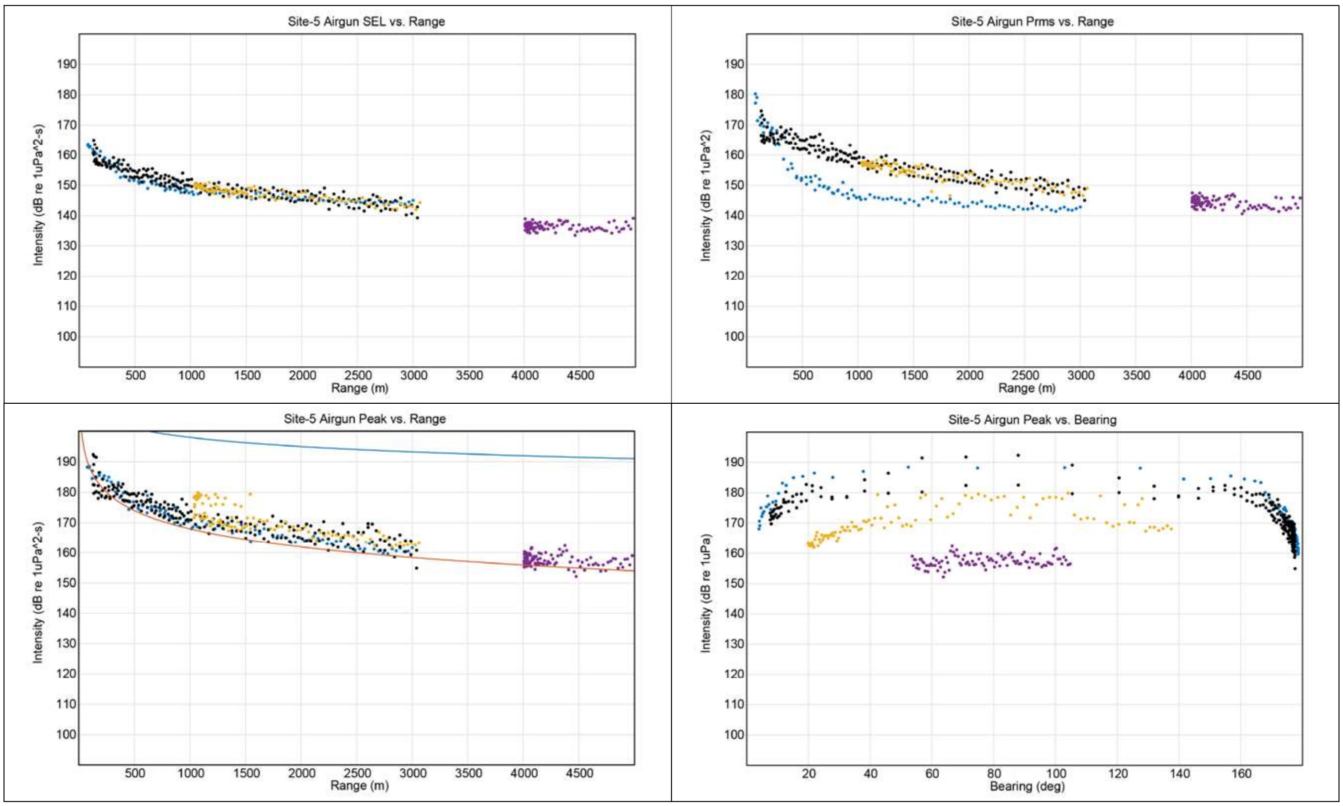


Figure 4.38.5-2. Range results for MiniGI-1 signals at Site 5 from Run28 for positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9, combined), and F (Buoy10).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Positions, A = black; D = blue; E = yellow; F = purple.

The plan view is shown in **Figure 4.38.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -4,500 to 4,500-m marks on the y-axis. The CPA is at 50,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -3,000 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above background noise. Acoustic signals were received at positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9), and F (Buoy10), however F did not have strong enough signal reception for plan view plot threshold thus does not appear. Recordings at each buoy had strong acoustic peak amplitudes, presumably at the CPA.

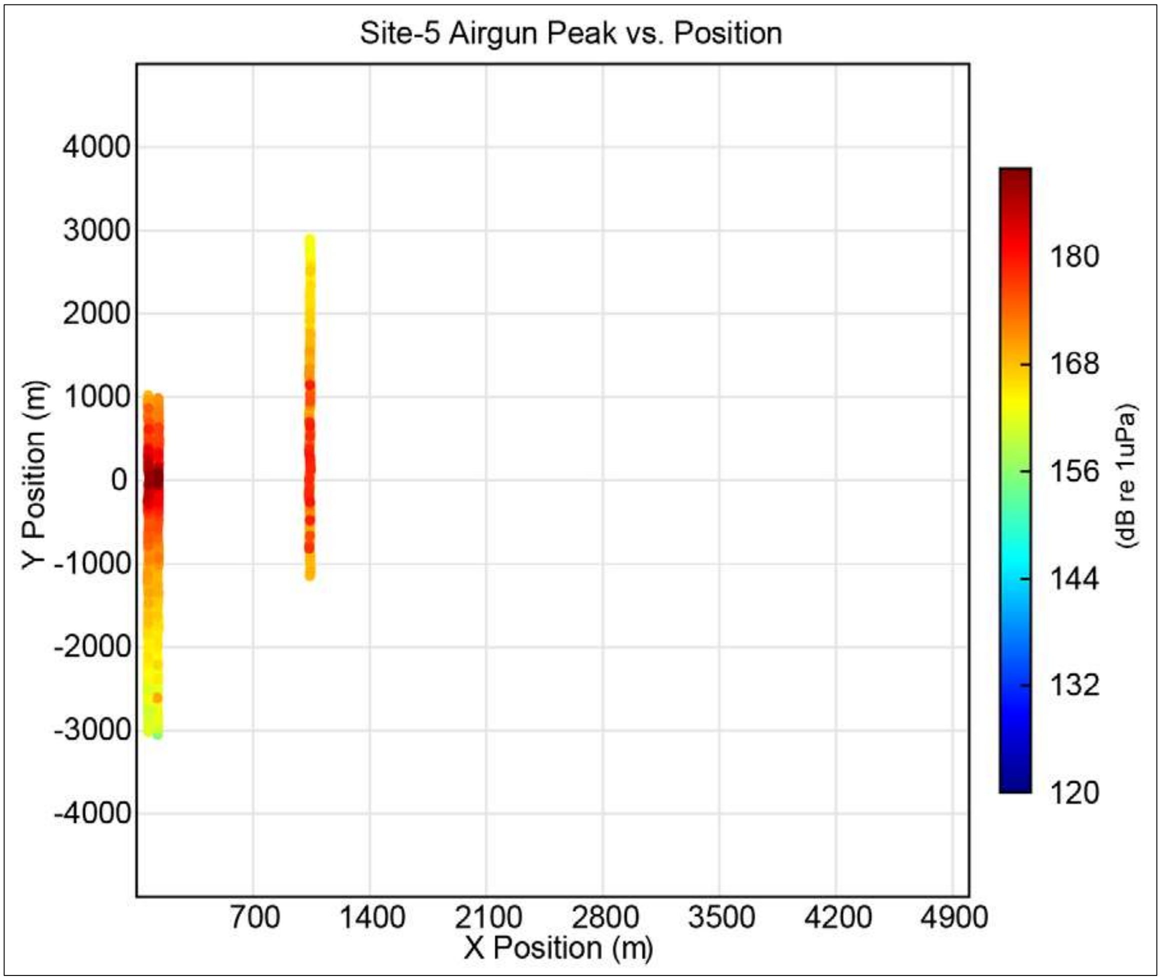


Figure 4.38.5-3. Plan view of received peak level for MiniGI-1 at Site 5 for positions D (Buoy6), A (Buoy12), E (Buoy8 and Buoy9).

Table Source Summary

A summary of source specifications from the field measurement results are provided in **Table 4.38.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results. The estimated source levels are 10 dB lower than the NUWC report values, and this difference is not due to buoy position errors because many distant buoys which are insensitive to exact range captured signals. These differences are due to calibration errors (**Section 2.6.3.**1).

Table 4.38.5-1. MiniGI-1 source levels, Mode 5, at Site 5.

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Mini GI (30/30) Mode 5	NA	NA	NA	1 gun Full 30/30	229	218	205
NUWC	NA	2,500 psi at 3 m depth	NA	1 gun Full 30/30	228	223	199

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; m = meter; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; psi = pounds per square inch; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

4.39 Applied Acoustics Delta Sparker, 2.4 kJ, Low Power (Mode 1)

The Delta Sparker acoustic source generates a low-frequency, high-amplitude signal with a peak frequency below 500 Hz. The operational parameter settings for Mode 1 were a power setting of 2.4 kJ, low power, and 0 to 10 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.39-1** is the selected frequency band (0 to 8 kHz) and SPL_{pk} (178 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.39-1. Bandpass determination for the Delta Sparker acoustic source, 2.4 kilojoules, low power, at Site 5, Run1.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	173.64
0-25	174.60
0-20	177.46
0-12	178.35
0-8	**177.75**
0-4	177.44
0-2	148.25

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Delta Sparker, Mode 1, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.39-1**.

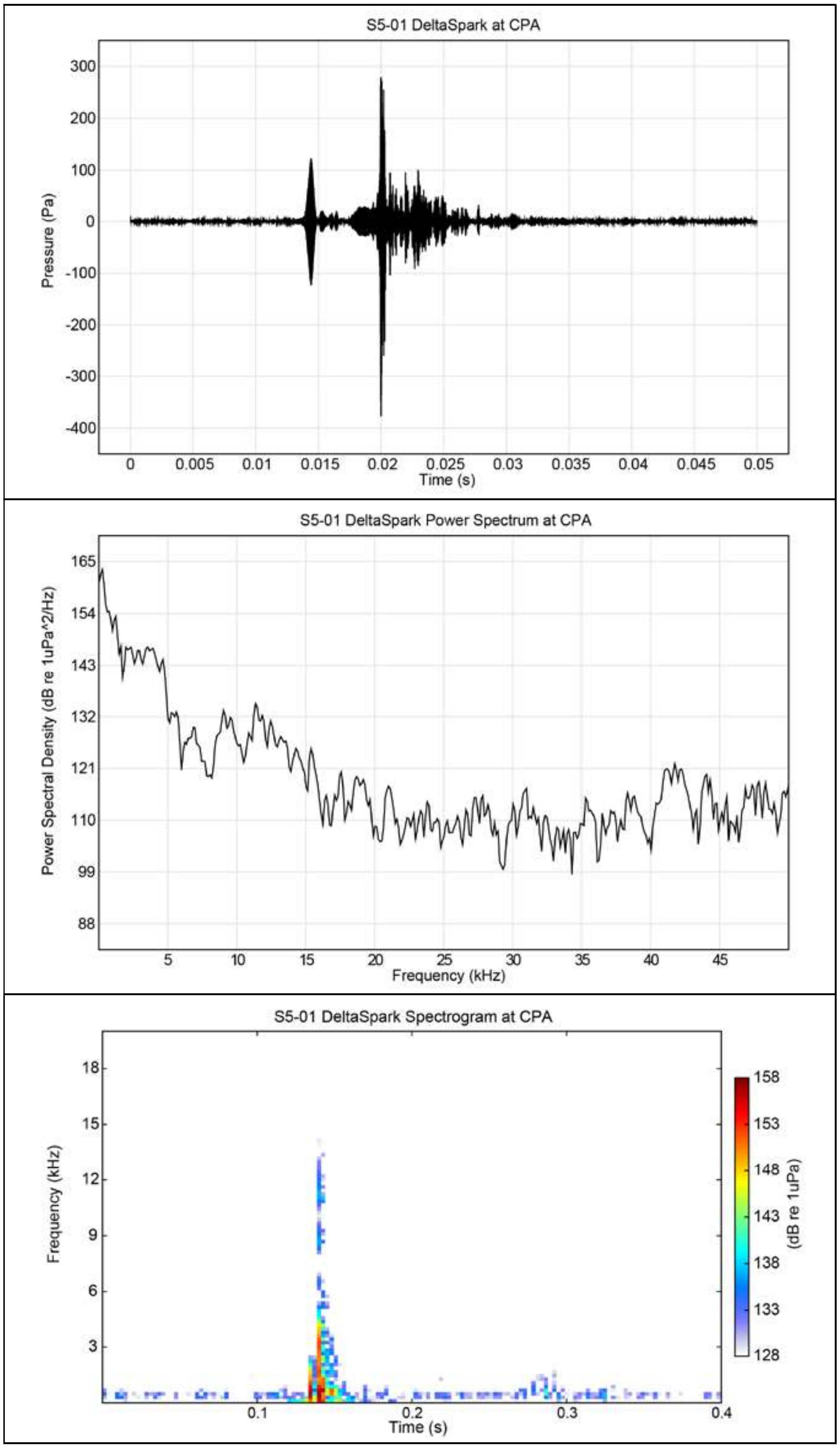


Figure 4.39-1. Delta Sparker, 2.4 kilojoules, measured signal characteristics at closest point of approach (CPA) at Site 5, Run1.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.39.1 Site 1 – Mud, 10 m Depth

The Delta Sparker, Mode 1, was not deployed or operated at S1.

4.39.2 Site 2 – Sand, 10 m Depth

The Delta Sparker, Mode 1, was not deployed or operated at S2.

4.39.3 Site 3 – Mud, 30 m Depth

The Delta Sparker, Mode 1, was not deployed or operated at S3.

4.39.4 Site 4 – Sand, 30 m Depth

The Delta Sparker, Mode 1, was not deployed or operated at S4.

4.39.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Delta Sparker, Mode 1, had valid acoustic recordings in Run1 at positions D (Buoy6), B (Buoy5), A (Buoy12), and E (Buoy8 and Buoy9). Noise issues, due to strumming and other low-frequency sound were a problem at positions B (Buoy5) and E (Buoy9), but the noisy data were filtered to extract the signals, yielding some useful signal receptions.

Run Summary

The percentile plots for the available recordings of the Delta Sparker, Mode 1, are shown in **Figure 4.39.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 100^{th} percentiles. The top left panel shows position D (Buoy6) for Run1, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The top right and bottom panels show the valid recorded acoustics at positions B (Buoy5), A (Buoy12), and E (Buoy8). The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The signal is clearly seen on all buoys for all transmissions.

The results panels (**Figure 4.39.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Delta Sparker at S5, positions D (Buoy6), B (Buoy5), A (Buoy12), and E (Buoy8 and Buoy9) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to approximately 3,700 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 221 dB re 1 µPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016). The received levels appear lower than expected as the propagation is worse than spherical spreading. At this site, the source passed closer to position A than position D.

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for positions D, B, A and E at all nearly at 90°, which is expected for an omnidirectional source.

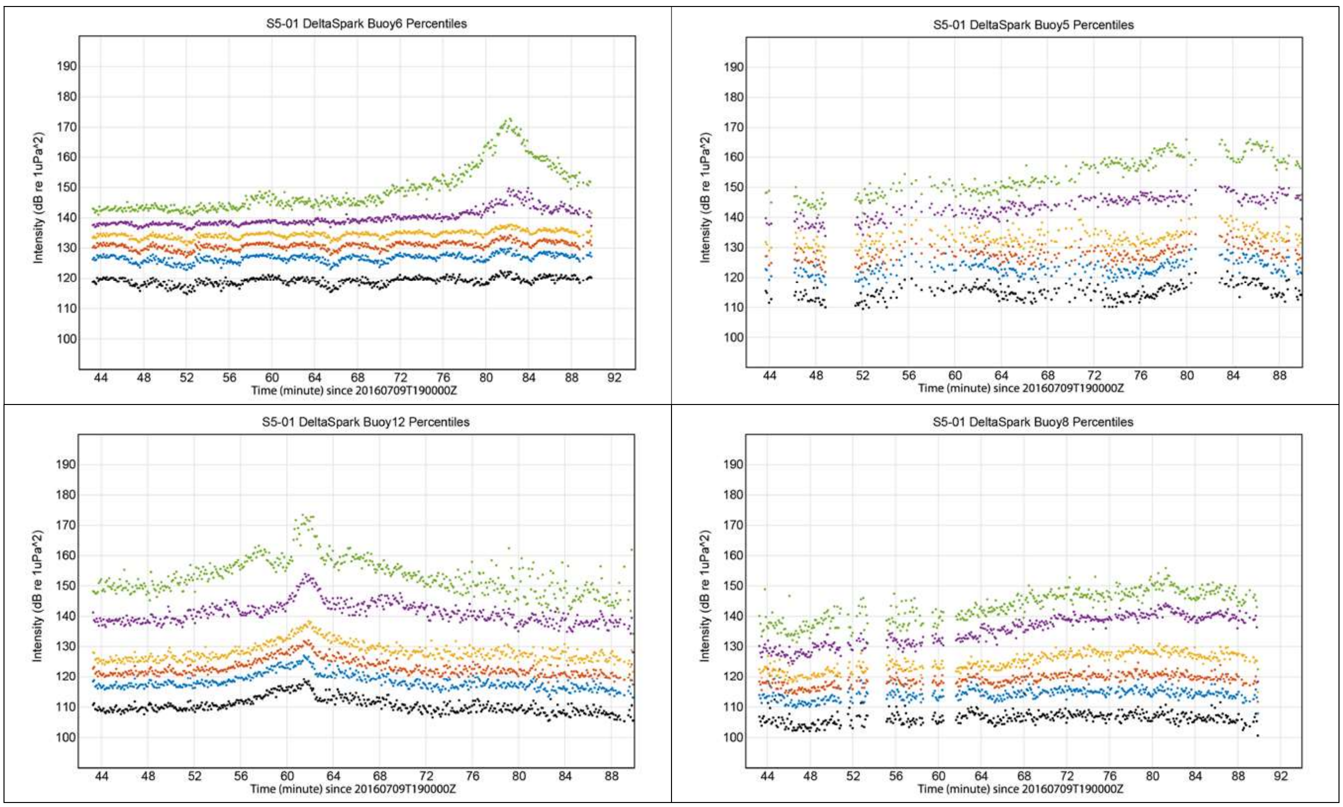


Figure 4.39.5-1. Percentile plots of Delta Sparker signals, 2.4 kilojoules, at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

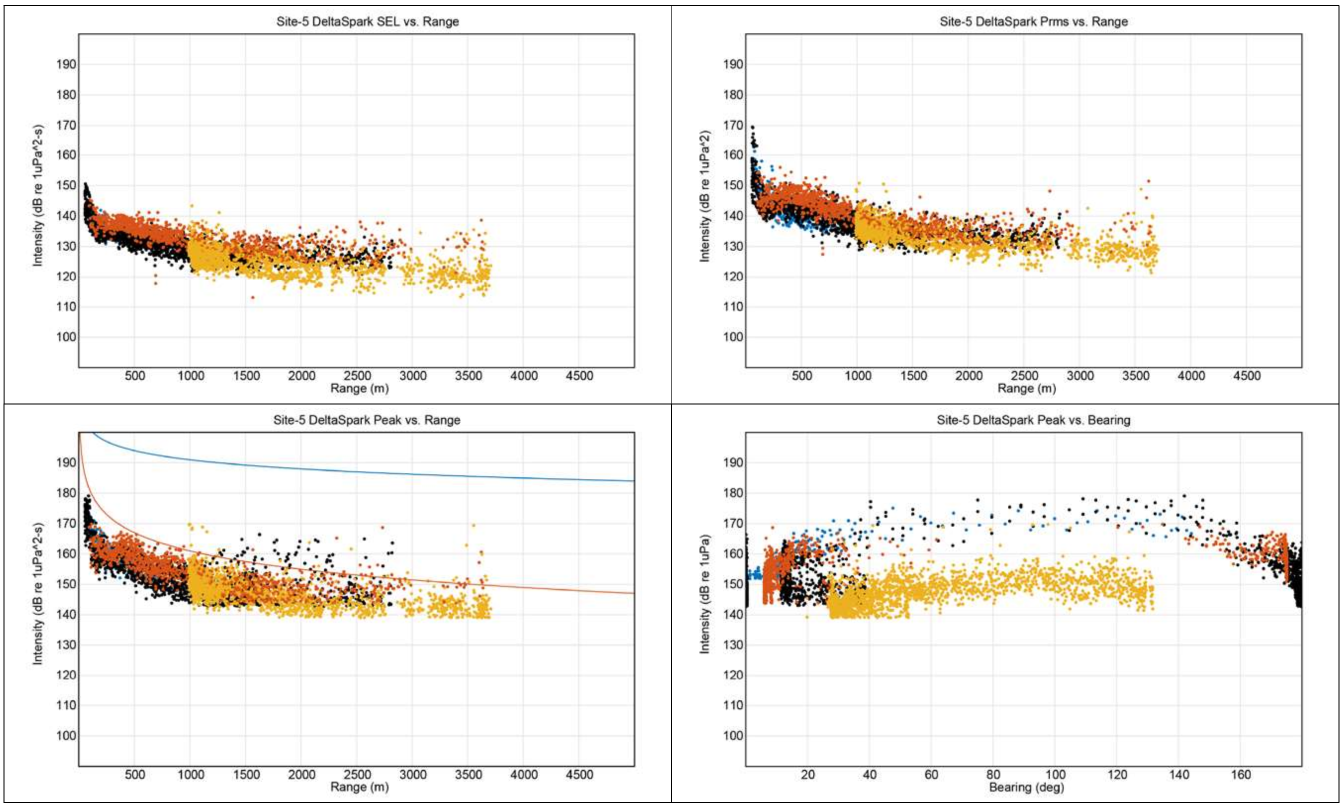


Figure 4.39.5-2. Range results for Delta Sparker signals, 2.4 kilojoules, at Site 5 from Run1 for positions D (Buoy6), B (Buoy5), A (Buoy12), and E (Buoy8 and Buoy9, combined).

Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing.

Note: Range was not taken out of bearing. Legend: Positions, A = black; B = red; D = blue; E = yellow.

The plan view is shown in **Figure 4.39.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -5,000 to 5,000-m marks on the y-axis. The CPA is at 56,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing, which can be sensitive to the source's directivity pattern. Acoustic signals were received at positions D (Buoy6), B (Buoy5), A (Buoy12), and E (Buoy8 and Buoy9). Recordings at each buoy had acoustic peak amplitudes, presumably at the CPA.

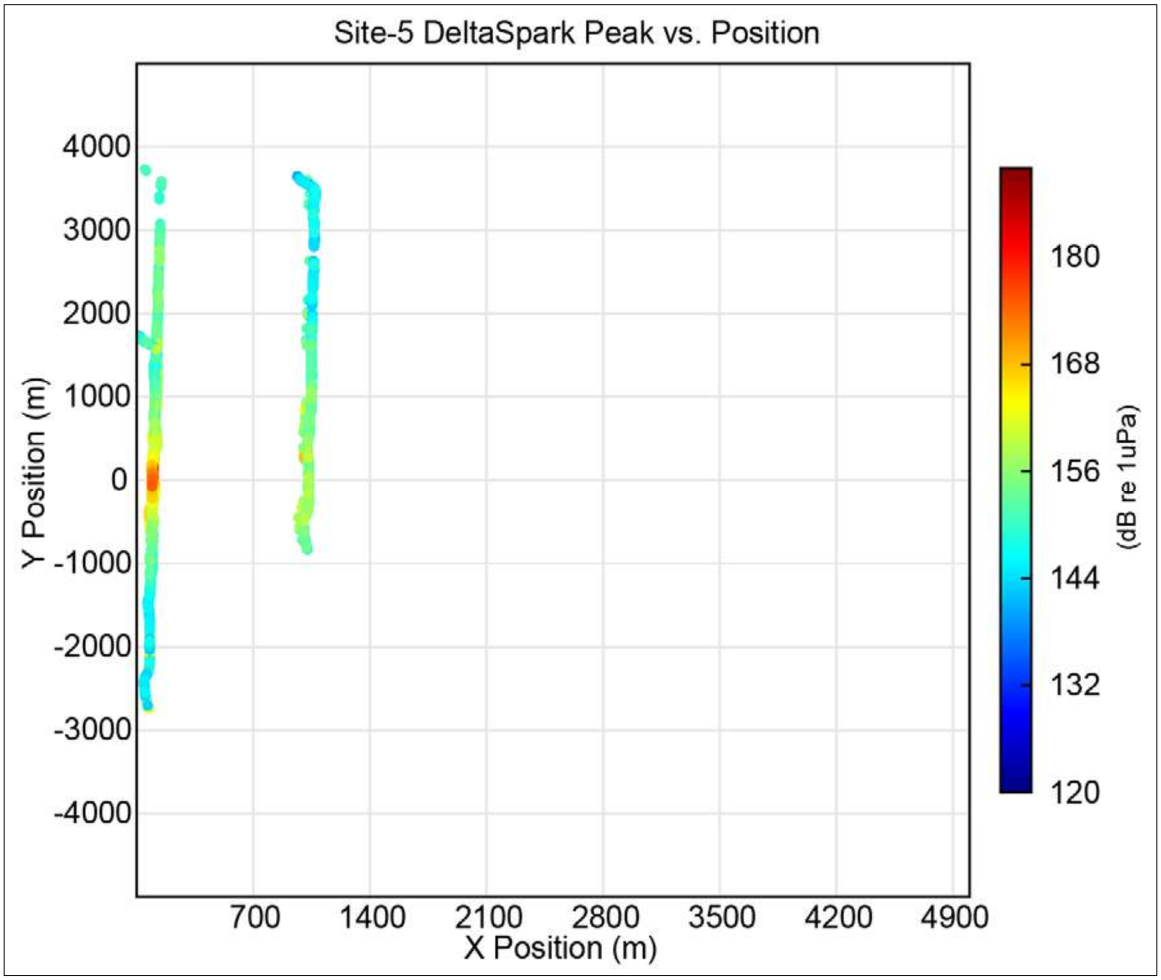


Figure 4.39.5-3. Plan view of received peak level for Delta Sparker, 2.4 kilojoules, at Site 5 for positions D (Buoy6), B (Buoy5), A (Buoy12), and E (Buoy8 and Buoy9).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.39.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.39.5-1. Delta Sparker, 2.4 kilojoules, source levels, Mode 1, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	Frequency (kHz)	Power: J, %, Level	Power SL	Plates, # guns, inserts	Pk	rms	SEL
Delta Sparker Mode 1	NA	2.4 kJ	NA	NA	204	186	177
NUWC	NA	2.4 kJ	NA	NA	221	205	185

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; kJ = kilojoule; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.40 Applied Acoustics Delta Sparker, 1.5 kJ, Low Power (Mode 2)

The Delta Sparker acoustic source generates a low-frequency, high-amplitude signal with a peak frequency below 500 Hz. The operational parameter settings for Mode 2 were a power setting of 1.5 kJ, low power, and 0 to 20 kHz output frequency. A frequency bandpass for signal processing was chosen based on the highest peak pressures within a specified band. The bolded row in **Table 4.40-1** is the selected frequency band (0 to 12 kHz) and SPL_{pk} (169 dB re 1 µPa) applied to the signal for further analysis. The criterion for band selection was defined as the smallest band without energy loss (i.e., 0.2 to 0.3 dB) within the peak energy levels and without a rapid drop of energy.

Table 4.40-1. Bandpass determination for the Delta Sparker acoustic source, 1.5 kilojoules, low power, at Site 5, Run2.

Frequency Band (kHz)	SPL_{pk} (dB re 1 µPa)
0-50	168.02
0-25	167.87
0-20	169.74
0-12	**168.51**
0-8	165.45
0-4	150.70

dB re 1 µPa = decibels relative to one micropascal; kHz = kilohertz; SPL_{pk} = peak sound pressure level.

The source signal characteristics recorded at the CPA are reported from only one site for simplicity. The Delta Sparker, Mode 2, signal in pressure time-waveform, mean-square sound pressure spectral density (generally known as power spectral density), and spectrogram are shown in **Figure 4.40-1**.

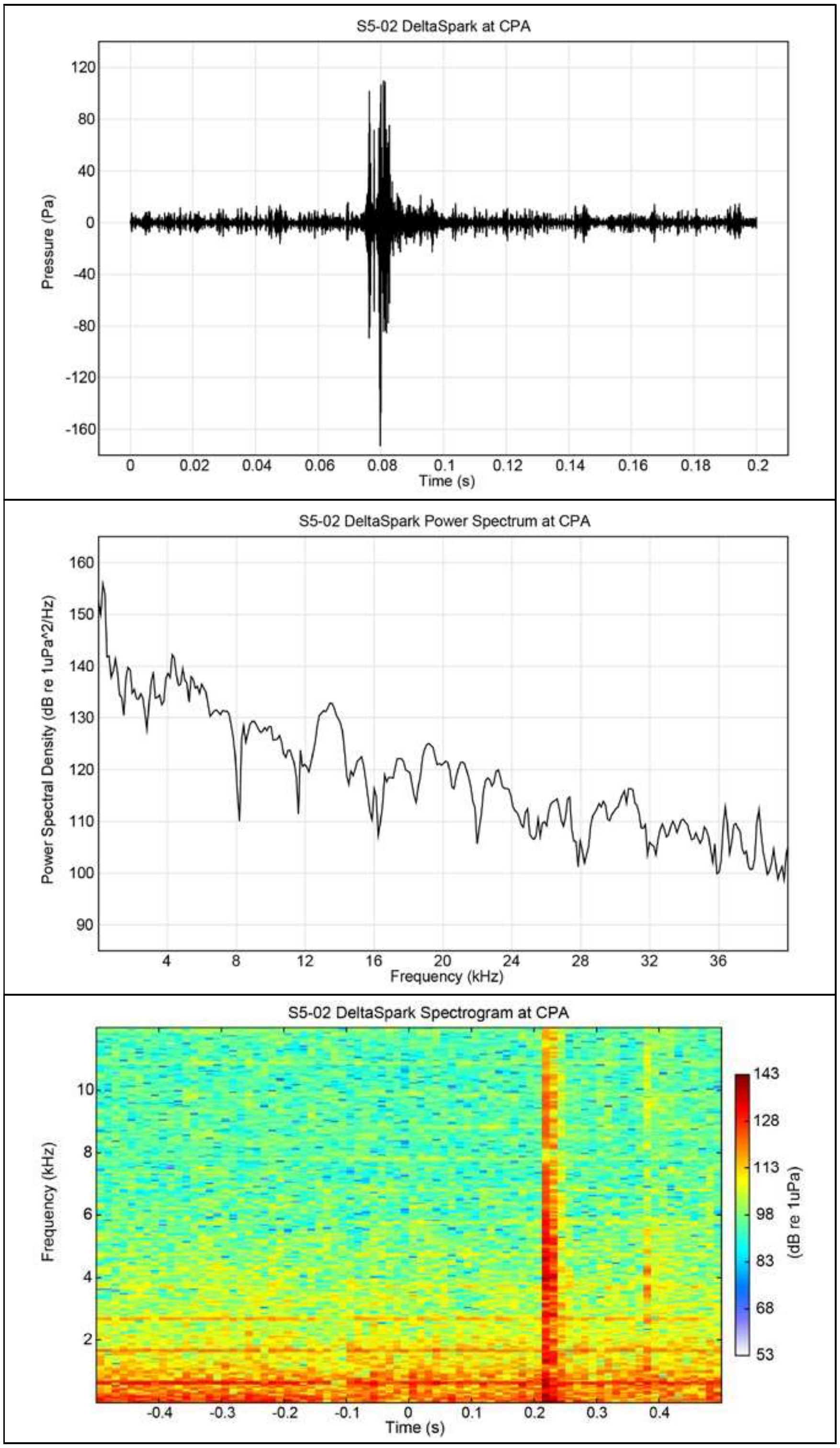


Figure 4.40-1. Delta Sparker, 1.5 kilojoules, measured signal characteristics at closest point of approach (CPA) at Site 5, Run2.
Top: Time-waveform of a signal; Middle: Power spectral density;
Bottom: Spectrogram.

4.40.1 Site 1 – Mud, 10 m Depth

The Delta Sparker, Mode 2, was not deployed or operated at S1.

4.40.2 Site 2 – Sand, 10 m Depth

The Delta Sparker, Mode 2, was not deployed or operated at S2.

4.40.3 Site 3 – Mud, 30 m Depth

The Delta Sparker, Mode 2, was not deployed or operated at S3.

4.40.4 Site 4 – Sand, 30 m Depth

The Delta Sparker, Mode 2, was not deployed or operated at S4.

4.40.5 Site 5 – Sandy-Silt, 100 m Depth

At S5, the Delta Sparker, Mode 2, had valid acoustic recordings in Run2 at position D (Buoy6). The acoustic data at positions B (Buoy5), A (Buoy12), and E (Buoy8) were corrupted.

Run Summary

The percentile plots for the available recordings of the Delta Sparker, Mode 2, are shown in **Figure 4.40.5-1**. Each dot in the time window is the processed result from a single receiver, showing the quality of the recording and the rise in Signal to Noise Ratio as the source passed CPA. The pulse peak values are plotted as a function of GMT for the run. The peak pulse intensity is sorted into 5th, 25th, 50th, 75th, 90th, and 100th percentiles. The top left panel shows position D (Buoy6) for Run2, where the received signal is observed, and its influence on the peak value as well as on the smaller percentiles. The 20-dB difference between the signal-floor percentile of 5 percent and 100 percent shows the acoustic data are valid. The top right and bottom panels show the corrupted recordings at positions B (Buoy5), A (Buoy12), and E (Buoy8).

The results panels (**Figure 4.40.5-2**) show the acoustic metrics versus range/bearing for all buoys with valid acoustic data. An automated bandpass filter of 25 dB peak to 5 percent ratio was applied to the collected data. For the Delta Sparker at S5, only position D (Buoy6) had acoustic signals. The top left panel is the SEL versus range, showing received signal energy at ranges from 100 to approximately 500 m. The top right panel is the SPL_{rms} as a function of range, computed over the 90 percent cumulative intensity. The bottom left panel shows the SPL_{pk} intensity as a function of range and includes two reference curves: spherical spreading [20 $\log_{10}$ (*range*)] and cylindrical spreading [10 $\log_{10}$ (*range*)], which predict received levels for a 220 dB re 1 μPa m source. The source level used was reported by the NUWC report (Crocker and Fratantonio, 2016).

The bottom right results panel is the SPL_{pk} versus bearing plot, which shows the received peak level for position D at approximately broadside (90°), which is expected for good buoy navigation and an omnidirectional source.

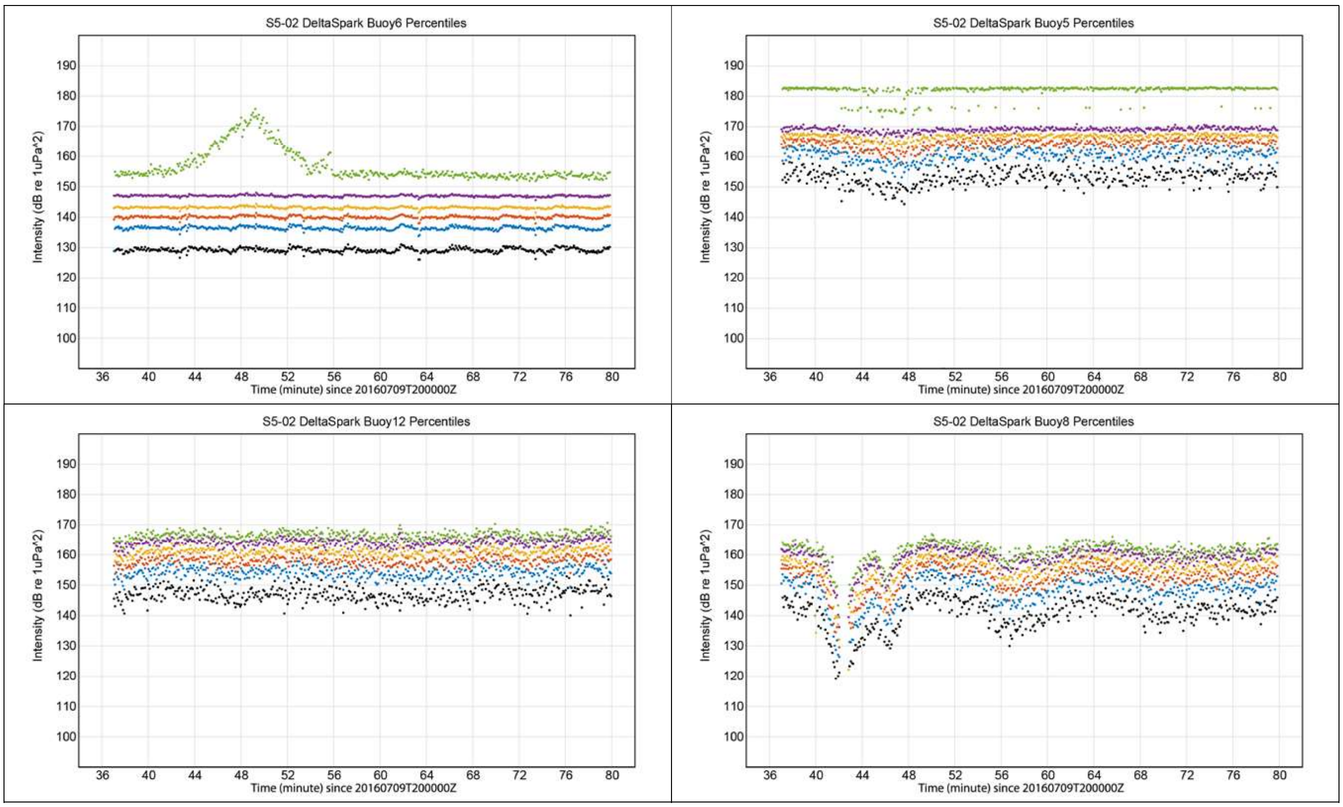


Figure 4.40.5-1. Percentile plots of Delta Sparker signal, 1.5 kilojoules, at Site 5.
Top left: Closest buoy percentiles of SPL_{pk} arrival at position D (Buoy6); Top right: SPL_{pk} arrival at position B (Buoy5); Bottom left: SPL_{pk} arrival at position A (Buoy12); Bottom right: SPL_{pk} arrival at position E (Buoy8). Legend: Percentiles, 5^{th} (black), 25^{th} (blue), 50^{th} (red), 75^{th} (orange), 95^{th} (purple), and 100^{th} (green).

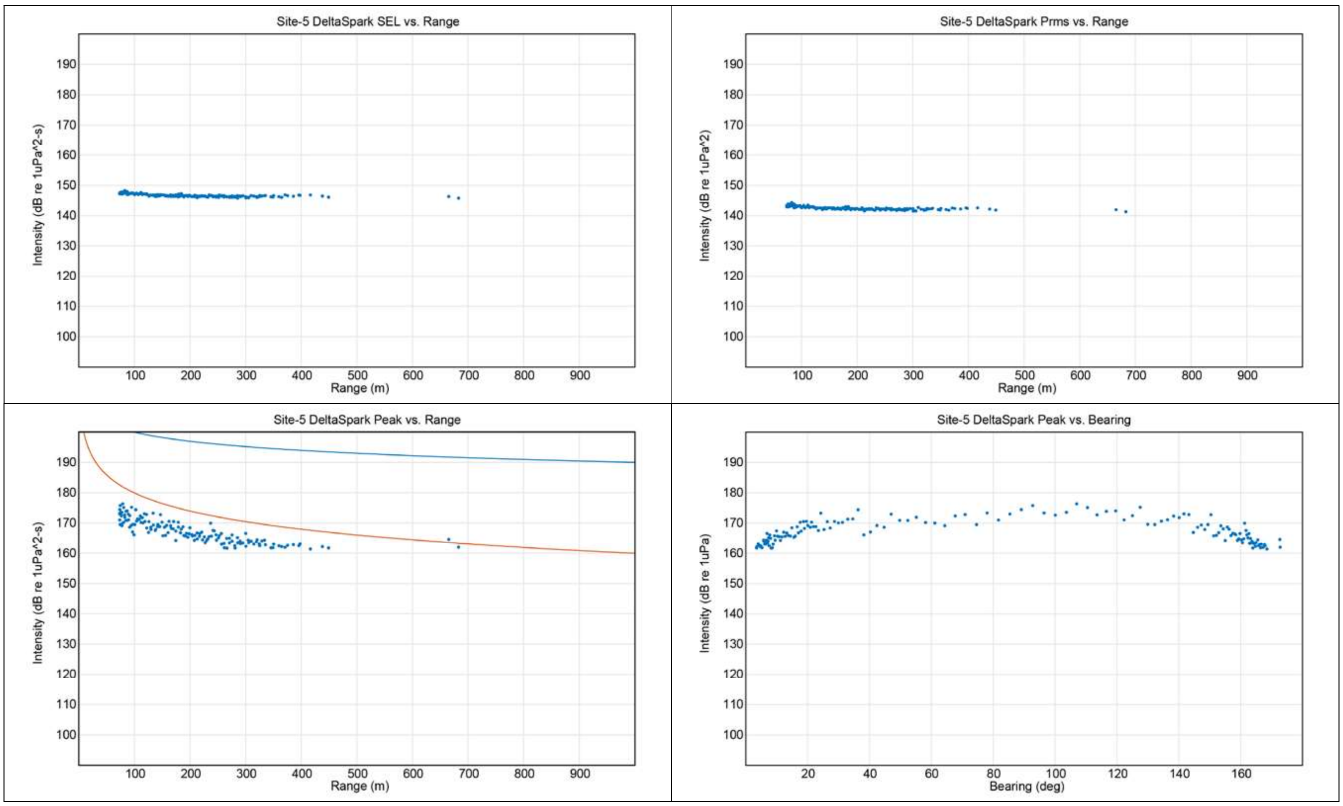


Figure 4.40.5-2. Range results for Delta Sparker signals, 1.5 kilojoules, at Site 5 from Run2 for position D (Buoy6).
Top left: SEL versus range; Top right: SPL_{rms} versus range; Bottom left: SPL_{pk} versus range, the blue line is cylindrical spreading [10 $\log_{10}$ (*range*)] and the red line is spherical spreading [20 $\log_{10}$ (*range*)]; Bottom right: SPL_{pk} versus bearing. Note: Range was not taken out of bearing. Legend: Position, D = blue.

The plan view is shown in **Figure 4.40.5-3**, where the peak received level is plotted as a function of geographic separation between the moving source on the vessel (y-axis) and the receiver mooring (x-axis). The source position is represented at the 0-m mark on the x-axis and along the -1,000 to 1,000-m marks on the y-axis. The CPA is at 73,0 m (x,y). The plan view provides the opportunity to evaluate propagation loss as a function of range and bearing. At the nearest buoy, the gradual rise of the received source level is seen starting approximately at -400 m (y-axis) as the CPA was approached. The gradual fall in received source level is seen as the CPA was passed, until the signal was not detected above the background noise. Acoustic signals were received at position D (Buoy6) and had acoustic peak amplitudes, presumably at the CPA. The highest amplitude signal for position D is seen at approximately 0 m on the y-axis.

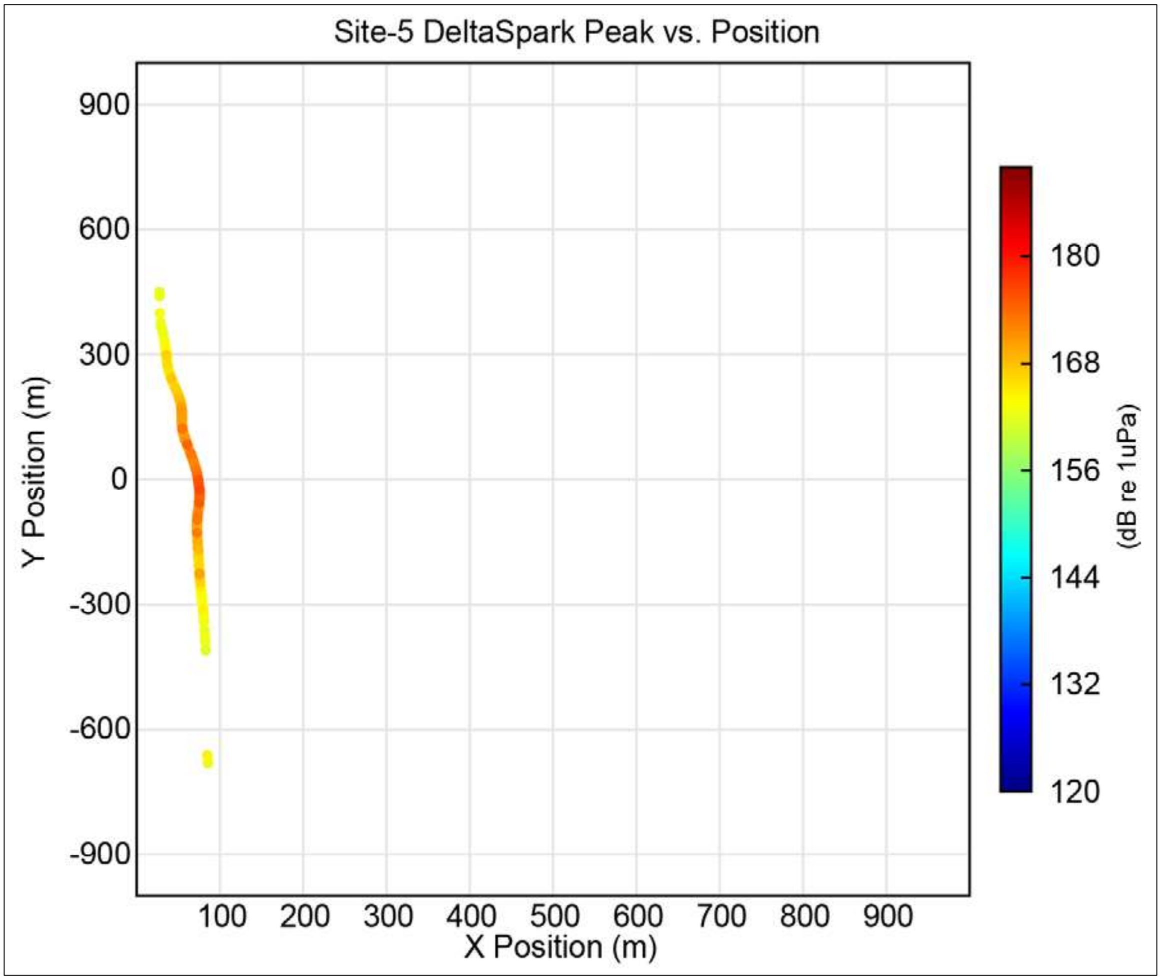


Figure 4.40.5-3. Plan view of received peak level for Delta Sparker, 1.5 kilojoules, at Site 5 for position D (Buoy6).

Table Source Summary

A summary of source specifications from the NUWC report (Crocker and Fratantonio, 2016) and the field measurement results are provided in **Table 4.40.5-1**. The estimated source levels were calculated from the measurements using a cylindrical spreading loss [10 $\log_{10}$ (*range*)] for comparison with the NUWC results.

Table 4.40.5-1. Delta Sparker, 1.5 kilojoules, source levels, Mode 2, at Site 5. Comparison with NUWC tank measurements (From: Crocker and Fratantonio, 2016).

Source Settings					Source Level (dB re 1 µPa m)		
Mode	**Frequency (kHz)**	**Power: J, %, Level**	**Power SL**	**Plates, # guns, inserts**	**Pk**	**rms**	**SEL**
Delta Sparker Mode 1	NA	1.5 kJ	NA	NA	208	180	184
NUWC	NA	1.5 kJ	NA	NA	220	204	183

dB re 1 µPa m = decibels relative to 1 micropascal meter; J = joule; kHz = kilohertz; kJ = kilojoule; NA = not applicable; NUWC = Naval Undersea Warfare Center; Pk = peak source level; rms = root-mean-square source level; SEL = source sound exposure level; SL = source level.

This Page Intentionally Left Blank

4.41 Environmental Acoustic Summary

To evaluate HRG received source levels in a variety of ocean environments, five sites with a combination of different bottom substrates and water depths were chosen at which conduct observations (**Table 2.2-1**). These included two shallow water sites: S1 was mud and 10 m water depth; S2 was sand and 10 m water depth; two intermediate water sites: S3 was mud and 30 m water depth, and S4 was sand and 30 m water depth; and one deep water site: S5 was sandy-silt and 100 m water depth. Unconsolidated (soft) sediments, such as mud, are expected to attenuate acoustic signals such that the signal has a high loss of amplitude, but mud sediments also can be transparent to acoustic energy, allowing deeper consolidated (hard) sediment layers to reflect the sound back into the water column. For the deep water site (S5), the water depth and the temperature-driven sound speed are expected to play a major role in increasing propagation such that the acoustic signals travel much farther with a high fidelity compared to shallow water sites.

Acoustic propagation in shallow water is sensitive to not only the bottom conditions (such as the sand and mud types selected for this study) but also to the sound speed profile and surface conditions. At each site, a set of ship-based Conductivity-Temperature-Depth casts were taken to measure the temperature and conductivity (to estimate salinity), and a sound speed profile was generated. The sound speed profile was considerably consistent across sites. A sound speed profile from S3 is shown in **Figure 4.41-1**. The sound speed profile has a strong downward refraction, which is consistent with a warm surface, as would be expected to occur in mid-summer. For sources operating near the surface (applicable to all sources tested in this project), the acoustic energy refracted away from the surface and was driven towards the seafloor. The downward refraction emphasizes the sensitivity of the acoustic propagation to the sediment and can lead to a spreading law that is greater than spherical [$20 \log_{10}$ (*range*)]. During the cruise, the sea-state was less than a Beaufort Sea State of 2; therefore, it is expected that surface roughness will not be a significant influencing factor on propagation. For the first deployment (located at S4), there was no wind and the surface was flat (glassy, Beaufort Sea State of 0).

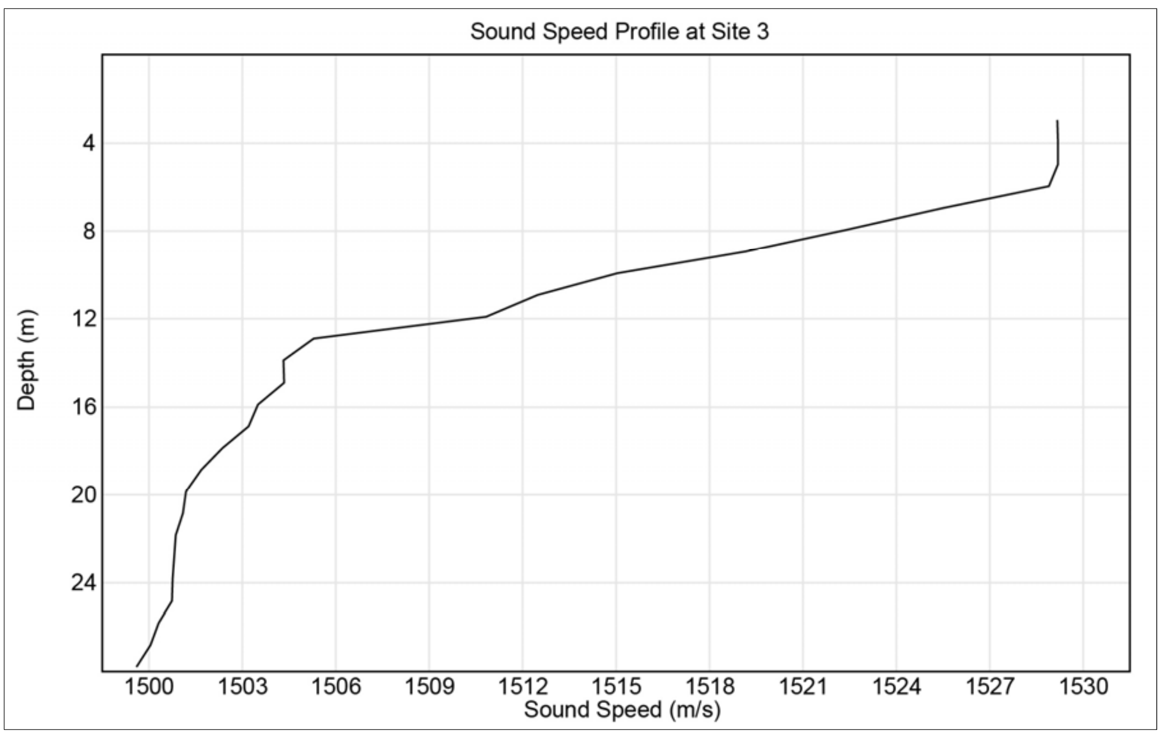


Figure 4.41-1. An example sound speed profile from Site 3.

For each source that had a source level provided in the NUWC report (Crocker and Fratantonio, 2016), the cylindrical [10 $\log_{10}$ (*range*)] and spherical [20 $\log_{10}$ (*range*)] propagation curves were included among the results figures. The modeled propagation curves can be used to estimate the propagation conditions at each site. However, this modeling method is not as accurate for high frequencies, where attenuation by the seawater (i.e., volume attenuation) is an additional mechanism of energy loss, especially when the sources are directional. As described in **Section 4.0,** the estimates of propagation type were used to calculate back to 1 m to determine an estimated source level (SEL, SPL_{pk}, SPL_{rms}) based on the received signals at the CPA.

To summarize the data, a table of the estimated source level results at each site is provided in **Table 4.41-1.** As each source has a wide range of signal characteristics, a few basic overarching conclusions based on a comparison of the acoustics at each site are discussed. There are more similarities than differences at the shallow (S1 and S2) and intermediate (S3 and S4) sites. Water depth was the primary environmental influence on signal propagation. Acoustic signal frequency was also a major factor on signal propagation, as expected, due to volume attenuation. A comparison of the ET512i source (**Section 4.21**) received signals across all five sites is shown in **Figure 4.41-2**. There are a few obvious issues with calibration (**Section 2.6.3.1**), but the propagation improves going from 10 m water depth (S1 and S2) to 30 m water depth (S3 and S4) to 100 m water depth (S5). For the 10 m and 30 m water depths, the propagation is better over sand (S2 and S4) than mud (S1 and S3). There are instances of the estimate of the source levels at S1 being louder than at S5, which is an indication of data quality and if a simple spreading law is capable of describing propagation accurately. Source level differences like these are best resolved through a modeling study because there are assumptions of the propagation being spherical or cylindrical, and propagation is likely more complex. The source levels reported in **Table 4.41-1** are estimates; more accurate source levels are provided in the NUWC report (Crocker and Fratantonio, 2016).

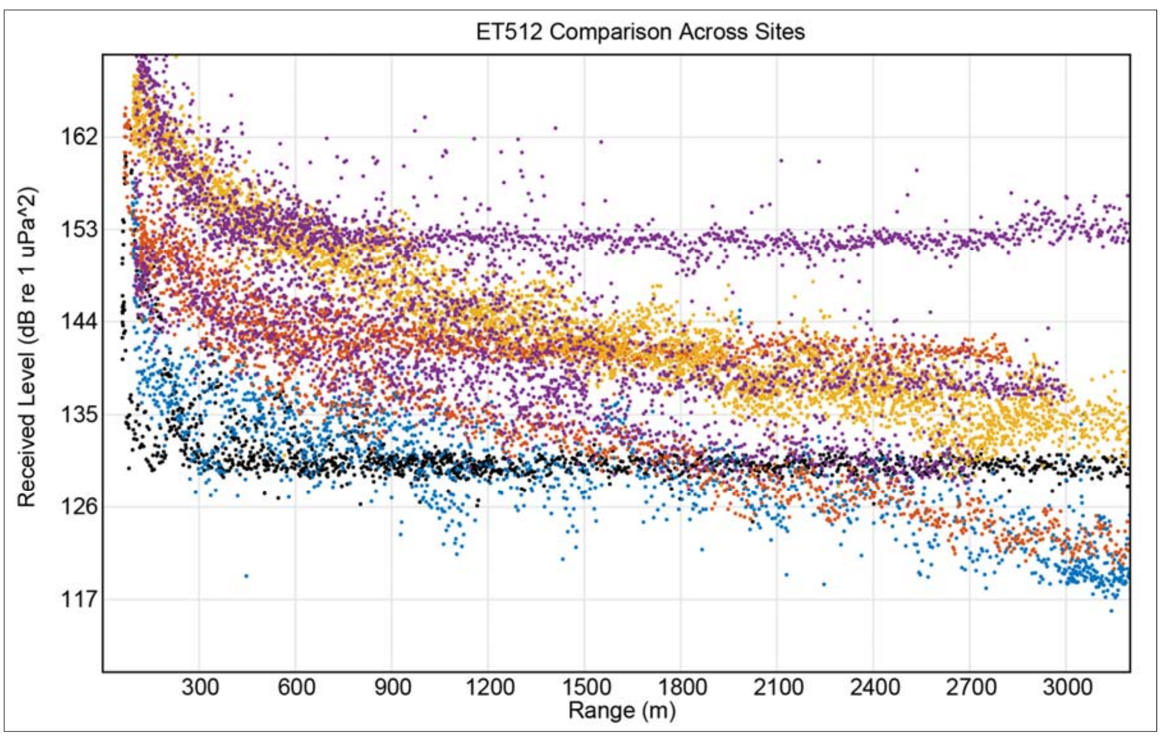


Figure 4.41-2. Comparison of received levels for the EdgeTech 512i, Mode 1, across all five sites. EdgeTech 512i is from Section 4.20. Plotted received signals are from positions D and B. Site 1 (10 m mud) = black; Site 2 (10 m sand) = blue; Site 3 (30 m mud) = red; Site 4 (30 m sand) =yellow; Site 5 (100 m sandy-silt) = purple.

A direct comparison of results from four omnidirectional sources deployed at all five sites can be made as their acoustic signals interact with the environment in similar manners. The four sources are the ET512i (**Section 4.21**), Knudsen 3260 (**Section 4.23**), 252 S-Boom (**Section 4.26**), and Mini Sparker (**Section 4.28**). The benefit of comparing the received signals versus range across sites is that all signal receptions at the buoy position are included, which provides robustness against errors in buoy navigation and calibration. A brief comparison of the measured propagation for the received peak level versus range across the five sites is provided for two sources: the ET512i, Mode 1 (**Section 4.21**) and Mini Sparker, Mode 1 (**Section 4.28**), in **Figures 4.41-2** and **4.41-3**, respectively (plotted from positions D and B, the two recording positions with the best signal to noise ratio). For the Mini Sparker signals, at S1 (mud), there was more than a 10-dB loss in amplitude than at the sand seafloor (S2) received peak levels, but the acoustic propagation at both sites resembles spherical spreading more than cylindrical. In comparison at 30 m water depth, S3 (mud), and S4 (sand) showed little difference in received peak levels and matched spherical propagation. As expected, the 100 m water depth S5 (sandy-silt) showed notably better propagation than the other four test sites. For the ET512i (Mode 1, **Section 4.21**), the results in 10 m water depth at S1 (mud) and S2 (sand) were similar. For the 30 m water depth, S3 (sand) had better propagation than S4 (mud), which was expected. The 100 m water depth, S5 (sandy-silt), had much better propagation than the other test sites, and most closely approximated cylindrical spreading, which was expected.

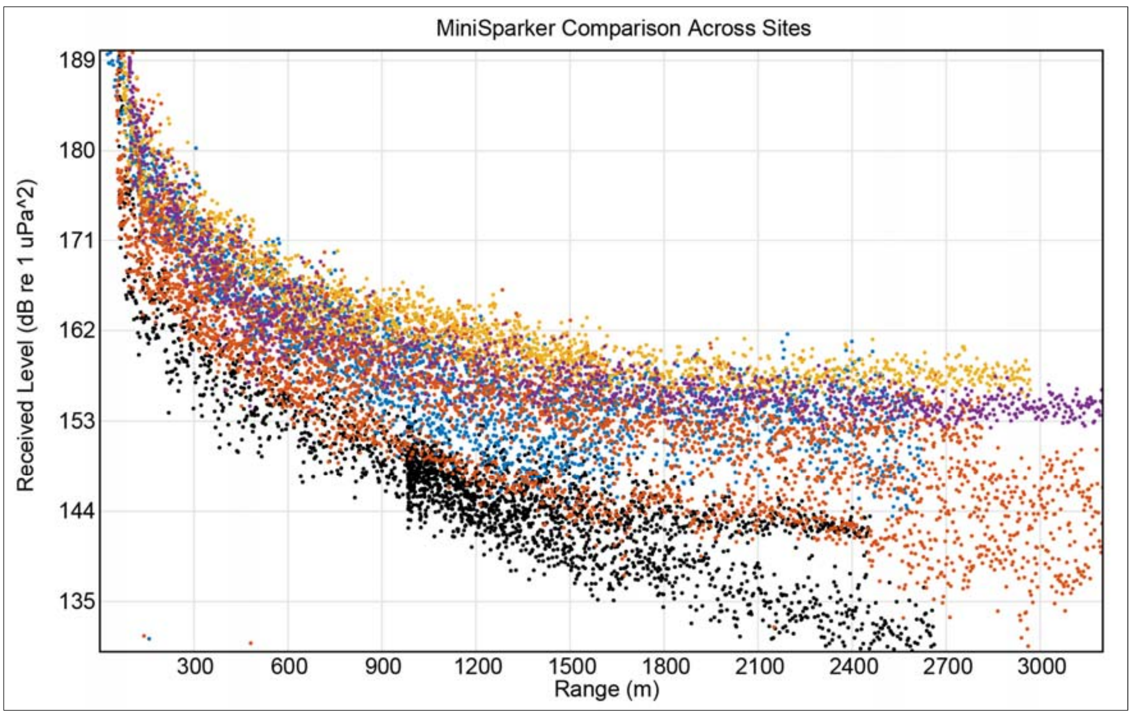


Figure 4.41-3. Comparison of received levels for the Mini Sparker, Mode 1, across all five sites. EdgeTech 512i is from Section 4.20. Plotted received signals are from positions D and B. Site 1 (10 m mud) = black; Site 2 (10 m sand) = blue; Site 3 (30 m mud) = red; Site 4 (30 m sand) =yellow; Site 5 (100 m sandy-silt) = purple.

For **Table 4.41-1**, there were several reasons for a cell to be void of data, and these details are captured in the table. Reasons a cell may not contain data include the following: if the source was not operated at a site; the source had technical issues; the source signal was too weak to be captured; and recording equipment issues. The propagation model used to calculate an estimated source level metric back to 1 m is listed in the table: cylindrical (10 log r) or spherical (20 log r) spreading. Each source has a specific set of adjustable parameters, and parameters that were not relevant to the specific sources are indicated by a dash.

Table 4.41-1. Estimated source levels for each high-resolution geophysical sound source at each test site. Read this Memorandum prior to using this table.

Source Settings									Site 1 (10 m, mud)				Site 2 (10 m, sand)				Site 3 (30 m, mud)				Site 4 (30 m, sand)				Site 5 (100 m, sandy-silt)			
Ch. 4.x	Source	Mode	Freq. (kHz)	Power: Setting, J, %	Power, SL	Plates, Guns, Inserts	Pulse Width, Cycles	Beam Width, Range	Prop. Model	SL Pk	SL rms	SL SEL	Prop. Model	SL Pk	SL rms	SL SEL	Prop. Model	SL Pk	SL rms	SL SEL	Prop. Model	SL Pk	SL rms	SL SEL	Prop. Model	SL Pk	SL rms	SL SEL
1	Reson 7125	1	200	100%	220 dB	-	300 µs	-	20 log r	223	209	186	20 log r	229	211	203	20 log r	228	216	186	20 log r	222	194	172	20 log r	203	180	165
2	Reson 7125	2	200	50%	190 dB	-	300 µs	-	NA	Weak Signal			NA	Weak Signal			NA	Weak Signal			NA	Weak Signal			NA	Weak Signal		
3	Reson 7111	1	100	-	200 dB	-	0.17 ms	1.5°	NA	Source Not Operated			NA	Source Not Operated			20 log r	198	193	158	20 log r	202	190	165	20 log r	200	187	167
4	Reson 7111	2	100	-	200 dB	-	0.17 ms	3°	NA	Source Not Operated			NA	Source Not Operated			20 log r	196	193	164	20 log r	198	182	164	20 log r	197	189	169
5	Klein 3000	1	132	-	-	-	50 µs	400-m range	20 log r	220	214	176	20 log r	223	217	180	20 log r	210	200	166	NA	Weak Signal			NA	Source Not Operated		
6	Klein 3000	2	132	-	-	-	200 µs	200-m range	20 log r	200	185	165	20 log r	225	215	165	20 log r	218	211	172	NA	Weak Signal			NA	Source Not Operated		
7	EdgeTech 4200	1	100	100%	-	-	-	50-m range	20 log r	196	188	163	20 log r	192	184	162	NA	Weak Signal			NA	Recording Equip. Issues			NA	Source Not Operated		
8	EdgeTech 4200	2	100	100%	-	-	-	100-m range	20 log r	194	189	164	20 log r	197	190	168	20 log r	187	179	157	NA	Recording Equip. Issues			NA	Source Not Operated		
9	SwathPlus	1	234	100%	-	-	12 cycles	-	20 log r	209	192	171	20 log r	214	196	178	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated		
10	SwathPlus	2	234	100%	-	-	60 cycles	-	NA	Source Not Operated			20 log r	206	212	184	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated		
11	SwathPlus	3	234	100%	-	-	50 cycles	-	NA	Source Not Operated			20 log r	199	183	164	20 log r	226	195	184	NA	Weak Signal			NA	Source Not Operated		
12	SwathPlus	4	234	100%	-	-	250 cycles	-	NA	Source Not Operated			NA	Source Not Operated			20 log r	216	203	173	20 log r	203	193	166	NA	Source Not Operated		
13	EK60	1	38	100%	-	-	512 µs	-	NA	Source Not Operated			NA	Source Not Operated			20 log r	190	174	158	20 log r	195	179	165	10 log r	198	186	162
14	EK60	2	38	100%	-	-	1,024 µs	-	NA	Source Not Operated			NA	Source Not Operated			20 log r	196	183	165	20 log r	196	178	166	NA	Source Not Operated		
15	EK60	3	38	50%	-	-	512 µs	-	NA	Source Not Operated			NA	Source Not Operated			20 log r	195	186	170	20 log r	196	179	166	10 log r	192	181	157
16	ET424 3100P	1	4-24	100%	-	-	10 ms	-	20 log r	189	187	164	20 log r	202	192	173	20 log r	170	155	141	20 log r	172	156	145	NA	Source Not Operated		
17	ET424 3100P	2	4-24	100%	-	-	1 ms	-	NA	Source Not Operated			20 log r	173	158	143	20 log r	169	148	134	20 log r	173	158	145	NA	Source Not Operated		
18	ET424 3200XS	1	4-24	100%	-	-	10 ms	-	20 log r	198	193	169	20 log r	209	204	182	20 log r	179	165	144	NA	Weak Signal			NA	Source Not Operated		
19	ET424 3200XS	2	4-24	100%	-	-	1 ms	-	20 log r	199	192	163	20 log r	205	191	165	NA	Recording Equip. Issues			20 log r	173	157	144	NA	Source Not Operated		
20	ET512i	1	0.5-7.2	100%	-	-	30 ms	-	20 log r	199	197	171	20 log r	188	180	162	20 log r	187	177	159	20 log r	184	175	162	10 log r	189	184	172
21	ET512i	2	2-12	100%	-	-	20 ms	-	20 log r	198	192	174	20 log r	194	186	168	20 log r	184	176	160	20 log r	188	175	159	NA	Weak Signal		
22	ET512i	3	0.5-8	100%	-	-	5 ms	-	NA	Source Not Operated			20 log r	178	165	149	20 log r	183	174	159	20 log r	190	175	162	10 log r	184	168	152
23	Knudsen3260	1	-	Level 1	-	-	8 ms	-	20 log r	204	202	176	20 log r	203	201	181	20 log r	202	188	172	20 log r	204	196	177	20 log r	201	198	179
24	Knudsen3260	2	-	Level 4	-	-	32 ms	-	20 log r	213	210	191	20 log r	214	211	191	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated		
25	Knudsen3260	3	-	Level 4	-	-	64 ms	-	NA	Source Not Operated			20 log r	211	205	190	20 log r	215	210	192	20 log r	213	205	191	10 log r	215	211	192
26	252 S-Boom	1	0.1-5	1000 J	Low Power	3 Plates	-	-	20 log r	207	197	176	20 log r	207	198	176	20 log r	207	192	174	20 log r	213	197	185	20 log r	214	190	182
27	252 S-Boom	2	0.1-5	200 J	Low Power	1 Plate	-	-	NA	Source Not Operated			20 log r	203	188	167	20 log r	200	182	169	20 log r	200	194	174	20 log r	201	179	174
28	Mini Sparker	1.0	-	700 J	Low Power	-	-	-	NA	Source Not Operated			20 log r	218	204	190	20 log r	220	205	191	NA	Source Not Operated			20 log r	222	192	200
28	Mini Sparker	1.1	-	700 J	High Power	-			NA	Source Not Operated			20 log r	217	207	192	20 log r	210	197	184	NA	Weak Signal			NA	Source Not Operated		
28	Mini Sparker	1.2	-	750 J	High Power	-			20 log r	221	209	191	20 log r	213	205	176	NA	Source Not Operated			20 log r	210	186	185	NA	Source Not Operated		
29	Mini Sparker	2	-	500 J	High Power	-	-	-	20 log r	211	200	181	20 log r	210	201	180	20 log r	209	194	182	20 log r	211	196	181	10 log r	205	182	173
30	251 Boomer	1	-	200 J	Low Power	-	-	-	20 log r	210	197	178	20 log r	201	194	173	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated		
31	251 Boomer	2	-	100 J	Low Power	-	-	-	NA	Source Not Operated			20 log r	196	191	168	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated		
32	Bubble Gun	1	-	-	-	2 Plates	-	-	NA	Source Not Operated			20 log r	206	199	177	NA	Technical Source Issues			NA	Recording Equip. Issues			20 log r	203	196	182
33	Bubble Gun	2	-	-	-	1 Plate	-	-	20 log r	203	182	175	20 log r	205	193	171	NA	Technical Source Issues			20 log r	199	187	175	NA	Technical Source Issues		
34	MiniGI-2	1	-	-	-	2 Guns, No Insert	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	226	210	198
35	MiniGI-1	2	-	-	-	1 Gun, No Insert	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	219	208	193
36	MiniGI-1	3	-	-	-	1 Gun, No Insert	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	216	207	191
37	MiniGI-1	4	-	-	-	1 Gun, 15 ci Insert	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	216	207	191
38	MiniGI-1	5	-	-	-	1 Gun, Full 30/30	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	229	218	205
39	Delta Sparker	1	-	2,400 J	Low Power	-	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	204	186	177
40	Delta Sparker	2	-	1,500 J	Low Power	-	-	-	NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			NA	Source Not Operated			10 log r	208	180	184

µs = microsecond; 10 log r = cylindrical spreading; 20 log r = spherical spreading; Ch. = chapter; dB = decibel; dB re 1 µPa m = decibels relative to 1 micropascal meter; Freq. = frequency; J = joule; kHz = kilohertz; kJ = kilojoule; m = meter; ms = millisecond; NA = not applicable; Prop. = propagation; SEL = sound exposure level (in dB re 1µPa^2 s); SL = source level; - = not applicable for reported setting for source.
Note: Table 4.41-1 is formatted to print on an 11” x 17” page.

4.41.1 Isopleth Ranges

One of the primary purposes of this study was to provide field measurements of HRG sources under typical operational parameters at test sites with different environmental conditions. Regulatory managers need science based information to predict potential acoustic impacts on marine life. For marine mammals, the threshold-based acoustic exposure criterion for behavioral disruption is an SPL_{rms} of 160 dB re 1 µPa for impulsive sources (NMFS, 2016). The received levels recorded at the test sites inform the propagation ranges for each source and can be used to validate and improve predictive propagation models that estimate impacts to an environment and the animals within that environment.

After the acoustic data were processed and analyzed, the measurements were used to determine the approximate distances at which the received level for each source was an SPL_{rms} of 160 dB re 1 µPa. **Table 4.41-2** shows the range to the SPL_{rms} 160 dB re 1 µPa isopleth for each HRG source operational mode at the five test sites. The isopleth distance varied based on frequency, depth, and bottom type. The range was less than 200 m for all sources tested, except for the airgun source. Where applicable, the standard deviation (SD) is included and indicates the precision of the estimated range. Some SDs are small (e.g., 1 to 3 m), which indicates there was at least one good signal on one buoy. Some SDs are large (e.g., 367 m), either because there were multiple buoys or a slow decay in the received level. When a source was not deployed at a site, it is indicated with an "SNO" for "source not operated"; when a source was deployed and operational but the signal was not captured because the signal was too weak, it is indicated by "WS" for "weak signal." When a captured signal was less than 160 dB re 1 µPa, range determination is reported as an estimate of "less than a distance" that the signal was captured, indicated by "<" range in meters. In these instances, SD is not applicable. Each source has a specific set of adjustable parameters. Parameters that are not relevant to the specific sources are indicated by a dash.

Table 4.41-2. Calculated isopleth at SPL_{rms} 160 dB re 1 µPa for each high-resolution geophysical sound source at each test site. Read this Memorandum prior to using this table.

Source ID			Source Settings							Isopleth , SPL_{rms} 160 dB re 1 µPa				
Ch. 4.x	Source Name	Mode	Freq. (kHz)	Power (Setting , J, %)	Power, SL	Plates, Guns, Inserts	Pulse Width, Cycles	Beam Width, Range	S1, 10 m Mud Range (m ± SD)	S2, 10 m Sand Range (m ± SD)	S3, 30 m Mud Range (m ± SD)	S4, 30 m Sand Range (m ± SD)	S5, 100 m Sandy-Silt Range (m ± SD)
1	Reson7125	1	200	100%	220 dB	-	300 µs	-	56 ± 1	67 ± 21	94 ± 35	52 ± 1	101 ± 43
2	Reson7125	2	200	50%	190 dB	-	300 µs	-	WS	WS	WS	WS	WS
3	Reson7111	1	100	-	200 dB	-	0.17 ms	1.5°	SNO	SNO	<90	<90	<70
4	Reson7111	2	100	-	200 dB	-	0.17 ms	3°	SNO	SNO	<90	<100	151 ± 50
5	Klein3000	1	132	-	-	-	50 µs	400-m range	50 ± 1	81 ± 28	92 ± 29	<90	SNO
6	Klein3000	2	132	-	-	-	200 µs	200-m range	<50	98 ± 15	103 ± 26	<100	SNO
7	ET4200	1	100	100%	-	-	-	50-m range	<60	<100	WS	REI	SNO
8	ET4200	2	100	100%	-	-	-	100-m range	<50	<30	85 ± 10	REI	SNO
9	SwathPlus	1	234	100%	-	-	12 cycles	-	56 ± 1	57 ± 26	SNO	SNO	SNO
10	SwathPlus	2	234	100%	-	-	60 cycles	-	SNO	68 ± 26	SNO	SNO	SNO
11	SwathPlus	3	234	100%	-	-	50 cycles	-	SNO	<115	115 ± 21	WS	SNO
12	SwathPlus	4	234	100%	-	-	250 cycles	-	SNO	SNO	107 ± 17	43 ± 1	SNO
13	EK60	1	38	100%	-	-	512 µs	-	SNO	SNO	115 ± 20	<110	94 ± 23
14	EK60	2	38	100%	-	-	1,024 µs	-	SNO	SNO	<60	<105	SNO
15	EK60	3	38	50%	-	-	512 µs	-	SNO	SNO	93 ± 1	<80	91 ± 11
16	ET424 3100P	1	4-24	100%	-	-	10 ms	-	65 ± 2.2	14 ± 0.5	<55	<60	SNO
17	ET424 3100P	2	4-24	100%	-	-	1 ms	-	SNO	<90	<80	WS	SNO
18	ET424 3200XS	1	4-24	100%	-	-	10 ms	-	66 ± 4	37 ± 17	<60	<55	SNO
19	ET424 3200XS	2	4-24	100%	-	-	1 ms	-	63 ± 2.9	40 ± 15	REI	<55	SNO
20	ET512i	1	0.5-7.2	100%	-	-	30 ms	-	83 ± 9.1	<90	97 ± 22	152 ± 44	86 ± 25
21	ET512i	2	2-12	100%	-	-	20 ms	-	69 ± 4.8	26 ± 11.6	83 ± 1	132 ± 30	<115
22	ET512i	3	0.5-8	100%	-	-	5 ms	-	SNO	30 ± 16	83 ± 1	<90	45 ± 10
23	Knudsen3260	1	-	Level 1	-	-	8 ms	-	69 ± 4.5	55 ± 33	<85	<90	45 ± 10
24	Knudsen3260	2	-	Level 4	-	-	32 ms	-	69 ± 6.7	117 ± 48	SNO	SNO	SNO
25	Knudsen3260	3	-	Level 4	-	-	64 ms	-	SNO	102 ± 44	118 ± 43	157 ± 39	70 ± 20
26	252 S-Boom	1	0.1-5	1000 J	Low Power	3 Plates	-	-	71 ± 8	62 ± 40	118 ± 37	170 ± 50	<70
27	252 S-Boom	2	0.1-5	200 J	Low Power	1 Plate	-	-	SNO	23 ± 3.1	<85	156 ± 34	<85
28	Mini Sparker	1.0	-	700 J	Low Power	-	-	-	SNO	338 ± 121	300 ± 142	SNO	92 ± 20

Table 4.41-2. **Calculated isopleth at SPL_{rms} 160 dB re 1 µPa for each high-resolution geophysical sound source at each test site (Continued). Read this Memorandum prior to using this table.**

Source ID			Source Settings						Isopleth , SPL_{rms} 160 dB re 1 µPa				
Ch. 4.x	Source Name	Mode	Freq. (kHz)	Power (Setting, J, %)	Power, SL	Plates, Guns, Inserts	Pulse Width, Cycles	Beam Width, Range	S1, 10 m Mud Range (m ± SD)	S2, 10 m Sand Range (m ± SD)	S3, 30 m Mud Range (m ± SD)	S4, 30 m Sand Range (m ± SD)	S5, 100 m Sandy-Silt Range (m ± SD)
28	Mini Sparker	1.1	-	700 J	High Power	-			SNO	338 ± 121	248 ± 161	WS	SNO
28	Mini Sparker	1.2	-	750 J	High Power	-			147 ± 52	213 ± 168	SNO	194 ± 104	SNO
29	Mini Sparker	2	-	500 J	High Power	-	-	-	122 ± 31	148 ± 70	138 ± 65	156 ± 60	169 ± 46
30	251 Boomer	1	-	200 J	Low Power	-	-	-	53 ± 2.3	50 ± 13	SNO	SNO	SNO
31	251 Boomer	2	-	100 J	Low Power	-	-	-	SNO	65 ± 8.5	SNO	SNO	SNO
32	Bubble Gun	1	-	-	-	2 Plates	-	-	SNO	49 ± 13.3	196 ± 102	REI	<80
33	Bubble Gun	2	-	-	-	1 Plate	-	-	<43	72 ± 4	TSI	<55	TSI
34	MiniGI-2	1	-	-	-	2 Guns, No Insert	-	-	SNO	SNO	SNO	SNO	270 ± 112
35	MiniGI-1	2	-	-	-	1 Gun, No Insert	-	-	SNO	SNO	SNO	SNO	273 ± 50
36	MiniGI-1	3	-	-	-	1 Gun, No Insert	-	-	SNO	SNO	SNO	SNO	273 ± 100
37	MiniGI-1	4	-	-	-	1 Gun, 15 ci Insert	-	-	SNO	SNO	SNO	SNO	285 ± 134
38	MiniGI-1	5	-	-	-	1 Gun, Full 30/30	-	-	SNO	SNO	SNO	SNO	945 ± 367
39	Delta Sparker	1	-	2,400 J	Low Power	-	-	-	SNO	SNO	SNO	SNO	273 ± 131
40	Delta Sparker	2	-	1,500 J	Low Power	-	-	-	SNO	SNO	SNO	SNO	<73

µs = microsecond; Ch. = chapter; dB = decibel; dB re 1 µPa = decibels relative to 1 micropascal; Freq. = frequency; J= joule; kHz = kilohertz; kJ = kilojoule; m = meter; ms = millisecond; REI = recording equipment issues, no signals captured; SD = standard deviation; SL = source level; SNO = source not operated; TSI = technical source issues; WS = weak signal; < # = received signal level was less than 160 dB; - = not applicable or reported setting for source.

4.41.2 Harmonics

Some sources generate significant levels of energy outside of the main operating band. These can be either harmonics, which are multiples of the fundamental frequencies, or sidebands, which are a result of energy leaking into adjacent spectral bands. This project focused on three acoustic metrics (SEL, SPL_{pk}, SPL_{rms}), and the processing band was specifically chosen to be the smallest band around the acoustic center frequency that produced a broadband peak within 1 dB of the maximum. In other words, the sidebands or harmonics that did not impact the peak level were not included in the acoustic processing. Energy that is out-of-band and is 20 dB or more down from the peak does not affect the computed acoustic metrics. It should be noted, however, that relative to the ambient noise background, there can be energy outside of the main bands. Effort was taken in the power spectral density plots to include a wide enough frequency band to show when a source had sidebands or harmonics.

The following sources have energy in their side bands:

- Reson 7125 (**Sections 4.1** and **4.2**); sidebands are 30 dB down
- Klein 3000 (**Sections 4.5** and **4.6**); sidebands are 20 dB down

The following sources have harmonics:

- Klein 3000 (**Sections 4.5** and **4.6**); possible harmonics.
- ET424 (**Sections 4.15** to **4.19**); possible 1st harmonic at 20 kHz, which is 15 dB down
- Knudsen 3260 (**Sections 4.22** to **4.25**); 3 to 4 harmonics, each harmonic is 10 dB down from the previous.
- Mini Sparker (**Sections 4.28** and **4.29**); possible harmonics.

There was not time to analyze the harmonics further.

5 CONCLUSIONS

Acoustic results from 17 HRG sources and 40 operational modes were captured and analyzed to provide signal characteristics for each source and received levels at varying ranges from the source. Field measurements were taken in the summer of 2016 off the coast of Delaware; data were analyzed from summer 2016 to spring 2018. Due to challenges during field measurements (for details see **Section 2.5.1.1**, **2.6.3.1**, **Appendix B)**, the acoustic data set required more visual and hand processing than anticipated; however, the data set is rich and expansive despite field challenges that affected the data set. Data results can be found in the summary table, **Table 4.41-1**.

A notable finding of this study was the sensitivity of sound propagation to water depth, frequency, and to a lesser extent, seafloor type (in shallow water). Sources that generated low frequencies (<10 kHz) in deep water (100 m) received clear signals at the 5-km range, which were the farthest captured signals. In general, there was slightly better propagation (less loss) over sand than over mud. The effect of seafloor type was less pronounced than the effect of different water depths on propagation. Attenuation by seawater (i.e., volume attenuation), which increases with frequency, led to some of the high-frequency source signals being weakly observed or not observed at 100 m. Sources that generated high frequencies (>50 kHz) displayed directionality, meaning there was a large fall-off of the received level with range, especially when the source/receiver pair was outside of the source's main beam.

Many of the HRG sources radiated sound intensity at harmonics of the transmit frequency; however, none of the sources radiated detectable levels of sound at sub-harmonics. For signals with significant energy in the harmonics, this energy was captured in the results.

The primary objective of this project was to measure the received level for many HRG sources as a function of position in multiple propagation environments. The field measurement was designed to have range and bearing diversity for every source transmission, permitting the evaluation of the 3-dimensional acoustic field. With significant hardware failures at sea, the number of functioning receivers was reduced, and constant maintenance was required to sustain recording buoy functionality. The real-time responses in the field led to a very useful dataset, albeit with fewer recording positions and with less redundancy at each position, resulting in less source/receiver acoustic diversity. The range-bearing dependence was created by the movement of this ship. For almost all operated sources, two to four buoys recorded acoustic data that permitted the evaluation of the received level from these sources at ranges from 50 m to 5 km and at all bearings from closing (0°), through broadside (90°), and through opening (180°). This large dataset, in conjunction with high-fidelity modeling, will lead to a better understanding of the full 3-dimensional field for HRG sources in shallow water (less than 100 m) environments.

This Page Intentionally Left Blank

6 REFERENCES

Ainslie, M. A. 2010. Principles of Sonar Performance Modeling. Springer, 2010. pg 431.

Crocker S.E. and F.F. Fratantonio. 2016. Characteristics of sounds emitted during high-resolution marine geophysical surveys. Naval Undersea Warfare Center Division New Port (NUWC-NPT) Technical Report 12,203. For Bureau of Ocean Energy Management (BOEM), Environmental assessment division and United States Geological Survey (USGS). 259 pp.

CSA Ocean Sciences Inc (CSA). 2016. Field sampling test plan. Propagation characteristics of high-resolution geophysical surveys: open water testing. Contract M15PC00011. For BOEM, division of environmental assessment. 32 pp.

International Organization for Standardization (ISO). 2017. ISO 18405 Underwater Acoustics – Terminology. International Organization for Standardization, Geneva, Switzerland. 62 pp.

National Marine Fisheries Service (NMFS). 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service Technical Memorandum OPR-55. 178 pp.

This Page Intentionally Left Blank

APPENDICES

This Page Intentionally Left Blank

Appendix A

Capstone Report

This Page Intentionally Left Blank

Capstone: Summary of Equipment and Data Deliverable for Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing

Contract M15PC00011

Vessel: R/V *Hugh R. Sharp*
Survey Start: 27 June 2016
Survey End: 15 July 2016
Port of Mobilization and Deployment: Lewes, Delaware
CSA Document Reference: CSA-BSEE-FL-17-1881-2921-05-QAC-01-VER02

R/V *Hugh R. Sharp.* Photo courtesy of University of Delaware.

Prepared for:	Prepared by:
BOEM Bureau of Ocean Energy Management **U.S. Department of Interior** **Bureau of Ocean Energy Management** Division of Environmental Assessment 45600 Woodland Road, Mailstop VAM-OEP Sterling, Virginia 20166 Telephone: (703) 787-1742	CSA Ocean Sciences Inc. **CSA Ocean Sciences Inc**. 8502 SW Kansas Avenue Stuart, Florida 34997 Telephone: (772) 219-3000

Data Processing and QA/QC Report
Propagation Characteristics of High-Resolution Geophysical Surveys:
Open Water Testing
R/V *Hugh R. Sharp*

CSA DOCUMENT NO. CSA-BSEE-FL-18-1881-2921-05-QAC-01-VER04

Version	Date	Description	Prepared by:	Reviewed by:	Approved by:
01	03/23/17	Initial draft for review	A. Pittman	M.J. Barkaszi	M. Halvorsen
02	03/29/17	Post draft review	A. Pittman/ R. Cady	N. Kraft	M. Halvorsen
03	05/02/18	Revisions	M. Halvorsen	n/a	M. Halvorsen
04	09/21/18	Final Revisions	K. Jones	n/a	M. Halvorsen

The electronic PDF version of this document is the Controlled Master Copy at all times. A printed copy is considered to be uncontrolled and it is the holder's responsibility to ensure that they have the current version. Controlled copies are available upon request from the Document Production Department

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

This Page Intentionally Left Blank

LIST OF ACRONYMS AND ABBREVIATIONS

BOEM	Bureau of Ocean Energy Management
COC	chain-of-custody
CSA	CSA Ocean Sciences Inc.
CTD	conductivity, temperature, and depth
DGPS	differential global positioning system
HRG	high-resolution geophysical
m	meters
NOAA	National Oceanic and Atmospheric Administration
OASIS	Ocean Acoustical Services and Instrumentation Systems
QA	Quality Assurance
R/V	research vessel
Seiche	Seiche Ltd.
TB	terabyte
USGS	U.S. Geological Survey

This Page Intentionally Left Blank

1. OVERVIEW

The Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) acknowledge a need for field measurements of high-resolution geophysical (HRG) sources operating in shallow water to better predict the resulting sound exposure levels received by marine life. CSA Ocean Sciences Inc. (CSA) was retained by BOEM under the project 'Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing'. The goal of the project is to measure the three-dimensional (3D) sound fields produced by approximately 17 underwater acoustic sources commonly used in HRG surveys and to document the sound propagation from each source in shallow-water environments.

The research vessel (R/V) *Hugh R. Sharp* was mobilized on 27 and 28 June 2016 in Lewes, Delaware. The offshore survey was conducted in two legs: 29 June through 7 July, and 8 through 15 July. Testing took place at five test locations along the U.S. Atlantic Coast (**Figure A-1**). During this project, CSA worked cooperatively with the U.S. Geological Survey (USGS), Ocean Acoustical Services and Instrumentation Systems (OASIS), Seiche Ltd. (Seiche), Hydro dB, and Noise Control Engineering (NCE).

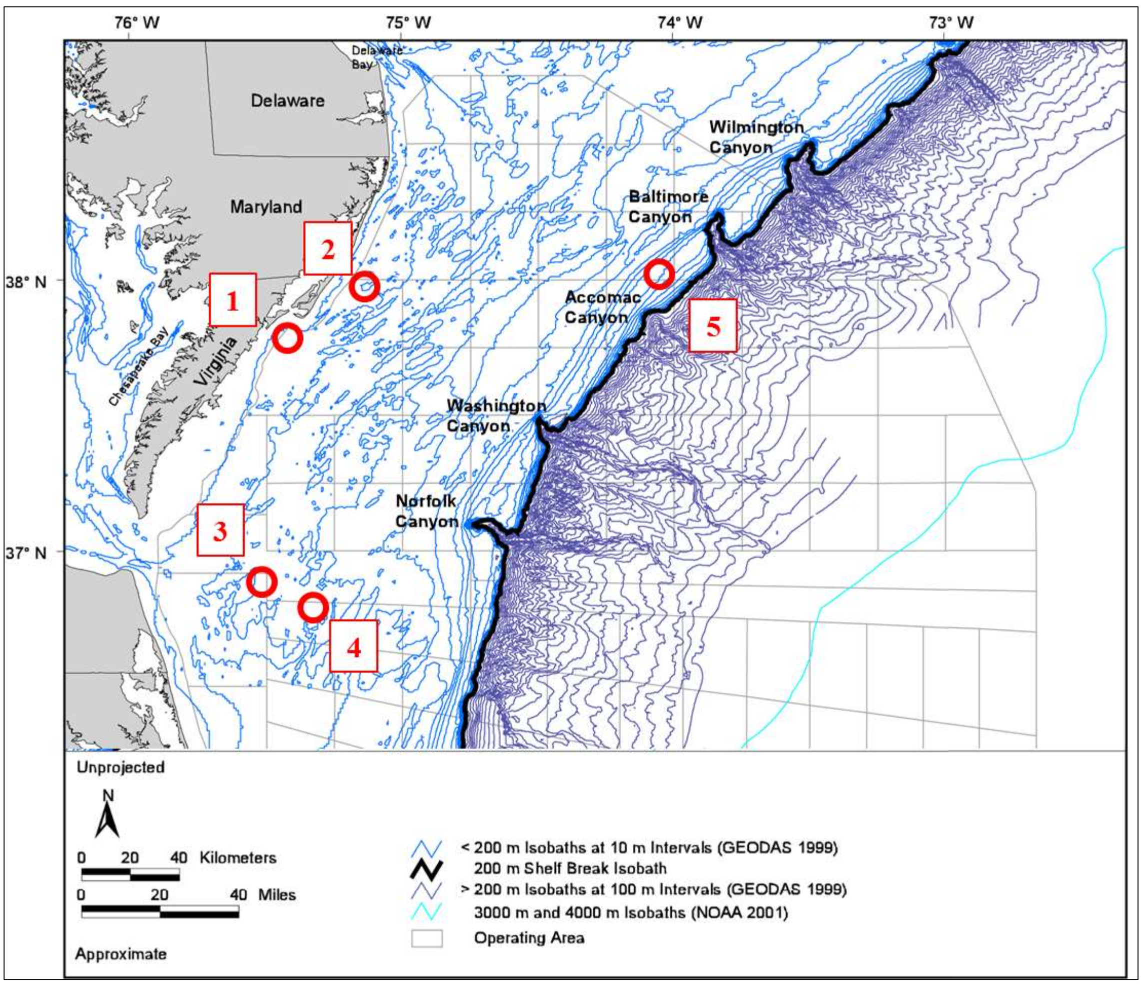


Figure A-1. Map of the five test locations for data collection during the field survey as part of the Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing.

The contracted study (Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing) collectively describes the acoustic measurements and analyses that resulted from the field data collection program. This appendix serves to summarize survey equipment and describe (and accompany) the processed data set and associated metadata (approximately 27 terabytes [TB]) as part of BOEM Contract M15PC00011. This survey generated approximately 8.52 TB of raw acoustic data. The acoustic data set will be used to support a separate investigation focused on the validation and improvement of predicative propagation modeling of the tested sources. A summary of survey equipment is provided in **Section 2.0**, and the data deliverable is described in **Section 3.0**.

2. EQUIPMENT SUMMARY

An overview of the equipment used during the contracted study is shown in **Figure A-2**. Arrows indicate the flow of data acquisition from the equipment to data archives for analysis.

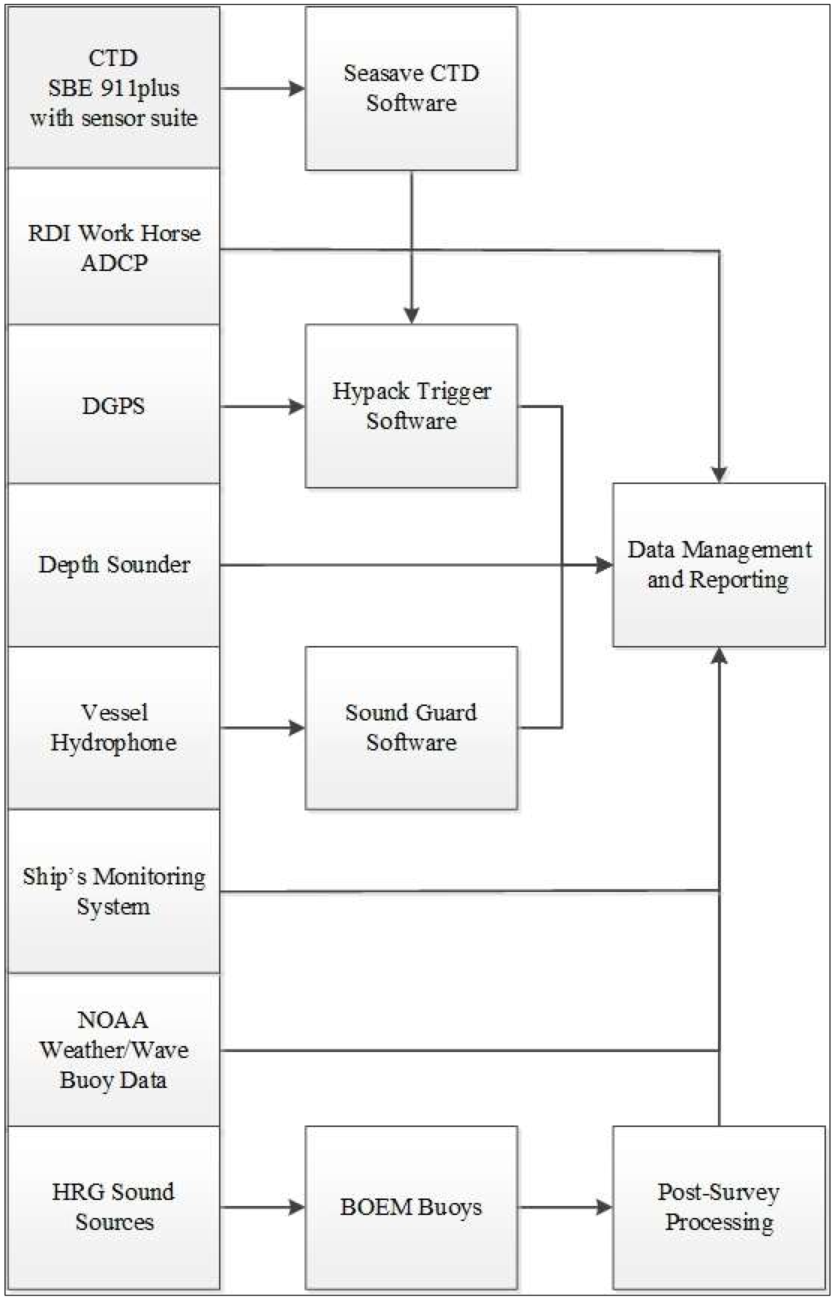


Figure A-2. Data acquisition flow for equipment from the R/V *Hugh R. Sharp* during the study, Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing.
Legend: ADCP = acoustic Doppler current profiler; BOEM = Bureau of Ocean Energy Management; CTD = conductivity, temperature, and depth; DGPS = differential global positioning system; NOAA = National Oceanic and Atmospheric Administration; RDI = Teledyne RD Instruments; SBE = Sea-Bird Electronics.

The HRG sources for this study can be grouped into four main categories: side-scan sonars, multibeam echosounders, seismic sources (e.g., boomer, sparker, airgun), and sub-bottom profilers. **Tables A-1** and **A-2** provide an account of the HRG sources used during the survey at each site and the corresponding dates of testing. The top portion of the table provides the dates of testing at each site. HRG sources often were tested more than once at a site; this is designated by deployment #1, 2, or 3. The site number and water depth at each site are provided as well.

Table A-1. High-resolution geophysical deployment dates for sound sources that were tested during this study.

HRG Sound Source Deployment	Site 1 10 m Mud	Site 2 10 m Sand	Site 3 30 m Mud	Site 4 30 m Sand	Site 5 100 m Sandy-Silt
Dates of Deployment #1	6-7 July	5-6 July	2 July	29-30 June	9-10 July
Dates of Deployment #2	--	13-14 July	3 July	30 June- 1 July	10-11 July
Dates of Deployment #3	--	--	12-13 July	4 July	11 July

-- = not relevant; HRG = high-resolution geophysical.

Table A-2. High-resolution geophysical sound sources that were tested during this study.

HRG Sound Source	Abbreviated Name	# of Modes Tested	Site 1 10 m Mud	Site 2 10 m Sand	Site 3 30 m Mud	Site 4 30 m Sand	Site 5 100 m Sandy-Silt
Applied Acoustics (AA) Delta Sparker	Delta Sparker	2	No	No	Yes	Yes	Yes
AA 252 S-Boom	S Boom	2	Yes	Yes	Yes	Yes	Yes
AA 251 Boomer (single plate)	Boomer	2	Yes	Yes	Yes	Yes	Yes
Falmouth Scientific, Inc. (FSI) Bubble Gun (dual plate)	Bubble Gun	2	Yes	Yes	Yes	Yes	No
Edgetech (ET) 4200 side-scan	ET4200	2	Yes	Yes	Yes	Yes	No
Edgetech 424 Chirp 3100P side-scan; topside	ET424 3100P	2	Yes	Yes	Yes	Yes	No
Edgetech 424 Chirp 3200XS side-scan; topside	ET424 3200XS	2	Yes	Yes	Yes	Yes	No
Edgetech 512i side-scan	ET512i	3	Yes	Yes	Yes	Yes	Yes
Sercel Mini GI (30/30); one airgun	MiniGI-1	4	No	No	Yes	Yes	Yes
Sercel Mini GI (30/30); two airguns	MiniGI-2	1	No	No	Yes	Yes	Yes
Klein 3000 side-scan	Klein	2	Yes	Yes	Yes	Yes	No
Knudsen 3260 Chirp (Sharp) side-scan	Knudsen 3260	2	Yes	Yes	Yes	Yes	Yes
Reson (R) 7111 multibeam echosounder	R7111	2	No	No	Yes	Yes	Yes
Reson 7125 (Sharp) multibeam echosounder	R7125	2	Yes	Yes	Yes	Yes	Yes
SIG 2 Mini Sparker	Mini Sparker	2	Yes	Yes	Yes	Yes	Yes
Simrad EK60 38 kHz multibeam echosounder	EK60	3	No	Yes	Yes	Yes	Yes
SEA SWATHPlus –interferometric sonar	SwathPlus	4	Yes	Yes	Yes	Yes	No

HRG = high-resolution geophysical; Sharp = sources that were hull-mounted on the R/V *Hugh R. Sharp*; No = sound source was not tested; Yes = sound source was tested.
Survey dates: 28 June to 15 July 2016.

3. DATA DELIVERABLE

3.1. DATA BACKUP PROTOCOL

Field data collected during the study were copied to approximately 12 external hard drives and 1 thumb drive. The copies provided were accompanied by electronic chain-of-custody (COC) forms. An inventory of all files contained within each hard drive was provided with the accompanying data deliverable.

Upon arrival at CSA, the data from each hard drive were copied to a segregated holding area on the CSA network to ensure a viable copy of the data remained in existence should any hard drive fail. Data fields in each primary hard drive were compared with the data of its corresponding hard drive to determine if each data set had the same file names, file types, file sizes, directories, and number of files. Once this quality assurance (QA) procedure was completed and it was determined that the primary and backup copies were exact duplicates, the data on the primary hard drives were copied to a location on the CSA network and protected as “Read-Only”. The data also were backed up to magnetic tape for long-term storage at an off-site location. A copy of the data was placed on two new external hard drives and sent via FedEx to OASIS for analysis. CSA personnel kept one secure copy of the final data deliverable that accompanied this report.

3.2. FIELD SURVEY DOCUMENTS (9.41 GB)

Supporting documents relating to data collection, field activities, and study progress were generated during the study. These documents included two logbooks that were kept by the survey team for the duration of the study’s field effort, NUWC data, trigger data, and relevant emails.

CSA operations personnel maintained a logbook documenting operational activities (also known as events) during the survey. Additionally, the vessel captain maintained a field log that included notes and deviations to the original sampling plan. Each logbook was scanned, and electronic copies were provided with the data deliverable. COC forms tracked possession of the data sets, and project emails provided details of daily events and shore support coordination.

3.2.1. Shipboard Data

R/V *Hugh R. Sharp* personnel collected ancillary data as part of routine operations. Data from an acoustic Doppler current profiler (ADCP); conductivity, temperature, and depth (CTD) casts; the shipboard differential global positioning system (DGPS) and position orientation system; and a ship-based sound monitoring system (SMS) were collected and provided to CSA as baseline information. Global positioning system (GPS) data were used to support the acoustic analysis and source positioning. The rest of the data were not used in the acoustic analysis but were provided to CSA as supplementary reference data and submitted as part of the final data deliverable.

3.2.2 USGS Data

During the survey, navigation data were collected by USGS using Hypack navigational software and a position orientation system DGPS. Navigation data included the Hypack background files, log files, and target files. Navigation data were provided in the data deliverable as native raw format.

The USGS downloaded weather and wave data from buoy Station 44093, which is owned and maintained by the Virginia Department of Mines, Minerals, and Energy, and from buoy Station 44009 in Delaware Bay. The data were found on the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center website. While on site, weather/wave information was retrieved during a storm event. The USGS provided weather and wave data that, although not used as part of the post-processing effort, were submitted as part of the final data deliverable.

3.3. DIGITAL PHOTOGRAPHS (3.12 GB)

Digital photographs were collected by CSA, Seiche, R/V *Hugh R. Sharp*, and USGS personnel. Photographs show the equipment, sea state, operations, and vessel logbook. Representative digital photographs were incorporated into a Photo Documentation Report (Appendix B of the final report). The raw photographs were also submitted as part of the final data deliverable.

3.4. RAW DATA (8.51 TB)

The data collected by each acoustic acquisition buoy were stored on a USB memory stick housed in a Pelican™ Case located on top of the buoy. The acoustic buoys were recovered at the end of each deployment, the memory stick was removed by Seiche personnel, and the data were downloaded twice, once onto an external hard drive and again onto a second external hard drive. The memory sticks then were reformatted (all data erased) and reinstalled into the buoy systems. The data were organized into folders according to site number and subfolders by buoy number. At the conclusion of the survey, all primary and backup hard drives were given to the CSA field lead. All memory sticks were reformatted a final time to ensure no data remained on them. Additional digital survey-related information (e.g., shipboard cruise data, photos, logs, daily operational summaries) was added to the primary and backup hard drives. The two sets of hard drives (primary and backup) were divided between the CSA field team for separation during return travel to the CSA main office in Stuart, Florida. Both the original and backup data sets returned to the main office intact. A description of data backup methods are discussed in **Section 3.1.**

3.5. PROCESSED DATA (17.29 TB)

Oasis formatted the data into a file type that was compatible with their software programs (.ts). CSA followed the same protocol for data backup and storage as outlined in **Section 3.1**.

3.6. FINAL REPORT (640 MB)

A digital version of the final report is included with the report figures on a single 1-TB hard drive. Seven hard copies of the report and 15 DVDs were shipped by FedEx.

Appendix B

Photo Documentation Report

This Page Intentionally Left Blank

Table of Contents

Page

This Page Intentionally Left Blank

LIST OF PHOTOS

LIST OF PHOTOS

1. INTRODUCTION

1.1. STUDY OBJECTIVES

The goal of the Propagation Characteristics of High-Resolution Geophysical Surveys: Open Water Testing study was to accurately measure the sound field produced by 17 underwater acoustic sources commonly used in high-resolution geophysical (HRG) surveys and to document the propagation of sound output from each source in 10, 30, and 100 m water depth.

1.2. PHOTO DOCUMENTATION PURPOSE

This appendix provides photographic documentation of the study's field efforts, including the acoustic HRG sources used. This document does not contain all the digital photos taken during the survey; however, all digital photos will be included on external hard drives that were part of the final deliverable.

2. SURVEY VESSEL

Photo B-1. **Survey vessel, R/V *Hugh R. Sharp*.**
Arriving at port in Lewes, Delaware. Photo source: http://www1.udel.edu/udmessenger/vol21no1/stories/otg-sharp.html.

Photo B-2. **The R/V *Hugh R. Sharp* docked.**
At the University of Delaware shipyard in Lewes, Delaware. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-3. **View of the R/V *Hugh R. Sharp* back deck.**
The winch (foreground) was used to deploy and retrieve field survey equipment. Photo courtesy of CSA Ocean Sciences Inc.

3. SURVEY EQUIPMENT AND HIGH-RESOLUTION GEOPHYSICAL SOURCES

Survey equipment was delivered to the University of Delaware where it was assembled dockside by the CSA Ocean Sciences Inc. team and mobilized onto the R/V *Hugh R. Sharp*.

Photo B-4. Survey equipment on the dock.
Equipment ready to be transferred on board the R/V *Hugh R. Sharp*. Photo courtesy of CSA Ocean Sciences Inc.

3.1. HIGH-RESOLUTION GEOPHYSICAL SOURCES

The following images show the acoustic HRG sources operated during field sampling. Most images are in-field photographs; however, a few images were retrieved from vendor websites since they were for hull mounted instruments or due to poor photo quality.

Photo B-5. Edgetech 512i side-scan sonar.
Views of the front (left) and rear (right). Photos courtesy of U.S. Geological Survey (left) and CSA Ocean Sciences Inc. (right).

Photo B-6. Knudsen 3260 CHIRP side-scan sonar (rackmount case is shown).
A 3.5-kHz 2×2 transducer array (not shown) was mounted into the R/V *Hugh R. Sharp*'s transducer keel, 1 m below the keel bottom. Photo source: https://knudseneng.com/products/chirp_3260.

Photo B-7. Reson 7111 multibeam echosounder.
The transducer was mounted on the R/V *Hugh R. Sharp*'s side-mount pole off the starboard side. Photo source: http://www.teledyne-reson.com/products/echo-sounder-seabat/depth-sounder-seabat-7111/.

Photo B-8. **Applied Acoustics 252 S-Boom.**
Photo source: http://www.appliedacoustics.com/wp-content/uploads/2015/10/S-Boom-Brochure.pdf.

Photo B-9. **Edgetech 4200 side-scan sonar.**
Photo courtesy of U.S. Geological Survey.

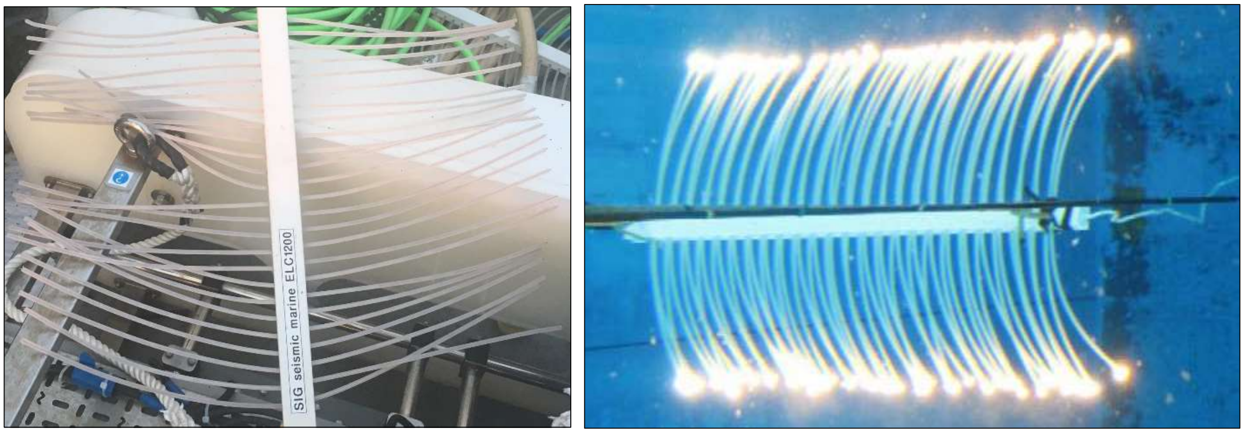


Photo B-10. **SIG 2 Mini-Sparker ELC820.**
On the left is a Mini-Sparker on deck; photo courtesy of CSA Ocean Sciences Inc. On the right is an actively sparking Mini-Sparker; photo source: https://www.marine-seismic-equipments.net/seismic-sources/.

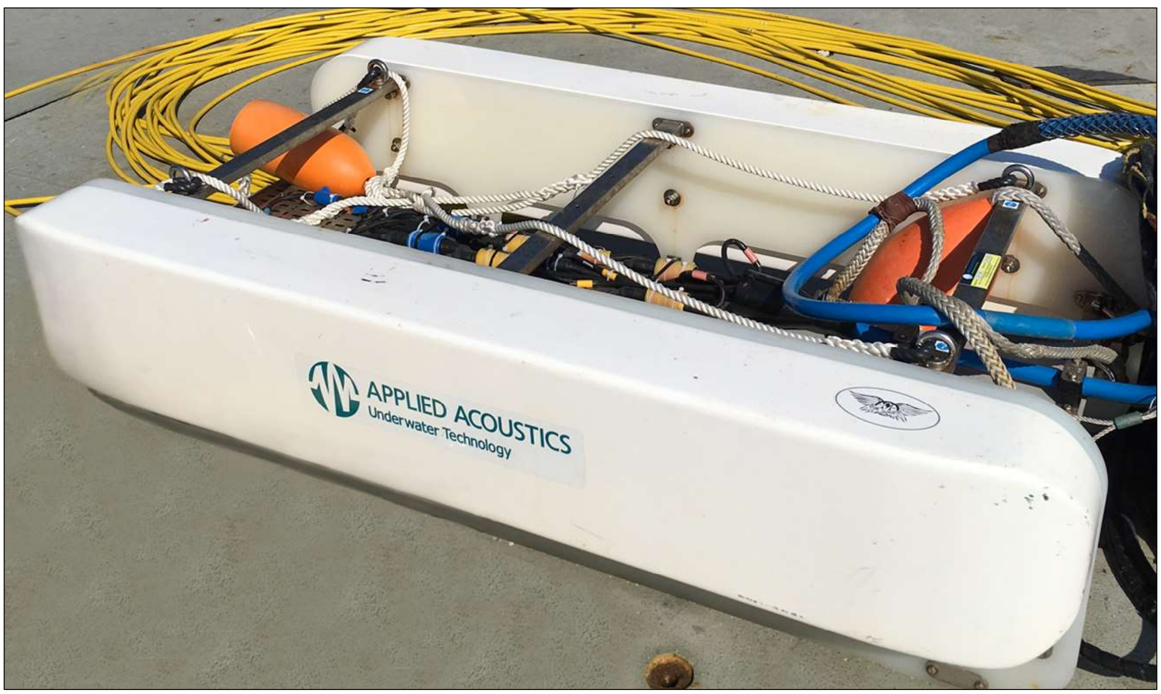


Photo B-11. **Applied Acoustics 251 Boomer (single plate).**
Photo courtesy of U.S. Geological Survey.

Photo B-12. **SEA SWATHPlus Interferometric Sonar.**
The transducers were mounted on the R/V *Hugh R. Sharp*'s side-mount pole on the starboard side. Photo courtesy of U.S. Geological Survey.

Photo B-13. **Edgetech SBP 424 tow vehicle for 3100p and 3200XS CHIRP side-scan sonar.**
These units have three components: a 3100/3200 rack mount processor; an SB-424 tow vehicle (shown), and a tow cable. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-14. **Klein 3000 side-scan sonar.**
Photo courtesy of U.S. Geological Survey.

Photo B-15. **FSI Bubble Gun (dual plate).**
Photo courtesy of CSA Ocean Sciences Inc.

Photo B-16. **Sercel Mini GI.**
The two Mini GI airguns (silver with blue marking) were used in two configurations during the survey: one airgun and two airguns (shown above). Photo courtesy of U.S. Geological Survey.

Photo B-17. **Applied Acoustics Delta Sparker.**
Photo source: http://www.appliedacoustics.com/wp-content/uploads/2015/12/Delta-Sparker.pdf.

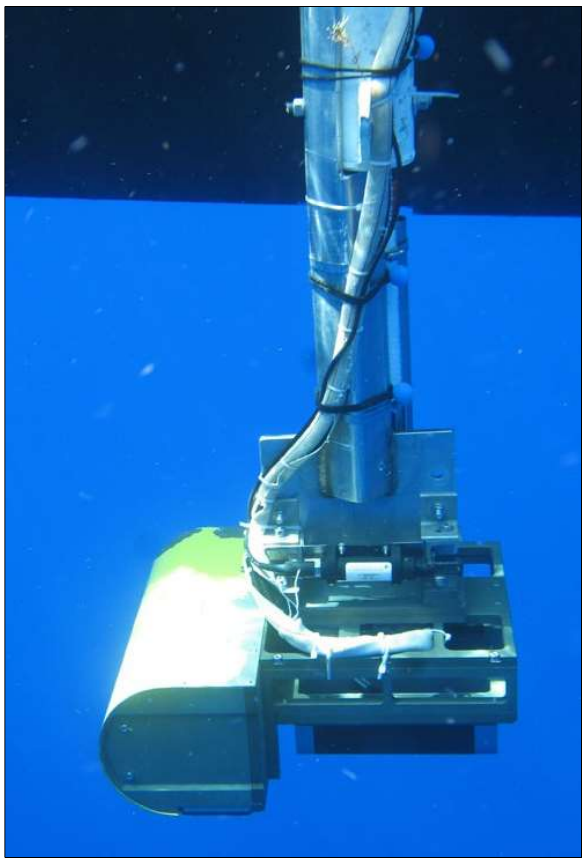


Photo B-18. **Reson 7125 multibeam echosounder (representative photo is not from this survey).**
The transducer array was mounted into the R/V *Hugh R. Sharp*'s transducer keel 1 m below the keel bottom. Photo source: http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/sept19/media/0919_sonar_600.jpg.

Photo B-19. Simrad EK60.
The EK60 transducer (red) was mounted on the R/V *Hugh R. Sharp*'s transducer keel 1 m below the keel bottom. Photo courtesy of U.S. Geological Survey.

3.2. ACOUSTIC ACQUISITION EQUIPMENT

The following images depict the acoustic recording buoys provided by Seiche Ltd.

Photo B-20. Acoustic acquisition buoys.
The large yellow disc provides flotation, and the yellow cylinder integrated with the silver pole is the acoustic data acquisition cylinder. The hydrophone arrays (not shown here) attached to the black connector at the end of the silver pole. Assembly took place on the dock. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-21. Close-up of the acoustic data acquisition cylinder.
The cylinder contained twin acquisition systems consisting of a micro-computer, a data acquisition (DAQ) card, and connectors at each end to integrate with the hydrophone array and control box. Photo courtesy of U.S. Geological Survey.

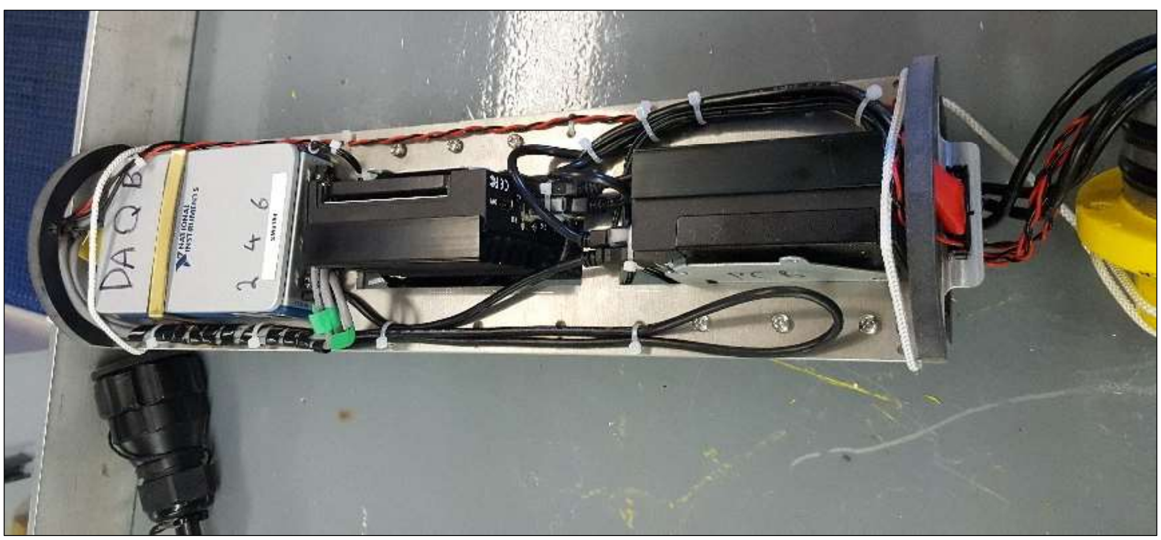


Photo B-22. Internal view of the data acquisition cylinder, showing the twin acquisition systems.
The black boxes are the two micro-computers, the silver boxes are two stacked data acquisition (DAQ) cards, and the connectors at each end of the cylinder are for integration to the hydrophone array (connector at left side of photo) and control box (connector on right side of image). Photo courtesy of CSA Ocean Sciences Inc.

Photo B-23. A control box for the acoustic acquisition buoy.
The control box was mounted on top of the flotation disc and housed the battery, memory, and data connections to the acoustic data acquisition cylinder. The global positioning system (GPS) antenna is the grey puck on the outside of the box. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-24. Interior of a control box for the acoustic acquisition buoy.
The black box is the battery, and the USB data storage device (thumb drive) is on the right. Photo courtesy of CSA Ocean Sciences Inc.

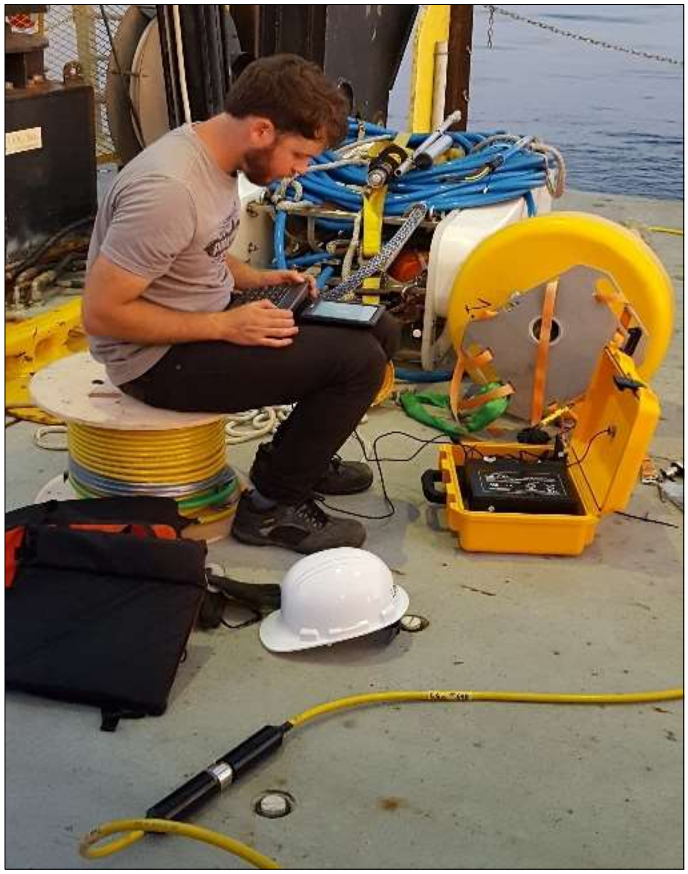


Photo B-25. **Programming acquisition system.**
Seiche Ltd. personnel programing the buoy acquisition system via keyboard and monitor connected through USB ports in the control box. Photo courtesy of CSA Ocean Sciences Inc.

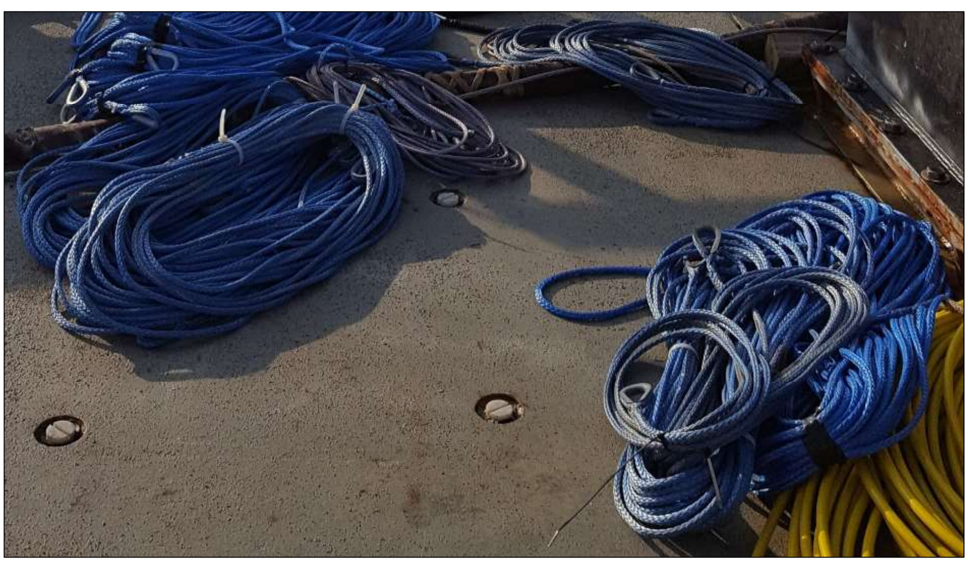
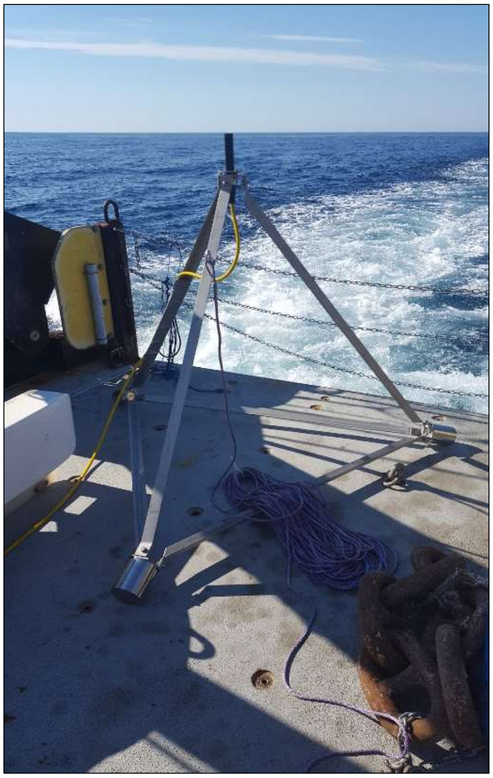


Photo B-26. **High-density polyethylene mooring line coiled on deck prior to a deployment.**
The line served as part of the mooring connecting the anchor to the buoy/float. Photo courtesy of CSA Ocean Sciences Inc.



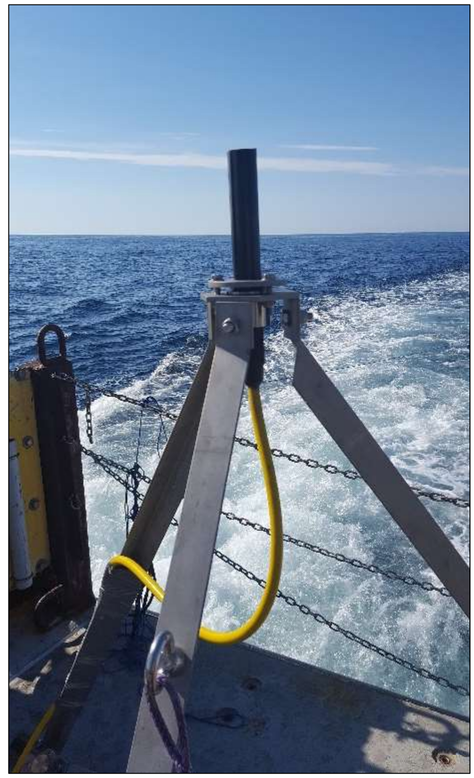


Photo B-27. **The tripod platform placed at position D.**
Position D was placed directly under the vessel track, with the hydrophone (thin black cylinder at tripod apex) and yellow hydrophone cable attached. The mooring and buoy for this hydrophone was placed 50 to 100 m to the side of the vessel track line. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-28. **Yellow hydrophone cable coiled on deck and ready for deployment.**
The 200-m cable was attached to position D (located directly under the vessel track) on a tripod platform. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-29. Anchor chain section served as bottom mooring for the buoys.
Photo courtesy of CSA Ocean Sciences Inc.

3.3. DEPLOYMENT OF ACOUSTIC ACQUISITION EQUIPMENT

The following series of images depicts an example of the acoustic buoy deployment process.

Photo B-30. **Process of acoustic acquisition buoy deployment.**
Anchor chain being deployed by CSA Ocean Sciences Inc. personnel, followed by lift and release of the acoustic acquisition buoy by CSA personnel with the assistance of R/V *Hugh R. Sharp* deck crew. The tripod platform being placed at position D is visible in the lower left corner of the images. The yellow hydrophone cable can be seen in the hand of the crew member on the far left. Photos courtesy of CSA Ocean Sciences Inc.

3.4. Retrieval of Acoustic Acquisition Equipment

The following series of images depicts an example of the acoustic buoy retrieval process.

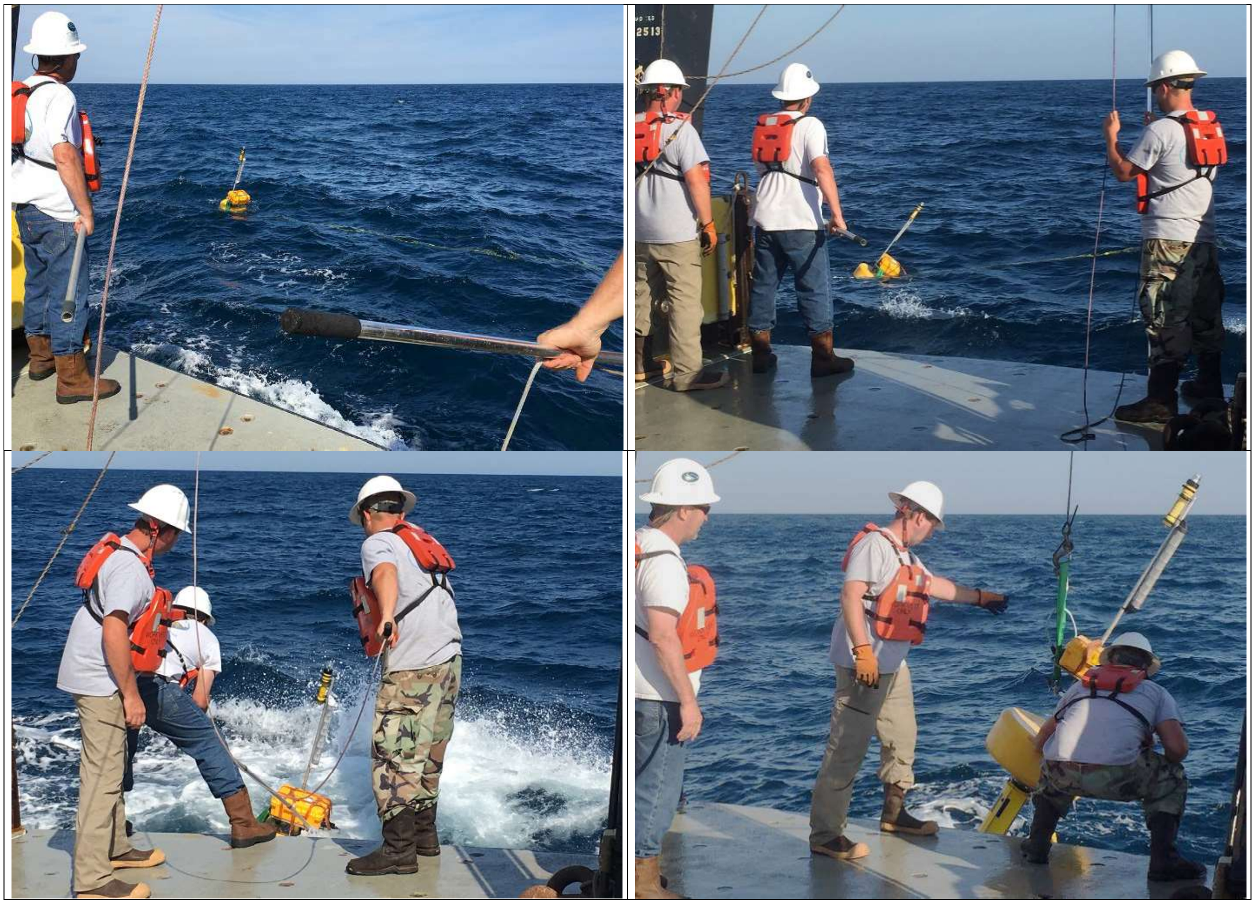


Photo B-31. Retrieval process of an acoustic acquisition buoy.
The R/V *Hugh R. Sharp* backs down on the buoy, and then the buoy is hooked with a long reach (pole) and secured to the winch cable via the green strap. Retrieval was performed by CSA Ocean Sciences Inc. personnel with the assistance of R/V *Hugh R. Sharp* deck crew. Photos courtesy of CSA Ocean Sciences Inc.

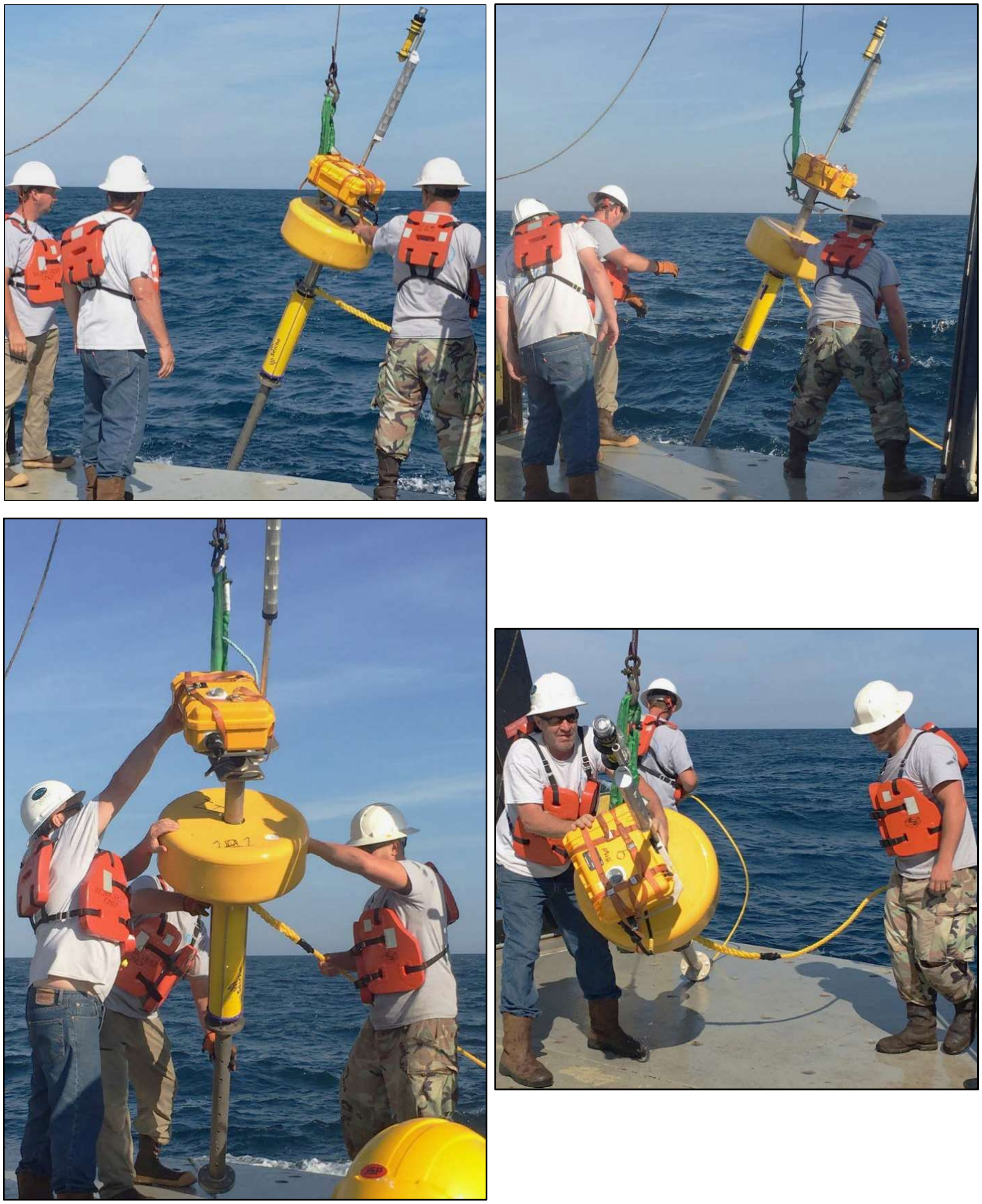


Photo B-32. Retrieval process of an acoustic acquisition buoy (continued).
The buoy is lifted out of the water by the winch, guided on board by personnel, then gently laid down on the deck. Retrieval was performed by CSA Ocean Sciences Inc. personnel with the assistance of R/V *Hugh R. Sharp* deck crew. Photos courtesy of CSA Ocean Sciences Inc.

4. OPERATIONS

4.1. HIGH-RESOLUTION GEOPHYSICAL SOURCE DEPLOYMENTS

The following images show a few of the HRG sources in various states of deployment and active ensonification.

Photo B-33. Retrieval of the Edgetech 4200 (between two personnel).
Photo courtesy of CSA Ocean Sciences Inc.

Photo B-34. The compressor provided compressed air for the airguns.
The primary compressor control panel is shown at the top of the photo. The secondary/backup compressor shown in the red frame at the bottom of the photo, and the compressed air storage tanks (yellow) contained compressed air prior to delivery to the airguns. Photo courtesy of U.S. Geological Survey.

Photo B-35. Photos of the Mini GI airguns and associated red floats.
Top left, the floats and airgun system ready for deployment. Top right, the active Mini GI airguns in the water. Bottom, the surface bubbles around the floats resulting from airgun pulses. Photos courtesy of CSA Ocean Sciences Inc.

Photo B-36. Photo of the Applied Acoustics 251 Boomer (white pontoon) just under water surface.
Photo courtesy of CSA Ocean Sciences Inc.

Photo B-37. Photo of the SIG 2 Mini-Sparker (white pole with fringe, which are the electrodes) in preparation for deployment.
Photos courtesy of CSA Ocean Sciences Inc.

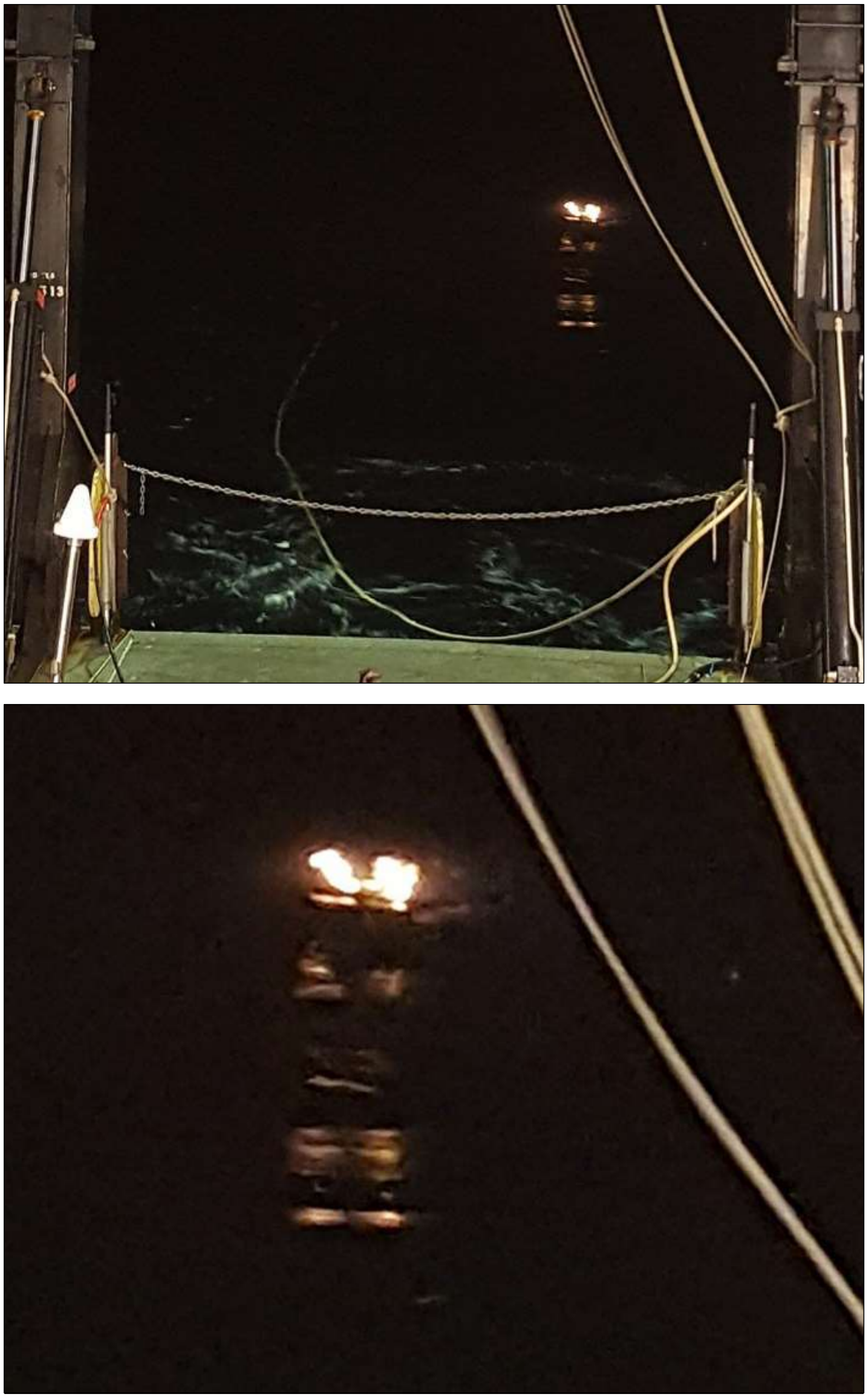


Photo B-38. The SIG 2 Mini-Sparker.
Top is Mini-Sparker during an active sparking event. Bottom is zoomed in on active sparking. Photos courtesy of CSA Ocean Sciences Inc.

5. TECHNICAL CHALLENGES

Ultimately, the survey collected a rich acoustic data set; however, technical issues were encountered during the field activities that affected the collection of a complete data set. Primarily, the acoustic acquisition buoys did not have sufficient positive buoyancy to keep the heavy control boxes from submerging. Furthermore, poor seals on the control boxes allowed water intrusion that negatively impacted the electronics. The main solutions were to waterproof the control boxes and employ a Norwegian float system.

Photo B-39. Photo of an acoustic buoy in calm waters.
The yellow float (disc) should be resting higher above the water line; this image shows lack of positive buoyancy with too much of the float below the water line. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-40. Close-up of internal components of a control box.
Top shows water intrusion on the USB hub, which resulted in failure to record data. Bottom image shows the USB hub melted from saltwater intrusion. Photos courtesy of CSA Ocean Sciences Inc.

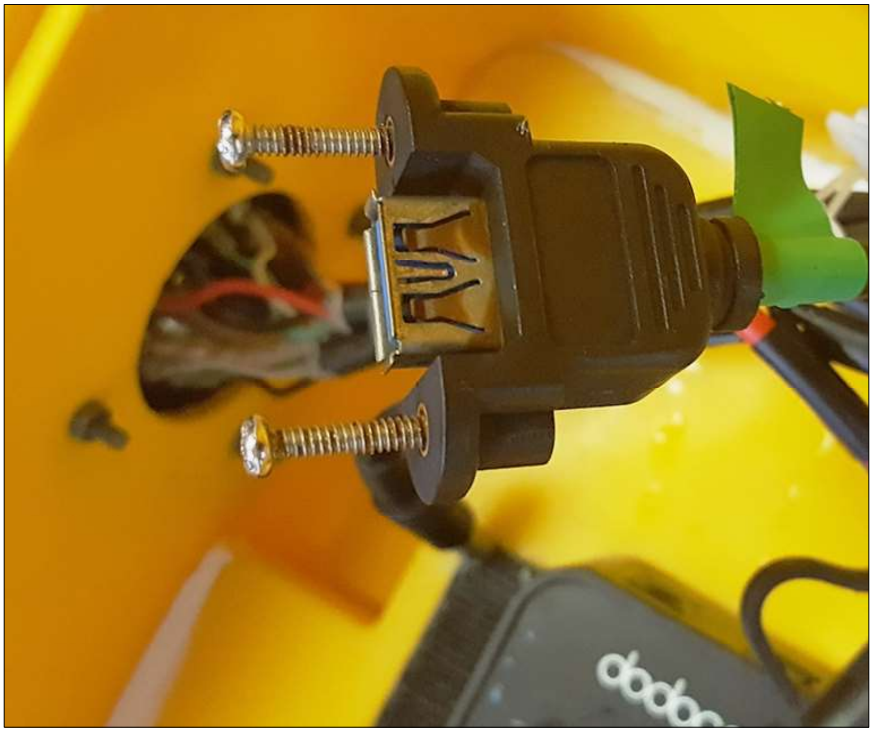


Photo B-41. **Internal component corrosion.**
Close-up of internal component of a control box showing corrosion (rust) on a female connector resulting from saltwater intrusion. Once corroded, the connector would no longer make a connection. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-42. **External connector corrosion.**
Close-up of the external connector to the control box showing early corrosion (rust and white precipitate) on the connector, resulting from saltwater intrusion due to the lack of an O-ring. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-43. A local fishing vessel (Fish Finder).
Fish Finder was chartered to deliver additional supplies to the R/V *Hugh R. Sharp* so the damaged acoustic acquisition buoys could be repaired and redesigned. Supplies were transferred in a watertight barrel using a painter line. Photos courtesy of CSA Ocean Sciences Inc.

Photo B-44. Redesigned control box.
Left, the global positioning system (GPS) and bulkhead connectors sealed with marine sealant (white) to prevent water intrusion. Right, inside of a redesigned control box showing all potential sites of water intrusion have been sealed with marine sealant (white). Photos courtesy of CSA Ocean Sciences Inc.

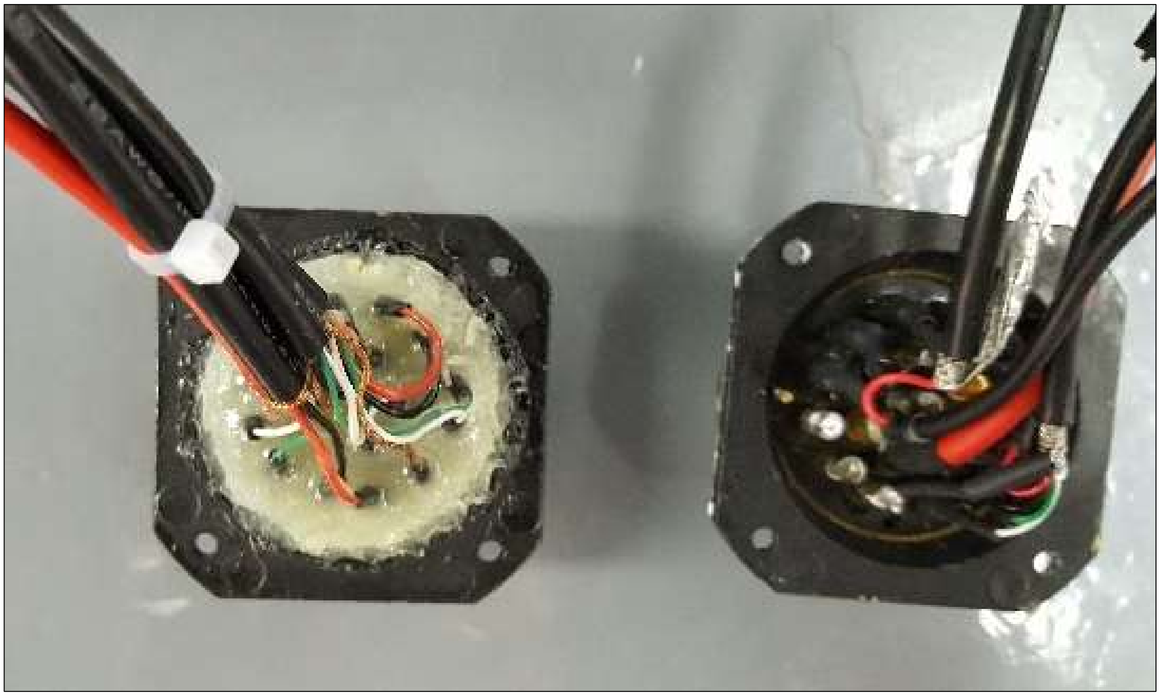


Photo B-45. **Control box connector pre and post waterproofing.**
The control box connector on the right is original design; the connector on the left is after waterproofing with a marine epoxy to prevent water intrusion. Photos courtesy of CSA Ocean Sciences Inc.

Photo B-46. **Deployed acoustic acquisition buoy in various sea states.**
Calm conditions (top), moderate conditions (bottom left), and rough conditions (bottom right). The control boxes were mounted 6 inches above the sea surface with a slight list. Under calm conditions, the control boxes occasionally would be submerged by wave action causing slight water intrusion that led to intermittent USB failures. Under rough conditions, the control box was partially to fully submerged allowing water to enter the control box through the mounting hole for the global positioning system (GPS) antenna and through the bulkhead connector for the cable to the data acquisition cylinder. Water intrusion decreased the amount of acoustic data collected. Photos courtesy of CSA Ocean Sciences Inc.

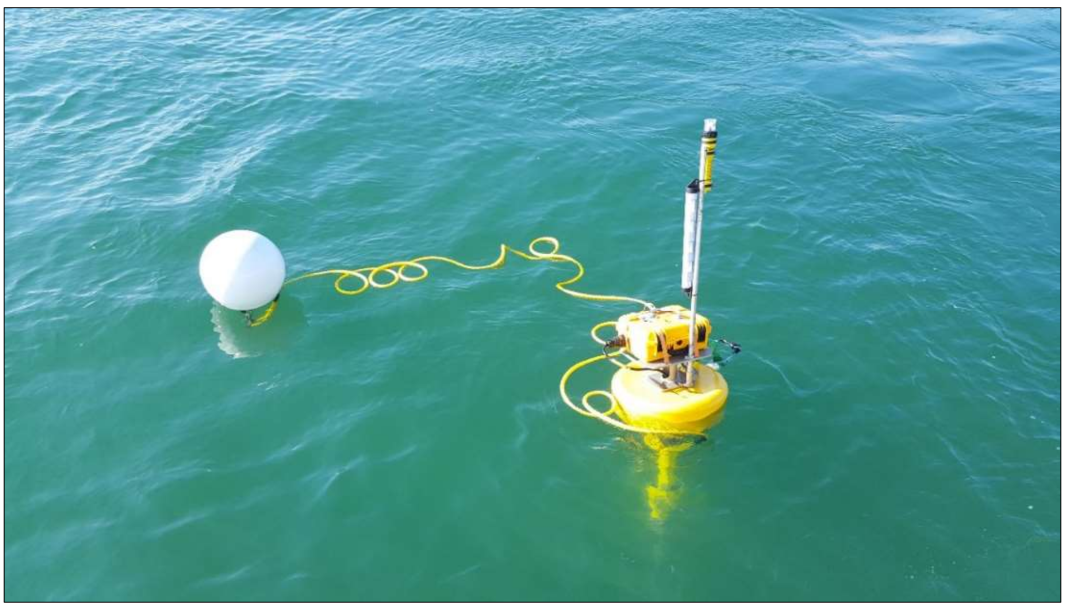


Photo B-47. Redesigned acoustic acquisition buoy.
Image of the modified mooring design (i.e., a white Norwegian float was anchored to the seafloor via a mooring line and the float was attached to the recording buoy with a yellow tailing line). Top, the buoy drifted to the end of the 30-m yellow tailing line and the red float was an indicator to mark this as the buoy at position D. Bottom, redesigned acoustic acquisition buoy showing a white Norwegian float and yellow tailing line connected to the free-floating acoustic buoy. This modification to the mooring design was used to allow the acquisition buoy to float higher in the water during rougher conditions by removing downward force on the buoy from the (anchored) mooring. Photos courtesy of CSA Ocean Sciences Inc.

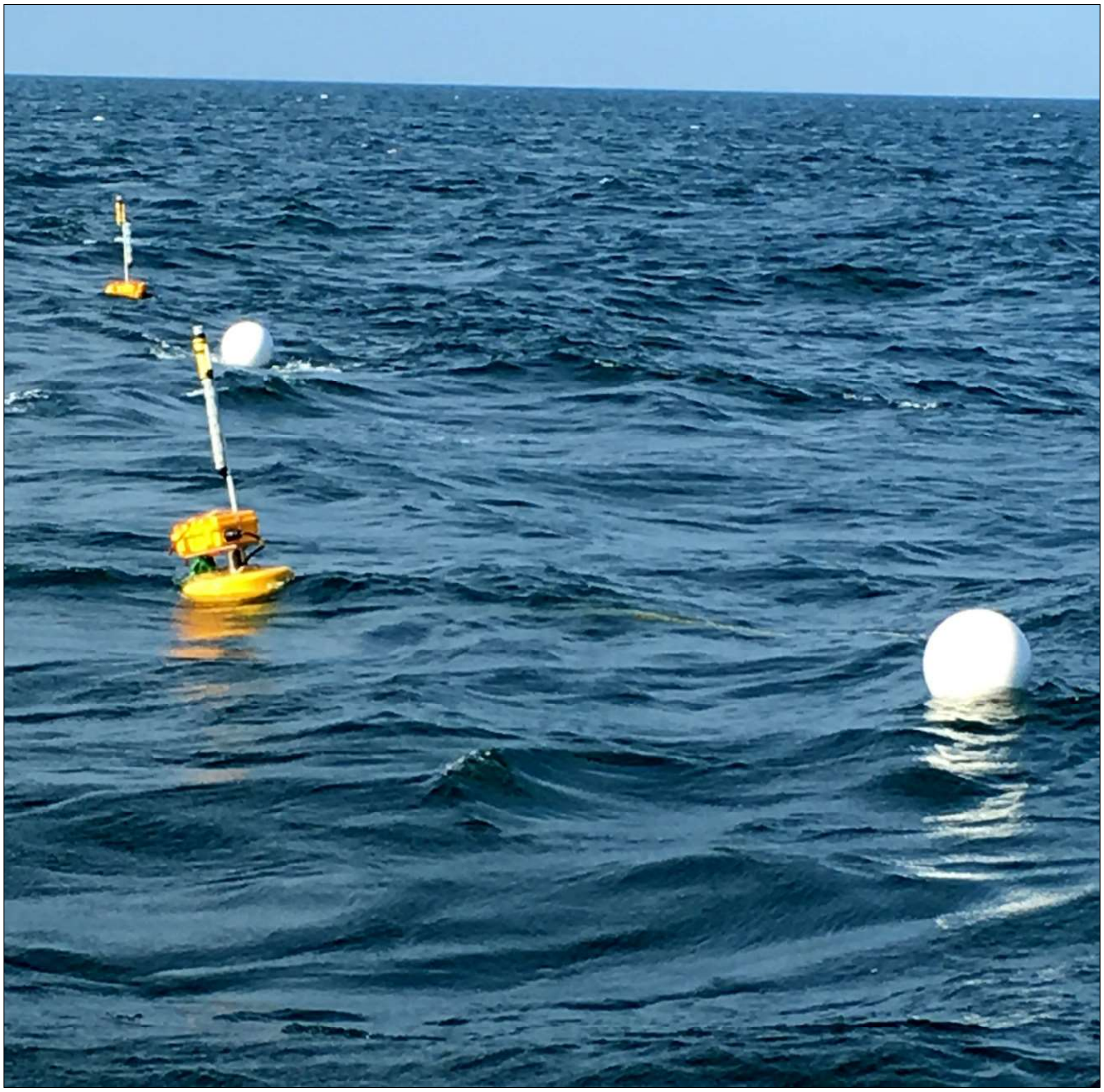


Photo B-48. **Position of two buoys at a designated field array as part of the redesign (i.e., position $E_{1,2}$).** Each buoy has a high- or low-sensitivity hydrophone array attached to provide the necessary dynamic range. The Norwegian float system is part of the redesign. Photos courtesy of CSA Ocean Sciences Inc.

Photo B-49. **Strong currents were encountered at Site 5.**
Currents caused the acoustic buoys to pull taut at the end of the bridle and mooring line, which resulted in the control box submerging. In addition, the current caused the hydrophone array cable to drift away from the intended vertical position. Photo courtesy of CSA Ocean Sciences Inc.

Photo B-50. **Acoustic acquisition buoy in strong currents.**
Currents caused the control box and buoy to completely submerge. However, the control boxes were waterproofed as part of the redesign, and there was minimal (if any) water intrusion. Photo courtesy of CSA Ocean Sciences Inc.

This Page Intentionally Left Blank

Appendix C

Data Acquisition Status

This Page Intentionally Left Blank

Tables C-1 to **C-5** show the approximate data acquisition status at each sampling site for each high-resolution geophysical (HRG) source's operational mode. The buoy position of the field array is designated by letters A to F (see Section 2.1 of the Open Water Testing Report for details) and includes a high-sensitivity (HS) and a low-sensitivity (LS) hydrophone.

This Page Intentionally Left Blank

Table C-1. Site 1 compilation of data acquisition status of each HRG source's operational mode at each buoy position (A to F).

Site 1 HRG Sources	Mode	A-HS	A-LS	B-HS	B-LS	C-HS	C-LS	D-LS	E-HS	E-LS	F-HS
Edgetech 512i	0.5-7.2 kHz, 30 ms, 100% power							1 X	1 X	1 X	1 X
Edgetech 512i	2-12 kHz, 20 ms, 100% power							1 X	1 X	1 X	1 X
Edgetech 512i	0.5-8 kHz, 5 ms, 100% power										
AA252 S-Boom	3 plates, 1,000 J							1 X	1 X	1 X	1 X
AA252 S-Boom	1 plate, 200 J										
Edgetech 4200 Side-scan	100 kHz, 50-m range							1 X	1 X	1 X	
Edgetech 4200 Side-scan	100 kHz, 50-m range							1 X	1 X	1 X	
SIG 2 Mini-sparker ELC 820	700 J							1 X	1 X	1 X	1 X
SIG 2 Mini-sparker ELC 820	500 J							1 X	1 X	1 X	1 X
Knudsen 3260 (Sharp)	Power 1, 8-ms pulse							1 X	1 X	1 X	1 X
Knudsen 3260 (Sharp)	Power 4, 32-ms pulse							1 X	1 X	1 X	1 X
SwathPlus	50 cycles, 100% power, 234 kHz							1 X	1 X	1 X	
SwathPlus	250 cycles, 100% power, 234 kHz										
Edgetech 424, 3100P Top	4-24 kHz, 10 ms, 100% power							1 X	1 X	1 X	
Edgetech 424, 3100P Top	4-24 kHz, 1 ms, 100% power							1 X	1 X	1 X	
Edgetech 424, 3200XS Top	4-24 kHz, 10 ms, 100% power							1 X	1 X	1 X	1 X
Edgetech 424, 3200XS Top	4-24 kHz, 1 ms, 100% power							1 X	1 X	1 X	1 X
Reson 7125 (Sharp)	100% power							1 X	1 X	1 X	
Reson 7125 (Sharp)	50% power							1 X	1 X	1 X	
FSI Bubble Gun	Dual plates							1 X	1 X	1 X	
FSI Bubble Gun	Single plate										
Klein 3000 Side-scan	50-m range, 132 kHz							1 X	1 X	1 X	
Klein 3000 Side-scan	100-m range, 132 kHz							1 X	1 X	1 X	
AA251 Boomer Plate	200 J							1 X	1 X	1 X	
AA251 Boomer Plate	100 J							1 X	1 X	1 X	

AA = applied acoustics; FSI = Falmouth Scientific, Inc.; GPS = global positioning system; HRG = high-resolution geophysical; HS = high frequency; J = joule; kHz= kilohertz; LS = low frequency; m = meter; ms = millisecond.
Green = acoustic data recorded; Red = buoy deployed, but no data recorded; Gray = no buoy deployed; Pink = run skipped due to time constraints; X = no GPS on board buoy; number inside cell = number of deployments.
Note: D-HS and F-LS hydrophones were not included during any testing.

Table C-2. Site 2 compilation of data acquisition status of each HRG source's operational modes at each buoy position (A to F).

Site 2 HRG Sources	Mode	A-HS	A-LS	B-HS	B-LS	C-HS	C-LS	D-LS	E-HS	E-LS	F-HS
Edgetech 512i	0.5-7.2 kHz, 30 ms, 100% power			2 X	1,2			1 X	2		2
Edgetech 512i	2-12 kHz, 20 ms, 100% power			2 X	1,2			1 X	2		2
Edgetech 512i	0.5-8 kHz, 5 ms, 100% power			2 X	2				2		2
AA252 S-Boom	3 plates, 1,000 J			2 X	1,2			1 X	2		2
AA252 S-Boom	1 plate, 200 J			2 X	1,2			1 X	2		2
Edgetech 4200 Side-scan	100 kHz, 50-m range			2 X	1,2			1 X	2		2
Edgetech 4200 Side-scan	100 kHz, 50-m range			2 X	1,2			1 X	2		2
SIG 2 Mini-sparker ELC 820	700 J			2 X	1,2			1 X	2		2
SIG 2 Mini-sparker ELC 820	500 J			2 X	1,2			1 X	2		2
Knudsen 3260 (Sharp)	Power 1, 8-ms pulse			2 X	1,2			1 X	2		2
Knudsen 3260 (Sharp)	Power 4, 32-ms pulse			2 X	1,2			1 X	2		2
SwathPlus	50 cycles, 100% power, 234 kHz			2 X	1,2			1 X	2		2
SwathPlus	250 cycles, 100% power, 234 kHz			2 X	2				2		2
Edgetech 424, 3100P Top	4-24 kHz, 10 ms, 100% power			2 X	1,2			1 X	2		2
Edgetech 424, 3100P Top	4-24 kHz, 1 ms, 100% power			2 X	1,2			1 X	2		2
Edgetech 424, 3200XS Top	4-24 kHz, 10 ms, 100% power			2 X	1,2			1 X	2		2
Edgetech 424, 3200XS Top	4-24 kHz, 1 ms, 100% power			2 X	1,2			1 X	2		2
Reson 7125 (Sharp)	100% power			2 X	1,2			1 X	2		2
Reson 7125 (Sharp)	50% power			2 X	1,2			1 X	2		2
FSI Bubble Gun	Dual plates			2 X	1,2			1 X	2		2
FSI Bubble Gun	Single plate			2 X	1,2			1 X	2		2
Klein 3000 Side-scan	50-m range, 132 kHz			2 X	1,2			1 X	2		2
Klein 3000 Side-scan	100-m range, 132 kHz			2 X	1,2			1 X	2		2
AA251 Boomer Plate	200 J			2 X	1,2			1 X	2		2
AA251 Boomer Plate	100 J			2 X	1,2			1 X	2		2

AA = applied acoustics; FSI = Falmouth Scientific, Inc.; GPS = global positioning system; HRG = high-resolution geophysical; HS = high frequency; J = joule; kHz= kilohertz; LS = low frequency; m = meter; ms = millisecond.
Green = acoustic data recorded; Red = buoy deployed, but no data recorded; Gray = no buoy deployed; Pink = run skipped due to time constraints; Yellow = HRG sound source malfunction;
X = no GPS on board buoy; number inside cell = number of deployments.
Note: D-HS and F-LS hydrophones were not included during any testing.

Table C-3. Site 3 compilation of data acquisition status of each HRG source's operational modes at each buoy position (A to F).

Site 3 HRG Sources	Mode	A-HS	A-LS	B-HS	B-LS	C-HS	C-LS	D-LS	E-HS	E-LS	F-HS
Edgetech 512i	0.5-7.2 kHz, 30 ms, 100% power	3 X		1 X	1,3			3	3	3	3
Edgetech 512i	2-12 kHz, 20 ms, 100% power	3 X		1 X	1,3			3	3	3	3
Edgetech 512i	0.5-8 kHz, 5 ms, 100% power	3 X		1 X	1,3			3	3	3	3
Reson 7111	200 dB, 1.5 ms, 3 degrees	3 X	2 X		1,3			3	3	3	2,3
Reson 7111	200 dB, 0.17 ms, 1.5 degrees	3 X	2 X		1,3			3	3	3	2,3
AA S-Boom	3 plates, 1,000 J	3 X		1 X	1,3			3	3	3	3
AA S-Boom	1 plate, 200 J	3 X		1 X	1,3			3	3	3	3
Edgetech 4200 Side-scan	100 kHz, 50-m range	3 X		1 X	1,3			3	3	3	3
Edgetech 4200 Side-scan	100 kHz, 50-m range	3 X		1 X	1,3			3	3	3	3
SIG 2 Mini-sparker ELC 820	700 J	3 X	2 X		1,3			3	3	3	2,3
SIG 2 Mini-sparker ELC 820	500 J	3 X	2 X		1,3			3	3	3	2,3
Knudsen 3260 (Sharp)	Power 1, 8-ms pulse	3 X		1 X	1,3			3	3	3	3
Knudsen 3260 (Sharp)	Power 4, 32-ms pulse	3 X		1 X	1,3			3	3	3	3
EK60 38 kHz	100%	3 X		1 X	1,3			3	3	3	3
EK60 38 kHz	50%	3 X		1 X	1,3			3	3	3	3
SwathPlus	50 cycles, 100% power, 234 kHz	3 X		1 X	1,3			3	3	3	3
SwathPlus	250 cycles, 100% power, 234 kHz	3 X		1 X	1,3			3	3	3	3
Edgetech 424, 3100P Top	4-24 kHz, 10 ms, 100% power	3 X			3			3	3	3	3
Edgetech 424, 3100P Top	4-24 kHz, 1 ms, 100% power	3 X			3			3	3	3	3
Edgetech 424, 3200XS Top	4-24 kHz, 10 ms, 100% power	3 X	2 X		3			3	3	3	3
Edgetech 424, 3200XS Top	4-24 kHz, 1 ms, 100% power		2 X								2 X
Reson 7125 (Sharp)	100% power	3 X	2 X		3			3	3	3	3
Reson 7125 (Sharp)	50% power	3 X	2 X		3			3	3	3	3
FSI Bubble Gun	Dual plates		2 X		2 X						2 X
FSI Bubble Gun	Single plate		2 X		2 X						2 X
Klein 3000 Side-scan	50-m range, 132 kHz	3 X	2 X		3			3	3	3	3
Klein 3000 Side-scan	100-m range, 132 kHz	3 X	2 X		3			3	3	3	3

AA = applied acoustics; dB = decibel; FSI = Falmouth Scientific, Inc.; GPS = global positioning system; HRG = high-resolution geophysical; HS = high frequency; J = joule; kHz= kilohertz; LS = low frequency; m = meter; ms = millisecond.
Green = acoustic data recorded; Red = buoy deployed, but no data recorded; Gray = no buoy deployed; Pink = run skipped due to time constraints; Yellow = HRG sound source malfunction; X = no GPS on board buoy; number inside cell = number of deployments.
Note: D-HS and L-LS hydrophones were not included during any testing.

Table C-4. Site 4 compilation of data acquisition status of each HRG source's operational modes at each buoy position (A to F).

Site 4 HRG Sources	Mode	A-HS	A-LS	B-HS	B-LS	C-HS	C-LS	D-LS	E-HS	E-LS	F-HS
Edgetech 512i	0.5-7.2 kHz, 30 ms, 100% power	1	1	1	1	1	1	1	1	1	1
Edgetech 512i	2-12 kHz, 20 ms, 100% power	1	1	1	1	1	1	1	1	1	1
Edgetech 512i	0.5-8 kHz, 5 ms, 100% power	1	1	1	1	1	1	1	1	1	1
Reson 7111	200 dB, 1.5 ms, 3 degrees	1	1	1	1	1	1	1	1	1	1
Reson 7111	200 dB, 0.17 ms, 1.5 degrees	1	1	1	1	1	1	1	1	1	1
AA252 S-Boom	3 plates, 1,000 J	2			3 X			2		2	3 X
AA252 S-Boom	1 plate, 200 J	2			3 X			2		2	3 X
Edgetech 4200 Side-scan	100 kHz, 50-m range	2			3 X			2		2	3 X
Edgetech 4200 Side-scan	100 kHz, 50-m range	2			3 X			2		2	3 X
SIG 2 Mini-sparker ELC 820	700 J	2			3 X			2		2	3 X
SIG 2 Mini-sparker ELC 820	500 J				3 X					2	3 X
Knudsen 3260 (Sharp)	Power 1, 8-ms pulse	2			3 X			2		2	3 X
Knudsen 3260 (Sharp)	Power 4, 32-ms pulse	2			3 X			2		2	3 X
EK60 38 kHz	100%				3 X					2	3 X
EK60 38 kHz	50%				3 X					2	3 X
SwathPlus	50 cycles, 100% power, 234 kHz				3 X					2	3 X
SwathPlus	250 cycles, 100% power, 234 kHz				3 X					2	3 X
Edgetech 424, 3100P Top	4-24 kHz, 10 ms, 100% power	2			3 X			2		2	3 X
Edgetech 424, 3100P Top	4-24 kHz, 1 ms, 100% power				3 X					2	3 X
Edgetech 424, 3200XS Top	4-24 kHz, 10 ms, 100% power				3 X					2	3 X
Edgetech 424, 3200XS Top	4-24 kHz, 1 ms, 100% power				3 X					2	3 X
Reson 7125 (Sharp)	100% power				3 X					2	3 X
Reson 7125 (Sharp)	50% power				3 X					2	
FSI Bubble Gun	Dual plates				3 X					2	
FSI Bubble Gun	Single plate				3 X					2	
Klein 3000 Side-scan	50-m range, 132 kHz										
Klein 3000 Side-scan	100-m range, 132 kHz										

AA = applied acoustics; dB = decibel; FSI = Falmouth Scientific, Inc.; GPS = global positioning system; HRG = high-resolution geophysical; HS = high frequency; J = joule; kHz= kilohertz; LS = low frequency; m = meter; ms = millisecond.
Green = acoustic data recorded; Red = buoy deployed, but no data recorded; Gray = no buoy deployed; X = no GPS on board buoy; number inside cell = number of deployments.
Note: D-HS and F-LS hydrophones were not included during any testing.

Table C-5. Site 5 compilation of data acquisition status of each HRG source's operational modes at each buoy position (A to F).

Site 5 HRG Sources	Mode	A-HS	A-LS	B-HS	B-LS	C-HS	C-LS	D-LS	E-HS	E-LS	F-HS
Edgetech 512i	0.5-7.2 kHz, 30 ms, 100% power		1,2		1,2			1,2	1,2	1,2	1,2
Edgetech 512i	2-12 kHz, 20 ms, 100% power		1,2		1,2			1,2	1,2	1,2	1,2
Edgetech 512i	0.5-8 kHz, 5 ms, 100% power		1,2		1,2			1,2	1,2	1,2	1,2
Reson 7111	200 dB, 1.5 ms, 3 degrees		1,2		1,2			1,2	1,2	1,2	1,2
Reson 7111	200 dB, 0.17 ms, 1.5 degrees		1,2		1,2			1,2	1,2	1,2	1,2
AA252 S-Boom	3 plates, 1,000 J		1,2		1,2			1,2	1,2	1,2	1,2
AA252 S-Boom	1 plate, 200 J		1,2		1,2			1,2	1,2	1,2	1,2
SIG 2 Mini-sparker ELC 820	700 J		1,2		1,2			1,2	1,2	1,2	1,2
SIG 2 Mini-sparker ELC 820	500 J		1,2		1,2			1,2	1,2	1,2	1,2
Knudsen 3260 (Sharp)	Power 1, 8-ms pulse		1,2		1,2			1,2	1,2	1,2	1,2
Knudsen 3260 (Sharp)	Power 4, 32-ms pulse		1		1			1	1	1	1
EK60 38 kHz	100% power		1,2		1,2			1,2	1,2	1,2	1,2
EK60 38 kHz	50% power		1,2		1,2			1,2	1,2	1,2	1,2
Reson 7125 (Sharp)	100% power		1,2		1,2			1,2	1,2	1,2	1,2
Reson 7125 (Sharp)	50% power		1,2		1,2			1,2	1,2	1,2	1,2
GI Gun one gun	One gun		2,3		2,3			2,3	2,3	2,3	2,3
GI Gun one gun with inserts	One gun w/ inserts		2		2			2	2	2	2
GI Gun two guns	Two guns		2,3		2,3			2,3	2,3	2,3	2,3
Delta Sparker	3 kJ (1.5)		1	1	1			1	1	1	1
Delta Sparker	6 kJ (2.4)		1	1	1			1	1	1	1
FSI Bubble Gun	Dual plates										
FSI Bubble Gun	Single plate										

AA = applied acoustics; dB = decibel; FSI = Falmouth Scientific, Inc.; GPS = global positioning system; HRG = high-resolution geophysical; HS = high frequency; J = joule; kHz= kilohertz; kJ = kilojoule; LS = low frequency; m = meter; ms = millisecond.
Green = acoustic data recorded; Red = buoy deployed, but no data recorded; Gray = no buoy deployed; Pink = run skipped due to time constraints; Yellow = HRG sound source malfunction; X = no GPS on board buoy; number inside cell = number of deployments.
Note: D-HS and F-LS hydrophones were not included during any testing.

This Page Intentionally Left Blank