OCS Study
BOEM 2021-025

Field Observations During Offshore Wind Structure Installation and Operation, Volume 1

US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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DISCLAIMER

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ABOUT THE COVER

Cover photo: Coastal Virginia Offshore Wind Project Underwater Sound Monitoring. Courtesy of HDR RODEO Team. Used with permission.

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List of Abbreviations and Acronyms

°	degrees
AIFF	Auto Interchange File Format
ARIS	Adaptive Resolution Sonar Imaging
BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
BSH	Bundesamt für Seeschifffahrt und Hydrographie
CTD	Conductivity, Temperature, and Depth
CVOW	Coastal Virginia Offshore Wind
dB	decibel(s)
DOI	Department of the Interior
Dominion	Dominion Energy, Inc
GLM	generalized linear model
Hz	Hertz
kHz	kilohertz
kJ	kilojoule(s)
kts	knots
km	kilometer(s)
LB	lift boat
L_{pk}	Peak Level
L_{pp}	Peak-to -peak Level
L_{rms}	Root-mean-square level
m	meter(s)MARU Marine Autonomous Recording Unit
met tower	meteorological tower
mm	millimeter(s)
mm/s	millimeters per second
MOW	Maryland Offshore Wind
MW	megawatts
N	north
OBX	Ocean Bottom Recorders Geophone and Hydrophone Sensor System
Nm/s	Newton meters per second
Pa	pascal(s)
PAM	passive acoustic monitoring
PSD	power spectral density
μPa	microPascal

rms	root mean square
RODEO	Real-Time Opportunity for Development Environmental Observations
SD	standard deviation
SEL	sound exposure level
SHRU	Several Hydrophone Recording Units
SPL	sound pressure level
SPL_{peak}	peak sound pressure level
SST	sea surface temperature
U.S.	United States
V/μPa	Volt per micropascal
VLA	Vertical Line Array
vs.	versus
W	west

Editorial Note

To facilitate presentation, review, and perusal of the large quantity of observations and data generated under Task Order 140M0118F0006, the task order deliverable was divided into the following three standalone volumes:

1. ***Volume 1*** (this volume): contains methods, observations, data analyses, results, and conclusions from ***underwater acoustic monitoring*** conducted during the ***construction phase*** of the Maryland Meteorological Tower Project and the Coastal Virginia Offshore Wind Pilot Project.

2. ***Volume 2***: contains methods, observations, data analyses, results, and conclusions from ***underwater acoustic monitoring*** conducted during the ***operational phase*** of the Coastal Virginia Offshore Wind Pilot Project.

3. ***Volume 3***: contains methods, observations, data analyses, results, and conclusions from ***turbidity, biofouling, and corrosion monitoring*** conducted during the ***operational phase*** of the Coastal Virginia Offshore Wind Pilot Project.

Executive Summary

Underwater acoustic monitoring was conducted under the Bureau of Ocean Energy Management's (BOEM's) Real-Time Opportunity for Development Environmental Observations (RODEO) Program during the **construction phase** of the following offshore wind power structures:

1) a meteorological tower that was proposed to be constructed in the Maryland Wind Energy Lease Area by the Maryland Offshore Wind (MOW) Project, and

2) two monopile wind turbines installed off the coast of Virginia by the Coastal Virginia Offshore Wind (CVOW) Project.

Monitoring methods, results, data analyses and interpretation, and conclusions and recommendations for future monitoring are presented in this report.

MOW Project Met Tower Installation Monitoring

Future plans for the United States (U.S.) Wind MOW Project call for installing 32 offshore wind turbines approximately 17 miles from the coast of Ocean City, Maryland, in 20 to 30 meters of water. The facility is projected to generate approximately 270 megawatts of power. To provide data for the siting of the turbines, a meteorological tower (met tower) was planned for installation at the site. Two separate attempts were made by the project developer, U.S. Wind, to install the met tower, the first in August 2018 and the second approximately 12 months later.

Based on the information relayed to BOEM and the RODEO Team in late August 2019, the RODEO monitoring team was mobilized, and a suite of underwater acoustic sensors were deployed around the construction site to start collecting background underwater sound data prior to the start of the pile driving. RODEO Program monitoring plans included placement of sensors both at ***short-range*** from the site (within 1.5 kilometers [km]) and at ***long-range*** (15 to 30 km), and conducting both ***unattended*** (using stationary platforms that are deployed on the seabed prior to the start of construction and retrieved after construction is completed) and ***attended*** monitoring (deploying towed or dipped hydrophones from a vessel during active pile driving).

However, due to a confluence of factors, including contractual issues within the construction team, the efforts to construct the met tower were abruptly terminated by U.S. Wind on 26 September 2019. Upon termination of the construction project, per BOEM's guidance, the accompanying RODEO Program monitoring was also discontinued on this date, except for the unattended background sound monitoring. The attended monitoring portion of the BOEM-approved Work Plan was not implemented because pile driving was not conducted.

Ambient underwater noise collected within the Project area was analyzed and the results are reported in this document. Preliminary analyses of data collected by two Vertical Line Arrays (VLA) and a Geosled/Ocean Bottom Recorders Geophone and Hydrophone Sensor System over a four-week period indicated that ambient noise was largely dependent on sea state. Noise from shipping activity, storms, and marine fauna were also recorded.

Analyses of data collected by Marine Autonomous Recording Units at four different stations, as well as an LS1 acoustic recorder, revealed spatial variations in the lower levels of acoustic energy in the lower frequencies, and higher energies in the higher frequencies. These variations could be attributed to sound propagation as a function of depth, where lower frequency sounds propagate farther in deeper waters and higher frequency sounds propagate farther in shallower waters. Two of the four monitoring sites were located near the shipping lanes, but the sounds recorded between 100 and 1,000 Hertz (Hz), where most of the energy from shipping noise occurs, were not particularly different than the site away from the shipping lanes. Unexpectedly, the sites closer to the shipping lanes had lower overall cumulative noise levels than sites farther away. Overall, data recorded by the RODEO Program had a similar range of sound levels (101.5 and 121.1 decibels referenced to 1 micropascal root mean square [dB re 1 μPa rms]) as compared to those observed during other passive acoustic monitoring studies conducted in the southern part of the Maryland Wind Energy Area (approximately 108 to 123 dB re 1 μPa rms).

CVOW Project Turbine Installation Monitoring

The CVOW pilot project consists of two 6- megawatt wind turbine generators (A01 and A02), located 43 km east of Virginia Beach, Virginia. During the installation of the monopile foundation for Turbine A02 by impact pile driving, a noise mitigation system (double bubble curtain) was employed. No bubble curtain was used during the pile driving for Turbine A01 in order to compare noise levels with and without the mitigation system in place. Both turbines were installed in May 2020.

Underwater acoustic monitoring was conducted during pile installation in order to 1) measure changes in sound pressure levels (SPLs), 2) record sound levels in the water column and vibrations in the sediment, 3) detect particle-motion, and 4) assess the effectiveness of a noise mitigation system to reduce underwater noise generated during pile installation. The Project owners (Dominion Energy, Inc. [Dominion]) were required to collect underwater acoustic data during installation *only* in the short-range (within 1.7 km) of the turbine locations. The RODEO Program monitoring plans included placement of sensors both at ***short-range*** from the turbines (within 3 km) and at ***long-range*** (7.5 to 30 km). Per the BOEM-approved Work Plan, both **unattended** and **attended** monitoring were conducted. Key conclusions from the monitoring data analyses are listed below:

- VLA monitoring data indicated that the bubble curtain performance on noise mitigation had strong frequency and range dependencies. The attenuation of pile driving sounds below 200 Hz at short-range was less than the attenuation at long-range, but above 200 Hz the noise reduction was consistent at both short and long ranges. This is likely due to the effects of scattering and mode coupling on pile driving sound propagating through the bubble curtain and could be related to the bubble size distribution and the azimuthal orientation of the bubble curtain. More thorough investigation of these factors is recommended for future research. Taken together, data from the VLAs and the Geosled/Ocean Bottom Recorders Geophone and Hydrophone Sensor System systems also highlighted the importance of azimuthal and depth dependencies of the bubble curtain performance. The wavelengths associated with sound at frequencies below 50 to 60 Hz were larger than the depth of water, and as such, the sound waves were likely interacting with the seafloor, highlighting the crucial role of the seafloor in controlling sound propagation.

- Towed hydrophone array recordings also indicated that the noise mitigation system was more effective at reducing sound levels at higher frequencies, and the largest differences in received SPLs were seen above 200 Hz. Towed array results showed differences of up to 10 dB in recorded sound levels (Peak Level [L_{pk}] and Peak-to-peak Level [L_{pp}] metrics) for mitigated versus unmitigated pile driving. These results were consistent with monitoring conducted by Dominion.

- Results from the long-range measurements (15 to 30 km) conducted using dipped hydrophones indicated that the bubble curtain reduced noise levels by between 11 and 23 dB depending on the distance from the sound source, sensor depth, and noise metric. Attenuation was present at all frequencies where significant energy existed in the pulse, from 80 Hz up to 4 kilohertz (kHz), at 20 km. At frequencies above 4 kHz, the noise reduced to near background levels in the unmitigated pulse, although this was relative to the ambient noise in that specific location and time.

Overall, results from both attended and unattended monitoring indicated that the effectiveness of the noise attenuation system employed at CVOW was dependent on sound frequency. Bubble curtain performance also varied with depth and distance from the piling, and results showed strong azimuthal (i.e., instrument orientation) and frequency dependencies of bubble curtain effectiveness. **Table ES-1** summarizes the measurements with and without the bubble curtain.

Table ES-1. Summary of peak pressure measurements of CVOW pile driving with and without the double bubble curtain. Measurements at similar water depths are shown.

Range	Measurement System	Water Column Location	Peak Pressure Level with no Bubble Curtain (dB re 1 μPa)	Peak Pressure with Bubble Curtain (dB re 1 μPa)	Difference (dB)
1.5 km	Geosled	~1 m above seafloor	182	178	4
3.0 km	SHRU VLA #1	Mid-water	177	171	6
4.4 km[1]	Towed array	Mid-water	171	165	6
6.5 km[1]	Towed array	Mid-water	172	165	7
7.2 km[1]	Towed array	Mid-water	171	163	8
7.5 km	SHRU VLA #2	Mid-water	170	157	13
20 km	Dipped Hydrophone	~1 m above seafloor	150	132	18
20 km	Dipped Hydrophone	Mid-water	151	128	23

Note: dB = decibel(s); dB re 1 μPa = decibels referenced to 1 micropascal; km – kilometer(s): m = meter(s); SHRU = Several Hydrophone Recording Units; VLA = Vertical Line Array.

Evaluation of the differences between the peak pressure with and without the bubble screens indicates the following:

- The bubble curtain reduced the peak pressure from 4.2 to 23.1 dB depending on the range.
- The smallest reductions were found at the nearest ranges while the largest reductions were measured at the farthest ranges. The mechanism causing this variation is not well understood but could be related to the bubble size distribution and the azimuthal orientation of the bubble curtain. Another possibility is the propagation of sound through the seabed (which would not be attenuated by the bubble curtain in the water) contributed to the peak pressure levels in both foundations at close ranges.
- The pile driving peak pressure levels also showed some dependency of measurement depth (<3 dB) possibly due to the dominance of the low-frequency energy (and hence long wavelengths as compared to the water depth).

One of the limitations of this study was the limited information that was available on the characteristics of the bubble curtain including the depth-dependent bubble size distribution and the effect of the current on bubble curtain shape and orientation. Photographs of the bubble curtain taken during active operations do show some ellipticity. Despite these limitations, 1) it is clear that the bubble curtain reduced the peak pressure, as measured by all attended and unattended monitoring platforms, by 4.2 to 23.1 dB depending on range, depth, and azimuth, and 2) it is also clear that the bubble curtain was effective for frequencies

[1] The towed array collected data from 1.5 to 9 km. The data at the ranges listed are representative.

above 200 Hz in all attended and unattended monitoring. The performance of the bubble curtain at lower frequency is more complicated and requires further analysis and modelling.

As relevant and appropriate, CVOW Project monitoring data were compared to results from monitoring conducted under the RODEO Program at the Block Island Wind Farm, the only other offshore wind farm constructed to date in the U.S. However, the findings from the comparison should be interpreted with caution because of key differences in turbine foundations, construction methods, and environmental conditions at the two sites, which can significantly influence received noise levels.

The data, results, conclusions, and recommendations presented in this report were generated for BOEM by the HDR RODEO Program Team under IDIQ Contract M15PC00002, Task Order 140M0118F0006.

1 Introduction

This report presents methods, observations, data analyses, results, and conclusions from real-time environmental monitoring surveys conducted under the Bureau of Ocean Energy Management's (BOEM's) Real-Time Opportunity for Development Environmental Observations (RODEO) Program during the **construction** phase of the following offshore wind power structures:

1) a meteorological tower that was proposed to be constructed in the Maryland Wind Energy Lease Area by the Maryland Offshore Wind (MOW) Project, and

2) two monopile wind turbines installed off the coast of Virginia by the Coastal Virginia Offshore Wind (CVOW) Project.

1.1 The RODEO Program

The purpose of the RODEO Program is to make direct, real-time measurements of the nature, intensity, and duration of potential stressors during the construction and initial operations of selected proposed offshore wind facilities. The purpose also includes recording direct observations during the testing of different types of equipment that may be used during future offshore development to measure or monitor activities and their impact-producing factors.

BOEM conducts environmental reviews, including National Environmental Policy Act analyses and compliance documents for each major stage of energy development planning which includes leasing, site assessment, construction, operations, and decommissioning. These analyses include 1) identification of impact-producing factors (stressors) and receptors such as marine mammals and seafloor (benthic) habitats, and 2) evaluation of potential environmental impacts from the proposed offshore wind development activities on human, coastal, and marine environments. The analyses require estimations of impact-producing factors such as noise and the effects from the stressor on the ecosystem or receptors. Describing the impact-producing factors requires knowledge or estimates of the duration, nature, and extent of the impact-generating activity.

The RODEO Program monitoring data may be used by BOEM as inputs to analyses or models that evaluate the effects or impacts from future offshore wind turbine construction and operations, as well as facilitate operational planning that would reduce potential impacts to the greatest extent possible. The understanding and insights gained from the RODEO Program data analyses will help BOEM to identify, reduce, and mitigate environmental risks in the future, and significantly increase the efficiency and efficacy of BOEM's regulatory review process for offshore wind development in the United States (U.S.) Finally, data collected by the RODEO Program will support prioritization of future monitoring efforts and risk retirement. For example, if the RODEO Program monitoring data indicate that likelihood of impacts from a particular project development phase is low or inconsequential, then such phases may not be monitored during future projects.

It is important to note that the RODEO Program is not intended to duplicate or substitute for any monitoring that may otherwise be required to be conducted by the developers of the proposed projects. Therefore, RODEO Program monitoring was limited to selected parameters only. Also, RODEO Program monitoring is coordinated with the industry and is not intended to interfere with or result in delay of industry activities.

All RODEO Program field activities were conducted in accordance with a BOEM-approved Field Sampling Plan, which included a project-specific Health and Safety Plan (**Appendix A**).

1.2 The Maryland Offshore Wind (MOW) Project

U.S. Wind holds the lease for an offshore wind project to be located approximately 27 kilometers (km) from the coast of Ocean City, Maryland. Future plans call for installing 32 offshore wind turbines in 20 to 30 meters (m) of water that will generate approximately 270 megawatts (MW) of power. A substation will collect the energy from the turbines and transmit the electricity to the shore using underwater cables.

To collect site-specific meteorological data for finalizing the offshore wind turbine locations within the lease area, U.S. Wind planned to install a meteorological tower (hereafter referred to as met tower, location 38º 21.1648 N; 74º 45.2130 W) in water depth of 27 m (**Figure 1**). The RODEO Program monitoring for the MOW Project was intended to record underwater sound generated by pile driving during the installation of this met tower.

Two separate attempts were made by U.S. Wind to install the met tower, the first was in fall (August) 2018 and the second approximately 12 months later. Based on the information relayed to BOEM and the RODEO Program Team in late August 2019, the monitoring team was mobilized, and a suite of underwater acoustic sensors were deployed around the construction site to start collecting background underwater sound data prior to the start of the pile driving.

However, due to a confluence of factors, including contractual issues within the construction team, the efforts to construct the met tower were abruptly terminated by U.S. Wind on 26 September 2019. Upon the premature termination of the construction project per BOEM's guidance, the accompanying RODEO Program monitoring was also discontinued on this date. Selected background underwater data that were collected within the Project area were analyzed, and the results are reported in this document.

1.3 The Coastal Virginia Offshore Wind (CVOW) Project

The CVOW project is owned by Dominion Energy, Inc. (Dominion) and is located off the coast of Virginia Beach, Virginia, on an 8.6-square kilometer (2,135-acre) site leased by the Virginia Department of Mines Minerals and Energy. This is the first offshore wind farm in federal waters and only the second in the U.S.

Dominion had an agreement with the Department of Mines, Minerals, and Energy to build and operate two 6 MW wind turbines on monopile foundations at this site during the first phase of the Project. The turbine location (**Figure 2**) coordinates are as follows:

- Turbine 1: 36° 53.7772 N; 75° 29.4980 W
- Turbine 2: 36° 53.2100 N; 75° 29.4943 W

Phase 1 included laying of a 34-kilovolt submarine power distribution line that runs from the turbines to a connection point in Dominion's electrical system near Camp Pendleton. The transmission line is buried approximately 2 m under the seabed for much of its length, and it comes ashore through a 1,000 m conduit installed under the beach.

For Phase 1 construction, Dominion partnered with Ørsted of Denmark. Installation of the two turbines was completed in May 2020, and the wind farm became operational in October 2020.

Under the RODEO Program, underwater passive acoustic monitoring (PAM) was conducted during the installation of the two turbines. Results and conclusions from the ***construction phase monitoring*** efforts are presented in this report. A second round of underwater PAM, as well as turbine structure biofouling monitoring, is planned for the operational phase of the Project. Results and conclusions from the CVOW Project ***operational phase monitoring*** will be presented in the accompanying Volume 2.

1.4 Report Organization

Key results, observations, and conclusions from environmental monitoring conducted during the construction of offshore wind structure at the two sites are summarized in individual sections in this report. Selected raw data and detailed discussions are contained in technical reports, which are provided as digital appendices to this summary report. This report is organized as follows:

- **Section 1** presents an overview of the RODEO Program and includes a summary description of the two offshore wind structures that were monitored under Task Order 140M0118F0006.
- **Section 2** contains methods and key observations from underwater PAM conducted at the MOW Project met tower site.
- **Section 3** describes methods, results, conclusions, and recommendations from analyses of underwater acoustic data collected during the CVOW Project construction phase.
- **Section 4** lists the references cited in this report.

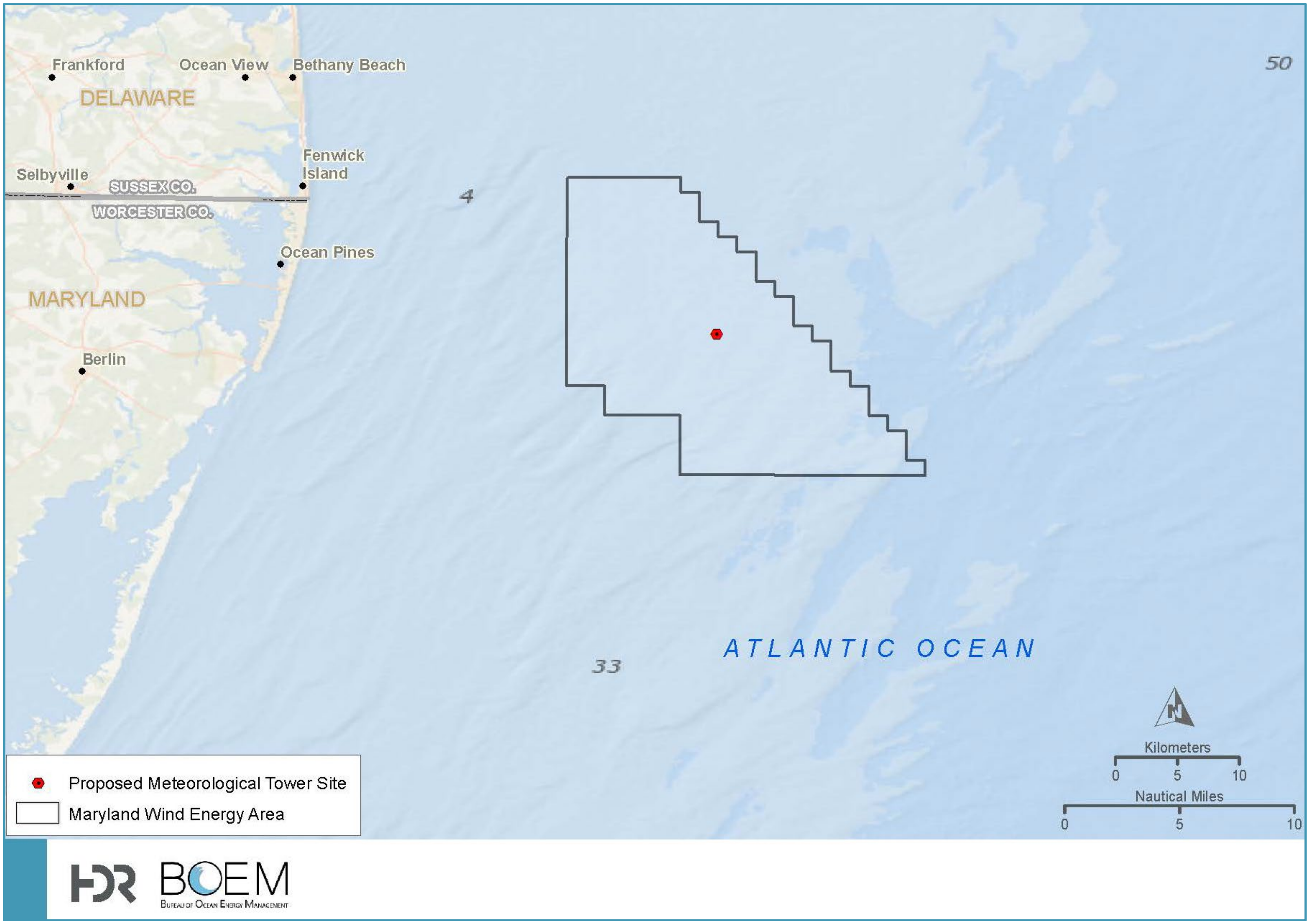

Figure 1. Proposed location for the U.S. Wind Meteorological Tower within the Maryland Wind Energy Lease Area

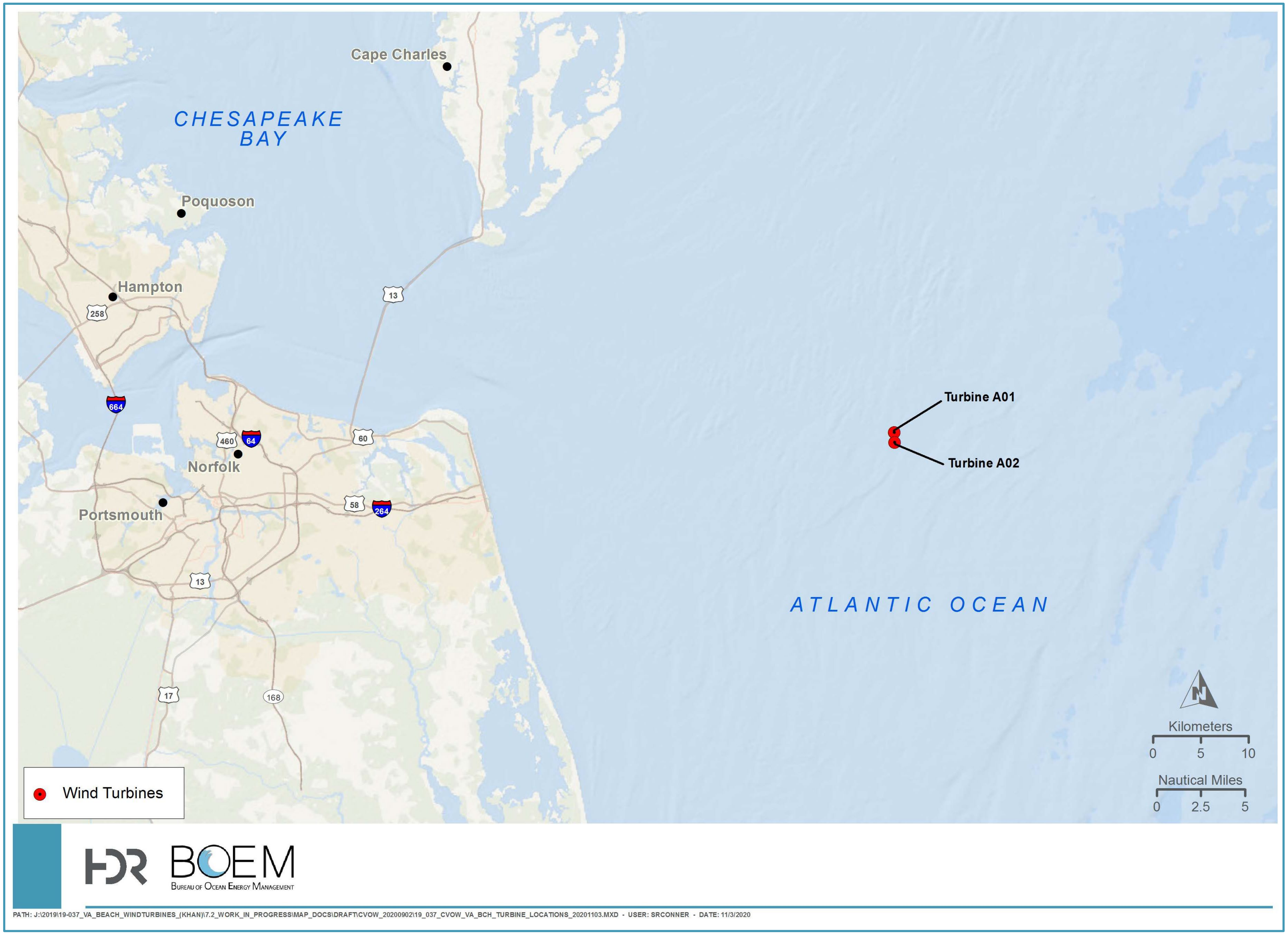

Figure 2. Location of the two CVOW Project Monopile Turbines

2 MOW Project Met Tower Underwater Passive Acoustic Monitoring

2.1 Monitoring Objectives

The primary objective was to measure underwater sound generated by pile driving during the installation of the proposed met tower. The real-time monitoring data would be used to determine changes in sound pressure levels (SPLs) and detect particle-motion due to the pile driving. The project developer (U.S. Wind) was required to collect underwater acoustic data during active pile driving *only* in the short-range (within 1.7 km) of the proposed met tower location. RODEO Program monitoring plans included placement of sensors both at ***short-range*** from the site (within 1.5 km) and at ***long-range*** (15 to 30 km). Per the BOEM-approved Work Plan, both ***unattended*** and ***attended*** monitoring were planned. However, since pile driving was not conducted, the attended monitoring portion of the plan was not implemented.

2.2 Data Recording Systems

Unattended monitoring included placement of heavy moorings equipped with different types of recording systems on the seafloor at pre-determined locations around the construction site (**Table 1** and **Figure 3**). The unattended systems were programmed to collect data over multiple weeks to capture sounds before, during, and after the proposed pile driving was completed. The stationary moorings were deployed on 22 and 23 August 2019 and retrieved approximately 8 weeks later. The *R/V* Tiki XIV, a 24 m steel trawler, based out of Lewes, Delaware, was used to deploy and retrieve the stationary moorings. Additional information on the different types of recording systems deployed at the met tower site is presented in **Table 2**.

2.2.1 Vertical Line Arrays (VLA)

Two VLAs equipped with Several Hydrophone Recording Units (SHRUs) were deployed within the Project area at locations listed in **Table 1**. The locations were rotated -12 degrees (°) N to match the angles of the proposed pile. A schematic of the VLA configuration is shown in **Figure 4**. Water depth at both VLA locations was 27.0 m, and the four hydrophones on each VLA were mounted at depths of 13.7 m, 15.3 m, 18.8 m, and 20.4 m. Sampling frequency for both VLAs was 19,531.2 Hertz (Hz).

Table 1. SHRU VLA Location Coordinates

	Latitude	Longitude	Comments
Meteorological Tower	38° 21.1648 N	74° 45.2128 W	
SHRU VLA 907	38° 21.0640 N	74° 45.7250 W	766 meters (m) west of the proposed tower
SHRU VLA 910	38° 20.7610 N	74° 44.9980 W	810 m south of the proposed tower

2.2.2 Geosled

A heavy iron sled with two SHRU electronics packages mounted on it was positioned approximately 725 m north of the proposed tower location at latitude 38° 21.5220 N and longitude 74° 45.4190 W. A four-element tetrahedral hydrophone array and a three-axis geophone were mounted on this sled (**Figure 5**). The tetrahedral array hydrophones were low sensitivity (-201 decibels [dB]) using 6 dB preamp gain. SBE39 temperature and pressure sensors were also mounted on the sled.

Table 2. Underwater passive acoustic monitoring systems selected for deployment at the MOW Project Met Tower Site

Systems	Data Collection Objective	Distance(s) from the Proposed Met Tower	Depth	Deployment Dates
Unattended Monitoring				
Two Vertical Line Arrays (VLAs)	Short-range pressure signal	766 meters (m) (west of the met tower location) 810 m (south of the met tower location	27 m	22 Aug 2019 – 16 Oct 2019
One Geosled with tetrahedral hydrophone array and a three-axis geophone	Short-range particle velocity in the water column and at the seabed, pressure signal at a fixed range	725 m North	27 m	22 Aug 2019 – 16 Oct 2019
One Ocean Bottom Recorder (OBX) Seismic Sensor System	Range dependence of short-range particle velocity in the water column and at the seabed, pressure signal	730 to 1,150 m with 5 m spacing	27 m	22 Aug 2019 – 16 Oct 2019
Marine Autonomous Recording Units (MARU)	Long-range pressure signal	15 to 30 kilometers (km)	20 – 40 m	29 Aug 2019 – 15 Oct 2019
LS1 acoustic recorder	Long-range pressure signal	15 km	~ 30 m	7 Jun 2019 – 30 Oct 2019*
Attended Monitoring				
Towed Array	Range dependence of long-range pressure signal	N/A	N/A	N/A
Dipped hydrophone	Azimuthal dependence of pressure signal at short-range	N/A	N/A	N/A

*The LS1 system stopped recording on 3 Sep 2019.

Note: Since pile driving was not conducted at the met tower site, the attended monitoring portion of the plan was not implemented.

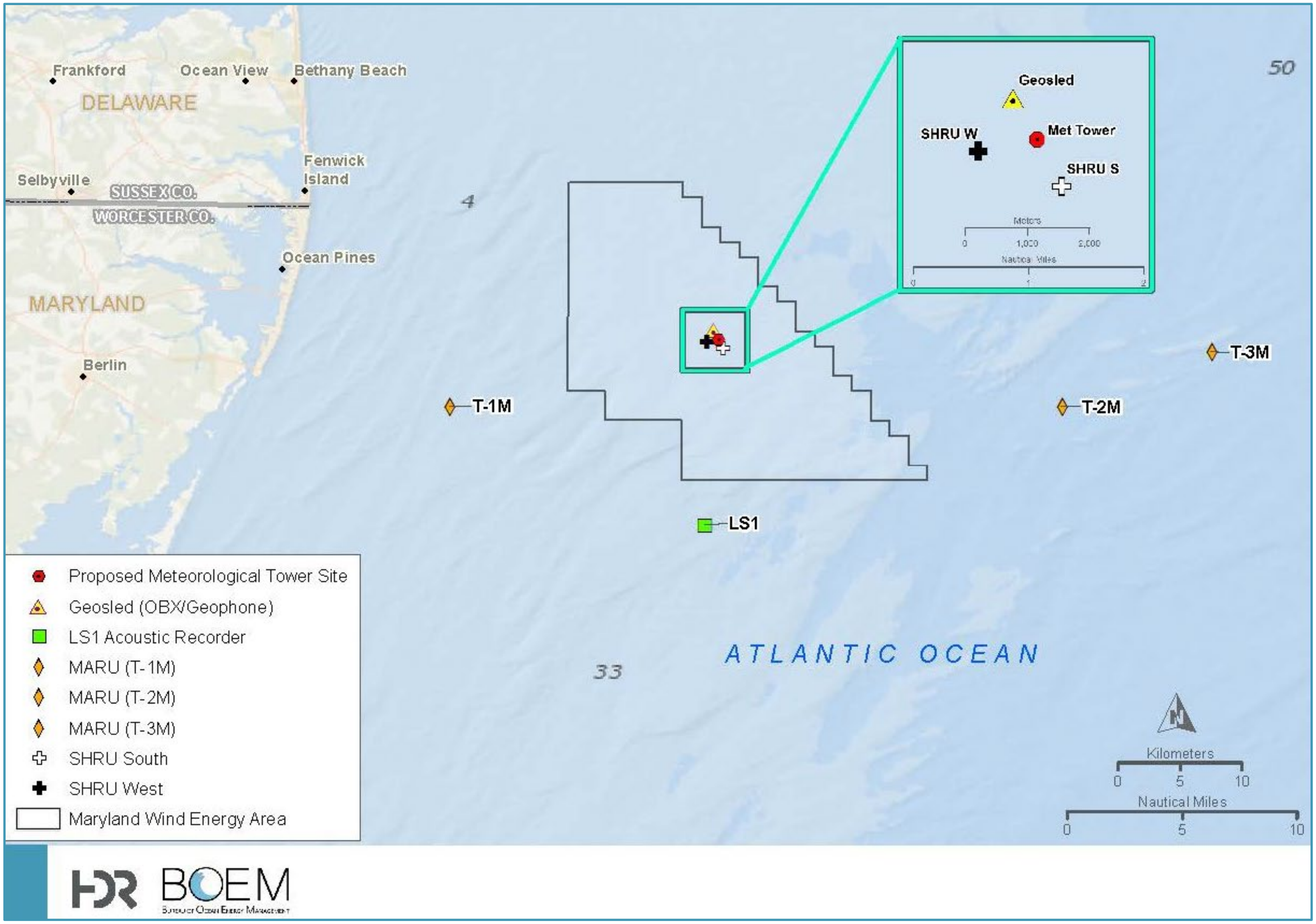

Figure 3. Locations of monitoring equipment deployed around the MOW Project Met Tower Site

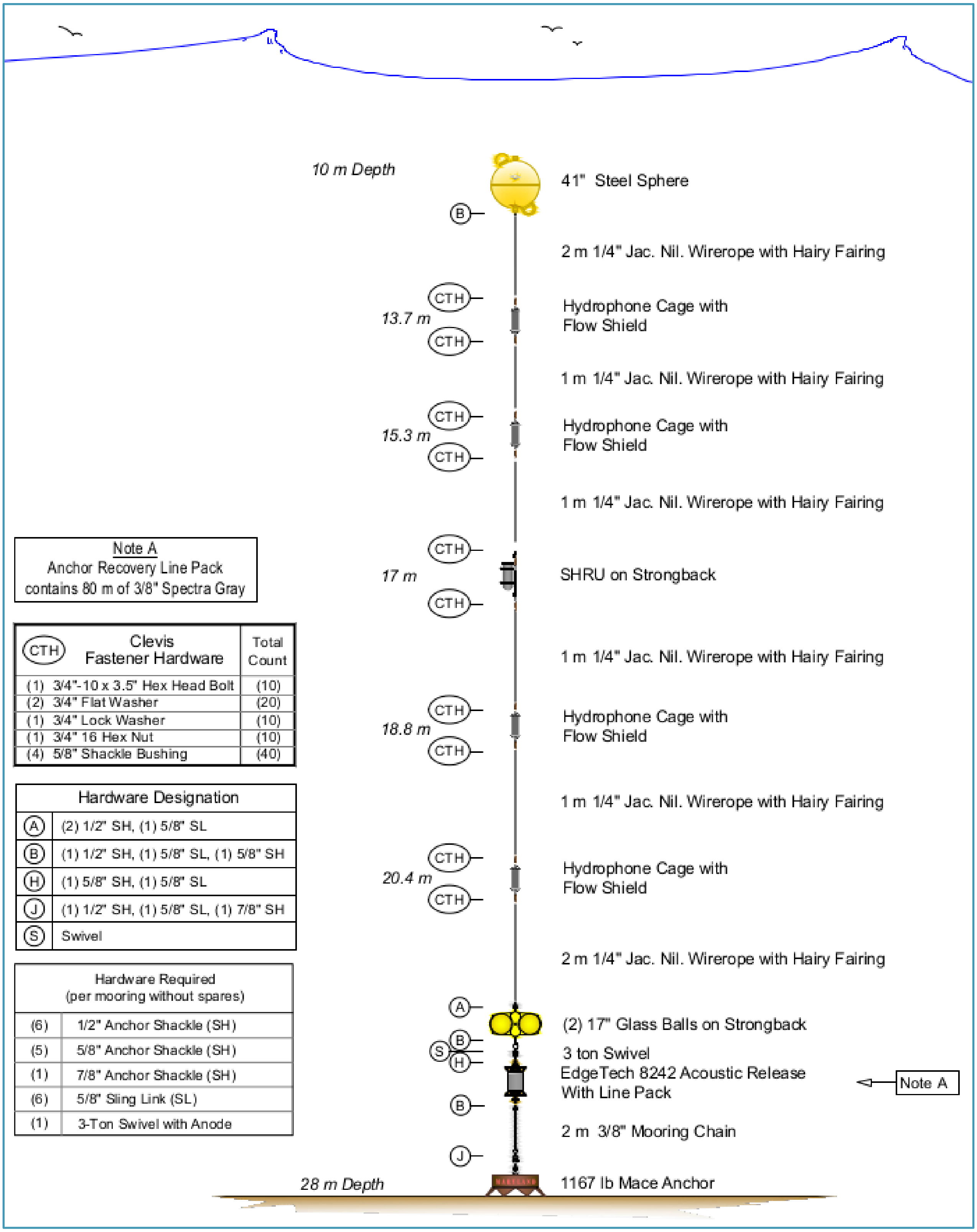

Figure 4. VLA mooring configuration

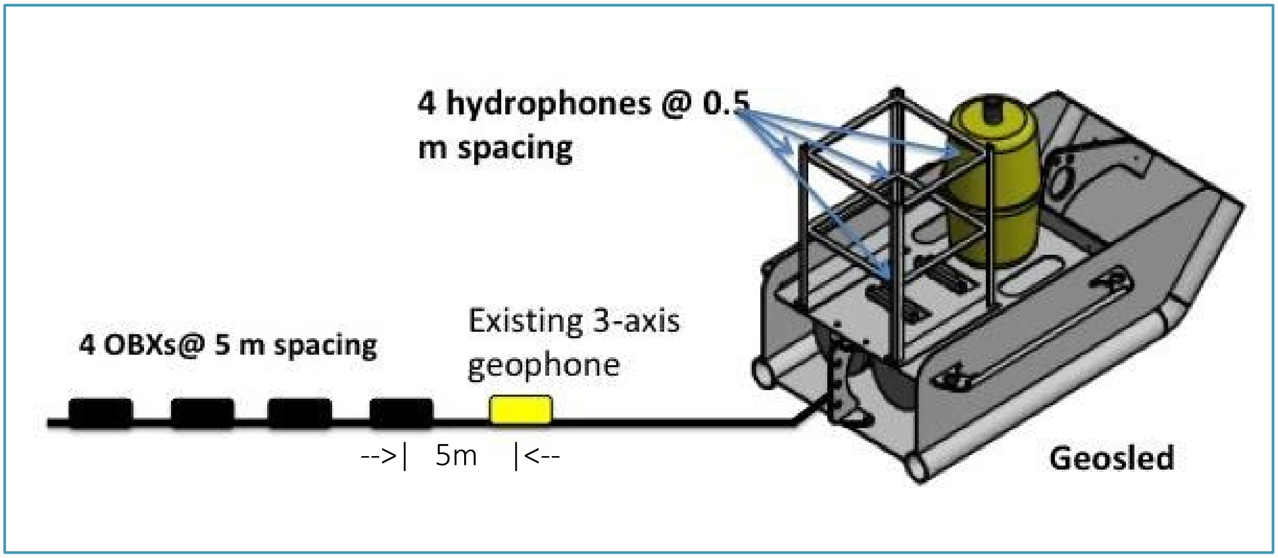

Figure 5. Geosled configuration showing the nominal spacing of the three-axis geophone and OBX system (actual distances of the geophones and the OBXs are listed in Table 3)

Figure 6. Close up view of the three-axis geophone (right panel) and OBX system (left panel)

2.2.3 OBX Seismic Sensors

Sound waves in water have both a pressure and a particle-motion component, yet few studies of underwater acoustic ecology have measured the particle-motion component of sound. Fish, and many marine invertebrates, detect and use the particle-motion component of sound to navigate their environment (Nedelec et al. 2016). It is therefore important to gather data to better understand the particle-motion component of underwater sound. Particle-motion levels cannot always be predicted from sound pressure measurements (Popper and Hawkins 2018). An Ocean Bottom Seismometer array, manufactured by the Geospace Corporation, was therefore deployed at the site to collect data necessary for particle-motion analyses.

The array consisted of four self-contained units Ocean Bottom Recorders Geophone and Hydrophone Sensor System (OBXs) (**Figure 6**) and was anchored to the Geosled behind the three-axis geophone as shown in the schematic in **Figure 5**. Actual distances of the three-axis geophone and the OBX systems from the sled are listed in **Table 3**. Each OBX has four channels which record both acoustic pressure and particle velocity in three mutually perpendicular directions. The OBX package also contained a pitch and roll sensor which measures the pitch and roll at 1-minute intervals and were sampled at 4 kilohertz (kHz). The three-axis geophone was sampled at 9,765.625 Hz and the hydrophones on the tetrahedral array sampled at 19,531.25 Hz.

Table 3. Relative positions of the 3-axis geophone and OBX systems

Sensor ID	Distance from the sled (facing South) (meters)
3-axis URI Geophone	5.2
OBX13449	9.4
OBX13880	14.3
OBX14010	19.2
OBX14396	24.1

2.2.4 Marine Autonomous Recording Units (MARUs)

Acoustic data were collected at three long-range sites (**Figure 3)** using Cornell's Marine Autonomous Recording Units (MARUs; **Figure 7**). Deployed MARUs recorded at a 10 kHz sample rate with an effective recording bandwidth of 10 Hz to 4,000 Hz, and a sensitivity of -168 dB (re: 1 Volt per micropascal [V/µPa]) with a flat frequency response ± 3.0 dB re 1 µPa. Deployment and recovery details for the three MARUs are shown in **Table 4**. All audio files were processed using the Raven-X software package (Dugan et al. 2016).

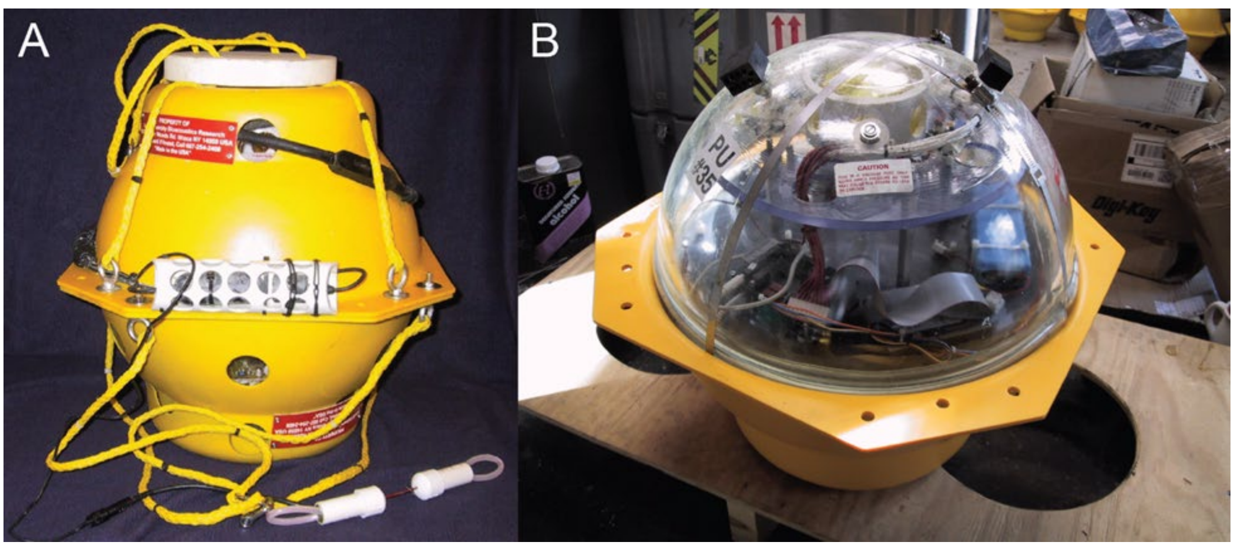

Figure 7. Detailed photographs of the MARU with A) external and B) internal views

Table 4. MARU deployment and recovery details. All data sampled at 10 kHz and 12-bit resolution. (Dates are given as MM-DD-YYYY, hh:mm:ss)

Site	Water Depth (meters)	Start Time [UTC]	End Time [UTC]	Hours Recorded
T-1M	20.1	08-29-2019, 12:57:15	10-15-2019, 08:11:00	1,123
T-2M	35.8	08-29-2019, 12:50:34	10-15-2019, 04:24:00	1,119
T-3M	40.3	08-29-2019, 12:42:13	10-15-2019, 03:32:00	1,118

2.2.5 LS1 acoustic recorder

Acoustic data were also collected at a fourth long-range site using an LS1 acoustic recorder (Loggerhead Instruments, Sarasota, Florida). This site was located approximately 15 km south of the proposed met tower location and 31 km from Ocean City, Maryland (**Figure 3** and **Figure 8**). The LS1 was deployed on 7 June 2019 on a mooring approximately 1.5 m above the ocean floor. The hydrophone was programmed to a duty cycle of 2 minutes on and 10 minutes off with a sensitivity of -180 dB V/µPa, a gain of 2.05 dB, and sampling rate of 48 kHz. The device was recovered on 30 October 2019.

Figure 8. Photograph of the mooring with the acoustic release at the bottom (left side of image), the LS1 acoustic recorder in the center of the line, and a sub-surface buoy at the top (right side of image).

To obtain measures of ambient sound levels, acoustic recordings from the LS1 were analyzed using PAMGUARD's Noise Monitor (Gillespie et al. 2008). To characterize the sound levels in this region, a generalized linear model (GLM) with Gaussian error distribution was used to determine variations in average hourly broadband and low-frequency sound levels.

2.3 Preliminary Data Analyses and Key Results

Background data collected by all the recorders were quality checked and *representative datasets* were selected for preliminary analyses. Key results are summarized below. All data are available for additional analyses in the future.

2.3.1 VLA Data

The depth time series from the SBE30 temperature and pressure sensors mounted on the sled is shown in **Figure 9**. The depth time series from the four SBE30 temperature and pressure sensors mounted on the west VLA is shown in **Figure 10**. **Figure 11** compares temperature and pressure recorded by the sensors on the west VLA and the sled.

A spectrogram from the southern VLA during period of calm sea conditions is shown in **Figure 12**. This figure shows some low-frequency, motion noise caused from the mooring. The mooring noise was seen on all four hydrophones but was not exactly collated between them. For the same time period, low-frequency signals were also recorded by the sensors on the west VLA and the sled. A zoomed in version of the spectrogram shown in **Figure 13** highlighting the lower frequency bands shown in **Figure 12**. Selected images from the monitoring gear recovered in October 2019 after approximately 8 weeks of underwater deployment are shown in **Appendix B**.

2.3.2 Geosled Data

A spectrogram of data collected by the four channels of the tetrahedral array hydrophones on 2 September 2019 is shown in **Figure 14**. These data show some low-frequency noise caused by the mooring. The mooring noise was seen on all four hydrophones. Similar sound levels were also recorded on other deployed recorders (VLAs) during the same time period. A snippet of the data recorded on 6 October 2019 by the three-axis geophone is shown in **Figure 15**. These data mostly show random noise.

2.3.3 OBX Data

Approximately 1 terabyte of high-quality data were recorded by the OBX recorder. **Figure 16** shows root mean square (rms) values for the entire duration of deployment of the OBX at the proposed met tower location.

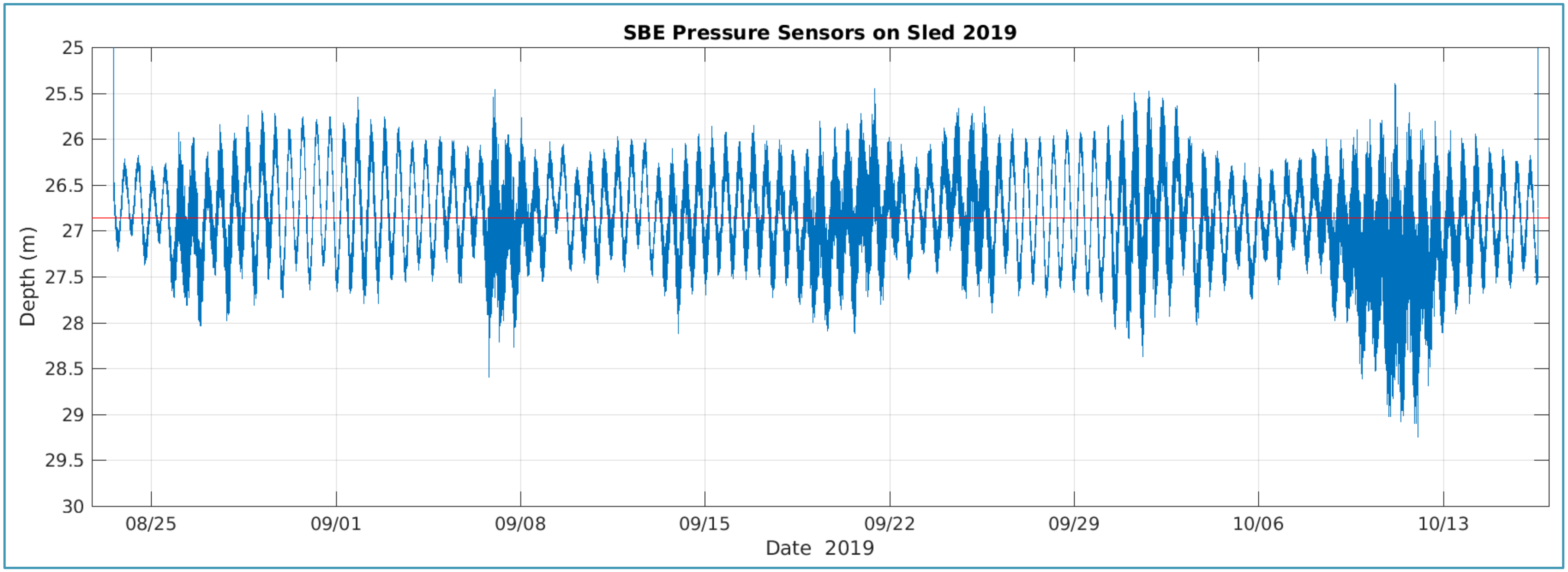

Figure 9. Depth time series from the sled SBE39 temperature and pressure sensor recording

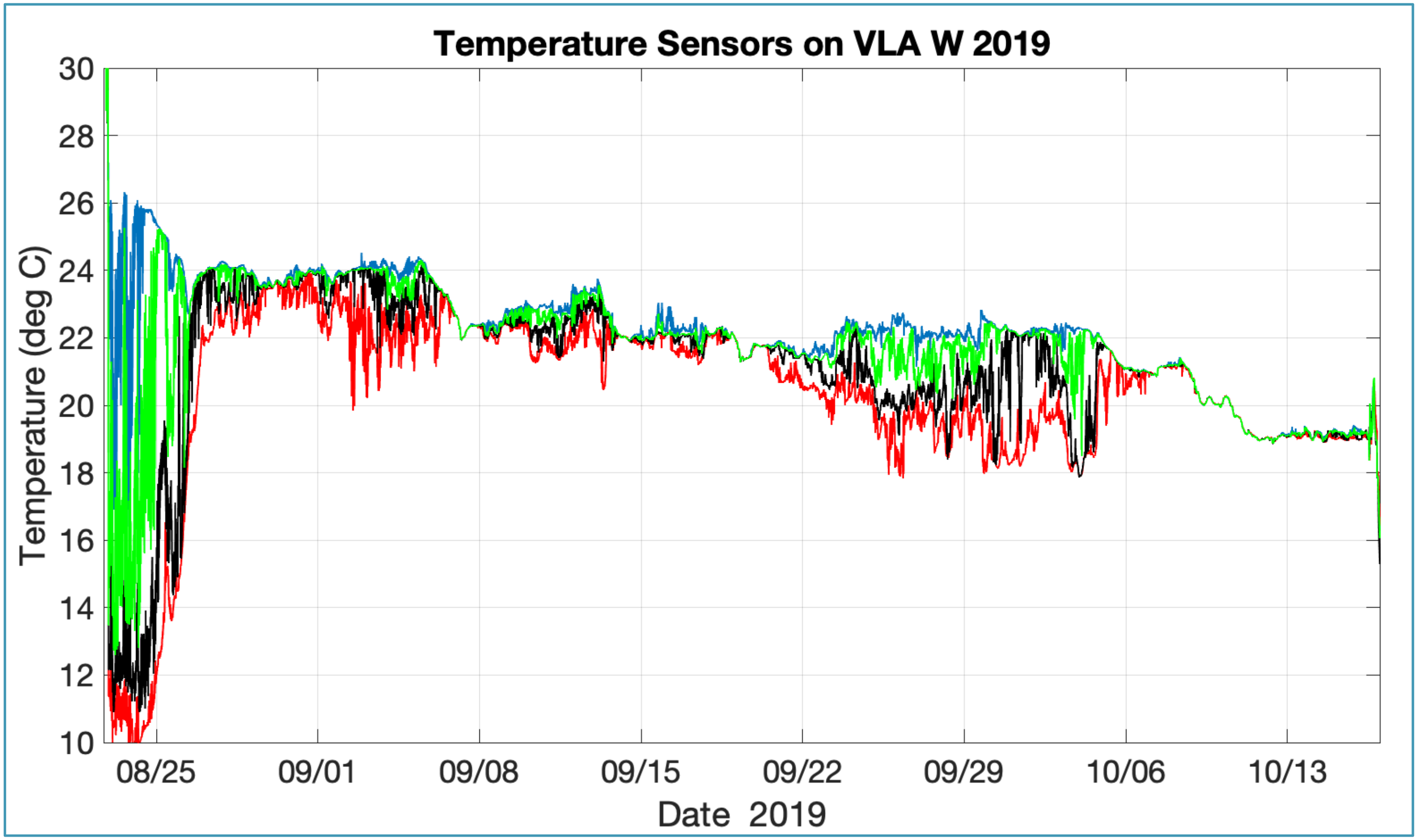

Figure 10. Temperature time series from the West VLA SBE39 temperature and pressure sensor recording

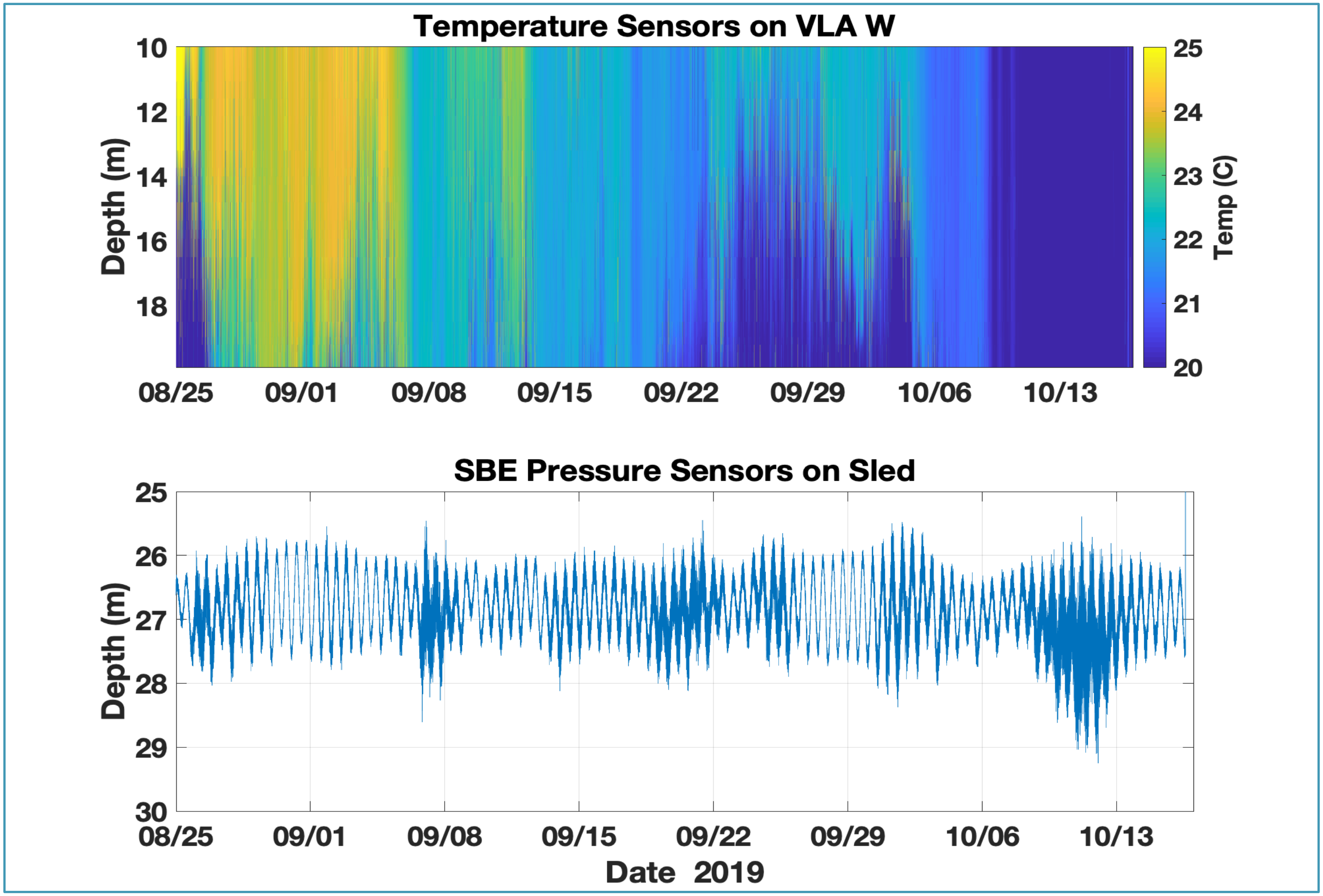

Figure 11. Comparison of temperature and pressure from sensors on the West VLA and the sled

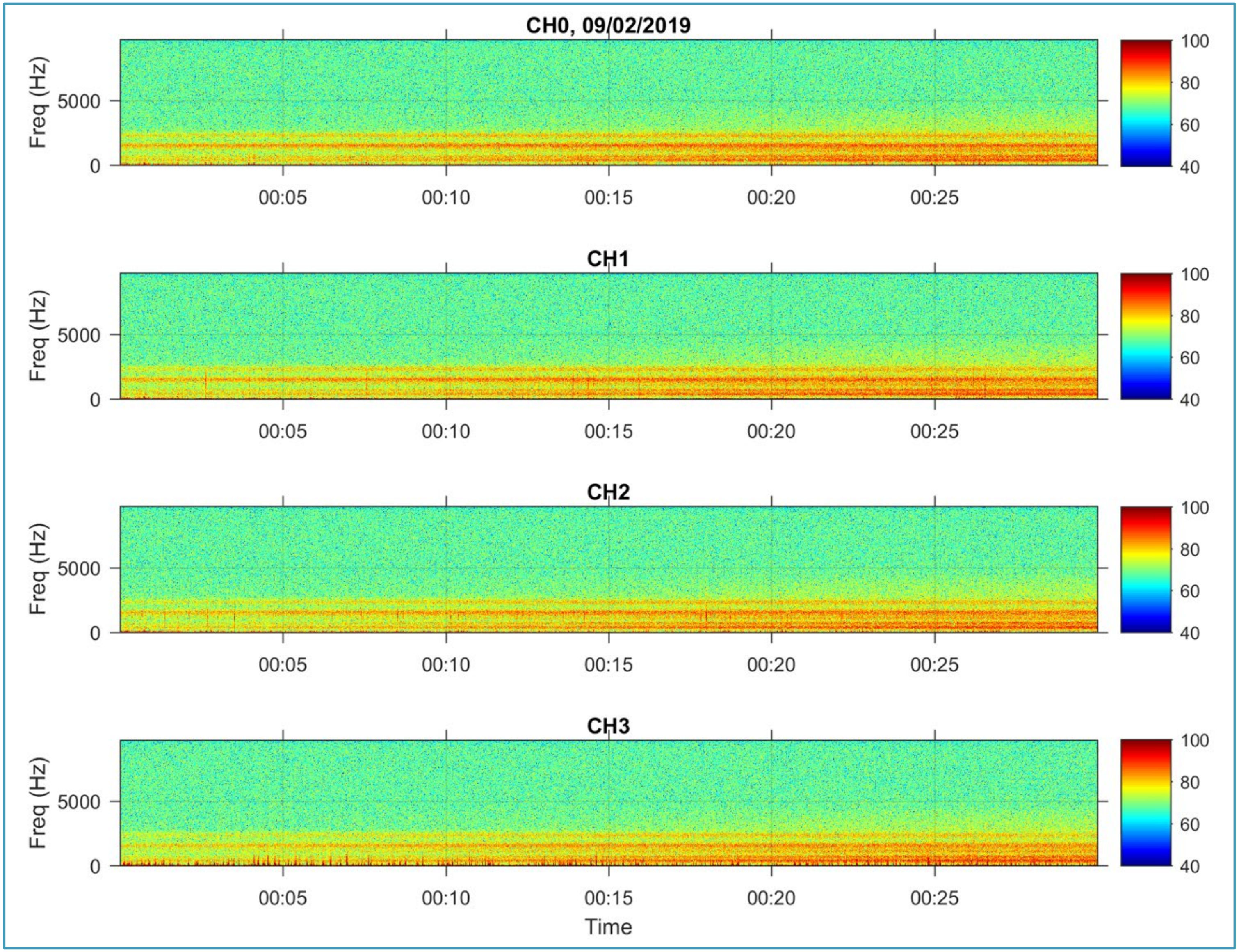

Figure 12. Comparison of temperature and pressure from sensors on the West VLA and the sled

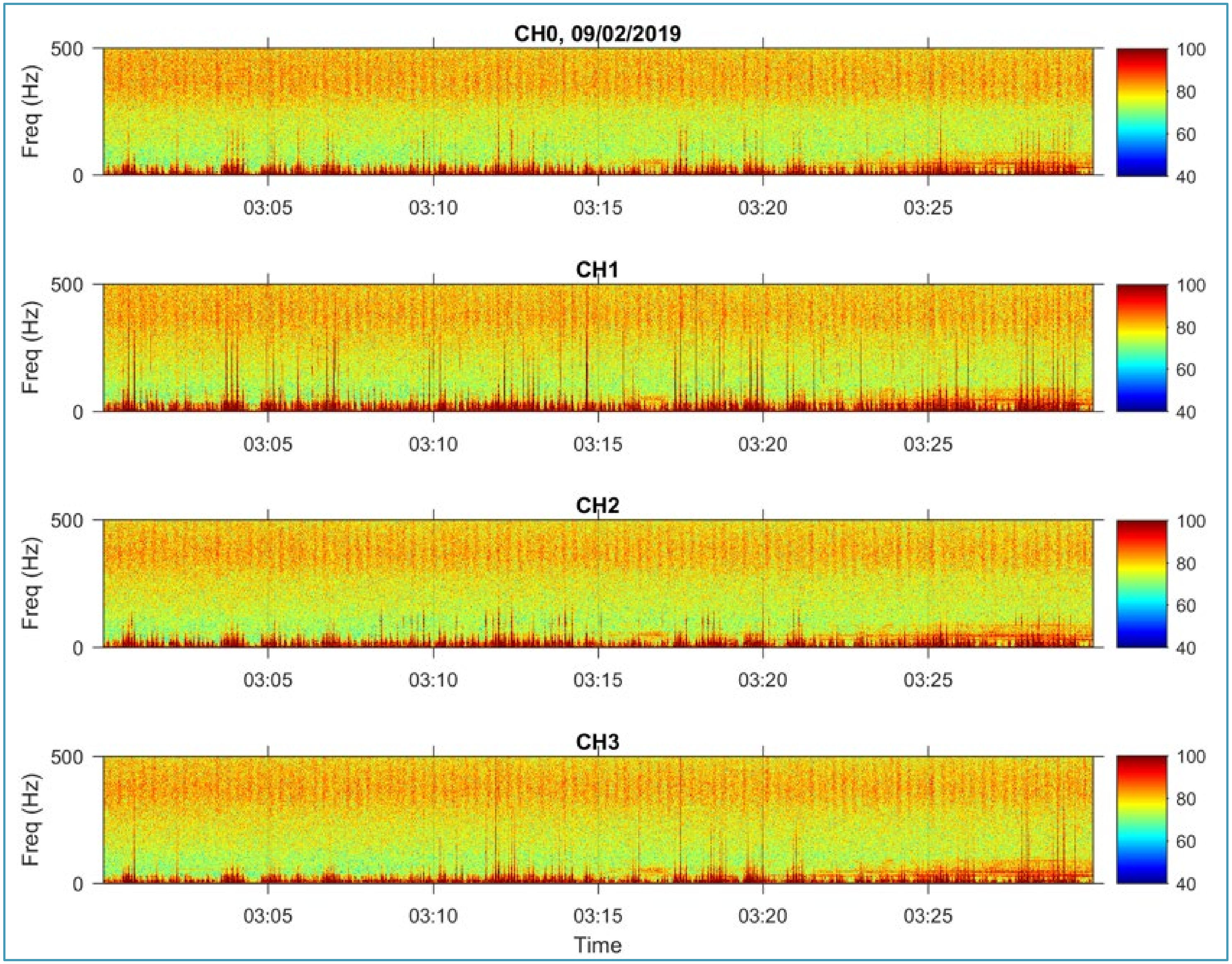

Figure 13. Spectrogram from south VLA zoomed into the lower frequency bands

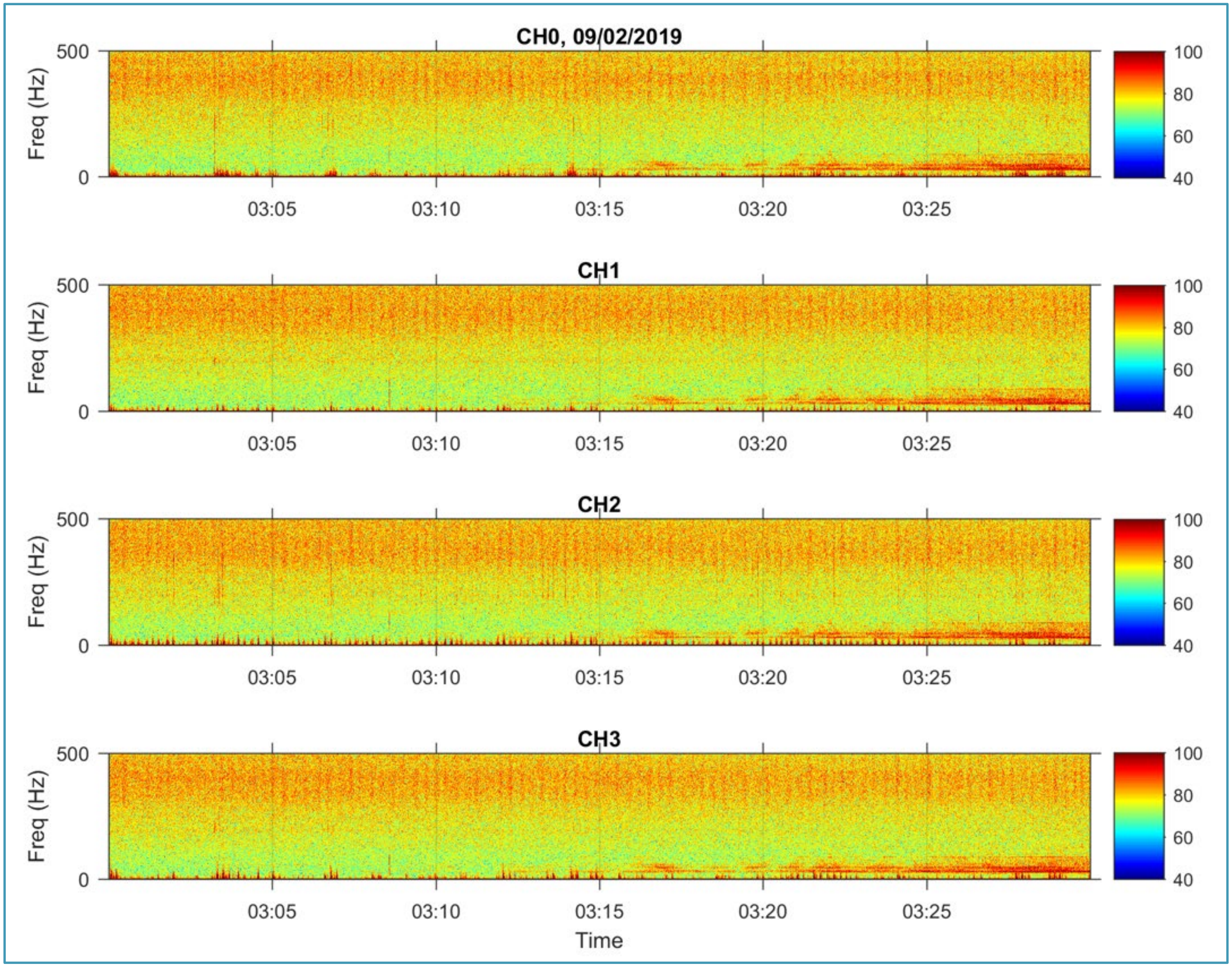

Figure 14. Spectrogram of four channels from the tetrahedral array attached to the sled on 2 September. Noise here is similar to SHRUs 907 and 910. SHRU910 data show some low-frequency, mooring motion noise. The mooring noise was seen on all four hydrophones but was not exactly collated among them

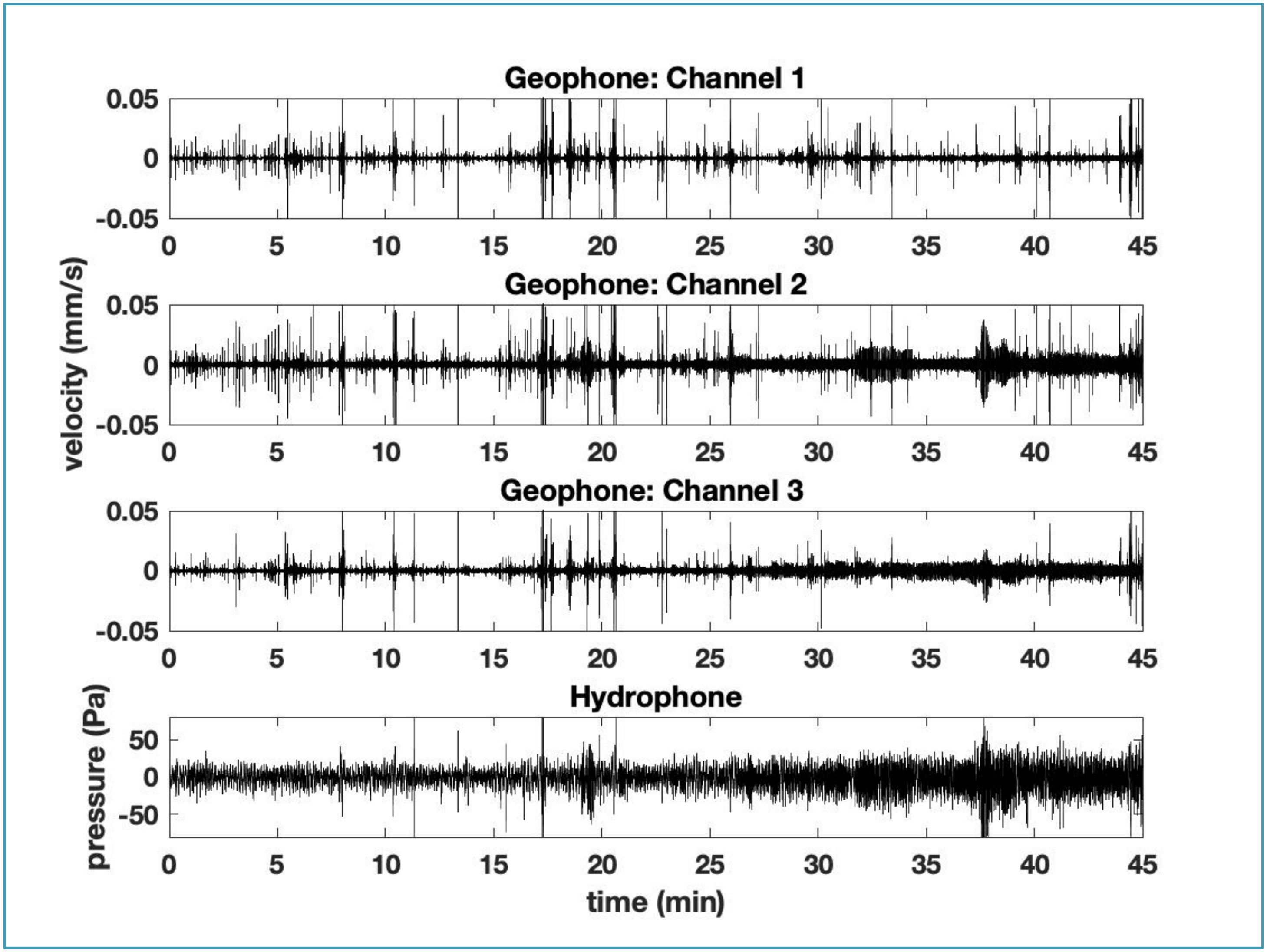

Figure 15. Three-axis geophone and hydrophone data. Three channels consist of velocity components, and the fourth consists of hydrophone pressure data

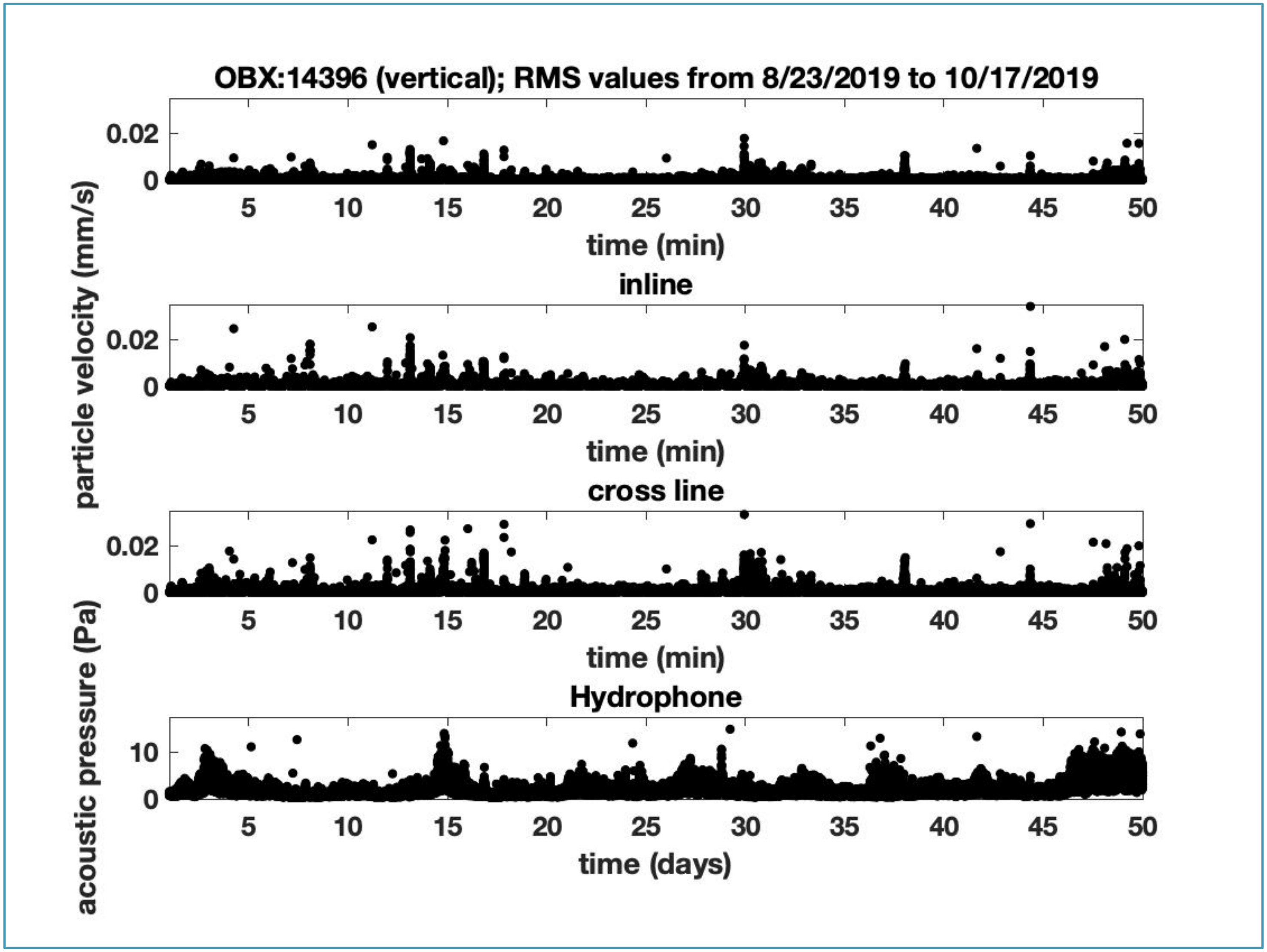

Figure 16. The root mean square (rms) values calculated using 1-minute windows for the duration of the OBX deployment near the proposed Maryland met tower. Particle velocity data in the vertical, inline and cross line directions, as well as hydrophone pressure data, are shown

2.3.4 MARU Data

The average power spectrum density levels by site are shown in **Figure 17**. At the shallowest site (T-1M), a different noise pattern was recorded across the entire frequency range, with median dB values much lower than the other sites in the 20 to 50 Hz range. It deviated from the other sites in the mid-frequency range of around 1,000 Hz, where it was approximately 5 dB louder with a peak of 85 dB around 1,800 Hz. Sites T-2M and T-3M measured similar patterns of noise levels throughout the total frequency range (**Figure 18**).

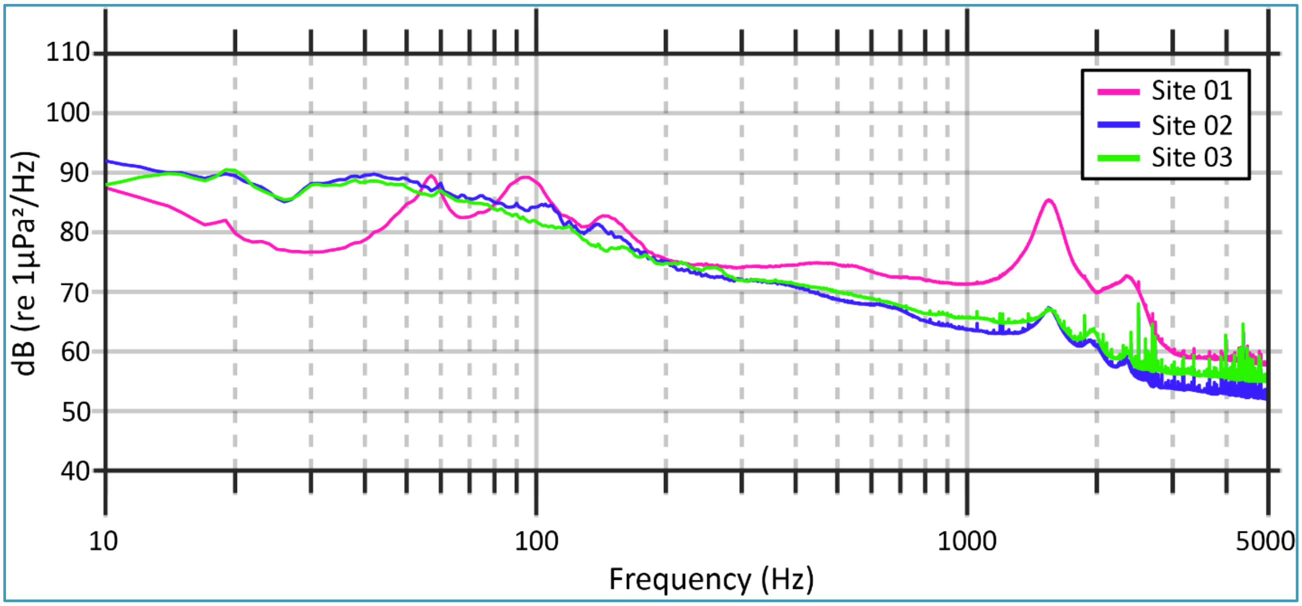

Figure 17. Average power spectrum density levels for each site

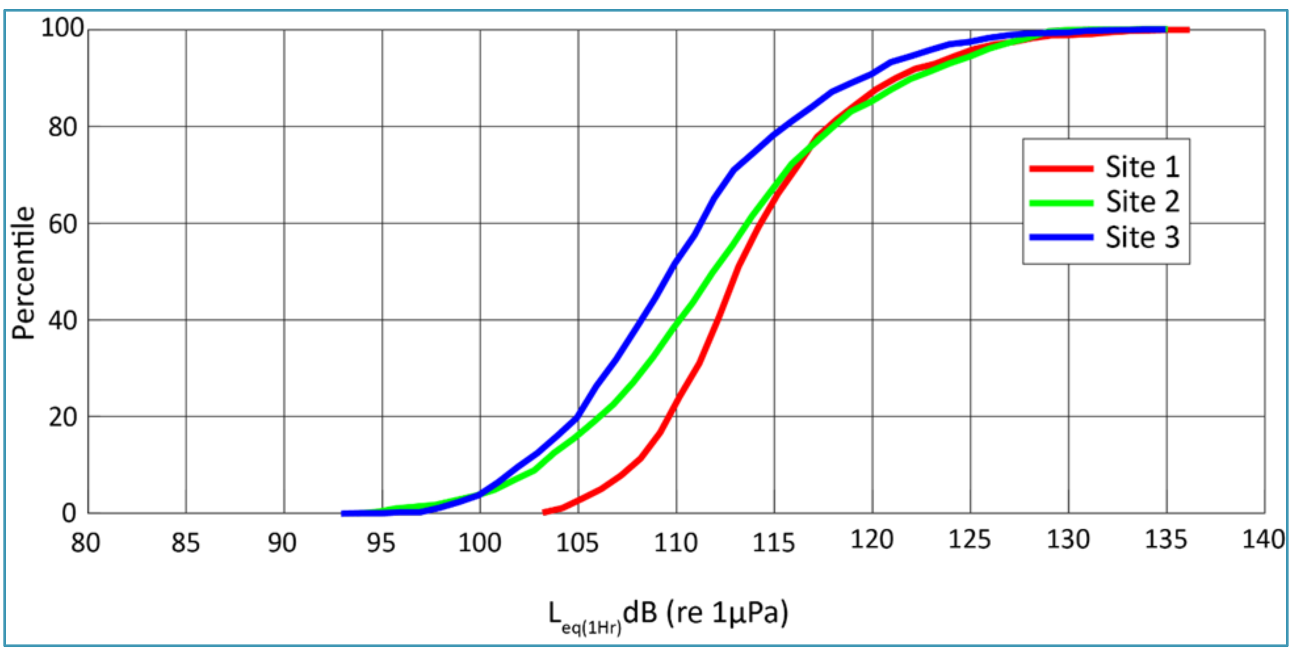

Figure 18. Cumulative distribution of full-band acoustic energy at each location

2.3.5 LS1 Acoustic Recorder Data

Acoustic data were collected for 88 days during 7 June 2019 to 3 September 2019.[2] Most of the ambient noise recorded was at low frequencies (<1 kHz), even on days with lower sound levels (**Figure 19**). The minimum hourly sound levels were 95.6 dB re 1 µPa rms (standard deviation [SD] = 0.3, broadband) and 93.9 dB re 1 µPa rms (SD = 0.35, low-frequency) at 0400 on 22 July, and maximum hourly sound levels were 125.1 dB re 1 µPa rms (SD = 7.7) for both broadband and low frequencies at 0600 on 13 August (**Figure 20**). The higher hourly sound levels tended to be caused by boat noise.

The mean daily broadband sound level was 108.0 dB re 1 µPa rms (SD = 5.3) and the daily low-frequency sound levels was 107.1 dB re 1 µPa rms (SD = 5.7). The minimum daily sound levels were 101.5 dB re 1 µPa rms (SD = 5.4, broadband) and 100.5 dB re 1 µPa rms (SD = 5.8, low-frequency) on 15 July and the maximum average daily sound levels reached 121.1 dB re 1 µPa rms (SD = 1.5, broadband) on 30 August and 121.0 dB re 1 µPa rms (SD = 0.9, low-frequency) on 31 August. Tropical Storm Erin passed through the area on 15 August 2019. There were also several instances of high wind conditions in mid-July and late August. Higher daily sound levels occurred when there were high wind conditions and storms but were also attributed to boat noise.

The results of the GLM indicated that sound levels were significantly higher during crepuscular hours for both the broadband (p <0.01; **Table 5**, **Figure 20b**) and low-frequency bands (p <0.01; **Table 5**, **Figure 20d**). The daily sound level showed a rapid increase in sound levels during the recording period from mid-July through August (R^2 = 0.838 (0.84), p <0.01; **Figure 21**).

Table 5. Results of the GLM analyzing average hourly broadband and low frequency sound levels in relation to the categorical variable of crepuscular (0400–0700 and 1900–2100) and non-crepuscular periods, and results of the GLM for daily broadband and low frequency sound levels

<table>
<tr><th colspan="6">Broadband sound (hourly): crepuscular GLM</th></tr>
<tr><th></th><th>Estimate</th><th>Standard error</th><th colspan="2">t</th><th>P</th></tr>
<tr><td>Intercept</td><td>109.29</td><td>0.29</td><td colspan="2">375.09</td><td></td></tr>
<tr><td>Non-crepuscular</td><td>-1.44</td><td>0.34</td><td colspan="2">-4.30</td><td><0.01</td></tr>
<tr><th colspan="6">Low frequency sound (hourly): crepuscular GLM</th></tr>
<tr><th></th><th>Estimate</th><th>Standard error</th><th colspan="2">t</th><th>P</th></tr>
<tr><td>Intercept</td><td>108.11</td><td>0.34</td><td colspan="2">314.05</td><td></td></tr>
<tr><td>Non-crepuscular</td><td>-1.34</td><td>0.39</td><td colspan="2">-3.43</td><td><0.01</td></tr>
<tr><th colspan="6">Broadband sound (daily): linear model</th></tr>
<tr><th>Model</th><th>F-stat</th><th>Standard error</th><th>df</th><th>R^2</th><th>P</th></tr>
<tr><td>Mean SPL ~ Day + Day2</td><td>222.5</td><td>2.2</td><td>86</td><td>0.84</td><td><0.01</td></tr>
<tr><th colspan="6">Low frequency (daily): linear model</th></tr>
<tr><th>Model</th><th>F-stat</th><th>Standard error</th><th>df</th><th>R^2</th><th>P</th></tr>
<tr><td>Mean SPL ~ Day + Day2</td><td>230.2</td><td>2.3</td><td>86</td><td>0.84</td><td><0.01</td></tr>
</table>

[2] The LS1 instrument was supposed to record for up to 332 days given the battery life indicated by the manufacturer and programmed duty cycle. However, recording ceased early on 3 September 2019.

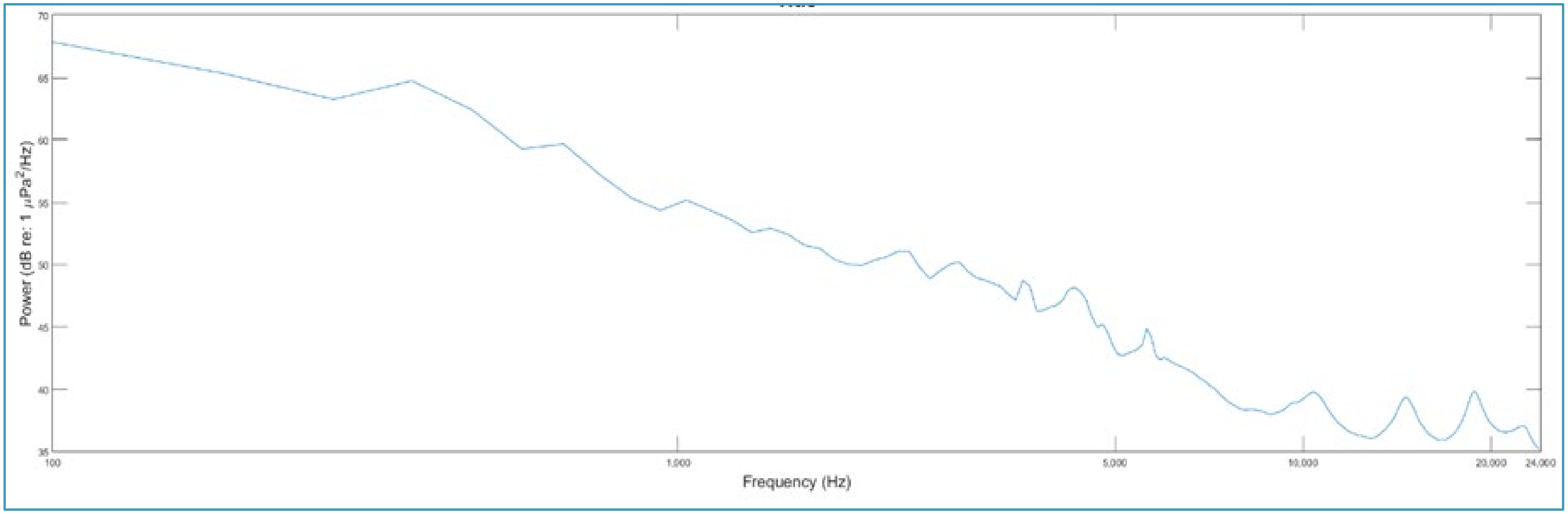

Figure 19. Power spectral density for a day with relatively low ambient noise levels (15 July 2019)

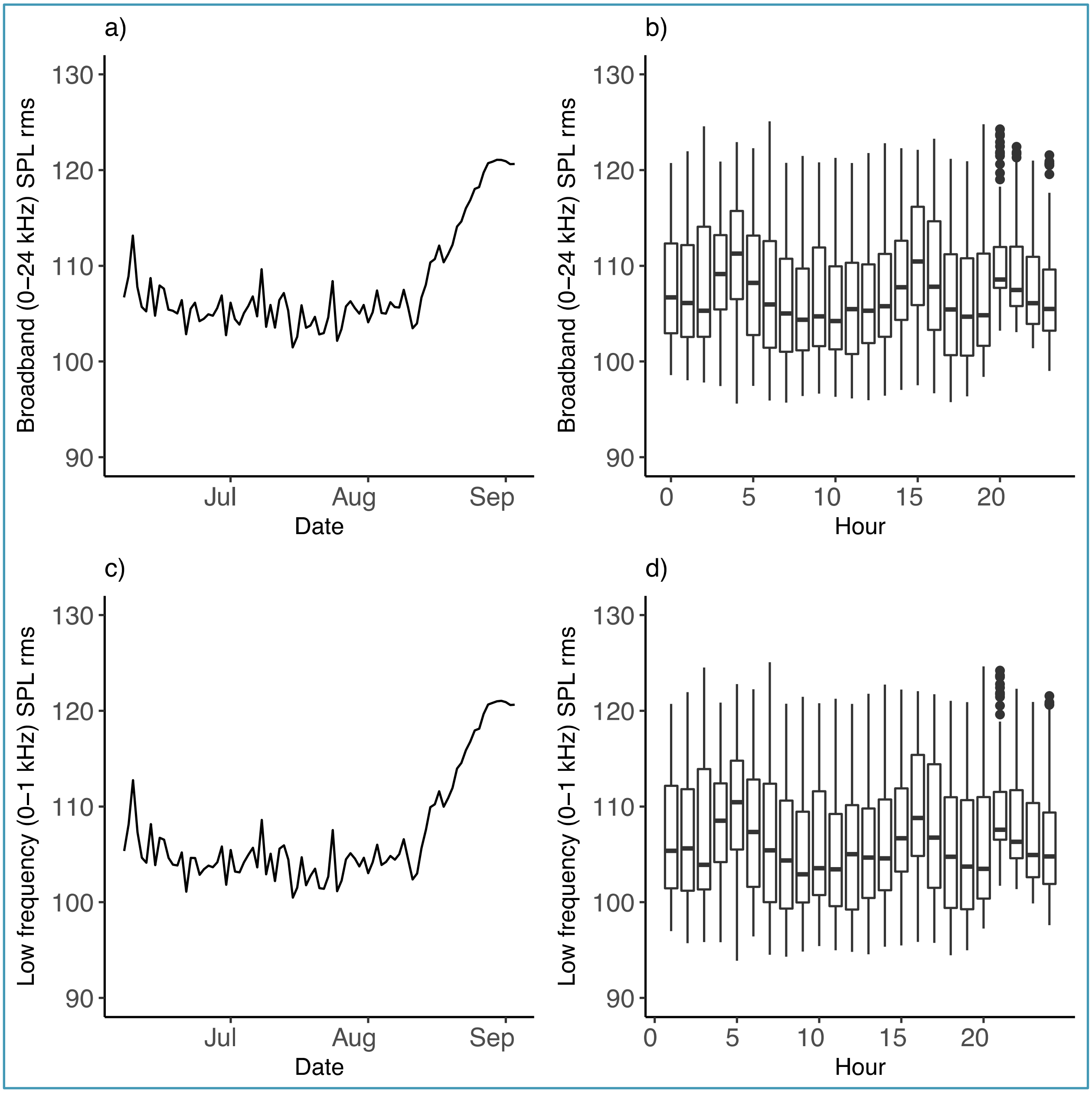

Figure 20. Average daily (a) broadband and (c) low frequency sound pressure levels, and average, first, and third quartile hourly sound pressure levels for (b) broadband and (d) low frequency sound levels with outliers

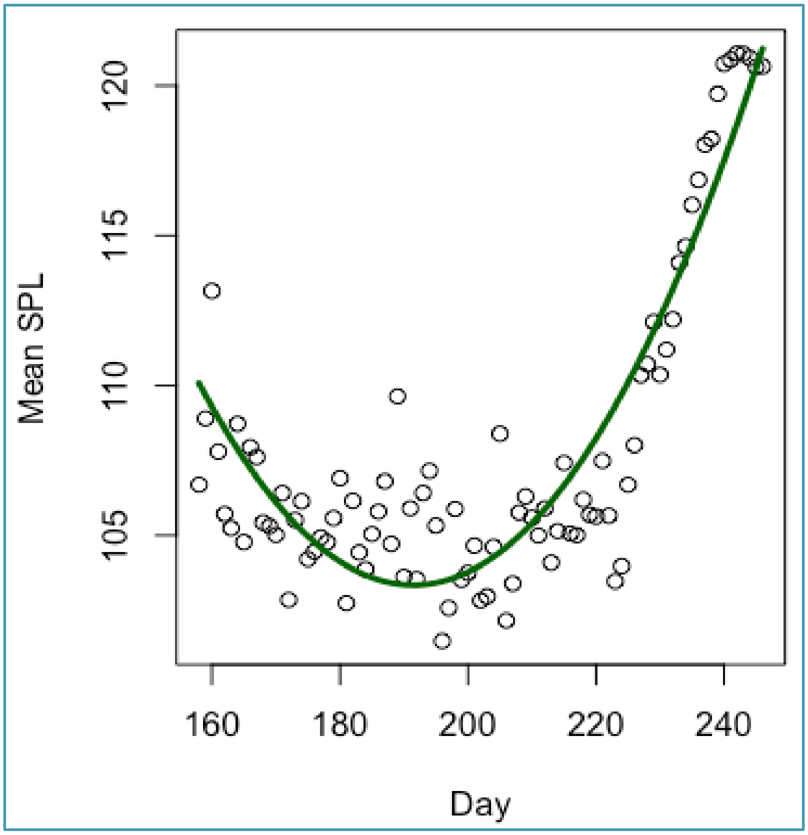

Figure 21. Daily (Julian day: 158 = 7 June; 246 = 3 September) mean SPL (circles) and predicted daily SPLs based on a quadratic linear model (green line)

2.4 Conclusions and Discussion

Preliminary VLA data analysis indicated that ambient noise was dependent on sea state. Shipping noise was also recorded on the VLAs. An improved hydrophone cage design was developed and successfully field tested during this monitoring; this design is recommended for use in future offshore monitoring programs. Preliminary analyses of Geosled and OBX data indicated that the equipment performed as intended. The systems measured ambient noise from local shipping activity, storms, and biologics. The dataset provides a baseline for comparing the pressure and particle velocity signals to those from future construction activities.

Preliminary analyses of data collected by the MARUs and LS1 indicated that Site T-1M showed lower levels of acoustic energy in the lower frequencies and higher energies in the higher frequencies than those at the other two sites measured. This could be due to sound propagation as a function of depth, where lower frequency sounds propagate farther in deeper waters and higher frequency sounds propagate farther in shallower waters (Kuperman 1996, Bass and Clark 2003, Carey 2006). Despite Sites T-2M and T-3M being located near the shipping lanes, they were not different than Site T-1M between 100 and 1,000 Hz, where most of the energy from shipping noise occurs, and had lower overall cumulative levels than Site T-1M.

Overall, data recorded at the met tower site by the RODEO Program had a similar range of sound levels (101.5 and 121.1 dB re 1 µPa rms) as compared to those observed during a previous PAM study conducted in the southern part of the Maryland Wind Energy Area (approximately 108 to 123 dB re 1 μPa rms; Bailey et al. 2019).

Following a decrease in sound levels on 11 and 12 August, sound levels increased as Tropical Storm Erin approached the region. Dominated by the storm, sound levels continued to increase rapidly for the remainder of the recording period (**Figure 20**). As expected, vessel noise, which is common in the region from both recreational and commercial traffic, was also recorded (Bailey et al. 2019).

Additional details on the analyses of data from the MARUs and the LS1 recorder are contained in the technical report presented in **Appendix B**.

3 CVOW Project Wind Turbines Underwater Passive Acoustic Monitoring

3.1 Monitoring Objectives

The CVOW pilot project consists of two 6 MW wind turbine generators, located 43 km east of Virginia Beach, Virginia (**Figure 22**). The turbine foundations are monopiles with a diameter of 7.8 m and a length of approximately 67 m. The installation of monopile foundations in the seabed involved pile driving, an activity that results in high underwater noise levels. These noise levels can potentially cause injury or disturb underwater life, such as marine mammals, sea turtles, and fish. Underwater acoustic monitoring was conducted during installation of the two monopile foundations in order to: 1) measure changes in SPLs; 2) record sound levels in the water column and vibrations in the sediment; 3) detect particle-motion; and 4) assess the effectiveness of a noise mitigation system to reduce underwater noise generated during pile installation.

The turbines were designated as A01 (northern turbine) and A02 (southern turbine). A noise mitigation system (double big bubble curtain, hereafter referred to simply as bubble curtain) was implemented during pile driving for Turbine A02 to test efficacy of underwater noise attenuation. No bubble curtain was used during the pile driving for Turbine A01 for comparison.

The bubble curtain system consisted of two independent air hoses placed at the seabed encircling the pile. When in operation, air was pumped from a supply vessel via compressors placed on the deck of the vessel. The curtain had 1.5-millimeter (mm) holes interspaced at 250 mm. Air bubbles would leave the hose nozzles and rise to the water surface, thus forming a bubble curtain.

The project owners (Dominion) were required to collect underwater acoustic data *only* in the short-range (within 1.7 km) of the turbine locations. RODEO Program monitoring included placement of sensors both at ***short-range*** from the turbines (within 3 km) and at ***long-range*** (7.5 to 30 km). Per the BOEM-approved Work Plan, both ***unattended*** and ***attended*** monitoring were conducted.

3.2 Data Recording Systems

Unattended monitoring included placement of heavy stationary moorings equipped with different types of recording systems on the seafloor (**Table 6**) at pre-determined locations around the construction site (**Figure 22**). The unattended systems were programmed to collect data over multiple weeks to capture sounds before, during, and after the proposed pile driving was completed. These moorings were deployed on 23 May 2020 and retrieved approximately 2 weeks later using *R/V Warren Jr* stationed out of Boston, Massachusetts.

Pile driving for turbine A02 was conducted on 25 May 2020 from 15:33 to 17:14 and for Turbine A01 on 30 May 2020 from 11:23 to 12:38 (UTC-4). Attended PAM was conducted during pile driving for both turbines using a towed hydrophone array and a dipping hydrophone system. Additional information on the different types of recording systems deployed at the CVOW Project Site is presented in **Table 6**.

Table 6. Underwater passive acoustic monitoring systems selected for deployment at the CVOW Project Site

Systems	Data Collection Objective	Distance(s) from Turbine Foundations	Depth	Deployment Dates
Unattended Monitoring				
Vertical Line Arrays (VLA)	Short-range pressure signals	3.0 kilometers (km)	26 meters (m)	23 May – 8 June 2020
	Long-range pressure signals	7.5 km		23 May – 8 June 2020
Geosled with tetrahedral hydrophone array and a 3-axis geophone	Short-range particle velocity in the water column and at the seabed, pressure signal at a fixed range	1.5 km	26 m	23 May – 8 June 2020
Ocean Bottom Recorders (OBX) Geophone and Hydrophone Sensor System	Range dependence of short-range particle velocity in the water column and at the seabed, pressure signal	1,505 m to 1,525 m with 5 m spacing in between each recorder	26 m	23 May – 8 June 2020
Attended Monitoring				
Towed Array	Range dependence of near and long-range pressure signals	2.3 to 9.8 km	~10 m when towed at 3 knots (kts) and ~5 m when towed at 5 kts	25 May and 30 May 2020
Dipped hydrophone	Long range dependence of pressure signal	15 to 30 km	14 to 30 m	25 May and 30 May 2020

For the RODEO Program monitoring, short range was defined as <3 km and long range was defined as 7.5 to 30 km.

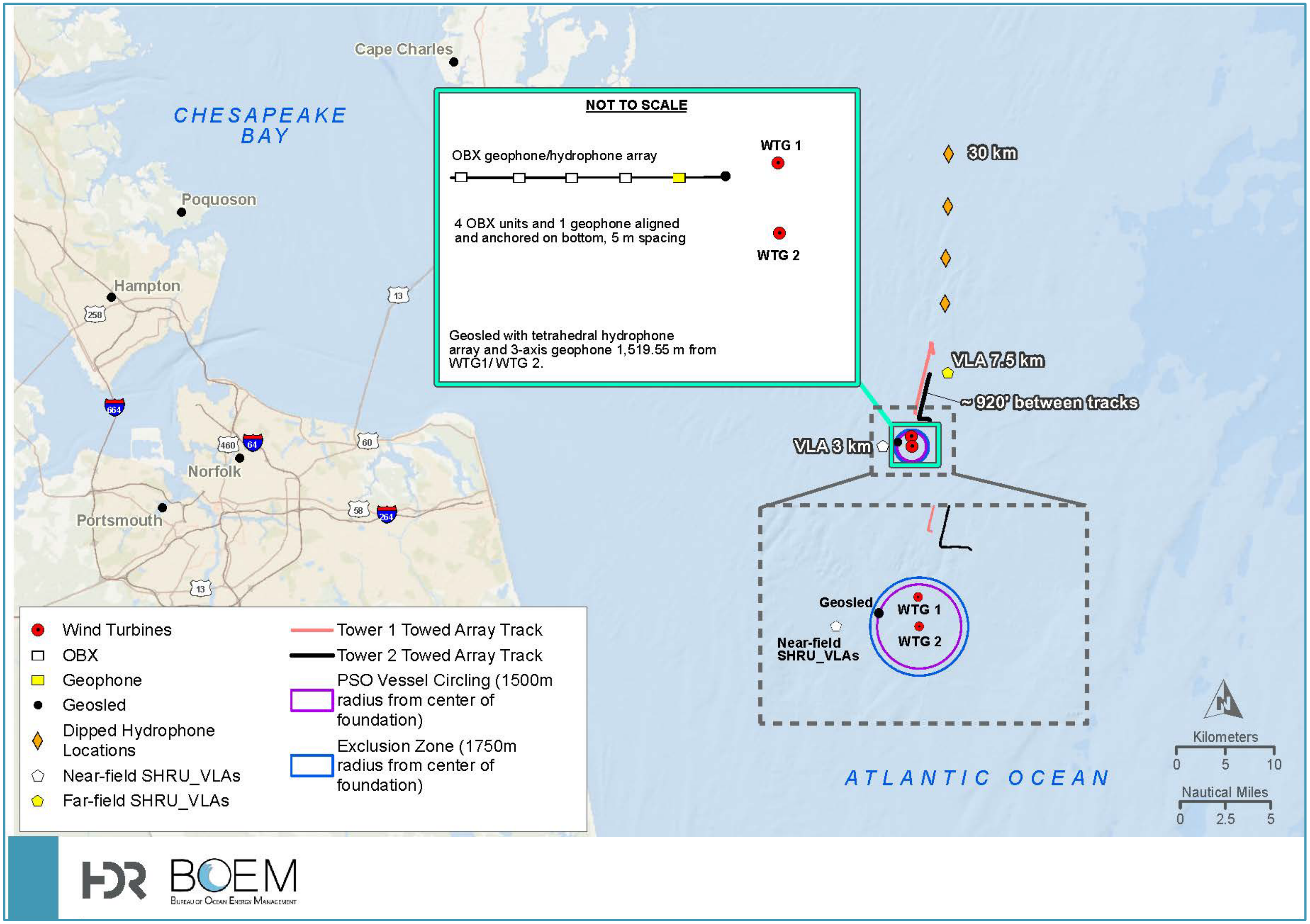

Figure 22. Locations of underwater passive acoustic monitoring systems deployed at the CVOW Project Site

3.2.1 Vertical Line Arrays (VLA)

Two VLAs equipped with SHRUs (**Figure 23**) were deployed within the CVOW Project area at locations listed in **Table 7**. The VLA acoustic receivers were modified to sample at approximately 20 kHz using 24-bit data samples. The four hydrophones on each VLA were low sensitivity (-204 dB) using 6 dB preamp gain. Each VLA was also equipped with temperature and pressure sensors. Water depth at both VLA locations was 26.0 m, and the four hydrophones on each VLA were mounted at depths of 13.7 m, 15.3 m, 18.8 m, and 20.4 m. Exact sampling frequency for both VLAs was 19,531.3 Hz. VLA hydrophone calibration data is shown in **Appendix C**.

Table 7. SHRU VLA Location Coordinates

Sensor ID	Latitude	Longitude	Comments
SHRU VLA 910	36° 53.4938 N	75° 31.4899 W	Short-range VLA (~3.0 km)
SHRU VLA 913	36° 57.2452 N	75° 26.8800 W	Long-range VLA (~7.5 km)

3.2.2 Geosled

A heavy iron sled with two SHRU electronics packages mounted on it was positioned 1.5 km west of the turbine locations at latitude 36º 53.4936 N and longitude 75º 30.4580 W. A four-element tetrahedral hydrophone array and a three-axis geophone were mounted on this sled (**Figure 24**). The tetrahedral array hydrophones were low sensitivity (-204 dB) using 6 dB preamp gain. SBE39 temperature and pressure sensors were also mounted on the sled. Geosled hydrophone calibration data is also shown in **Appendix C**.

3.2.3 OBX Seismic Sensors

Sound waves in water have both a pressure and a particle-motion component, yet few studies of underwater acoustic ecology have measured the particle-motion component of sound. Fish, and many marine invertebrates, detect and use the particle-motion component of sound to navigate their environment (Nedelec et al. 2016). It is therefore important to gather data to better understand the particle-motion component of underwater sound. Particle-motion levels cannot always be predicted from sound pressure measurements (Popper and Hawkins 2018). An Ocean Bottom Seismometer array, manufactured by the Geospace Corporation, was therefore deployed at the site to collect data necessary for particle-motion analyses.

The array consisting of four self-contained units (OBXs) was anchored to the Geosled behind the three-axis geophone as shown in the schematic in **Figure 24.** A close-up photo of the geophone and OBX system is shown in **Figure 25**. Actual distances of the three-axis geophone and the OBX systems from the sled are listed in **Table 8**. Each OBX has four channels, which record both acoustic pressure and particle velocity in three mutually perpendicular directions. The OBX package also contains a pitch and roll sensor which measures the pitch and roll at 1-minute intervals. The geophones sampled at 9,765.6 Hz and the hydrophones on the tetrahedral array sampled at 19,531.3 Hz. The OBX sensors were factory-calibrated in early 2020. Laser calibration of sensors could not be performed prior to instrument deployment due to COVID-19 restrictions.

Table 8. Relative positions of the 3-axis geophone and OBX systems

Sensor ID	Distance from the Geosled (meters)
3-axis URI Geophone	5
OBX13988	10
OBX13449	15
OBX14010	20
OBX14396	25

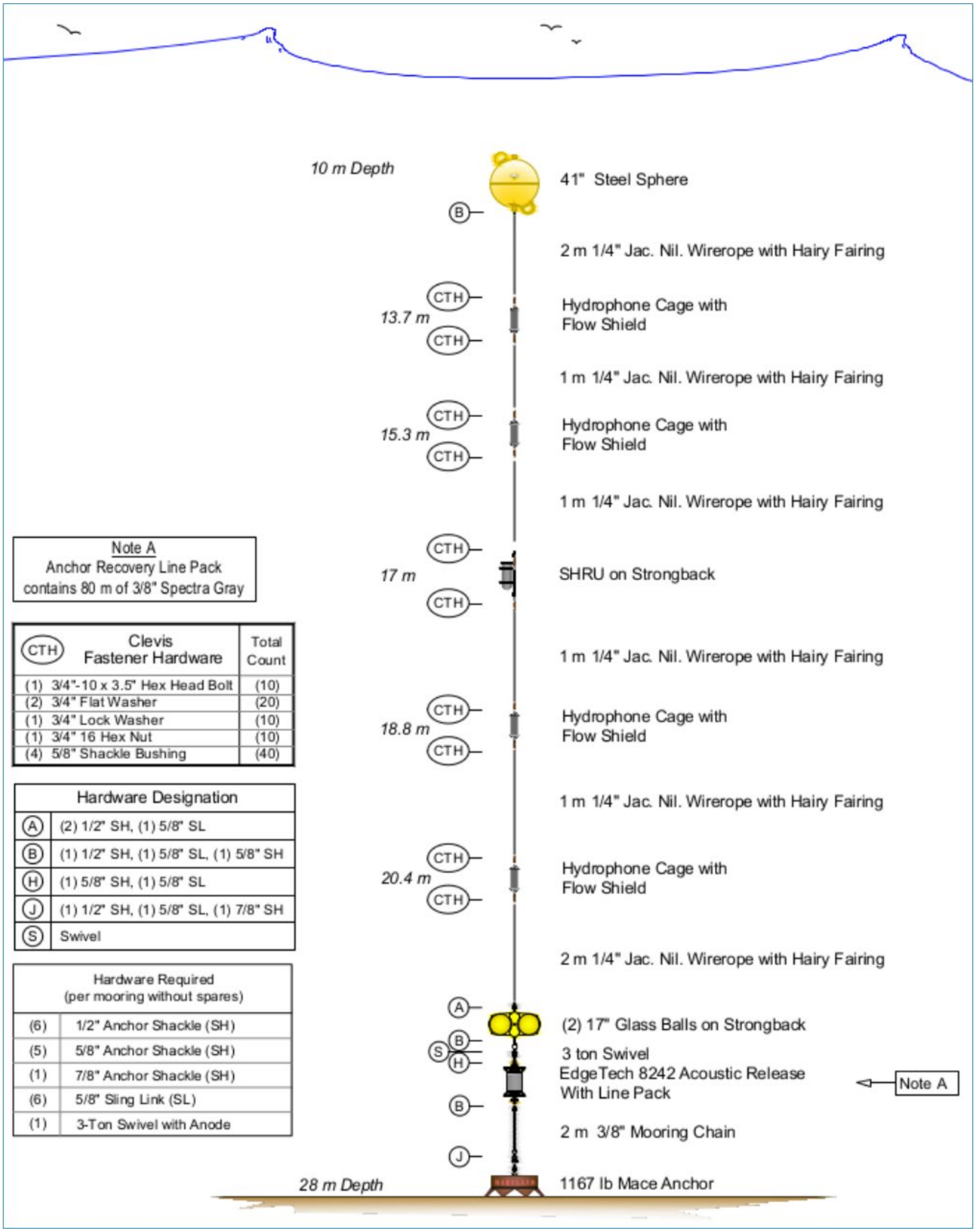

Figure 23. VLA mooring Configuration

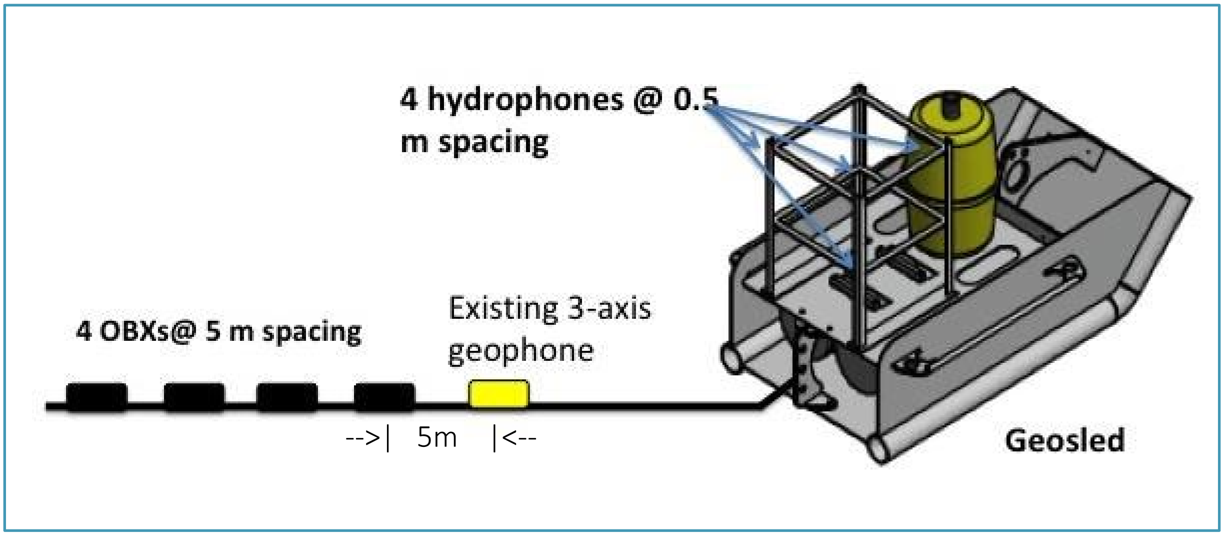

Figure 24. Geosled configuration showing the nominal spacing of the three-axis geophone and OBX system (actual distances of the geophones and the OBXs are listed in Table 8)

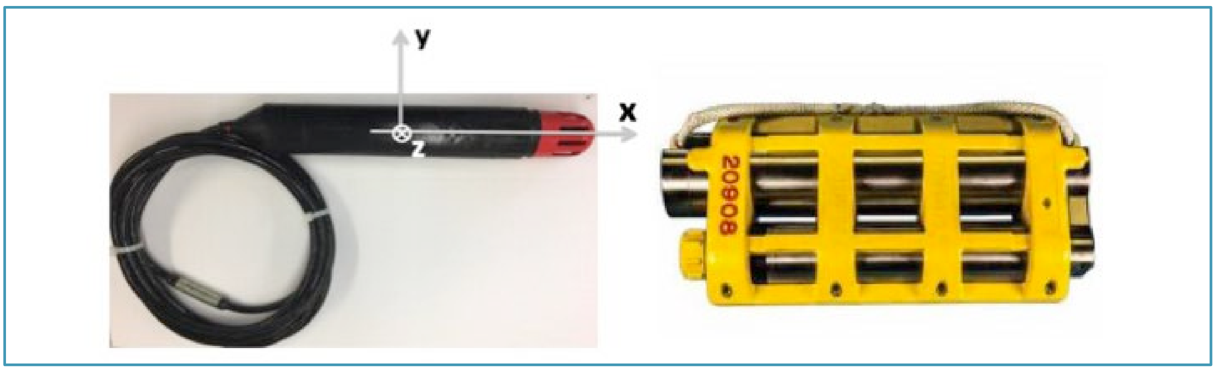

Figure 25. Close up view of the three-axis geophone (right panel) and OBX system (left panel)

3.2.4 Attended Monitoring with Towed Arrays

A vessel-based towed array (**Figure 26**) was deployed during active pile driving conducted for both turbines (25 May 2020 for Turbine A02 and 30 May 2020 for Turbine A01). The array was composed of eight elements spaced irregularly over a 120 m length, with 50 m of lead in cable, powered by two 12-volt batteries. Analog data were conditioned with an Alligator SCS-820 Bessel-function low-pass filter system that also provided adjustable signal gain.

Data were digitized at a sampling rate of 100 kHz per channel with a 16 bit-depth using a National Instruments NI-USB 6356 converter. A laptop computer saved the data in 30-second-long multichannel files using Raven Pro v 1.5 (https://ravensoundsoftware.com/) in Auto Interchange File Format. The hydrophone elements have a sensitivity of -194 dB re 1V/µPa and the array has a flat frequency response to 4 kHz, with the sensitivity falling off at higher frequencies (Frankel et al. 2014).

Vessel location data was recorded on a portable hand-held Global Positioning System unit (Garmin MAP76). The towed array tracks started 2 km northeast from the turbine locations and were executed at a heading of 15° TRUE (**Figure 27**).

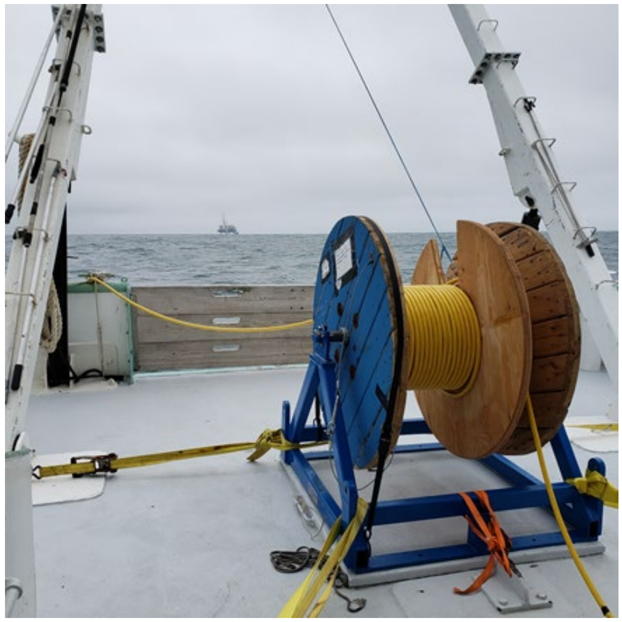

Figure 26. Towed array deployed off the stern of the *R/V* Tiki XIV during one of the piling events. The lift barge used for the piling can be seen in the background

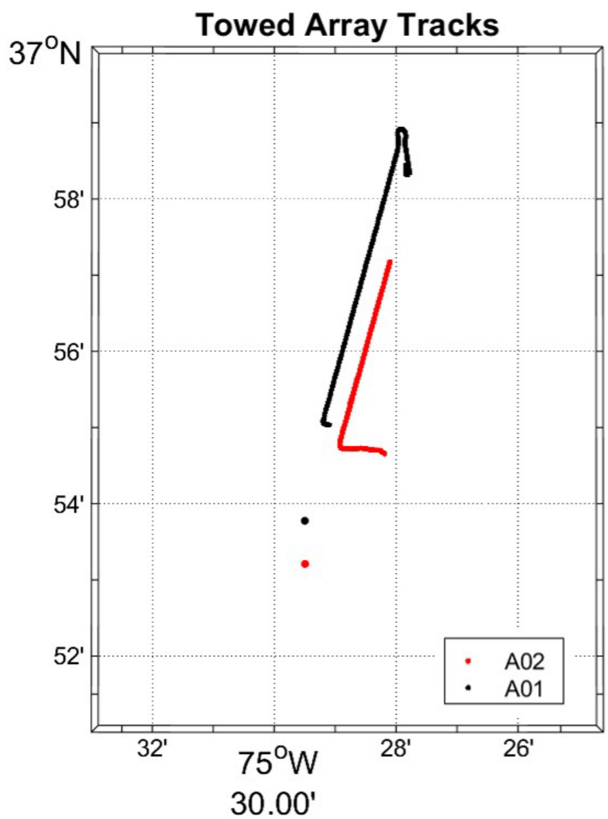

Figure 27. Towed array tracks during the piling of Turbine A01 (black) and A02 (red). Both tracks had a heading of 15° TRUE

The length of the towed array transect was dictated by the duration of pile driving. Turbine A02 was installed in 106 minutes, and Turbine A01 in 73 minutes. The array was towed at a speed of between 3 and 5 knots (kts; 1.5 to 2.6 meters per second) on both days. The deepest hydrophone on the array was estimated to be at a depth of approximately 10 m when towed at 3 knots and approximately 5 m when towed at 5 kts. The measurements from this deepest hydrophone are presented in this report. The distance of the towed array from the turbine foundation over the length of the tow track for both days is shown in **Figure 28**. The data were collected over similar distances during both piling events, which allows for direct comparison of the two events at the same distances.

During both rounds of towed array monitoring a VEMCO fish tag receiver was attached to the end of the array at the request of Naval Facilities Engineering Command Atlantic. At the end of the monitoring the VEMCO receivers were returned to Naval Facilities Engineering Command Atlantic for data download and analyses.

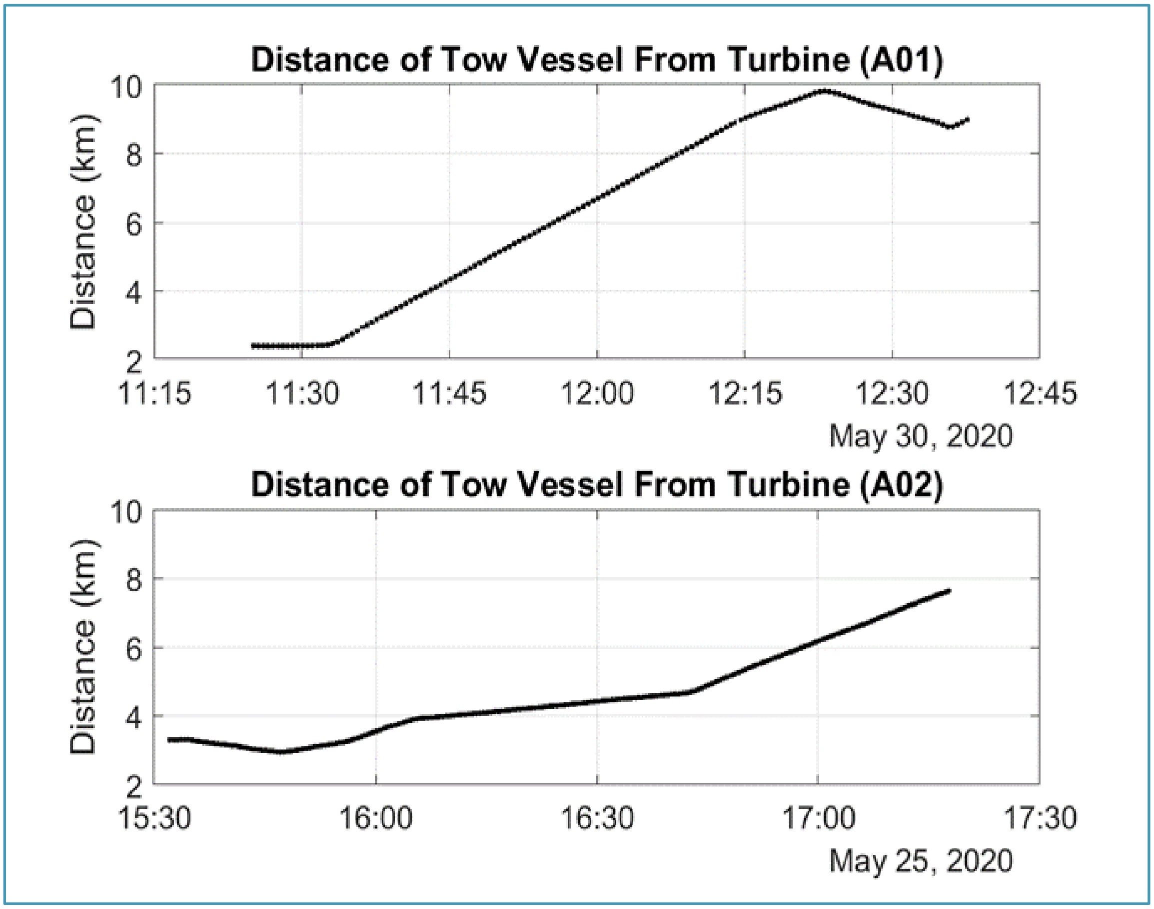

Figure 28. Distance of the survey vessel *R/V* Tiki XIV from each of the turbine foundations during piling activity. The vessel started close to the turbine and moved farther away once piling began.

3.2.5 Attended Long-range Measurements Using Dipped and Fixed-Location Hydrophones

Underwater noise levels were recorded for each piling event using a fixed-location hydrophone, deployed prior to each pile installation and retrieved afterward, and mobile, vessel-based measurements were taken along a transect directed 15° from the turbine foundations (**Figure 22**). Measurements started at 15 km from the piling, and at each transect measurement position, data were recorded at two depths: mid-water and approximately 1 m above the seabed. The measurement locations were in line with the coast and effectively a continuation of the towed array track but at a longer range.

3.2.5.1 Fixed monitor measurements

An OceanSonics icListen hydrophone was deployed at a fixed location from the foundation for each measurement day. The hydrophone was fixed at a mid-water depth of 14 m and at approximately 15 km (±20 m) from the location of the piling. The monitor was set to sample the noise levels continuously, with 5-minute sample periods at a sample frequency of 256 kHz at 24-bit resolution.

3.2.5.2 Transect measurements

The fixed monitor location served as the first location on the long-range transect. The transect continued with measurements taken with a Brüel & Kjær type 8106 hydrophone deployed from the side of the survey vessel *R/V* Integrity. The survey vessel's engines and other equipment which might have caused acoustic interference with the measurements were turned off and the vessel was allowed to drift while measurements were taken. The hydrophone was attached to an anti-heave buoy to stabilize the hydrophone while undertaking measurements, reducing the effect of surface waves. The hydrophone was allowed to float and drift freely from the vessel to minimize flow noise during measurements. Hydrophone drifts extended to 10 to 15 m from the start position, before the hydrophone was recovered and redeployed. The Global Positioning System position was logged at the start of the drift and at the closest point to the vessel (typically within 5 m of the actual hydrophone position).

Mobile, vessel-based measurements were taken at 20 km, 25 km, and 30 km from the piling (**Figure 22**). These followed a bearing of approximately 15° from the piling location, parallel to the coastline. At each location, sound data was recorded together with details of the vessel's position and other relevant environmental information (e.g., weather conditions, wave height). Measurements were repeated at each location and taken at two depths: mid-depth, and approximately 1 m above the seabed. This was done by recovering the hydrophone and changing the length of the riser line in order to re-deploy the hydrophone at the second depth. The depth of water along the transect was between 27 and 30 m.

3.3 Oceanographic Information

The CVOW Project is located near the bifurcation of the Gulf Stream and is therefore subject to rapidly changing oceanographic conditions. This phenomenon was also observed during the monitoring period. Shipboard conductivity, temperature, and depth (CTD) casts were performed during deployment and recovery of the moored sensors. CTD measurements included complete water column measurements of salinity (C), temperature (T), and pressure (D), and water column sound speed profiles were estimated from these three oceanographic measurements.

Figure 29 shows the sea surface temperature around the time of sensor deployment (left panel) and recovery (right panel). CTD water column profiles at deployment and recovery are shown in **Figure 30**. Note that the water column profiles at mooring recovery show a substantial change in temperature and salinity, which may have led to downward refracting sound propagation during the deployment period.

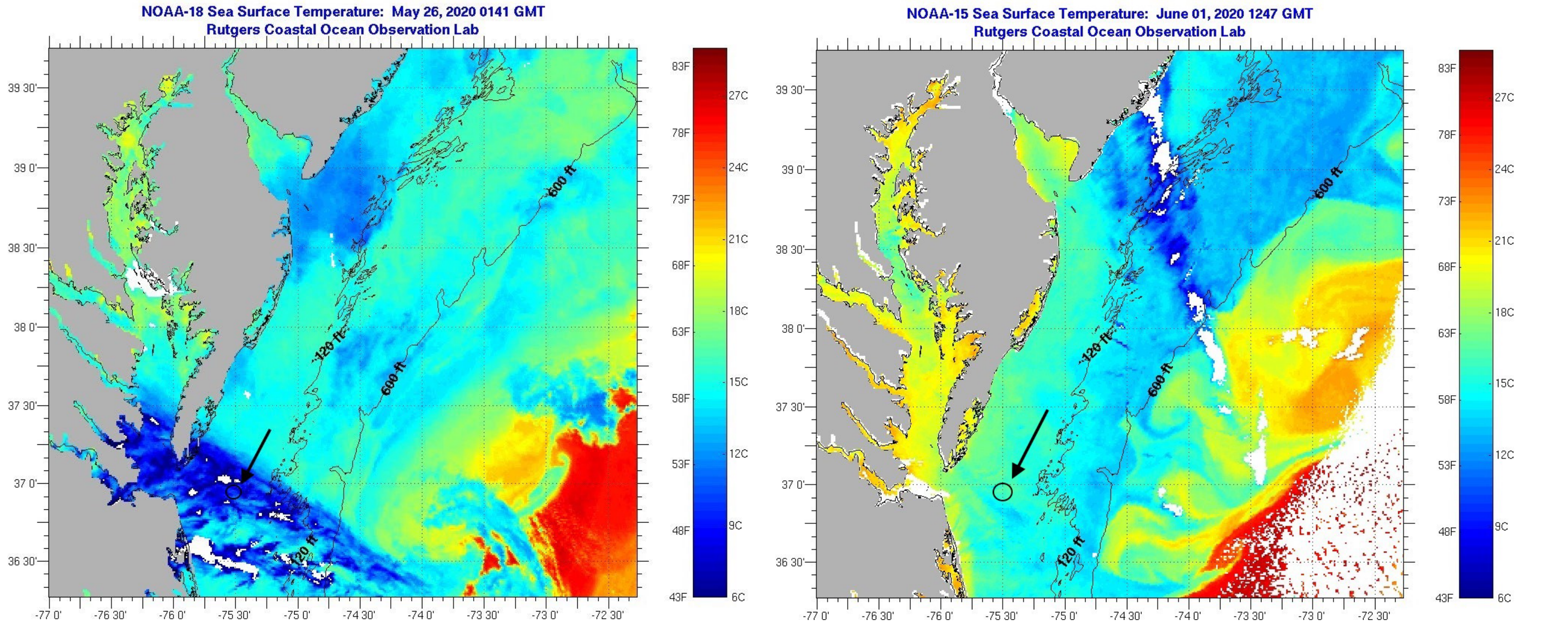

Figure 29. Sea surface temperature (SST) in the greater project area. The right panel shows SST on 26 May 2020, and the left shows SST on 1 June 2020. Black arrows and circles indicate project location. Data taken from the Coastal Ocean Observatory Lab, Rutgers University, 2020

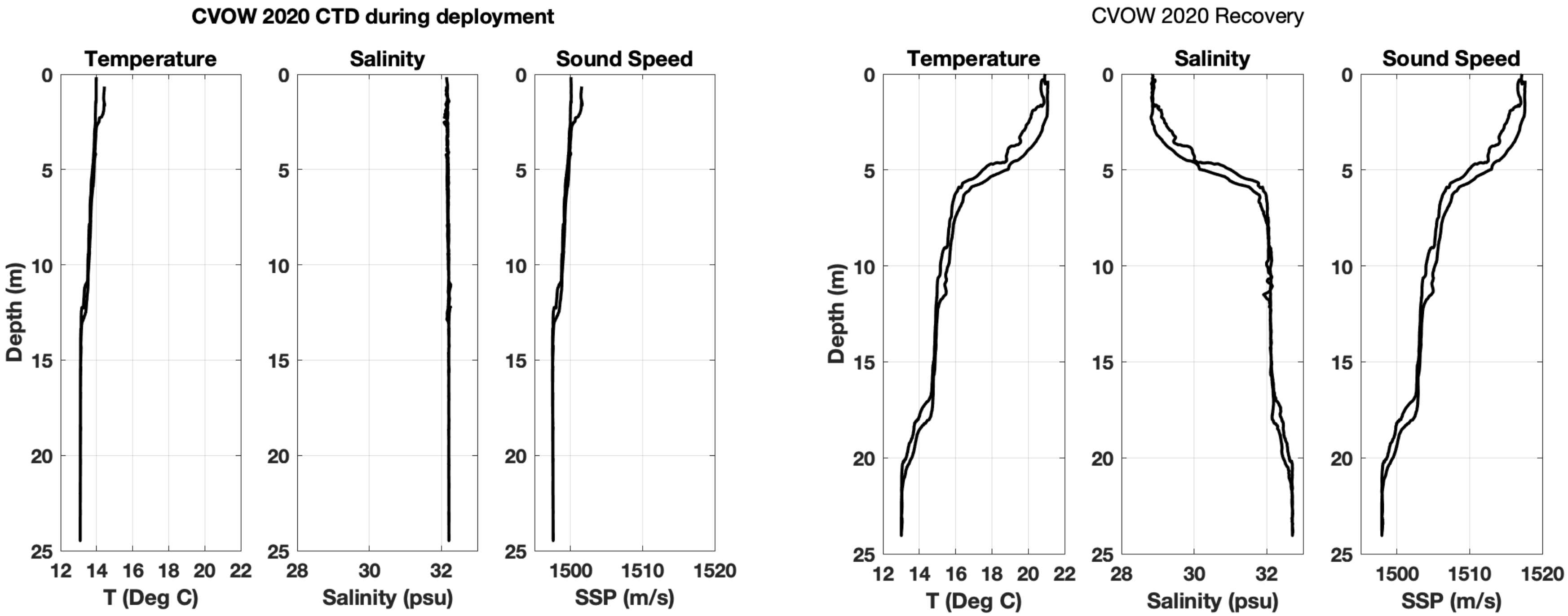

Figure 30. CTD profiles (up and down cast) taken during mooring deployment on 23 May (left panel) and recovery on 8 June (right panel).
Note: The water column was mostly homogenous at deployment, likely due to the cold-water runoff from a storm prior to deployment, as is also seen in the sea surface temperature images in **Figure 29**

3.4 Data Analyses and Key Results

The piling profile for both installation events, as recorded by the developer, is shown in **Figure 31**. The hammer employed during construction (IHC S-3000 hydrohammer), was capable of driving at energies of up to 3,000 kilojoules (kJ).

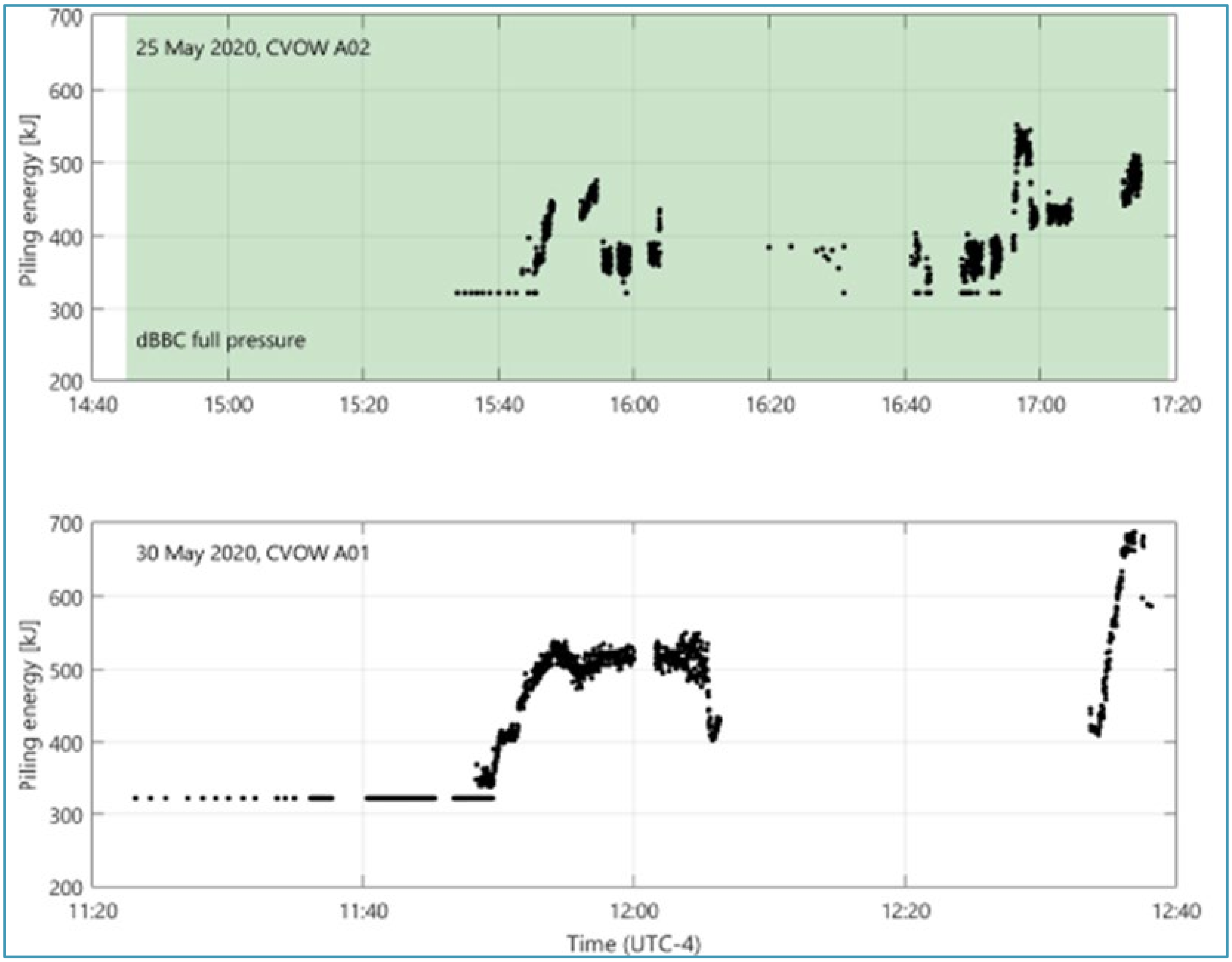

Figure 31. Energy per blow as used during the two piling events to install monopiles at CVOW, May 25 (upper panel) and May 30 (lower panel). From: WaterProof 2020

Note that the hammer was driving at under 20 percent of its capacity for almost the entire piling duration. There were large breaks in piling, with few or no strikes, on both days. The hammer energy also increased over the course of both piling events.

3.4.1 VLAs and Geosled Monitoring

VLA monitoring data indicated that the effectiveness of the noise mitigation system was strongly dependent on the frequency of pile driving noise (**Figure 32**). The attenuation of lower frequency sounds (<200 Hz) was not as much as the higher frequencies, which were reduced by approximately 20 dB. Results also showed strong azimuthal (i.e., instrument orientation) dependency of bubble curtain effectiveness (**Figure 33**).

Figures 34-36 show detailed time series of soundscape parameter measurements made by the VLAs and Geosled, including L_{pk}, L_{pp}, Root-mean-square level (L_{rms}), sound exposure level (SEL), and kurtosis. The definitions of these parameters are provided in **Appendix D**. The mean and SD of these measurements from each hydrophone channel are summarized in **Tables 9-14**. All sound pressure data are shown in dB.

The lower frequency signals from the short-range VLA and Geosled tetrahedral array, which were deployed about 3 km to the west of the pile driving, showed similar SPLs during each turbine installation, as seen in **Figures 34 and 35**, with the higher frequencies diverging above 300 Hz. At 100 Hz, the sound levels recorded by the Geosled with and without the bubble curtain were quite close, 128 dB and 129 dB respectively. However, at 500 Hz a 20 dB difference can be clearly observed (**Figure 33**). Not taking into account attenuation with range, the near-field VLA and the Geosled showed similar SPLs during each turbine installation, as seen in **Figures 34 and 35**. The long-range VLA, which was located 7.5 km northeast of the turbine site, showed substantially different signal levels with and without the bubble curtain (**Figures 33 and 36**). Higher frequency attenuation was observed on all receivers. The long-range VLA receivers showed slightly stronger attenuation at all frequencies than receivers closer to the construction site, possibly due to the effects of scattering and mode coupling on pile driving sound propagating through the bubble curtain.

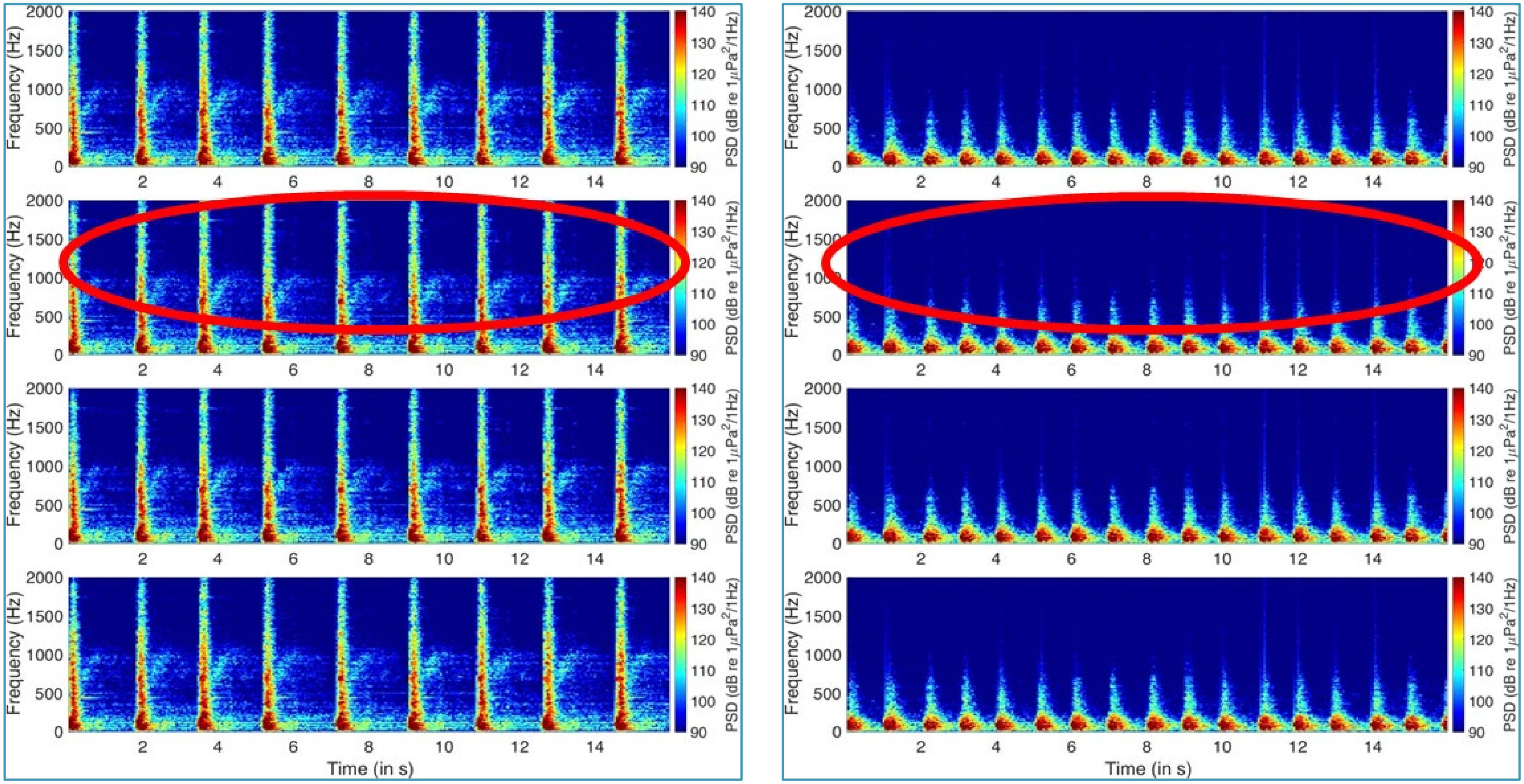

Figure 32. Spectrogram examples of the Geosled tetrahedral array data
Note: The right panel shows the four hydrophone channels for 15 seconds on 25 May 2020 during pile driving of A02, which utilized a bubble curtain. The left panel shows a corresponding spectrogram on 30 May during pile driving of Turbine A01 (no bubble curtain). Noise attenuation in the high frequencies can be clearly seen on all hydrophones (red circles).

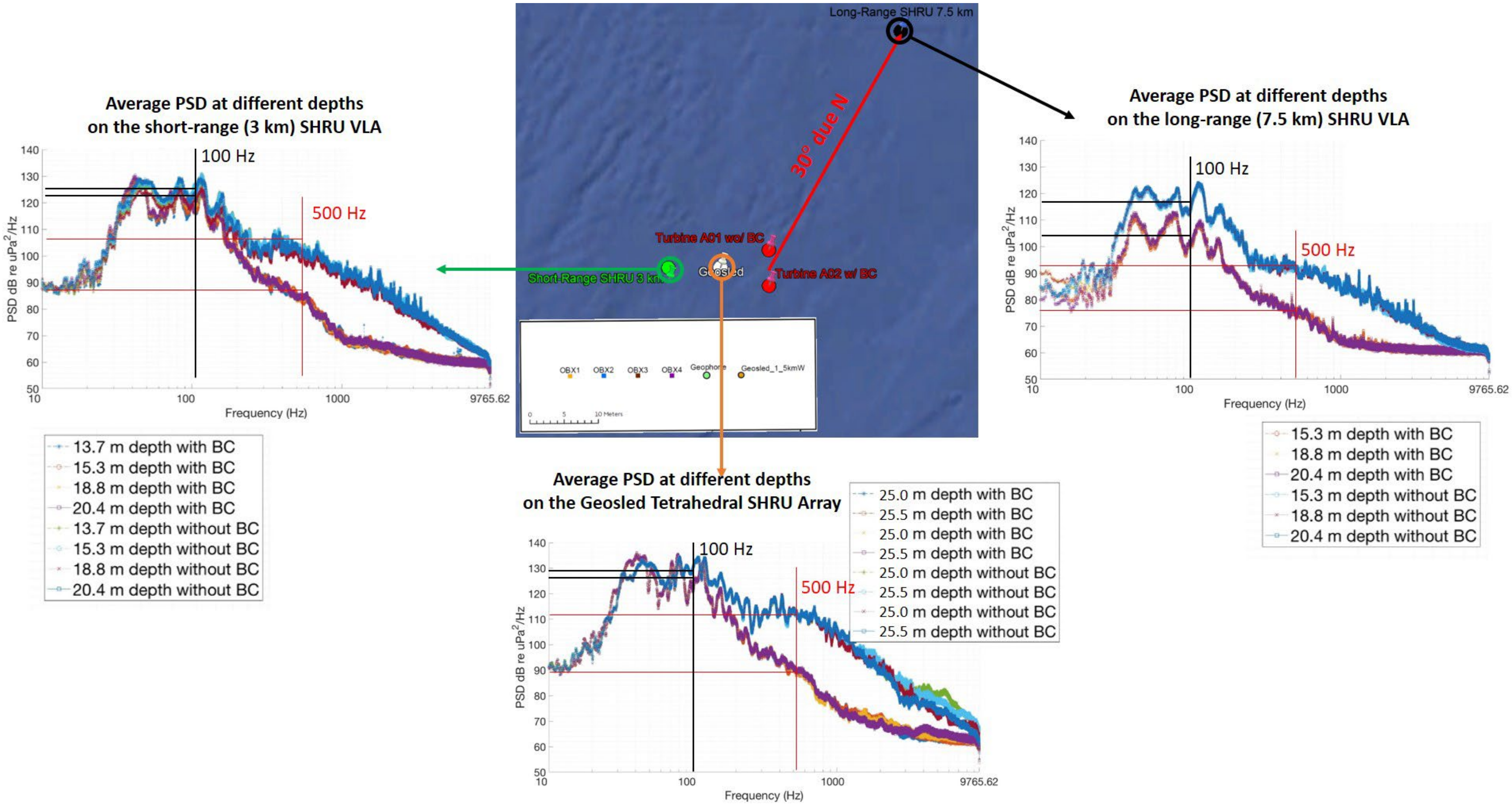

Figure 33. Levels of recorded pile driving sound at various distances and azimuths, with and without noise mitigation. Power spectral density (PSD) on all of the VLAs and the tetrahedral array are shown

Note: The upper right panel shows the average PSD from the short-range VLA at 3.0 km. The middle panel shows instrument orientation (azimuth) in relation to the turbine foundations. The upper left panel shows the average PSD from the long-range VLA at 7.5 km. The lower panel shows the PSD at the Geosled tetrahedral array.

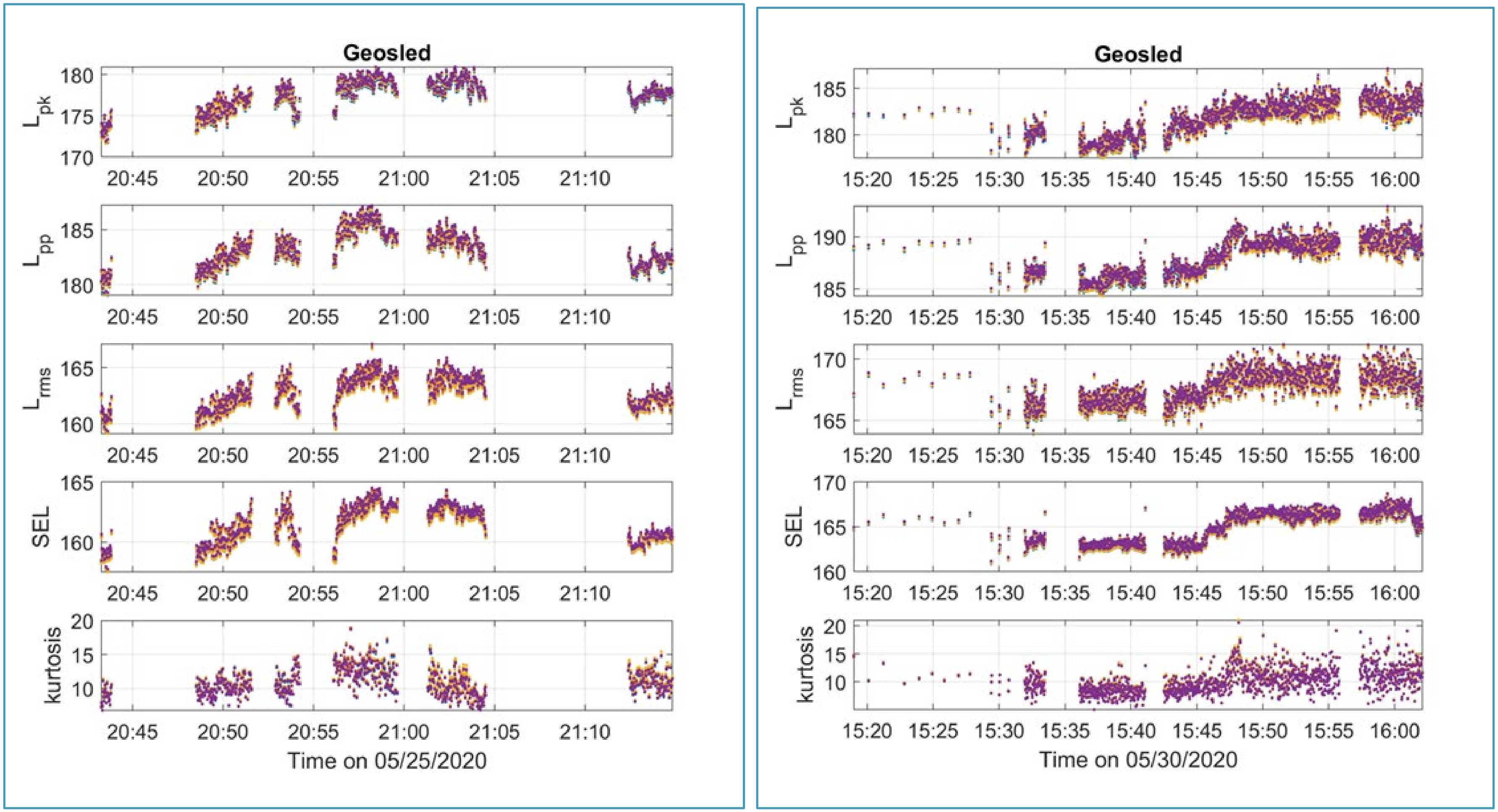

Figure 34. Geosled sound pressure statistics in dB, with the use of a bubble curtain (left panel) and without (right panel). Each channel is represented by a different colored dot and each strike is plotted. The spread (thickness) of the levels show depth-dependence of sound at the site

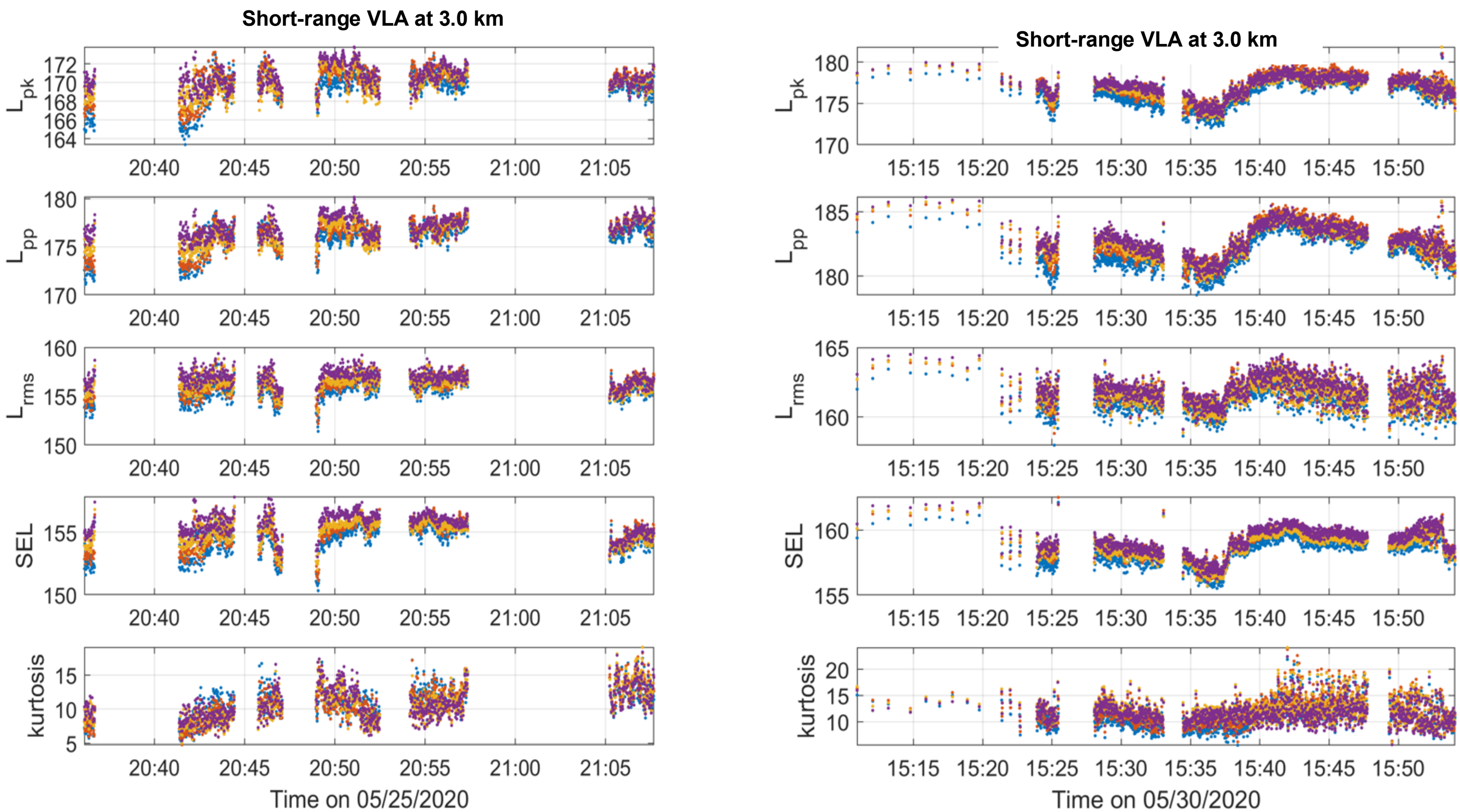

Figure 35. Short-range VLA sound pressure statistics in dB, with the use of a bubble curtain (left panel) and without (right panel). Each channel is represented by a different colored dot and each strike is plotted. The spread (thickness) of the levels show depth-dependence of sound at the site

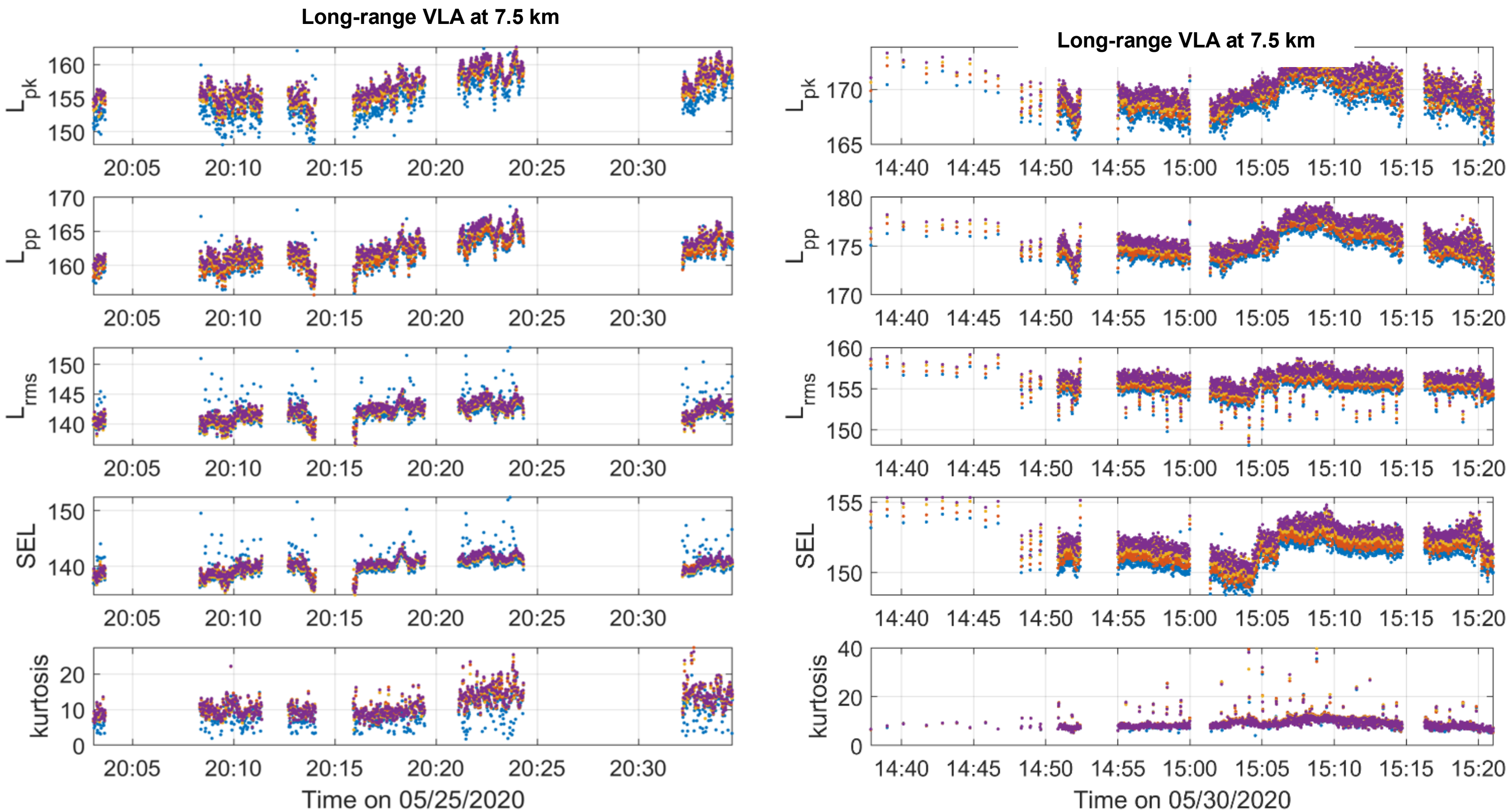

Figure 36. Long-range VLA sound pressure statistics in dB, with the use of a bubble curtain (left panel) and without (right panel). Each channel is represented by a different colored dot and each strike is plotted. The spread (thickness) of the levels show depth-dependence of sound at the site

Table 9. Sound level statistics in dB for Geosled on 25 May 2020 with the bubble curtain

	L_{pk}	L_{pp}	L_{rms}	SEL	kurtosis
CH1: Mean	177.4	183.1	162.6	161.2	11
SD	1.77	1.58	1.34	1.47	2
CH2: Mean	177.6	183.3	162.7	161.3	11
SD	1.79	1.59	1.36	1.49	2
CH3: Mean	177.5	183.2	162.6	161.2	11
SD	1.82	1.57	1.33	1.45	2
CH4: Mean	177.7	183.4	162.9	161.5	11
SD	1.79	1.59	1.36	1.49	2

Table 10. Sound level statistics in dB for short-range VLA on 25 May 2020 with the bubble curtain

	L_{pk}	L_{pp}	L_{rms}	SEL	kurtosis
CH1: Mean	169.5	175.9	155.6	154.4	11
SD	1.71	1.53	1.02	1.14	2
CH2: Mean	170.2	176.3	156.2	154.9	11
SD	1.54	1.52	0.95	1.07	2
CH3: Mean	170.0	176.4	156.3	155.0	11
SD	1.30	1.20	0.79	0.89	2
CH4: Mean	170.6	177.1	156.9	155.6	11
SD	1.22	1.03	0.79	0.89	2

Table 11. Sound level statistics in dB for long-range VLA on 25 May 2020 with the bubble curtain

	L_{pk}	L_{pp}	L_{rms}	SEL	kurtosis
CH1: Mean	154.8	161.5	142.1	140.3	9
SD	2.63	2.09	2.04	2.14	3
CH2: Mean	156.5	161.8	142.1	140.3	11
SD	2.20	2.04	1.22	1.26	3
CH3: Mean	156.6	162.5	141.9	140.1	11
SD	2.35	2.05	1.53	1.52	3
CH4: Mean	157.0	162.8	142.2	140.4	12
SD	2.31	2.04	1.53	1.52	3

Table 12. Sound level statistics in dB for Geosled on 30 May 2020 without the bubble curtain

	L_{pk}	L_{pp}	L_{rms}	SEL	kurtosis
CH1: Mean	181.7	188.0	167.6	164.8	10
SD	1.87	1.72	1.26	1.74	2
CH2: Mean	181.8	188.1	167.7	164.9	10
SD	1.81	1.70	1.25	1.73	2
CH3: Mean	181.7	188.0	167.6	164.8	10
SD	1.82	1.68	1.25	1.73	2
CH4: Mean	181.9	188.2	167.8	165.1	10
SD	1.85	1.70	1.25	1.73	2

Table 13. Sound level statistics in dB for short-range VLA on 30 May 2020 without the bubble curtain

	L_{pk}	L_{pp}	Lr_{ms}	SEL	kurtosis
CH1: Mean	176.3	181.9	161.2	158.4	11
SD	1.55	1.36	0.92	1.02	2
CH2: Mean	177.1	182.7	161.7	158.9	12
SD	1.46	1.33	0.90	1.00	2
CH3: Mean	176.9	182.6	161.6	158.8	12
SD	1.31	1.21	0.90	1.00	2
CH4: Mean	177.1	182.8	162.0	159.2	12
SD	1.26	1.15	0.92	1.02	2

Table 14. Sound level statistics in dB for long-range VLA on 30 May 2020 without the bubble curtain

	L_{pk}	L_{pp}	L_{rms}	SEL	kurtosis
CH1: Mean	168.8	174.8	155.0	151.2	9
SD	1.46	1.37	1.00	0.99	2
CH2: Mean	169.5	175.2	155.4	151.6	9
SD	1.40	1.38	0.99	0.97	3
CH3: Mean	170.0	175.8	156.0	152.2	9
SD	1.42	1.41	0.99	0.96	2
CH4: Mean	170.2	176.0	156.2	152.4	9
SD	1.40	1.41	0.99	0.96	2

3.4.2 OBX Seismic Sensors

This section presents selected results from the data measured on the OBX sensors. Representative signals depicting the particle velocities and acoustic pressure on the seabed are shown to highlight the quality of the data[3]. Spectral content of the data is presented with particular emphasis on the effect of the bubble curtain. Since the major goal of the particle-motion measurements is to assess the impact on marine life, the observed data is also compared with behavioral audiograms of some fishes which have low-frequency sensing capabilities.

Representative particle velocity and pressure data collected on OBX4 over a 1-minute period, and approximately 50 hammer impact events, are shown in **Figure 37**. The velocities in the vertical, inline and crossline directions (top three panels) and pressure (bottom panel) measured by one of the OBX sensors are shown in this figure. The signals display no distortions (clipping for example) and the magnitudes of the peak particle velocities and pressures appear reasonable. For example, the peak vertical velocity is approximately 2.0 millimeters per second (mm/s) and this compares well (in an order-of-magnitude sense) with measurements made by Bruns et al. (2014) (~0.35 mm/s at 250 m). The peak values (pressure and particle velocities) corresponding to each of these 50 events are plotted in **Figure 38**.

The peak values (**Figure 38**, left panel**)** correspond to foundation A01, installed on 30 May 2020, for which the noise mitigation system (bubble curtain) was not utilized. The right panel shows the corresponding peak values for foundation A02, installed on 25 May 2020, when the bubble curtain was utilized. The mean peak pressure without the bubble curtain was 2023 Pascals (Pa) ($SPL_{peak} = 186\ dB\ re\ 1\mu Pa$) with a SD of 129 Pa. The mean and SD with the bubble curtain were 1470 Pa ($SPL_{peak} = 183\ dB\ re\ 1\mu Pa$) and 143 Pa, respectively. Because the two piling events were conducted on separate days, inferences regarding the effectiveness of the bubble curtain in reducing peak pressure should be made cautiously due to the differences in oceanographic conditions (currents and sound speeds) on these days. The left panel in **Figure 39** shows the peak particle velocities (top two subplots) and pressure (bottom subplot) corresponding to the pile hammer impact events shown in **Figure 37**. These data correspond to measurements in water using the tetrahedral array. Pressure and particle velocities are shown with the noise mitigation system in place (25 May 2020, in red) and without (30 May 2020, in black). The mean and SD of the peak values calculated using the tetrahedral array data were 1219 Pa (125 Pa) without the bubble curtain and 886 Pa (93 Pa) with the bubble curtain, respectively. The mean particle velocities (vertical and radial) without the bubble curtain were 0.16 mm/s (104 dB re 1 Newton meters per second (Nm/s)) and 0.48 mm/s (114 dB re 1 Nm/s) respectively. With the bubble curtain, these values were reduced to 0.12 mm/s (102 dB re 1 Nm/s) and 0.31 mm/s (110 dB re 1 Nm/s) (**Figure 38,** right panel). The vertical component of the peak particle velocities calculated using the tetrahedral array data, for the same events also showed lower in-water values. The radial component does not show a substantial difference (between the OBX and tetrahedral array data). The mean particle velocities (vertical and radial) without the bubble curtain were 0.1 mm/s (100 dB re 1 Nm/s) and 0.5 mm/s (114 dB re 1 Nm/s) respectively. With the bubble curtain, these values were reduced to 0.05 mm/s (94 dB re 1 Nm/s) and 0.3 mm/s (110 dB re 1 Nm/s).

Figure 40 shows the power spectra of particle velocity (vertical and radial components) and the acoustic pressure measured by OBX 14396 from multiple (~ 50 events over 1 minute) hammer impact events. The white line in the subplots show the mean spectra. These spectra are remarkably consistent with very little

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[3] The OBX sensors were factory-calibrated in early 2020. Laser calibration of sensors could not be performed prior to instrument deployment due to COVID-19 restrictions.

spread at low frequencies (< ~150 Hz) (**Figure 40**). This indicates (at this frequency range) consistency in the source level and/or no perturbation in the medium properties along the propagation path within the 1-minute time interval. It is likely that the sediment-borne path provided the stable propagation path which might have resulted in the tightly aligned spectra in the low-frequency (<150 Hz) band.

Figure 41 shows a comparison of time series of particle velocities (vertical as well as radial components) during a single representative hammer impact event. The red lines indicate piling with the bubble curtain in use, and the black lines are without the bubble curtain. Note that the effect of the bubble curtain on particle velocities was weak. The L_{pk} were 106 dB re 1 nm/s (vertical) and 114 dB re 1 nm/s (radial). The bubble curtain had a positive impact, in terms of reduction in L_{pk} by 8 dB re 1 nm/s. This early arrival may most likely correspond to the water arrivals. The behavior of late arrivals did not follow a consistent pattern over time. It should also be noted that these two events are from two different days with different sound propagation conditions (which will likely affect the water borne arrivals) and slightly different hammer energies (**Figure 31**).

Spectrograms of OBX hydrophone data from two representative pile hammer impact events, with and without the use of a bubble curtain, are shown in **Figure 42**. The color bars are the same in both panels in this figure are same to allow direct comparison between the two. The right panel shows significant reduction in the main arrival (around 0.2 seconds) above 200 Hz. This reduction is not present in frequencies below 200 Hz. The bubble curtain was more effective in attenuating sounds at higher frequencies (>200 Hz) compared to frequencies below 200 Hz (**Figure 42**).

The frequency dependence of bubble curtain effectiveness was also observed in the geophone data (**Figure 43**). Both the vertical (top panels) and the radial components (bottom panels) show significant reduction in the velocity levels for frequencies above 200 Hz. The low-frequency arrivals appear to be present for a substantially longer duration (1 second) and the bubble curtain seems to have no effect on these low-frequency arrivals. As in the case of hydrophone data shown in **Figure 42**, the bubble curtain appeared to be more effective in the frequency range above 200 Hz compared to lower frequencies.

The frequency dependence of the bubble curtain performance is clearly observable in **Figures 42 and 43**. This is further illustrated in the power spectra for the OBX hydrophone (**Figure 44**) and geophone (**Figure 45**) data. The impact of the bubble curtain is evident in the hydrophone data (**Figure 44**) starting from 100 Hz, and the differences between the two curves become significant above 350 Hz. The difference is as high as 25 to 30 dB above 350 Hz. The impact of bubble curtain starts to be evident in the geophone data (**Figure 45**) above 350 Hz. Below 350 Hz, the differences between the two particle velocity spectra are not as significant compared to higher frequencies.

The right panel in **Figure 39** shows the power spectrum of vertical (top subplot) and radial (bottom subplot) particle velocity components measured with the noise mitigation system in place (25 May 2020, in red) and without (30 May 2020, in black). The frequency distribution of vertical particle velocity is similar to the OBX data, but radial particle velocity spectra appears somewhat different. The significant reduction in radial velocity levels when bubble curtain was employed above 350 Hz (seen in OBX data) is not as pronounced in the tetrahedral data. The reduction appears uniform for frequencies above 200 Hz. The spectral content of seabed and in-water particle-motion, including frequency dependent arrival directions of energy, is being further investigated.

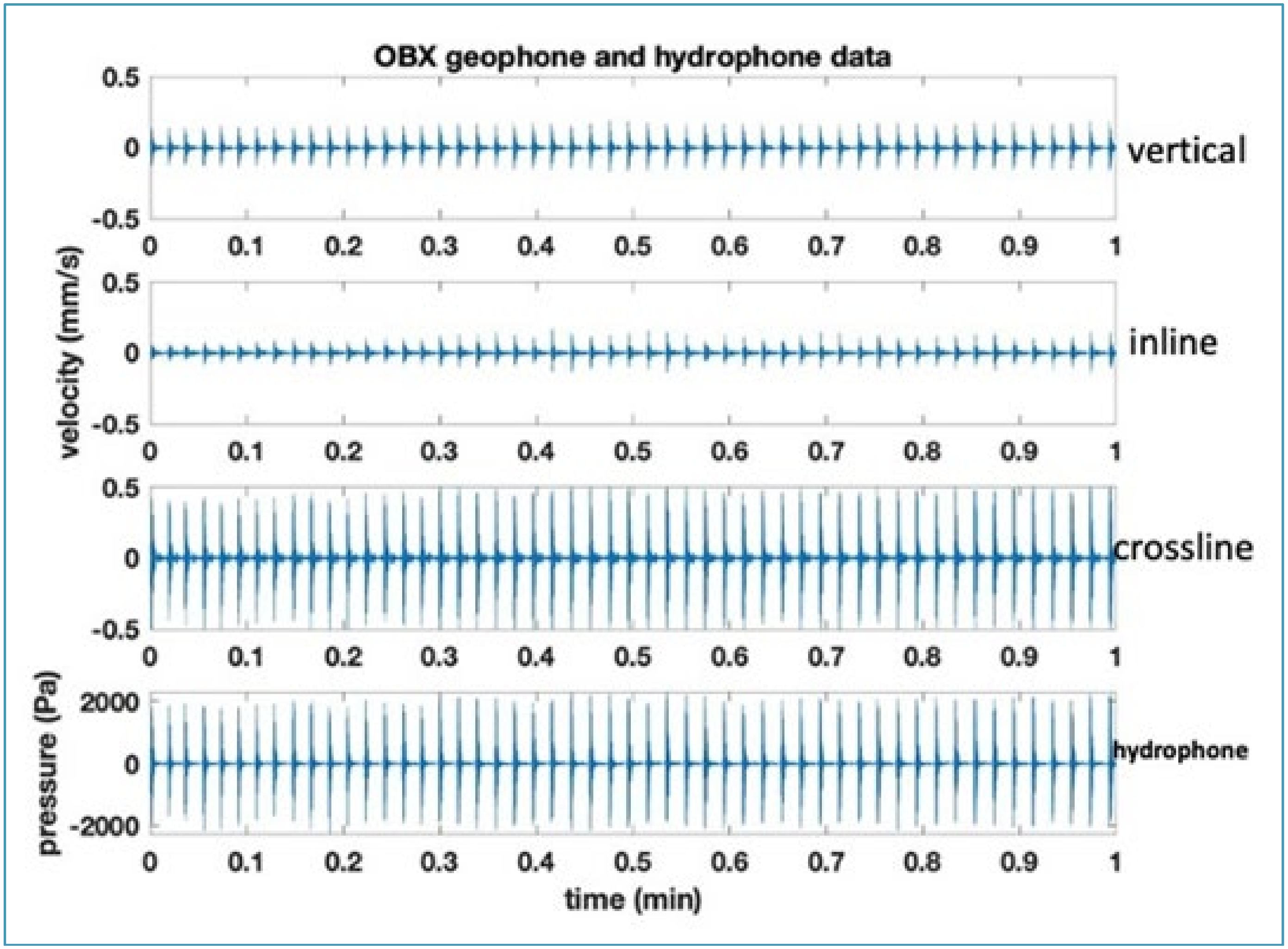

Figure 37. Particle velocity (three components) and pressure data recorded on from OBX4, positioned approximately 1.5 km from the turbine

Note: The crossline component of particle velocity is higher than the inline component because the OBX was oriented with the shorter dimension facing the incoming acoustic/seismic wave from the pile driving signal.

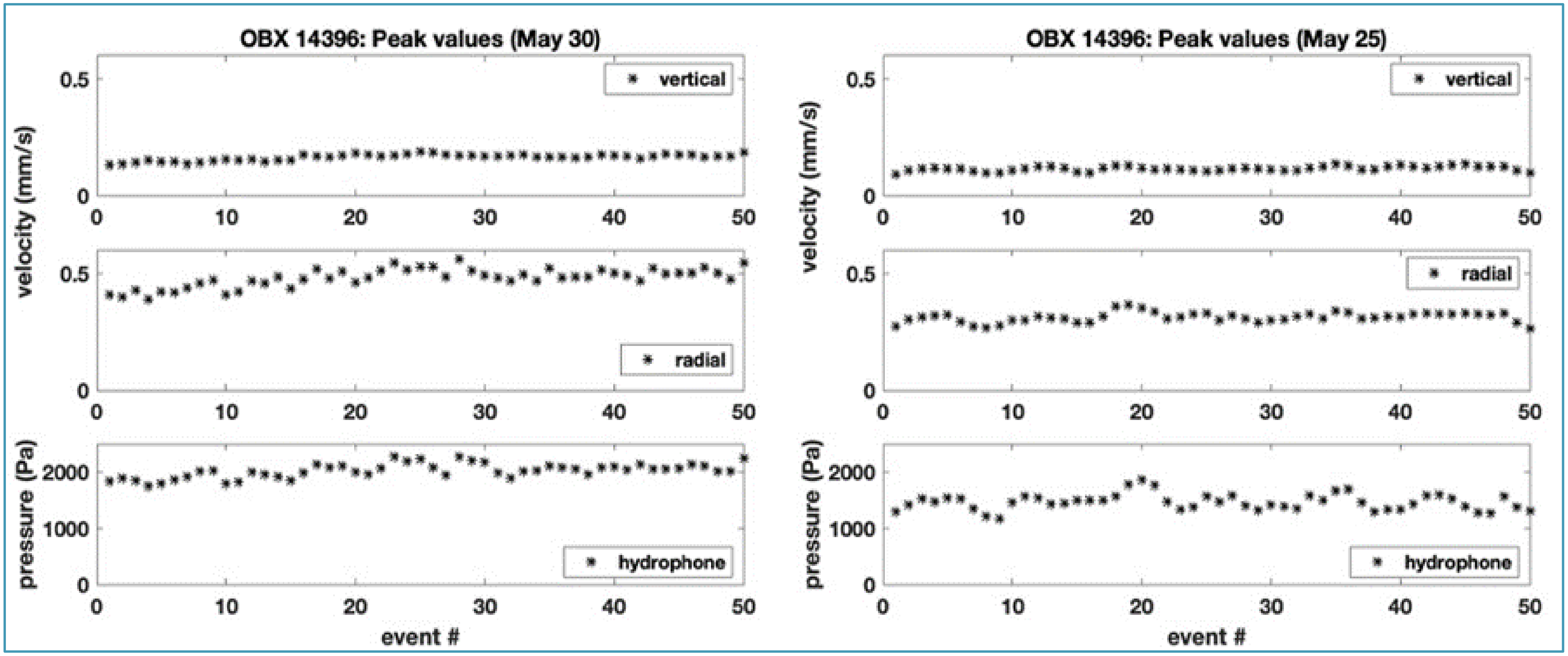

Figure 38. Peak particle velocities and pressures corresponding to the pile hammer impact events shown in Figure 37. Measurements are shown without (left panel) and with (right panel) the noise mitigation system

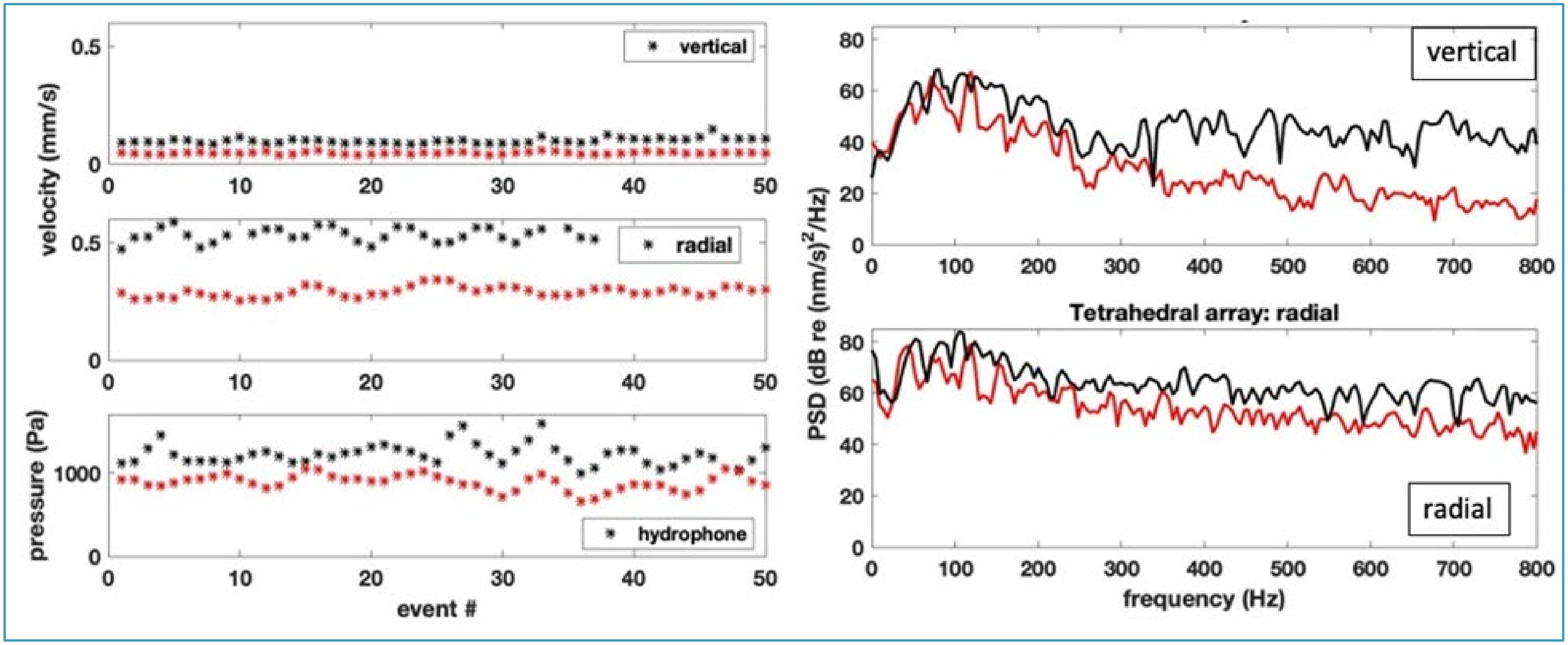

Figure 39. Peak particle velocity, pressure, and spectra shown with the noise mitigation system in place (25 May 2020, in red) and without (30 May, in black). The left panel shows peak particle velocities (top two subplots) and pressure (bottom subplot) corresponding to the pile hammer impact events shown in Figure 37. These data correspond to measurements in water using the tetrahedral array. The right panel shows the power spectrum of vertical (top subplot) and radial (bottom subplot) particle velocity components with the noise mitigation system in place (red) and without (black)

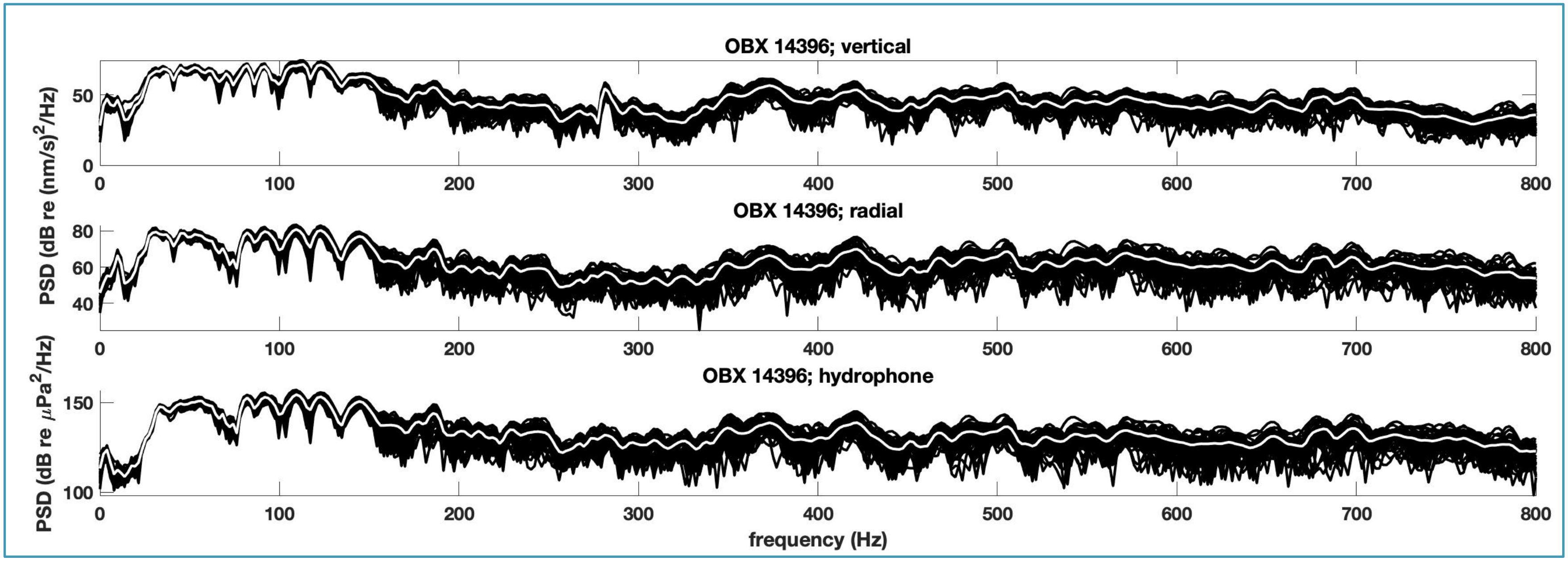

Figure 40. Power spectra of OBX data from multiple pile driving hammer impact events (approximately 50 events over 1 minute). The top two panels show the vertical and radial components of particle velocity, and the bottom panel shows the acoustic pressure data. The white line represents the mean of these spectra

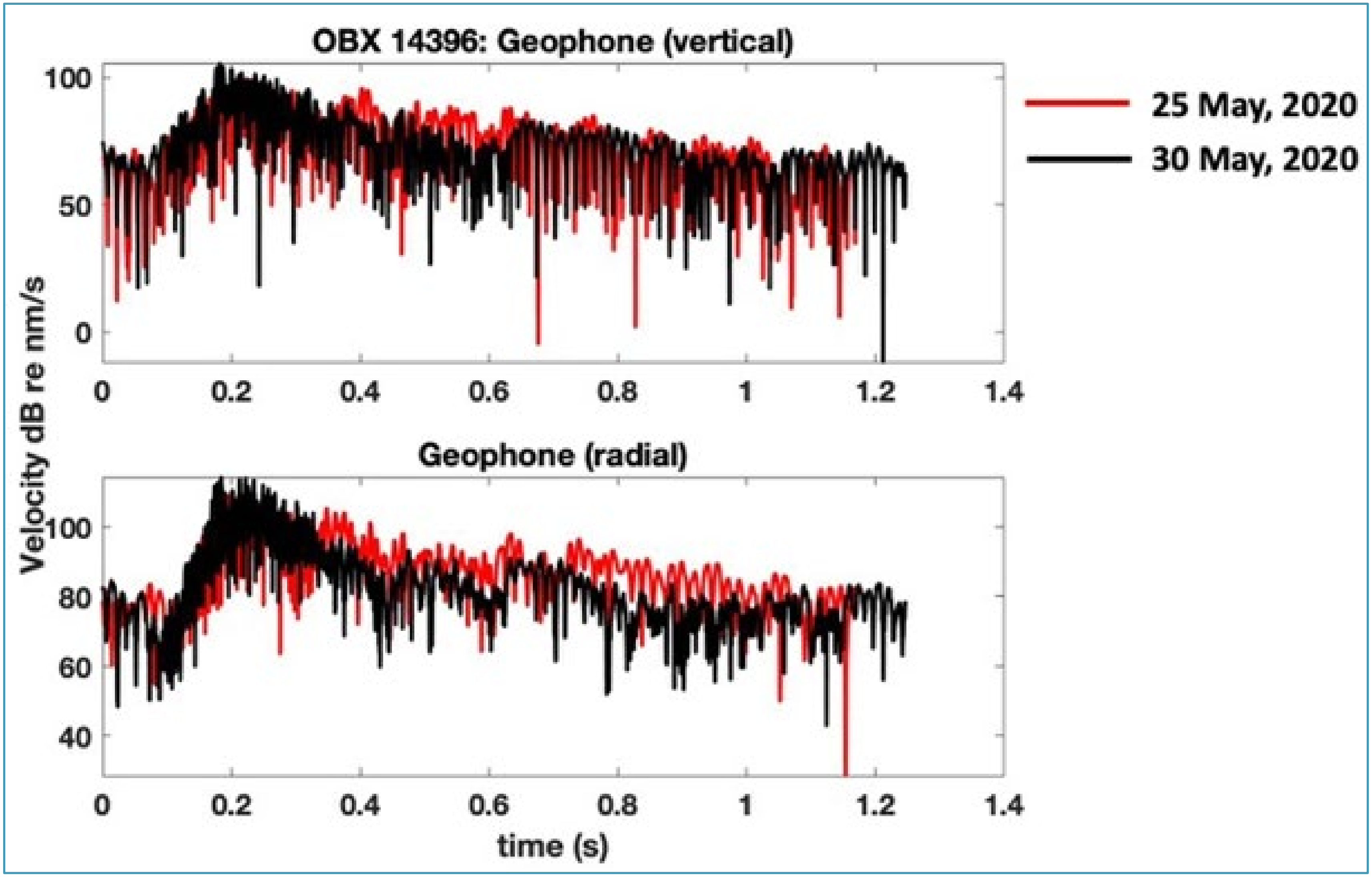

Figure 41. Acoustic particle velocity for vertical (top panel) and inline (bottom panel) components. Data from a single pile hammer impact event on 30 May 2020 (black, without bubble curtain) and 25 May 2020 (red, with bubble curtain) are shown

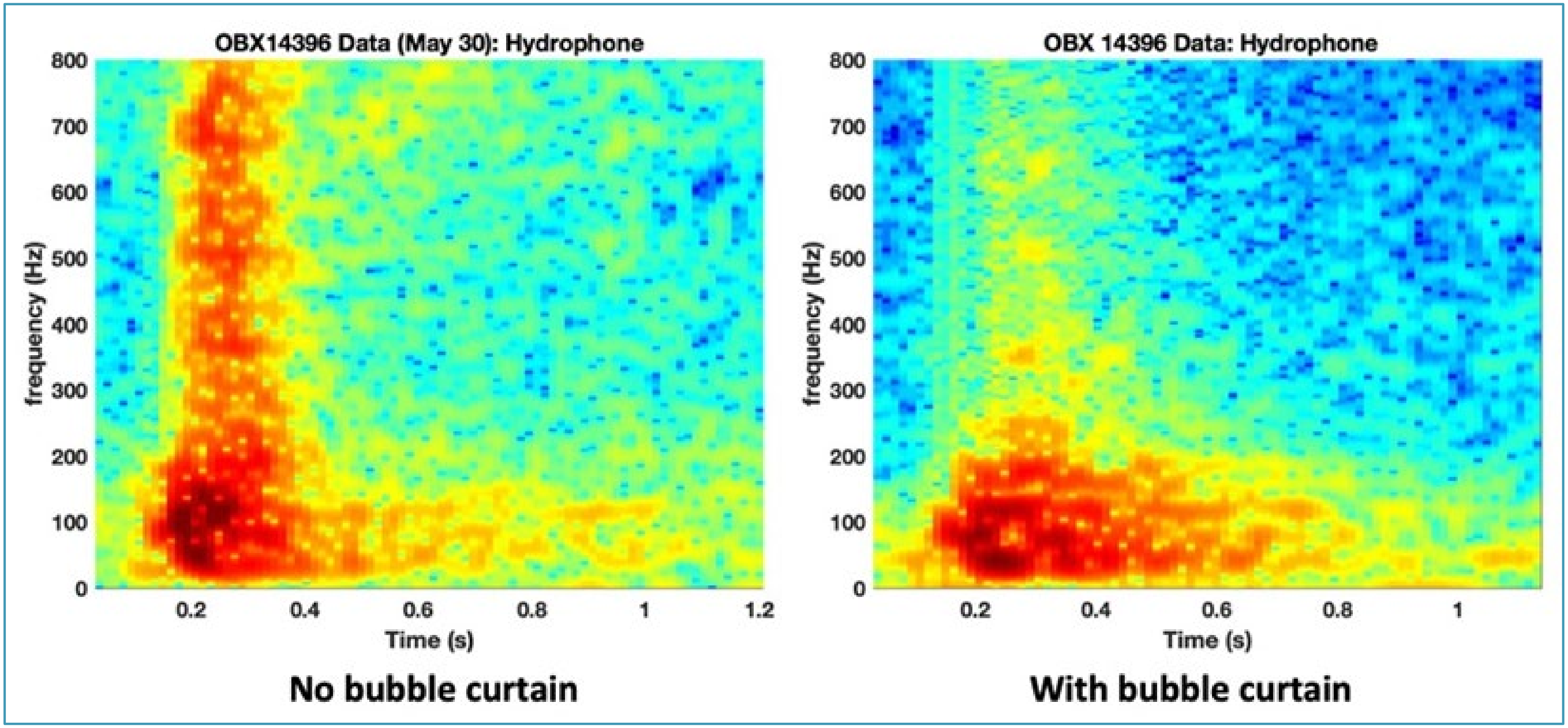

Figure 42. Comparison of the evolution of spectral content over time (OBX hydrophone) with and without the use of the noise mitigation system (bubble curtain)

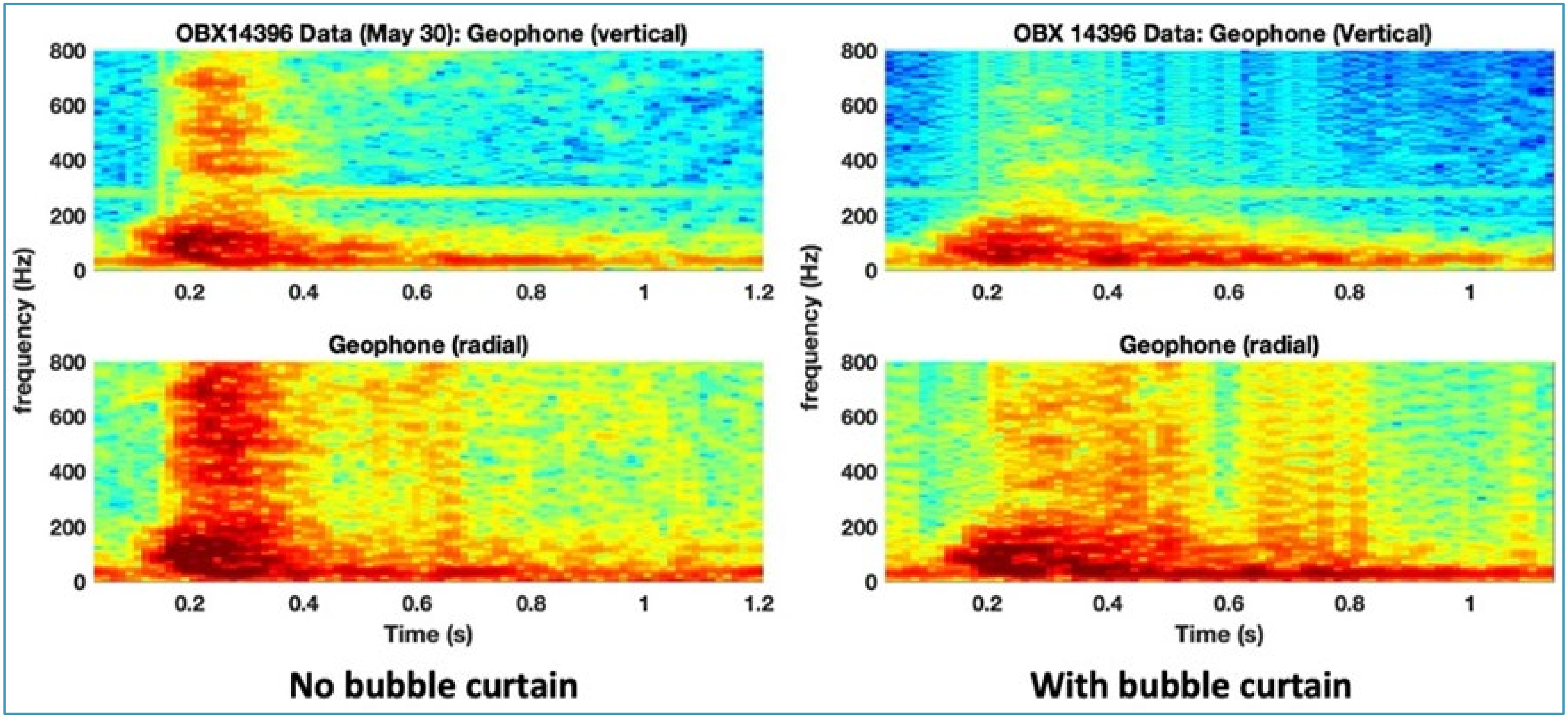

Figure 43. Comparison of the evolution of spectral content over time (OBX geophone) with and without the use of the noise mitigation system (bubble curtain)

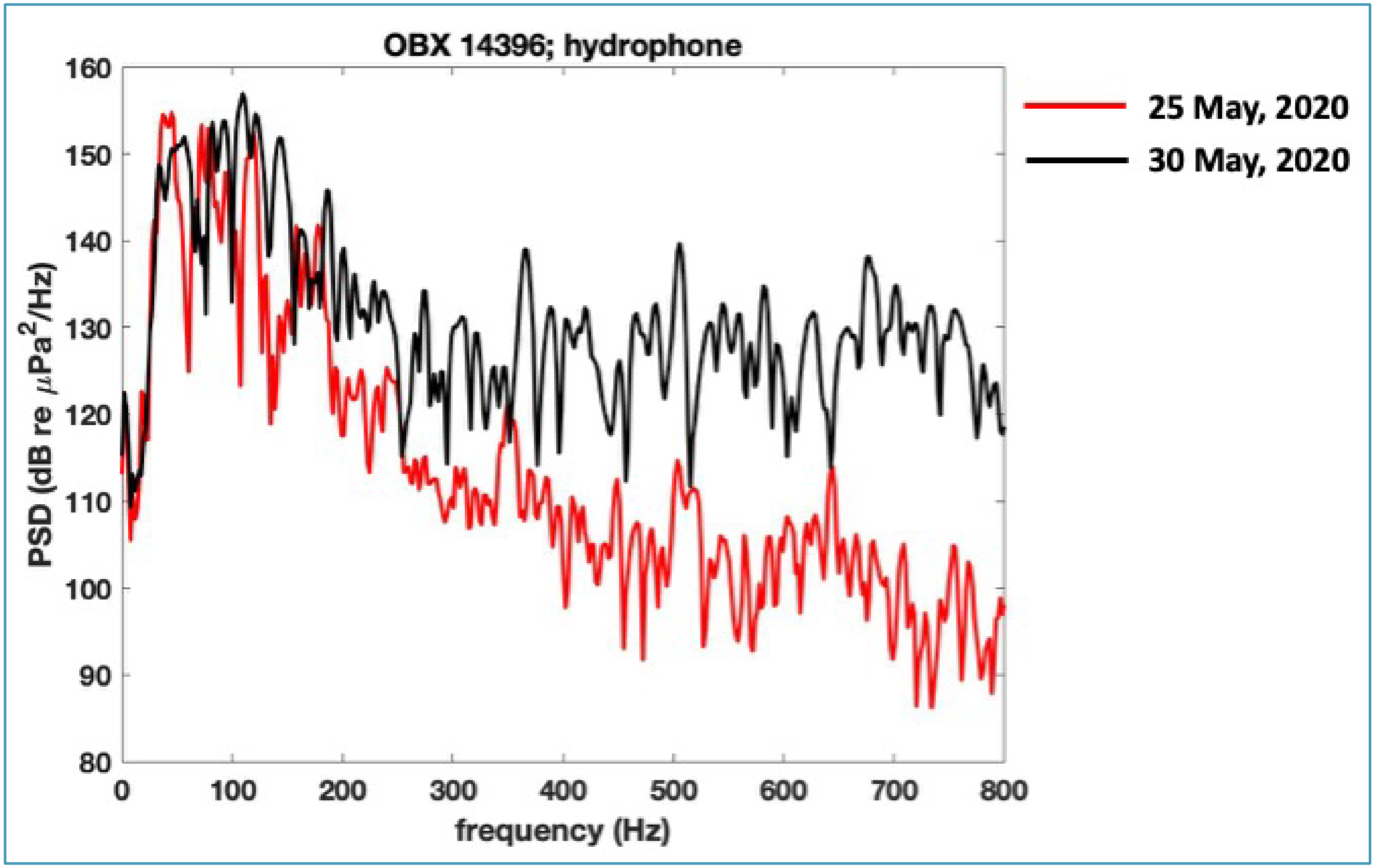

Figure 44. Power spectrum of OBX hydrophone data from 30 May 2020 (black) and 25 May 2020 (red)

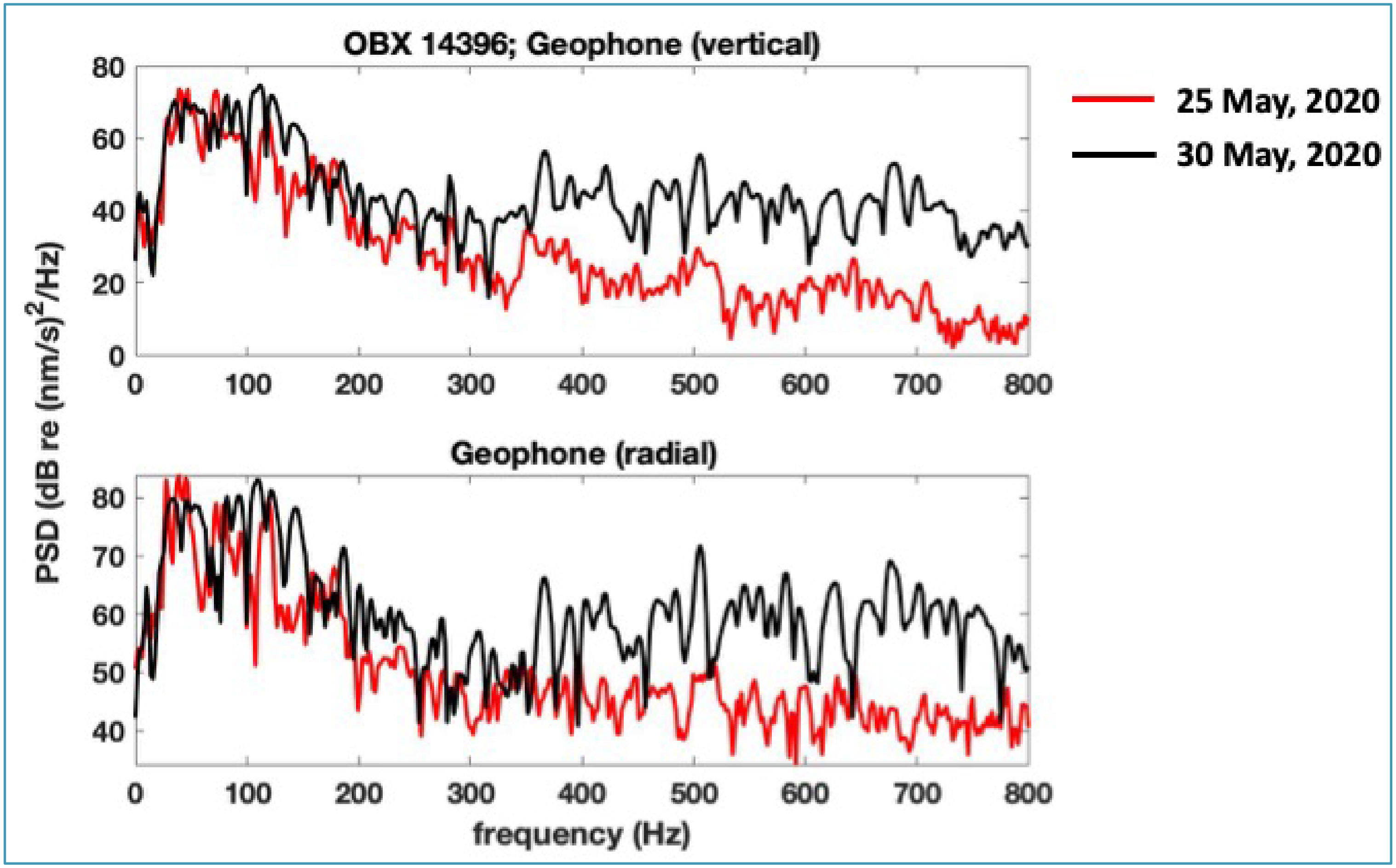

Figure 45. Power spectrum of OBX geophone data from 30 May 2020 (black) and 25 May 2020 (red)

In the context of potential impacts on marine organisms, particle velocity measurements are mainly a concern for fishes and invertebrates. Because fishes are sensitive to particle-motion, species living on or in the substrate will detect sounds transmitted through and on the substrate. Therefore, benthic fishes are likely to detect particle-motion associated with substrate transmission of sound (Popper and Hawkins 2018). Behavioral audiograms of four fish species capable of sensing low-frequency sounds (less than 500 Hz) were considered in order to provide biological context for the effectiveness of bubble curtain mitigation measures for fish.

Figure 46 shows measured particle acceleration (vertical component) during pile driving overlaid with behavioral audiograms for Atlantic salmon (*Salmo salar*, Hawkins and Johnstone 1978), dab (*Limanda*, Chapman and Sand 1974), Atlantic cod (*Gadus morhua*, Chapman and Hawkins 1973), and plaice (*Pleuronectes platessa*). Particle acceleration values were calculated using the measured particle velocities (on the seabed). **Figure 47** is similar to **Figure 46** except that it shows the radial component of the particle acceleration, and both figures compare measurements made during pile driving with and without the use of a bubble curtain. Note that the particle velocity levels measured on the seabed are well above the behavioral sensitivity for all fishes shown (**Figures 46 and 47**) up to a frequency of approximately 200 Hz.

Based on these data, it appears that the impact of construction may be more pronounced on fishes whose habitat is close to the seabed and sensitive to particle-motion in the frequency range below 200 Hz. The radial particle-motion appears to be higher than the vertical component (which can be expected given the geometry as shown in **Figure 48** and the possible presence of sediment-borne energy), and the bubble curtain does not appear to mitigate the impact below 200 Hz.

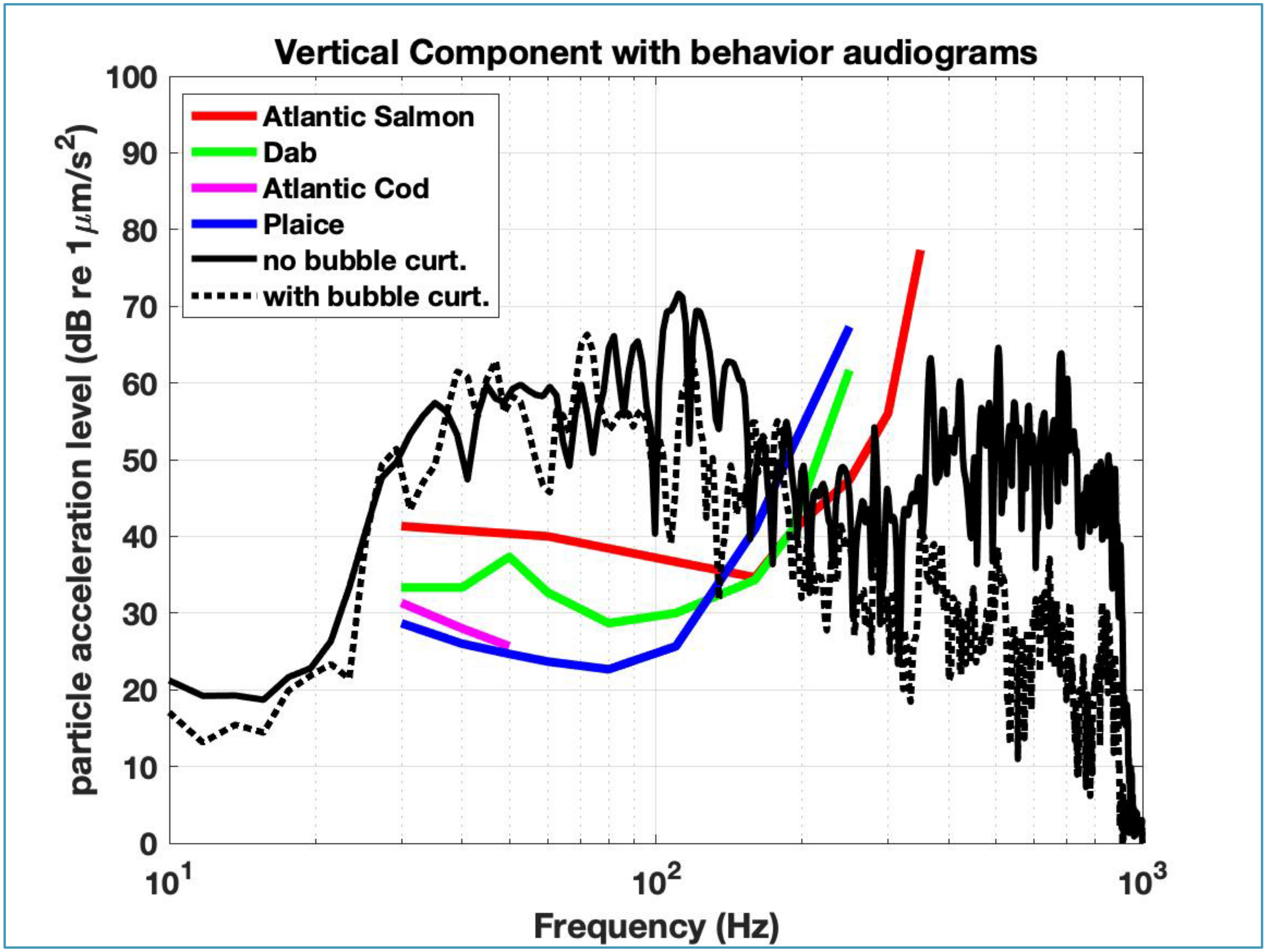

Figure 46. Particle acceleration levels (vertical component) during piling with and without a bubble curtain overlaid with behavioral audiograms for four fish species

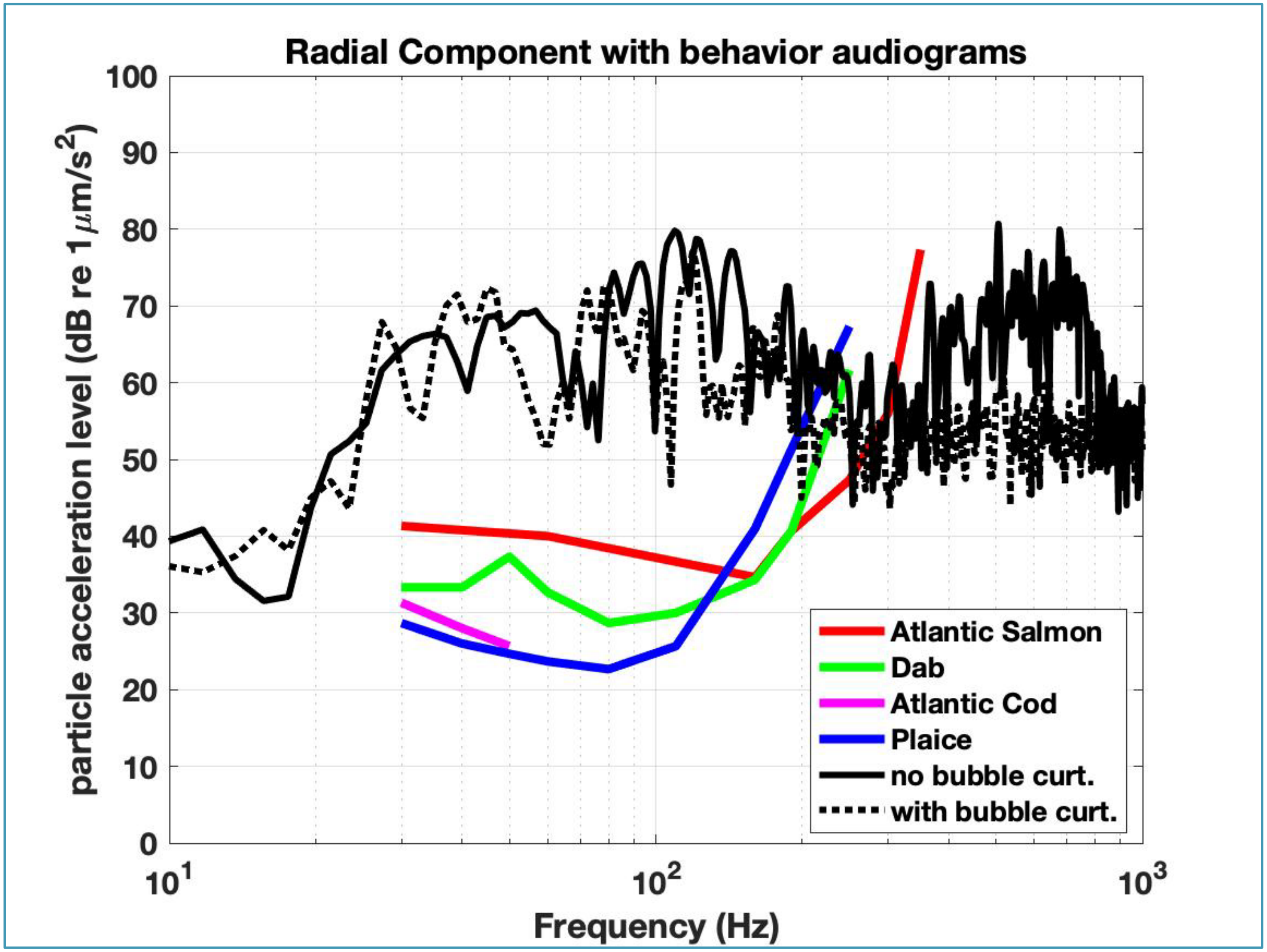

Figure 47. Particle acceleration levels (radial component) during piling with and without a bubble curtain overlaid with behavioral audiograms for four fish species

Preliminary analysis of the signals observed at the four OBX units and the tetrahedral array indicate no large-scale differences in the level or directionality of the particle velocity signals recorded on these instruments. This is expected since most of the energy was at low frequencies (peak energy around 100 Hz; at large wavelengths of ~15 m) and the OBX array aperture is only 15 m. But directional information can be extracted using the particle-motion components in the water and on the seabed. Preliminary results using the three particle velocity components derived from the tetrahedral array are shown in **Figure 48**. The known locations of the geosled and the turbines were used to validate the algorithm. The azimuth angle was calculated within 2° of the nominal deployment positions as shown in **Figure 48**. The dominant acoustic energy appears to come at an elevation angle of 6°. The geosled orientation was calculated to be 4.3° counterclockwise from East. This analysis can be extended to the OBX sensors but would be more complex due to multiple paths (i.e., sediment-borne paths). Algorithms are currently in development to accomplish this analysis.

3.4.3 Towed Array

The towed array recorded 1,520 hammer strikes (out of a total of 1,558) during the installation of pile A01, and 1,267 hammer strikes (out of a total of 1,373) during the installation of pile A02. The towed array did not capture every strike because the recording was turned off when the amplifier gains were adjusted in the measurement system. Strikes were recorded over ranges of 2.3 to 9.8 km during the installation of A01 and 2.9 to 7.6 km during the installation of A02. The total number of hammer strikes for each pile are reported in WaterProof (2020).

Received level metrics (L_{pk}, $L_{pk\text{-}pk}$, SEL, and SPL) were calculated for each hammer strike as a function of distance of the tow vessel from the foundation. Results are presented in **Figures 49** through **52**.

Received levels did not show a strong decrease over range that would be expected based on the physics of sound propagation underwater. This is most likely due to a varying source level caused by increasing hammer strike energy during the installation.

3.4.3.1 Bubble Curtain Effectiveness

The frequency content of the hammer strikes recorded with and without the bubble curtain was investigated to determine the frequency dependence of the noise mitigation system. **Figures 53** and **54** show a comparison of data that were recorded at a range of 3 km during both piling events. When the bubble curtain was in use, the recorded sound pressure amplitude was roughly one third of the pressure that was recorded when there was no bubble curtain (**Figure 53**). This pressure reduction relates to a 10 dB L_{pk} reduction when the bubble curtain was active.

Higher frequencies were attenuated to a greater degree when the bubble curtain was active, as compared to when the bubble curtain was inactive (**Figure 54**). Spectra of hammer strikes recorded on the towed array at a distance of 3 km with and without the bubble curtain further demonstrate the attenuation of frequencies between the two measurement days (**Figure 55**). The largest differences in SPLs were observed above 200 Hz.

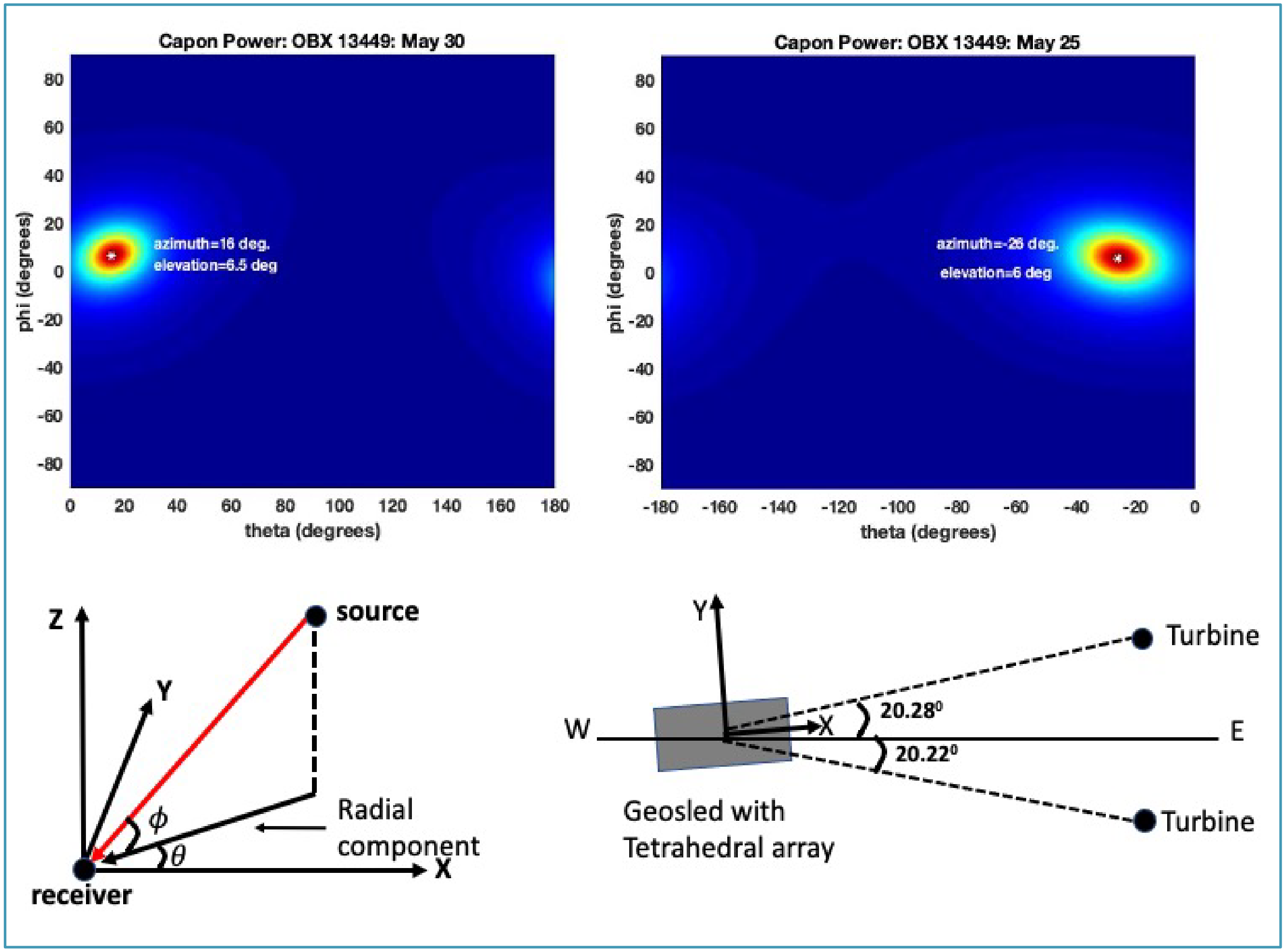

Figure 48. The Direction of Arrival (DOA) of acoustic energy calculated using the Capon method (Potty et al. 2019).
Note: The top left panel shows data from May 30, and the top right panel shows data from May 25. The bottom left panel defines the azimuth and elevation angles corresponding to the acoustic path from source to receiver. The bottom right panel shows the geosled oriented with a counterclockwise rotation (~4.3 degrees (°)) to match the results. With this new orientation, the Capon outputs match the deployed positions within 2°.

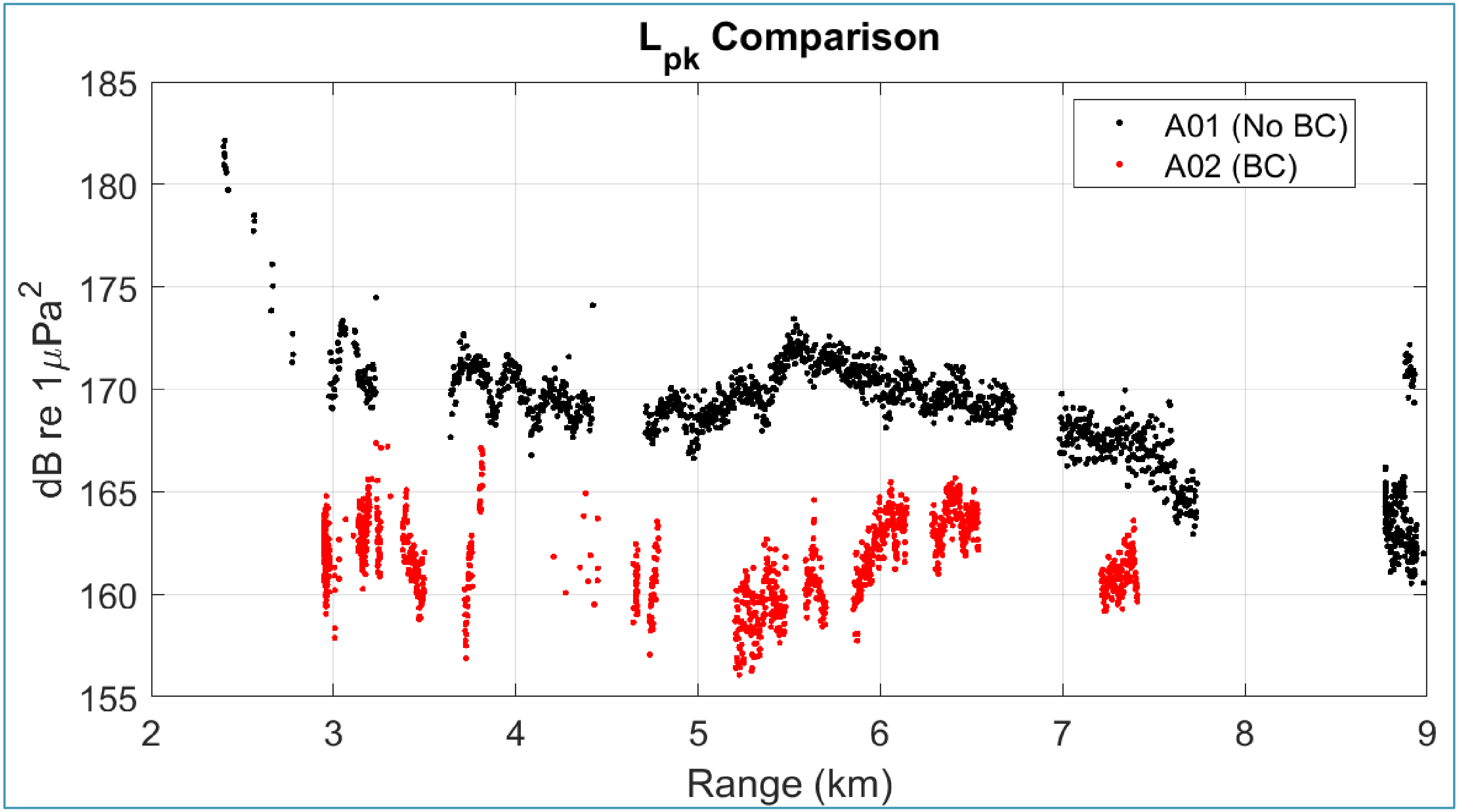

Figure 49. L_{pk} calculated for each individual hammer strike versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red)

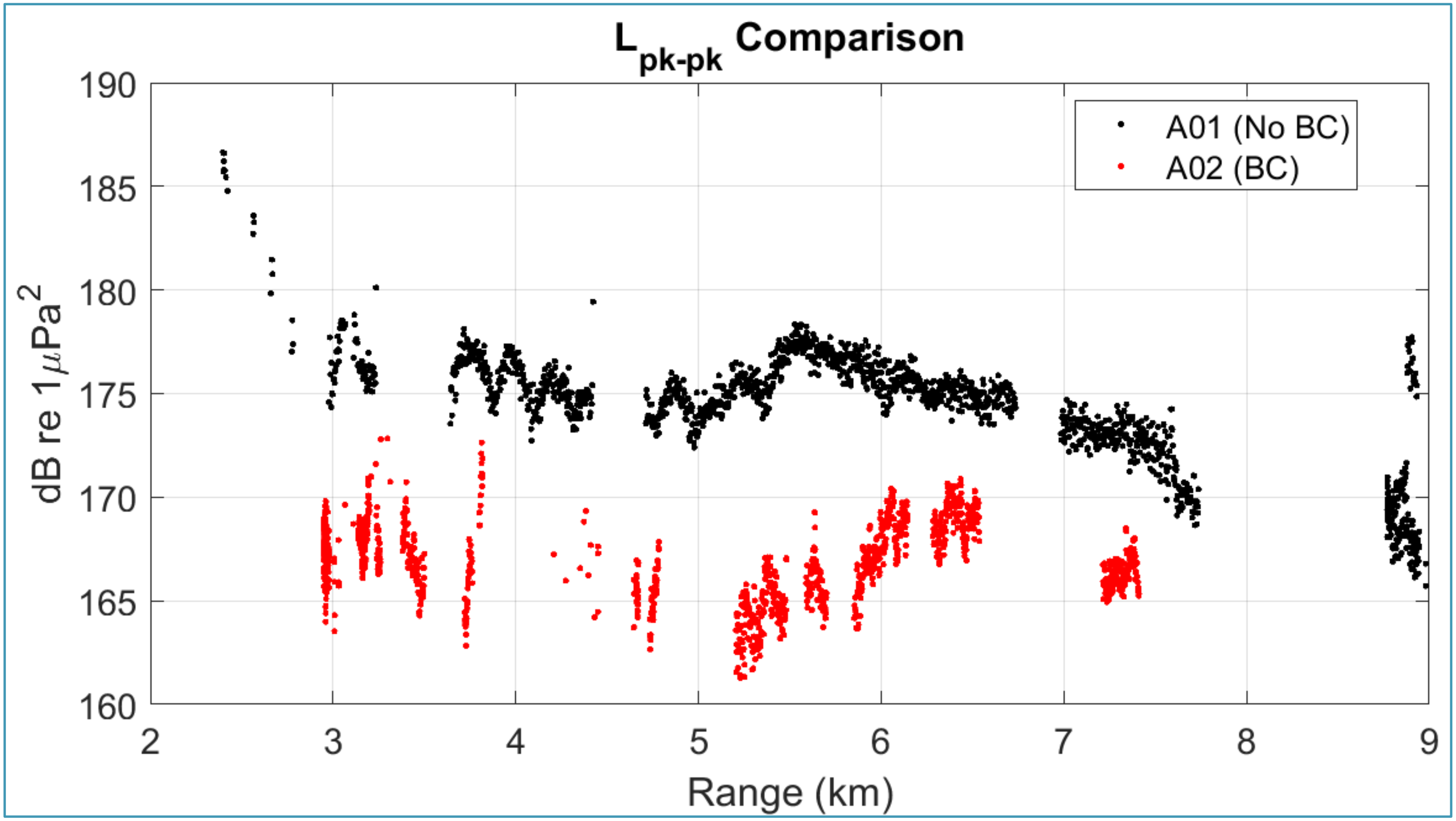

Figure 50. L_{pk-pk} calculated for each individual hammer strike versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red)

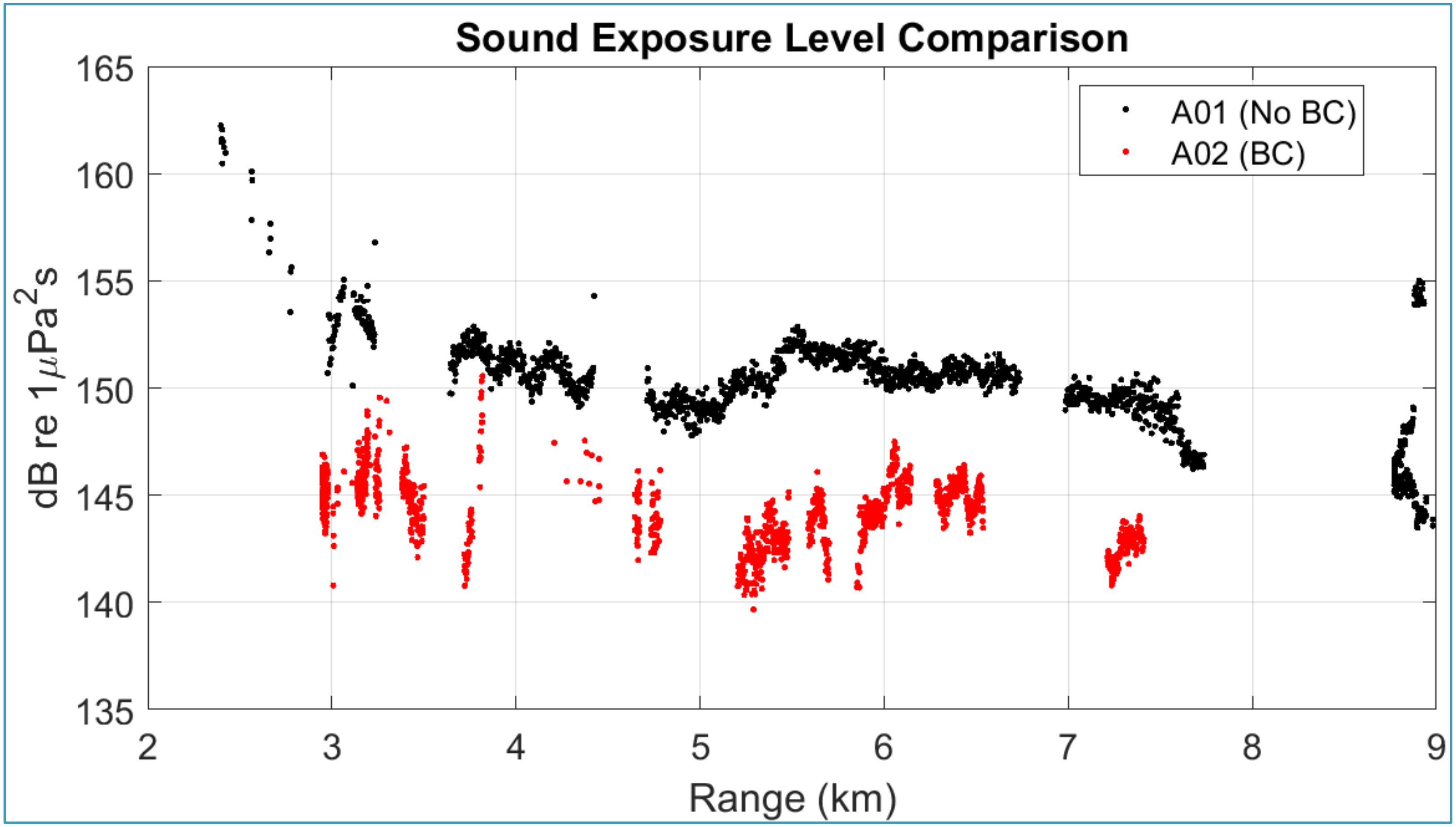

Figure 51. SEL calculated for each individual hammer strike versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red)

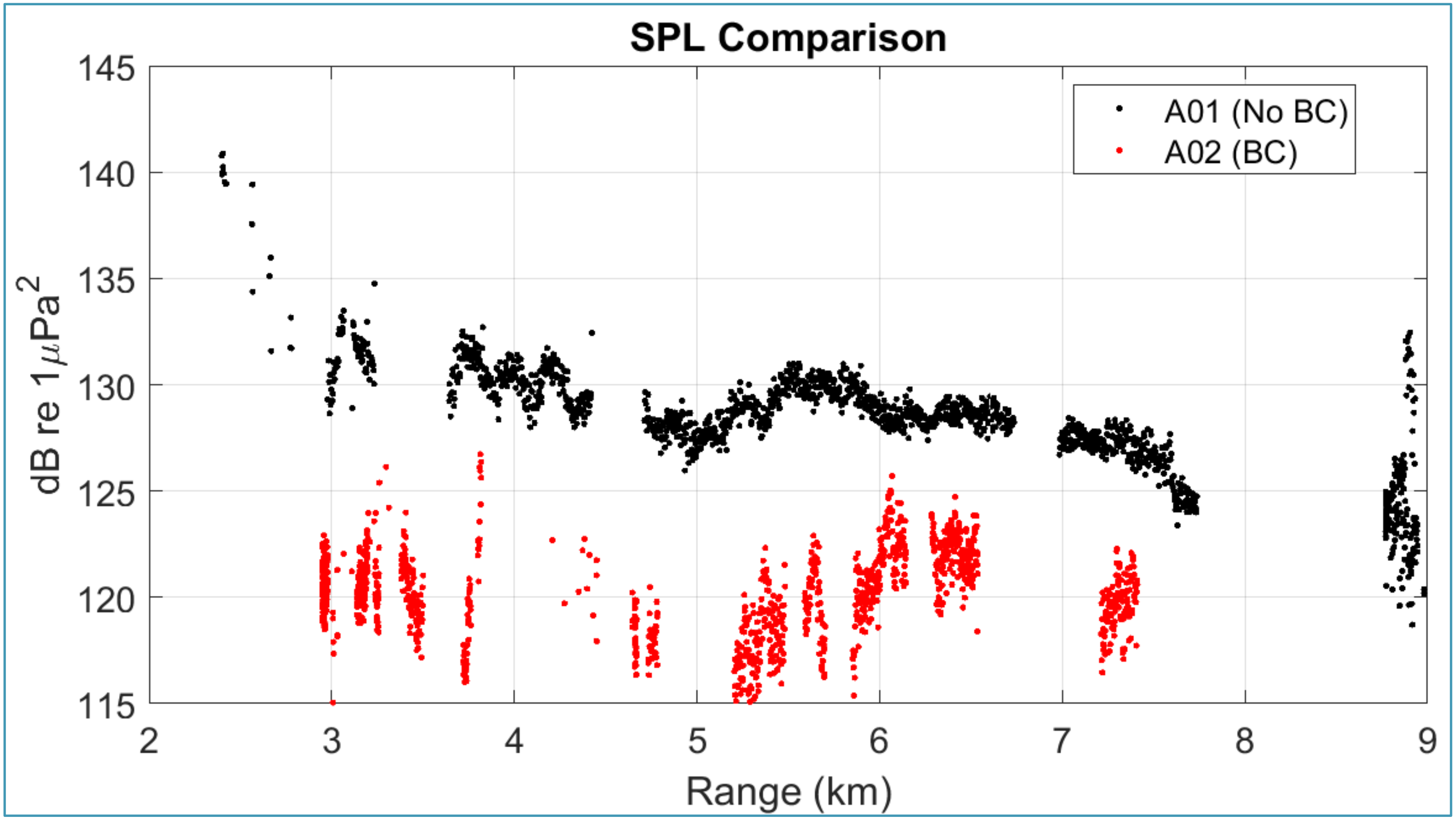

Figure 52. Root-mean-square sound pressure level calculated for each individual hammer strike versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red)

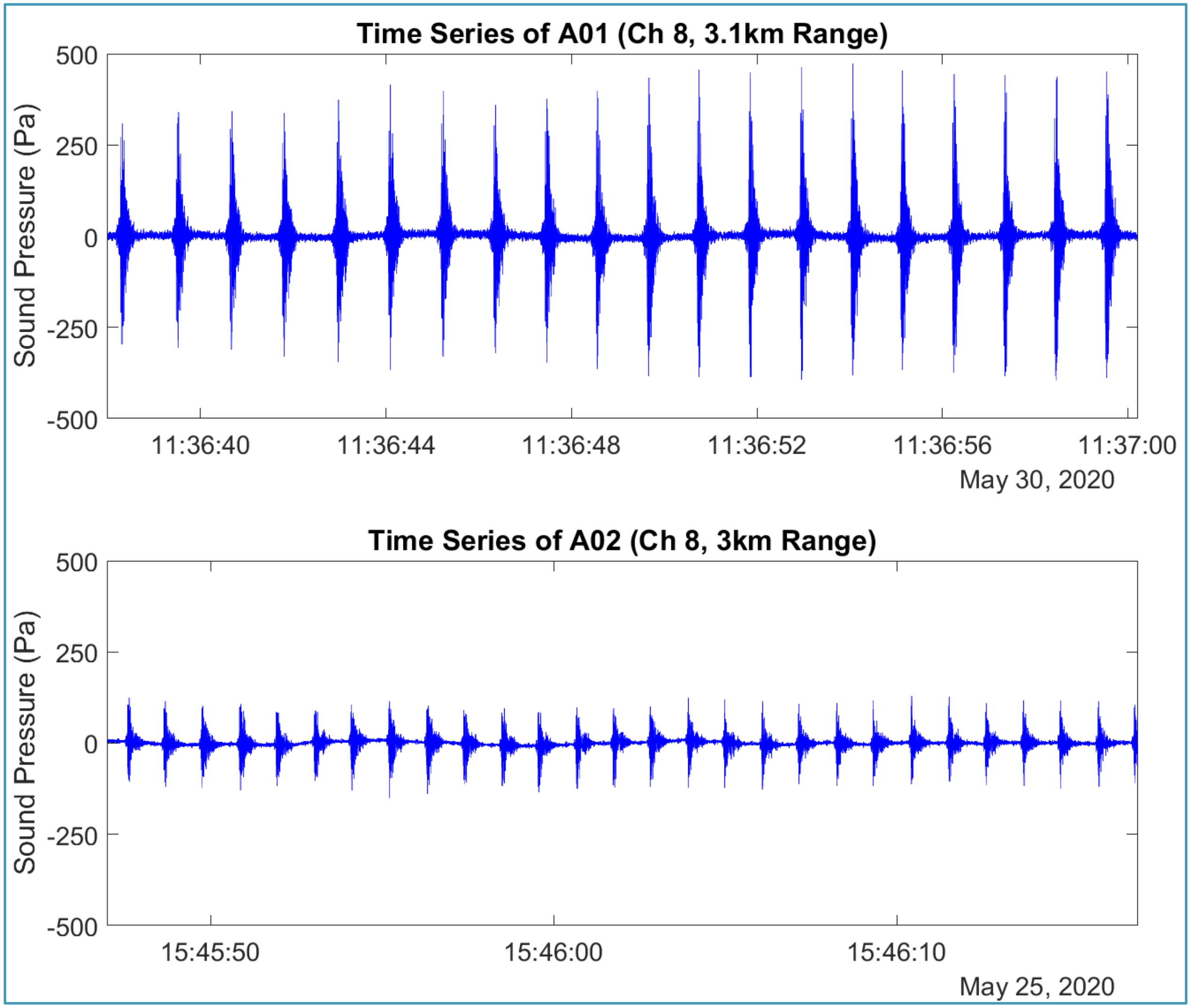

Figure 53. Comparison of the time series recorded at a range of 3 km during both piling events. When no bubble curtain was used (top panel) the measured sound pressure amplitudes at this range were higher than when a bubble curtain was used (bottom panel). The maximum L_{pk} in these time segments is 173 dB (top panel) and 163 dB (bottom panel)

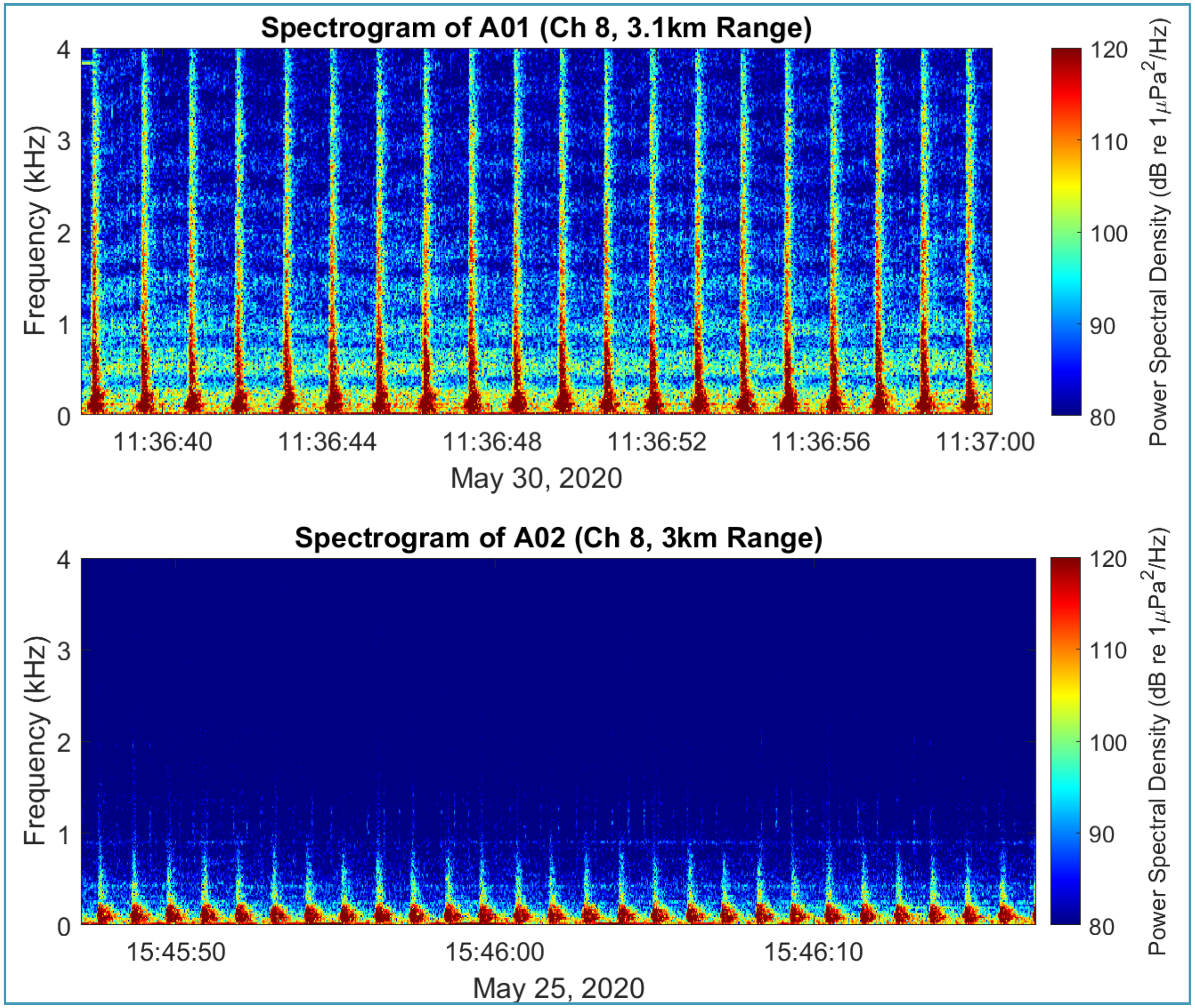

Figure 54. Comparison of the spectrograms of the example time segments shown in Figure 51. The higher frequencies were suppressed when the bubble curtain was used for the piling of A02 (bottom panel) as compared to when there was no bubble curtain used (top panel)

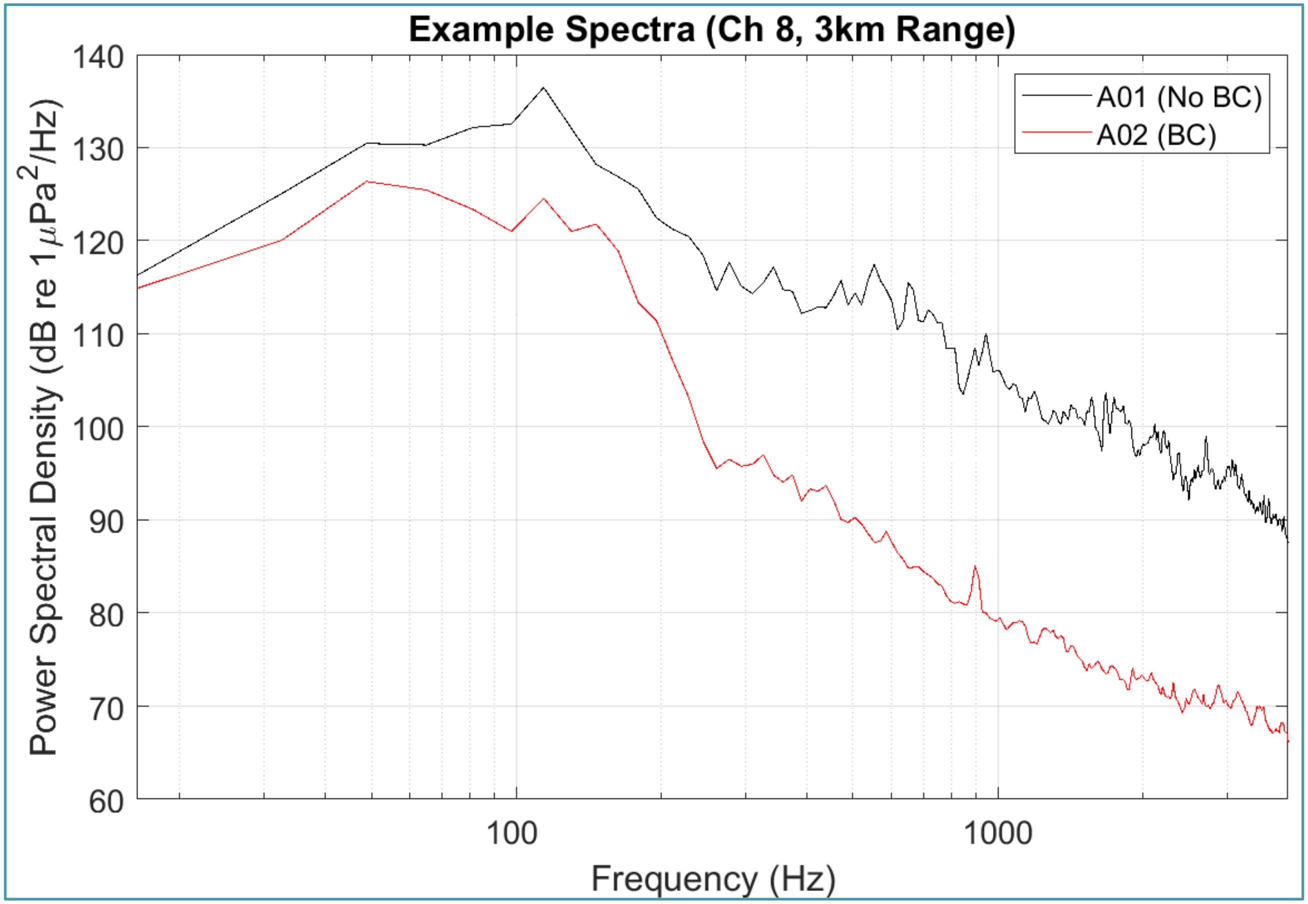

Figure 55. Spectral comparison of the example time segments shown in Figure 53. Differences between the two spectra increase above 200 Hz between the two measurement scenarios. Sound levels were attenuated more when the bubble curtain was in use

3.4.3.2 Kurtosis

The kurtosis calculated on each hammer strike recorded on one channel of the towed array, as a function of distance of the tow vessel away from the foundation, is presented in **Figure 56**. The data from A01, without bubble curtain, show the expected decrease in kurtosis with range. The kurtosis values obtained during the A02, with the bubble curtain, are lower than those during A01. The kurtosis also appears to increase with range. This may be the result of increased strike energy with time and/or a larger contribution from the sediment-borne propagation path greater ranges.

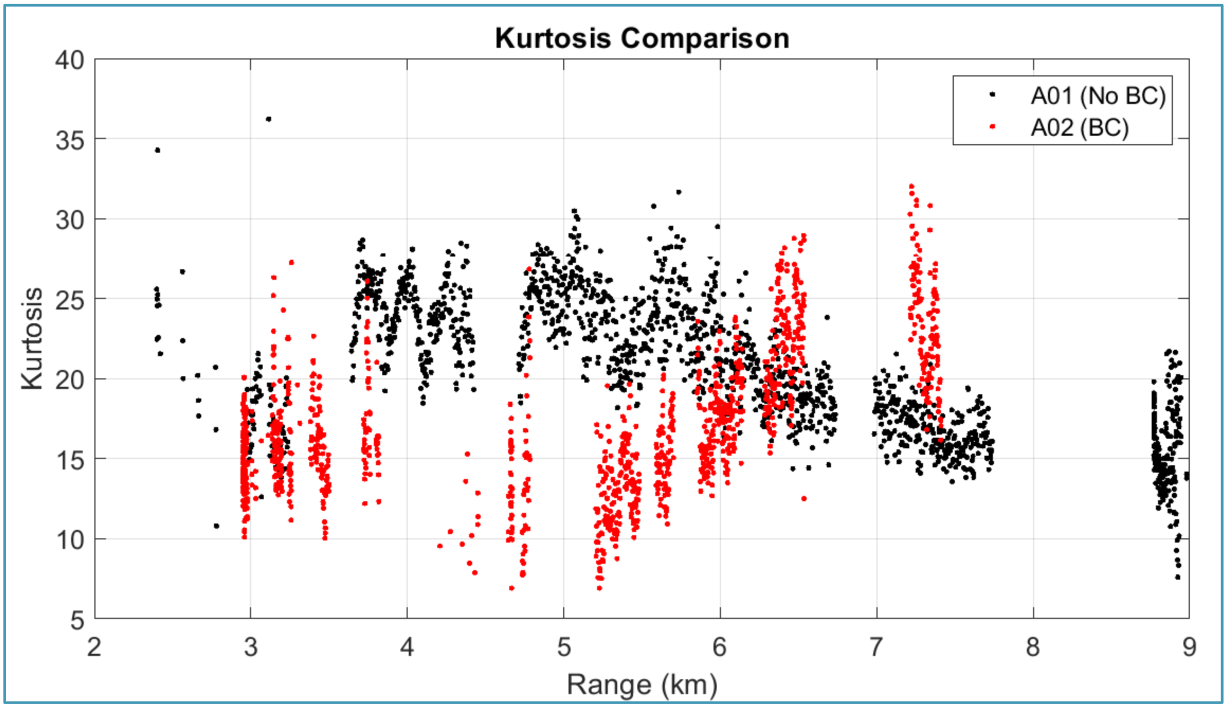

Figure 56. Kurtosis calculated for each individual hammer strike versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red)

3.4.4 Attended Long-range Measurements Using Fixed and Dipped Hydrophones

Figure 57 shows the complete dataset for noise levels around unmitigated piling from 11:20 to 12:40 local time on 30 May 2020, recorded at 15 km. Piling began at 11:23 and the entire sequence was completed at 12:39, 1 hour and 16 minutes later. A series of individual blows characterized the initial soft start, which lasted for 12 minutes. Continuous piling began at 11:37 and ended at 12:07. There were three short pauses of less than 3 minutes in this time.

At 12:07 there was a gap of approximately 28 minutes before piling restarted, with a period of continuous increase in hammer energy from 400 kJ to just under 700 kJ over a 5-minute duration before piling was complete.

Piling on 30 May 2020 was much less erratic than 25 May 2020, with blow energies ramping up smoothly and maintaining a more consistent level for extended durations. This provided more data for comparisons of blow energy with received noise levels (rather than a focus on the performance of the bubble curtain). Measurements were taken at 15 km with a fixed monitor. It was only possible to sample with the dipped hydrophone at 20 and 25 km due to the short duration of piling. The data at the fixed 15 km monitoring location on 30 May 2020 were more complete and therefore more reliable than those on 25 May 2020, with less extraneous noise on the hydrophone.

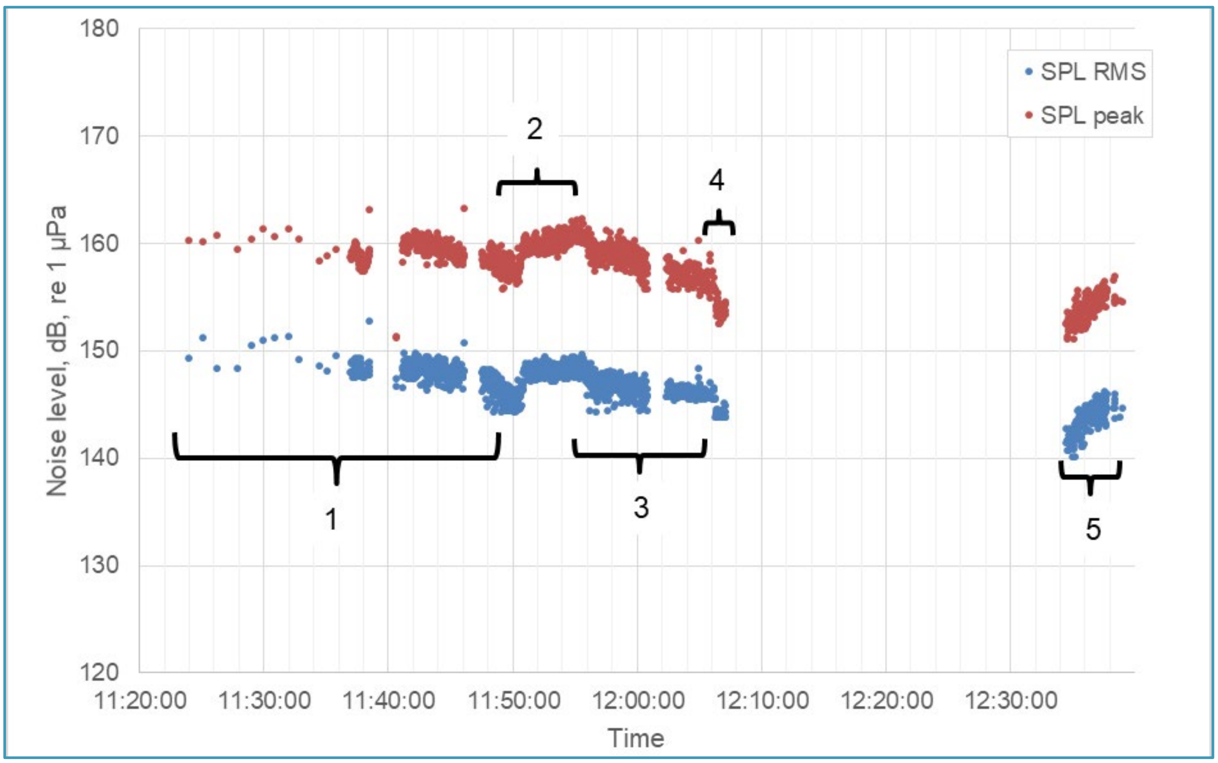

Figure 57. Overview of monitored noise levels over the piling period at 15 km on 30 May 2020
Note: An overall trend of a reduction in noise output at a fixed blow energy was observed over time (1 and 3), although blow energy increased over short timescales (2 and 5)

Analysis of the change in noise levels with range was undertaken using the data from 750 m to 30 km. Included are noise levels measured at 750 m, and 3,000 m or 4,900 m (day dependent) (WaterProof 2020), from the VLA at 7.5 km, fixed monitor at 15 km, and vessel-based measurements. All these measurements were taken on a north to northeast direction from the pile installation location. All measurements compared in this section were taken at mid-water.

3.4.4.1 Pile Driving for Turbine A02

The variation in noise levels between the maximum and minimum sampled across the entire piling sequence on 25 May 2020, from 750 m to 30 km, is presented in **Table 15**. The lowest, minimum recorded noise levels, collected at >10 km, were low enough to be on the order of background noise levels and therefore influenced by ambient noise. Signal was still detected at the frequency peaks, around 100 Hz. See **Section 3.4.4.3** and **Section 3.4.4.4** for more details.

Table 15. Maximum and minimum noise levels during entire piling sequence at each reported distance, mid-water, on 25 May

	SPL_{peak} (dB re 1 µPa)		SEL_{ss} (dB re 1 µPa²s)	
Distance (m)	Max	Min	Max	Min
750*	178	168	160	149
3,000*	173	160	154	143
7,500**	161	150	144	135
15,000	150	142	134	125
19,800	***	126	***	115
30,000	134	***	123	***

* Estimated levels from WaterProof 2020

** Estimated levels from 7.5 km VLA

*** Samples at these ranges at mid-water on the survey vessel were not taken at times representative of high or low (as appropriate) noise levels, over the piling sequence, with reference to the complete dataset.

These noise levels are plotted in **Figure 58** with a simple N.logR+αR line of best fit. For this, the peak sound pressure level (SPL_{peak}) used N=11 and single-strike sound exposure level (SEL_{ss}) used N=10. The absorption coefficient, α, was 0.001 dB/m for all datasets.

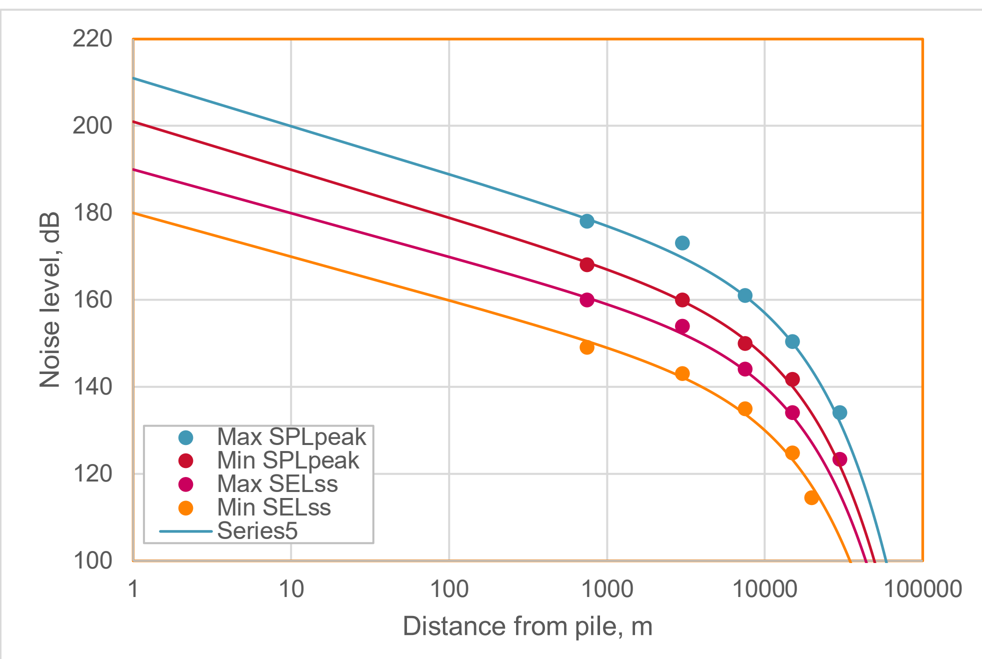

Figure 58. Underwater noise levels showing a line of best fit using a simple N.logR+αR fit, May 25

3.4.4.2 Pile Driving for Turbine A01

The variation in noise levels between the maximum and minimum sampled across the entire piling sequence on 30 May 2020, from 750 m to 25 km, is shown in **Table 16.**

Table 16. Maximum and minimum noise levels during entire piling sequence at each reported distance, mid-water, 30 May 2020

	SPL_{peak} (dB re 1 µPa)		SEL_{ss} (dB re 1 µPa^{2}s)	
Distance (m)	**Max**	**Min**	**Max**	**Min**
750*	190	182	170	162
4,900*	176	168	158	150
7,500**	174	164	154	147
15,000	163.2	151.1	143.6	135.0
20,000	151.9	***	136.4	***
25,000	144.7	137.7	132.2	123.5

* Estimated levels from WaterProof 2020

** Estimated levels from 7.5 km VLA

*** Noise levels at 20 km were only sampled at mid-water at soft start, before the survey vessel moved out to 25 km. As seen later in the report, this tended to represent some of the highest noise levels measured during the piling sequence and as such a reasonable minimum noise level at 20 km is not available.

As previously, these noise levels are plotted in **Figure 59** with a simple N.logR+αR line of best fit. The same coefficients have been applied, with SPL_{peak} using N=11 and SEL_{ss} using N=10. The absorption coefficient, α, was 0.001 dB/m for all datasets.

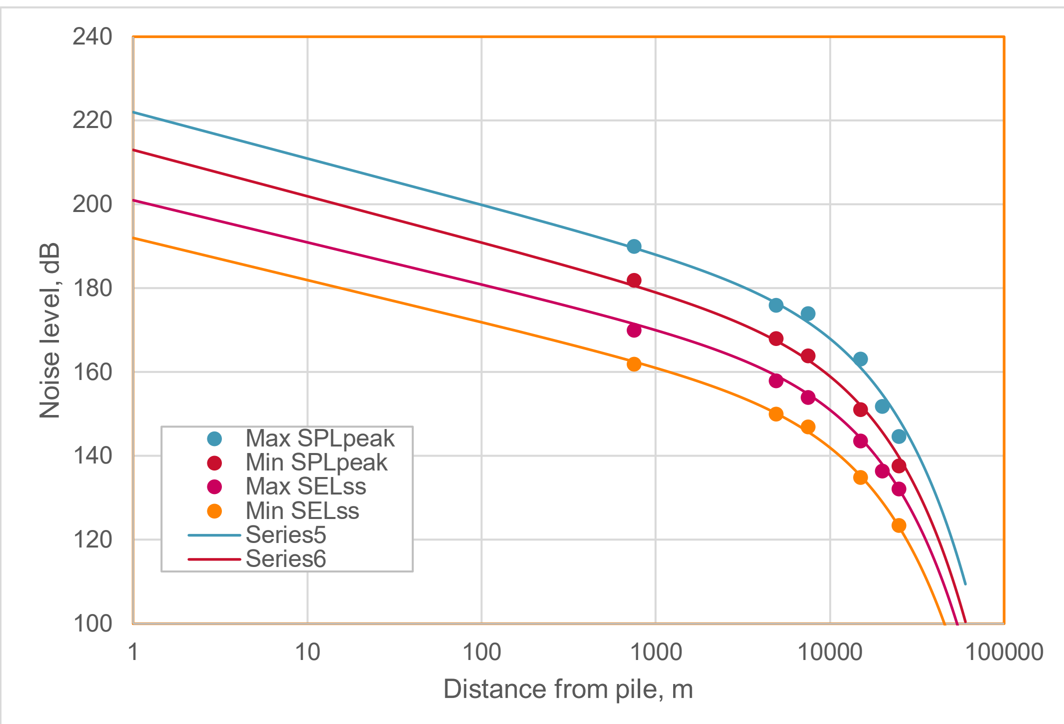

Figure 59. Underwater noise levels showing a line of best fit using a simple N.logR+αR fit, May 30

A waveform and spectrogram for 25 May 2020, with the bubble curtain, are shown in **Figure 60** demonstrating the frequencies in which piling energy was present. This was taken at the period of maximum blow energy, approximately 500 to 550 kJ. The greatest sound energy was focused between 50 Hz and 300 Hz, although the pulses extend up to 4,000 Hz before being lost in the background noise.

A spectrogram analysis was also undertaken for the unmitigated piling noise on 30 May 2020 and is shown in **Figure 61**. The period at maximum blow energy (approximately 680 kJ at the end of the piling sequence) was chosen as an example.

The majority of the energy was from 40 Hz to 300 Hz as was the case on 25 May 2020, but the energy extended higher up the frequency spectrum, with some signal still visible above background at just under 10 kHz, although most remained under 5 kHz.

The attenuation of high frequencies at this range is significant in terms of impacts on marine mammals, particularly toothed whales (odontocetes). The majority of the piling noise occurred at frequencies that these species are relatively insensitive to. Even without the bubble curtain, the limited energy over 4 kHz is below the peak hearing sensitivity of most odontocetes, the peak of which is over 10 kHz.

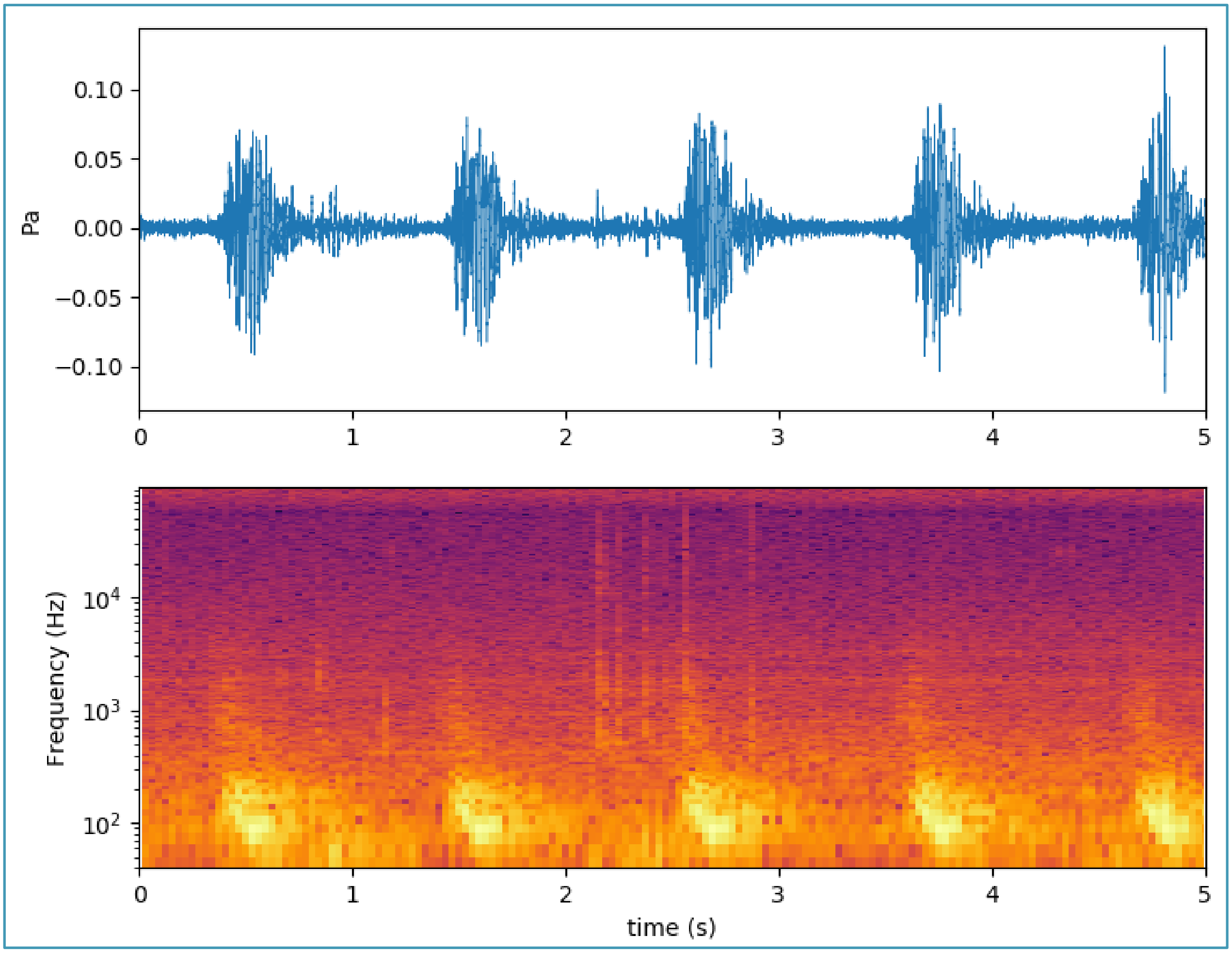

Figure 60. Five-second waveform and spectrogram for a period from 1,658 at 15 km, 40 Hz to 96 kHz, showing five pulses, on 25 May with bubble curtain, blow energy approximately 550 kJ

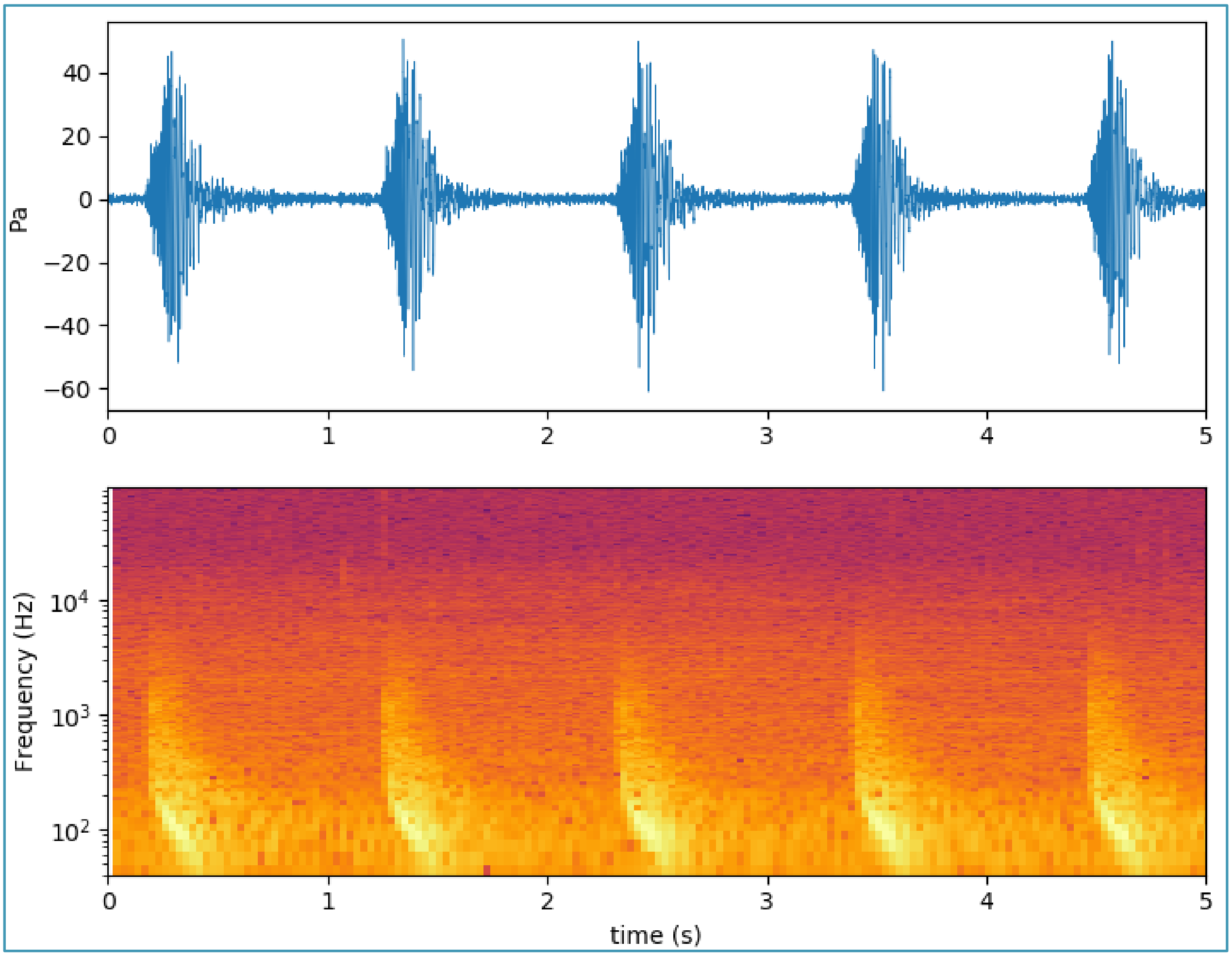

Figure 61. Five-second waveform and spectrogram showing five pulses at maximum blow energy, no bubble curtain, from 40 Hz to 96 kHz, around 12:37, 30 May 2020

3.4.4.3 Comparison of Mid-water and Seabed Measurements

Noise levels were measured from the survey vessel between 20 km and 30 km at both mid-water and 1 m above the seabed to investigate the effect this has on noise levels, and whether the bubble curtain reduced the noise levels.

The results for 25 May 2020 (with the bubble curtain) are shown in **Table 17**, and for 30 May 2020 (without the bubble curtain) in **Table 18**. The two days are separated to focus on the effect of depth rather than the effect of the bubble curtain, which is investigated separately in following sections.

Figure 62 shows the 1/3rd octave band frequency analysis for the measurements taken at mid-water and 1 m above the seabed on 25 May 2020.

The increase in the noise levels near the seabed was almost entirely comprised of increases at low frequency, under 100 Hz, and predominately 50 Hz and below. This increase in low frequency noise appears to be partly driven by background noise at the seabed, which was 5-10 dB higher than the equivalent background noise at 15 m depth. There was a generally negligible effect on frequencies over 100 Hz.

Table 17. Measured noise levels at mid-water vs. 1 m above the seabed, recorded on 25 May 2020 (with bubble curtain active). All levels are averaged over 20 seconds

	SPL_{peak} (dB re 1 µPa)			SEL_{ss} (dB re 1 µPa^{2}s)		
Distance (m)	Mid-water	Seabed	Change	Mid-water	Seabed	Change
20,000	128.3	130.3	+2	116.4	125.4	+6.1
30,000	132.0	137.5	+5.5	117.5	124.8	+9.3

Table 18. Measured noise levels at mid-water vs. 1 m above the seabed, 30 May 2020 (no bubble curtain). All levels are averaged over 20 seconds

	SPL_{peak} (dB re 1 µPa)			SEL_{ss} (dB re 1 µPa^{2}s)		
Distance (m)	Mid-water	Seabed	Change	Mid-water	Seabed	Change
20,000	151.4	152.3	+0.9	135.4	137.6	+2.2
25,000	139.6	141.2	+1.6	125.8	123.9	-1.9

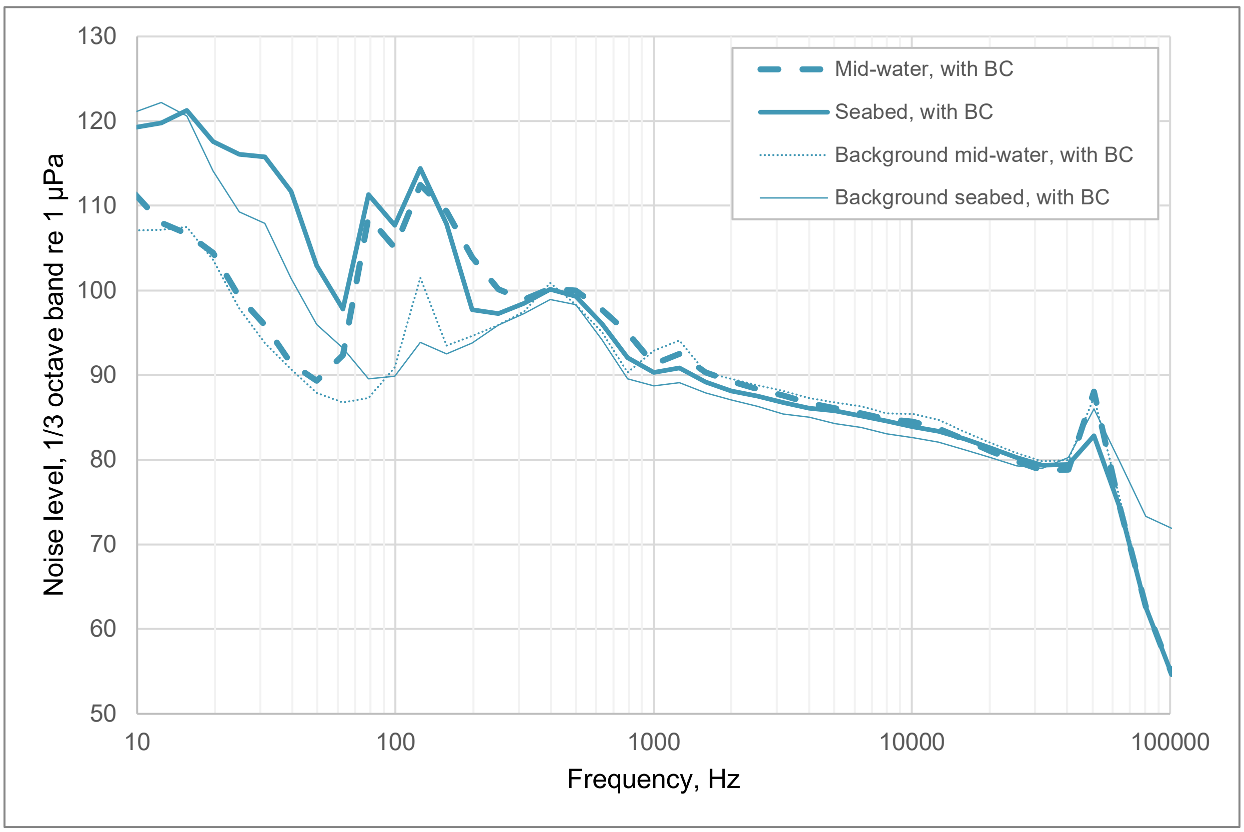

Figure 62. Frequency analysis, mid-water vs. 1 m above seabed measurements, 30 km, 1/3rd octave band, 25 May 2020

A frequency analysis for the above broadband measurements is shown in **Figure 63** for 30 May 2020 (no bubble curtain). Noise levels at low frequencies below approximately the 80 Hz 1/3rd octave band were highly variable. Low-frequency background noise levels had a significant influence near the seabed, as can be seen in the increased low-frequency levels at background in both **Figure 62** and **Figure 63**. From approximately 100 Hz and above, noise levels were largely unaffected by the change in position in the water column.

In general, the difference between the measurements at the seabed and mid-water was negligible except at low frequencies, where noise levels varied by up to 20 dB in 1/3rd octave bands. This is likely attributable to variations in the background noise levels, as can be seen in **Figures 62 and 63** in the absence of piling.

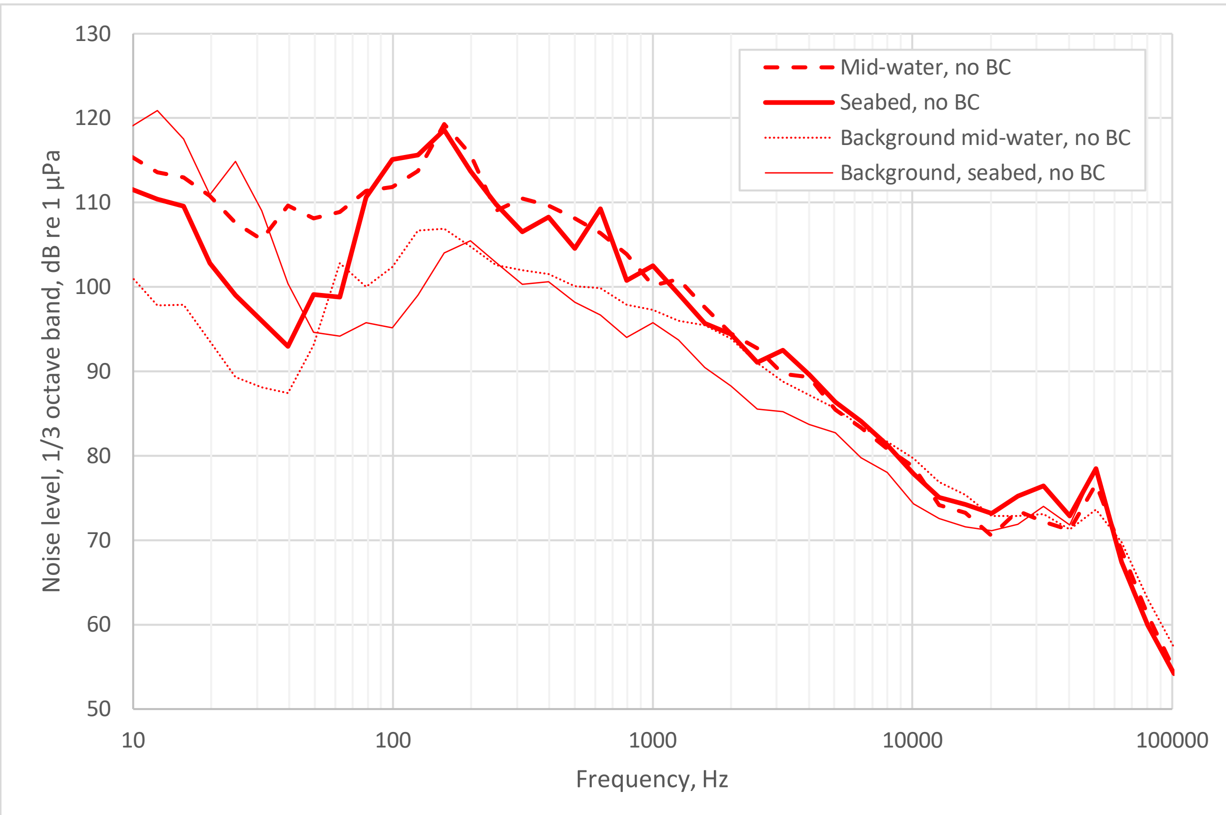

Figure 63. Frequency analysis, mid-water vs. 1 m above seabed measurements, 25 km, 1/3rd octave band, 30 May 2020

3.4.4.4 Comparison of Measurements with and without the Bubble Curtain

Key to the study at CVOW was a direct comparison and identification of the effectiveness of the bubble curtain installed around the foundation installation location. The locations of the measurement transects on 25 May 2020 (pile installed with the bubble curtain) and on 30 May 2020 (pile installed without the bubble curtain) followed the same path. The path was in the direction of the current and conditions on the two days were similar. Bubble curtain performance appeared to be azimuthally dependent (see **Section 3.4.1**) with maximum benefit seen in the direction of current, but whether this is causal has not been confirmed. The piling energies used were also similar, but to ensure as close a comparison as possible, the data presented here was recorded during the soft start, with the energies in use being virtually identical and the piles in the same situation. Noise data here was taken at 20 km (±200 m) as this was the furthest position where data were collected on both days (**Table 19**).

Table 19. Measured noise levels with and without the bubble curtain (BC), 20 km from pile. All levels are averaged over 10 to 20 pulses.

	SPL_{peak} (dB re 1 µPa)			SEL_{ss} (dB re 1 µPa^{2}s)		
	No BC	With BC	Change	No BC	With BC	Change
Mid water	151.4	128.3	-23.1	135.4	116.4	-19.0
Seabed	150.3	132.3	-18.0	134.1	122.5	-11.6

Overall noise levels were clearly reduced when the bubble curtain was active, and the benefit was greatest at mid-water. It is likely that the noise levels shown in **Table 19** with the bubble curtain active were low enough to be influenced in part by background noise. This would have the effect of increasing these levels, which would potentially reduce the magnitude of the change values.

The frequency dependence of bubble curtain effectiveness as measured from the dipped hydrophone is shown for mid-water measurements in **Figure 64**, and for 1 m above the seabed in **Figure 65**. Background noise levels are also included, which were recorded within 30 minutes of the piling measurements and at the mid-water and 1 m above the seabed, as appropriate. The combined frequency spectra of all pile strikes are shown in **Figure 66**.

At 20 km from the piling, majority of the energy in the unmitigated pulse was in the 63 Hz to 1 kHz 1/3rd octave bands. At the location where measurements were taken, the noise levels were of the order of background noise by 2 kHz. The bubble curtain appeared to be effective in attenuating the noise in this entire range of frequencies. Based on this sample, the greatest attenuation was in the 125 Hz band.

At frequencies below 50 Hz and above 2 kHz, the noise levels were actually greater when the bubble curtain was active. This is because for these frequency bands, piling noise had reached background noise, which was higher on 25 May 2020.

For the measurement location 1 m above the seabed, the impact of the bubble curtain was apparent between 63 Hz and 3,000 Hz 1/3rd octave bands. In the 125 Hz band, the attenuation was over 26 dB, even greater than in mid-water. This seems counter-intuitive when considering the broadband results in **Table 19**, which showed a smaller overall attenuation for the measurements at 1 m above the seabed. This can be explained by the increase in the low-frequency levels under 50 Hz with the bubble curtain active. At this location, the pulse had been attenuated sufficiently such that the greatest energy in the spectrum is at very low frequency, caused by the ambient noise. This increases the overall broadband noise level, not the pile strike pulse itself. This effect would be unlikely to show where measurements were taken closer to the pile.

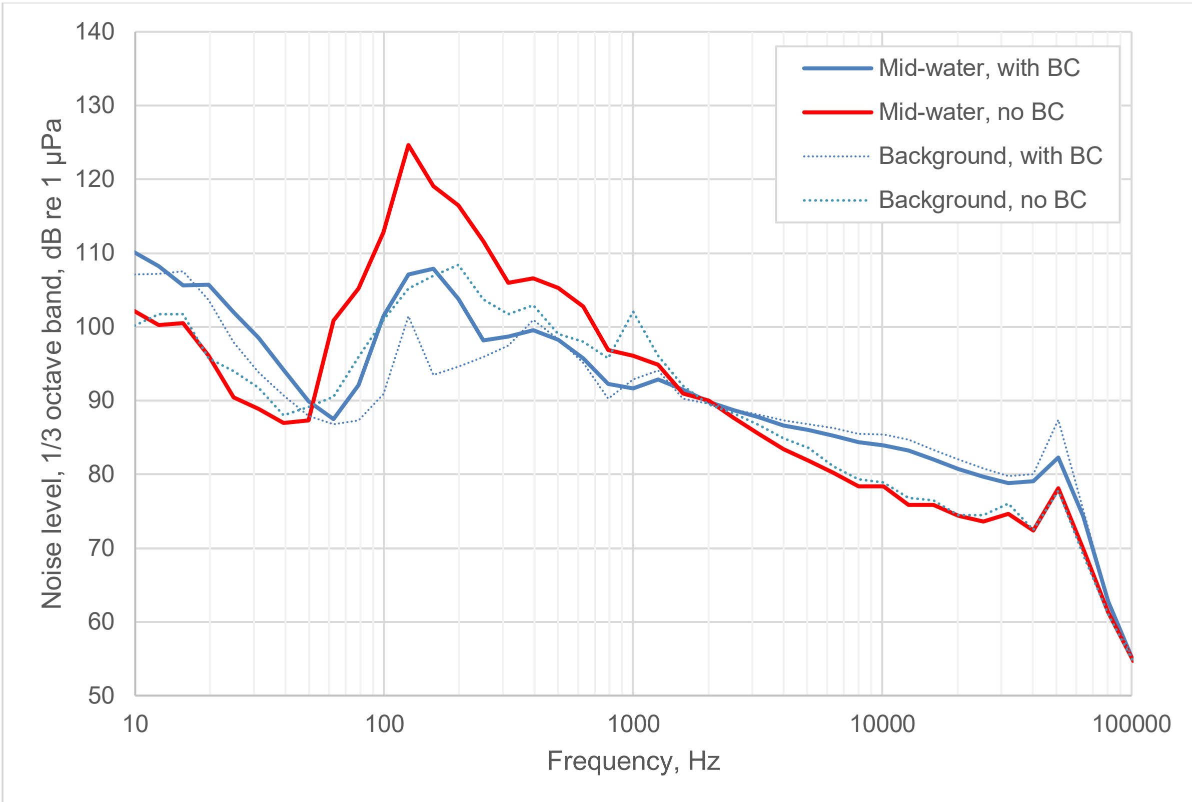

Figure 64. Frequency analysis, mid-water measurements, 20 km, 1/3rd octave band

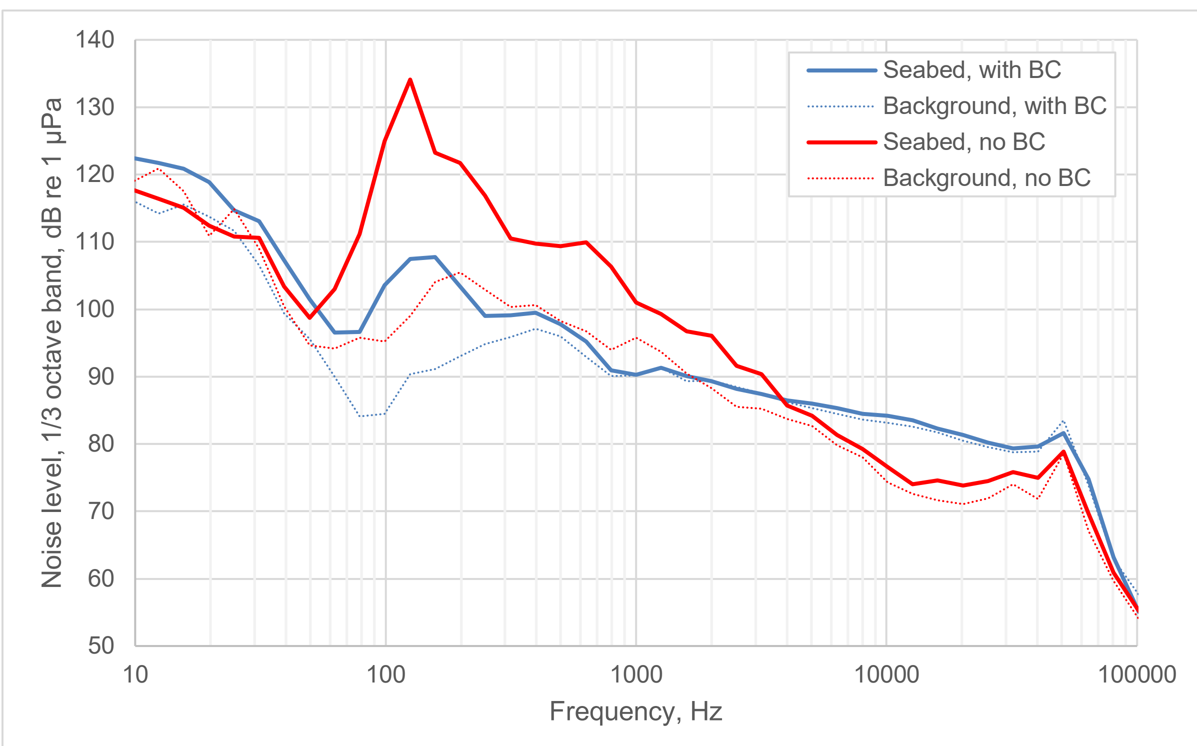

Figure 65. Frequency analysis, 1 m above sea-bed measurements, 20 km, 1/3rd octave band

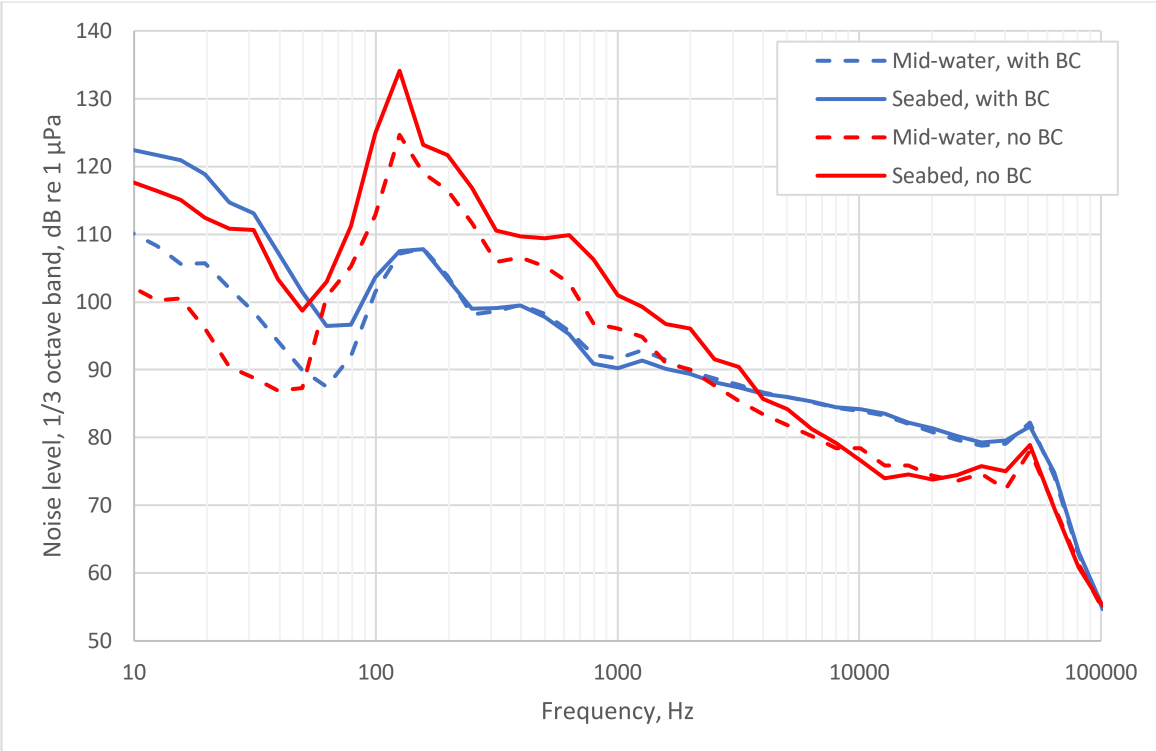

Figure 66. Frequency analysis, combined mid-water and seabed measurements, 20 km, 1/3rd octave band

3.5 Conclusions and Discussion

3.5.1 Overall conclusions from the CVOW Project Monitoring

Underwater acoustic data were recorded and analyzed for short- and long-range locations during pile driving conducted for the two monopile turbines installed by the CVOW Project. An underwater noise mitigation system consisting of a bubble curtain assembly was tested at one of the two turbines allowing for data to be compared between pile driving conducted with and without noise mitigation.

VLA monitoring results highlighted the importance of azimuthal, depth, and frequency dependencies of the bubble curtain performance in mitigating piling noise. Likewise, data recorded on the OBX sensors found strong frequency-dependence of bubble curtain effectiveness; specifically, that it was more effective in mitigating frequencies above 200 Hz. The wavelengths associated with sound at frequencies below 50 to 60 Hz were larger than the depth of water, and as such, the sound waves were likely interacting with the seafloor. The cut-off frequency of the waveguide with a water depth of 26 m is likely to be 35 to 40 Hz, thus any sound propagating below these frequencies is usually not possible without penetrating deep into the ocean bottom. These factors influence sound propagation at low frequencies because the seafloor plays a crucial role in controlling sound propagation. For future projects where bubble curtains are considered for noise mitigation, it is recommended that detailed characterization of the site-specific bubble characteristics be conducted to allow for detailed evaluation of performance at low frequencies.

Towed hydrophone array recordings also indicated that the noise mitigation system was more effective at reducing sound levels at higher frequencies, and the largest differences in received SPLs were seen above

200 Hz. Towed array results showed differences of up to 10 dB in recorded sound levels (L_{pk} and L_{pk-pk} metrics) for mitigated versus (vs.) unmitigated piles, and these results were consistent with those recorded by U.S. Wind.

Results from the long-range measurements conducted using a dipped hydrophone indicated that the bubble curtain reduced noise levels by between 11 dB and 23 dB depending on distance from the sound source, sensor depth, and noise metric. Attenuation was present at all frequencies where significant energy existed in the pulse, from 80 Hz up to 4 kHz, at 20 km. At frequencies above 4 kHz the noise reduced to near background levels in the unmitigated pulse, although this is relative to the ambient noise in that specific location and time.

It is important to note that the long-range dipped hydrophone and towed array measurements were taken on a transect at 15° to north, which corresponds with the azimuthal sampling locations taken on the VLAs nearer the pile. The greatest attenuation from the bubble curtain was identified on this transect.

The noise level at 1 m above the seabed was higher in almost all cases, with the increases primarily at frequency bands below 100 Hz. This may be partly associated with increased background noise near the seabed, although this was also seen at much closer ranges (750 m to 5,000 m in other studies of the same piling event) where the noise level is expected to be considerably above background noise. There may also be a contribution from reflections or reradiated ground borne piling noise.

The low noise levels recorded by the dipped hydrophone at higher frequency bands (in excess of 2 to 4 kHz) was due to both the natural, faster attenuation of high-frequency noise with distance, and also to the frequency-dependent effects of the noise mitigation system, as identified in other parts of this study. This suggests that mitigated piling noise may be less of a concern for odontocetes than baleen whales, which communicate at low frequencies. No energy from piling noise pulses above 10 kHz was detected by the dipped hydrophones at any position.

Overall, results from both attended and unattended monitoring demonstrated the frequency-dependent nature of the noise attenuation system employed during the CVOW pile driving. Bubble curtain performance varied with depth, distance, and azimuthal direction. The underwater noise levels produced by a pile strike was also shown to decrease with time for a given blow energy. Somewhat counterintuitively, noise levels during the planned ‘soft start’ were at times higher than the minimum noise levels measured during the actual pile driving period. This was probably due to the fact that the blow energy remained low throughout the piling process, relative to the capability of the hammer. This observation applies to VLA data at 3.0 km and 7.5 km, as well as the measurements at longer ranges.

In addition to the depth dependency of signal levels, which could be associated with water column effects and the bubble size changes due to water pressure, the moorings also demonstrated signal changes at different azimuths. This was probably associated with control and position of the bubble curtain and changes in bathymetry and bottom parameters along the propagation path.

3.5.2 Comparisons to Block Island Wind Farm Monitoring

The only other offshore wind farm constructed in the U.S. prior to the CVOW Project is the Block Island Wind Farm (BIWF). This five-turbine, 30 MW facility is located 4.5 km from Block Island, Rhode Island. For this Project, jacket turbine foundations were anchored to the seabed using impact pile driving. RODEO Program underwater acoustic monitoring was also conducted during the pile driving at BIWF (HDR 2018, HDR 2019a, b, c).

As relevant and appropriate, underwater acoustic data collected during the pile driving for the only two offshore wind farms to be constructed in the U.S. were compared and contrasted. The data comparison findings should, however, be interpreted with great caution because of the following key differences between the foundations and the pile driving conducted at the two sites, which could significantly influence received noise levels:

- BIWF turbines have jacket type foundations and they were anchored to the seabed with angled/ raked piles (1.4 m pin pile/jacket in frame); the CVOW turbines have 7.8 m vertical monopile foundations;
- Piles used for the BIWF Project (diameter of 1.5 m and a length of 62 m) were smaller than those for the CVOW Project (diameter of 7.8 m and a length of 68 to 70 m);
- Impact pile driving hammer and the hammer energy were different for the two projects, <160 kJ at BIWF vs. >320 kJ for CVOW; and
- Key site-specific conditions that influence underwear sound propagation including water depth, bottom type, and oceanographic conditions varied at the two sites.

Likewise, measurements were performed slightly differently at the two sites. At BIWF, measurements were made at 500 m from the turbines during piling vs. 1,500 m at CVOW.

3.5.2.1 OBX Seismic Sensors

The peak particle velocity measured on the seabed at 500 m from the BIWF turbines was approximately 120 dB re 1 Nm/s (HDR 2019c). The values measured at CVOW (with no bubble curtain) are approximately 114 dB re 1 Nm/s. The particle acceleration measurements at both sites, overlaid with behavioral audiograms for four species of fish, are compared in **Figure 67**. The CVOW data show lower levels compared to BIWF, even though in both cases the levels were above the behavioral thresholds of the fishes for frequencies below 200 Hz.

The BIWF data also showed differences in levels measured on the seabed compared to in-water levels (measured on the tetrahedral array). The difference in peak particle velocity levels were approximately 10 dB re 1 Nm/s. This difference was observed in the CVOW Project even though the difference was lower at 5 dB re 1 Nm/s. Overall however, particle velocity measurements at CVOW agreed with values reported in the literature and with those measured at BIWF.

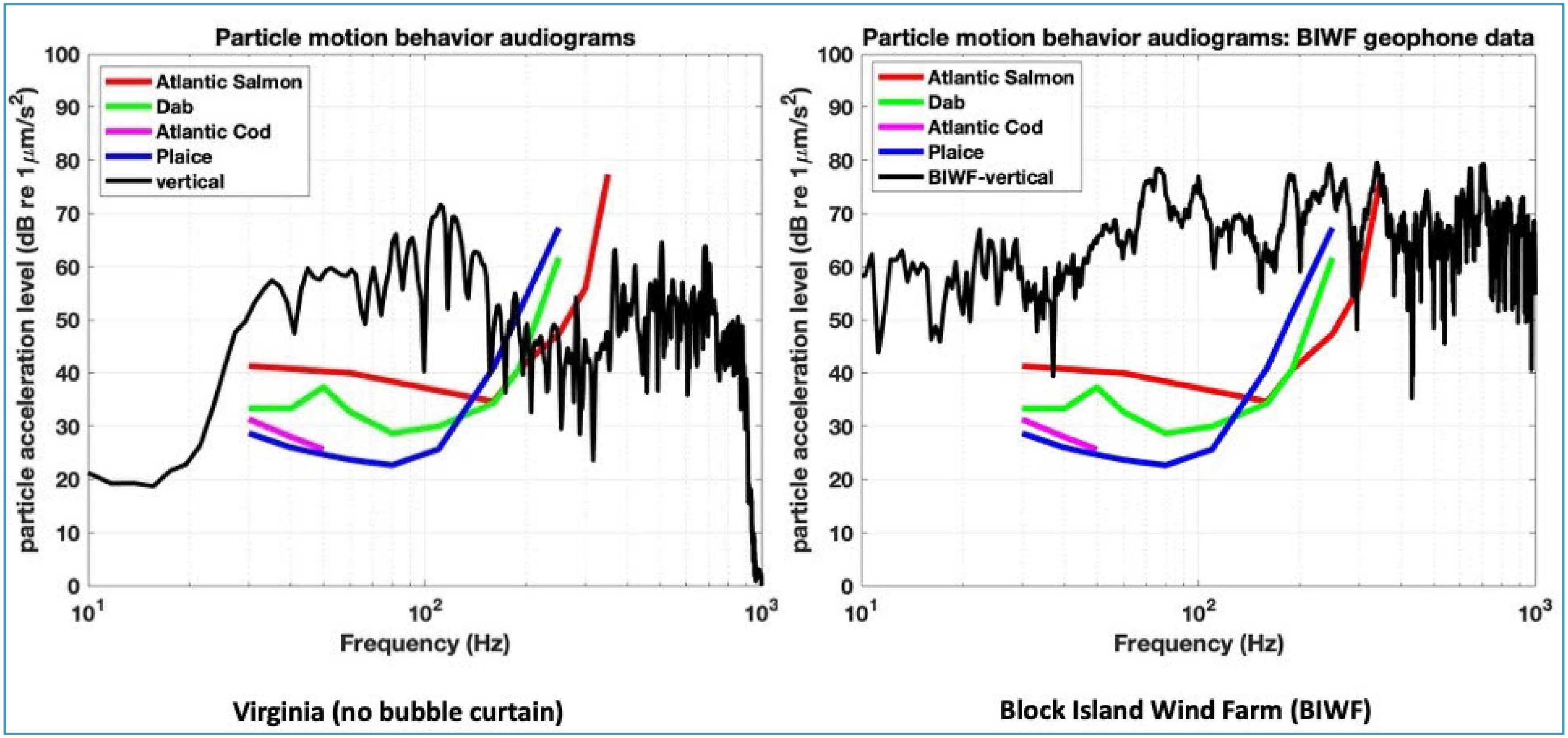

Figure 67. Particle acceleration measured on the seabed with geophone during CVOW (left panel) and BIWF (right panel) construction. All measurements are shown without a noise mitigation system in place (no bubble curtain was used at BIWF)

Note: The geophone used to collect the data shown in the right panel had a lower resonant frequency than the one used in Virginia and might explain the lower levels in the left panel in the 10 to 30 Hz region.

3.5.2.2 Towed Array

Towed array measurements were made at the BIWF during the installation of three piles on 2 September 2015 and 17 September 2015 (HDR 2018, Amaral et al. 2020) were compared to the CVOW measurements. The comparison using one channel of the towed array (channel 8) is shown in **Figures 68 through 70**.

The BIWF turbines had jacket foundation structures, which were comprised of four legs (referred to as A2, B2, A1, and B1). These legs were inclined inwards at an angle of roughly 13°, which produced an azimuthally dependent sound field. Analysis of the measurements from the BIWF showed that the measured sound levels from the hammer strikes recorded on legs A2 and B2 were consistently higher than those from legs A1 and B1. This was due to the orientation of the legs in relation to the towed array and the inclination of the foundation legs was the dominant factor influencing the received sound levels at the BIWF (Amaral et al. 2020).

The B2 and A2 legs were angled away from the towed array and the A1 leg was angled towards the towed array when the measurements were recorded. In this orientation, the sound radiated from the B2 and A2 leg was directed horizontally through the water column and had less boundary interaction and subsequent loss. The sound radiated from the A1 leg was directed more towards the seafloor and was attenuated at a faster rate, which accounted for the lower sound levels and kurtosis values. The monopiles used for the CVOW Project were driven straight into the seafloor and therefore should not exhibit this azimuthal dependency caused by driving piles at an oblique angle.

3.5.2.3 Long-range Measurements Using Dipped Hydrophone

Table 20 summarizes key differences between BIWF and CVOW sites that could influence received long-range noise levels as recorded by the dipped hydrophones. These differences should be considered when comparing and interpreting monitoring results from the two sites.

Table 20. Key differences between BIWF and CVOW that could influence received noise levels

	BIWF	CVOW
Water depth	10–53 m	25–30 m
Transect	Out to sea, increasing water depth	Following coast, constant water depth
Time of year	August to September	May
Foundation	1.4 m pin pile/jacket, in frame	7.8 m monopile
Orientation	Angled/raked	Vertical
Hammer energy	<160 kJ	>320 kJ

Noise levels were collected at midwater-depth at 20 km from the piling at BIWF, and both sets of data are shown in **Table 21**. CVOW data are from 30 May 2020, without the bubble curtain (there was no bubble curtain used at BIWF). Overall, noise levels sampled at CVOW were considerably louder than those at BIWF at the same distance, although this should be expected given the difference in the parameters shown in **Table 20** (primarily larger piles and greater hammer blow energy).

Table 21. Noise levels measured at BIWF and CVOW, 20 km, mid water

	BIWF	CVOW
SPL_{peak} (re 1 μPa)	134–142 dB	150–152 dB
SEL (re 1 $\mu Pa^2 s$)	119–123 dB	133–136 dB

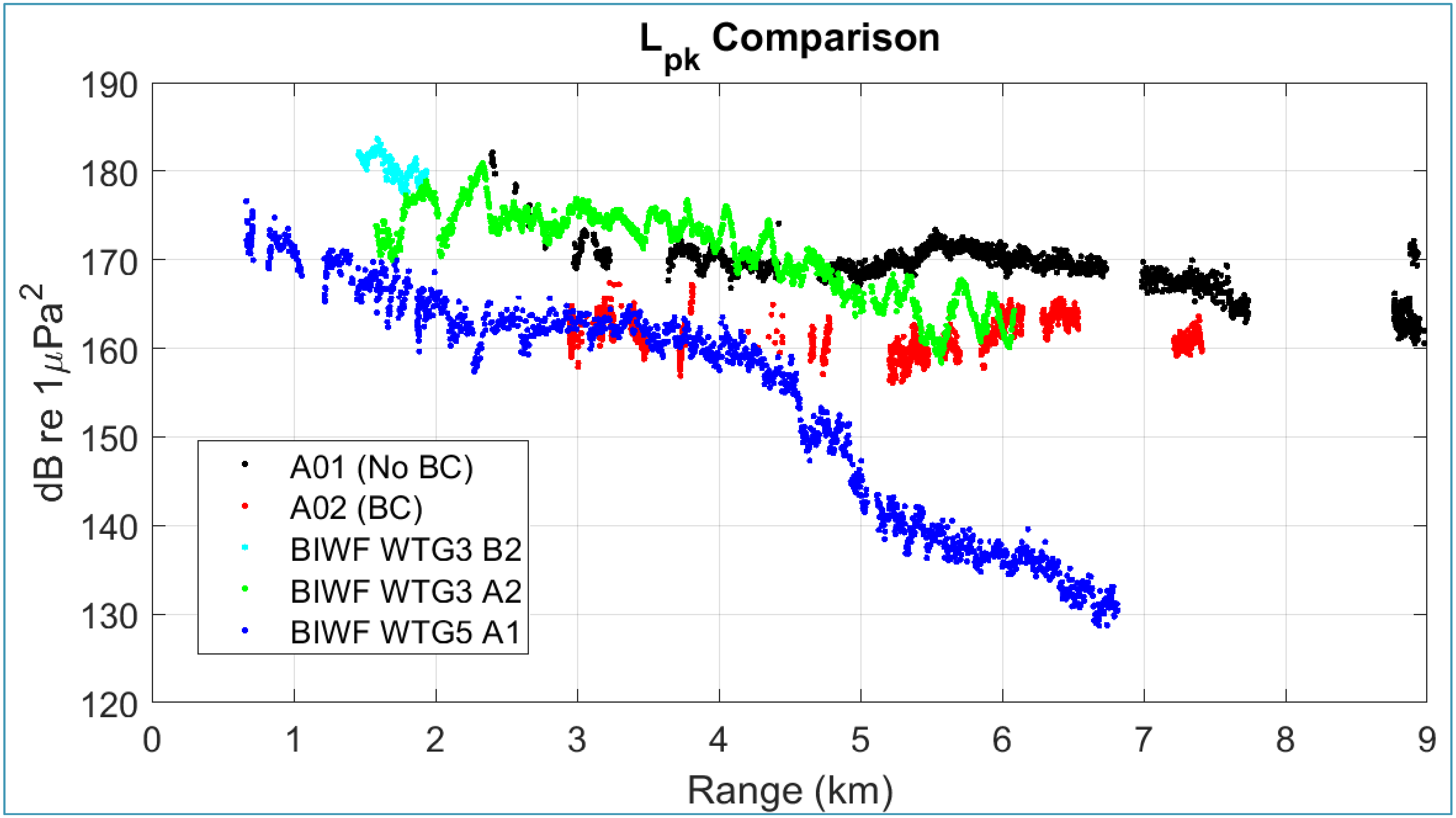

Figure 68. L_{pk} calculated for each individual hammer strike recorded on a single channel of the towed array versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red) at the CVOW project compared to the measurements taken at BIWF

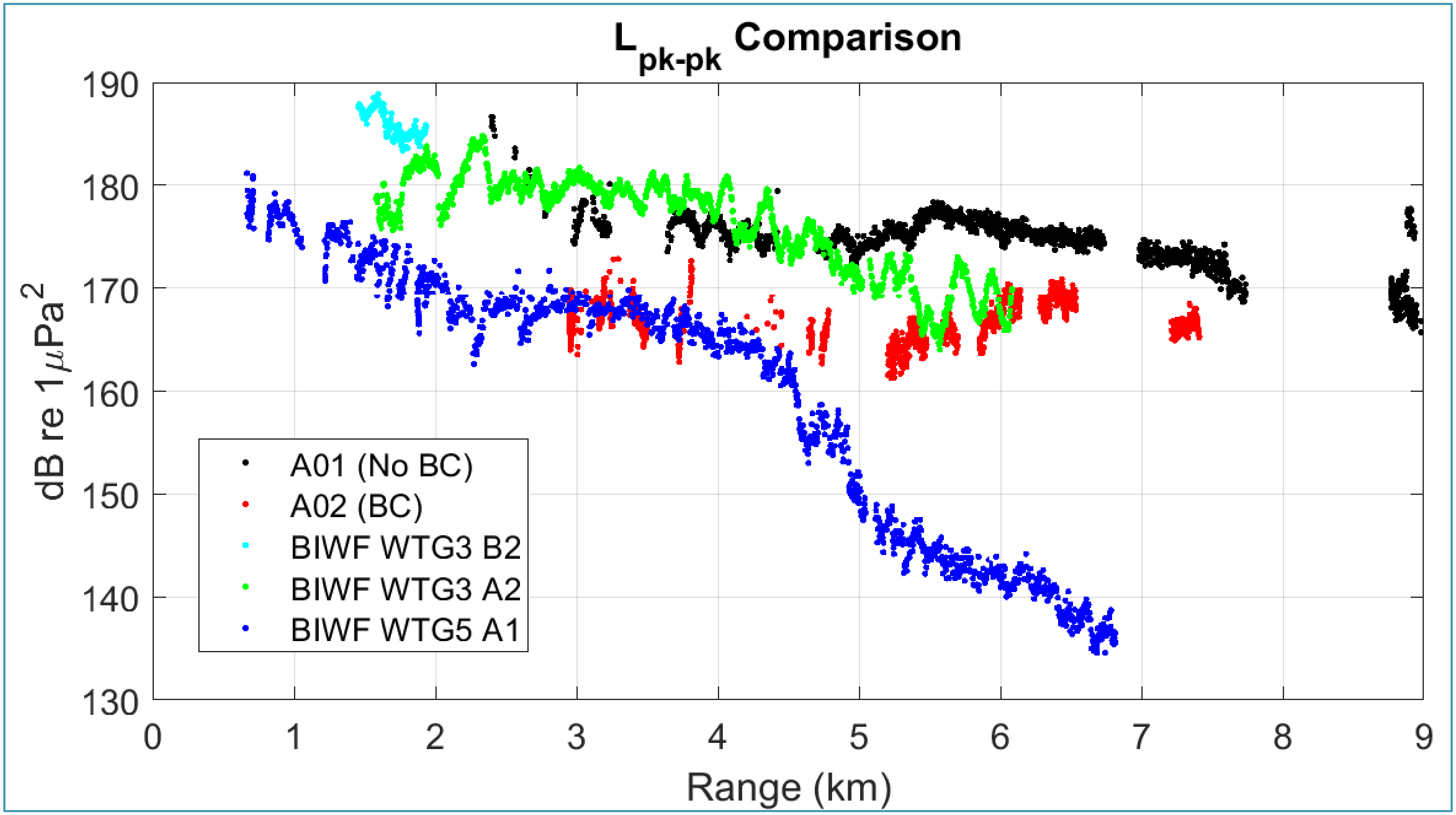

Figure 69. L_{pk-pk} calculated for each individual hammer strike recorded on a single channel of the towed array versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red) at the CVOW project compared to the measurements taken at BIWF

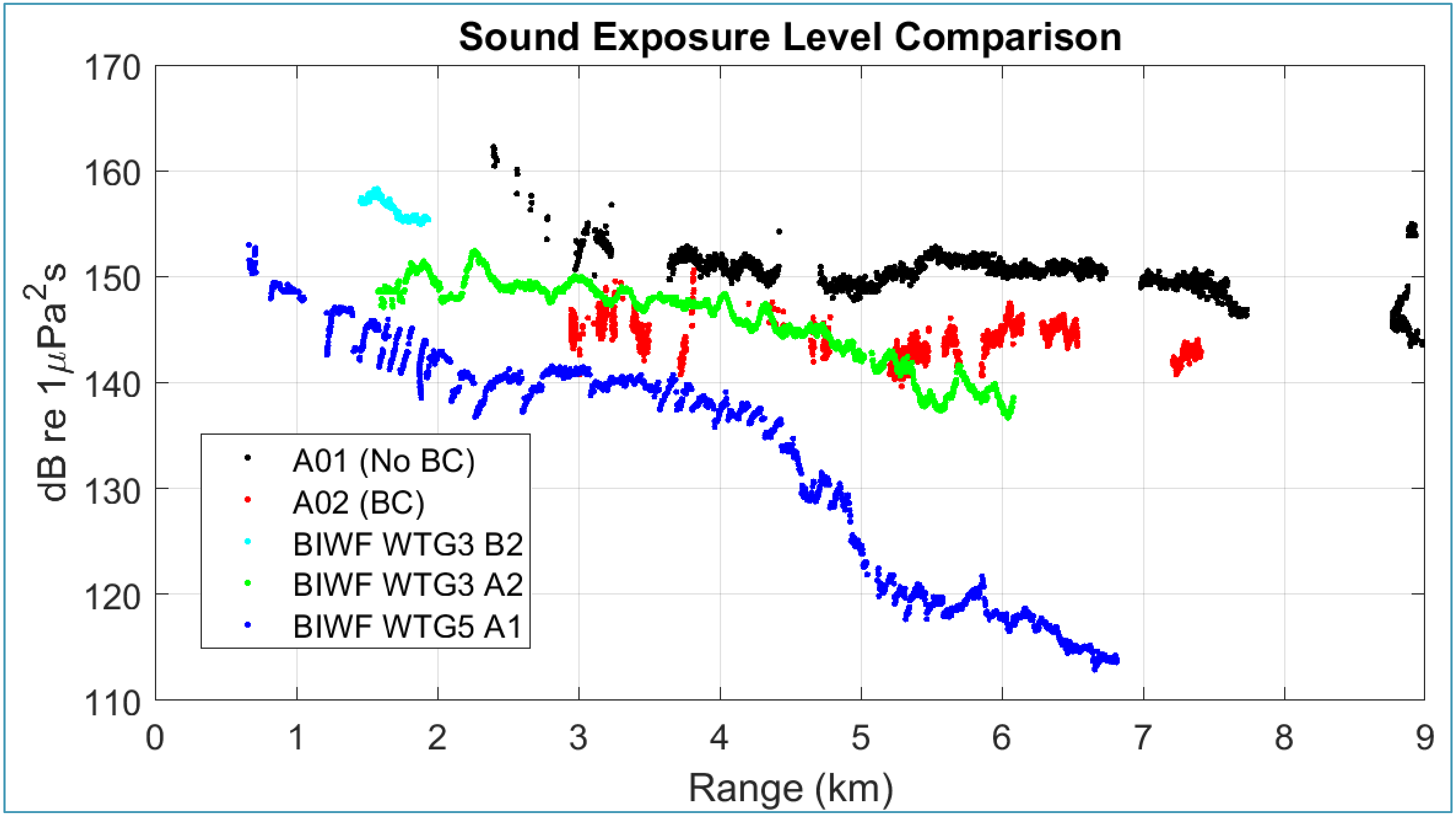

Figure 70. SEL calculated for each individual hammer strike recorded on a single channel of the towed array versus range of the tow vessel from the foundation during the installation of A01 (black) and A02 (red) at the CVOW project compared to the measurements taken at BIWF

3.6 Recommendations for Advanced Data Analyses

A more detailed analysis of signal strengths from individual piles at CVOW, as recorded by the VLA hydrophones, would provide insight into the dependency of piling noise on the depth of the pile.

Likewise, it would be interesting to investigate the azimuthal dependencies observed during this study at different frequencies. Sound propagation in shallow water is best described using normal modes. An acoustic normal mode decomposition of different frequency bands would allow investigation of the acoustic modal dependency of bubble curtain effectiveness. Additionally, data collected by the VLAs could be used to create a site-specific three-dimensional sound propagation model that includes environmental variables and bottom characteristics in order to better understand the spatial dependency of sound propagation.

Understanding the propagation of acoustic energy along the seabed is one of the key factors that explains the effectiveness of the noise mitigation system used at CVOW. It would therefore be useful to further analyze the differences in pressure and particle velocity levels on the seabed using the OBX and geophone data, and in water using the tetrahedral data. The particle velocity model used in this study could also be fine-tuned to better understand the attenuation of the particle velocity field as a function of range. A potential approach is the Finite Element Method, which while highly accurate, is computationally intensive.

It would be useful to model the bubble curtain performance, as previously reported in the literature (Rustemeier et al. 2012, Bohne et al. 2019). Any such effort would require characterization of the bubble distribution, and a coordinated analysis approach involving multiple sensors involved in this study. See **Section 3.7** for details.

There is little information available on the background levels of particle-motion in aquatic environments. There is a need to investigate natural ambient particle-motion levels and determine the directional characteristics of natural sounds from different sources (Popper and Hawkins 2018). The data collected in Maryland offers a relatively long-duration data set of ambient noise and particle velocity conditions in the coastal ocean (approximately 30 m water depth). A series of storms passed by the measurement locations during the deployment period, and further analyses of these data would be extremely useful in characterizing the impact of the storm on ambient conditions, especially particle-motion.

Additional analysis of data collected on the directional sensors would allow development of methods for the estimation of bottom parameters based on horizontal to vertical ratio of particle-motion, as well as development of algorithms to localize and track marine mammals and vessels using data from a single vector sensor or an array of vector sensors.

Further analysis of towed array data would allow better characterization of the pile driving signals. Advanced data analyses could include the calculation of the following:

- Rise time: The rise time of a signal is the time it takes for a signal to rise from 10 percent to 90 percent of its maximum absolute value of sound pressure, as defined in ISO 10843 (1997);
- Decay time: The decay time of a signal was calculated as the time it takes for the signal to decay to 95 percent of the cumulative signal energy from the time of peak sound pressure; and
- Pulse duration: The time interval that contains 90 percent of the sound energy as defined in ISO 18406 (2017).

It would also be useful to correlate these metrics, and those already calculated (SPL, SEL, and kurtosis), with the initial strike energy of the hammer during each individual strike. The kurtosis measurements from the Geosled suggest increased kurtosis with increased strike energy. This comparison would determine the relationship of the received sound level on the initial strike energy used by the hammer. The complete pile driving logs from the developer would be required to perform this analysis. Incorporating the BIWF data into the strike energy vs. received level analysis would also provide a more informative method of comparing the CVOW and BIWF measurements.

It would be useful to further investigate the impulsive vs. non-impulsive nature of piling noise recorded in this study and how this aligns with research by Hastie et al. (2019) and Martin et al. (2020). Aspects of piling noise such as pulse length, rise time, and kurtosis, should be viewed in the context of the potential risk that these pulses will have to species, over simple SPL_{peak} and SEL thresholds.

Long-range noise measurements clearly showed a reduction in level as the piling event progressed at a given blow energy. Likewise, at a fixed blow energy, the noise level dropped on restart after a pause in piling. It would be of value to investigate other datasets for this effect and look for causes. One hypothesis is that this effect is caused by a reduction in area of pile in the water column (where the pile is driven below the water surface) and a reduction in mobility of the pile itself as it is driven further into the seabed.

3.7 Recommendations for Future Monitoring

The suite of monitoring systems deployed at CVOW (VLAs, towed array, the Geosled tetrahedral array, three-axis geophone, OBXs, and dipped hydrophone assembly) was effective in capturing the data required for the analysis of changes in sound levels associated with underwater pile driving. Study results indicated that the bubble curtain assembly tested during CVOW pile driving was effective in attenuating some of the higher sound frequencies. More testing and monitoring of the bubble curtain system is recommended at future facilities. The bubble curtain used for the CVOW Project appeared to have directionally dependent attenuation, and sensors placed at additional locations during future monitoring would better elucidate that directionality. Future monitoring should therefore also include consideration of more directional diversity.

In 2013, the German Federal Maritime Agency issued a standardized methodology for the evaluation of noise mitigation systems that allows comparison of results across projects (Bundesamt für Seeschifffahrt und Hydrographie (BSH) 2013). In accordance with this approach, results from monitored piles throughout the German Exclusive Economic Zone were compiled into comprehensive database known as MarinEARS (Bellman et al. 2020). Implementation of monitoring practices consistent with BSH (2013) specifications at future U.S. facilities would facilitate comparison of results with the information in the MarinEARS database.

The BSH (2013) specifications for hydrophone configurations can be used to assess the directional and depth dependence of noise attenuation systems. In instances where directionally dependent attenuation would be expected, such as the use of a bubble curtain in an area subject to strong currents, the BSH (2013) specifications include detailed methods for monitoring design that help assess the directional dependence of attenuation. Specifically, there is a general requirement that at least four hydrophones be used, where two hydrophones are placed along a minimum of two directions extending from the noise source. A minimum of two sets of two hydrophones would ideally be placed at a 90° aspect angle (+/- 30°) from one another and the sound source. For each monitored direction extending from the sound source, the first hydrophone would be placed within 750 to 1,100 m of the piles (unless operationally unfeasible) and the second hydrophone would be placed at double the distance of the first one from the sound source (1,500 to 2,200 m). Further, it is recommended by BSH (2013) specifications that the hydrophones be installed 2 to 3 m above the seabed. In accordance with these recommendations, future monitoring efforts should include an array of hydrophones on a minimum of two directions extending from the pile. One of these directions should reflect the direction the current to account for its influence on the bubble curtain noise mitigation effectiveness.

If depth dependence of mitigation effectiveness is observed, the BSH (2013) specifications suggest the placement of hydrophones at multiple depths, including in proximity to the seabed and in the middle of the water column to evaluate the extent of depth dependent effects. In these instances, a minimum of two hydrophones per depth at each measuring point is recommended. Future monitoring efforts should continue to use VLAs which feature four hydrophones and consider placing them along multiple directions extending from the pile.

The methods described above can be used to assess the received noise levels at designated distances from an unmitigated and mitigated pile. However, this approach does not account for the fact that the noise source values for an unmitigated pile and a pile within a bubble curtain may differ, which has the potential to introduce uncertainty in noise reduction estimates. To address this issue, the BSH (2013) specifications include a suggested hydrophone array configuration for the evaluation of bubble curtains where a reference hydrophone is placed within the bubble curtain in addition to the stations outside of the curtain. This reference hydrophone allows for the assessment that the noise source levels from the mitigated and unmitigated piles are consistent and would produce reliable estimates of noise attenuation. Future monitoring efforts could include one or more hydrophones within the bubble curtain, if operationally feasible and allowed by the developer, to confirm that noise source levels for each pile are consistent. If it is not feasible to place one or more hydrophones within the bubble curtain, future monitoring plans could consider conducting monitoring of unmitigated and mitigated pile driving on the same pile to control for noise source level variability.

For the CVOW Project, piles (unmitigated and mitigated) were driven at separate locations, on different days, and under different environmental conditions, all of which may influence noise measurements (see **Section 3.3**). These variables could be better controlled during future efforts by monitoring unmitigated and mitigated noise levels at the same pile on the same day, or under objectively similar conditions. This would reduce uncertainty in the evaluation of the effectiveness of a mitigation technology. *For* example, BSH (2013) specifications require that driving of piles for purposes of comparison of mitigation take place during identical operating conditions and similar environmental conditions such as current speed, sea state, bathymetry, and background noise. When monitoring of unmitigated and mitigated pile driving occurs at the same pile, the BSH (2013) recommends measuring the unmitigated portion of the pile first, prior to use of technologies such as bubble curtains, which may alter the acoustic environment due to the lingering bubbles and entrained air in the area even after the bubble curtain was deactivated.

As mentioned previously, CVOW Project monitoring demonstrated that the bubble curtain performance at frequencies below 200 Hz was not significantly different from the pile driving conducted with no bubble curtain. This is generally consistent with the findings of more than 700 monitored pile installations in the North and Baltic Sea, namely that bubble curtains are most effective at mitigating frequencies above 1,000 Hz and do not effectively mitigate lower frequencies (Bellman et al 2020). While these results do not indicate a malfunction of the bubble curtain, directionality of mitigation effectiveness was still noted. It is therefore recommended that for future monitoring efforts, short range measurements of the bubble curtain be taken using high-frequency acoustic systems, such as an acoustic doppler current profiler, echosounder, Adaptive Resolution Sonar Imaging (ARIS), and potentially using underwater video, if conditions allow. Vagle et al. (2010) utilized 100 to 200 kHz echosounders as well as a 300 kHz acoustic doppler current profiler to assess the location, structure, and bubble size distribution of a naturally occurring bubble curtain composed of methane seeping from the sediments in Sakinaw Lake in British

Columbia. Bubble size distributions were estimated using measurements of bubble rise rates through the water column (Vagle et al. 2010). The goal of this sensing would be the assessment of the depth-dependent bubble size distribution, which is required for accurate modelling of the acoustic performance of the bubble curtain.

Documentation of bubble curtain characteristics during future monitoring efforts would be valuable to the scientific community. This could be done with an autonomous underwater vehicle equipped with a camera to observe the bubble curtain along the entire water column. Because the visible range of underwater cameras can be limited by light, turbidity, or bubbles, a more useful alternative would be ARIS, which utilizes 48 to 96 pulsed sonar beams to produce an acoustic image, where the image color represents the intensity of acoustic return. ARIS imagery can be collected regardless of lighting or turbidity and is generally collected within a cone shaped field of view and has a reliable range of approximately 30 m. If visibility is poor, ARIS would allow for a more efficient visual assessment of bubble curtain than a traditional camera and can be readily mounted on remotely operated underwater vehicles.

Azimuthal (directional) dependence was shown to have an effect on underwater noise emissions at both CVOW and BIWF, but for different reasons: pile rake was an influencing factor for BIWF, and the bubble curtain an influencing factor at CVOW (one hypothesis is that orientation of the piles to water current is important). Comparative long-range monitoring is recommended where azimuthal influence could occur (such as for raked piles and bubble curtains), parallel and perpendicular to the parameter of influence (rake orientation and current).

Finally, this study was only able to investigate the use of a large hammer at low (<25 percent) energies, and the performance of these hammers at full power should be investigated for future projects.

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Appendix A: Field Sampling Plan and Health and Safety Plan

Real-Time Opportunity for Development of Environmental Observations (RODEO)

Field Observations During Offshore Wind Structure Installation and Operation – Field Sampling Plan

Block Island, Rhode Island

Contract No. M15PC00002,
Task Order No. 140M0118F0006

November 19, 2017

Prepared for:

BOEM
Bureau of Ocean Energy Management

Bureau of Ocean Energy Management
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Acronyms and Abbreviations

BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
COR	Contracting Officer's Representative
DOI	Department of Interior
MLA	Maryland Lease Area
MSR	Monthly Status Report
RODEO	Real-time Opportunity for Development Environmental Observations
RFP	Request for Proposal
SSS	Side Scan Sonar
TO	Task Order
URI	University of Rhode Island
WTG	Wind Turbine Generator

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1 Introduction and Background

This Field Sampling Plan describes the HDR Team's approach for conducting individual tasks under Contract No. M15PC00002_Task Order (TO) No. 140M0118F0006 (Field Observations during Offshore Wind Structure Installation and Operation). It also includes a deliverables schedule and a description of the work products that will be produced under this TO.

KEY PERSONNEL: The following key individuals will lead and direct the execution of this TO:

1. Anwar Khan (Program and Task Order Manager)
2. James Elliot (Deputy Task Order Manager)
3. Randy Gallien (Senior Technical Advisor)
4. Ryan Thompson (QA/QC Officer)
5. Carl Hager (Senior Acoustician)
6. Jessica Aschettino (Field Team Leader)
7. James Miller (Technical Project Manager)
8. Paul English (Technical Project Manager)
9. Robin Newman (Field Team Leader)

In addition, the TO execution team will also include several different technical specialists, subject matter experts, scientists, engineers, and support professionals such as boat operators and field personnel.

1.1 Deliverables Schedule

The period of performance for this TO is 30 months from the date of award. Work products will be delivered per the schedule shown in **Table 1**.

1.2 DOI Scientific Integrity Policy Acknowledgment

HDR acknowledges that scientific integrity is vital to U.S. Department of the Interior (DOI) activities under which scientific research, data, summaries, syntheses, interpretations, presentations, and/or publications are developed and used. We recognize that failure to uphold the highest degree of scientific integrity will result not only in potentially flawed scientific results, interpretations, and applications but will damage HDR and DOI's reputation and ability to uphold public trust.

All work performed under this TO will comply with the DOI Scientific Integrity Policy posted to http://www.doi.gov.

Table 1: Deliverable Schedule

Deliverables	Distribution	Due Date
A. Monthly Status Reports for TO	COR, CO, DES - one (1) copy (digital) each via email.	Six weeks after contract award and monthly thereafter.
B. Technical Report(s) (Draft Copy)	CO – cover letter via email COR, DES– one (1) digital copy each via CD or ftp	Six months (6) after recovery of equipment.
C. Technical Report(s) (Final Copy)	CO - copy of cover letter only, via email COR, DES – one (1) electronic copy each on CD	Within thirty (30) days of receipt of BOEM review comments for Technical Report (Draft Copy).
D. Technical Summary(s) (Draft Copy)	COR, CO, DES & BAC– one (1) digital copy each	Concurrent with submission of Technical Report (Draft Copy).
E. Final Technical Summary(s) (Final Copy)	COR, DES– one (1) digital copy CO – one (1) hard copy	Concurrent with submission of Technical Report (Final Copy).
F. Webinar and Power Point Presentation	COR, DES – one (1) digital copy each on CD	Concurrent with submission of Technical Report (Final Copy).

BOEM = Bureau of Ocean Energy Management
CO = Contracting Officer
COR = Contracting Officer's Representative
DES = Chief, Division of Environmental Sciences

2 Task Order Objectives and Scope of Work

2.1 Introduction

The U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Office of Renewable Energy Programs, requires monitoring during the installation and operation of offshore wind structures at two different locations in the Mid-Atlantic region. The first location is off the coast of Virginia where two wind turbines are to be installed and made operational by spring of 2020 (**Figure 1**). The second location is in the Maryland Lease Area (MLA) where a meteorological tower is proposed to be installed in Spring 2018 (**Figure 2**). Installation of the offshore structures at both locations will include pile driving. The specific installation technology is not known at this time.

After installation, there may be an opportunity to conduct testing of monitoring equipment at either or both sites. For example, scour monitors, which were previously tested at the Block Island Wind Farm. Sediments in the mid-Atlantic, particularly in the Virginia area, are highly mobile sands and this affords the opportunity to evaluate the scour monitoring equipment under different geological environment. Additional technologies that could be tested at one or both locations include monitors for corrosion, turbidity, and biofouling.

Under this task order (TO), the HDR Team will 1) monitor sound generated by pile driving during the installation of the proposed offshore structures at both locations, and 2) develop and implement methods to test selected monitoring equipment at the MLA location.

As required by BOEM, the project developers will conduct sound source verification studies near their installations. Monitoring performed by the HDR Team under this TO will not duplicate the developers efforts, but rather augment them.

The work proposed to be performed under this TO falls within the objectives identified in the basic contract and specifically Tasks C.5.2.1 and C.5.3.

2.2 Monitoring Objectives

The objective of this TO is to provide a record of impact producing activities during construction and operation of offshore wind structures in the Mid-Atlantic. The specific technical objectives are:

- Measure underwater sound generated by the pile driving during the installation of a wind turbine and a meteorological tower.
- Test scour monitors in a mobile sand environment.
- Test monitoring methodologies for corrosion, turbidity, and biofouling.

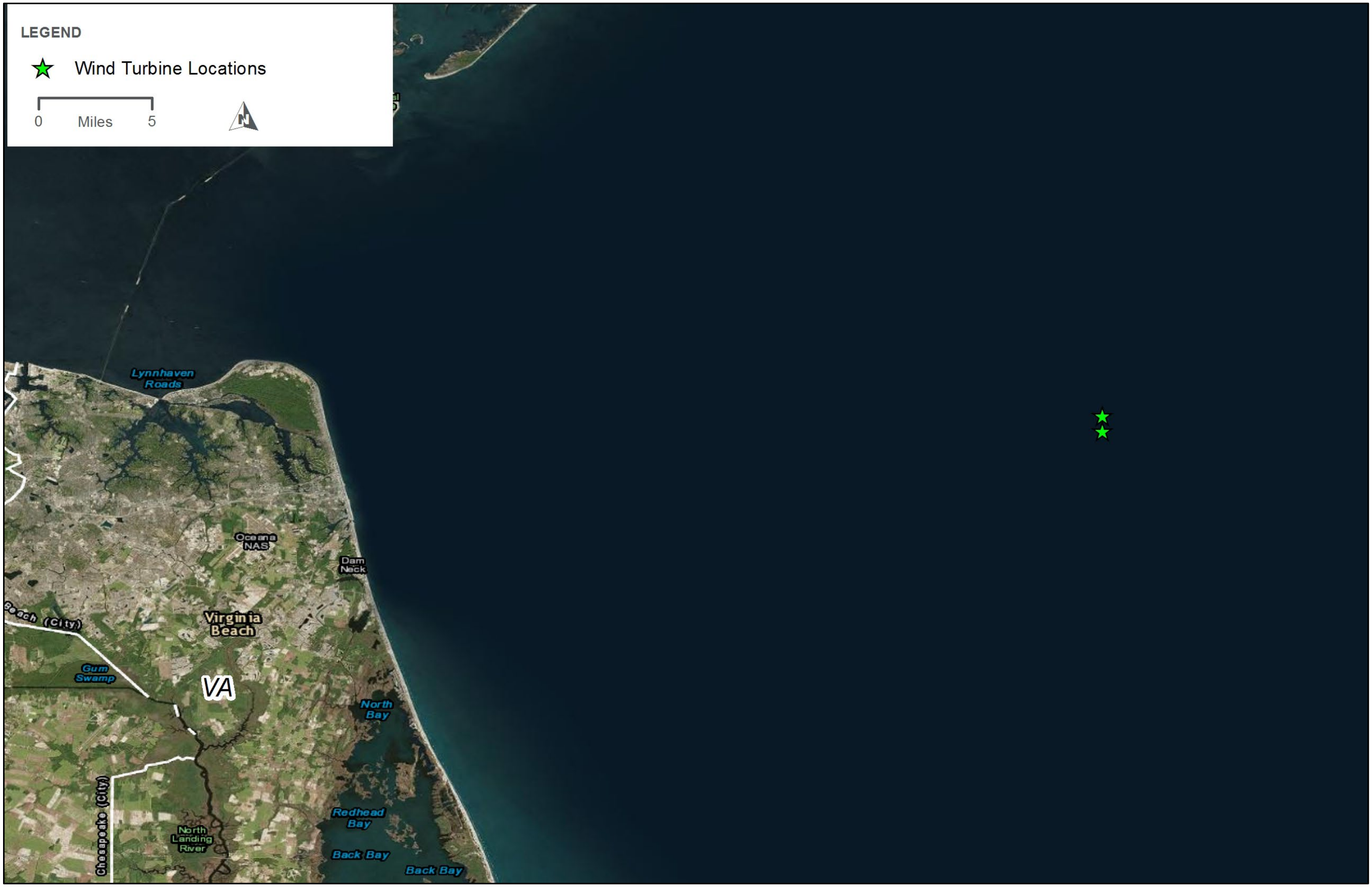


Figure 1: Proposed locations of Two Wind Turbines off the Virginia Coast

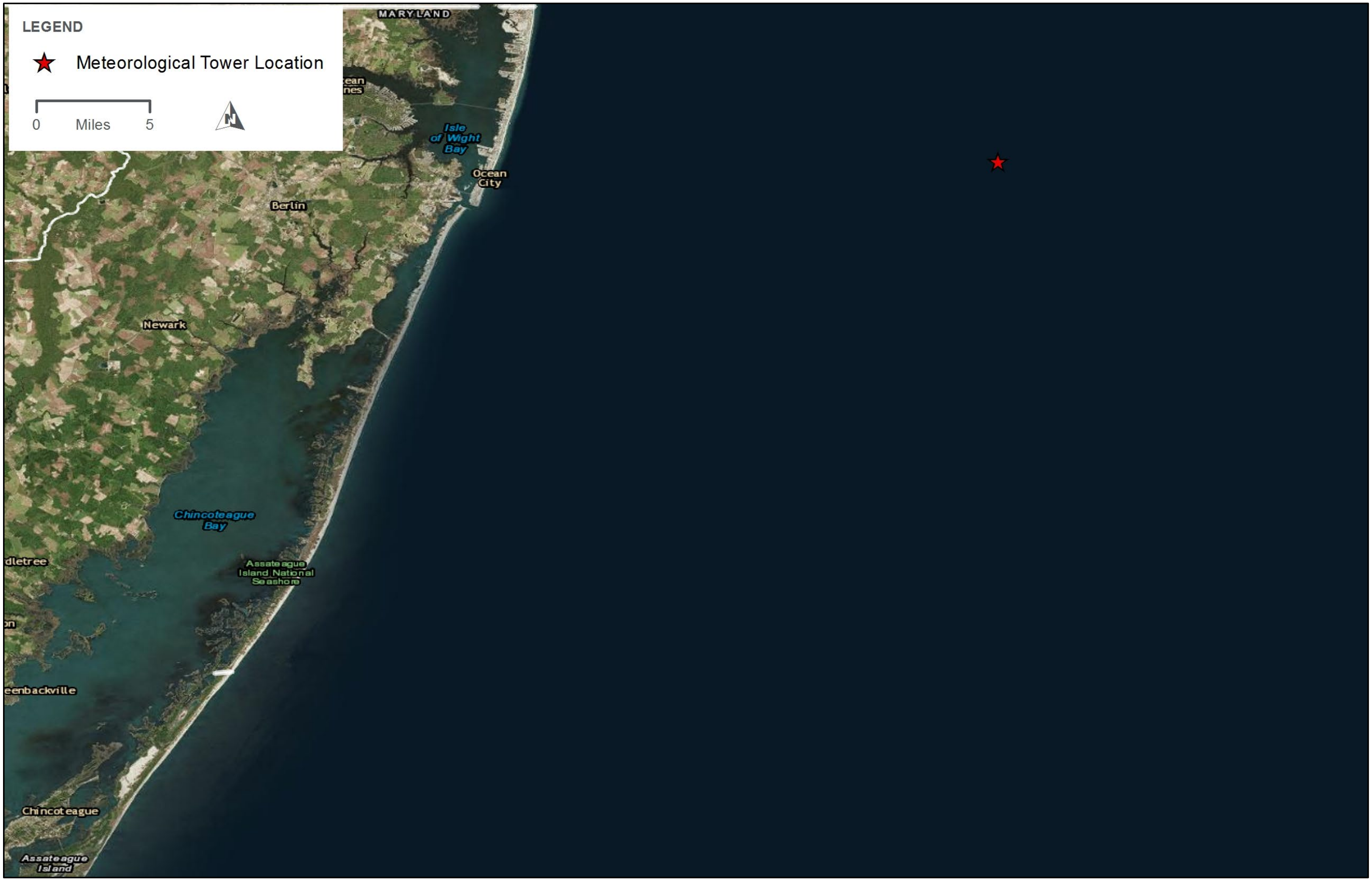


Figure 2: Proposed locations of Meteorological Tower off the Maryland Coast

2.3 Scope of Work

This study shall be conducted in the Mid-Atlantic region offshore of Virginia and Maryland. The proposed locations for the two turbines off Virginia are latitude: 36.896286; longitude: -75.491633 (NAD 83) and latitude: 36.886821; longitude: -75.491572. The proposed location for the meteorological tower is latitude: 38.352747; longitude -74.753546. Specific foundation design for the two 8 MW turbines is not known at this time and therefore **it is assumed that the turbines will have monopile foundations**.

The specific timeframe for installation are yet to be determined. The Virginia wind turbines are projected to be operational in spring, 2020. **It is therefore assumed that construction will be initiated in late 2018 and continue into 2019**.

The meteorological tower installation is proposed for spring 2018. No construction activities can be carried out in this area between November and March due to seasonal restrictions to prevent harm to marine mammals. **Therefore it is assumed that construction will be initiated after April 2018**.

At both locations, construction is expected to occur within a one week (7 working days) period.

Note:

1. **The implementation approach and accompanying cost estimate are based on the specifications of the met tower and turbines provided in Attachment A and B of the RFP dated 13 September 2017. If the specifications are altered prior to project implementation, the monitoring methods presented below and the estimated cost may have to be reassessed.**
2. **Execution of all field tasks is weather dependent. The HDR Team will make every effort to meet the data collection schedule agreed to with BOEM.**

2.4 Tasks

The HDR Team's approach and methods for conducting the various tasks listed in the RFP are described below:

2.4.1 Underwater Sound Monitoring – VA Wind Turbines

Background:

Under this task, the HDR Team will conduct underwater sound monitoring to:

1. Measure changes in sound pressure levels during the construction of two wind turbines, and
2. Record sound levels in the water column and vibrations in the sediment during operations.

Particle motion detection shall also be included in the construction monitoring.

The developer is required to collect data within 1.7 km of the turbine location. Therefore, the HDR Team will primarily focus on far field monitoring, defined as 1 to 30 kilometers (km) away from the sound source. One monitoring station, however, will be placed in the near-field, approximately 750 meters from the sound source. During the construction phase, which is expected to last for up to one week (7 days), moorings will be set prior to the start of the installation and retrieved after installation is completed.

BOEM will facilitate communication with the developers, as necessary. Monitoring conducted under this subtask will not duplicate pile driving monitoring required to be conducted by the developer as part of their approved site plan.

Data collected during the installation of the offshore wind turbine structures will be compared with model results using a standard sound propagation model. The sound levels will also be compared to those collected at Block Island Wind Farm during the installation of the foundations in 2015.

Methods

The proposed data collection approach and methods draw heavily upon lessons learned from underwater sound monitoring conducted during the pile driving associated with the installation of the turbines at the Block Island Wind Farm in Rhode Island. **Table 2** shows the systems to be used to monitor the underwater acoustic field near the Virginia wind turbine construction site. A schematic layout showing proposed relative locations of the various recorders is shown in **Figure 3**.

Table 2: Acoustic monitoring systems to be used to monitor underwater acoustic signals near VA wind turbine construction.

Systems	Organization(s) responsible	Goals	Range(s) from WTGs	Comments
Geosled with tetrahedral hydrophone array and 3-axis geophone	URI/WHOI	Near field particle velocity in the water column and at the seabed, pressure signal at a fixed range	750 meters	Range could be shorter if allowed by developer. Sample rate of 10 kHz.
Vertical Line Arrays (VLA)	WHOI/URI	Far field pressure signal	7.5 km and 30 km	Sample rate of 10 kHz.
Geospace OBX Geophone and Hydrophone Sensor System	URI	Range dependence of near field particle velocity in the water column and at the seabed, pressure signal	750 to 1150 meters	Configurable, sample rate of 4 kHz.
Towed Array	MAI	Range dependence of far field pressure signal	750 m to 30 km	Max range determined by duration of pile driving. If time allows, sub-bottom structure could be imaged with WHOI source.
Dipping hydrophone	Subacoustech and MAI	Azimuthal dependence of pressure signal in the near field	750 meters at various azimuths	Range could be shorter if allowed by developer. Sample rate of 44 kHz.

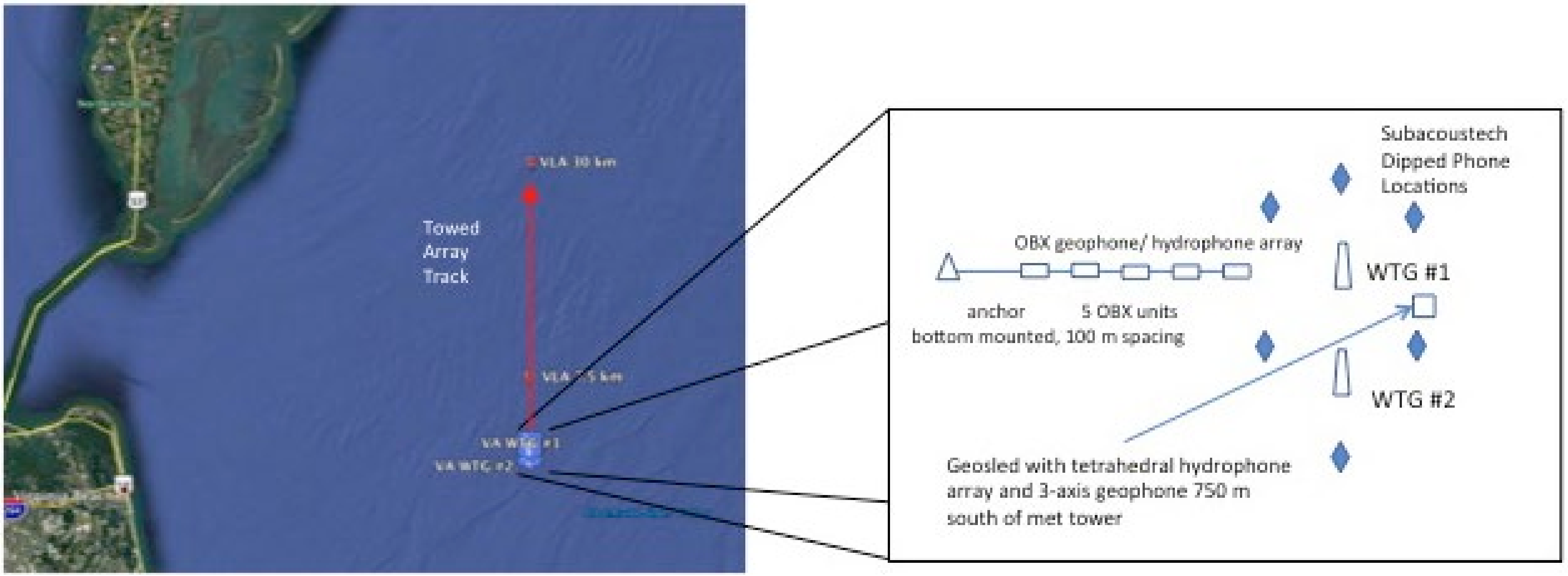


Figure 3: Left panel: A map of the area showing Virginia Beach and the approximate locations planned for the two offshore wind turbines along with two vertical line arrays of hydrophones at ranges of 7.5 and 30 km due north of the tower.

Note: Also shown as a red line is the towed array track. The right panel (inset) shows the close in systems including the Geosled with the tetrahedral hydrophone array and the 3-axis geophone 750 meters south of the wind turbines. To the west, an array of OBX bottom-mounted geophone/hydrophone systems are planned with 100 meter spacing between the 5 units. Also shown are nominal locations for a dipping hydrophone system to be deployed by Subacoustech with support from MAI.

The following subtasks will be conducted under Task 2.4.1:

Subtask 2.4.1.1 – Field Data Collection during Construction Phase

Under this subtask, the following five sets of acoustic recorders will be deployed in the field:

1. **URI Geosled** – The URI Geosled contains a tetrahedral hydrophone array with a phone spacing of 0.5 meters (m). The purpose of the tetrahedral array is to measure the pressure signals generated by the pile driving as well as the particle velocity of the pile driving signal. The Geosled is mounted on the seafloor and show in **Figure 4**. A 3-axis geophone is also part of the Geosled system and measures the particle motion at the seabed. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks (CSAC). The sample rate for both systems is about 10 kilohertz (kHz).

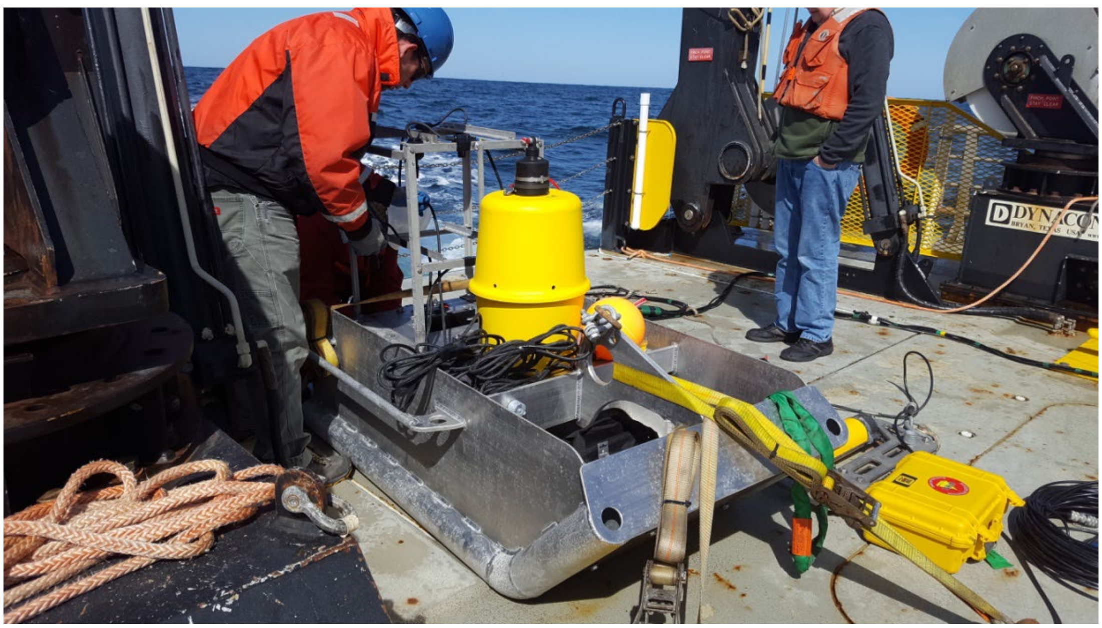


Figure 4: The URI Geosled containing a tetrahedral hydrophone array and 3-axis geophone along with Several Hydrophone Receive Units for data acquisition.

2. **Vertical Line Arrays** – Two Vertical Line Arrays of four hydrophones each will be deployed at a range of 7.5 kilometers (km) and 30 km. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks (CSAC). The sample rate for both systems is about 10 kHz. The configuration of the Vertical Line Arrays will be similar to that shown in **Figure 5**.
3. **OBX Ocean Bottom Recorder** – To the west, an array of OBX bottom-mounted 3-axis geophone/hydrophone systems are planned with 100-

meter spacing between the 5 units. The closest system will be 750 meters from the wind turbines. The sample rate of these systems is configurable with a maximum of 4 kHz. These systems will measure both the pressure signal and the particle velocity signal of the pile driving at the seabed. **Figure 6** shows one of the OBX systems.

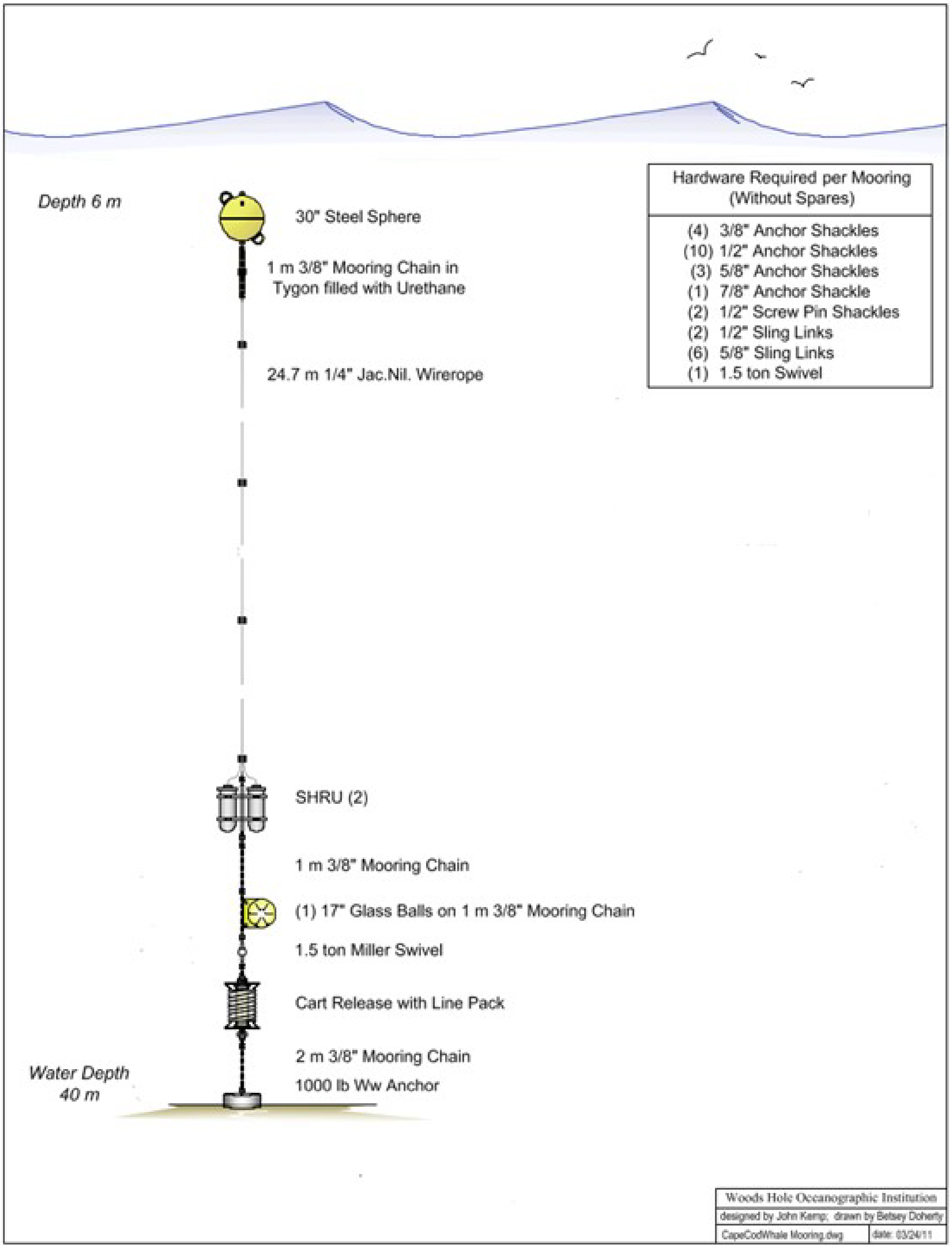


Figure 5: Mooring design proposed for the Virginia wind turbine construction monitoring.

Note: One Vertical Line Array will be deployed 7.5 km north of the turbines and a second system at 30 km. These systems measure the far-field pressure signal of the pile driving.

Figure 6: The Geospace OBX Ocean Bottom Recorder containing a 3-axis geophone and a low sensitivity hydrophone. Five of these systems are proposed to be deployed.

4. **Dipping Hydrophone** – This system from Subacoustech provides an efficient way to measure the azimuthal dependence of the acoustic pressure field around the pile driving. Acoustic pressure measurements will be sampled in six locations as shown in **Figure 3**, with sound pressure measurements taken at minimum two depths: mid-water and 1 m above the sea bed. The dipped hydrophone will be deployed in six locations surrounding the pile being installed, with approximately one minute of sampling of piling noise taken at each location before mobilizing to the next location, sequentially. Sample rate for this system is 350 kHz.

5. **Towed Array** – A towed array arrangement is the most effective tool for getting at the transition from impulse to non-impulse signals and the proposed large monopiles will provide a very unique opportunity to see where these signals become non-impulsive. For the proposed monitoring,

a towed hydrophone array is proposed to be deployed on the research vessel by Marine Acoustics, Inc.

This array is composed of 8 hydrophones of non-regular spacing. The towed array depth is a function of boat speed and best performance is achieved with a boat speed of 2-3 knots (kts). The sample rate is configurable up to 64 kHz, though the array itself has a flat frequency response to 4 kHz with sensitivity falling off at higher frequencies . The goal of the towed array measurements is to measure the details of the range dependence of the pile driving pressure signal. The transition between impulsive and non-impulsive signals as characterized by measures such as kurtosis is of great interest to regulators such as NMFS. **Figure 7** shows the towed array deployed near the Block Island Wind Farm. A similar system will be deployed at the Virginia wind turbine site.

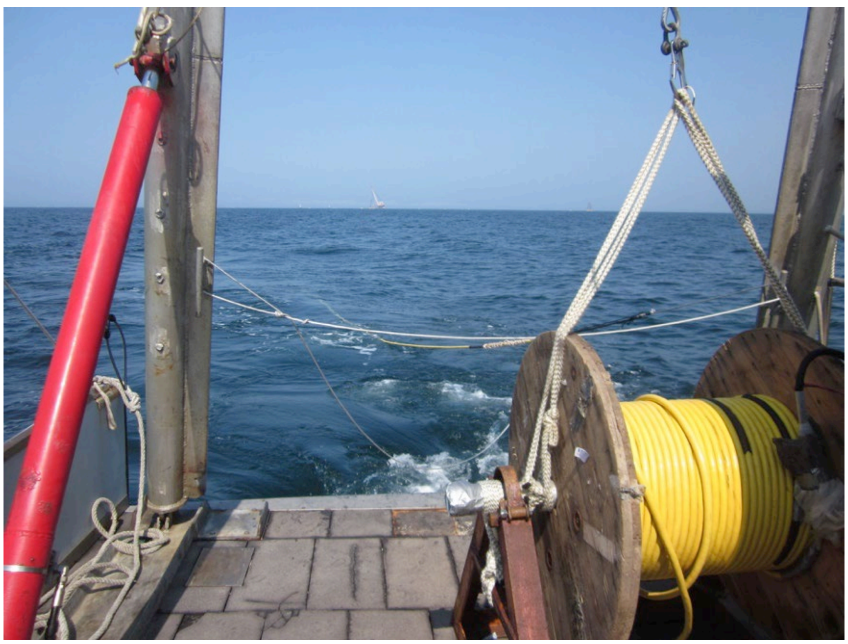


Figure 7: Towed array of hydrophones as deployed in the field work for monitoring the construction of the Block Island Wind Farm.

Data recorders will be deployed in the field using a vessel of opportunity. A possible ship that could support this field work is the R/V Rachel Carson as shown in **Figure 8**. The ship is owned by the University of Maryland and is appropriate for the deployment and recovery of the systems described above in the area proposed for siting the two wind turbines. The homeport for this ship is in Solomon, Maryland and conveniently located for the field operations required for this task. Recorders will be deployed and activated at least 24 to 48 hours before piling begins. The timing of the towed array and dipping hydrophone measurements will be coordinated with the developer to ensure sampling days overlap with active piling. **The stationary equipment will be recovered 24 hours after the piling ends in order to record data for the entire 7-day construction period.**

Figure 8: The Research Vessel Rachel Carson operated by the University of Maryland.

Subtask 2.4.1.2 – Field Data Collection during Operational Phase

Under this subtask, the following four sets of acoustic recorders will be deployed in the field after the turbines have become operational:

1. **URI Geosled** – The URI Geosled contains a tetrahedral hydrophone array with a phone spacing of 0.5 m. The purpose of the tetrahedral array is to measure the pressure signals generated by the operations as well as the particle velocity of the any noise generated by the wind turbines. The Geosled is mounted on the seafloor and shown in **Figure 5**. A 3-axis geophone is also part of the Geosled system and measures the particle motion at the seabed. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks (CSAC). The sample rate for both systems is about 10 kHz.
2. **Vertical Line Arrays (VLA)** – Two Vertical Line Arrays of four hydrophones each will be deployed at a range of 750 m and 7.5 km. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks (CSAC). The sample rate for both systems is about 10 kHz. The configuration of the Vertical Line Arrays will be similar to that shown in **Figure 5**
3. **Ocean Bottom Recorder** – An array of OBX bottom-mounted 3-axis geophone/hydrophone systems are planned with 10 meter spacing

between the 5 units. The closest system will be 50 meters from the wind turbines. The sample rate of these systems is configurable with a maximum of 4 kHz. These systems will measure both the pressure signal and the particle velocity signal of the operational noise at the seabed.

4. **Dipping Hydrophone** – This system from Subacoustech provides an efficient way to measure the azimuthal dependence of the acoustic pressure field around the operational noise. Acoustic pressure measurements will be sampled in six locations as shown in **Figure 3**, with sound pressure measurements taken at minimum two depths: mid-water and 1 m above the sea bed. The dipped hydrophone will be deployed in six locations surrounding the pile being installed, with approximately one minute of sampling of piling noise taken at each location before mobilizing to the next location, sequentially. The sample rate for this system is 350 kHz.
5. **Towed Array** – A towed hydrophone array is proposed to be deployed on the research vessel by Marine Acoustics, Inc. The array is composed of 8 hydrophones of non-regular spacing. The towed array depth is a function of boat speed and best performance is achieved with a boat speed of 2-3 kts. The sample rate is configurable up to 64 kHz. The goal of the towed array measurements is to measure the details of the range dependence of the operational noise pressure signal and to assist in the assessment of the sub-bottom geoacoustic properties. **Figure 7** shows the towed array deployed near the Block Island Wind Farm. A similar system will be deployed near the Virginia site.

Data recorders will be deployed in the field using a vessel of opportunity. A possible ship that could support this field is the R/V Rachel Carson as shown in **Figure 8**. The ship is owned by the University of Maryland and appropriate for the deployment and recovery of the systems described above in the region of the wind turbines. The homeport for this ship is in Solomon, Maryland and conveniently located for the field operations required for this task.

Subtask 2.4.1.3 – Data Analyses

The following types of data will be collected by the various recording devices during construction and operation of the wind turbines:

- Pressure signals as measured by hydrophone systems.
- Seafloor particle velocity signals as measure by the geophones
- In-water particle velocity calculated from the tetrahedral hydrophone array signals.

From these data, the following list shows the possible measures of interest:

- rms sound pressure level (SPL) in dB re 1 μPa.
- peak sound pressure level (SPL_{peak}) in dB re 1 μPa.
- peak-to-peak sound pressure level ($SPL_{peak\text{-}peak}$) in dB re 1 μPa.
- sound exposure level (SEL) in dB re 1 $\mu Pa^2 s$.
- kurtosis of the pressure signal.
- rms particle velocity level (PVL) in in dB re 1 nm/s.
- peak particle velocity level (PVL_{peak}) in in dB re 1 nm/s.
- peak-to-peak particle velocity level ($PVL_{peak\text{-}peak}$) in in dB re 1 nm/s.

The end points of the analyses are an assessment of the impact of the construction and operational noise on species of interest such as marine mammals, fish, and others. Data and resulting measures will be compared to those from the Block Island Wind Farm.

Subtask 2.4.1.4 – Reporting

A report will be written that documents the performance of the acoustic systems deployed for the construction and operation of these wind turbines. An outline of this report including appendices is given below:

- Introduction and summary of results
- Description of area including oceanographic, geological, and geographic information
- Description of equipment utilized
- Measurements during construction
  - Pressure measurements
  - Particle velocity measurements in the water column
  - Particle velocity measurements at the seafloor
  - Oceanographic measurements including conductivity, temperature and depth measurements from which sound speed profiles can be estimated.
- Analysis of measured data
  - Acoustic quantities measured including SPL, SEL, and Kurtosis
  - Analysis of particle velocity measurements
- Comparison to the BIWF data

- Conclusions
- Appendices
  - Mooring diagrams
  - Equipment spec sheets
  - Pile driving schedule
  - Ship tracks

Task-Specific Technical Assumptions

1. This task will most likely be implemented in 2019.
2. The following equipment will be deployed during the construction phase:
   a. URI will deploy a Geosled with four hydrophones in tetrahedral configuration, one 3-axis geophone and hydrophone package, five Geospace OBX 3-axis bottom-mounted geophones (each with a hydrophone) for a ***total of 9 days*** (starting 1 day prior to construction, 7 days of construction, and ending 1 day after construction is completed).
   b. WHOI will deploy two Vertical Hydrophone Arrays each with four hdyrophones and Chip-Scale Atomic Clocks for a ***total of 9 days*** (starting 1 day prior to construction, 7 days of construction, and ending 1 day after construction is completed).
   c. MAI will deploy a towed array with eight hydrophones for ***1 day*** in parallel with construction pile driving. The timing of the towed array measurements will be coordinated with the developer to ensure sampling days overlap with active piling.
3. During the operational phase:
   a. URI will deploy a stationary Geosled for ***2 months*** (1 month during winter and one month during summer).
   b. WHOI will deploy the Vertical Line Arrays for ***2 months*** ((1 month during winter and one month during summer, in parallel with the URI geosled).
   c. WHOI will also deploy a chirp sonar to gather data to support sub-seafloor mapping.
   d. MAI will deploy the towed array for **2 days** (one day during summer and one day during winter) in association with WHOI deploying a chirp sonar for sub-seafloor mapping. The main goal of the parallel towed array and chirp sonar deployments is to estimate the

properties of the seabed and develop an understanding of the acoustic waveguide in which propagation of the construction and operation noise occurs.

4. The costs for this task are based on the following assumptions:
    a. The URI Geosled will be prepared and mobilized for deployment by WHOI. Costs associated with preparing and mobilizing the geosled to the project site are included in the WHOI cost estimate.
    b. URI and WHOI will collaborate on preparing, mobilizing, and deploying the VLAs.
    c. The Geospace OBX bottom recorders will be prepared for deployment by Geospace and those costs are included in the URI cost estimate. Costs of supplies needed for the deployment and recovery of the Geospace OBX bottom recorders are also included in the URI cost estimate.
    d. MAI will prepare and deploy the towed array; associated costs are included in the MAI cost estimate.
    e. Subacoustech will prepare and deploy the dipping hydrophone during the construction phase only; associated costs are included in the Subacoustech cost estimate. A minimum of two hydrophones will be utilized from the survey vessel for the dipping hydrophone. Two surveyors will be present for monitoring and handling equipment. The timing of the dipping hydrophone deployment will be coordinated with the developer to ensure sampling days overlap with active piling.
    f. All field work performed by URI, WHI and MAI will be conducted using the Research Vessel *Rachel Carson*, which will be leased from the University of Maryland. Vessel rental costs are included in the URI cost estimate. Ten (10) ship days are assumed for the construction phase monitoring and five (5) ship days are assumed for deploying and recovering equipment during summer and winter during the operational phase.
    g. A small boat will be required to support Subacoustech field work for the construction phase; cost of this boat is included in the HDR cost estimate.
5. A standalone draft and final Technical Report and draft and final Technical Summary will be prepared under Task 2.4.1.

6. Monitoring conducted under this task by the HDR Team will not duplicate pile driving monitoring required to be conducted by the developer as part of their approved site plan.

2.4.2 Optional Task – Evaluation of Scour Monitors (MD Met Tower or VA Wind Turbines)

Background

Reductions in seabed level around offshore structures, otherwise known as scour, can lead to problems for many industry sectors. Scour pits are caused by perturbations in tidal and wave induced currents moving around foundations. This can lead to changes in the supporting sediment layers, with the potential to impact the integrity of offshore structures. The Fugro scour monitoring system offers offshore developers the opportunity to capture scour events from a self-contained unit, recording continuous changes to seabed levels around a structure. Monitoring the development of scour pits, assists with establishing appropriate preventative measures, such as rock dumping, ensuring the structural integrity of offshore developments.

Under this task, two (2) scour monitors will be installed on the legs of either the MLA meteorological tower or one of the two VA turbines. An Acoustic Wave and Current profiler (AWAC) will also be placed at an appropriate location in the vicinity of the tower to measure waves and currents. The monitoring will occur for a one (1) year time period. Performance of the task is dependent on the cooperation of the lessee and the installation of brackets on the legs of the tower during fabrication. It is assumed that BOEM will facilitate the required discussions with the developers to get the brackets installed on the foundation during its fabrication. The HDR Team can offer an alternative approach if the installation of brackets is not possible during fabrication.

Methods

Subtask 2.4.2.1 – Provide Developer with Specifications for Foundation Mounts

The HDR Team staff will work with project engineers to develop the specification for fabricating and attaching a mounting flange to the foundation. This has been easily undertaken on previous projects and is a tried and tested methodology. The mount location will take into consideration the required height above seafloor to ensure the mud mats don’t interfere with the sensor’s acoustic beams. The mounts will also be positioned in alignment with the primary current axis, to allow the sensors to monitor the most extreme influence of scour.

Subtask 2.4.2.2 – Modify the Scour Monitors for Attachment to the Foundations

The HDR Team will develop a housing unit to store the scour monitor. The unit will be designed to be directly attached to pre-installed flange, mounted on the platform jacket. The housing unit will likely be comprised of stainless steel and will be slightly larger than the scour monitor (see **Figure 9** below).

Subtask 2.4.2.3 – Scour Monitor Deployment

The Fugro scour monitoring system (**Figure 9**) is an inexpensive and reliable solution for continuously capturing scour events when installed on offshore foundations.

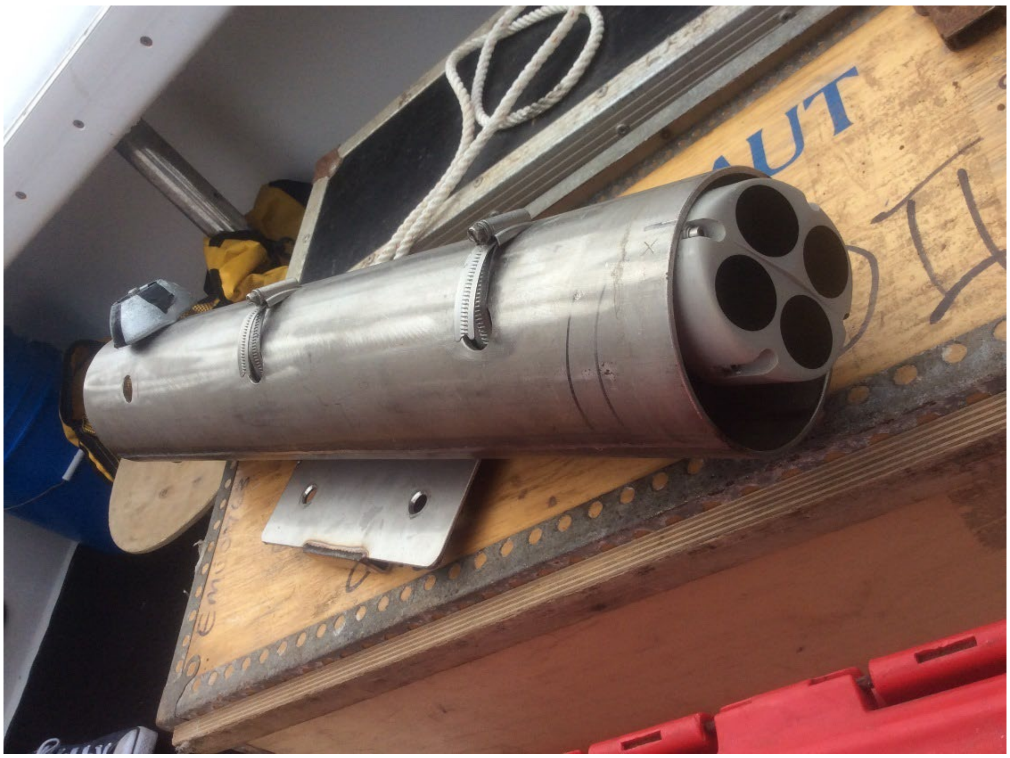


Figure 9: Fugro scour monitor acoustic device.

The system uses four narrow acoustic beams to detect the along-beam distance from the sensor to the seabed at four points away from the structure (as pictured in **Figure 10**). Angles are orientated at 5, 10, 15 and 20 degrees from the vertical. A depth sounding is calculated from the reflection of each beam off the seabed, which produces a time-series of seabed elevation.

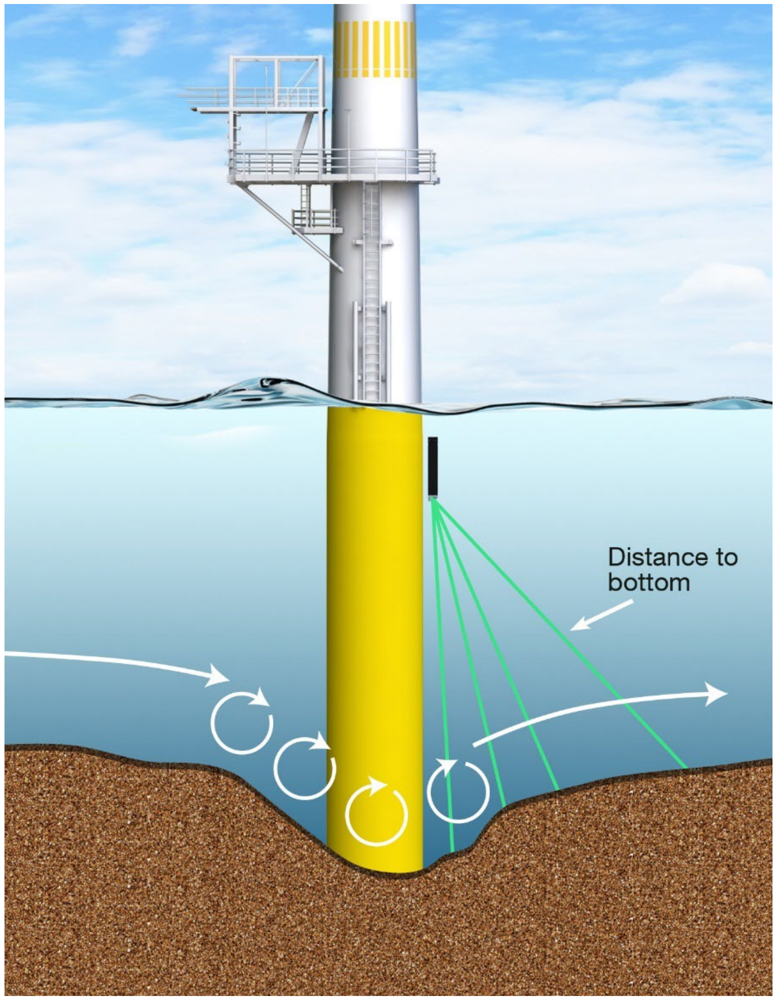


Figure 10: Scour illustration around a monopile.

The instrument can be programmed to capture data at a user-specific sampling rate. We recommend configuring the instrument to record data every 1 – 10 minutes, dependent on the client's requirements. A frequent sampling rate will provide a more robust time series data set, capable of recording small changes in seabed elevation caused by variable weather and current conditions.

The monitors will be installed on the foundation using a five-person team (two (2) divers, one (1) boat captain, and two (2) HDR Team personnel to provide guidance and supervision). The installation will be performed under the direct supervision of HDR Team personnel. The installation team will use a suitably sized boat that can house air tanks, umbilicals, and all required dive gear. Assuming normal sea and weather conditions cooperating, we anticipate that scour monitors can be installed in one (1) day.

Subtask 2.4.2.4 – Acoustic Wave and Current Meter (AWAC) Deployment

A seabed mounted Nortek AWAC will be deployed within the vicinity of the met mast for the collection of wave statistics and current velocity data (**Figure 11**). The meter will record sea conditions and storm events throughout the projects duration. This data will be used to understand the potential impacts of waves, currents and storms on scouring around the turbine foundation. The instrument is also capable of measuring sea temperature, tidal levels and turbidity.

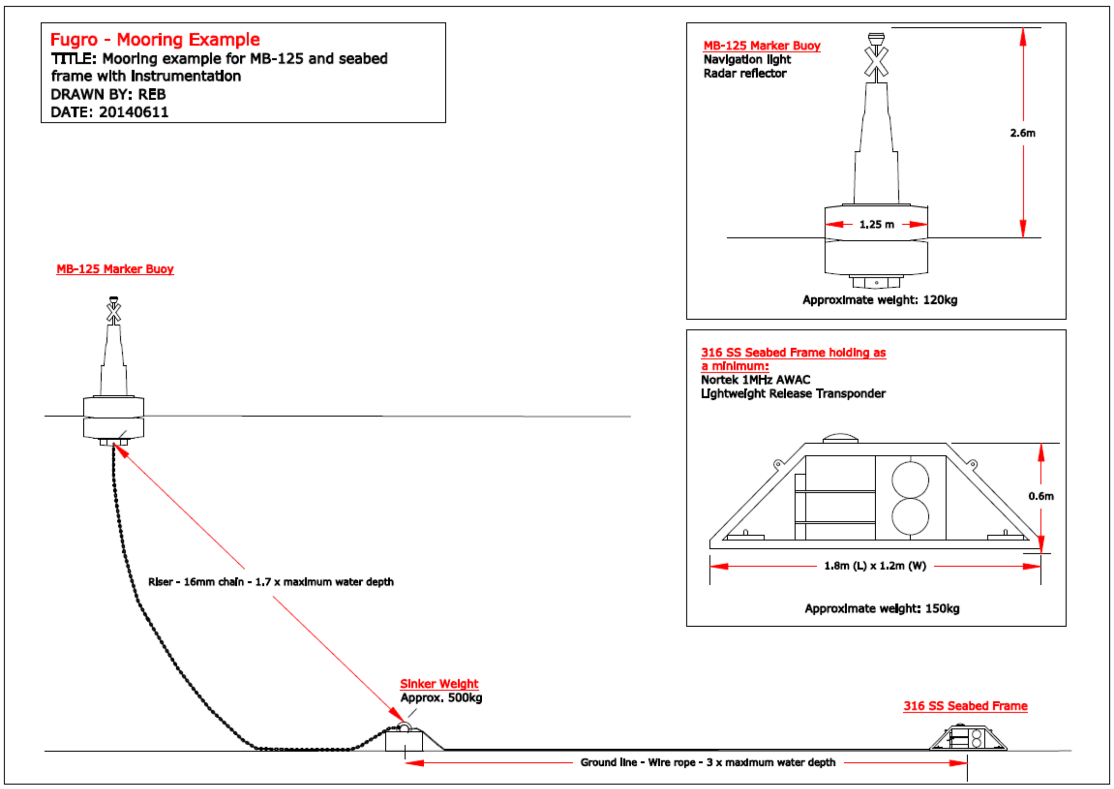


Figure 11: L-shaped AWAC Mooring.

The AWAC uses three acoustic beams, offset from the vertical at 25°, to measure current velocities and directions. Data are collected for each “cell” in the water column with the cell size defined according to the measurement requirements and instrument frequency. Tidal height measurements are collected using the instruments’ in built pressure sensor. Wave measurements are obtained by the vertical “Acoustic Surface Tracking” (AST) beam, which produces a highly accurate trace of surface elevations. Wave statistics may also be derived using the pressure signal. This dataset is used as a quality control check on the AST measurement.

The echo intensity function of the AWAC measures energy that is reflected from particles in the water column, which, when calibrated with water samples, can be used to determine turbidity levels. Data is collected throughout the water column and will be concurrent with current measurements (i.e. every 10 minutes). Water samples will be collected during installation and maintenance visits.

The AWAC will be secured to the seabed using a bespoke frame, which will be attached to a Surface Marker Buoy (SMB) using an L-shaped mooring design (**Figure 11**). This design ensures an undisrupted acoustic path from the instrument on the seabed to the sea surface when using acoustic instruments. The mooring also reduces the possibility of frame movement. The design has two primary functions:

1. Mark the equipment location as a warning for marine users; and
2. Aid in the recovery of the equipment.

Each SMB is equipped with a yellow navigation light, programmed to meet local licensing requirements (typically, set to 5 flashes every 20 seconds) to warn marine traffic to its presence. The buoy is attached to the frame through a coupling of metal strops or chain. A ground line strop links the frame to the anchor weight and the riser links the weight to the SMB. All strops will be designed according to anticipated on site conditions and joined using rated shackles which are moused before deployment.

The HDR Team will ensure that the selected mooring is suitably ballasted for the expected environmental conditions. The marker buoys would be fitted with robust GPS buoy trackers, enabling constant monitoring of the buoys location. The seabed frames and moorings are designed to minimize the risk of intentional and accidental third party interference. Each mooring is designed to be location specific, catering for site depth, anticipated wave and tidal conditions and other factors.

Deployment methods for L-shaped moorings are flexible and can be adapted to suit the vessel. Deployment typically follows the sequence below:

1. The moorings and instruments will be mobilized on to a vessel with suitable lifting gear.
2. All instruments will be checked prior to deployment and the sampling regime set up.
3. The mooring will be configured and connected with wire strops laid out in figures of eight.
4. The SMB will be lifted from the vessel into the sea. This will be tied off if required.
5. The sinker weight will be lifted from the vessel and lowered to sea level before securing to a bollard or similar.

6. Once at the desired location, the frame will be lowered to the seabed using the winch or crane attached to a release hook.
7. Once on the seabed the frame is released as close as practical to the licensed position. A GPS fix is then taken.
8. The depth will be recorded on the relevant log sheets.
9. The angle of the frame will be checked by interrogating the sensor throughout the deployment to make sure that the frame is upright.
10. The winch/crane wire is then returned to the drum.
11. The ground-line will then be paid out and the sinker weight released, positioning will be at approximately the ground-line distance away from the seabed frame – another GPS fix will be taken.
12. The riser line will be released along with the SMB.

Subtask 2.4.2.5 – Scour Monitor Servicing, Maintenance, and Retrieval

Each scour monitoring unit is fully self-contained, with an internal power supply and data storage capacity. The HDR Team suggest scheduling maintenance visits every three months. The units will, therefore, be serviced at three, six, and nine months after deployment.

Maintenance of both the scour monitor and AWAC will be undertaken on the same site visit. Servicing will include retrieval of stored data, replacement of batteries, removal of biofouling and peripheral checks, ensuring that the equipment is functioning at its optimum ability. Each servicing event is expected to last for up to two days. Divers will be used to service the scour monitors, and HDR Team personnel will service the AWAC from a vessel equipped with appropriate lifting equipment.

Data collected by the instruments will be returned to our offices for processing and analysis. A report will be submitted to the client on a quarterly basis, following each maintenance visit. See subtask 2.4.2.5 for further information on our data processing methods.

To reduce costs, the HDR Team will consider using vessels that are already on site supporting the project. If the available vessels on site are determined to be unsuitable for servicing the equipment, a third-party vessel will be chartered for operations.

We have identified two high quality, marine construction dive companies that the HDR Team has worked with in the past. The two companies are located in the Norfolk area and have previous experience handling scour monitors at the Block Island Offshore Wind Farm.

At the end of the deployment period, the scour monitors and AWAC will be recovered and the final set of data downloaded. Individual quarterly data sets will be compiled into a single data set for further analysis and evaluation.

Subtask 2.4.2.5 – Data Analyses

Data will be processed using Fugro's bespoke oceanographic software suite; OceanV3. This software package is a comprehensive data processing and presentation software suite that has been developed over more than 20 years to manipulate and present complex time series data. The software is based on a unique relational data format that includes all metadata and an unlimited two-dimensional data array. The data format is designed to be compatible with all spreadsheet software, easily imported into GIS software and simple to import into all the industry standard modelling software.

OceanV3 also includes detailed automated QC tools that flag suspect data for further investigation. The flagging system is based on simple numeric flags as follows:

0. Data passes all automated tests.
1. Data point lower than expected predefined or user defined minimum.
2. Data point higher than expected predefined or user defined maximum.
3. Data flat lines for extended period.
4. Rate of change exceeded.
5. No value recorded; null in raw data.

In addition, the number of records anticipated and number of records recorded is compared. The number of anticipated records is calculated based on the date and time of the first and last records divided by the sample interval. The number of records in the data set is counted. This allows an instant check that the data are continuous, as expected and flags up any gaps that require further investigation. The maxima, minima, means and standard deviations of each data type are also calculated and can easily be saved for reporting, this also allows a level of gross error checking for a user as they can spot failures or investigate further to understand why the data are not within expected ranges.

As a final stage, data are classified as 'good', 'suspect' or 'bad'. Data are considered to be good if they pass all the quality control checks, are within a reasonable range and show no signs that they have been affected by factors other than the one being measured. Suspect data are data which show no sign of instrument malfunction but appear to have been affected by more than the factor under investigation.

Examples of this are seen during deployment or servicing operations where erroneous values can be generated. Suspect data can pass the initial quality control tests but are obvious during the data visualization and higher-level quality testing. Finally, bad data are characterized as data which fail the quality control testing procedures. For instance, the sensor may fail, either through instrument failure or due to an environmental influence, such as build-up of biofouling on an acoustic transducer or physical damage.

OceanV3 data are then made available for standardized time series reporting; multiple data files can be opened to allow data to be compared between sites and sensors. Multiple automated data presentation routines are built into the software allowing rapid presentation of data and statistical investigations.

Each data type collected by all the proposed current measuring instruments is processed using OceanV3 and delivered in a *.csv comma delimited file format. All metadata is included in the file header information, as in the example given in **Figure 12**.

Current Data – Observed currents are considered to be a combination of three components – the tidal stream, the mean drift and the residual drift. These three components equate to the current forced by the tidal motion, the current resulting from any uniform flow such as river discharge and a final random component such as meteorological effects.

In order to separate these three components, the current dataset is subjected to harmonic analysis extracting a series of periodic curves with the frequency of the major tidal constituents. After the constants for the tidal constituents have been derived, they are used to reconstruct the tidal stream.

All raw and processed data will be provided to the Client via ftp or on CD. Current data would be provided as ASCII comma delineated files of ADP bin data, with associated positions and water levels, usually reduced to Lowest Astronomical Tide.

J/1/01/1334

Flood Use Case Sensor Deployment

SemsorGrid4Env

Current Meter / AWAC

5104 (serial number)

Deployed: 21/09/09 11:11 Recovered: 14/12/09 10:00

Latitude: 50°39'50.4"N Longitude: 000°57'23.5"W

Site depth: 15m Instrument height off seabed: 0.6m

Processed on 17/12/2009

Local Variable Parameters: Local Gravity 9.81124 Magnetic Variation: -2.1 Mean Water Density: 1.0250 Barometric Pressure: 1013

12 (number of columns)

Sample Interval: 10

Year,Month,Day,Hour,Minute,Second,Julian Day,Depth (m),Temperature (°C),Pitch (°),Roll (°),Volts (V)

Figure 12: Example of OceanV3 metadata.

Wave Data – The acoustic profiler measures the instantaneous head of water both as pressure; using a precision strain gauge and as range to the surface; using a narrow, vertical acoustic beam.

Acoustic Ranges, Initial Processing – Raw acoustic ranges are converted to heights by the instrument manufacturer’s software; these values from the wave burst are de-trended and de-meaned to produce a “stable” surface wave trace. The de-trended data are stored for comparison to the calculated wave parameters and are then analyzed to produce a one-dimensional wave energy spectrum.

Pressure Signal, Initial Processing – Raw pressure values from the wave burst are first de-trended to remove the longer-term effects of the tidal slope as this can weigh the spectrum toward the longer period data. Once de-trended, passing the pressure data through a Fourier curve fitting routine produces a one-dimensional wave energy spectrum. The spectrum is then scaled up to remove the effect of depth attenuation of the pressure signal and the effects of signal loss due to damping effects. This scaled spectrum is used to calculate the non-directional components of the wave climate. Additionally, the expected surface signal is produced; this can be compared to the calculated wave parameters to allow data verification.

Directional Processing – The three-dimensional wave measurements (depth/height, easting component and northing component) are then passed through an additional series of routines that produces a cross-spectral density matrix allowing the wave energy to be broken down by direction as well as by frequency. From this the peak direction (coming direction) of the waves can be extracted along with energy against direction spectra.

The procedure adopted for processing can be summarized as:

- Input n points of water level, u and v vector data.
- De-mean and de-trend data. The tidal slope is calculated using a multi-dimensional polynomial.
- Apply Fourier Transforms to the adjusted water level, u and v data series.
- Apply pressure compensation algorithms were applicable.
- Compute and smooth cross-spectra.
- Compute cross-spectral density matrix.
- Compute inverse cross-spectral density matrix.
- Apply directional analysis equations to inverse matrix.
- Normalize spectra.
- Output (f, □), S(f) and □ max.
- Compute spectral moments (mn) for the major directional axis.

The wave parameters are calculated using a variety of approaches in order to attempt to define the wave climate as closely as possible. To this end the significant wave height is calculated as 4 x standard deviation of the water surface level elevations, the mean of the largest third of the waves as defined by the peak to trough and trough to peak heights, in addition to spectrally. The maximum wave height is defined spectrally assuming the wave climate is Rayleigh distributed as well as the maximum trough to peak or peak to trough elevation recorded throughout the sample burst.

The zero up crossing period and mean periods are calculated spectrally, by counting the interval between zero up crossings in the de-meaned and de-trended data and by counting the number of waves and dividing the total record time by the number of counted waves. By using multiple approaches the HDR Team will provide the highest quality data possible.

Scour Data – Raw data from scour monitor will be imported into Fugro's OceanV3 software and quality control and visual checks will then be carried out. A *.csv file will be created and profiles will then be produced in the OceanV3 format. **Figures 13** and **14** illustrate time series data downloaded from a scour monitor installed on a pier compared with data taken from a wave measuring deployed in close proximity. The data clearly indicates a correlation between a sudden increase in wave height and the erosion of sediment around the structure.

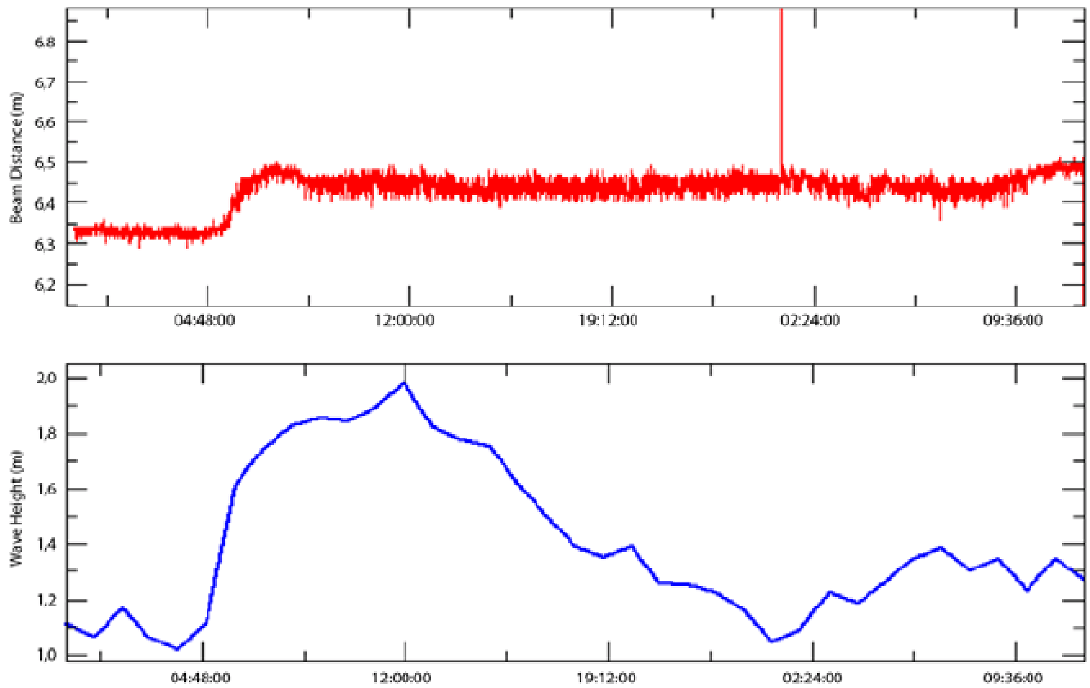


Figure 13: Example of Short Term Scour Data.

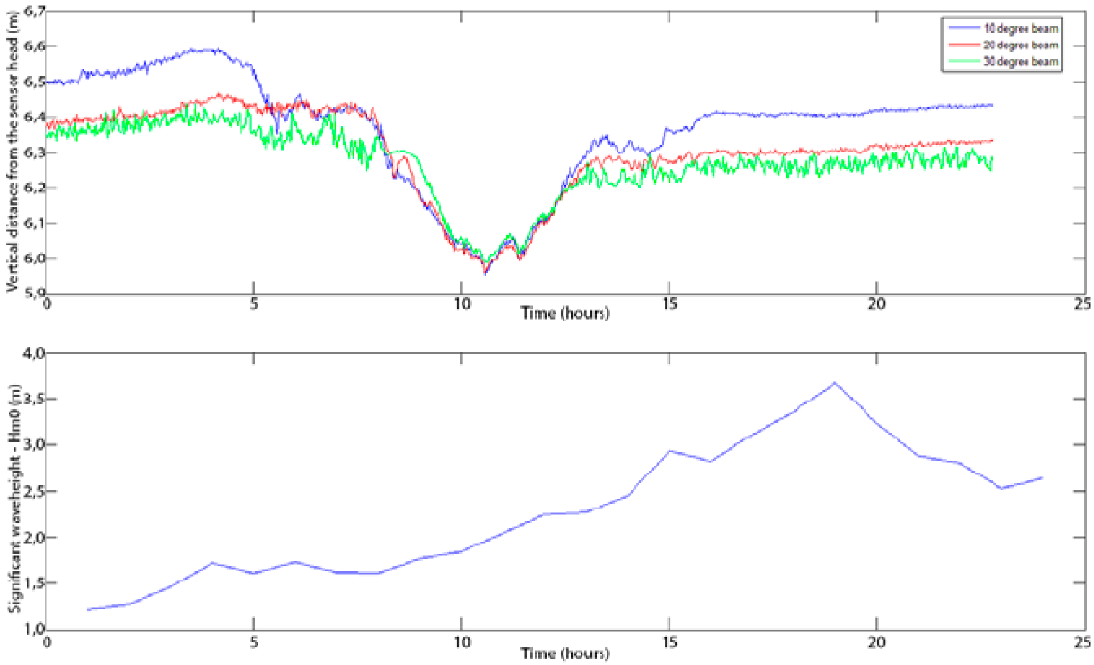


Figure 14: Example of Longer Term Scour Data.

Each individual beam will have an associated depth with it. Using the beam orientations, the four beams will be used to provide four depth measurements that will be used to generate a depth profile of the scour hole. The beam transect profile will be oriented along the principle tidal axis and therefore, a transect along the expected major axis of the scour hole will be generated. The final data will be provided as a depth below mean lower low water (MLLW) at each measurement point by combining the range to the bed data level data from the instrument deployment information and the sea-level measurements from the AWAC.

Depth Measurements – Depths will be measured using basic acoustic sounding principles (converting travel time to distance) and accounting for the orientation (inclination) of the beams. Depth data will be presented as described below:

1. All data will be presented as time series of comma separated values in OceanV3 format. OceanV3 format is a unique relational data format that includes an infinite two-dimensional data array with all relevant metadata. All data from all instruments will be submitted in this standard format irrespective of the instrument or measurement type. All raw data will also be available if requested.
2. Time series of the depth below mean lower low water at each measurement point.

3. Time series of acoustic signal return from each beam, converted to suspended sediment concentration estimates.
4. Multivariate analysis and presentation will be undertaken to show the relationship between wave action, current speed, wave induced orbital current, SSC and scour depth.

In the technical report, scour development and any subsequent infill will be described. Information on maximum scour depth and extent, duration maximum scour existed, scour rate, infill rate, and infill amount if occurred, will be presented.

Subtask 2.4.2.6 – Reporting

A draft report will be prepared and submitted to BOEM for review and comments within 60 days following retrieving the scour monitors at the end of the deployment period. The report will describe the methods for equipment deployment, servicing, and retrieval; data analysis; and findings and recommendations from the data evaluation.

The scour event descriptions will include the measured depth, duration, and rates and amount of infilling. The AWAC data will be reduced and interpreted to characterize the wave and current profile conditions that occurred during scour events. The report will also include a ‘Lessons Learned’ section and recommendations for future deployments. The report will also include figures and graphs that display the scour events and time series of the data.

Task-Specific Technical Assumptions

1. This optional task, if funded, will most likely be implemented in 2019.
2. It is very possible that the project developer may not permit the HDR Team to work on the foundations; therefore it is assumed that the scour monitors will be installed by divers retained by the project developers.
3. A total of 11 days of vessel use is assumed. This includes 3 days for installation, 2 days for servicing at 3-month, 6-month, and 9-month interval and 2 days for data download and equipment retrieval at the end of deployment after 12-months.

2.4.3 Monitoring methods for corrosion, turbidity, and biofouling (MD Met Tower or VA Turbines)

Background

Under this task, the HDR Team will evaluate methodologies for measuring corrosion, turbidity, and biofouling on either the MD Met Tower or the VA turbines during the first year of operation. This task will be initiated as soon as possible after the offshore structure is installed, weather permitting.

Methods

The monitoring methods will follow guidance provided in the document *"Guidelines for Structural Health Monitoring for Offshore Wind Turbine Towers & Foundations*." The following subtasks will be performed:

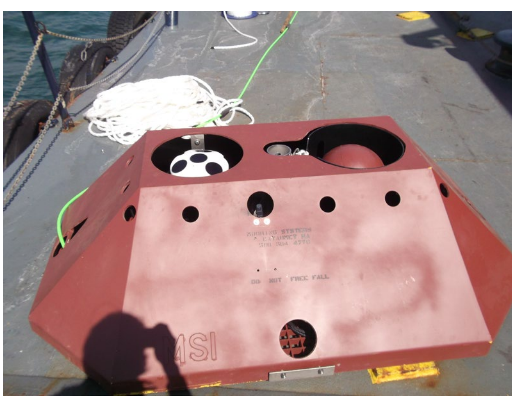
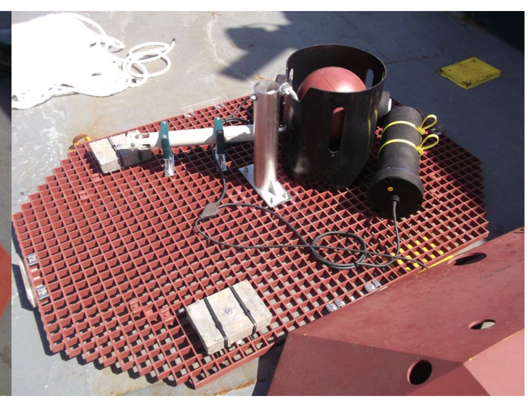
Subtask 2.4.3.1 – Corrosion Monitoring

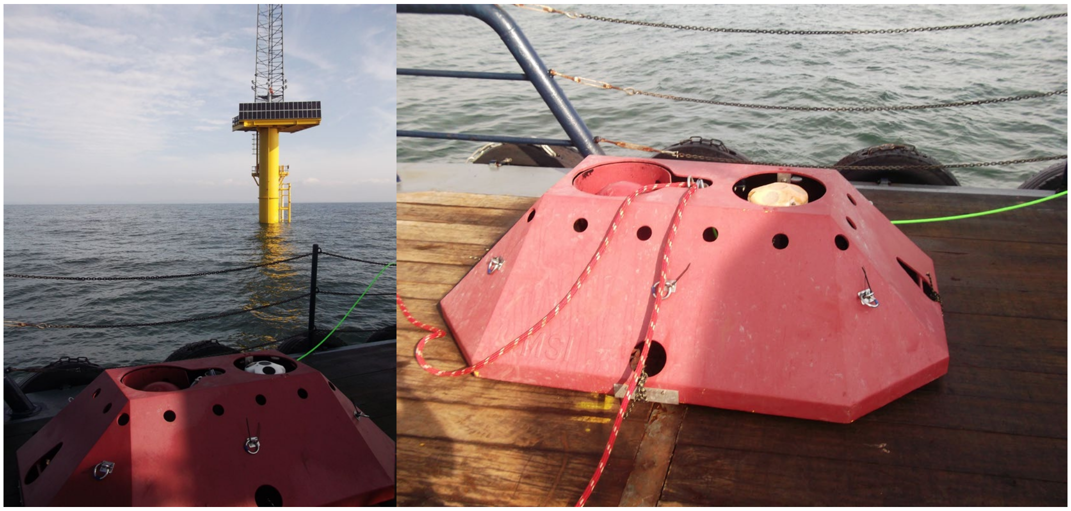
Significant corrosion of foundation structures of offshore facilities can occur where preventative measures are inadequate or have failed. In acknowledgement of this, periodic diver, and other types of surveys, to visually inspect the foundation for signs of corrosion, and to check the integrity of existing protection systems, will most likely be undertaken as part of the developer's routine assessment and compliance monitoring program.

In parallel to these, the HDR team proposes to conduct studies for signs of corrosion on representative samples of the foundation material at adjacent locations and to compare findings with those of the compliance monitoring. The studies will allow very close (laboratory) inspection and assessment of corrosion over time and will help assess the relative success of the preventative measures that are in place on the foundation through comparison with compliance monitoring data. This type of study will also provide information on the characteristics of local biofouling in conjunction with the proposed SCUBA diver biofouling studies presented in Subtask 2.4.3.3 below.

It is proposed that the monitoring will involve the deployment of representative samples of foundation material within the water column. Samples will be fixed, as far as practicable, at known water depths using a series of moored buoys positioned at agreed locations around the foundation. For this study it is recommended to use a 1.2 m buoy with a rope riser from which material samples can be attached. Chain and clump weight will be used to fix the buoy to the seabed. Samples of the foundation material will be fixed to the riser rope using clamps at pre-agreed depths and will remain in the water column until retrieval and inspection. The use of a rope riser is particularly recommended in this instance to avoid potential electrolytic reaction between the sample and metal mooring components which may lead to unintentional and accelerated corrosion of the sample and unrepresentative results. Indeed, the use of metal components in the proposed deployment systems will be minimized as far as is practicable to eliminate unanticipated sample corrosion and as advised in the BSEE Guidelines indicated above. Note that whilst best efforts will be made to fix each sample to the rope, the samples themselves may be subject to both horizontal and vertical movement in the water column and may change their orientation in relation to current flows. This will contrast the fixed and static position of the foundation. Whether this will significantly influence corrosion aspects of the samples relative to the foundation is not known at present.

Note that an alternative deployment option using non-metallic frames or pods can be offered. Examples of the pods in question are provided in the photos below.



This option includes placing the representative samples of foundation material either on or in the pods which are then weighted and placed on the seafloor and attached to a L shaped mooring similar to that proposed for the AWAC deployment discussed in sub task 2.4.2.4 above. Pods can also be fitted with diver locator beacons or acoustic release devices to facilitate re-location and recovery. The pods are fabricated from fiberglass but may have some metal components, but the quantity of metal used is not thought to cause any problems associated with accelerated sample corrosion and may be easily mitigated. This option is more expensive than the buoy and riser rope method due to the purchase of the pods, weights and mooring components, and the modifications needed to fix the samples to them. An indicative cost up-lift for this option over the rope rise technique is estimated at $37,500. However, the advantage of the pods is that each sample will remain static in the water for the duration of the monitoring program and will not be subject to the same degree of movement in the water column as the rope riser option.

The detailed positioning of the samples, both in relation to the foundation and within the water column, will pre-agreed but for the purposes of this proposal it is assumed that samples will be placed in close proximity to the foundation (within a few to 100m) and in a mid-water position. The costs presented assume that the rope riser technique will be used and allow for up to six individual fixed buoys to be placed around the foundation and one sample per buoy (total six samples of foundation material). The final survey design will be discussed and agreed prior to commencement of the study.

Individual samples will be retrieved after 6 months placement in the water column and then at 3 or 6 monthly intervals thereafter, as agreed. The timings of the retrievals of the samples will, as far as possible, coincide with planned AWAC service visits to optimize vessel use and weather windows; however for the purposes of this proposal, it is assumed that separate, dedicated visits will be made.

The estimated costs for this subtask provide for up to 6 separate visits to site to retrieve or monitor the 6 samples over a period of up to 2 years. The final frequency of monitoring visits and the duration of the study will be discussed and agreed to with BOEM prior to the commencement of the work. The duration of the monitoring is assumed to be up to 2 years although a longer period of time may be required to achieve meaningful observations. Costs assume that 2 vessel days will be required to collect each sample and to undertake servicing of the remaining buoyed systems.

Once retrieved, samples will be photographed and described in terms of obvious corrosion and biofouling cover. Signs of corrosion may include failures in the paint system including cracking, bubbling and flacking of the paint, loss of lamination or appearance of rust patches. Hand held ultrasonic thickness gauges or digital vernier calipers may be used to monitor the thickness of the metal of the foundation over time. Parameters of corrosion for recording will be agreed prior to the commencement of the study. Where necessary, samples will be transported to a local laboratory for detailed inspection.

The size of the samples used during the monitoring will need to be discussed in terms of representativeness, practicality of deployment, recovery and transportation to receiving laboratories (if used). Sourcing the samples will also need to be considered and it is assumed that suitable material will be available from the manufacturer. The manufacturer will need to provide samples which have been pre-drilled, to allow fixing and mounting to the buoys, and which have been treated and coated in the same way as the foundation. Direct communication access with the manufacturer will therefore be vital to allow the requirements for sample fabrication and delivery arrangements to be discussed and agreed prior to deployment.

The HDR team typically do not undertake corrosion monitoring studies on offshore foundations and these surveys will be new to our field and laboratory teams. However, it is envisaged that any conspicuous corrosion will be detectable by the field surveyors for recording and that suitable comparison with compliance monitoring data can be made. Any obvious links between observed corrosion and biofouling growth will be recorded. The HDR team will continue to liaise with BOEM during the interim period to agree other measures and corrosion indicators to continually refine the current monitoring proposal. It is assumed that relevant water quality parameters for the sites in question are already known from Environmental Assessment and/or compliance monitoring. Where required, appropriate measures of water quality can be collected to clarify or update existing data and to provide environmental context for the findings of the current proposals. Costs for water quality measurements are currently excluded from this proposal and require prior agreement as to the final scope.

Deliverables will include a series of field reports presenting site observations of corrosion for each sample together with representative photographs. A total of 6 field reports will this be provided. Notes on biofouling cover and any obvious correlation with corrosion feature will be made and comparison with compliance monitoring data will be provided. Where appropriate, recommendations for study refinements or additional measurements will be proposed. Any deviations from the sampling plan, problems encountered, and associated solutions will be documented. On completion of the program, the field reports will be synthesized into one overall monitoring report. This will document the development of corrosion over the monitoring period, compare observations with compliance monitoring data and, if possible, assess the relative effectiveness of the corrosion mitigating systems installed on the foundation.

It is noted that the current proposals will not allow assessment of microbial induced corrosion (MIC) which appears to have received little attention to date. This aspect is largely outside of the experience of the HDR team but we would be pleased to discuss additional scope to encompass possible study should this topic be of interest to BOEM.

Subtask 2.4.3.2 – Turbidity Monitoring

In our experience, a combined turbidity measurement campaign, employing both optical backscatter (OBS) and acoustic backscatter (ABS) yields the most robust results. This is due to the different responses of acoustic and optical sensors with respect to grain size, shape and other factors. ABS should also be collected in order to provide reliable suspended sediment data as the sediment values increase. The acoustic measurements will penetrate through the suspended sediments and can return a profile through the water column at up to 2 Hz.

For the collection of both OBS and ABS turbidity, the HDR Team would recommend deploying an Aquatec AQUAlogger (OBS sensor) and Nortek ABS sensor. By combining the survey operations, summarized in Subtask 2.4.2.4, with the turbidity monitoring, we can provide cost savings associated with operations. The AQUAlogger will be deployed alongside the AWAC on a seabed frame, and collect OBS turbidity data concurrently with ABS turbidity, wave, tidal, current and temperature data. For further information on the methodology and procedure for deploying instruments on a seabed frame, please see Subtask 2.4.2.4.

Alternatively, if the deployed AWAC subtask is not pursued, the OBS system could be mounted on the met mast alongside the scour unit.

Equipment

The AQUAlogger is a compact, self-contained data recorder with an on board Seapoint turbidity meter for the measurement of Optical Backscatter (OBS); used as a proxy for turbidity measurement. Turbidity values are recorded over four automatically switched gain ranges, ensuring excellent resolution over the whole measurement range.

A typical measurement regime would comprise a burst of 60 seconds at a sampling rate of 1 Hz every 10 minutes. For deployments greater than 15 days in length, we would recommend the use of a modular mechanical wiper to keep the optical lens free of biofouling, thus helping to ensure high data quality. External battery packs will be fitted to extend the life of your deployments.

Turbidity is recorded in Formazine Turbidity Units (FTU), which can be converted to values of suspended sediment concentration through the collection of local water samples. The HDR Team maintains an extensive data bank of turbidity data, which can be used to strengthen analysis of your data where necessary.

The HDR Team assume that the Nortek AWAC will be provided primarily for the measurement campaign described in Section 2.4.2.4. The required ABS data will be extracted from this instrument, negating the need for a separate acoustic instrument.

Water Sampling

For the collection of water samples, The HDR Team recommend the use of the Niskin Bottle. The Niskin Bottle is a 2.5 liter, non-metallic, free-flushing water sampler featuring a spring closure. The mechanism allows water samples to be reliably collected from a defined depth in the water column with minimal contamination.

The sampler is typically attached to a weighted wire rope to facilitate vertical transit through the water column. Deployment wire weightings will be adjusted according to on-site current conditions. The device can be lowered through the water column either mechanically or by hand with the deployment wire marked at pre-set depth intervals so as to ensure that water samples are taken from the relevant depths. In the case of near seabed samples, care will be taken to ensure the sampler does not rest on the seabed so as not to disturb sediments, thus contaminating the sample.

Samples are typically taken from surface, mid-water and near seabed locations at time intervals to coincide with OBS and ABS sample collection. A minimum 1 liter sample is typically required for most laboratory tests. Sterile sample bottles will be used so as to avoid sample contamination. All samples will be clearly and uniquely labelled, detailing the time and date of recovery, sample depth and client name. The sample will then be stored ready for dispatch to a local laboratory.

Data Processing

The HDR Team are well versed with using multiple methods for monitoring suspended sediments in a variety of conditions. As a result, we have developed an extensive database of calibration data.

In terms of OBS analysis, data from each measurement burst are first averaged to create one record per measurement burst (for example every 10 minutes). Pre and post-deployment data are removed. The data are then visualized to establish any quality issues such as excessive rates of change (data spikes) or data gaps. Suspect data are investigated; where possible in relation to other data sets such as current or wave data to assist in establishing their validity. Data which do not pass quality control tests can either be flagged or replaced with null values.

The suspended sediment concentration values obtained through laboratory analysis of the water samples are used to construct a site-specific calibration. A regression is drawn up between OBS values (in FTU) and the suspended sediment concentration values (in mg/l). The equation of the best-fit line is then used to convert the OBS values into an estimate of suspended sediment concentration.

The Nortek AWAC operates by measuring the strength of an acoustic signal, which is reflected back by particulate matter in the water. This raw echo intensity data can be used to extract information about the suspended sediment load in the water column. The raw amplitude (counts) values first have to be normalized (to remove the effect of signal attenuation through the water) and converted to a Decibel scale. Finally, the suspended sediment concentration values obtained through laboratory analysis of site specific water samples are used to construct a site-specific calibration. A regression is also drawn up between acoustic backscatter values (in normalized decibels) and the suspended sediment concentration values (in mg/l). The equation of the best-fit line is then used to convert the acoustic backscatter values into an estimate of suspended sediment concentration.

Subtask 2.4.3.3 – Biofouling Monitoring

Offshore wind turbine foundations offer surfaces for colonization and growth of marine fouling species and have the potential to represent hotspots of marine biomass compared to surrounding natural hard substrata (Krone et al., 2013[1]). However, the potential implications of localized high biomass on linked ecosystem components, such as feeding or refuge for fish and higher trophic levels ("reef effects"), are poorly understood, and the role of artificial hard surfaces as facilitators for the spread of species, including non-natives, remains unclear.

Biofouling can also raise some engineering concerns. For example, biofouling increases the effective diameter of underwater structures and alters its hydrodynamic drag and mass (Miller & Macleod, 2016[2]) potentially increasing structural fatigue. Certain species may be more problematic than others in this respect. For example, neutrally buoyant kelp won't add mass to the structure but may increase drag. Barnacles and mussels, on the other hand, add substantial weight to the structure and increase the diameter and roughness of the surface. The composition and growth rates of fouling communities are typically location specific and reflect larval availability and the prevailing physical conditions within the locale.

Considering the uncertainties above, this section presents our proposal for the conduct of a biofouling monitoring study at the Maryland OWF meteorological mast. Data collected will help address questions concerning the biofouling organisms present, how quickly they grow, the development of any "reef effects" and whether there are any particularly vulnerable places on the foundation structure with respect to biofouling. It is also anticipated that information drawn from this study would be used to contextualize observations of near-field benthic modifications that are currently being made at Block Island Wind Farm. The survey will be conducted by Fugro in collaboration with BOEM under HDR management.

Biofouling Monitoring Approach

From the literature (i.e. Schröder, 2006), initial colonization of marine foundations by biofouling species is extremely quick and is characterized by a highly dynamic phase of succession by different dominating species prior to stable communities becoming established.

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[1] Krone, R., Gutow, L., Joschko, T.J. & Schröder, A. (2013). Epifauna dynamics at an offshore foundation – Implications of future wind power farming in the North Sea. Mar. Env. Res, 85, 1-12

[2] Miller, G.G. & Macleod, A.K. (2016). Marine growth mapping and monitoring: Feasibility of predictive mapping of marine growth. A report by SAMS Research Services to the Offshore Renewable Energy Catapult, Glasgow, UK. 51pp.

To capture dynamic successional information of biofouling, it will be necessary to take observations very soon after foundation installation (within approximately 2 weeks) followed by regular repeat visits within the first-year post construction. A follow-up survey in the future would also be required to confirm the final climax community. Such a program will require careful coordination and cooperation between field scientists, developer and installation sub-contractors. Also, the collection of biofouling samples from the met mast will likely require permission from the developer and there may be legal challenges to overcome. Weather constraints add a further layer of complexity over the execution of marine monitoring plans.

To overcome these potential challenges, as far as is practicable, and to ensure useful data are collected, the HDR team propose a three-tier approach to the biofouling monitoring plan as follows.

TIER 1 – A SERIES OF SCUBA DIVER VIDEO AND PHOTOGRAPHY SURVEYS OF THE STRUCTURE THROUGHOUT ITS VERTICAL PROFILE IN THE WATER COLUMN.

These surveys will involve the collection of video and stills images using SCUBA divers and will provide information on the presence and growth of the dominant biofouling species, the vertical distribution (zonation) patterns of species and communities and the development of any reef effects. Semi-quantitative abundance data for species can also be collected using standard methodologies such as SACFOR (see **Table 3**) (Hiscock et al., 1996[3]).

The diver video and photography surveys will cover the entire vertical profile of the structure, from the splash zone to the seafloor. Images of the seafloor / scour protection material surrounding the base of the foundations will also be collected. All video and still images will be collected in digital format and returned to Fugro for analysis for species presence and estimated abundance / cover measures. The presence and use of the foundation by fish and other motile species will be recorded and the presence of any non-native species will be highlighted.

The first diver study will be conducted approximately 2 weeks post installation followed by repeat surveys at frequencies of 6 weeks, 6 months and 12 months post installation (or as agreed). This program of monitoring will describe the initial arrival and growth of primary colonizers as well as the development and over-growth of subsequent, and competitively superior, arrivals. A further visit 24 months post-installation is also proposed to record the climax communities present.

[3] Hiscock, K., ed. (1996) Marine Nature Conservation Review: rationale and methods. Peterborough, Joint Nature Conservation Committee. (Coasts and seas of the United Kingdom, MNCR series)

The field aspects of the diver studies will be led by two experienced scientific divers from Fugro (UK) and who have previous experience of similar studies of offshore renewables (monopile) foundations at Kentish Flats and Barrow Offshore Wind Farms. In addition to the two Fugro divers, there will be three locally sourced experienced divers (to provide in water and surface support) in compliance with the UK HSE approved code of practice for scientific diving projects (HSE, 2014[4]).

Two divers will be used at a time to collect video and still images of the biofouling on the structure, scour material and surrounding seabed, ensuring that all different surface types are covered. A detailed plan of the foundation will need to be provided to inform and agree the final dive strategy. The duration of each two-person dive is estimated to be approximately 20 – 25 minutes assuming a depth of around 25 – 30 meters. Up to 4 x two-person dives may be achieved in a single day, totaling around 80 – 100 minutes of diver video footage and photography each day.

[4] Health and Safety Executive (2014). *Scientific and Archaeological Diving Projects. Diving at Work Regulations 1997. Approved Code of Practice and Guidance*. P. 36

Table 3: SACFOR abundance scale used for littoral and sub-littoral fauna

% Cover	Growth form			Size of individuals/colonies			Density	
	Crust/ meadow	Massive / Turf	<1cm	1-3 cm	3-15 cm	>15 cm		
>80%	S		S				>1/0.001 m^2 (1x1 cm)	>10,000/m^2
40-79%	A	S	A	S			1-9/0.001 m^2	1000-9999/ m^2
20-39%	C	A	C	A	S		1-9 / 0.01 m^2 (10 x 10 cm)	100-999 / m^2
10-19%	F	C	F	C	A	S	1-9 / 0.1 m^2	10-99 / m^2
5-9%	O	F	O	F	C	A	1-9 / m^2	
1-5% or density	R	O	R	O	F	C	1-9 / 10m^2 (3.16 x 3.16 m)	
<1% or density		R		R	O	F	1-9 / 100 m^2 (10 x 10 m)	
					R	O	1-9 / 1000 m^2 (31.6 x 31.6 m)	
						R	<1/1000 m	

S= super-abundant, A = abundant, C = common, F = frequent, O = occasional, R = rare.

Deliverables will include a series of interim field reports describing the methods used, the observations made, any problems encountered and how these were overcome for each field visit. A comprehensive study report will be prepared at the end of the campaign describing the development of the biofouling, the key species involved and any interactions with fish and other species.

TIER 2 – A SERIES OF DIVER VIDEO, PHOTOGRAPHY AND QUANTITATIVE SAMPLING OF THE STRUCTURE THROUGHOUT ITS VERTICAL PROFILE IN THE WATER COLUMN.

In addition to the diver and photography studies described in Tier 1, quantitative samples of the biofouling community will be collected and returned to Fugro (UK) laboratories (or a suitable local organization) for detailed species taxonomy, enumeration and biomass determination. Samples will be collected from the structure within a 15cm x 15cm quadrat with the use of a putty scraper, or similar, at depths which represent each distinct species depth band (zone), or at 5m depth intervals where distinct zonation patterns are not apparent.

A maximum of 7 depth bands are therefore envisaged to be sampled corresponding to 0m, 5m, 10m, 15m, 20m, 25m, and bottom depths. A total of 2 scrape samples will be collected at each depth (total 14 samples per survey). The first 7 samples will be collected by the divers at each depth from external surfaces and as they descend to the base of the foundation. The second set of 7 samples will be collected from sheltered or internal surfaces of the foundation structure as the divers ascend to the surface.

Samples will be placed within a sealed labelled plastic bag and preserved in buffered saline formalin prior to delivery to the laboratory. The field team conducting these surveys will be as described above for Tier 1. A total of two days per survey is assumed to collect all of the scrape samples.

Deliverables will include interim field reports covering the aspects mentioned above together with an overall monitoring report providing a quantitative assessment of biofouling including detailed species compositions of each distinct fouling community, or 5m depth band, and the weight (biomass) of key species. Estimates of the overall weight of the biofouling on the structure throughout the monitoring period will be calculated.

TIER 3 – SETTLEMENT PLATE STUDIES.

This survey will involve the deployment of plates (tiles) at various depths close to the location of the met mast. The exact method of deployment has yet to be determined but it is likely to include fixing suitable plates within frames (see example photo below) and then deploying the frames within the water column at fixed (known) depths.

The final designs of the frames and settlement plates are expected to be refined over time in line with the final buoy deployment solution and in consideration of the physical conditions likely to be encountered offshore at Maryland. Fugro will consult internally with staff with previous experience of settlement plates and with oceanographers with experience of the deployment of offshore buoy systems form which settlement plates may be attached.

While Fugro are experienced in ocean buoy deployments, and have staff with previous settlement plate research experience, the use of the plates in this context and for this application will be experimental and will not have been conducted by Fugro before. Nevertheless, it is considered that the use of settlement plates would provide valuable information on the characteristics of biofouling in this region and could prove to be a practical and cost-effective alternative to the use of divers during future monitoring campaigns elsewhere.

Figure 15: Example of a settlement frame with plates.

Note: A modified design is likely to be used at Maryland (Photo courtesy of Portsmouth University).

An efficient solution would be to deploy the settlement plates as part of the AWAC monitoring (see Task 2.4.2). For instance, the same buoy system used for marking the AWAC on the seabed could be used to support the settlement plates in the water column. The advantage of this arrangement is that selected plates could be recovered every 3 months as part of the routine servicing of the AWAC equipment and returned to the laboratory for biofouling analysis at minimal additional cost. The data obtained will provide a record of the succession of biofouling at 3 month intervals over one year for this area.

Using this arrangement, settlement plates will deployed at the seafloor by attachment to the AWAC frame) and at mid depth (~15m) and close to the surface (~3m) by attaching to the mooring chain. Four plates will be fixed at each depth. One plate from each set will be recovered at each 3, 6, 9 and 12-month interval corresponding to the AWAC servicing schedule. Upon recovery in the field, each plate will be placed in a sealed, labelled plastic bucket and preserved in buffered saline formalin prior to delivery to the laboratory for species and biomass analyses.

The dimensions of the plates have yet to be confirmed and will ideally be made of the same grade steel and covered with the same paint coating as the met mast. Otherwise, other material may be used noting that any differences in micro-structure and chemical composition will caveat conclusions.

Deliverables will include interim field reports following each site visit together with an end of survey report presenting all results of the yearlong monitoring campaign. Where possible, a comparison of survey data with that collected during the diver studies will be made to determine whether the biofouling of the plates was representative of the foundation conditions.

Frequency of surveys

Table 4 summarizes the proposed survey schedule for the Tier 1, 2, and 3 surveys. Diver surveys will be conducted soon after the installation of the foundation on the seabed to capture information on the initial colonization, and at 6-week, 6-month, 12 months and 24-month intervals thereafter.

The settlement plate surveys will be conducted at the same as the AWAC servicing (every 3 months) and would be largely independent of the foundation installation program.

Table 4: Summary of proposed biofouling monitoring survey schedule.

Survey type	Post installation						
	2 weeks	6 weeks	3 months	6 months	9 months	12 months	24 months
Diver (Tier 1 and 2)	✓	✓		✓		✓	✓
Settlement plates (Tier 3)			✓	✓	✓	✓	

Data Analyses

Biological material retrieved from the diver scrape samples or from the settlement plates will be identified to species level, where possible, enumerated and weighed using the wet blot method with appropriate conversion to ash free dry weight. Each dominant species will be weighed to four decimal places. Less conspicuous or cryptic fauna will be grouped to phylum level and weighed. A voucher collection of species will be prepared. Data will be reported for each scrape and/or plate sample as a spreadsheet species and biomass matrix.

The analysis will be required to be undertaken within specialist laboratories with experience of handling and treating biofouling material. There is preference to use a suitable local laboratory but where this is not possible, then samples will be transferred to Fugro UK taxonomy labs. Fugro routinely transport biological samples for taxonomic analyses throughout the world and have comprehensive sample preservation, courier and tracking procedures in place.

Data derived from the monitoring will include species richness, abundance and biomass together with estimates of the overall mass of biofouling on the structure. Comparisons of species measures and community composition between depth zones and sampling occasions will be made using the Bray-Curtis similarity index, sample clustering with MDS and Permanova+.

Reporting

Interim field reports will be prepared following each field visit and will describe field methods used, dates of field data collection, any problems and solutions together with recommendations for future monitoring.

Final results will be reported within a technical report and will include;

- Distribution of key species, biomass and biotopes;
- Presence of non-native species;
- Estimates of biomass on the foundation during each sampling occasion;
- Community differences between depth zones and between sampling occasions;
- Interactions with fish and other motile species (reef effects).

Task-Specific Technical Assumptions

1. This will most likely be implemented in 2019.

2. For Subtask 2.4.3.1 – Corrosion Monitoring
    a. 6 samples will be tested over 2 years.
    b. 6 trips over 2 years to retrieve or monitor the 6 samples.
    c. 2 vessel days per visit to collect each sample and to undertake servicing of the remaining buoyed systems.
3. For Subtask 2.4.3.2 – Biofouling Monitoring
4. For Subtask 2.4.3.3 – Biofouling Monitoring
    a. Costs are provided for the Tier 2 approach only.
    b. Suggested approaches for Tier 1 and 3 are provided for BOEM's consideration. Costs for implementing one or both of these suggested approaches will be provided upon request.
    c. A total of 5 surveys will be conducted under this sub-task.
    d. Each survey will be conducted by 2 certified divers and it will last for up to 2 days. A total of 40 hours per diver per survey is included in the cost estimate to cover round trip travel, mobilization, field surveys, and demobilization.
5. The settlement plates may be subject to movement within the water column and may be made of a different material compared to the met mast. The settlement plates may therefore not be wholly representative of the met mast or foundations in terms of biofouling characteristics.
6. Monitoring conducted under this task by the HDR Team will not duplicate monitoring required to be conducted by the developer as part of their approved site plan.

2.4.4 Underwater Sound Monitoring – MD Meteorological Tower

Background

Under this task, the HDR Team will conduct underwater sound monitoring to measure changes in sound pressure levels and detect particle motion during the construction of the MLA met tower. **It is the HDR Team's judgment, that met tower operations are highly unlikely to produce measureable underwater sound. Therefore no monitoring is recommend during the operational phase.**

The developer is required to collect data within 1.7 km of the turbine location. Therefore, the HDR Team will primarily focus on conducting far field monitoring, defined as 1 to 30 kilometers (km) away from the sound source.

One monitoring station, however, will be placed in the near-field, approximately 750 meters from the sound source.

BOEM will facilitate communication with the developers, as necessary. Monitoring conducted under this subtask will not duplicate pile driving monitoring required to be conducted by the developer as part of their approved site plan.

Data collected during the installation of the offshore wind turbine structures will be compared with model results using a standard sound propagation model. The sound levels will also be compared to those collected at Block Island Wind Farm during the installation of the foundations in 2015. Table 5 summarizes the different types of monitoring proposed for the met tower.

Table 5: A summary of the underwater acoustic measurement systems proposed for the monitoring of the met tower construction.

Systems	Organization(s) responsible	Goals	Range(s) from Met Tower	Comments
Geosled with tetrahedral hydrophone array and 3-axis geophone	URI/WHOI	Near field particle velocity in the water column and at the seabed, pressure signal at a fixed range	750 meters	Range could be shorter if allowed by developer. Sample rate of 10 kHz.
Vertical Line Arrays (VLA)	WHOI/URI	Far field pressure signal	7.5 km and 30 km	Sample rate of 10 kHz.
Geospace OBX Geophone and Hydrophone Sensor System	URI	Range dependence of near field particle velocity in the water column and at the seabed, pressure signal	750 to 1150 meters	Configurable, sample rate of 4 kHz.
Towed Array	MAI	Range dependence of far field pressure signal	750 m to 30 km	Max range determined by duration of pile driving. If time allows, sub-bottom structure could be imaged with WHOI source.
Dipping hydrophone	Subacoustech and MAI	Azimuthal dependence of pressure signal in the near field	750 meters at various azimuths	Range could be shorter if allowed by developer. Sample rate of 44 kHz.

Methods

The proposed data collection approach and methods draw heavily upon lessons learned from underwater sound monitoring conducted during the pile driving associated with the installation of the turbines at the BIWF, Rhode Island. A summary of the proposed acoustic monitor deployment scheme is shown in **Figure 16**; additional details are provided below.

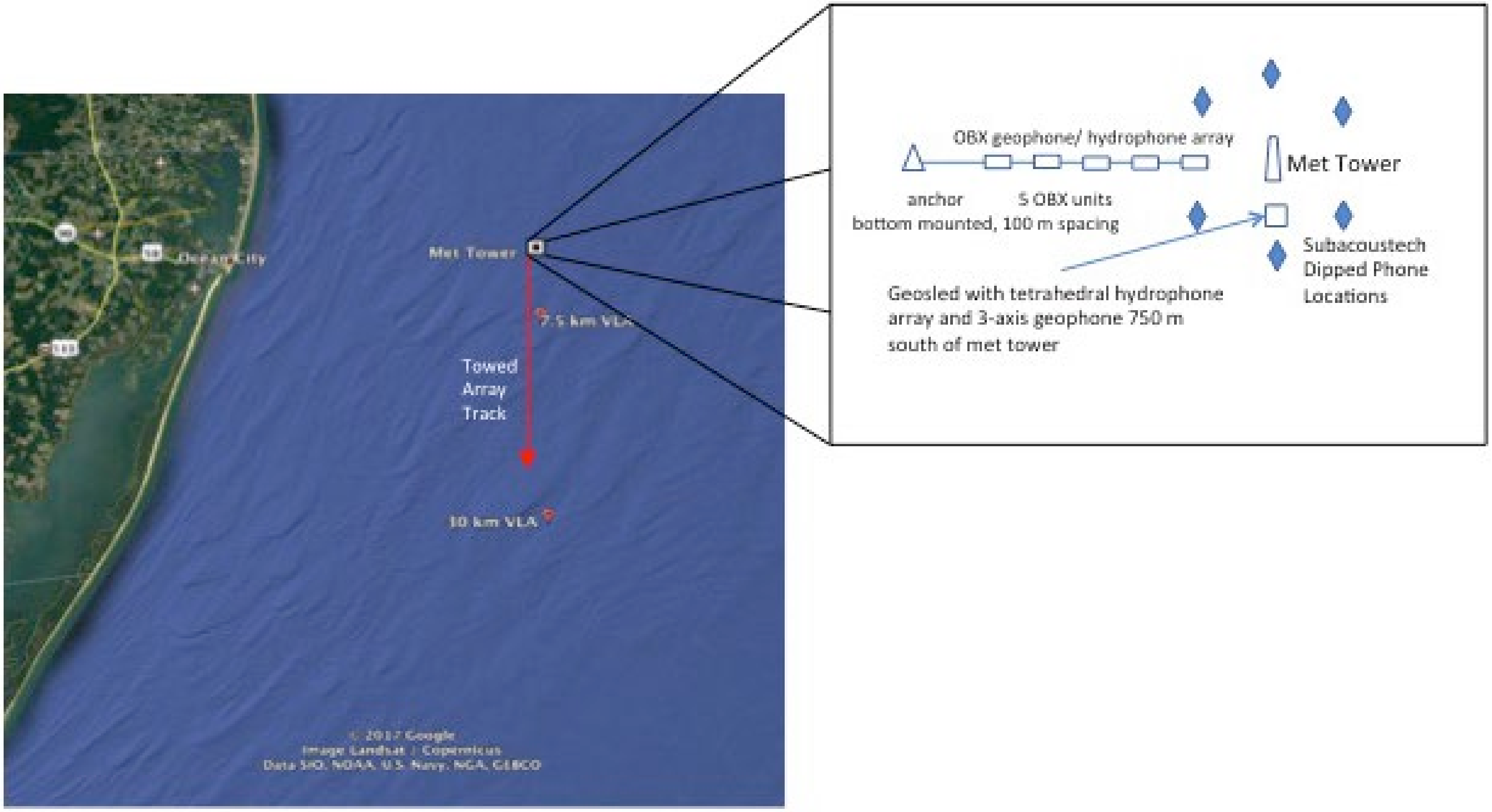

Figure 16: Left panel: A map of the area showing Ocean City, MD and the approximate location planned for the Met Tower along with two vertical line arrays of hydrophones at ranges of 7.5 and 30 km due south of the tower.

Note: Also shown as a red line is the towed array track. The right panel (inset) shows the close in systems including the Geosled with the tetrahedral hydrophone array and the 3-axis geophone 750 meters south of the met tower. To the west, an array of OBX bottom-mounted geophone/hydrophone systems are planned with 100 meter spacing between the 5 units. Also shown are nominal locations for a dipping hydrophone system to be deployed by Subacoustech with support from MAI.

The following subtasks will be conducted:

Subtask 2.4.4.1 – Field Data Collection during Construction Phase

Under this subtask, the following five sets of acoustic recorders will be deployed in the field:

1. **URI Geosled** – The URI Geosled contains a tetrahedral hydrophone array with a phone spacing of 0.5. The purpose of the tetrahedral array is to measure the pressure signals generated by the pile driving as well as the particle velocity of the pile driving signal. The Geosled is mounted on the seafloor and show in **Figure 4**. A 3-axis geophone is also part of the Geosled system and measures the particle motion at the seabed. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks (CSAC). The sample rate for both systems is about 10 kHz.
2. **Vertical Line Arrays** – Two Vertical Line Arrays of four hydrophones each will be deployed at a range of 7.5 km and 30 km. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks (CSAC). The sample rate for both systems is about 10 kHz. The configuration of the Vertical Line Arrays will be similar to that shown in **Figure 5**.
3. **OBX Ocean Bottom Recorder**– To the west, an array of OBX bottom-mounted 3-axis geophone/hydrophone systems are planned with a 100 meter spacing between the 5 units. The closest system will be 750 meters from the Met Tower. The sample rate of these systems is configurable with a maximum of 4 kHz. These systems will measure both the pressure signal and the particle velocity signal of the pile driving at the seabed. **Figure 6** shows one of the OBX systems.
4. **Dipping Hydrophone** – This system from Subacoustech provides an efficient way to measure the azimuthal dependence of the acoustic pressure field around the pile driving. Acoustic pressure measurements will be sampled in six locations as shown in Figure 3, with sound pressure measurements taken at minimum two depths: mid-water and 1 m above the sea bed. Sample rate for this system is 350 kHz.
5. **Towed Array** – A towed hydrophone array is proposed to be deployed on the research vessel by Marine Acoustics, Inc. The array is composed of 8 hydrophones of non-regular spacing. The towed array depth is a function of boat speed and best performance is achieved with a boat speed of 2-3 kts. The sample rate is configurable up to 64 kHz though the array itself has a flat response to 4 kHz with decreased sensitivity at higher frequencies. The goal of the towed array measurements is to measure the

details of the range dependence of the pile driving pressure signal. The transition between impulsive and non-impulsive signals as characterized by measures such as kurtosis is of great interest to regulators such as NMFS. **Figure 7** shows the towed array deployed near the Block Island Wind Farm. A similar arrangement will be deployed during construction at the met tower site

Data recorders will be deployed in the field using a vessel of opportunity. A possible ship that could support this field is the R/V Rachel Carson as shown in **Figure 8**. The ship is owned by the University of Maryland and appropriate for the deployment and recovery of the systems described above in the region of the met tower. The homeport for this ship is in Solomon, Maryland and conveniently located for the field operations required for this task.

Recorders will be deployed and activated at least 24 to 48 hours before piling begins. They will be recovered 24 hours after the piling ends in order to record data for the entire 7-day construction period. The timing of the towed array and dipping hydrophone measurements will be coordinated with the developer to ensure sampling days overlap with active piling.

Subtask 2.4.4.2 – Data Analyses

The following types of data will be collected by the various recording devices during construction of the met tower:

- Pressure signals as measured by hydrophone systems.
- Seafloor particle velocity signals as measure by the geophones
- In-water particle velocity calculated from the tetrahedral hydrophone array signals.

From these data, the following list shows the possible measures of interest:

- rms sound pressure level (SPL) in dB re 1 μPa.
- peak sound pressure level (SPL_{peak}) in dB re 1 μPa.
- peak-to-peak sound pressure level ($SPL_{peak\text{-}peak}$) in dB re 1 μPa.
- sound exposure level (SEL) in dB re 1 $\mu Pa^2 s$.
- kurtosis of the pressure signal
- rms particle velocity level (PVL) in in dB re 1 nm/s.
- peak particle velocity level (PVL_{peak}) in in dB re 1 nm/s.
- peak-to-peak particle velocity level ($PVL_{peak\text{-}peak}$) in in dB re 1 nm/s.

The end points of the analyses are an assessment of the impact of the construction and operational noise on species of interest such as marine mammals, fish, and others. Data and resulting measures will be compared to those from the Block Island Wind Farm.

Subtask 2.4.4.3 – Reporting

A report will be written that documents the performance of the acoustic systems deployed for the construction the met tower. An outline of this report including appendices is given below:

- Introduction and summary of results
- Description of area including oceanographic, geological, and geographic information
- Description of equipment utilized
- Measurements during construction
  - Pressure measurements
  - Particle velocity measurements in the water column
  - Particle velocity measurements at the seafloor
  - Oceanographic measurements including conductivity, temperature and depth measurements from which sound speed profiles can be estimated.
- Analysis of measured data
  - Acoustic quantities measured including SPL, SEL, and Kurtosis
  - Analysis of particle velocity measurements
- Comparison to the BIWF data
- Conclusions
- Appendices
  - Mooring diagrams
  - Equipment spec sheets
  - Pile driving schedule
  - Ship tracks

Task-Specific Technical Assumptions

1. This task will most likely be implemented in 2018.

2. It is the HDR Team's judgment, that met tower operations are highly unlikely to produce measureable underwater sound. Therefore no monitoring is recommend during the operational phase.
3. The following equipment will be deployed during the construction phase:
   a. URI will deploy a Geosled with four hydrophones in tetrahedral configuration, one 3-axis geophone and hydrophone package, five Geospace OBX 3-axis bottom-mounted geophones (each with a hydrophone) for a ***total of 9 days*** (starting 1 day prior to construction, 7 days of construction, and ending 1 day after construction is completed).
   b. WHOI will deploy two Vertical Hydrophone Arrays each with four hdyrophones and Chip-Scale Atomic Clocks for a ***total of 9 days*** (starting 1 day prior to construction, 7 days of construction, and ending 1 day after construction is completed).
   c. MAI will deploy a towed array with eight hydrophones for ***1 day*** in parallel with construction pile driving. The timing of the towed array deployment will be coordinated with the developer to ensure sampling days overlap with active piling.
4. The costs for this task are based on the following assumptions:
   a. The URI Geosled will be prepared and mobilized for deployment by WHOI. Costs associated with preparing and mobilizing the geosled to the project site are included in the WHOI cost estimate.
   b. URI and WHOI will collaborate on preparing, mobilizing, and deploying the VLAs.
   c. The Geospace OBX bottom recorders will be prepared for deployment by Geospace and those costs are included in the URI cost estimate. Costs of supplies needed for the deployment and recovery of the Geospace OBX bottom recorders are also included in the URI cost estimate.
   d. MAI will prepare and deploy the towed array; associated costs are included in the MAI cost estimate.
   e. Subacoustech will prepare and deploy the dipping hydrophone; associated costs are included in the Subacoustech cost estimate. A minimum of two hydrophones will be utilized from the survey vessel for the dipping hydrophone. Two surveyors will be present for monitoring and handling equipment. The timing of the dipping hydrophone deployment will be coordinated with the developer to ensure sampling days overlap with active piling.

f. All field work performed by URI, WHI and MAI during both phases will be conducted using the Research Vessel Rachel Carson, which will be leased from the University of Maryland. Vessel rental costs are included in the URI cost estimate. Ten (10) ship days are assumed for the construction phase monitoring and five (5) ship days are assumed for deploying and recovering equipment during summer and winter during the operational phase.

g. A small boat will be required to support Subacoustech field work during the construction phase; cost of this boat is included in the HDR cost estimate.

5. A standalone draft and final Technical Report and draft and final Technical Summary will be prepared under Task 2.4.1.
6. Monitoring conducted under this task by the HDR Team will not duplicate pile driving monitoring required to be conducted by the developer as part of their approved site plan.

2.4.5 Project Management

This TO will be implemented by a team of experienced and qualified experts.

Monthly Status Reports (MSR)

For the duration of this TO, the HDR Program/Project Manager will prepare and submit to BOEM a TO status report each month via email. The MSR will contain summary descriptions of activities performed by the HDR Team under this TO during the reporting period. It will also show status of each individual tasks (in terms of percentage complete), identify any issues or concerns that the Team had to deal with during the reporting period, and a summary of work to be likely to be accomplished during the next reporting period.

A draft MSR will be submitted for BOEM review and input. The draft MSR will be finalized by addressing comments provided by BOEM, if any.

Status Update Phone Calls

As necessary, the HDR Project Manager will schedule periodic conference calls with the BOEM CO and COR to provide updates, address issues, and ensure team coordination.

Presentation Webinars

The HDR Team will host a webinar at the end of the project to share the results of the study using Powerpoint. The webinar will include:

1. Project objectives, design, and methods;

2. Activities conducted during the course of the TO performance;

3. Project results and conclusions.

Each slide shall contain the BOEM logo. These logos will be supplied digitally by the COR. Charts, graphs, maps, etc. may be included as slides. The Contractor shall add notes to the PowerPoint file in the notes page of each slide in sufficient detail to stand alone as an independent description of the project. This will enable an informative presentation on the project using only the PowerPoint file.

Task-Specific Technical Assumptions

1. This task will be incrementally implemented over the period of performance for this TO.
2. No in-person project meetings will be conducted under Task 2.4.5. All coordination with BOEM staff will be conducted via conference calls.
3. A draft MSR will be submitted to BOEM by the 15th of the month following the reporting period.
4. The draft MSR will be finalized by addressing comments provided by BOEM, if any.

2.5 Schedule and Distribution of Deliverables

Work products (Deliverables) prepared under this TO will be transmitted to the recipients listed in Section 2.6 of the RFP per schedule shown in Table 1. All correspondence related to this TO will be clearly marked with the contract and TO number on the first page, and in the subject line of email messages.

The following key work products will be prepared under this TO:

A. Monthly Status Reports (MSRs)

See **Section 2.4.5** for a description of the reports that will be produced under this TO.

B. Technical Report(s) (Draft Copy)

The HDR Team will prepare and submit a Technical Report (Draft Copy), within six (6) months of after recovery of all equipment. This report will conform to the specifications found at BOEM's web site: http://www.boem.gov/Environmental-Studies-Program-Report-Specifications/. It will describe the methods, results, and recommendations from each individual task performed under this TO and include the geophysical surveys summary reports prepared at the end of each annual survey.

As appropriate, the draft report will also include digital files using the format indicated in the report specifications for use as report cover graphics. These will be readily identified with the subject of the report. A paper reproduction shall be submitted with the draft report. With prior COR approval, HDR may submit a suitable illustration depicting the subject of the report. (More than one graphic may be submitted.)

The Draft Technical Report will be reviewed by the COR and BOEM's Editorial Staff until deemed accepted by BOEM. The draft version will be prepared as if it were the Final Report (i.e., with identical pagination, format, cover art, forward matter, figures, tables, etc.). BOEM and designated reviewers will have 30 days to review the Draft Technical Report. BOEM will notify HDR in writing with any required changes, corrections, or additions. All corrections will be incorporated into the Technical Report (Final Copy) and submitted as a digital copy in pdf format.

HDR will not provide copies of this Technical Report (Draft Copy), nor any subsequent revisions prepared during the review process, nor data contained within, nor any portions thereof, to any parties not specifically designated by BOEM. If a need arises to do so, the Program Manager will obtain the written approval of the CO prior to releasing the draft report.

C. Technical Reports (Final Copy)

The HDR Team will incorporate any additional comments, recommendations, corrections, suggestions and editorial requirements made by BOEM into the Technical Report (Final Copy).

The Team will prepare a digital version of the Technical Report (Final Copy) as a single file (prepared in PDF with bookmarks and database files). Digital files will be submitted according to schedule shown in Table 1. Two copies of the CD containing (on one disk, when possible) the Technical Report (Final Copy) in MSWord and PDF versions and the Webinar Presentation will be submitted. The label will include the report title, contract number, BOEM report number, Contractor name, and report date.

D. Technical Summery (Draft Copy)

The HDR Team will prepare a Technical Summary (Draft Copy) of the TO Technical Report and submit it concurrently with the Technical Report (Draft Copy). The summary will be approximately two pages in length, and it will strictly confirm with a format provided for Technical Summary Specifications on BOEM's website (http://www.boem.gov/Environmental-Studies-Program-Report-Specifications/).

The digital file will compatible with MS Word format. Questions regarding formats and or requests for samples or templates, if any, will be directed to the COR.

E. Technical Summery (Final Copy)

The HDR Team will incorporate BOEM's comments, recommendations, corrections, and suggestions into the Technical Summary (Final Copy).

F. Archiving of Datasets and Analysis Results

The HDR Team will provide all data including analysis of said data and associated metadata, in an acceptable format (per specifications listed on the BOEM website. Observational data acquired in field as well as data, maps, and figures generate in the lab will also be submitted, as agreed to with BOEM at the end of the contract. This deliverable will be completed after all QA/QC procedures are finalized including the analysis by the individual task leaders. Any changes in data formats during contract performance will be discussed with the COR and BOEM Technical Staff and will be agreed upon in advance. The HDR Team will archive the data at the National Oceanographic Data Center and submit a receipt to BOEM confirming data archiving.

G. Webinar and Powerpoint Presentation

The HDR Team will host a webinar at the end of the project to share the results of the study using MS Powerpoint. The webinar presentation will include the following:

1. Project objectives, design, and methods;
2. Activities conducted during the course of the TO performance;
3. Project results and conclusions.

Each slide will contain the BOEM logo. These logos will be supplied digitally by the COR. Charts, graphs, maps, etc. may be included as slides. Notes will be added to the MS PowerPoint file in the notes page of each slide in sufficient detail to stand alone as an independent description of the project. This will enable an informative presentation on the project using only the PowerPoint file.

3 Health and Safety

A TO- and site-specific Safety, Health, and Environmental Plan will guide all field activities conducted under this Field Plan. The HDR Team Program Management Staff is committed to the health and safety of each employee that participates in the field data collection effort. It is essential that all Task Managers and Field Supervisors insist on the maximum safety performance and awareness of all employees under their direction, by enthusiastically and consistently administering all health and safety rules and regulations.

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RODEO Program Monitoring for the Coastal Virginia Offshore Wind (CVOW) Project

Revised 15 May 2020

(Addendum to the CVOW Project 2017 Field Plan)

1. RODEO Program Overview

The purpose of the Bureau of Ocean Energy Management's (BOEM's) Real-Time Opportunity for Development Environmental Observations (RODEO) Program is to make direct, real-time measurements of the nature, intensity, and duration of potential stressors during the construction and initial operations of selected proposed offshore wind facilities. The purpose also includes recording direct observations during the testing of different types of equipment that may be used during future offshore development to measure or monitor activities and their impact producing factors.

BOEM conducts environmental reviews, including National Environmental Policy Act analyses and compliance documents for each major stage of energy development planning which includes leasing, site assessment, construction, operations, and decommissioning. These analyses include 1) identification of impact producing factors (stressors) and receptors such as marine mammals and seafloor (benthic) habitats, and 2) evaluation of potential environmental impacts from the proposed offshore wind development activities on human, coastal, and marine environments. The analyses require estimations of impact-producing factors such as noise and the effects from the stressor on the ecosystem or receptors. Describing the impact-producing factors requires knowledge or estimates of the duration, nature, and extent of the impact-generating activity. Since there have been no offshore facilities constructed in the United States prior to the Block Island Wind Farm (BIWF), model predictions will be primarily used to forecast likely impacts from future projects.

The RODEO Program data may be used by BOEM as inputs to analyses or models that evaluate the effects or impacts from future offshore wind turbine construction and operations, as well as facilitate operational planning that would reduce potential impacts to the greatest extent possible. The understanding and insights gained from the BIWF monitoring program data analyses will help BOEM to identify, reduce, and mitigate environmental risks in the future, and significantly increase the efficiency and efficacy of BOEM's regulatory review process for offshore wind development in the United States. Finally, data collected by the BIWF monitoring program will support prioritization of future monitoring efforts and risk retirement. For example, if the BWIF monitoring data indicates that likelihood of impacts from a particular project development phase is low or inconsequential, then such phases may not be monitored during future projects.

The RODEO Program is not intended to duplicate or substitute for any monitoring that may otherwise be required to be conducted by the developers of the proposed projects. Therefore, RODEO monitoring was limited to selected parameters only. Also, RODEO Program monitoring is coordinated with the industry and is not intended to interfere with or result in delay of industry activities.

2. CVOW RODEO Program Monitoring Overview

The RODEO Program monitoring for the CVOW Project will take place during active construction of project's first phase, which calls for the development of two 6-megawatt wind turbines on a 2,135-acre site located approximately 27 miles east off the coast of Virginia Beach, Virginia. The turbine location coordinates are:

- Turbine 1 - 36° 53'46.63" N; 75° 29'29.88" W
- Turbine 2 - 36° 53'12.6" N; 75° 29'29.66" W

The site is leased by the Virginia Department of Mines Minerals and Energy, and Dominion Energy has an agreement with the Department of Mines Minerals and Energy to build and operate the turbines at this location. Each of the two turbines will have a 26.2-foot monopile foundation that will be installed on the seabed by pile driving. An approximately 80-foot diameter scour protection will be installed at the based of each foundation. The turbines are scheduled to be in operation by late 2020 and will lay the ground work for potential large-scale development in an 112,800-acre commercial wind site Dominion Energy has leased from BOEM.

The monitoring surveys will be implemented in accordance with a pre-approved Field Sampling Plan, which will include a project-specific Health and Safety Plan. A brief summary of the proposed monitoring plan is presented below.

3. CVOW RODEO Program Monitoring Plan

The RODEO Project Delivery Team will conduct underwater acoustic monitoring within the CVOW Project Area during the pile driving for the installation of the two turbine monopile foundations to 1) measure changes in sound pressure levels, 2) record sound levels in the water column and vibrations in the sediment, and 3) detect particle motion.

The developer is required to collect data within 1.7 kilometers (km) of the turbine location. Therefore, the RODEO Project Delivery Team will primarily focus on far field monitoring, defined as 1 to 30 km away from the sound source. One monitoring station, however, will be placed in the near-field, approximately 3000 meters (m) from the sound source. During the construction phase, which is expected to last for up to one week (7 days), the moorings will be deployed at pre-selected locations prior to the start of the installation and retrieved after installation is completed. In addition, a towed array and a dipped hydrophone will be deployed during impact pile driving.

Monitoring data will be compared with model results using a standard sound propagation model. The sound levels will also be compared to those collected at the BIWF at Rhode Island during the installation of the wind turbine foundations.

Methods

The proposed data collection approach and methods draw heavily upon lessons learned from underwater acoustic monitoring conducted during the pile driving associated with the installation of the BIWF turbine foundations. Five different monitoring systems will be deployed to monitor the underwater acoustic field near the turbine construction site (**Table 1)**. A schematic layout showing proposed relative locations of the various systems is shown in **Figure 1**. The actual locations for placing the monitoring platforms will be finalized in consultation with BOEM prior to the start of the monitoring.

Table 1: Acoustic monitoring systems proposed for deployment near the CVOW Project Area to monitor underwater acoustic signals during the installation of the two monopile turbines

Systems	Goals	Range(s) from WTGs	Comments
Geosled with tetrahedral hydrophone array.	Near field particle velocity at the seabed, pressure signal at a fixed range	1500 m	Sample rate of 10 kHz.
Far Field Vertical Hydrophone Arrays	Water column far field pressure signal	7.5 km	Sample rate of 10 kHz.
Near Field Vertical Hydrophone Arrays	Water column near field pressure signal	3 km	Sample rate of 10 kHz
Geospace OBX and Geophone Hydrophone Sensor System	Range dependence of near field particle velocity at the seabed, pressure signal	1.5 km with 5 meter sensors spacing	Configurable, sample rate of 4 kHz.
Towed Array	Range dependence of far field pressure signal	750 m to 30 km	Max range determined by duration of pile driving.
Dipping hydrophone	Very long range dependence of pressure signal in the near field	15 to 40 km	Sample rate of 44 kHz.

Additional details of the systems listed in **Table 1** are provided below:

a. **Geosled** – A Geosled contains a tetrahedral hydrophone array and a three-axis geophone system will be placed on the seafloor at a pre-determined location. The purpose of the tetrahedral array is to measure the pressure signals generated by the pile driving that will be used to fix the monopiles of the two turbines to the seafloor as well as the particle velocity of the pile driving signal. The three-axis geophone will measure particle motion at the seabed. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks. The sample rate for both systems is about 10 kilohertz (kHz).

b. **Vertical Line Arrays** – Two Vertical Line Arrays consisting of four hydrophones each will be deployed at a range of approximately 3 and 7.5 km, respectively. The signals from the sensors are recorded on two Several Hydrophone Receive Units containing Chip-Scale Atomic Clocks. The sample rate for both systems is about 10 kHz.

c. **OBX Ocean Bottom Recorder** – An array of OBX bottom-mounted three-axis geophone/hydrophone systems will be located to the west of the project area with 5 m spacing between the four units. The closest system will be about 1500 m equidistant from each turbine. The sample rate of these systems is configurable with a maximum of 4 kHz. These systems will measure both the pressure signal and the particle velocity signal of the pile driving at the seabed.

d. **Towed Array** – A towed array arrangement is the most effective tool for getting at the transition from impulse to non-impulse signals and the proposed large monopiles will provide a very unique opportunity to see where these signals become non-impulsive. This array is composed of eight hydrophones of non-regular spacing. The towed array depth is a function of boat speed and best performance is achieved with a boat speed of 2 to 3 knots. The sample rate is configurable up to 64 kHz, though the array itself has a flat frequency response to 4 kHz with sensitivity falling off at higher frequencies. The goal of the towed array measurements is to measure the details of the range dependence of the pile driving pressure signal. The transition between impulsive and non-impulsive signals as characterized by measures such as kurtosis is of great interest to regulators such as National Marine Fisheries Service.

e. **Dipping Hydrophone Monitoring** – Use of a hand-held hydrophone that is dipped in the water column at pre-determined locations at a selected frequency is an efficient way to measure the azimuthal dependence of the acoustic pressure field around the pile driving. Acoustic pressure measurements will be sampled in six locations, with sound pressure measurements taken at minimum two depths: mid-water and 1 m above the sea bed. The dipped hydrophone will be deployed in six locations surrounding the pile being installed, with approximately one minute of sampling of piling noise taken at each location before mobilizing to the next location, sequentially. Sample rate for this system is 350 kHz.

All monitoring systems will be deployed and retrieved using a vessel of opportunity. The timing of the towed array and dipping hydrophone measurements will be coordinated with the developer to ensure sampling days overlap with active piling. The stationary equipment will be recovered after the piling ends in order to record data for the entire 7-day construction period.

Data Analysis

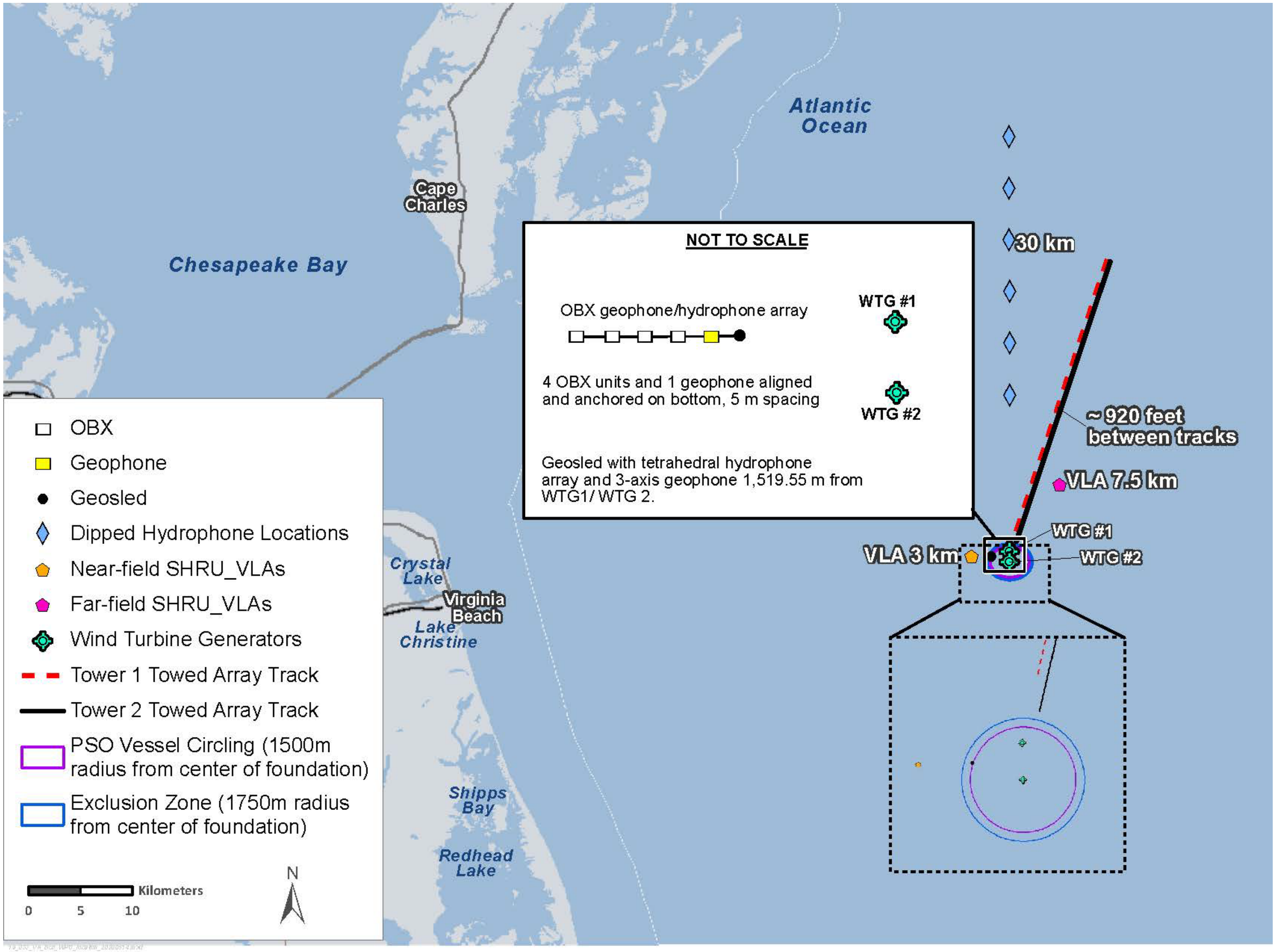
The following types of data will be collected by the various recording devices:

- pressure signals as measured by hydrophone systems
- seafloor particle velocity signals as measure by the geophones
- in-water particle velocity calculated from the tetrahedral hydrophone array signals.

From these data, the following list shows the possible measures of interest:

- rms sound pressure level (SPL) in dB re 1 μPa
- peak sound pressure level (SPLpeak) in dB re 1 μPa
- peak-to-peak sound pressure level (SPLpeak-peak) in dB re 1 μPa
- sound exposure level (SEL) in dB re 1 $\mu Pa^2 s$
- kurtosis of the pressure signal
- rms particle velocity level (PVL) in in dB re 1 nm/s
- peak particle velocity level (PVLpeak) in in dB re 1 nm/s
- peak-to-peak particle velocity level (PVLpeak-peak) in in dB re 1 nm/s.

The end points of the analyses are an assessment of the impact of the construction noise on species of interest such as marine mammals, fish, and others. Data and resulting measures will be compared to measurements recorded at the BIWF.



Data Source: ESRI Streetmap 2010

Figure 1: Proposed locations for placement of the BOEM's RODEO Program acoustic monitoring platforms

RODEO Fixed Mooring Locations

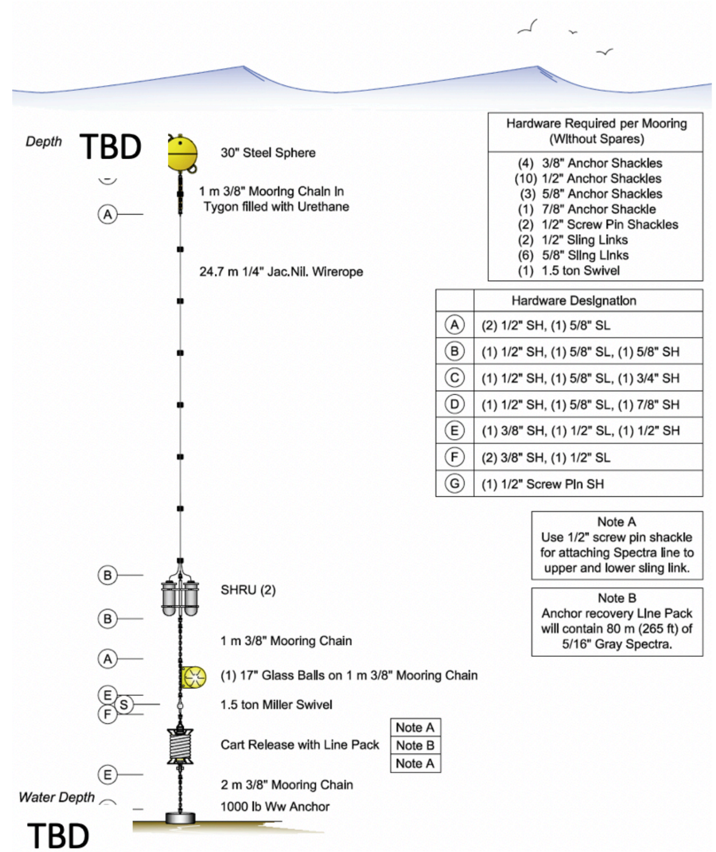
Mooring Name	Longitude	Latitude
Near field SHRU1	-75.5075	36.8916
Near field SHRU2	-75.5248	36.8916
Far field SHRU3 @ 7.5 km north	-75.4916	36.9638
Far field SHRU4 @ 15 km north	-75.4916	37.0313
OBX 1	-75.5073	36.8914
OBX 2	-75.5246	36.8914
OBX 3	-75.5133	36.8916
OBX 4	-75.5190	36.8916
Geosled	-75.5011	36.8916

Fixed moorings will be deployed on April 25-26, 2020 from the R/V Virginia.
Moorings will be recovered on May 7-8, 2020 by the R/V Virginia.

Figure 2. RODEO moorings coordinates

Several Hydrophone Receive Unit (SHRU)

- Vertical array of hydrophones
- Data acquisition system
- Heavy anchor (1000 lb)
- 30' steel sphere for main buoyancy



This graphic for illustration only and is not the final mooring design.

Figure 3. SHRU Vertical Hydrophone Array Sketch

Towed hydrophone array

- Towed array with eight elements will be used to collect data on May 1 and 3, 2020
- Track will start 1 km north of A01 on both days.
- Digitized at 64 kHz/channel
- WHOI depth sensors used to measure array depth
- Array deployed from the R/V Tiki XIV

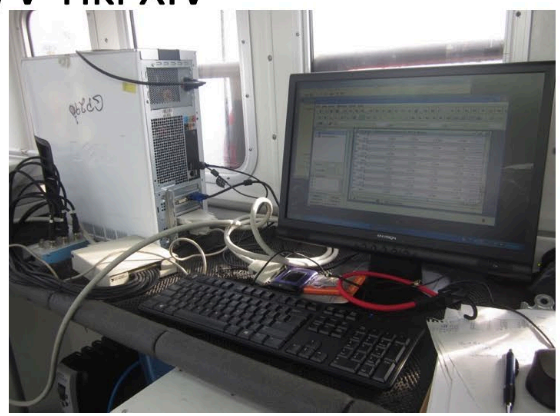
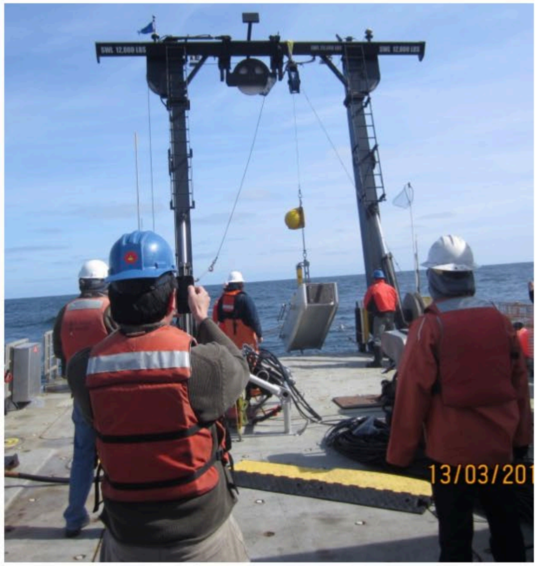


Figure 4. Towed hydrophone array for monitoring impact pile driving during CVOW construction.

Geosled

- Geosled will have a tetrahedral hydrophone array and a 3-axis geophone.



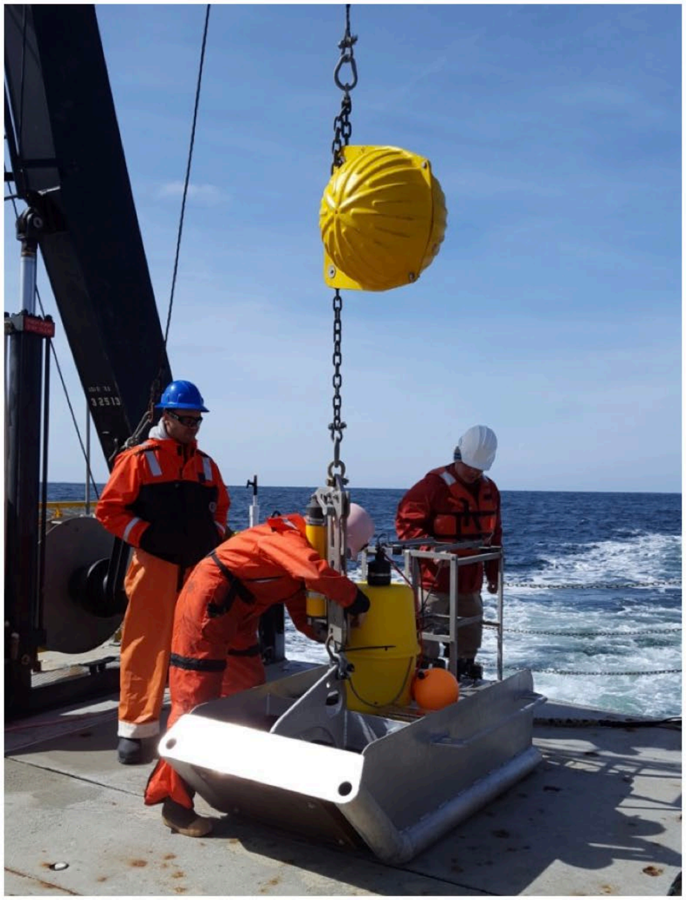


Figure 5. Geosled to be deployed 1 km from A01 and A02 turbine locations to measure acoustic and seismic signals from impact pile driving

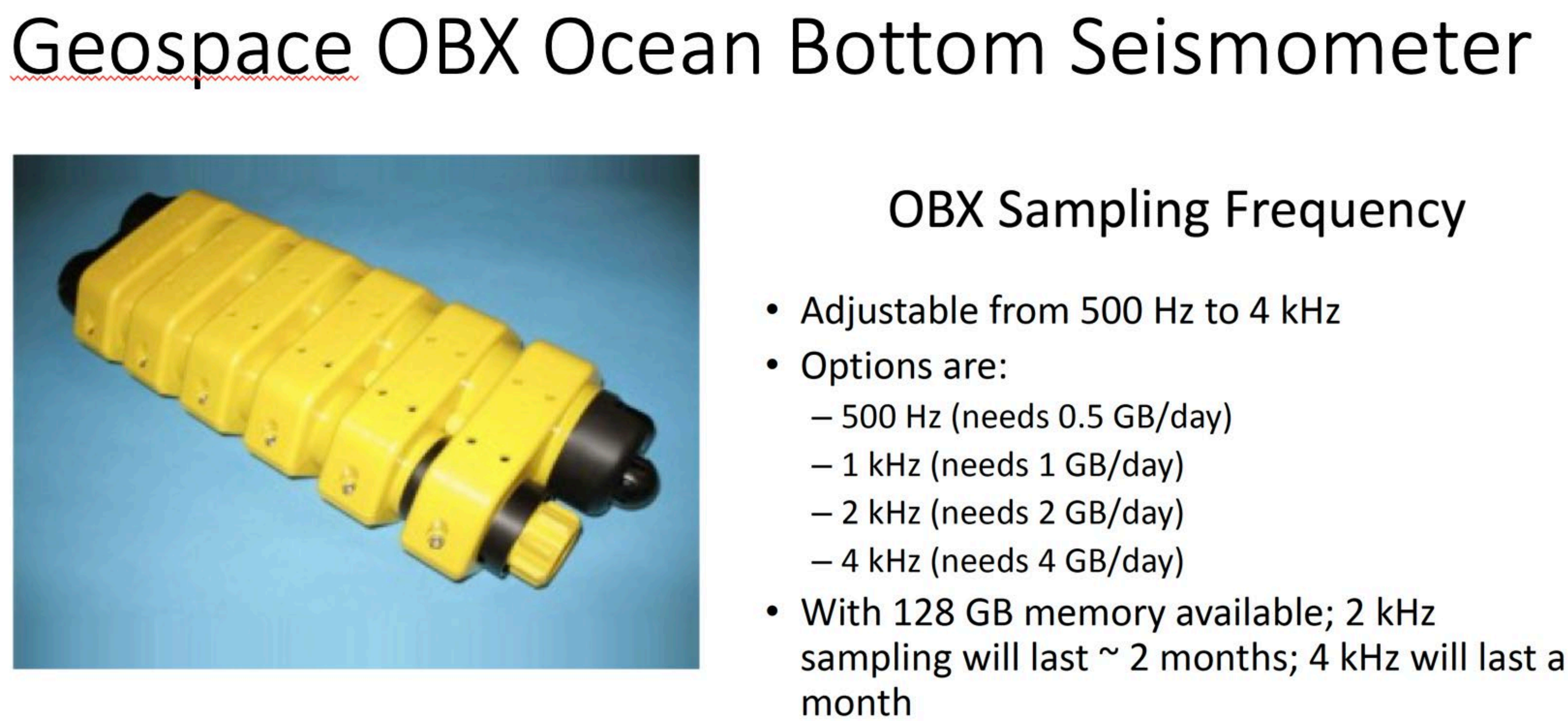


Figure 6. Geospace OBX ocean bottom seismometer

Site-Specific Safety, Health, and Environmental Plan

Real Time Opportunity for Development of Environmental Observations (RODEO)

Field Observations During Offshore Wind Structure Installation and Operation (Coastal Virginia Offshore Wind Project)

RODEO IDIQ Contract No.: M15PC00002
Task Order No.: 140M0118F0006

HDR Project No.: 10101137

Prepared by:

HDR

Athens AL Project Office
300 North Madison Street,
Athens, AL 35613

July

2020

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SIGNATURE PAGE

Field Observations during Offshore Wind Structure Installation and Operation
(Coastal Virginia Offshore Wind Project)

RODEO IDIQ Contract No.: M15C00002; Task Order No.: 140M0118F0006

HEALTH AND SAFETY PLAN

		Cell Phone No.
Business Class Manager/Principal-In-Charge:	Ryan Thompson	610-909-0351
HDR EOC Health and Safety Manager	Larry Simon	941-266-9104
Program/Project Manager:	Anwar Khan	954-494-2084

Preparation Date:	July 2019
Revision Date:	July 2020
Expiration Date:	April 2022

APPROVALS

Ryan Thompson

Larry Simon

Anwar Khan

Prepared by:
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Athens AL Project Office
300 North Madison Street
Athens, AL 35611

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Appendices

Figures

Tables

Acronyms and Abbreviations

°C	Degrees Celsius
°F	Degrees Fahrenheit
AHA	Activity Hazard Analysis
BPM	Beats per minute
CO	Contracting Officer
COR	Contracting Officer's Representative
dBA	Decibels, A weighted
EMS	Emergency Medical Service
EPIRB	Emergency Position-Indicating Radio Beacon
FA	First Aid
GPS	Global Positioning System
JHA	Job Hazard Analysis
mph	miles per hour
OSHA	Occupational Safety and Health Administration
PIC	Principal-In-Charge
PFD	Personal Flotation Device
Plan	Site-Specific SH&E Plan
PM	Program/Project Manager
PPE	Personal Protective Equipment
HSM	Health and Safety Manager
SC	Safety Coordinator
SH&E	Safety, Health, & Environmental
SOP	Standard Operating Procedure
SPF	Sun Protection Factor
SSHO	Site Safety and Health Officer
SWA	Stop Work Authority
QA/QC	Quality Assurance/Quality Control
USCG	U.S. Coast Guard
UV	Ultraviolet
UVA	Ultraviolet A
UVB	Ultraviolet B
UVC	Ultraviolet C

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Table 1. Emergency Contact List

Department	Telephone Numbers
United States Coast Guard 13th Coast Guard District	Main: (757) 852-3400 Emergency: (800) 982-8813 Radio Channel VHF # 16
Marine Forecast – Norfolk:	Norfolk Weather http://forecast.weather.gov/MapClick.php?lat=36.948794297566366&lon=-76.37832641601562&site=akq&unit=0&lg=en&FcstType=text NOAA weather marine VHF: channel 21
24-Hr Emergency Department:	(757) 444-3333 or dial 911
HDR Satellite Phone Number	011 881651403002
WorkCare Incident Intervention:	(888) 449-7787
Hospitals (emergency medical facility):	Sentara Norfolk General Hospital 600 Gresham Drive Norfolk, VA 23510 Telephone: (757) 388-3000 Sentara Virginia Beach General Hospital 1060 First Colonial Road Virginia Beach, VA 23454 Telephone: (757) 395-8000
Non-emergency medical facility:	Patient First Urgent Care 332 Newtown Road Virginia Beach, VA 23455 (757) 473-8400
Emergency Responders: *In Event of Emergency, call for help as soon as possible.*	Police Department…………911 Fire Department……………911 Ambulance…………………911 Give the following information: 1) **Where you are**. Address, cross streets, or landmarks 2) **Phone Number** you are calling from 3) **What happened** – type of injury, accident 4) **How many persons** need help 5) **What is being done** for the victim(s) 6) **You hang up last**. Let whomever you called hang up first.
HDR Project Manager:	Anwar Khan (954-494-2084) Anwar.Khan@hdrinc.com
Field Team Leaders:	Anwar Khan (954-494-2084) Anwar.Khan@hdrinc.com Mark Cotter (508-944-4664) Mark.Cotter@hdrinc.com
Shore Contact:	Jessica Aschettino (757-477-6554) Jessica.Aschettino@hdrinc.com
HDR Program Manager:	Anwar Khan 954-494-2084 Anwar Khan@hdrinc.com
HDR Business Class Manager:	Ryan Thompson (610-909-0351) Ryan Thompson@hdrinc.com
HDR EOC Safety Manager:	Larry Simon (941-266-9104) Larry.Simon@hdrinc.com
HDR Safety Director:	Jeff Kleinfelter 760-450-6497

	Jeff.Kleinfelter@hdrinc.com
Vessel Captains:	TBD
Poison Control Center:	800-222-1222
Chemical Transportation National Response and Emergency Center:	National Response Center 800-424-8802 CHEMTREC 800-424-9300

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1. Introduction

HDR has prepared this Site-Specific Safety, Health, and Environmental (SH&E) Plan (Plan) to guide field activities that will be performed by HDR under BOEM's RODEO Program in support of the Coastal Virginia Offshore Wind (CVOW) Project, which calls for the development of two 6-megawatt wind turbines on a 2,135-acre site located approximately 27 miles east off the coast of Virginia Beach, Virginia.

Location of the project site is shown in **Figure 1**. The site is leased by the Virginia Department of Mines Minerals and Energy, and Dominion Energy has an agreement with the Department of Mines Minerals and Energy to build and operate the turbines at this location. Each of the two turbines will have a 26.2-foot monopile foundation that will be installed on the seabed by pile driving. An approximately 80-foot diameter scour protection will be installed at the base of each foundation. The turbines are scheduled to be in operation by late 2020 and will lay the ground work for potential large-scale development in an 112,800-acre commercial wind site Dominion Energy has leased from BOEM.

The RODEO Program monitoring for the CVOW Project will take place during both 1) active construction of project's first phase, and 2) operational phase. Active construction phase monitoring will include deployment, servicing, and retrieving of underwater acoustic monitoring equipment. During the operational phase, turbidity, corrosion, and biofouling will be monitored. **This HASP addresses work to be performed by HDR and subcontractors during the operational phase of the CVOW project.** For this phase, there will be 1) two cruises to deploy and retrieve acoustic recording equipment (to be performed by the Woods Hole Oceanographic Institution [WHOI]) and 2) up to nine cruises to perform corrosion/biofouling/turbidity monitoring, and collect metocean data (to be performed by Fugro). Subcontractor staff will take the lead on all field activities; HDR staff may join subcontractor staff on one or more of these cruises in an oversight role.

The HDR Project Manager (PM) will maintain and update this Plan (per **Section 1.5,** Safety and Health Plan Revisions) as necessary during the course of the work, based on newly recognized hazards and hazardous conditions, or newly assigned task order changes received from the Contracting Officer (CO) or other authorized representative. This Plan will be a "living" document and will be administrated by the HDR "RODEO" project manager and Site Safety and Health Officer (SSHO) and Field Team Leader (FTL). This Plan is applicable to all field observation and monitoring activities and services performed by HDR during the installation and operation of the two offshore structures.

1.1 Plan Objective

The objective of this Plan is to define the HDR SH&E measures to be implemented to address worker safety, health, and the protection of the environment to be followed by all HDR staff during the deployment, servicing, and retrieval of underwater acoustic monitoring equipment associated with the installation of two wind turbines off the coast of Virginia. Work performed under this contract will comply with applicable federal and state Occupational Safety and Health (OSHA) laws and regulations. Through careful planning and implementation of corporate and site-specific SH&E protocols, HDR will strive for zero accidents and incidents on the project.

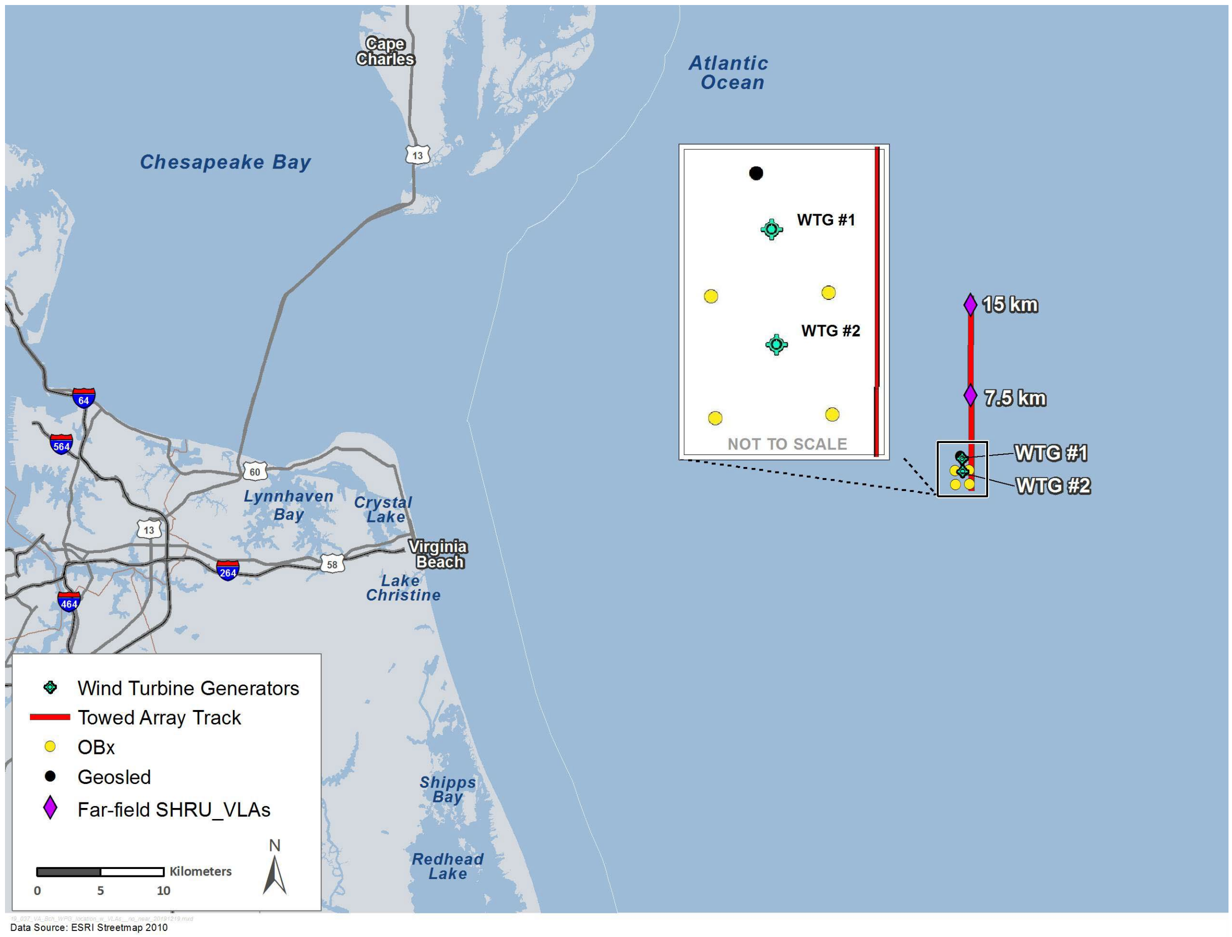

Figure 1: Proposed Wind Turbine Monitoring Locations off the Virginia Coast

1.2 Safety, Health, and Environmental Policy Statement

HDR's management team is committed to ensuring the health and safety of each and every employee. There is no place at HDR for an employee who will not work safely or who will endanger the health and safety of their fellow workers and/or the environment. It is essential that all managers and supervisors insist on the maximum safety performance and awareness of all employees under their direction by enthusiastically and consistently administering all health and safety rules and regulations. It is HDR's policy to take the necessary actions—in engineering, planning, designing, assigning and supervising work operations—to create a safe work site. HDR will:

- Promote safe and healthful working conditions.
- Provide guidance on the proper use of all necessary personnel protection equipment (PPE) to support the safety and health of on-site subcontractor staff.
- Require that site work be planned to provide a range of protection based on the degree of hazards encountered under actual working conditions.
- Provide site workers with the information and training required to make them fully aware of known and suspected hazards that may be encountered, and of the appropriate methods for protecting themselves and their co-workers.

1.3 Project Health and Safety Expectations

The health and safety of workers and clients, and the protection of the environment, are a fundamental responsibility assumed by HDR under this contract. HDR will:

- Promote project health and safety with an objective of zero lost-time accidents.
- Manage activities in a proactive way that effectively increases the protection of HDR site workers, and the environment.
- Reduce health and safety risks by identifying and eliminating hazards from site activities.
- Carry out site activities in a manner that complies with all applicable safety, health, and environmental laws and regulations.

The success of our SH&E program is ensured by our ability to seamlessly integrate our health and safety procedures into a site-specific document that establishes safe and healthy work conditions for on-site operations.

1.3.1 Safety Attitude

Disrespectful or rude behavior will not be tolerated. Discussions will be kept on a professional level. Safety awareness and cooperation is paramount in maintaining a work environment that is free of unsafe conditions or acts. Safety must be put above everything and considered at all times.

1.3.2 Discrimination

HDR, Inc. is an Equal Opportunity Employer. There is a zero tolerance level for discrimination in any form. Those who engage in sexual, racial, ethnic, age, religious or other types of discrimination will not be tolerated. These acts are grounds for immediate dismissal. Everyone on this Project is a paid professional and needs to act as such.

1.4 Project Health and Safety Compliance Program

Compliance with the requirements of applicable federal and state laws will be accomplished through a combination of written programs, employee training, workplace monitoring, and system enforcement. Regular inspections by HDR supervisors and SH&E personnel, in addition to our culture of employee ownership and total involvement in the SH&E program, will produce an atmosphere of voluntary compliance. However, disciplinary action for violations of project requirements will be taken, when necessary.

HDR's safe and efficient work practices require a spirit of teamwork and cooperation, in addition to uniform standards of expected behavior, from all employees. . Employees who refuse or fail to follow the standards set forth by this plan, the HDR Corporate SH&E Program, and/or regulatory standards will subject themselves to disciplinary action up to, and potentially including, termination. In cases not specifically mentioned, employees are expected to use their best judgment and refer any questions to their supervisors.

1.5 Safety and Health Plan Revisions

The development and preparation of this Plan is based on site-specific information provided to HDR. Should any unforeseen hazards become evident during the performance of the work, the PM shall bring such hazards to the attention of the Health and Safety Manager (HSM), both verbally and in writing, for resolution as soon as reasonably possible. In the interim, the designated HDR Site Safety and Health Officer (SSHO) will take the actions necessary to maintain safe working conditions to safeguard on-site personnel, visitors, and the environment.

No changes to this Plan will be allowed until the situation has been reviewed and a formal addendum has been prepared. Changes to this Plan will be documented and approved by the PM and the HSM. Relevant SH&E Forms for the Project are contained in **Appendix A**. A map of the Project site and a map and driving directions to the designated non-emergency medical facility are included in **Appendix B**. A description of the vessel(s) that will be used for field work is shown in **Appendix C**.

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2. Organization and Responsibilities

All personnel are responsible for continuous adherence to this Plan during the performance of their work. The project personnel identified in the sections below have been designated as competent persons and will assume the authority and responsibility of their assignments herein. While the HDR SH&E team directs and supervises the Corporate SH&E Program, the responsibility for safety and health extends throughout our organization from top management to every employee. For this reason, it is each person's duty to notify project management personnel if a hazardous condition is identified and to make a "stop work" call if the condition represents an immediate danger to life or health. The following are the HDR project personnel positions and responsibilities for this project:

- *Business Class Manager/Principal-In-Charge:* Ryan Thompson
- *Program/Project Manager:* Anwar Khan
- *SSHO*: Kristen Ampela
- *Field Team Leaders:* Anwar Khan, Mark Cotter
- *Other HDR staff:* Michael Richlen, Dan Engelhaupt
- *Shore contact:* Jessica Aschettino
- *Health and Safety Manager:* Larry Simon
- *Vessel Captains:* TBD

2.1 Project Manager

The PM reports directly to the Business Class Manager (BCM), who also serves as the Project Principal-In-Charge (PIC). The PM directs and manages the survey team in execution of the project activities in compliance with all contract and technical requirements. Technical direction will be given by the PM to the FTL who will be responsible for directing, overseeing, and managing all field activities covered under this Plan.

The PM's responsibilities include direction of data gathering and serving as the first line manager responsible for team safety. The PM will ensure that survey personnel are briefed on QA/QC requirements, survey design, and ship safety requirements prior to embarking on each survey day. The PM will support the FTL and ensure that all safety concerns are brought to the attention of the PIC. The PM will also support the FTL in identifying and implementing required mitigation actions. For the purposes of this project, the PM may also serve as the FTL.

As necessary, the PM will conduct daily tailgate safety meetings and necessary oversight of operations to ensure that health and safety requirements are continuously observed and implemented. The PM directs and manages all aspects of the project in compliance with all contract and technical requirements, serves as the primary liaison with the Contracting Officer Representative (COR), and is responsible for implementation of HDR's SH&E policy. The PM is specifically responsible for:

- Ensuring that appropriate SH&E training is provided on any equipment received.
- Immediately reporting any incident that results in injury or death to the HDR SH&E Director.
- Ensuring regular updates of the Job Hazard Analysis (JHA).
- Implementing specific checklists and timelines to ensure full implementation of this Plan.
- Ensuring self-audits are conducted at the start of the Project.
- Monitoring proper use and maintenance of specified PPE and communication equipment.
- Maintaining a high level of health and safety awareness among team members and communicate pertinent matters to them promptly.
- Implementing SH&E requirements at the Site.

2.2 Field Team Leader(s) (FTL)

The FTL will report directly to the PM. The FTL will direct and manage the technical aspects of the survey in compliance with all contract task order procedural and technical requirements. The FTL is responsible for direct communication with the PM as necessary during monitoring survey activities. The FTL may assist with preparation of draft correspondence, submittals, and other SH&E documentation required for the Project, and will submit such documentation to the PM for approval and transmittal to the COR. The FTL may also assist with the preparation of reports and documentation, and provide technical and safety direction to the PM and inspection personnel during execution of the survey. For the purposes of this project, the PM may also serve as the FTL.

The FTL will prepare immediate and follow-on incident reports and will coordinate with the PM and/or PIC as soon as practicable to obtain decisions on ultimate safety incident resolution as well as follow all the responsibilities outlined below.

2.3 Site Safety and Health Officer

The SSHO will coordinate with the FTL to ensure site compliance with specified SH&E requirements, federal OSHA regulations, and all aspects of this Plan. Site compliance includes, but is not limited to: AHA, air quality monitoring, use of PPE, decontamination site control, standard operating procedures (SOP) used to minimize hazards, safe use of engineering controls, the emergency response plan, confined space entry procedures, spill containment program, and preparation of records. The SSHO will be responsible for conducting a daily inspections and documenting results on the Site Safety Inspection Form, located in **Appendix A**. The SSHO will:

- Stop work activities if unacceptable health or safety conditions exist, and take necessary action to re-establish and maintain safe working conditions.
- Consult and coordinate any modifications to this Plan with the PM and/or the PIC.
- Conduct accident investigations and prepare accident reports.
- Review results of daily inspections and document health and safety findings in the Daily Safety Inspection Log.
- Consult with the PM and/or the PIC at the earliest opportunity to safely do so, concerning safety incidents.
- Coordinate health and safety activities with the boat captains and any other Subcontractor(s) to ensure that the planned work objectives reflect adequate health and safety considerations.
- Perform site-specific training and briefing sessions for employees prior to the start of field activities at the site and a briefing session each day before starting work.
- Promote proper use and maintenance of specified PPE and communication equipment.

2.4 Health and Safety Manager

The HSM will:

- Assist with the development and oversight of this Plan.
- Be available for consultation during project emergencies.
- Ensure accident reporting and investigations are completed.
- Provide consultation as needed to ensure that this Plan is fully implemented.
- Coordinate any modifications to this Plan with the PM and SSHO as needed.
- Provide HDR personnel with support for upgrading/downgrading of the level of PPE.
- Assist in evaluating and recommending changes to engineering controls, work practices, and required PPE.
- Approve this Plan by signature.

2.5 Principal-In-Charge

The PIC has final approval of this Plan. The PIC will coordinate with the HSM as necessary, and will make recommendations relative to needed Project safety requirements. The PIC will:

- Evaluate all safety incidents to ensure appropriate actions are taken in a timely manner.
- Provide guidance for recommended changes to this Plan.

- Provide guidance to the HSM, PM, and SSHO as necessary as to any needed changes, revisions, or modifications necessary to this Plan.

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3. Safe Work Practices for Working on or Around Water

HDR employees must recognize the inherent hazards associated with working in and around water, whether directly exposed through wading/swimming, or potentially exposed while performing services on surface watercraft or near water bodies. This Plan presents information and guidelines for all HDR personnel that perform surface services on or around water where the potential for drowning exists. This procedure also applies to boating and water operations associated with the use of large open water craft.

NOTE: ***Activities in many states are regulated by state OSHA plans, which may have certain requirements that differ, and are more stringent than the federal requirements presented here. When performing services in these state plan areas, HDR will comply with the state promulgated OSHA regulations. It is not anticipated these will differ significantly from the federal regulations presented herein.***

In addition to this Plan, the HDR Corporate SH&E Program, SH&E Procedure #018 – Water and Boating Safety , should be referenced for further guidance on boating and water safety. The PM shall determine if any project task under this Plan will subject HDR personnel to water hazards, and incorporate appropriate preplanning into the Project design. Preplanning includes the identification and acquisition of necessary equipment (personal flotation devices [PFDs], skiffs, etc.) and the verification that exposed personnel have the knowledge and training to correctly use the equipment. Project personnel shall read, understand and follow the contents of this Plan when engaged in site activities that present water hazards.

3.1 Training and Records Retention

Each HDR employee who is subject to water hazards will be provided awareness level training on the applicable contents of this Plan and the use of PFDs. Training shall be provided by the Safety Coordinator (SC) or other designated employee who, through experience and/or past training, has the necessary water safety knowledge and skills. The training session must include a demonstration of the correct way to don a life vest, and the importance of pre-use inspection. It is the responsibility of the PM to identify affected project personnel, and to verify they have received this training through coordination with their SC. The training will be documented, and record of this training will be maintained in the local office, and a copy forwarded to HDR Corporate Safety for retention.

Crew Chiefs who are responsible for operation of boats will be expected to participate in a Coast Guard or Power Squadron Safe Boating Program.

3.2 PFDs and Protective Equipment

A personal flotation device is a floating aid designed to keep the wearer from drowning, by adding sufficient buoyancy to the torso when the wearer is free floating in deep water. The classification "PFD" includes apparel such as life vests (commonly called "life preservers"), float suits, and float coats as well as retrieval life rings. PFDs must meet design and use criteria regulated by the United States Coast Guard (USCG) and must include the HDR logo. **Table 2** presents the various USCG classifications and OSHA approvals:

Table 2. PFDs

Classification	Design	OSHA/ Comments
Type I – Offshore Life Jacket	Designed to turn an unconscious person in water to vertical position. Open ocean apparel. Designed with minimum 35 lbs. buoyancy	While acceptable, they are very bulky and will limit mobility. Emergency use only. Not for everyday use.
Type II – Nearshore Buoyant Vest	Designed to turn an unconscious person to a vertical position. Coastlines, Great Lakes, etc. >15½ lbs. buoyancy.	While acceptable, they are very bulky and will limit mobility. Not for everyday use.
Type IV – Throwable Device (Life Ring)	Throw rings designed to be thrown into the water for rescue. Not worn on body. Minimum 16½ lbs. buoyancy.	Required in boats, on wharfs and in certain shore situations.
Type V – Special Use Device	Catchall category - various designs for specific water activities – includes deck suits, work vests, hybrid PFDs, etc. Minimum 15½ lbs. buoyancy.	Acceptable for HDR activities as long as mfg. label does not exclude from use in planned activity1.

[1]There are many new Type V PFDs marketed recently. If a question arises as to whether they may be approved for HDR use, check the manufacturer's instructions and limitations. OSHA specifies that only Type V PFDs approved for "commercial" or industrial" use are allowed to be worn during employment activities. This prohibits the use, by HDR personnel, of some specialty PFDs, including inflatables, that are advertised for recreational use.

3.2.1 Life Vests/Preservers, Float Coats, and Float Suits

For cold weather work on boats, or on floating docks where the risk of falling into the water is present, if the water plus air temperature is less than 110 degrees Fahrenheit a float coat or a float suit must be worn in lieu of a vest-type PFD.

- Water temperature + air temperature < 110˚F = float coat or suit required.
- Water temperature + air temperature ≥ 110˚F = vest-type PFD allowed.

USCG approved International Orange life vests* classed as Type III or Type V shall be provided to, and worn by, all HDR employees in the following circumstances:

- On floating pipelines, pontoons, barges, rafts, or stages.
- On structures extending over or adjacent to water, except where guardrails (not safety nets) are provided for employees, or where the employee is protected from falling into water at all times through the use of a personal fall positioning or arrest system (harness, lanyard, anchorage, self-retracting lifeline, etc. PFDs are required when nets are the form of fall protection employed. See HDR SH&E Procedure #12 - Fall Protection).
- Working alone at night where there are drowning hazards, regardless of other safeguards (e.g., guardrails, etc.) provided.

- In skiffs, small boats, or launches.
- Wherever there is a drowning hazard. HDR considers any body of water with a depth of 2 feet or greater a drowning hazard. This depth could be shallower in some circumstances depending on factors such as flow velocities, water temperature, ability to rescue injured employees, and existence of other hazards.

Before and after each use, the PFD shall be inspected for defects which would alter its strength or buoyancy. The design requirements for PFDs specify that any device with less than 13 pounds buoyancy is defective, and shall be removed from service. While HDR has no field method of determining the buoyancy rating, employees should examine the PFD to determine the original float material is present, that all seams are sealed and securely stitched, and that all buckles and straps are in working order. If a defect is noticed, DO NOT USE!

All newly purchased PFDs shall be equipped with retro-reflective tape. These are required when working on US Corps of Engineers (USACE) projects. Existing HDR-owned PFDs without this tape, but otherwise acceptable, may continue to be used on non-USACE projects (daylight only).

PFDs provided on vessels used on the Great Lakes or ocean service shall be equipped with approved PFD lights (work vests are exempt from this lighting requirement if an additional approved PFD is available on board).

3.2.2 Life Rings/Ring Buoys

Type IV life rings (no rope attached) and ring buoys (rope attached) shall be U.S. Coast Guard approved. Ring buoys should have attached at least 90 feet of 3/8-inch solid braid polypropylene or equivalent. Life rings or ring buoys shall be readily available and shall be provided, regardless of the fall protection provided, at the following places:

- at least one on each safety skiff;
- at least one on all motor boats up to 40 feet in length and at least two for motor boats 40 feet in length or longer;
- at least two on any other piece or group of floating barge up to 100 feet in length and one additional for each increase in length of 100 feet or fraction thereof; and
- at least one at intervals of not more than 200 feet on pipelines, walkways, wharves, piers, bulkheads, lock walls, scaffolds, platforms, and similar structures extending over or immediately adjacent to water, unless the fall distance to the water is more than 45 feet, in which case a life ring shall be used. The length of line for ring buoys at these locations shall be evaluated based on the specific potential hazards, but may not be less than 70 feet.

PFD lights shall be required whenever there is a potential need for life rings to be used after dark. On shore installations, at least one life ring, and every third one thereafter, shall have a PFD light attached. PFD lights on life rings are required only in locations where adequate general lighting (e.g., floodlights, light stanchions) is not provided. On Coast Guard certified vessels, Type IV PFDs are required to have automatic floating electric water lights: on all other floating barges or plants, at least one life ring, and every third one thereafter, shall have an automatic floating electric water light attached.

3.2.3 Safety Blocks

At navigation locks, docks, wharves or other shoreline installations where the movement of docked vessels presents a hazard to overboard employees, safety blocks should be available. These are quickly thrown into the water to protect employees who have fallen into the water from being crushed by the wave movement of docked vessels. If the use of blocks is found unacceptable, alternative safety measures (positive fall protection, barriers) shall be developed.

3.2.4 Emergency Position Indicating Radio Beacon (EPIRB)

ACR GlobalFix™ iPro GPS EPIRB offers the latest in marine electronic life-saving technology. The iPro allows you to interface your onboard GPS to ensure that your latitude/longitude (LAT/LON) are stored inside so the coordinates are transmitted in the first data burst. iPro's internal GPS is optimized for cold starts and will pinpoint your exact location faster than standard GPS enable EPIRBs.

3.2.5 Additional PPE

Hard Hats must be worn in specified areas, including plant sites and all boats equipped with boom and masts that are in use for towing equipment, and any other areas specified by the supervisor or designated Crew Chief. Safety Glasses or Goggles must be worn if exposure exists from formalin or other chemicals used in the field/on board vessels.

3.3 Vessel(s)

The exact vessels to be used for the operational monitoring phase are yet to be determined, but will be similar to those chartered previously from Tiki Adventures, Inc. of Ocean City, MD (e.g. the 80-foot steel trawler *R/V* Tiki XIV and the smaller *R/V* Integrity). Additional information is presented in **Appendix C**.

The vessel safety measures described below are for informational purposes only. The procured vessels will follow their own organizational safety guidelines.

3.3.1 Boat Equipment

Many items of equipment are required for safe boat operation. Some are needed to meet legal requirements, others for safety in basic operations, or for the general comfort and health of the crew. HDR considers compasses, depth finders, radar, GPS, charts, cellular phones and basic boating equipment as safety equipment. Without such items, accidents could easily occur.

- When mounting radar equipment, note that a "safety distance" of ~3 feet must be maintained when the apparatus is in operation.

These basic items of required equipment, and the quantities required of each depend upon the size class of the vessel, the type of boating activities, the particular water body and other factors (e.g., the amount of electrical power available on board, work operations, and required professional gear).

3.3.2 Marine Radio

Marine radios transmit along VHF/FM frequencies and are much more reliable than Citizen's Band (CB) radios. In addition to this more advanced technology, Marine Radios have designated channels that are monitored 24/7. Channel 16 is the international channel for all distress calls.

3.3.3 Emergency Radio Calls/ Distress

How to call for help:

- Make sure your radio is transmitting on Channel 16.
- If you are in distress:
  - Call "MAYDAY, MAYDAY, MAYDAY".
- If you are not in distress:
  - Call "Coast Guard".
- What to tell the Coast Guard:
  - Your location or position;
  - Exact nature of the problem or emergency;
  - Number of people on board;
  - Your boat's name, registration, and description; and
  - Safety equipment on board.

When to call back:

- A medical emergency develops,
- A storm approaches,
- Your boat begins to take on water, and/or
- Your last reported position changes.

Table 3 lists some useful Channels to know, the most important of which is: CHANNEL 16 VHF/FM 2182 kHz HF/SSB for international distress, safety and calling.

Table 3. Radio Calls

Channel Number MHz	Ship Transmit	Ship Receive MHz	Use
6	156.300	156.300	Intership Safety
07A	156.350	156.350	Commercial
9	156.450	156.450	Boater Calling. Commercial and Non-Commercial.
10	156.500	156.500	Commercial
13	156.650	156.650	Intership Navigation Safety (Bridge-to-bridge). Ships >20m length maintain a listening watch on this channel in US waters.

Channel Number MHz	Ship Transmit	Ship Receive MHz	Use
16	156.800	156.800	International Distress, Safety and Calling. Ships required to carry radio, USCG, and most coast stations maintain a listening watch on this channel.
21A	157.050	157.050	USCG only
22A	157.100	157.100	USCG Liaison and Maritime Safety Information Broadcasts. Broadcasts announced on channel 16.

3.3.4 Abandon Ship

The situations that could lead to abandoning ship include collision with another vessel or fixed object, running aground, being holed by ice or floating debris, capsizing or swamping in high winds or seas, and fire aboard. Abandon ship is the most serious of all emergencies on the water.

The Procedures used in abandon ship situations vary with the condition and location of the boat and with the weather. For example, do not attempt to stay aboard a gasoline-powered outboard on fire; however, an outboard swamped by high seas will probably float if it is wood or has built-in flotation. In the latter situation, do not abandon ship. Once the decision to abandon ship is made by the Crew Chief, his instructions must be carefully followed. In case of collision with another vessel, fixed object, ice, or floating debris in deep water, the Crew Chief will:

- Ascertain if any of the crew has been injured.
  - If one or more crew members have been injured, direct the remaining crew members to administer first aid and ensure the victims' life jackets are secured properly.
- Determine the extent of damage to the vessel.
  - Examine hull for holes and/or leaks and, if water is entering the hull, turn on the bilge pump.
  - If water is entering the hull, estimate the length of time the boat can stay afloat and whether emergency repairs can be made.

If water is entering the hull at a slow rate and the boat is operable:

- Head for the nearest docking area after the injured have been secured.
- While heading for the docking area, instruct crew members to launch the life raft if the boat appears to be sinking before it reaches a docking area.
- Detail a crew member to act as lookout and use flares or other distress signals as required, to signal any passing vessel to act as escort.
- Place a MAYDAY distress call and inform the Coast Guard of the situation and the intended course of action.
- If the boat appears to be sinking and land is near, consider GENTLY running the boat aground to prevent sinking.

If the boat is filling rapidly:

- Initiate abandon ship Procedures immediately.
- Direct two crew members to release and launch the life raft.
- Place a MAYDAY distress call on the marine radio.
- Give the order to abandon ship, being certain that injured crew members are placed in the life raft first, and that all crew are in the life raft before leaving boat.
- Once in the life raft, direct one crew member to act as lookout and use flares or other distress signals to signal any passing vessel for aid.

3.3.5 Running Aground

The Crew Chief will:

- Ascertain whether any of the crew has been injured and, if so, have first aid administered.
- Examine the boat for damage or influx of water.
- If the boat is not taking on water and does not have any holes that would be submerged when the boat is re-floated, attempt to unground.
  - If the boat is aground by the bow (facing forward) and the nearest deep water is astern, cast a light anchor as far astern as possible.
  - While the stern anchor rope is being pulled with a winch, attempt to back the boat into deep water. A close watch will be kept on the engine temperature as the cooling water intake may be blocked. Moving all equipment and crew weight to the stern may aid in ungrounding.
  - If the boat does not unground, determine whether the tide is rising or falling (in tidal areas). If the tide is rising, leave an anchor astern to prevent the boat from being driven further aground, and inform the laboratory of the situation by marine radio or cellular phone.
  - If the boat runs aground at high tide, the assistance of another vessel will probably be required to re-float it.
- If the boat is taking on water, no attempt to unground should be made unless the hole or leaks have been blocked.
  - Cast a light anchor as far off the bow as possible to prevent the boat from being ungrounded by wind, wave or tidal action.
  - If the boat will rest on the bottom with the superstructure above water after sinking, direct the crew to prepare to abandon ship, but do not execute this operation unless waves are sweeping the boat or the boat capsizes.
  - Direct two crew members to release, inflate, and launch the life raft. Direct the remaining crew members to assist in the launch if needed.
  - Make a MAYDAY distress call on the marine radio, and proceed as directed by Coast Guard authorities. However, decide whether or not to abandon ship, as conditions require. When the decision to abandon ship is made, notify the Coast Guard.
  - It is likely that, having abandoned ship, the boat crew in the life raft will quickly be washed or blown ashore. They should be prepared for a rough landing. Alternatively, consider remaining moored to the boat until help arrives.

3.3.6 Swamping or Capsizing

If the engine or steering fails in high seas, the boat is in danger of swamping or capsizing. In such cases, the Crew Chief will:

- Immediately deploy an anchor.
- Ensure that all crew's life jackets are secured properly.
- Detail two crew members to be ready to launch the life raft when directed.
- Place a call to the U.S. Coast Guard on the marine radio. If the situation deteriorates, a MAYDAY call will be made.
- If the boat starts to take on more water than can be cleared with the bilge pumps, the life raft should be launched and a MAYDAY distress call made.
- Order, "abandon ship" when it becomes obvious the boat will sink shortly. Prior to leaving the boat, make a MAYDAY distress call.

3.3.7 Operational Breakdowns

There are two important operational breakdowns that have been experienced by HDR field crews:

- Fouling of a boat's propeller with ropes or nets,
- Snagging of gear on obstructions on the bottom of a river or lake.

Any attempt to correct the situation must be supervised by the Crew Chief and his/her instructions must be followed. Consideration will be given to the season, location, current, and turbidity of water.

3.3.8 Person Overboard

- All personnel are required to wear a PFD when on the boat. Falls overboard account for a large percentage of annual boating injuries and deaths. In most of the cases documented, had the person falling overboard been wearing a life jacket, he/she would have survived. The following Procedures will be followed for "person overboard" rescues: When a person falls overboard, the boat operator should take the boat out of gear (e.g., transmission placed in neutral) and look for the person.
- After determining location of the person, approach the area against the current so the boat will not drift over the person in the water. Stop the boat when the person is within reach of a boat hook or life ring. He/she should be brought immediately into the boat.
- If the person in the water is injured or unconscious, the victim should be lifted into the boat with great care.
- No one will deliberately enter the water during person overboard rescues. If the victim is unconscious or injured, and cannot be otherwise retrieved into the boat, the Crew Chief or a volunteer from the crew may go overboard with a safety line tied to the boat in order to retrieve the victim.
- First aid should be ready for the victim as he/she may be suffering from shock, exposure or suffocation. Emergency medical aid may be obtained by placing a MAYDAY distress call on the marine radio or, if available, by calling 911 on a cellular phone.

3.3.9 Missing Person Overboard

When it is noticed that a crew member is missing, it must be assumed that he or she has fallen overboard. The following Procedures must be followed:

- The boat crew will determine when and where the missing crew member was last seen, and, with the aid of compass and charts, retrace their course to that point.
- While the initial search is being conducted, a radio call will be placed to the U.S. Coast Guard to "stand by" and then to the field supervisor to advise of the situation. If after 5 min of searching the missing person has not been found, the Coast Guard must be contacted for search and rescue aid.
- Until a formal Rescue Director from the Coast Guard or local rescue facility arrives, the Crew Chief will retain command of all rescue operations.

A person remaining in water colder than 70°F (21°C) for any length of time will be suffering from exposure and the Crew Chief should be prepared to rescue an unconscious or immobile person. Immediate emergency medical aid must be ready in case the person in the water is in an advanced stage of hypothermia.

3.3.10 Fire Aboard

There is little that can be done to put out a boat fire unless it is detected in its very early stages. Fire extinguishers are on board all boats. Dry-powder A/B/C type extinguishers should be turned over and shaken frequently, as boat vibration tends to cake the powder. If possible, the fire department or other emergency services should be notified of any fire. If fire spreads to the vicinity of a fuel tank, the crew must abandon ship rapidly.

The person discovering the fire will yell, "FIRE ABOARD" and describe its location and intensity. The following Procedures will be implemented in the event of a boat fire:

- To control fire:
  - Cut off air supply to fire - close hatches, ports, doors, ventilators, etc.
  - Immediately spray portable fire extinguishers at the base of the flames for combustible materials, flammable liquids or electrical fires OR apply water for fires in ordinary combustible materials.
- If fire is in machinery space, shut off fuel supply and ventilation.
  - Maneuver vessel to minimize effect of wind on fire.
  - If the fire cannot be rapidly extinguished, the Crew Chief should:
  - Direct the crew to prepare to abandon ship;
  - Send a MAYDAY distress call on the marine radio;
  - On gasoline-powered outboards and inboards, the abandon ship call will be made whenever open flames are apparent;
  - On diesel-powered inboards, the crew will abandon ship, following the direction of the Crew Chief, as soon as it becomes apparent the fire cannot be contained, or reaches the vicinity of fuel lines or tanks.

- In all cases where a boat is abandoned due to fire aboard, it is the Crew Chief's responsibility to see that all crew members are off the boat before he/she leaves (see also the section on Abandon Ship below).

3.3.11 Portable Fire Extinguisher Use

Using fire extinguishers or any method to suppress fires is an inherently dangerous activity, requiring an understanding of the mechanics of fire initiation and propagation, proper use and limitations of the extinguisher, correct body placement, and escape routes. The simultaneous integration of all these factors, combined with the panic situation present, makes proper application of firefighting techniques much more difficult than most employees assume.

Workers may use a portable fire extinguisher only if:

- They have completed portable fire extinguisher training (see Section 9.0 of SH&E Procedure #027).
- The fire is small and they have verified that someone has reported the fire to 911.
- The fire alarm has been sounded to initiate evacuation procedures.
- They know what materials are burning and are certain they have the correct class of portable fire extinguisher for the class of fire (using the wrong type of extinguisher on a fire can intensify the fire or lead to personal injury).
- They have an unobstructed escape route with an exit at their back in case of failure to extinguish the fire.

3.3.12 Sanitary Provisions

The Tiki XIV (if used) has 4 double guest cabins with in-cabin lavatories and showers.

3.4 Inclement Weather

Inclement weather may occur while on the Project site or during travel to and from the Project. The SSHO will monitor the weather and weather forecasts for conditions that may require the field team to stop work or evacuate the site (high winds, heavy rain, lightning, fog, etc.). Daily meetings/briefings led by the SSHO will include discussion of any anticipated inclement weather conditions that may impact the field team and the proper actions to take if facing these conditions. As appropriate, these discussions will include stop work and communication procedures, evacuation routes and shelter locations in the case of remote project work, etc. All on-site supervisory personnel must be familiar with the actions required when severe weather is imminent.

The National Weather Service issues weather watches and warnings by county, for a specified time period. Sirens are sounded to alert the public when weather warnings are issued, but there is no audible signal to announce when the warning is over. Seek shelter immediately and monitor media channels for updates or changes to warning time frames.

Field personnel performing work outdoors should carry clothing appropriate for potential inclement weather. Personnel are to take heed of the weather forecast for the day and pay attention for signs of changing weather that indicate an impending storm. Signs include towering thunderheads, darkening skies, or a sudden increase in wind. If stormy weather ensues, field personnel should discontinue work and seek shelter until the storm has passed.

3.5 Winter Operations

This project has the potential to be ongoing in the cooler months of October through May. Decisions to cancel a field operation due to severe weather conditions will be based on information provided to the SSHO by the PM. Employees must be prepared to work in cold temperatures, and should have the following cold weather gear available:

- Insulated under clothing (multiple layers are recommended).
- Survival coat or suit.
- Hooded jacket.
- Insulated socks and gloves.
- Insulated boots, waders, or hip boots.

The information provided reviews the different cold related illness, prevention and first aid requirements. Frostbite and hypothermia are the two most serious safety problems during the cold weather (refer to HDR SH&E Procedure #29, *Cold Stress*). Workloads for crews using boats with outboard engines and little protection from the weather should be designed with weather conditions in mind. Cold related injuries require immediate removal from the cold environment and proper medical treatment. The supportive first aid measures included in this Plan are to be used only until proper medical treatment by a qualified physician can begin.

The crew on boats will not be expected to complete the same amount of work performed under ideal conditions. The SSHO will have to assess the weather conditions (wind, precipitation, temperature etc.) before initiating a field survey. The SSHO and PM will make the final decision as to whether a survey (i.e., trawls, seines, larval tows, water quality, etc.) is canceled due to weather.

3.5.1 Hypothermia

Hypothermia results when the body core temperature falls below 95°F (35°C). If the body core temperature drops below this critical level, the victim cannot produce enough body heat to recover. Prolonged exposure to cold air or to immersion in cold water at temperatures well above freezing can lead to hypothermia. Hypothermia is a medical emergency. Untreated, it can lead to ventricular fibrillation (heart attack) and death.

Signs and symptoms of hypothermia:

- Uncontrollable shivering
- Dizziness
- Weakness
- Slurred speech
- Impaired judgment, disorientation, or incoherence
- Apathy, listlessness, or sleepiness
- Decreased pulse and breathing rates

- Loss of consciousness

Hypothermia first aid:

- Call for emergency medical services (EMS).
- Remove the victim to a warm area out of any wind.
- Remove all cold and/or wet clothing.
- Wrap in warm blankets.
- If conscious and able to converse, give the victim warm (non-caffeinated, non-alcoholic) liquids to drink.
- Keep the victim awake until medical assistance arrives.

3.5.2 Frostbite

Pain in the extremities is commonly the first early warning sign of the onset of cold stress. While frostbite (the actual freezing of body tissue) will occur only at absolute temperatures below freezing (32°F (0°C)) (regardless of wind speed), unpleasant cold sensations in extremities may be felt at higher temperatures and heat loss in extremities can assist in the onset of hypothermia. Extremities most commonly affected are your toes, fingers, nose, and ears.

Frostbite can also occur when bare skin comes into contact with objects whose surface temperature is below freezing (despite warm ambient temperatures) or when skin is exposed to either an escaping gas with a high vapor pressure or a liquid with a very low boiling point. Examples include liquid ammonia, gasoline, and other alcohols. All liquids must have heat added to them in order to evaporate. The liquid acquires the necessary heat from its immediate surroundings. If the liquid is on human skin, the heat will be drawn from the warm skin surface, resulting in very rapid cooling of the skin surface.

Frostbite damage may be reversible if properly treated in the first 12 to 24 hours. Sometimes the area affected is particularly sensitive to cold temperatures for months to years afterward. If left untreated, frostbitten areas may become gangrenous.

Signs and symptoms of frostbite:

- Sharp prickling sensation in affected area.
- Area feels cold and numb.
- Incipient frostbite (frostnip) – skin is blanched or whitened (because of a lack of oxygen) and feels hard on the surface.
- Moderate frostbite - large blisters.
- Deep frostbite - tissues are cold, pale, and hard.

Frostbite first aid:

- For minor frostbite:
  - Gradually warm the affected body parts by placing them next to warm skin (such as the abdomen and the armpit).
  - Contact WorkCare (888-449-7787) for further guidance.

- For more serious frostbite:
  - When EMS is available, or there is any chance that the part may refreeze (for example, you are in a remote site and warming up in a shelter but must return to the cold to get back to your vehicle/permanent shelter), do not try to rewarm the frostbitten area. If a frostbitten area is rewarmed and gets frozen again, more tissue damage will occur. It is safer for the frostbitten area to be rewarmed by medical professionals.
  - If EMS is not readily available, and there is no chance refreezing will occur, rewarm the affected body part by immersing it in warm water for 20 to 30 minutes. The water should be just above normal body temperature (not too hot).
  - Loosely cover and protect the area from contact.
  - Do not rub the frostbitten part, and do not break any blisters.
  - Provide warm drinks (non-caffeinated, non-alcoholic), and do not let the victim smoke.
  - Be aware that the tissue may itch and/or hurt intensely as it thaws.
  - The victim should not use the affected limb or area until cleared by a physician.

3.5.3 Immersion Foot

Immersion foot, also known as trench foot, is an injury of the feet resulting from prolonged exposure to wet and cold conditions. The condition may be aggravated by tight footwear. Immersion foot can occur at temperatures as high as 60°F if the feet are constantly wet. Injury occurs because wet feet lose heat 25-times faster than dry feet. Therefore, to prevent heat loss, the body constricts blood vessels to shut down circulation in the feet. Skin tissue begins to die because of lack of oxygen and nutrients and due to the buildup of toxic products.

Signs and symptoms of immersion foot:

- Reddening or discoloration of the foot,
- Numbness,
- Swelling,
- Tingling pain,
- Blisters or ulcers, and
- Bleeding under the skin.

Immersion foot prevention:

- Put on clean, dry socks daily.
- Thoroughly clean and dry the feet after exposure.
- When sleeping or resting, do not wear socks.

Immersion foot first aid:

- Remove shoes/boots and wet socks.
- Treat in a manner similar to frostbite.

3.5.4 Cold Water Immersion

Cold water immersion creates a specific condition known as immersion hypothermia. It develops much more quickly than standard hypothermia because water conducts heat away from the body 25 times faster than air. Typically people in temperate climates don't consider themselves at risk from hypothermia in the water, but hypothermia can occur in any water temperature below 70 °F. Survival times can be lengthened by wearing proper clothing (wool and synthetics and not cotton), using a personal flotation device (life vest, immersion suit, dry suit), and having a means of both signaling rescuers (strobe lights, personal locator beacon, whistles, flares, waterproof radio) and having a means of being retrieved from the water.

3.5.5 Equivalent Chill Temperature

The Equivalent chill temperature is the temperature that it feels like outside to people and animals. Equivalent chill temperature is based on the rate of heat loss from exposed skin caused by combined effects of wind and cold. As the wind increases, heat is carried away from the body at an accelerated rate, driving down the both the skin temperature and eventually the internal body temperature. Therefore, the wind makes it feel much colder. If the temperature is 0°F and the wind is blowing at 15 miles per hour (mph), the wind chill is -19°F. At this equivalent chill temperature, exposed skin can freeze in 30 minutes.

The Equivalent Temperature Table, presented in **Table 4**, should be reviewed along with local temperature and wind speed data prior to extended work in the cold, and preventative work restrictions and preventions, presented herein, should be followed.

3.6 Heat Stress

All Project employees will be familiar with the signs of dehydration, heat stress, heat stroke, and sunburn. HDR SH&E Procedure #028, *Heat Stress*, outlines the requirements of supervisors and Project teams for developing and documenting site-specific heat illness prevention procedures for assignments involving exposure to the following: working in environments with a temperature at or approaching 80°F (26.7°C), performing extended services in the proximity of radiant heat sources (foundries, etc.), and wearing semi-impermeable or impermeable clothing in temperatures exceeding 69.8°F (21°C). It is recommended that all on-site employees download the free OSHA-NIOSH Heat Safety Tool mobile device app to calculate risk based on the Heat Index.

HDR, Inc. and all HDR Subcontractors are responsible for furnishing drinking water, cups, and ice for their employees on the Project. There may be a collection point established for used containers at some designated location, and HDR Subcontractors will be expected to cooperate. No common drinking cups are allowed, and all drinking water must originate from a potable source.

Table 4. Cooling Power of Wind on Exposed Flesh Expressed as Equivalent Temperature (under calm conditions)

Estimated Wind Speed (in mph)	Actual Temperature Reading (°F)											
	50	**40**	**30**	**20**	**10**	**0**	**-10**	**-20**	**-30**	**-40**	**-50**	**-60**
	Equivalent Chill Temperature (ºF)											
Calm	50	40	**30**	**20**	**10**	**0**	**-10**	**-20**	**-30**	**-40**	**-50**	**-60**
5	48	**37**	**27**	**16**	**6**	**-5**	**-15**	**-26**	**-36**	**-47**	**-57**	**-68**
10	40	**28**	**16**	**4**	**-9**	**-24**	**-33**	**-46**	**-58**	**-70**	**-83**	**-95**
15	**36**	**22**	**9**	**-5**	**-18**	**-32**	**-45**	**-58**	**-72**	**-85**	**-99**	**-112**
20	**32**	**18**	**4**	**-10**	**-25**	**-39**	**-53**	**-67**	**-82**	**-96**	**-110**	**-121**
25	**30**	**16**	**0**	**-15**	**-29**	**-44**	**-59**	**-74**	**-88**	**-104**	**-118**	**-133**
30	**28**	**13**	**-2**	**-18**	**-33**	**-48**	**-63**	**-79**	**-94**	**-109**	**-125**	**-140**
35	**27**	**11**	**-4**	**-20**	**-35**	**-51**	**-67**	**-82**	**-98**	**-113**	**-129**	**-145**
40	**26**	**10**	**-6**	**-21**	**-37**	**-53**	**-69**	**-85**	**-100**	**-116**	**-132**	**-148**
Wind speeds greater than 40 mph have little additional effect.	LITTLE DANGER In < hr. with dry skin. Maximum danger of false sense of security.				INCREASING DANGER Danger from freezing of exposed flesh within one minute.			GREAT DANGER Flesh may freeze within 30 seconds.				
	Trench foot and immersion foot may occur at any point on this chart											

Equivalent chill temperature requiring dry clothing to maintain core body temperature above 36 Celsius (°C; 98.6 ºF) per cold stress threshold limit value (TLV).
** Developed by the U.S. Army Research Institute of Environmental Medicine, Natick, MA.*

In the event an employee demonstrates the signs of a heat-induced illness, the affected individual will be moved to a cool environment and allowed to cool down following the administration of first aid treatment, as needed and appropriate. Sun exposure is also a serious concern. All team members will be required to have sunglasses and sunscreen (SPF 30 or greater) readily available to avoid sun blindness and sunburn.

3.6.1 Heat Related Illness

The following subsections describe signs, symptoms, and treatment of common heat-related illnesses. Employees experiencing signs or symptoms of a heat-related illness are to report the exposure to their supervisor and submit an incident report in IndustrySafe (https://www.industrysafe.com/hdrinc). For non-emergency illness symptoms, regardless of how minor, employees are to also call WorkCare at (888) 449-7787 for medical consultation. For life threatening or other serious symptoms of a heat related illness, employees are to seek immediate medical care.

Heat Rash (Prickly Heat) – Heat rash is a painful temporary condition caused by clogged sweat pores, typically from hot sleeping quarters. Commonly observed in tropical climates, heat rash is caused by the plugging of sweat ducts due to the swelling of the moist keratin layer of the skin which leads to inflammation of the sweat glands. Heat rash appears as tiny red bumps on the skin, and can impair sweating, resulting in diminished heat tolerance.

Treatment: Heat rash can usually be cured by providing cool sleeping quarters; body powder may also help absorb moisture.

Heat Cramps – Heat cramps are characterized by painful intermittent spasms of the voluntary muscles following hard physical work in a hot environment. Heat cramps usually occur after heavy sweating, and often begin at the end of the workday. The cramps are caused by a loss of electrolytes, principally salt. This results in fluids leaving the blood and collecting in muscle tissue, resulting in painful spasms.

Treatment: Increase ingestion of commercially available electrolytic sports drinks (because of individual sensitivity, it is best to double the amount of water required by package directions for powdered formulas, or add water to the liquid form).

Heat Syncope (Fainting) – Heat Syncope or fainting is a mild form of heat illness that often results from physical exertion when it is hot. It occurs when your body, in an effort to cool itself, causes the blood vessels to dilate to such an extent that blood flow to the brain is reduced. Symptoms include faintness, dizziness, headache, increased pulse rate, restlessness, nausea, vomiting and brief loss of consciousness.

Treatment: Have the victim lie or sit down in the shade or a cool area and elevate the feet. Have the victim drink cool fluids containing low levels of salt, such as sports drinks, and refrain from vigorous activity. **If fainting has occurred, the victim is not allowed to return to work until authorized by WorkCare or another medical provider.**

Heat Exhaustion – Heat exhaustion is characterized by profuse sweating, weakness, low blood pressure, rapid pulse, dizziness, and frequent nausea and/or headache. The skin is cool and clammy, and appears pale. The body core temperature is normal or depressed. Victim may faint and/or vomit. This is the most common form of serious heat illness encountered during employment activities.

Treatment: Move victim to a cool area, loosen clothing, and provide rest and plenty of fluids. Any worker who is a victim of heat exhaustion may not be exposed to a hot working environment for an absolute minimum of 24 hours. **If fainting has occurred, the victim is not allowed to return to work until authorized by WorkCare or another medical provider.**

Heat Stroke – This is the most serious heat disorder, and is life-threatening. Heat stroke is a true medical emergency. This results when the body's heat dissipating system is overwhelmed and shuts down (thermoregulatory failure). Heat stroke results in a continual rise in the victim's deep core body temperature, which is fatal if not checked. The symptoms are hot, dry, flushed skin, elevated body core temperature, convulsions, delirium, unconsciousness, and possibly, death.

Treatment: Move the victim to a cool area, cool the body rapidly by immersion in cool (not cold) water or sponging the body with cool water, and treat for shock and obtaining immediate medical assistance. Treatment response time is critical when assisting a victim of heat stroke! Do not give coffee, tea, or alcoholic beverages.

3.6.2 Effects of Personal Protective Clothing and Equipment

Normal work clothing, which allows some passage of air and sweat from the skin to the environment, is considered permeable. The restriction of air circulation is not usually of significant health concern, unless the volume of clothing worn is great. Some personal protective equipment and clothing, such as Tyvek™ coveralls, respirators, etc. are designed to prevent air/liquid environmental contaminants from passing through the clothing and contacting the skin.

The impermeable nature of this fabric also prevents heat and sweat from passing through and escaping the suit. Additionally, the extra weight of this equipment and clothing and the restriction of body motions that it imposes causes the wearer to work harder than normal, and more heat is generated. When impermeable clothing/equipment is worn, more metabolic heat than usual is generated, and the heat cannot readily escape the clothing. Cool outside air temperatures do not help significantly, since the clothing/equipment is impermeable. Therefore, use of impermeable protective clothing can greatly increase the potential for heat-related illnesses, even in relatively benign ambient temperatures.

3.6.3 Acclimatization

Individual susceptibility to heat-related illness can vary widely between workers. Workers become gradually acclimatized when exposed to hot conditions for several weeks. Physical changes in blood vessels and in sweating occur to dissipate heat more effectively. PMs are responsible for developing a site-specific plan for heat acclimatization when the heat index is high (at or above 39.5°C or 103°F) to protect workers while they adjust, particularly on the first few days of the job. Note that the heat index values are based on shady, light wind conditions. Exposure to full sunshine can increase heat index values by up to 5°C and 15°F.

3.6.4 Provision of Water and/or Other Drinking Fluids

Fluids are a key preventive measure to minimize the risk of heat related illnesses. HDR employees shall have access to potable drinking water or other drinking fluids. Where the supply of water is not plumbed or otherwise continuously supplied, drinking fluids shall be provided in sufficient quantity at the beginning of the work shift to provide at least one liter per employee per hour for the entire shift. Employees may begin the shift with smaller quantities of drinking fluids if they are able to replenish their supply during the shift. The beverages should be cool 10°C to 15.5°C (50°F to 60°F), and readily available (as close as possible to employees). Coffee, Tea and other warm beverages should be avoided. Employees are encouraged to maximize daily fluid intake and realize that thirst is not an adequate indicator of sweat loss. Drinking fluids should be consumed at a target rate of 0.2 liter (one cup) every 15 to 20 minutes, at a minimum.

If drinking fluid containers are being shared by employees disposable/single use drinking cups need to be provided, or employees may use their own cup. In addition, a supervisor or designated employee shall be assigned to monitor the quantity and condition of the drinking fluids. When drinking fluid levels within a container drop below 50%, the fluids need to be replenished.

3.6.5 Access to Shade and Rest Areas

Access to rest and shade or other cooling measures are important preventative steps to minimize the risk of heat related illnesses.

Every worker is unique in his/her ability to handle heat. Work/rest periods should be based on the individual's capacity to safely handle the heat, not on a predetermined or inflexible time length. As such, employees shall be allowed and encouraged to take a preventative cool-down rest in the shade when they feel the need to do so to protect them from overheating. When possible, rest areas should be readily accessible and near supplies of drinking fluids. Air conditioned construction offices, trailers, and work vehicles make good rest areas.

- At or below 29°C (80°F), employees shall have timely access to a rest area with shade that is either open to the air or provided with ventilation or cooling for a period of no less than five minutes. Such access to shade shall be permitted at all times.
- For temperatures above 29°C (80°F), one or more areas with shade shall be provided at all times while employees are present. The amount of shade present shall be at least enough to accommodate the employees on recovery or rest periods, so that they can sit in a normal posture fully in the shade without having to be in physical contact with each other. The amount of shade present during meal periods shall be at least enough to accommodate the number of employees on the meal period who remain onsite.

An individual employee who takes a preventative cool-down rest:

- Shall be monitored and asked if he or she is experiencing symptoms of heat illness;
- Shall be encouraged to remain in the shade; and
- Shall not be ordered back to work until any signs or symptoms of heat illness have abated, but in no event less than 5 minutes in addition to the time needed to access the shade.

If an employee exhibits signs or reports symptoms of heat illness while taking a preventive cool down rest or during a preventative cool-down rest period, appropriate first aid shall be provided or emergency response procedures shall be activated.

3.6.6 Emergency Response Procedures

Employees are directed to immediately report to their supervisor or PM, symptoms or signs of heat illness in themselves or in co-workers. Employees should not delay in reporting these observations. To help ensure proper medical care is provided with minimal delay, supervisors shall take the following steps:

- Provide First Aid: Should an HDR employee exhibit signs or symptoms of possible heat illness, the treatment procedures described in Section 6.0 shall be implemented. An employee exhibiting signs or symptoms of heat illness shall be monitored and shall not be left alone or sent home without being offered assistance. If the signs or symptoms are indicators of severe heat illness (such as, but not limited to, decreased level of consciousness, staggering, vomiting, disorientation, irrational behavior or convulsions), the employer must implement emergency response procedures.
- Contact EMS: If EMS is required, the SSHO (or a designee) shall contact EMS. Once contact is established, stay on the phone with EMS to provide clear and precise directions to the work site. If a land line and cell phone coverage are not available, prior to initiating field work, arrangements (satellite phone, two way radio, etc.) shall be made to contact EMS with minimal delay.
- Determining Directions to the Site: Prior to beginning field work, the directions from the nearest medical facility to the site shall be documented in the site-specific SH&E Plan and/or JHA forms and shall be kept immediately available at the job site.
- Plan for Remote Locations: If potential heat stress victims will be working at remote locations where EMS cannot physically reach, provisions shall be made for transporting the victims to a point where they can be reached by an EMS provider.

3.7 Sunburn Prevention

Ultraviolet (UV) rays are a part of sunlight that is an invisible form of radiation. UV rays can penetrate and change the structure of skin cells. There are three types of UV rays: ultraviolet A (UVA), ultraviolet B (UVB), and ultraviolet C (UVC). UVA is the most abundant source of solar radiation at the earth's surface and penetrates beyond the top layer of human skin. Scientists believe that UVA radiation can cause damage to connective tissue and increase a person's risk for developing skin cancer. UVB rays penetrate less deeply into skin, but can still cause some forms of skin cancer. Natural UVC rays do not pose a risk to workers because they are absorbed by the Earth's atmosphere.

Light-colored sand reflects UV light and increases the risk of sunburn. At work sites with these conditions, UV rays may reach workers' exposed skin from both above and below. Workers are at risk of UV radiation even on cloudy days. Many drugs increase sensitivity to sunlight and the risk of getting sunburn. Some common ones include thiazides, diuretics, tetracycline, doxycycline, sulfa antibiotics, and non-steroidal anti-inflammatory drugs, such as ibuprofen.

Sunburn is an often painful sign of skin damage from spending too much time outdoors without wearing a protective sunscreen. Years of overexposure to the sun lead to premature wrinkling, aging of the skin, age spots, and an increased risk of skin cancer. In addition to the skin, eyes can get burned from sun exposure. Sunburned eyes become red, dry, painful, and feel gritty. Chronic exposure of eyes to sunlight may cause pterygium (tissue growth that leads to blindness), cataracts, and possibly macular degeneration, a leading cause of blindness.

Take the following steps to protect yourself from exposure to UV radiation:

- Take breaks in shaded or indoor areas.
- Wear sunscreen with a minimum Sun Protection Factor (SPF) of 30.
- Sunscreens should be applied generously (a minimum of 1 ounce, or enough to fill a standard-sized shot glass) at least 20 minutes before sun exposure. Special attention should be given to covering the ears, scalp, lips, neck, tops of feet, and backs of hands.
- Sunscreens should be reapplied at least every 2 hours and each time a person gets out of the water or perspires heavily.
- Another effective way to prevent sunburn is by wearing appropriate clothing.
- High-SPF clothing has been developed to provide more protection for those with photosensitive skin or a history of skin cancer.

Workers should also wear wide-brimmed hats and sunglasses with 100 percent UV protection and with side panels to prevent excessive sun exposure to the eyes.

Symptoms of sunburn may include:

- Red, warm, and tender skin;
- Swollen skin;
- Blistering;
- Headache;
- Fever;
- Nausea; and
- Fatigue.

There is no quick cure for minor sunburn; however, symptoms can be treated with the following:

- Aspirin, acetaminophen, or ibuprofen to relieve pain and headache and reduce fever.
- Drinking plenty of water helps to replace fluid losses.
- Cool baths or the gentle application of cool wet clothes on the burned area may also provide some comfort.
- Workers with sunburns should avoid further exposure until the burn has resolved.
- Additional symptomatic relief may be achieved through the application of a topical moisturizing cream, aloe, or 1 percent hydrocortisone cream.
- A low-dose (0.5–1 percent) hydrocortisone cream, which is sold over the counter, may be helpful in reducing the burning sensation and swelling and speeding up healing.

If blistering occurs:

- Lightly bandage or cover the area with gauze to prevent infection.

- The blisters should not be broken, as this will slow the healing process and increase the risk of infection.
- When the blisters break and the skin peels, dried fragments may be removed and an antiseptic ointment or hydrocortisone cream may be applied.

Seek medical attention if any of the following occur:

- Severe sunburns covering more than 15 percent of the body,
- Dehydration,
- High fever (>101°F), and/or
- Extreme pain that persists for longer than 48 hours.

3.8 Biological Hazards

This section presents the potential biological hazards that exist at various sites throughout this Project.

3.8.1 Bees, Wasps, and Hornets

Noxious insects are ubiquitous and can be encountered during field activities.

- Bees build hives in rock crevices and holes in trees.
- Wasps and hornets build nests in man-made structures and other areas where they are protected from the elements.

The two greatest risks from most insect stings are allergic reaction (which can be fatal in rare cases) and infection. General guidelines to follow if you experience an insect sting are as follows:

- If you are allergic, carry an EpiPen and ensure your co-workers are informed of your allergy and the location of the EpiPen.
- Do not drink a lot of liquids, as this can cause vomiting.
- Remove the stinger by gently scraping it out with a blunt-edged object, such as a credit card or dull knife. Do not try to pull it out; this can release more venom into your body.
- For all types of stings, wash the area carefully with soap and water. Do this two to three times a day until the skin is healed.
- Apply a cold pack (an ice pack wrapped in a cloth).
- Apply a paste of baking soda and water for 15 to 20 minutes.
- Over-the-counter acetaminophen products can reduce pain.
- Any employee who receives multiple stings should seek immediate medical attention.
- Any employee who knows that they are allergic to insect stings/bites should consult their physician concerning the prudence of carrying self-administered injectable epinephrine.
- If any sting victim is complaining of a rapid heartbeat or tightness in the chest, keep the individual calm and in the shade. Seek medical attention immediately.

3.8.2 Venomous Spiders

Black widows (*Latrodectus mactans*) are found throughout North America, but are most common in the southern and western areas of the United States. The black widow is a moderately large, glossy black spider with very fine hairs over its body that give it a silky appearance. The abdomen is a characteristic red, crimson, or yellow marking in the form of an hourglass. Only the female is poisonous; the male, which is smaller, is harmless. They are usually found in in damp and dark places such as woodpiles, tree stumps, under eaves, fences, under rocks, and trash piles and other areas where debris has accumulated. They may also be found living in outdoor toilets where flies are plentiful. Black widow spiders build webs between objects, and bites usually occur when humans come into direct contact with these webs. A bite from a black widow can be distinguished from other insect bites by the two puncture marks it makes in the skin. The venom is a neurotoxin that produces pain at the bite area and then spreads to the chest, abdomen, or the entire body.

The brown recluse (*Loxosceles reclusa*), also known as the violin spider, is most commonly found in the Midwestern and southern states of the United States. It is brown in color with a characteristic dark violin-shaped (or fiddle-shaped) marking on its head and has six equal-sized eyes (most spiders have eight eyes). Brown recluse spiders are usually found in workplaces with secluded, dry, sheltered areas such as underneath structures logs, or in piles of rocks or leaves. If a brown recluse spider wanders indoors, they may be found in dark closets, shoes, or attics. The brown recluse spider cannot bite humans without some form of counter pressure, for example, through unintentional contact that traps the spider against the skin. Bites may cause a stinging sensation with localized pain. A small white blister usually develops at the site of the bite. The venom of a brown recluse can cause a severe lesion by destroying skin tissue (skin necrosis).

Bites from black widow and brown recluse spiders can be harmful and potentially deadly to humans. If In the unlikely event you an employee is are bitten while conducting work on behalf of HDR, do the following:

- If the victim is having a severe reaction, notify call 911 or other EMS assistance.
- Clean the affected area with soap and water.
- Apply a cold compress to reduce the pain and swelling and to slow the spread of venom.
- Remove any rings or constricting items, since the bitten area may swell.
- Take steps to slow the rate at which the venom spreads in the victim’s body.
- Have the victim stay still. Place the injured site below the level of the victim’s heart and immobilize the injured site in a comfortable position.
- Watch for signs of shock.
- Raise the affected limb, if possible.
- Seek medical attention by calling the Incident Intervention Care Team or transporting to the nearest clinic.
- DO NOT apply a tourniquet.
- DO NOT raise the site of the bite above the level of the victim’s heart.

- DO NOT give the victim aspirin, stimulants, or pain medication unless directed by a physician.

3.8.3 Ticks

A tick is a tiny brown mite that attaches itself to the skin of a mammal, bird or reptile and sucks blood. Ticks range in size from one to four millimeters but may greatly enlarge as they consume blood. There are hundreds of species of ticks and they can be found almost everywhere in woods or grasslands. Ticks are generally most active April through October and peak in the months of June through August.

Lacking wings, ticks climb onto small bushes or tall grass usually close to the ground, and wait for an animal or person to pass near them. They are attracted by carbon dioxide, which is generated during respiratory exhalation. As a host animal or human passes by, they latch on to the skin with their legs, use their “nose” to secure themselves, and cut a hole into the skin by means of a pair of sharp mandibles that saw back and forth. Blood is then sucked into their abdomen until fully engorged, at which time they drop off.

Ticks infected with bacteria, viruses, or parasites can pass diseases (see Table 3) to humans and animals when they attach to the skin to feed. In most cases, an infected tick must be attached for at least 12 hours to transmit pathogens. Symptoms for all tick-borne diseases can include headache, fatigue, muscle aches, and fever. With Lyme disease you may also experience joint pain.

Table 5. Tick-Borne Diseases

Disease	Rash Symptoms	U.S. Geographic Distribution
Lyme Disease	Circular (“bullseye” appearance) rash may appear within 3-30 days, typically before the onset of fever. Rash occurs in approximately 70-80% of infected persons and begins at the site of a tick bite. It may be warm, but is not usually painful.	Northeast, North Central, Pacific Coast
Erlichiosis	In about 30% of adults, a rash appears after the onset of fever.	East, Southeast, Central
Rocky Mountain Spotted Fever	Varies greatly from person to person in appearance, location, and time of onset. Rash occurs in approximately 90% of people. Most often, the rash begins 2-5 days after the onset of fever as small, flat, pink, non-itchy spots on the wrists, forearms, and ankles and spreads to the trunk. It sometimes involves the palms and soles. In some patients, a red to purple, spotted rash is occurs the sixth day or later after onset of symptoms with the infection.	Southeast, Atlantic Coast
Southern Tick-Associated Rash Illness	Nearly identical to that of Lyme disease, with a red, expanding "bulls eye" lesion that develops around the site of a lone star tick bite.	Southeast, Atlantic Coast
Tularemia	A skin ulcer appears at the site where the organism entered the body. The ulcer is accompanied by swelling of regional lymph glands, usually in the armpit or groin.	All states except Hawaii
Babesiosis	Rash is not typical.	Northeast, Midwest, Northwest
Anaplasmosis	Rash is not typical.	Northeast, North Central, Pacific Coast
Colorado Tick Fever	Rash is not typical.	Northwest, Rocky Mountains
Powassan	Rash is not typical.	Northeast

Disease	Rash Symptoms	U.S. Geographic Distribution
Encephalitis		
Q Fever	Rash is not typical.	Throughout the U.S.
Tick-Borne Relapsing Fever	Rash is not typical.	Rocky Mountains, Pacific Coast

3.8.4 Recommended Controls and Prevention

The following actions are recommended to prevent insect and arachnid bites and stings:

- Complete the HDR University eLearning – *Biological Hazards: Insects and Arachnids*.
- Do not wear perfumes or colognes when performing field activities as they often attract stinging insects.
- Workers with a history of severe allergic reactions to insect bites or stings should carry an epinephrine auto injector (EpiPen) and should wear a medical identification bracelet or necklace stating their allergy.

For mosquitos/ticks:

- Check the Center for Disease Control and Prevention website for travel notices and updated maps of areas with mosquito and tick-borne disease transmission.
  - http://www.cdc.gov/niosh/topics/outdoor/mosquito-borne/other.html
  - http://www.cdc.gov/ticks/index.html
- Use insect/mosquito repellents containing 20–30% DEET on exposed skin in accordance with product label instructions and reapply as directed.
- If DEET cannot be used for some reason (such as a personal sensitivity or the potential for cross-contamination when conducting environmental sampling), select an alternative EPA-registered product.
  - https://www.epa.gov/insect-repellents/regulation-skin-applied-repellents
- Apply sunscreen prior to applying insect repellent.
- Treat clothing and gear with permethrin (see HDR catalog) or purchase permethrin-treated items.
- Wear light-colored long-sleeved shirts and long pants so you can easily see ticks on your clothing; tuck your pants into your socks to form a barrier.
- Wear hats with mosquito netting to protect the face and neck.
- Avoid non-essential outdoor activities at sunrise, sunset, and early evening when mosquitoes are most active.
- Avoid high grass if possible and walk in the center of trails to avoid ticks in overhanging grass and brush.
- Check your body, gear, and clothing for ticks, paying close attention to the head, armpits, and groin area. A daily total-body skin inspection greatly reduces the risk of infection since ticks may take several hours to two days to attach to the skin and feed.
- Put your clothes in a dryer on high heat for an hour to kill any remaining ticks.

For spiders:

- Wear protective clothing such as a long-sleeved shirt and long pants, hat, gloves, and boots when handling stacked or undisturbed piles of materials.
- Store apparel and outdoor equipment in tightly closed plastic bags.
- Inspect or shake out any clothing, shoes, towels, or equipment before use to remove spiders.
- Keep your tetanus boosters up-to-date (every 10 years). Spider bites can become infected with tetanus spores.
- Minimize the empty spaces between stacked materials.
- Remove and reduce debris and rubble from around outdoor work areas.
- Trim or eliminate tall grasses from around outdoor work areas.

3.9 Housekeeping

Responsibility for good housekeeping rests with each employee and shall be enforced by the SSHO. Keep all work areas clear (including all inside and outside areas). Supplies and material to be used, salvaged, or scrapped shall be stacked out of the way. Clean up all spills immediately to prevent slipping.

3.10 Noise and Hearing Conservation

Noise exposure may have a potential to occur during site observation and monitoring activities, especially when working around vessels and or heavy equipment. Noise has been defined as unwanted sound. The OSHA standard allows 90 A-weighted decibels (dBA) for a full 8 hours, and for a lesser time, when the levels exceed 90 dBA. It is usually safe to assume that if you need to shout to be heard at arm's length, the noise level is at 90 dBA or above.

Based on the nature of activities to be performed on site, the use of heavy equipment, power tools, and other noise producing devices, personnel may be exposed to noise levels in excess of the allowable limits. Therefore, hearing protection will be utilized by personnel operating or working in areas near equipment emitting noise levels at or above 85 dBA. Employees exposed to 85 dBA or a noise dose of 50 percent must participate in the Hearing Conservation program including initial and annual audiograms.

Hearing protection will be maintained in a clean and reliable condition, inspected prior to use and after any occurrence to identify any deterioration or damage, and damaged or deteriorated hearing protection repaired or discarded. In work areas where actual or potential high noise levels are present at any time, hearing protection must be worn by employees working or walking through the area. Areas where tasks requiring hearing protection are taking place may become hearing protection required areas as long as that specific task is taking place.

High noise areas requiring hearing protection should be posted and employees must be informed of the requirements in an equivalent manner. When hearing protection must be worn, either ear plugs or ear muffs with an NRR30 will provide adequate protection.

3.11 Slip, Trip, and Fall Prevention

Employees shall:

- Maintain work areas free from slip, trip, and fall hazards.
- Correct or immediately report slip, trip, and fall hazards.

3.11.1 Slick and Slippery Surfaces

- Wear proper footwear for better traction on slippery surfaces (non-slip soles). The harder and smoother the bottom of the shoe, the more slippery it is. Leather soles tend to be very slippery, on slick surfaces.
- Point your feet slightly outward, keeping your center of balance under you.
- Take slow, small steps.
- Use your feet as probes to detect possible slip, trip and fall hazards.
- Hold on to rails or other stable objects.
- Get your feet underneath your body quickly to maintain your balance after an initial step. Protect the more vulnerable parts of your body like your head, neck and spine if you do fall - make a conscious effort to tuck your chin so your head doesn't strike the ground with a full force.
- When moving from carpet to tile or dry tile to wet tile, etc. the friction (grip) between the sole of the shoe and the floor surface lessens. Alter your stride to take shorter, slower steps.
- When entering a building, remove as much snow and water from your boots as possible. Be alert for floors and stairs that may be wet and slippery.
- Use special care when entering and exiting vehicles—use the vehicle for support.
- Streets and sidewalks that have been cleared of snow and ice should still be approached with caution. Dew, fog or water vapor can freeze on cold surfaces and form an extra-thin, nearly invisible layer of ice that can look like a wet spot on the pavement. It often shows up early in the morning or in areas that are shaded from the sun.
- Never walk on any elevated surface (scaffold, outside fixed stairway, ladder) when ice is present!

3.11.2 Rough and Rocky Terrain

- Wear sturdy-soled lace up boots with ankle support.
- Double tie your boot laces and tuck the loops inside the boot to prevent tripping.
- Take regular rest breaks and stay hydrated. Fatigue and dehydration can contribute to slip, trip, and fall incidents (as well as heat related incidents).
- Wear flexible soled shoes when hiking around marshy, boggy areas. Big, heavy boots with flat, solid soles result in a much greater suction force that hinders you when you try to pull your foot out. Beware of stepping into mud and clay which may display strong suction forces.
- Carry a long stick or pole. Besides making hiking easier, you can use it to poke and prod any suspicious ground. If the stick sinks or makes the ground ripple, do not step! Also, if you do get stuck in mud, clay, or quicksand, you can push yourself out with the stick.

- Watch for rocks that may be unstable or slippery.
- Step lightly and check for firm ground on steep inclines.
- Stay alert and keep your eyes open to safely navigate uneven and slippery areas.
- Maintain distance from others to avoid collisions.
- Don't grab onto tree branches or brush. Wear safety glasses to prevent catching a limb in the eye (another repeat incident type for HDR field staff).
- Slow down so you will have more time to react to a problem.
- Take care of your feet (treat "hot spots" before they become blisters).
- In extreme conditions; use gaiters to prevent sand and gravel from entering your boots.
- If you are carrying a backpack or other gear/equipment, check the pack weight to make sure it is distributed evenly and centered on your back. A top-heavy pack will raise your center of gravity and make you more likely to stumble if you become off balance. The straps of the pack should be tightened to prevent sudden shifts of weight that could unbalance you.

3.12 Safe Driving/Journey Management

Vehicle drivers must complete HDR's Safe Driving course on HDR University and must meet the driver eligibility criteria specified in HDR's Vehicle Use Policy and Procedures. Vehicles must meet the insurance, use, and maintenance requirements specified in HDR's Vehicle Use Policy and Procedures. In addition, seat belts shall be worn at all times when driving and rules of the road will be obeyed while operating a vehicle in the performance of work on behalf of HDR. Personnel will not ride on boats hauled by trailers nor ride in the bed of a pickup truck.

A journey management plan must be developed for all high-risk vehicle travel that cannot be avoided to reach the job site (i.e., the trip cannot be eliminated or combined with another, the trip cannot be performed by a 3rd party contractor, there is not a safer way to travel (air, rail), etc.). The purpose of journey management planning is to identify hazards and ensure project management and others are aware of a driver's itinerary and route for emergency/security reasons.

High-risk vehicle travel includes:

- Night driving;
- Driving more than 4 hours at a time;
- Driving distances greater than 200 miles;
- Driving on mountain roads/unpaved roads;
- Driving in adverse weather; and/or
- Driving in areas with security concerns.

Prior to executing the journey, the driver must be fully briefed about the journey and the associated risks and the Journey Management Plan must be reviewed with all affected employees.

The use of tobacco products is prohibited in all HDR-owned, -leased, or -maintained vehicles or equipment, and in any vehicle or equipment while occupied or operated in the performance of work for HDR. HDR personnel are required to comply with all federal, state, and local regulations regarding the use of cellular devices while driving. If a cellular device must be used during vehicle operation, a hands-free device must be used. Under no circumstances is text messaging or any use of a keyboard allowed while operating a vehicle.

4. Injuries and Medical Emergencies

By its very nature, there is a possibility of injuries or medical emergencies when conducting field work. A small work boat cannot carry the amount of medical equipment or trained personnel needed to deal with the range of medical emergencies that may be encountered.

A well-prepared first aid kit, a marine radio, field staff with basic first aid training, and prearrangements with local ambulance services are provided (an optional cellular phone could also be used to contact local emergency personnel).

Most medical emergencies will be self-evident, but some have mild symptoms. The SSHO or other certified first aid provider should be on the lookout for the following:

- Shock,
- Chemicals in eyes,
- Advanced stages of hypothermia,
- Frostbite,
- Early stages of heart attack,
- Heat exhaustion, and
- Back injuries.

The SSHO will have personnel with the above injuries taken to a hospital immediately. An ambulance can be obtained by making a marine radio call through the local marine operator or calling 911 on a cellular telephone.

If a marine operator cannot be reached, a medical safety call should be made. The Coast Guard should be informed of the situation and asked if they can arrange to have an ambulance sent to the location where the boat will be docking.

If the boat cannot reach shore for medical aid, a MAYDAY distress call should be made on the marine radio.

The following must be adhered to:

- Every boat shall be equipped with a moisture-tight, portable first aid kit.
- Field employees must report all injuries and any first aid treatment received to the SSHO.

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5. Subcontractors

The following Subcontractors are expected to participate in and support field activities under this Project:

- Woods Hole Oceanographic Institution (underwater acoustic monitoring) and
- Fugro (metocean, biofouling, corrosion, and turbidity monitoring).

For any field work performed by HDR subcontractors, each subcontractor must develop their own Site-Specific SH&E Plan related to their specific on-site activities. The subcontractor's Site-Specific SH&E Plans must be at least as comprehensive as this Plan as it relates to the Subcontractor's services and shall comply with all applicable laws and requirements of the Prime Agreement. Unless otherwise agreed upon in writing, each Subcontractor is responsible for providing all safety equipment and safety training for their employees.

HDR is not responsible for approval of the Subcontractor's plans or the means and methods set forth by the subcontractor; our obligation is to verify the Subcontractor's plan exists and is applicable and relevant to the work to be performed.

All Subcontractor staff will operate under their respective institution's Health and Safety Plan or a Job Hazard Analysis (JHA) or Activity Hazard Analysis (AHA) that addresses the hazards associated with the work that they are being subcontracted to perform for HDR. The HDR PM will work closely with each Subcontractor to ensure that they are aware of the SH&E requirements that apply to this Program.

Subcontractor personnel must report all hazards, accidents, incidents, injuries, illnesses, and/or environmental spills immediately to the SSHO. In addition, Subcontractors are required to inspect their work sites daily for any hazards. All recognized hazards should be brought to the SSHO for corrective action.

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6. Reporting Unsafe Conditions/Practices

Responsibility for effective SH&E management extends to all levels of the Project and requires effective communication between employees, supervisors, management, and Subcontractors. Accident prevention requires a proactive policy on near misses, close calls, unsafe conditions, and unsafe practices. All personnel must report any situation, practice, or condition which might jeopardize the safety of our projects staff, visitors, equipment, or the environment. All unsafe conditions or unsafe practices will be corrected immediately. HDR has a policy of zero tolerance for unsafe conditions or unsafe practices.

Although HDR is not responsible for the health and safety or means and methods of other employer's work, when HDR employees (or HDR Subcontractors) could be exposed to unsafe conditions/practices created by another contractor, or when observed unsafe conditions/practices pose a risk of serious injury or death to those exposed (regardless of company affiliation), the observing employee is obligated to notify someone who can take appropriate corrective action.

6.1 Exposure to HDR/HDR Subcontractors

If an HDR employee identifies an unsafe condition/practice by another contractor that impacts the ability of HDR or HDR subcontractors to conduct project activities in a safe manner, the employee is to:

- Move away from the unsafe condition/practice to prevent exposure.
- Notify HDR supervision for reporting to the creating/controlling contractor's senior management.
- Document the notification in the project field logbook, daily report, or other records based on contract requirements.
- Take reasonable alternative protective measures to prevent exposure to HDR employees and HDR subcontractors until the unsafe condition/practice is corrected or a reasonable explanation is provided as to why no real hazard exists.

6.2 Exposure to Others (Non-HDR Employees/Non-HDR Subcontractors)

If an HDR employee observes an unsafe condition/practice by another contractor (not contracted with HDR) to which HDR/HDR subcontractors are not exposed but, in the employee's judgment, poses a serious hazard or imminent danger to others that could be exposed, the employee is to:

- Immediately warn those in imminent danger, regardless of company affiliation.
- Immediately notify HDR supervision for reporting to the creating/controlling contractor's senior management.
- When describing the serious hazard or imminent danger observation, do not provide any means or methods or specific remedies for correction. Our obligation is strictly limited to informing site supervision of the observation.

- Make it clear that our notification is advisory only and should not be construed as a direction or a stop-work order - the non-HDR contractor is solely responsible for determining and implementing the necessary corrective action.
- Document the notification in the project field logbook, daily report, or other records based on contract requirements.

6.3 Regulatory Inspection Protocols

It is our expectation that all employees will follow the requirements set forth in this Plan as well as all regulations that apply to their work location. HDR is committed to cooperating with regulatory and/or compliance inspection personnel as applicable on our project sites. HDR does not authorize any HDR employee to prohibit a properly identified representative from prompt admittance to any work area. Therefore, we will not require warrants for occupational SH&E officials' entry into any project location where HDR is engaged. We will cooperate with all inspectors in accordance with local regulatory requirements.

Guidelines for HDR actions during the inspection are summarized as follows.

Activity	HDR Action
Arrival of Inspector(s)	HDR project personnel are to contact their Regional SH&E Manager if an occupational SH&E inspector appears onsite to conduct an investigation involving HDR personnel.
Meeting with Site Representative	All HDR project sites require designation of an on-site SH&E Representative. The SH&E Representative is responsible for interaction with the inspector(s) and must be summoned immediately upon arrival of an inspector(s) at the site.
Credential Verification	Immediately upon arrival of the inspector(s), the SH&E Representative is to request and document the inspector's identification. If the Inspector is missing his/her Identification card, or the identity of the inspector(s) is in question, a call to his/her home office is an acceptable practice to verify authenticity of credentials and inspection authorization.
Inspection	The SH&E Representative is to accompany the Inspector(s) at all times during the visit. HDR should attempt to replicate all photos, samples, or notes collected by the inspector(s), paying special attention to where the Inspector(s) goes, who is talked to, what sampling is done, which instruments are used, and any specific comments that are made. Site personnel are to conduct themselves in a professional manner when interacting with regulatory officials. The following guidelines should be adhered to during the inspection. • Keep all responses short and to the point without elaboration. Personnel should not volunteer information not specifically asked for by the inspector and should avoid statements that might be construed as an admission of noncompliance. • Do not demonstrate any operations for the Inspector(s) that are not part of the daily normal planned activities. • If possible, immediately remedy any alleged violation(s) identified by the Inspector(s). If an employee violates a work rule during an inspection, the same remedial/disciplinary action will be taken as if the Inspector(s) was not present. Failure to correct a violation noticed during the inspection may itself result in a citation. • Regulations may require the maintenance of certain safety and health records. If the Inspector(s) requests to review records, grant access to the documents.

6.4 Incident Reporting and Investigation

In the event of an incident, the most important immediate action is to provide medical assistance to those that may need it and to ensure the safety of others that may be affected.

6.4.1 Incident Reporting

All work-related near miss, injury, illness, damage, environmental, and security incidents involving HDR employees, HDR Subcontractors, and/or other parties at HDR work sites must be reported to the SSHO and investigated as soon as possible following occurrence.

Employees involved in or witness to an incident:

1. All incidents:
    a. Notify supervisor to arrange for post-incident drug and alcohol testing (if applicable).
    b. Notify Project Manager for client reporting.
    c. Submit Incident Report in IndustrySafe (https://industrysafe.com/hdrinc).
2. Non-emergency injury/illness incidents:
    a. Contact WorkCare (888-449-7787) for medical consultation.
3. Serious incidents (incidents involving death, hospitalization, amputation, loss of an eye, significant damage, and/or environmental impact):
    a. Notify Director of SH&E or Regional SH&E Manage for regulatory reporting.

6.4.2 Incident Investigation

All incidents will be investigated by the Regional SH&E Manager with assistance from the on-site SH&E representative, project manager, and/or local safety coordinator and documented in IndustrySafe.

6.5 IndustrySafe

IndustrySafe is HDR's online management system for incident reporting and tracking. HDR employees are required to fill out an online incident report form within 24 hours for emergency, non-emergency, and near miss incidents through IndustrySafe at https://www.industrysafe.com/hdrinc/default.asp. For Subs and contract labor employees, the HDR PM or Team Lead must enter the information as there is no external access to IndustrySafe. Login information for HDR employees is explained below.

Please note that once you open IndustrySafe you may get a prompt to allow pop-ups. Please select the option to allow pop-ups for the site.

Steps for reporting an incident and a near miss:

- Login[1]

[1] If you are unable to access IndustrySafe at the time of the incident, contact your local Safety Coordinator to enter the report for you. Following submittal of a report, you will contacted by the following: Regional SH&E Management and/or local Safety Coordinator.

   - If you are connected to the HDR network, your login to IndustrySafe will be automatic by following this link: https://industrysafe.com/hdrinc/.
   - If you are not connected to the HDR network, go to https://www.industrysafe.com/hdrinc/ and enter your HDR network user name and password to login.
   - If your login information does not work or you are unsure of your HDR credentials, you should email IT support at ITHelp@hdrinc.com.
- Select "Incidents" on the top of the IndustrySafe home page.
- Click the green plus sign.
- Complete the form with the near miss/incident information.

6.6 Stop Work Authority

Personal safety takes priority over all project deadlines, demands, and any other considerations. At all times and on all sites, it is HDR's policy, practice, and responsibility to provide a place of employment where HDR employees can conduct project-related activities in a safe and healthy environment. HDR strives to ensure the health and safety of its employees by identifying and mitigating recognized hazards to avoid or eliminate potential for injury or illness.

HDR employees need to be conscious for the safety of other project personnel and are expected to promote safe work habits. HDR employees are encouraged and empowered by HDR to maintain a safe workplace and only work when the hazards have been removed, controlled, or mitigated. No HDR employee is expected or obligated to perform work they consider unsafe or damaging to the environment.

Employees are to immediately report SH&E concerns to their local Safety Coordinator, supervisor, and/or PM. In addition, Stop Work Authority (SWA) allows any HDR employee to stop work conducted by HDR or HDR subcontractors where there is a serious hazard or imminent danger. Once invoked, the activity in question will be stopped and reviewed by those performing the work and their immediate supervisors. Work will not resume until all stop work issues and concerns have been adequately addressed. There will be no retribution for invoking SWA.

6.7 Disciplinary Action

Should an employee commit a SH&E violation (any act contrary to the SH&E requirements set forth in this manual or those established by a client or governmental regulations), intentional or not, disciplinary action may result. Depending on the severity of the violation, the employee will typically be retrained to reinstruct the employee on the proper conduct expected. This retraining, and the circumstances necessitating it, will be documented and retained in the employee's personnel file.

For serious first time violations and repeat violations in which an offending employee continues to exhibit a disregard for the same or similar SH&E procedures after retraining, the responsible manager shall consult with the Director of SH&E and the Director of Employee Relations. As appropriate to the situation, actions could include any one, or a combination, of the following forms of disciplinary action: verbal warning; written warning; probation; suspension; and/or discharge. This is not an all-inclusive list and, because HDR is an at-will employer, it reserves the right to terminate at will without prior disciplinary action.

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7. SH&E Equipment and Supplies

7.1.1 Personal Protective Equipment (PPE)

PPE must be worn by employees when engineering controls or administrative practices cannot adequately control those hazards. The standard PPE for the RODEO Project includes:

- Long pants and long-sleeved shirts shall be worn for all field work
- Sunglasses
- Closed-toe, non-slip footwear
- A US Coast Guard-approved Type III or Type V PFD must be worn when working over or adjacent to water and be marked for use as a work vest, for commercial use or for use on vessels. Hearing protection shall be worn when exposures exceed 85 dBA and employees shall be enrolled in HDR's Hearing Conservation Program as applicable (see SH&E Procedure #026 – *Noise (Hearing Conservation)*).

Specific PPE related to COVID-19 hazards/controls (see COVID-19 JHA for more details):

- Masks
- Gloves
- Face shields
- Hand sanitizer

7.1.2 Other Equipment and Supplies

- Facial mask to prevent wind burn, if needed.
- Sunscreen.
- Insect repellant.
- Communication equipment.
- Thermometer (heat strain monitoring).
- Emergency response equipment and supplies.
- 2-way radios and/or satellite phones

8. Medical Support

8.1 First Aid/CPR Capability

At least one person currently trained in first aid/CPR must be present on-site. On multi-employer worksites, this may be a contractor or client employee, as long as they agree to provide coverage. At initial project kick-off meeting, all first aid responders will be identified so workers know who to go to if the need arises. For this Project, the following individuals have been trained to provide first aid.

First Aid Responder	Training Expiration Date
Anwar Khan	August 2021
Kristen Ampela	March 2021
Dan Engelhaupt	November 2020
Michael Richlen	November 2020
Mark Cotter	November 2020

8.2 Non-life threatening injuries and illnesses

All non-life threatening injuries and illnesses will be managed by the WorkCare Incident Intervention Team by calling **WorkCare's Incident Intervention Hotline.**

HDR Injury/ Illness Reporting Hotline:

(888) 449-7787

The occupational nurse or physician discusses the injury or illness and surrounding circumstances with the injured person. The injured or ill employee is provided guidance on appropriate treatment options (triage). Appropriate treatment details are handled by the occupational nurse or physician. The HDR HSM will be notified by the WorkCare occupational nurse or physician via email immediately after each contact.

All injuries or illness (even those that are so minor and may only require first aid on-site) which occur from the performance of HDR work, while on business travel, or business commute must be reported to WorkCare and the employee's immediate supervisor. An HDR SH&E representative will follow up and contact the employees supervisor and PM to ensure any needed corrective actions are implemented to ensure no one else gets hurt.

8.3 Project Designated Medical Facility for non-emergencies

Medical facility for non-emergencies*	Patient First Urgent Care
Address	332 Newtown Rd, Virginia Beach, VA 23455
Phone number	(757) 473-8400

Hours of operation	8 am – 10 pm daily

A map and driving directions to the designated non-emergency medical facility is shown in **Attachment B**.

8.4 Life Threatening Medical Emergency

Life threatening illnesses or injuries will require an immediate emergency call to 911. When calling 911, you must initially state, “I have a medical emergency.” This statement routes you directly to medical services rather than placing your call in line with other types of emergencies (i.e., fire or police).

Serious incidents must be reported to the HSM within the first hour. Serious incidents are those that involve any of the following:

- Work-related death, or life-threatening injury or illness of an HDR employee or Subcontractor;
- Missing person;
- Acts or threats of terrorism;
- Event that involves a fire, explosion, or property damage; and/or
- Spill or release of hazardous materials or substances that involves a significant threat of imminent harm to site workers, neighboring facilities, the community, or the environment.

Immediately notify the HSM and HDR SH&E Director, Jeff Kleinfelter, of any fatality or other catastrophic incidents (i.e., in-patient hospitalization, amputation, or loss of an eye). The SH&E Director will report the incident to OSHA and any additional regulatory agencies as applicable.

Additional Considerations:

- Stop Work and notify all project staff and Subcontractors.
- Always leave the area immediately if it is unsafe.
- Call the appropriate emergency number for assistance, see **Table 1**.
- Remain calm and follow any instructions provided by emergency dispatch personnel.
- Secure the area and shut down any hazardous operational equipment.
- Render first aid (FA) to the extent of your training, experience, and FA equipment available. A FA kit should be available in each vehicle and vessel for use by those with current FA training. Contact WorkCare for non-life threatening basic FA instruction as needed. WorkCare will help walk HDR employees through FA measures based on the contents of the local FA kit available.
- For contact with hazardous chemicals, follow chemical specific Safety Data Sheet information for first aid measures.
  - For inhalation exposures, remove to fresh air and follow Safety Data Sheet information for first aid measures.

Identify the type and amount of hazardous chemicals released if possible.

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9. Communication/Remote Site Safety

The following actions will be taken by all staff while the vessel is away from shore:

- Inform the shore contact by phone that you are departing and your vessel's planned activities for the day—which boat you will be on and which area you will be monitoring. HDR sat phone number is 011 881651403002.
- Ensure VHF radios are available and in working order.
- Notify the shore based observer by phone once the vessel has returned to shore.
- If the shore based observer follower does not hear from you within thirty minutes of the agreed upon return to shore time, shore based observer will attempt to contact the vessel via VHF radio.
    - If unable to make contact, the remaining vessels will be dispatched to search for the vessel in the pre-determined area of operation. If the search for the vessel is unsuccessful, the shore based observer shall notify the local Coast Guard (see contacts page) and request that they contact the vessel on VHF channel 16 to check on their safety and status before beginning an all-out search for the missing vessel.
    - At this point, the shore based observer should notify the PM and keep them informed as to the status of the missing vessel.

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10. Drugs and Alcohol

The manufacture, distribution, possession, use, or being under the influence of drugs is prohibited while performing work for HDR. This includes the use or possession of prescription medications without a valid prescription.

Employees whom HDR management/supervision reasonably believes directly or indirectly caused a work-related injury or property damage will be required to undergo drug and alcohol impairment testing. Such testing will be conducted as soon as practicable, but not later than 32 hours after the incident for drugs and not later than six hours for alcohol.

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11. Training

All HDR project personnel must meet the training requirements provided in this section.

11.1 Mandatory HDR Employee SH&E Training

Personnel working in the must be currently trained in the following SH&E topics:

- HDR General Safety Awareness.
- HDR Emergency Action Planning.
- Disaster Communication.
- HDR Safe Driving.
- HDR Slips, Trips, and Falls.

11.2 Task Specific Training

Additional topics maybe needed per Project scope of work or exposure. Prior to initiating site activities, the HDR SSHO will conduct a SH&E "Kick-off" or "Tail-gate" meeting. At this time, pertinent HDR procedures and this Plan will be discussed in detail with special attention being given to site physical hazards, PPE, emergency procedures, etc. Upon completion of this meeting and briefing, all routine field personnel in all areas, including Subcontractors, will be required to read and sign the acceptance sheet of this Plan. Applicable field forms/documents can be found in **Appendix A**. Applicable HDR Procedures are:

- SH&E Procedure #003 – Slip, Trip, and Fall Prevention
- SH&E Procedure #029 – Cold Stress
- SH&E Procedure #028 – Heat Stress
- SH&E Procedure #006 – Hazard Communication
- SH&E Procedure #026 – Noise (Hearing Conservation)
- SH&E Procedure #030 – First Aid, CPR, and AED Program
- SH&E Procedure #018 – Water and Boating Safety
- SH&E Procedure #034 – Biological Hazards

The HDR PM and SSHO will maintain an onsite copy of the certifications indicating that all HDR personnel have satisfied the minimum training requirements. Supporting documentation and certificates will remain on file with the HDR PM/SSHO. Field work will not be allowed to take place in the absence of adequate documentation.

Additional site-specific training covering new site hazards, procedures, and contents left out of the approved Plan will be modified and added by the HDR HSM/PM/SSHO for all on-site employees, prior to the commencement of any work not outline in this Plan, and also for visitors new to the Project.

The HDR SSHO will be responsible for maintaining a list on-site of training records and expiration dates of applicable training for all project personnel. In addition, a full review of this Plan and task specific JHAs will be completed prior to commencement of the Project. .

A pre-job safety meeting will be held before the vessel departs on its initial survey on the first day of the fieldwork to review the use of PFD and vessel safety features.

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12. Field Hazard Analysis and Risk Assessment

All field team members and Subcontractors are responsible for being actively involved in the HDR hazard analysis and risk assessment process, which involves the identification, assessment, and prioritization of risks and measures to eliminate, minimize, monitor, and/or control them. Consideration is given to the safety, health, and security of workers, the public, and the environment.

Job hazard analysis (JHA) forms are used to document the process and identify the sequence of work, specific hazards anticipated, and control measures to be implemented to eliminate or minimize each hazard. The JHA form also lists the necessary equipment and training required to perform the task safely.

Initial JHAs for tasks associated with this field work effort are included in Appendix D. Prior to initiating a task, the field team must confirm the JHA is complete and adequately identifies and controls associated hazard. If there is a change in the scope of the work, if work conditions change, if new hazards are identified, or the controls prove inadequate or ineffective, the field team must revise the JHA as necessary, review with the team, and have each team member sign it before any work is conducted. Revisions can be handwritten on the form.

Jobsite SH&E meetings (i.e., toolbox talks or tailgate meetings) are required at the start of each day for field work assignments. Safety briefing documentation must include the names of employees present and topics discussed. The HDR PM will provide a written JHA for each field work assignment task. Applicable JHAs will be reviewed at the start of each day. Each JHA must be kept in the Project's electronic files, and on-site during the duration of the Project field work. Revisions are to be made daily by field staff if conditions change.

12.1 JHA Record Retention

All HDR field team members involved in the task must sign the JHA form in the field to acknowledge completion of the review and concurrence with the job steps, hazards, and controls described in the JHA. The SH&E Representative shall keep completed JHAs in a binder at the job site until the work is complete. After the work is complete, the electronic version of the initial JHA will be updated to include improvements that were identified in the field to assure better planning and a safer work experience the next time the task is performed. A copy will be forwarded to Corporate SH&E for inclusion in the JHA library.

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13. Job Site Inspections, Audits, and Observations

13.1 Self-audit/Take 5

A self-audit/Take 5 is a proactive safety process used by employees to confirm they are prepared and confident in their ability to do an assigned task before they begin (they have the necessary training, knowledge, equipment, resources, etc.). The process involves employees "taking 5" (spending approximately 5 minutes) to review the task hazards, associated risks, and control measures prior to exposure. The PM is responsible for establishing a documented self-audit/Take 5 system for the Project to ensure critical elements of preparation are considered by team members before beginning assigned tasks. An HDR self-audit checklist is located in **Appendix A**.

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13.2 Job Site Inspections

The SH&E Representative is responsible for conducting and documenting regular job site inspections to confirm compliance with the Site-Specific SH&E Plan and proper identification of site hazards and conditions. Based on site and weather conditions and the nature of work being performed by HDR staff, the SH&E Representative will make a determination regarding the frequency of inspections and the type and level of documentation required. At a minimum an inspection is recommended at the start of each field day. Inspection findings could be documented along with remedial actions taken in the field log book.

13.3 Corporate SH&E Field Audits

Corporate SH&E is responsible for conducting field audits. Sites selected for audit are based on a project's scope and duration, anticipated hazards/exposures, potential for environmental impact, and the frequency and complexity of the work being performed. PMs can contact a Regional SH&E Manager to request a formal audit by a qualified safety professional at any time.

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A

Health and Safety Forms

- Job-Site Safety, Health, and Environmental Meeting Form
- Self Audit
- HDR Float Plan
- Project Safety, Health, and Environmental Orientation Form
- Worker/Visitor Review and Acknowledgement of the Site Health and Safety Plan
- Project Hazard Identification Form
- Stop Work Authority Form

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JOB-SITE SAFETY, HEALTH, AND ENVIRONMENTAL MEETING FORM

Project: ______________________________

Task: ______________________________

Date: ______________________ Time: ____________

Location/Work Area: ______________________________

Attendees: ______________________________

Topics (check off list as completed):

- ❑ Review assigned duties and tasks for the day
- ❑ Discuss anticipated site conditions (access, weather, etc.)
- ❑ Review the Project-Specific SH&E Plan and Job Hazard Analysis (JHA) forms for the day's work
- ❑ Confirm team roles (on-site SH&E Representative, first aid/CPR responders, Short Service Employee mentors)
- ❑ Discuss emergency procedures and equipment (satellite phone, whistles, horns, etc.)
- ❑ Identify necessary medications and individual team member's medical situations/precautions (if staff is willing to share with team)
- ❑ Review lessons learned from any reported incidents and the status of any corrective actions
- ❑ Confirm everyone is comfortable with daily plan of action

Summary of Work Conducted and Planned:

____

____

____

____

____

Attendees:

Name (print)	Signature	Name (print)	Signature

Meeting Conducted by:

______________________________ ______________________________

Name (printed) Signature

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Employee Self-Audit-#7 Part 1

(Field Visit Checklist)

Project Manager, please fill out this form during project start-up and provide a copy to each employee on the H&S Field Staff (page 2). Return original pages 1&2 to your section's Admin for filing.

Project Manager's Name & Office ______________________ ______________

Project Name & Number ______________________ ______________

GENERAL – *before field visit*

- ☑ Review the HDR Project Safety Form/Guide for this project (PM will provide copy).
- ☑ Know what Personal Protective Equipment (PPE) is required and acquire them. (H&S Pro #21) (Hard Hats, Safety Glasses, Traffic Vests, Steel Toe Boots, etc.)
- ☑ Acquire any special equipment if necessary. (Respiratory Protection (H&S Pro #9) and/or Air Monitoring (H&S Pro #25))
- ☑ Check to see if a first aid kit is in the vehicle, if not, check one out from the front desk.
- ☑ Check the location of the nearest medical facility from the project location.
- ☑ Will work include overnight travel? (HDR Safety Memo: Travel Safety Guidelines and someone receives copy of itinerary)

MISCELLANEOUS – *during or after field visit*

- All accidents require the completion of an Accident/Incident Report. (See your OSC)
- Complete a Potential Unsafe Conditions Report for all potentially (serious) unsafe conditions. (See your OSC)

DOES YOUR PROJECT ASSIGNMENT INCLUDE THE FOLLOWING?

PROJECT SPECIFIC TASKS	YES	NO	Not sure? Research
Electrical – *Lockout/Tagout* (H&S Pro #4 & #7)	☐	☐	☐
Demolition (H&S Pro #22)	☐	☐	☐
Drill Rigs (H&S Pro #37)	☐	☐	☐
Excavation (H&S Pro #5)	☐	☐	☐
Work in Elevated Areas (H&S Pro #12)	☐	☐	☐
Noise (Hearing Conservation) (H&S Pro #26)	☐	☐	☐
Permit-Required Confined Spaces (H&S Pro #1)	☐	☐	☐
Portable Ladders (H&S Pro #2)	☐	☐	☐
Work at a Remote Site (H&S Pro #38)	☐	☐	☐
Work on or around a Drill Rig (H&S Pro #37)	☐	☐	☐
Work on Aerial Lifts (H&S Pro #36)	☐	☐	☐
Bridge Inspection (H&S Pro #15)	☐	☐	☐
Work on or around a Railroad (H&S Pro #14)	☐	☐	☐
Work in or around Traffic (H&S Pro #17)	☐	☐	☐
OTHER??	☐	☐	☐

COULD EMPLOYEES BE EXPOSED TO THE FOLLOWING ON YOUR PROJECT?

ENVIRONMENTAL HAZARDS	YES	NO	Not sure? Research
Biological Hazards (H&S Pro #34) (snakes, spiders, mites, insects, noxious plants, bacteria, fungi, etc.)	☐	☐	☐
Cold Temperatures (H&S Pro #29)	☐	☐	☐
High Temperatures/Humidity (H&S Pro #28)	☐	☐	☐
CHEMICAL HAZARDS			
Asbestos (H&S Pro #10)	☐	☐	☐
Bloodborne Pathogens (H&S Pro #8)	☐	☐	☐
Hazardous Waste (H&S Pro #20)	☐	☐	☐
Lead/Lead-Based Paint (H&S Pro #11)	☐	☐	☐
OTHER??	☐	☐	☐

Any questions concerning Health & Safety on your project, please feel free to contact:

- Office Safety Coordinators (OSC): Kevin Ashby at 602.522.7726 or Kurt Watzek at 602.522.4327
- Regional Health & Safety Coordinator: Brad Kruger at 402.399.1267

Employee Self-Audit-#7 Part 1

(Field Visit Employee List)

Project Manager, please provide each employee a copy of the completed self-audit on page 1 of this document and a completed copy of the Project Safety Form/Guide. Return original pages 1&2 to your section's Admin for filing.

Project Manager's Name & Number ______________________ ________________

Project Name & Number ______________________________ ________________

Employees expected to complete field work on project:

	Name	Home Office if Different from this one
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		

All listed staff were provided a completed copy of page 1 of this document (Field Visit Checklist) and a completed copy of the Project Safety Form/Guide.

______________________________________ ______________

Project Manager Signature Date

HDR FLOAT PLAN

(FOR EXAMPLE PURPOSES ONLY; VESSEL OPERATORS WILL FOLLOW THEIR OWN FLOAT PLAN FORMAT)

Date:___/___/___ Submitted By: ____________________

Vessel Name: ________________ Engine type/manufacturer: ________________

Fuel capacity (hours): ____

Vessel Description:

Hull Material: ______________________________ Color: ________________

Manufacturer ____

Registration #: ________________________ Length: ______________________

Width: ______________________________ Draft: ______________________

Vessel Operator:

Name/Phone : ________________________ Experience Level: ______________

Health ____

Tow Vehicle:

Make ______________ Model ____________________ Color ___________

Plate # ______________ Location Parked: ________________________________

Itinerary:

Depart From:	Time:	Arrive at destination:	Time:	Arrival:

Destination/route:*	Purpose for trip:*	Weather condition by shore:	How Far out are you going?

Upon Return, vessel operator will check in with:

Float Plan Follower (via phone call or text message)

***Persons Aboard*:**

Name	Age	Swim	Medical Conditions	Emergency Contact #

Equipment Checklist:

# PFDs:		**Medical Kit:**		**Flashlight:**		**Emergency contact List:**	
# Flares:		**Fire Extinguisher:**		**Anchor:**		**Paddles or oars:**	

Cell Phone # ______________________
Proper scale charts corrected, reviewed & aboard? ______
Radio Type: VHF/CB/other

*Attach complete description of work to be accomplished waypoints w/ estimated times of arrival and departure and a coms. Schedule and contact w/ shore based personnel. Refer to HDR Small Boat Operations Manual for Coms. Procedures.

PROJECT SAFETY, HEALTH, AND ENVIRONMENTAL ORIENTATION FORM

Project: ______________________________

Date: ______________________________

Location: ______________________________

Attendees: ______________________________

Topics

- ❑ Review assigned duties and tasks
- ❑ Discuss anticipated site conditions (access, weather, etc.)
- ❑ Review the Site-Specific SH&E Plan and Job Hazard Analysis (JHA) forms
- ❑ Confirm training, equipment/supplies, medical clearance, and vaccinations have been acquired for all field team members
- ❑ Review emergency procedures and reporting and investigation procedures for near miss, injury/illness, damage, and environmental incidents
- ❑ Discuss environmentally safe work practices (spill/release management, hazardous waste, solid waste, protected ecological/cultural resources, etc.)

Notes/Comments

____

____

____

____

____

____

____

Team Member Signatures:
I have been briefed on and understand and agree to follow the requirements of the Site-Specific SH&E Plan and JHAs for this project.

____________	____________	____________
____________	____________	____________
____________	____________	____________
____________	____________	____________
____________	____________	____________

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HDR STAFF/VISITOR
REVIEW AND ACKNOWLEDGEMENT OF THE SITE HEALTH AND SAFETY PLAN

Project Name: Field Observations During Offshore Wind Structure Installation and Operation

Project No.: 10101137

Project Location: Offshore from Norfolk, VA

Client/Contract No.: BOEM/RODEO IDIQ Contract

I have been briefed on and understand the requirements of the Site Health and Safety Plan for the above site. By signing below, I acknowledge and agree to follow the Site Health and Safety Plan for this project.

Date	Name (Printed)	Company	Signature

Project Hazard Identification Form

(To be completed at the Development Phase for projects involving field work)

Date: 8/10/2019	**HDR Project No.:** 10101137	**HDR Project Manager:** Anwar Khan
Client:	**Project Name:** Field Observations During Offshore Wind Structure Installation and Operation	
HDR subcontractors/sub consultants on site? ☒ Yes ☐ No		

Services Provided by HDR Personnel

☒ On-site observation	☐ Structural Condition Survey
☐ Walk-through survey	☐ Not Applicable
☒ Data gathering	☐ Other (explain) _____
☐ Inspection	

Potential Hazards

☐ Confined spaces or potential for engulfment	☐ Radioactive material
☐ Working at elevated heights or platforms	☒ Non-ionizing radiation (includes sunburn)
☐ Trenches or excavations	☐ Asbestos
☐ Electrical hazards other than office	☐ Lead-based paint
☐ Inadequate ventilation	☐ Mobile machinery/other non-vehicle transportation
☐ Exposure to air contaminants	☐ Facility equipment with moving parts
☐ Exposure to excessive noise	☒ Heat/cold stress
☐ Vehicle traffic	☒ Biological, e.g., snakes, poison ivy, bears
☒ Working over or near a waterway	☐ Unrecognized safety risks to HDR personnel
☐ Working near airplane runway/taxiway	☐ Other (explain) _____
☐ Contact with solid or liquid chemicals/wastes	
☐ Biohazard/sewage/landfill wastes	

Project Location

☐ Construction or demolition site	☐ Airport related site
☐ Industrial facility	☐ Research facility
☐ Municipal water/wastewater facility or fluid transfer	☐ Federal government facility/site
☐ Health care, justice, or other commercial building	☐ Non-ionizing radiation tower/communications site
☐ Landfill or potential waste site	☐ Track, roadway, or other ground transportation
☐ Natural habitat site with minimal development	☐ Rail or highway bridge
☒ Wilderness or remote locations	☐ Known or highly suspected hazardous waste site
☒ Open waterway site	☒ Other (explain) 25 miles offshore
☐ Waste recovery/recycling facility/site	
☐ Power generation facility/site	
☐ Railroad property	

Other Employers on Site

☐ General contractor	☐ Municipal or utility employee
☐ Client representative	☐ Another A/E type firm
☐ Equipment or material vendor	☐ Government regulator or inspector
☒ Subcontractor	☐ Not applicable
☐ Building or site owner or manager	☐ Other(s) (explain) _____
☒ General public	

Scope and Budget Considerations

Labor and other direct costs for SH&E staff (full time and part-time)		
a.	Staffing/time for SH&E document development, review, and updates	☒
b.	Staffing/time for SH&E audits and inspections	☒
c.	Staffing/time for evaluating subcontractor SH&E conformance	☒
Site access and security requirements		
a.	Background checks/ e-rail security badges for railroad sites	☐
b.	Government clearance protocols	☐
c.	Other client/contract-required access requirements (fencing, signage, etc.)	☐
Environmental programs and/or permits		
a.	Archeological and cultural resources	☐
b.	Storage, use, handling, and disposal of hazardous waste/hazardous materials	☐
c.	Surface and ground water quality (spill prevention/response, storm water management)	☐
d.	Dewatering or other water discharge activities	☐
e.	Earth work (e.g. cleaning, grading, drilling, excavation)	☐
f.	Air quality (equipment emissions, dust generation)	☐
g.	Pollution prevention and waste minimization	☐
h.	Biological resources (wetlands/sensitive habitats)	☐
i.	Environmental permits that may be required prior to performance of work	☐
Medical Clearance/Vaccinations		
a.	Chemical-specific exposure monitoring (asbestos, lead, etc.) List:	☐
b.	Hazardous Waste Operations and Emergency Response (HAZWOPER) (annual/biennial physical exams_	☐
c.	Hearing Conservation Program (annual audiograms for noise exposure)	☐
d.	Respirator clearance	☐
e.	Rope access (biennial physical exams)	☐
f.	Hepatitis B vaccination (must be offered for assignments with exposure to blood/bodily materials)	☐
g.	Other (e.g., rabies vaccination, travel vaccinations)	☐

Personal Protective Equipment					
a.	Chemical Protective Clothing	☐	g.	Hardhat	☐
b.	Eyewear	☐	h.	Hearing Protection	☐
c.	Fall Protection	☐	i.	High Visibility Clothing (safety vests)	☐
d.	Flame Resistant Clothing	☐	j.	Personal Flotation Devices	☒
e.	Footwear	☐	k.	Respirator	☐
f.	Gloves	☐	l.	Hearing protection	☐
Other Equipment/Supplies					
a.	Portable fire extinguisher	☐	f.	Lighting	☐
b.	First aid kits/supplies	☒	g.	Traffic control	☐
c.	Exposure monitoring instruments	☐	h.	Barrier/shields	☐
d.	Communication equipment	☒	i.	Other	☐

Exposure Monitoring and Associated Equipment		
a.	Chemical	☐
b.	Noise (including pile driving, riding in non-commercial aircraft)	☐

c. Radiation (including nuclear gauge, XRF)	☐
Drug and Alcohol Testing (pre-assignment, random, post-accident, for cause, etc.)	☐
Rewards and Recognition	☐

STOP WORK AUTHORITY

All staff have the authority and responsibility to STOP work when a potential hazard has been identified.

PROJECT NAME:	
PROJECT NUMBER:	
DATE OF OBSERVATION:	**TIME:**
EMPLOYEE OBSERVING:	
LOCATION ON PROJECT SITE:	
DESCRIPTION OF OBSERVED POTENTIALLY UNSAFE CONDITION:	
CHANGES MADE TO CORRECT THE HAZARD:	
WORK RESUMED AT (DATE/TIME):	

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B

Project Site Maps

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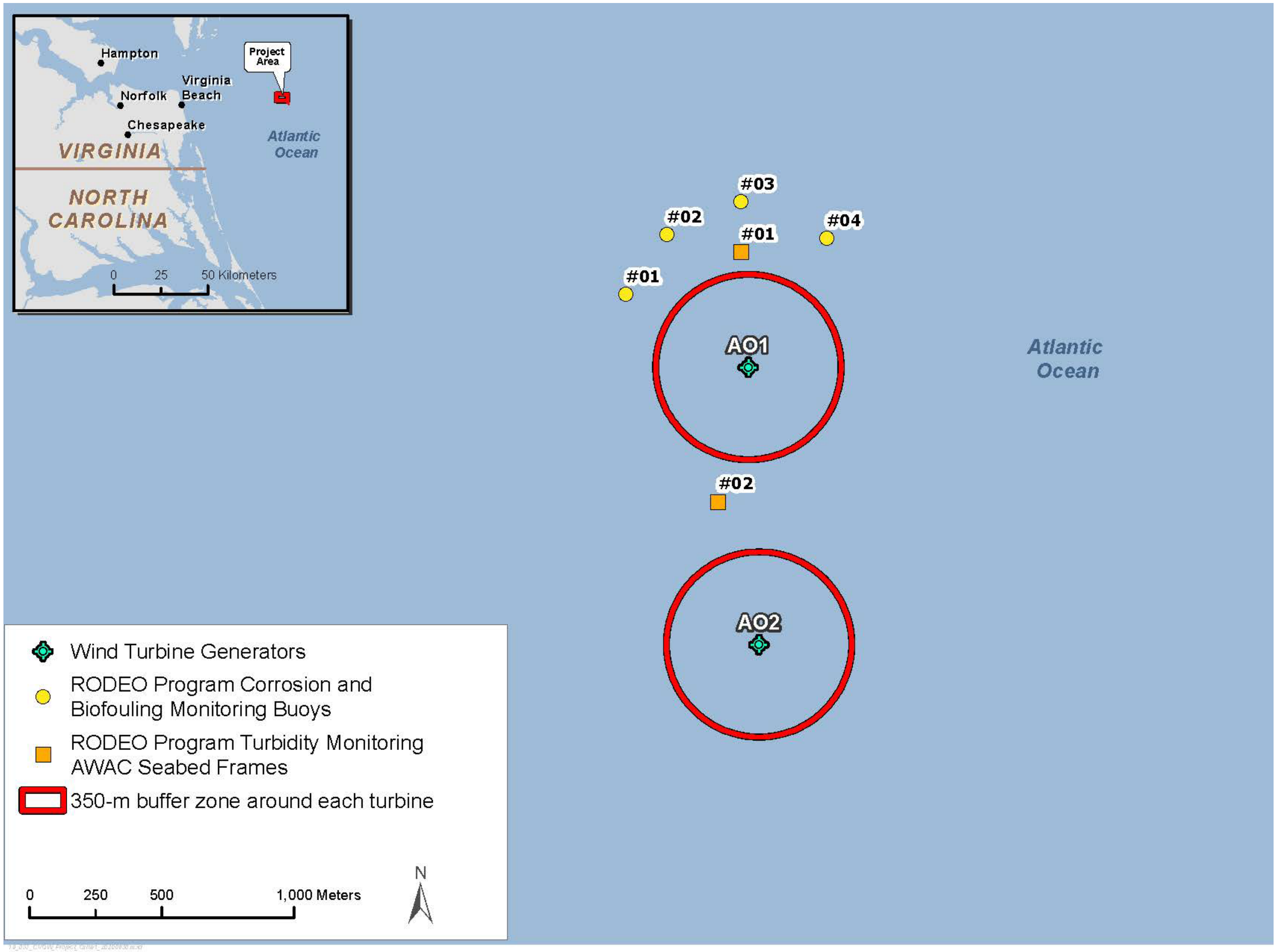
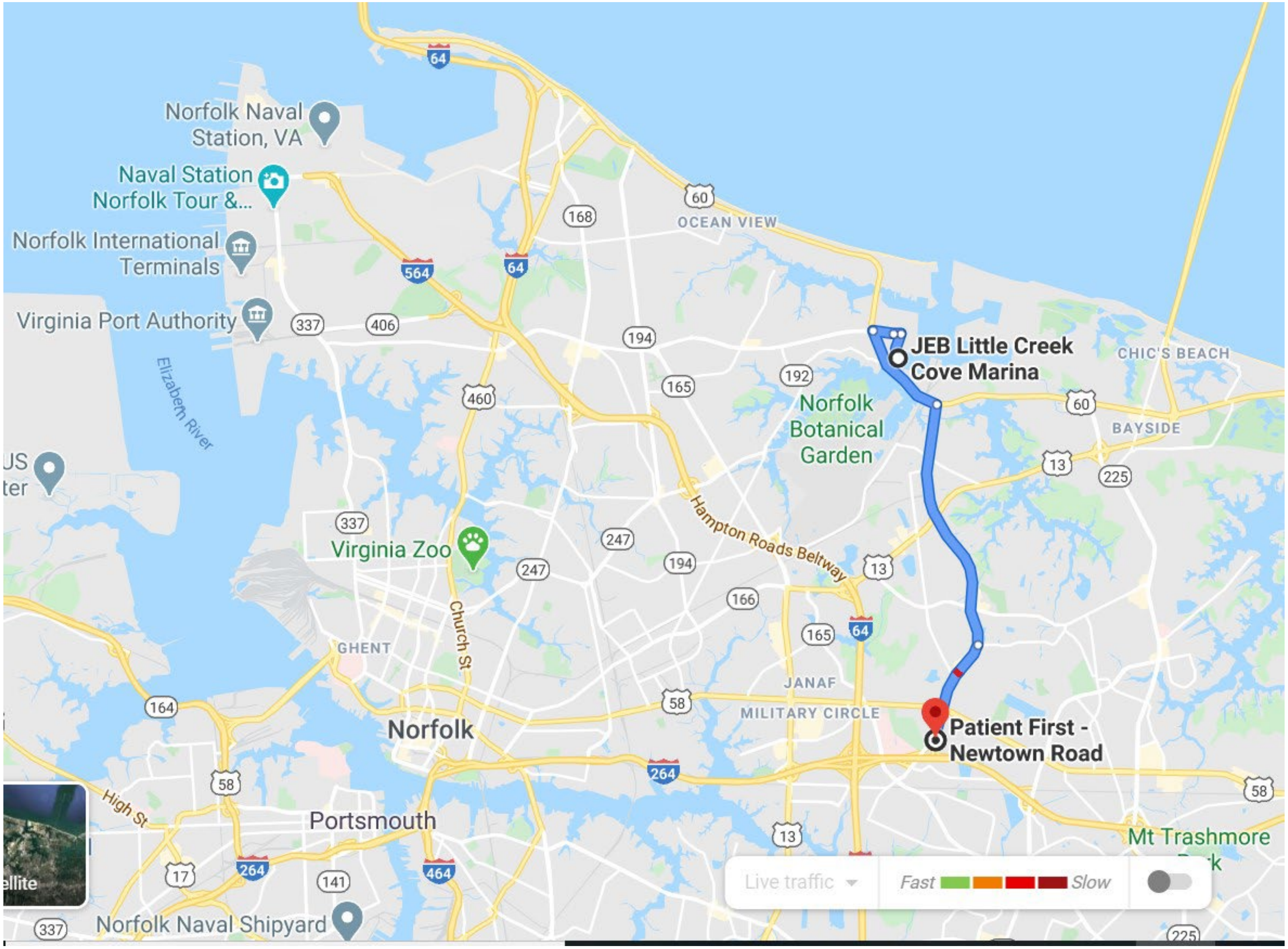


Data Source: ESRI Streetmap 2010

Proposed Wind Turbine and RODEO Program Monitoring Buoy Locations off the Coast of Virginia



Map of the designated non-emergency medical facility (Patient First, Virginia Beach) in relation to JEB Little Creek Marina.

Google Maps JEB Little Creek Cove Marina to Patient First - Newtown Road

Drive 6.1 miles, 14 min

JEB Little Creek Cove Marina
1101 Okinawa Rd bldg 1517, Virginia Beach, VA 23459

Take Amphibious Dr and Midway Rd to US-60 E/Shore Dr

3 min (0.7 mi)

1. Head southwest on Okinawa Rd toward Amphibious Dr
   ⚠ Restricted usage road

   62 ft
2. Turn right onto Amphibious Dr
   ⚠ Restricted usage road

   0.3 mi
3. Turn left at Midway Rd
   ⚠ Restricted usage road

   479 ft
4. Continue onto Midway Rd
   ⚠ Restricted usage road

   0.2 mi

Take Diamond Springs Rd to Cleveland St in Norfolk

12 min (5.4 mi)

5. Turn left onto US-60 E/Shore Dr

   1.2 mi
6. Turn right onto Diamond Springs Rd
   Pass by Little Caesars Pizza (on the right in 2.5 mi)

   3.0 mi
7. Continue onto Newtown Rd
   Pass by McDonald's (on the right in 1.1 mi)

   1.2 mi

Continue on Cleveland St to your destination in Virginia Beach

49 s (0.1 mi)

8. Turn left after Wendy's (on the right)

   394 ft
9. Turn right
   Destination will be on the left

   200 ft

Patient First - Newtown Road
332 Newtown Rd, Virginia Beach, VA 23462

Driving Directions to the designated non-emergency medical facility (Patient First, Virginia Beach) from JEB Little Creek Marina.

C

Vessel Description

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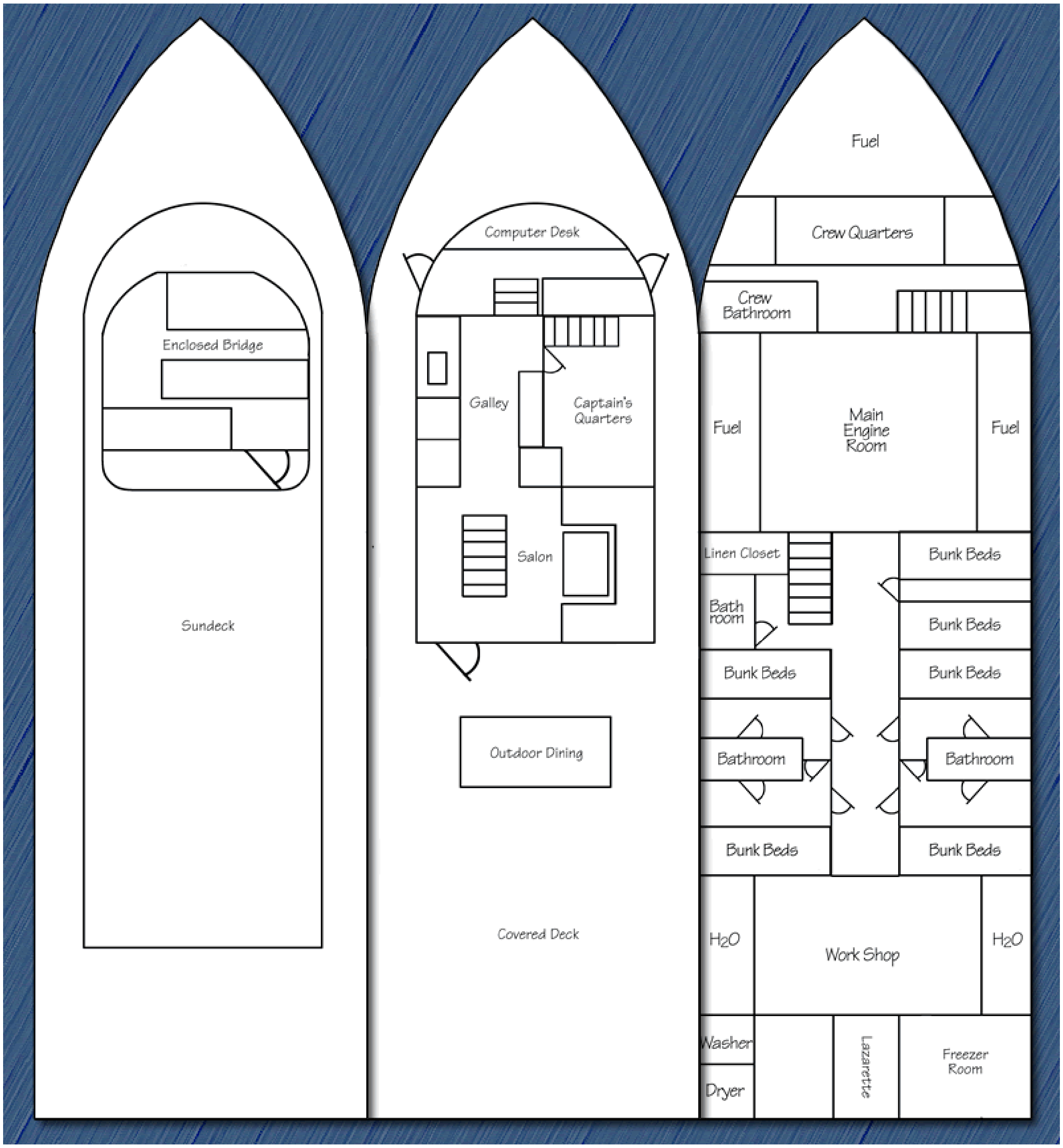
The vessels planned for use on this project are TBD, but will be similar to those chartered in the past from Tiki Adventures, located at 12928 Swordfish Drive, Ocean City, MD 21842 (410-713-1623). As an example, the 80-foot steel trawler Tiki XIV is equipped with a custom built 17-foot Carolina Skiff that swings off the deck.

A layout of the vessel is shown below:



Tiki XIV Layout

A smaller vessel, the *R/V* Integrity (or similar) may also be used.

D

Job Hazard Analysis

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JOB HAZARD ANALYSIS

DEPLOYMENT AND RETRIEVAL OF UNDERWATER ACOUSTIC MONITORING SYSTEMS

<table>
<tr><td>Date Prepared:</td><td>06 January 2020</td><td colspan="6">Overall Risk Assessment Code (RAC) (Use highest code)</td><td>M</td></tr>
<tr><td>Project Name:</td><td>Field Observations During Offshore Wind Structure Installation</td><td colspan="7">Risk Assessment Code (RAC) Matrix</td></tr>
<tr><td>Project Location:</td><td>Offshore from Norfolk, VA</td><td colspan="2" rowspan="3">E =Extremely High Risk
H = High Risk
M =Moderate Risk
L =Low Risk</td><td colspan="5">Probability (P)</td></tr>
<tr><td>Project Number:</td><td>10101137</td><td rowspan="2">Frequent (F)</td><td rowspan="2">Likely (L)</td><td rowspan="2">Occasional (O)</td><td rowspan="2">Seldom (S)</td><td rowspan="2">Unlikely (U)</td></tr>
<tr><td>Prepared by (Name/Title)::</td><td>Anwar Khan</td></tr>
<tr><td>Reviewed by (Name/Title):</td><td>Elizabeth Keigher</td><td rowspan="4">Severity (S)</td><td>Catastrophic (C)</td><td>E</td><td>E</td><td>H</td><td>H</td><td>M</td></tr>
<tr><td colspan="2" rowspan="5">Task Description: Vessel based equipment deployment, servicing, and retrieval and recording of environmental observations</td><td>Critical (Cr)</td><td>E</td><td>H</td><td>H</td><td>M</td><td>L</td></tr>
<tr><td>Marginal (M)</td><td>H</td><td>M</td><td>M</td><td>L</td><td>L</td></tr>
<tr><td>Negligible (N)</td><td>M</td><td>L</td><td>L</td><td>L</td><td>L</td></tr>
<tr><td colspan="7">RAC is developed after correctly identifying all hazards and fully implementing all controls.
Step 1: Review each “Hazard” with identified safety “Controls” and determine RAC
– P “Probability” is the likelihood to cause an incident, near miss, or accident.
– S “Severity” is the outcome if an incident, near miss, or accident did occur
Step 2: Identify RAC for each “Hazard” and indicate overall highest RAC at the top of AHA</td></tr>
</table>

Job Steps	Hazards	Controls	P	S	RAC
1. Gather Tools and Equipment	1.2 Equipment Malfunction/Failure	1.1.1 Inspect equipment and ensure available (GPS and navigator, Depth sounder / fish finder (available on the boat), Marine and VHF radio, Satellite telephone (optional), Camera equipment, Laser range finders, PFD’s, Personal gear – hats, gloves, sunglasses, etc., Water and food for the day)	S	M	L
2. Load Equipment on Truck	2.1 Load equipment to bed and cab of truck: Loads and Environment.	2.1.1. Assess the load, weight/ size and shape 2.1.2. Assess the conditions 2.1.3. Assess the number of people required 2.1.4. Assess the distance to be travelled 2.1.5. All staff who are required to manually handle loads shall be trained in manual handling techniques 2.1.6. Staff shall be rotated and given frequent breaks when manually handling loads for long period during their work activities. 2.1.7. Check that the route of travel is free from obstructions and	S	M	L

Job Steps	Hazards	Controls	P	S	RAC
		hazards before the movement starts. 2.1.8. Hand protection shall be worn.			
3. Drive to port with gear and equipment/ Mobilization to Project Sit	3.1. Vehicle Safety	3.1.1. HDR employees who may be using a motor vehicle for HDR company business should read and become familiar with HDR H&S Procedure #32, Defensive Driving, and the HDR Vehicle Policy. Defensive Driving courses are encouraged and are offered through most State motor vehicle departments. 3.2.1. All HDR employees using a vehicle on company business shall hold a valid driver's license. This license must be in the vehicle that is being driven. 3.3.1. Drivers shall not be under the influence of alcohol 3.4.1. Avoid driving while fatigued. Methods for fighting fatigue include pulling to the side of the road and resting, rolling down the windows and turning up the radio. 3.5.1. Take extra care while backing. Use a spotter to help you back up safely if necessary. Do not rely just on mirrors. 3.6.1. Do not exceed speed limit2.1.1Seat belts will be worn at all times when driving and rules of the road will be obeyed while engaged in company business.	U	CR	L
4. Crew to unload gear and board vessel	4.1 Loads and Equipment	4.1.1 See Controls of 2.1	S	M	L
	4.2 Slips Trips and Falls	4.2.1 Caution will be exercised to prevent slips on rain-slick surfaces, stepping on sharp objects, etc. Work will not be performed on elevated platforms without fall protection PPE. Check soles of boots and shoes for wear. Footwear should have soles that provide good traction.	S	Cr	M
	4.3 Over Water Work / Drowning	4.3.1 All personnel on a boat, barge, and on the docks will be required to wear a Personal Flotation Device (Type V minimum) 4.3.2 Complete review and training on HDR H&S Procedure #18, Water and Boating Safety 4.3.3 If protected from falling into the water by a guardrail or other means, a PFD is not required unless you are working alone at night 4.3.4 If wading into shallow water, waders must be worn in addition to a PFD 4.3.5 Rescue buoy (life ring) is readily available 4.3.6 Use the water safety checklist located in H&S Procedure #18 4.3.7 A skiff needs to be in place and ready for rescue 4.3.8 If working in swift moving water, complete additional swift water rescue training	S	Cr	M

Job Steps	Hazards	Controls	P	S	RAC
	4.4 Pinching and Crushing	4.4.1 Care will be taken by field employees when working with boats coming in and out of wharves to prevent pinching or crushing of body parts during operations	U	Cr	L
5. Deploy underwater monitoring devices • • Retrieve recorders for servicing and redeploy if required • • Record field data and acoustic measurements	5.1. Electrical Equipment Hazards	5.1.1. Personnel should assume all electrical equipment is live with current and caution should be taken to avoid any contact with electrical equipment. Electrical dangers can include short-circuit arcing faults and shock or electrocution.	U	CR	L
6. Off Shore Boating	6.1. Deterioration of weather conditions. High Winds and Rain and/or Storms	6.1.1. In case of extreme weather, vessel operations may cease or be delayed	S	Cr	M
	6.2 Hypothermia	6.2.1. Personnel will dress appropriately and regulate body temperature to avoid cold stress 6.2.2. Personnel shall review controls in SH&E Plan. 6.2.3. If the water and the air temperature do not add up to at least 110° Fahrenheit, a float coat or suit is required to be worn in addition to the PFD	U	Cr	M
	6.3 Heat Disorders	6.3.1. Personnel will dress and hydrate appropriately to avoid heat disorders 6.3.2. Personnel shall review controls in SH&E Plan	U	Cr	M

Equipment Requirements	Training Requirements	PPE Requirements
• GPS and Navigator • Depth sounder / fish finder (available on the boat) • Marine and VHF radio • Satellite Telephone (optional) • Camera Equipment • Laser range finders	• HDR General Safety Awareness • HDR Decision Driving • HDR Disaster Communication • HDR Heat Stress • HDR Cold Stress • HDR PPE	• Pants • Sleeved Shirt • Sunglasses, as needed • Facial mask to prevent wind burn, as needed • Closed toe footwear • Sunscreen

• PFD's • Hard Hat • Personal gear (hats, gloves, sunglasses, etc.) • Water and food for the day	• HDR H&S Procedure #18 Water and Boating Safety	• Personnel Floatation Device (PFD).

JOB HAZARD ANALYSIS FORM

WORKING OVER OR NEAR WATER

Date	06 January 2020	Overall Risk Assessment Code (RAC) (Use highest code)							M
Project Name:	Field Observations During Offshore Wind Structure Installation and Operations, CVOW Project	Risk Assessment Code (RAC) Matrix							
Project Location:	Offshore from Norfolk, VA	E =Extremely High Risk H = High Risk M =Moderate Risk L =Low Risk		Probability (P)					
Project Number:	10101137			Frequent (F)	Likely (L)	Occasional (O)	Seldom (S)	Unlikely (U)	
Prepared by (Name/Title):	Anwar Khan								
Reviewed by (Name/Title):	Elizabeth Keigher	Severity (S)	Catastrophic (C)	E	E	H	H	M	
			Critical (Cr)	E	H	H	M	L	
			Marginal (M)	H	M	M	L	L	
			Negligible (N)	M	L	L	L	L	
		RAC is developed after correctly identifying all hazards and fully implementing all controls. **Step 1:** Review each "Hazard" with identified safety "Controls" and determine RAC – P "Probability" is the likelihood to cause an incident, near miss, or accident. – S "Severity" is the outcome if an incident, near miss, or accident did occur **Step 2:** Identify RAC for each "Hazard" and indicate overall highest RAC at the top of JHA							

Job Steps	Hazards	Controls	P	S	RAC
1. Driving in the vicinity of water ways.	1.1 Falls of vehicle into water.	1.1.1 Maintain a safe distance while driving near water. 1.1.2 Park parallel to water never facing towards it. 1.1.3 Obey mandatory site speed limit. 1.1.4 Carry out pre use checks of vehicle.	U	Cr	L
	1.2 Collision with vehicle/ workers.	1.2.1 Only employees with a valid driver's license for the type of vehicle should be allowed to drive 1.2.2 Use designated access roads only.	U	Cr	L

Job Steps	Hazards	Controls	P	S	RAC
		1.2.3 Follow defensive driving techniques. 1.2.4 Obey mandatory site speed limit.			
2. Arrival at site.	2.1 Falls on same level.	2.1.1 Ensure the use of appropriate foot wear. 2.1.2 Ensure that the area is free from waste/ scrap material. 2.1.3 Use designated walk ways only. 2.1.4 Walk two (2) meters away from the water. 2.1.5 Wear a life jacket while near or over water.	**U**	**Cr**	**L**
	2.2 Collision with plant.	2.2.1 Use designated walk ways only. 2.2.2 Never walk behind any moving plant. 2.2.3 Ensure Proper lighting is in place. 2.2.4 Ensure the use of a high visibility vest.	**U** **U**	**Cr** **Cr**	**L** **L**
3. Carrying out inspections within 2 (two) meters of the water's edge.	3.1 Falls on same level.	3.1.1 Ensure the use of appropriate foot wear. 3.1.2 Ensure that the area is free from waste/ scrap material. 3.1.3 Use designated walk ways only. 3.1.4 Ensure that edge protection is in place. 3.1.5 Wear a life jacket while near or over water.	**U**	**Cr**	**L**
	3.2 Fall Into Water	3.2.1 Ensure that edge protection is in place. 3.2.2 Maintain a safe distance from edge while walking.	**S**	**Cr**	**M**

Job Steps	Hazards	Controls	P	S	RAC
	3.3 Drowning.	3.3.1 Always wear a life jacket while working over or near water. 3.3.2 Ensure that rescue/ emergency procedures are in place. 3.3.3 Ensure that floatation devices are available around the area and in good condition. 3.3.4 Always use buddy system while working over or near water.	**U**	**Cr**	**L**
4. Transport on a shuttle boat.	4.1 Fall into water.	4.1.1 Always wait till the boat is secured and only then get on/ off the boat. 4.1.2 Standing on the boat while the boat is in motion is not permitted. 4.1.3 Always follow the instructions of the boat operator. 4.1.4 Life jackets must be worn while travelling on boat. 4.1.5 Ensure that the boat is not crowded/ over loaded.	**S**	**Cr**	**M**
5. Inspection of pier/ more structure.	5.1 Falls on same level.	5.1.1 Ensure the use of appropriate foot wear. 5.1.2 Ensure that the area is free from waste/ scrap material. 5.1.3 Use designated walk ways only. 5.1.4 Ensure that edge protection is in place. 5.1.5 Wear a life jacket while near or over water.	**U**	**Cr**	**L**
	5.2 Use of Ladder.	5.2.1 Refer to Portable Ladder Pro #2			

Job Steps	Hazards	Controls	P	S	RAC
	5.3 Falls from height.	5.3.1 Always maintain 3 point contact while using ladder. 5.3.2 Ensure stairs are clear from any obstruction & non slippery. 5.3.3 Ensure rungs of the ladder are clear of mud/grease & are not damaged. 5.3.4 Ensure proper footwear is worn and is free from mud/grease. 5.3.5 Ensure ladder extends 1 meter from the top landing platform. 5.3.6 Ensure ladder is safely positioned at 75 degree angle (1:4 ratio). 5.3.7 Do not carry a load on a ladder 5.3.8 Ensure that adequately illumination is provided on site. 5.3.9 Always face the ladder when climbing up or down	**U**	**Cr**	**L**
	5.4 Fall into water.	5.4.1 Ensure safe access & egress to the structure in line with local legislations. 5.4.2 Never lean on guard rails.	**U**	**Cr**	**L**
	5.5 Drowning.	5.5.1. Always wear a life jacket while working over or near water. 5.5.2 Ensure that rescue/ emergency procedures are in place. 5.5.3 Ensure that floatation devices are available around the area and in good condition. 5.5.4 Always use buddy system while working over or near water.	**U**	**Cr**	**L**

Equipment Requirements	Training Requirements	PPE Requirements
• Personal Protective Equipment.	• SH&E Site Induction.	• PPE to be inspected monthly. • All Employees are to report unsafe conditions as they are observed to their immediate supervisor and a project safety committee member. • Effort should be made to communicate findings to contractor.

My signature confirms I have read and understand this J/AHA and I will abide by the recommended controls		
Print Name	**Signature**	**Date**

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Appendix B: Maryland Meteorological Tower Supplementary Report

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Passive Acoustic Monitoring of Ocean Ambient Sound Levels Near the Meteorological Tower Installation Site in the Maryland Offshore Wind Energy Area

Final Report

February 2020

Aaron N. Rice and Daniel P. Salisbury
Center for Conservation Bioacoustics, Cornell Lab of Ornithology
Cornell University
Ithaca, NY 14850

and

Helen Bailey, David Secor, Caroline Wiernicki, and Amber Fandel
University of Maryland Center for Environmental Science
Chesapeake Biological Laboratory
Solomons, MD 20688

List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
CCB	Center for Conservation Bioacoustics, Cornell University
dB	Decibel (referenced to 1 μPa)
HF	High Frequency Band (1122-4470 Hz)
L_{eq}	Sound Level Equivalent
LF	Low Frequency Band (1.12-112 Hz)
LTSA	Long Term Spectral Average
MF	Mid Frequency Band (112-1122 Hz)
PAM	Passive Acoustic Monitoring
TB	Terabyte
TOB	1/3rd octave band
UMCES	University of Maryland Center for Environmental Science
UTC	Universal Time Coordinated

1. Objectives

Underwater sound impacts and sound propagation related to meteorological tower (hereafter referred to as met tower) and windfarm construction are unclear. With their high source level, pile driving sounds from offshore construction have the potential to propagate large distances (Bailey et al. 2010). For example, at an offshore wind installation site off of Scotland, source levels of wind turbine pile driving are >200 $dB_{p\text{-}p}$ and detectable out to <80 km (Bailey et al. 2010). Pile driving noise has the potential to disrupt the behavior of fishes and cetaceans in the area (e.g., Bailey et al. 2010, Casper et al. 2017, Halvorsen et al. 2012, Kastelein et al. 2016, Tougaard et al. 2009), and during the extended time course of construction activity, there is the potential for pile-driving to induce both acute and chronic impacts to organisms.

As part of the BOEM-funded RODEO effort (https://www.boem.gov/RODEO), Cornell University and the University of Maryland Center for Environmental Science (UMCES) were contracted by HDR to conduct cross-shelf archival passive acoustic monitoring associated with the met tower construction. Three recording sites were the same recording locations used in a previous PAM effort documenting whale occurrence and ambient noise levels around the Maryland Wind energy Area, and a fourth site was co-located with ongoing research to determine the effect of pile-driving of a meteorological tower on black sea bass (*Centropristis striata*). Additional concurrent recordings were made by URI, WHOI, and MAI, and those data are reported in separate reports.

Despite the fact that attempts were made to install the met tower in 2018 and 2019, the tower was never built due to a confluence of factors. The meteorological tower was transported from Louisiana to the site offshore of Maryland in late August to early September of 2019. US Wind communicated that they were on track for a September timeframe installation. Unfortunately, on September 26, 2019 US Wind communicated that due to contractual issues, they were cancelling the installation in 2019. As the meteorological tower was not installed during the project period, we are unable to report on the corresponding installation sound levels or the effect of the installation on black sea bass.

This report focuses on the acoustic recordings and sound levels obtained during summer 2019, which can inform our understanding of existing acoustic conditions and ambient noise levels in the wind planning area and be used in the future for planning and noise impact assessment purposes.

2. Cornell Data Collection

Acoustic data were collected using Cornell's Marine Autonomous Recording Units (MARUs). MARUs are a digital audio recording system contained in a positively buoyant 43 cm glass sphere, shown in Figure 1, that is deployed on the bottom of the ocean for periods of weeks to months (Calupca et al. 2000). A hydrophone mounted outside the sphere is the mechanism for acquiring sounds that are recorded and stored in a binary digital audio format on internal electronic storage media. The MARU can be programmed to record on a daily schedule and deployed in a remote environment, where it is held in place by an anchor, suspended approximately 2 m above the seafloor. At the conclusion of a deployment, the MARU is sent an acoustic command to release itself from its anchor and float to the surface for recovery, illustrated in Figure 2. After the recovery, the MARU data are extracted, converted into audio files and stored on a server for analysis. The unit is then refurbished (batteries and hard drive replaced, etc.) in preparation for a subsequent deployment. Data recorded by a MARU are thus accessible only after the device is retrieved. Deployed MARUs recorded at a 10 kHz sample rate with high-pass and low-pass filters set at 10 Hz and 4000 Hz, respectively, and a bit depth of 12 bits. The high-pass filter was implemented to reduce electrical interference produced by the MARU, while the low-pass filter reduced aliasing. The effective recording bandwidth of 10 Hz to 4000 Hz had a sensitivity of -168 dB (re: 1V/ μPa) with a flat frequency response ± 3.0 dB re 1 μPa.

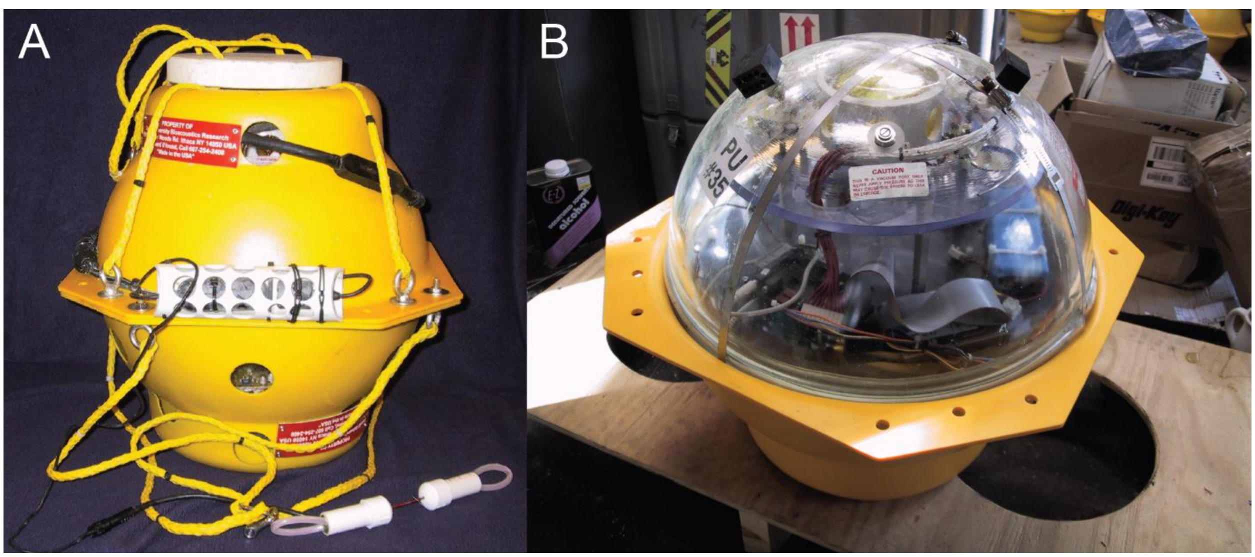

Figure 1. Detailed photographs of the MARU with A) External and B) Internal views.

Figure 2. Field operations photographs shown as: A) Cornell's research vessel used for deployment and recovery of recording equipment, the R/V Jaeger. B) The deck of the R/V Jaeger loaded with MARUs and AMARs. C) A field technician recovers a MARU. D) The recovered MARU is hauled on deck. Photo credits: Fred Channell (A); Kristin Hodge (B, C, D).

Deployment details are summarized in Table 1 below. Water depth was shallow and varied from approximately 20 m to 40 m for the deepest site T-3M. Deployment and recovery field operations were successful with no problems occurring during routine operational procedures. Units were deployed in the same locations (with the same names) as the UMCES-Cornell previously funded PAM effort around the wind energy area from 2014-2017 (Bailey et al. 2018).

Table 1: MARU deployment location details.

Site	Instrument ID	Latitude (°N)	Longitude (°W)	Water depth (m)
T-1M	PU212	38.303302	74.948370	20.1
T-2M	PU151	38.303091	74.504692	35.8
T-3M	PU211	38.343238	74.395900	40.3

MARUs collected a total of 3,360 hours of continuous acoustic data. Details on start/end dates and times for each site are listed in Table 2 and reported in UTC.

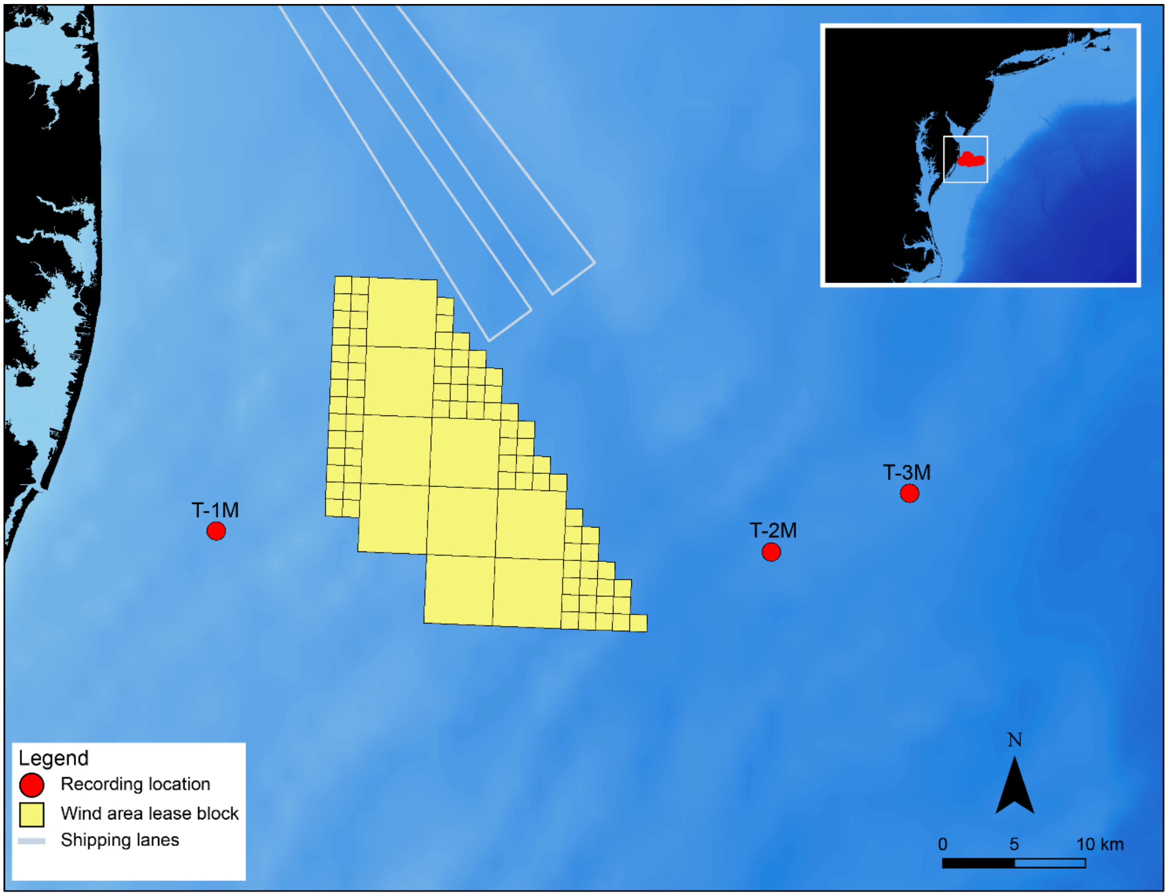

Figure 3. Deployment locations of the Cornell MARUs, September-October 2019 off the coast of Maryland, USA. Wind area lease blocks are shown as yellow squares.

Table 2: Deployment and recovery details on collected acoustic data sets. All data sampled at 10 kHz and 12-bit resolution. (Dates are given as MM-DD-YYYY, hh:mm:ss).

Site	Start [UTC]	End [UTC]	Hours Recorded
T-1M	08-29-2019, 12:57:15	10-15-2019, 08:11:00	1,123
T-2M	08-29-2019, 12:50:34	10-15-2019, 04:24:00	1,119
T-3M	08-29-2019, 12:42:13	10-15-2019, 03:32:00	1,118

The quality of the data collected was excellent and no issues (electronic noise, drop-outs, etc.) were detected during the manual Q/A process. All audio files were processed using the in-house developed Raven-X software package (Dugan et al., 2018). This Matlab-based package features parallelized data processing capabilities which enables users to process large audio archives at significantly improved throughput rates. Raven-X features a Noise Analyzer module (Dugan et al. 2016) which was used to calculate noise levels and distributions.

3. UMCES Data Collection

In 2018, UMCES had planned to deploy the acoustic recorder at a farther site that was 27 km from the meteorological tower location. However, the tower installation was delayed and in 2019 that farther site was no longer being studied for black sea bass. We therefore used the next most distant site available that included an acoustic telemetry array for black sea bass (PI: David Secor). We deployed an LS1 acoustic recorder (Loggerhead Instruments) at the site 38.2176 °N, -74.7635 °W (Figure 4), approximately 15 km south of the proposed meteorological tower location and 31 km from Ocean City, MD. The LS1 was deployed on June 7, 2019 on a mooring approximately 1.5 m above the ocean floor (Figure 5) attached to approximately 40 kg of weight plates. The hydrophone was programmed to a duty cycle of two minutes on and ten minutes off with a sensitivity of -180 dB V/µPa, a gain of 2.05 dB, and sampling rate of 48 kHz. The device was recovered on October 30, 2019.

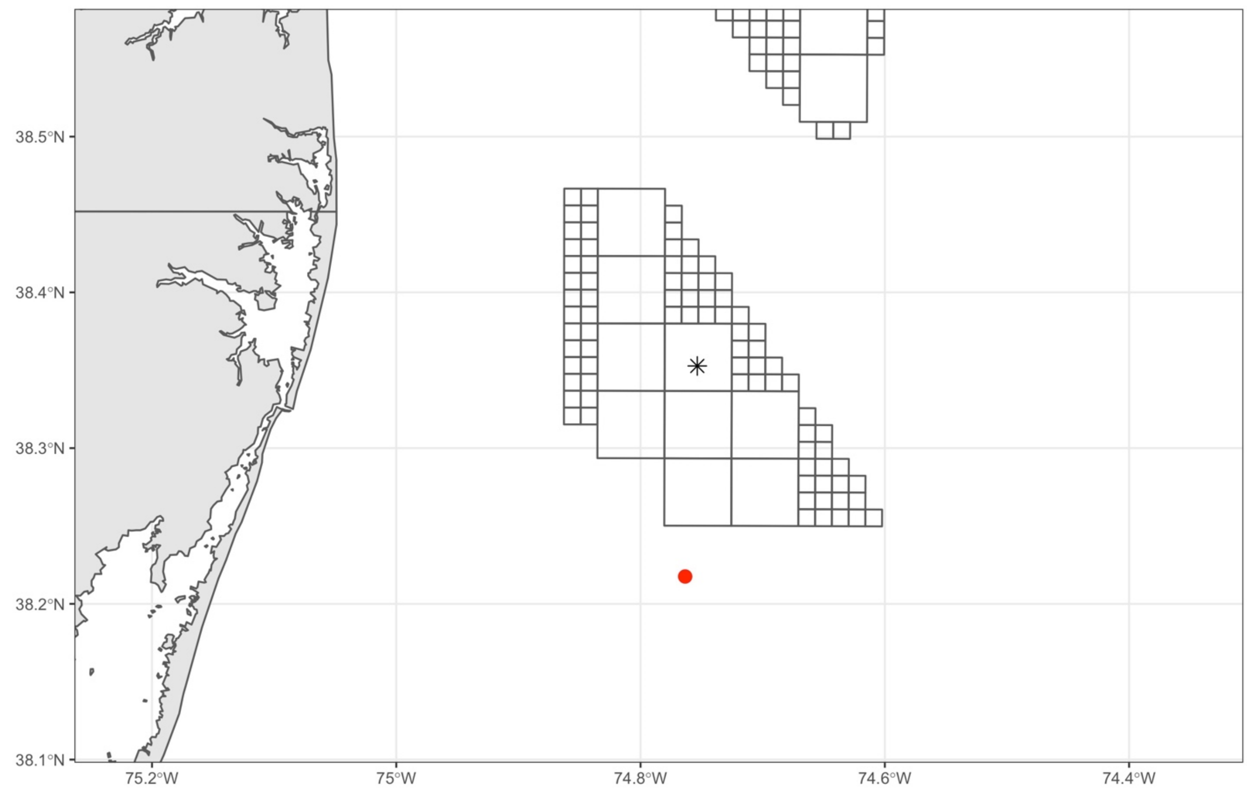

Figure 4. Location of LS1 hydrophone (red circle), located approximately 15 km from the proposed location of the meteorological tower (*) in the Maryland Wind Energy Area (black squares) offshore of Ocean City, Maryland.

Figure 5. Photograph of the mooring with the acoustic release at the bottom (on the left of the image), the LS1 acoustic recorder in the center of the line, and a sub-surface buoy at the top (on the right).

The LS1 instrument was predicted to record for 332 days with the given battery life and duty cycle. A total of approximately 783 GB of memory was available, and the size of a two-minute file was 0.01 GB. However, recording ceased early on September 3, 2019. The device likely ceased recording because the battery life was significantly less than predicted. We are investigating the cause of the early recording termination with the manufacturer.

To obtain measures of ambient sound levels, acoustic recordings from the LS1 were analyzed using PAMGUARD's Noise Monitor (Gillespie et al., 2008). The root-mean-square sound pressure levels (rms SPL) were calculated for both broadband (0-24 kHz) and low frequency sound (0-1 kHz). Measurements of the minimum, maximum, mean, and median for each band's sound pressure levels were calculated every minute, averaged for each hour, and then averaged as a daily sound level. To characterize the sound levels in this region, a generalized linear model (GLM) with Gaussian error distribution was used to determine variations in average hourly broadband and low frequency sound levels. Crepuscular (0400-0700 and 1900-2100) and non-crepuscular hours (all other hours) of the day were treated as a categorical explanatory variable. A GLM was also fitted to the daily average broadband and low frequency sound levels with day of the year as a linear and quadratic explanatory variable to determine whether there were significant changes in sound levels during the summer period.

4. Cornell Results – Ambient Sound Levels

Figure 6 summarizes the acoustic data collected at site T-1M between August 31, 2019 00:00 UTC and October 15, 2019 00:00 UTC. There are broadband "short duration" sounds between 100-1000 Hz, that start out strong and decrease in sound level over the course of the recording, likely due to diel shipping activity. There is another narrower band sound source at around 1500 Hz, of an unclear sound source.

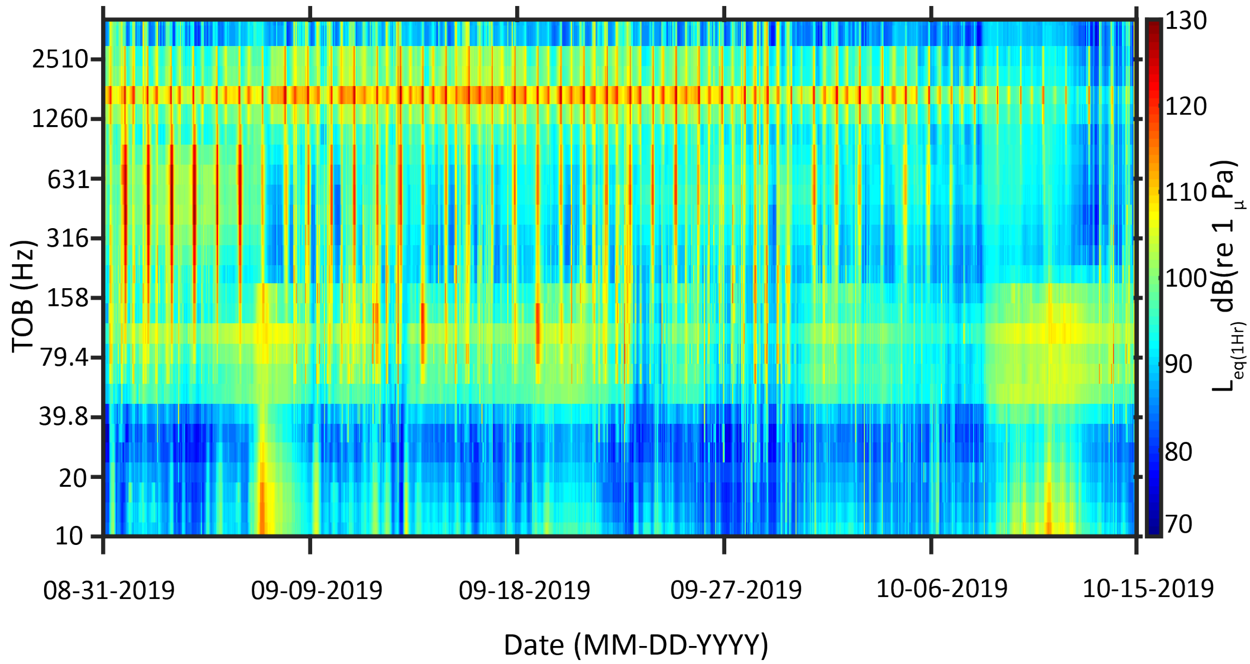

Figure 6. Long-term spectral average (LTSA) plot for Site T-1M based on hourly Leq levels measured in 1/3 octave frequency bands (TOB (Hz) from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

The cumulative distribution of hourly L_{eq} levels for the total bandwidth (1.12-4470 Hz) recorded at Site T-1M are illustrated in Figure 8. The 50th percentile levels were estimated at 112 dB re. 1μPa with a range of 103-136 dB re. 1μPa. Figure 8 shows the cumulative distribution of hourly L_{eq} levels for low-frequency (LF: 1.12-112 Hz), mid-frequency (MF: 112-1122 Hz) and high frequency (HF: 1122-4470 Hz). Median noise levels were highest in the high-frequency band (108 dB re. 1μPa) and lowest in the mid-frequency band (105 dB re. 1μPa).

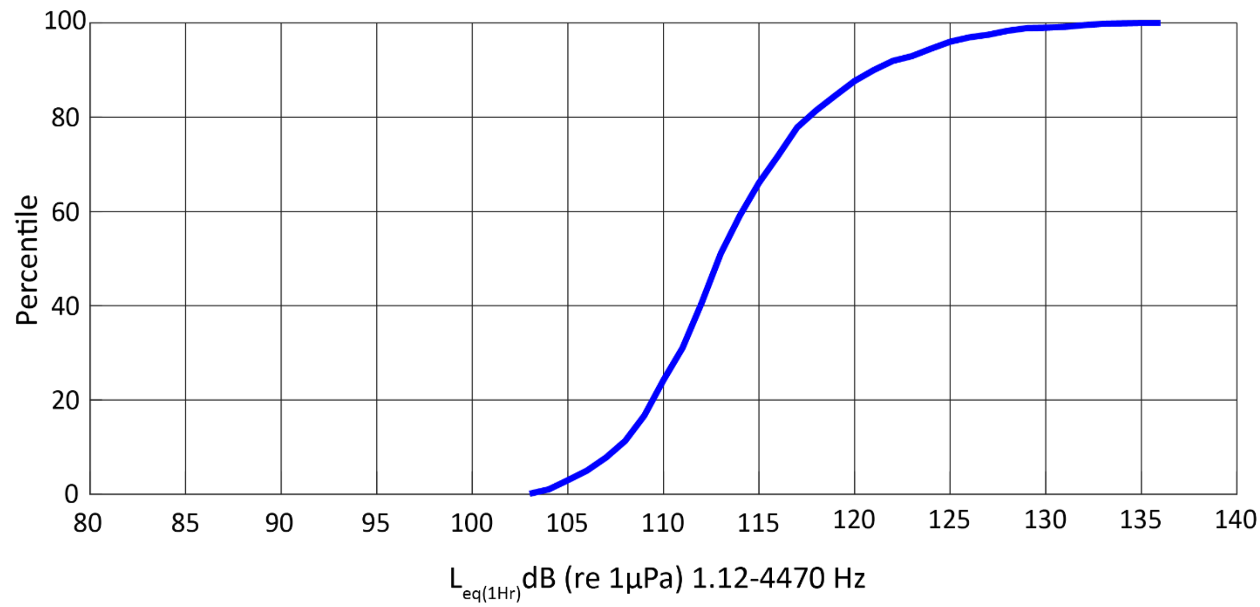

Figure 7. Cumulative distribution of hourly L_{eq} levels recorded at Site T-1M for the total recorded bandwidth from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

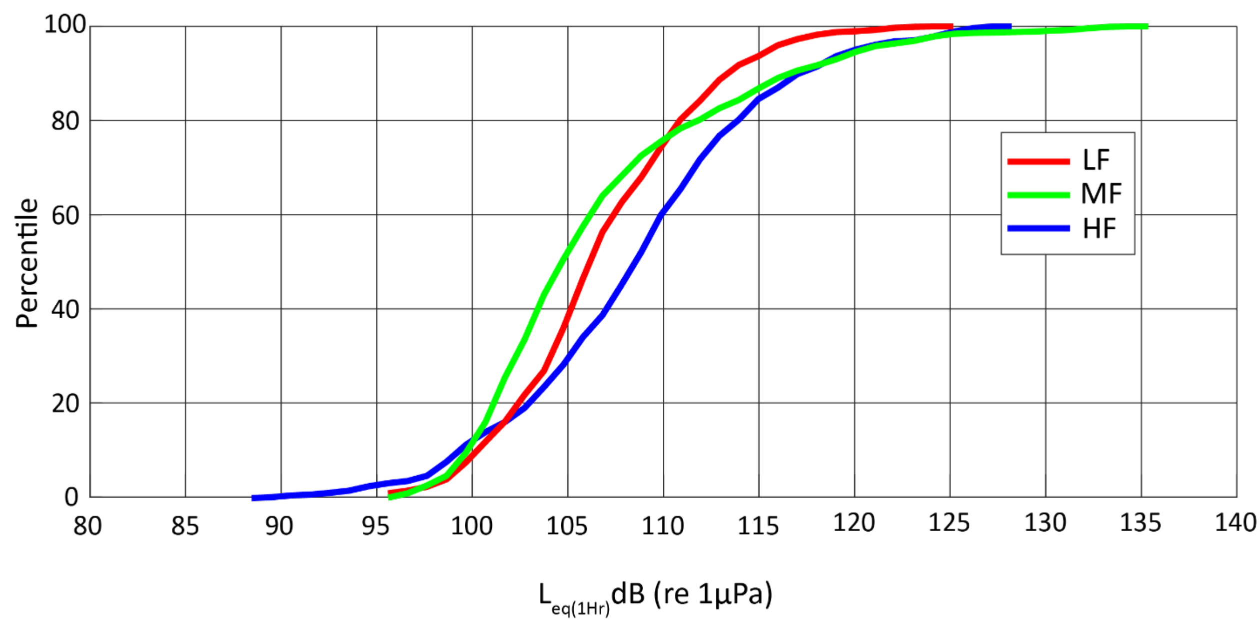

Figure 8. Cumulative distribution of hourly L_{eq} levels recorded at Site T-1M for the low (1.12-112 Hz), mid (112-1122 Hz) and high (1122-4470 Hz) frequency bands from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

Figure 9 summarizes the acoustic data collected at site T-2M between August 31, 2019 00:00 UTC and October 15, 2019 00:00 UTC and shows a difference in acoustic activity from site T-1M. The broadband sounds between 100-1000 Hz are not present, and the repeated sound at 1500 Hz has a lower sound level on T-2M. The acoustic event in October is due to storm activity.

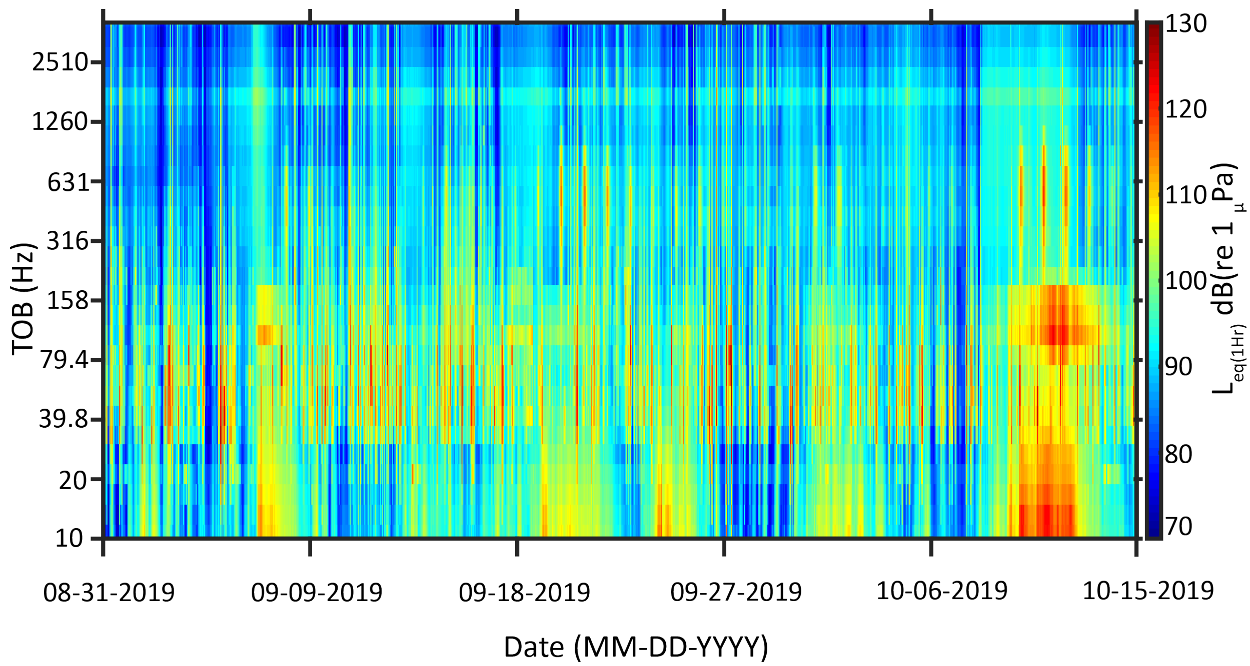

Figure 9. Long-term spectral average (LTSA) plot for Site T-2M based on hourly Leq levels measured in 1/3 octave frequency bands (TOB (Hz) from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

Cumulative distribution of hourly L_{eq} levels for the total bandwidth (1.12-4470 Hz) recorded at Site T-2M are illustrated in Figure 10. The 50th percentile levels were estimated at 112 dB re. 1µPa with a range of 94-135 dB re. 1µPa. Figure 11 shows percentiles of hourly L_{eq} levels for low-frequency (LF: 1.12-112 Hz), mid-frequency (MF: 112-1122 Hz) and high frequency (HF: 1122-4470 Hz). Differing from Site T-1M, median noise levels were highest in the low-frequency band (111 dB re. 1µPa) and lowest in the high-frequency band (95 dB re. 1µPa).

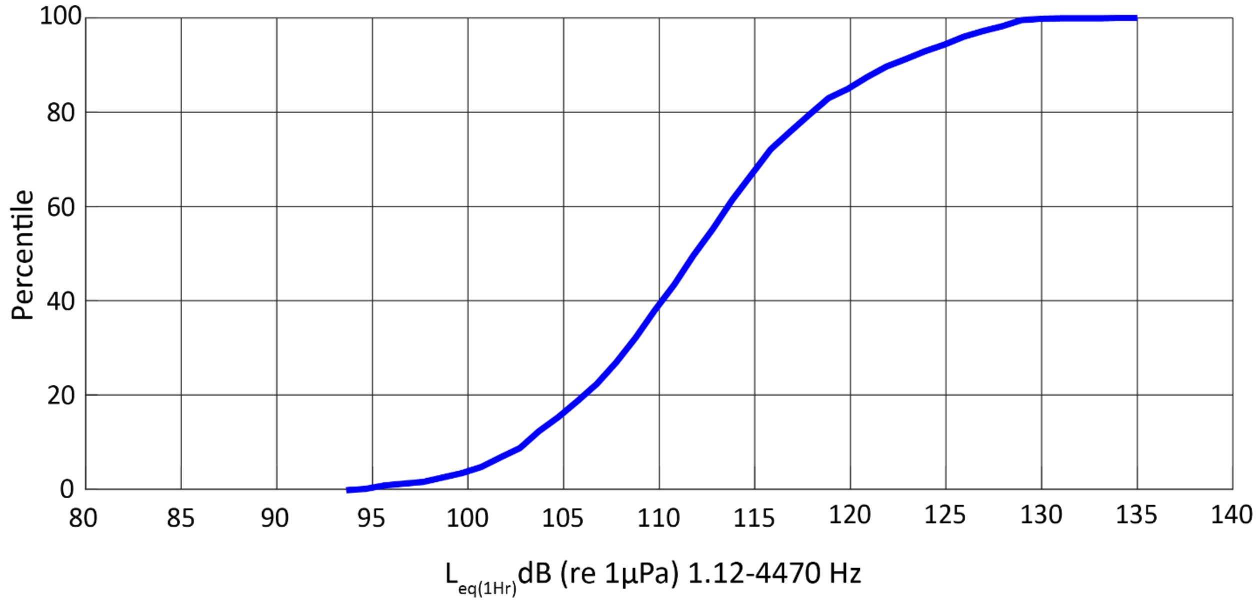

Figure 10. Cumulative distribution of hourly L_{eq} levels recorded at Site T-2M for the total recorded bandwidth from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

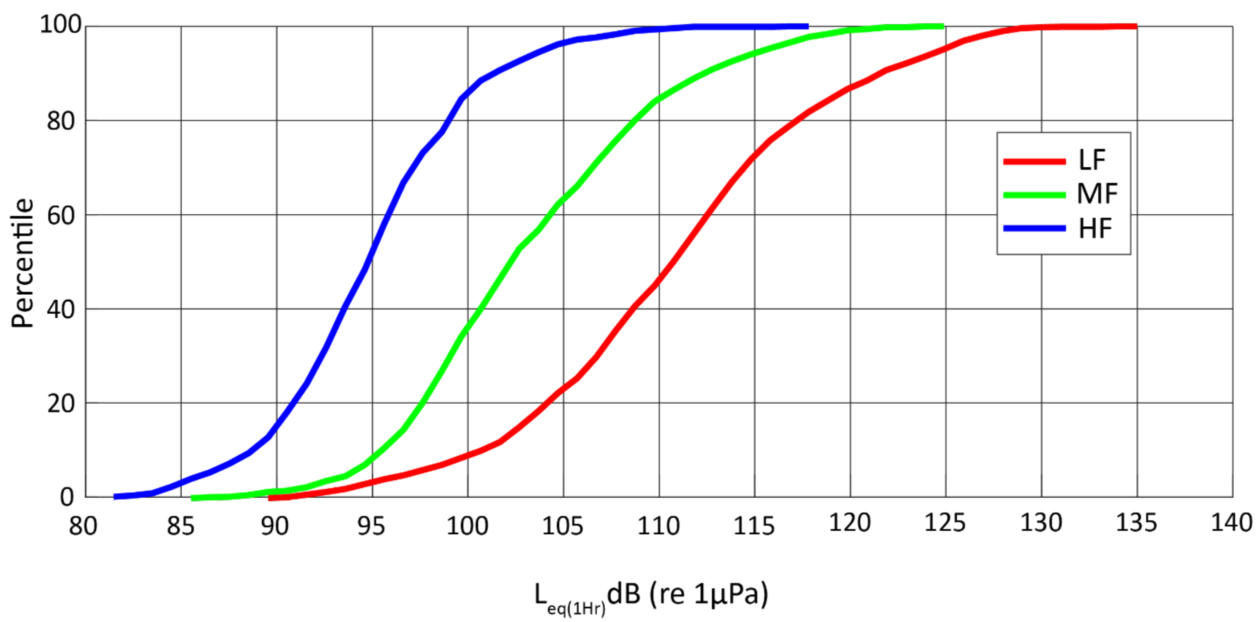

Figure 11. Cumulative distribution of hourly L_{eq} levels recorded at Site T-2M for the low (1.12-112 Hz), mid (112-1122 Hz) and high (1122-4470 Hz) frequency bands from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

Figure 12 summarizes the acoustic data collected at site T-3M between August 31, 2019 00:00 UTC and October 15, 2019 00:00 UTC.

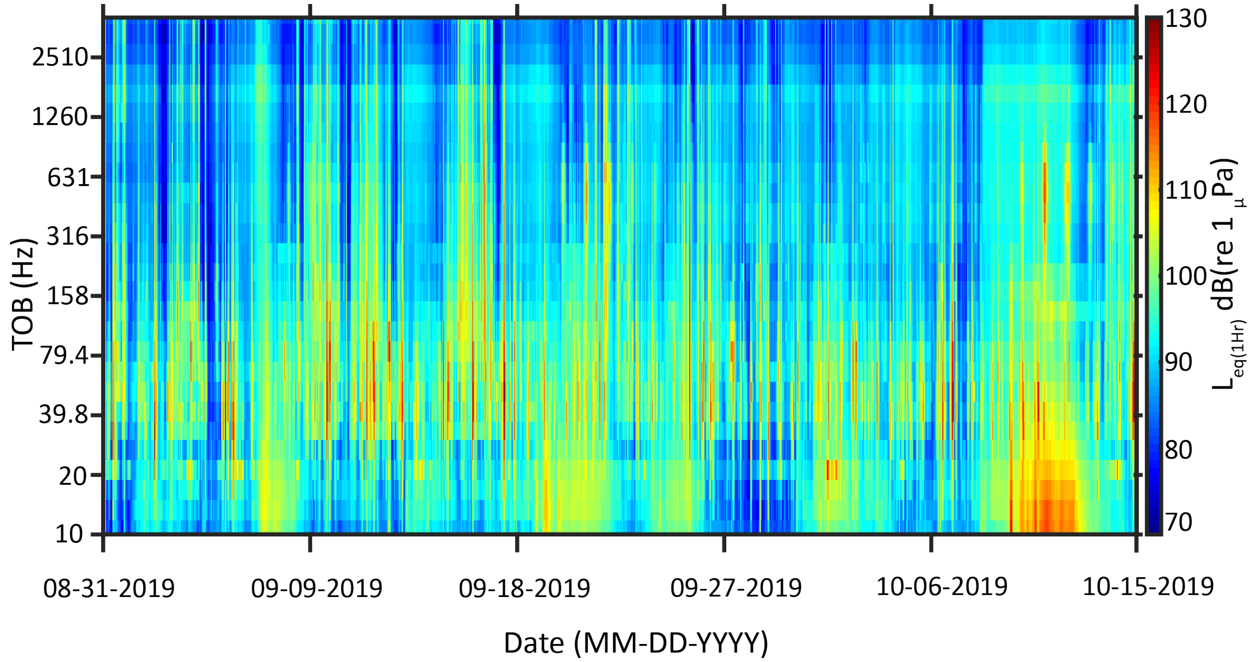

Figure 12. Long-term spectral average (LTSA) plot for Site T-32M based on hourly Leq levels measured in 1/3 octave frequency bands (TOB (Hz) from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

The cumulative distribution of hourly L_{eq} levels for the total bandwidth (1.12-4470 Hz) recorded at Site T-3M are illustrated in Figure 13. The 50th percentile levels were estimated at 110 dB re. 1µPa with a range of 93-135 dB re. 1µPa. Figure 14 shows percentiles of hourly L_{eq} levels for low-frequency (LF: 1.12-112 Hz), mid-frequency (MF: 112-1122 Hz) and high frequency (HF: 1122-4470 Hz). Similar to Site T-2M, median noise levels were highest in the low-frequency band (107 dB re. 1µPa) and lowest in the high-frequency band (94 dB re. 1µPa).

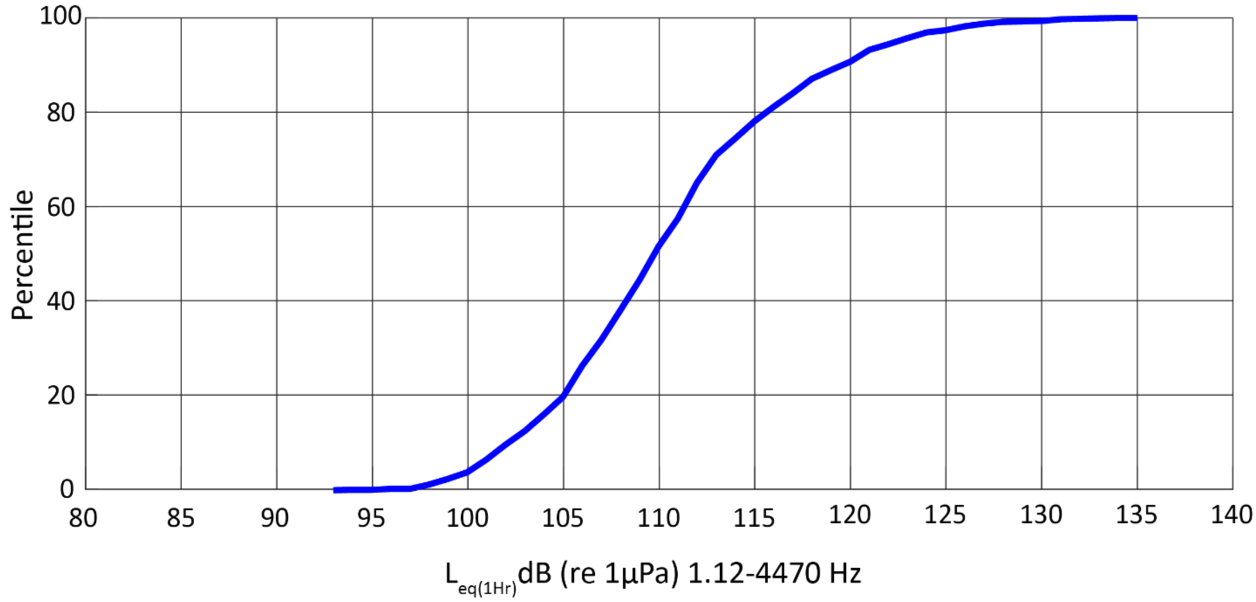

Figure 13. Cumulative distribution of hourly L_{eq} levels recorded at Site T-3M for the total recorded bandwidth from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

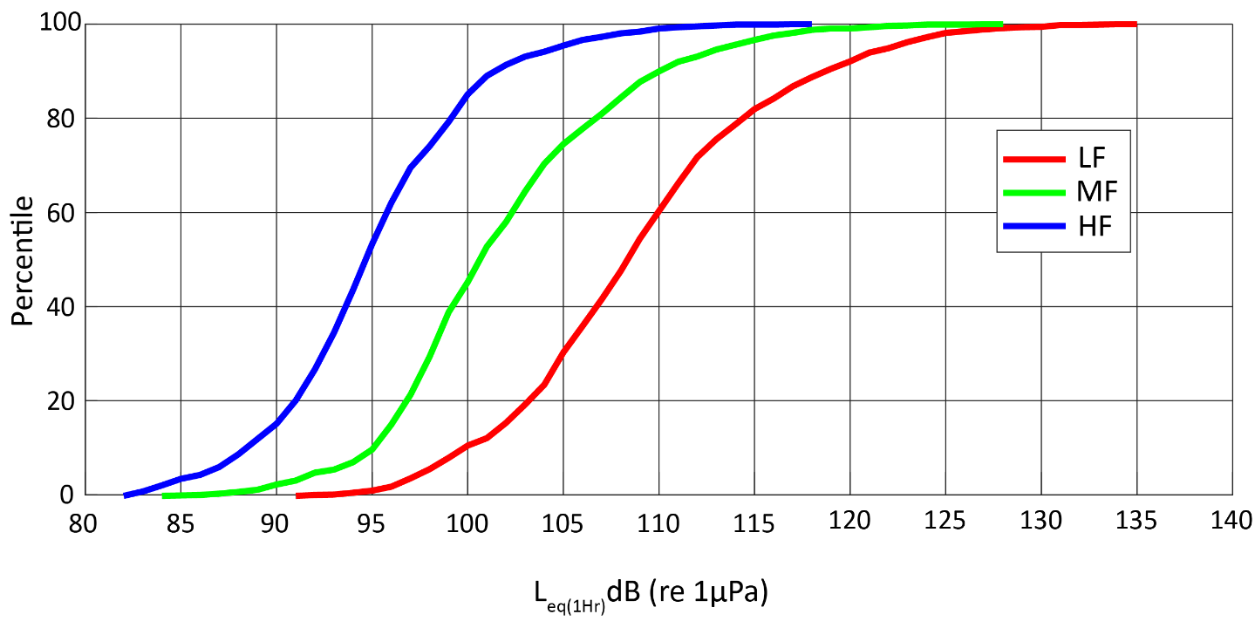

Figure 14. Cumulative distribution of hourly L_{eq} levels recorded at Site T-3M for the low (1.12-112 Hz), mid (112-1122 Hz) and high (1122-4470 Hz) frequency bands from August 31, 2019 00:00 – October 15, 2019 00:00 UTC.

In a comparison of sound levels across locations, the average power spectrum density (PSD) levels by site are shown in Figure 15. The shallowest Site T-1M has a different noise pattern across the entire frequency range, with median dB values much lower than the other sites in the 20-50 Hz range. It deviates again from the other sites in the mid-frequency range of around 1000 Hz, where it is about 5 dB louder and at a peak of 85 dB around 1800 Hz. Site T-2M and Site T-3M measured similar patterns of noise levels throughout the total frequency range (Figure 16).

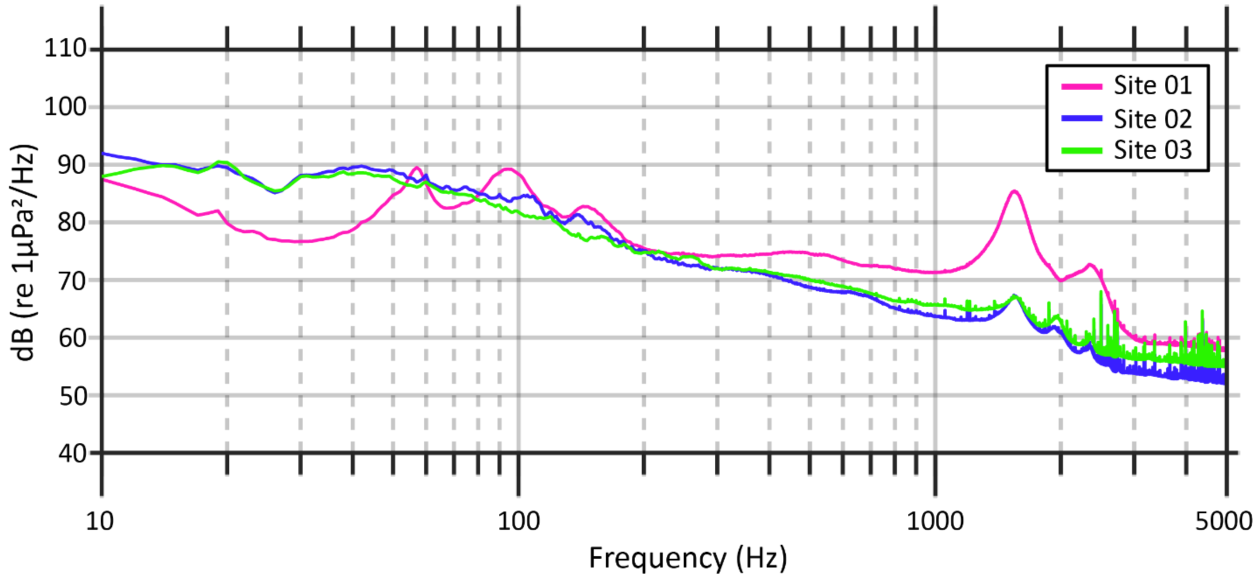

Figure 15. Average power spectrum density (PSD) levels by site.

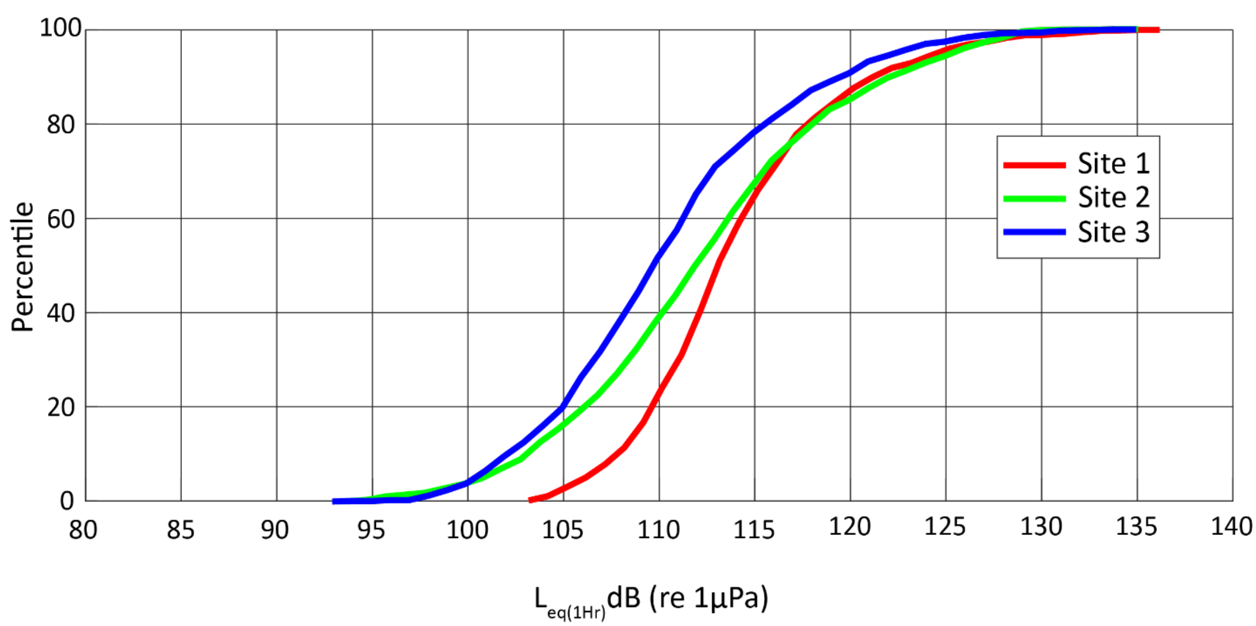

Figure 16. Cumulative distribution of full-band acoustic energy at each location.

5. UMCES Results

Acoustic data were collected for 88 days during 7 June – 3 September 2019. The majority of ambient noise was at low frequencies (<1 kHz), even on days with lower sound levels (Figure 17). The minimum hourly sound levels were 95.6 dB re 1 µPa rms (sd = 0.3, broadband) and 93.9 dB re 1 µPa rms (sd = 0.35, low frequency) at 0400 on July 22, and maximum hourly sound levels were 125.1 dB re 1 µPa rms (sd = 7.7) for both broadband and low frequencies at 0600 on August 13 (Figure 18). The higher hourly sound levels tended to be caused by boat noise.

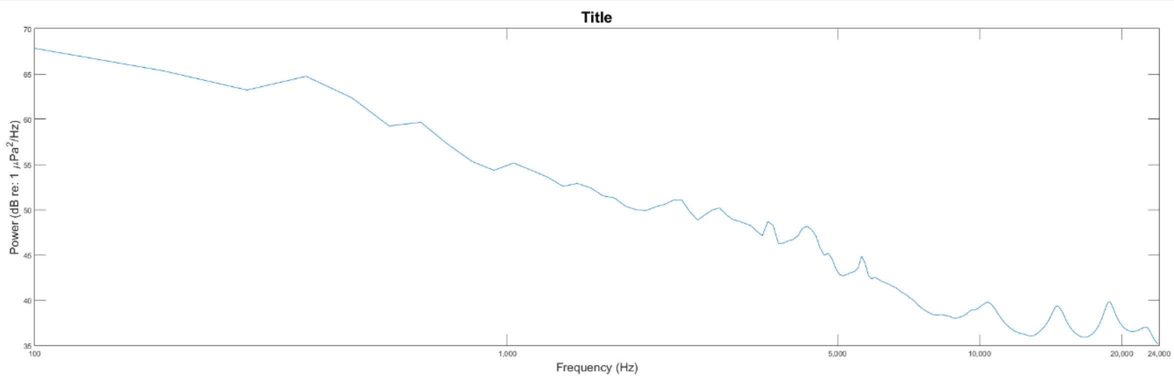

Figure 17. Power spectral density for a day with relatively low ambient noise levels (15 July 2019).

The mean daily broadband sound level was 108.0 dB re 1 µPa rms (sd = 5.3) and the daily low frequency sound levels was 107.1 dB re 1 µPa rms (sd = 5.7). The minimum daily sound levels were 101.5 dB re 1 µPa rms (sd = 5.4, broadband) and 100.5 dB re 1 µPa rms (sd = 5.8, low frequency) on 15 July and the maximum average daily sound levels reached 121.1 dB re 1 µPa rms (sd = 1.5, broadband) on August 30 and 121.0 dB re 1 µPa rms (sd = 0.9, low frequency) on August 31. Tropical Storm Erin passed through the area on August 15. There were also several high wind conditions in mid-July and late August. Higher daily sound levels occurred when there were high wind conditions and storms but were also attributed to boat noise.

The results of the GLM indicated that sound levels were significantly higher during crepuscular hours for both the broadband ($p < 0.01$; Table 3, Figure 4b) and low frequency bands ($p < 0.01$; Figure 18d). The daily sound level showed a rapid increase in sound levels during the recording period from mid-July through August ($R^2 = 0.838$, $p < 0.01$; Figure 19).

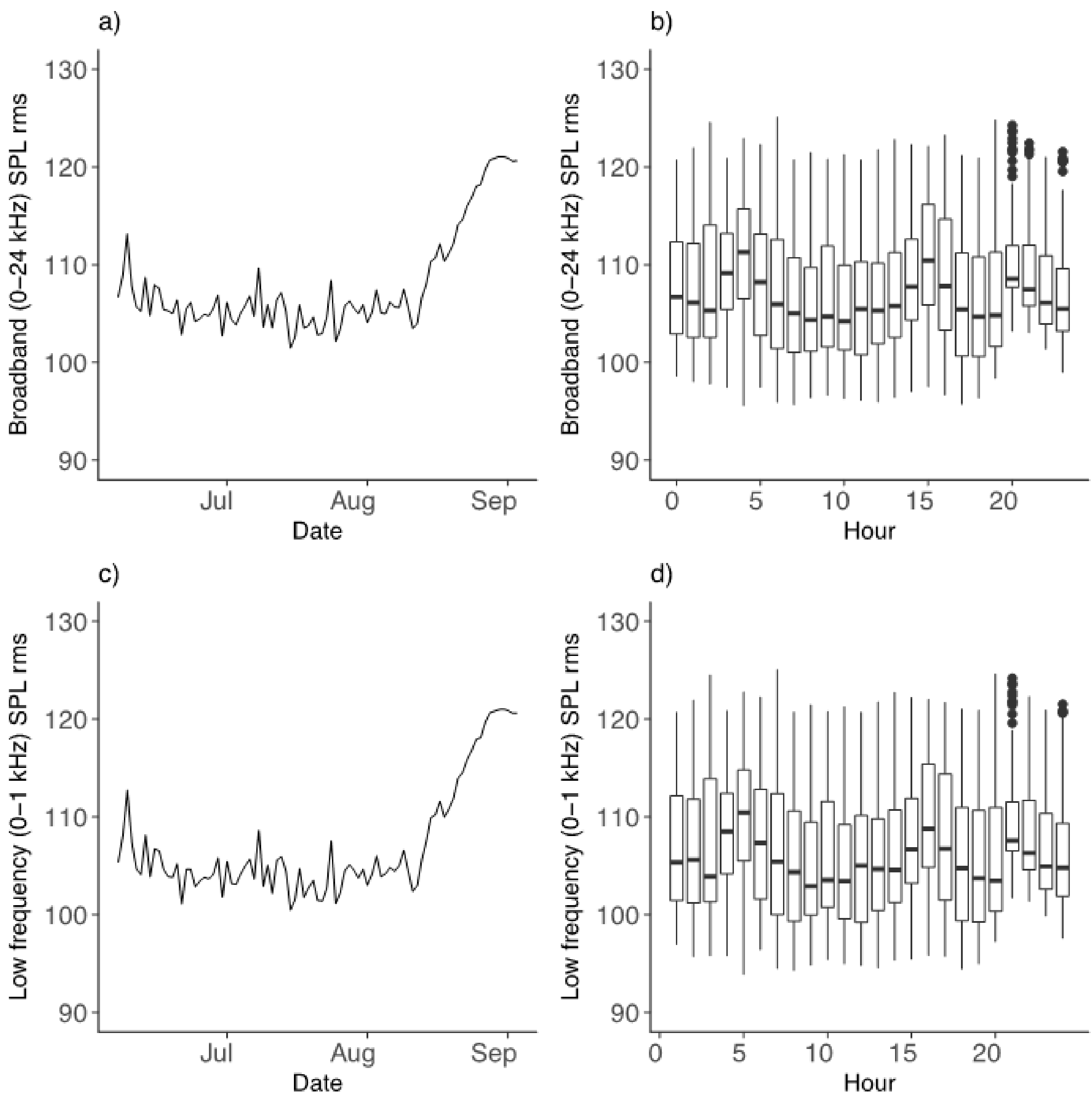

Figure 18. Average daily (a) broadband and (c) low frequency sound pressure levels, and average, first, and third quartile hourly sound pressure levels for (b) broadband and (d) low frequency sound levels with outliers.

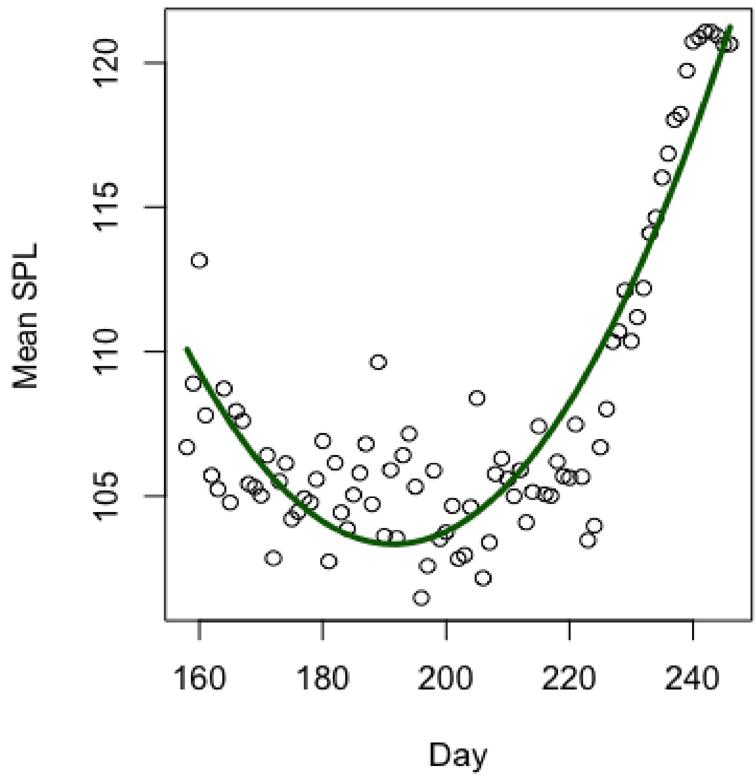

Figure 19. Daily (Julian day: 158 = June 7, 246 = September 3) mean sound pressure levels (SPL; circles) and predicted daily SPLs based on a quadratic linear model (green line).

Table 3. Results of the generalized linear model (GLM) analyzing average hourly broadband and low frequency sound levels in relation to the categorical variable of crepuscular (0400-0700 and 1900-2100) and non-crepuscular periods, and results of the GLM for daily broadband and low frequency sound levels.

Broadband sound (hourly): crepuscular GLM					
	Estimate	Standard error		t	P
Intercept	109.29	0.29		375.09	
Non-crepuscular	-1.44	0.34		-4.30	<0.01
Low frequency sound (hourly): crepuscular GLM					
	Estimate	Standard error		t	P
Intercept	108.11	0.34		314.05	
Non-crepuscular	-1.34	0.39		-3.43	<0.01
Broadband sound (daily): linear model					
Model	F-stat	Standard error	df	R^2	P
MeanSPL ~ Day + Day^2	222.5	2.2	86	0.84	<0.01
Low frequency (daily): linear model					
Model	F-stat	Standard error	df	R^2	P
MeanSPL ~ Day + Day^2	230.2	2.3	86	0.84	<0.01

6. Discussion and Conclusions

Site 1 has lower levels of acoustic energy in the lower frequencies and higher energies in the upper frequencies. This could likely be due to sound propagation as a function of depth, where lower frequency sounds propagate farther in deeper waters and higher frequency sounds propagate farther in shallower waters (Bass and Clark 2003, Carey 2006, Kuperman 1996). It is interesting that with sites T2 and T3 being located near the shipping lanes, they are not particularly different than T1 between 100-1000 Hz, where most of the energy from shipping noise occurs, and have lower overall cumulative levels than site T1.

Our analyses indicated that this study site had a similar range of sound levels (101.5 and 121.1 dB re 1 µPa rms) to that observed at site A-7M during summer from our previous passive acoustic monitoring study that was nearby within the southern part of the Maryland Wind Energy Area (approximately 108 to 123 dB re 1 µPa rms; Bailey et al. 2018).

Following a decrease in sound levels on August 11 and 12, sound levels increased as Tropical Storm Erin approached the region. Sound levels continued to increase rapidly for the remainder of the recording period (Figure 5). Much of the ambient sound was also attributed to boat noise, which is common in the region from both recreational and commercial vessel traffic (Bailey et al. 2018).

7. References

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Appendix C: Hydrophone Calibration Reports

C.1 Vertical Line Array Hydrophone Calibration

HIGH TECH, INC.

21120 Johnson Road
Long Beach, MS 39560

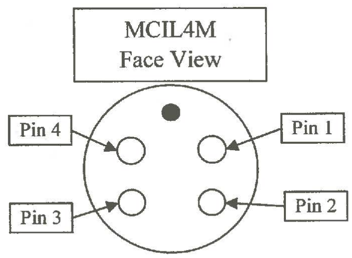
Tel. (228) 868-6632
Fax (228) 868-6645
hightechinc@att.net

722/1/3 Hydrophone Information

07/11/19

Model# HTI-94-SSQ

Connector: Subconn MCIL4M/MCDLSF



Pin Out

Pin 1	+7 to 30VDC
Pin 2	Signal Output
Pin 3	VDC Return / Shield
Pin 4	VDC Return / Shield

Caution: DO NOT apply voltage to signal output.
This will permanently damage hydrophone.

Test Data

Serial Number	Hydrophone Sensitivity dB re: 1V/uPa	Current mA	Cable Length
722013	-204.0	1.18	3 meters
722014	-204.1	1.22	3 meters
722015	-204.0	1.31	3 meters
722016	-204.2	1.14	3 meters
722017	-203.9	1.14	5 meters
722018	-203.7	1.15	3 meters
722019	-204.0	1.17	5 meters
722020	-203.9	1.32	5 meters
722021	-203.9	1.26	5 meters
722022	-204.1	1.36	5 meters
AVG	**-204.0**	**1.23**	
VAR	**0.0**	**0.01**	
STD	**0.1**	**0.08**	
MAX	**-203.7**	**1.36**	
MIN	**-204.2**	**1.14**	
DIF	**0.5**	**0.22**	
+/-	**0.25**	**0.11**	
Hydrophone Count:	**10**		

Sensitivity was measured using the comparison method
Reference hydrophone = 083001
Measurements traceable to USRD Orlando, FL

Hydrophones listed on this page:
- Leaked less than 0.1uA @ 27VDC after 1hr @ 100PSI hydrostatic pressure
- Passed shield integrity test
- Have the same Polarity Response

C.2 Geosled Hydrophone Calibration

HIGH TECH, INC.

21120 Johnson Road
Long Beach, MS 39560

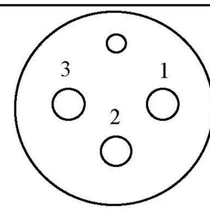
Tel. (228) 868-6632
Fax (228) 868-6645
hightechinc@att.net

722/1/2 Hydrophone Information 08/05/15
Model# HTI-94-SSQ
Connector: MCIL3M and MCDLSF Locking Sleeve
Cable Length: 12 inches

Pin Out

Pin 1	+7 to 30VDC
Pin 2	Signal Output
Pin 3	VDC Return / Signal Gnd

Subcon MCIL3M
Face View



Test Data

Serial Number	Hydrophone Sensitivity dB re: 1V/uPa	Current mA
722009	-203.5	0.98
722010	-203.8	0.99
722011	-203.9	0.97
722012	-203.8	0.99
AVG	**-203.8**	**0.98**
VAR	**0.0**	**0.00**
STD	**0.2**	**0.01**
MAX	**-203.5**	**0.99**
MIN	**-203.9**	**0.97**
DIF	**0.4**	**0.02**
+/-	**0.2**	**0.01**
Hydrophone Count:	**4**	

Sensitivity was measured using the comparison method
Reference hydrophone = 083001
Measurements traceable to USRD Orlando, FL

Hydrophones listed on this page:
- Leaked less than 0.1uA @ 27VDC after 1hr @ 100PSI hydrostatic pressure
- Passed shield integrity test
- Have the same Polarity Response

Appendix D: Sound Level Measurements and Definitions, Transmission Loss Model, and Ray Model

D.1 Sound Level Measurements and Definitions

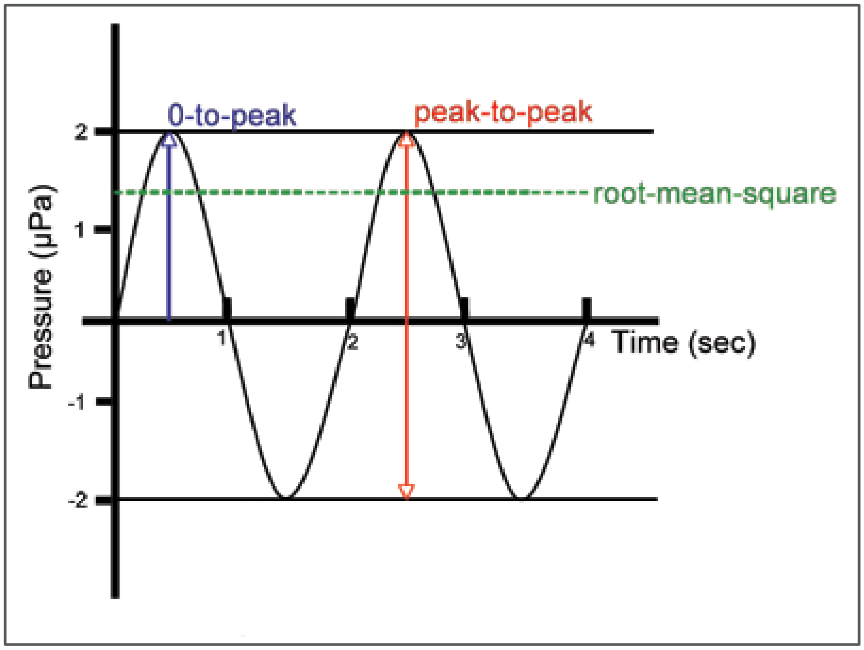


Figure D-1: A simple sound wave and three common methods used to characterize the loudness of a sound signal
Note: Sound pressure time series with a zero-to-peak sound pressure (i.e., amplitude) of 2 µPa, peak-to-peak sound pressure of 4 µPa and rms sound pressure of √2 µPa.

- peak sound pressure level (SPL_{peak}) in dB re 1 µPa.
  Peak sound pressure is measured from the range from zero to the largest signal level as shown in Figure 15.
- peak-to-peak sound pressure level ($SPL_{peak\text{-}peak}$) in dB re 1 µPa.
  Peak to peak sound pressure level is measured from the minimum sound pressure level to the maximum pressure level as shown in Figure 15.
- rms sound pressure level (SPL) in dB re 1 µPa.
  The root-mean-square pressure (rms) is directly related to the intensity of a sound wave. All mammal ears are sensitive to intensity. rms sound pressure level of a sine wave is shown in Figure 15. rms sound intensity is calculated as

$$L_{rms} = 20\log_{10}\frac{\sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} p(t)^2\,dt}}{p_0}$$

where t is time and p is the pressure level.

- sound exposure level (SEL) in dB re 1 μPa^{2}s.

  Sound exposure level (SEL) is a measure of energy that takes into account both received level and duration of exposure. SEL is a common metric since it allows sound exposures of different durations to be related to one another in terms of total acoustic energy. However, the duration of a sound event should be specified because there is no accepted standard duration over which the summation of energy is measured.

  $$E = \int_{t_1}^{t_2} p(t)^2\, dt \; , \quad SEL = 10 \log_{10} \frac{E}{E_0}$$

  Sound Exposure Levels normalized to 1 second are a very useful way of comparing different sound events and sources.

- kurtosis of the pressure signal, β.

  $$\beta = \frac{\mu_4}{\mu_2^2} \; ,$$

  where μ2 and μ4 are the second and fourth moments of the pressure signal p(t) defined as the following.

  $$\mu_2 = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \left[p(t) - \overline{p} \right]^2 dt \; , \text{ and } \; \mu_4 = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \left[p(t) - \overline{p} \right]^4 dt$$

  where t1 and t2 are the signal duration and $\overline{p}$ is the mean of p(t).

D.2 Transmission Loss Model

Using the CTD casts performed during deployment and recovery, a range dependent parabolic equation (PE) acoustic model RAM [ref] was setup with realistic sound speeds, depths, bathymetry and bottom parameters. The sound speed change in the water column from deployment to recovery show sound propagation differences in the higher frequency where the bubble cloud would have more of an effect. The results are shown in **Figure D-2**.

D.3 Ray Model

Using the same realistic sound speeds, depths, bathymetry and bottom parameters as the PE model in the previous section, ray tracing was performed from the turbine locations to the short-range VLA at 3.0 km. Ray tracing was also performed from the turbine location to the long-range VLA. Rays also show the deployment/recovery sound speed difference in their propagation (**Figure D-3** and **D-4**). All data are shown in dB.

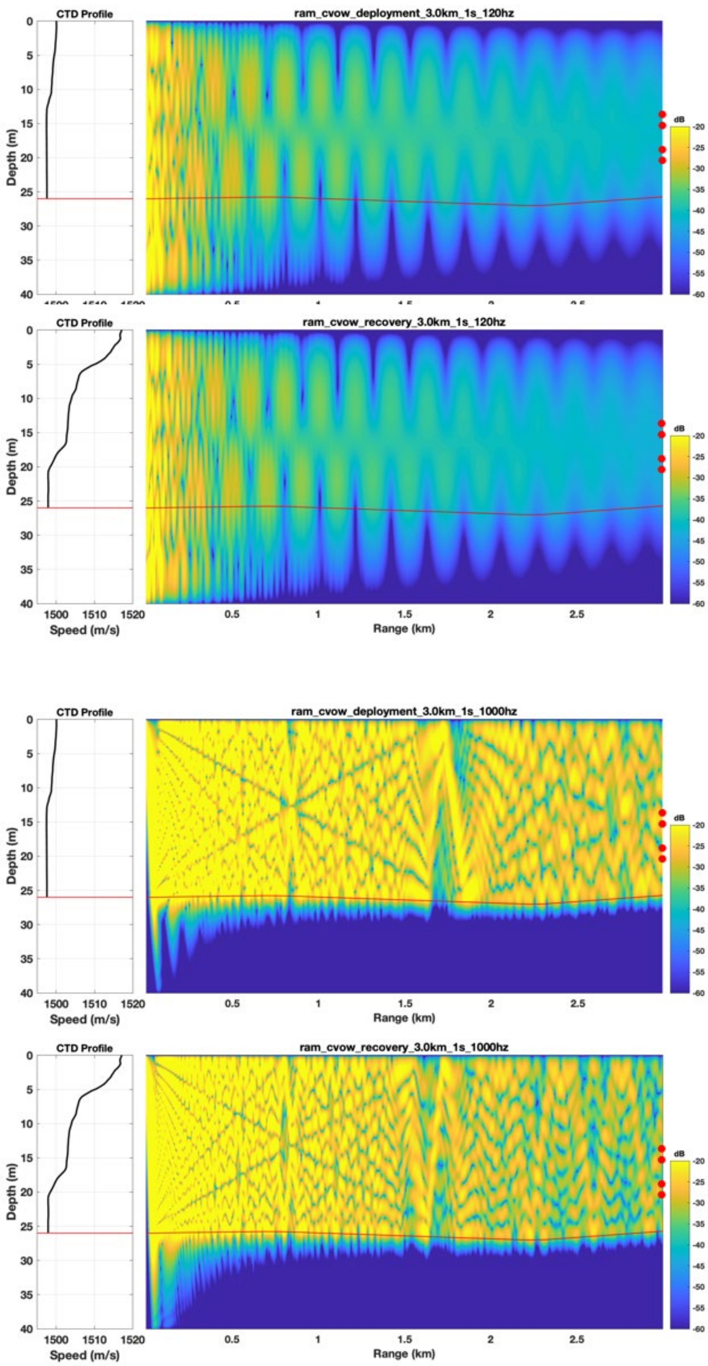


Figure D-2. Four panels for the 3.0 km VLA, showing a comparison of transmission loss (TL) at 120 Hz and 1000 Hz from the mitigated pile to the VLA, using the RAM PE model

Note: The sound speed profile (SSP) for each model run is shown on the left in each panel. Left panels show water column CTD sound speeds obtained at deployment on 23 May, and right panels show CTD sound speeds obtained during recovery on 7 June. The bathymetry and bottom parameters remain the same. The red line displays the bathymetry along that PE run. The red square shows the position and depths of the 4 hydrophones on the VLA. The higher frequency sound propagation is being affected by the differing SSPs.

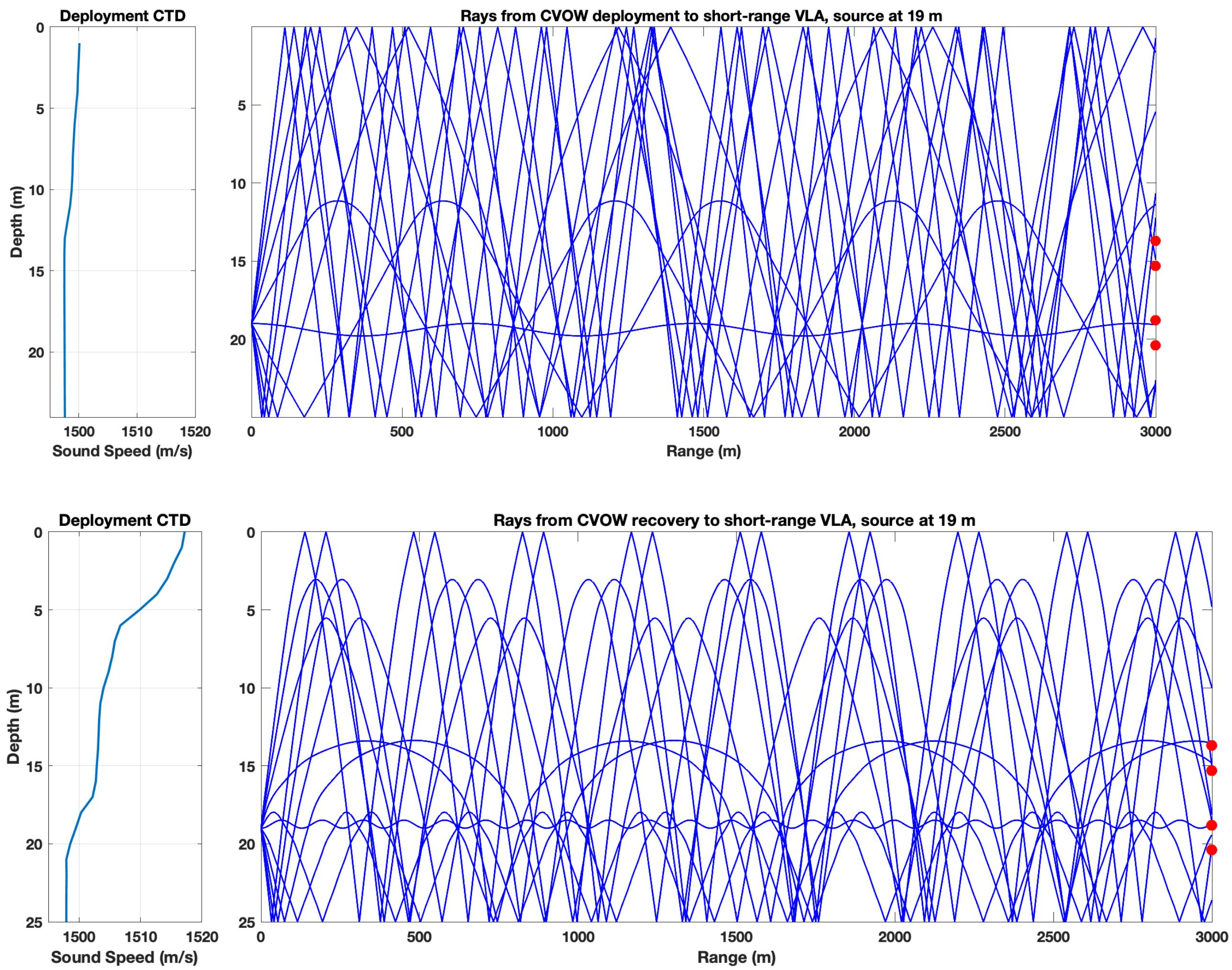


Figure D-3. Comparison of ray traces from the turbines to the short-range VLA

Note: The top panel shows the rays traced using the water column sound speed profile taken during deployment, and the bottom panel shows rays traced using the recovery water column sound speed profile. The red dots indicate the depth locations of the hydrophones on the VLA.

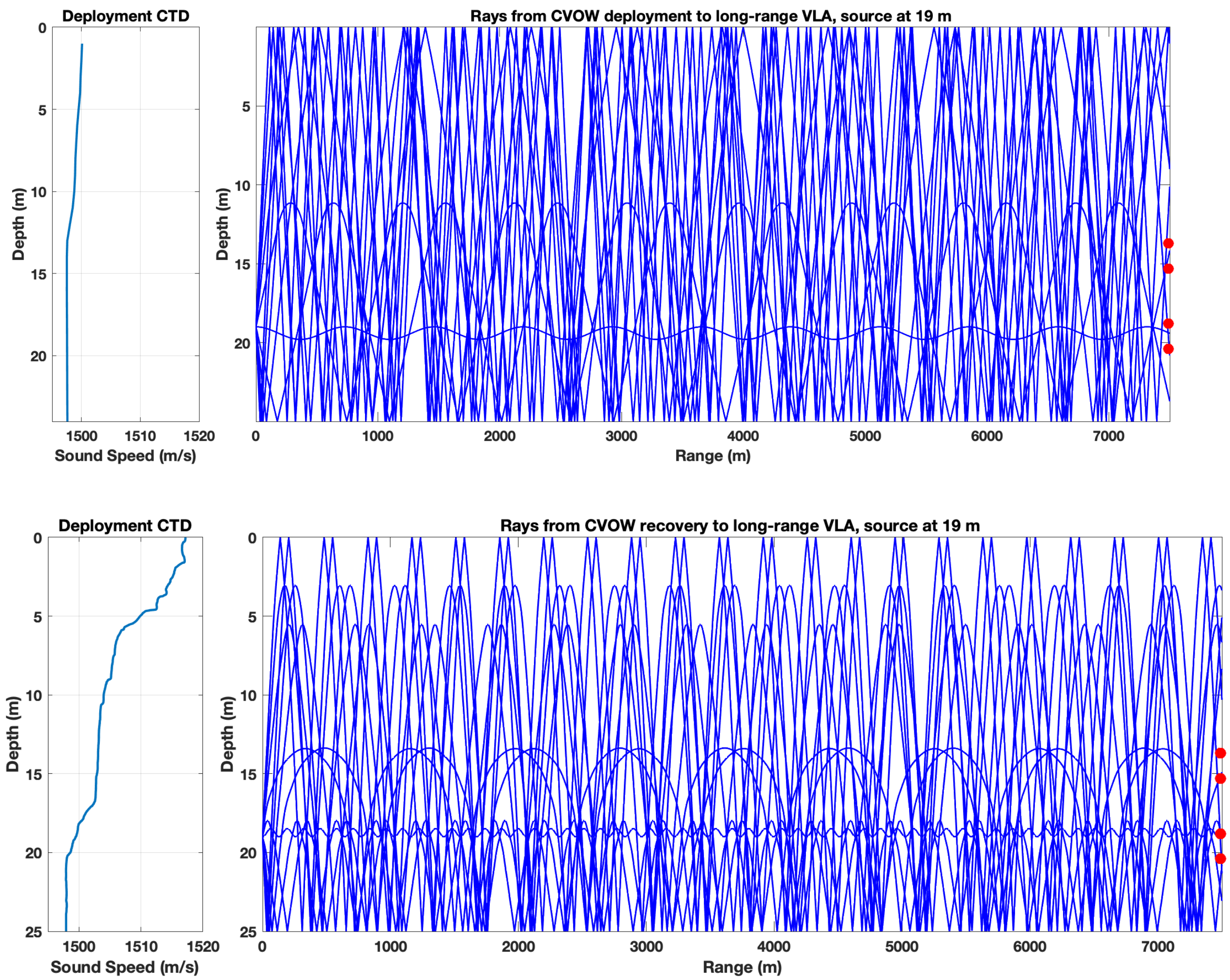


Figure D-4. Comparison of ray traces from the turbines to the long-range VLA

Note: Top panel shows the rays traced using the water column sound speed profile taken during deployment, and the bottom panel shows rays traced using the recovery water column sound speed profile. The red dots indicate the depth locations of the hydrophones on the VLA.

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