WHOI-2020-04

Woods Hole Oceanographic Institution

Acoustic and oceanographic observations collected during the Nomans Island experiment in Spring 2017

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Hansen D. Johnson, Arthur E. Newhall, Ying-Tsong Lin, and
Mark F. Baumgartner

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Technical Report

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Abstract

The Woods Hole Oceanographic Institution (WHOI) has developed a digital acoustic monitoring (DMON) instrument and low-frequency detection and classification system (LFDCS) to detect and classify baleen whales in near real-time from autonomous platforms. This document provides a detailed description of the data, sensors, and research activities pertaining to the Nomans Island experiment, which was designed to evaluate the range-dependent accuracy of the DMON/LFDCS on mobile and fixed platforms. The experiment took place over a 4-week period (28 Feb to 31 Mar) in the spring of 2017 at a shallow (30m) site approximately 15 km Southwest of Martha's Vineyard, USA. A DMON/LFDCS-equipped Slocum glider was deployed alongside an extant DMON/LFDCS moored buoy to provide the means to compare system performance between platforms. Vertical and horizontal hydrophone line arrays were deployed in the same area to facilitate call localization. A short transmission loss trial was conducted shortly after the array deployments. The Slocum glider and several sensors mounted to the arrays provided environmental data to characterize variability in water column structure and sound speed during the study period.

Technical Report
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1. Introduction

The Woods Hole Oceanographic Institution (WHOI) has developed a passive acoustic monitoring (PAM) system comprised of a low-power recorder (digital acoustic monitoring instrument; DMON) and on-board detection algorithm (low-frequency detection and classification system; LFDCS) that detects, classifies and reports the sounds of baleen whales (right, fin, sei, blue, and humpback) in near real-time from autonomous platforms (Baumgartner and Mussoline, 2011). The DMON/LFDCS system is fully operational on Slocum gliders (Baumgartner et al., 2013; 2020) and moored buoys (Baumgartner et al., 2019). These platforms are particularly useful for management applications because they can monitor consistently for weeks to months at a time, regardless of weather conditions, at no risk to human operators, and at a comparatively low cost compared to traditional visual surveys.

As with visual surveys, PAM performance depends on a variety of biological and environmental factors. For PAM, the source, propagation conditions, receiver, and detection process all influence the probability of detection. A limitation of many PAM systems, including the DMON/LFDCS, is the sound detection range uncertainty from the monitoring platform. The primary objective of the field campaign described here was to conduct an experiment to characterize the range-dependent accuracy of the near real-time whale alert system on mobile and fixed platforms.

The study was conducted at a relatively shallow (~30m) site approximately 15 km SW of Noman's Island, MA, USA (Figure 1). A DMON/LFDCS Slocum glider as well as a horizontal hydrophone line array (HLA) and a co-located vertical hydrophone line array (VLA) were deployed in close proximity to an extant DMON/LFDCS moored buoy on February 28, 2017. The systems were recovered on either March 28 or March 31, 2017. This report provides details on the instrumentation, research cruises, and data collected during the experiment.

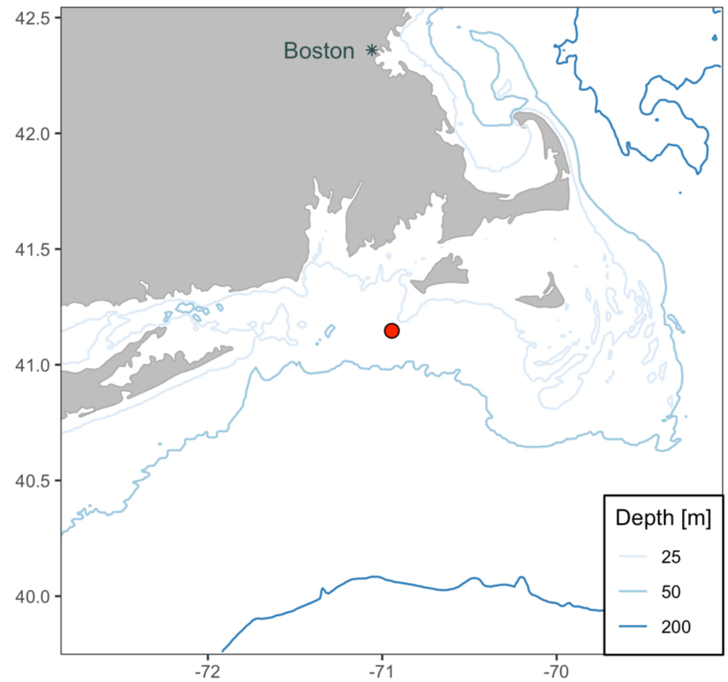


Figure 1. Location of Nomans Island study site ~15 km SW of Martha's Vineyard, MA, USA

2. Cruises

2.1 Deployment

The deployment of the HLA/VLA and DMON/LFDCS Slocum glider occurred on 28 February 2017 from the *R/V Tioga*. All deployments were made successfully and without incident.

Table 1: Cruise participants on 28 February 2017

Name	Role
Lin, Y.-T.	Co-principle investigator
Baumgartner, M.	Co-principle investigator
Dunn, J.	Mooring technician
Johnson, H.	Graduate Student
Khan, C.	Whale observer
Alatalo, P.	Biological technician
Hanley, I.	Deck boss
Houtler, K.	Captain

2.2 Recovery 1

The first recovery cruise was made with the *R/V Tioga* on March 28, 2017. The DMON/LFDCS Slocum glider was recovered first without incident. The VLA was recovered, serviced, and re-deployed at the same location. Numerous release attempts were made to recover the HLA. The on-bottom device was receiving the release command successfully, but no recovery float appeared at the surface. The vessel was not equipped with the appropriate grappling gear to attempt a manual recovery.

Table 2: Cruise participants on 28 March 2017

Name	Role
Lin, Y.-T.	Co-principle investigator
Dunn, J.	Mooring technician
Llanos, N	Mooring technician
Koski, P.	Engineer
Johnson, H.	Graduate Student
Alatalo, P.	Biological technician
Hanley, I.	Deck boss
Houtler, K.	Captain

2.3 Recovery 2

A WHOI dive team was brought along for the second recovery attempt from the *R/V Tioga* on March 31 2017. They successfully located and attached a recovery cable to the HLA. The release on the HLA failed due to damage that presumably occurred during the deployment in rocky terrain. The dive team were also employed to recover the VLA after a release malfunction.

Table 3: Cruise participants on 31 March 2017

Name	Role
Lin, Y.-T.	Co-principle investigator
Baumgartner, M.	Co-principle investigator
Donahue, M.	Mooring technician
Newhall, A.	Acoustic technician
Johnson, H.	Graduate Student
O'Brien, E.	Research diver
Caramanna, G.	Research diver
Alatalo, P.	Biological technician
Hanley, I.	Deck boss
Houtler, K.	Captain

3. Instrumentation

3.1 Digital acoustic monitoring instrument (DMON)

The digital acoustic monitoring (DMON) instrument is comprised of a hydrophone, low-power programmable digital signal processor, 32 GB of flash memory, and serial output for transmission of detection data to the monitoring platform (Hurst and Johnson, 2007). The system has a 36 dB re μPa/√Hz noise floor at 2 kHz and a sensitivity of −169 dB re V/μPa at 2 kHz. A full description of the DMON configuration for near real-time PAM is provided by Baumgartner et al. (2013).

3.2 Low-frequency detection and classification system (LFDCS)

The LFDCS algorithm orchestrates the detection and classification process on board the DMON. Briefly, the algorithm produces smoothed spectrograms of the audio data, removes spurious broadband noise and continuous tonal noise, and uses a contour-following algorithm to create pitch tracks of tonal sounds from the spectrogram. All detection and classification data are archived internally, but it sends an 8 Kb/hr subset of these pitch tracks back to shore via iridium satellite approximately every 2 hrs. These are subsequently divided into 15-minute analysis periods and displayed such that a trained analyst can manually review them for the presence of different species (Baumgartner and Mussoline, 2011).

3.3 DMON/LFDCS Slocum glider

A Slocum glider (Teledyne Webb Research) is a battery-powered, buoyancy-driven underwater autonomous vehicle capable of profiling the water column for weeks to months at slow horizontal speeds (~20km/day). The glider used for this experiment was a G2 Slocum glider with 200 m buoyancy engine and alkaline battery pack (Figure 2). The glider was fitted with an internal DMON1. The hydrophone was potted in faired acoustically transparent urethane and mounted on the topside of the science bay, close to the midpoint of the glider. The DMON was configured to record continuously at a sampling rate of 2000 Hz. The glider was also equipped with an unpumped CTD (Neil Brown), and WET Labs ECO puck fluorometer (Seabird Scientific). The system and performance are described in detail by Baumgartner et al. (2013; 2020)

The glider was deployed from the *R/V Tioga* at 41.1447, -70.9363 at 17:16 UTC on February 28, 2017, and recovered at 41.1654, -70.9671 at 12:00 UTC on 28 March 2017. It was configured to profile from 4 meters above bottom to 3m below the surface, and surface for communications every 2 hrs. It held station at the DMON/LFDCS moored buoy for the first two-weeks of the deployment (28 Feb to 15 March), and then began to fly an approximately circular pattern centered on the buoy for the remainder of the deployment (Figure 3).

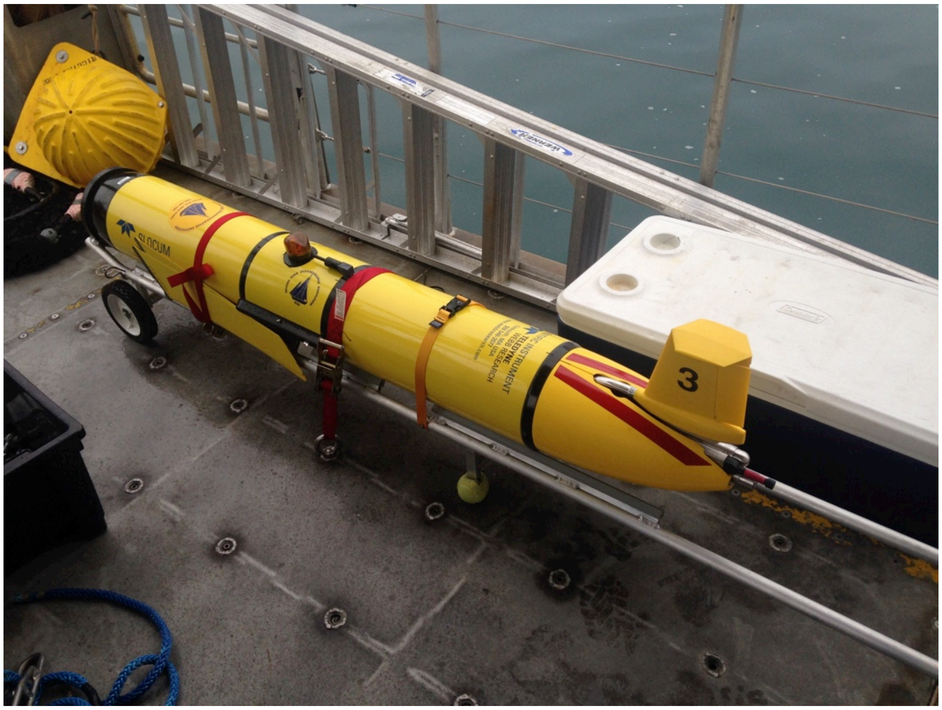


Figure 2: DMON/LFDCS Slocum glider on deck and ready for deployment

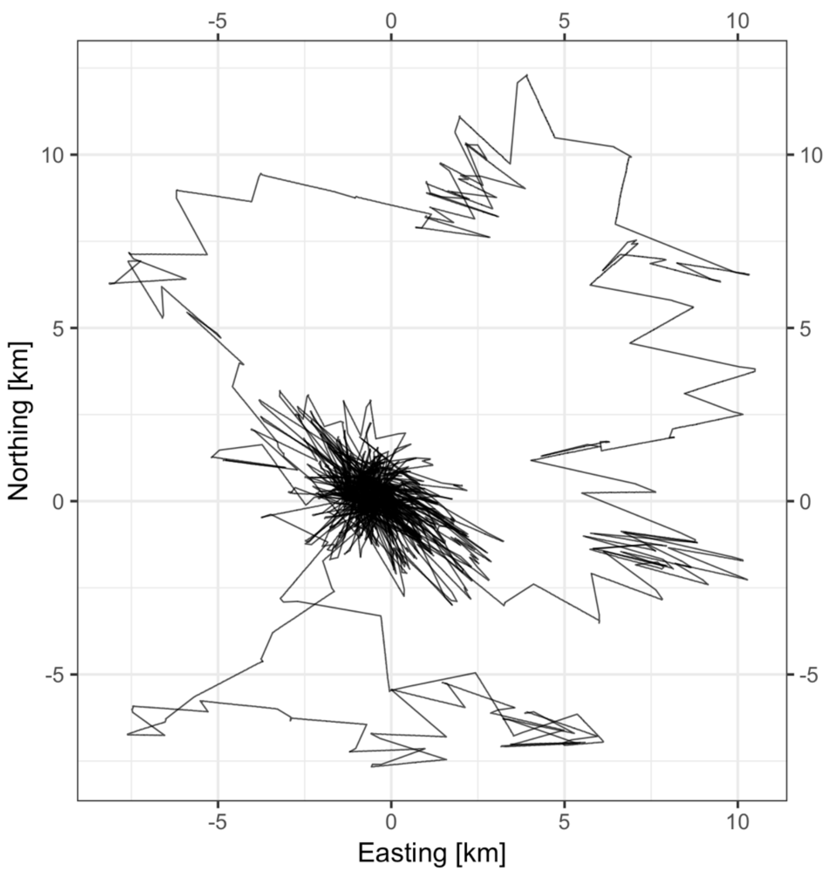


Figure 3: Path of DMON/LFDCS Slocum glider in coordinates relative to deployment location

3.4 DMON/LFDCS moored buoy

The DMON/LFDCS moored buoy system was chiefly comprised of a multi–function node (MFN) that rested on the bottom connected to a surface buoy (Figure 4) by a conductive stretch hose. The MFN acted as the anchor and housed the recovery system and DMON recorder. The surface buoy contained the power supply and platform communication systems. The system is described in greater detail by Baumgartner et al. (2019). The mooring was equipped with a DMON1 encased in an oil-filled acoustically transparent urethane housing. It was configured to sample at 2000 Hz. It generated and stored pitch track data continuously, but only recorded raw audio on a 50% duty cycle (30 min / hour). The mooring was deployed at 41.1462, -70.9448 on 28 September 2016 by John Kemp and others from the *R/V Neil Armstrong*. The mooring was recovered the following year on 19 October 2017.

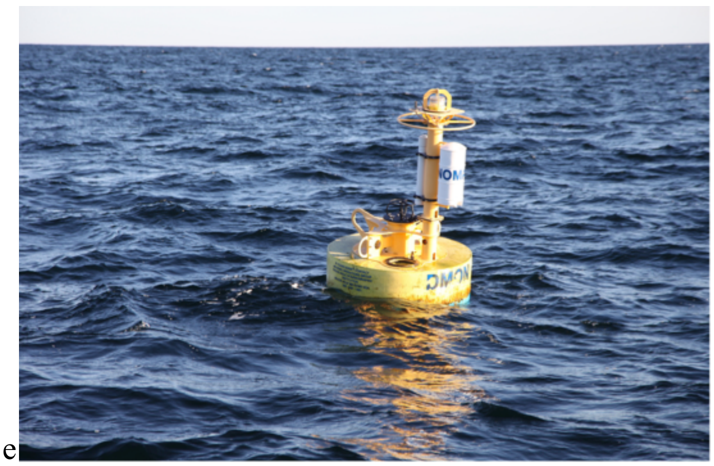
e 

Figure 4: Surface float of the DMON/LFDCS moored buoy

3.5 Horizontal Hydrophone Line Array (HLA)

The horizontal hydrophone line array (HLA) was comprised of 8 hydrophones positioned at 7.5m intervals along a 60m cable coated with hairy fairing. Hydrophones were model HTI-90-U (High-Tech Inc**).** They were placed within plastic tubing with ends baffled by elastic fabric. The recorder was designed by Webb Research Corporation (WRC). It sampled all channels at 4 kHz continuously for the entire deployment. Elements were assigned channel numbers based on their position relative to the WRC recorder, where element 1 was closest and element 8 was farthest. The WRC recorder, a PORT pop-up acoustic release system with a PORT LF-SD release and a Seabird SBE39 temperature-pressure sensor (Seabird Scientific) were housed within a custom-built steel anchor sled. The far end of the hydrophone cable was secured with a small lead weight. Table 4 provides the HLA specifications and timing information. See Newhall et al. (2010) for more detailed discussion on the data format, including sample MATLAB code for reading raw audio data, and equation to convert from the 16-bit raw data stored by the array to sound pressure level (SPL). See Section 7 for a mooring diagram.

Table 4: Horizontal hydrophone line array specifications

Number of elements	8
Element spacing [m]	7.5
Sample rate [kHz]	4
Hydrophone sensitivity [dB re 1V/uPa]	-173
Recorder gain [dB]	23
Time check start	
Time [UTC]	2017-2-28 13:50:07
Offset [sec]	-91.80e-3
Time check end	
Time [UTC]	2017-03-31 21:52:09
Offset [sec]	+1049.0e-3
Clock drift rate [sec/day]	0.0364

The HLA was deployed from the *R/V Tioga* on 28 February at approximately 41.1465 deg. N, 70.9435 deg. W (Figure 5). Section 4 describes the process by which elements were acoustically localized after the deployment. It was recovered with diver assistance on March 31, 2017.

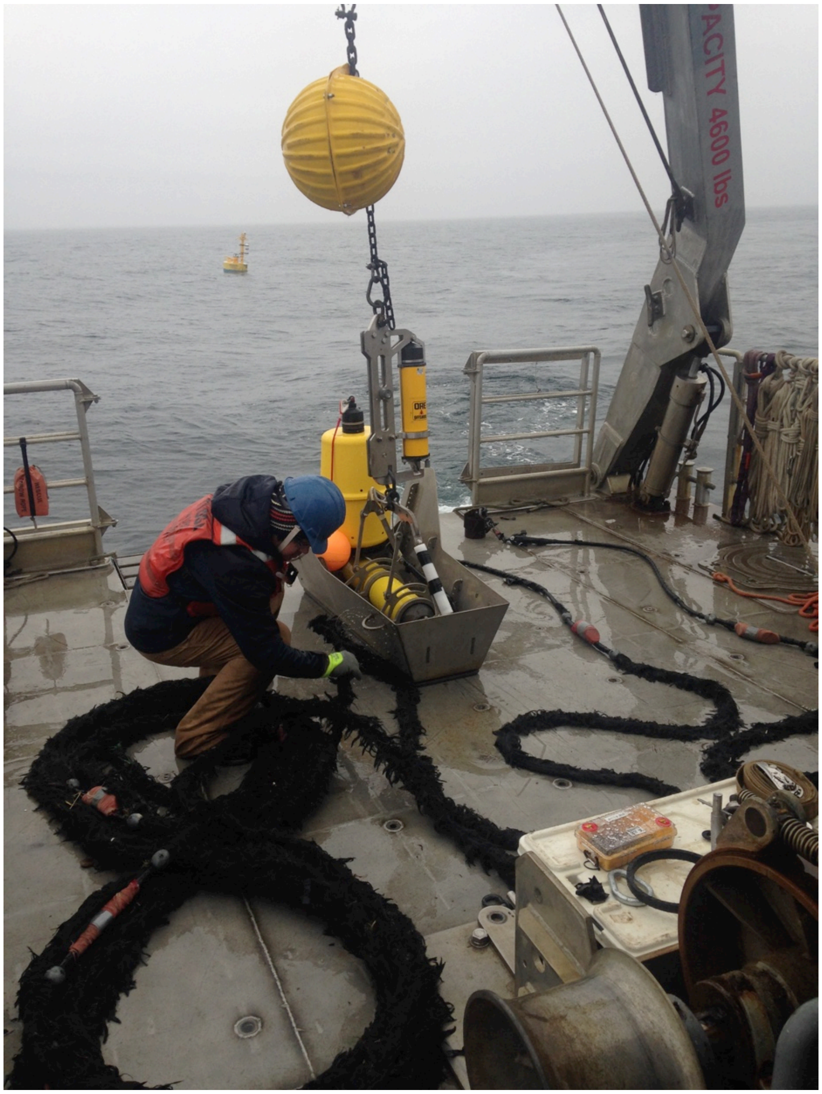


Figure 5: HLA on deck and ready for deployment

3.6 Vertical Hydrophone Line Array (VLA)

The vertical hydrophone line array (VLA) used in this study consisted of a Several Hydrophone Receiving Unit (SHRU), 4 hydrophones, several environmental sensors, and additional standard mooring components. The SHRU was suspended several meters above the anchor and acoustic release system. The hydrophones and environmental sensors were secured to a 15m wire rope that extended from the top of the SHRU to a steel sphere suspended approximately 8 meters below the surface. Hydrophones were model HTI-90-U **(**High-Tech Inc) and secured to wire using vibration-damping rubber mounts. The SHRU sampled the hydrophones continuously at a rate of 9.7656 kHz for the full deployment period. Table 5 provides the VLA specifications and timing information. See Newhall et al. (2010) for a description of the SHRU electronics, data formatting, MATLAB processing, and additional engineering specifications. The VLA channels were named sequentially such that channel 1 was the shallowest and channel 4 was the deepest. Environmental sensors were placed relatively close to each element;

with Star-Oddi Starmon temperature sensors (TPOD) close to elements 1-3 and a Seabird SBE39 temperature/pressure sensor near element 4. The latter was especially important as its pressure sensor provided the ability to measure and account for array tilt. See Section 7 for a detailed mooring diagram.

Table 5: Vertical hydrophone line array specifications

Number of elements	4
Element spacing [m]	2
Sample rate [kHz]	9.7656
Hydrophone sensitivity [dB re 1V/uPa]	-170
Recorder gain [dB]	26
Time check start	
Time [UTC]	2017-02-28 12:15:45
Offset [sec]	-2.0e-6
Time check end	
Time [UTC]	2017-03-28 13:03:03
Offset [sec]	-182.5e-3
Clock drift rate [sec/day]	-0.0065

The VLA was deployed from the *R/V Tioga* at 41.1467 deg. N, 70.9449 deg. W on February 28, 2017, and recovered on 28 March 2017 (Figure 6).

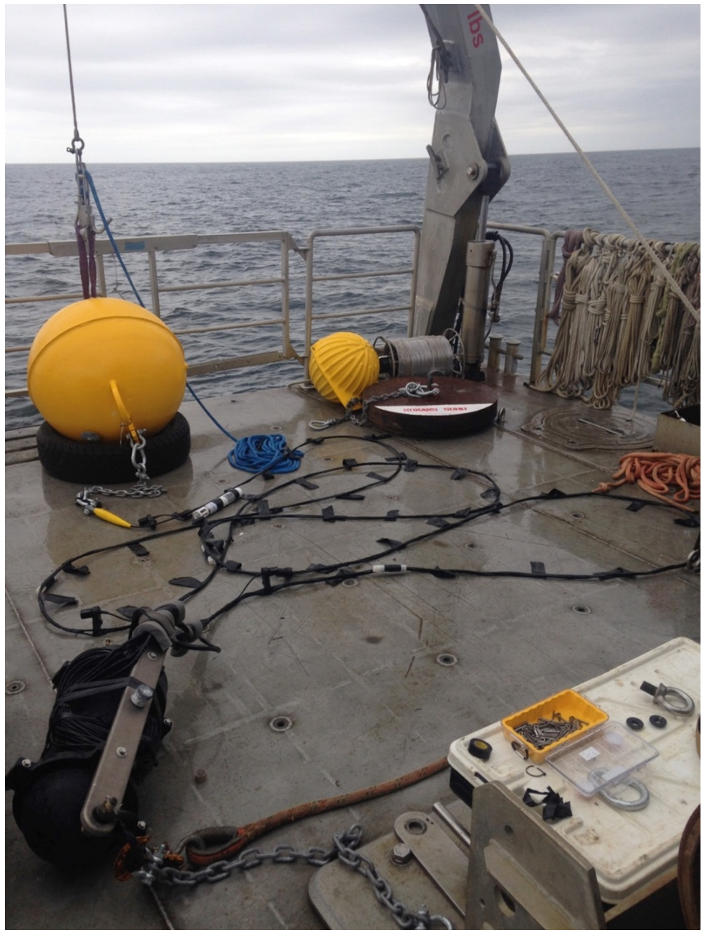


Figure 6: VLA on deck and ready for deployment

4. Hydrophone Array Localization

4.1 Using signal transmissions

A localization procedure was conducted following the HLA deployment to determine the precise position of each array element. Signal transmissions were produced at 4 stations, each approximately 200m from the deployment location. The signal was a 0.2 s duration linear chirp from 700 to 2000 Hz and was repeated every 0.5 s for at least 2 minutes at each station. The transmissions were triggered by a satellite GPS pulse-per-second (PPS) signal for timing accuracy. Start times of sound transmissions at each station are shown in the table below. A portable underwater transducer (LL916C; Lubell Labs) was used as the sound source.

Table 6: Transmission start times used for array element localization

Station	Start time (UTC)
1	17:05:40
2	17:11:00
3	17:16:30
4	17:21:00

These start times were combined with the ship GPS track to determine the precise position of the ship at the time of each transmission. After recovery, the difference between transmission and arrival times, and an assumed sound speed of 1468 m/s, was used to determine the one-way travel time of each signal from source to each array element. Least squares triangulation was applied to the travel times from each station to determine the position of each element. This procedure revealed that the HLA had some curvature after it was deployed. Table 7 provides the precise element locations on the deployment day. Figure 7 shows the relative positions of all static systems after deployment on February 28.

Table 7: Estimated positions of each element of the HLA. The X and Y coordinates are in meters relative to element 1.

Element	Latitude	Longitude	X [m]	Y [m]
1	41.14665	-70.94352	0	0
2	41.14660	-70.94347	3.86	-5.88
3	41.14654	-70.94346	5.09	-12.16
4	41.14648	-70.94343	7.31	-19.60
5	41.14641	-70.94340	9.74	-27.16
6	41.14637	-70.94343	7.29	-31.08
7	41.14639	-70.94350	1.24	-29.06
8	41.14642	-70.94354	-1.59	-26.23

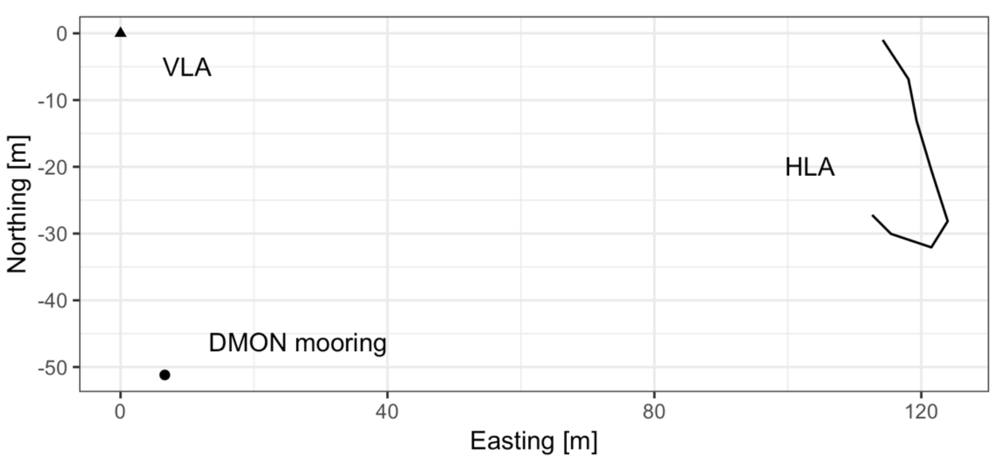


Figure 7. Mooring positions in coordinates relative to the vertical hydrophone line array

4.2 Using vessel noise

When the HLA was recovered, it was immediately evident that the system had moved with respect to its deployed position. The exact position of each array element is critical for accurate beamforming, so efforts were made to localize the array elements during the deployment using sources of opportunity. The *R/V Tioga* provided such a source when it revisited the study area for zooplankton sampling on March 6, 13, and 18. The vessel noise and known position were used to localize the array elements following similar methods described by Morley et al. (2009) and summarized briefly below.

A 4-second audio snippet was selected and bandpass filtered between 100-1500Hz to isolate vessel noise. The mean GPS position of the vessel during the audio snippet was determined. The HLA channels were cross-correlated in the time domain to identify the time delay in each channel. These steps were then repeated for the duration of the vessel transit of the area (at least 30 minutes). A loess smoother (width 0.25) was applied to the cross-correlation time series and points that deviated from the smooth curve by more than 5 ms were excluded from the analysis. The direct path arrival time from the propeller of the *R/V Tioga* (draft = 5 ft) to the nominal array location was estimated using the water depth and sound speed derived from the array environmental sensors. Finally, the same iterative least squares approach as described previously was used to triangulate each hydrophone based on the estimated signal arrival times from each vessel position.

This method was first applied to the vessel noise data from February 28. The estimated element positions were nearly identical to those produced on the same day using the standard sound transmission protocol described in the previous section. The noise-based localization routine was then applied to data from subsequent Tioga trips on March 6, 13, and 18. The array positions derived with this method were further validated by using them to beamform to the vessel noise and computing the difference between the estimated source bearing and the true bearing based on the known location of the *R/V Tioga*.

Figure 8 shows the positions of the array elements estimated from each survey. The variation in the absolute position of the array between surveys is likely an artefact of the localization procedure. The relative positions of each element within the array on each survey day are the most informative. The results suggest that the array moved slightly between February 28 and March 6, and dramatically between March 13 and 18. Storm events on 2-3 March and 14-15 March correspond with the presumed timing of the array movement.

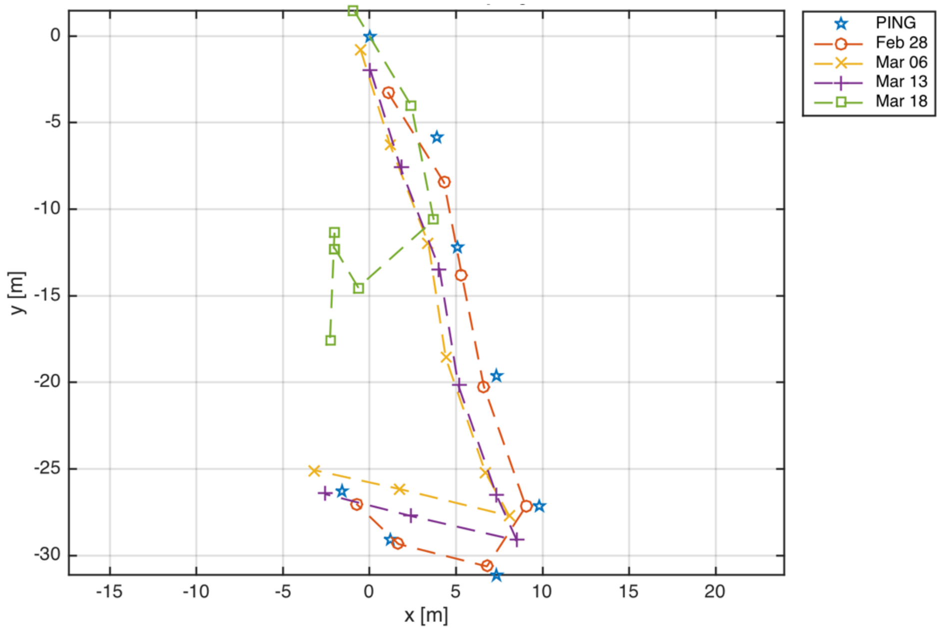


Figure 8: Positions of each horizontal line array element estimated using signal transmissions (PING) or from vessel noise (Feb 28, Mar 06, Mar 13, Mar 18). Element positions are expressed relative to the position of channel 1 estimated using signal transmissions.

5. Transmission loss using a towed source

A brief transmission loss experiment was conducted as the vessel departed the deployment area on February 28, 2017. The same Lubell underwater transducer used for the array localization was used to transmit a frequency-modulated upsweep signal (2s duration, 500-800 Hz) at approximately 160 dB re 1 uPa/Hz @ 1m at 2-second intervals as the vessel steamed NNE away from the study site. The source was towed at a depth of approximately 6 m (see temperature/pressure data below) and speed of 3-4 knots. A SBE39 temperature/pressure (T/P) sensor (Seabird Scientific) was attached to the source to record transducer depth and water temperature sampling at 1 Hz (Figure 9). Figure 10 shows the source arrivals at the VLA as a function of transmission time and reduced pulse time, as well as the distance from the source to the receiver (S2R).

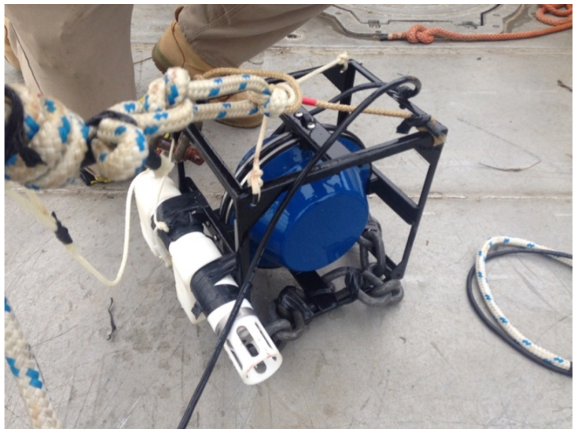


Figure 9: Towed Lubell source and attached SBE39 temperature/pressure sensor.

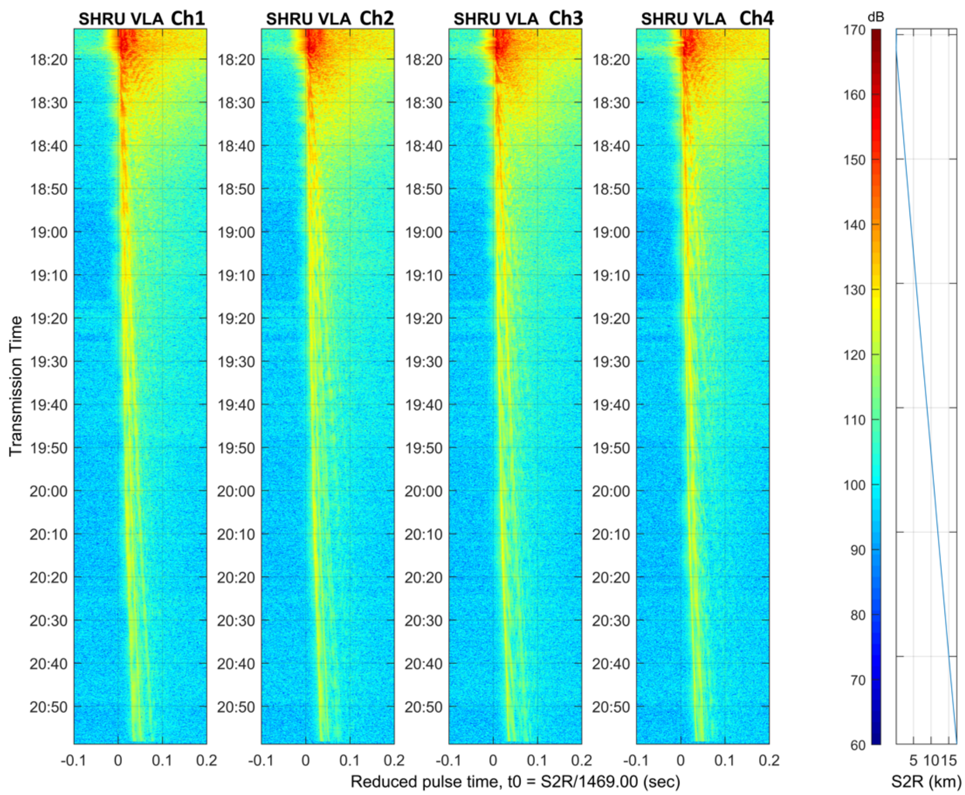


Figure 10: Source arrivals at the SHRU VLA as a function of transmission time and reduced pulse time, as well as the distance from the source to the receiver (S2R)

6. Data

6.1 Environmental

All environmental sensors (TPODs, SBE39s, and Glider CTD) successfully recorded temperature for the full deployment except one TPOD which stopped sampling early due to its battery life. They were all in close agreement throughout the study period, regardless of depth, suggesting that the water column was well mixed throughout the study period (Figure 11, 12). Despite the lack of depth structure, there were several occasions where the temperature of the entire water column shifted abruptly by several degrees. The stationary pressure sensors (i.e., SBE39s on VLA and HLA) revealed intense storm activity, recording high-frequency variation in pressure consistent with waves of up to 8 m in height (Figure 12). Unfortunately, the conductivity cell of the glider CTD malfunctioned so there were no salinity measurements recorded for the study period.

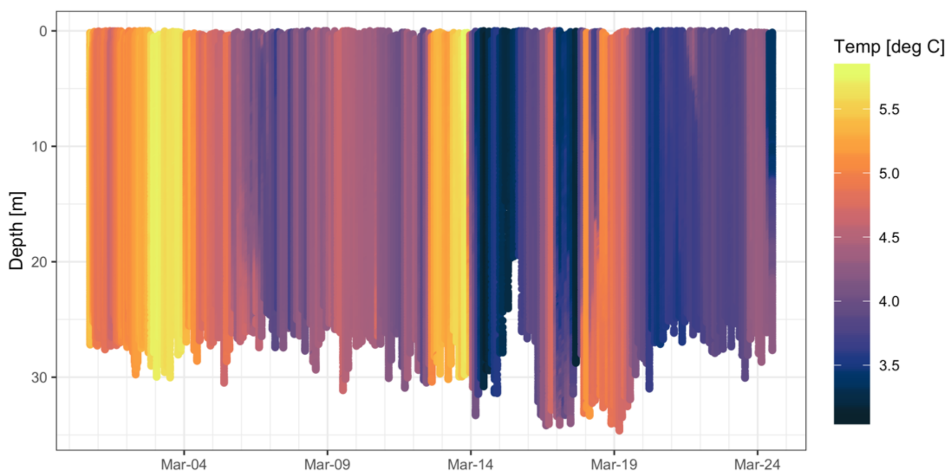


Figure 11: Time series of temperature and depth recorded by the DMON/LFDCS Slocum glider

Figure 12: Temperature (top) and pressure (bottom) data recorded by sensors on the HLA and VLA. Sensor position is provided in the mooring diagram in Section 7.

6.2 Acoustic

The HLA stopped recording when its battery ran out at approximately 1800 UTC on March 23, while the VLA recorded until the system was recovered on March 31. Significant storm-induced noise was present in the acoustic records of both systems (Figure 13), which approximately coincided with the observed movement of the HLA. The DMON/LFDCS glider and buoy successfully recorded acoustic throughout the full study period. Numerous calls from right, fin, sei and humpback whales were recorded (Figure 14).

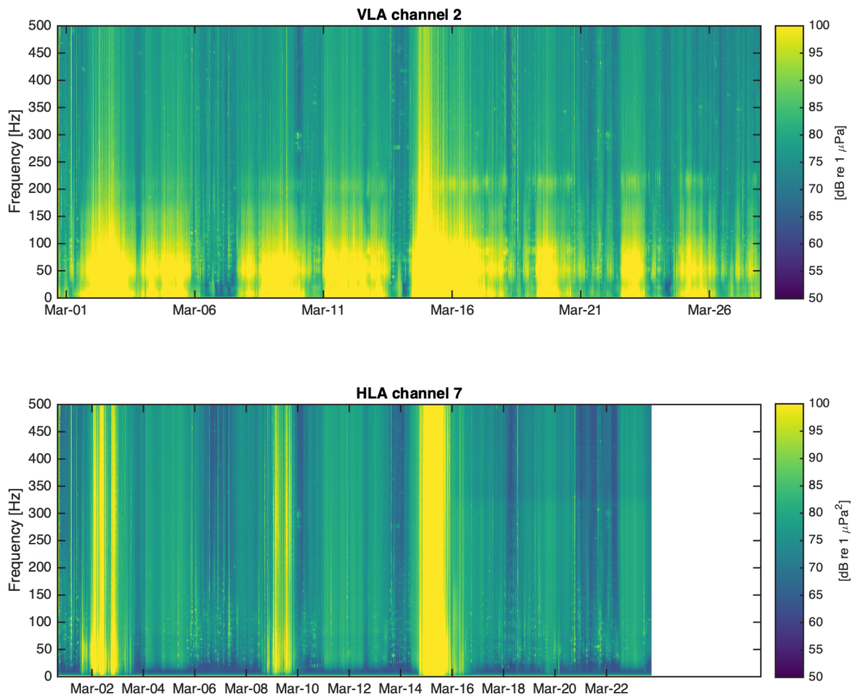


Figure 13: Long-term spectrograms from channel 2 of the VLA and channel 7 of the HLA highlighting periods of storm-induced noise

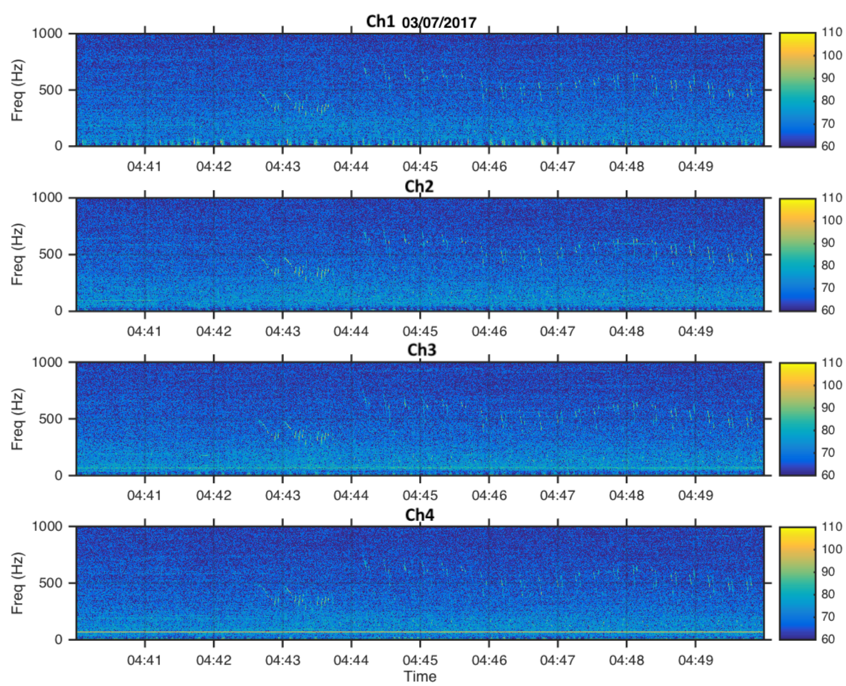


Figure 14. Example spectrograms of humpback whale song recorded on the VLA on 07 March 2017

7. Mooring diagrams

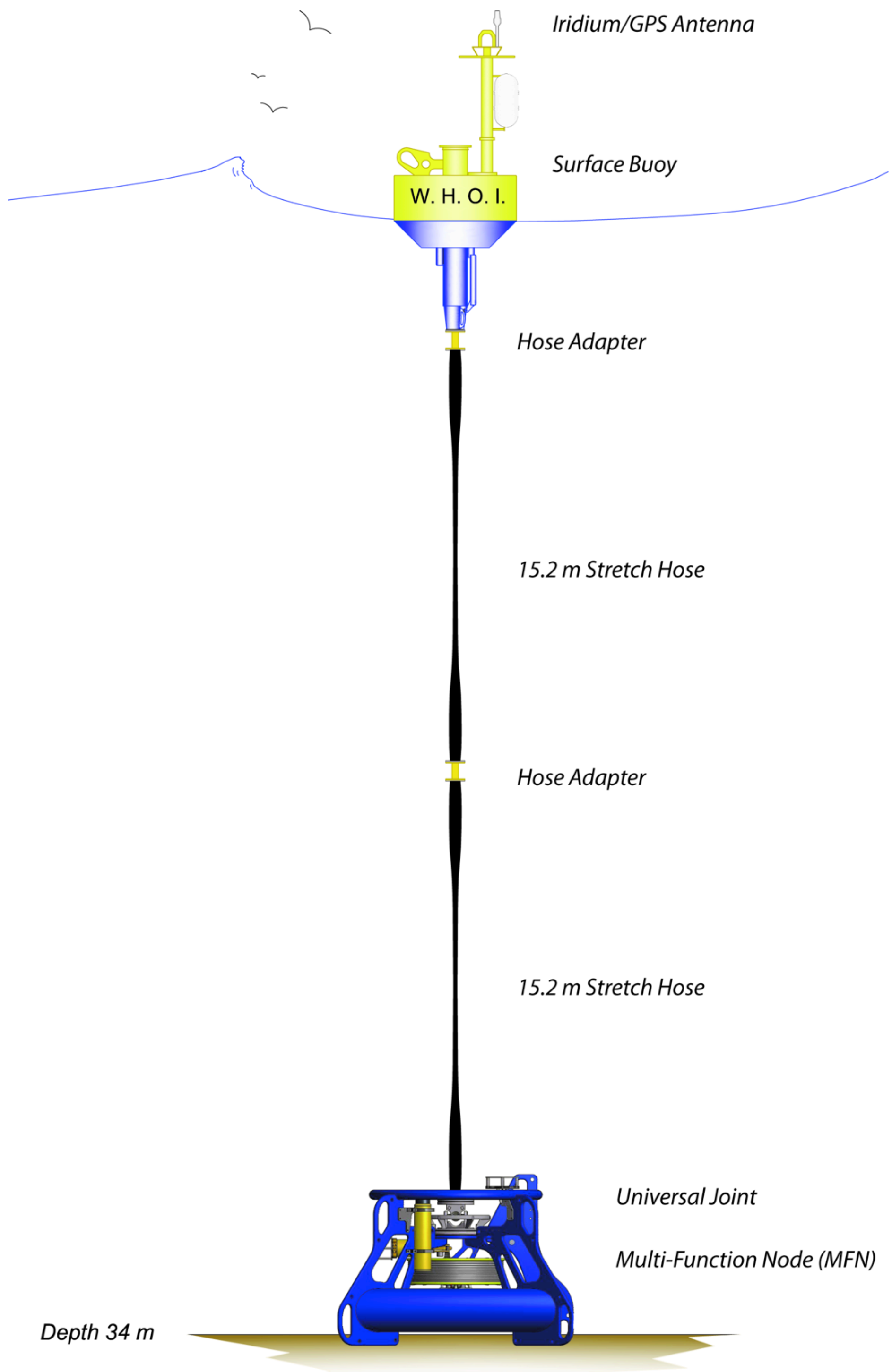
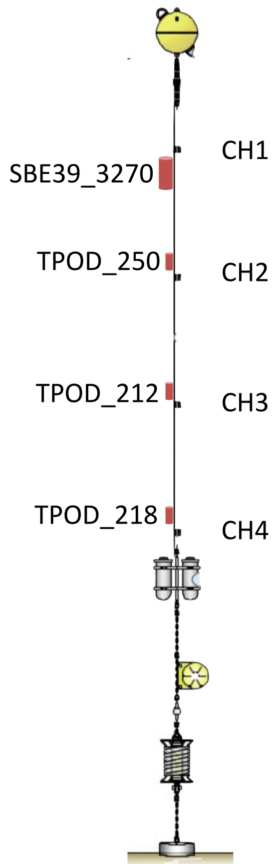


Figure 15. Mooring diagram of the DMON/LFDCS moored buoy



ID	Height [m]
Top eye	15.01
CH1	14.6
SBE39_3270	14.4
TPOD_250	10.5
CH2	10
TPOD_212	5.35
CH3	5
TPOD_218	1.1
CH4	0.61
Bottom eye	0

Figure 16. Mooring diagram of the vertical line array

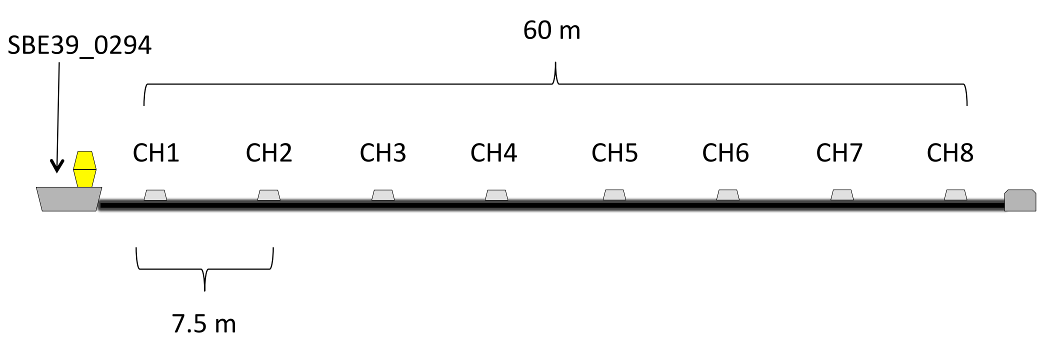


Figure 17. Mooring diagram of the horizontal line array

Acknowledgements

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16. Abstract (Limit: 200 words)

The Woods Hole Oceanographic Institution (WHOI) has developed a digital acoustic monitoring (DMON) instrument and low-frequency detection and classification system (LFDCS) to detect and classify baleen whales in near real-time from autonomous platforms. This document provides a detailed description of the data, sensors, and research activities pertaining to the Nomans Island experiment, which was designed to evaluate the range-dependent accuracy of the DMON/LFDCS on mobile and fixed platforms. The experiment took place over a 4-week period (28 Feb to 31 Mar) in the spring of 2017 at a shallow (30m) site approximately 15 km Southwest of Martha's Vineyard, USA. A DMON/LFDCS-equipped Slocum glider was deployed alongside an extant DMON/LFDCS moored buoy to provide the means to compare system performance between platforms. Vertical and horizontal hydrophone line arrays were deployed in the same area to facilitate call localization. A short transmission loss trial was conducted shortly after the array deployments. The Slocum glider and several sensors mounted to the arrays provided environmental data to characterize variability in water column structure and sound speed during the study period.

17. Document Analysis a. Descriptors

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low-frequency marine mammal classification
marine mammal detection system

b. Identifiers/Open-Ended Terms

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