Pile Driving Passive Acoustic Monitoring Plan

Submitted To:

National Marine Fisheries Service

Office of Protected Resources

Silver Spring, MD;

National Marine Fisheries Service

Greater Atlantic Regional Fisheries Office – Protected Resource Division

Gloucester, MA;

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Bureau of Safety and Environmental Enforcement

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1 Introduction

This passive acoustic monitoring Plan (PAM Plan) is proposed in connection with the planned foundation installation activities for the Revolution Wind Farm (RWF) Project. This PAM Plan meets the requirements of the Revolution Wind Incidental Take Regulation (ITR) issued by the National Marine Fisheries Service (NMFS) on 20 October 2023, §217.274(c)(16) and Letter of Authorization Mitigation Requirements 3(c)(9) and (c)(16), Endangered Species Act Section 7 Consultation Biological Opinion (BiOp) issued by NMFS Greater Atlantic Fisheries Office (GARFO) on 21 July 2023 [GARFO- 2022-03532], as superseded on 30 April 2024 [GARFO-2024-00419], Terms and Conditions (T&Cs) 12(a), and the Conditions of COP Approval issued by the Bureau of Ocean and Energy Management (BOEM) 17 November 2023 Condition 5.4.4. Additional details on these conditions are included in Table 1.

The PAM Plan (as per COP Approval Condition 5.4.4) is designed for real time acoustic monitoring by the PAM operator(s) of clearance and shutdown zones for marine mammal call detection and mitigation during offshore foundation installation. The PAM Plan does not include any real-time vessel transit corridor monitoring. Revolution Wind requires that all vessels under contract to the Project travel at 10 knots or less throughout the duration of construction activities. This is addressed explicitly in the *Vessel Strike Avoidance Plan* (as per COP Approval Condition 5.4.7) which received all agencies' (NMFS Office of Protected Resources [OPR], NMFS GARFO Protected Resource Division (PRD) (NMFS GARFO – PRD), BOEM, and Bureau of Safety and Environmental Enforcement [BSEE]) approvals on February 29th, 2024. Additionally, this PAM Plan does not include acoustic data collection associated with the *Sound Field Verification (SFV) Plan* (as per COP Approval Condition 5.4.5). The SFV Plan is a stand-alone Plan and will be referenced for all procedures and reporting protocols regarding SFV activities.

PAM is intended to be complementary to visual monitoring, extending the detection range for NARWs and other mysticete whales (e.g., humpback whales) and to increase situational awareness for visual PSOs. The minimum visibility zone will be visually cleared as described in the Pile Driving Monitoring Plan (PDMP) Section 3.5**Error! Reference source not found.**. Acoustic detections will be analyzed, and localized where possible, in real-time using custom designed software (see Section 1.3 for further details). If there is uncertainty on the species identification for a vocalization, a conservative approach will be taken, and any low-frequency vocalization that cannot be ruled out as a NARW, will be considered a NARW, and appropriate mitigation actions taken. All detections will be recorded and archived for subsequent reporting (as described in Section 2 of this plan and PDMP Section 5**Error! Reference source not found.**). Full PAM detection data and metadata will be submitted following the requirements described in Section 2.1.

This plan has been updated from previous versions to include the use of two (2) SeaPicket PAM systems as a redundancy and additional layer of precautionary protection for detecting whale calls that originate from within the 10 km PAM clearance/shutdown zone for NARW prior to and during pile driving. This plan addresses use of the SeaPicket system during the installation of the first four (4) piles (B47, B12, B11, B08 [USCG AK12, AE11; AE10; AE07]). Once completed, an appendix to this plan will be submitted showing the SeaPicket deployment locations that will provide PAM coverage during the remaining foundation installations. No pile driving on the remaining sixty-three (63) foundation installations will be conducted until the appendix showing SeaPicket locations covering the sixty-three (63) locations has been approved by the federal agencies.

Table 1. Relevant Conditions from COP Approval, Final ITR, LOA, and BiOp

Condition	Detail
COP Condition 5.4.4	The Lessee must prepare and implement a Pile Driving PAM Plan. The Lessee must submit this plan to BOEM, BSEE, NMFS GARFO, and NMFS OPR at least 180 days before impact pile driving is planned. BOEM, BSEE, and NMFS GARFO will review the plan and will provide comments within 45 days of receipt of the plan. NMFS GARFO will assess whether this plan is consistent with the requirements outlined in the July 21, 2023 BiOp and its Incidental Take Statement (ITS) and provide comments to BOEM and BSEE. If BOEM and BSEE inform the Lessee that the plan is inconsistent with those requirements, the Lessee must resubmit a modified plan that addresses the identified issues within 30 days of receipt of the comments but at least 15 days before the start of foundation installation activities. BOEM, BSEE, and NMFS GARFO will discuss a timeline for review of the modified plan to meet the Lessee's schedule to the maximum extent practicable. The Lessee must obtain BOEM's and BSEE's concurrence with this plan prior to the start of any pile driving.
Final ITR § 217.274(c)(16)	LOA Holder must submit a Passive Acoustic Monitoring Plan (PAM Plan) to NMFS Office of Protected Resources for review and approval at least 180 days prior to the planned start of foundation installation activities (impact pile driving) and abide by the Plan if approved. No pile installation can occur if LOA Holder's PAM Plan does not receive approval from NMFS Office of Protected Resources and NMFS Greater Atlantic Regional Fisheries Office Protected Resources Division.
LOA Condition 3(c)(16)	Revolution Wind must submit a Passive Acoustic Monitoring Plan (PAM Plan) to NMFS OPR for review and approval at least 180 days prior to the planned start of foundation installation activities (impact pile driving) and abide by the Plan if approved. Revolution Wind must obtain both NMFS OPR and NMFS GARFO Protected Resources Division's concurrence with this Plan prior to the start of any pile driving. The PAM Plan must include a description of all proposed PAM equipment, address how the proposed passive acoustic monitoring must follow standardized measurement, processing methods, reporting metrics, and metadata standards for offshore wind. The PAM Plan must describe all proposed PAM
BiOp Terms and Conditions (T&C) 12(a)	Passive Acoustic Monitoring Plan for Pile Driving. BOEM, BSEE, and/or Revolution Wind must submit this plan to NMFS GARFO at least 180 calendar days before impact pile driving is planned. BOEM, BSEE, and Revolution Wind must obtain NMFS GARFO's concurrence with this Plan prior to the start of any pile driving.
BiOp T&C 8 (i)	BOEM and BSEE, must require Revolution Wind to submit full detection data, metadata, and location of recorders (or GPS tracks, if applicable) from all real-time hydrophones used for monitoring during construction within 90 calendar days after completion of foundation installation and to submit full acoustic recordings from all real-time hydrophones within 90 days after pile driving has ended and instruments have been pulled from the water.

1.1 PAM Systems and Deployment Locations

In accordance with ITR § 217.274 (c)(9), the real-time PAM systems will not be placed closer than 1 kilometer (km) to the pile being driven to reduce the amount of masking. Revolution Wind will provide adequate demonstration and justification for the detection range of the system planned for deployment while considering potential masking from concurrent pile driving and vessel noise. The PAM system will be able to detect a vocalization of NARWs up to 10 km.

Revolution Wind will use two types of PAM systems to conduct the required monitoring, RSA-ORCA systems and SeaPicket systems. In accordance with ITR § 217.275 (c)(1), acoustic monitoring will begin with deployment of the PAM systems at least 60 minutes prior to pile driving, continue throughout monopile installation, and extend at least 30 minutes post-piling, at which point the systems will be recovered for relocation to the next pile, if necessary. Consistent with LOA condition 4(c)(3), PAM data from the 24 hr period prior to pile driving collected on these systems and all other available sources will be reviewed and inform the situational awareness of the project.

1.1.1 RSA-ORCA System

Revolution Wind will use four moored real-time RSA-ORCA PAM systems deployed at 5 km from pile being installed. The RSA-ORCA is a multichannel (5 channels) subsea acoustic recorder with an ~200 dB sensitivity and a sampling rate of 48 kHz. Acoustic data is transmitted from the RSA-ORCA to the monitoring station on the installation vessel in real time using RAJANT HAWK Breadcrumb. The RAJANT HAWK BreadCrumb WifiMesh system has a 20 MHz channel bandwidth at 94 dBm and 80 MHz channel bandwidth at 68 dBm. The transmission range of the RSA-ORCA has been tested to reach ~8 km at 200 KB of data per second and therefore well within the necessary 80 KB per second data rate at a 5 km range required for this project. Testing for the RAJANT HAWK system has taken place in the North Sea and on the installation vessel earlier this year. The initial campaign in the North Sea (Q1 2024) tested the overall concept while the second campaign in the North Sea (Q2 2024) was intended to troubleshoot and overload the tested system in multiple challenging situations to test the response while in the field and test the stability of the system under stress. This year, every testing campaign in the U.S. has been conducted alongside the installation vessel to test the system in any unexpected conditions which may arise during the Revolution Wind campaign with results showing transmission ranges exceeding the 5 km required range during piling operations.

The four moored real-time RSA-ORCA PAM buoys will be deployed at perpendicular headings at a distance of 5 km from the installation vessel. Figure 1 shows the indicative locations of the positions of the PSO vessels, PAM deployment vessel, and placement of the four RSA-ORCA PAM devices in relation to the pile location during summer. The relevant clearance and shutdown zones in relation to the deployment location of each PAM device are also shown in Figure 1. Each mooring (Figure 2) consists of a large marker buoy with lights, reflectors, and a bank of batteries (expected to last 2–3 days between changes) to enable the telemetry equipment to communicate with the receiving station on the installation vessel. In an effort to reduce mooring noise, metal has been limited to a minimum to reduce any possibility of metal-on-metal noise. Any remaining metal components will have a rubber coating to further reduce noise. The in water mooring lines have been reduced in length to reduce the slack on the connecting chain to reduce the risk of noise from movement within the water. The buoy positions will be calculated using an internal global positioning system (GPS) receiver. Further details on the PAM hardware and software as well as PAM deployment procedures are provided Appendix A (section 1.3) and B, respectively.

Revolution Wind will use a mooring design consisting of a single mooring line (no loops of any sort) designed to reduce the risk of potential entanglement or entrainment of listed species in accordance with Project Design Criteria (PDC) 6 of the Offshore Wind Site Assessment and Site Characterization Activities Programmatic Consultation. The mooring setup will use high modulus polyethylene (HMPE) rope given its strength, easy handling and rigidity. The HMPE mooring line will include a quick release (g-hooks) that can easily be cut by Project personnel, if necessary. Revolution Wind will use the shortest practical line length for the relevant pile installation location's water depth. Hydrophone cables will be attached (at regular intervals) to the HMPE mooring line to prevent entrapping species inside while preventing cable strum (ensuring quality data). Hydrophone buoy deployment will take place from the SFV deployment vessel(s) which will have PSOs on board monitoring a 500 m zone surrounding the deployment location. Should any species be observed, operations will be stopped until the animal(s) have departed the 500 m zone surrounding the deployment location. In the unlikely event that a live or dead marine protected species becomes entangled, Revolution Wind will follow the relevant reporting protocols detailed in PDMP section 5.5 and the Offshore Wind Site Assessment and Site Characterization Activities Programmatic Consultation PDC 8 and provide any on-water assistance as requested.

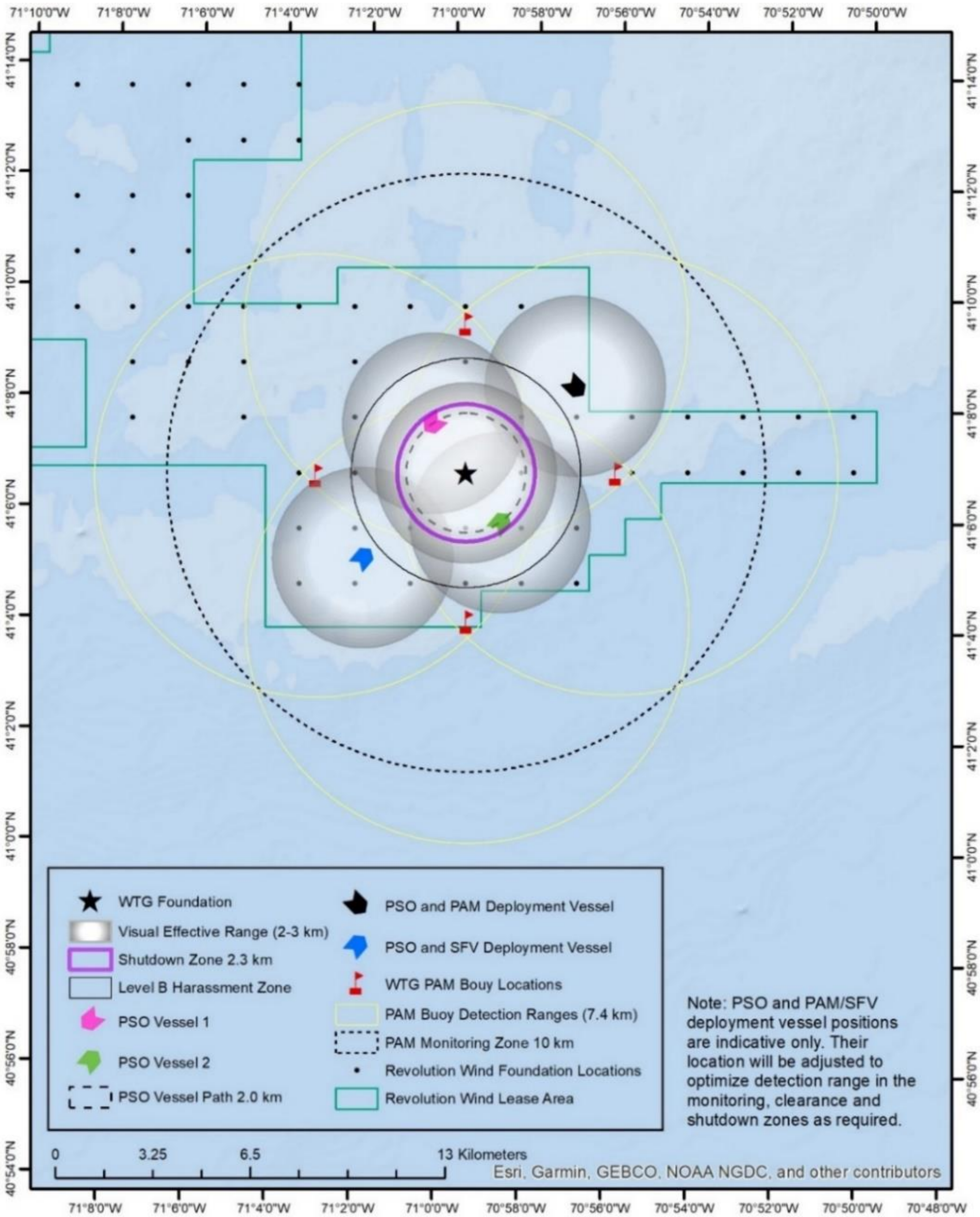

Figure 1. Indicative locations of personnel and RSA-ORCA PAM system equipment during each pile driving event occurring in summer.

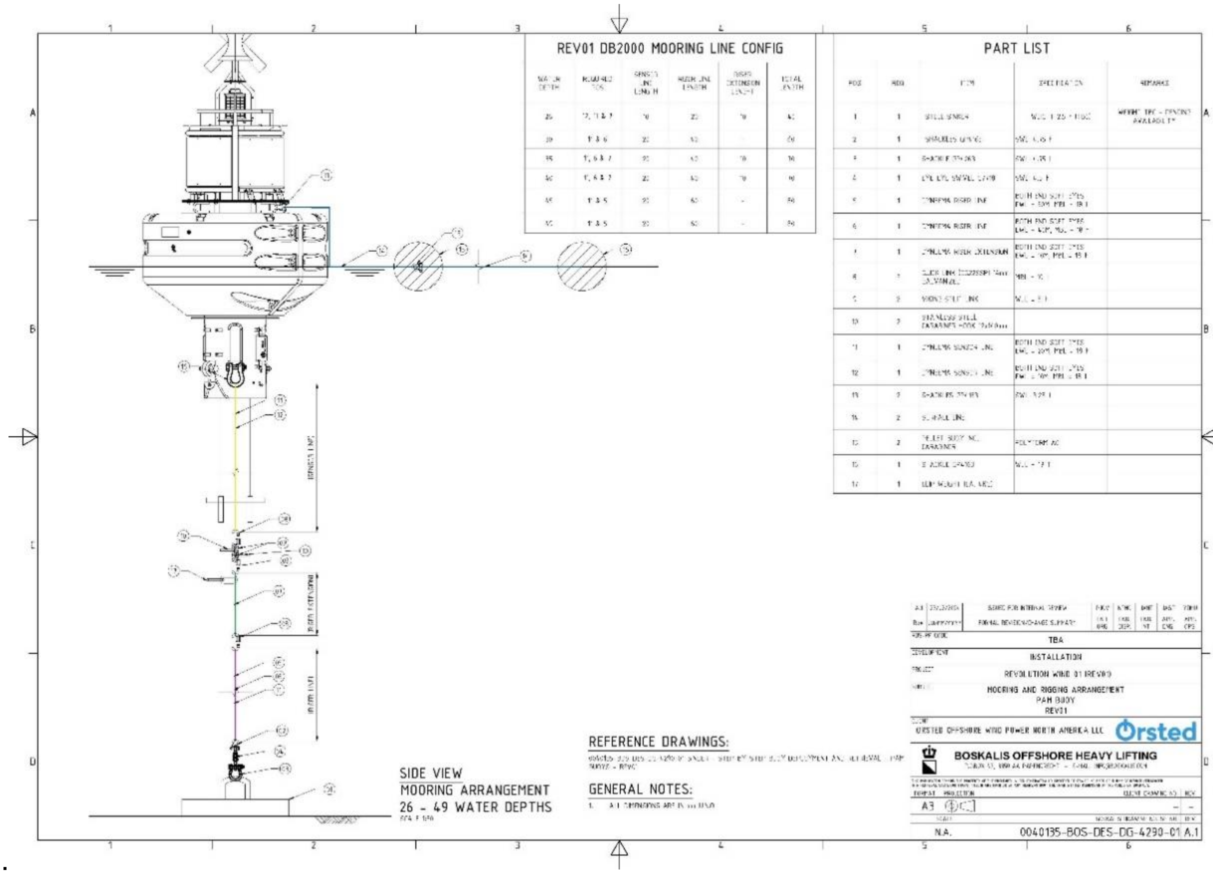

Figure 2. Moored real-time RSA-ORCA PAM system diagram

1.1.2 SeaPicket System

As an additional precautionary measure, to provide redundant near-real-time coverage of the 10 km PAM clearance/shutdown zone for NARW and long-range directional acoustic detections with the ability to localize marine mammal calls, the project will use ThayerMahan SeaPicket bottom mounted acoustic arrays (SeaPicket system). SeaPicket systems consist of a Maritime Applied Physics Corporation (MAPCORP) 605S buoy with a single point mooring system, a linear 32-channel acoustic hydrophone array (frequency response 30–1,100 Hz) laid on the bottom and anchored at two points on the seafloor, and a data cable running up to the buoy. The array employed herein is a 32-channel, low-power hydrophone array and leader built by Raytheon Missiles and Defense (RMD) in Portsmouth, RI. The array includes high-precision, non-acoustic sensor modules forward, mid, and aft, which measure array heading, pitch, and depth, and is designed to reduce flow noise. System and sensor design elements are incorporated for the mitigation of unwanted system motion-related noise. The hydrophones are piezoelectric crystals with a sensitivity of -199 dB re 1V/µPa. A thin array cable connects all 32 hydrophones to the flex hose which has an imbedded data cable to transmit information to the buoy payload bay. An analog-to-digital converter (ADC) is integrated into each channel, and hydrophone response is digitized with 24-bit precision at a sample rate of 2.5 kHz. Hydrophones are uniformly spaced at one half-wavelength for a design frequency of 625 Hz, or 1.2 m spacing and 37.2 m total aperture length. An array receiver or node card converts array telemetry to Ethernet User Datagram Protocol (UDP) packets for transmission to the embedded digital signal processor (DSP).

The hydrophone array has been designed primarily to detect calls from low-frequency cetaceans. Empirical demonstration of the detection abilities of the 32-channel hydrophone array are available in Premus et al. (2022) and summarized in Section 1.2.2 below. Signal processing aboard the buoy will include automated detectors/classifiers for NARW upcalls and humpback whale calls.

The buoy will include data archiving (full 30–1,100 Hz bandwidth), data processing and communications electronics and a re-chargeable battery pack housed in watertight enclosures, with solar panels, communications antennae, and lights mounted on the superstructure (Figure 3). Additional specifications of the SeaPicket are in Appendix C.

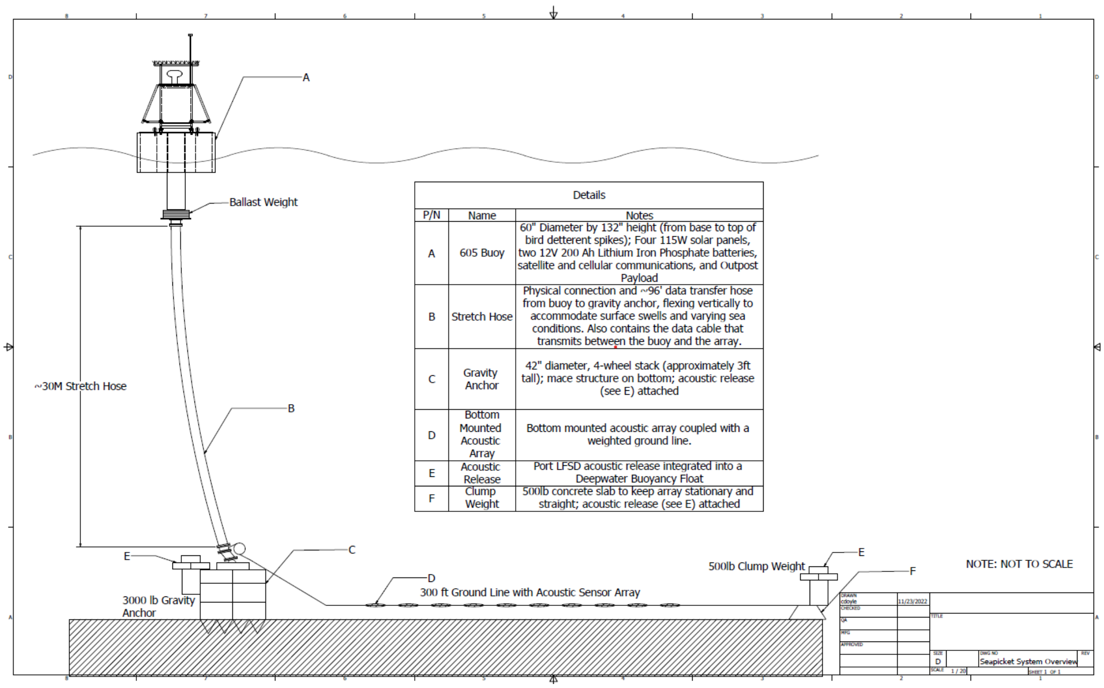

Figure 3. Moored near real-time SeaPicket PAM system.

During installation of the first four (4) piles, the two (2) SeaPickets will be deployed as shown in Figure 4. The locations (Table 2; Figure 4) were chosen to optimize acoustic detections within the 10 km PAM clearance/shutdown zone for NARW around the four pile locations. These locations provide full acoustic detection coverage of the 10 km PAM clearance/shutdown zone for NARW assuming detection ranges of 13.5 km to over 20 km as supported by materials in Section 1.2.2 and Appendix F. Additional acoustic modeling is currently being conducted to determine the optimal SeaPicket deployment locations for the remaining sixty-three (63) foundation locations. These locations will be provided in Appendix E as soon as they are available.

Table 2. Geographic location of the SeaPicket deployment locations (WGS 1984).

SeaPicket ID	Latitude	Longitude
SP 1 (North)	41.244840	-71.118338
SP 2 (South)	41.163069	-71.003848

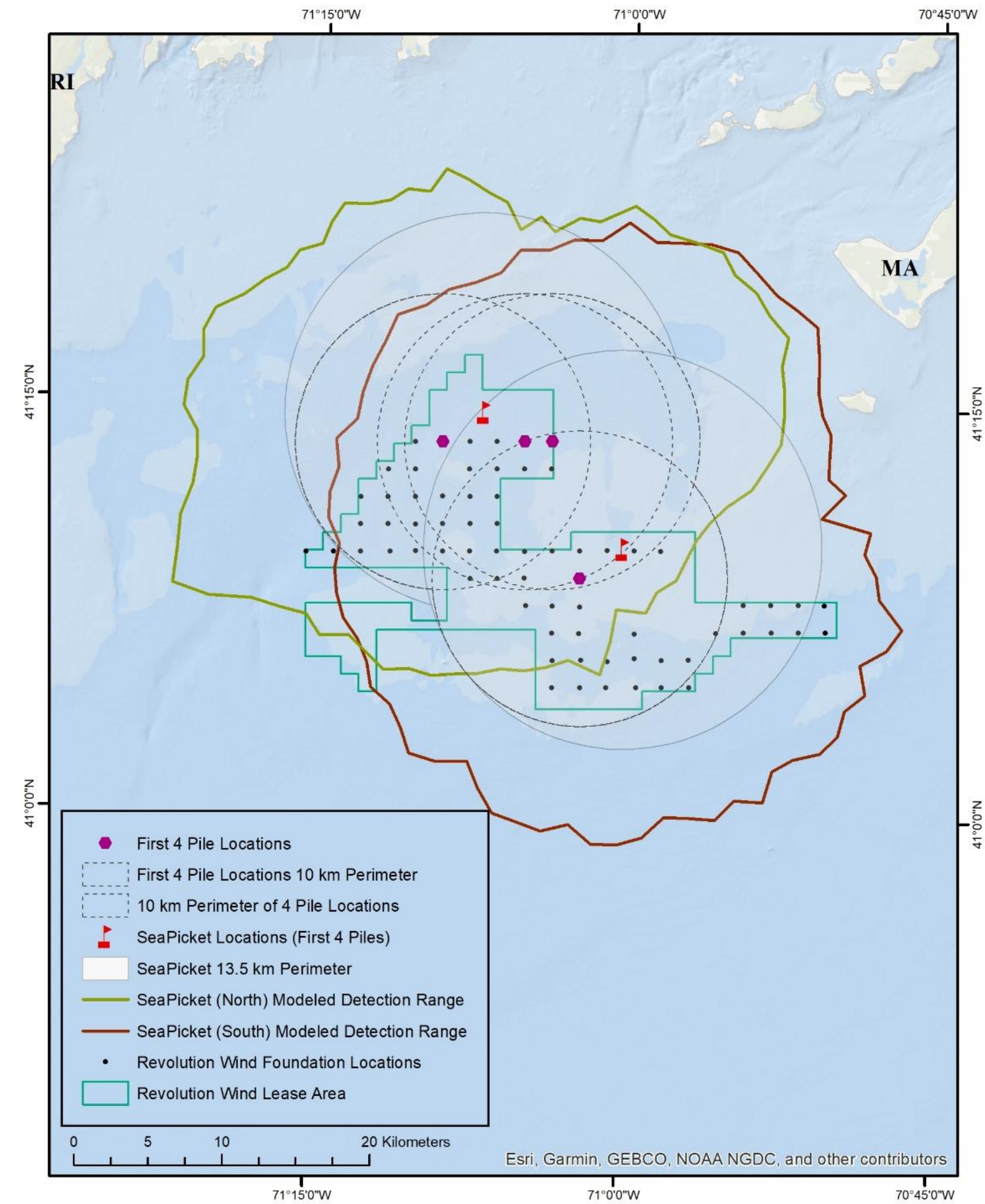

Figure 4. Deployment locations of the SeaPicket systems during installation of the first four piles (B47, B12, B11, B08 [USCG AK12, AE11; AE10; AE07]). NARW detection range predictions at 250 Hz are shown in orange and blue contours and correspond to a calculated transmission loss of 81 dB for the 32-channel array.

1.2 Detection Range Analysis

1.2.1 RSA-ORCA System

Based on data collected using archival recorders, Clark et al. (2010); Laurinolli et al. (2003); and Davis et al. (2017) estimate that maximum detection ranges for NARW to be from eight to 16 km, dependent on recording equipment, location, and environmental conditions. Van Parijs et al. (2021) also indicates an acoustic detection range of 10 km for vocalizations of baleen whale species such as NARW upcalls and sperm whale clicks (Figure 4; Van Parijs et al. 2021). In order to further evaluate the estimates provided by the referenced authors, the expected detection range of NARW calls sources was considered and calculations performed. Specifically, the passive sonar equation (Received Level (RL) = Source Level (SL) – Transmission Loss (TL)) and a transmission loss model were used to estimate at what distance a NARW vocalization drops below expected background noise levels and is no longer detectable by PAM equipment. The inputs needed were therefore an estimate of the source level of a NARW call, the expected background levels at the PAM system location, and the expected transmission loss.

NARWs create low frequency vocalizations (most energy under 500 Hz) and source level estimates range widely depending on the frequency band analyzed, accuracy of whale call location estimates, and transmission loss assumptions. For example, Parks and Tyack (2005) estimated NARW call source levels of 137–162 dB re 1µPa SPLrms for tonal calls and 174–192 dB re 1µPa SPLrms for broadband gunshot calls. Clark et al. (2010) estimated source levels at 172 dB re 1µPa SPLrms while Clark et al. (2011) used a large sample size and narrower frequency band to arrive at an estimate of 165 dB re 1µPa SPLrms.

Ambient noise levels are expected to be between 105 and 112 dB in the Southern New England Area (Rice et al. 2014; Van Parijs et al. 2023). Van Parijs et al. (2023) found that within this area, the monitoring site in the Revolution Wind lease area had the lowest ambient noise levels of 105 dB. However, due to the presence of installation vessels the background sounds levels are anticipated to be at or above 112 dB re 1µPa SPLrms, the high end of ambient levels reported by Van Parijs et al. (2023). Based on background sound measurements during the South Fork wind installations (between 50 – 440 Hz), the average background levels were around 112 dB re 1µPa SPLrms at 10 km from the pile and around 123 dB re 1µPa SPLrms at 3 km from the pile. Specific to the Revolution Wind location, recent equipment testing prior to installation activities provided acoustic measurements at 3 km from where the first foundation will be installed while the installation vessel was at the site along with two additional support vessels nearby. Background sound levels at 3 km (which is closer than the 5 km distance at which the RSA-ORCA systems will be deployed) were measured at 114 dB re 1µPa SPLrms. Using an average source level of 172 dB re 1µPa SPLrms and an expected background level of 114 dB results in 58 dB of transmission loss that can occur between where the call is made and where it would be received on a PAM recorder. On the other end of the range, using an average source level of 160 dB re 1µPa SPLrms and a background level of 123 dB re 1µPa SPLrms leaves 37 dB re 1µPa SPLrms of transmission loss that can occur.

Next, an appropriate spreading loss coefficient to use in the calculation needs to determined. Given the water depth and environmental conditions a value of 10 (cylindrical spreading) could be assumed. However, based on a source level of 160 dB re 1µPa SPLrms, this would yield a detection range of 63 km, which is unrealistic except in ideal conditions. Using a value of 15 for the spreading loss coefficient, sometimes referred to as "practical spreading", results in a detection range of approximately 1.6 km, which is inconsistent with the references cited in the previous paragraph and unrealistically short based on detections of mid-frequency cetaceans at approximately 2 km from a PAM station during South Fork Wind installation activities (Appendix A). While testing the PAM buoys on April 26th, 2024, a low-frequency cetacean call with a received level of approximately 140 dB re 1µPa SPLrms was detected at the same time as a visual detection of a non-NARW baleen whale was recorded at a distance of 4.8 km from the PAM buoy. Analysis of the call indicated it was likely a fin or sei whale. Source levels for fin whale calls have been estimated to average 162–164 dB re 1µPa SPLrms (Miksis-Olds et al. 2019) and as high as 189 dB re 1µPa SPLrms (Sirovic et al. 2017). Sei whale call source levels have been estimated at 177 dB re 1µPa SPLrms (Romagosa et al. 2015). Using this range of source level values and a received level of 140 dB dB re 1µPa SPLrms the spreading loss coefficient associated with this detection would range from 6.62 (assuming 164.4 dB re 1µPa SPLrms call source level), to 10.05 (assuming a 177 dB re 1µPa SPLrms source level), and up to 13.3 (assuming a 189 dB re 1µPa SPLrms source level). The more realistic values of 10.05 and 13.3 suggest a spreading loss coefficient between 10 and 15 is reasonable to assume. Using a value of 12.5, the midway point between 10 and 15, the lowest source level estimate of 160 dB re 1µPa SPLrms and the highest background level of 123 dB re 1µPa SPLrms, the estimated detection distance would be 912 m. On the other end of the spectrum, using the higher source level estimate of 172 dB re 1µPa SPLrms and lower background level of 114 dB re 1µPa SPLrms yields an estimated detection distance of 43.7 km. If the midpoints of both values are used, a call source level of 166 dB re 1µPa SPLrms and a background level of 119 dB re 1µPa SPLrms, the result is an estimated detection distance of 6.3 km.

An alternative analysis was also performed using propagation loss modeling from the South Fork Wind sound field verification measurements (Küsel et al. 2024). This analysis used the cylindrical spreading loss model fit to the South Fork Wind sound source verification data where the transmission loss coefficient was 10 and the absorption coefficient was -1.5 (Figure F-6 in the report). To test the validity of this model to the Revolution Wind location we assumed an average source level of 176 dB re 1µPa SPLrms for the fin whale call detected by the PAM buoy on April 26th, 2024 and a background level of 114 dB re 1µPa SPLrms. This results in a detection range of the fin whale call of 6.6 km, which is consistent with the visual detection distance of 4.8 km. Applying the South Fork Wind propagation loss model to a NARW call with a source level of 160 dB re 1µPa SPLrms and a background level of 114 dB re 1µPa SPLrms results in an estimate detection range of 5.7 km. Alternatively, if a NARW call source level of 172 dB re 1µPa SPLrms and a background level of 123 dB re 1µPa SPLrms are assumed, then the detection range would be 7 km.

The various inputs and analysis approaches described above reflect the fact that the underwater acoustic environment can be quite variable. Nonetheless, when considering the range of appropriate input values, the results indicate that it is reasonable to expect that the detection range of a NARW call on the RSA-ORCA systems is at least 5 km. Since the PAM buoys are placed at 5 km from the pile location, a detection range of 5 km or greater will allow for effective monitoring out to the 10 km PAM clearance/shutdown zone for NARW.

Because the detection range will vary on an almost continuous basis, the PAM operator will run the PAMGuard SIDE module (https://gisserver.intertek.com/JIP/DMS/ProjectReports/Cat4/PAMGuard/JIP-Proj4.9.2_PAMGuardAssuranceModule_MM_DetectionPAM_2020.pdf) every hour as per PAMGuard default setting to estimate the detection probability of NARW calls under the in-situ field conditions. If the probability falls below the minimum detection range of 5 km (covering out to the 10 km PAM clearance/shutdown zone for NARW), the data during the period analyzed will be re-analyzed during post-processing by at least two independent PAM operators to ensure no detections were missed.

During pile driving, sound levels are expected to reach 160 dB re 1µPa SPLrms for approximately 0.1–0.9 seconds on average depending on the distance from the piling center. Pile strikes are usually produced at a rate of 1 strike every two seconds, as observed during pile driving activities on South Fork Wind (2023). Pile driving sound levels will be reduced while the duration of the peak sound levels will increase with increasing distance from the pile. For example, Bailey et al. (2010) note that at close ranges, the initial peak of a pile driving waveform is very pronounced, lasting approximately 0.01s within 1 km of the source (total waveform duration 0.2 s); however, the duration of this peak increases to 0.2 s at 40 km (total duration approximately 0.6 s). Tygonis et al. (2013) found that the average NARW upcall is 1.49 seconds in duration and Parks and Tyack (2005) found that NARW upcalls often occur in bouts so it is likely that multiple calls would occur. Therefore, the durations of both individual calls and bouts of calls are likely to be longer than the pile noise received at the PAM buoy locations, allowing a PAM operator to detect a NARW vocalization between pile driving strikes.

The four-buoy configuration therefore allows monitoring of the 10 km PAM Clearance/Shutdown zone for NARW around the pile and localization within the PAM clearance and shutdown zones for wind turbine generator (WTG) and offshore substation (OSS) foundation installations.

1.2.2 SeaPicket System

During the spring demonstration project summarized in ThayerMahan (2022, 2023), these systems were tested to demonstrate their ability to detect mysticete whale and other marine mammal calls. The SeaPicket systems, as well as a mobile acoustic array towed by a wave glider USV, provided directional whale acoustic detections at long ranges. Although we do not plan to use the USVs as part of this monitoring plan, the same acoustic sensor as the SeaPickets was installed on the USV. In Figure 5, the acoustic information from the same marine mammal detection is shown for each system (SeaPickets: AVON and BRISTOL; wave glider: MARY R). An acoustic analyst reviewed the data and confirmed a positive marine mammal detection, then used the directional information from each sensor to create an Area of Uncertainty within the ThayerMahan's Mission Data software (Figure 6). In this case, the location of the marine mammal call was determined to have come from within a 2 NM (3.7 km) by 5 NM (9.3 km) ellipse.

In another example, simultaneous detections on both MARY R (USV) and AVON (SeaPicket) produced an Area of Uncertainty (AOU) about 22 NM (40.7 km) from MARY R (Figure 7). Additionally, long-range detections of vocalizing whales by ThayerMahan acoustic systems were corroborated by independent monitoring assets deployed by other research organizations such as WHOI and NOAA. Figure 8 shows detections on the WHOI Martha's Vineyard Buoy, with near simultaneous detection by AVON (with some time difference due to distance). Of note, some additional biological transients down bearings were detected by AVON and not detected by the WHOI buoy.

Additional materials regarding the detection and localization capabilities of the SeaPicket systems have been previously shared with agency personnel through various forums. A compilation of these materials are provided in Appendix F for reference.

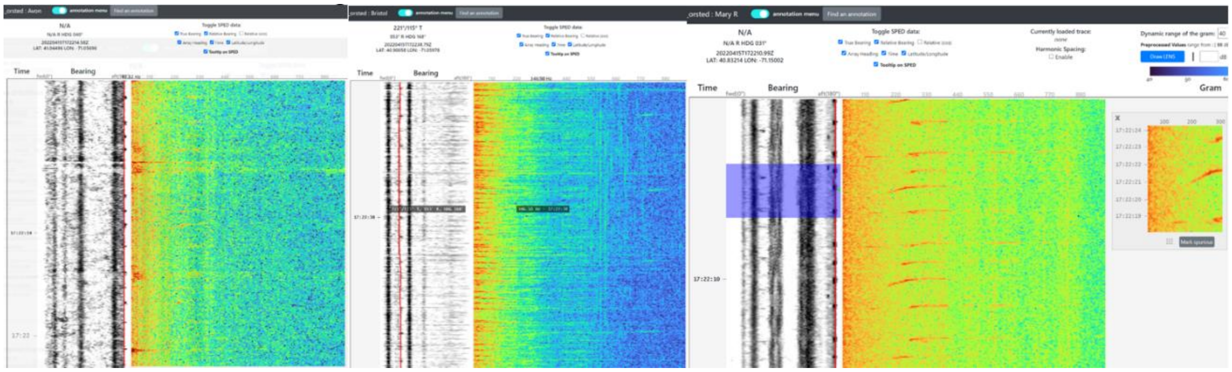

Figure 5. Simultaneous acoustic detection across three platforms (AVON, BRISTOL, and ELLEN). Note the bearing to each detection and that MARY R's system had an autodetection.

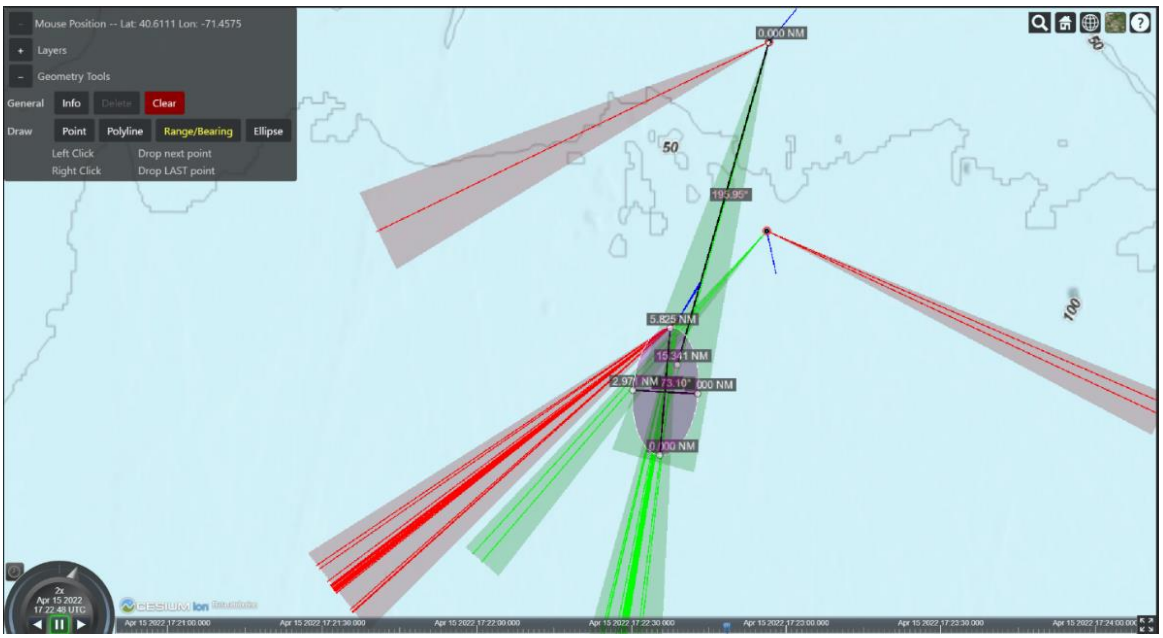

Figure 6. Localization using three sensors (AVON [SeaPicket], BRISTOL [SeaPicket], and MARY R [USV]). The distance to AVON was approximately 28 km, BRISTOL was approximately 13 km, and MARY R was approximately 9 km.

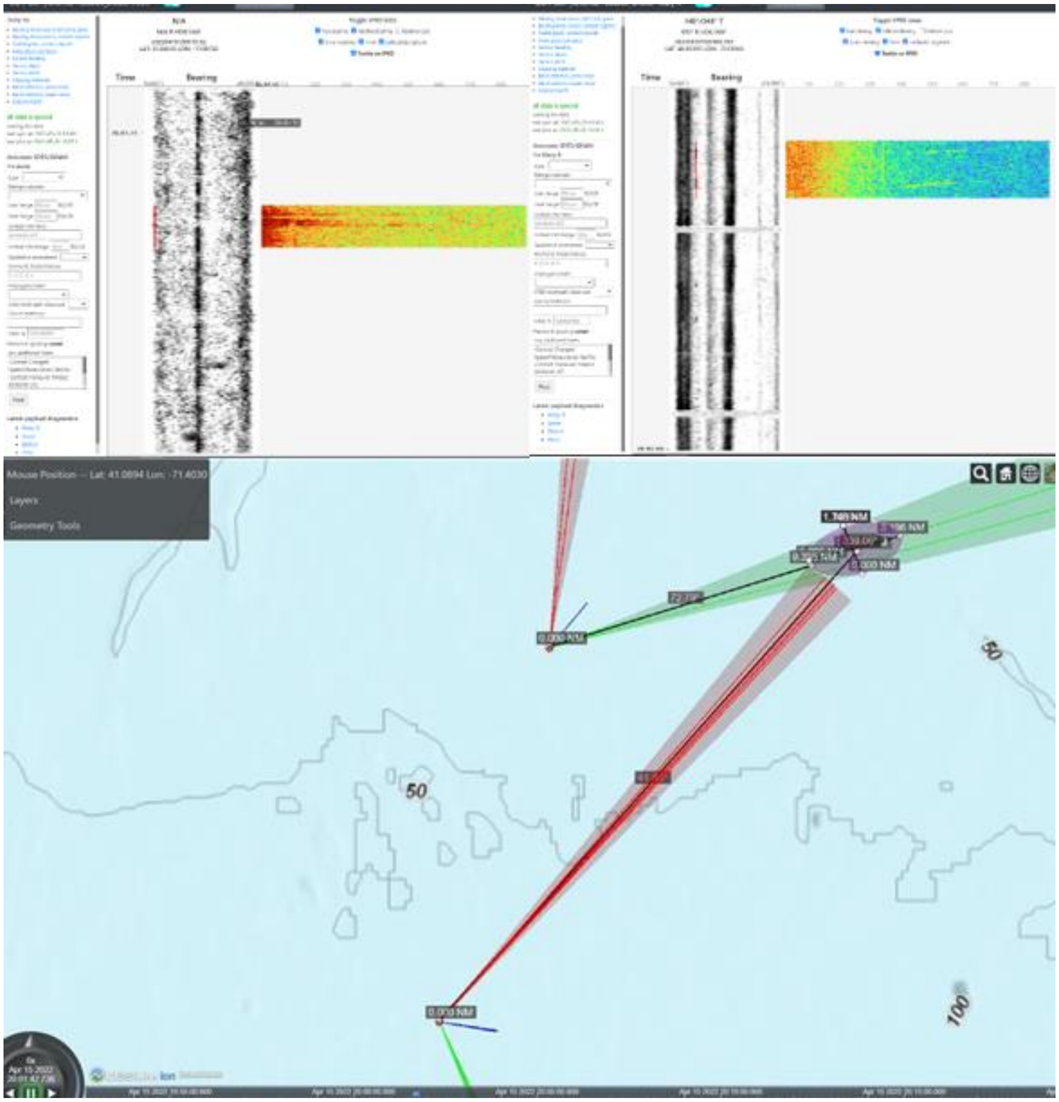

Figure 7. Simultaneous Detections on MARY R and AVON; detection distance estimated at approximately 22 NM from MARY R.

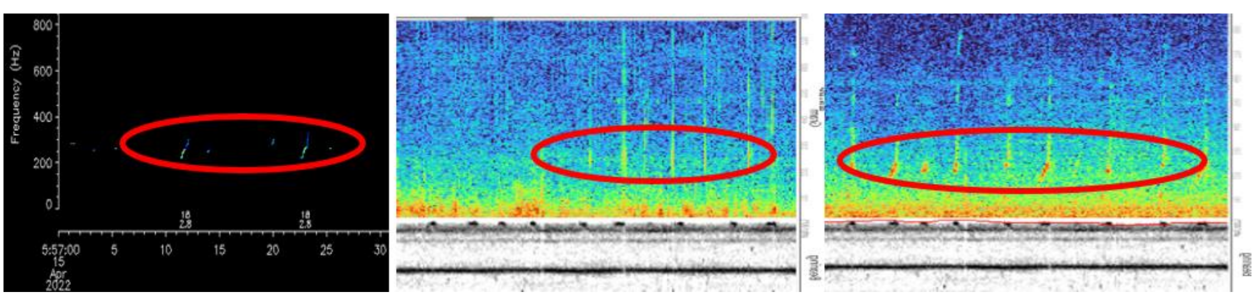

Figure 8. Spectrograms showing detections on 15 April 2022 from 05:57.00 to 05:57.30. Left panel - WHOI Martha's Vineyard Buoy; Middle panel: AVON Detections at bearing 200˚N – 240˚N; Right panel: AVON Detections at 075˚N.

1.3 PAM Data Collection, Transmission, and Analysis

1.3.1 RSA-ORCA System

The moored PAM system is designed to effectively measure marine mammal vocalizations in "real time" with the PAM system and operator (onboard the installation vessel) detecting a call in less than 5 minutes (likely 1–2 minutes) from when the call was received at the hydrophone. As described in Section 1.1.1, a hydrophone will be attached to the buoy and deployed below the surface electronics pod at a depth greater than half the water depth. The sampling rate will be 48 kHz with a sensitivity rating of ~200 dB re 1 V/µPa for marine mammal detections. Clipping is unlikely given the sensitivity and sample rate of the hydrophones. Clipping can be verified on the spectrogram observed by the PAM operator where the sample rate and peak to peak voltage can then be adjusted within PAMGuard as required. Any unwanted background noise sources will be minimized as described above in the second paragraph of Section 1.1.1 to produce high quality, accurate data. Some ambient noises associated with the vessels (e.g., DP thrusters) and the impact pile strikes themselves cannot be reduced to improve biological signal to noise ratio and may mask some marine mammal vocalizations because most anthropogenic sound overlaps the frequency range of mysticete vocalizations. This PAM Plan takes into account the potential for masking from pile-driving and vessel noise in evaluating the detection range of the PAM systems and they will not be placed closer than 1 km from the pile being installed.

There will be two receiving stations on the BL2 and one on each of the PSO vessels. Each station will have a high quality Wi-Fi antenna that will allow for point-to-point data transfer of the Full-bandwidth (2 Hz to 24 kHz) acoustic data (sound files) from the four buoys to the PAM receiving stations. Once connection is established, all standard communication protocols happen in a few milliseconds. Approximately 10 second audio files are created on the buoys, which are then compressed and placed in a queue ready to be transferred. Some artificial latency is created within this process lasting ~45 seconds and is induced to ensure the integrity of the data being transmitted.

There will be one PAM operator based on the bridge alongside the on-duty PSOs to ease communication between the two parties. The PAM operator will be monitoring the four acoustic data streams from the PAM buoys in real time, split across two monitors, actively monitoring for marine mammal vocalizations. The PAM operator will use PAMGuard for all PAM data visualization and all four incoming data streams will be viewed as a spectrogram up to 24 kHz (sampling rate 48 kHz) to assist in verifying the detections (as shown in Figure 9). Each audio stream will be monitored by the on-duty PAM operator in real-time.

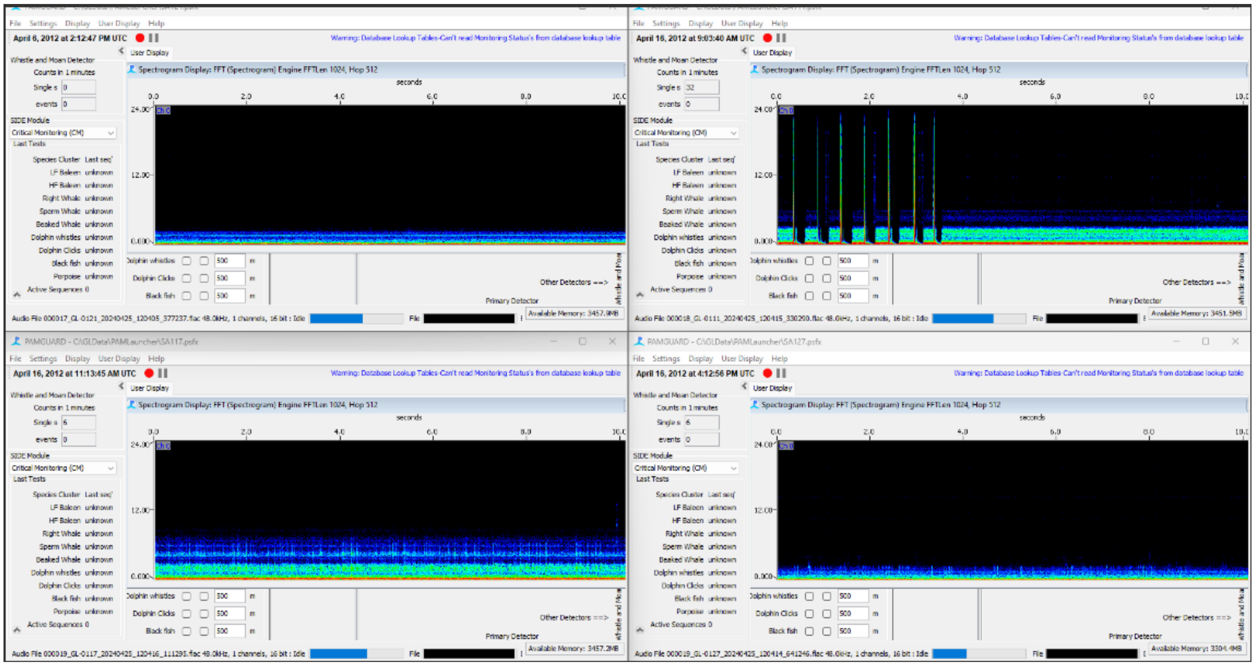

Figure 9. User interface of PAMGuard

PAMGuard has been widely developed and used in the field for both mitigation purposes and pure science applications. Since 2020, PAMGuard is listed as the acoustic analysis software for marine mammal research in over 300 peer reviewed publications (based on a google scholar search). Based on user data, PAMGuard releases typically generate between 1,500 and 3,500 downloads (Macaulay and Gillespie 2022). Once a detection and localization software for real-time towed PAM arrays used in mitigation, PAMGuard now contains advanced acoustic analysis capabilities (both real time and post processing) including suite of auto-detectors, beamfomer, bearing calculator, and QA/QC module. While other acoustic analysis software can also perform these functions, the familiarity that the marine mammal mitigation community has with PAMGuard, combined with its robust stability for real-time analysis, make it a highly acceptable for mitigation monitoring.

Agencies have recommended PAM methodologies and standards for monitoring offshore wind energy development (Van Parijs et al. 2021). PAMGuard meets all the analysis and software standards set forth in the Van Parijs et. al agency standards paper. Particularly in high-noise environments, PAM systems must be able to determine effective listening ranges. PAMGuard is the only known software product that offers a QA/QC module using an open-source Signal Injection and Detection Evaluator (SIDE) software module providing users with the ability to predict detection performance and document real-time automated detector and human operator effectiveness as a function of distance (i.e., range) between a detector and the sound source (Barkaszi et al. 2020). This capability was specifically called out as a PAMGuard capability in the agency recommendation paper described above (Van Parijs et al., 2021). BOEM and NMFS have accepted marine mammal detections and localizations reported in PSO mitigation reports since the early 2000’s. Recently, PAMGuard was used for the basis of a coastal acoustic buoy system for offshore wind; an evaluation of bearing accuracy and exclusion zone monitoring was conducted using the software (Palmer et al. 2022). Based on those study results, detection ranges of

4–7.3 km were achieved depending on the source and ambient noise levels. More recent in situ data collected on April 26, 2024, resulted in a detection range of 4.87 to 5.16 km from the buoy.

Detection methodology will include the use of PAMGuard built-in detectors including the Whistle and Moan detector and the Right Whale edge detector. All audio data will be processed continuously during clearance, active piling, and post-pile driving using the PAMGuard Right Whale Edge Detector and Whistle and Moan Detector to help identify and classify potential whale calls in the spectrograms. Both detectors highlight possible vocalizations within the PAMGuard spectrogram and will use different colors so that the PAM operator can easily distinguish between detections. The pitch tracks created by PAMGuard detectors will be superimposed over the streamed audio data, therefore they will have the same duration and frequency as the potential whale call identified in the audio stream. No filters will be applied during the monitoring process. There are no gain settings in the PAM buoy hardware, however a PAM operator can change the gain or peak to peak voltage within PAMGuard if required.

The combination of manual detection of vocalizations while watching near real-time incoming data and built-in PAMGuard detectors will help ensure vocalizations are detected. Pitch tracks will be picked up by PAMGuard since the PAM operators will see the incoming data streams. The Whistle and Moan Detector is designed to detect any frequency modulated calls including odontocete whistles and mysticete vocalizations. As further described in section 1.4, all PAM operators will complete the Whale Vocalization Training so as to understand how to distinguish between NARW calls and other mysticete calls (e.g., humpback whales). The Right Whale Edge Detector will be utilized to identify any NARW vocalizations during the Project. This module takes constant background measurements and adjusts its setting automatically to respond to changes in ambient noise levels that would be expected during pile driving activities due to increased vessel noise and pile installation. Therefore, the detector should not be significantly affected by construction noise during pile driving. Gillespie (2004) tested the Right Whale Edge Detector against sound files containing only NARW calls, and a sound file containing non-NARW calls. There were right whale upsweeps detected by a human operator in which 1,897 were confirmed by the Right Whale Edge Detector. This gives a detection probability of 90% for NARW upsweep calls. When analyzing the non-NARW call sound files, Gillespie (2004) found a false positive rate of 1 – 2 calls per audio stream per day.

Analysis of the DCLDE (2013) 2023 NOAA NEFSC Baleen Whale (including North Atlantic Right Whale) data set has been carried out using PAMGuard. Through a preliminary analysis, we found that a threshold of 4 dB and a Fast Fourier Transform (FFT) window of 256 produced the most conservative detection results for the North Atlantic Right Whale (NARW). A conservative analysis approach, focused on NARW call detection, was determined to be the most appropriate. This approach results in a higher percentage of detections when compared to the NOAA annotations of NARW calls in the dataset, but it also produces the highest level of false positives. A detailed analysis using those settings was carried out on the largest contiguous dataset, the 2009 week-long dataset. Through an analysis of the 2009 week of data, with runs for both NARW and broader low-frequency calls, a 75% detection rate and 66% false positive rate were achieved for the confirmed Right Whale Detections.

Detection on two of the four PAM buoys provides the necessary data to localize calls. If any animal(s) are detected on multiple PAM buoys during piling operations and the detection is able to be identified and localized, the appropriate mitigation (e.g., immediate shutdown for any NARW/unidentified large whale detection at any distance within the 10 km PAM clearance/shutdown zone for NARW, or non-NARW large whale species localized within the 2,300 m [4,400 m in December] clearance/shutdown zone) will be called for immediately upon localization by the PAM operator onboard the installation vessel and directly communicated to the Lead-PSO on duty If the vocalization is identified to be a delphinid species, an immediate shutdown is not required given that the PAM clearance and shutdown zone for delphinids is the noise abatement system (NAS) perimeter.

If the animal is detected on a single PAM buoy and therefore unable to be localized, a conservative approach will be taken, and the PAM operator will call for an immediate delay/shutdown of piling operations until the animal is able to be localized. Following delay/shutdown of piling operations, the PAM operator will notify the bridge team/DP and radio the detection to all Project vessels (including all PSOs). All additional data QA/QC to support mitigation requirements will occur after mitigation has been requested/implemented. This includes the PAM operator running the detection through the localization software, which will be communicated across all vessels to provide awareness of the protected species. While the PAM operator works to validate the detection and verify localization, one on-duty PSO will record the sighting into *Mysticetus*, while the other two PSOs remain on watch from the bridge wings of the vessel. Any additional post-processing or re-analysis of PAM data will occur after the relevant mitigation measure has been requested/implemented. And any follow-up notes taken during this time will be shared in *Mysticetus* once the sighting has ended or at the end of monitoring on that day. Piling will remain delayed/shutdown as long as the marine mammal(s) are acoustically detected on any one of the four buoy systems and will not restart until 30 mins has elapsed since the last detection.

As described above in Section 1.1, custom software written in the Python programming language will be used for localizing marine mammal calls detected on the RSA-ORCA PAM systems. Using the difference in time between sound files rather than absolute real time, the software assumes single path propagation, good signal-to-noise ration (SNR) and constant sound speed and applies a hyperbolic equation intersection to give an estimated distance and bearing to the vocalizing animal. Error will be based on the area of the polygon where the intersections occur, calculated as the square root of the sum of the squared residuals for the model, and will be displayed as +/- m. This error will always be included to produce a conservative estimate of distance to piling center (e.g., a detection localized to 5.1 km +/- 0.2 km will be treated as if it was at 4.9 km). For all cases where the intersection of a potential NARW call is within the 10 km PAM Clearance/Shutdown zone for NARW, PAM operators will be conservative and assume a NARW is within the closest range to piling based on the error bars. When all four systems detect the vocalization, the position of the source will be more accurate. If the vocalization is detected within the 10 km PAM Clearance/Monitoring zone for NARW, mitigation actions will be taken as described in Section 3.5 of the PDMP.

When there is no requirement for mitigation or monitoring, each mooring will be placed in a standby state to preserve battery. Any noise from the mooring itself has been minimized as follows:

- Reducing the number of mechanical shackles to as low as practical;
- Reducing the amount of equipment in the water by putting all electronic components in an isolated section of the surface buoy – this also means fewer connections between the buoy computer and hydrophone;
- Hydrophone cage to protect the hydrophone from debris; and
- Attachment to the mooring rope is by cable ties.

1.3.2 SeaPicket System

As described in Section 1.1.2, each SeaPicket system detects acoustic signals using a 32-channel linear acoustic array. The received signals undergo onboard processing with relevant data then transmitted every five minutes to a shoreside command center via satellite communication. The onboard processing will include classifiers specifically developed to identify the North Atlantic right whale upcall and humpback whale calls. Autodetection classifiers for other additional species are in development and will be used as they become available. Using a web-based interface, SeaPicket operators will be on duty shoreside to review and analyze incoming data. ThayerMahan employees with experience using the SeaPicket systems will be operating and monitoring the incoming data at the shoreside command center. If the SeaPicket Operator(s) is a qualified and NMFS approved PAM Operator then no additional personnel would be needed and they would serve as the required PAM Operator and carry out the associated responsibilities. If the SeaPicket Operators are not NMFS approved PAM Operators, then a NMFS approved PAM Operator will be on duty in the command center with the SeaPicket Operators. The NMFS approved PAM Operator will review potential detections made by the SeaPicket Operators and conduct the data recording, mitigation and monitoring decision making, and direct communications to the Lead PSO (located on the installation vessel) required of PAM Operators via radio, phone, or other direct communication method).

The SeaPicket Operators will classify and tag the data using the following hierarchy to create contact/detection reports and discuss any uncertainties with the on-duty PAM Operator to ensure potential call detections are not missed:

1) Investigate all auto-detected/classified alerts first.
    a. Annotate classified alerts for valid detections of marine mammal calls based upon the visual characteristics of the detection.
    b. Look for other potential detections around auto-classified detections that could be potential missed detections and “tag them” (i.e. mark them within the acoustic data visualization software) as detections if they are determined to be valid marine mammal calls.
    c. If the detection(s) was determined to not be valid (i.e. it was not a potential marine mammal), the SeaPicket Operators would not tag the data.
2) Evaluate non-classifier detections throughout the data. Look for distinct short-duration transients in data and interrogate them.
    a. The SeaPicket Operator will conduct a review based on the call signature and the existing database of marine mammal calls to confirm a marine mammal call.
3) Tag transients that appear to be valid marine mammal detections. If unsure, tag as “biologic” and "other”.
4) Synthesize and correlate the tagged line of bearing information to generate a contact report for any of the marine mammal calls tagged as such in 1–3 above within MissionData (ThayerMahan’s Geo-based visualization software for acoustic sensors) that will automatically propagate to *Mysticetus*.
5) As soon as a detection report for a marine mammal is available it will be entered or automatically pushed into the *Mysticetus* cloud database. The vessel-based computers running *Mysticetus* automatically sync to the cloud resulting in the acoustic detections becoming visible to the vessel-based PSOs on a map display.
6) If the PAM Operator determines that the location of call overlaps with an applicable mitigation zone (e.g. PAM clearance/shutdown zone for NARW or clearance/shutdown zone for non-NARW large whales) the PAM Operator located in the Command Center will initiate direct

communications with the vessel-based Lead PSO on the installation vessel (via radio, phone, or other direct communications method). The lead PSO will assess the information provided and will take the necessary mitigation actions. No direct communication will be made between the PAM operator monitoring the RSA-ORCA PAM systems and the PAM operator(s) located in the command center monitoring the SeaPicket system(s). All communications regarding PAM detections will go directly to the Lead PSO.

   a. This same procedure and communications will occur if the area of uncertainty around a localized whale call overlaps a relevant mitigation zone even if the call itself is localized outside of the mitigation zone.

7) If a call cannot be localized, the PAM Operator will use other available information, including the location of the pile being installed relative to the SeaPicket system(s) on which the call was detected and the call amplitude on the system(s), and their professional judgement to determine if the animal may be within a relevant mitigation zone. If it is determined to potentially be within a mitigation zone, then the appropriate mitigation measures will be requested by the PAM operator through communications with the vessel-based Lead PSO on the installation vessel (via radio, phone, or other direct communication method).

The duration of time from when a call is received by a SeaPicket system to when it can be reviewed by a PAM Operator is less than 15 minutes and typically 5-10 minutes. Additional details describing the time required for potential marine mammal calls to be transmitted, reviewed, and communicated to the Lead PSO (via radio, phone, or other direct communication method) are provided in Appendix D.

1.4 PAM Operator Qualifications

All PAM operators will have undergone the Whale Vocalization training program as described in Section 3.2.1 of the PDMP). Any crew joining that has not undergone the Whale Vocalization training program (trainees) will be required to undertake this training prior to joining the Project. Per ITR § 217.275(a)(11) and LOA Condition 4(a)(11), PAM operators will demonstrate they have prior experience with real-time acoustic detection systems and/or have completed specialized training for operating PAM systems and detecting and identifying Atlantic Ocean marine mammals sounds in particular: NARW sounds, humpback whale sounds, and how to deconflict them from similar NARW sounds, and other co-occurring species' sounds in the area including sperm whales. Revolution Wind will report all PAM operators' completion of the described specialized PAM training to meet the requirements of LOA Condition 4(a)(11) to NMFS OPR. Additional PAM Operator requirements include:

- Distinguish between whether a marine mammal or other species sound is detected, possibly detected, not detected, and similar terminology will be used across companies/projects;
- Where localization of sounds or deriving bearings and distance are possible;
- Demonstrate experience using this technique of PAM monitoring;
- Be independent observers (e.g., not construction personnel);
- Be able to demonstrate experience with relevant acoustic software and equipment;
- Have qualifications and relevant experience/training to safely deploy and retrieve equipment and program the software;
- Be able to test software and hardware functionality prior to operation (as necessary);

- Have evaluated their acoustic detection software using the PAM Atlantic baleen whale annotated data set available from the National Centers for Environmental Evaluation (NCEI) and provide evaluation/performance metric; and,
- Review and classify acoustic detections in real-time (prioritizing NARW and noting detection of other cetaceans) during real-time monitoring periods.

Per ITR § 217.275(a)(9), Revolution Wind will provide NMFS with a list of previously approved PAM operators for review and confirmation of their approval at least 30 days prior to commencement of impact pile driving activities, or 15 days prior when new PAM operators are required after activities have commenced.

1.5 PAM Monitoring and Mitigation Protocols

Monitoring and mitigation measures related to the PAM operator role and standards are described in Section 3.2 of the PDMP. Any additional measures related to PAM deployment are as follows:

1) PAM will be conducted during all impact pile driving;
2) All PAM operators monitoring the RSA-ORCA systems will be located on the installation vessel while PAM operators monitoring the SeaPicket systems will be located on shore;
3) PAM will begin at least 60 minutes prior to initiation of impact pile driving, continue throughout installation, and extend at least 30 minutes post installation;
4) The PAM clearance and shutdown zone will be mapped in the PAM monitoring software user-interface prior to beginning PAM monitoring (Table 3);
   a. If a PAM system (either RSA-ORCA or SeaPicket) malfunctions during the 60-minute clearance period, the PAM operator will notify the Lead PSO and call for a delay in pile driving activity until the systems is fully functional or a replacement system has been deployed as close as possible to the original location. Following repair or deployment of the replacement system, once all systems are functional, re-start of the 60-minute clearance period will begin.
   b. If a PAM system malfunctions during pile driving, the PAM Operator will notify the Lead PSO and call for a shutdown of piling activity until the systems is fully functional or a replacement system has been deployed as close as possible to the original location. Following repair or deployment of the replacement system, once all systems are functional, pile driving may continue without clearance and soft start if the delay was less than 30 minutes. If the delay was greater than 30 minutes, clearance and soft-start procedures will be completed as described in PDMP section 3.5.2 and 3.5.3 will be followed.
5) As per LOA Condition 3(c)(6), 3(c)(11), and 3(c)(13), if any marine mammal is detected (visually or acoustically) within the species specific clearance and shutdown zones (Table 3), a delay or shutdown will be required.
6) The 10-km PAM Clearance/Shutdown zone for NARW will be established for situational awareness. Any acoustic detections of marine mammals, including NARWs, within this zone will be relayed to the entire PSO project team and if localisation is possible, it will be plotted on *Mysticetus*.
7) At a minimum, the PAM operator will immediately communicate all detections of marine mammals in the 10-km PAM Clearance/Shutdown zone for NARW to the Lead PSO, including

any determination regarding species identification, distance, and bearing and the degree of confidence in the determination;

8) All NARW calls detected on any PAM buoy during the clearance period will follow the measures as described below:
    a. Any acoustic detection of a NARW within the PAM clearance/shutdown zone for NARWs (10 km) will trigger a delay to the commencement of pile driving. The clearance zone will only be declared clear if no NARW acoustic detections within the PAM clearance/shutdown zone for NARWs have occurred during the 60 minute clearance zone monitoring period of which 30 consecutive minutes will be determined to be clear of marine mammals directly prior to commencing these activities.
    b. If a PAM operator can confirm (e.g., probable detections or greater) that a vocalization originated from a NARW located within the PAM clearance/shutdown zone for NARWs, the detection will be treated as a visual detection and impact pile driving will not commence.
    c. If impact pile driving is delayed due to the presence of a NARW, impact pile driving will not begin until the NARW has not been acoustically detected for 30 minutes.
9) During impact piling, if a NARW call is acoustically detected at any distance within the 10 km PAM Clearance/Shutdown zone for NARW, pile driving will be shut down per ITR § 217.274(c)(11).
10) PAM Operators will work and communicate with visual PSOs to compare PAM detections with any concurrent visual sightings, and these will be initially noted in *Mysticetus* for subsequent review during the end of day QC by the Lead PSO.
11) PAM operators will review the Daily Project Protected Species Awareness Bulletin (issued by Orsted every four hours), which includes areas where protected species may be present.
    a. Data within the Bulletin will come from near-real time sightings/detections received from the WhaleAlert App, WhaleMap, the Sea Turtle Sighting Hotline (http://seaturtlesightings.org), any sightings reported by Trained Lookouts, and data from Mysticetus.

All PAM detections and associated analyst reviews will be archived and all information regarding monitoring and detections will be reported using a standard format (Table 4).

Table 3. Relevant PAM monitoring, clearance and shutdown zones during impact pile driving in summer and winter[1]

Species	North Atlantic Right Whale		Other Large Whales		Delphinids		Harbor Porpoise		Seals	
	WTG	OSS	WTG	OSS	WTG	OSS	WTG	OSS	WTG	OSS
PAM Monitoring Zone (km)	10		10		10		10		10	
PAM Clearance Delay and Shutdown (m)	At any distance within the PAM Monitoring Zone		2,300 (4,400)	1,600 (2700)	NAS	NAS	1,400 (2,400)	900 (1,300)	500 (900)	400 (400)

[1]Winter (i.e., December) distances are presented in parentheses.

Condition 4(c)(3) of the LOA requires that "Revolution Wind must conduct PAM for at least 24 hours immediately prior to pile driving or UXO/MEC detonation activities. The PAM operator must review all detections from the previous 24-hour period immediately prior to impact pile driving and UXO/MEC activities". The review of acoustic detections from the previous 24-hrs is intended to increase the probability of detecting the presence of a NARW given their calling behavior in this region (Davis et al. 2023). Since the SeaPicket systems will not typically be moved between pile driving events, they will provide continuous PAM data for the 24-hr period prior to pile driving that will be used to meet this requirement. Revolution Wind understands this condition to be such that if gaps in the available PAM data (daytime and nighttime) have been identified, the Project will utilize all other data available from the previous 24-hour period for situational awareness (e.g., visual vessel-based sightings, *Mysticetus* data records, and all available real-time PAM data from other systems) in the Project Area. This data will be used to inform the PSOs and PAM operators of in field conditions and the likelihood of marine mammal presence leading into subsequent pile driving activities. In addition, Revolution Wind will use existing real-time PAM sources within the surrounding area which pull data into WhaleAlert (e.g. New York Bight SE buoy and Gulf of Maine Slocum Glider) to establish situational awareness in the period leading up to a pile installation. Prior to pile installation, Revolution Wind will review data from the PAM buoy deployed from the previous pile as well as the PAM buoys deployed for the upcoming pile. Revolution Wind will also have vessels continuously active in the field during pile installation and those vessels will have Trained Lookouts contributing to the overall situational awareness for the Project, and information from the Trained Lookouts will be available to the PSOs prior to pile driving. During any potential gaps in PAM coverage during the 24-hour period leading up to installation of the upcoming pile, the PSOs and Trained Lookouts will utilize all available *Mysticetus* data from the previous 24-hour period, Trained Lookout data, and WhaleAlert data to provide additional situational awareness. Should the Project experience weather down time in which PAM buoys were not deployed, requiring additional PAM buoy deployment would result in significant delays to the Project's overall construction schedule.

Per ITR § 217.274(g)(2), all acoustic monitoring activities and acoustic detections of marine mammals will be recorded. For all real-time monitoring deployments, the following information will be reported:

- Location of hydrophone (latitude & longitude; in decimal degrees) and site name;
- Bottom depth and depth of recording unit (in meters);
- Recorder (model & manufacturer) and platform type (i.e. bottom-mounted, electric glider, etc.), and instrument ID of the hydrophone and recording platform (if applicable);
- Time zone for sound files and recorded date/times in data and metadata (in relation to UTC i.e., EST time zone is UTC-5);
- Duration of recordings (start/end dates and times; in ISO 8601 format, yyyy-mmddTHH:MM:SS.sssZ (where Z indicates the time zone: "yyyy-mm-ddTHH:MM:SS.sssZ" for UTC, otherwise offset from UTC indicated i.e. "yyyy-mm-ddTHH:MM:SS.sss-05:00" for UTC-5));
- Deployment/retrieval dates and times (in ISO 8601 format);
- Recording schedule (must be continuous);
- Hydrophone and recorder sensitivity (in dB re 1 μPa);
- Calibration curve for each recorder;
- Bandwidth/sampling rate (in Hz);
- Sample bit-rate and bit depth of recordings; and
- Detection range of equipment for relevant frequency bands (in meters).
- For each acoustic detection, the following information will be recorded:

- Species identification (if possible);
- Call type and number of calls (if known);
- Temporal aspects of vocalization (date, time, duration, etc., date times in ISO 8601 format);
- Confidence of detection (no detection, possible detection, detection);
- Comparison with any concurrent visual sightings;
- Location and/or directionality of call (if determined) relative to acoustic recorder or construction activities;
- Location of recorder and construction activities at time of call;
- Name and version of detection or sound analysis software used, with protocol reference;
- Minimum and maximum frequencies viewed/monitored/used in detection (in Hz);
- Name of PAM operator(s) on duty.
- If a call is a confirmed NARW call, the detection information will be reported as soon as possible, and no longer than 24 hours, after the detection to NMFS via the 24-hour North Atlantic right whale Detection Template (https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates).

These detection data will be saved and provided to BOEM and NMFS as described in Section 5 of the PDMP.

Table 4. PAM monitoring and detection recording information and format

COLUMN_NAME	DEFINITION	ENTRY OPTIONS
UNIQUE_ID*	A unique ID for the recorder on the metadata sheet that this detection data can be linked to. There should be only one unique ID for any recorder entered. For each UNIQUE_ID and SPECIES combination, there should be the same combination of values for all of the following fields: CALL_TYPE, DETECTON_METHOD, PROTOCOL_REFERENCE, and ANALYSIS_SAMPLING_RATE_HZ. If multiple values are used across one UNIQUE_ID and SPECIES for any of these fields marked with an asterisk (*), enter all values and separate with a semicolon (";"). A unique ID should have a combination with the minimum components: organization name or code, region or location of data collection, date for data (typically Year and Month of the first date of data collection), and site name or instrument ID for the particular recorder. Additional components could include project name, platform or recorder type, etc., as needed.	Text string
ANALYSIS_PERIOD_START_DATETIME	Start date time of validated data analyzed, for the time scale of the analysis, in ISO8601 format (YYYY-MM-DDThh:mm:ssZ) (i.e., the start date and time for the time bin of reporting right whales detected for that row of data); for daily presence, the start date would be the beginning date and time for that analysis day). Z in date time refers to date time stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on	(YYYY-MM-DDThh:mm:ssZ)

COLUMN_NAME	DEFINITION	ENTRY OPTIONS
	ISO8601 formats and time zones.	
ANALYSIS_PERIOD_END_DATETIME	End date time of validated data analyzed, for the time scale of the analysis, in ISO8601 format (YYYY-MM-DDThh:mm:ssZ) (i.e. the end for the time bin of reporting right whales detected for that row of data). Z in date time refers to date time stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in ISO8601 format (YYYY-MM-DDThh:mm:ssZ)
ANALYSIS_PERIOD_EFFORT_SECONDS	The amount of time, in seconds, the effort occurred in (i.e. if the first 5 minutes of every hour analyzed was looked at, this number would be 300).	Numeric
ANALYSIS_TIME_ZONE	The time-zone that the analysis was conducted in and that the time stamps in the ANALYSIS_PERIOD_START_DATETIME match (these may differ from the time zone of the sound files, for example if sound files are in UTC, but analysis was conducted on a local time zone, the analysis time zone would be i.e. UTC- 5).	Text string
SPECIES_CODE*	The species for which analysis was conducted for and the detection "ACOUSTIC_PRESENCE" column pertains to. See Species Code tab to find the appropriate code to use for each species.	see SPECIES_CODE field on Species_Co des tab
ACOUSTIC_PRESENCE	Whether the species was detected, possibly detected, not detected, or not analyzed for. Entry options: D, P, N, M. "D" denotes a day with validated species' presence, "P" for days that cannot definitively confirm species' presence, "N" for no true detections, and "M" for data that has not been analyzed for that species' presence, or if the data is missing (i.e., if no recordings are available for that time- use M here for data gap times within a deployment).	"D"; "P"; "N"; "M"
N_VALIDATED_DETECTIONS	The number of detections validated and found "true" during the analysis period. This column may be left blank if total true detections was not tallied for the analysis.	Numeric or NA

COLUMN_NAME	DEFINITION	ENTRY OPTIONS
CALL_TYPE_CODE*	The call type used for the analysis period to determine the species' presence. See the Call_Type_Code tab to use the appropriate CALL_TYPE_CODE listed for the call type and species descriptions. If an additional call type is used that is not listed in Call_Type_Codes, or a combination of call types are used that are not currently listed, please let nmfs.pacmdata@noaa.gov know upon submission so this field can be updated accordingly. There should be only one code listed per row. No commas should be used in this field.	see CALL_TYPE_ CODE field on Call_Type_C odes tab
DETECTION_METHOD*	How the data was reviewed for this species' presence, either "Manual" for hand browsing, or the detector used. For example, Manual, LFDCS, ISRAT, Pamguard Click Detector. If there is an available version of the detector, include here (i.e. ISRAT v3.5). If multiple detectors for this SPECIES and UNIQUE_ID were used, separate multiple entries with semicolon (";").	Text string
PROTOCOL_REFERENCE*	Published reference, DOI, or link to documentation for the detector used, and/or analysis method. If not available, "Unpublished" should be used. Separate multiple entries with a semicolon (";") and have doi in parenthesis following Author Year (if available). Do not use commas in this field.	Text string
DETECTION_SOFTWARE_NAM E	The software used for the detection method. This could be either the standalone software program (i.e. PAMGUARD, Raven), or the name of the programming language the detection method was written in (i.e. IDL, MATLAB).	Text string
DETECTION_SOFTWARE_VERSI ON	The version number of the software used, if applicable.	Text string
MIN_ANALYSIS_FREQUENCY_RANGE_HZ	The minimum frequency (Hz) used for this analysis, if applicable. Default value is 0 (Hz). If middle frequencies were viewed for this analysis (i.e., 200 – 1,000 Hz), this value would be 200.	Numeric
MAX_ANALYSIS_FREQUENCY_RANGE_H Z	The maximum frequency (Hz) used for the analysis, if applicable. For example, if the original recordings had a sample rate of 48kHz, and the data was either resampled to 2kHz for the analysis, or only viewed at up to 1kHz, then this value would be 1000. Default value is relative to the recordings' sample rate (i.e. if sample rate is 48 kHz, the default value for this field is 24000).	Numeric
ANALYSIS_SAMPLING_RATE_HZ	The sample rate used for the analysis. For example, if the recorder had a sample rate of 48kHz, and the data was resampled to 2kHz for the analysis, then this value would be 2000.	Numeric

COLUMN_NAME	DEFINITION	ENTRY OPTIONS
QC_PROCESSING	Was the analysis conducted in real time (i.e. the recorder did not have to be retrieved for the analysis), or was analysis done post-processing recordings (i.e. analysis done after the recorder was retrieved)?	"Real-time" or "Archival"
LOCALIZED_LATITUDE	The estimated latitude (in DD) of the localized detection, if applicable	Numeric in DD
LOCALIZED_LONGITUDE	The estimated longitude (in DD) of the localized detection, if applicable	Numeric in DD
DETECTION_DISTANCE_M	The estimated distance (in meters) of the detection, if applicable	Numeric
LOCALIZATION_DISTANCE_M ETHOD	The method used to localize and/or estimate distance for the detections. Do not use commas in this field.	Text string
LOCALIZATION_DISTANCE_PROTOCOL	Published reference, DOI, or link to documentation for the localization/distance estimation method used (and/or analysis method). If not available, "Unpublished" should be used. Separate multiple entries with a semicolon (";") and have doi in parenthesis following Author Year (if available). Do not use commas in this field.	Text string
LOCALISATION_ERROR	Error margin of localised position of detection based on the area of the polygon where the intersections occur, calculated as the square root of the sum of the squared residuals for the model, and will be displayed as +/- m	Numeric
UNIQUE_ID	A unique ID for the recorder that the detection data can be linked to. There should be only one UNIQUE_ID for any recorder/deployment entered. A unique ID should have a combination with the minimum components: organization name or code, region or location of data collection, date for data (typically Year and Month of the first date of data collection), and site name or instrument ID for the particular recorder. Additional components could include project name, platform or recorder type, etc., as needed.	Text string
PROJECT	The name of the project or experiment.	Text string
DATA_POC_NAME	The name of the point of contact for the data (data POC).	Text string
DATA_POC_AFFILIATION	The data POC's primary affiliation.	Text string
DATA_POC_EMAIL	The data POC's email address.	Text string
STATIONARY_OR_MOBILE	Is the recorder moored (stationary) or moving (mobile)?	"Stationary" or "Mobile"

COLUMN_NAME	DEFINITION	ENTRY OPTIONS
PLATFORM_TYPE	The type of platform the recorder is on. This is shown in the second drop down menu on PACM. Entry options for moored recorders: "Bottom-mounted", "Surface-buoy"; Entry options for mobile recordings: "Electric-glider", "Wave-glider", "Towed-array", "Linear-array", "Drifting-buoy", "Tag".	"Bottom-Mounted"; "Surface-buoy"; "Electric-glider"; "Wave-glider"; "Towed-array"; "Linear-array"; "Drifting-buoy"
PLATFORM_NO	ID or number of the platform (such as an independent, dedicated mooring or glider) a recorder is deployed on, if applicable. For example, a slocum glider's platform ID: we04. For SoundTrap500s, this would be the serial number of the recording unit (not the serial number of the hydrophone)	Text string
SITE_ID	The site or station ID. For example, a line of three recorders off Cape Hatteras could have the following individual site IDs: H1, H2, and H3.	Text string
INSTRUMENT_TYPE	Recording instrument type if available, or the hydrophone manufacturer. Examples: DMON, AMAR, MARU, HARP, SoundTrap, HTI, APC.	Text string
INSTRUMENT_ID	Serial or unit ID number of the recording instrument or hydrophone. In the case of SoundTrap500s, this would be the hydrophone serial number.	Text string
CHANNEL	The recording channel. Single channel data would be entered as 1.	Numeric
MONITORING_START_DATETI ME	The start date time in the ISO8601 format (YYYY- MM-DDThh:mm:ssZ) for the start of usable data for that deployment (i.e. the recorder is on and in the water). Z in date time refers to date time stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in ISO8601 format (YYYY-MM-DDThh:mm:s sZ)
MONITORING_END_DATETIME	The end date time, in ISO8601 format (YYYY- MM-DDThh:mm:ssZ), for the end of usable data for that deployment (i.e. the recorder is off or no longer in the water). Z in date time refers to date time stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in ISO8601 format (YYYY-MM-DDThh:mm:s sZ)
SOUNDFILES_TIMEZONE	The time zone the sound files are in, with relation to UTC (i.e. EST would be entered as UTC-5).	Text string
LATITUDE	Latitude of recorder, in decimal degrees (DD). For mobile data, this field will be blank and will refer to the GPS submitted data instead.	Numeric in DD
LONGITUDE	Longitude of recorder, in decimal degrees (DD). For mobile data, this field will be blank and will refer to the GPS submitted data instead.	Numeric in DD

COLUMN_NAME	DEFINITION	ENTRY OPTIONS
WATER_DEPTH_METERS	Water depth (meters) where the recorder is located (may be blank for mobile data).	Numeric
RECORDER_DEPTH_METERS	Depth of the recorder (meters) in the water column (may be blank for mobile data).	Numeric
SAMPLING_RATE_HZ	Sampling rate of raw sound recordings, in Hz.	Numeric
RECORDING_DURATION_SEC ONDS	Recording schedule: the amount of time, in seconds, the recorder is on and recording. For continuous recordings, this entry will be "3600" and the following field (RECORDING_INTERVAL_SECONDS) will be "0". For duty cycled data, this is the amount of time the recorder is turned "on" for. If the first 10 minutes of every hour is recorded, then RECORDING_DURATION_SECONDS is "600" and RECORDING_INTERVAL_SECONDS is "3000".	Numeric
RECORDING_INTERVAL_SEC ONDS	Recording schedule: the amount of time, in seconds, the recorder is not recording within the recording cycle. For continuous recordings, this entry will be "0" and the RECORDING_DURATION_SECONDS field will be "3600". For duty cycled data, this is the amount of time the recorder is turned "off" for. If the first 10 minutes of every hour is recorded, then RECORDING_DURATION_SECONDS is "600" and RECORDING_INTERVAL_SECONDS is "3000".	Numeric
SAMPLE_BITS	The sample bit rate of recordings, if known.	Numeric
SUBMITTER_NAME	Name of who is submitting the data.	Text string
SUBMITTER_AFFILIATION	Primary affiliation of who is submitting the data.	Text string
SUBMITTER_EMAIL	Email of who is submitting the data.	Text string
SUBMISSION_DATE	The date the data is being submitted or was compiled in ISO8601 format (YYYY-MM- DDThh:mm:ssZ). Z in date time refers to date time stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in ISO8601 format (YYYY-MM-DDThh:mm:s sZ)

2 Reporting

All reporting will be submitted to NMFS-OPR (pr.itrp.monitoringreports@noaa.gov; itp.esch@noaa.gov); NMFS-GARFO – PRD (nmfs.gar.incidental-take@noaa.gov); BOEM, (renewable_reporting@boem.gov); BSEE via TIMSWeb with a notification email sent to BSEE at protectedspecies@bsee.gov; and United States Army Corps of Engineers (USACE) at cenae-r-@usace.army.mil.. Submittal requirements to BSEE will follow reporting requirements under JOIN NTL 2023-N01 Appendix B.

2.1 General

As per ITR § 217.275(g)(12)) and BiOp T&C 8(i) and LOA Condition 4(g)(12), full detection data, metadata, and location of recorders (or GPS tracks, if applicable) from all real-time PAM hydrophones used for monitoring during construction will be submitted within 90 calendar days after pile-driving has ended and instruments have been pulled from the water.

- Reports will use the webform templates of the NMFS Passive Acoustic Reporting System website at https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates.
- Full acoustic recordings from all-real time hydrophones will be sent to the National Centers for Environmental Information (NCEI) for archiving within 90 calendar days after pile driving has ended and instruments have been pulled from the water.
- Confirmation of both submittals will be sent to NMFS GARFO – PRD at nmfs.gar.incidental-take@noaa.gov.

2.2 Training

- As per ITR § 217.275(g)(1)), prior to initiation of foundation installation, Revolution Wind will demonstrate in a report submitted to NMFS-OPR (its.esch@noaa.gov) that all required training for Revolution Wind personnel (including PAM operators) has been completed.
- Training certificates for the PAM personnel will be provided at least 90 days prior to the start of foundation installation activity.

2.3 Vessel Strike Avoidance Reporting

As described within the *Vessel Strike Avoidance Plan* submitted for agency review on January 9, 2024, Revolution Wind does not intend to utilize a potential acoustic monitoring program in combination with visual observers to allow vessels 65 ft or longer to travel at >10 knots within certain areas and times where they would otherwise be restricted to 10 knots or less. All vessels, regardless of size will adhere to the 10-knot speed restriction. Should circumstances change this current determination by the Project, this Pile Driving PAM Plan would be updated and re-submitted to include a detailed description of the methods and procedures related to PAM of a vessel transit corridor that would allow, should NMFS approve the proposed Plan, vessels to transit at >10 knots outside of active SMAs, DMAs, or acoustically triggered Slow Zones.

2.4 North Atlantic Right Whale Reporting

All requirements surrounding visual and acoustic NARW reporting measures will be followed as described within PDMP Section 5.4. As per § 217.275(g)(11)) and COP Condition 5.14.1, if a NARW is acoustically detected at any time by a project-related PAM system, Revolution Wind will ensure the detection is reported as soon as possible and no longer than 24-hours after the detection to NMFS.

- Reports will be submitted to BOEM (at renewable_reporting@BOEM.gov), BSEE (Submittal requirements to BSEE will follow reporting requirements under JOINT NTL 2023 -N01 Appendix B), Right Whale Sighting Advisory System (RWSAS). Reports can also be made to the U.S. Coast Guard (USCG) through channel 16 or through the WhaleAlert App (http://www.whalealert.org/);

- Revolution Wind will submit a summary report to NMFS-OPR (PR.ITP.MonitoringReports@noaa.gov) and NMFS GARFO – PRD (nmfs.gar.incidental-take@noaa.gov) within 24 hours including the data collection details described in Section PDMP section 3.7;
- Acoustic detection will be reported as soon as possible and no later than 24-hours after the detection via the 24-hour North Atlantic right whale Detection Template (https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates). Calling the hotline is not necessary when reporting PAM detections via the template.

2.5 Monthly Reporting

All requirements surrounding monthly reporting will be followed as described within PDMP Section 5.13. Revolution Wind will compile and submit monthly reports to NMFS OPR during foundation installation on the 15th of the month for the previous month using the webform on the NMFS NARW Passive Acoustic Reporting System website (https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates). Monthly reports will also be provided to BOEM (renewable_reporting@boem.gov), BSEE (Submittal requirements to BSEE will follow reporting requirements under JOINT NTL 2023-N01 Appendix B), and NMFS GARFO – PRD (nmfs.gar.incidental-take@noaa.gov). All real-time PAM data included in the webform on the NMFS NARW Passive Acoustic Reporting System will be submitted to PACM on a monthly basis (on the 15th of the month for the previous month).

- The monthly report will include information described in ITR § 217.275(g)(5).

2.6 Annual Reporting

All requirements surrounding final reporting will be followed as described within PDMP Section 5.14. Revolution Wind will submit a draft annual report on all visual and acoustic monitoring conducted under the ITR and COP Approval no later than 90 days following the end of a given calendar year as described in ITR § 217.275(g)(6) and LOA Condition 4(g)(6).

- Revolution Wind will provide a final report within 30 days following resolution of NMFS' comments on the draft report. If no comments are received from NMFS within 30 days of NMFS' receipt of the draft report, the report will be considered final.
- All draft and final monitoring reports will be submitted to NMFS-OPR (PR.ITP.MonitoringReports@noaa.gov and itp.esch@noaa.gov), BOEM (renewable_reporting@boem.gov), and BSEE (Submittal requirements to BSEE will follow reporting requirements under JOINT NTL 2023 -N01 Appendix B) and NMFS-GARFO – PRD, Protected Resources division (nmfs.gar.incidental-take@noaa.gov).

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Appendix A – RSA-ORCA PAM System Specifications

Title:

Passive Acoustic Monitoring: Equipment specification and supporting statements

Project:

NEP

05 May 2024

1 RS Aqua – RSA Orca

1.1 Overview

Gardline have selected RS Aqua to supply the passive acoustic monitoring recorders (RS ORCA) for the NEP project. RS Orca pushes data to the integrated telemetry system consisting of RAJANT mesh network proven technology for near real time data transmission. RAJANT and power supply are all integrated with the RSA-ORCA multichannel subsea acoustic recorder, which further consists of two Geospectrum M36-900 hydrophones, per mooring for PAM during the NEP project.

1.2 RS Aqua

1.2.1 Company background

RS Aqua is a technology company with nearly 40 years' experience in the UK and global market. RS Aqua has extensive experience in a range of marine industries providing technology and services to provide leading performance, quality, and reliability in all of their products.

1.3 Passive Acoustic Monitoring System

The PAM buoy systems are made up of an ORCA acoustic recording unit and DB2000 buoy used for communications and Rajant Hawk BreadCrumb for data transmission.

1.3.1 DB2000 and Rajant Hawk BreadCrumb

The DB 2000 is a meteorological/oceanographic data buoy. The DB 2000 comprises a 1.9m diameter hull constructed from multiple-section polyethylene floats bolted around the central structure, with through-hull access for underwater instrumentation and cabling. The robust design of the DB 2000 enables it to withstand harsh sea conditions and allows long periods without interim servicing.

Its hollow steel central core houses the power packs for the Rajant system and ORCA unit with and a large external solar panel for powering the ORCA unit.

Passive Acoustic Monitoring (PAM) Buoys (DB2000)		
Quantity	10 pcs	
Power	12V 110Ah battery	
Communication	5.8GHz radio frequency, WiFi AIS Class B transponder Teltonika 4G modem	
Memory	2TB, SSD Drive	
Supplier	Boskalis	

Owner	Boskalis	

Acoustic data is transmitted using Rajant Hawk BreadCrumb® to the installation deployment vessel in real-time. The Hawk is a high-performance BreadCrumb platform. Combined with Rajant's patented InstaMesh protocol, the Hawk is capable of integrating Kinetic Mesh wireless networks with other networks such as LTE/5G which however will not be used for NEP.
The transmission range of the buoys has been tested to be from 8km at 200KB of data per second and therefore within the 5000 m range to the installation vessel and the data level for the project (80KB per second per vessel). These ranges have been confirmed during offshore verification test to verify functionality of the monitoring system. Near real-time audio stream and spectrogram display are viewed in PAMGuard. RAJANT and InstaMesh Protocol was applied in numerous projects worldwide to allow for data transfer on Boskalis's vessels working offshore.

In addition, transmission range tests were performed offshore, on project trials. Radio connection was established with two buoys to the buoy deployment vessel [this was confirmed working and achieved in two separate field tests] as well as initial testing over an estuary. Testing was carried out at over the distance required (>5 km) and achieved satisfactory connection to allow transfer of audio files via secure file transfer protocol. Testing around distance required in project achieved over 1 Mb/s. Approximately 10 second files are created on the buoys which are then compressed and put in a queue ready to be transferred. Some artificial latency is created in this process which is at most 45 seconds and is induced to ensure data integrity. All standard communication protocols once connection is established are in the order of milliseconds.

Key factors	Rajant HAWK BreadCrumb WiFi MESH
Quantity	10pcs
Power	80 Dcells
Antenna Connector	Type N (female)
Frequency	U-NII-1: 5150 – 5250 MHz U-NII-2A: 5250 – 5350 MHz U-NII-2C: 5470 – 5725 MHz U-NII-3: 5725 – 5850 MHz
Modulation	OFDM with up to 256-QAM
Max. Physical Layer Data Rate	866.7 Mbps (throughput varies)
Max. RF Transmit Power	30 dBm
Receive sensitivity	94 dBm (@ 6 Mbps, 20 MHz channel bandwidth) to -68 dBm (@ 866.7 Mbps, 80 MHz channel bandwidth)
Supplier	Boskalis

Key factors	Rajant HAWK BreadCrumb WiFi MESH
Owner	Boskalis

1.3.2 RSA-ORCA Multichannel Subsea Acoustic Recorder

For passive acoustic monitoring Gardline have selected the RSA-ORCA acoustic recorder. The RSA-ORCA is a subsea acoustic recorder that accommodates up to 5 hydrophone channel inputs. The high sampling rates allow it to capture, record and process acoustic data in real time.

Key factors	ORCA 72D
Number of Channels	5
ADC number of Bits	16
Dynamic range per channel	95.5 dB
Sampling rate	Up to 384kHz total over the channels (48 kHz on NEP)
Power	External solar panel, back up lithium in the Buoy.
Memory	2 TB SSD & 1 TB SD internal
Communications	Ethernet High Speed USB for Download Realtime data
Processing system	TRAC software
Maximum Water depth	750m
Operational Temperature	-10° C to 50° C

1.3.3 Geospectrum M36-900 hydrophones

GeoSpectrum Technologies specializes in underwater acoustic transducers and systems and supplies its products to the defence and surveillance, oil and gas and environmental sectors. Two Geospectrum hydrophones, supplied by RS Aqua, will deployed from the DB2000 for mitigation monitoring.

Key factors	Geospectrum Hydrophones
Hydrophone type	M36-900
Unamplified Sensitivity (dB re V/µPA)	-200
Maximum depth	900 m
Maximum frequency	250 kHz

An example frequency response curve from calibration of an M36-900 hydrophone is presented in Figure 1.1 below. It shows a flat response over the relevant frequency range.

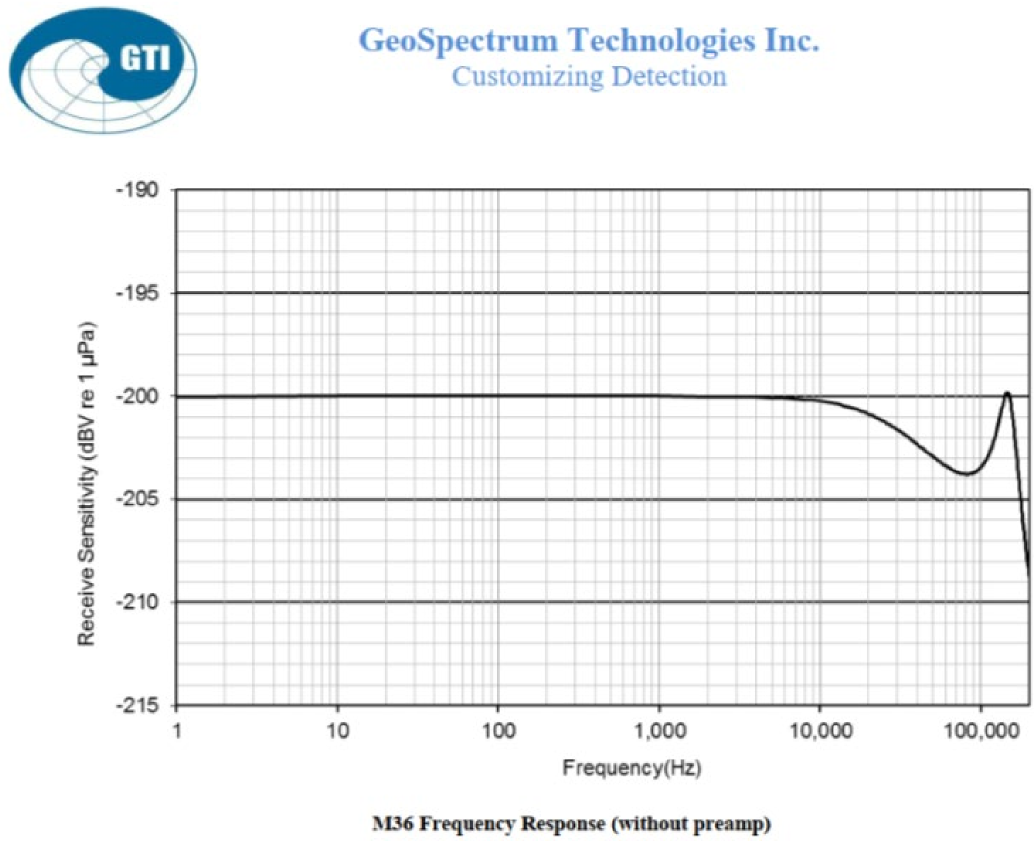

Figure 1-1 Example frequency response curve from M36-900 hydrophone sensitivity calibration.

1.3.4 Data transmission Software

Speficially developed software is used to directly stream raw data from RS Aqua device and subsequently notifies PC onboard the Bokalift 2 used by the PAM operators, via TCP protocol. The data file is then automatically transferred via SFTP. PAM Guard is notified of the files arrival and generates spectrograms continuously.

1.3.5 Data visualization Software and call detection Software (PAMGuard)

PAMGUARD is a sophisticated software package that can be used by the expert user to set up industry/research PAM infrastructure (Gillespie *et al.*, 2008; 2013; Keating *et al.*, 2015; Bailey *et al.*, 2021; Hung *et al.*, 2021). It can also be configured for operational use by PSO / PAM operators. Central to the software design is a flexible core architecture which allows the integration of a range of additional plug-ins which is supported by BOEM (Shane et al., 2022).

PAM analysts will view PAMGuard and the incoming stream through PAMGuard spectrograms. Example spectrogram is provided below (Figure 1-2) for reference.

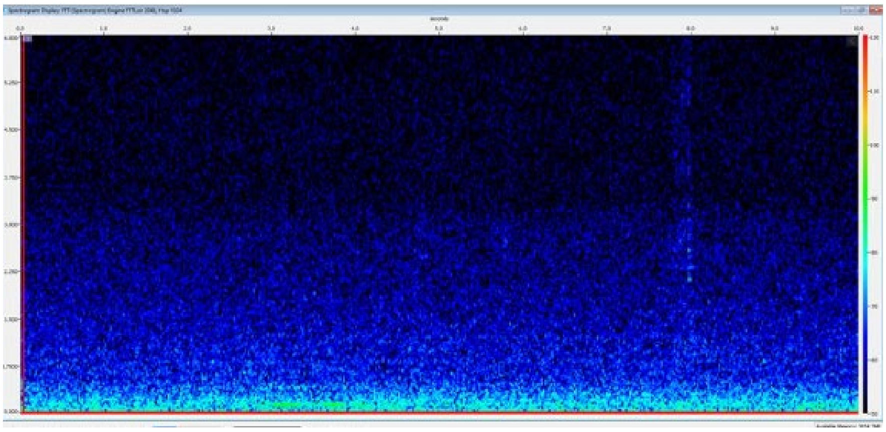

Figure 1-2: Example of a PAMGuard spectorgram.

Clipping is unlikely as hydrophones have an -200 dB sensitivity and a sample rate of only 48 kHz. Clipping can be verified on the spectrogram observed by the PAM operator and then the sample rate and peak to peak voltage can be adjusted within PAMGuard as required.

1.4 Planned Array Pattern

Acoustic monitoring using the moored real-time PAM system will be conducted during daylight as complementary to visual surveys and increase situational awareness for visual PSOs. Passive Acoustic monitoring will be conducted for a minimum of 60 minutes prior to, during and 30 minutes after piling operations as stated in the Revolution Wind LOA document.

PAMGuard software (Gillespie *et al.*, 2008; 2013; Keating *et al.*, 2015; Bailey *et al.*, 2021; Hung *et al.*, 2021) will be utilized in order to map the mitigation zone, and any acoustic detections will then be analysed in real-time to avoid any unnecessary operational delays, and localized where possible (See Section 1.6 below). All relevant adjustable parameters used in PAMGuard acoustic detection algorithm will be recorded in Mysticetus.

Four moored real-time PAM systems will be deployed at perpendicular headings at a distance of 5 km from the sound source (or adjusted as per BOEM guidance and/or to ensure all equipment is placed within the APE), as displayed in Figure 1.1. Each mooring consists of a large marker buoy with lights, reflectors and a bank of batteries to enable the telemetry equipment to communicate with the base station, on the installation vessel.

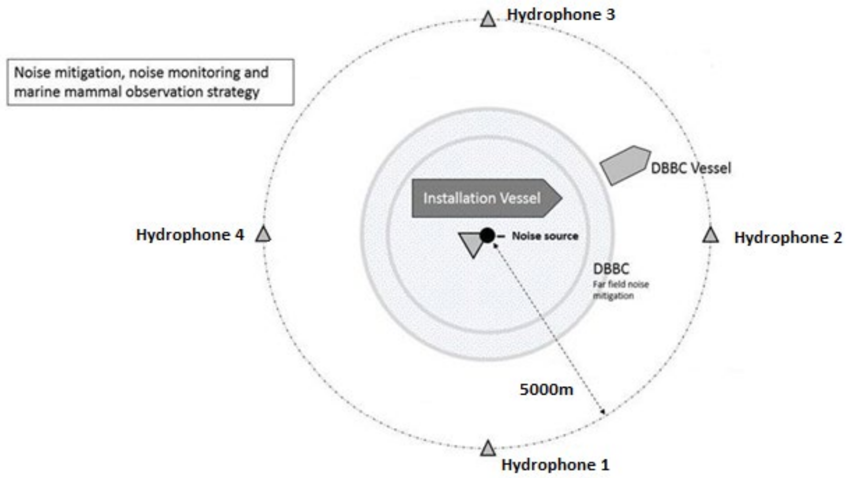

Figure 1-3 Mooring Locations of Real-time moored PAM systems in Relation to Piling Activities.

The buoy placement at 5 km from the sound source allows the PAM to detect low frequency marine mammals across a greater area than the 10 km PAM monitoring zone specified in the LOA document. We can confirm placement accuracy of the buoys will be within 10m of the stated locations. It is worth noting that detection range of vocalizing marine mammals is dependent on the frequency, amplitude, intensity, environmental conditions, and direction of the vocalization. To provide the best coverage of the water column, two hydrophones will be located at approximately half water depth; one in use and the other as a backup.

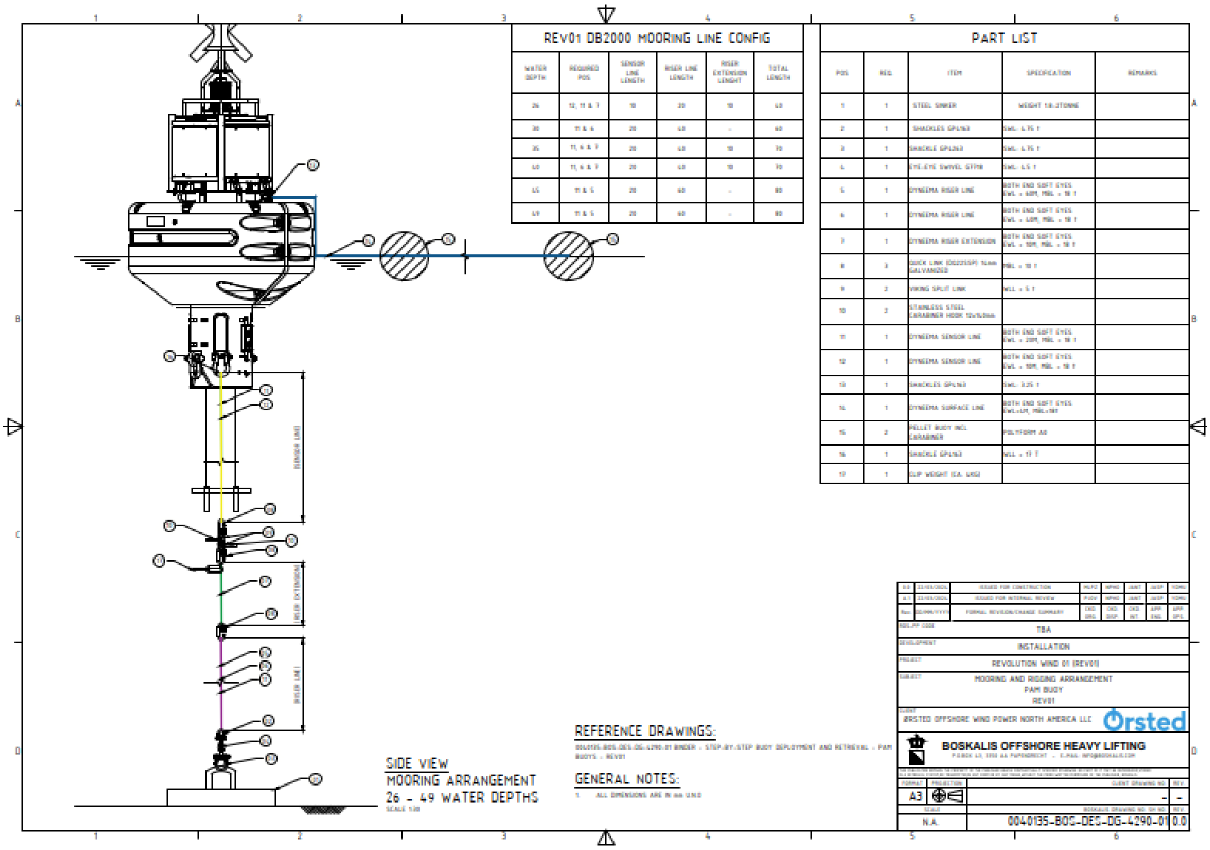

Figure 1-4 Moored Real-Time PAMs Diagram.

1.5 Detection Range

Detection Method and Protocols

The PAM operator will use PAMGuard for all data visualisation and all four incoming data streams will be viewed as a spectrogram up to 24 kHz to assist in verifying the detections (sampling rate 48 kHz). Each audio stream will be monitored by a PAM operator in real-time. Each spectrogram will also be linked to a Whistle & Moan Detector, and a Right Whale Edge detector to alert the user to any low frequency whale moans, and specifically North Atlantic Right Whale calls. The Right Whale Edge Detector is used in conjunction with the Whistle & Moan Detector, to avoid misidentification of other Mysticete low frequency calls as NARW calls. The Whistle & Moan Detector is designed to detect any frequency modulated calls including odontocete whistles and Mysticete vocalisations. All PAM operators will complete the Whale Vocalization Training so as to understand how to distinguish between NARW calls and other Mysticete calls (e.g. humpback whales). Both detectors highlight possible vocalisations within the PAMGuard spectrogram and will use different colours so that the PAM operator can easily distinguish between detections. No filters are applied during the monitoring process. There are no default gain settings in the PAM buoy hardware, however a PAM operator can change the gain or peak to peak voltage within PAMGuard, if required. The combination of manual detection of vocalisations whilst watching near real time incoming data and inbuilt PAMGuard detectors will help ensure all vocalisations are detected. Since the PAM operators will see the incoming data streams, and the detectors working, all pitch tracks will be visible upon a detection picked up by PAMGuard (Figure 1-5).

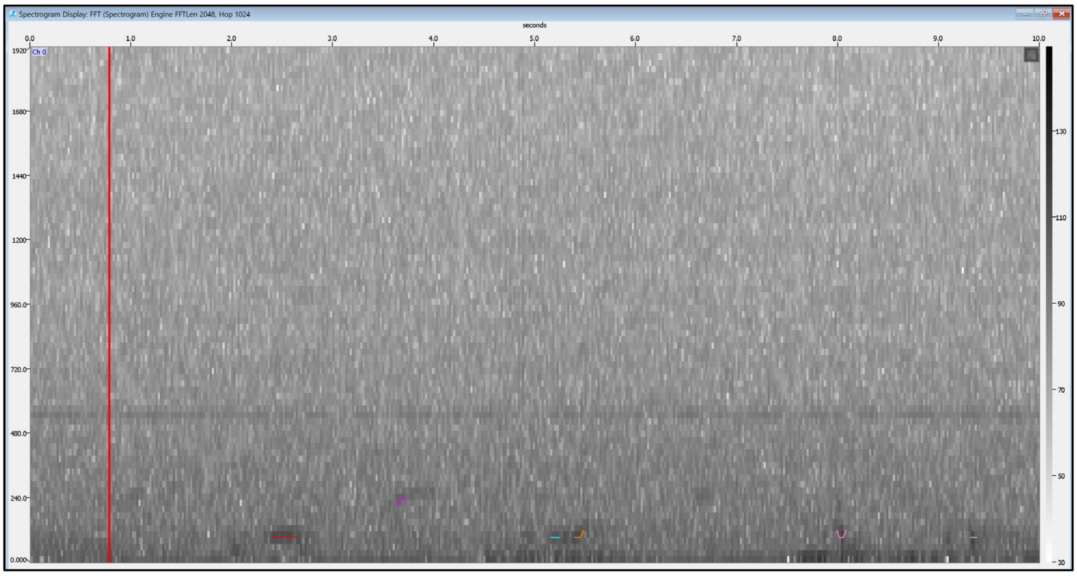

Figure 1-5: Example spectrogram with detections.

The right whale edge detector module takes constant background measurements and adjusts its setting automatically to respond to changes in ambient noise levels that would be expected during pile driving activities due to increased vessel noise and pile installation. Therefore, performance of the detector should not be significantly affected by construction noise including pile driving.

Gillespie (2004) tested the right whale edge detector against sound files containing only NARW calls, and a sound file containing non-NARW calls. There were 2,077 right whale upsweeps detected by a human operator in which 1,897 were confirmed by the Right Whale Edge Detector.

This gives a detection probability of 90%. When analysing the non-NARW call files, the study found a false positive rate of 1-2 calls per audio stream per day.

Detection Range

North Atlantic Right Whales produce a variety of low frequency sounds such as moans, belches and pluses which hold most of their acoustic energy under 500 Hz. They also produce “up calls” that rises from around 50 Hz to 440 Hz. Source levels produced by North Atlantic Right Whales have been estimated to vary from 137 to 162 rms re 1 µPa/m for tonal calls and 174 to 192 dB rms 1 µPa/m for broadband gunshot calls (Parks & Tyack, 2005).

Ambient noise levels to assess signal to noise ratio were used from JASCO Applied Sciences Turbine Foundation and Cable Installation at South Fork Wind Farm, Underwater Acoustic Modelling of Construction Noise, Figure 1.3 below.

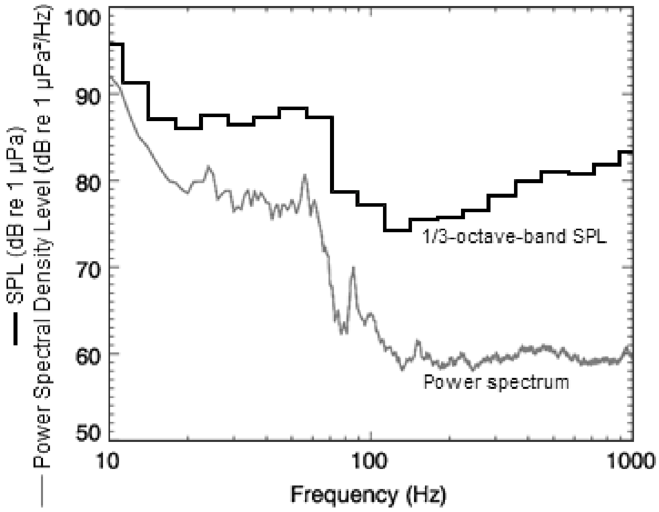

Figure 1.3 JASCO Power spectrum and the corresponding 1/3 octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

Clark, C. et al; 2010 and Laurinolli, M. et al; 2003 in Davis, G. et al; (2017) estimate that maximum detection ranges for North Atlantic Right Whales are from 8 to 16 km, dependent on recording equipment, location, and environmental conditions. This is reconfirmed in a paper from M. Van Parijs et al (2021), confirming NARW detection range of 10 km in most habitats. Further, in this paper BOEM and NOAA minimum standards for PAM monitoring uses PAMGuard as an example detection software similar to what is proposed in this PAM Plan.

In order to verify the estimates provided by the authors above, a transmission loss calculation was conducted to estimate at what distance a right whale vocalisation drops below ambient noise levels and is no longer detectable by PAM equipment.

Ambient noise levels are expected to be between 105 and 112 dB in the Southern New England area (Rice et al., 2014 & Van Parijs et al., 2023). Van Parijis et al., 2023 found that within this range, the site within which Revolution Wind is located had the lowest ambient noise levels, and therefore the lowest range value of 112 dB was used in the below calculations.

The mean calculated source level of NARW upcalls (160 rms dB re 1µPa-m) was used to estimate detection ranges. Upcalls were used instead of broadbands calls, as these types of calls are more commonly produced by NARW (Parks et al., 2011).

Using these values in the transmission loss equation (see Equation 2 below) with a coefficient of geometric spreading set to 10 (due to the shallow water conditions found at the Revolution Wind Site, Kusel et al. 2024), the detection range for NARW calls is estimated to be 63 km, meaning that localisation should be possible for all detections within the 10 km PAM monitoring zone.

Equation 1 $$TL = SL - RL$$

Equation 2 $$TL = 10log_{10}(range)$$

There were also dolphin vocalisations detected (Figure 1-6) that were accompanied by a confirmed visual sighting that was estimated to be approximately 7 km from piling centre, and therefore approximately 2 km from the PAM buoy.

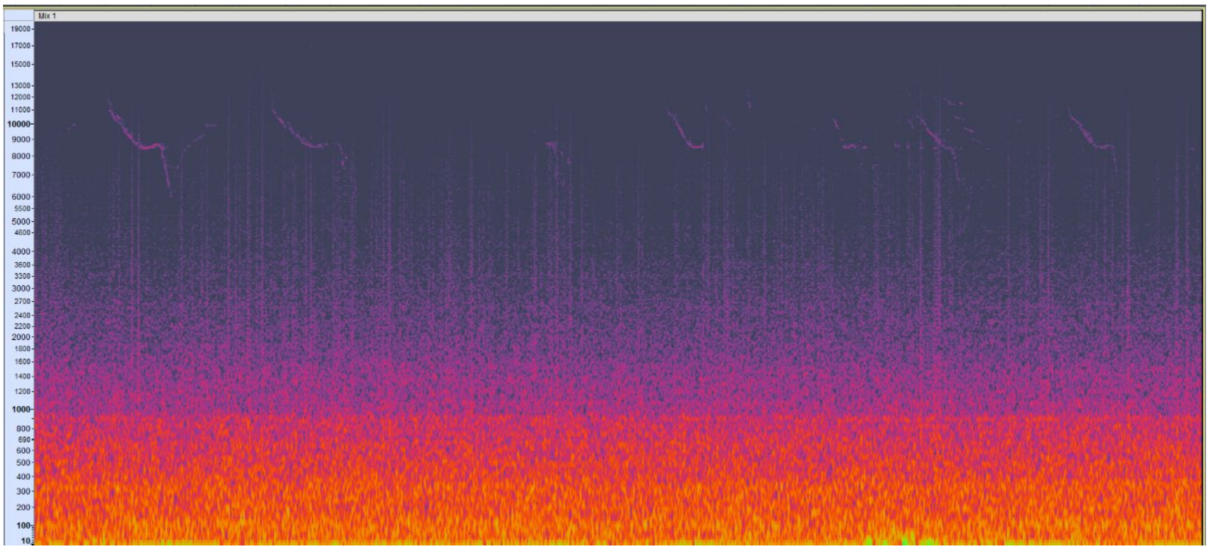

Figure 1-6: Spectogram of Dolphin vocalisations during SFW 2023.

A transmission loss coefficient of 10 was initially considered as this is more consistent with field observations and data than a value of 15 or 20. For example, if a spreading loss coefficient of 15 was used, the resulting detection range of a NARW upsweep in the presence of 112 dB ambient sound levels would be nly 1.6 km. Whereas Figure 1-5 shows the medium-frequency dolphin vocalisations detected 2 km away from the recorder. In addition, a value of 10 was used by JASCO in their final report on the SFW project, using a model based on damped cylindrical spreading theory (E.T. Kusel, 2024).

To assess detection range whilst construction activities, an average ambient noise level was used as observed during South Fork Wind. Since NARW calls are between 50 – 440 Hz, an average ambient noise within this frequency band was used (112 dB). Using a spreading loss coefficient of 10 the detection range would be 63 km. Alternatively, using a spreading loss coefficient of 12.5, halfway between 10 and 15, the estimated detection range is a more realistic 6.9 km. Since the buoys are placed at 5 km away from piling centre, they only need to achieve a 5 km detection range in order to be able to monitor the 10 km zone from piling centre.

Since the duration of NARW calls is longer than the average pile driving strike, it is expected that the NARW call would be visible in between pile driving strikes. Pile driving strikes range from 0.1 to 0.9 seconds on average, depending on distance from piling centre, and are usually produced at a rate of 1 strike every two seconds, as observed during pile driving activities on South Fork Wind (2023), ref Figure 1-7. Trygonis et al 2013 found that the average NARW upcall is 1.49 seconds in duration.

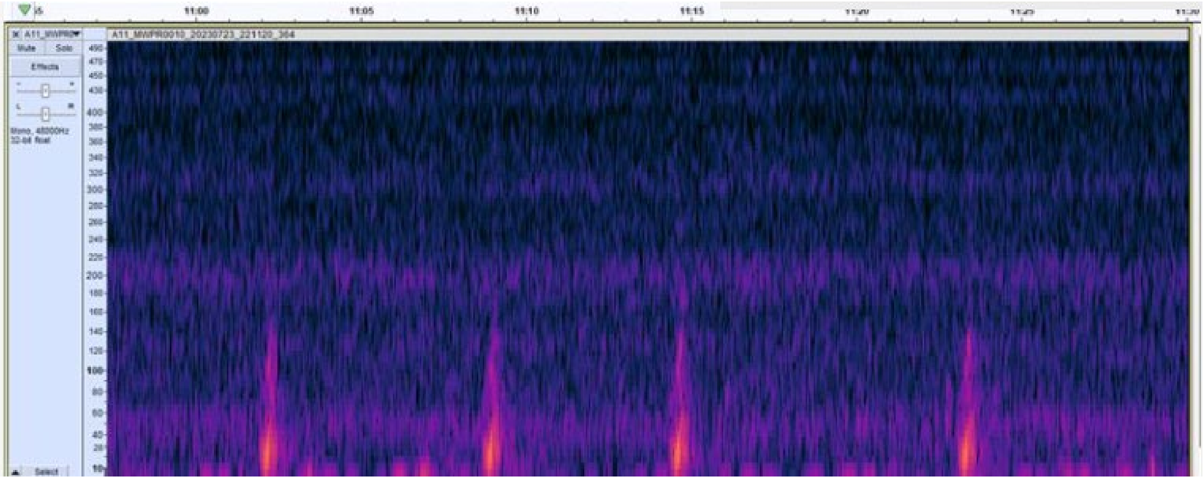

Figure 1-7: Spectrogram during piling with clear breaks between hammer streaks allowing for mammal detection.

Using the formulas above and a spreading loss coefficient of 12.5, the detection range of a 160 dB NARW call under different ambient noise levels has been calculated, ref. Table 1-1 below.

Table 1-1: Detection ranges and Ambient noise levels

Ambient noise level	Detection range
90 dB	398 km
95 dB	159 km
100 dB	63.1 km
105 dB	25.1 km
110 dB	10 km
115 dB	4 km
120 dB	1.6 km
125 dB	0.6 km
130 dB	0.3 km
135 dB	0.1 km
140 dB	0.0 km
145 dB	0.0 km
150 dB	0.0 km
155 dB	0.0 km
160 dB	0.0 km

The hydrophones have a flat frequency response at the low frequency range of a NARW call, and therefore, detection range is expected to correlate with the calculated transmission loss ranges as per above.

1.6 Localisation

Localisation of marine mammals will focus on low frequency cetaceans; due to the short wavelength of high frequency vocalisations it is anticipated that these will not be received at enough hydrophones to triangulate the vocalising species.

The localisation of acoustic signals will be done via a time difference of arrival analysis (TDOA), this will be used to determine the distance from emitting source (e.g. a Whale) to the receivers (the 4x PAM Buoys where upon the unknown coordinates of the emitter can be calculated. At minimum for the localisation to work the emitted signal will need to be detected on at least three receivers. The primary output of this localisation routine will be a range & direction (angle) to target relative to the pile location.

Detection on two of the four PAM buoys provides the necessary data to localize the vocalization source. Using the difference in time between sound files rather than absolute real time, the software assumes single path propagation, good signal to noise ratio and constant sound speed and applies a hyperbolic equation intersection to give an estimated distance and bearing to the vocalising animal. Error will be based on the area of the polygon where the intersections occur, calculated as the square root of the sum of the squared residuals for the model, and will be displayed as +/- m. This error will always be included to produce a conservative estimate of distance to piling centre, and appropriate action will be taken if the estimated location, allowing for error, is less than 4.4 km (for clearance) or 2.3 km (for shutdown). For all cases where the intersection is within the 10 km PAM monitoring zone, PAM operators will be conservative and assume NARW is within the closest range to piling based on the error bars. When all 4 systems detect the vocalization, the position of the source will be accurate. If the vocalisation is only detected on one or two PAM buoys, a conservative approach will be taken, and mitigation actions will be undertaken. All relevant adjustable parameters used in PAMGuard acoustic detection algorithm will be recorded in Mysticetus.

1.6.1 Testing of Localisation Algorithm

The in-house localization algorithm has been tested during offshore tests with two buoys with satisfactory outcome (error margin of 200m). A noise source (9 Khz, 185 dB re 1 μPa) was deployed with known frequency and source level from a known location offshore. The two installed PAM buoys detected the noise source and by running the localization software the noise source location was calculated and verified to be in line with the deployment coordinates taking into account the error margin. This test was repeated several times at different locations providing the similar results.

Position calculated using the positional PAM moorings and time of arrival of the signal at each buoy to calculate the noise source location and cross-reference this with the location of the vessel of which the noise source was deployed.

Example of the localization test outcome is provided below for reference.

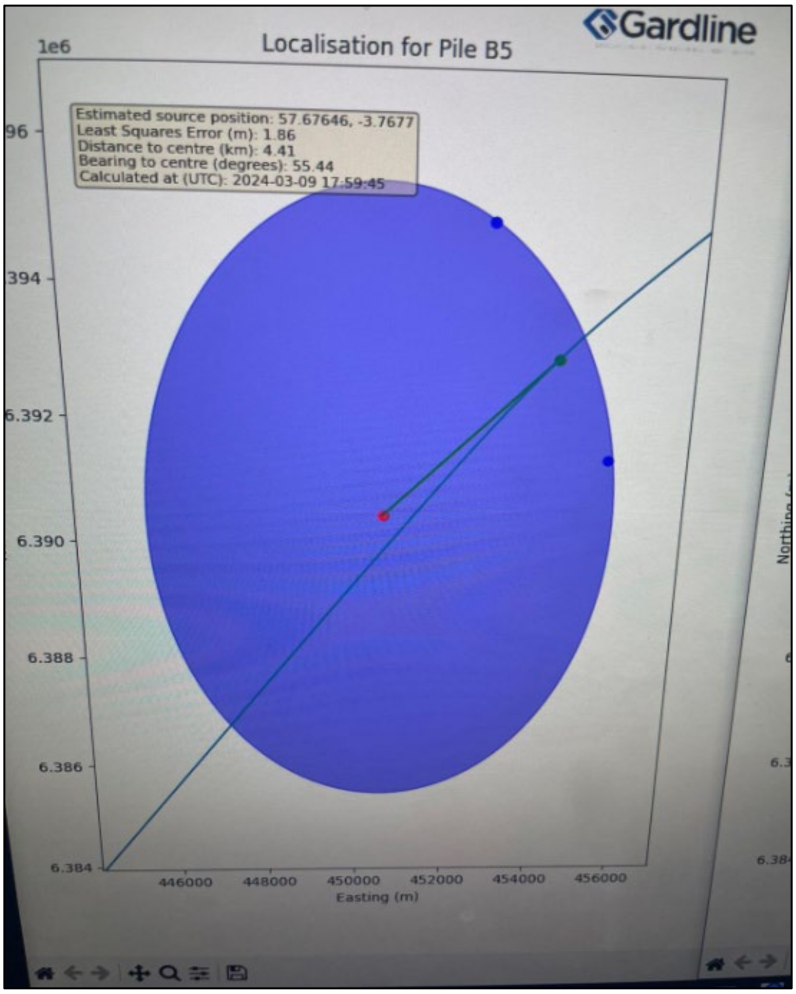

Figure 1-8: Example of localization software output.

1.7 References

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Appendix B – PAM & SFV Mooring Deployment Procedure

Document Title: PAM Mooring deployment and retrieval procedure - REV01	
Operator:	Ørsted Offshore Wind Power North America LLC
Project Name:	Revolution Wind 01(REV01)
Scope:	Foundations, OSS
Contract Number:	REV01 - WK00119171
Document Type:	PR - Procedure
Ørsted Document Number:	Internal only
Ørsted Revision:	NA
Originator:	Boskalis Offshore Contracting LLC
Contractor Document Number:	0040135-BOS-OPS-PR-0069-01
Contractor Revision:	0.0
PO Number:	P0040135
RDS-PP Code:	N/A
Spare Parts Number:	N/A
Serial Number:	N/A

Revision Record					
Ørsted Revision	**Reasons for Issue**	**Date**	**Author**	**Checked**	**Accepted**
A	Issued for Review	29/03	T.Jansen PE	BOS Ops Manager	A.Bourgraaf PM
0.0	Issued for construction	05/04	T.Jansen PE	BOS Ops Manager	A.Bourgraaf PM

Change Log		
Ørsted Revision	**Location**	**Brief description of change**
A	All	First issue
0.0	All	Issued for construction

Boskalis

Ørsted

PAM Mooring deployment and retrieval procedure - REV01

DOCUMENT NUMBER:	**0040135-BOS-OPS-PR-0069-01**
PROJECT NAME:	**Ørsted US Projects**
PROJECT NUMBER:	**P0040135**
CLIENT NAME:	**Ørsted Offshore Wind Power North America LLC**
CLIENT REFERENCE:	**Internal only**

DOCUMENT CONTROL

General document data	
Document Title:	PAM Mooring deployment procedure - REV01
Document Number:	0040135-BOS-OPS-PR-0069-01
Project Name:	Ørsted US Projects
Project Number:	P0040135
Client Name:	Ørsted Offshore Wind Power North America LLC
Client Reference:	Internal only
Client Revision Number:	0
Boskalis Entity:	Boskalis Offshore Contracting LLC

Revision log

Revision	Date	Prepared by	Reviewed by	Interdisciplinary check	Approved by
Rev. A	29-Mar-2024	T.Jansen PE	BOS Ops Manager	-	A.Bourgraaf PM
Rev. 0	05-Apr-2024	T.Jansen PE	BOS Ops Manager	-	A.Bourgraaf PM

Change log

Revision	Section	Change
Rev. A	All	Issued for internal review
Rev. 0	All	Issued for construction

TABLE OF CONTENTS

1. INTRODUCTION

1.1. Project Description

Ørsted Offshore Wind Power North America LLC, hereafter referenced as Employer is developing the US wind farm Projects Revolution Wind (REV01). Together these Projects are referred to as the Northeast Program (NEP). The wind farms, located ~30km Southeast of Block Island:

- Revolution Wind Offshore Wind Farm (REV01)

  The capacity of the wind farm will be around 715MW and will consist of 65 turbines and 2 offshore substations. The water depths in the field location range from 31 to 47m below the MLLW.

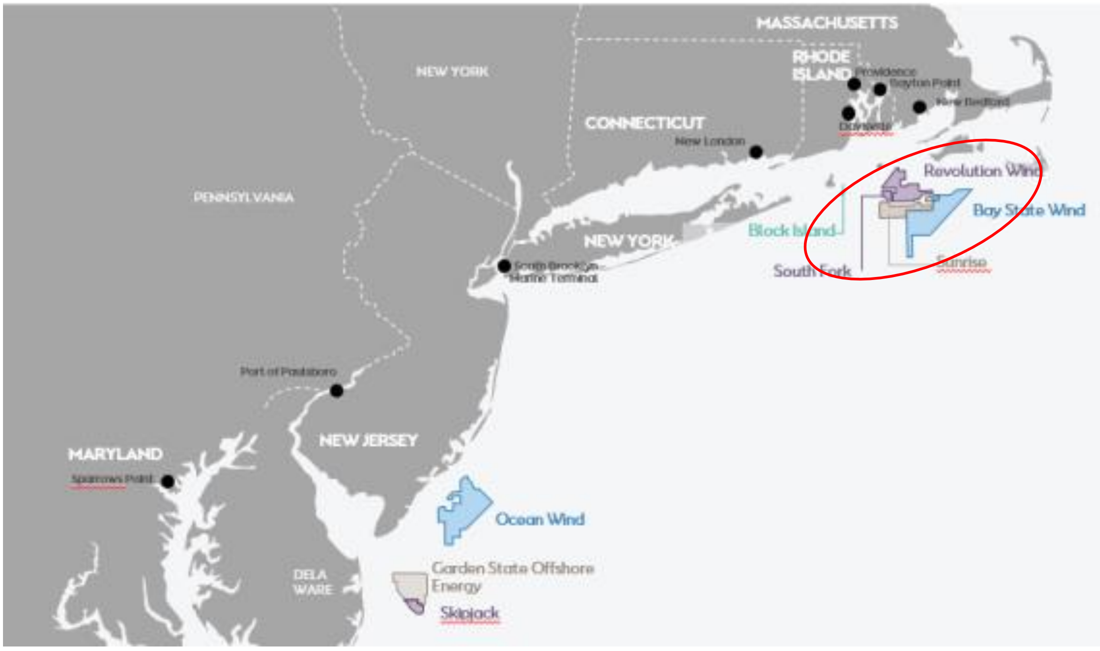


Figure 1-1 Working area

1.2. Contractor's scope of work

The Contractor's T&I scope of work is to be executed in the summer of 2024:

Revolution Wind Offshore Wind Farm (REV01):

- Design and Supply for transport and installation equipment.
- Procedures for transport and installation methodologies.
- Transport and installation of the Wind Turbine Generators (WTG) foundations.
- Transport and installation of Offshore Sub Stations (OSS).
- Supply, plus transport and installation of Scour protection materials (Rock).

In general, WTG Foundation components:

- Monopile.
- Anode Cage.
- External Platform.
- Internal Platform.

The OSS Foundation components:

- Monopile.

- Anode Cage.
- J-tube(s).
- Boat landing.
- Module Support Frame (MSF).
- Topside.

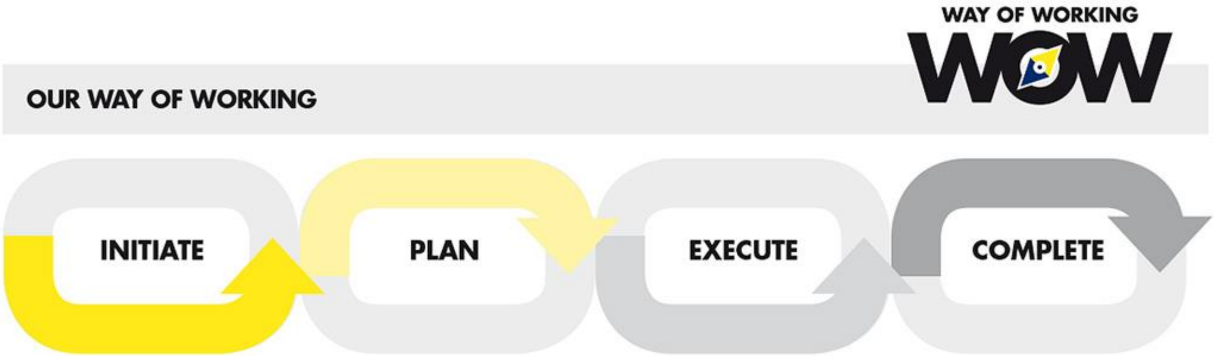
All Foundation components will be supplied by the Employer.

1.3. Scope of Document

The purpose of this document is to present the scope, method, and procedures by which the Contractor will perform deployment of the Passive Acoustic Monitoring (PAM) equipment during REV01 foundation installation campaign.

CONTRACTOR and Subcontractor’s employees, plus all other involved in the Project are required to adhere to this plan.

This document forms part of the Boskalis Way of Working, the integrated quality management system applicable to all operations in Boskalis. The Boskalis Way of Working is structured around four Phases as pictured below. This PAM Mooring deployment procedure - REV01 is typically prepared in the PLAN Phase, where the main implementation is taking place in the EXECUTE Phase.



2. REFERENCES, ABBREVIATIONS, DEFINITIONS

2.1. References

Boskalis Documents			
No.	**Document No.**	**Document Title**	**Revision/Date**
[1]	0040135-BOS-SHE-RP-0013-01	HIRA Noise monitoring and PSOs	0.0
[2]	0040135-BOS-DES-DG-4290	Mooring drawing PAM DB2000 buoy and step-by-step deployment procedure	0.0
[3]	0040135-BOS-OPS-PR-0039-01	Noise monitoring procedure	A1
[4]	-	Pile driving monitoring plan	A1
[5]	0040135-BOS-DES-DG-1121-00	Binder - Sound monitoring layout - REV01	A1
[6]	0040135-BOS-PLA-MA-0069-01	Mobilization and Demobilization manual Josephine K Miller	0.0

2.2. Abbreviations

Abbreviation	Full meaning
APE	Area of Potential Effect
BDV	Buoy Deployment Vessel
BL2	Bokalift 2
BOEM	Bureau of Ocean Energy Management
DP	Designated Person
EZ	Exclusion Zone
HLV	Heavy Lift Vessel
IHA	(NOAA) Incidental Harassment Authorization
LGP	Lead Gardline Protected Species Observer
MZ	Monitoring Zone
NARW	North Atlantic right whale
NM	Noise monitoring
NMFS	National Marine Fisheries Service
OCM	Offshore Construction Manager

Abbreviation	Full meaning
OWF	Offshore Wind farm
PAM	Passive Acoustic Monitoring
PECP	Permit and Environmental Compliance Plan
PP	Polypropylene
PSMMP	Protected Species Mitigation Measures Plan
PSO	Protected Species Observer
RPC	Replenishment Port Call
SMA	Seasonal Management Area
SOG	Speed Over Ground
RPC	Replenishment Port Call
REV	Revolution 01 OW

2.3. Definitions

Definition	Full meaning
Employer	Ørsted Wind Power North America LLC
Contractor	Boskalis Offshore Contracting LLC

3. SCOPE OF WORK

The potential acoustic impact of piling equipment during operations on protected species is recognized on a worldwide scale. As a result, the regulatory agencies of a number of countries have included protected species mitigation measures within their licensing agreements. It is a requirement to have passive acoustic monitoring equipment during pile driving to monitor for vocalizing marine mammals and produce assessments of noise levels in the subsea environment.

As a result, there are several project requirements involving acoustic equipment during the foundation installation of the REV01 OWF. As part of these requirements, four passive acoustic monitoring buoys are required deployed at 5 kilometre radial from the monopile respectively OSS foundation Figure 3-1. These buoys are meant to register and localize vocalizing marine mammals and assess their presence in the Exclusion Zone (EZ) or Monitoring Zones (MZ) upon which appropriate measures will be taken to ensure no harm is inflicted to the marine mammals.

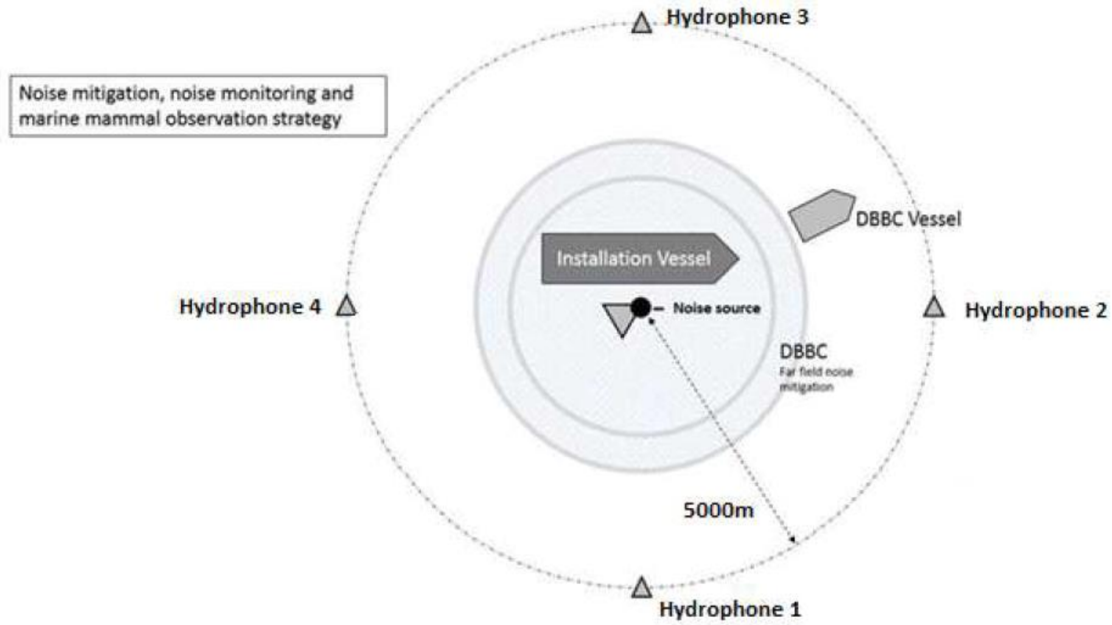


Figure 3-1: PAM buoy monitoring station layout.

For further details regarding the relevant procedures reference is made to [3] and [4].

3.1. Passive Acoustic Monitoring

A total ten DB2000 buoys PAM recorder equipment and telemetry are mobilized for the REV01 campaign. Data of the PAM buoys is send to to the foundation installation vessels, BL2 where PAM operators are stationed assessing the real time data.

3.2. Deployment Locations

Deployment locations of the buoys are predefined for each foundation installation location, buoy locations are provided in [5]. Foundation locations and buoy locations are provided and displayed on the vessel installed survey system.

3.3. Weather limits

The weather conditions have been determined in order to respect the vessel stability and mooring restrictions, limitations to ensure safe access of personnel on the vessel and the operational window. During deployment/retrieval operations the operational limits (Table 3-1) are mainly governed by the motion of the vessel and its ability to maintain position during deployment/retrieval of PAM buoys.

Working limits are however always subject to discretion of OCM and vessel Master. Master has the overall responsibility of the vessel and can overrule any procedural set limits.

Table 3-1: Environmental limitations buoy operations (4 stations).

Limiting Factor	Sea Limit [m]	Wind limit [m/s]	Tpop [h]	Tc [h]	Tr [h]
Buoy deployment operations	Hs: 1.5	U10: 20	04:30	+02:15	06:45
Buoy retrieval operations	Hs: 1.5	U10: 20	04:30	+02:15	06:45
Deck buoy works	Hs: 2.0	n/a	n/a	n/a	n/a
Required weather window [h]			09:00	+04:00	13:00

The environmental limits as provided as per above, are an indication. Exact limits are subject to vessel capabilities, actual combination of limit factors and vessel heading.

Operational limits and safe working conditions are discussed on board prior to the start of operations together with Master and OCM, operations will only commence if deemed safe and in agreement.

4. EQUIPMENT AND PERSONNEL

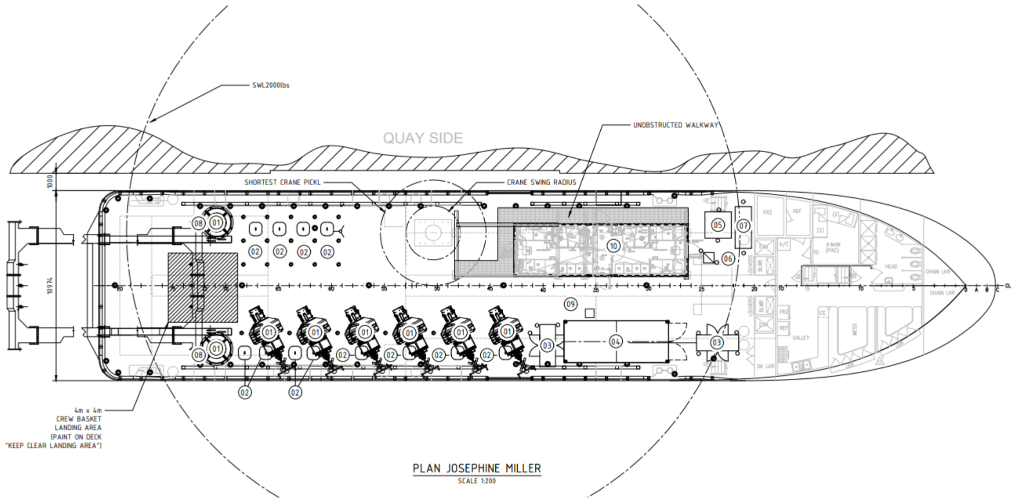
4.1. Josephine K Millers

The vessel Josephine K. Miller is chartered as buoy deployment and retrieval vessel. For detailed specifications of the vessel, please refer to Annex B. Vessel will be mobilized and demobilized from Providence Port, with a premobilization in New York.

Buoy deployment vessel – Josephine K. Miller		
A-Frame	SWL: 15 Ton	
A-Frame Main Winch	Line Pull: 30 Te	
	Drum capacity: Ø25.4mm: 1436m	
Pedestal crane	9 ton	
Vessel Dimensions	57.91 m x 10.97m	
Station Keeping	Kongsberg DP-1	

The Josephine K. Miller is outfitted with an aft installed A-frame with max. Lifting capacity of 12Te a deck crane, main towing which and two tugger winches.

Deck layout is provided below for reference, complete deck layout top view and side view arrangement drawing is provided in Annex B.



STOWAGE PLAN

POS	ITEM	QTY	LENGTH [m]	WIDTH [m]	HEIGHT [m]	MASS [t]	SUM MASS [t]
1	PAM BUOY TYPE DB2000	8	2,2	1,4	4.02	0.9	7.2
2	CLUMP WEIGHT	12	0.77	0.73	0.73	1.8	25.2
3	GENSET (FOR ACCOM. CONTAINER)	2	2,67	0.95	1.735	1.9	3.8
4	GUARDLINE STORAGE CONTAINER	1	6,1	2,4	2,62	5	5
5	PRESSURE SET - (FOR ACCOM. CONTAINER)	1	6,1	2,4	1.2	N/A	N/A
6	LIFT PUMP (FOR ACCOM. CONTAINER)	1	6,1	2,4	2,62	N/A	N/A
7	MSD = MARINE SANITATION DEVICE	1	6,1	2,4	2,62	N/A	N/A
8	PAM BUOY - STORAGE FRAME	2	1	1	1.2	0.15	0.3
9	SWITCHBOARD GENSETS (FOR ACCOM. CONT.)	1	0.5	0.5	1.8	0.7	0.7
10	ACCOMMODATION CONTAINER	1	10.06	3.48	3.2	19.5	0.3

GENERAL NOTES

1. ALL MEASUREMENTS ARE IN mm UNLESS NOTED OTHERWISE

Figure 4-1: Josephine Miller deck layout.

4.2. Installation vessel

Foundation installation operations are conducted with the Bokalift 2. Details of the Bokalift 2 are listed in Table 4-1 below.

Table 4-1: Bokalift 2 vessel details.

HLV Bokalift 2		
Main hoist capacity	4000mt @ 28m (without super fly jib) 3200mt @ 38m (with super fly jib)	
Aux. hoist (super fly jib) capacity	800mt @ 63m	
Station keeping	DP2	
Free deck space	7500m^2	
Accommodation	146 pax.	
Transit speed	10 knots	
Owner	Boskalis	

4.3. Passive Acoustic Monitoring Buoys

The PAM buoy systems are made up of an ORCA acoustic recording unit and DB2000 buoy used for communications and data transmission. Each buoy will have two recording channels to which two Geospectrum M36-900 hydrophones are connected via a data cable. One primary and one secondary that can be used if the primary channel fails and provide full hydrophone redundancy. In total, 10 fully functioning and tested buoy systems will be placed on the PAM deployment vessel. For the buoy specification refer to Annex A. The buoy systems have an internal 125 Ah battery and solar charging capabilities to allow autonomous operation.

Acoustic data is transmitted over Wi-Fi (RAJANT) to the installation deployment vessel in (near) real-time. The transmission range of the buoys is approximately 6,000 m and therefore within the 5,000 m range to the installation vessel. Live audio stream and spectrogram display are viewed in PAMGuard.

Passive Acoustic Monitoring (PAM) Buoys – DB - 2000		
Quantity	10 pcs	
Power	12V 125 Ah battery + 4x 50W Solar pannels	
Communication	WiFi, AIS Class B and 4G modem.	
Sampling Rates ORCA recorder	24-384 kHz	
Memory	3 TB	

Owner	BOS	

4.4. Deck and bridge Equipment

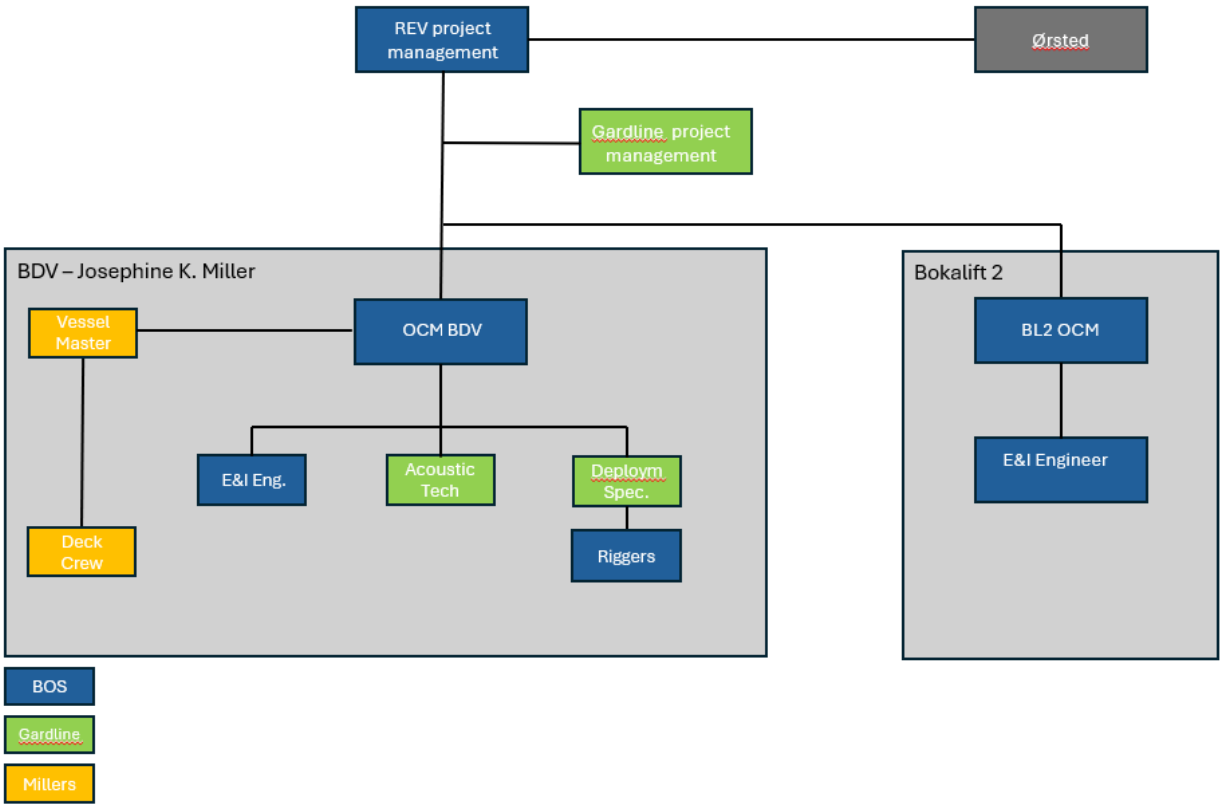
Below table outlines equipment that will be used on the buoy deployment vessel. Note that the list provides a overview of the key equipment solely. Detailed packing list is included in [6].

Equipment	Pcs	Supplying Party	Remarks
DB2000 Mooring spread (including anchors)	12	BOHL	
20ft Rigging container	1	GL	
Deployment vessel – RAJANT system	1	E&I	
Deployment vessel – PAMGuard set-up	1	Gardline	
Survey system (GPS, monitor, PC)	1	BOS	
Starlink	1	BOS	
Accommodation container + 2x 56 kW generator	1	Millers	

4.5. Personnel and organization

On board the BDV several parties will be present during the offshore operations. Organogram and roles and responsibilities are outlined in this section to ensure all parties are aligned and aware of their role within the project.

4.5.1.Organogram



4.5.2. Roles and Responsibilities

Function	Party	Action
REV Project Management	Boskalis	• Main contractor • Overall responsibility Offshore Operations • Client contact • Planning and Reporting • Budget
Gardline Project management	Gardline	• Service provider PAM buoys, PSO and SFV incl. equipment • Personnel provision • Equipment management including spares • Permits
BL2 OCM	Boskalis	• Overall responsible for Offshore foundation installation operations incl. auxiliary support spread

Function	Party	Action
		• Offshore planning incl. PAM, SFV and PSO scope • Reports to REV Project management
BDV OCM	Boskalis	• Overall responsible for PAM buoy deployment and retrieval operations as per contractual and permit requirements • Daily progress reporting (meetings and written) • Liaise with vessel BDV Master on day to day business and planning • Offshore planning PAM buoy deployment • Coordinate and oversees safe execution of back deck operations incl. correct positioning of PAM buoys. • Reports to OCM BL2 and REV Project management
E&I Engineer	Boskalis	• Responsible for telemetry RAJANT system • Maintenance and trouble shooting PAM-DB2000 buoys together with Gardline • Starlink internet connectivity first point of contact • Liaises with E&I engineer on board BL2 • Reports to OCM BDV
Acoustic technician	Gardline	• Responsible for proper functioning of DB-2000 buoys and PAM data collection • Functionality of RAJANT networks for data transmission • Provide support in deployment and retrieval of acoustic equipment back deck; • Maintenance of DB-2000 PAM buoys; • Verify functioning data stream and data availability at BL2 • Interface with PAM Operators BL2 • Spare part tracking and inventory • Reports to OCM BDV
Deployment technician	Gardline	• Responsible for safe deployment and retrieval of PAM DB2000 buoys • Prepare buoy mooring setups with Abs/riggers • Rig buoys with support of Abs/riggers • Prepare aft deck for deployment/retrieval • Coordinate back deck works with riggers. • Deploy and retrieve PAM buoys as per procedure • Maintain buoy mooring setups • Reports to OCM BDV
Riggers	Boskalis	• Responsible for safe rigging, slinging and back deck works • Rigging of buoy mooring setups and A-frame winch • Prepare and maintain buoy mooring setups

Function	Party	Action
		• Coordinate with AB winch operator and A-frame operator • Responsible for sea fastening of project equipment • Reports to OCM BDV

4.6. Personnel Protective Equipment

All personnel will wear the appropriate Personnel Protective Equipment, for the tasks at hand with as minimum the PPE as listed in table below. Reference is also made to [1].

Personnel Protective Equipment	Activity
Hard hat	Standard operations
High visibility jacket and trousers or coverall with high visibility stripes	Standard operations
Safety Glasses	Standard operations
Safety Gloves	Standard operations
Safety Shoes/Boots	Standard operations
Long sleeves and trousers	Standard operations
Lifejacket incl. PLB	When working within 1m from quayside or when barrier is removed from stern
Harness attached to SRL	When working within 3m from vessel stern with barrier removed. SRL connect to hard point on deck.
Rain Gear	Standard operations when relevant
Ear Protection	When noise above >80 dB or when required by RIA/safety instructions

5. MOORING SCHEMATICS PAM BUOYS

5.1. PAM Buoy Mooring

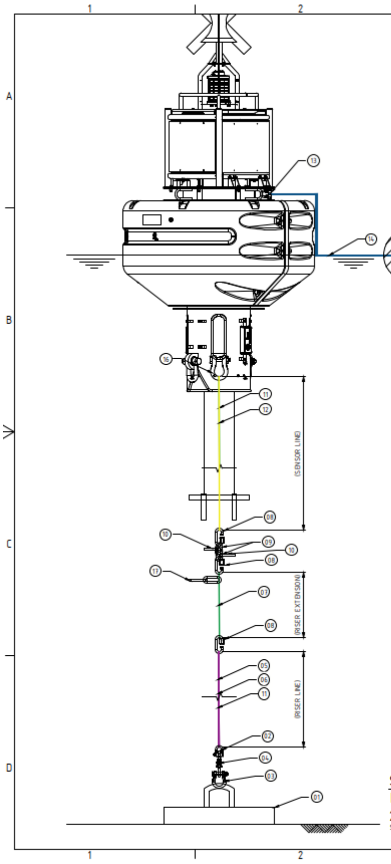
To ensure the buoy and hydrophones remain at the correct location and are easier to deploy and retrieve, the below mooring line configuration is used. Buoy is kept in position using a dead weight anchor between 1.8-2.0Te. Length of the sensor and riser lines are tailored to the deployment water depths. As rule of thumb, at least 1.5x water depth is considered for the entire mooring length.

Table with mooring line lengths per water depth are provided below in Table 5-1.

Table 5-1: PAM DB2000 mooring line configuration.

REV01 DB2000 MOORING LINE CONFIG					
WATER DEPTH	REQUIRED POS	SENSOR LINE LENGTH	RISER LINE LENGTH	RISER EXTENSION LENGHT	TOTAL LENGTH
26	12, 11 & 7	10	20	10	40
30	11 & 6	20	40	-	60
35	11, 6 & 7	20	40	10	70
40	11, 6 & 7	20	40	10	70
45	11 & 5	20	60	-	80
49	11 & 5	20	60	-	80

In this design the hydrophones are connected to the DB2000 Float by individual cables. At any one time only one hydrophone is active (other spare). Complete mooring setup is provided below in Figure 5-1 and in Annex A for detailed drawing.



REV01 DB2000 MOORING LINE CONFIG					
WATER DEPTH	REQUIRED POS	SENSOR LINE LENGTH	RISER LINE LENGTH	RISER EXTENSION LENGHT	TOTAL LENGTH
26	12, 11 & 7	10	20	10	40
30	11 & 6	20	40	-	60
35	11, 6 & 7	20	40	10	70
40	11, 6 & 7	20	40	10	70
45	11 & 5	20	60	-	80
49	11 & 5	20	60	-	80

PART LIST

POS	REQ.	ITEM	SPECIFICATION	REMARKS
1	1	STEEL SINKER	WEIGHT 1.8-2TONNE	
2	1	SHACKLES GP4163	SWL: 4.75 t	
3	1	SHACKLE GP4263	SWL: 4.75 t	
4	1	EYE-EYE SWIVEL G7718	SWL: 4.5 t	
5	1	DYNEEMA RISER LINE	BOTH END SOFT EYES EWL = 60M, MBL = 18 t	
6	1	DYNEEMA RISER LINE	BOTH END SOFT EYES EWL = 40M, MBL = 18 t	
7	1	DYNEEMA RISER EXTENSION	BOTH END SOFT EYES EWL = 10M, MBL = 18 t	
8	3	QUICK LINK (DQ22SSP) 14mm GALVANIZED	MBL = 10 t	
9	2	VIKING SPLIT LINK	WLL = 5 t	
10	2	STAINLESS STEEL CARABINER HOOK 12x140mm		
11	1	DYNEEMA SENSOR LINE	BOTH END SOFT EYES EWL = 20M, MBL = 18 t	
12	1	DYNEEMA SENSOR LINE	BOTH END SOFT EYES EWL = 10M, MBL = 18 t	
13	1	SHACKLES GP4163	SWL: 3.25 t	
14	1	DYNEEMA SURFACE LINE	BOTH END SOFT EYES EWL=4M, MBL=18t	
15	2	PELLET BUOY INCL CARABINER	POLYFORM A0	
16	1	SHACKLE GP4163	WLL = 17 T	
17	1	CLIP WEIGHT (CA. 4KG)		

SIDE VIEW
MOORING ARRANGEMENT
26 - 49 WATER DEPTHS
SCALE 1:30

REFERENCE DRAWINGS:
0040135-BOS-DES-DG-4290-01 BINDER - STEP-BY-STEP BUOY DEPLOYMENT AND RETRIEVAL - PAM BUOYS - REV01

GENERAL NOTES:
1. ALL DIMENSIONS ARE IN mm U.N.O

0.0	22/03/2024	ISSUED FOR CONSTRUCTION	MLPZ	NPHO	JANT	JASP	YDMU
A.1	22/03/2024	ISSUED FOR INTERNAL REVIEW	PJOV	NPHO	JANT	JASP	YDMU
Rev.	DD/MM/YYYY	FORMAL REVISION/CHANGE SUMMARY	CKD. ORG.	CKD. DISP.	CKD. INT.	APP. ENG.	APP. OPS.

ROS-PP CODE: TBA
DEVELOPMENT: INSTALLATION
PROJECT: REVOLUTION WIND 01 (REV01)
SUBJECT: MOORING AND RIGGING ARRANGEMENT PAM BUOY REV01
CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC Ørsted

BOSKALIS OFFSHORE HEAVY LIFTING
P.O.BOX 43, 3350 AA PAPENDRECHT - E-MAIL: INFO@BOSKALIS.COM

FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
A3		-	-
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4290-01	0.0

Figure 5-1 PAM buoy’s mooring configuration

5.2. Soft Attachment Illustration

Below is an example of how to create a soft attachment for attaching the hydrophones to Riser line if required.

Figure 5.3 Soft Attachment Illustration.

6. TASK PLAN

During the offshore operations, PAM buoys will deployed and retrieved following the BL2 offshore installation progress. In order to ensure deployment and retrieval operations are conducted in safe and controlled matter personnel should familiarize themselves and follow below task plan steps.The below outlined task plan for the deployment and retrieval of the DB-2000 buoys is to be read in conjunction with the risk assessment [1] and task plan storyboard in Annex C.

Considerations:

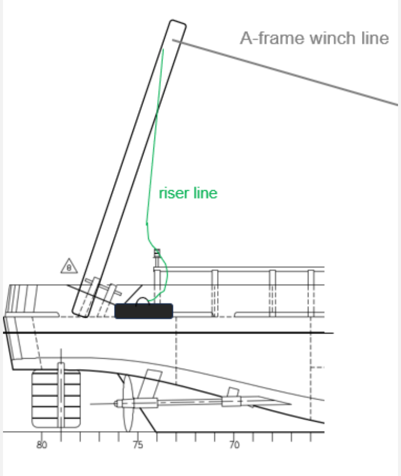
1. A Toolbox talk should be carried out before any aft deck operations, discussing the planned operations, environment conditions, communication channels, vessel approach and any safety issues.
2. Correct PPE should be worn on deck.
3. Lone working on aft deck is not allowed.
4. Radio communication is established prior to operations and maintained throughout aft deck operations.
5. Line of sight must be maintained between winch operator/A-frame operator and deployment specialist at all times to enable communication verbally and visually.
6. Only required and authorized personnel is allowed on deck during operations.
7. Care must be taken of snagging the winch line.
8. Do not put ‘hands on the line’ unless required.
9. At all times, manage the slack and lead of the line going overboard, adjust winch/vessel position accordingly.
10. Never stand under a load and maintain safe distance.
11. Lifting operations are always performed within operational limits and use of tag-lines to control load.
12. Ensure any lifting gear is in good condition and suitably used.
13. Ensure the mooring remains connected to the vessel at all times until ready to release.
14. Keep the deck tidy to avoid trip hazards.
15. Carry out a pre-deployment/retrieval ‘Walk the Line’ checks.
16. Last minute risk assessment in case of minor deviations from this pre-agreed and approved procedure.

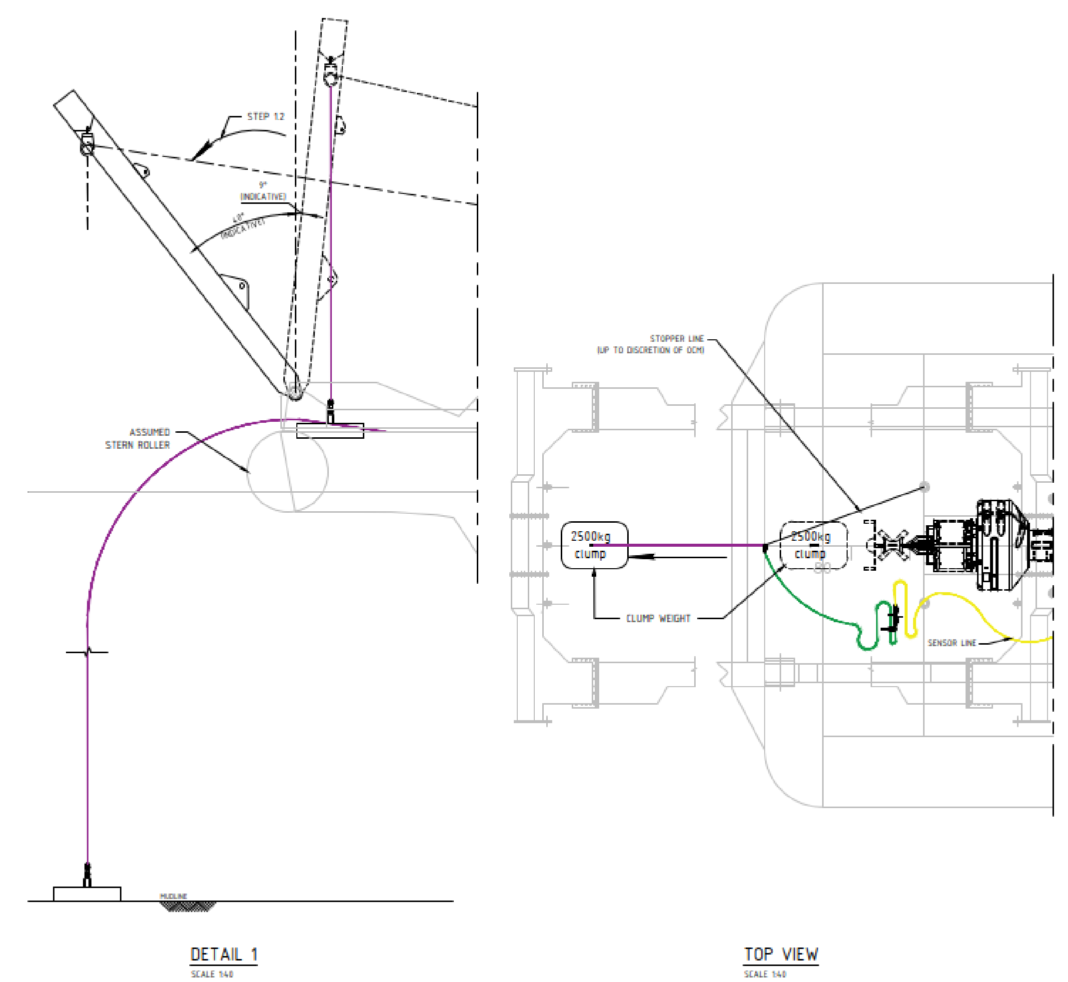
Table 6-1: Rolls and abbreviations referred to in task plan.

Rolls	Abbreviation
OCM	OCM
E&I Engineer	EIE
Deployment Specialist	DSPEC
Acoustic technician	ATEC
Rigger	Rig
Marine bridge Crew	MBC
Marine deck crew	MDC

6.1. PAM DB-2000 Buoy Deployment Procedure

PAM Buoy (6.1.1) Step by Step DB-2000 PAM buoy deployment procedure – with A-frame		
Task	**Description**	**Resp.**
A	**Buoy deployment**	
A1	Marine coordination: inform relevant authorities / BL2 of intended deployment locations and obtain approval	OCM
A2	Assess weather and vessel movements. Asses weather forecast and wave rider buoy data (if available), to confirm favorable weather window of sufficient length is available and weather is within operational limits.	OCM, MBC
A3	Function check recording chain. Program buoys to deployment settings and start recording, tap-test hydrophones and verify incoming signal on buoy deployment vessel and receptor (BL2/ BDV). Ref. to GL operational checklist – pre-deployment.	ATEC, EIE
A4	A Toolbox talk should be carried out on the bridge before start of any aft deck operations with relevant involved stakeholders, discussing deployment locations + approach, environment conditions, task division, communication means, involved risks and any safety issues.	OCM, All
A5	Inspection of Work Area, including functional check deck equipment, work area should be clear of obstacles or tripping hazards, everyone is wearing correct PPE, required materials are orderly arranged and within reach.	DSPEC, MDC, RIG
A6	Buoy preparations: • Check voltage batteries; • Disconnect the buoy from any (external power) fit dummy plugs and ensure electrical components are well protected, secure connections with locking mechanisms. • Check hydrophones secured in cage. Check data cable connection to buoy, locking sleeves in place. • Attach one lifting rope to lifting eye perpendicular to antenna bracket and bundle on buoy hand-rail. • Boot-up buoy and function check buoy including data transmission verification between BDV back-back deck, bridge and BL2. • Check subcon connections data-cable/hydrophone, locking sleeves in place.	ATEC, DSPEC
A7	Deck preparations: Prepare winch, rigging material, riser line, sensor line tag lines and stopper ropes. Prepare following rigging: 1. 1x 2t 1m webbing sling 2. 2x 12m 22mm slip ropes acting as tag lines 3. 2x stopper lines assembly – safety hook, 22mm 2m PP rope(spliced eyes both ends) and 3.25t anchor bow shackle 4. 1x foundry hook 6.7t with 6mm 15m tag line attached to back side	DSPEC, MDC, RIG
A8	Buoy deployment vessel sails to planned buoy deployment location on instruction of OCM. On arrival position vessel with bow in current and hold position in DP mode.	MBC, OCM
A9	Winch up riser line to A-frame winch (check water depth deployment location for riser line lengths!); connect winch wire to riser line via g-hook. Back wind, the riser line onto the	MDC

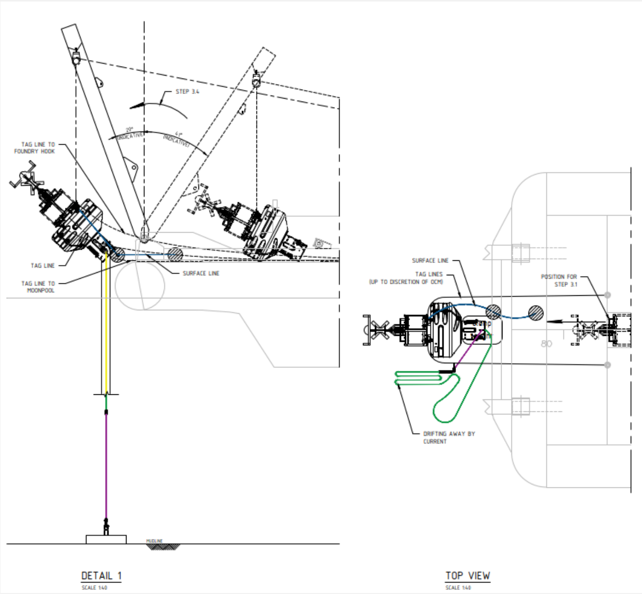
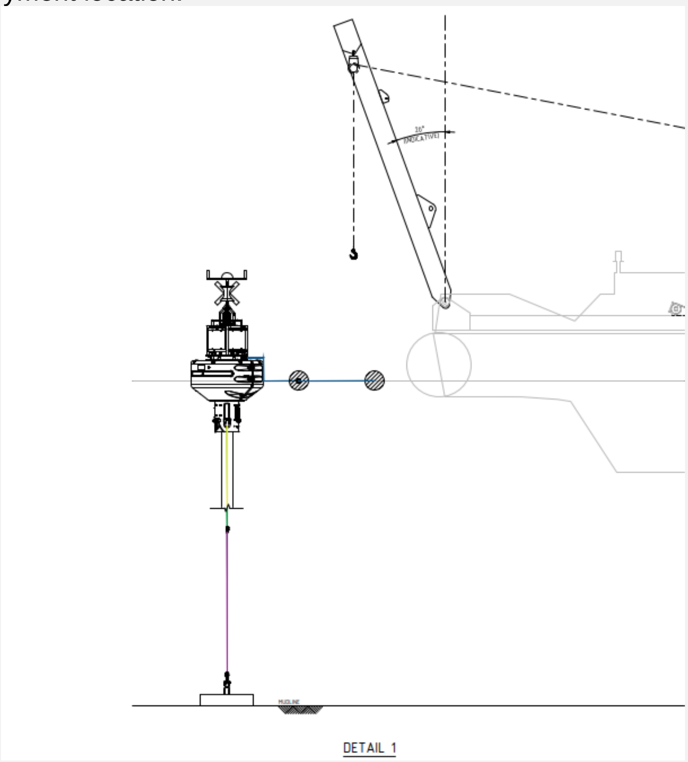
PAM Buoy (6.1.1) Step by Step DB-2000 PAM buoy deployment procedure – with A-frame		
Task	**Description**	**Resp.**
	winch via the lifting block on the A-frame. Secure 4.75T anchor bow shackle at other end of riser line onto anchor.	
A10	Release anchor from sea fastening position. Replace anchor using pellet truck and position anchor underneath A-frame.	DTEC, MDC
A11	Disconnect riser line 4.75t anchor bow shackle from stopper line safety hook on deck and connect to 3.2t anchor swivel (if not already done in step A9). Make sure to insert split pins and bow both legs ends to secure it properly. 	DTEC, MDC
A12	Prepare sensor line (check water depth deployment location) and layout line over deck. Release sea fastening of buoy. Attach 2x 12m 22mm PP slip rope to opposite side of lifting eyes in line with antenna bracket. Connect one end of slip rope to hard points located on port and starboard side A-frame beams at aft deck. Slip ropes will be used as tag lines during lift.	DTEC, MDC
A13	Release sea fastening of buoy. Drag buoy over deck. Place buoy under A-frame next to anchor with Antennae pointing towards vessel aft, with sensor line fitted inside the ballast foot recession. Secure the buoy with two rubber wedges to prevent rolling of buoy.	MDC, RIG, DTEC
A14	Deployment technician confirms with bridge vessel in position and request green light to start deployment via radio. Upon confirmation received, deployment can start.	DTEC, MBC
A15	**Anchor deployment** Lead one end of 12m 22mm PP slip rope to anchor top shackle and connect to hard point on deck. MDC holds other end in hand to control load. Hoist anchor from deck using A-frame winch. Control load using slip rope. Rotate A-frame outward whilst keeping anchor at same height by paying out A-frame winch. One A-frame has reached maximum rotation outwards, release slip rope attached to anchor and start paying out riser line using the A-frame winch to lower anchor to seabed. Once slack is observed in riser line, request bridge to note down deployment coordinates and take a mark in the survey system.	DTEC, MDC, RIG

PAM Buoy (6.1.1) Step by Step DB-2000 PAM buoy deployment procedure – with A-frame		
Task	**Description**	**Resp.**
		
A16	Continue spooling out the riser line until the end of the riser line is reached and quick-link g-hook connection is reachable by boot hook. MDC/RIG keeps anchor side riser line hand tight, managing slack of line. If, required, request vessel to move ahead slowly. Rotate A-frame back inwards. Connect riser line quick link to deck stopper safety hook. Disconnect A-frame winch wire from riser line G-hook. ***Be careful of the slack and lead of line as there is risk of ropes entangled into the propeller. Keep close communication between deck crew and bridge.***	MDC, RIG, DTECH
A17	Connect G-hook at end of riser line to sensor line recessed link using the G-hook and attach clip weight (1kg shackle/dead weight) to spliced eye at top of riser line.	MDC, RIG DTECH
A18	**Buoy deployment** To deploy the buoy several rigging methods can be used, the safest and therefore base case scenario is using a foundry hook, this is however at OCM's discretion.	OCM, MBC, DTEC, RIG

PAM Buoy (6.1.1) Step by Step DB-2000 PAM buoy deployment procedure – with A-frame		
Task	**Description**	**Resp.**
	Method - Foundry hook (base case) 1. Prepare foundry hook assembly (3.25t anchor bow shackle, 6.7t foundry hook and tag line 6mm), rig 3.25t anchor bow shackle to A-frame winch swivel hook, connect foundry hook to upward facing buoy lifting eye and keep tag line in hand. 2. Release stopper line connected to sensor line/riser line recessed link and manage slack sensor line. Continue to pay out sensor line. Make sure to lift carefully handle hydrophones and lift them over the stern till free whilst paying out sensor line. 3. Continue paying out sensor line and manage slack until only DB-2000 buoy remains on deck. 4. Pay in A-frame winch wire to create tension on the sling and lift buoy from deck. Hold two slip ropes by hand to control buoy movement, one slip rope per MDC. 5. Rotate A-frame outwards and maintain same lifting height by paying out the A-frame winch wire. 6. Once the buoy is above water and clear from the stern of the vessel the winch wire can be paid out to lower buoy into the water. Continue to pay A-frame winch wire to create slack. When slack is created, foundry hook can be pulled out of lifting eye pulling on tag line. 7. Pull in one end of slip ropes through lifting eyes. 8. Inform bridge buoy is released and request to move forward 9. Manage slack on surface line including pellet buoy and slowly pay out whilst vessel pulls line from deck moving forward. 10. Rotate A-frame back inwards. 11. Buoy deployment completed. **OR** (contingency method) ***Method - Double Sling*** 1. Connect one end of 3t 5m webbing sling to A-frame winch swivel hook. Lead other end to upward facing lifting eye of buoy and connect back to swivel hook A-frame winch wire. 2. Release stopper line connected to sensor line/riser line recessed link and manage slack sensor line. Continue to pay out sensor line. Make sure to lift carefully handle hydrophones and lift them over the stern till free whilst paying out sensor line. 3. Continue paying out sensor line and manage slack until only DB-2000 buoy remains on deck. 4. Pay in winch wire to create tension on the sling and lift buoy from deck. Hold two slip ropes by hand to control buoy movement, one slip rope per MDC. 5. Rotate A-frame outwards and maintain same lifting height by paying out the A-frame winch wire. 6. Once the buoy is above water and clear from the stern of the vessel the winch wire can be paid out to lower buoy into the water. 7. Spool off winch wire till sufficient slack is created and swivel hook can be pulled in by hand. In case required, rotate A-frame inwards to help getting swivel hook in reach. MDC can release one end of sling eye from swivel hook and pull sling through lifting eye of buoy. 8. Pull in one end of slip ropes through lifting eye. 9. Inform bridge buoy is released and request to move forward	

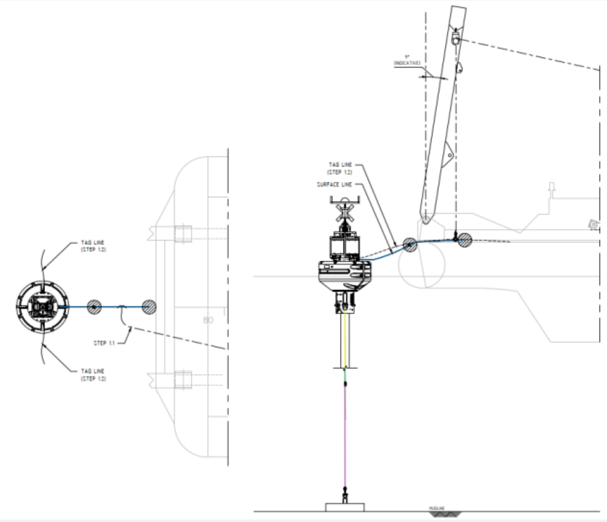
PAM Buoy (6.1.1) Step by Step DB-2000 PAM buoy deployment procedure – with A-frame		
Task	**Description**	**Resp.**
	10. Manage slack on surface line including pellet buoy and slowly pay out whilst vessel pulls line from deck moving forward. 11. Rotate A-frame back inwards. 12. Buoy deployment completed. **OR** ***Method – Quick release hook*** 1. Connect quick release hook (WLL:2 ton) to A-frame winch swivel hook, together with one side of the 3t 2m webbing sling. Lead other side of sling through lifting eye of buoy (connected to surface line). Connect the other end of webbing sling into quick release hook and secure. Hold release line of quick release in hand. 2. Release stopper line connected to sensor line/riser line recessed link and manage slack sensor line. Continue to pay out sensor line. Make sure to lift carefully handle hydrophones and lift them over the stern till free whilst paying out sensor line. 3. Continue paying out sensor line and manage slack until only DB-2000 buoy remains on deck. 4. Pay in A-frame winch wire to create tension on the sling and lift buoy from deck. Hold two slip ropes by hand to control buoy movement, one slip rope per MDC. 5. Rotate A-frame outwards and maintain same lifting height by paying out the A-frame winch wire. 6. Once the buoy is above water and clear from the stern of the vessel the winch wire can be paid out to lower buoy into the water and activate the quick release hook by pulling the release line 7. Pull in one end of slip ropes through lifting eyes. 8. Inform bridge buoy is released and request to move forward 9. Manage slack on surface line including pellet buoy and slowly pay out whilst vessel pulls line from deck moving forward. 10. Rotate A-frame back inwards 11. Buoy deployment completed.	

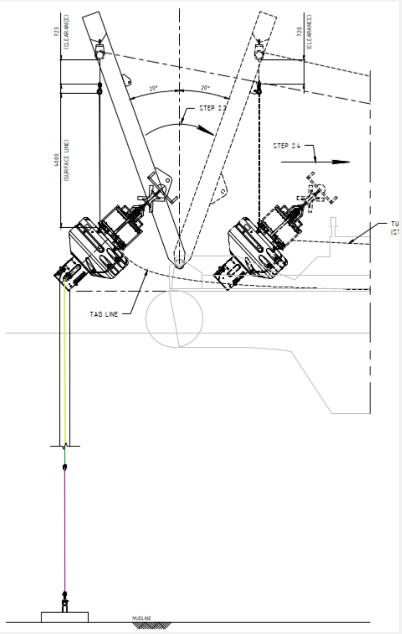
PAM Buoy (6.1.1) Step by Step DB-2000 PAM buoy deployment procedure – with A-frame

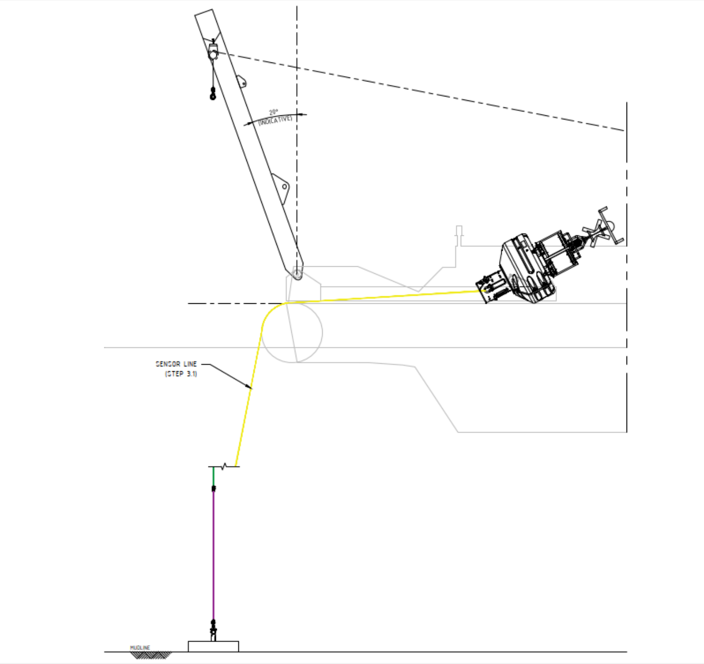
Task	Description	Resp.
		
A19	Inform all relevant stations of buoy deployment location coordinates and starting sailing away from deployment location. 	OCM, MBC
A20	Tidy deck and remove stopper lines and secure A-frame winch wire to hard point on deck.	MDC, DTEC

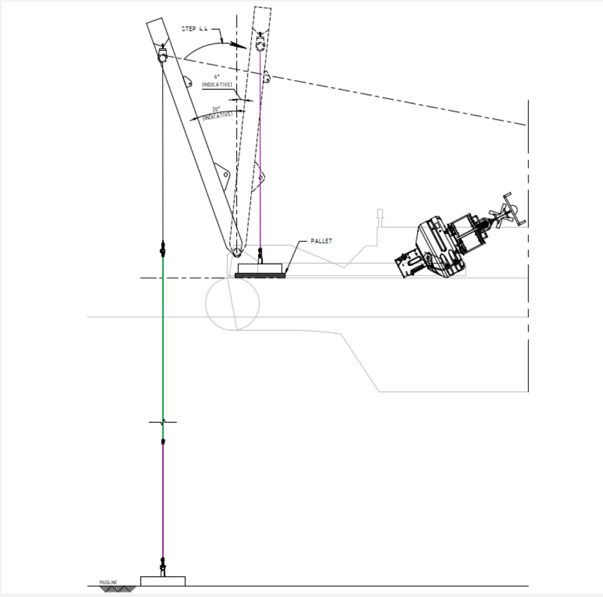
6.2. PAM DB-2000 Buoy Retrieval Procedure

PAM Buoy (6.2) Step by Step DB-2000 PAM buoy recovery procedure – with A-frame		
Task	**Description**	**Resp.**
B1	**Buoy Retrieval**	
B1	Marine coordination: inform relevant authorities / BL2 of intended retrieval operations and obtain approval including preferred retrieval order (if any).	OCM, MBC
B2	Assess weather and vessel movements. Asses weather forecast and wave rider buoy data (if available), to confirm favorable weather window of sufficient length is available and weather is within operational limits.	OCM, MBC
B3	Carry out toolbox talk on the bridge before start of any aft deck operations with relevant involved stakeholders, discussing retrieval locations + approach, environment conditions, task division, communication means, involved risks and any safety issues.	OCM, MBC, DTEC, MDC,RIG
B4	Inspection of Work Area, including function check deck equipment, work area should be clear of obstacles or tripping hazards, everyone is wearing correct PPE, required materials are orderly arranged and within reach.	DTEC, MDC, RIG
B5	Deck preparations: Prepare winch, crane, rigging material, riser line, tag lines and stopper ropes. Prepare following rigging/equipment: 1. Secure end of 2x 15m 18mm slip rope to hard point on either side of the A-frame aft beam and towards hardpoint at centreline 2. 2x stopper lines assembly – safety hook, 22mm 2m PP rope (spliced eyes both ends) and 3.25t anchor bow shackle 3. A-frame winch wire terminated with 3.25te anchor bow shackle, g-hook and swivel crane hook	DTEC, MDC, RIG
B6	Buoy deployment vessel sails to planned buoy retrieval location. Position vessel with stern in current and hold position in DP mode, down stream of DB-2000 buoy. Rotate A-frame outwards.	MBC
B7	Slowly back the vessel towards the surface buoy. Be mindful of the lead of the line and position of the stern thrusters. DTECH keeps MBC informed guide them towards the surface buoy and if deemed required request vessel bridge crew to turn of thruster closest to line.	DTEC, MBC
B8	Grapple the surface line and pull in. Cconnect soft eye end at pellet buoy to A-frame winch swivel hook. Remove floats. Release winch wire and lifting line and sail ahead till drop point of buoy anchor is situated behind the vessel with no risk of line entanglement. Whilst sialing forward, pay out the winch line to till buoy steadily towed behind the vessel.	MDC, RIG, DTEC, MBC

PAM Buoy (6.2) Step by Step DB-2000 PAM buoy recovery procedure – with A-frame		
Task	**Description**	**Resp.**
		
B9	Once anchor drop point is located behind the vessel. Stop vessel, pay in winch wire till buoy in in reach of boats hook. Load the 18mm slip rope into the hook&moor boat hook and pull through lifting eye on opposite sides of the buoy and buoy side towards stern. Repeat this step for the second and third slip rope and secure other free ends of slip rope to cleat or hard point on opposite sides of aft deck.	MDC, RIG, DTECH
B10	Pay in winch wire to take out slack of winch wire/lifting line and stop.	MDC, DTEC, RIG
B11	Pay out tag lines, hold all three ends by hand to control buoy movement. If required, request MBC to move forward to free buoy from stern of vessel.	MDC, DTEC, RIG
B12	Once buoy is free from stern roller start paying in A-frame winch wire, when buoy is lifted high enough to pass over stern roller, start rotating A-frame inwards. Keep buoy low over deck and control buoy movements with tag lines. Position buoy on aft deck secure the buoy using two rubber wedges to prevent rolling.	MDC, DTEC, RIG

PAM Buoy (6.2) Step by Step DB-2000 PAM buoy recovery procedure – with A-frame		
Task	**Description**	**Resp.**
	 ⚠ ***Be careful of the slack and lead of line as there is risk of ropes entangled into the propeller. Keep close communication between deck crew and bridge.***	
B13	Inform all stations buoy is retrieved.	OCM, MBC, RIG
B14	Once buoy is on deck haul in the sensor line by hand till recessed link is reached connect to riser line. In case there is too much tension on the sensor line, MBC can be requested to move vessel astern. Be careful to not damage the PAM hydrophones while pulling in the sensor line. Manage slack and lead. Detach the A-frame swivel hook from lifting line.	MDC, DTEC, RIG

PAM Buoy (6.2) Step by Step DB-2000 PAM buoy recovery procedure – with A-frame		
Task	**Description**	**Resp.**
		
B15	Move vessel a stern to align stern with anchor deployment location. Manage slack and lead of riser line.	MDC, DTEC, RIG
B16	Move buoy to side of aft deck, lash and skid with wedges to free-up aft deck for anchor retrieval.	MDC, DTEC, RIG
B17	When connection riser line/senor line is reached, secure safety hook of stopper to quick link of sensor line. Manage slack and lead. Rotate A-frame outwards. Connect A-frame winch wire shackle to spliced eye of riser line. Disconnect clip weight from riser line. Disconnect sensor line from riser line by detaching riser line g-hook from recessed link. Manage slack and lead of riser line.	MDC, DTEC, RIG
B18	Disconnect stopper and start paying in winch wire, manage slack and lead by hand till tension is created. Continue paying in winch wire till anchor surfaces just clear of above freeboard height of vessel aft. Request MBC to note down anchor retrieval coordinates.	MDC, DTEC, RIG

PAM Buoy (6.2) Step by Step DB-2000 PAM buoy recovery procedure – with A-frame		
Task	**Description**	**Resp.**
		
B19	Rotate A-frame inwards keep lifting height just above freeboard height of vessel aft by paying in winch wire. When anchor is above aft deck, lower down to aft deck. Secure anchor on deck and position anchor and buoy in storage position.	MDC, DTEC, RIG
B20	Inform all stations ‘’anchor on deck’’ and move to next location.	OCM, MBC
B21	Clean up aft deck for next deployment/retrieval.	MDC, DTEC

Note. The above recovery procedures assume that the vessel is positioned with the stern into the current. This is the preferred method (Option A - Figure 6.1), however, depending on the environmental conditions at the time, recovery may want to be reversed where the bow is into the current, take note that the clump weight and mooring line will be beneath the vessel if this option is selected (Option B-Figure 6.1).

The method selected will be at OCM//Masters’ discretion and may vary from location to location.

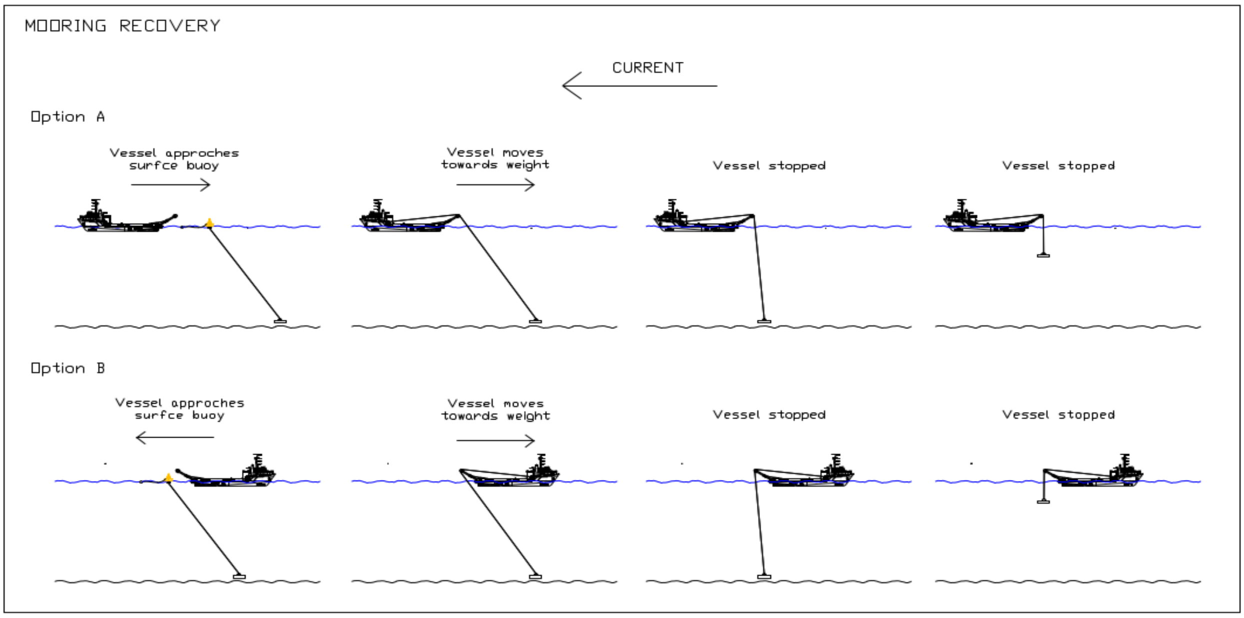


Figure 6.1 Mooring Recovery methods.

ANNEX A - DB2000 BUOY SPECIFICATION

The DB 2000 is a meteorological/oceanographic data buoy. The DB 2000 comprises a 1.9m diameter hull constructed from multiple-section polyethylene floats bolted around the central structure, with through-hull access for underwater instrumentation and cabling. The robust design of the DB 2000 enables it to withstand harsh sea conditions and allows long periods without interim servicing.

Its hollow steel central core houses the power packs for the Rajant system and ORCA unit with and a large external solar panel for powering the ORCA unit.

Passive Acoustic Monitoring (PAM) Buoys (DB2000)	
Quantity	10 pcs
Power	12V 110Ah battery
Communication	5.8GHz radio frequency, WiFi AIS Class B transponder Teltonika 4G modem
Memory	2TB, SSD Drive
Supplier	Boskalis
Owner	Boskalis

Acoustic data is transmitted using Rajant Hawk BreadCrumb® to the installation deployment vessel in real-time. The Hawk is a high-performance BreadCrumb platform. Combined with Rajant's patented InstaMesh protocol, the Hawk is capable of integrating Kinetic Mesh wireless networks with other networks such as LTE/5G.

The transmission range of the buoys has been tested to be from 8km at 200KB of data per second and therefore within the 5000 m range to the installation vessel and the data level for the project (80KB per second per vessel). Live audio stream and spectrogram display are viewed in PAMguard.

Passive Acoustic Monitoring (PAM) transmission Rajant Hawk BreadCrumb	
Quantity	10 pcs
Power	80 D cells
Antenna Connector	Type N (female)
Frequency	U-NII-1: 5150 – 5250 MHz U-NII-2A: 5250 – 5350 MHz U-NII-2C: 5470 – 5725 MHz U-NII-3: 5725 – 5850 MHz
Modulation	OFDM with up to 256-QAM
Max. Physical Layer Data Rate	866.7 Mbps (throughput varies
Max. RF Transmit Power	30 dBm
Receive sensitivity	94 dBm (@ 6 Mbps, 20 MHz channel bandwidth) to -68 dBm (@ 866.7 Mbps, 80 MHz channel bandwidth)
Supplier	Boskalis
Owner	Boskalis

MOBILIS

river and sea equipement

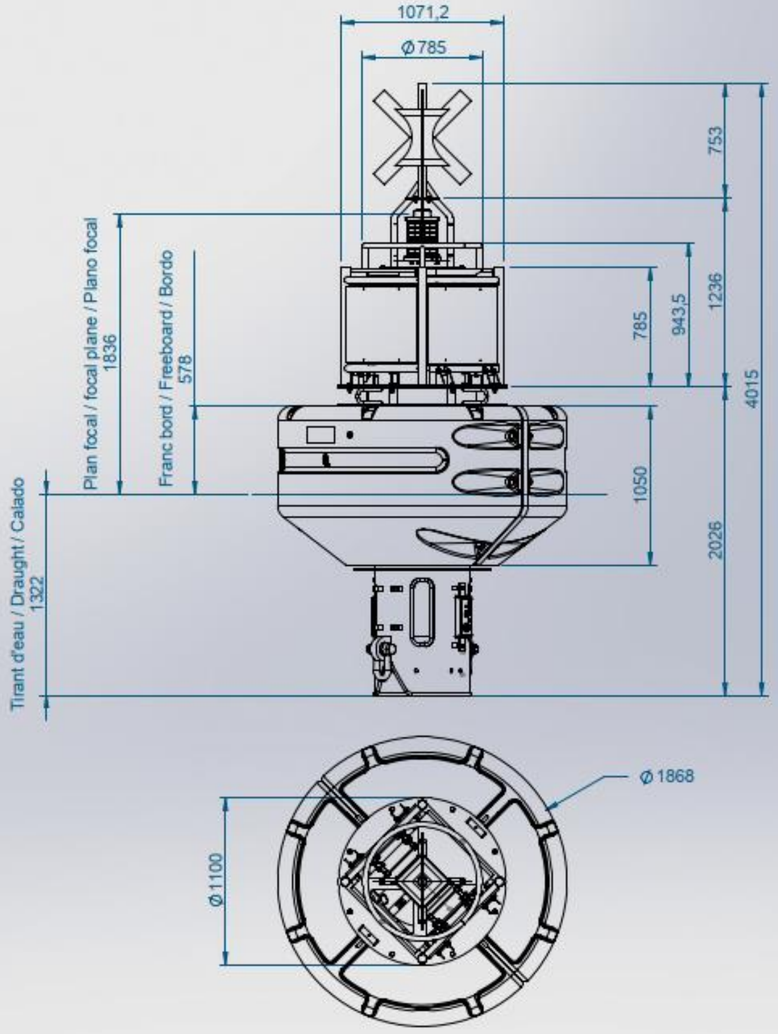
DB 2000
Boskalis

M_VC_DTB_2000_202179_51187	IALA	ISO 9001:2015	par ANK	REF	ED
MOBILIS - BP 80049 -13792 Aix-en-Provence cedex 3- France - Tel.: +33 (0)4 42371500 Fax: +33 (0)4 42371501 www.mobilis-sa.com E-mail: mobilis@mobilis-sa.com Images specifications et dimensions non-contractuelles / Images and specifications for information only			rev: 0	IT10	03
			n°: 1/2	13/02/2020	

MOBILIS

river and sea equipement

DB 2000
Boskalis



Spécifications générales *General Specifications* Especificaciónes generales		
Masse *Weight* Masa	Kg	**756**
Surface Visible *Visible Area* Superficie visible	m²	**2.3**
Flottabilité Net *Net Buoyancy* Flotabilidad Neta	L	**1332**

Spécifications matière *Material specifications* Especificaciones del material	
Structure *Structure* Estructura	**Acier-S235(S355) Galvanisé à chaud** *Hot dip galvanized S235(S355) steel* Acero S235(S355) galvanizado en caliente
Flotteur *Float* Flotador	**Polyéthylène moyenne densité** *Polyethylene medium density* Polietileno media densidad
Mât *Mast* Mástil	**Aluminium 5083/5086 qualité marine** *Aluminium 5083/5086 marine grade* Aluminio 5083/5086 de grado marino
Voyant *Top Mark* Marca tope	**Aluminium 5083/5086 qualité marine** *Aluminium 5083/5086 marine grade* Aluminio 5083/5086 de grado marino
Réflecteur Radar *Radar Reflector* Reflector radar	**Aluminium 5083/5086 qualité marine** *Aluminium 5083/5086 marine grade* Aluminio 5083/5086 de grado marino
Lest *Ballast* Lastre	**Fonte grise** *Cast iron* Hierro fundido gris

M_VC_DTB_2000_202179_51187

par ANK	REF	ED
rev: 0	IT10	03
n°: 2/2	13/02/2020	

IALA

CERTIFIED ISO 9001:2015

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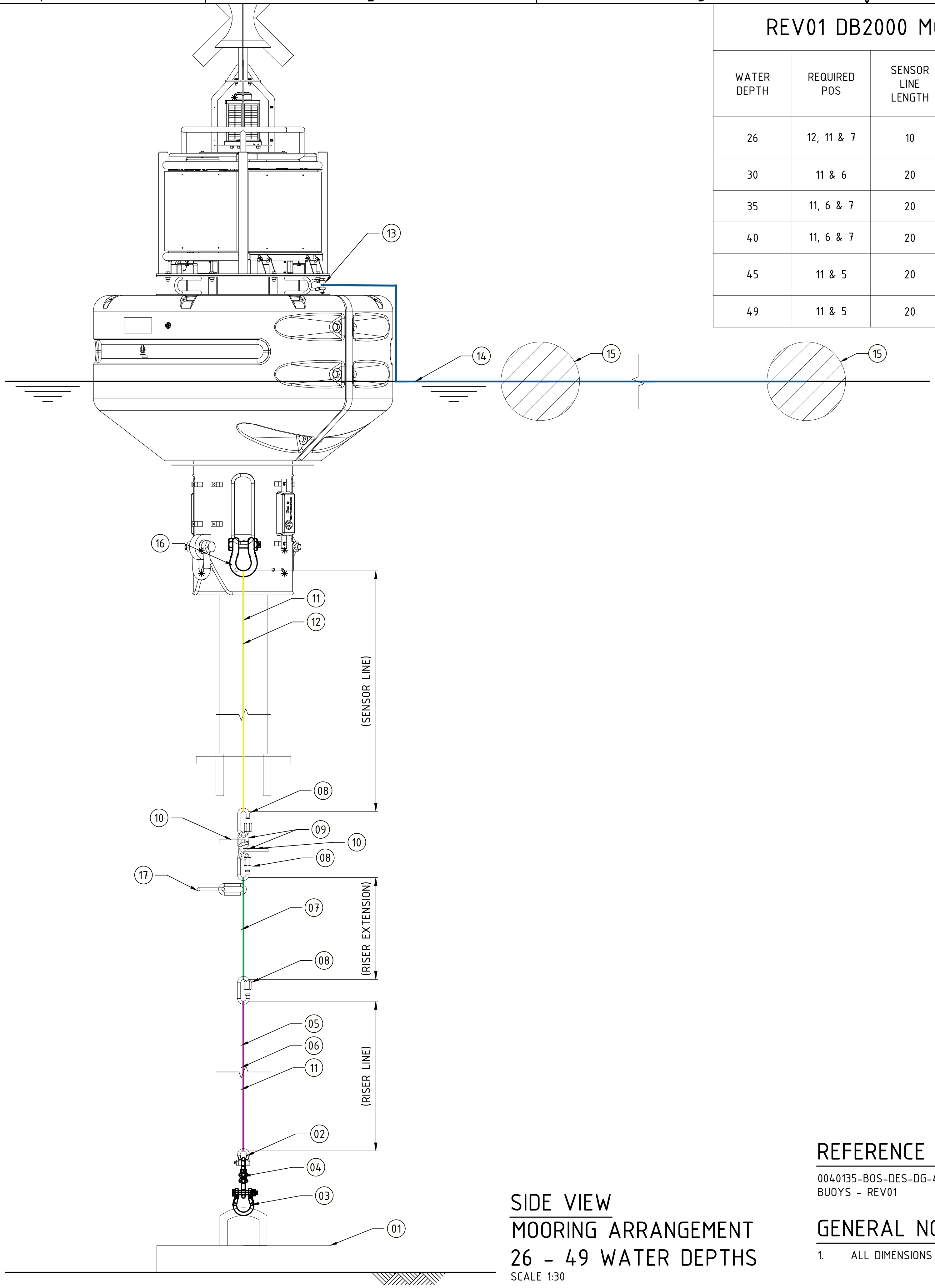
www.mobilis-sa.com E-mail: mobilis@mobilis-sa.com
Images specifications et dimensions non-contractuelles / Images and specifications for information only



REV01 DB2000 MOORING LINE CONFIG

WATER DEPTH	REQUIRED POS	SENSOR LINE LENGTH	RISER LINE LENGTH	RISER EXTENSION LENGHT	TOTAL LENGTH
26	12, 11 & 7	10	20	10	40
30	11 & 6	20	40	-	60
35	11, 6 & 7	20	40	10	70
40	11, 6 & 7	20	40	10	70
45	11 & 5	20	60	-	80
49	11 & 5	20	60	-	80

PART LIST

POS	REQ.	ITEM	SPECIFICATION	REMARKS
1	1	STEEL SINKER	WEIGHT 1.8-2TONNE	
2	1	SHACKLES GP4163	SWL: 4.75 t	
3	1	SHACKLE GP4263	SWL: 4.75 t	
4	1	EYE-EYE SWIVEL G7718	SWL: 4.5 t	
5	1	DYNEEMA RISER LINE	BOTH END SOFT EYES EWL = 60M, MBL = 18 t	
6	1	DYNEEMA RISER LINE	BOTH END SOFT EYES EWL = 40M, MBL = 18 t	
7	1	DYNEEMA RISER EXTENSION	BOTH END SOFT EYES EWL = 10M, MBL = 18 t	
8	3	QUICK LINK (DQ22SSP) 14mm GALVANIZED	MBL = 10 t	
9	2	VIKING SPLIT LINK	WLL = 5 t	
10	2	STAINLESS STEEL CARABINER HOOK 12x140mm		
11	1	DYNEEMA SENSOR LINE	BOTH END SOFT EYES EWL = 20M, MBL = 18 t	
12	1	DYNEEMA SENSOR LINE	BOTH END SOFT EYES EWL = 10M, MBL = 18 t	
13	1	SHACKLES GP4163	SWL: 3.25 t	
14	1	DYNEEMA SURFACE LINE	BOTH END SOFT EYES EWL=4M, MBL=18t	
15	2	PELLET BUOY INCL CARABINER	POLYFORM A0	
16	1	SHACKLE GP4163	WLL = 17 T	
17	1	CLIP WEIGHT (CA. 4KG)		

SIDE VIEW
MOORING ARRANGEMENT
26 - 49 WATER DEPTHS
SCALE 1:30

REFERENCE DRAWINGS:

0040135-BOS-DES-DG-4290-01 BINDER - STEP-BY-STEP BUOY DEPLOYMENT AND RETRIEVAL - PAM BUOYS - REV01

GENERAL NOTES:

1. ALL DIMENSIONS ARE IN mm U.N.O

Rev.	DD/MM/YYYY	FORMAL REVISION/CHANGE SUMMARY	CKD. ORG.	CKD. DISP.	CKD. INT.	APP. ENG.	APP. OPS.
0.0	22/03/2024	ISSUED FOR CONSTRUCTION	MLPZ	NPHO	JANT	JASP	YDMU
A.1	22/03/2024	ISSUED FOR INTERNAL REVIEW	PJOV	NPHO	JANT	JASP	YDMU

RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: MOORING AND RIGGING ARRANGEMENT
PAM BUOY
REV01

CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

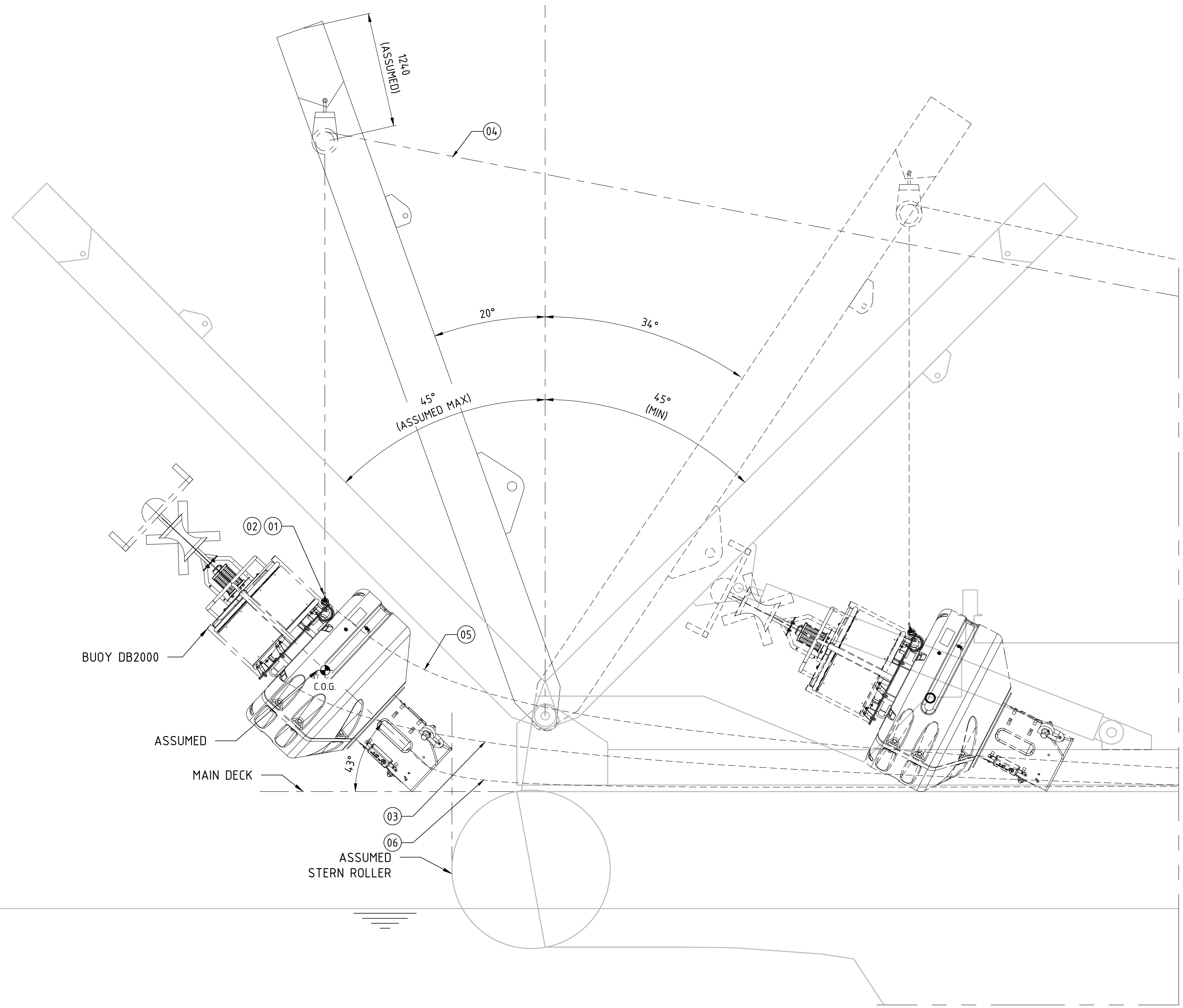
Ørsted

BOSKALIS OFFSHORE HEAVY LIFTING
P.O.BOX 43, 3350 AA PAPENDRECHT - E-MAIL: INFO@BOSKALIS.COM

FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
A3		-	-
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4290-01	0.0

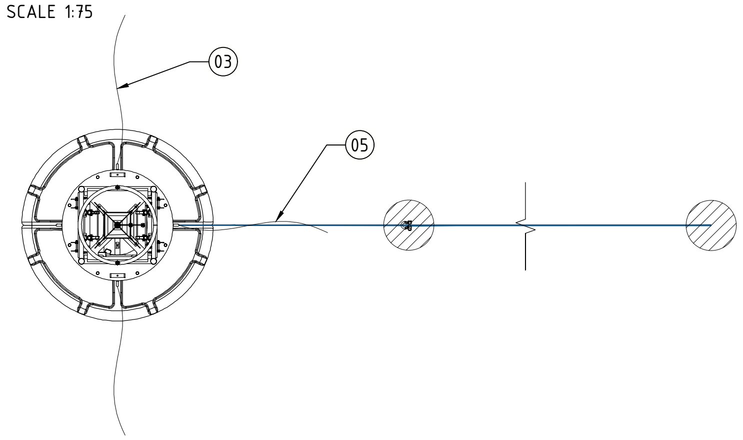
PART LIST

PART	REQ.	ITEM	REMARKS
1	1	SHACKLE 3.25t	ATTACHED TO FOUNDRY HOOK
2	1	FOUNDRY HOOK	
3	2	TAG LINES	
4	1	WINCH LINE WITH SOFT EYE ON END	
5	1	TAGLINE ATTACHED TO FOUNDRY HOOK	
6	1	TAGLINE THROUGH MOONPOOL	

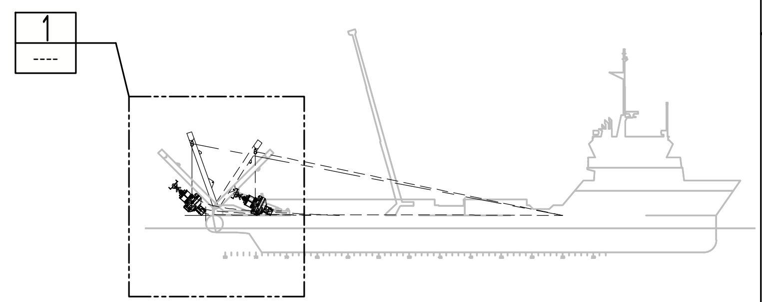


DETAIL 1
DEPLOYMENT ARRANGEMENT
26 - 49 WATER DEPTHS
SCALE 1:50

TOP VIEW
SCALE 1:75



KEYPLAN
SCALE 1:500



NOTES:
1. FOR GENERAL NOTES & REFERENCE SEE SHEET 1

Rev.	DD/MM/YYYY	FORMAL REVISION/CHANGE SUMMARY	CKD. ORG.	CKD. DISP.	CKD. INT.	APP. ENG.	APP. OPS.
0.0	22/03/2024	ISSUED FOR CONSTRUCTION	MLPZ	NPHO	JANT	JASP	YDMU
A.1	22/03/2024	ISSUED FOR INTERNAL REVIEW	PJOV	NPHO	JANT	JASP	YDMU

RDS-PP CODE	TBA
DEVELOPMENT	INSTALLATION
PROJECT	REVOLUTION WIND 01 (REV01)
SUBJECT	MOORING AND RIGGING ARRANGEMENT PAM BUOY REV01
CLIENT	ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
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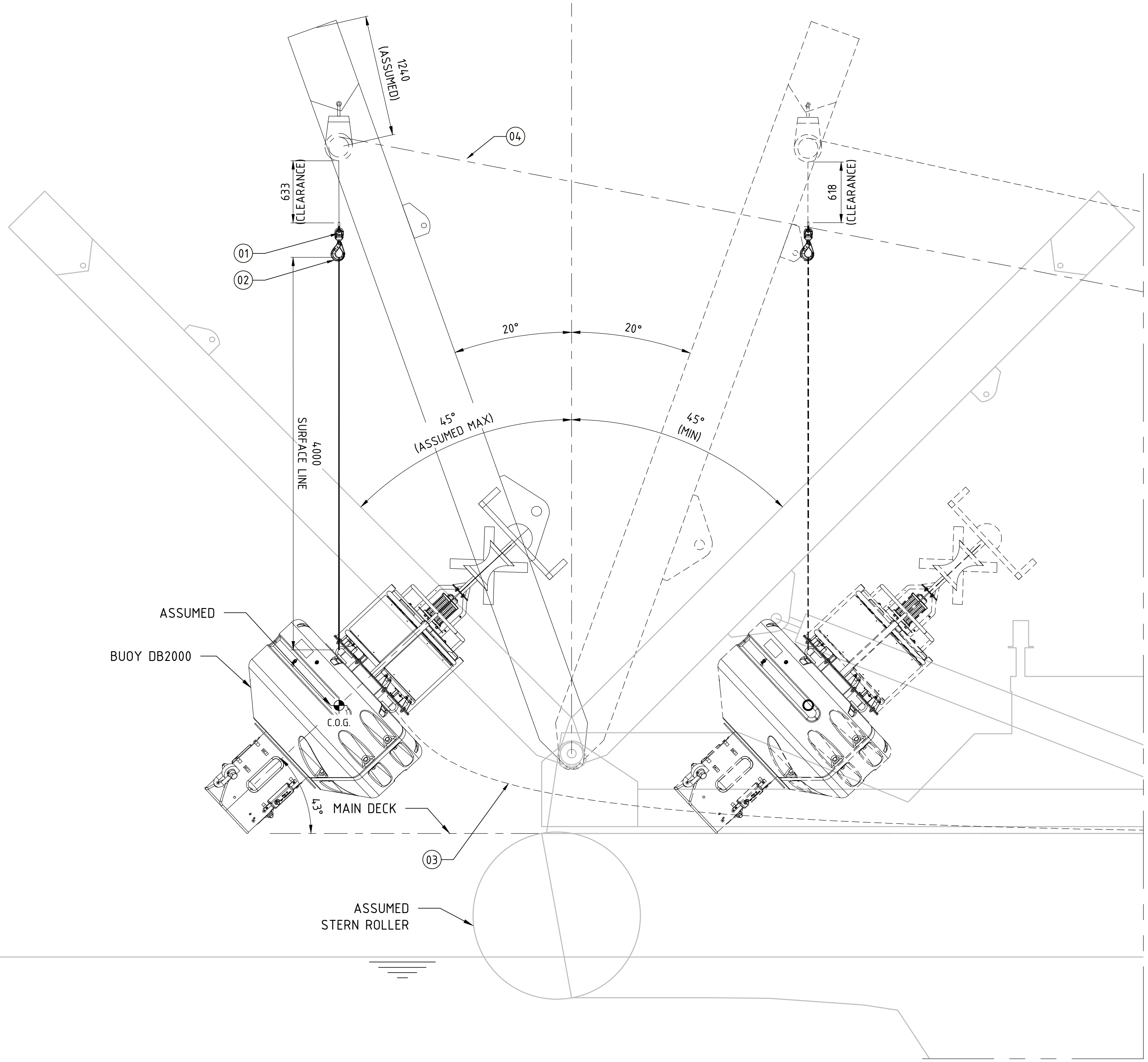
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4290-02	0.0

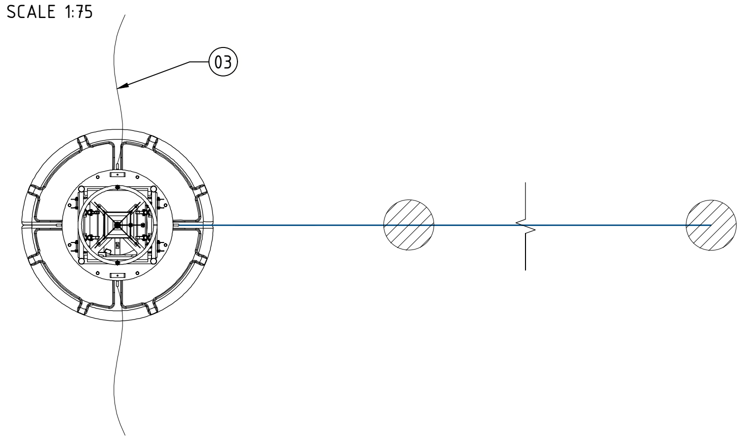
PART LIST

PART	REQ.	ITEM	REMARKS
1	1	SHACKLE 3.25t	
2	1	SAFETY HOOK YE.8.086.08	
3	2	TAG LINES	
4	1	WINCH LINE WITH SOFT EYE ON END	

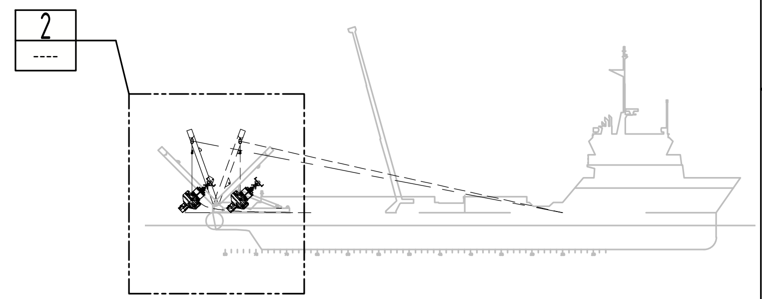


DETAIL 2
RECOVER ARRANGEMENT
26 - 49 WATER DEPTHS
SCALE 1:50

TOP VIEW
SCALE 1:75



KEYPLAN
SCALE 1:500



NOTES:
1. FOR GENERAL NOTES & REFERENCE SEE SHEET 1

Rev.	DD/MM/YYYY	FORMAL REVISION/CHANGE SUMMARY	CKD. ORG.	CKD. DISP.	CKD. INT.	APP. ENG.	APP. OPS.
0.0	22/03/2024	ISSUED FOR CONSTRUCTION	MLPZ	NPHO	JANT	JASP	YDMU
A.1	22/03/2024	ISSUED FOR INTERNAL REVIEW	PJOV	NPHO	JANT	JASP	YDMU

RDS-PP CODE	TBA
DEVELOPMENT	INSTALLATION
PROJECT	REVOLUTION WIND 01 (REV01)
SUBJECT	MOORING AND RIGGING ARRANGEMENT PAM BUOY REV01
CLIENT	ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
A3		-	-
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4290-03	0.0

ANNEX B – JOSEPHINE MILLER

190 FOOT CLASS - DP1 - MULTI PURPOSE VESSEL
M/V JOSEPHINE K MILLER

DIMENSIONS

LENGTH	190 ft	57.91 m
BEAM	36 ft	10.97 m
DEPTH	12 ft	3.66 m
LIGHT DRAFT	6.5 ft	1.98 m
LOADED DRAFT	10 ft	3.04 m

CAPACITIES

FUEL CAPACITY	63,236 USG	239.37 m^3
FRESH POTABLE WATER	25,824 USG	97.75 m^3
*ADDITIONAL STORAGE	117,600 USG	445.16 m^3
POTABLE WATER	30,000 USG	113.56 m^3
LUBE OIL	660 USG	2.49 m^3
DIRTY OIL	1165 USG	4.41 m^3
HYDRAULIC OIL	616 USG	2.33 m^3

CARGO DECK

TONNAGE	485US Ton	440 LT
STRENGTH	617 lb/sf	3012 kg/m^2
LENGTH	100 F	30.48 M
WIDTH	32 F	9.14 M
CLEAR SPACE	3200 SF	297.28 sq m

ELECTRONICS AND CONTROLS

GYRO COMPASS	(2) Sperry
DYNAMIC POSITIONING	(1) Konsgberg
DP REFERENCES	C Joy, C-POS
GPS	(2) Furuno GP-32
DGPS	(2) Trimble
WIND TRACKER	(1) Kongsberg OMC 139
MAIN ENGINE CONTROLS	(1) ZF
RADAR	(2) Furuno FR-8122
SSB RADIO	(1) Furuno FS-1503
VHF	(3) Icom M-504
LOAD HAILER	(2) Standard Horizon VLH-3000
FATHOMETER	(1) Furuno FCV-620
INTERFACED CHARTPLOTTER	(1) Furuno S-52
AIS	(1) Furuno FA- 150

SPECIAL EQUIPMENT

ANCHOR CHAIN	Size 1" GR 2 1170 ft
ANCHOR	2 - 2000 LB
LIFE RAFTS	2
WALK-IN COOLER	YES
WALK-IN FREEZER	YES
A/C & HEATER	7 Mini Splits
FIRE MONITOR	1

OPTIONAL EQUIPMENT

15 TON A-FRAME	SEE PAGE 84
14 TON CRANE	SEE PAGE 78
9 TON PEDDESTAL CRANE	SEE PAGE 79
PAM FOUNDATION GRID	YES

ACCOMODATIONS

CABINS/BERTHS	5
2 PERSON CABINS	2
4 PERSON BERTHS	1
6 PERSON BERTHS	2
CERTIFIED TO CARRY	20

DISCHARGE RATES

FUEL PUMP RATE	300GPM	68.2 m3/hr
FRESH POTABLE WATER	400GPM	90.8 m^3/hr

PERFORMANCE

MAXIMUM SPEED	12 KNOTS
CRUISING SPEED	10 KNOTS
MAXIMUM HP	2240 BHP@ 1600 RPM

01 DECK

LENGTH	10 ft	3 m
WIDTH	30 ft	9.14 m
DISTANCE ABOVE DECK	10.5 ft	3.20 m

MACHINERY

MAIN ENGINES	(2) CAT3508B
TOTAL HORSEPOWER	2240HP
PROPULSION	DIESEL
GENERATORS	(2) John Deere 6081 AFM 75/170KW
BOW THRUSTER	(1) John Deere 6125 AFM 75/450HP
RUDDER	SPADE - INDEPENDENT RUDDERS

MAIN WINCH

LINE PULL	30 TONS	
DRUM CAP. 1in - 25.4 mm WIRE	4714 ft	1436 m
DRUM CAP. 1-1/2 in - 38.1 mm WIRE	2066 ft	629 m
DRUM CAP. 2 in - 50.8 mm WIRE	1040 ft	317 m

TUGGER

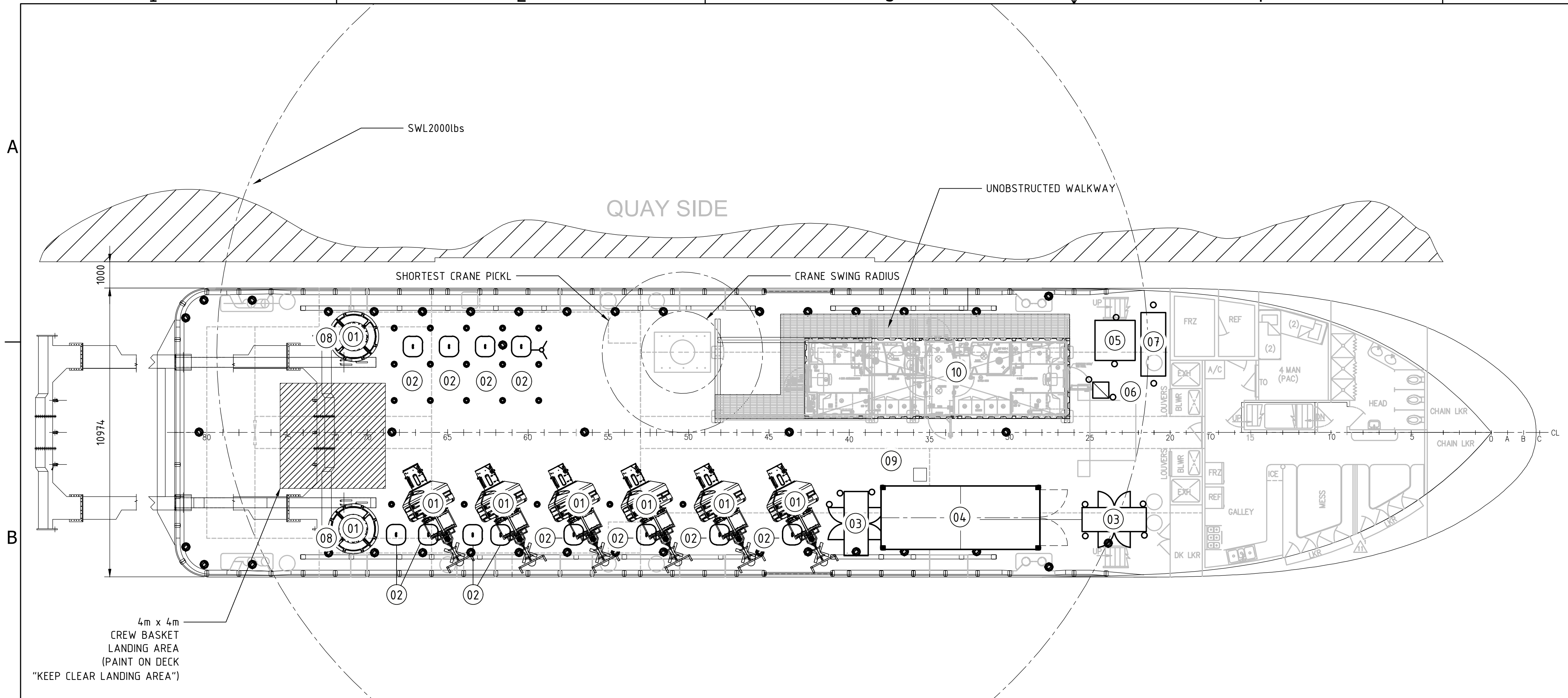
LINE PULL x 2	6 TON	
DRUM CAP 1/2 in - 12.7 mm WIRE	814 ft	198 m
DRUM CAP. 5/8 in - 15.9 mm WIRE	472 ft	144 m
DRUM CAP. 3/4 in - 19 mm WIRE	322 ft	98 m

STERN ROLLER

LENGTH	16 ft	4.87 m
DIAMETER	36in	.914 m

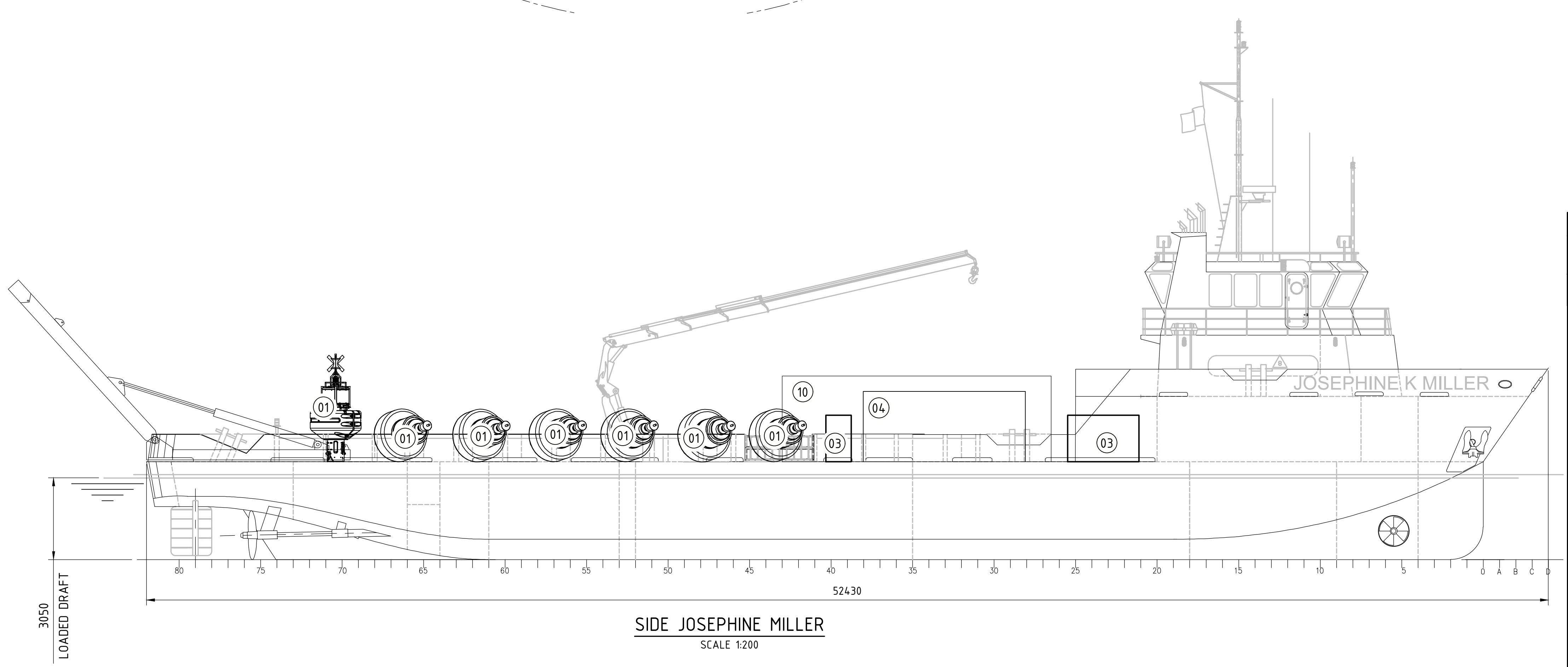
GENERAL

OWNER	MILLER'S TUG & BARGE, INC.
BUILDER	MARINER SHIPBUILDING
YEAR BUILT	2009
OFFICIAL NUMBER	1221799
FLAG	USA
USCG	SUB I & L
ABS	LOADLINE
GROSS TONNAGE	91 Ton
NET TONNAGE	62 Ton



PLAN JOSEPHINE MILLER

SCALE 1:200



SIDE JOSEPHINE MILLER

SCALE 1:200

STOWAGE PLAN

POS	ITEM	QTY	LENGTH [m]	WIDTH [m]	HEIGHT [m]	MASS [t]	SUM MASS [t]
1	PAM BUOY TYPE DB2000	8	2,2	1,4	4.02	0.9	7.2
2	CLUMP WEIGHT	12	0.77	0.73	0.73	1.8	25.2
3	GENSET (FOR ACCOM. CONTAINER)	2	2,67	0.95	1.735	1.9	3.8
4	GUARDLINE STORAGE CONTAINER	1	6,1	2,4	2,62	5	5
5	PRESSURE SET - (FOR ACCOM. CONTAINER)	1	6,1	2,4	1.2	N/A	N/A
6	LIFT PUMP (FOR ACCOM. CONTAINER)	1	6,1	2,4	2,62	N/A	N/A
7	MSD = MARINE SANITATION DEVICE	1	6,1	2,4	2,62	N/A	N/A
8	PAM BUOY - STORAGE FRAME	2	1	1	1.2	0.15	0.3
9	SWITCHBOARD GENSETS (FOR ACCOM. CONT.)	1	0.5	0.5	1.8	0.7	0.7
10	ACCOMMODATION CONTAINER	1	10.06	3.48	3.2	19.5	0.3

GENERAL NOTES

1. ALL MEASUREMENTS ARE IN mm UNLESS NOTED OTHERWISE

REFERENCE DRAWINGS

A.1	28/03/2024	ISSUED FOR INTERNAL REVIEW	JFOC	NPHO	DIHO	YDMU	JASP
REV.	DD/MM/YYYY	FORMAL REVISION/CHANGE SUMMARY	CKD. ORG.	CKD. DISP.	CKD. INT.	APP. OPS.	APP. ENG.

RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: DECK LAYOUT PSO VESSELS
REV01
-

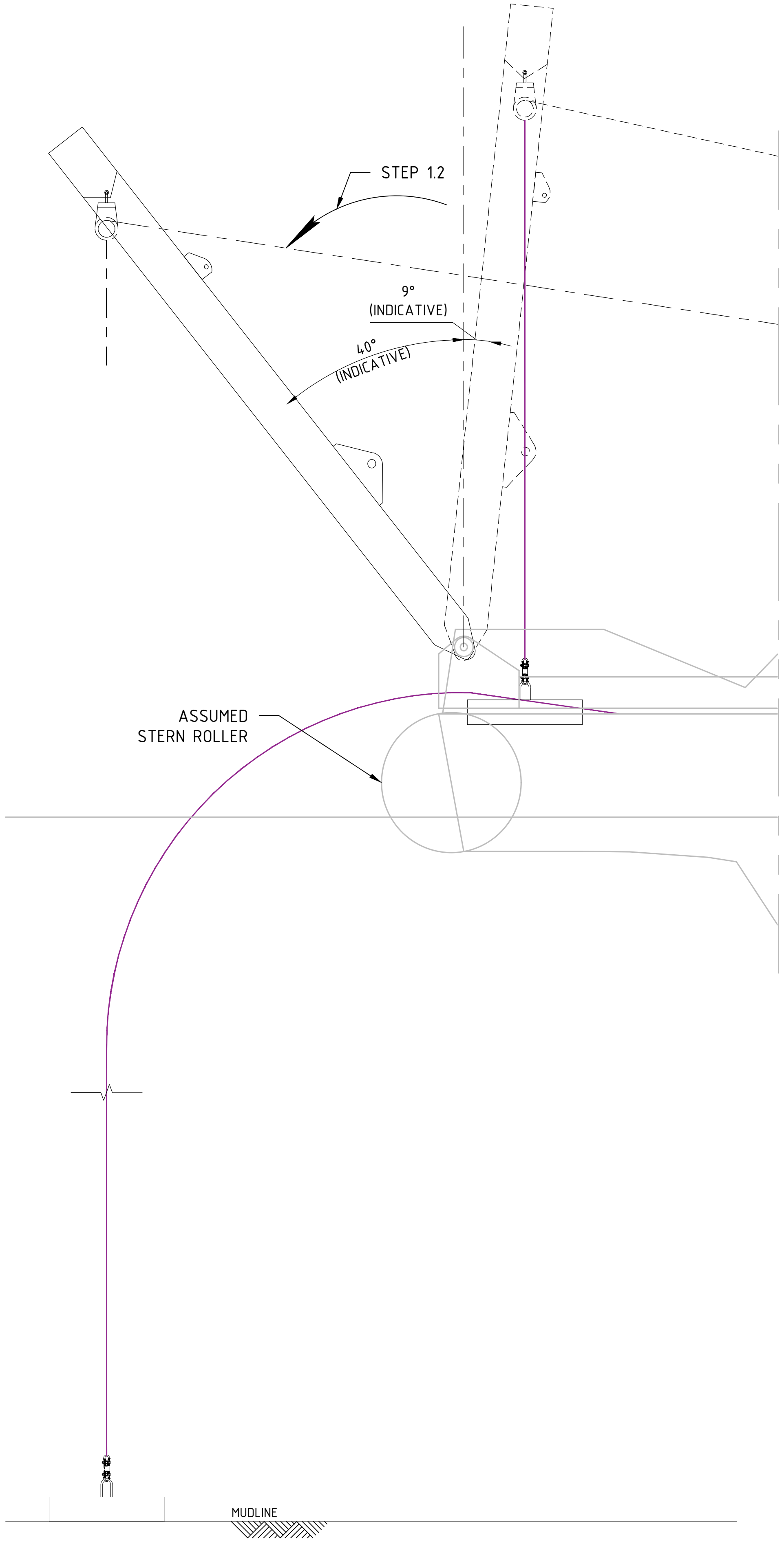
CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

BOSKALIS OFFSHORE HEAVY LIFTING
P.O.BOX 43, 3350 AA PAPENDRECHT - E-MAIL: ROYAL@BOSKALIS.COM

FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
A3		-	-

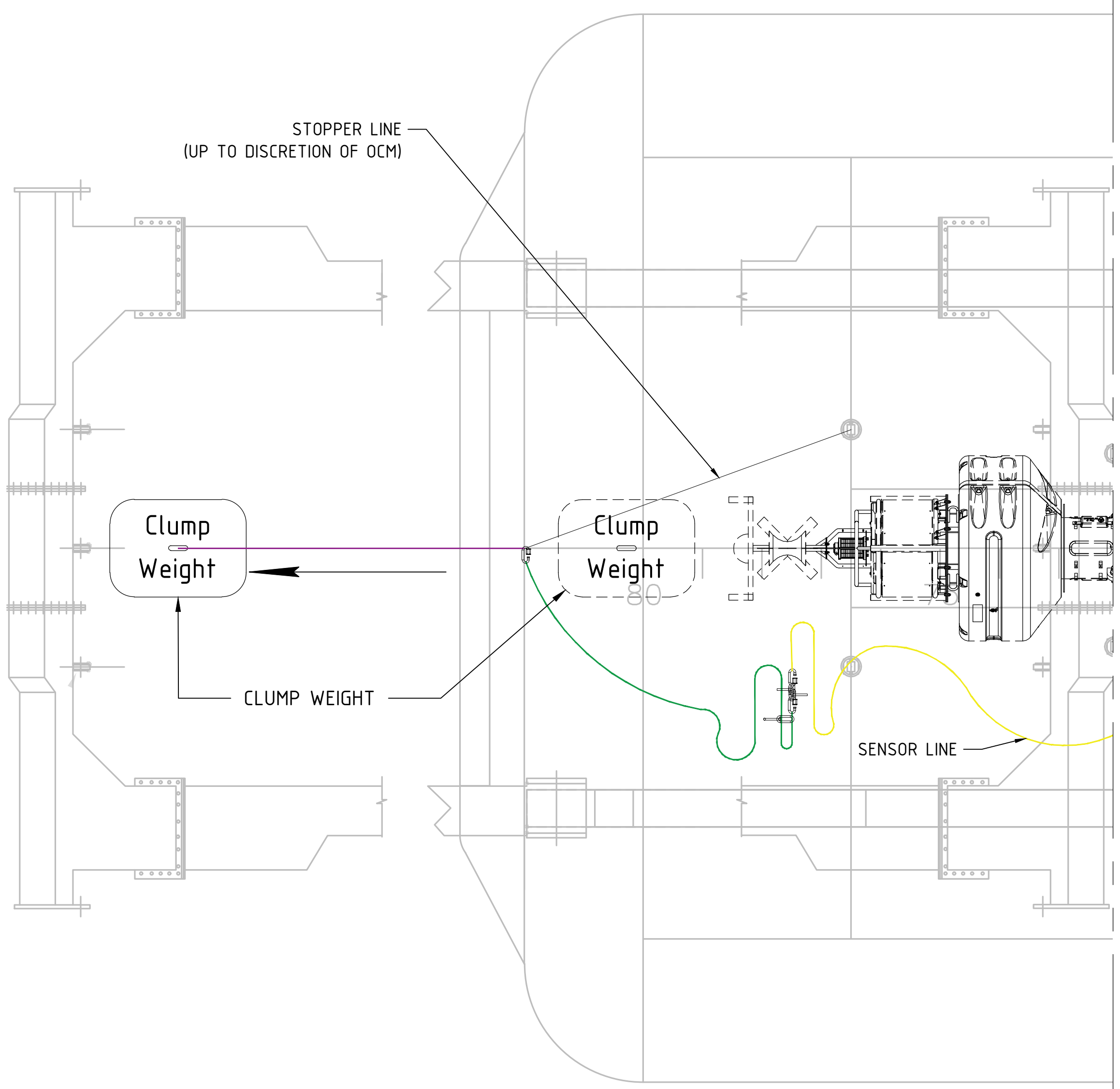
SCALE	BOSKALIS DRAWING NO.	SHEET	REV.
1 : 200	0040135-BOS-DES-DG-0662	01 of 03	A.1

ANNEX C – DEPLOYMENT AND RETRIEVAL STORY BOARD



DETAIL 1

SCALE 1:40



TOP VIEW

SCALE 1:40

STEPS DEPLOYMENT

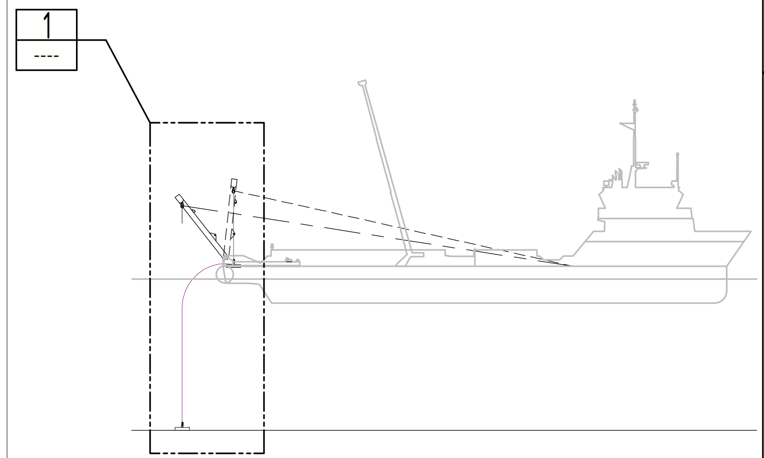
START POINTS
- CLUMP WEIGHT POSITIONED BELOW A-FRAME
- BUOY MOORING LINE LENGTH PREPARED FOR WATER DEPTH AS PER (0040135-BOS-DES-DG-1121-00 AND 0040135-BOS-DES-DG-4290-00)
- RISER LINE CONNECTED TO CLUMP WEIGHT
- BUOY PLACED BELOW A-FRAME AND READY FOR DEPLOYMENT
- RISER LINE SPOOLED ONTO WINCH
- VESSEL IN POSITION; GREEN LIGHT TO LAUNCH CLUMP WEIGHT
- SLIP ROPE ATTACHED TO CLUMP WEIGHT

STEP 1
1.1 A-FRAME TO PICK UP CLUMP WEIGHT
1.2 ROTATE A-FRAME OUTBOARD
1.3 RELEASE SLIP ROPE AND DEPLOY CLUMP WEIGHT
1.4 REQUEST BRIDGE TO NOTE DOWN DEPLOYMENT COORDINATES ONCE RISER LINE IS SLACK

STEP 2
2.1 CONTINUE SPOOLING OUT THE RISER LINE UNTIL END IS REACHED - PULL IN WINCH WIRE TO RISER LINE CONNECTION TO DECK
2.2 ROTATE A-FRAME BACK INWARDS.
2.3 MOVE VESSEL AHEAD IF REQUIRED
2.4 ATTACH RISER LINE TO STOPPER LINE ON VESSEL
2.5 CONNECT SENSOR LINE TO RISER LINE. ATTACH CLIP WEIGHT TO SPLICED EYE AT TOP OF RISER LINE

KEYPLAN

SCALE 1:750



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A.1	22/03/2024	ISSUED FOR INTERNAL REVIEW	PJOV	NPHO	JANT	JASP	YDMU

RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL PAM BUOYS REV01

CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

Ørsted

BOSKALIS OFFSHORE HEAVY LIFTING
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FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
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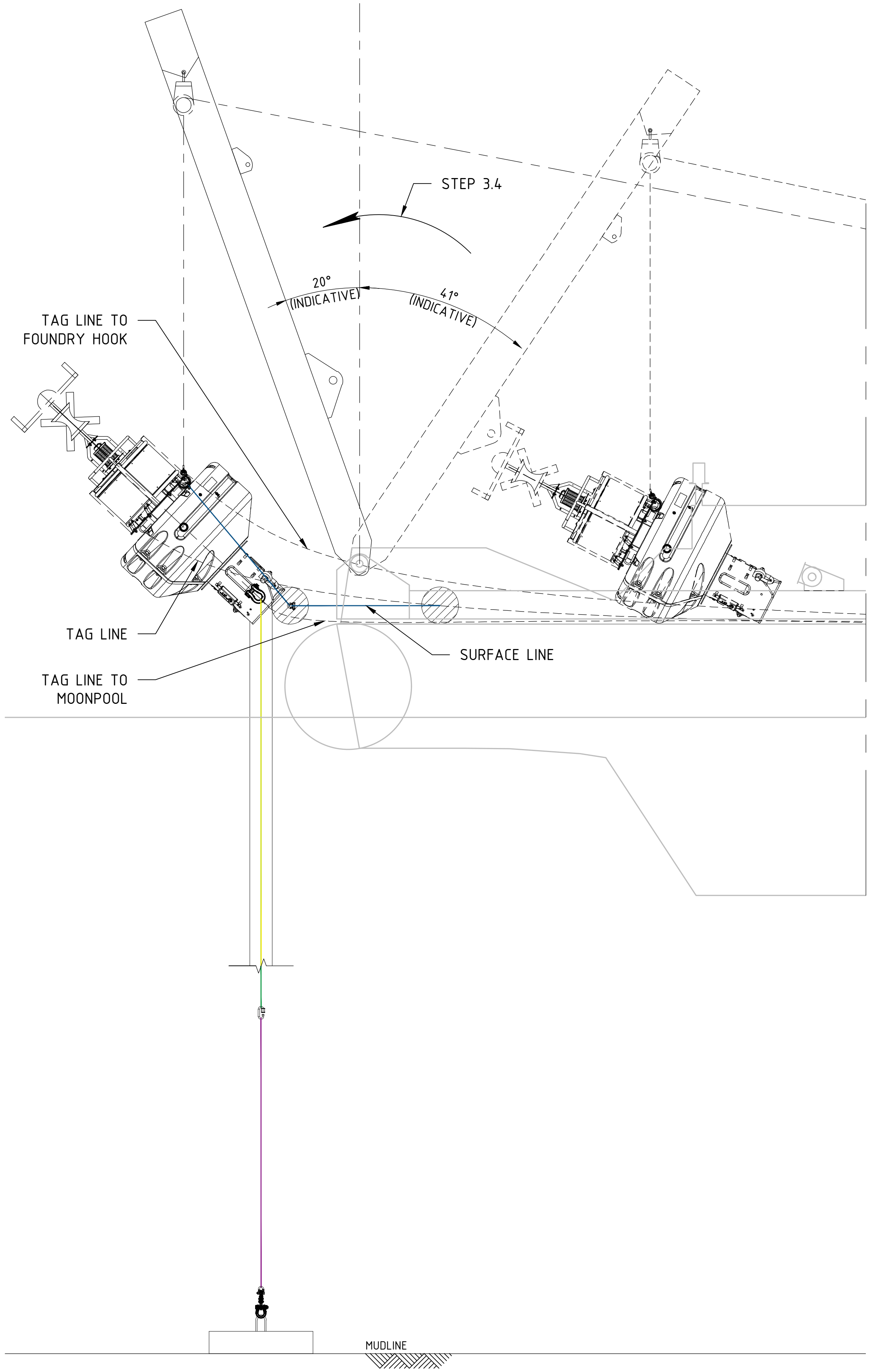
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4298-01	0.0

STEPS DEPLOYMENT

STEP 3
3.1 VERIFY BUOY IN POSITION BELOW A-FRAME
3.2 PAY OUT SENSOR LINE CAREFULLY - MANAGE SLACK ON SENSOR LINE
3.3 PAY IN WINCH WIRE AND LIFT BUOY OFF DECK. CONTROL WITH TWO TAG LINES AND TAGLINE CONNECTED TO MOONPOOL VIA TUGGER
3.4 ROTATE A-FRAME OUTWARDS - LOWER BUOY INTO WATER
3.5 PAY OUT WINCH TO SLACKEN WINCH LINE - ONCE BUOY IS FLOATING PULL TAGLINE ATTACHED TO FOUNDRY HOOK TO RELEASE HOOK FROM BUOY
3.6 PULL VESSEL FORWARD SEVERAL METERS
3.7 PULL TAGLINES THROUGH EYES ON BUOY, RELEASING THEM FROM BUOY



DETAIL 1

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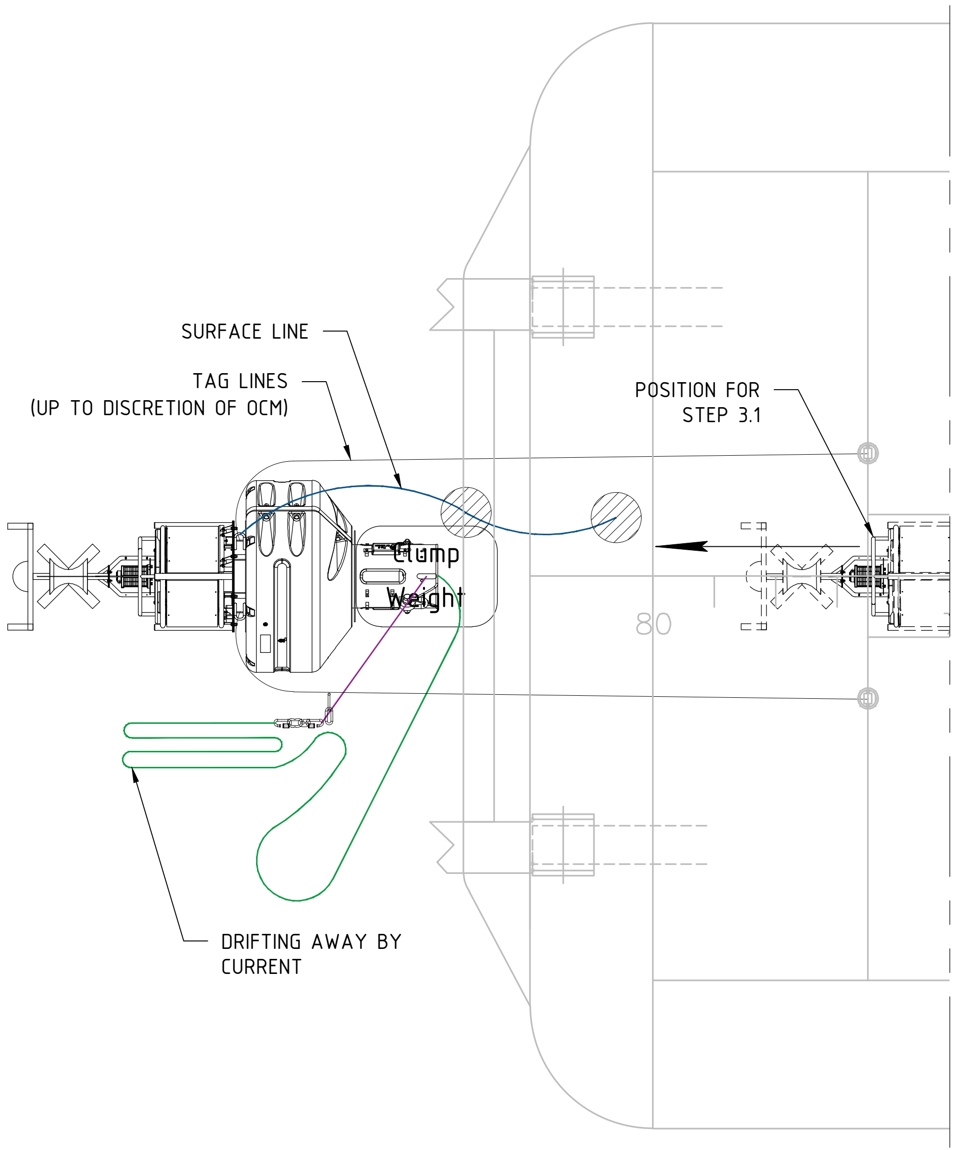
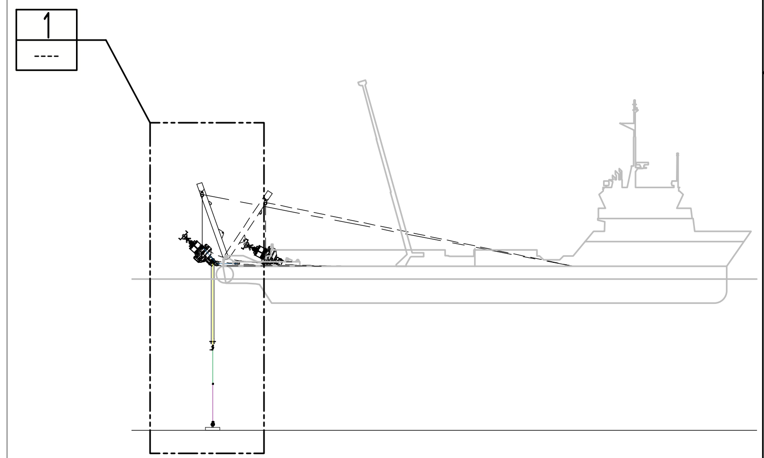


TOP VIEW

SCALE 1:40

KEYPLAN

SCALE 1:750



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Rev.	DD/MM/YYYY	FORMAL REVISION/CHANGE SUMMARY	CKD. ORG.	CKD. DISP.	CKD. INT.	APP. ENG.	APP. OPS.

RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL
PAM BUOYS
REV01

CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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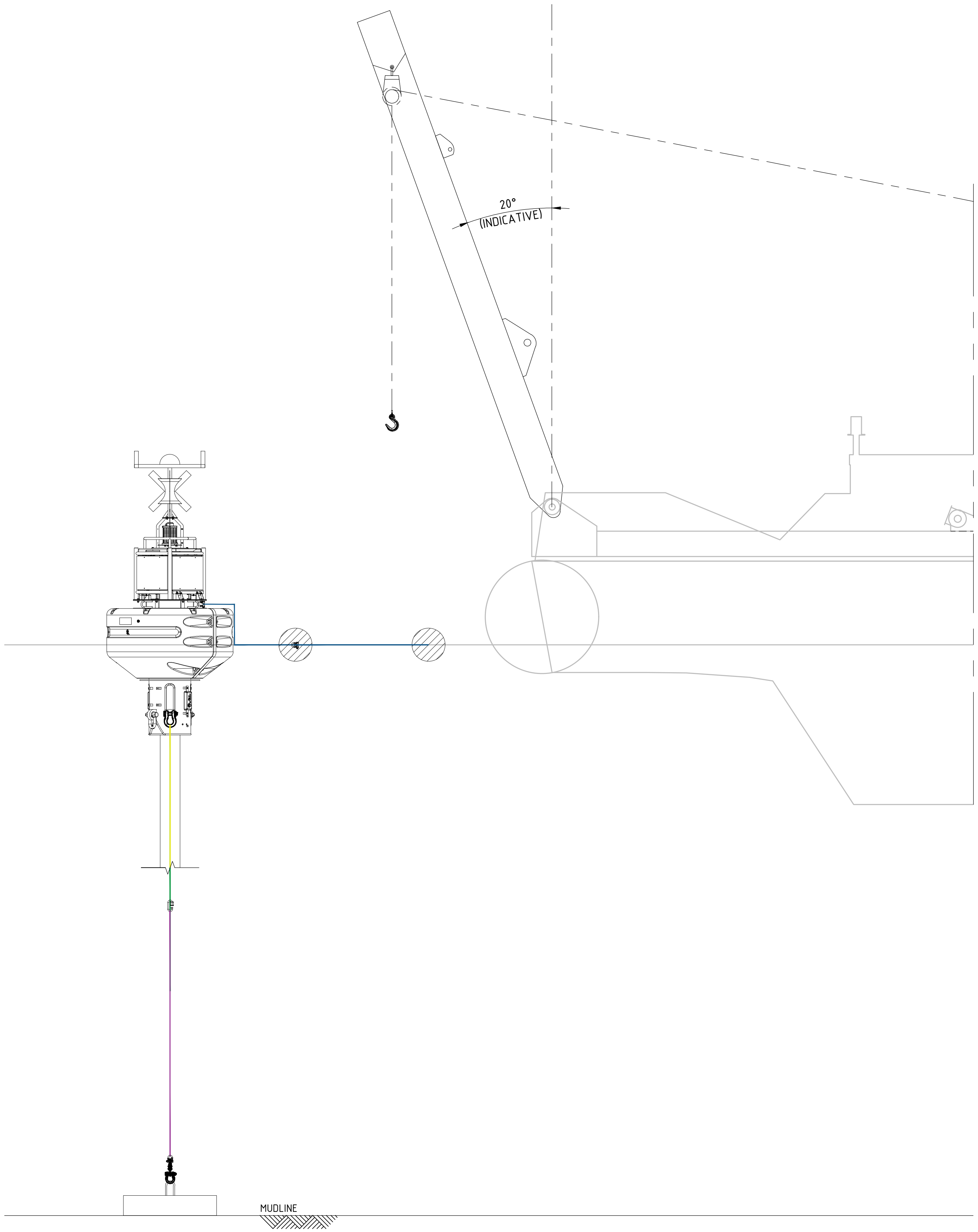


DETAIL 1

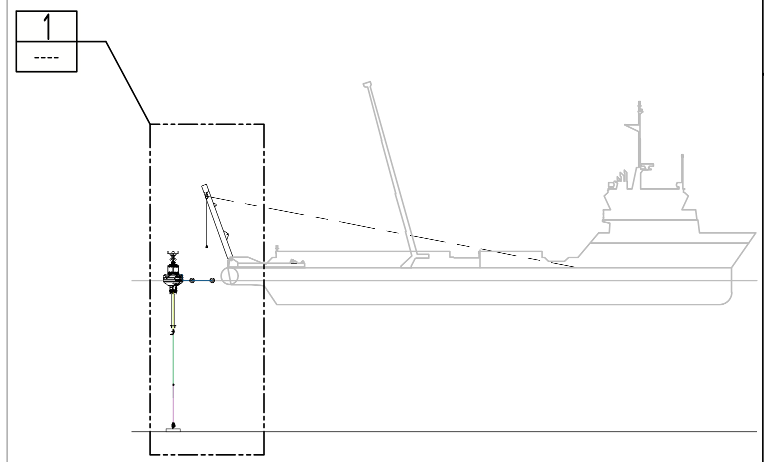
SCALE 1:40

STEPS DEPLOYMENT

STEP 4
4.1 RELEASE SLIP ROPES
4.2 DEPLOY SURFACE LINE INCLUDING PALLET BUOYS
4.3 INFORM BRIDGE BUOY IS DEPLOYED - MOVE VESSEL FORWARD

KEYPLAN

SCALE 1:750



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RDS-PP CODE	TBA
DEVELOPMENT	INSTALLATION
PROJECT	REVOLUTION WIND 01 (REV01)
SUBJECT	STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL PAM BUOYS REV01
CLIENT	ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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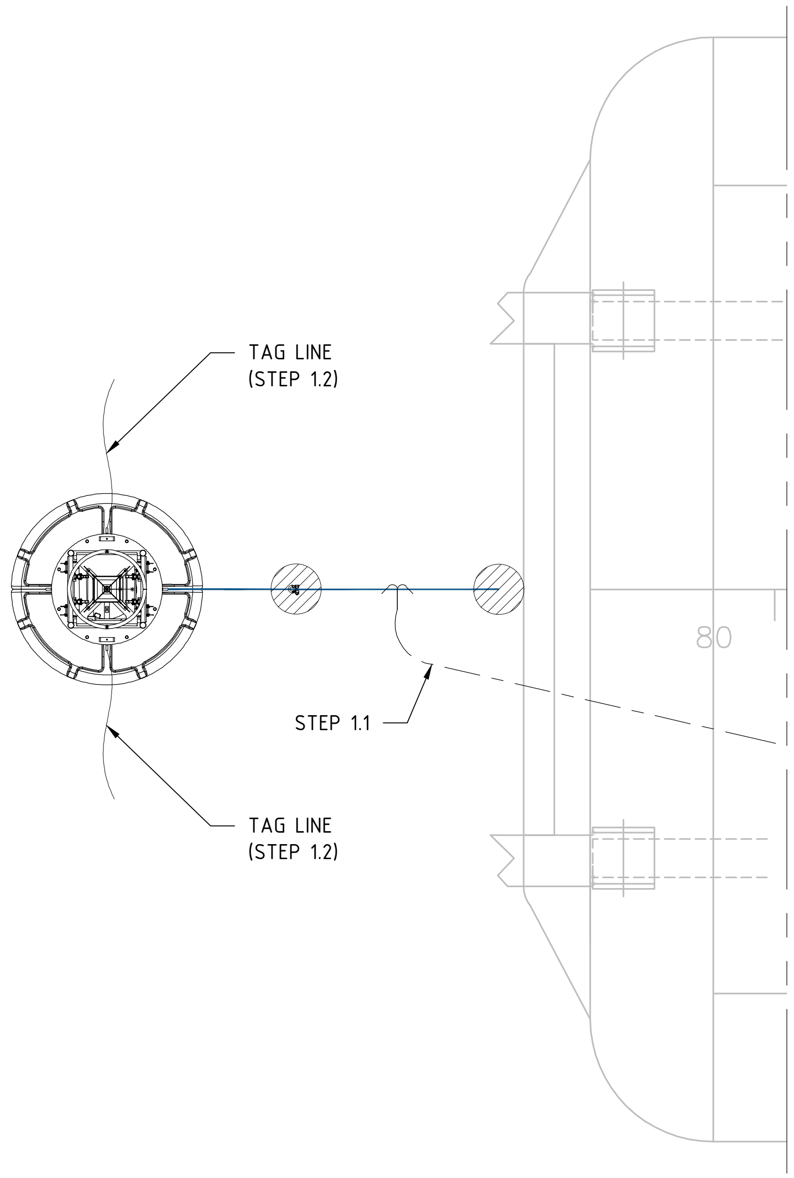
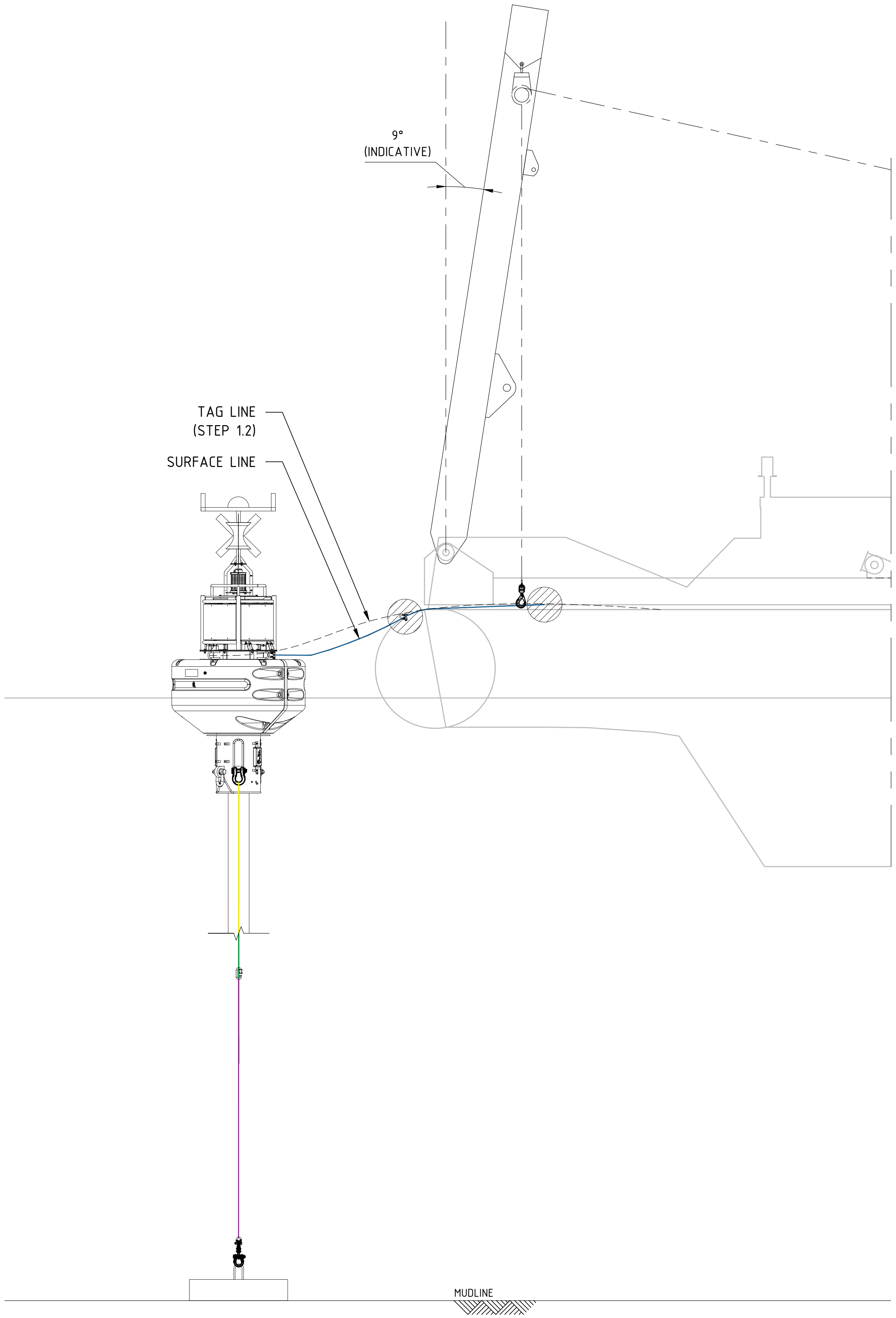
STEPS RECOVERY

START POINTS
- CONFIRM BUOY POSITION RELATIVE TO ANCHOR DEPLOYMENT LOCATION (GPS FIX)
- APPROACH BUOY WITH STERN INTO CURRENT AND VESSEL ON DP, DOWN STREAM OF BUOY

STEP 1
1.1 GRAPPLE SURFACE LINE AND CONNECT TO THE WINCH LINE
1.2 CONNECT TWO TAG LINES TO BUOY USING BOAT HOOK SYSTEM
1.3 ROTATE A-FRAME OUTWARDS TO CREATE CLEARANCE BETWEEN AFT OF VESSEL AND BUOY



TOP VIEW
SCALE 1:40



DETAIL 1
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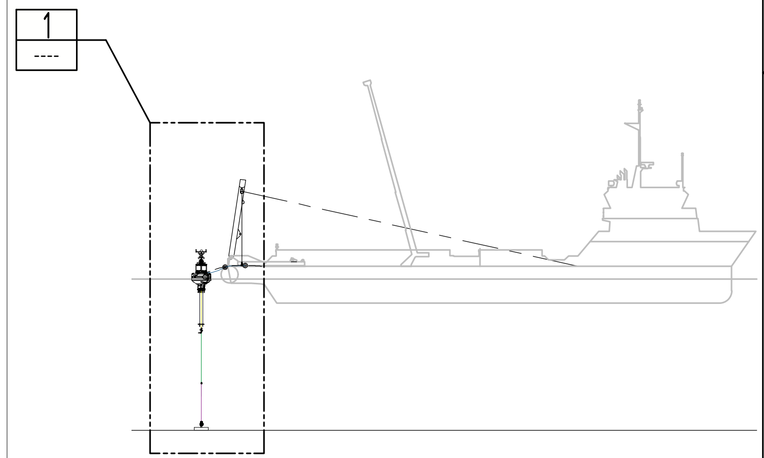
KEYPLAN
SCALE 1:750



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RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL
PAM BUOYS
REV01

CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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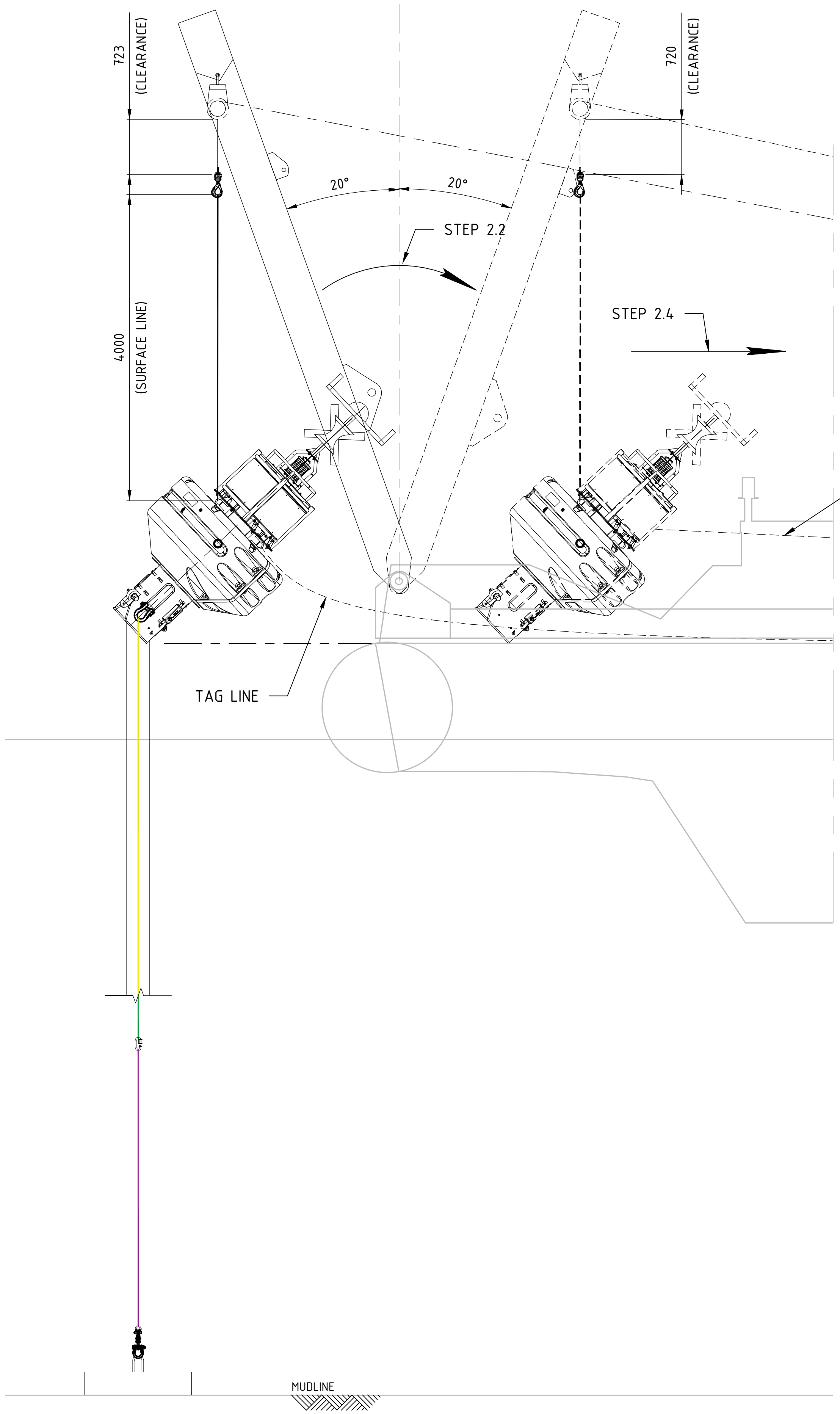
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4298-04	0.0

STEPS RECOVERY

STEP 2
2.1 HOIST IN SURFACE LINE, LIFTING BUOY OUT OF THE WATER, MOVE VESSEL AFT WARDS CREATING SOME SLACK ON THE SENSOR LINE IF REQUIRED
2.2 ROTATE AFRAME INWARDS
2.3 LOWER BUOY ONTO DECK AND CONNECT TO STOPPER LINE
2.4 IF POSSIBLE, PULL BUOY FURTHER TOWARDS BOW USING TUGGER WINCH, FREEING UP SPACE ON AFT DECK
2.5 SEAFASTEN BUOY TEMPORARILY WITH WHEEL CHOCKS



DETAIL 1

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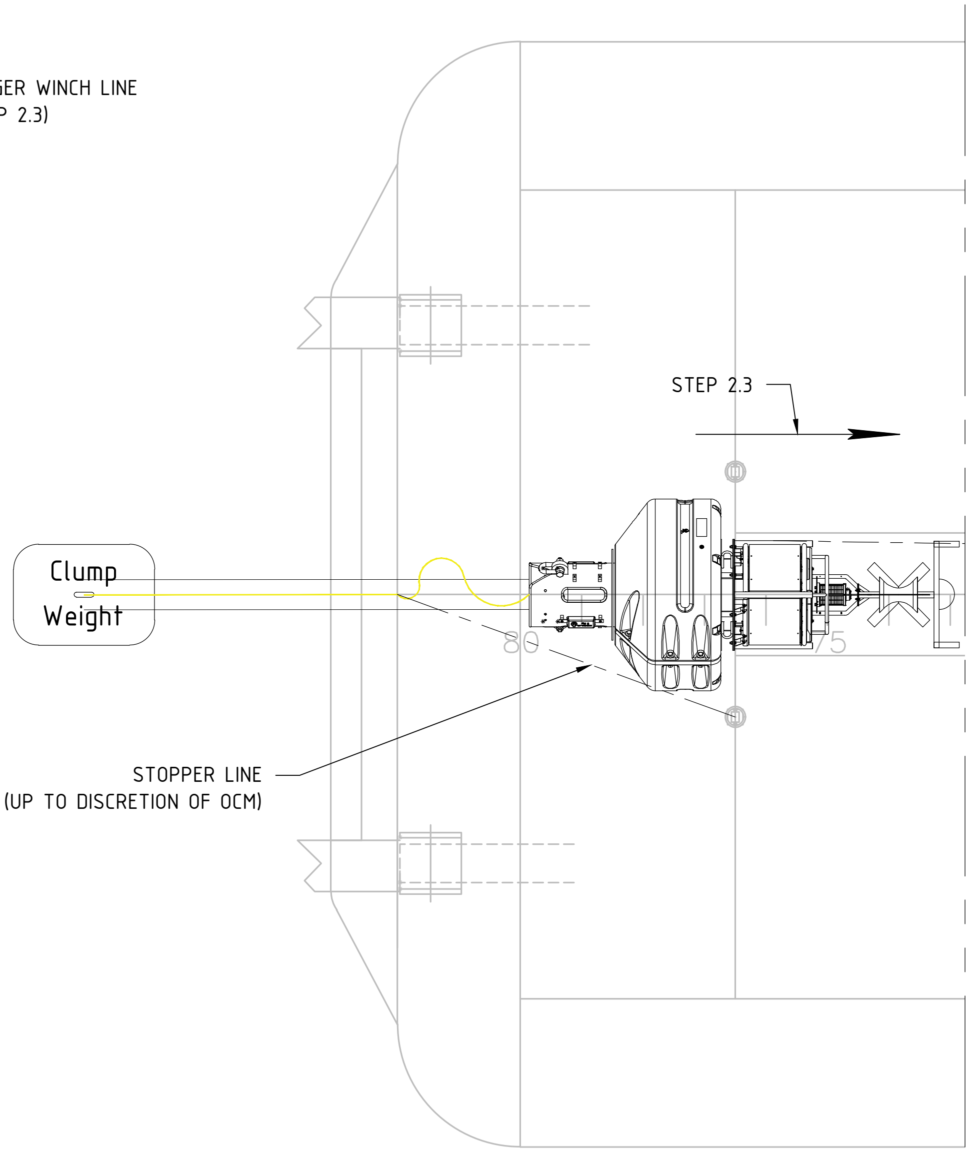
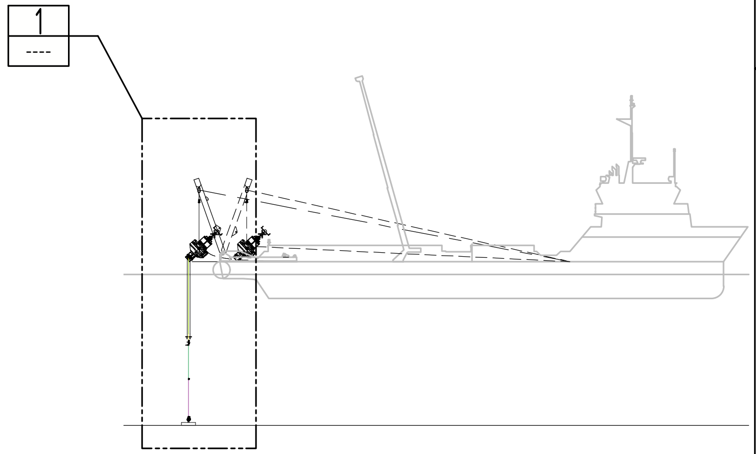


TOP VIEW

SCALE 1:40

KEYPLAN

SCALE 1:750



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SUBJECT	STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL PAM BUOYS REV01
CLIENT	ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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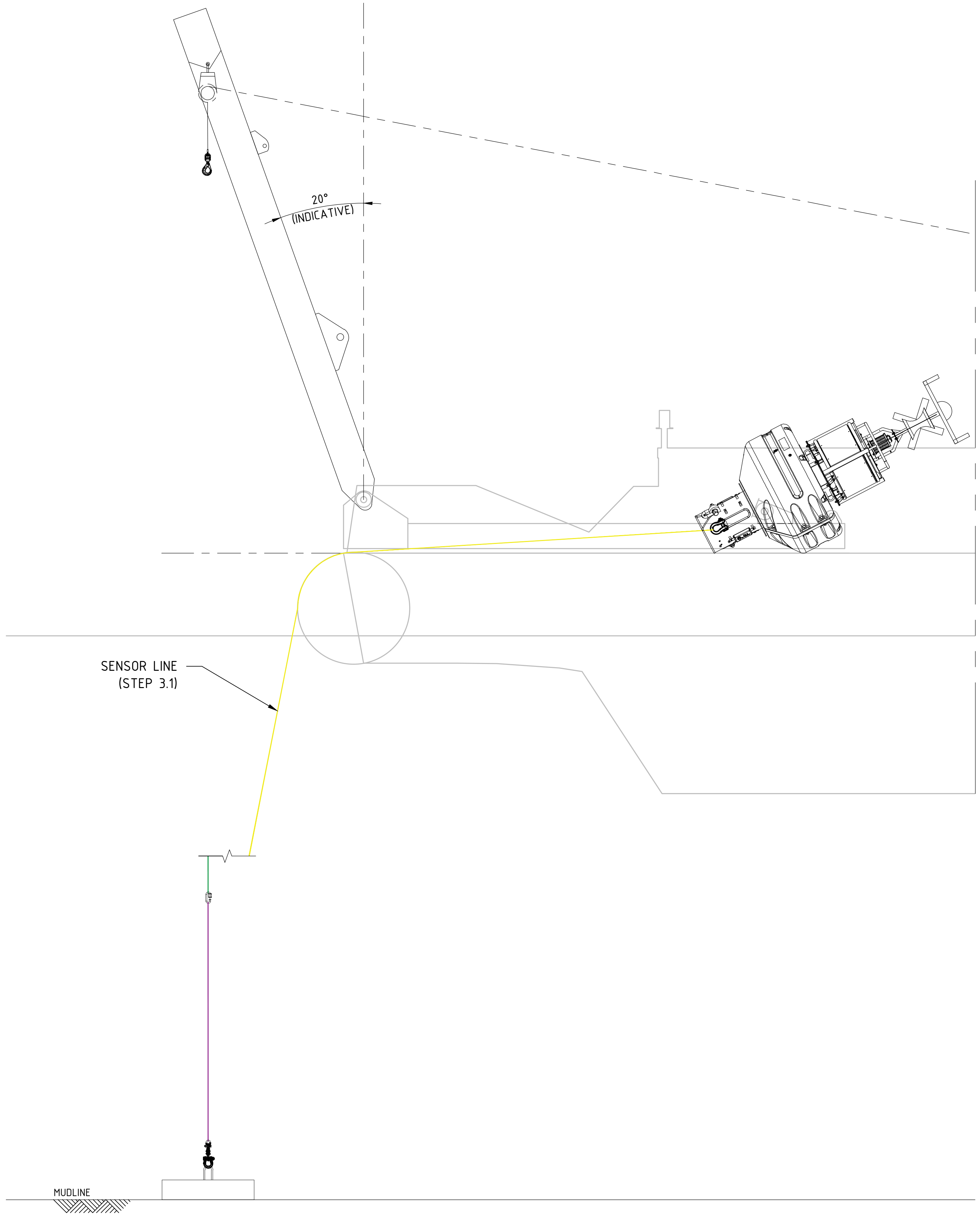
STEPS RECOVERY

STEP 3
3.1 CREATE SLACK ON SENSOR LINE BY MOVING VESSEL BACKWARDS
3.2 PAY-IN SENSOR LINE BY HAND TILL CONNECTION SENSOR LINE - RISER LINE IS ON DECK

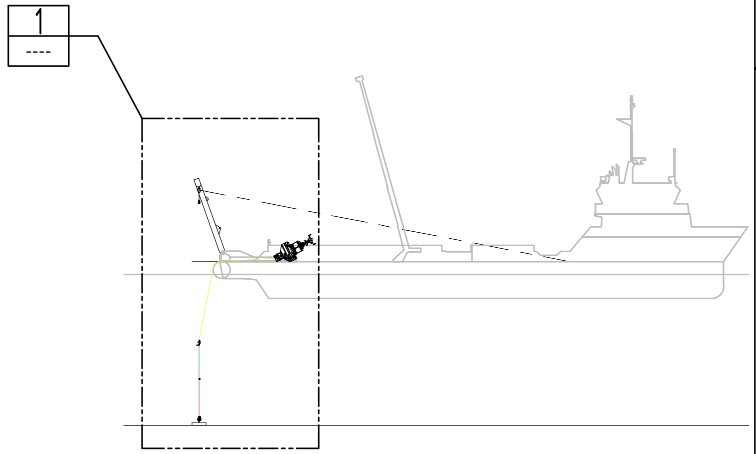


DETAIL 1

SCALE 1:40

KEYPLAN

SCALE 1:750



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RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL
PAM BUOYS
REV01

CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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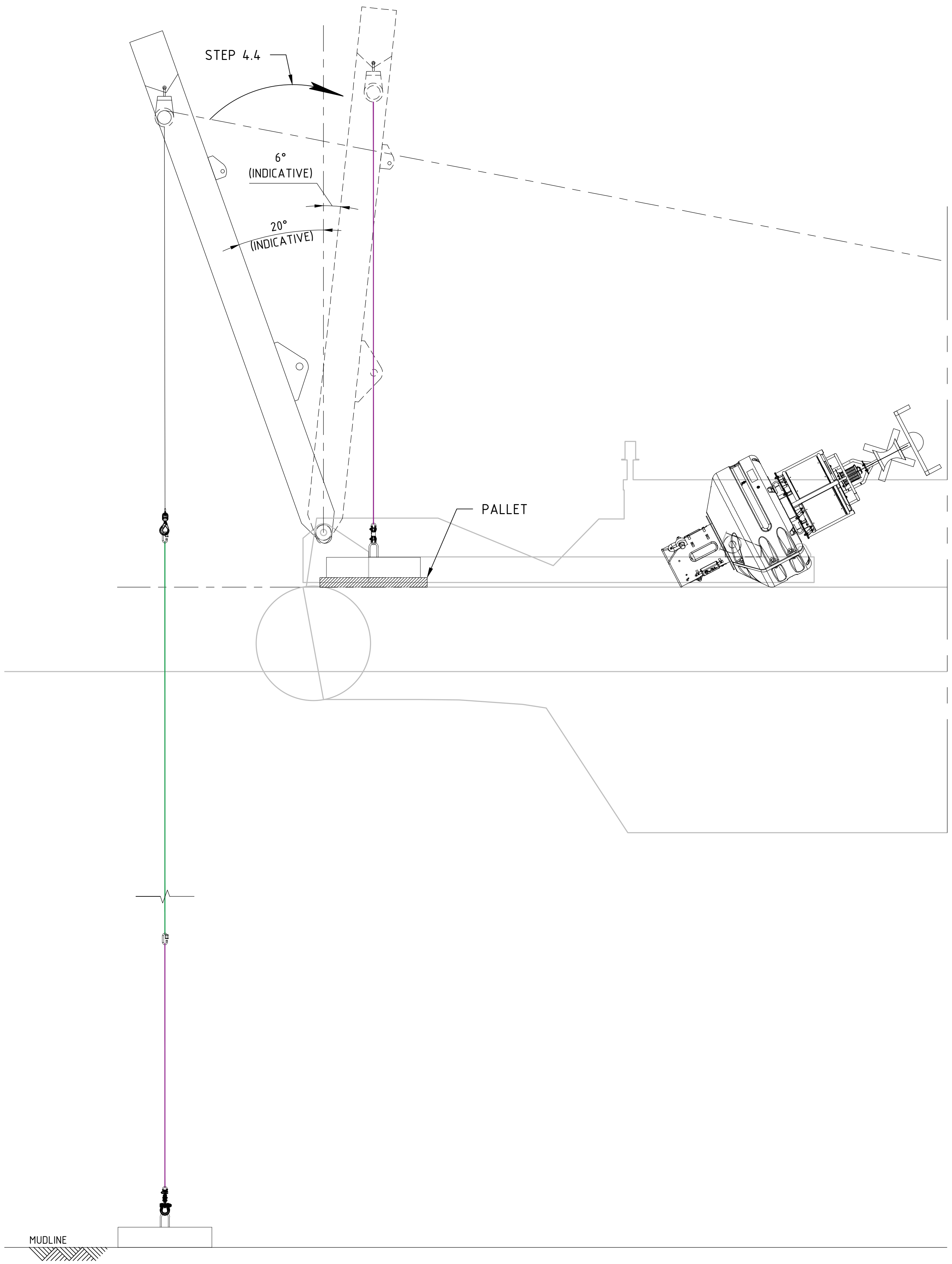


DETAIL 1

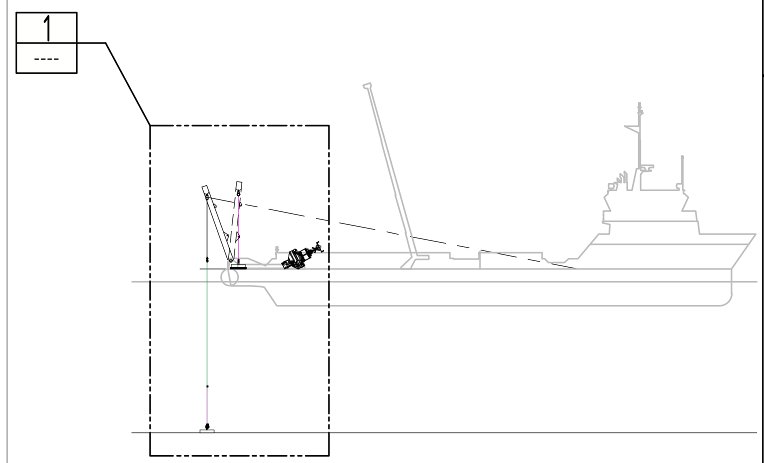
SCALE 1:40

STEPS RECOVERY

STEP 4
4.1 CONNECT RISER LINE (OR RISER EXTENSION) TO WINCH LINE AND ROTATE A-FRAME OUTWARD
4.2 WINCH IN CLUMP WEIGHT
4.3 MOVE VESSEL BACKWARDS IF REQUIRED
4.4 ONCE CLUMP WEIGHT IS OUT OF THE WATER, ROTATE IN THE A-FRAME AND LOWER CLUMP WEIGHT ONTO PALLET

KEYPLAN

SCALE 1:750



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RDS-PP CODE: TBA

DEVELOPMENT: INSTALLATION

PROJECT: REVOLUTION WIND 01 (REV01)

SUBJECT: STEP-BY-STEP BOUY DEPLOYMENT AND RETRIEVAL PAM BUOYS REV01

CLIENT: ØRSTED OFFSHORE WIND POWER NORTH AMERICA LLC

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FORMAT	PROJECTION	CLIENT DRAWING NO.	REV.
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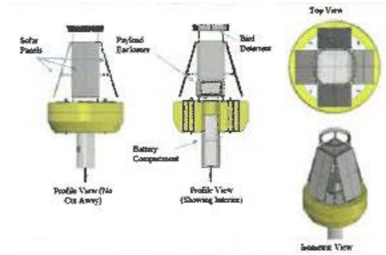
SCALE		BOSKALIS DRAWING NO. SH NO.	REV.
N.A.		0040135-BOS-DES-DG-4298-07	0.0

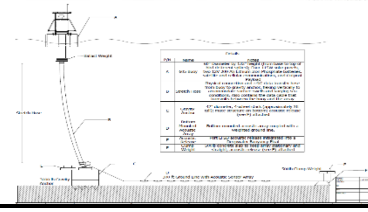
ANNEX D – BINDER DEPLOYMENT LOCATIONS

Appendix C – SeaPicket PAM System Specifications

SeaPicket Description

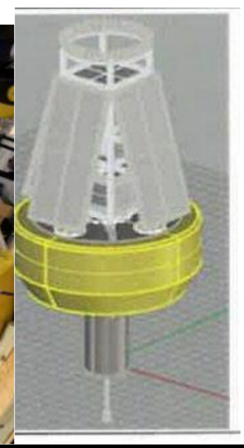
Overall System Function	Buoy based acoustic detection system
Sea State	Survive up to Sea State 6
Water Depths	50-250 feet of water
Acoustic Detection Ranges	Depending upon deployment location and background noise; from 10 nm to 20 nm
Acoustic Detection Targets	Commercial Vessels, Recreational Vessels, Pile Driving, Marine Life; ability to differentiate based on high array gain
Data Reporting Periodicity	Up to real-time reporting, but depends upon customer requirements
System Endurance	90 to 180 Days during winter, depending upon reporting requirements of customer





Buoy

Hull Dimensions	60" Diameter by 132" height (from base to top of bird deterrent spikes)
Weight	634lbs (919lb with payloads and ballast)
Material	Hull: Cross-linked polyethylene foam, polyurea coating with 316 stainless steel deck and hardware Tower: Marine grade 5052 aluminum

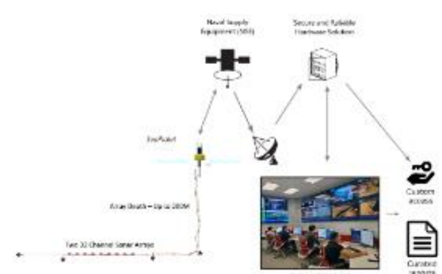


Power Systems

Function	Generation and storage of power to all onboard system
Generation	Four (4), 115W 12V DC, marine grade semiflexible solar panels with wet-mate connector
Storage	Two 12V 200Ah Lithium Iron Phosphate Batteries
Location	Batteries: Center Well of Buoy; Solar Panels on exterior

Communications Systems

Function	Provide communications (payload, control systems)
Sat Comms	Cell modem, Hughes, 9202 BGAN; Starlink, (depending upon distance from shore and customer requirements



	Mooring System (Single Point Design)	
Function	Physical connection & data transfer hose from SeaPicket buoy to gravity anchor, flexing vertically to accommodate surface swells and varying sea conditions. Also contains the data cable that transmits between the buoy and the array.	
Size	Appox. 3” in diameter; length varies with depth but typically 96’ in length for 100’ deployment depth	
Material	Proprietary rubber compound https://www.eomoffshore.com/_files/ugd/9aa783_354e9e6b724b47a8a8e4cd60908ecda1.pdf	
	Clump Weight	
Function	Provide bottom weight that maintains position on the sea floor	
Size	42" Diameter, 4-wheel Stack (approximately 3ft tall)	
Weight	3300 lbs. dry; 2800 lbs. wet	
Material	Steel Gravity Anchor with Bottom Mace; railroad wheel anchors	
	Anchor Weights	
Function	Hold acoustic array in place on ocean floor	
Weight	400 lbs.	

**Note: For Dual Point, double all quantities listed*

Appendix D – SeaPicket System Latency Memo

gsabra@thayermahan.com
120B LEONARD DRIVE
GROTON, CT 06340
860-822-3122

FROM: Greg Sabra, Director, Offshore Energy Programs
TO: Ocean Wind 1 Project

SUBJ: THAYERMAHAN ACOUSTIC DATA REPORTING

PURPOSE
To outline the reporting timeline of the ThayerMahan SeaPicket Acoustic Detection system for marine mammal monitoring and current capabilities

BOTTOM LINE
ThayerMahan currently provides acoustic alerts (from time of detection to the PSO operating offshore) in 5-13 minutes, but we are working to reduce transmission time to as close to five minutes as possible. A full analysis of this timing is listed below.

DISCUSSION
Over the past several years, ThayerMahan has been developing a unique, acoustic detection system for marine mammals that utilizes 32-channel arrays. These arrays provide:

1) <u>Long Range Detection Capability</u> – the ability to detect marine mammal acoustic transmissions well beyond that of the current single hydrophone-based system is a significant technical and practical (and commercial) advantage.
2) <u>Localization</u> – The ability to utilize two systems to localize marine mammal acoustic transmissions (especially at long ranges) enables better knowledge of marine mammal location and increases the time available for decisions regarding construction operations.
3) <u>Right Whale Identification</u> – The identification of the North Atlantic Right Whale, the primary species that is most notably concerning to BOEM/NOAA.
4) <u>Interfering Noise Rejection</u> – The use of arrays and the ability to “reject” other significant noise sources (e.g., pile driving, vessels, etc.) while still monitoring for marine mammals due to the array gain.
5) <u>Operational employment of remote systems for “real time” data acquisition</u> – The ability to utilize shore side operators (removing off-shore technicians) and receive acoustic data in “real time” is a major cost savings.
6) <u>Long Endurance</u> – The capability of our systems to be deployed once, rather than during every construction activity, or having to be reset during construction, provides practical and commercial savings to the customer.

The topic of discussion is point 5, regarding “real time” and what that means to the operational capability of the system. To understand the capabilities of the system, it is necessary to understand the background of the program and the improvements that have been made to get closer to “real time” information.

ThayerMahan

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120B LEONARD DRIVE
GROTON, CT 06340

860-822-3122

BACKGROUND

In the Spring of 2022, ThayerMahan worked extensively with Orsted to utilize this acoustic technology in a demonstration. ThayerMahan developed a concept of operations to provide acoustic alerts from a remote system to a shipboard PSO. This operation was used to identify the necessary steps to accurately pass information to end users. The major steps of the acoustics communications workflow included:

Step	Narrative	Method
1	On vehicle collection of acoustic data and batching/logging of the data	Automated computer processing
2	Edge processing of that data to highlight/classify potential marine mammals	
3	Transmission of those batched files from the vehicle to a shoreside server	Automated timing based on duty cycle of payload
4	Loading of those batched files onto a web interface by a shoreside analyst	Automated computer processing
5	Review of the data to validate and recognize valid marine mammal vocalizations	Manual review by PAM Operator
6	Creation of a contact report from ThayerMahan's system to Mysticetus shoreside cloud infrastructure	Manual creation by PAM Operator
7	Transmission of contact report from ThayerMahan's system to Mysticetus shoreside cloud infrastructure	Automated computer processing
8	Transmission of those contact reports from the Mysticetus cloud to the offshore Mysticetus computers manned by PSO's	Transmit/receive time from shore to ship

A graphical rendering of this workflow is shown on the following page. The design for the system was to implement as much automation as possible to reduce the "man in the loop" operation.

gsabra@thayermahan.com

120B LEONARD DRIVE
GROTON, CT 06340

860-822-3122

As was documented during the demonstration, this was an area for improvement for the SeaPicket system, as there were delays in transmitting acoustic data from the system to shore and in communicating whale detection reports back to the PSO vessel operating offshore. Since 2022, ThayerMahan focused on optimizing the process. Below is an analysis, based upon currently deployed SeaPicket systems, that shows time from detection to report.

ThayerMahan

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120B LEONARD DRIVE
GROTON, CT 06340

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SeaPicket 2023 - Process Steps for Acoustic Detection to reduce report time							
Step	Narrative	Method	Time Step	Controlling factors	Min	Max	How Latency was improved
1	On vehicle collection of acoustic data and batching/logging of the data	Automated computer processing	1 min	Software Program/Batching function	1	1	Reprogramed software to bin more frequently; improved classifier performance
2	Edge processing of that data to highlight/classify potential marine mammals			Software Program/Batching function			
3	Transmission of those batched files from the vehicle to a shoreside server	Automated timing based on duty cycle of payload	.5-4 mins	SATCOM transmission cycle; potential for "missed calls" due to environmental factors	1	6	Increased the "duty cycle" of the communications system
4	Loading of those batched files onto a web interface by a shoreside analyst	Automated computer processing	.5-2				
5	Review of the data to validate and recognize valid marine mammal vocalizations	Manual review by PAM Operator	1-5 mins	Analyst recognition of sound signal; arrival of different data sets to create localization	1	5	Improved classifier performance and web interface
6	Call from Acoustic Analyst to customer with relevant data (species, location, etc)	Manual entry/call by PAM Operator	1 min	What's APP, Teams, and/or vessel communications	1	1	Removed "automatic" reporting in lieu of rapid reporting
				Potential Range of Reporting	5	13	

While there are other ways to reduce this time from detection to reporting (for example, where possible, we have utilized cellular communication methods that can reduce steps 3-4 down to a minute, but these networks are not typically available offshore), we believe this current latency is in alignment with most other PAM systems (short of an onboard analyst) currently in the market.

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Additionally, because of the long-range capability of our system, the increased probability of detecting FURTHER away gives more time for the team to conduct mitigation efforts.

Appendix E – SeaPicket Deployment Locations for Remaining Foundation Installations

Appendix F – SeaPicket Detection Range Supporting Materials

Advanced Acoustic Technology Capabilities: Report of Previous Work

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Executive Summary

This report summarizes the demonstrated capabilities of ThayerMahan (TM) advanced acoustic services using state of the art passive acoustic monitoring (PAM) technologies to maintain high standards of marine species identification, localization, and protection within up to an 18-to-20-kilometer radius detection distance. The advanced performance of this system will enable faster and safer construction of offshore wind projects without imposing additional risk to marine mammals by facilitating whale detection at farther distances and more accurately than existing systems.

The report herein includes: 1) a comprehensive, up-to-date literature review of PAM systems for marine mammal monitoring, and 2) at-sea field demonstrations of PAM systems monitoring effectiveness, 3) application of these systems to provide acoustic alerts for vessels transiting to and from wind farms.

"Effective monitoring" of marine mammals during offshore operations in and around marine mammal mitigation zones and transit routes have the following characteristics:

- *Identification*: Capable of detecting, recognizing, and identifying target marine mammals (vocalizing cetaceans).
- *Detection Distance*: Detection capabilities that extend, at minimum, to agency-determined ranges established for minimizing and/or recording incidents of "take."
- *Rate and Probability of Detection*: Adequate detection probability (chance of detecting) based on animal occurrence within monitoring zones (true positive or true negative detections), while reducing false detections (false positives or false negatives).
- *Localization:* Proficient in determining locations within X meters of targeted marine mammals within the detection zone (i.e., in or outside of the required monitoring distances).
- *Environmental Conditions*: Capable of performing in challenging maritime conditions (e.g., low visibility, variable sea state, fog, precipitation, etc.).

Based on a literature review of PAM systems, the ability of a system to conduct effective monitoring as described above depends on a variety of factors including:

- Array design such as system gain, frequency range, and configuration,
- Depth of array in the water column, and
- Ambient and induced noise.

Results demonstrate that TM PAM systems provide highly accurate, long-range localized detection information, superior to single hydrophone systems. Advantages over industry standard, single hydrophone PAM include: 1) autonomous detection, classification, and reporting of North Atlantic right whales (NARW) in near real-time; 2) determination of bearing to, and in some cases localization of, vocalizing baleen whales; and 3) on-board signal processing algorithms for automatic filtering and rejection of ambient noise generated by nearby shipping, wind, and waves.

- *Identification*: The real-time NARW upcall auto-detector employed by the TM advanced PAM system demonstrated effective performance during both sound source testing and offshore data collection. TM acoustic analysts with specialized expertise in marine mammal acoustics verified the accuracy of the auto-detector for correctly classifying hundreds of NARW upcalls throughout day and night offshore testing to validate the performance of the real-time system. Non-NARW baleen whale vocalizations were also isolated from non-whale noise signals (including noise from transiting vessels). Acoustic analysts used real-time display products (e.g., detection surfaces, scissorgrams) with a frequency resolution tuned specifically for baleen whale detections to visually identify baleen whales by their characteristic frequency rate and temporal periodicity.

- *Detection Distance*: Most detections and localizations made by the TM advanced PAM system were from distances well beyond the acoustic detection range of the industry-standard vessel-towed PAM system and the visual detection range limits of Protected Species Observers (PSOs) aboard vessels. Detection distances of vocalizing whales over ten kilometers away were corroborated by independent acoustic monitoring assets deployed by Woods Hole Oceanographic Institute (WHOI), the National Oceanic and Atmospheric Administration (NOAA), and other research institutions in the same region. Support vessel repositioning based on multiple localized whale call detections by the TM advanced PAM system markedly increased PSO visual detections.
- *Rate and Probability of Detection*: The array-based TM advanced PAM system considerably outperformed the industry standard Seiche ship-towed PAM in both detection rates and detection probabilities. During both daytime and nighttime testing, the detection rate of the aggregate advanced TM PAM system exceeded that of the Seiche system, sometimes on the order of 10:1. For example, there were many periods when the Seiche system, once deployed, yielded no acoustic detections at all while the TM system returned verified acoustic detections.
- *Localization and Environmental Performance*: Field tests demonstrated detection sensitivity advantages of the TM advanced PAM system over the Seiche system including localization of vocalizing whales and the absence of acoustic contamination by radiated noise from the support vessel facilitated by coherent beamforming.

Advanced Acoustic Technology Capabilities Summary

Criteria	**Description of Criteria**	**Advanced Acoustic Capability**
Identification	Capable of detecting, recognizing, and identifying an object of interest (e.g., marine mammal)	Hydrophone arrays identify marine mammals in real-time with only limitations based on speed of communications between the array and the receiver.
Detection Distance	Able to detect marine mammals within protected zones	Hydrophone arrays have sufficient detection distance to monitor protected zones with a situational awareness zone with up to an 18-to-20-kilometer radius.
Rate and Probability of Detection	Sufficient detection rate and probability (chance of detecting based on animal availability) of detecting marine mammals (particularly whales) within the monitoring and mitigation zones	Enhanced array gain and sensitivity of ThayerMahan advanced acoustic systems yield higher detection rates and probabilities compared to industry standard Seiche (single hydrophone) systems.
Localization Accuracy	Capable of accurately determining distance to detected marine mammals	Advanced acoustics provides improved ability to locate marine mammals, increasing the likelihood of visual cueing, and decreasing the likelihood of false alarms that can result in unnecessary speed restrictions/shutdowns.
Environmental Conditions	Perform in the maritime conditions expected during monitoring (visibility, sea state, fog, precipitation, etc.)	Hydrophone arrays are not significantly impacted by visibility (fog and precipitation). Sea state does not impact acoustic performance up to safe operating limitations of CTV or other operations/maintenance platforms

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Glossary of Terms

The following definitions are provided to ensure a mutual understanding of terms used throughout this report.

Term	Definition
Acoustic Intelligence (ACINT)	ThayerMahan employee with experience analyzing acoustic data
Advanced	Integration of technology not conventionally applied within the marine mammal monitoring space
Biological Transient Noise/ Detection	An acoustic signature on an acoustic analysis display that has the appearance of a marine mammal vocalization
Detection	A marine mammal visual sighting or an acoustic signature of a marine mammal. Can be defined as per group, per individual, or per signal.
Detection Rate	The number of marine mammal detections per hour (as defined in Smith et al. 2020)
Enhanced Acoustic System Detection	A series of biological sounds seen on the acoustic analysis display interpreted by an ACINT to originate from one marine mammal or group of marine mammals near each other within a discrete time and reported within the MissionData system.
Passive Acoustic Monitoring (PAM)	Using passive listening equipment to measure, monitor, and determine the sources of sound in underwater environments for the acoustic behavior of marine animals (e.g., whale song, fish chorusing, snapping shrimp), natural abiotic sounds (e.g., wind, earthquakes), and human-generated sounds (e.g., cargo vessels).
Standard	A system that uses technology currently and conventionally used within the marine mammal monitoring space.
Standard Acoustic System Detection	Any acoustic event during which cetacean vocalizations were aurally and/or visually observed in PAMGUARD, regardless of the total duration of the event.
Trace Annotation	The marking of acoustic data classified as a possible species of interest (marine mammal).

1. Introduction

ThayerMahan (TM) specializes in integrating innovative unmanned acoustic detection systems to provide a common operating picture and maritime domain awareness platform for effective detection, classification, localization, and tracking of marine mammals (vocalizing cetaceans). This service provides improved marine mammal location accuracy and rapid, real-time or near real-time alerts with a system capable of withstanding a broader range of environmental conditions than standard systems. Ultimately, these advances increase the safety of marine mammals while minimizing total installation and maintenance time of offshore wind development.

ThayerMahan conducted both a literature review and field demonstrations to quantitatively evaluate the effectiveness of an advanced Passive Acoustic Monitoring (PAM) system using autonomous systems. To empirically evaluate system effectiveness, TM conducted operational deployments from April to May 2022 following a study design that reflected typical parameters and conditions (e.g., visibility and clearance zone distances, ambient vessel noise) encountered during offshore wind construction operations (Table 1 and Table 2).

Table 1. North Atlantic Right Whale (NARW) acoustic monitoring and mitigation zones for wind turbine generator (WTG) impact piling during the summer and winter seasons for the Ocean Wind, Revolution Wind, South Fork Wind, and Sunrise Wind lease areas (NMFS 2021, HDR 2022, LGL 2022a, LGL 2022b).

North Atlantic Right Whale (NARW) Seasonal Monitoring and Mitigation Zones (m)								
BOEM Lease Area	Summer (May-November)				Winter (December)			
	Minimum Required Visibility Zone	Visual Clearance Delay or Shutdown Zone	PAM Clearance Zone	PAM Clearance Delay or Shutdown Zone	Minimum Required Visibility Zone	Visual Clearance Delay or Shutdown Zone	PAM Clearance Zone	PAM Clearance Delay or Shutdown Zone
Ocean Wind	1650	any distance	3500	1650	2490	any distance	3800	2490
Revolution	2300	any distance	3900	2300	4400	any distance	4400	4400
South Fork	2200	any distance	5000	2000	NA	NA	NA	NA
Sunrise	3700	any distance	6500	3700	4300	any distance	7000	4300

NA = not authorized without approval from the Bureau of Ocean Energy Management (BOEM)

Table 2. Large whale monitoring and mitigation zones for wind turbine generator (WTG) impact piling during the summer and winter seasons for the Ocean Wind, Revolution Wind, South Fork Wind, and Sunrise Wind lease areas (NMFS 2021, HDR 2022, LGL 2022a, LGL 2022b).

Large Whale Seasonal Monitoring and Mitigation Zones (m)				
Lease Area	Summer (May-November)		Winter (December)	
	Clearance Zone	Shutdown Zone	Clearance Zone	Shutdown Zone
Ocean Wind	1650	1650	2490	2490
Revolution	2300	2300	4400	4400
South Fork	2200	2000	NA	NA
Sunrise	3700	3700	4300	4300

NA = not authorized without approval from BOEM

To govern system specifications for mitigation zone monitoring, one must first define “effective monitoring.” Effective monitoring of marine mammals during offshore operations in and around marine mammal mitigation zones has the following characteristics:

- *Identification*: Capable of detecting, recognizing, and identifying target marine mammals.
- *Detection Distance*: Detection capabilities that extend, at minimum, to agency-determined ranges established for minimizing and/or recording incidents of protected species “take”.
- *Rate and Probability of Detection*: Adequate detection probability (chance of detecting) based on animal occurrence within monitoring zones (true positive or true negative detections), while reducing false detections (false positives or false negatives).
- *Localization:* Proficient in determining locations within X meters of targeted marine mammals within the detection zone (i.e., in or outside of the required monitoring distances).
- *Environmental Conditions*: Capable of performing in challenging maritime conditions (e.g., low visibility, variable sea state, fog, precipitation, etc.).

Acoustic demonstrations to validate effectiveness of TM’s advanced acoustic system consisted of two test stages: 1) controlled testing using a generated sound source in an offshore environment to verify system performance, and 2) field testing comparing standard towed PAM and advanced ThayerMahan acoustic systems. The below objectives provided the framework and criteria for an “effective monitoring” plan (Table 3).

- **Objective 1 (Acoustic Sound Source Testing)**: Measure the total number of detections by the TM advanced PAM system of representative whale sounds generated and transmitted from an acoustic test source within the representative mitigation zone distances. Determine localization accuracy and the false positive rates.
- **Objective 2 (Acoustic Offshore Testing)**: Compare detection rates of marine mammals identified by the TM advanced PAM system versus the industry standard Seiche acoustic system within representative mitigation zone distances during daylight. Quantify the effect of environmental variables (e.g., sea state, fog, precipitation) on detection rates.

Table 3 - Effective monitoring requirements, capability definitions, acoustic test objectives, methods, and analyses.

Requirement	Capability	Acoustic Test Objectives	Acoustic Methods	Analysis
Identification	Capable of detecting, recognizing, and identifying an object of interest (e.g., marine mammal)	Objective 1: Measure the total number of ThayerMahan advanced PAM system detections of representative whale sounds transmitted from an acoustic test source within the representative mitigation zone distances and determine the false positive rates.	Sound Source Testing, Offshore Testing	NARW and humpback whale classifier performance; Spectrogram analysis of biological detections to identify call types
Detection Distance	Able to detect marine mammals within the monitoring and mitigation zone radii	Objective 2: Compare detection rates of marine mammals identified by the TM advanced PAM system versus the industry standard Seiche acoustic system within representative mitigation zone distances during daylight. Quantify the effect of environmental variables (e.g., sea state, fog, precipitation) on detection rates.	Offshore Testing and comparative distance testing	Analysis of detection range/distances
Rate and Probability of Detection	Quantify detection rate and probability of detection (chance of detecting based on animal availability) of marine mammals within the monitoring and mitigation zones	Objective 2: Compare detection rates of marine mammals identified by the TM advanced PAM system versus the industry standard Seiche acoustic system within representative mitigation zone distances during daylight. Quantify the effect of environmental variables (e.g., sea state, fog, precipitation) on detection rates.	Offshore testing and comparative performance	Detection rate calculations for standard and advanced methods
Environmental Conditions	Perform in the maritime conditions expected during the monitoring (visibility, sea state, fog, precipitation, etc.)	Objective 2: Compare detection rates of marine mammals identified by the TM PAM system versus the industry standard Seiche acoustic system within representative mitigation zone distances during daylight. Quantify the effect of environmental variables (e.g., sea state, fog, precipitation) on detection rates.	Offshore testing and comparative performance	Weather Impacts on Detection
Localization Accuracy	Capable of accurately estimating distance to detected marine mammals	Objective 1: Measure the total number of ThayerMahan advanced PAM system detections of representative whale sounds transmitted from an acoustic test source within the representative mitigation zone distances and determine the false positive rate and localization capability	Sound Source Testing	Localization calculation

2. Background: Passive Acoustic Monitoring for Marine Mammals

Mobile autonomous platforms such as buoyancy gliders and wave gliders instrumented with hydrophones have over a decade of proven employment in effective passive acoustic monitoring (PAM) of marine mammals (Premus et al. 2022). These autonomous maritime systems are advantageous over some traditional PAM approaches such as hydrophones deployed from support vessels because they are persistent, operating for long periods of time without manual intervention and without the contamination of own-ship radiated noise. Typically, these systems record and archive acoustic data for post-analysis and often employ some means of on-board data processing to support real-time detection and classification of marine species and reporting via satellite communications. Off the leeward coast of Hawai'i, Klinck et al. (2012) were among the first to deploy a hydrophone on a Seaglider for real-time detection and reporting of beaked whales and other odontocetes. Darling et al. (2019) deployed a Liquid Robotics (Kamuela, HI) wave glider instrumented with a single hydrophone for the measurement of baleen whale vocalizations verify humpback whale presence in offshore tropical waters during the winter breeding season. Baumgartner et al. (2020) reported on the effective use of Slocum gliders for near real-time estimates of baleen whale presence in the southwestern Gulf of Maine. Recently, Kowarski et al. (2020), motivated by the impact of anthropogenic activity on endangered NARWs in the Gulf of St. Lawrence, explored the practical challenges underlying the use of autonomous systems, in particular buoyancy gliders, for PAM applications, including the impacts of self-noise contamination, power consumption, and bandwidth for data transfer. Similarly, Baumgartner et al. (2021) investigated PAM-relevant engineering considerations with wave gliders, such as the potential noise produced by platform radiated noise mechanisms. Further, Fregosi et al., (2020a, 2020b) evaluated the effectiveness of both stationary and mobile autonomous recorder systems for marine mammal surveying, including the potential biases introduced by autonomous systems. The collective body of knowledge forms a basis to inform government regulatory bodies responsible for mitigating the impacts of anthropogenic activities such as offshore wind installation and operation on marine mammal habitat.

Past applications of stationary platforms and wave gliders in PAM systems largely relied on a single hydrophone to perform acoustic measurements. When operators employed hull-mounted or towed hydrophone arrays from autonomous platforms, they typically lacked coherent processing gain through beamforming, a processing functionality available when using multiple hydrophones (Baumgartner et al., 2021). Traditionally, hydrophone arrays in PAM systems were characterized by arrays towed from surface vessels (Thode, 2004; Thode & Guan, 2019; Wang et al., 2016). While vessel-towed approaches became standard practice, the background noise level was significantly impacted by the proximity of the support vessel, particularly if beamforming was not employed. One notable exception is Wang et al. (2016), which reported the use of a 160-element hydrophone array from a research vessel near Georges Bank in 2006. Comprised of four nested sub-apertures, each containing 64 hydrophones measuring array gains (AGs) of 18 dB, the system detected baleen whale vocalizations at ranges and signal-to-noise ratios (SNRs) up to two orders of magnitude greater than that possible with a single hydrophone. This system required a large research vessel supporting a large winch for launch/recovery and enough electrical power for the winch and the onboard computation; thus, the arrangement could not integrate with an autonomous platform. Nor did they provide a solution for data transmission from vessel to shore. The work of Gervaise et al. (2021) independently reinforced the findings of Wang et al. (2016) through a modeling study of coherently processed hydrophone arrays yielding up to 15 times the detection range of a single hydrophone for the NARW upcall in the Gulf of Saint Lawrence.

3. Advanced Acoustic System Capabilities Demonstration

3.1. Objectives

TM's acoustic demonstration consisted of two testing events: a controlled test utilizing a sound source to verify system performance and a field test comparison of a standard towed PAM system and advanced TM acoustic systems.

- **Objective 1 (Acoustic Sound Source Testing)**: Measure the total number of TM advanced PAM system detections of representative whale sounds transmitted from an acoustic test source within the representative mitigation zone distances and determine the false positive rate and localization capability.
- **Objective 2 (Acoustic Offshore Testing)**: Compare detection rates of marine mammals identified by the TM advanced PAM system versus the industry standard Seiche acoustic system within representative mitigation zone distances during daylight. Quantify the effect of environmental variables (e.g., sea state, fog, precipitation) on detection rates.

3.2. Equipment

3.2.1. ThayerMahan Advanced Passive Acoustic Monitoring System

The TM advanced PAM System is a modular acoustic system deployable as a mobile or fixed system. During acoustic testing, TM deployed three different platforms were for acoustic data collection: 1) Wave Glider, a mobile unit that propelled by wave motion, 2) SeaTrac SP-48, a mobile uncrewed surface vessel propelled by a battery-powered motor, and 3) SeaPicket, a fixed buoy system. Each system was utilized in different portion of testing, and results of the acoustic performance do not vary with the platform used.

3.2.1.1. Mobile Platforms

3.2.1.1.1. Wave Glider

Introduced by Liquid Robotics in 2007, the wave glider is an innovative maritime platform that generates forward propulsion by harnessing the orbital motion induced in the upper water column from wind-generated sea surface waves. The wave glider is comprised of three primary components: 1) the "sub", 2) the surface float, and 3) the umbilical. The key hydrodynamic innovation of the wave glider is the design of the sub (Figure 1a), which provides the propulsive mechanism of the glider, and to which a tow cable with acoustic sensors can attach (see section 3.2.1.3). The propulsive unit of the sub has a rack of six parallel fins or louvers whose orientation can rotate between two states: a) slanted at an upward angle that provides forward thrust upon heaving motion when the float encounters a surface

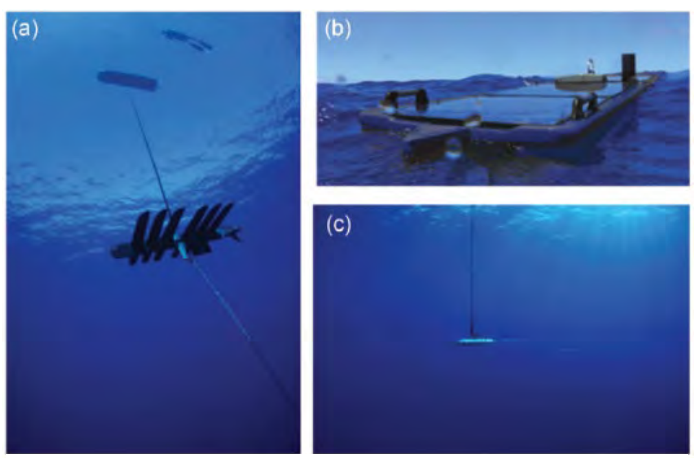


Figure 1 – Wave Glider mobile platform showing a) the "sub," b) the surface float, and c) the umbilical.

wave crest, and b) slanted downward for thrust and reset to maximum depth as the assembly sinks in the wave trough.

The surface float (Figure 1b) is instrumented with photovoltaic cells that provide capacity to recharge batteries that power all communications, command, and control functions, as well as the payload electronics and sensor. The float hosts several antennas that support weather sensing, automatic identification system (AIS), cell modem, and satellite communications. Command, control, and payload data transmission may be performed at any time, either continuously or on a scheduled or polled basis. This continuous transmission is a unique advantage not shared by the other two classes of autonomous platforms, unmanned underwater vehicles (UUVs) and buoyancy gliders, and a key enabler to continuous real-time acoustic monitoring applications. Typical battery capacity for four rechargeable alkaline battery trays is 4500 watt-hours (Wh). With a vehicle hotel (electronics, communication, and control systems) power draw of ten watts (W) and payload power consumption (detailed below) for the case of the 32-channel low power towed hydrophone array employed in this work of ten W, the total system (vehicle hotel + payload) power consumption is 20 W, or approximately 480 Wh/day. The maximum and typical charging capacity of the photovoltaic battery system meets and exceeds the charging rate required to support the total system power draw (20 W). The maximum solar charging rate is 192 W, but the actual recharge rate varies significantly depending on local solar conditions and cloud cover. At-sea experience with the system described herein has shown 70–80 W to be more typical, with a roll-off observed as maximum battery capacity is approached. At mid latitudes (e.g., those of the Northeast Atlantic), with occasional thruster use, the system demonstrated persistence at-sea unattended up to 50 days. Fifty days is also the point at which data storage becomes limited.

The umbilical (Figure 1c) mechanically connects the sub to the float and provides electrical connection for power and data transmission to and from the sensor payload. The umbilical has a hydrodynamic foil cross section to minimize drag and a built-in strength member. It is typically either four or eight meters in length. Prior to launch, the sub and umbilical must be carefully packaged into a temporary sled assembly designed to inhibit propulsion upon contact with the water until a quick release is activated to unfurl the assembly. Propulsion commences immediately upon the first subsequent surface wave encounter. Despite the surging nature of the sea surface forcing function, the motion of the sensor at depth is relatively calm as long as there is supporting sea state of at least Beaufort sea state 1. Last, the sub is also instrumented with a thruster designed to assist with navigation authority during calm seas or whenever otherwise needing additional mobility. In low to moderate sea states with sufficient wave action the vehicle can steer and transit well without the thruster. But in becalmed conditions the thruster may be necessary to generate sufficient propulsion to maintain the array straight and horizontal. Without a towed sensor array, typical wave glider speed is 1.3 knots. With the additional drag of the tow cable and array the vehicle speed is typically below 1 knot, depending on weather conditions and array/tow cable length.

3.2.1.1.2. SeaTrac SP-48 Uncrewed Surface Vessel

The SeaTrac SP-48 Uncrewed Surface Vehicle (USV) (SeaTrac Systems, Inc.) is a versatile 15-foot-long platform capable of deploying a wide range of sensors in most marine environments. The SP-48 uses an array of solar panels to charge a large internal battery pack that continually powers the USV and its payloads 24x7 on missions lasting up to months at a time. The USV uses a brushless electric motor for reliable propulsion with a cruising speed of 3 knots and maximum speed of 5 knots. The SP-48 can maintain navigational authority in strong currents, in the open ocean, and with sufficient agility to navigate through cluttered environments. Figure 2 shows cross-section and full boat renderings illustrating key attributes of the platform architecture.

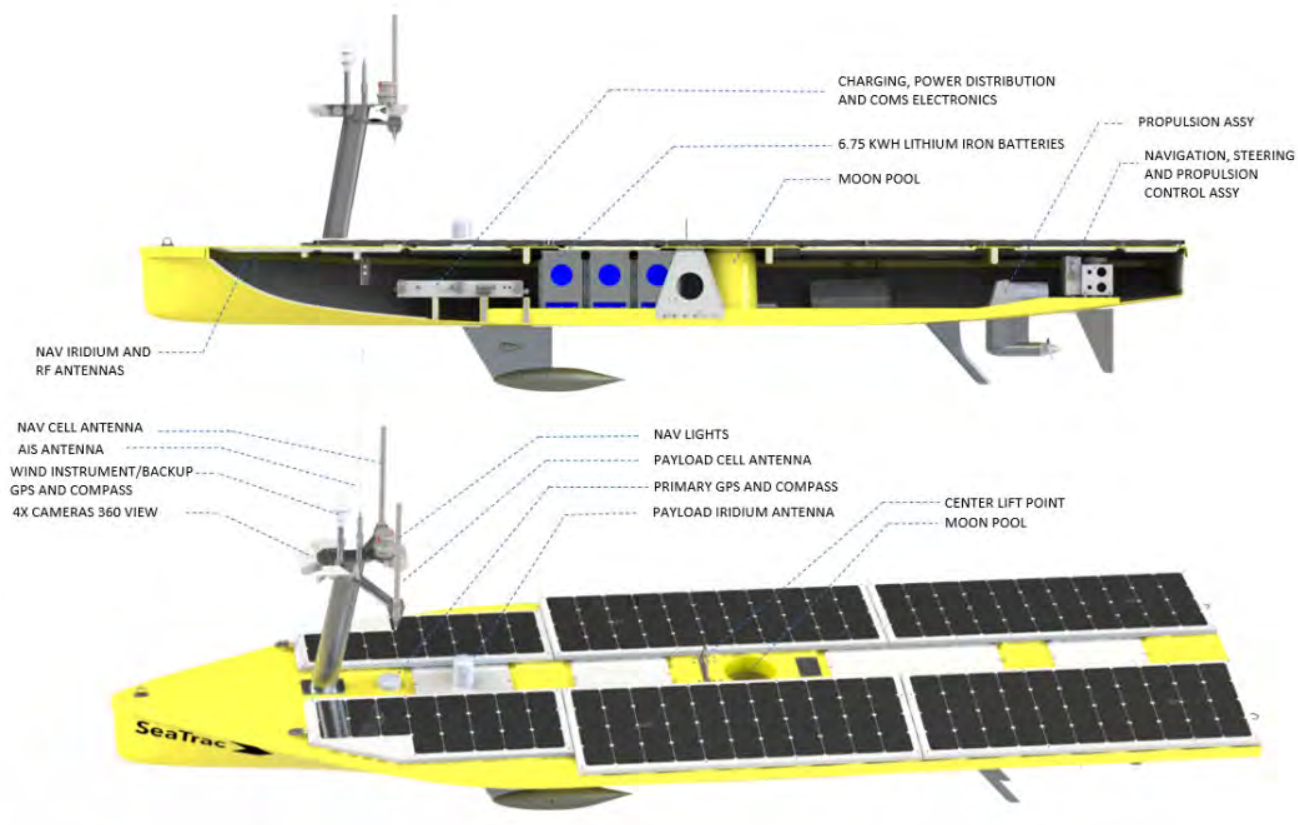


Figure 2. SeaTrac uncrewed surface vessel schematic.

Redundant communications methods including radio frequency (RF) for line of sight, cellular for nearshore when available, and satellite for over the horizon operations provide for real-time data streaming. The USV can be equipped with custom communications equipment including high bandwidth broadband radios and acoustic modems for underwater communications.

The standard onboard sensors including global positioning system (GPS), 360-degree cameras, AIS transceiver, and meteorological (met) station provide situational awareness to remote operations centers and enable effective remote piloting from near shore coastal environments to over the horizon missions. The SeaTrac Dashboard Control Software allows the pilot to manage the flow of data based on mission needs to provide key information about the system itself and the surrounding environment. The Dashboard software can monitor the status and health of the USV while executing programed missions. Configured alerts assist in piloting via notifications about battery levels, position, incoming traffic, and other key parameters. Application programming interfaces (APIs) are also available for third party control (JAUS, ROS, MOOS-IVP, etc.). Figure 3 shows a screenshot of the SeaTrac Dashboard (Figure 3).

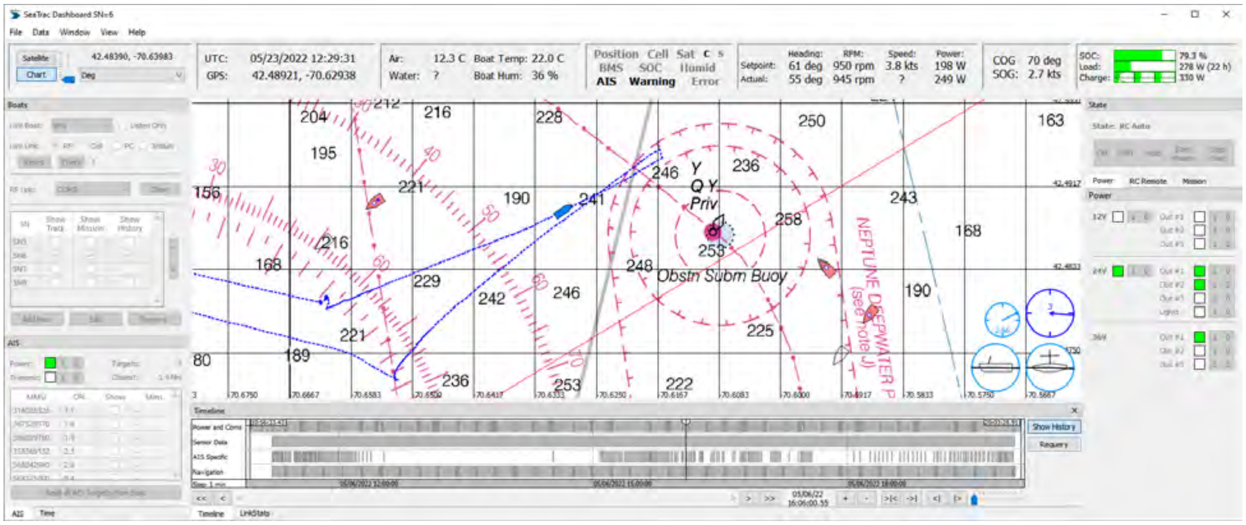


Figure 3. Navigation and piloting dashboard for SeaTrac.

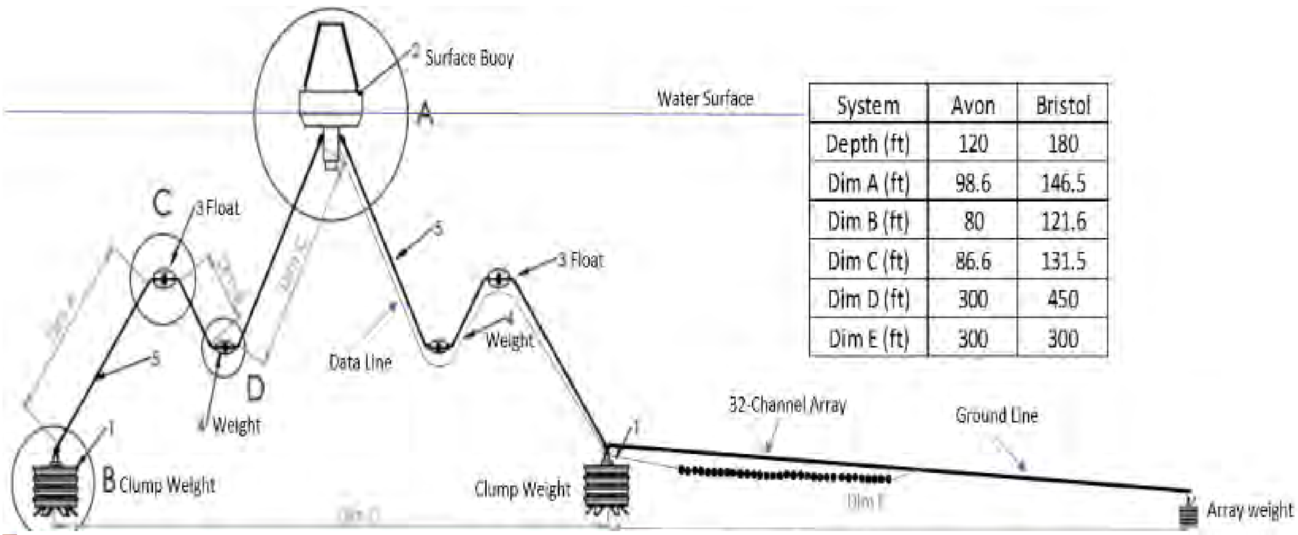
The USV has a moon pool through the center for easy mounting of payload sensors that need access to the water. A large payload bay supports topside units or equipment in a dry space. The SP-48 has been configured with multibeam sonars, Acoustic Doppler Current Profilers, hydrophone arrays, thermal cameras, and a wide range of scientific payloads.

The SP-48 can launch quickly from its trailer at any boat ramp or can deploy via crane from a pier or ship using the center point lift (Figure 4).

Figure 4 - Deployment of Seatrac uncrewed surface vessel.

3.2.1.2. Fixed Platform

ThayerMahan's SeaPicket buoy system (Figure 5) is comprised of 1) a fixed buoy (Maritime Applied Physics Corporation [MAPCORP] 605S) with two anchor lines, 2) a 32-channel linear acoustic hydrophone array (see 3.2.1.4) laid and anchored with clump weights at two points on the seafloor, and 3) a data and power cable running up to the buoy. A watertight enclosure on the buoy houses a re-chargeable battery pack, data processing, and communications electronics. Solar panels, communications antennae, and lights mount on the superstructure. Appendix B details SeaPicket specifications including buoy, power, and communications.



System	Avon	Bristol
Depth (ft)	120	180
Dim A (ft)	98.6	146.5
Dim B (ft)	80	121.6
Dim C (ft)	86.6	131.5
Dim D (ft)	300	450
Dim E (ft)	300	300

Figure 5. SeaPicket buoy system schematic, as deployed in 2022.

3.2.1.3. Acoustic Sensing Payload (Towed Configuration)

The advanced acoustic sensing payload used across the Wave Glider, SeaTrac, and SeaPicket systems was a 32-channel, low-power hydrophone array and leader built by Raytheon Missiles and Defense (RMD) in Portsmouth, RI. The array included high-precision, non-acoustic sensor modules forward, mid, and aft, to measure array heading, pitch, and depth, and designed to reduce drag and flow noise. System and sensor design elements mitigated unwanted system motion-related noise by using motion dampening and ensuring hydrodynamic design. The piezoelectric crystal hydrophone sensitivity of the array was -199 dB re 1V/µPa. An analog-to-digital converter (ADC) integrated into each channel, and hydrophone response digitized with 24-bit precision at a sample rate of 2.5 kHz. Hydrophones were uniformly spaced at one half-wavelength for a design frequency of 625 Hz, or 1.2 m spacing and 37.2 m total aperture length. Hydrophone and pre-amp power drew approximately 30 W/channel. An array receiver or node card converted array telemetry to Ethernet User Datagram Protocol (UDP) packets for transmission to the embedded digital signal processor (DSP). The full power draw for the acoustic sensor (array + receiver electronics) totaled less than 2 W.

When used in conjunction with the mobile vehicles (Wave Glider and SeaTrac), the advanced acoustic towed array had three major elements: 1) the hydrophone array (acoustic sensors), leader (to dampen the motion of the vehicle from the array), and drogue (found at the end of the array) ; 2) a weighted towfish housing the array receiver, embedded processor, network switch, and solid-state storage media; and 3) a tow cable and motion isolation system.

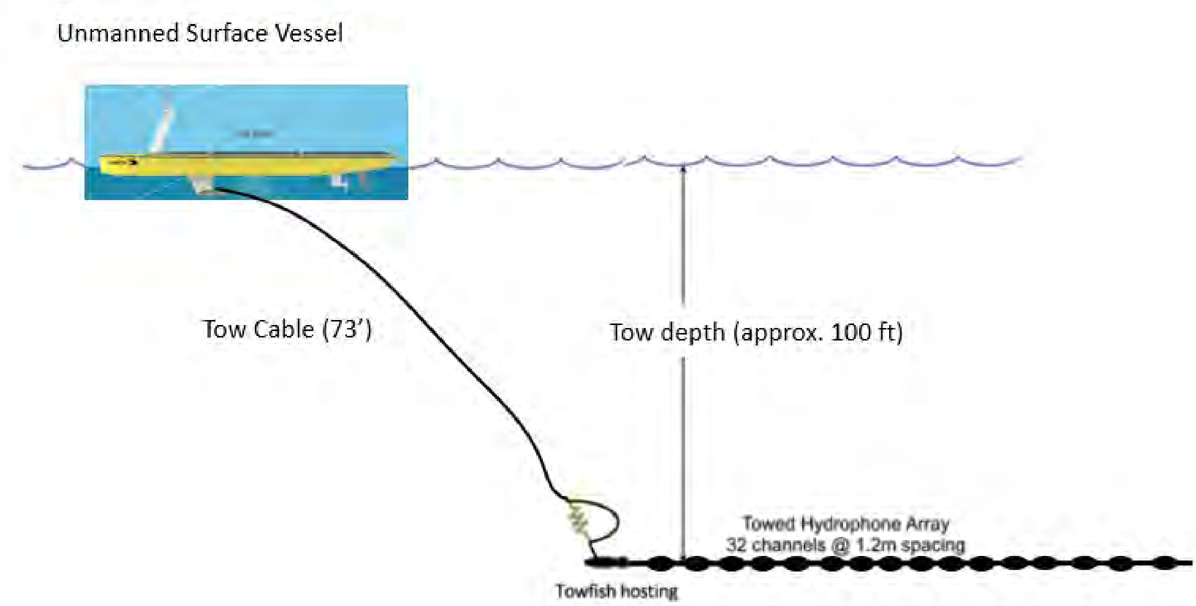


Figure 6 - Towed acoustic system via the SeaTrac System, showing two cable, towfish, and hydrophone array.

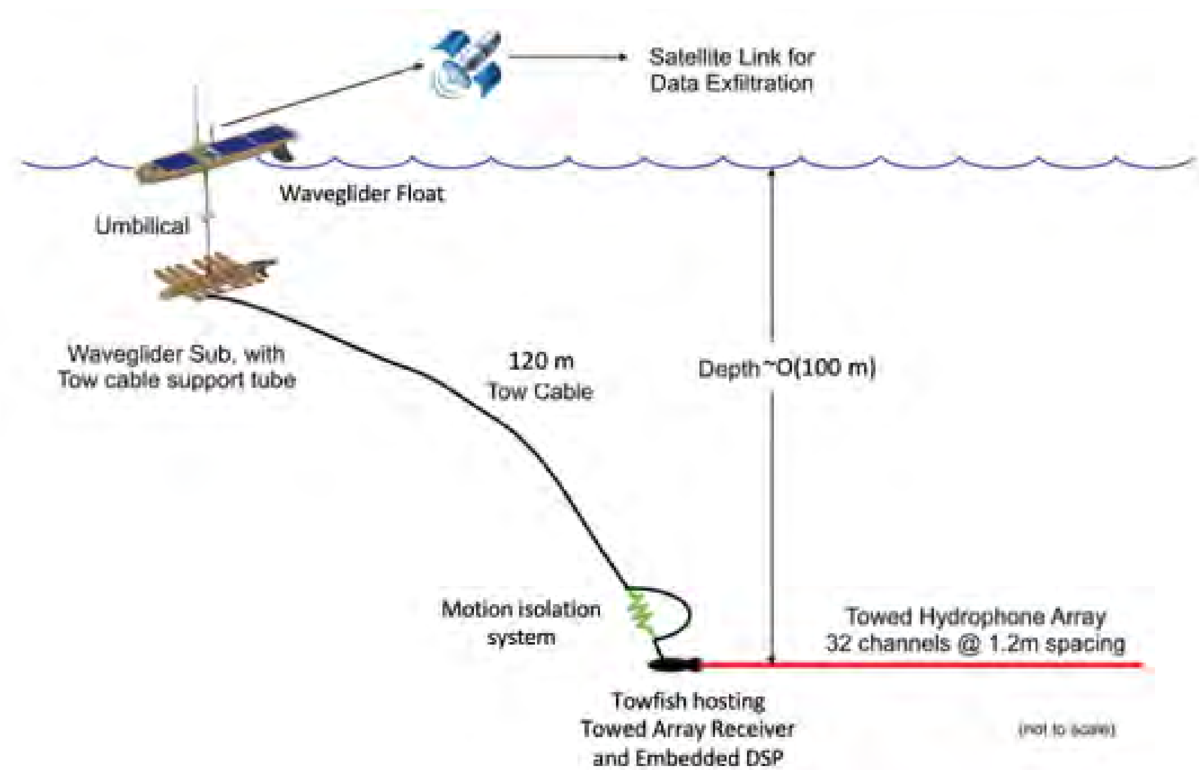


Figure 7 - Towed acoustic system via the WaveGlider system, showing two cable, towfish, and hydrophone array.

3.2.1.4. *Acoustic Sensing Payload (Bottom Mounted Configuration)*

The bottom mounted passive acoustic payload attached to the SeaPicket buoy system had equivalent specifications to the array described above (section 3.2.1.3), but with slight differences in attachment design and mechanisms. It had three major elements: 1) the bottom mounted hydrophone array, 2) a cable system running from the array to the payload box on the buoy (typically integrated into the mooring system), and 3) an embedded processor, network switch, and solid-state storage media. The array was weighted on a ground line to prevent movement of the system after deployment.

3.2.2. Standard Acoustic System

The standard acoustic system designed and manufactured by Seiche Limited (Figure 6) was comprised of 1) a 250-meter hydrophone array, 2) 100-meter deck cable, and 3) an electronics processing unit. The hydrophone array contained four hydrophones, two broadband elements with a frequency response of 200 Hz to 200 kHz, and two standard elements with a frequency response of 2 kHz to 200 kHz. Hydrophone sensitivity was -166 dB re 1 V/µPa for the standard elements and -157 dB re 1 V/µPa for the broadband elements. The array cable also incorporated a depth sensor.

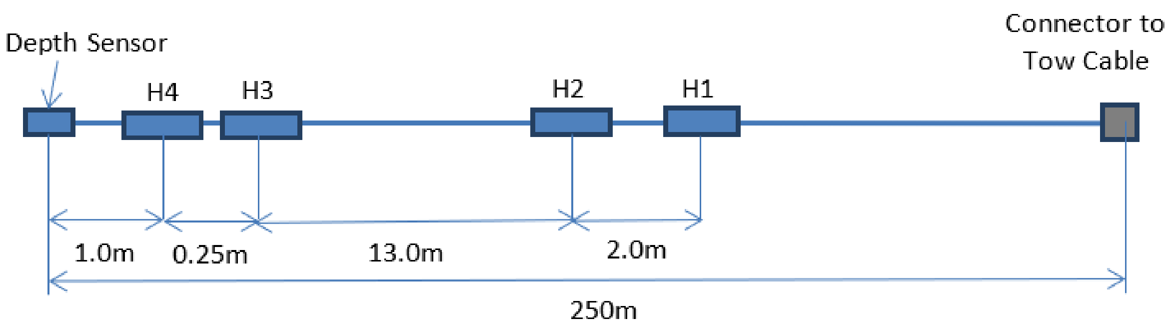


Figure 8. Standard acoustic system designed and manufactured by Seiche Limited.

The electronics processing unit contained two analogue-to-digital converters (ADCs) for sampling raw signals from the hydrophones, and an additional ADC for the depth sensor. The electronics processing unit provided power to the hydrophone array. One sound ADC, the National Instruments (NI) DAQ card, sampled acoustic signals at 500 kHz, while the second sound ADC, the Fireface 800, sampled acoustic signals at 48 kHz. Use of the two sound cards allowed for acoustic signal sampling at rates consistent with low, mid, and high frequency cetacean vocalizations.

3.2.3. Acoustic Projectors

J-9 and J-13 projectors (Figure 7) transmitted the representative acoustic waveforms and whale vocalizations required to test and validate the operation of the passive acoustic sensor system. The J-9 is a smaller unit, lower power, and doesn’t transmit at the range of frequencies that the J-13 an transmit. For detail, see Appendix B: Acoustic Equipment Specifications.

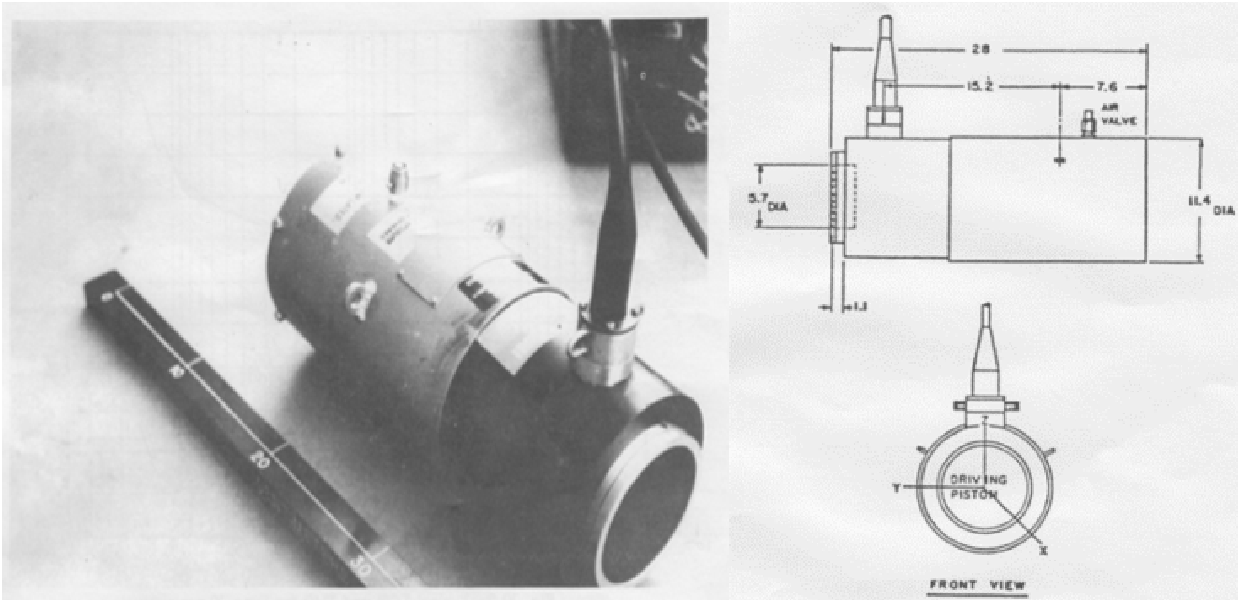


Figure 9. J-9 Acoustic source (left) with dimensions (right).

3.3. Methods

3.3.1. Acoustic Sound Source Testing

TM-conducted sound source testing events in Spring and Fall of 2022 and used both the fixed and mobile systems. During the testing, the support vessel deployed a Naval Research Laboratory (NRL)-developed and Naval Undersea Warfare Center-calibrated J-13 (used in the Spring Demonstration) and J-9 (used in the Fall Demonstration) sound source. Sound sources had operating frequencies of 50 Hz to 3 kHz with a maximum broadband source level of 160 dB re 1Pa @ 1m. Acoustic projectors were deployed with a reference hydrophone and spectrum analyzer to continuously monitor transmissions, with a source level fixed at 150 dB re 1Pa @ 1m during the demonstration to evaluate TM advanced PAM detection capabilities within the range of north Atlantic right whale sound production. This was considered a de-minimus transmission, and is lower than the expected actual transmission source of the NARW. The J-9 and J-13 acoustic projectors transmitted a pre-programmed 5-minute NARW vocalization wave file developed from annotated data distributed at the 2013 Detection Classification Localization and Density Estimation (DCLDE) Workshop hosted by the University of St. Andrews. GPS-derived coordinates for the support vessel and acoustic projector position provided known distances between the acoustic source and the TM PAM system, and source transmissions provided bioacoustic reference source to ground-truth and validate the performance of the TM advanced PAM system.

For all operations, the support vessel was between 1-3 KM of the ThayerMahan Acoustic Monitoring System (see Equipment section above), such that ocean current would maintain the vessel/platform separation, or the vessel would close in on the platform. Vessel/platform separation ranged from a minimum of 1 to a maximum of 3 km throughout sound source testing. For all operations, the sound source was deployed to a depth of 50 ft. Average water depth was 150ft. For each projected signal, the technician verified receipt of the signal with the Operations Center (OPCEN). For the spring, Sound Source testing occurred after the launch of the SeaPicket systems, and then again later after the launch of the mobile systems. In the Fall, sound source testing occurred on two separate days and across three locations in the Cape Cod Region.

Below was the testing that was used in both the Spring and the Fall:

- Day One testing
    - Test Location 1
        - Deployed J-9/13 to depth of 50’
        - Transmitted narrowband signals
        - Transmitted NARW signals, of various patterns and timing repeating every 5 mins
        - Transmitted 1 hr humpback signals
        - Recovered J-9
- Day two testing
    - Test Location 1
        - Deployed J-9/13 to 50’
        - Transmitted narrowband signals
        - Transmitted NARW signals, of various patterns and timing repeating every 5 mins
        - Recovered J-9/13; Transferred to Test Location 2
    - Test Location 2: Repositioned for better sensor to source positioning
        - Deployed J-9/13 to depth of 50’
        - Transmitted NARW signals, of various patterns and timing repeating every 5 mins
        - Transmitted humpback signals
        - Recovered J-9/13

TM acoustic analysts (ACINT) reviewed the transmitted and received sound signals via the ThayerMahan EXWEB data analysis platform. The ACINT annotated all received NARW calls or humpback calls to the log maintained by the technician operating the sound source.

3.3.2. Offshore Testing: Advanced versus Standard PAM System

Offshore field tests between 15 and 29 April 2022 compared TM advanced PAM and standard acoustic systems. The TM advanced PAM system consisted of four acoustic monitoring systems: two fixed ThayerMahan SeaPicket acoustic systems (Avon and Bristol) and two mobile wave glider unmanned surface vessel (USV)-based systems, one a Wave Glider (MARY R/ELLEN). The standard PAM system was a single vessel-towed hydrophone array manufactured by Seiche Limited. TM deployed in late March 2022 the two SeaPickets pre-demonstration and they remained in operation until 25 April 2022. The two USVs operated within the USV operating box (area to operate the USV for detections, approximately 10nm x 20 nm in size). The *Josephine Miller* with the Seiche standard acoustic system and followed the vessel paths indicated in Figure 4 to replicate PSO support vessel activities during monitoring activities. The *Josephine Miller* followed the northern vessel path from 15 to 18 April 2022 and the southern path from 21 to 25 April 2022. The vessel then moved into Cape Cod Bay for several days, with only one ThayerMahan acoustic system (WaveGlider MARY R) and the standard acoustic system, although deployment of the towed system was limited due safe transit and whale presence in the region.

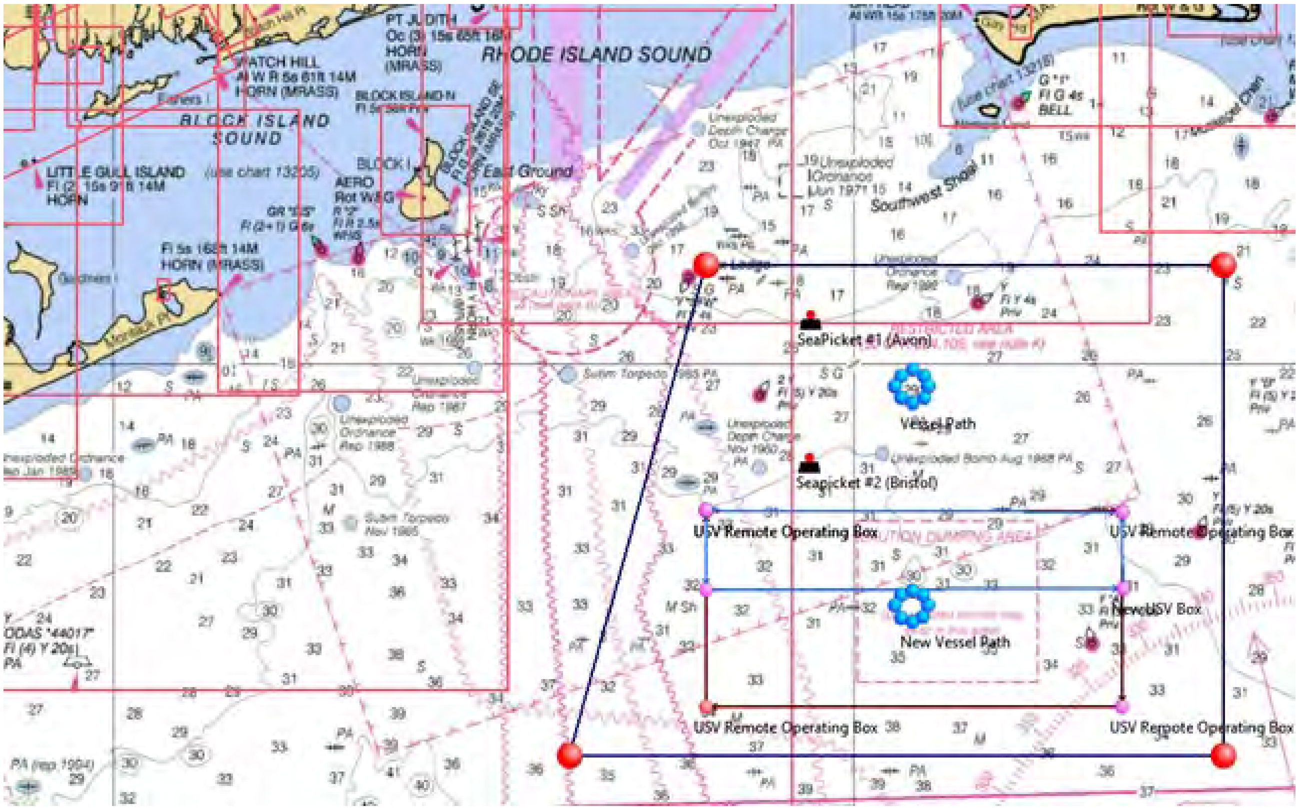


Figure 10 – Spring Deployment schematic of the ThayerMahan advanced acoustic systems and protected species observer (PSO) vessel path with the standard acoustic system. The testing box is the large, trapezoid shape marked by red dots; the USV operating box is marked by purple dots, and the projected vessel path is shown with blue dots, with both a northern and a southern path location.

3.3.2.1. NARW Detection Reporting

Data packets from the SeaPicket and USV systems were updated in the server every 10-minutes via satellite transmission enabling shoreside monitoring by TM ACINT specialists of all acoustic data. All TM advanced PAM housed onboard classifiers to identify NARW upcalls. Using a web-based interface, TM ACINT specialists monitored, reviewed, and analyzed incoming data, classifying and tagged the data using the following procedure to create detection reports:

1. Investigate all classifier alerts.
    a) Annotate classifier NARW upcall alerts for valid detection based upon the visual characteristics of the detection.
    b) Look for other potential detections around auto-classified detects that could be potential missed detections and tag them if valid.
    c) If the detection was not valid, do not tag the data.
2. Evaluate non-classifier detections throughout data. Look for distinct short-time transients which are indicative of marine mammal vocalizations, in data and interrogate them by “scissoring” the data (selecting broadband energy to determine the narrowband frequency information).
    a) Tag transients that appear to be valid marine mammal detections. If unsure, tag as Biologic and "other."

b) Plot the detection and make them as accurate as possible.
3. Triangulate valid detections when possible using MissionData (TM's Geo-based visualization software for acoustic sensors) and export detection reports.
4. Automatic push of detection reports directly into Mysticetus.
5. Coordinate with the Shoreside PSO in the Command Center to confirm report arrivals.

Upon completion of detection reports and uploading of data to the Mysticetus cloud, onboard computers synced via satellite to the shoreside server and data reports were displayed for PSO viewing. The shoreside PSO then reviewed daily acoustic detections and performed an analysis to "group" the detections into potential single sources. For example, if the ACINT put in three detections that had similar bearing/time resolution, the shoreside PSO grouped those into one potential marine mammal contact.

3.3.2.2. Standard Acoustic Monitoring

TM conducted daytime acoustic monitoring using standard PAM (Seiche system) when it was safe to tow the Seiche hydrophone array astern of the *Josephine Miller*.

The Seiche hydrophone array was deployed 150 m astern of the *Josephine Miller* from a center pulley block on the A-frame (Figure 9). A short deck cable interfaced the hydrophone array cable and the data processing electronics located within the main deck office module. A rack-mounted computer and two monitors facilitated vessel-based acoustic monitoring from inside the office module. PAMGUARD (64-bit Beta version 2.02.02) software was used to visualize, process, and analyze acoustic data in real-time. PAMGUARD configurations monitored for low (<3 kHz), mid (3-24 kHz), and high (24-250 kHz) frequency cetacean vocalizations. Spectrograms, as well as tonal and pulsed vocalization detectors aided visual observation of acoustic signals. Observers also monitored the raw audio signal using headphones. Low-mid frequency audio was continuously saved to an external hard drive, while high frequency data was continuously saved to binary files also viewable with PAMGUARD Viewer Mode (see Figures 10 and 11 for example displays spectrograms of mid and high frequency vocalizations). Mysticetus software collected PSO/PAM operator effort and acoustic detection data.

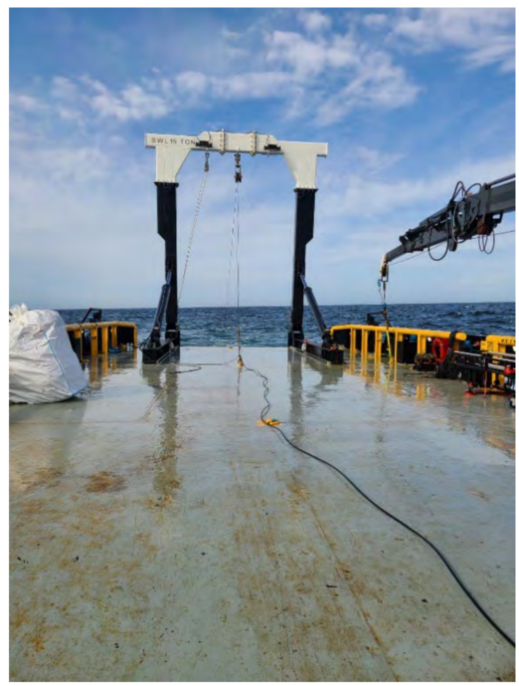


Figure 11. Seiche hydrophone array cable deployed through the center pully block on the Josephine Miller's A-frame.

Upon a marine mammal acoustic detection, the PSO/PAM operator used tracking and localization functions within PAMGUARD to calculate range to vocalizing marine mammals. If they achieved bearing details or a localization, the PSO/PAM operator pushed acoustic detection data to visual PSOs using Mysticetus, which automatically pushed data to the PSO when bearing and range data were entered.

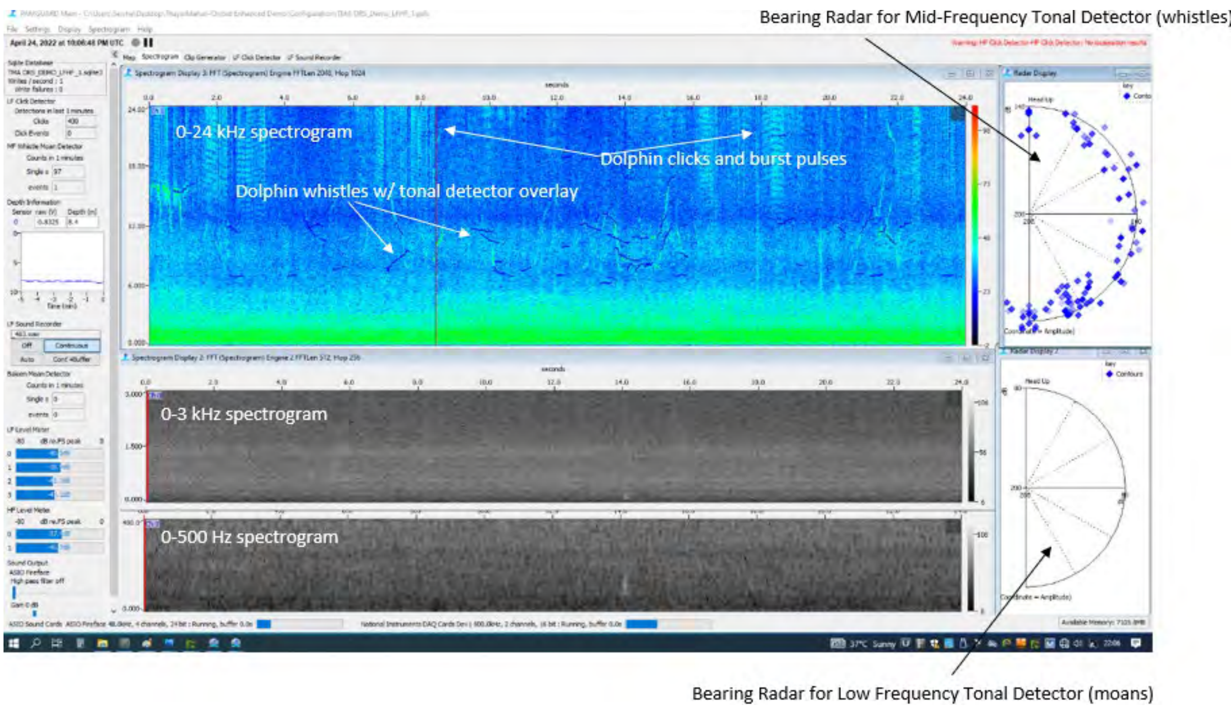


Figure 12. PAMGUARD image shows both the spectrograms for mid-frequency dolphin whistles and clicks.

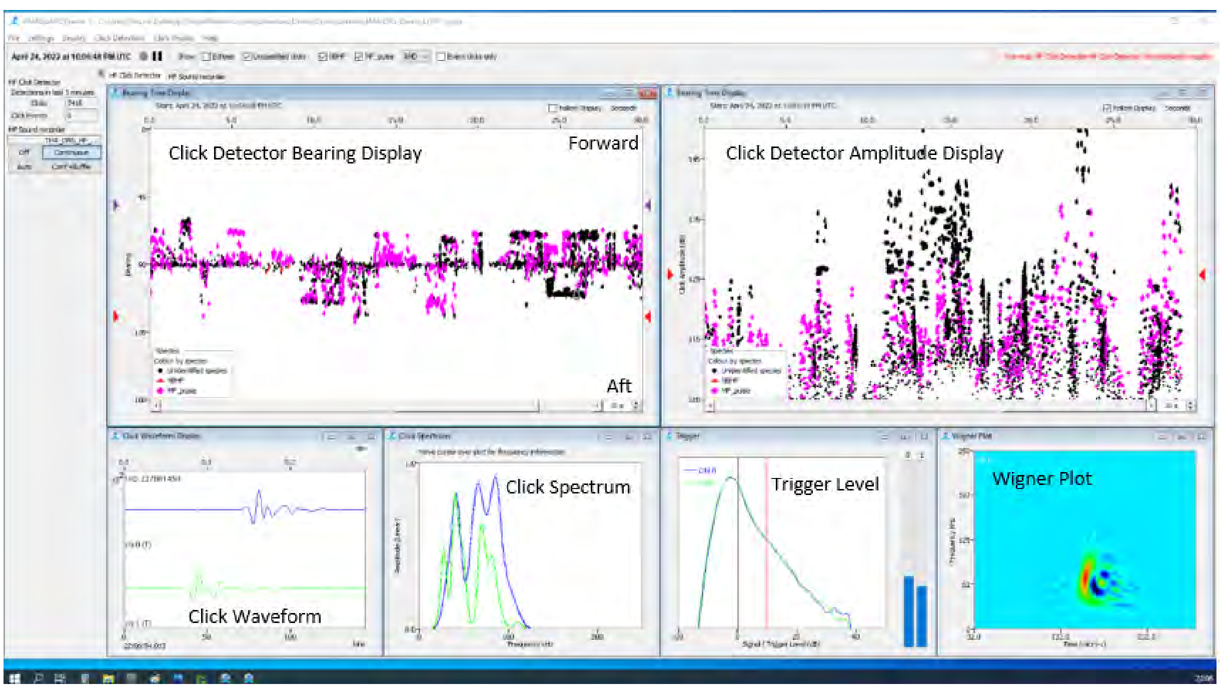


Figure 13. PAMGUARD image shows high frequency click detector with numerous dolphin clicks.

Detections were monitored until vocalizations were no longer detected aurally and/or visually in PAMGUARD. An acoustic detection was defined as any acoustic event during which cetacean vocalizations were aurally and/or visually observed in PAMGUARD, regardless of the total duration of the event. Cetacean vocalizations from the same species or general classification (unidentified dolphin, for example) detected greater than 15 minutes apart were considered separate detections.

3.4. Results

3.4.1. Acoustic Sound Source Testing

The acoustic sound source testing allowed for the transmittal of known acoustic noise into the water, at a set frequency, pattern, location, source level, and time, in order to determine the capability of the acoustic array to detect, identify, and localize the sound. The J9 broadcasted test tones (narrowband, NARW, and humpback) for a run time of 463 minutes (Table 4). TM analysts held 99%-100% of the time with no recorded massive or minimal loss of holding. The automated classifier onboard the TM advanced PAM system units detected 412 of the estimated 1287 J9-broadcasted NARW calls during the testing period, with an average detection rate of 32%, and with a range from 18.3-49.8% (Table 5). Of the total detections from the classifier there was a single spurious detection, giving the classifier a 99.998 % classification accuracy. TM ACINT specialists corrected all incidents of misclassified detections; thus, no false detections with associated whale locations were delivered. See Figure 12 for examples of test sounds as visualized in the ThayerMahan acoustic software. Localizations are provided in appendix D.

Table 4 – Sound Source Testing by timestamp (October 10th), event, acoustic sensor position, vessel position, distance, and bearing; OBCR is a constant tone at a set frequency; NARW is the north Atlantic right whale, and the humpback tone is humpback whale song.

Timestamp	**Event**	Acoustic Sensor (Vehicle) Position		Vessel Position		Distance	Bearing (Vehicle to Vessel)
		Lat	**Lon**	**Lat**	**Long**	**Meters**	**Degrees**
T18:15:00	Event 1: OBCR1 Tone Start	42.10	-69.69	42.09	-69.66	1989	119
T18:31:00	Event 2: OBCR1 Tone Secure	42.10	-69.68	42.09	-69.66	2093	118
T18:31:00	Event 3: NARW Tone Start	42.10	-69.68	42.09	-69.66	2093	118
T18:36:39	Event 4: CTD Cast	42.10	-69.68	42.09	-69.66	2026	118
T19:26:24	Event 5: NARW Tone; reduce Source level	42.09	-69.67	42.09	-69.65	1665	120
T20:04:26	Event 6: NARW Tone; reduce Source level	42.10	-69.66	42.09	-69.65	1402	124
T21:12:25	Event 7: NARW Tone Secure	42.10	-69.65	42.10	-69.64	885	117
T21:12:25	Event 8: Humpback Tone Start	42.10	-69.65	42.10	-69.64	885	117
T21:17:14	Event 9: Humpback Tone Secure	42.10	-69.65	42.10	-69.64	764	114

Table 5 – Detection rate of J-9 North Atlantic right whale (NARW) signals

Date/Time	**J9 Activity**	**Classifier Detects**	**J9 Rate (approx.)**	**Percent Detected**
20221010T1830-1926	NARW - 150dB	135	271	49.82%
20221010T1926-2004	NARW - 147dB	37	140	26.43%
20221010T2004-2112	NARW - 145dB	82	341	24.05%
20221013T0000-0052	NARW - 148dB	55	301	18.27%
20221013T0115-0200	NARW - 150dB	103	234	44.02%

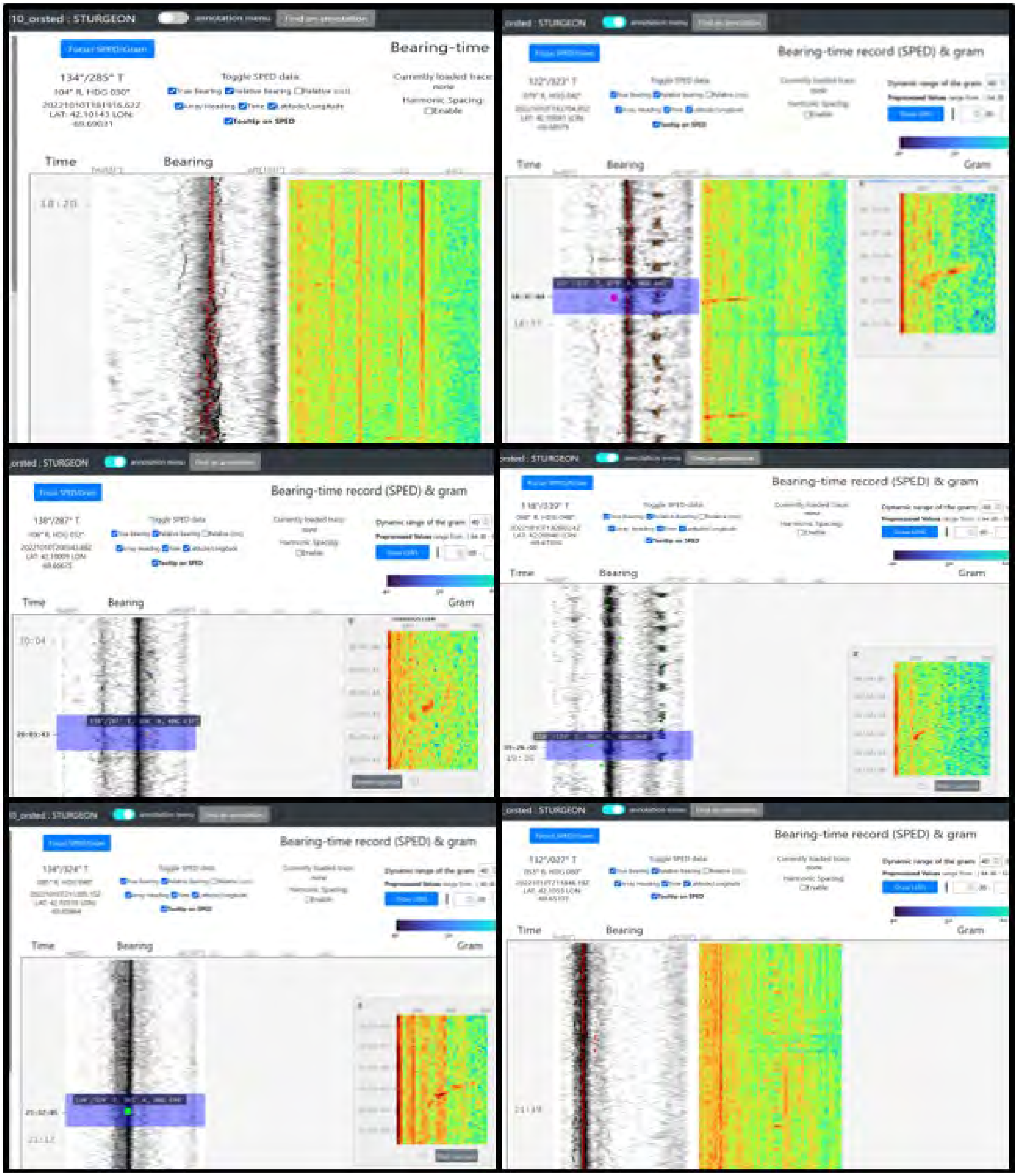


Figure 14 – Sound Source testing; Upper Left- Event 1, OBCR 1 Tone Start, Upper Right – Event 4: CTD Cast while NARW Tones Transmitted, Middle: Events 5 and 6, NARW Tone Transmission, Lower Left: Last NARW Transmission and switching to Humpback Tones, Lower Right: Humpback Tone Secured

3.4.2. *Advanced and Standard Acoustic System Offshore Field Tests: Rate and Probability of Detection*

Detection rate was calculated as the number of detections per survey hour (Smith et al. 2020) for the entire demonstration period, broken into the three study areas (North, South, and Cape Cod Bay). Detection rates were calculated for PAM detections made independently of the PSOs (i.e., detections not verified by the PSOs). We determined detection rates were “significantly different” if the 95% confidence intervals for both estimates did not contain the value of the other estimate under comparison.

The advanced ThayerMahan PAM system detection rates were significantly higher than those derived from the standard Seiche PAM system (Figure 13), indicating that the advanced TM acoustic systems detected significantly more marine mammal acoustics than the industry standard Seiche PAM .). Overall, the Seiche PAM hourly detection rates were 0.19 (95%CI: 0.03–0.35) versus 0.81 (95% CI: 0.46–1.15) for the TM acoustic systems-- an estimated 326% difference. Similar patterns were evident across North and South study regions (Figure 13 This conclusion assumes that the two systems have approximately the same false positive rates, though this assumption has not yet been examined. The difference in performance between systems was likely due to several factors including the ability of the advanced TM acoustic system to detect signals at a greater distance using a multi-channel array and that vessel engine noise likely contributed to masking the standard Seiche PAM’s ability to detect baleen whale vocalizations.

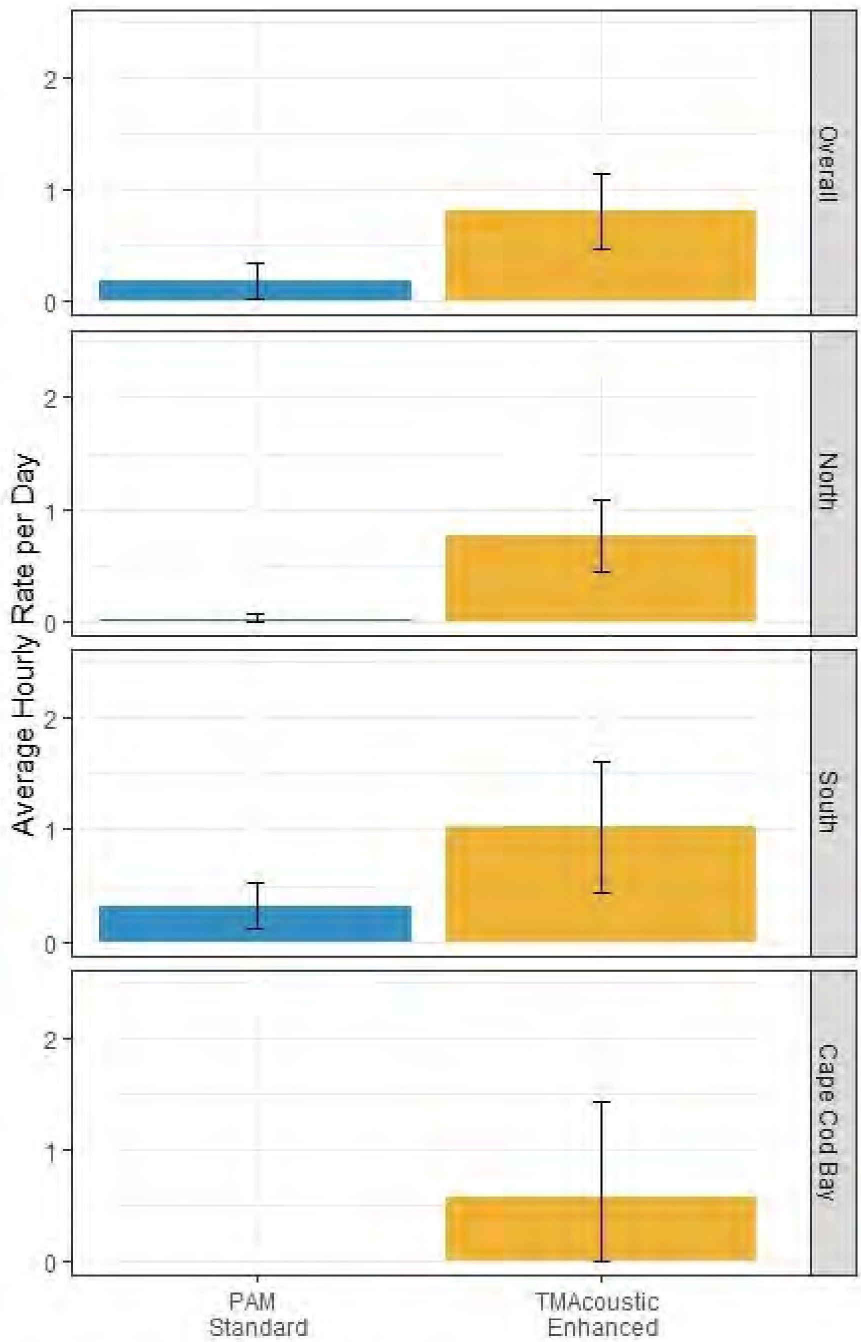


Figure 15 – Marine mammal detection rates for acoustic monitoring during the day from Seiche passive acoustic monitoring (PAM) and ThayerMahan advanced acoustic system. Error bars reflect the 95% confidence intervals. Note the standard PAM system was not operational in Cape Cod Bay which is not equivalent to a 0 value for detection rate.

3.5. Conclusions

3.5.1. *Identification: Real-time Automated Classification and Differentiation*

Figure 14 depicts six examples of spectrogram tiles recorded in the Digital Signal Processor (DSP) output log on WaveGlider MARY R, which was instrumented with a 32-channel towed array cut to 600 Hz, during sound source verification tests conducted on 15 April. Each gram tile corresponds to a NARW upcall transmitted by the J-13 source that was successfully detected and classified autonomously in real-time. These gram tiles pictured in Figure 14 give a qualitative measure of the signal-to-noise ratio (SNR) at the beamformer output associated with each detector report. Though not pictured here, the NARW detection reports logged by the DSP and transmitted shoreside via BGAN satellite also report on the SNR and confidence score associated with each real-time detection. Notice that the detected J-13 source transmissions are partially contaminated by radiated noise (ambient sound seen as orange and red pixels throughout spectrograms) from the support vessel's diesel generators. Due to the *de minimus (or played at the highest level that cannot cause potential marine mammal harm)* source level limit, and the noise contamination from the support vessel.

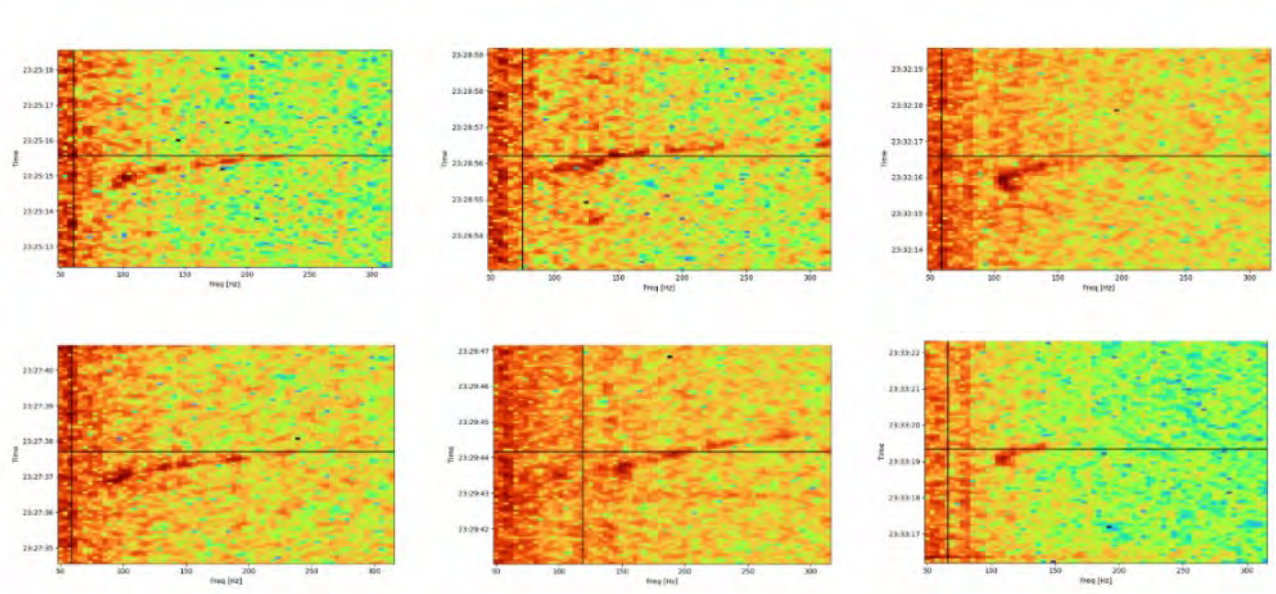


Figure 16 – Classifier gram tiles illustrating support for real-time Right Whale upcall auto-detector decisions.

3.5.2. *Detection Distance: Long Range Situational Awareness*

TM systems showed the ability to detect marine mammals from extremely long distances. In Figure 15, simultaneous detections on both the MARY R and AVON Wave Gliders produced an Area of Uncertainty (AOU) about 22 NM (40.7 km) from MARY R. This provided a high number of acoustic detections and demonstrated the system's capability.

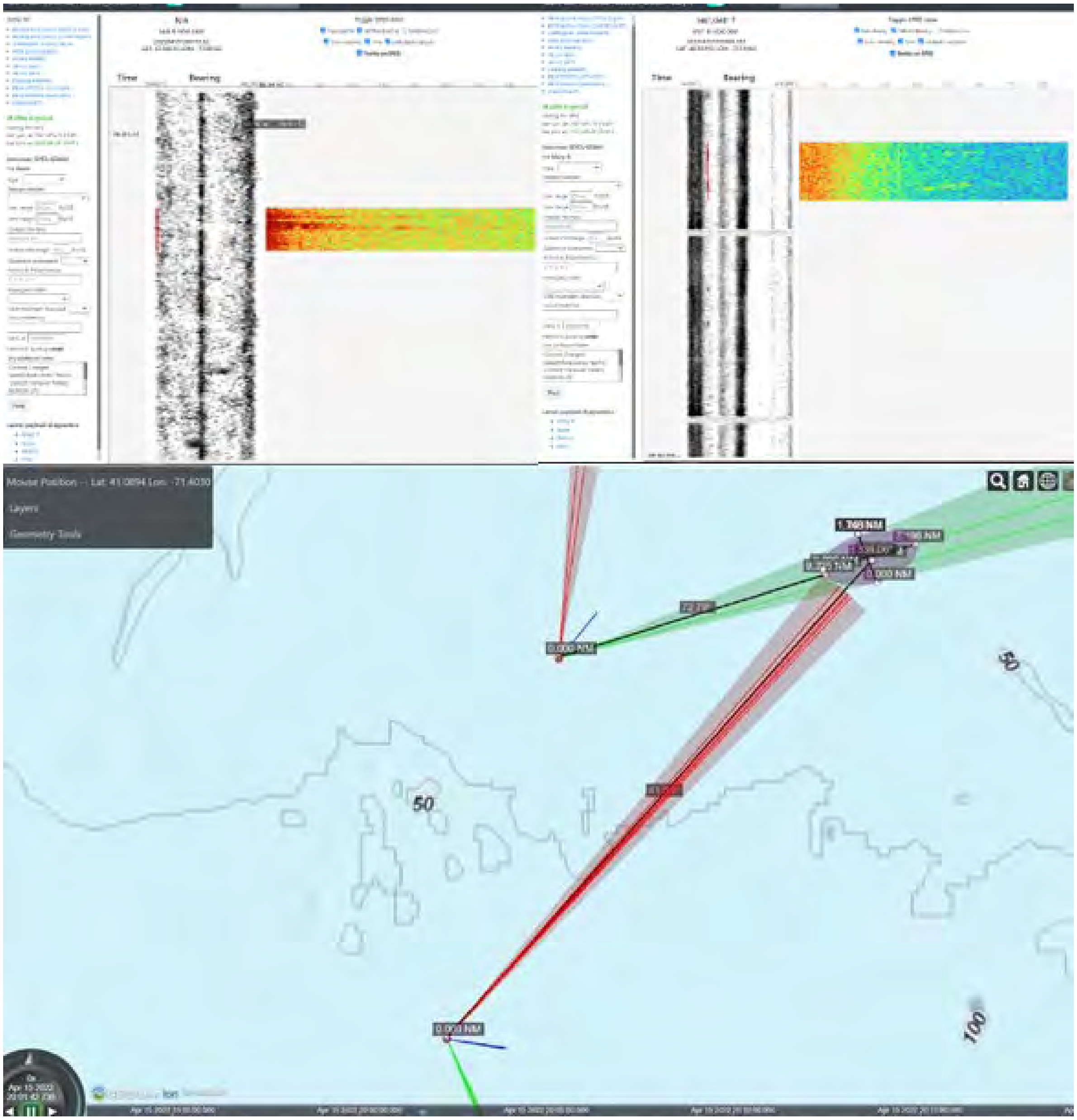


Figure 17 – Simultaneous Detections on MARY R and AVON; detection distance estimated at approximately 22 NM from MARY R.

Independent monitoring assets deployed by other research organizations such as WHOI and NOAA corroborated long range detections of vocalizing whales by TM acoustic systems. Figure 16 depicts detections of NARW made by the WHOI Martha's Vineyard Buoy (left panel), with near simultaneous detection by AVON (middle and right panels). Of note, some additional biological transients down bearings were detected by AVON and not detected by the WHOI buoy, which showed to be closer to the WHOI buoy.

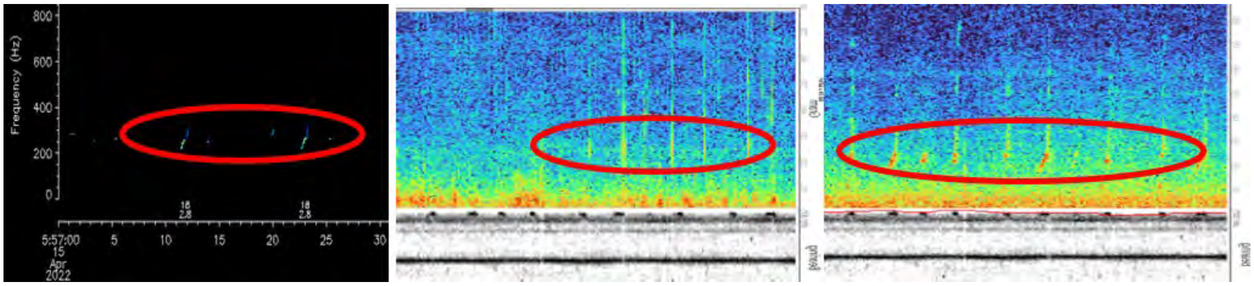


Figure 18 – Spectrograms showing detections at 4/15 from 0557.00 to 05557.30. Left - WHOI Martha's Vineyard Buoy, Middle: AVON Detections at bearing 200˚T/240 ˚T; Right: AVON Detections at 075˚T. Time differences between the WHOI buoy and AVON are due to different distances between the vocalizing whale and the acoustic receivers.

3.5.3. Localization: Localizing and Tracking Marine Mammals

The TM Enhanced Acoustic systems provided whale acoustic detections at exceptionally far ranges (20km to 30km) relative to industry standard (5 km). As described in methods (3.3.2.1), TM ACINT specialists reviewed incoming detections made by the classifier. Figure 17 (15 April) illustrates an example of concurrent detections. The ACINT comprehensively reviewed acoustic information on each system (SeaPickets: AVON and BRISTOL; wave glider: MARY R) and used that to push the contact into Mission Data. As shown in Figure 18, the ACINTs successfully conducted localization of these three sensors to create an Area of Uncertainty (AOU) within Mission Data. In this case, the sound source was localized within a 2 NM (3.7 km) by 5 NM (9.3 km) ellipse.

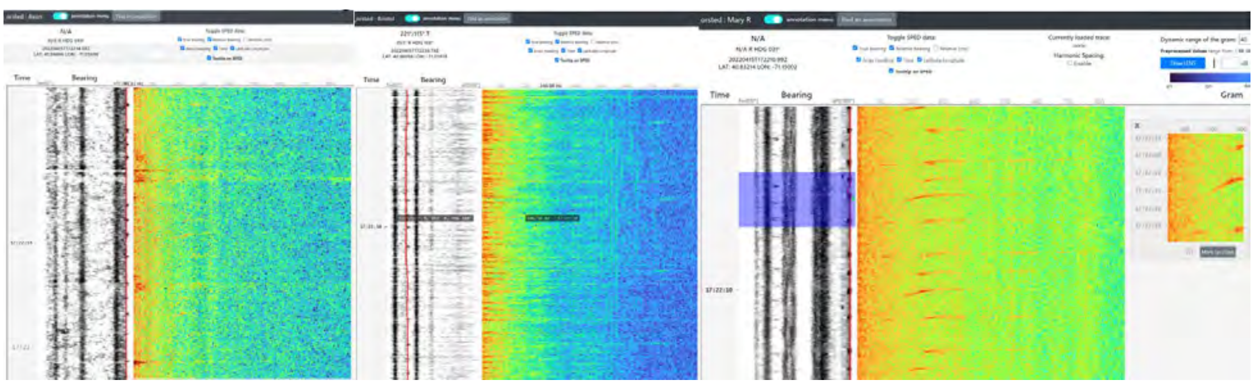


Figure 19 – Simultaneous Acoustic Detection across three platforms (AVON, BRISTOL, and ELLEN). Note the bearing to each detection and that MARY R's system had an autodetection.

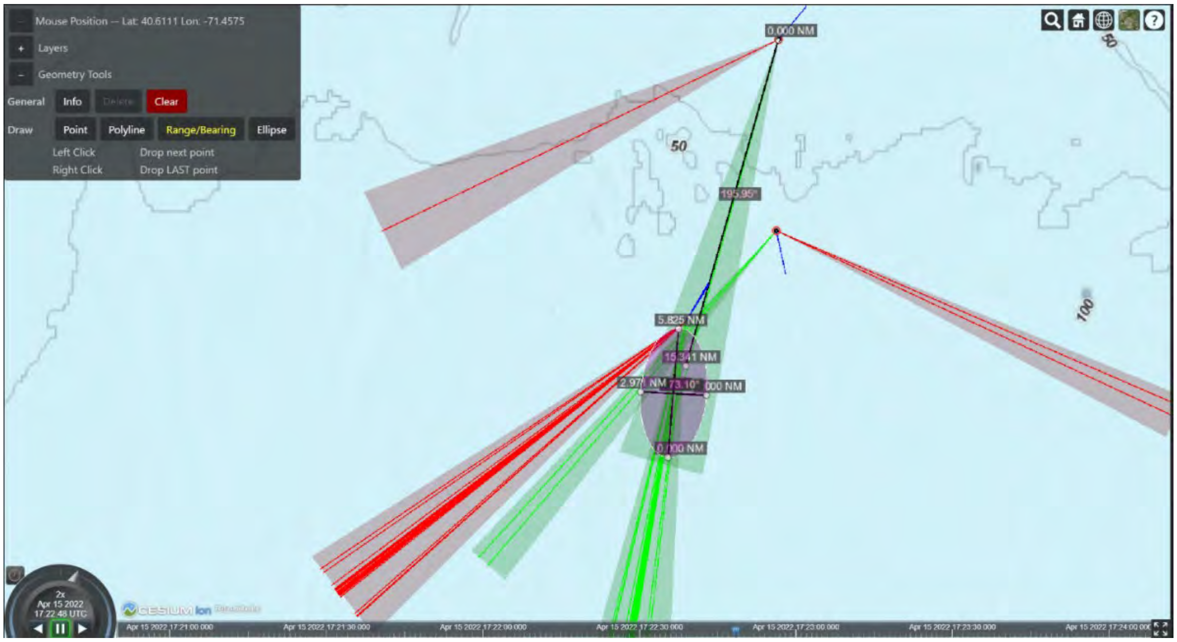


Figure 20 – Localization using three sensors (AVON, BRISTOL, and MARY R). The distance to AVON was approximately 15NM, BRISTOL was approximately 7 NM, and MARY R was approximately 5 NM.

3.5.4. Environmental Conditions: Performance of TM Advanced PAM System in Typical Offshore Sea Conditions

During the spring demonstration period of April 15-29 the SeaPicket systems performed extremely well physically. The acoustic systems functioned effectively throughout the operation period, in wave heights up to 16ft (Figure 19), with battery power persistently above 90%, and remaining in operation throughout all conditions. This included periods of reduced visibly (with 100% cloud cover) and heavy rain. Throughout inclement conditions, the acoustic data analysis, transmission, and detection report generation continued without interruption. When seas increased beyond a sea state of 6 (very rough conditions with wave heights exceeding 13-20 ft), for example April 19-20, ambient ocean noise from surface wave action made acoustic data unusable. Because offshore wind farm construction and vessel transport is expected to pause beyond a sea state of 5, this demonstrated successful operational performance capability of the system through sea states that could be experienced by transiting vessels and construction activities.

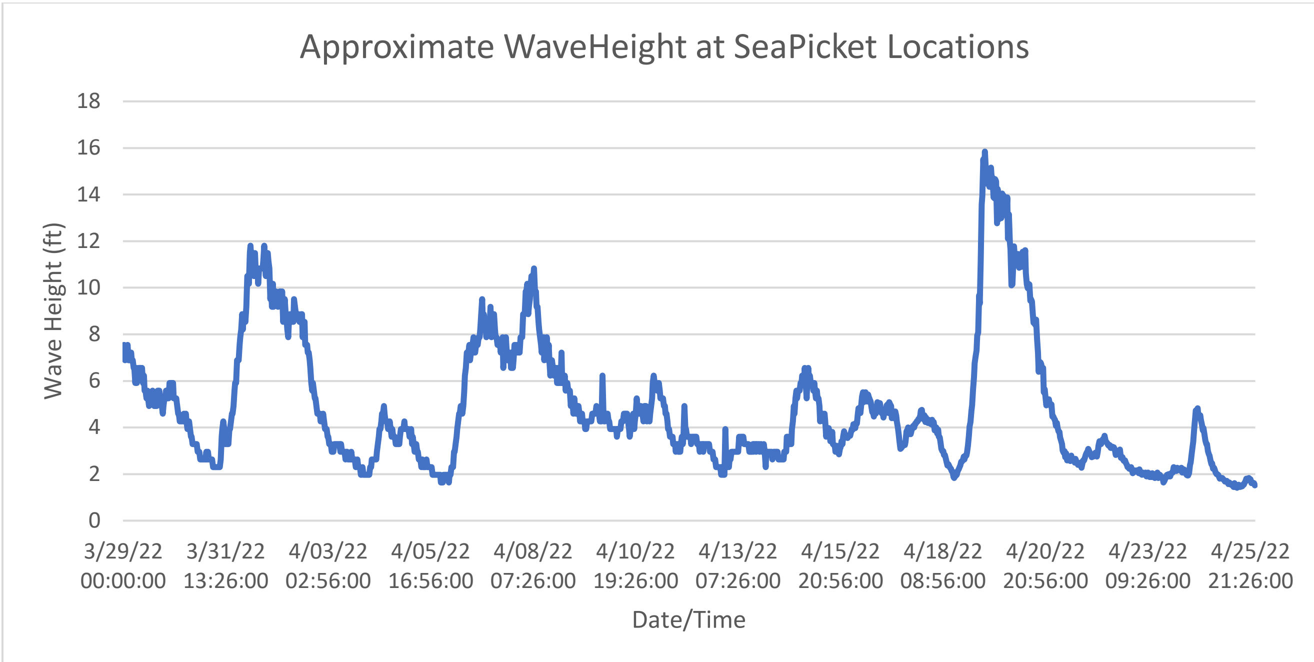
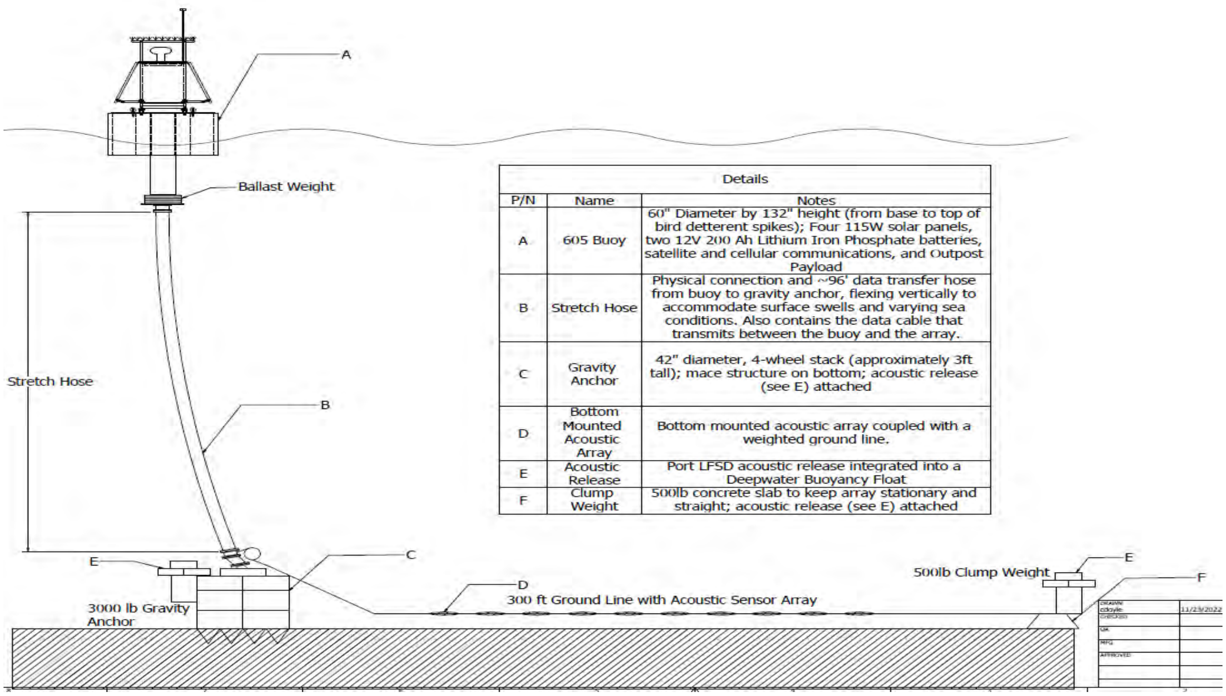


Figure 21 – Wave height at NOAA Buoy 44097, approximately 9 km from both SeaPickets

4. Future Applications

4.1. SeaPicket Improvements

Since field tests conducted in 2022, ThayerMahan has improved several aspects of the *SeaPicket*. Most notably, the mooring system was changed from a dual point to a single point. During additional at-sea tests conducted in October 2022, a new stretch hose configuration that integrates the mooring and data cables into a single line was tested and determined to be a more practical system design, including a reduced potential for entanglement risk. This configuration is commonly used on other acoustic buoy systems (such as those used by Cornell to support NARW detections along shipping lanes near Boston, MA).



Details		
P/N	Name	Notes
A	605 Buoy	60" Diameter by 132" height (from base to top of bird detterent spikes); Four 115W solar panels, two 12V 200 Ah Lithium Iron Phosphate batteries, satellite and cellular communications, and Outpost Payload
B	Stretch Hose	Physical connection and ~96' data transfer hose from buoy to gravity anchor, flexing vertically to accommodate surface swells and varying sea conditions. Also contains the data cable that transmits between the buoy and the array.
C	Gravity Anchor	42" diameter, 4-wheel stack (approximately 3ft tall); mace structure on bottom; acoustic release (see E) attached
D	Bottom Mounted Acoustic Array	Bottom mounted acoustic array coupled with a weighted ground line.
E	Acoustic Release	Port LFSD acoustic release integrated into a Deepwater Buoyancy Float
F	Clump Weight	500lb concrete slab to keep array stationary and straight; acoustic release (see E) attached

Figure 22 - SeaPicket with single mooring system

4.2. Detection Range Predictions for the Vineyard Wind Transit Route

To assist with asset allocation and planning for the passive acoustic monitoring of marine mammals near the Vineyard Wind transit lane operations, we modeled detection ranges for the SeaPicket system in the construction and operation/maintenance (OM) vessel transit lanes for Vineyard Wind.

4.2.1. Assumptions

Emphasis was placed on the North Atlantic Right Whale (NARW) upcall[1] using a parabolic equation (PE) transmission loss model[2] and range dependent bathymetry. From standard passive sonar equation reconciliation analysis, we can derive a figure of merit (FOM) for the transit lane environment as follows,[3]

$$FOM \equiv TL = SL - (NL - AG) - NRD, \quad (1)$$

where *TL* represents transmission loss, *SL* is the root mean square source level of the upcall, *NL* is the in-band ambient noise level at the hydrophone, *AG* denotes the array gain, and *NRD* is the system recognition differential, or SNR at the beamformer output required to yield the desired receiver operating point. The FOM can be interpreted as the maximum transmission loss the system can tolerate under the given assumptions for SL and NL and still meet the desired level of detection performance.

Using eq. (1), FOMs were computed for both a 32-channel hydrophone array cut to a design frequency of 300 Hz, and a single hydrophone, based on the following assumptions and model inputs:

- North Atlantic right whale up-call rms source level of 172 dB re $1\mu Pa^2$ @ 1 m.[4] NARW is assumed to be in the upper water column.

- Ambient noise spectrum level at hydrophone of 78 dB re $1\mu Pa^2/Hz$ corresponding to Wenz moderate shipping[5] at 300 Hz. This is supported by recent data collections.

- Upcall bandwidth of 200 Hz, which yields a total in-band noise level of 101 dB re $1\mu Pa$ (i.e., 78 dB + $10\log_{10}\Delta f$).

- Noise is assumed to be spatially isotropic. Isotropic noise assumption implies a theoretical array gain of $10\log_{10} N$, or 15 dB, for a 32-channel array at the array design frequency. This is a conservative estimate of array gain in a cluttered noise environment (due to anticipated shipping traffic).

- Nominal amount of array signal gain degradation (~ 1 dB) due to unmodelled array shape deviation from straight line yields a net array gain of 14 dB. Array is assumed to be bottom-mounted.

- In-band noise level at the array output is, therefore, NL - AG = (101-14) = 87 dB re $1\mu Pa$.

- Finally, an NRD of 7 dB is assumed based on our current NARW classifier development which imposes a 7 dB SNR threshold on any broadband spectral feature presented as a candidate for consideration by the spectrogram correlator-based NARW upcall classifier.

Substituting these values into eq. (1) yields a FOM of 78 dB for the hydrophone array, and 64 dB for the hydrophone. These FOM values are used in conjunction with the PE transmission loss model output to project 50% probability of detection range contours for each of the proposed SeaPicket locations under consideration for the Vineyard Wind transit lanes for construction, operations, and maintenance.

4.2.2. Vineyard Wind Transit Lane Predictions

Figure 21 shows detection range predictions for the three SeaPicket configuration in the construction vessel transit lane from New Bedford MA to the VW lease area. The colored contours depict 50% probability of detection range corresponding to the calculated FOM of 78 dB for the 32-channel array mounted on the seabed. Equivalent detection contours for a single hydrophone system at mid-water column depth corresponding to the 64 dB FOM are depicted in gray. The maximum detection ranges for SeaPicket 1, 2 and 3 are 22.3, 24.6, and 26.7 km, respectively, while maximum detection ranges for the single hydrophone are 9.6, 9.5, and 9.2 km, respectively.

As expected, transmission loss increases, and thus detection range degrades, as the bathymetry shoals to the northwest of the lease area toward Vineyard Sound, and eventually Buzzards Bay.

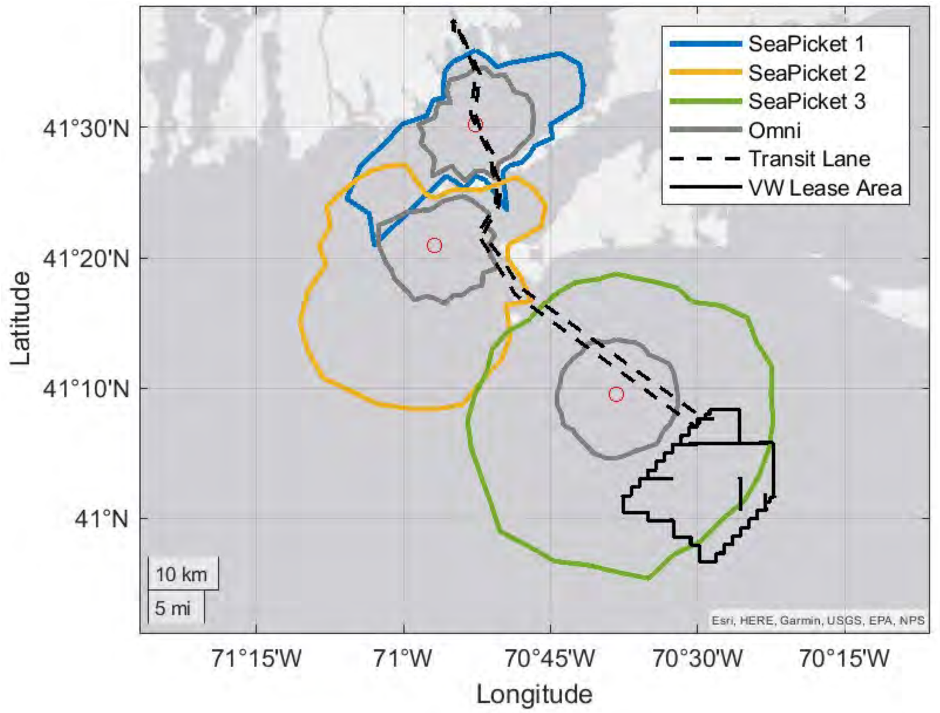


Figure 23 - NARW detection range predictions at 300 Hz for the construction vessel transit lane for SeaPicket 1 (blue), SeaPicket 2 (yellow), and SeaPicket 3 (green), respectively. The colored contours depict 50% probability of detection range contours corresponding to the calculated FOM of 78 dB for the 32-channel array. Single hydrophone detection contours corresponding to the 64 dB FOM are depicted in gray. The maximum detection ranges for the three arrays are 22.3, 24.6, and 26.7 km, respectively. Maximum detection ranges for the single hydrophone are 9.6, 9.5, and 9.2 km, respectively. The Vineyard Wind lease area is delineated in black.

Figure 22 shows detection range predictions for the four SeaPicket configuration for the construction vessel transit lane—the additional SeaPicket is depicted in purple and is proposed at the boundary between the detection contours of SeaPickets 2 and 3. This additional location will support overlapping coverage over a large tract to the southwest of the southern half of the transit lane, enabling localization of NARWs in this area. The maximum detection ranges for the four arrays are 22.3, 24.6, and 26.7 km, respectively as before, and 27.8 km for the fourth array. Maximum detection ranges for the single hydrophone are 9.6, 9.5, 9.2, and 9.0 km, respectively.

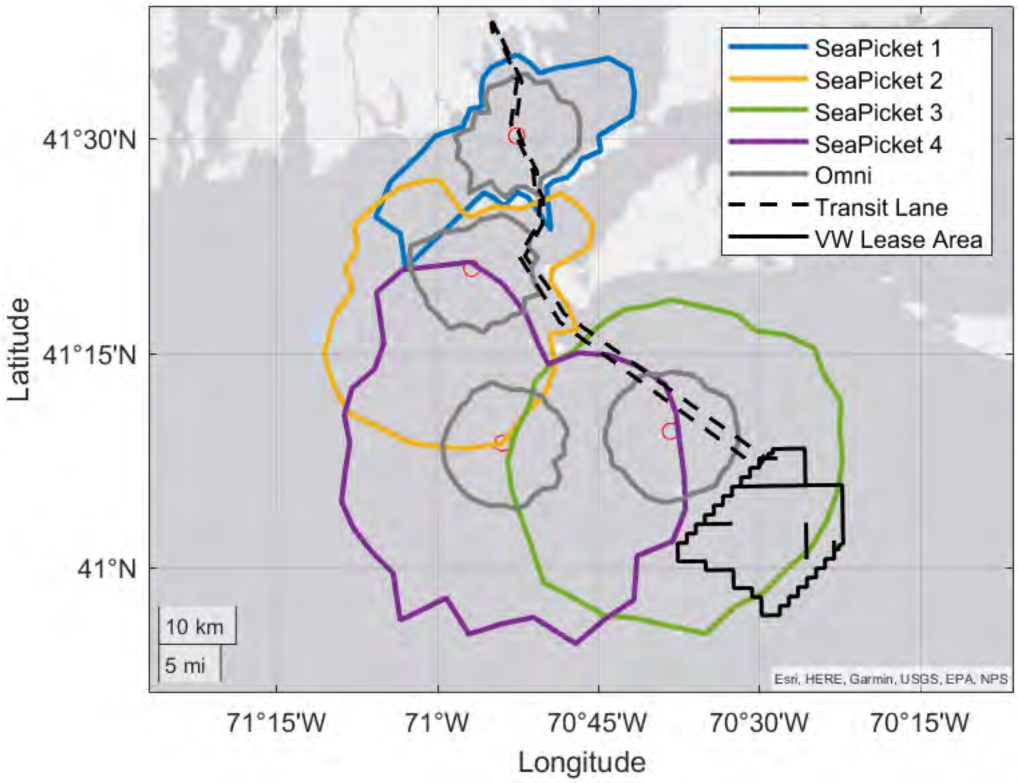


Figure 24 - NARW detection range predictions at 300 Hz for the construction vessel transit lane for SeaPicket 1 (blue), SeaPicket 2 (yellow), SeaPicket 3 (green), and SeaPicket 4 (purple), respectively. The colored contours depict 50% probability of detection range contours corresponding to the calculated FOM of 78 dB for the 32-channel array. Single hydrophone detection contours corresponding to the 64 dB FOM are depicted in gray. The maximum detection ranges for the three arrays are 22.3, 24.6, 26.7, and 27.8 km, respectively. Maximum detection ranges for the single hydrophone are 9.6, 9.5, 9.2, and 9.0 km, respectively.

4.2.3. Geo-acoustic Model Inputs

The sound speed profile employed in the PE model calculations, shown in Figure 23, was a typical summertime downward refracting profile taken from the World Ocean Atlas.

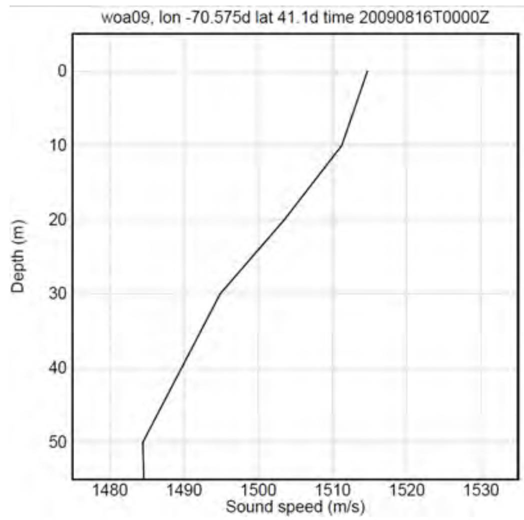


Figure 25 Sound speed profile employed in the PE model calculations

Seabed geoacoustic properties used in the transmission loss model are listed in Table 6.

Table 6 - PE Seabed model parameters

GEOACOUSTIC		usSEABED	
RB		0.0	
ZB	CB	0.0	1719.0
…	…	3.0	1800.0
-1	-1	-1	-1
ZR	RHO	0.0	1.946
…	…	3.0	2.03
-1	-1	-1	-1
ZA	ATTN	0.0	0.708
…	…	3.0	0.057
-1	-1	-1	-1

The bathymetric data in the transit lane area was extracted from the GEBCO 2022 database, a bathymetry data set developed through the Nippon Foundation-GEBCO Seabed 2030 Project (https://www.gebco.net/data_and_products/historical_data_sets/). The GEBCO database provides bathymetric data, in meters, on a 15-arc-second interval grid.

Note that range dependence in the TL model is only represented via the bathymetric data. Sound speed profile, seabed description, and ambient noise values are assumed to be range independent and the same values are applied for each SeaPicket location.

4.2.4. Summary

ThayerMahan presented predictions for NARW detection coverage using SeaPicket bottom mounted arrays for vessel transit lane monitoring during the construction and operations/maintenance phases of the Vineyard Wind project. Model parameters were selected to reflect realistic geo-acoustic environment properties and actual bathymetric variables to yield detection performance predictions that are as accurate to the deployment site as possible. Model results depict detection ranges in excess of 20 km in most cases, although exceptions do occur for the extremely shallow water depths encountered in Vineyard Sound, Buzzards Bay, and Muskeget Channel where ranges decrease significantly.

The proposed system will provide detection coverage sufficient to effectively and efficiently monitor the presence of NARWs during the VW construction periods. Detection range estimates are believed to be conservative, as they employ Wenz moderate to high shipping noise levels and an isotropic noise assumption. We expect actual detection performance during operations to be superior than the conservative model predictions, given anticipated anisotropy of the acoustic clutter distribution. Uncertainty in detection range estimates will be refined as we acquire actual acoustic data, e.g., detection, transmission loss, and ambient noise, in the operating environment. Structured calibrated source tests conducted at representative NARW source levels are needed to support the most rigorous quantification of real-time PAM detection performance that minimizes excessive reliance on models. This would need to be conducted beyond the de minimus testing done during field operations.

4.3. Classifier Evaluation Post-Field Work

The NARW classifier was constructed on a NARW recording from the 2013 St. Andrews DCLDE Workshop data set. This is the only data for which there is universally agreed upon ground truth NARW annotation by an independent expert analyst. The ThayerMahan spectrogram correlator uses an an acoustic kernel library developed from independent training data of NARW upcalls (exclusive of test data). The kernel threshold was empirically selected to yield a FAR (False Alarm Rate) of 1.25 per day (0.05 per hour) across all kernels in the library, or equivalently 5 FAs over the 96-hour NARW absent data set in the 2013 DCLDE distribution.

TM's early Pcc (probability correlation coefficient) vs SNR (signal to noise ratio) results corresponding to this FAR are summarized below (in blue) in Figure 26. This was implemented in MATLAB, but the real-time C language implementation in the onboard classifiers has been verified to yield very similar results to the MATLAB prototype. For comparison, the Python implementation of the Baumgartner and Mussoline (JASA 2011) feature-based NARW upcall classifier is also depicted (in red)—this slide has been shown to Baumgartner in a private communication during the 2022 DCLDE workshop held in Honolulu, HI. The Baumgartner-Mussoline result is regarded by some as state of the art for NARW autodetection. The TM spectrogram correlator outperforms the Baumgartner classifier by about a factor of 2-3x in positive coverage for the fixed FAR of 1.25 per day.

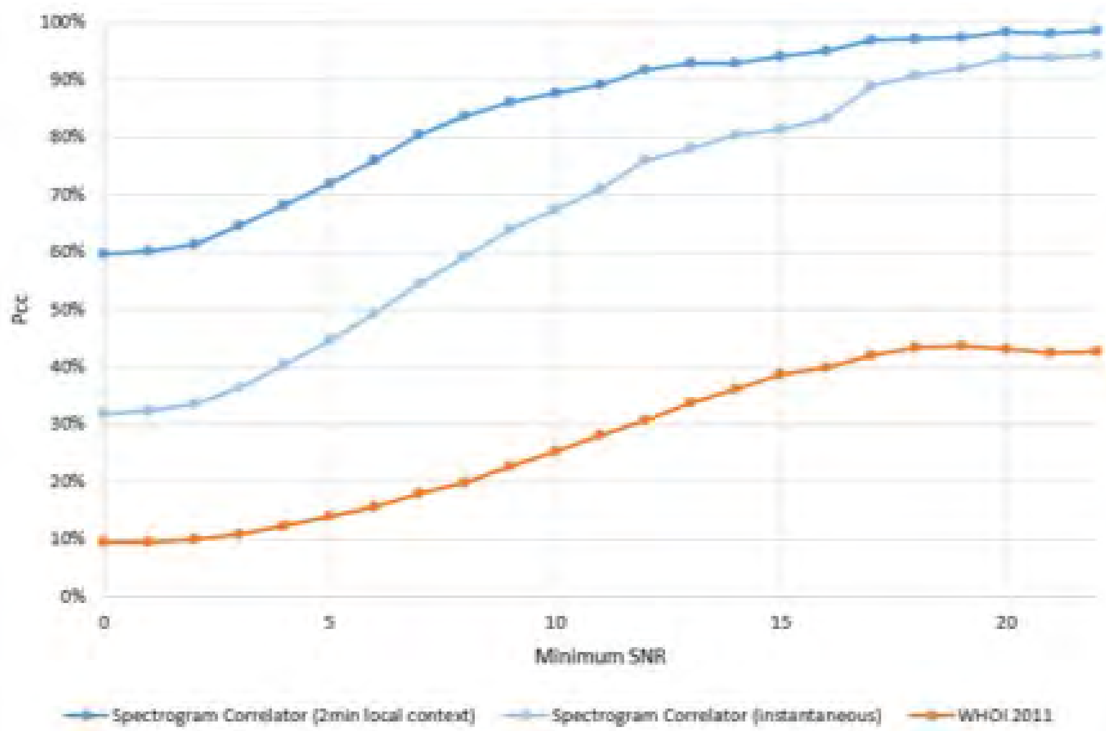


Figure 26 - Pcc vs SNR for Spectrogram Correlator (2 min local context), Spectrogram Correlator (instant), and WHOI 2011

ThayerMahan also derived False Positive Rate vs. Recall curves for our classifier using the St Andrews DCLDE 2013 NARW vocalization dataset . This is overlaid in Figure 27 on Shiu et al (2020), a more recent machine learning NARW upcall based model that is also viewed by many as the current state of the art (e.g. Palmer 2020):

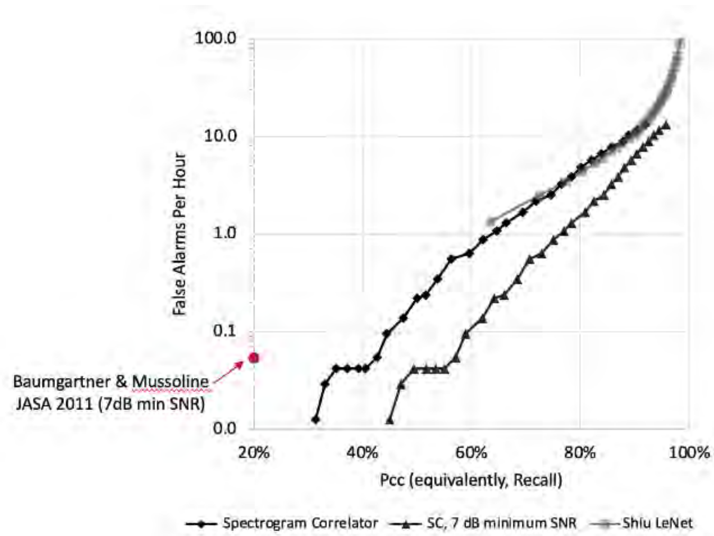


Figure 27 False Alarms per Hour vs Pcc for Spectrogram Correlator

The TM classifier over the entire data set (all SNRs) performed similarly to the best performing Shiu et al model, LeNet. If a minimum SNR of 7 dB is enforced (our recommended pre-screening condition which is employed in our real-time system), the TM classifier outperforms Shiu by a 10x reduction in false positive rate for a Recall (Pcc) just above 60%. Further, under the 7 dB minimum SNR condition, the TM classifier outperforms Baumgartner-Mussoline by a factor of 3x in Pcc for a false positive rate of 0.05/hour.

TM has qualitatively assessed the classifier performance using data collected on our bottom-mounted array and towed arrays from the field demonstration performed in Spring of 2022. An example from one of the bottom-mounted arrays (AVON) is shown below in Figure 28, a 1 minute excerpt from a 24-hour period on 31 March 2022. In this excerpt, 3 NARW up calls are clearly classified correctly and distinguished from broadband noise transients known to be not of biologic origin. Analysis of data from the companion SeaPicket bottom-mounted array, Bristol, during that same demo yielded FAR of 0.5/hour/32 beams, or 12 per day. With the benefit of the supervision of a trained TM analyst, we believe the ThayerMahan system FAR could be reduced to nearly zero.

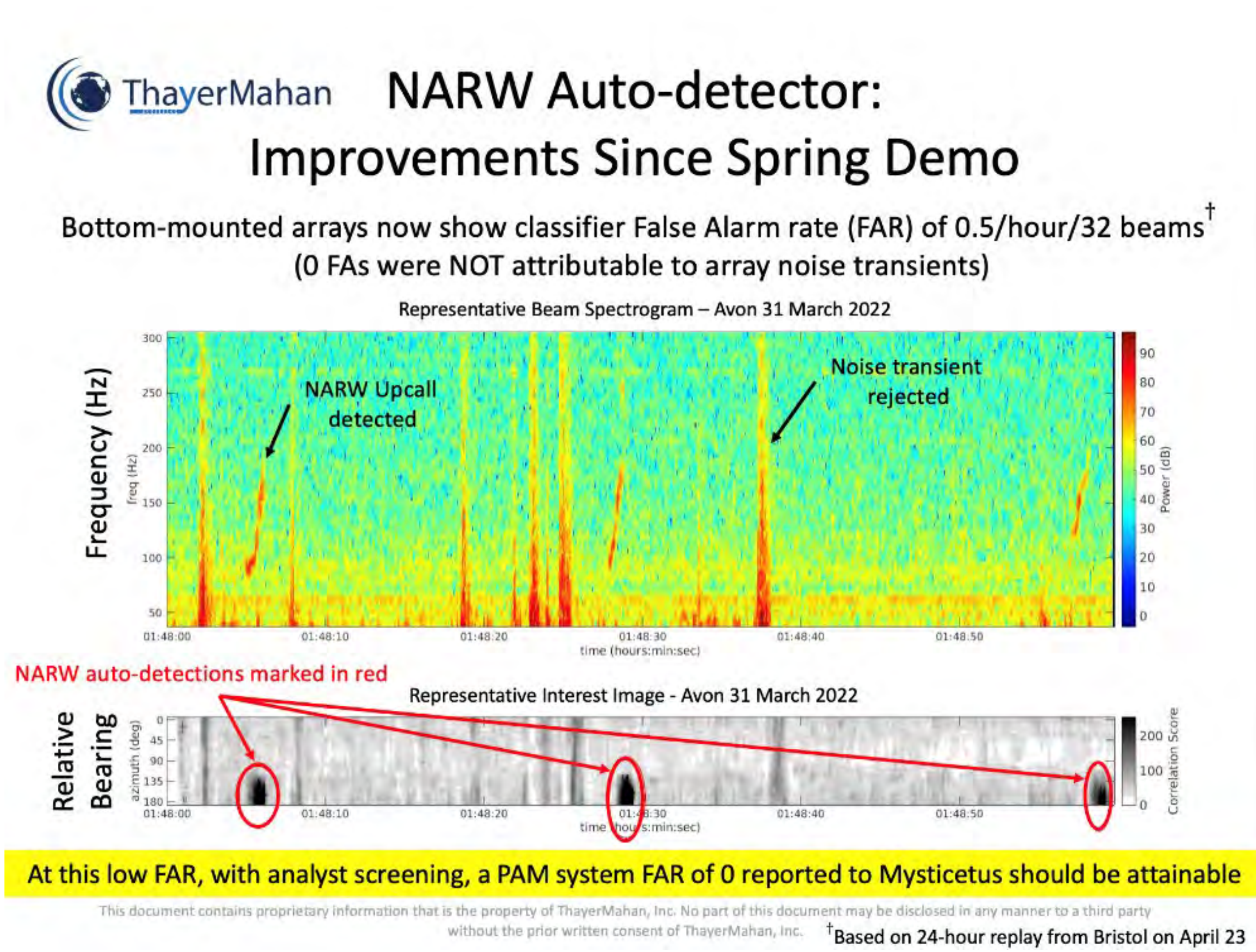


Figure 28 - NARW Auto-detector improvements

A more robust quantitative performance analysis of the TM classifier using data collected during the 2022 Orsted demo is pending completion of ground truth annotation. This is a considerable effort, far greater than the truthing of a single hydrophone data set, given the need to curate as many as three arrays capable of forming on the order 32 beams each over the course of multiple weeks—approximating a 100-fold increase in data rate relative to a single hydrophone.

Results from the ThayerMahan NARW classifier analysis, summarized above, will be submitted to the Journal of Acoustical Society of America (JASA) later this year.

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Appendix B: Acoustic Equipment Specifications

Seiche 4–Channel Passive Acoustic Monitoring System

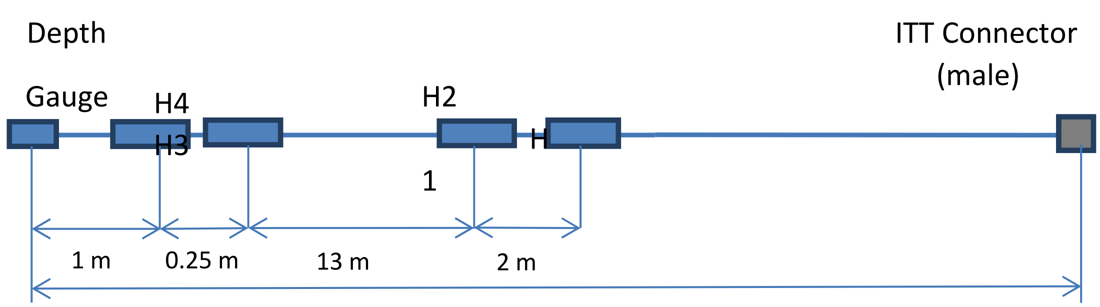
Seiche PAM systems can be custom designed for optimal demonstration performance. The hydrophone arrays can be tuned and manufactured to the required length for the target application. Typically, the sensor array isconstructed with 4 hydrophones and terminated with a depth sensor. The array has a total length of 250m for deployment behind the vessel. The length ensures sufficient distance from the vessel to detect vocalizations above the vessel's self-generated noise. The hydrophones are designed with pre-determined separation to allow for comprehensive detection of a broad range of mammals, covering high and lower sound frequencies. Frequency bandwidths and customized gains can also be incorporated, and electronic processing can be tailored to meet demonstration requirements. For instance, the installation of localremote monitoring to allow PAM monitoring from the bridge vessel or bespoke solutions to allow integrated multi-channel processing.

Typical array configurations include:

- 250 m Towed Array. This is our standard system which is built durability and versatility.
- 100 m Deck Cable. Used for all array options, providing easy and flexible interconnection between the array sections and on-board electronics.
- Electronic Data Capture & Processing Unit. Interface between the array and the user.
- Cetacean Detection and PAM Guard Software. Detection localization and classification of vocalizing animals.

1.1 250 m Towed Array

Seiche's standard system which is built to be durable and versatile.



250 m

4-Channel hydrophone array specifications

Mechanical Information	
Length	250 m
Depth Rating	100 m (not connector)
Diameter	14 mm over cable. 32 mm over mouldings. 64 mm over connectors
Weight	60 kg
Connector	ITT 19 pin 65 mm over connectors

Hydrophone elements	
H1	200 Hz to 200 kHz (-3 dB points)
H2	200 Hz to 200 kHz (-3 dB points)
H3	2 kHz to 200 kHz (-3 dB points)
H4	2 kHz to 200 kHz (-3 dB points)

Hydrophone spacing		
Spacing H1 – H2 (LF detection)	2 m	1.28 mSecs
Spacing H2 – H3	13 m	8.32 mSecs
Spacing H3 – H4 (HF detection)	0.25 m	0.16 mSecs

Hydrophone sensitivity	
Broadband channel sensitivity	-166 dB re 1 V/µPa (nominal)
Standard channel sensitivity	-157 dB re 1 V/µPa (nominal)

1.2 100 m deck cable

The deck cable is used for all array options and provides easy and flexible interconnection between thearray sections and the on-board electronics.

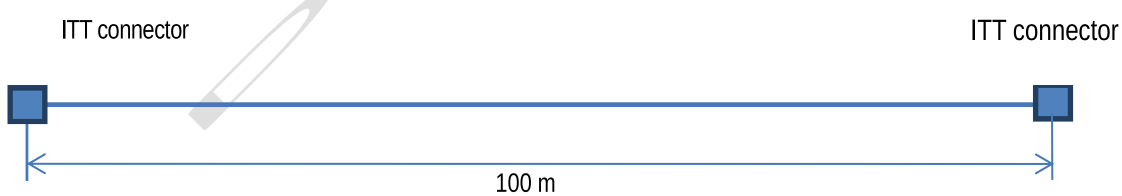


Figure 2: 100 m Deck cable Deck cable specifications

Mechanical Information	
Length	100 m
Diameter	14 mm
Connector	ITT 19 pin, 65 mm over connectors
Weight	25 kg

1.3 Electronic Data Capture & Processing Unit

This unit provides the interface between the array and the user. It houses the data capture and conversion electronics including a buffered input stage, an RF based remote headphone unit and internal power supplies. Headphones (supplied) can be directly connected into the interface ports for immediate access and monitoring of the audible signals received. Two displays are provided to aid in the visual monitoring ofthe received signals.

Figure 3: Electronic 8U base unit including PC and LF and HF monitors

1.4 Buffer Interface Unit

This is the main interface between the arrays and the electronics. It has a variety of filters and signal conditioning to provide the required signals for monitoring software and audible listening of the low frequency elements. Conversion of the analogue signal to digital takes place within this unit and samplingis at 500 kHz, 16-bit depth. The unit processes all signals received. It also provides access to the ‘raw’ signal prior to processing to aid fault finding and troubleshooting.

1.5 Fireface Audio Interface

This unit converts the analogue hydrophone outputs of the buffer box into a digital format. The signals arefiltered and amplified then fed to the rack-mounted PC via the firewire cable. The unit also allows forconnection of headphones to provide a mixed output signal allowing the user to monitor all the hydrophone channels simultaneously.

1.6 Headphone RF Transmitter

The radio system provides a remote headphone output from the audio system. This 16 kHz direct wiredconnection can be used to benefit from the full dynamic audio range.

1.7 Base Station PC

A typical rack-mounted PC system has an Intel quad core i5 processor with 8 GB of RAM. This custom-builtPC system has enough power to run both high and low frequency audio data through PAMGuard simultaneously from up to four hydrophones. Alternative configurations are available depending uponrequirements.

1.8 GPS and AIS

The Base station PC receives NMEA 0183 format Global Positioning System (GPS) positioning information from either a Seiche receiver or from the vessel's navigation system (a 9-pin d-sub to USB adapter is provided). Additional NMEA inputs may also be available, including Automatic Identification System (AIS) or heading data from a magnetic, gyro or GPS compass.

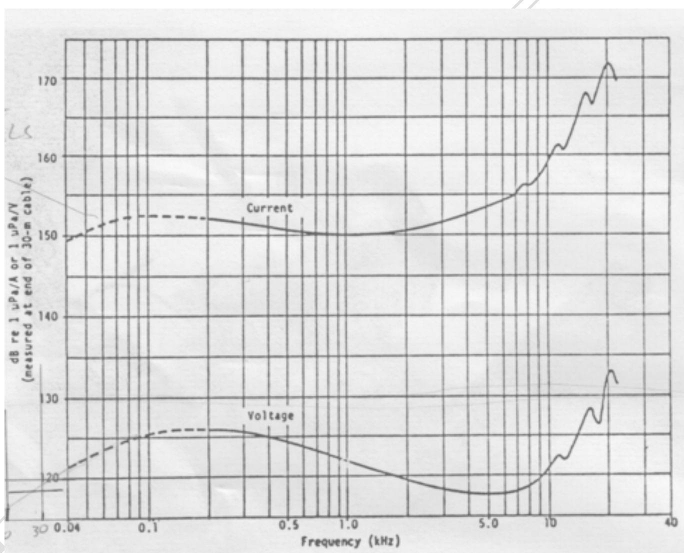
J-9 Sound Source

Naval Research Laboratory, NUWCDivNpt

Frequency Range: **40 Hz – 20 kHz (see below)**
Band Width: **100 – 200 Hz**
Source Level Range (dB re 1 µPa, 1m): **Not to exceed 150 dB re 1µPa@1m**
Source Level Dependence on Frequency:

Frequency	Maximum Source Level
100	150
200	152
400	150
1000	148
2000	144

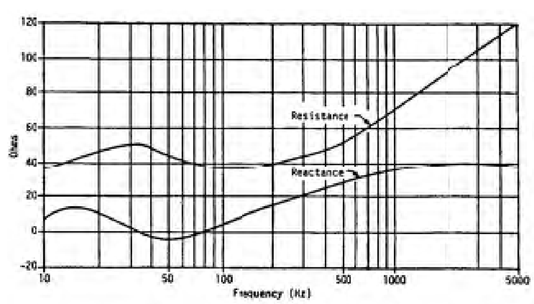
Pulse type (CW, LFM, PRN, etc.): **CW, FM, Noise**
Pulse Length: **1-3 sec**
Pulse Interval: **up to 5 min on, then 5 min off**
Duty Cycle (%) **Up to** 50% (FM)
Describe Beam Pattern: **Omni-directional**



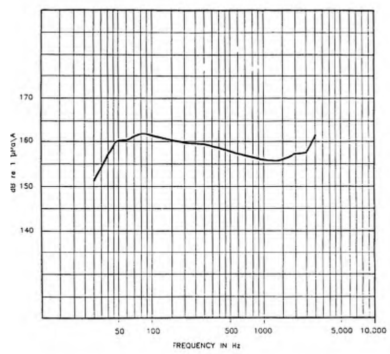
Transmit Voltage Response. Response below 200HZ is a function of depth. The bottom curve represents the expected output Source level for a 1 Vrms excitation. The maximum driving level is 20 Vrms, thus the maximum source level possible is 126 dB + 20

J-13 Sound Source Information

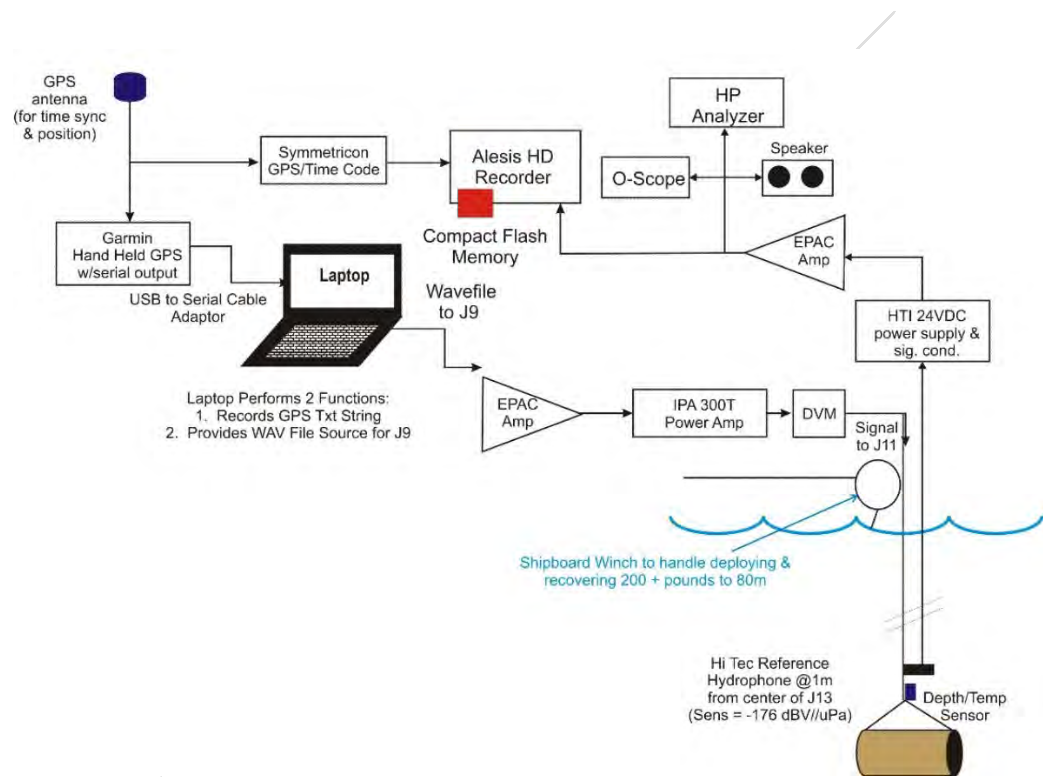
SOURCE MODEL	J-13
	Naval Research Laboratory, NUWCDivNpt
FUNCTION:	A transducer for the mid-audio, low-audio, and high infrasonic frequencies. Reversible but designed and used primarily as a demonstrationor.
DESIGN:	Electrodynamic (or moving coil) with a passive compensation system for hydrostatic pressures.
FREQUENCY RANGE:	30 to 3,000 Hz
TCR:	See below
MAXIMUM DEPTH:	22 m
TEMPERATURE RANGE:	0 to 35°C
MAXIMUM DRIVING SIGNAL:	Approximately 3 A but monitor acoustic output signal for distortion
ELECTRICAL IMPEDANCE:	See below
DIRECTIVITY:	Approximately omnidirectional within 5 dB to 2.5 kHz
WEIGHT:	55 kg (121 lbs)
SHIPPING WEIGHT:	80 kg (175 lbs)
CABLE CODE:	White - balanced signal output
	Black - balanced signal output
	Shield - ground



Typical Impedance for J-13 Demonstrationor



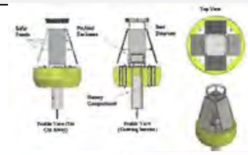
Typical TC for Type J-13 Demonstrationor with 30m cable

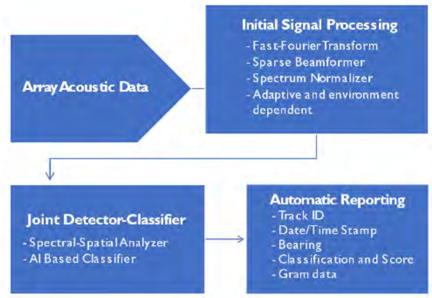


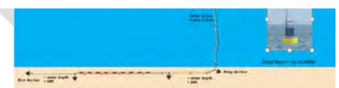
Schematic showing the equipment needed for ThayerMahan to support J9/13 sound source ops from a research vessel.

SeaPicket Overall Specifications

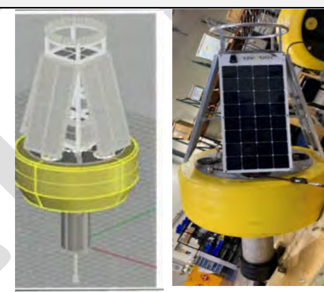
***SeaPicket* Overall Performance Parameters**	
Overall System Function	Buoy based acoustic detection system
Sea State	Survive up to Sea State 6
Water Depths	150-250 feet of water
Acoustic Detection Ranges	Depending upon deployment location and background noise; from 10 nm to 20 nm
Acoustic Detection Targets	Commercial Vessels, Recreational Vessels, Pile Driving, Marine Life; ability to differentiate based on high array gain
Data Reporting Periodicity	Up to real-time reporting, but depends upon customer requirements
System Endurance	30 Days during winter with 15 min reporting; 6 months with reduced reporting





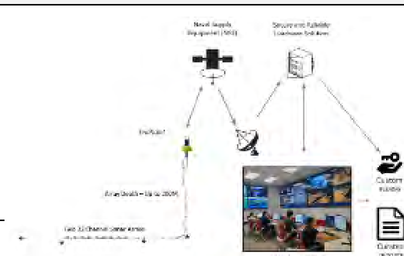


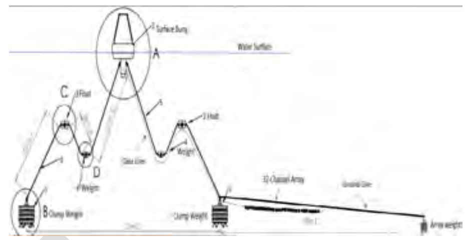
Buoy	
Hull Dimensions	60" Diameter by 132" height (from base to topof bird deterrent spikes)
Weight	634lbs (919lb with payloads and ballast)
Material	<u>Hull</u>: Cross-linked polyethylene foam, polyureacoating with 316 stainless steel deck and hardware <u>Tower</u>: Marine grade 5052 aluminum



Power Systems	
Function	Generation and storage of power to all onboardsystem
Generation	Four (4), 115W 12V DC, marine grade semi- flexible solar panels with wet-mate connector
Storage	Two 12V 200Ah Lithium Iron Phosphate Batteries
Location	Batteries: Center Well of Buoy; Solar Panels onexterior

Communications Systems	
Function	Provide communications (payload, control systems)



Tether		
Function	Provide strength member to connect clump weight to floating buoy	
Size	Mooring Line Strength Member; 9/16” Thickness	
Material	Ortland Toro 12-Strand HMPE, Red, with S/8" Crosby G-414 thimble on Each end	
Clump Weight		
Function	Provide bottom weight that maintains position on the sea floor	
Size	42" Diameter, 4-wheel Stack (approximately 3ft tall)	
Weight	3300 lbs. dry; 2800 lbs. wet	
Material	Steel Gravity Anchor with Bottom Mace; railroad wheel anchors	
Anchor Weights		
Function	Hold acoustic array in place on ocean floor	
Weight	400 lbs.	
**Note*: For Dual Point, double all quantities listed*		

Appendix C: Acoustic Species Detections

Protected Species Detections Table (15 April to 02 May 2022)

Number of Marine Mammal Detections by Monitoring Method		
	Enhanced	Standard
	TM Acoustic Detections	Seiche Acoustic Detections
North Atlantic Right Whale, *Eubalaena glacialis*	95	0
Fin Whale, *Balaenoptera physalus*	0	0
Minke Whale, *Balaenoptera acutorostrata*	0	0
Sei Whale, *Balaenoptera borealis*	0	0
Humpback Whale, *Megaptera novaeangliae*	46	0
Unidentified Mysticete Whale	8	6
Atlantic White-Sided Dolphin, *Lagenorhynchus acutus*	0	0
Short-Beaked Common Dolphin, *Delphinus delphis*	0	1
Unidentified Dolphin	1	23
Harbor Porpoise, *Phocoena phocoena*	0	1
Unidentified Dolphin / Porpoise	0	0
Unidentified Cetacean	76	0
Gray Seal, *Halichoerus grypus*	0	0
Harbor Seal, *Phoca vitulina*	0	0
Unidentified Pinniped	0	0
Totals	**226**	**31**

	Vessel Based Seiche PAM Effort (HH:MM)	ThayerMahan Command Center Effort (HH:MM)
	Night	Combined Day/Night
	59:43:00	244:30:00
Totals	**138:31:00**	**244:30:00**

	Seiche PAM Detection Rates (detections/hour effort)	ThayerMahan Detection Rates (detections/hour effort)
	Night	Combined Across all Assets
	0.285	0.908

Date	Seiche PAM Day		Seiche PAM Night		Seiche PAM Total		TM Acoustic Day			TM Acoustic Night			TM Acoustic Total		
	whale	dolphin	whale	dolphin	whale	dolphin	whale	dolphin	cetacean	whale	dolphin	cetacean	whale	dolphin	cetacean
15-Apr-22	0	0	0	0	0	0	3	0	1	0	0	0	3	0	1
16-Apr-22	0	1	1	0	1	1	7	0	0	1	0	0	8	0	0
17-Apr-22	0	0	0	2	0	2	13	0	4	9	0	14	22	0	18
18-Apr-22	0	0	0	0	0	0	6	0	5	5	0	6	11	0	11
19-Apr-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-Apr-22	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
21-Apr-22	0	0	0	0	0	0	1	0	0	1	0	4	2	0	4
22-Apr-22	0	2	1	0	1	2	9	0	0	14	0	0	23	0	0
23-Apr-22	0	2	0	1	0	3	3	1	4	6	0	4	9	1	8
24-Apr-22	3	2	0	4	3	6	10	0	11	3	0	0	13	0	11
25-Apr-22	0	4	1	7	1	11	4	0	0	2	0	4	6	0	4
26-Apr-22	0	0	0	0	0	0	5	0	0	0	0	0	5	0	0
27-Apr-22	0	0	0	0	0	0	17	0	10	7	0	4	24	0	14
28-Apr-22	0	0	0	0	0	0	13	0	4	2	0	0	15	0	4
29-Apr-22	0	0	0	0	0	0	0	0	0	7	0	1	7	0	1
30-Apr-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-May-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-May-22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**3**	**11**	**3**	**14**	**6**	**25**	**91**	**1**	**40**	**57**	**0**	**37**	**148**	**1**	**77**

ThayerMahan

Spring 2022 Demonstration

Localizations using two or more sensors

Background

Moored SeaPicket Sensors:
Avon and Bristol

Avon:
POSIT: 41.04496, -71.05696

Bristol:
POSIT: 40.90058-71.05979

Mobile Sensors:
Ellen and MaryR, locations various throughout period.

All sensors consisted of 32 element, 1.2m spaced arrays with a 600Hz design frequency, providing 15dB of array gain at 600Hz.

Abbreviations:

SMAJ: Semi-Major Axis
SMIJ: Semi-Minor Axis
nm: nautical miles
AOU: Area of Uncertainty

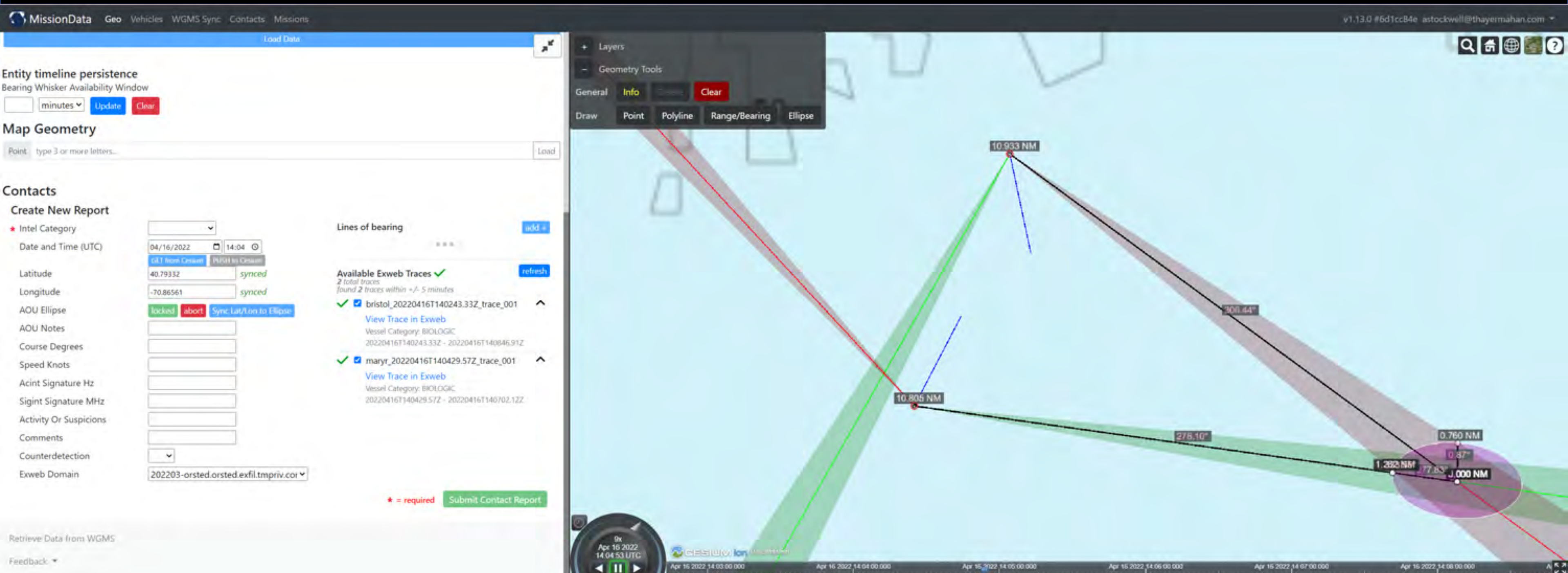
All times in UTC (EDT +4)

Summary Slide

Localization Number	PPT Slide	Date/Time	Time	Sensors	Distance (nm)
				Bristol	10.00
1	4	4/16/2022	1406	Mary R	10.00
				Bristol	3.50
2	5	4/16/2022	1651	Mary R	1.90
				Bristol	15.00
3	6	4/16/2022	1658	Mary R	17.00
				Bristol	5.00
4	7	4/16/2022	2004	Mary R	9.00
				Bristol	18.00
5	8	4/17/2022	0140	Mary R	10.00
				Bristol	11.00
6	9	4/17/2022	0150	Mary R	4.00
				Bristol	9.00
7	10	4/21/2022	0117	Avon	17.00
				Bristol	7.90
8	11	4/22/2022	0040	Ellen	1.80
				Bristol	3.50
9	12	4/23/2022	1742	Mary R	11.00
				Avon	1.60
10	13	4/25/2022	0018	Mary R	15.00
				Avon	14.00
				Bristol	7.00
				Ellen	3.20
11	14	4/15/2022	1722	Mary R	2.40
				Avon	5.20
12	15	4/1/2022	2019	Bristol	5.60
				Avon	8.68
13	16	4/6/2022	1444	Bristol	1.83
				Avon	13.09
14	17	4/14/2022	0047	Bristol	4.51
				Avon	13.04
15	18	4/15/2022	0012	Bristol	3.85

Localization Number	PPT Slide	Date/Time	Time	Sensors	Distance (nm)
				Avon	30.27
16	19	4/15/2022	0414	Bristol	25.12
				Avon	25.98
17	20	4/15/2022	0541	Bristol	20.40
				Avon	17.37
18	21	4/15/2022	0624	Bristol	9.60
				Avon	17.38
19	22	4/15/2022	0637	Bristol	9.59
				Avon	16.91
20	23	4/15/2022	0742	Bristol	9.10
				Avon	16.02
21	24	4/15/2022	0804	Bristol	8.25
				Avon	16.91
22	25	4/15/2022	0840	Bristol	9.06
				Avon	13.80
23	26	4/15/2022	0915	Bristol	5.80
				Avon	15.09
24	27	4/15/2022	0953	Bristol	7.27
				Avon	21.32
25	28	4/15/2022	1210	Bristol	15.92
				Avon	26.53
26	29	4/23/2022	0110	Bristol	19.96
				Avon	28.50
27	30	4/13/2022	1624	Bristol	23.40
				Mary R	6.10
28	31	4/15/2022	1840	Ellen	6.80
				Mary R	4.80
29	32	4/15/2022	1839	Ellen	5.00

4/16/22 1406UTC – Bristol/MaryR



Range to center of AOU(s):

10nm to Bristol

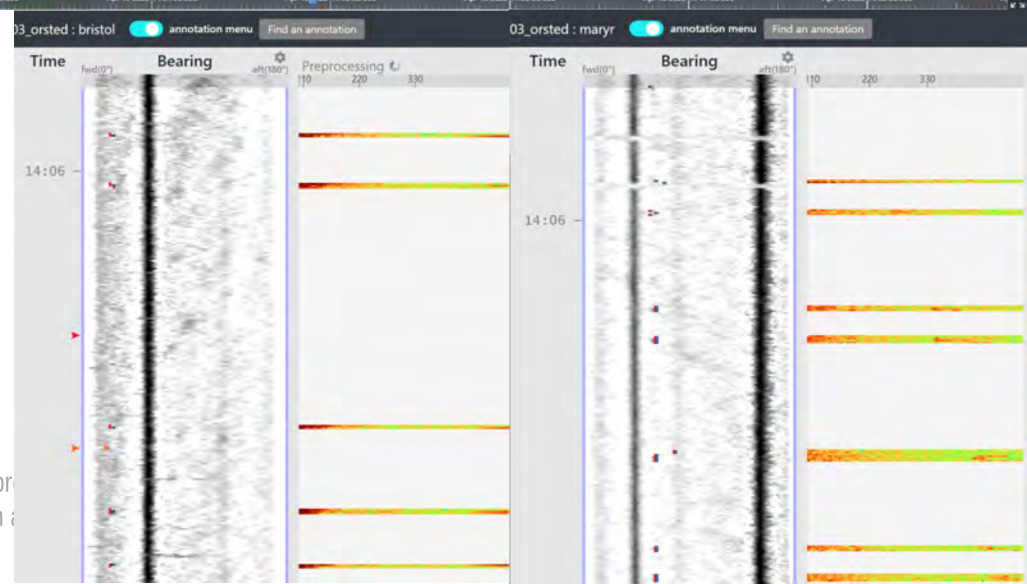
10nm to MaryR

AOU Size:

SMAJ: 1.2nm

SMIJ: 0.760nm

Note: Ambiguity resolved to easterly bearing based on low bearing rate observed during period and low source level.



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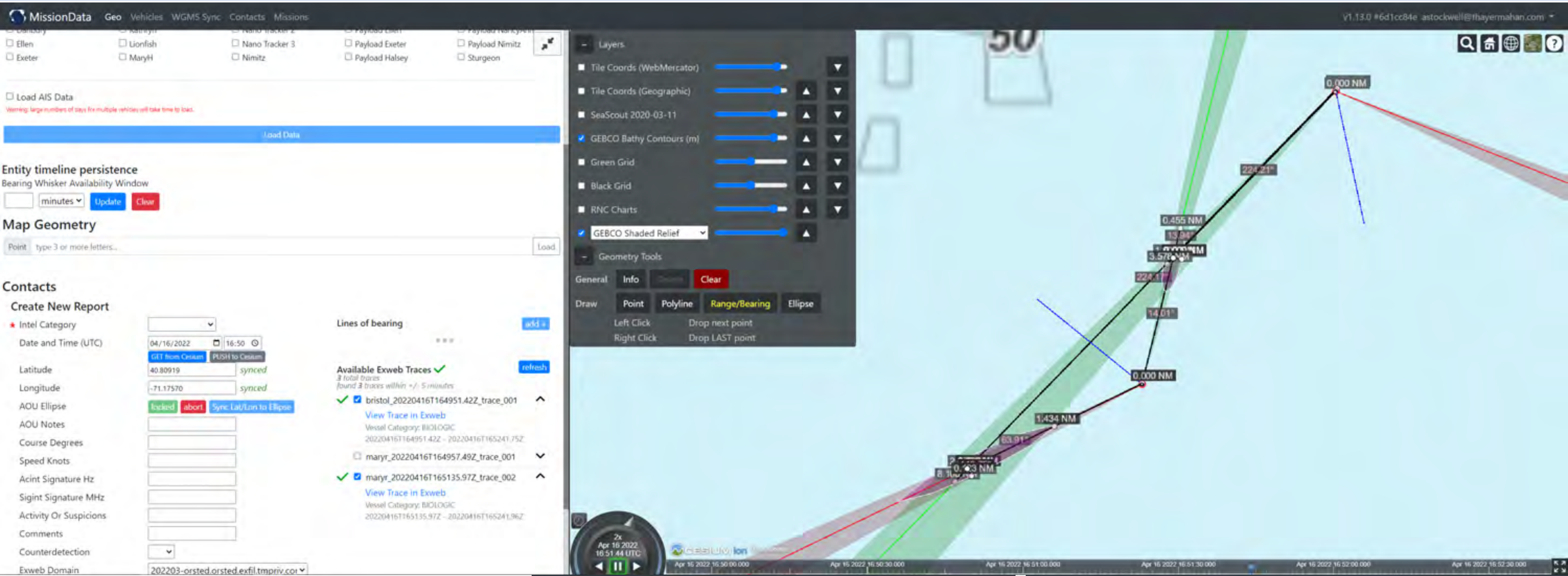
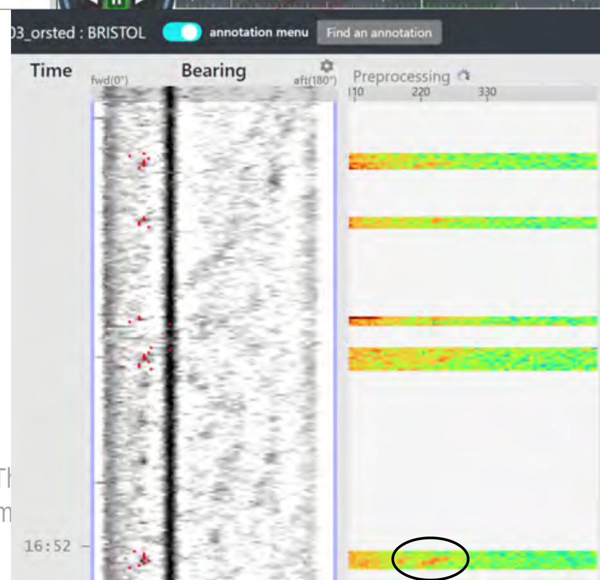
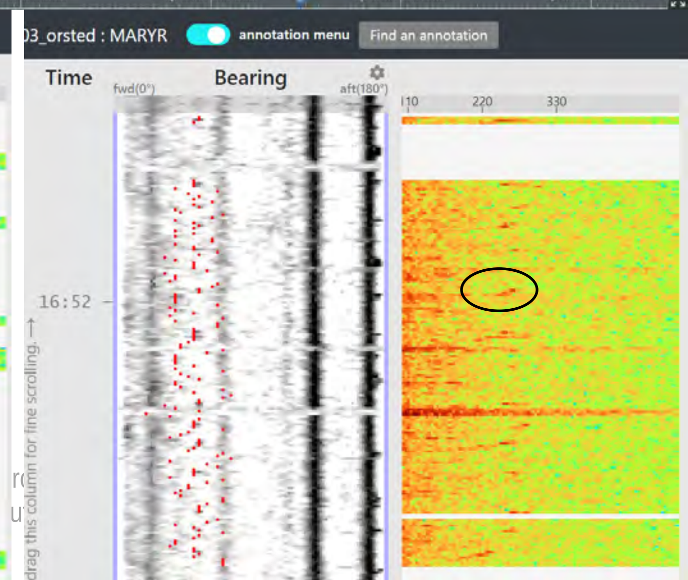
4/16/22 1651UTC – Bristol/MaryR







<u>Range to center of AOU(s):</u>

3.5 or 8nm to Bristol

1.9 or 2.8 nm to MaryR

<u>AOU Size:</u>

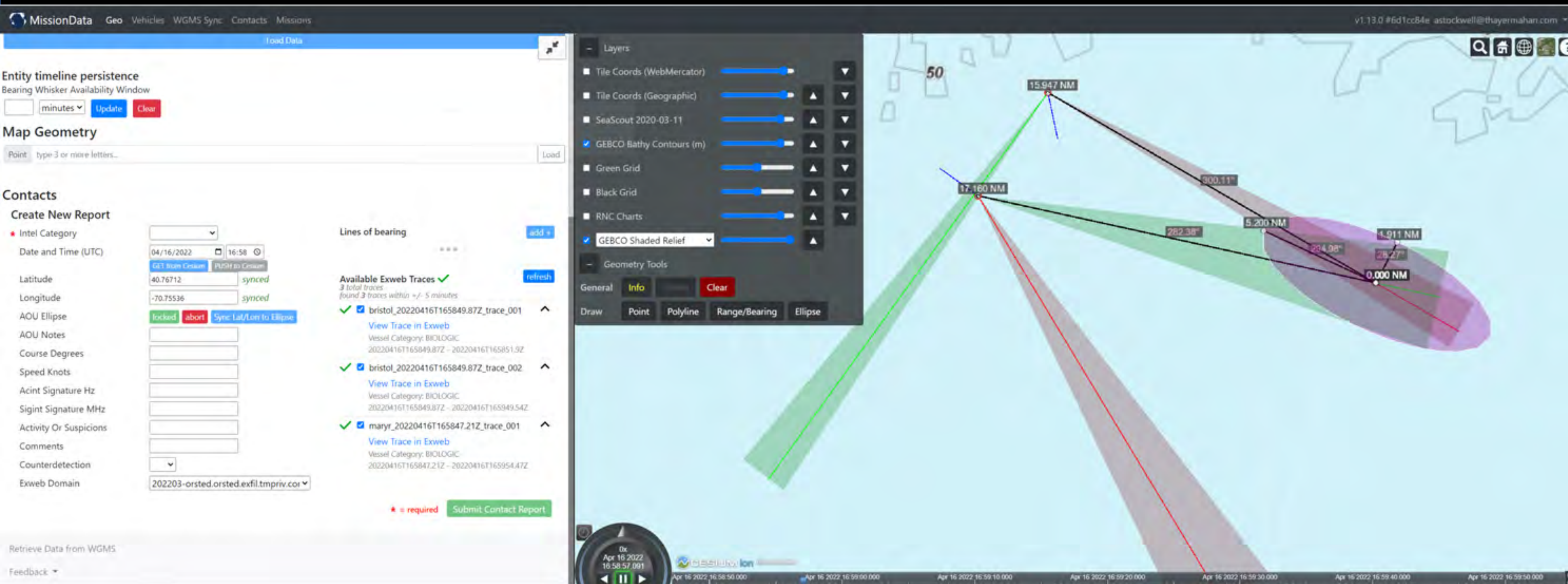
SMAJ: 1.4 or 0.455nm

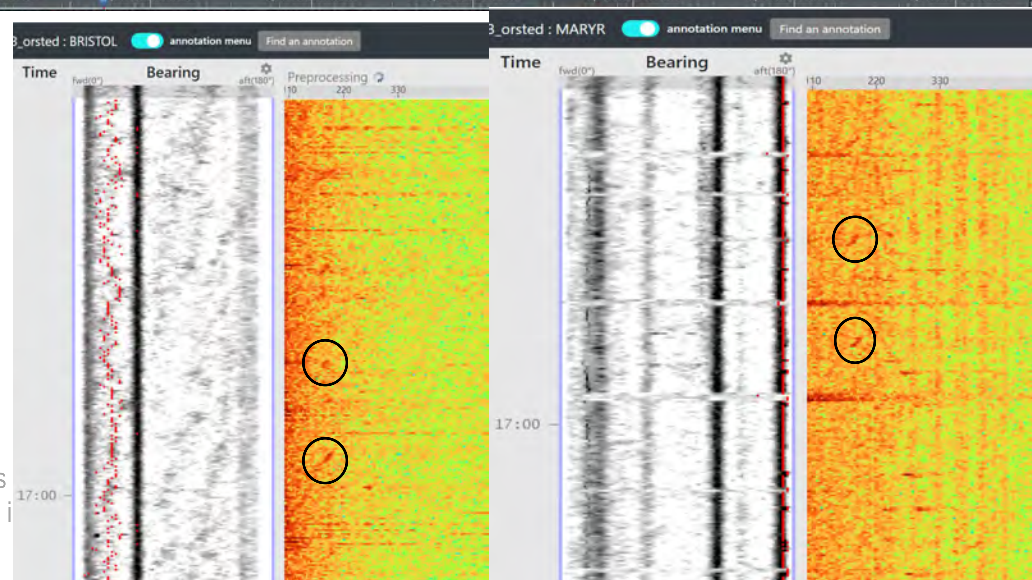
SMIJ: 0.123 or 0.128nm

Note:
Unable to definitively resolve bearing ambiguity in this case due to bearing line from Bristol crossing both bearings on MaryR

ThayerMahan

04/16/22 1658UTC – Bristol/MaryR





Range to center of AOU(s):

15nm to Bristol

17nm to MaryR

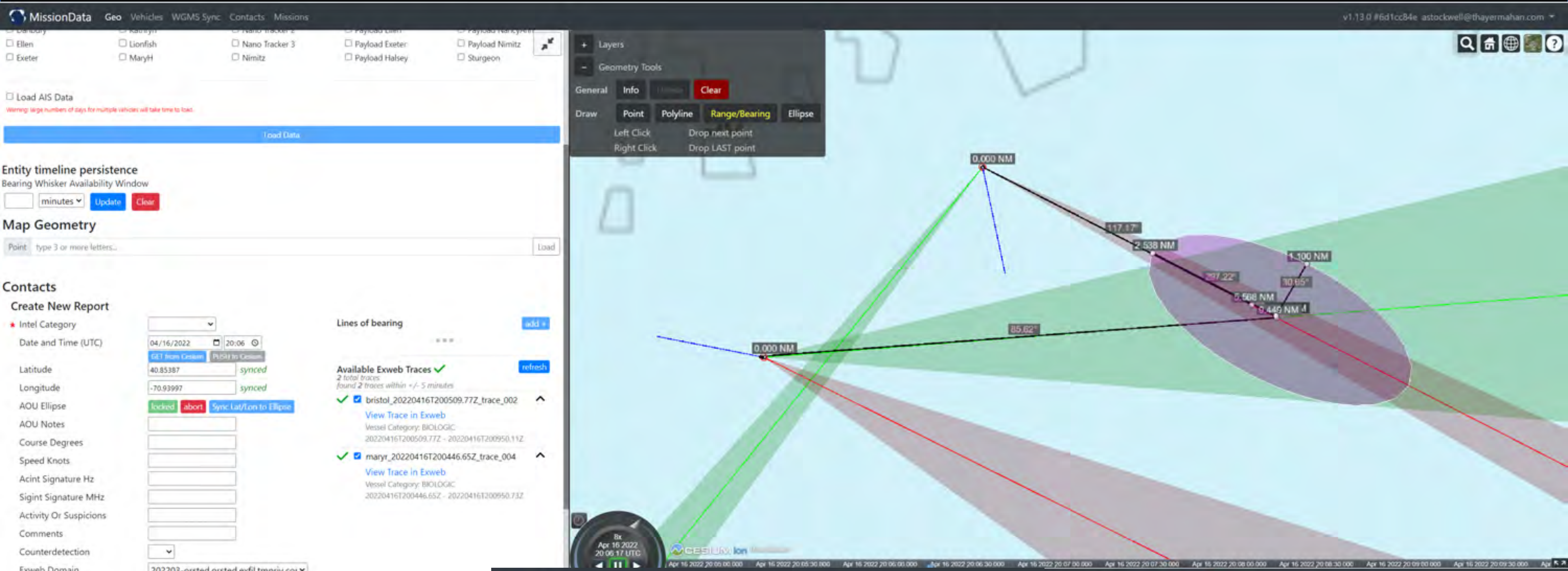
AOU Size:

SMAJ: 5.2nm

SMIJ: 1.9nm

ThayerMahan

4/16/22 2004UTC – Bristol/MaryR



Range to center of AOU:

5nm to Bristol

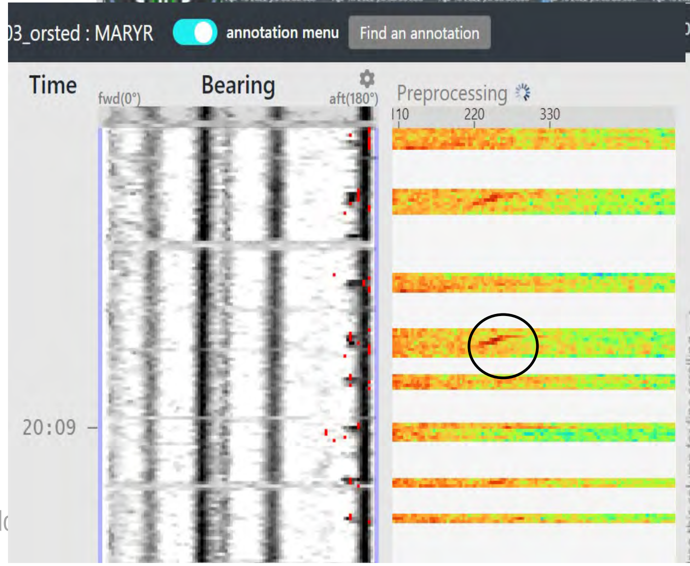
9nm to MaryR

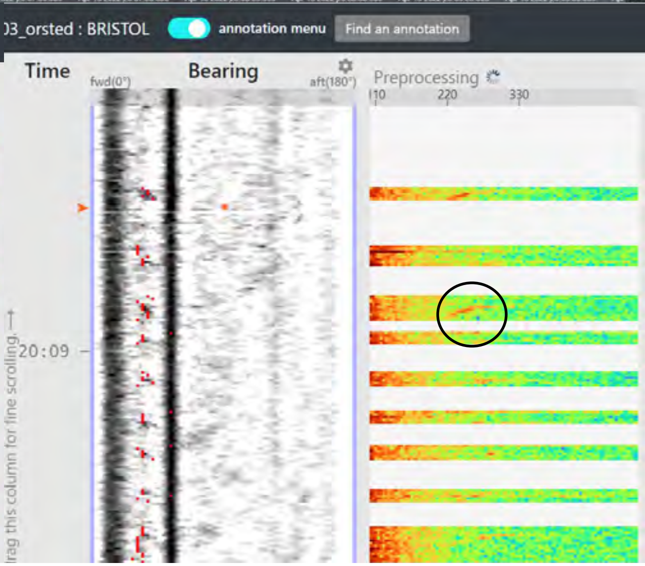
AOU Size:

SMAJ: 2.5nm

SMIJ: 1.1nm

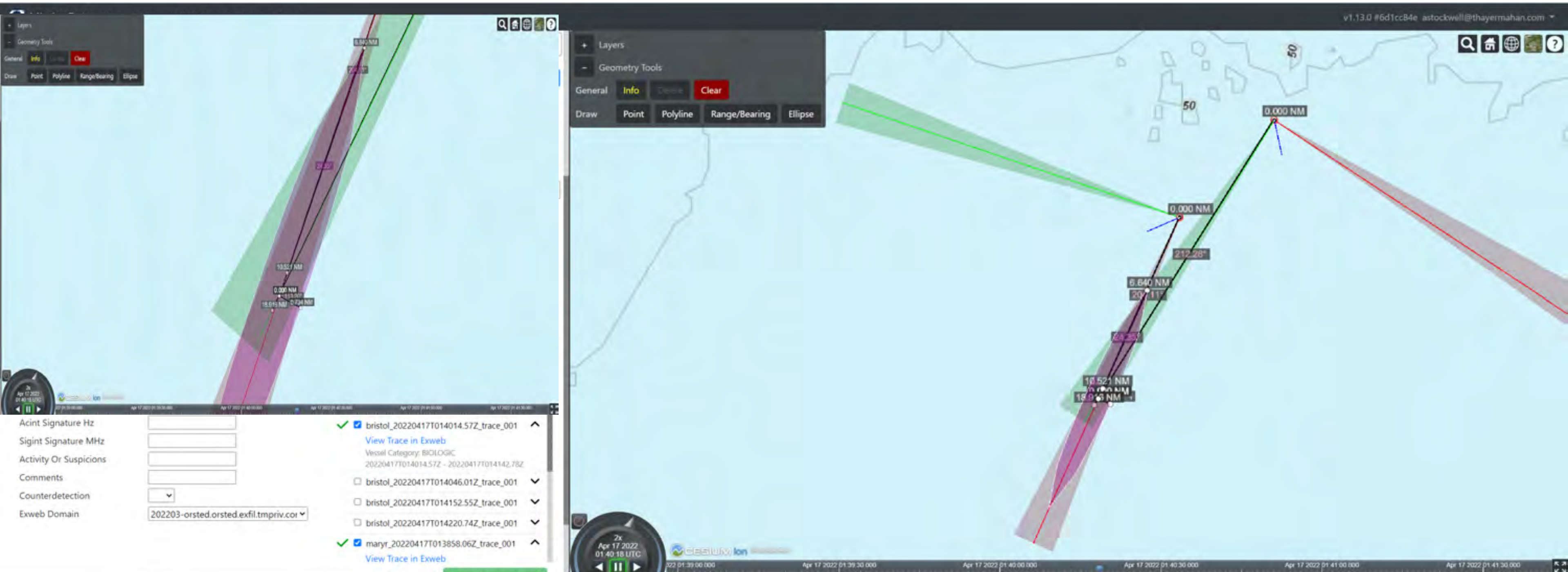
Note: Based on bearing geometry, it is assessed the longer range is correct here based on lack of contact bearing rate on MaryR's SPED surface. A closer contact would have exhibited high bearing rate in this case.



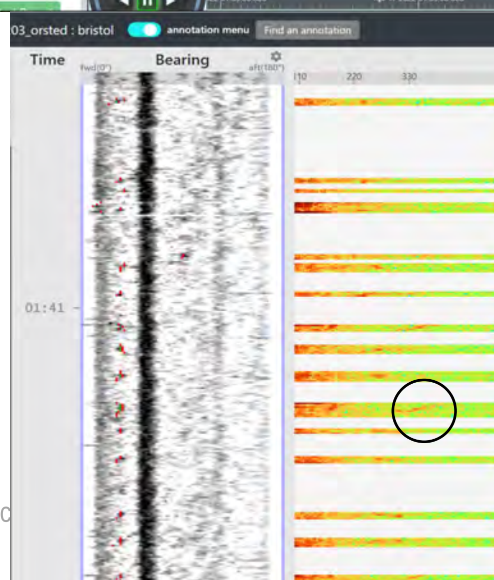


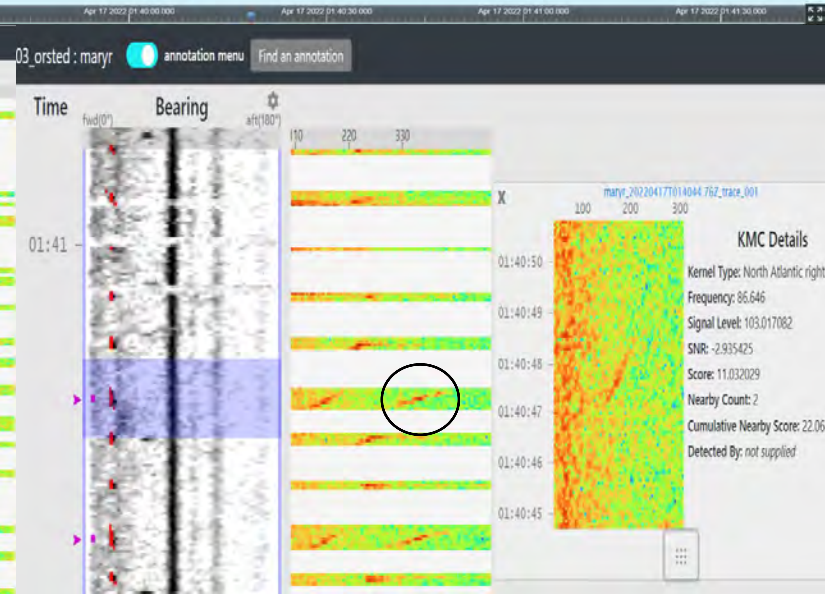
ThayerMahan

4/17/22 0140UTC – Bristol/MaryR



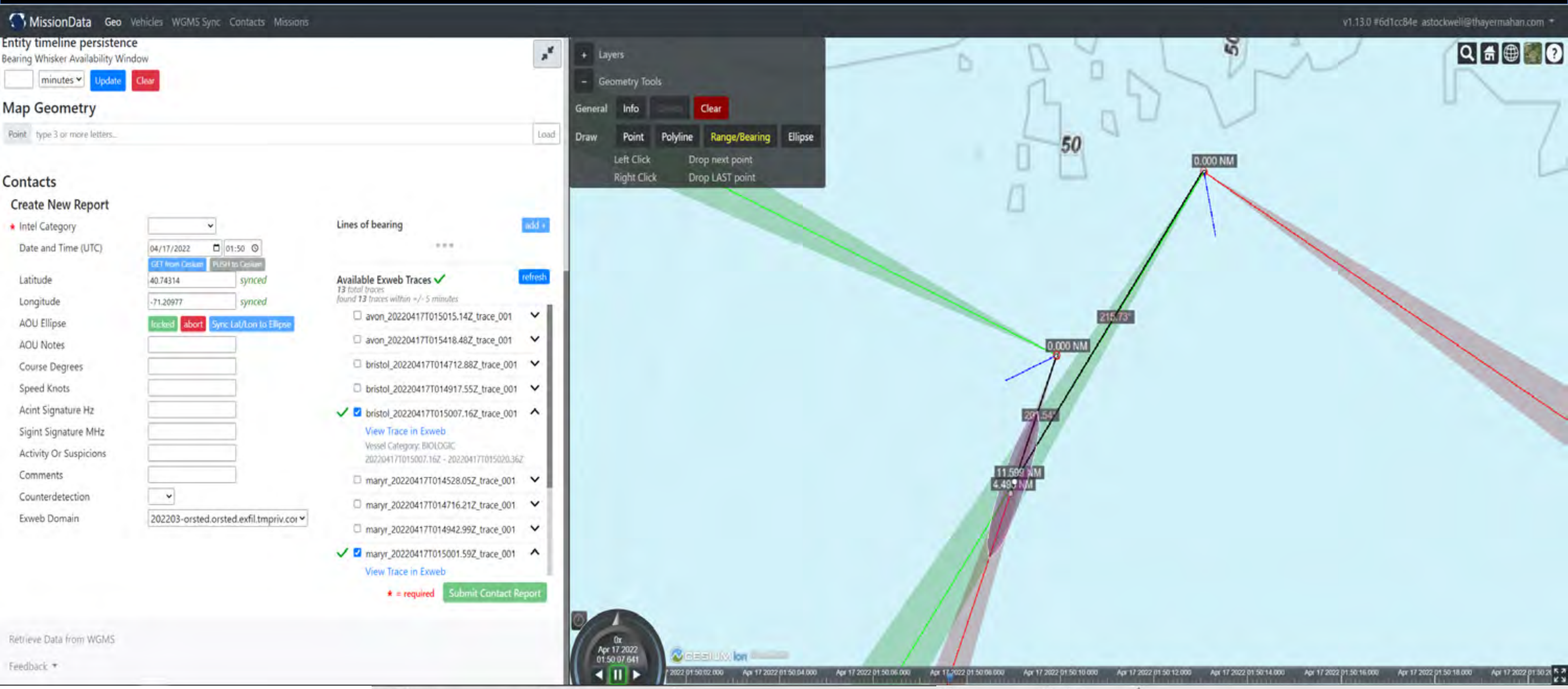
Range to center of AOU(s):
18nm to Bristol
10nm nm to MaryR
AOU Size:
SMAJ: 6.6 nm
SMIJ: 0.734nm

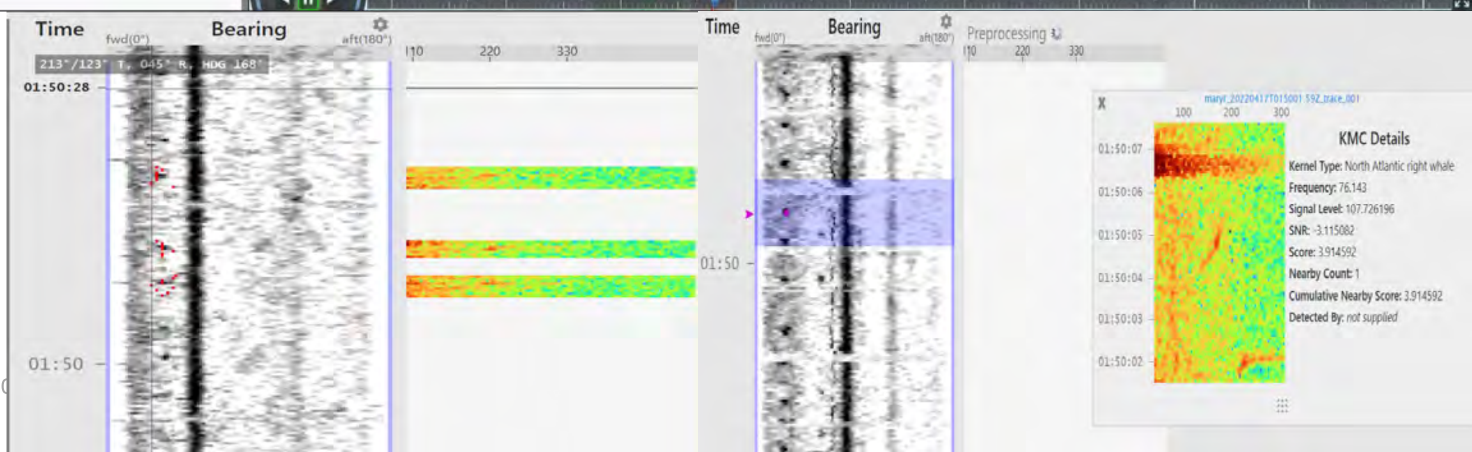




ThayerMahan

4/17/22 0150UTC – Bristol/MaryR





Range to center of AOU:

11nm to Bristol

4nm to MaryR

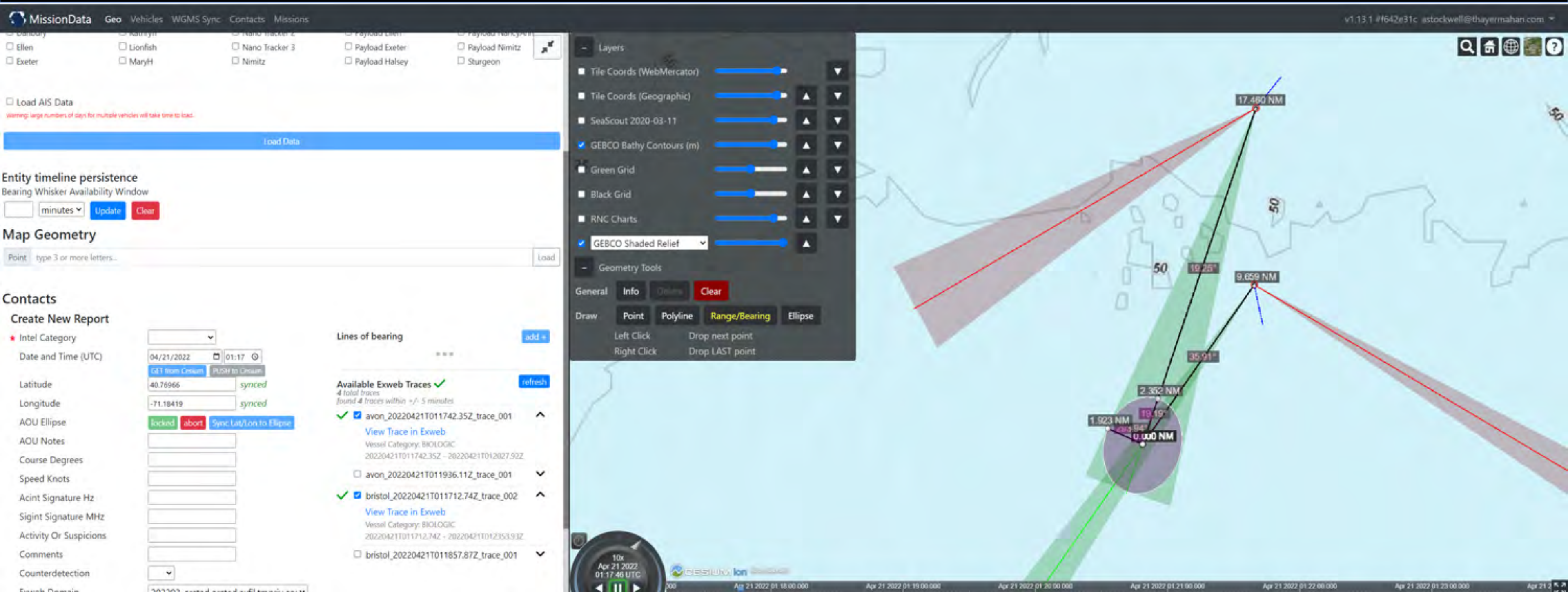
AOU Size:

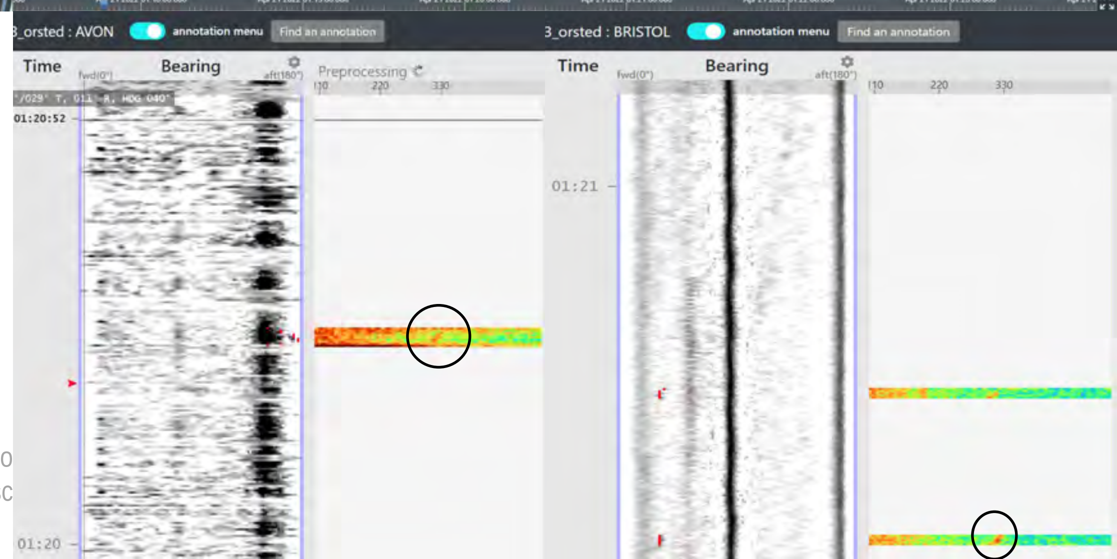
SMAJ: 2.2nm

SMIJ: 0.4nm

ThayerMahan

4/21/22 0117UTC – Avon/Bristol





Range to center of AOU(s):

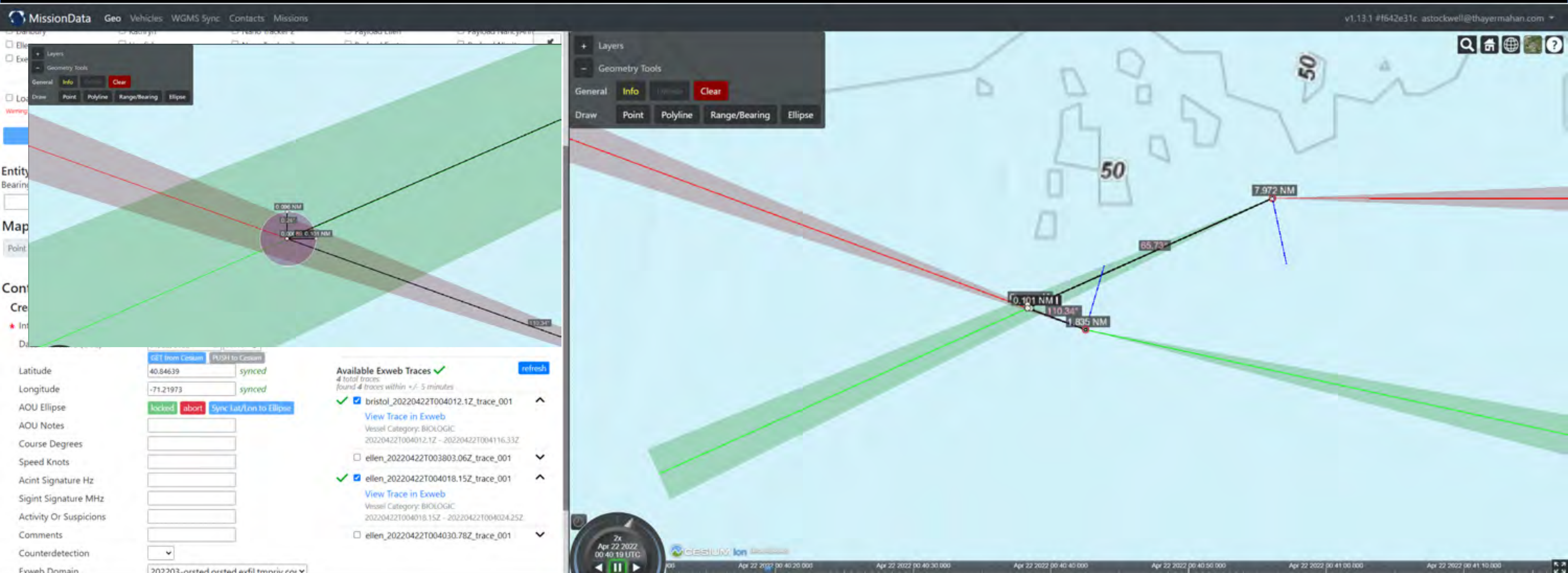
17nm to Avon
9nm to Bristol

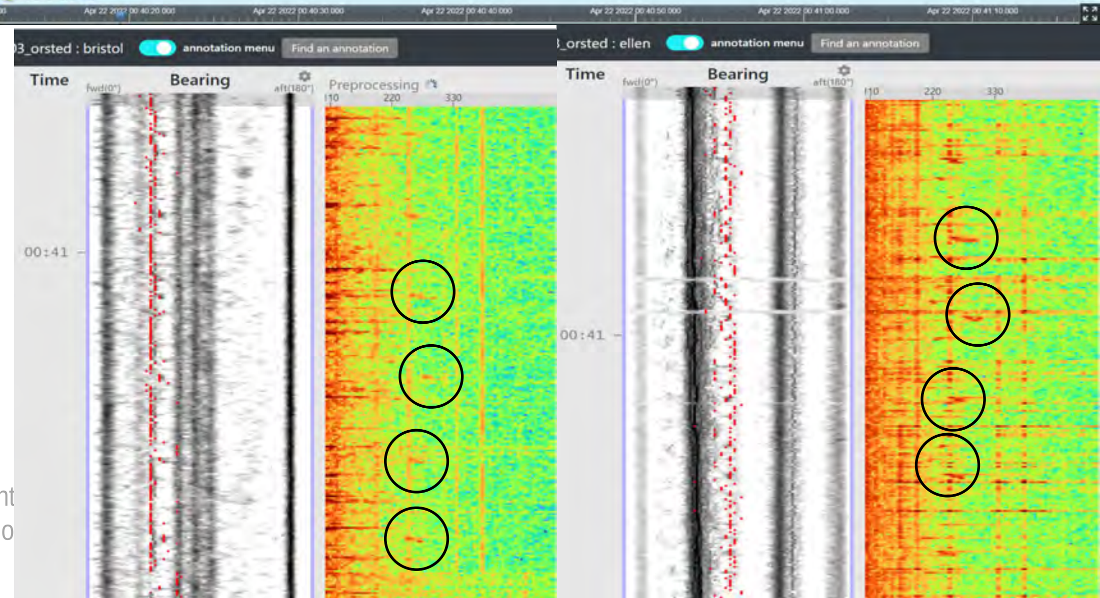
AOU Size:

SMAJ: 2.3nm
SMIJ: 1.9nm

ThayerMahan

4/22/22 0040UTC – Bristol/Ellen





Range to center of AOU(s):

7.9nm to Avon

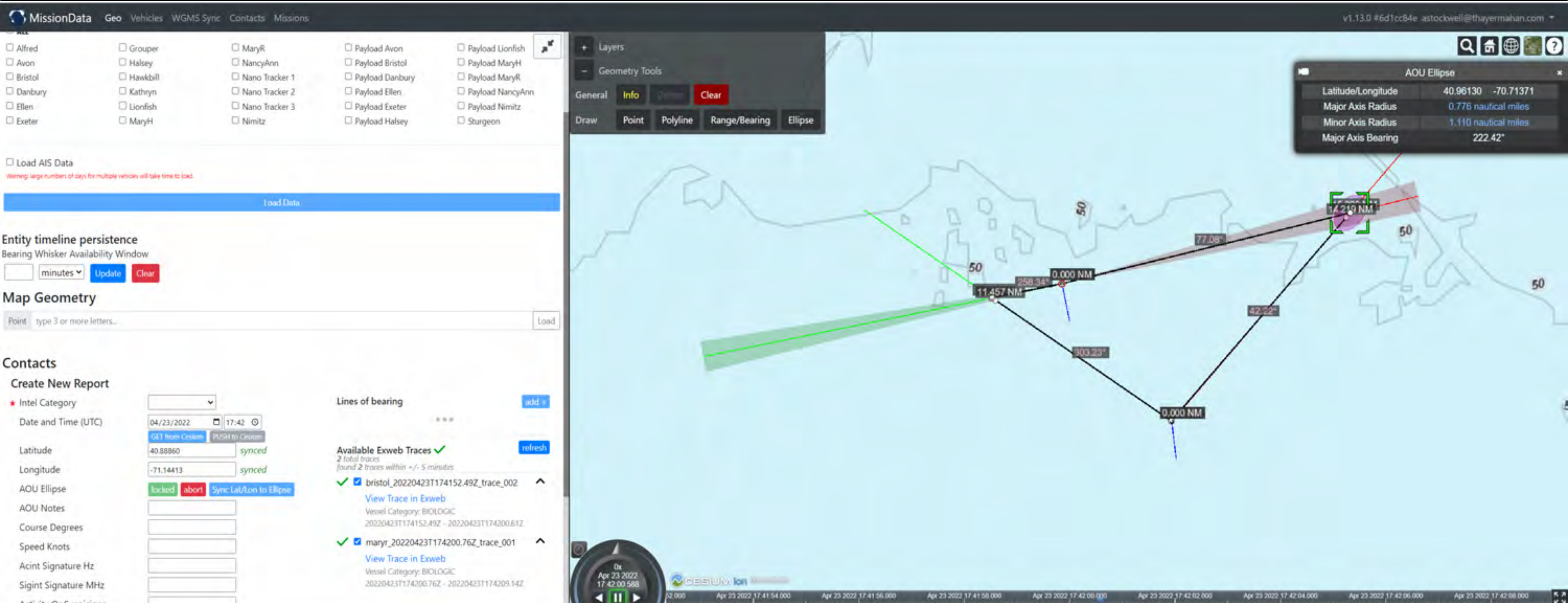
1.8nm to Ellen

AOU Size:

SMAJ: .101

SMIJ: .096nm

4/23/22 1742UTC – Bristol/MaryR



Range to center of AOU(s):

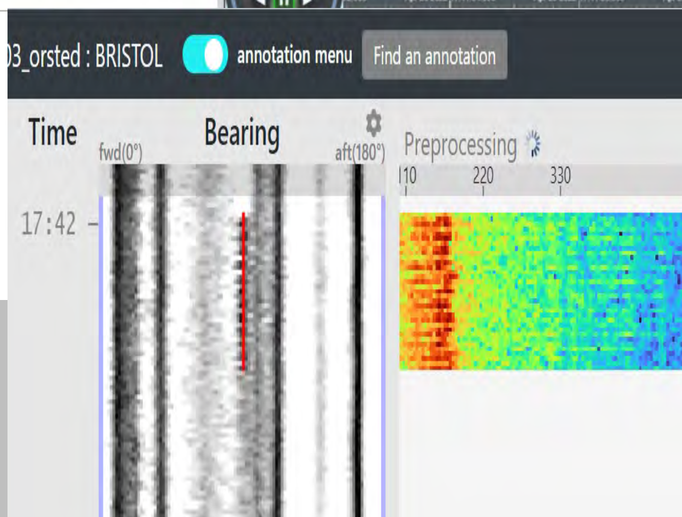
3.5 or 16nm to Bristol

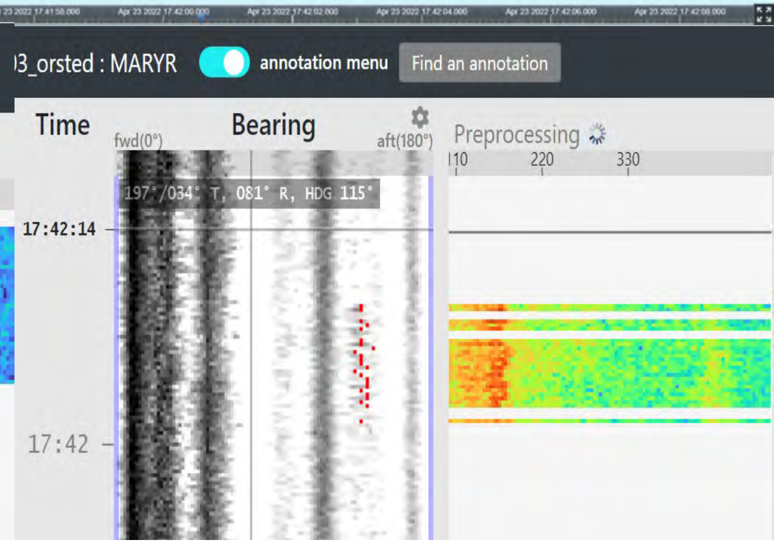
11 or 14 nm to MaryR

AOU Size:

SMAJ: 1.1 or 0.242nm

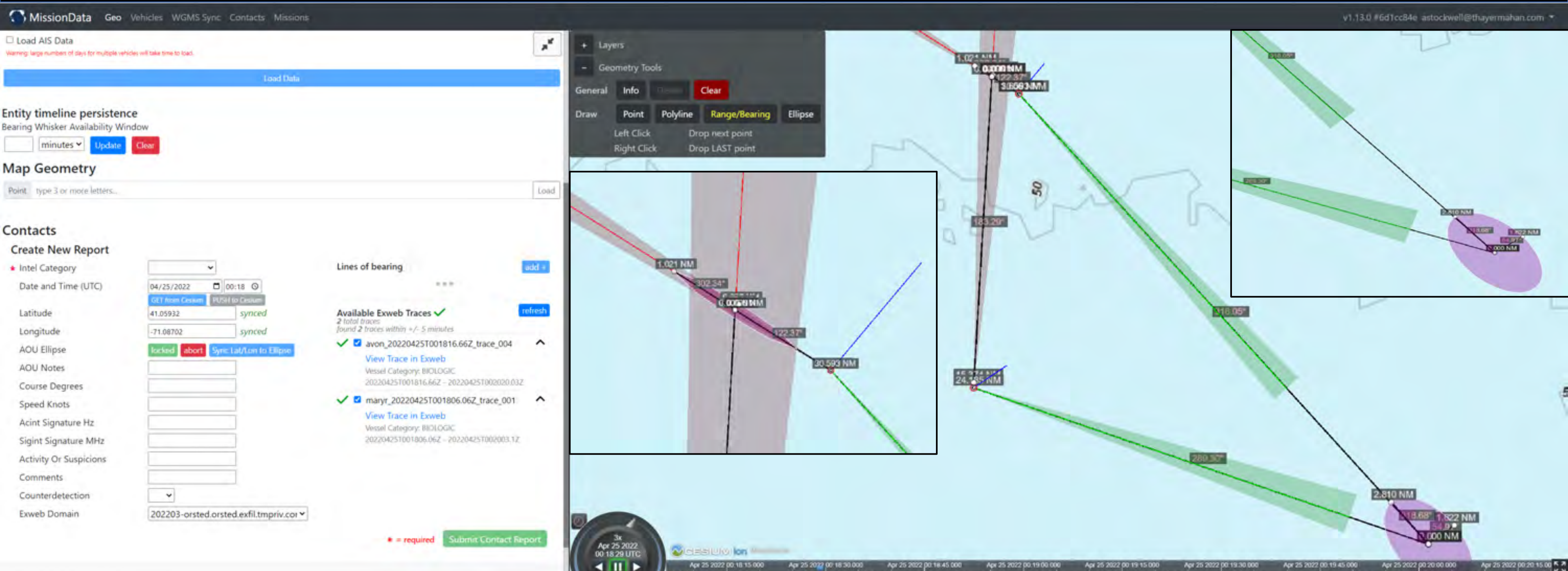
SMIJ: 0.783 or 0.216 nm





Note:
Unable to definitively resolve bearing ambiguity in this case due to bearing line from Bristol crossing both bearings on MaryR. Assess the westerly bearing based on higher source level seen at Bristol.

4/25/22 0018UTC – Avon/MaryR



Range to center of AOU(s):
1.6 or 30nm to Avon
15 or 24nm to MaryR

AOU Size:
SMAJ: 2.8 or 1.0nm
SMIJ: 1.6 or .097nm

Note: No detection held on Bristol at this time due to corrupted data

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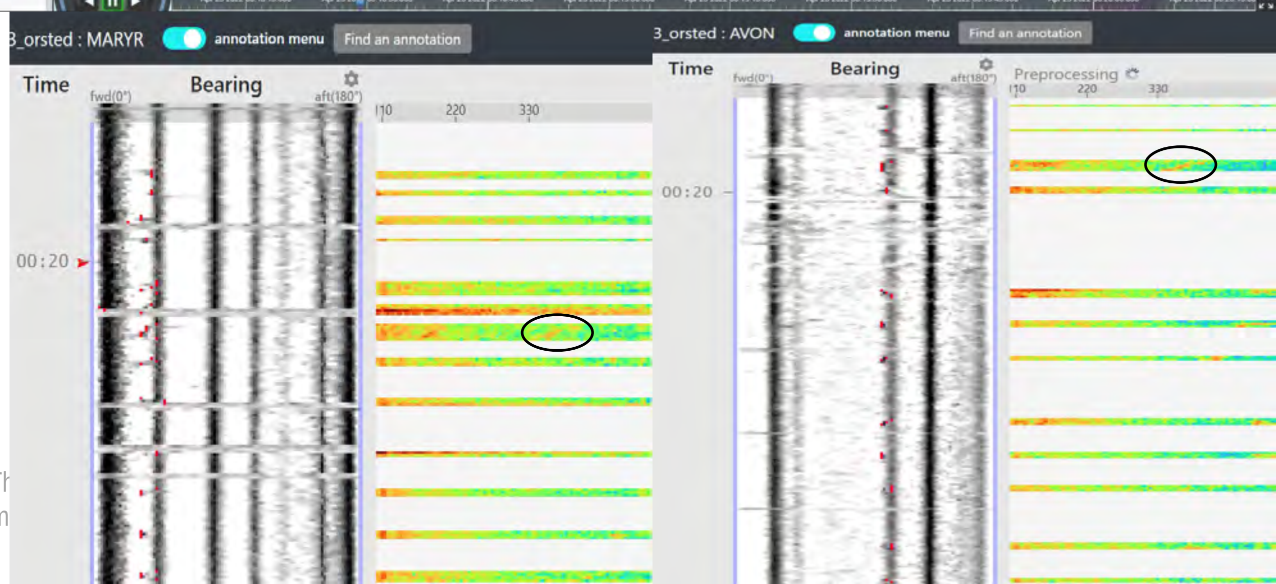
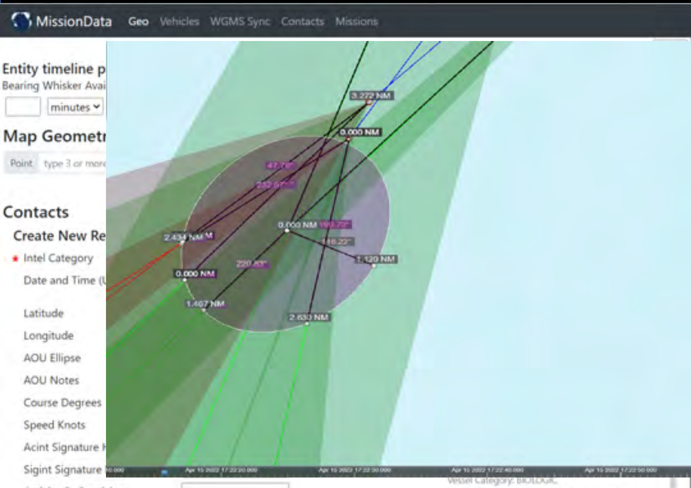
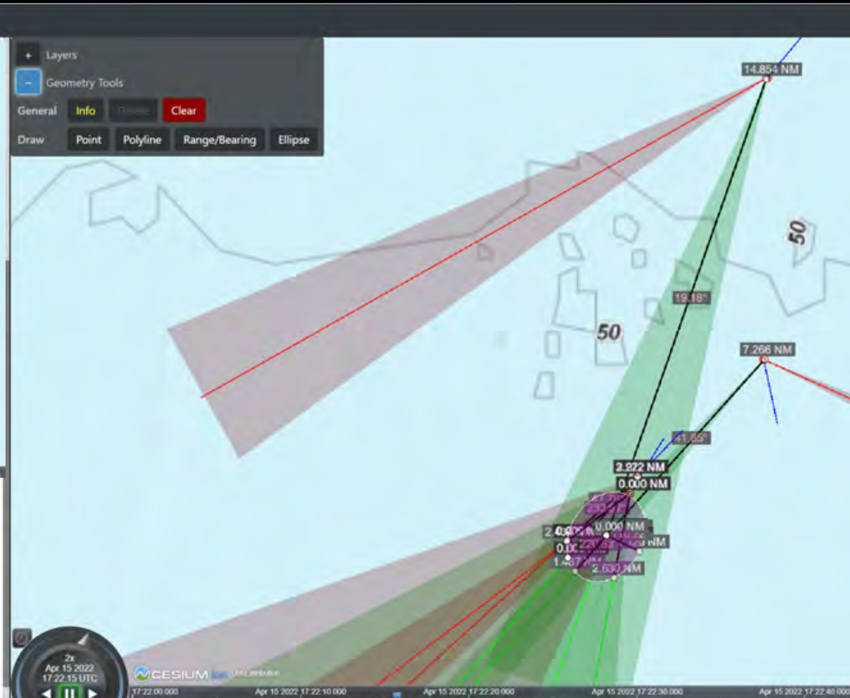


4/15/22 1722UTC – Avon/Bristol/Ellen/MaryR

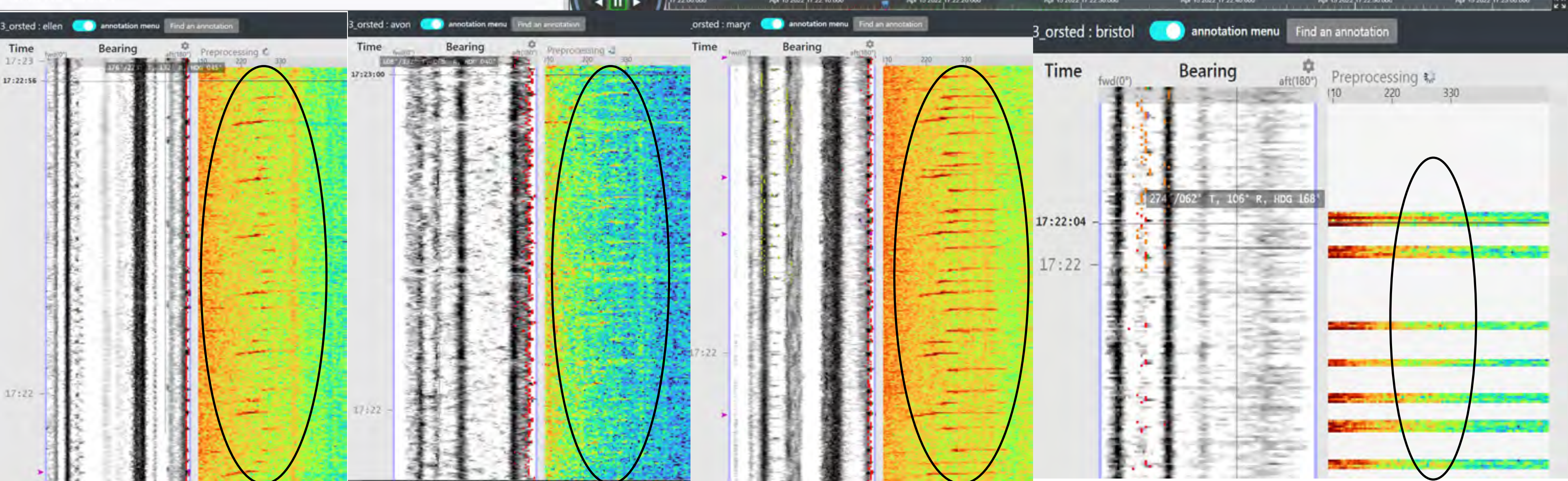




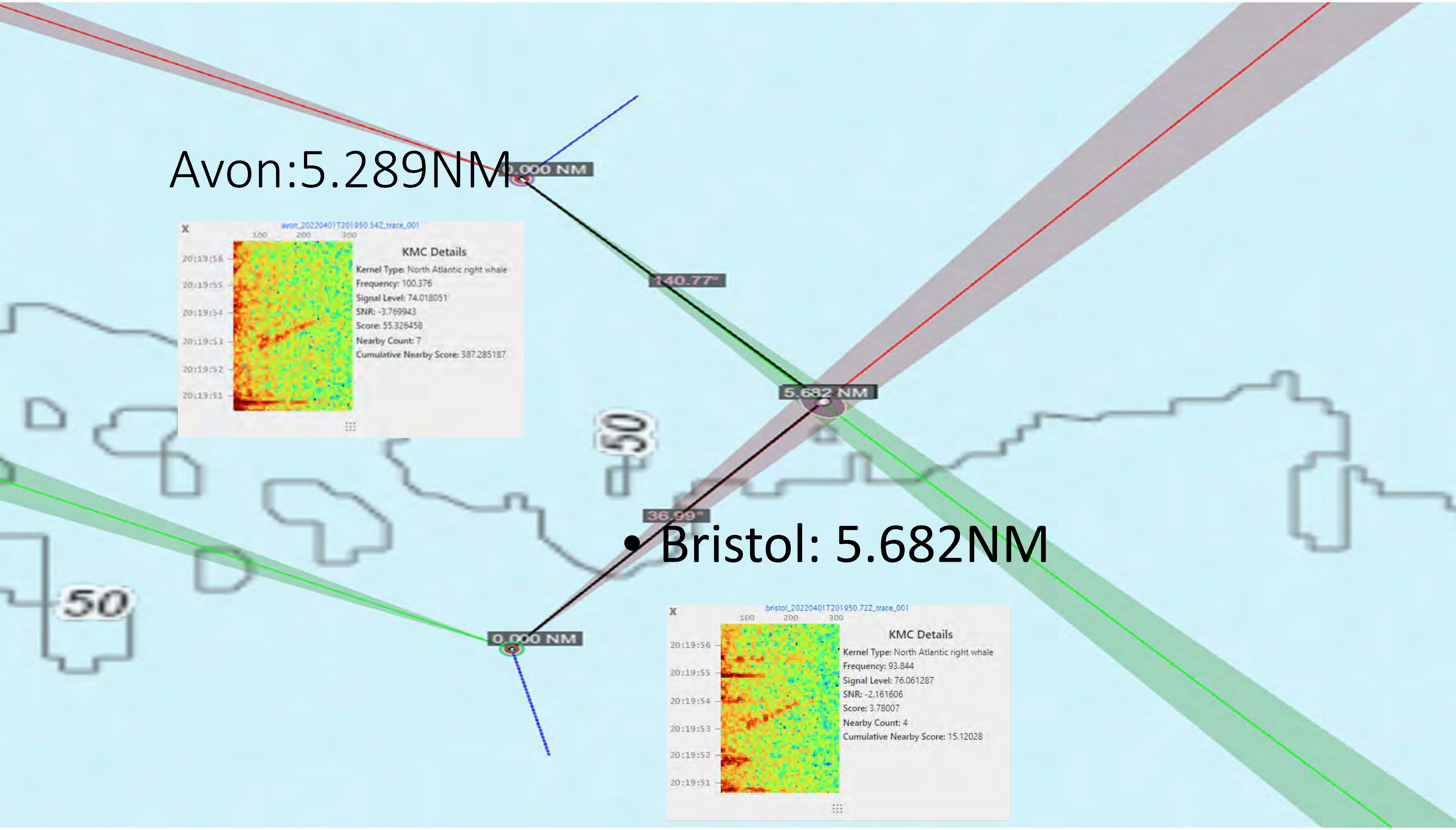
Range to center of AOU(s):
14nm to Avon
7nm to Bristol
3.2nm to Ellen
2.4nm to MaryR

AOU Size:
SMAJ: 1.4nm
SMIJ: 1.2nm

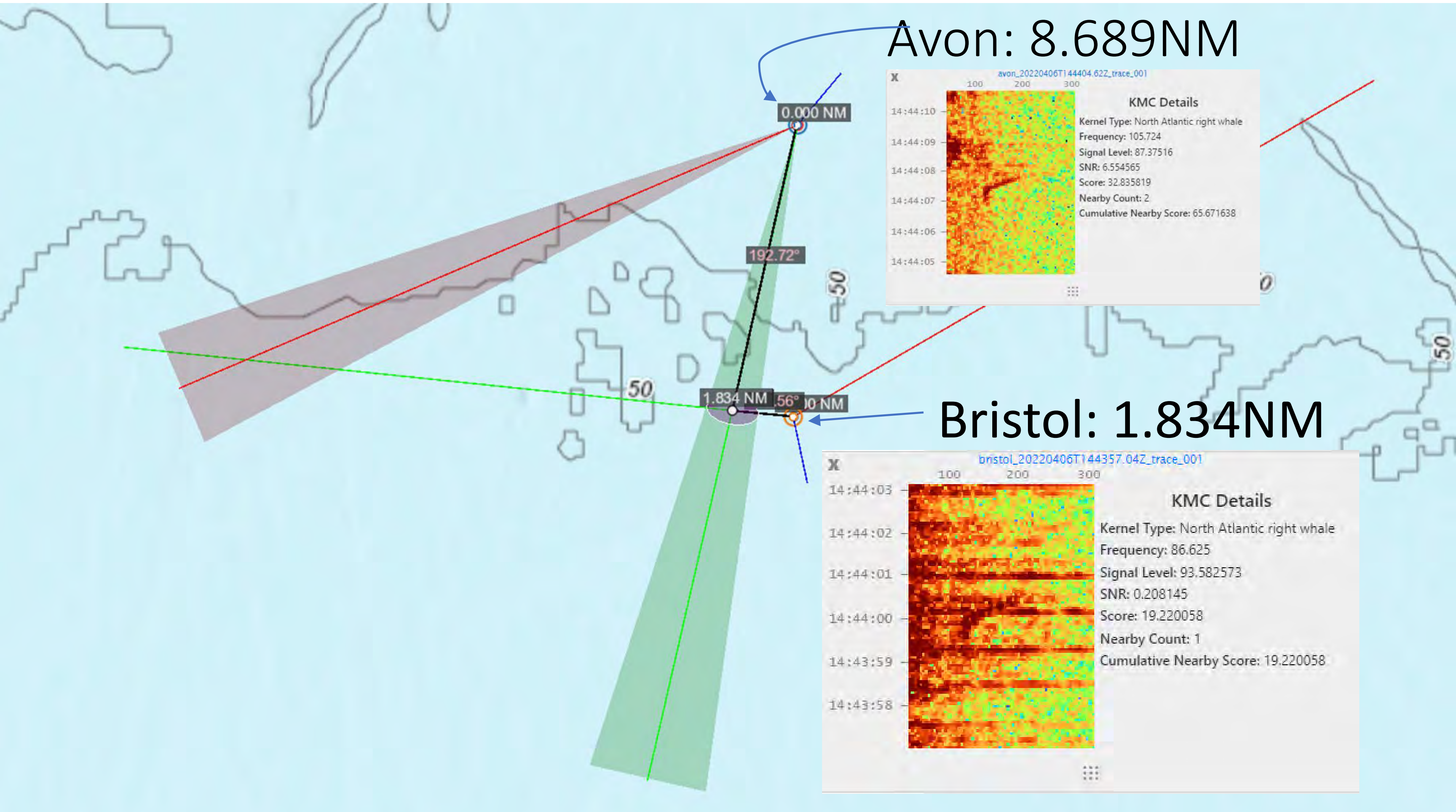
Note: This is a 4 sensor crossfix. The bearings for the mobile sensors Ellen and MaryR are in aft endfire, causing some inaccuracy based on beamwidth in endfire, but this detection demonstrates the full capability very well.



Avon/Bristol Detect 20220401T2019Z

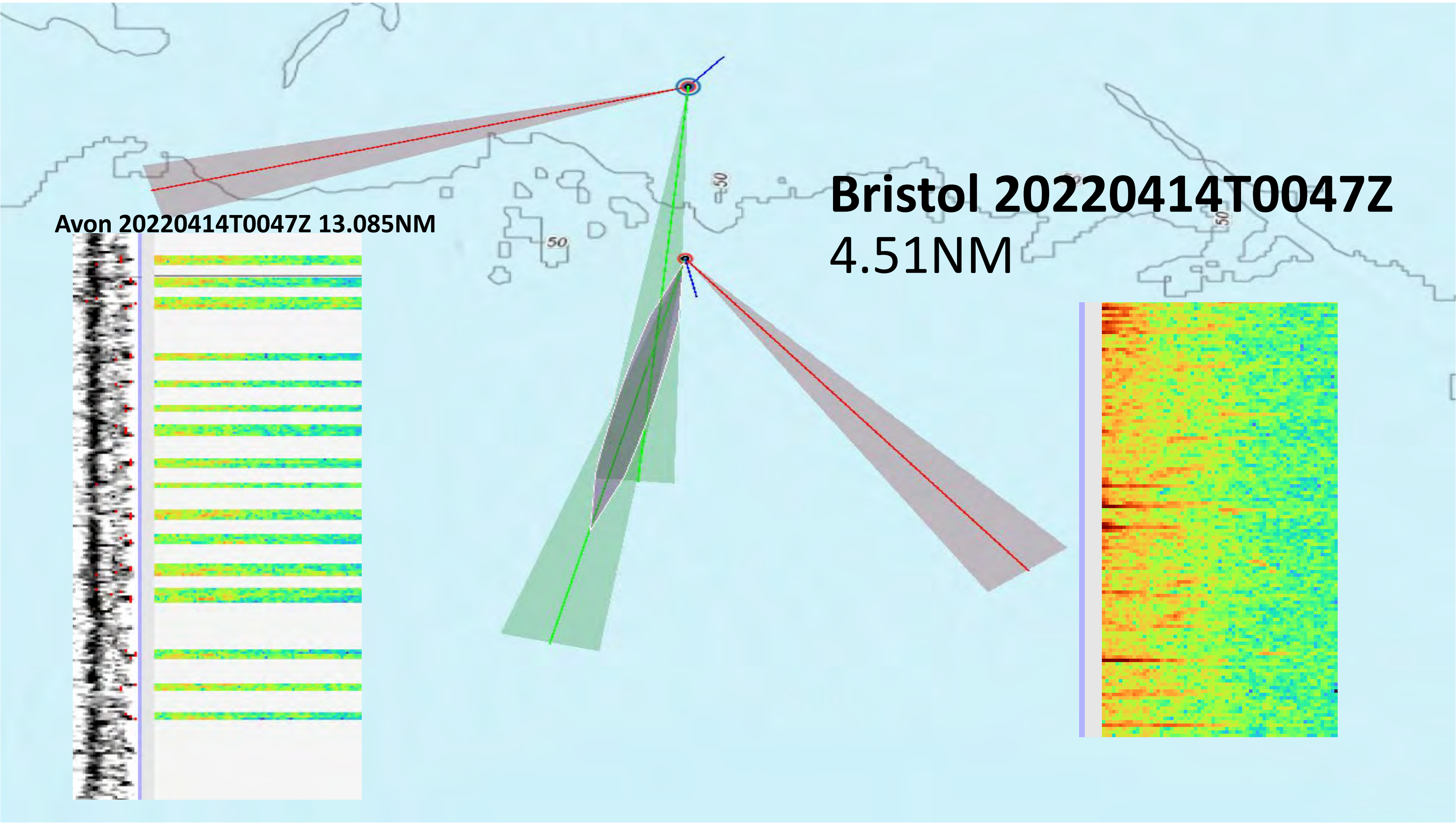


Avon/Bristol Detect 20220406T1444Z



ThayerMahan

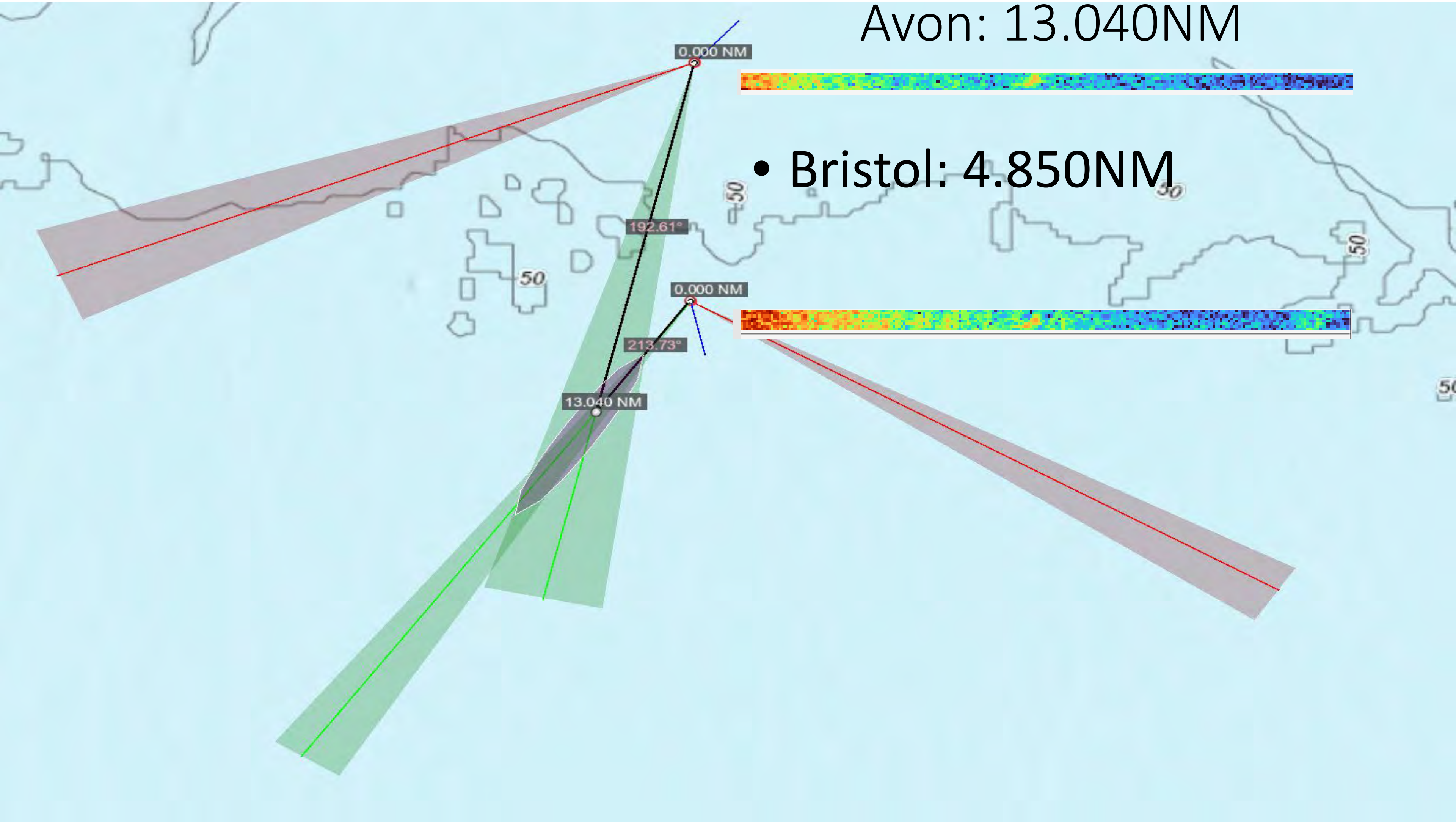
Avon/Bristol Non-Classifier Detect 20220414T0047Z



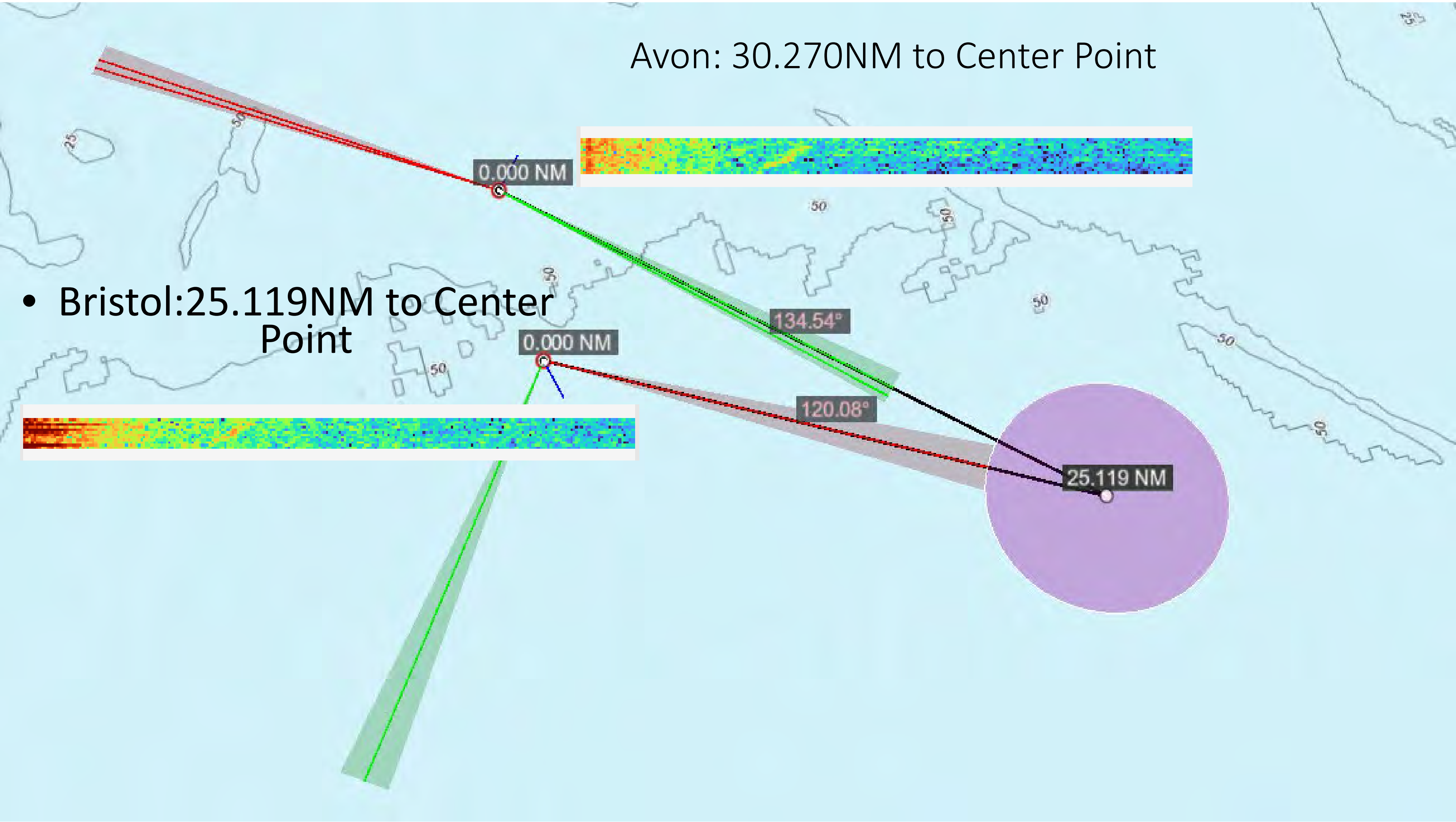
Avon/Bristol Detect 20220415T0012Z

Avon: 13.040NM

- Bristol: 4.850NM



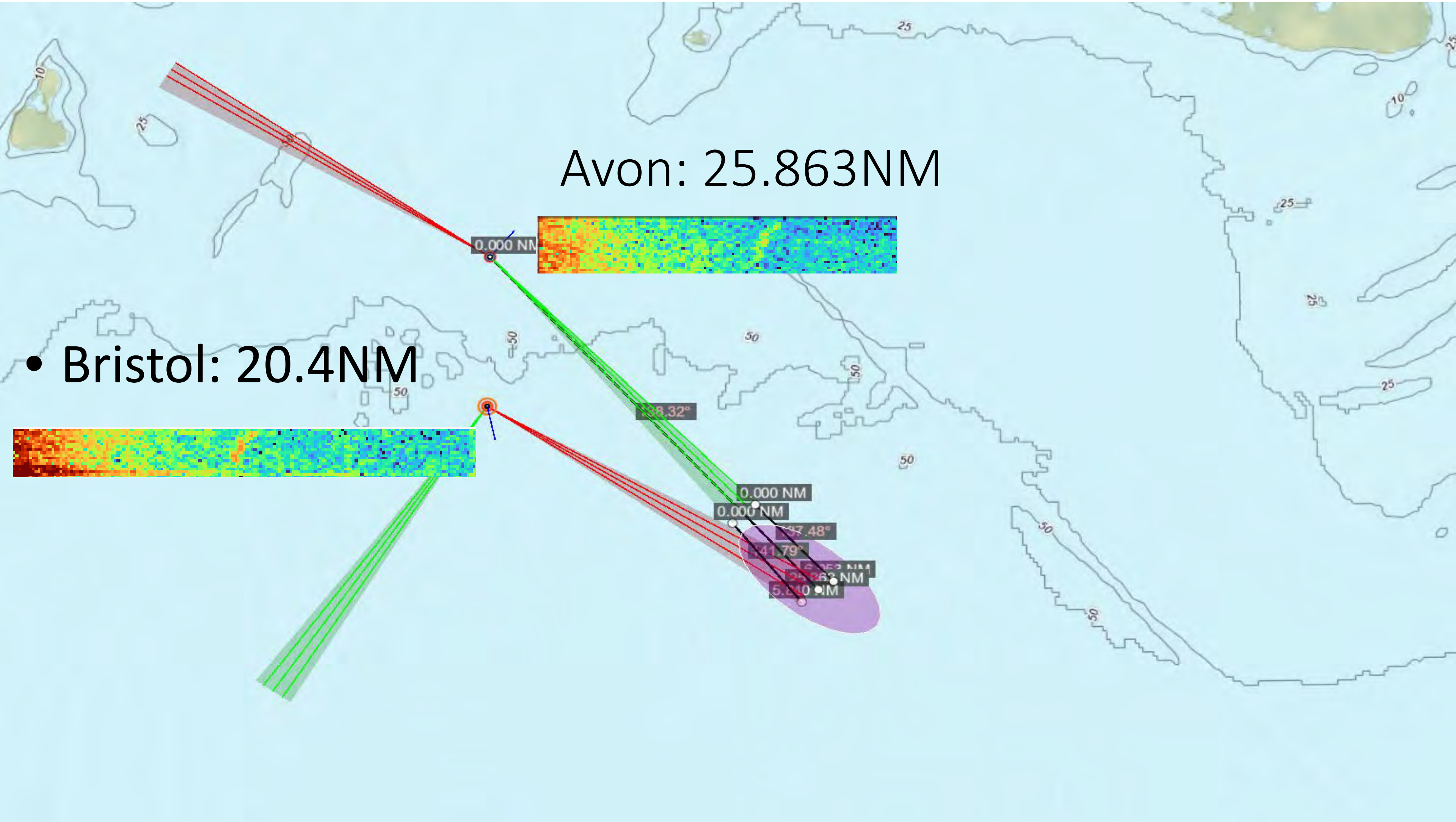
Avon/Bristol Detect 20220415T0414Z



Avon/Bristol Detect 20220415T0541Z

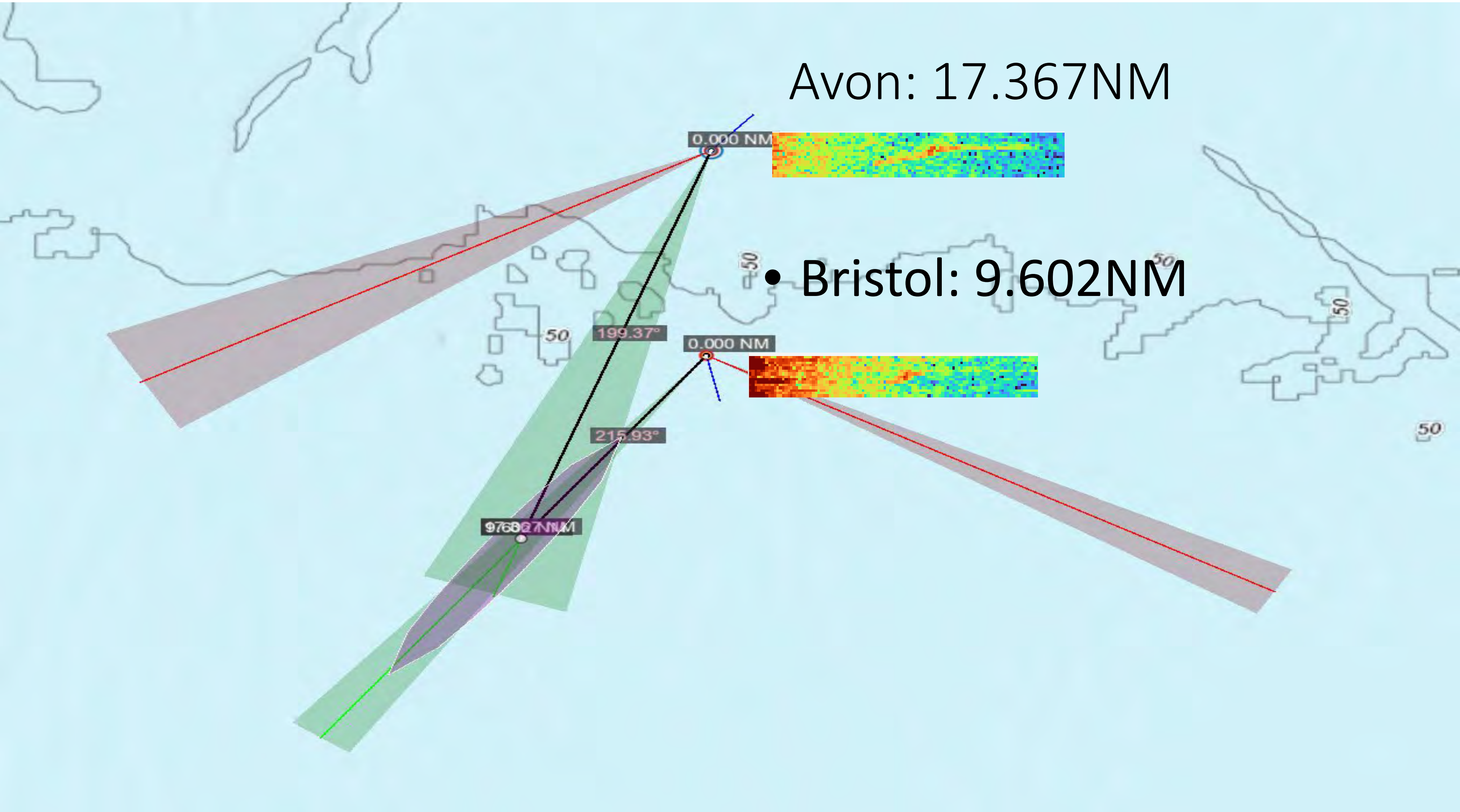
Avon: 25.863NM

- Bristol: 20.4NM



ThayerMahan

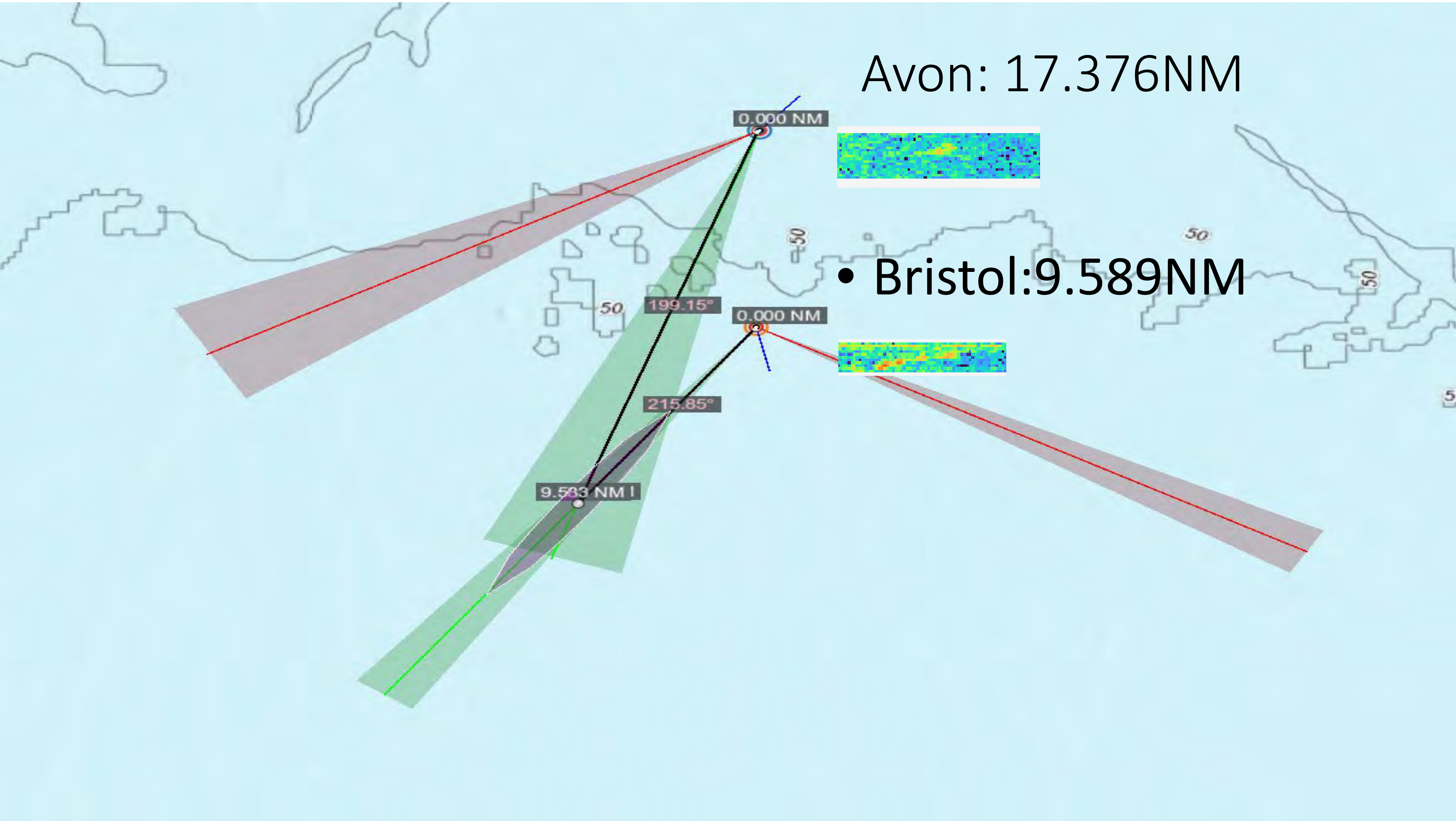
Avon/Bristol Detect 20220415T0624Z



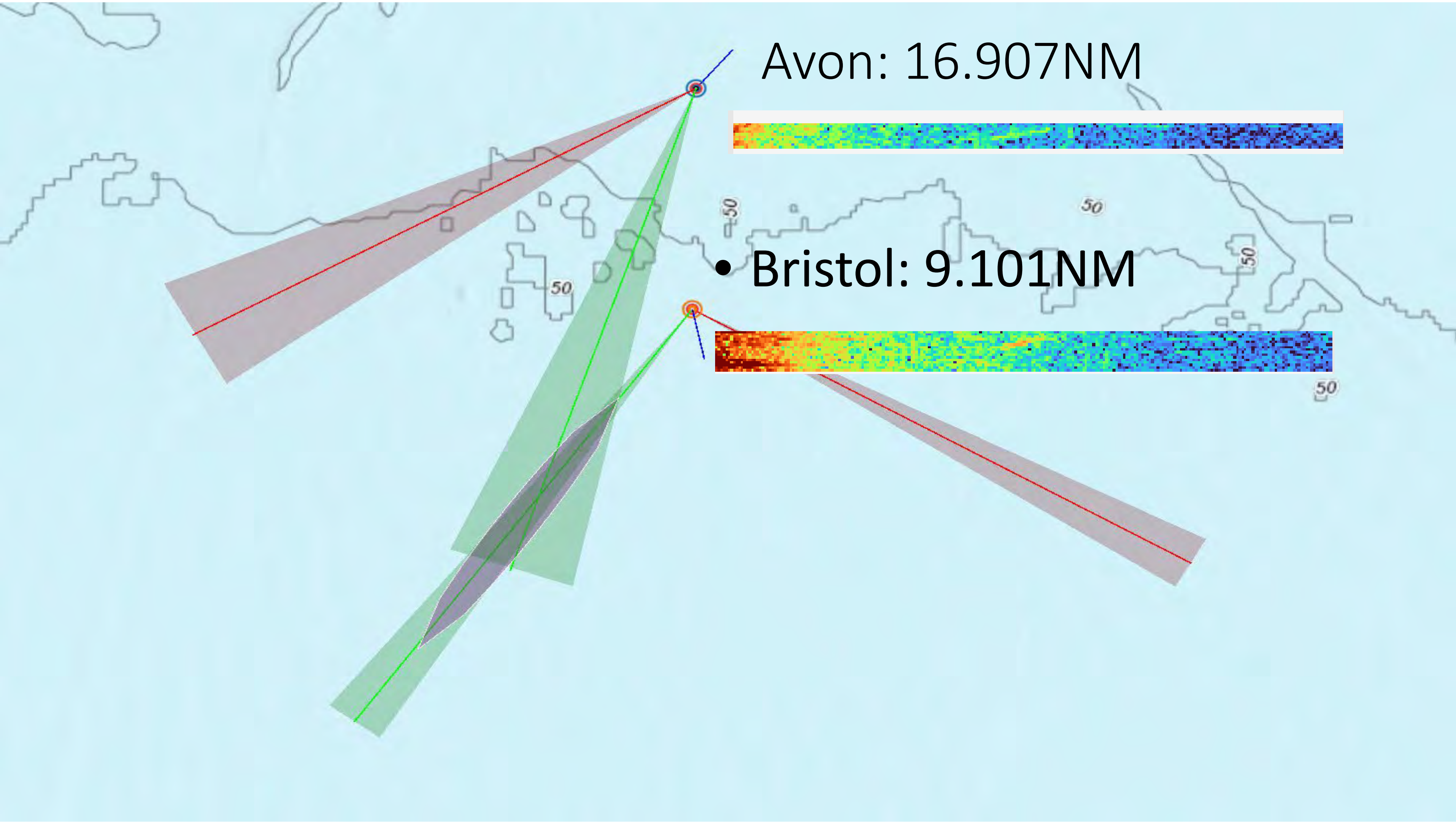
Avon/Bristol Detect 20220415T0637Z

Avon: 17.376NM

- Bristol:9.589NM

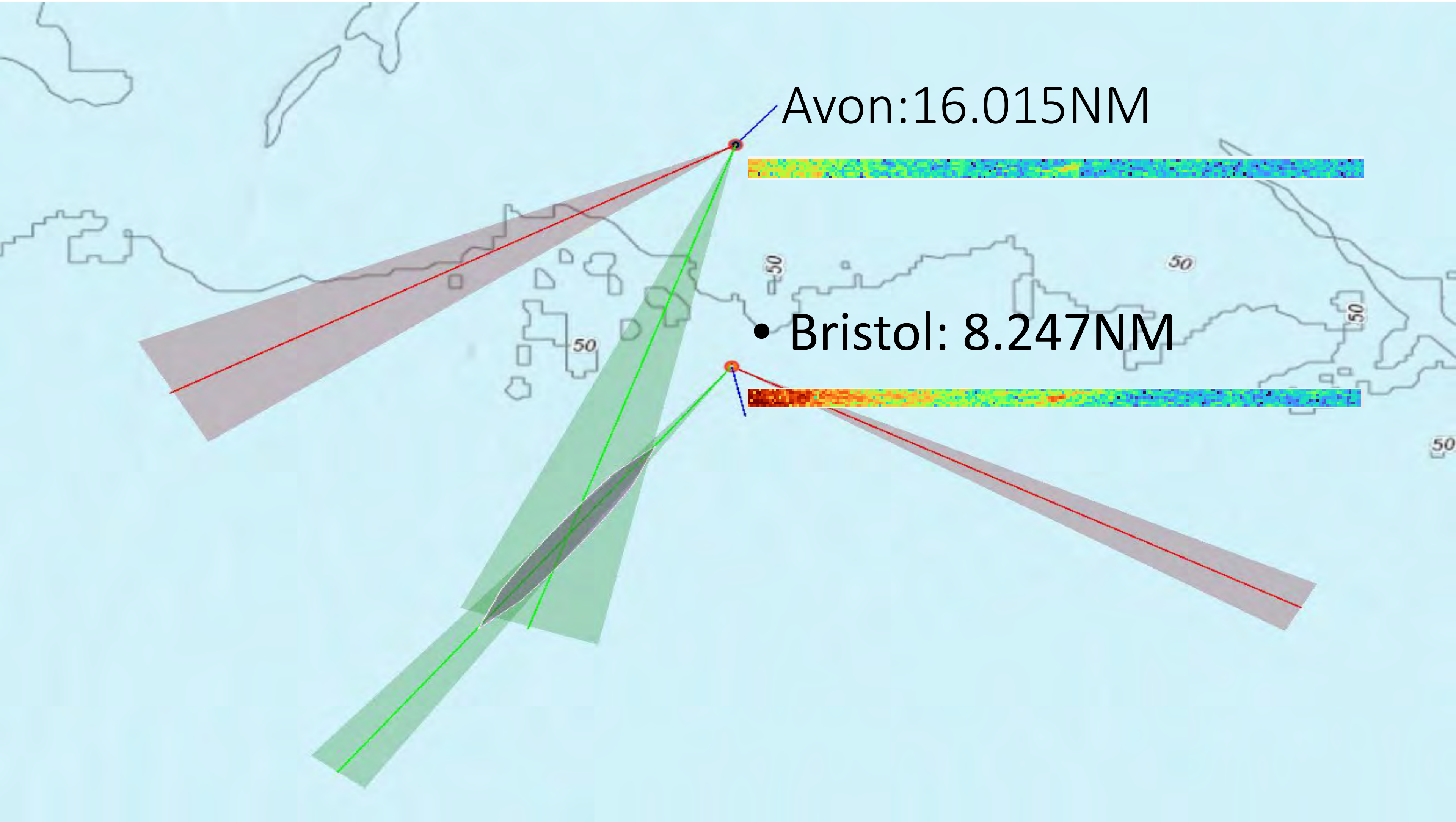


Avon/Bristol Detect 20220415T0742Z

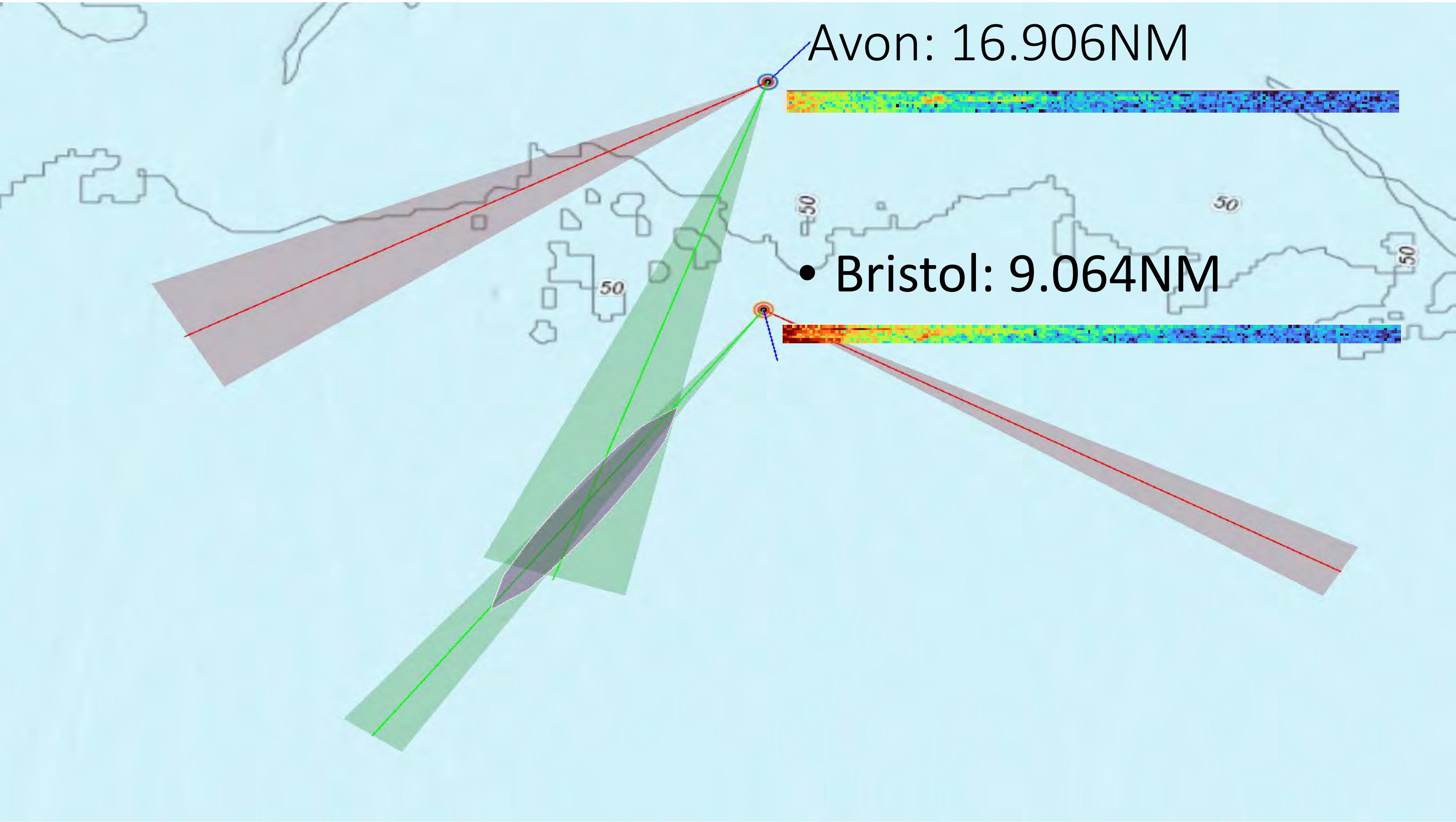


ThayerMahan

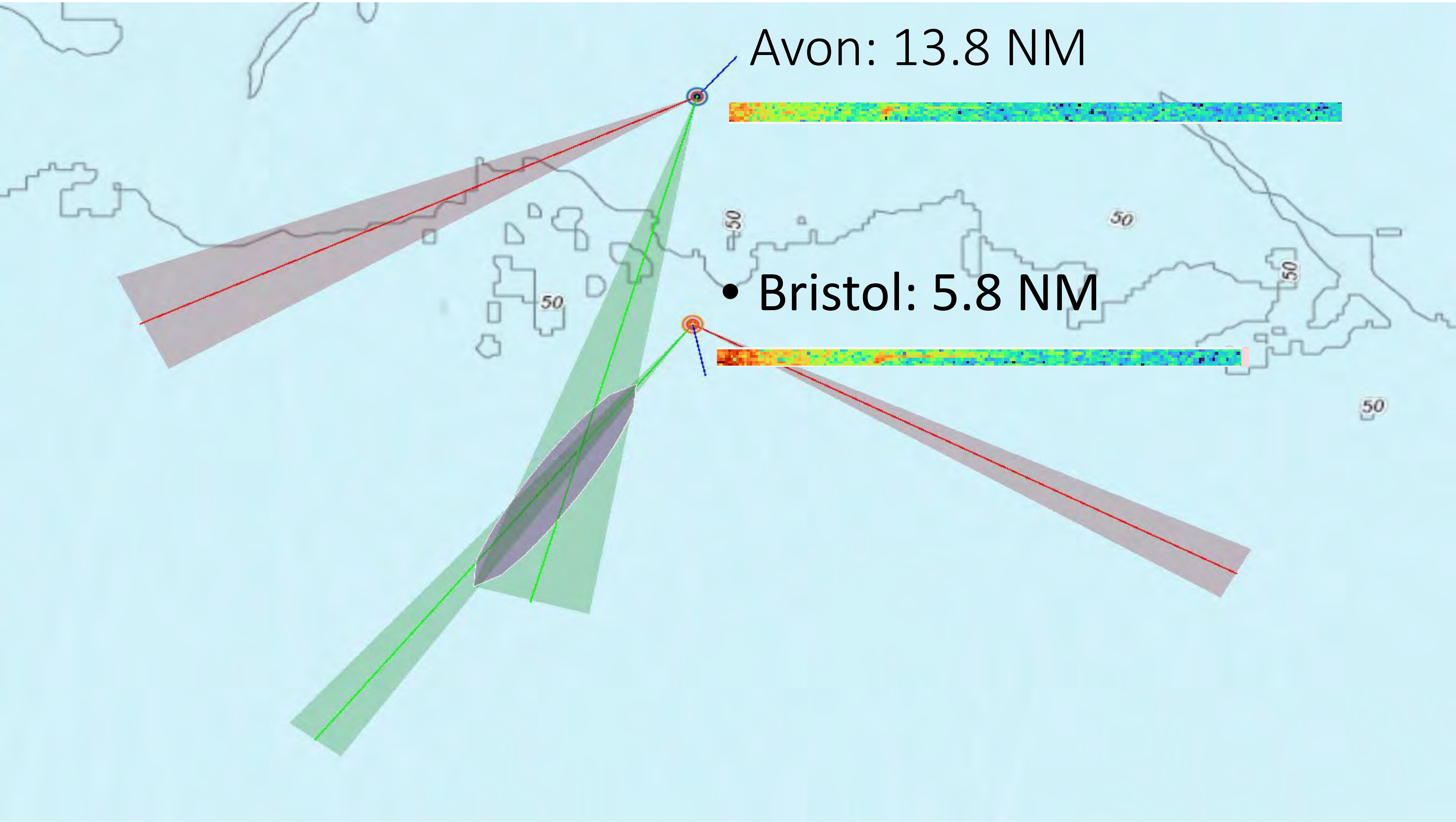
Avon/Bristol Detect 20220415T0804Z



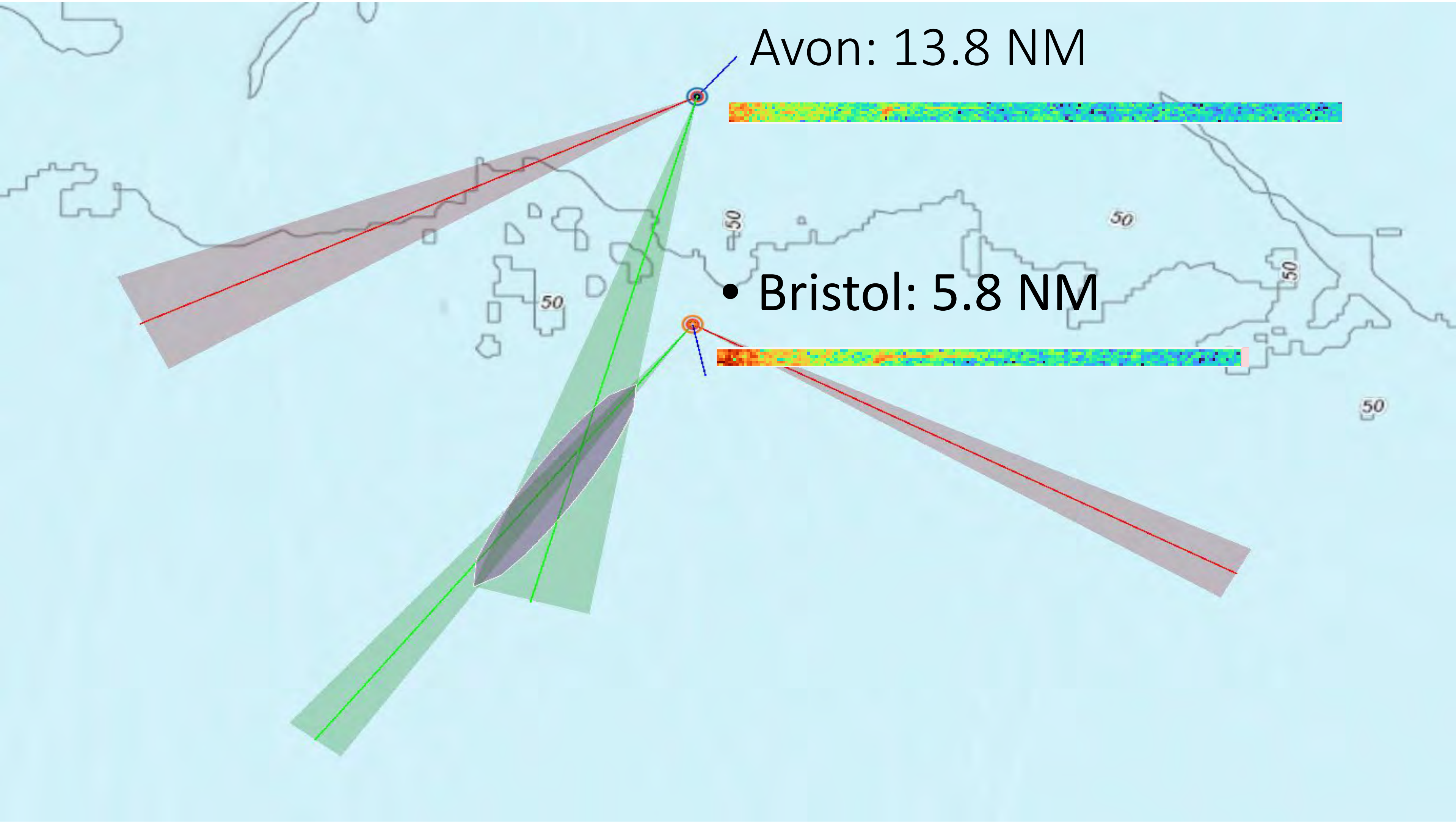
Avon/Bristol Detect 20220415T0840Z



Avon/Bristol Detect 20220415T0915Z

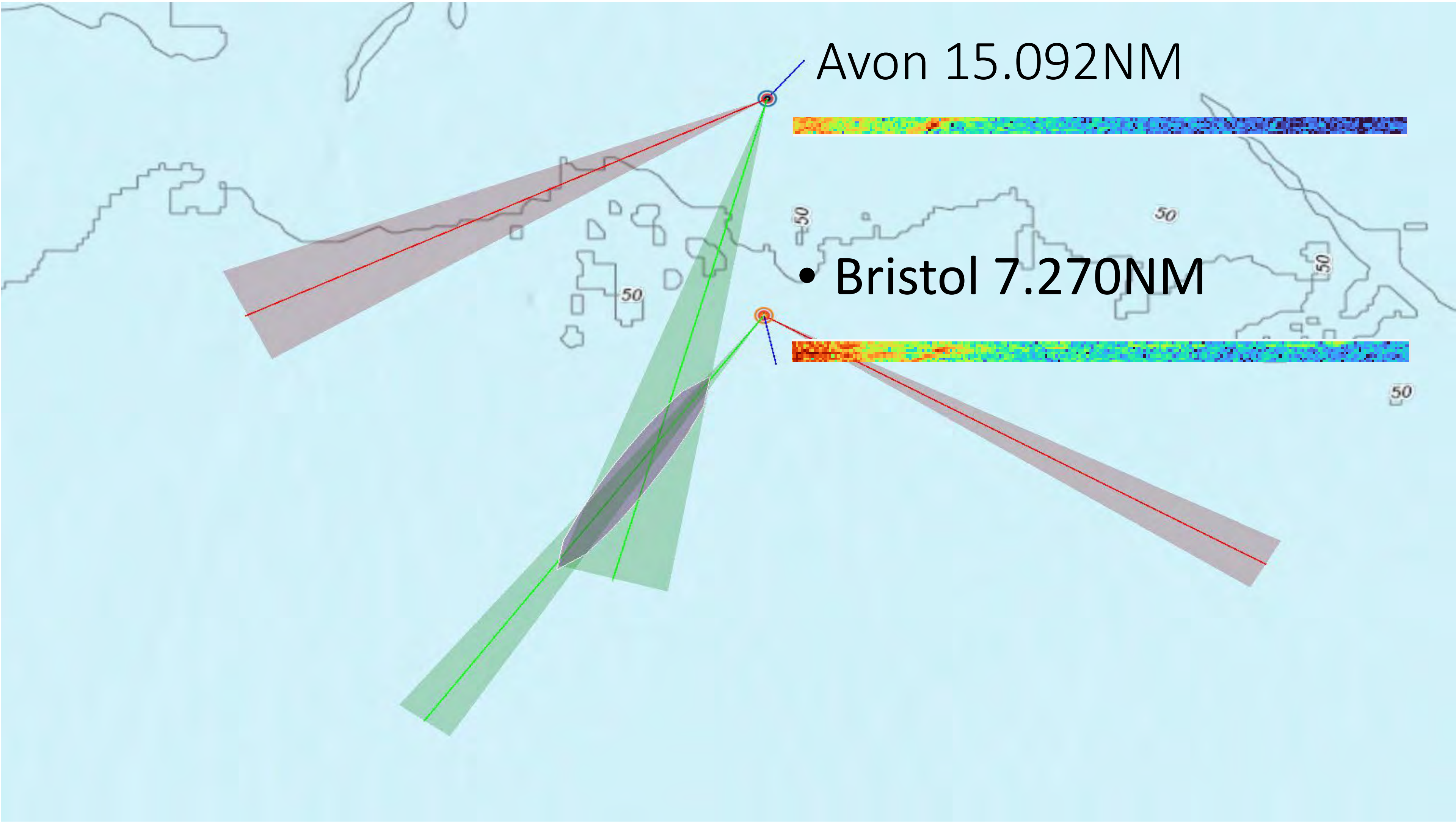


Avon/Bristol Detect 20220415T0915Z



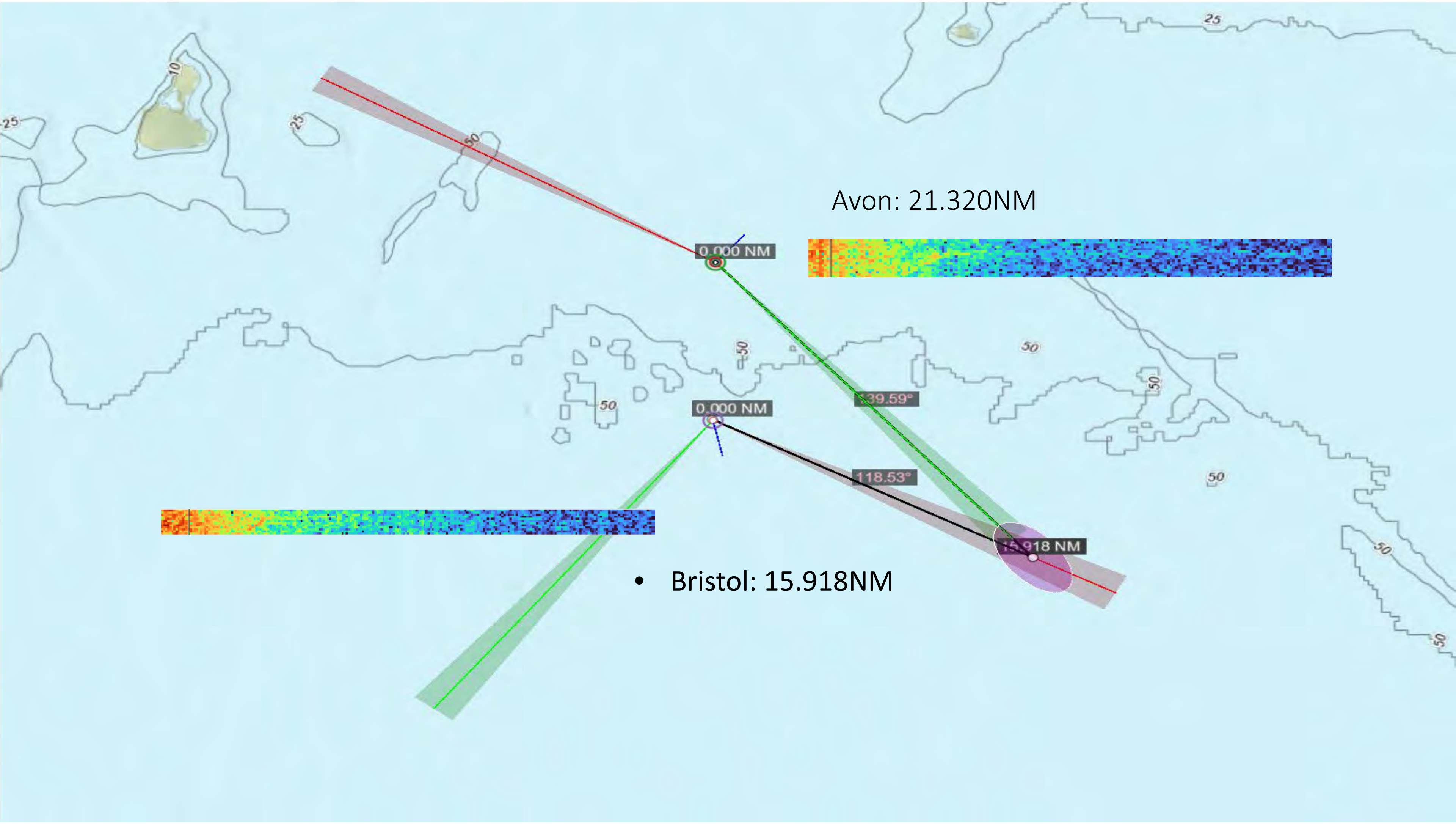
ThayerMahan

Avon/Bristol Detect 20220415T0953Z

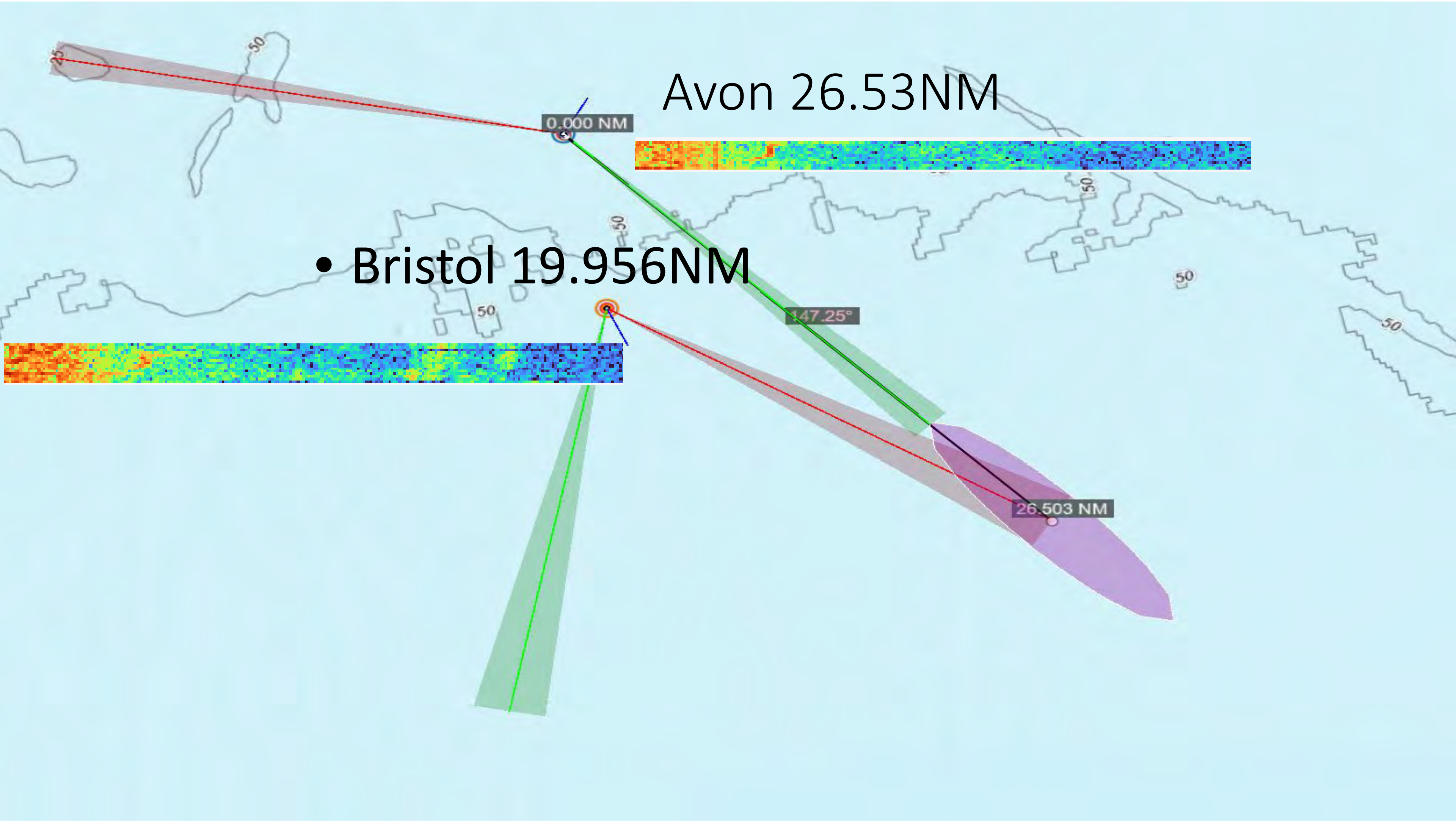


- Bristol 7.270NM

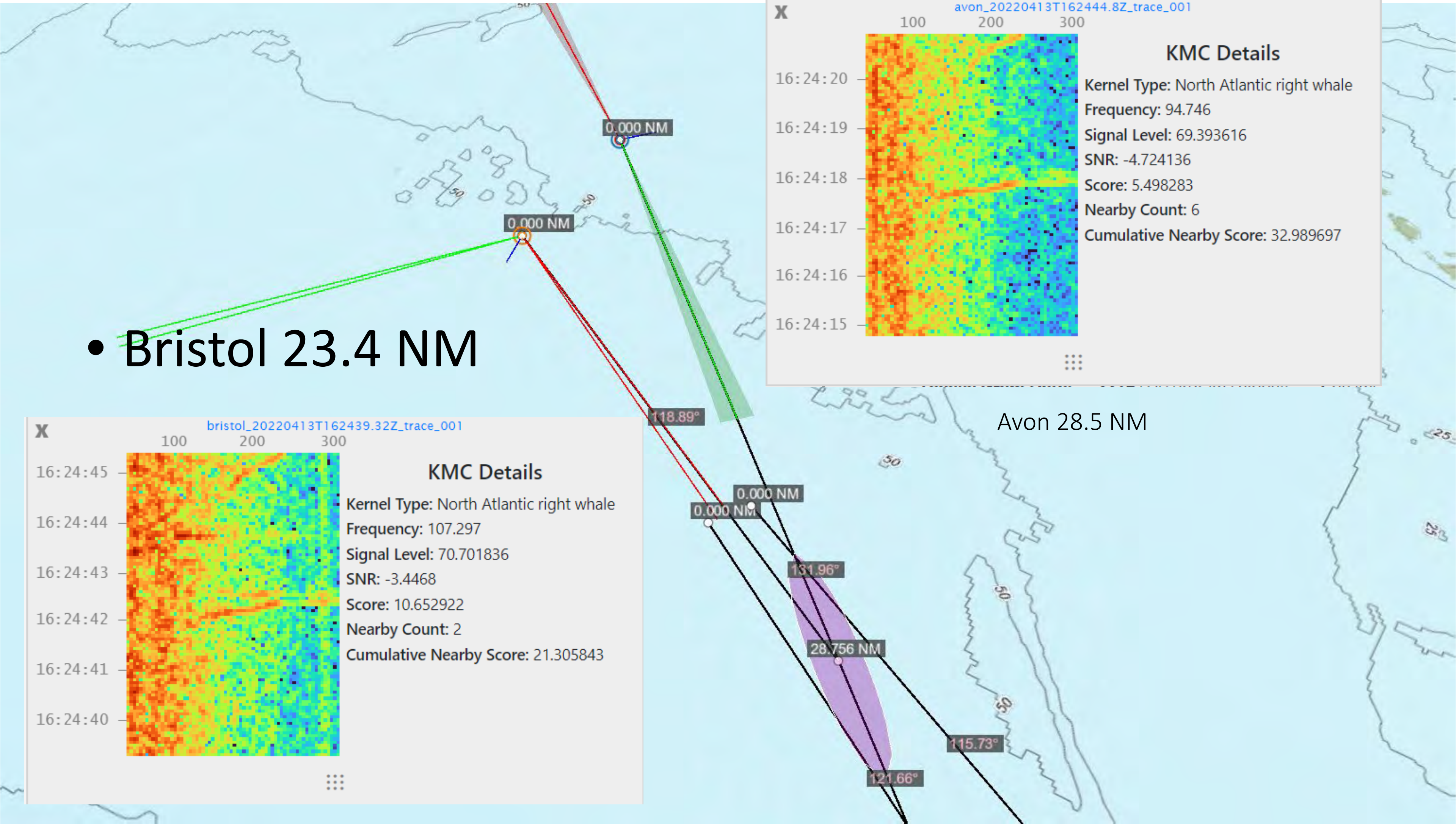
Avon/Bristol Detect 20220415T121021Z



Avon/Bristol Detect 20220423T0110Z



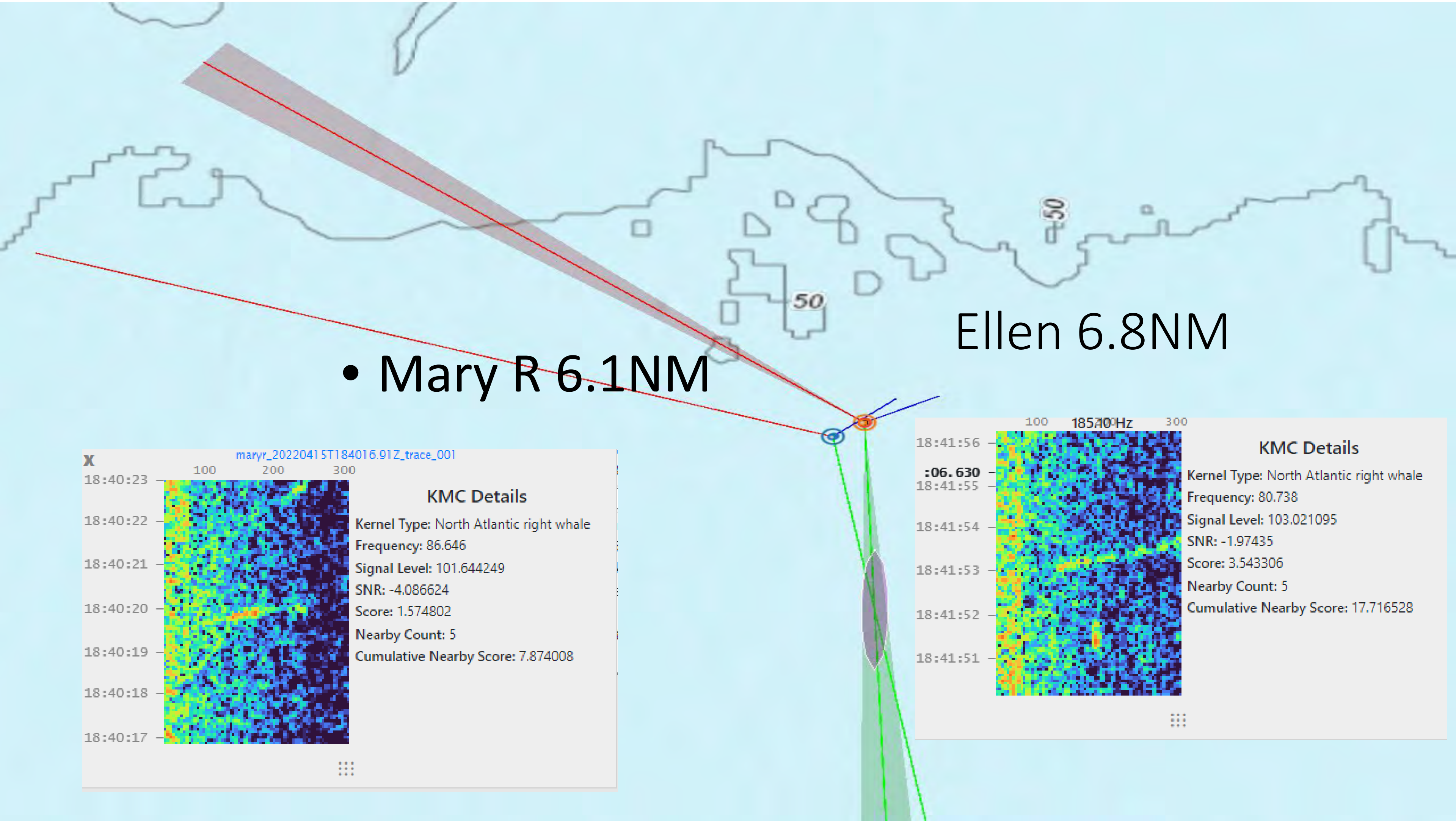
Avon/Bristol Classifier Detect 20220413T1624Z



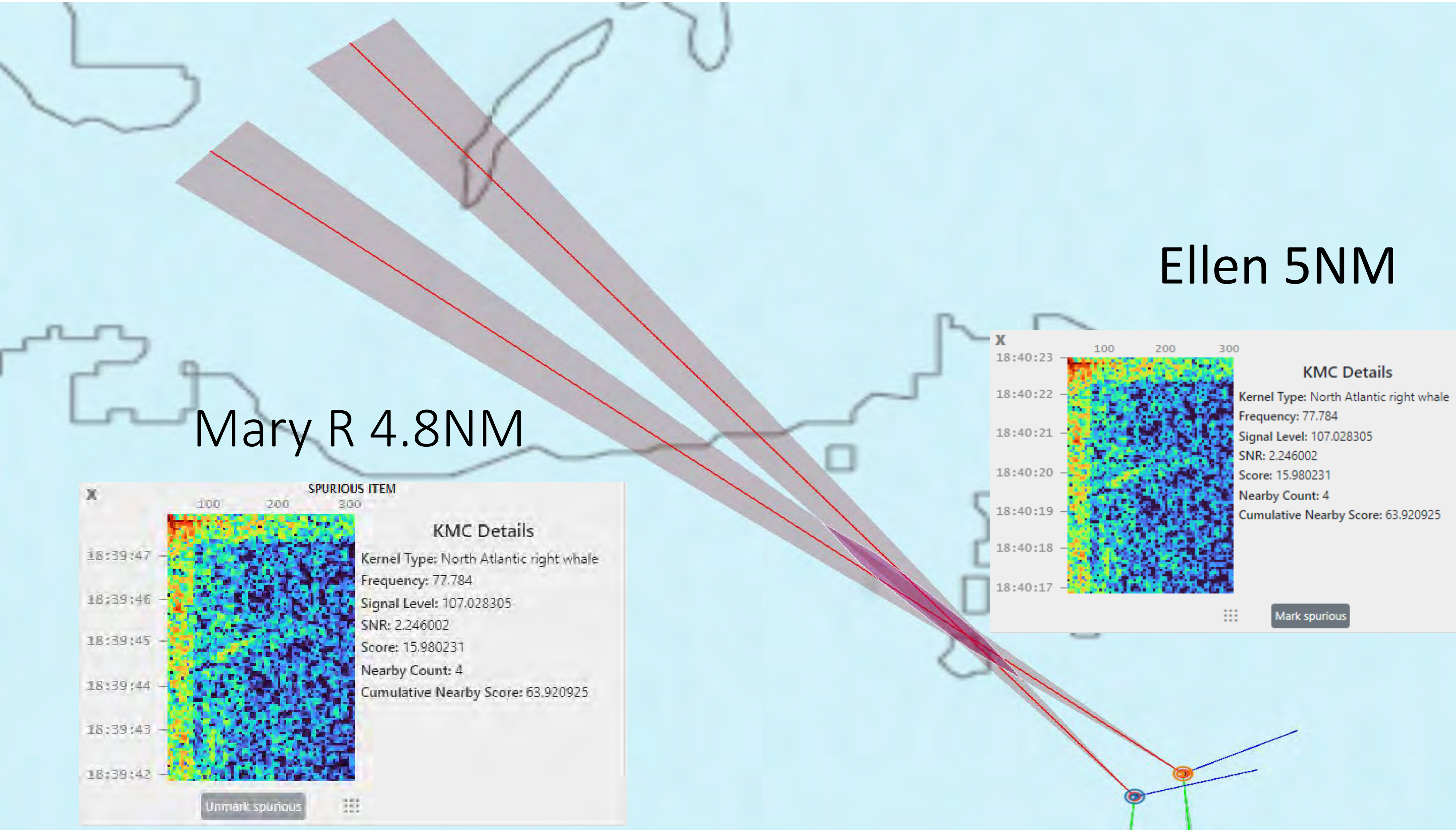
- Bristol 23.4 NM

Avon 28.5 NM

Mary R/Ellen Detect 20220415T1840Z



Mary R/Ellen Detect 20220415T1839Z



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The benefit of arrays for real-time, passive acoustic monitoring: Experimental results and detection performance predictions

Vince Premus, Phil Abbot, Greg Sabra, and Chris Clark
November 14, 2023

Ocean Acoustical Services and Instrumentation Systems, Inc.
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Presentation to BOEM, NOAA, and NMFS

Executive Summary

Arrays towed from manned platforms for detection and tracking of quiet targets have a long history in the US Navy anti-submarine warfare community; OASIS and ThayerMahan have operated UXVs instrumented with towed arrays since 2006

Most existing passive acoustic monitoring (PAM) systems are instrumented with single hydrophones; Many "array-based" PAM systems are ship-towed, multi-hydrophone systems, that are exposed to vessel noise and not coherently processed

Coherently beamformed arrays will outperform single hydrophones by spatially rejecting noise that masks low frequency baleen whale vocalizations; This noise rejection increases SNR, detection range, and area coverage

Arrays can also spatially resolve the relative bearing of vocalizing baleen whales, thereby providing capability to localize and track individuals, and measure their spatial distributions

Objective

- Overview experimental and modeling evidence of the powerful advantage held by arrays over single hydrophones for spatial noise rejection, spatial resolution, and detection range enhancement for baleen whale vocalizations
- Gain a better understanding of BOEM/NOAA/NMFS technical questions concerning the measured and modeled array detection ranges on North Atlantic Right Whale upcalls in the New England offshore wind lease environment

Key questions we seek to address in this brief: Why does the success of PAM for offshore wind depend on arrays? What advantage do arrays provide over single hydrophones?

Two Decades of Real-Time, Autonomous Passive Acoustic Monitoring

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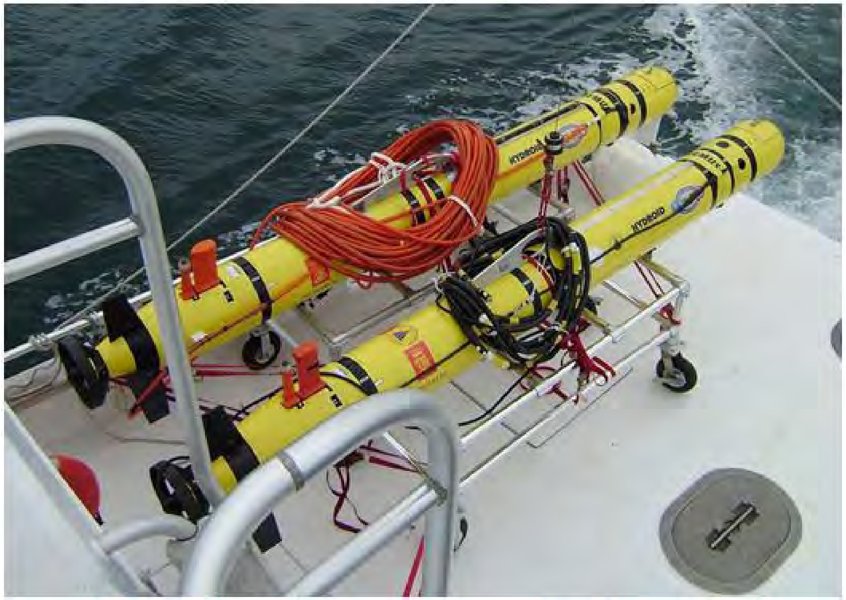

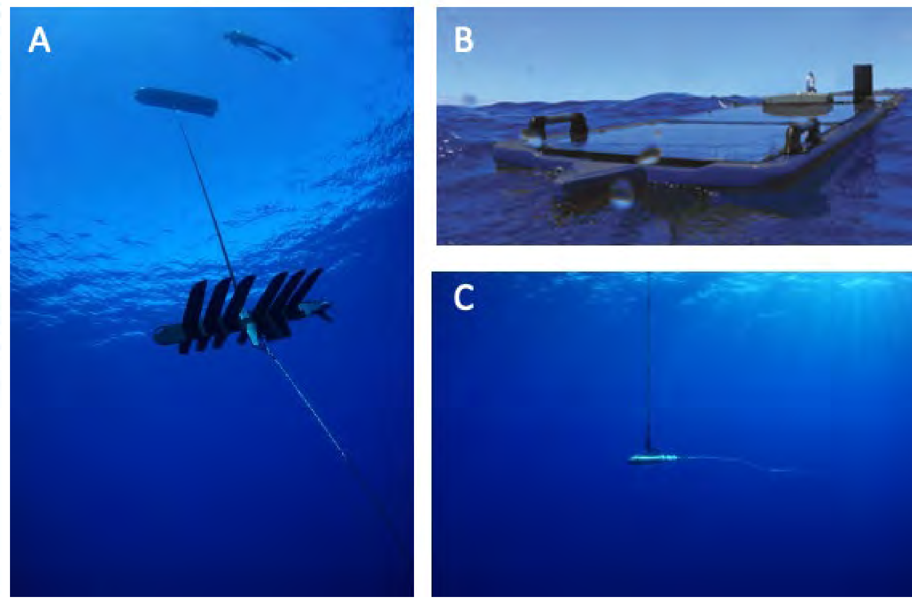

Recent Peer Reviewed Publications

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JASA ARTICLE

A wave glider-based, towed hydrophone array system for autonomous, real-time, passive acoustic marine mammal monitoring

Vincent E. Premus,[a] Philip A. Abbot, Vitaly Kmelnitsky, Charles J. Gedney, and Ted A. Abbot
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ABSTRACT:
An autonomous surface vehicle known as a wave glider, instrumented with a low-power towed hydrophone array and embedded digital signal processor, is demonstrated as a viable low-noise system for the passive acoustic monitoring of marine mammals. Other key design elements include high spatial resolution beamforming on a 32-channel towed hydrophone array, deep array deployment depth, vertical motion isolation, and bandwidth-efficient real-time acoustic data transmission. Using at-sea data collected during a simultaneous deployment of three wave glider-based acoustic detection systems near Stellwagen Bank National Marine Sanctuary in September 2019, the capability of a low-frequency towed hydrophone array to spatially reject noise and to resolve baleen whale vocalizations from anthropogenic acoustic clutter is demonstrated. In particular, mean measured array gain of 15.3 dB at the aperture design frequency results in a post-beamformer signal-to-noise ratio that significantly exceeds that of a single hydrophone. Further, it is shown that with overlapping detections on multiple collaborating systems, precise localization of vocalizing individuals is achievable at long ranges. Last, model predictions showing a 4× detection range, or 16× area coverage, advantage of a 32-channel towed array over a single hydrophone against the North Atlantic right whale upcall are presented for the continental shelf environment south of Martha's Vineyard.
https://doi.org/10.1121/10.0014169

(Received 1 December 2021; revised 22 August 2022; accepted 23 August 2022; published online 22 September 2022)
[Editor: Kathleen J. Vigness-Raposa] Pages: 1814–1828

I. INTRODUCTION

Mobile autonomous platforms such as buoyancy gliders and wave gliders have been instrumented with hydrophones and employed for the purpose of passive acoustic marine mammal monitoring (PAM) for over a decade. These autonomous, maritime systems exhibit distinct advantages over some traditional approaches such as hydrophones deployed from support vessels in that they are persistent and operate for long periods of time without manual intervention or own-ship radiated noise contaminating the acoustic measurements. These systems typically record acoustic data for post-analysis and often employ some means of on-board data processing to support real-time detection and classification of marine species and reporting via satellite communications link. Klinck *et al.*[1] were among the first to deploy a hydrophone on a Seaglider for the real-time detection and reporting of beaked whales and other odontecetes off the leeward coast of Hawai'i. Baumgartner *et al.*[2] reported on the use of Slocum gliders for near real-time estimates of baleen whale presence in the southwestern Gulf of Maine. Darling *et al.*[3] deployed a Liquid Robotics (Kamuela, HI) wave glider instrumented with a single hydrophone for the measurement of baleen whale vocalizations to test the hypothesis of humpback whale presence in offshore tropical waters during the winter breeding season. Recently, Kowarski *et al.*,[4] motivated by the impact of anthropogenic activity on endangered North Atlantic right whales in the Gulf of St. Lawrence in 2017, explored the practical challenges underlying the use of autonomous systems, in particular, buoyancy gliders, for PAM applications, including the impacts of self-noise, energy budget, and data transfer bandwidth. Similarly, Baumgartner *et al.*[5] have investigated some of the engineering issues associated with wave gliders, such as the potential self-noise and platform radiated noise mechanisms, that could compromise the platform's utility for PAM applications. The extensive body of work represented by these sources, and the references cited therein, now forms the foundation for research initiatives comparing the use of mobile autonomous and stationary recorders for marine mammal survey[6] and the potential biases introduced by autonomous systems for cetacean monitoring[7] and informs the work of government regulatory bodies responsible for mitigating the impacts of man-made activities such as offshore wind installation and operation on marine mammal habitat.[8]

Most of the applications of gliders and wave gliders to PAM rely on a single hydrophone to perform the acoustic

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Vehicle Motion-Related Noise Mitigation Analyses of a Waveglider Towed Array System for Passive Acoustic Marine Mammal Monitoring

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Abstract*— With the proliferation of offshore wind construction and the expected impact to marine mammal habitat by pile driving and increased support vessel traffic, passive acoustic marine mammal monitoring has rapidly become a high priority for academic and commercial research interests, as well as government regulatory agencies. Mobile autonomous sensing systems, such as wavegliders have demonstrated efficient, remote, real-time acoustic monitoring with wide-area coverage, particularly when instrumented with towed hydrophone arrays [1]. Arrays have significant advantages over single hydrophone systems due to their capacity for spatial noise rejection and spatial resolution of acoustic sources. Further, when the array is deployed deep below the sea surface through the use of a long tow cable, system noise levels are reduced by isolation from the various vehicle motion-related noise effects. In this paper, we review the design of a waveglider-based monitoring system first introduced in [1], and report on the noise performance of the system with particular emphasis on physical mechanisms that cause the system noise at low frequency. These include flow-induced effects from the waveglider itself, cable strum induced by vortex shedding from the tow cable, residual vertical motion at the sensor induced by surge and vortex shedding, and turbulent boundary layer flow noise over the moving hydrophone array.

***Keywords*—waveglider, towed array, flow noise, passive acoustics, marine mammal monitoring, offshore wind**

I. Introduction

Any mobile maritime acoustic sensing platform instrumented with a hydrophone or hydrophone array may be subject to motion-related noise mechanisms that can raise the system noise at low frequency, thereby degrading the signal-to-noise ratio needed to effectively detect marine mammals. These noise sources are caused by hydrodynamic flow effects or by moving mechanical parts on the platform. Some of the key flow-induced effects include the interaction of turbulent flow with the leading and trailing edges of control planes (wings, rudders, or umbilical), cable strum induced by vortex shedding from the use of a tow cable, uncompensated vertical motion at the sensor induced by platform surge and/or vortex shedding, and turbulent boundary layer (TBL) pressure fluctuations over the moving hydrophone. Also, near the sea surface, unwanted noise can result from sea surface agitation due to wind, waves breaking, and bubbles collapsing. In light of these potentially performance-limiting factors, the interpretation and mitigation of noise mechanisms associated with the waveglider towed array system are an important consideration in its use as a tool for passive acoustic monitoring of baleen whales and are the focus of this paper.

In this work, data results are presented from an at-sea deployment conducted near Stellwagen Bank in September 2019 [1]. These results are compared to earlier observations of flow-induced noise measured on a hydrophone deployed from a waveglider [2] and from buoyancy gliders [3, 4]. Measured wavenumber-frequency (k-ω) analysis and modeled turbulent boundary layer flow noise [5] are also used to analyze the noise mechanisms of the system at low frequency to establish the reduction of flow-related effects on the noise response of the system. The data and modeling analysis and its interpretation in the context of earlier autonomous hydrophone system measurements suggest that the waveglider-based, deep deployed towed hydrophone array is a quiet system and viable for the real-time passive acoustic monitoring of vocalizing baleen whales.

II. System Overview

A. The Waveglider

The autonomous system which is the focus of this work is the Outpost passive acoustic monitoring system first introduced by ThayerMahan in 2017 [6]. The Outpost system is based on the waveglider, an uncrewed surface vehicle (USV) introduced by Liquid Robotics in 2007 [7]. The waveglider is a maritime platform that generates forward propulsion by harnessing the orbital motion induced in the upper water column from wind-generated swell and sea surface waves. Depicted in Figure 1, the waveglider is comprised of three primary components: 1) the surface float, 2) the umbilical, and 3) the sub. The key hydrodynamic innovation of the waveglider is the design of the "sub." Shown in Fig. 1(a), it is the mechanism through which

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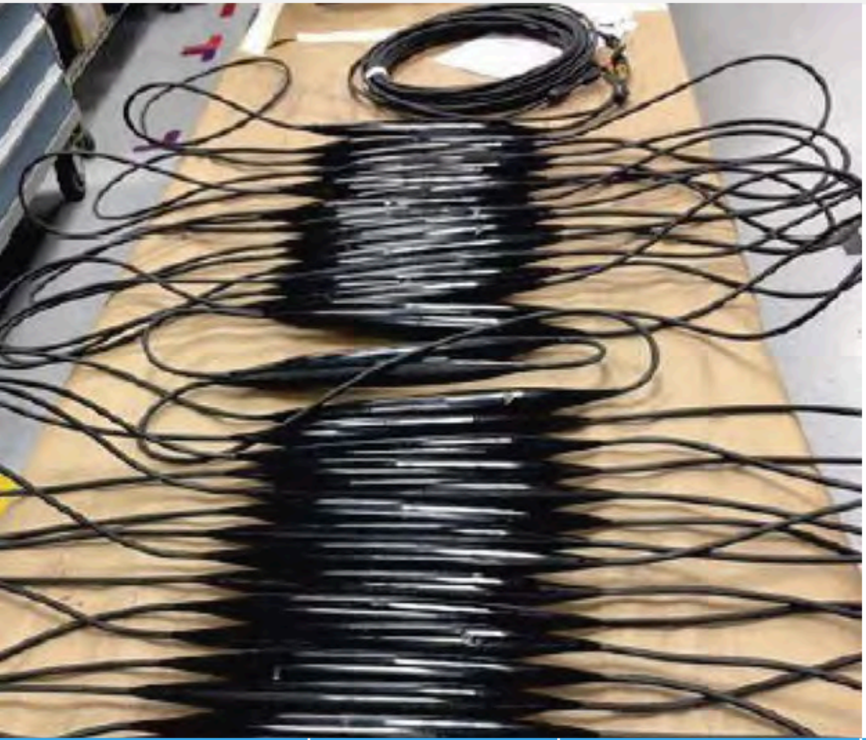
ThayerMahan Towed and Bottom Mounted Array Specification



- Built by Raytheon Missiles and Defense, Portsmouth RI
- 32-channel and 64-channel variants
- Low drag, laminar flow hydrophone jacket design
- High-precision NAS (heading, depth, pitch)
- Sensitivity -199 dBV re 1μPa; Pre-amp gain 10 dB
- ADC 24-bit precision; Sample rate 2.5 kHz
- Ethernet UDP interface to DSP
- Power draw ~30 mW/channel; Total array power draw less than 2W

Array	f_D (Hz)	Number Channels	Length (m)	Max Beamwidth (Deg)	Theoretical AG (dB)
Ray32/600	600	32	40	3.5	15
Ray32/300	300	32	80	3.5	15
Ray64/300	300	64	160	1.8	18

Plane Wave Beamforming: Why Arrays Work

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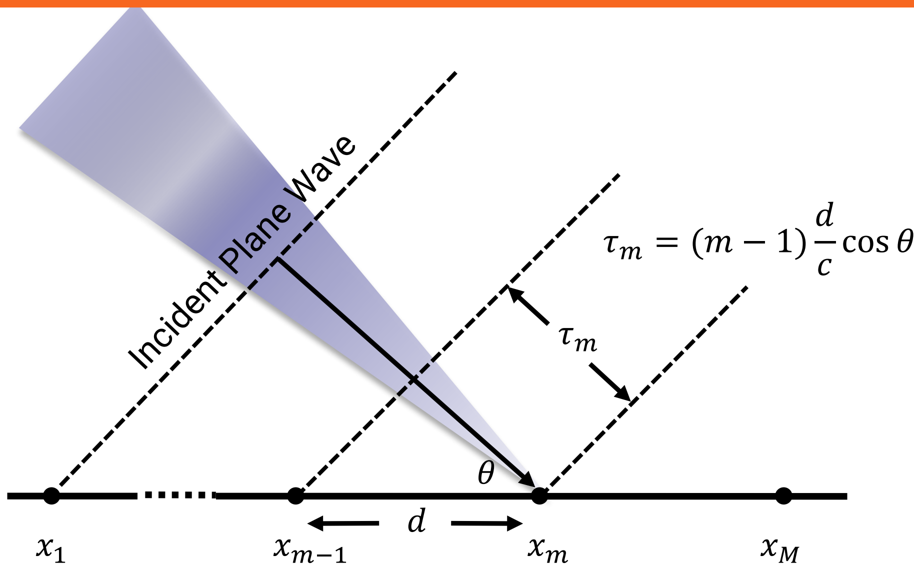
Delay and sum beamforming allows emphasis of one "look" direction over all others



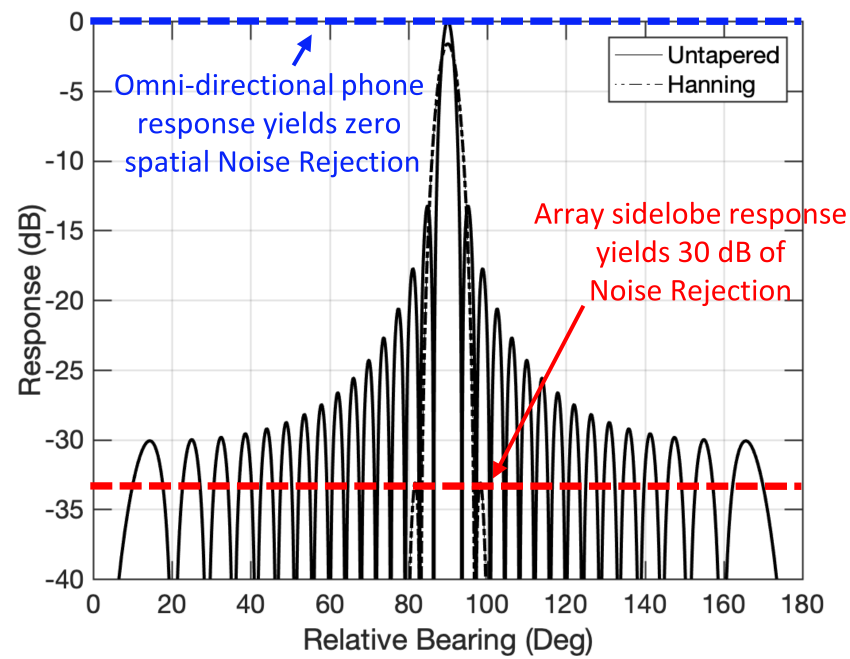
Time Domain

$$y(t) = \sum_{m=1}^{M} x_m(t - \tau_m)$$

Frequency Domain

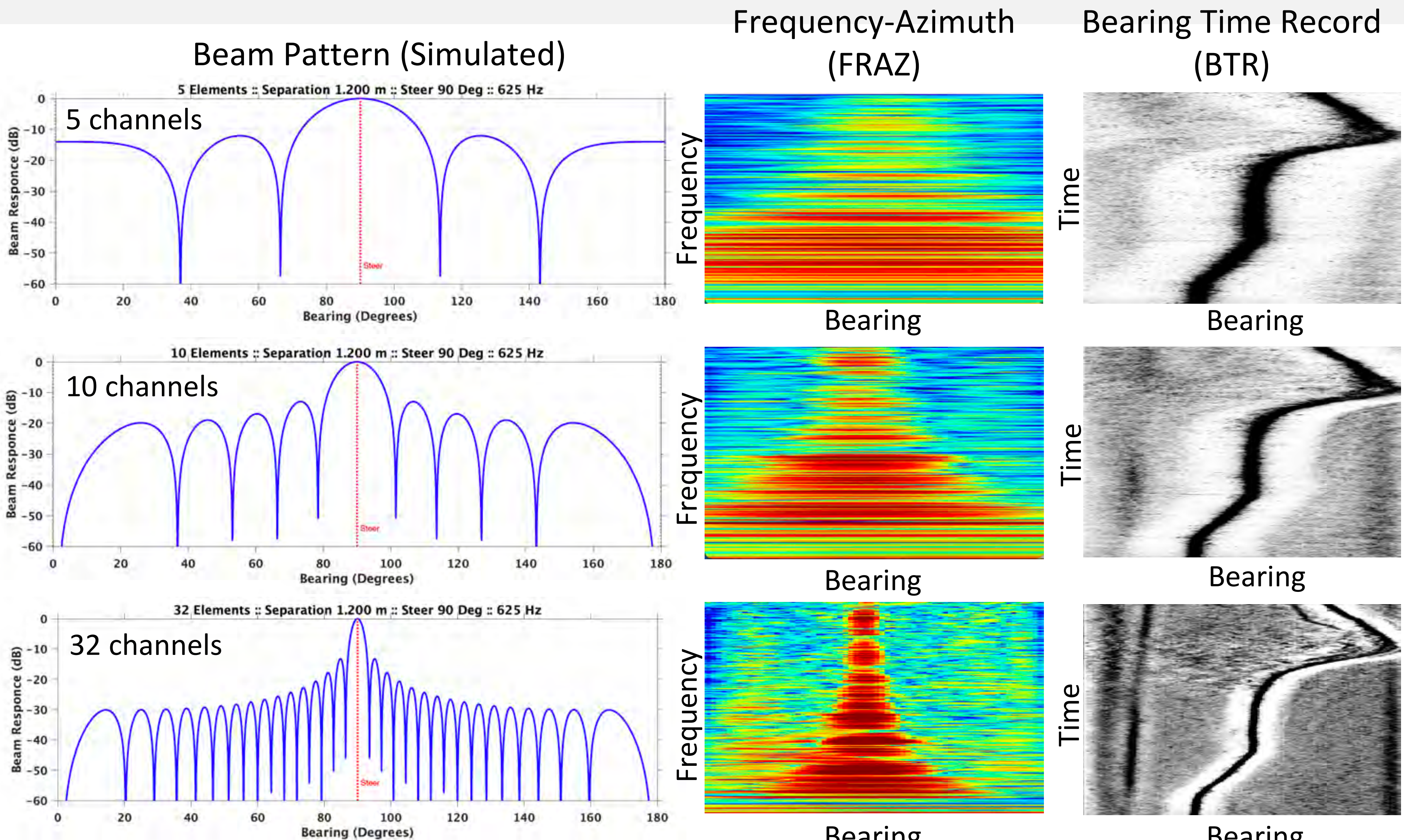
$$Y(\omega) = \sum_{m=1}^{M} X_m(\omega) e^{-j\omega\tau_m}$$

Beam Pattern at Design Frequency
for 32-Channel Array



Fast beamformer implementation steers beams to all look directions simultaneously in real-time

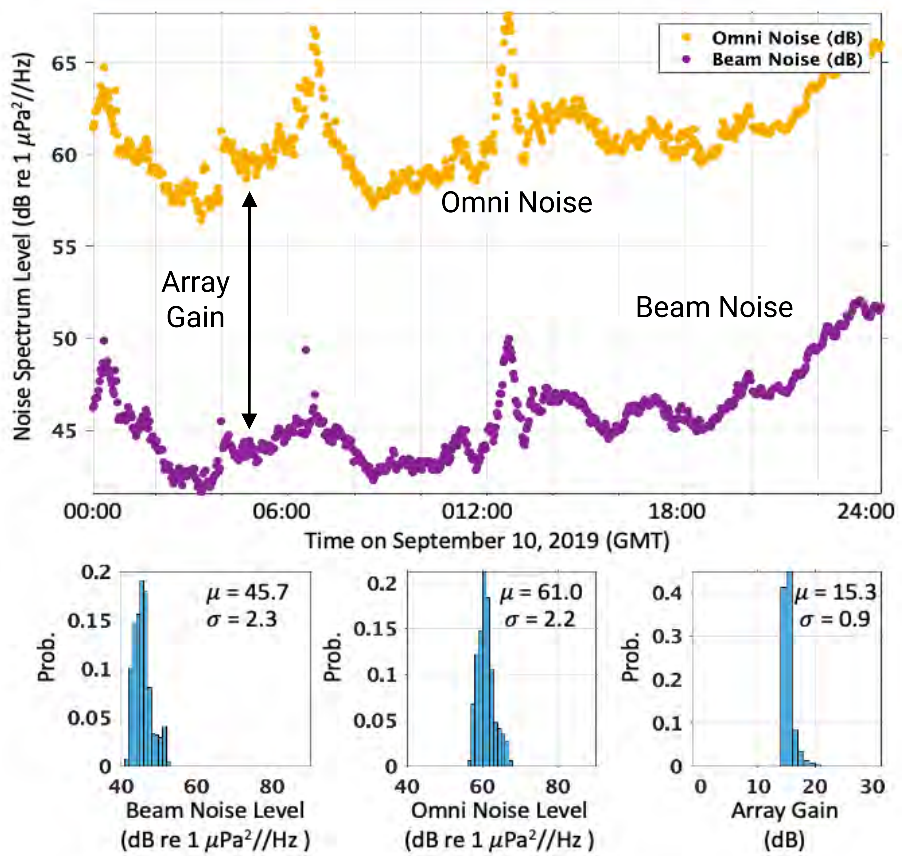
Array Performance vs Aperture Length



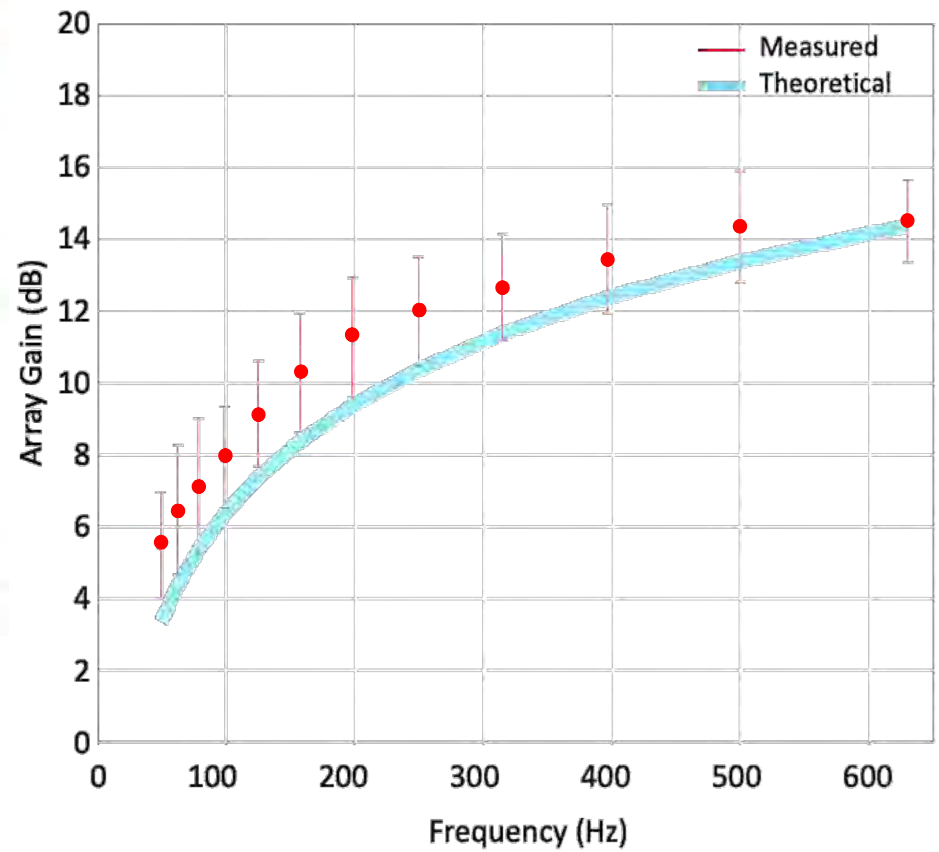
Array Performance Metrics: Array Gain Measurement

Stellwagen Bank September 2019, Mary R Ray32/600

Noise Time Series and Histograms @ 625 Hz

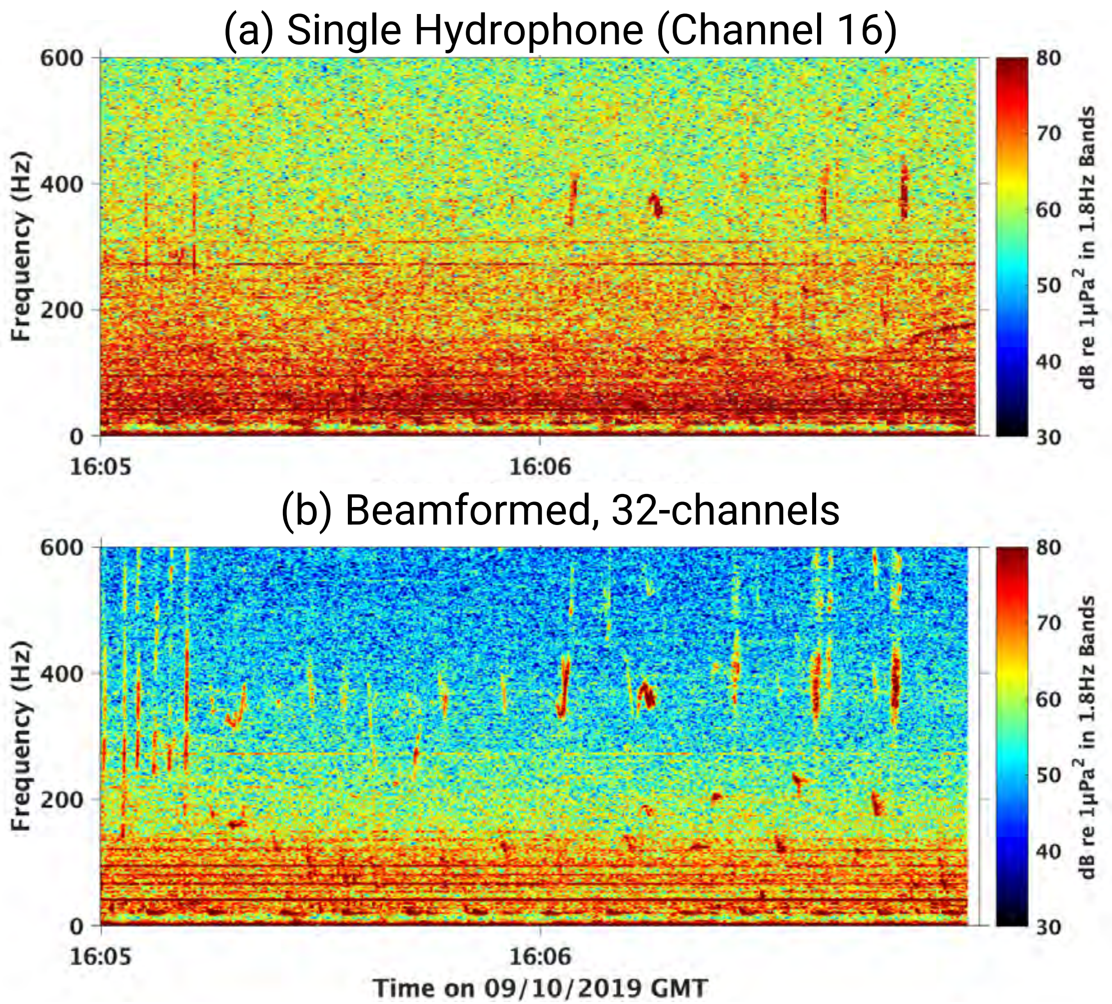


Array Gain Frequency Dependence



Beam noise level is always less than the omni—on average by $10\log_{10}N$ at the array design frequency

The Benefit of Coherent Array Gain: Noise Rejection



Beamforming spatially rejects noise, revealing calls that may be masked at the single hydrophone

The Benefit of Coherent Array Gain: Spatial Resolution

Stellwagen Bank September 2019, Mary R Ray32/600

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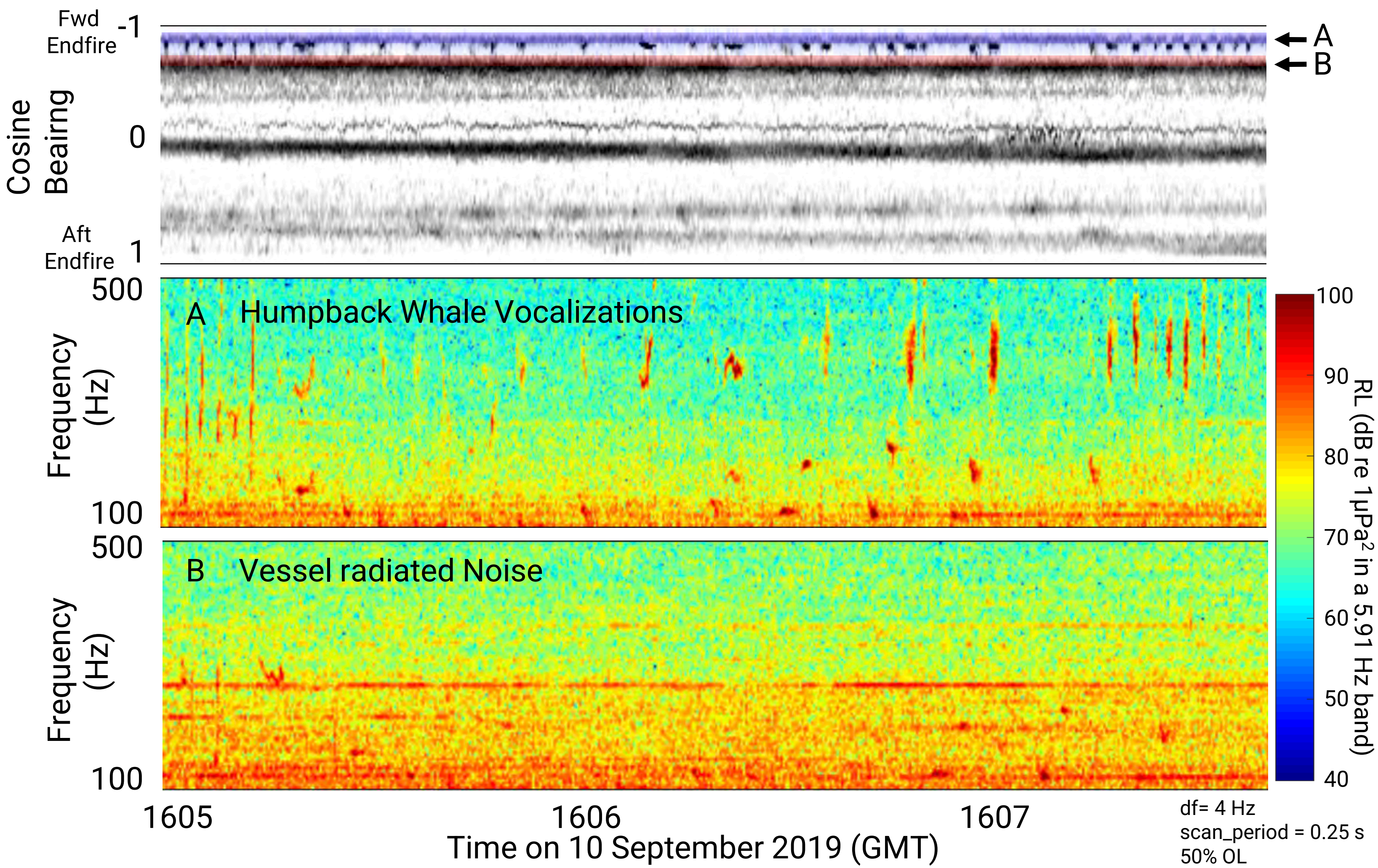
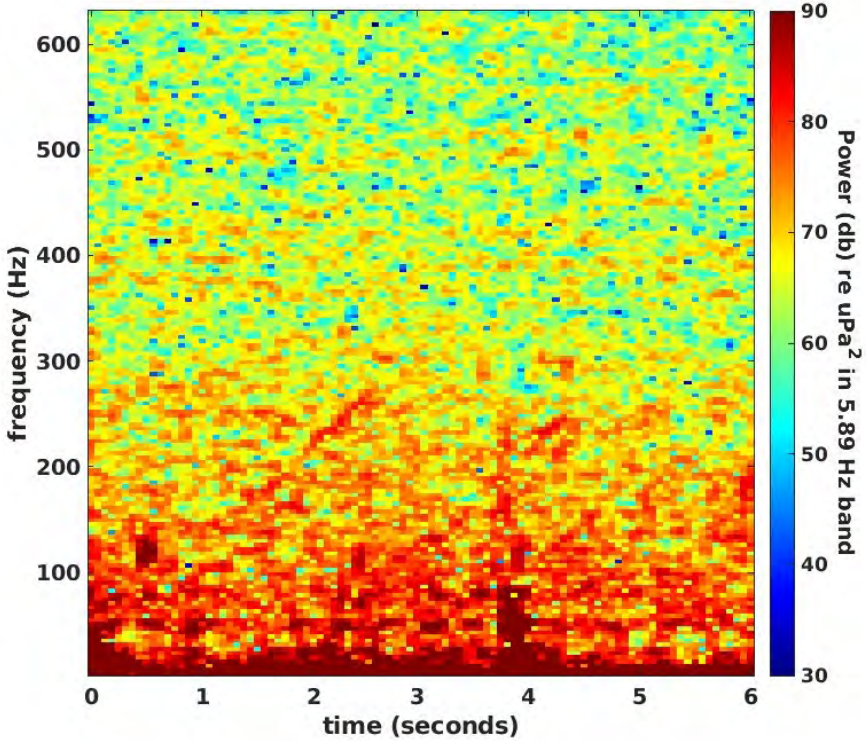


Array beamforming enables one to resolve closely spaced acoustic noise sources

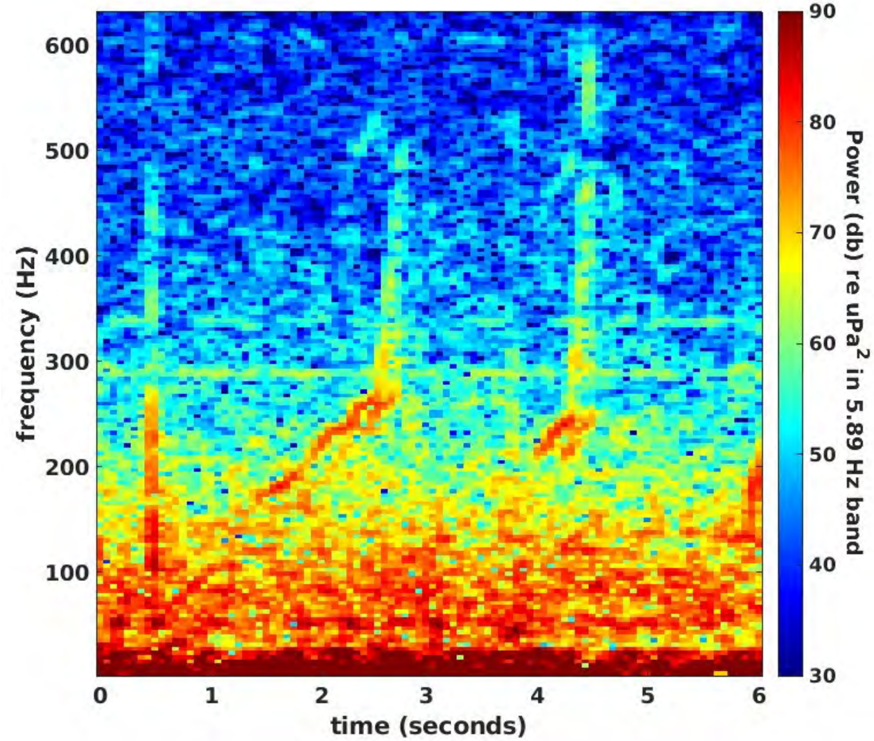
Single Hydrophone vs Array: North Atlantic Right Whale (NARW) Upcall Wavefiles

Single Hydrophone
SNR = 6dB



Bristol hydrophone wavefile.wav

Array
SNR = 15 dB



Bristol beamformed wavefile.wav

NARW upcall is nearly inaudible on the single hydrophone, but clearly detectable on the array

The Benefit of Array Gain: Long Range Localization of NARW Upcall

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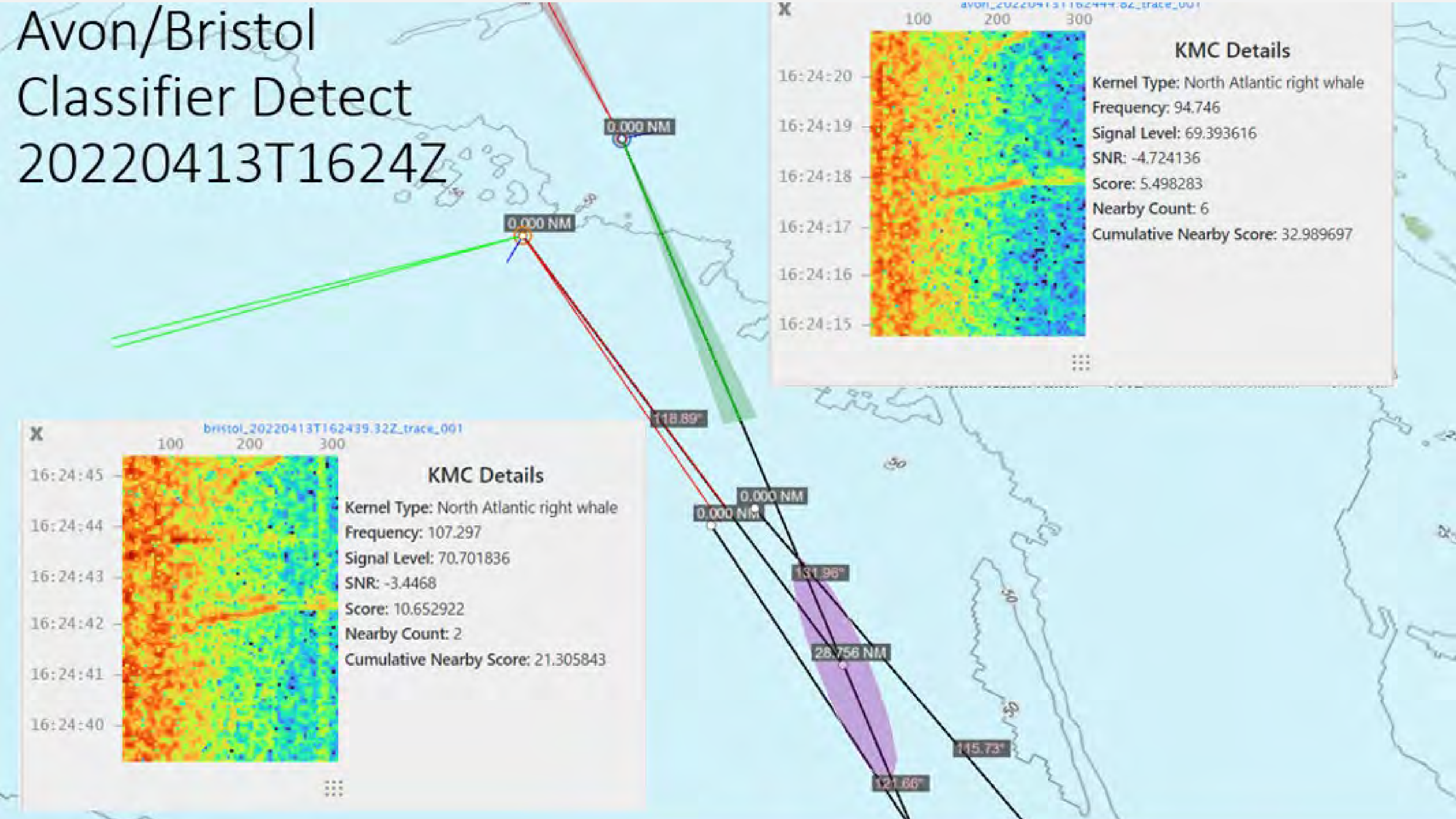

North Atlantic Right Whale upcall localization using two SeaPickets—Range 25-28 NM

Array Detection Performance Modeling Isotropic Noise Assumption

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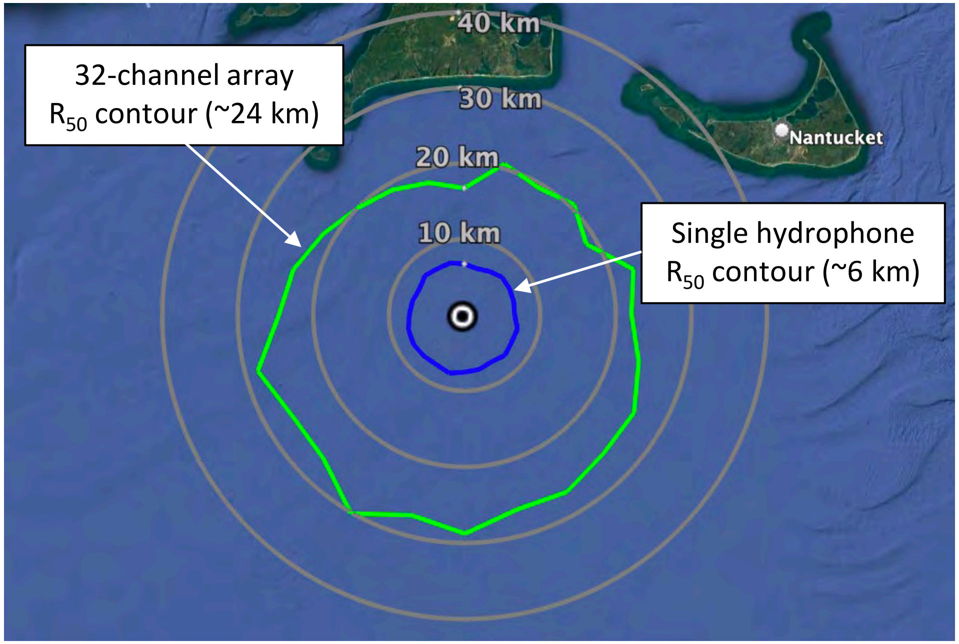
Passive Sonar Equation: At Initial Detection, SNR ≡ NRD

$$FOM \equiv TL = SL - (NL - AG) - NRD$$

Assumptions and Model Inputs:

- SL_{rms} = 172 dB re 1μPa @ 1m (Parks, 2013)
- NL = 101 re 1μPa^2 (in-band power, Wenz)
- AG = Array Gain = 14 dB (32-chan/300 Hz)
- NRD = 7 dB
- TL modeled using NSPE (Collins, 1993)
- Environmental model: WOA18
- Bathymetry: GEBCO 2022 database



Array FOM = 78 dB

Hydrophone FOM = 64 dB

Source: Premus, et al., *J. Acoust. Soc. Am.*, 152 (3), pp. 1814-1828, Sep 2022

Approximately 4x detection range advantage for the 32-channel array in the lease area TL environment

Array vs. Single Hydrophone NARW Detection Performance in VW Transit Lane: 3 SeaPicket Laydown

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f = 300 Hz

FOM_{ARRAY} = 78 dB

FOM_{PHONE} = 64 dB

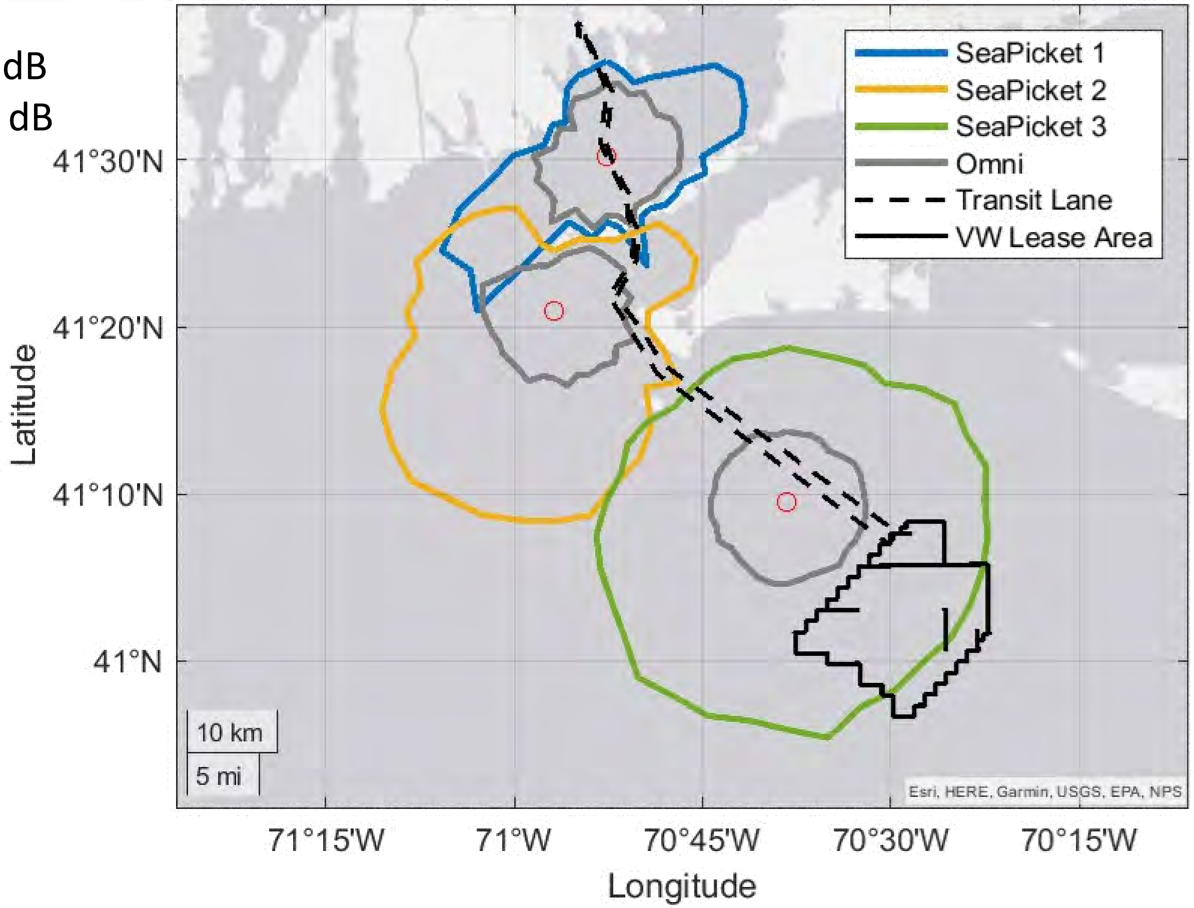

Figure 1 NARW detection range predictions at 300 Hz for the construction vessel transit lane for SeaPicket 1 (blue), SeaPicket 2 (yellow), and SeaPicket 3 (green), respectively. The colored contours depict 50% probability of detection range contours corresponding to the calculated FOM of 78 dB for the 32-channel array. Single hydrophone detection contours corresponding to the 64 dB FOM are depicted in gray. The maximum detection ranges for the three arrays are 22.3, 24.6, and 26.7 km, respectively. Maximum detection ranges for the single hydrophone are 9.6, 9.5, and 9.2 km, respectively.

Measured Detection Range Using J-9 NARW Replay Test
Ls = 150 dB rms re 1μPa @ 1 m, 15 August 2023

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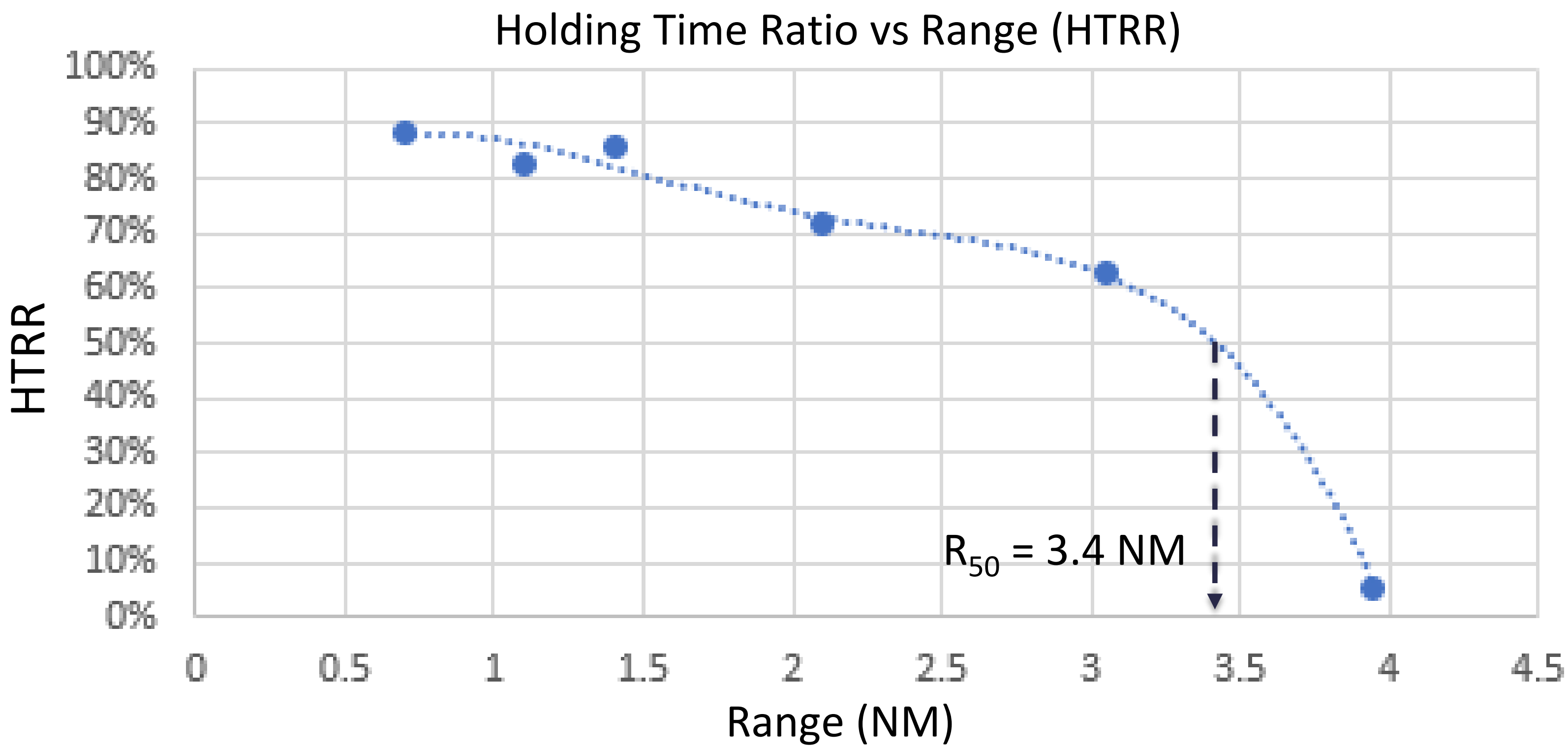

Zero False Alarms

J9 Test Times and total number of detections		Range at testing start/stop times in NM	
2327-0000Z	128 Detections	.8nm	0.6nm
0427-0541Z	263 Detections	1.1nm	1.1nm
0541-0639Z	206 Detections	1.1nm	1.7nm
0639-0730Z	212 Detections	1.7nm	2.5nm
0744-0832Z	86 Detections	2.5nm	3.6nm
0832-0845Z	18 Detections	3.6nm	4.3nm

Measured 50% Detection Range at 3.4 NM (6 km) for 150 dBrms source level (at zero False Alarm Rate)

TL Modeling for Martha's Vineyard Lease Area: Using Measured J-9 (150 dB) Detection Range to Extrapolate to Actual NARW Source Level (170 dB)

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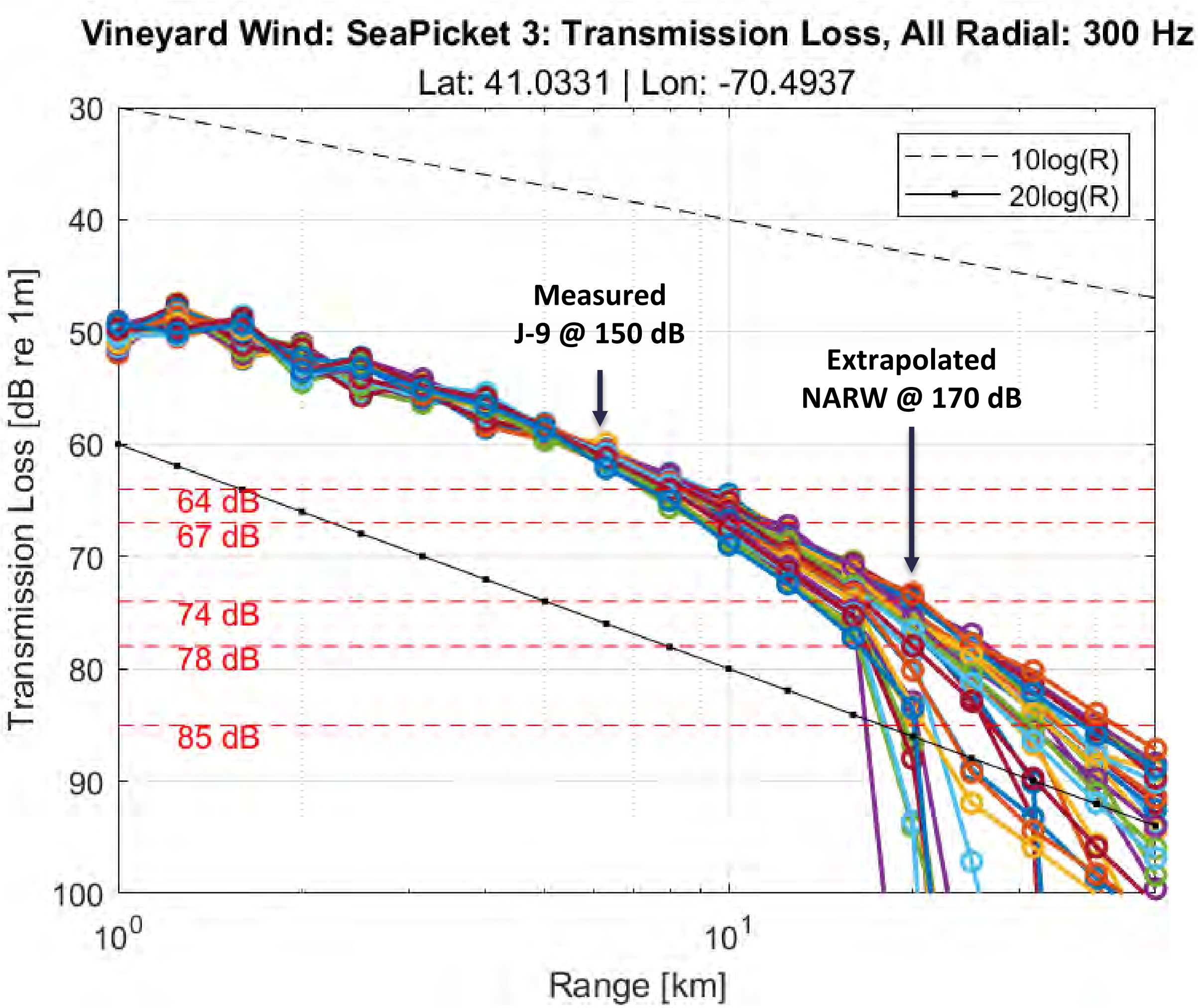

FOM [dB]	Min [km]	Max [km]
62	6	6
64	7.2	9.5
67	8.8	12.3
74	13.6	21.0
78	16.1	27.2
85	16.7	43.2

Figure to left shows the Transmission Loss at each radial (0-360°, 10° increments).

The table above shows the min/max detection range sampled at six FOMs.

R_{50} = 6 km (FOM 62 dB) for 150 dB J-9 extrapolates to $R_{50} \geq$ 20 km (FOM 82 dB) for actual NARW source level

Comparison of TM/OASIS and JASCO In-band Noise Measurements and Inferred Detection Ranges: Array vs Hydrophone

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$$FOM \equiv TL = SL - (NL - AG) - NRD$$

Sensor Type	Source Level, Ls (dB re 1uPa @ 1m)	Noise Level, Ln (dB re 1 uPa @ 1m)	Recognition Differential, N_{RD} (dB)	Figure of Merit, FOM (dB)	Detection Range (km) @ FOM	Comments
JASCO Omni	172	94	4	74	**17**	Using JASCO assumed Ln
TM Omni	172	101	4	67	10	Using measured Ln from Seapicket 2022 Orsted Demo Site
TM Array[1] TM Array[2]	172 172	101-11 = 90 94-11 = 83	4 4	78 85	20-30 **30-50**	[1]Using TM/OASIS measured Ln and in-band meas AG of 11 dB [2]Using JASCO assumed Ln

JASCO 17 km hydrophone detection range compares to 30-50 km for TM array for same input conditions

NARW Auto-detector: Improvements Since 2022 Spring Demo

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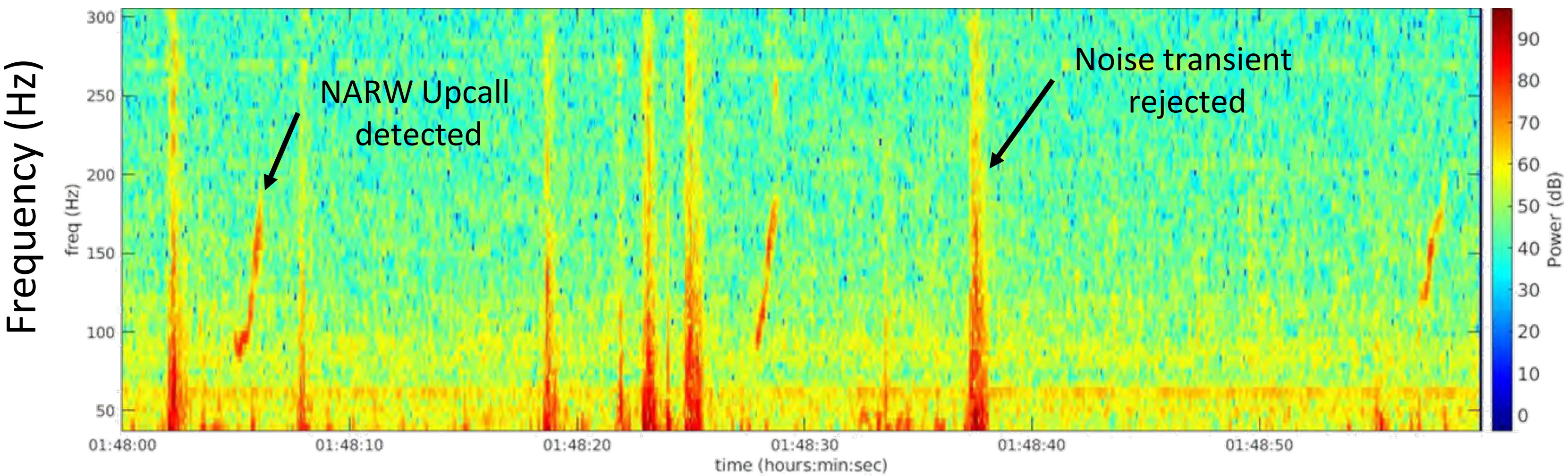
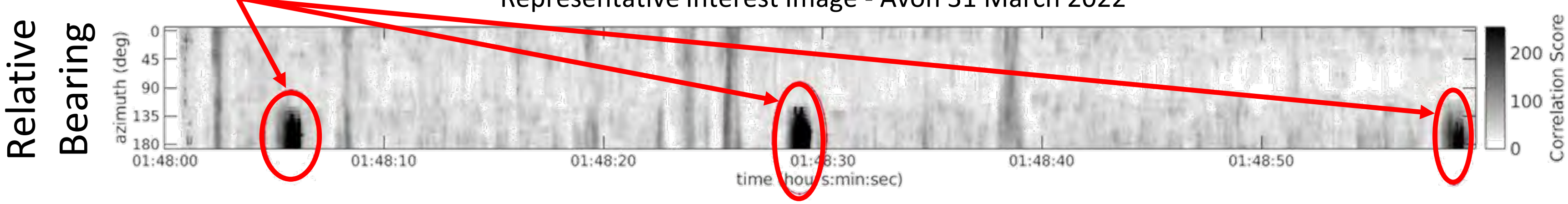
Bottom-mounted arrays now show classifier False Alarm rate (FAR) of 0.5/hour/32 beams†
(0 FAs were NOT attributable to array noise transients)

Representative Beam Spectrogram – Avon 31 March 2022



NARW auto-detections marked in red

Representative Interest Image - Avon 31 March 2022



†Based on 24-hour replay from Bristol on April 23

At this low FAR, with analyst screening, a PAM system FAR of 0 reported to Mysticetus should be attainable

NARW Classifier Performance vs Shiu et. al 2020 and Baumgartner/Mussoline 2011

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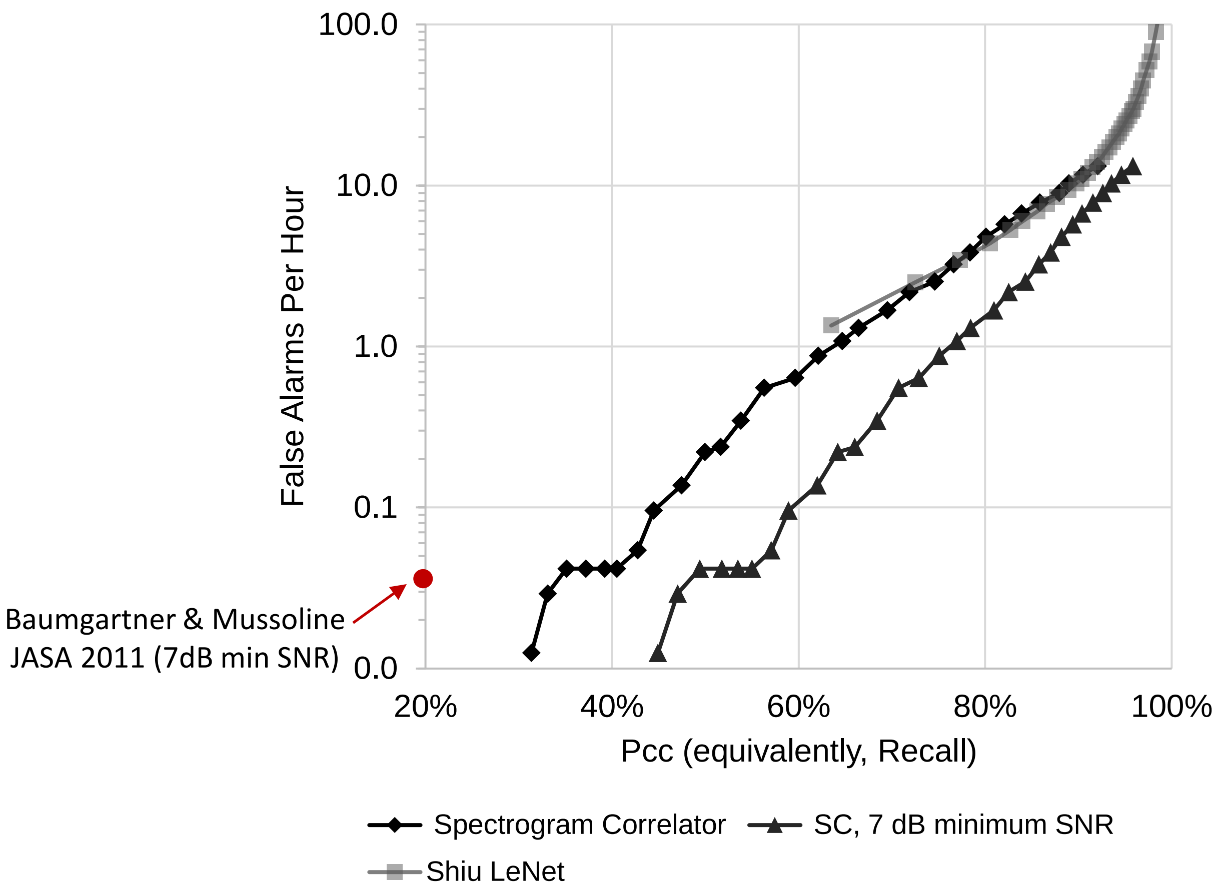
Data Source: St. Andrews 2013 DCLDE Workshop



Spectrogram correlator performs similarly to Shiu (2020) for all SNRs, but yields 10x FAR reduction for SNR ≥ 7 dB; Also, ~3x improvement in recall over Baumgartner (2011) for fixed FAR of 1.25 per day

Summary

Coherently beamformed arrays will outperform single hydrophones by spatially rejecting noise that masks low frequency baleen whale vocalizations

Spatial noise rejection of the array increases detection range by up to 4x, and area coverage by up to 16x, respectively, relative to single hydrophone in the Martha's Vineyard lease area

Audio wavefiles clearly demonstrate the detection advantage of arrays over single hydrophones

Arrays also spatially resolve the relative bearing of vocalizing mammals, enabling long range localization, tracking, and measurement of spatial distributions

The challenge imposed by anthropogenic noise on baleen whale detection demands the employment of arrays to minimize the impact of offshore wind on marine habitat.

Response to NOAA questions/comments relayed by Nick Sisson (NOAA GARFO) 15 Dec 2023
V. Premus, P. Abbot, T. Abbot, and C. Clark
16 January 2024

Nick's original questions denoted in italics:

We understand the benefits and capabilities of the array system and beamforming, as it relates to passive acoustic monitoring, as an effective marine mammal monitoring and mitigation tool during activities (transit lane monitoring, pile driving monitoring) related to offshore wind energy development. As offshore wind energy is deployed, it is critical to have tools such as these to effectively and reliably meet the monitoring requirements.

Please clarify what the Holding Time Ratio (HTRR) means. Please provide a definition and explanation if HTTR is the same thing as the detection rate (a detection and classification of a North Atlantic right whale upcall on the SeaPicket system) or does HTTR also include the additional detections that will be added from a PAM Operator on shore looking at the transmitted data in near real-time? Can you please clarify that the detection rate system performance is shown on slide 14 (the y-axis in the figure on slide 14 is labeled 'HTTR') of the presentation shared during the November 14th meeting? If not, please provide that information.

Holding Time Ratio vs Range, or HTRR, is a metric that quantifies the measured detection probability of a particular source of interest from calibrated, ground-truth reconstructed data. Since it measures detection of a specific source, and not just from any source, it attempts to combine detection and classification performance into one unified metric. It is defined as the product of probability of detection, P_d, and probability of correct classification, P_{cc}, as follows,

$$HTRR = P_{cc} \cdot P_d = \frac{Number\ of\ positive\ classifications}{Number\ of\ detections} \cdot \frac{Number\ of\ detections}{Total\ number\ of\ detection\ opportunities}$$

For the testing of baleen whale detector-classifiers, programmed source operations typically use a wave file developed from actual vocalizations prerecorded during an earlier test. The employment of a calibrated source allows performance to be quantified as a function of a known root mean square (rms) source level. The source GPS reconstruction also supports the quantification of performance as a function of range since the distance from source to receiver is known. Detection opportunities are divided into range bins (third-octave range bins are often employed, but the exact discretization method may vary depending on sample support).

It is important to note that HTRR, or any detection metric really, must be reported in conjunction with some account of false alarm (FA) performance, either the false alarm rate (FAR) or probability of false alarm, P_{fa}. Even if P_{fa} is zero, the unambiguous specification of a receiver operating point must include a statement of P_{fa}. Measurement of the FAR or P_{fa} requires that an analyst visually inspect every positive detection/classification decision for consistency with the signal model. In the case of beamformed array output, the HTRR metric also tests for spatial alignment of the detection event with the ground truth reconstruction—some tolerance on bearing error is allowed to account for the frequency-dependent beamwidth of the array response, as well as array position and orientation uncertainty.

HTRR is most straightforward to compute for programmed source operations because the total number of detection opportunities is known *a priori.* The calculation of detection probability or HTRR from naturally occurring baleen whale vocalizations is more labor intensive than that for a programmed source, because all detection opportunities must be manually identified and classified by a trained analyst-in-the-loop. Furthermore, the amount of labor required for comprehensive truthing of array data is multiplied, compared to truthing single hydrophone data, by the number of independent beams that are formed by the processing, not to mention by the increase in detection range due to array gain.

Lastly, the HTRR result reported in presentation slide 14 of the November 14 Teams video conference brief was for the instantaneous performance of the autonomous, real-time, spectrogram correlator classifier, without any supervision, real-time intervention or false alarm screening by the shoreside analyst. Upon receipt of the real-time results on shore, the PAM analyst inspected the results visually and compared them against the known playback schedule of the NARW wave file and used these results to compute the HTRR metric of the algorithm for each range bin. There is no reason why a system-level HTRR curve (one that includes the effect of human supervisor screening) could not also be computed to demonstrate the increase in system sensitivity that is possible with the involvement of a trained human analyst. However, the HTRR curve such as that shown in presentation slide 14 is typically used to characterize the performance of the automatic, real-time detector-classifier algorithm.

We acknowledge the results thus far, showing the effectiveness of the detector/classifier, primarily with synthesized calls, but are very interested in seeing the performance of the detector/classifier system when it is used with live calls with multiple species present. Given that the SeaPicket system is being proposed for real-time monitoring and mitigation to trigger vessel slow-downs and pile-driving delays and shutdowns, it is critical to understand the reliability of the detector/classifier. Can you please clarify if the performance of the detector/classifier has been compared against the annotated North Atlantic right whale acoustic dataset hosted by NCEI: (https://www.fisheries.noaa.gov/resource/data/noaa-nefsc-north-atlantic-right-whale-acoustic-data-and-annotations)? If so, what were the results?

The classifier results presented to date have always employed actual North Atlantic right whale (NARW) upcalls, never synthesized. The performance results for the J-9 acoustic source transmissions performed in August 2023 were based on a 5-minute wave file excerpted from the 2013 DCLDE Workshop database. As mentioned above, such a test methodology is most effective for at-sea, real-time performance characterization as it employs a calibrated source in a relevant noise environment accompanied by GPS positional reconstruction. It should be reemphasized that J-9 transmissions conducted to date have been limited to a 150 dB rms re 1μPa @ 1m source level to adhere to the *de minimis* permitting standard. Thus, the estimation of detection range for the true source level of the NARW necessitates some form of performance projection based on a computational model for transmission loss, as reported in presentation slide 15 of the November 14 Teams video conference brief.

The performance of the ThayerMahan (TM) spectrogram correlator-based classifier has been compared against the annotated NARW acoustic dataset hosted by NCEI,[1] at least for that portion of NCEI that comes from the St. Andrews 2013 DCLDE Workshop (approximately 80% based on the total reported call count). Figure 1, which was not briefed during the November 14 Teams video conference but does appear in the backup section of the briefing material, depicts our most recent summary of measured classifier performance to date. The plot shows FAR vs P_{cc} (i.e., recall) for the ThayerMahan spectrogram correlator algorithm relative to two other approaches that are widely held to represent the state-of-the-art for NARW classification, Baumgartner and Mussoline (JASA 2011) and Shiu *et. al* (Nature 2020). Baumgartner and Mussoline employ a feature-based correlator and pitch tracker, while Shiu *et al.* adopt a machine learning model. The results show that the TM spectrogram correlator (black diamonds) compares quite closely with the machine learning model of Shiu (gray squares) when no pre-screening on the basis of minimum SNR

[1] https://www.fisheries.noaa.gov/resource/data/noaa-nefsc-north-atlantic-right-whale-acoustic-data-and-annotations

is employed. Improved results when a minimum SNR threshold of 7 dB is imposed are also shown (black triangles). The TM classifier is observed to outperform the Baumgartner and Mussoline feature-based approach (red circle) by a factor of nearly 3x in P_{cc} for a fixed FAR of 1.25 per day (0.05 FA/hour).[2]

Based on these results, we believe that it is fair to conclude that the ThayerMahan spectrogram correlator-based classifier is indeed reliable, although we will continue to seek improvement in its performance with the analysis of new NARW data collected on current and future SeaPicket system deployments.

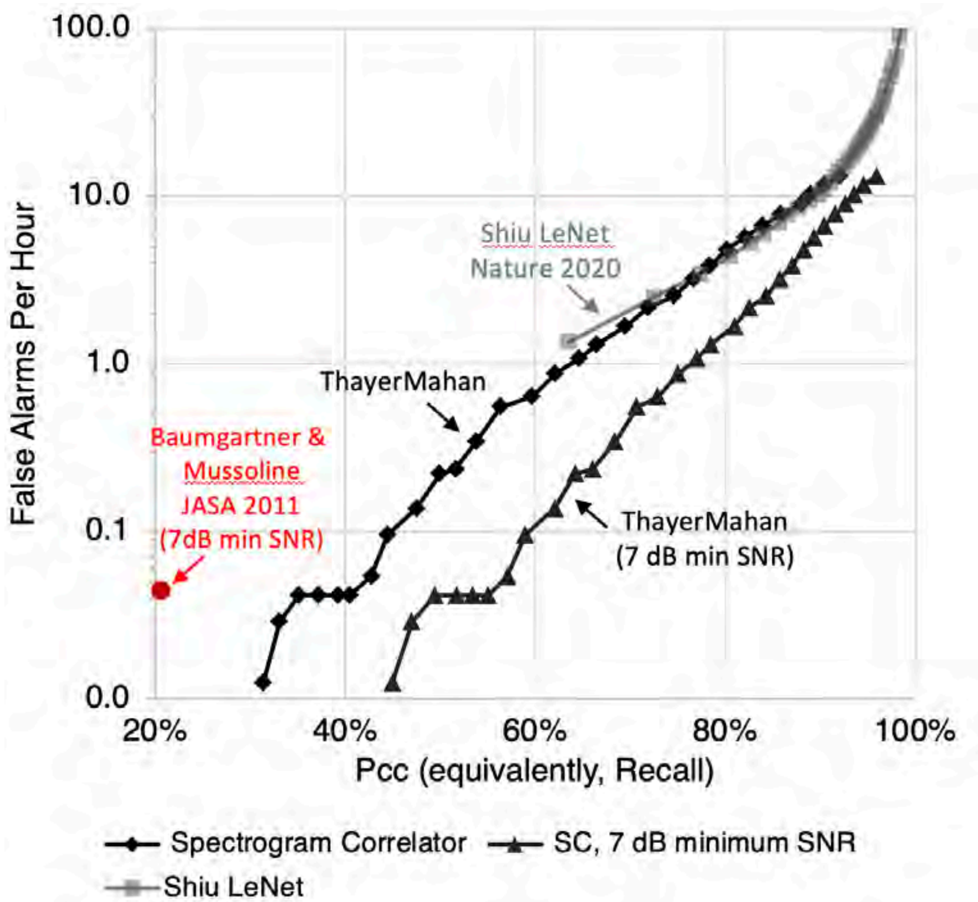


Figure 1 ThayerMahan North Atlantic right whale classifier performance compared against Baumgartner and Mussoline (J. Acoust. Soc. Am. 2011) and Shiu et. al (Nature 2020) for the 2013 St. Andrews annotated database.

Can you clarify and quantify the time lag between when a detection/classification takes place on a SeaPicket buoy and when the data are received by a PAM Operator to be able to analyze it?

Contact reports and associated spectrogram snippets are transmitted back to shore to the ThayerMahan PAM operator via BGAN satellite communication link virtually instantaneously—BGAN supports

[2] ThayerMahan spectrogram correlator kernel thresholds were originally trained on the DCLDE 2013 training database to yield a FAR of 1.25/day. During the 2023 field season, that operating point was adjusted to yield greater detection sensitivity (at the recommendation of Chris Clark) corresponding to a FAR of 1/hour. Real-time performance of the SeaPicket system since that update has been generally observed to be consistent with this new operating point. Further quantification of FAR rate will require truthing of SeaPicket data, preferably in coordination with a third-party trained analyst (e.g., from NOAA/NMFS).

continuous data exfiltration, thus no need for scheduled transmission as is the case for Iridium. ThayerMahan PAM operators monitoring the data feed shoreside at the operations center typically require on the order of one minute to validate a contact report and, if supporting data exists, correlate it with a concurrent detection on another system to generate a localization solution. Thus, the entire process, from initial detection to validation by a ThayerMahan PAM operator, to receipt of a warning at a transiting vessel and/or the lead PSO aboard the pile driving vessel, is estimated to take on the order of 5 minutes.

Can you clarify what data (i.e., spectrograms, scissorgrams, classified detections, raw audio files) are sent to the PAM Operator for review? Additionally, which frequencies are transmitted? It is currently unclear to us if all of the continuous acoustic recordings are sent as spectrograms to the PAM Operator to review, or if only snippets of the recordings are sent as spectrograms when a signal is detected on any of the hydrophones that stands out in the North Atlantic right whale upcall frequency band of interest. We are interested in learning more about if/how the PAM Operator can see and assess acoustic signals that were not picked up by the detector/classifier.

The real-time data feed transmitted to the ThayerMahan PAM operator consists of the following:

- Broadband display showing distribution of energy in bearing time record (BTR) format
- Spectrograms for a subset of “most interesting” beams in the broadband display
- Baleen whale contact reports including timestamp, lat/lon, relative bearing, species (i.e., right whale or humpback whale), and classifier confidence
- Spectrogram snippet illustrating support for any positive classifier decision in a 6 sec window, 50-300Hz band, centered on instant of detection

Wave files extraction is currently not automatic—this requires the download of the supporting segment of element data and offline beamforming and computation of inverse FFT for recovery of the beam time series and conversion to wave file format. A system software update to automate the extraction and transmission of wave files in real-time is currently in testing and is expected to be deployed shortly.

Figure 2 shows an example of the two primary forms for visualizing acoustic data collected on a SeaPicket beamformed array on April 15, 2022. We refer to these two visualizations as the broadband display (left panel) and the narrowband display (right panel). The broadband display shows total energy over the array operating band (40-600 Hz) as a function of bearing and time with time running vertically and bearing spanning 180° from left to right. The narrowband display (i.e., spectrogram) shows energy as a function of frequency and time over a PAM analyst-specified band (100-500 Hz is shown) for a particular bearing or sequence of bearings referred to as a track, with time running vertically and frequency horizontally. Data collected on the array was processed in real-time and transmitted via BGAN satellite uplink to a PAM operator at the ThayerMahan facility in Groton CT. The operator searched and manually annotated these data for detections of baleen whale sounds that had not been automatically identified by the onboard detector-classifier.[3] During this period of SeaPicket deployment, the humpback whale classifier had not yet been deployed on the SeaPicket system, so no autodetections of humpback sounds were relayed in real-time. However, later analysis at ThayerMahan revealed a humpback singer in the 180° bearing direction (see red line tracing in left panel indicating the sequence of humpback song notes) on the SeaPicket array system. This serves as a good example of two fundamental benefits of the beamforming system:

[3] It’s important to note that the humpback whale classifier software had not yet been deployed on the SeaPicket system.

determination of the direction to the sound source of interest and noise rejection such that the signal-to-noise ratio (SNR) of a sound originating from a certain direction has increased and is thus detectable at greater range.

The beamformed results shown in Figure 2 are always available to the shoreside PAM analyst regardless of the classifier performance. The broadband display processing for PAM is configured for a temporal granularity, or update rate, that is well-suited to detecting biologic transients such as NARW upcalls (e.g., 125 ms). Bioacoustic transients tend to exhibit an intermittent appearance in the broadband display, typically at a fixed bearing over the 1-2 minute time interval that is rendered at any given time. With a series of mouse clicks, the operator can specify a series of bearing-time points in the broadband display for which the spectrogram along that track is compiled and rendered. This allows the PAM analyst to make a decision through visual inspection about the presence of a baleen whale that the classifier may have missed.

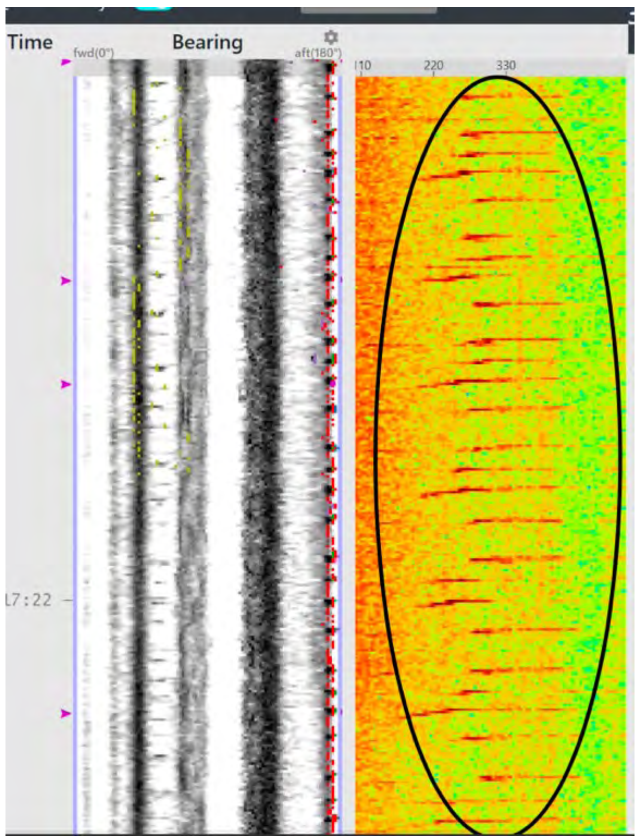


***Figure 2** Display excerpt for a SeaPicket system on April 15, 2022 1722 GMT showing broadband bearing-time display (left) and a narrowband (spectrogram) display on the right to illustrate the detection of a humpback singer at relative bearing 180°, and the individual notes in the song from the singer in the spectrogram corresponding to that bearing.*

Figure 3 shows an example of broadband (left panel, see small magenta arrow tips) and narrowband (spectrogram, right panel) displays resulting from the real-time detection of an NARW upcall on 9 November 2023. The magenta arrows pointing to magenta boxes overlaid on the broadband BTR denote the time and bearing of a real-time NARW autodetection generated by the classifier. The narrowband, 6 s spectrogram snippet on the right includes real-time autodetection of a NARW upcall, illustrating support for the classifier decision. The real-time classifier snippet always shows 6 s of data, centered on the detection, and is limited to the NARW upcall support frequency band, which we have assumed to be 50-300 Hz. These displays accompany every positive NARW upcall autodetection generated by the classifier.

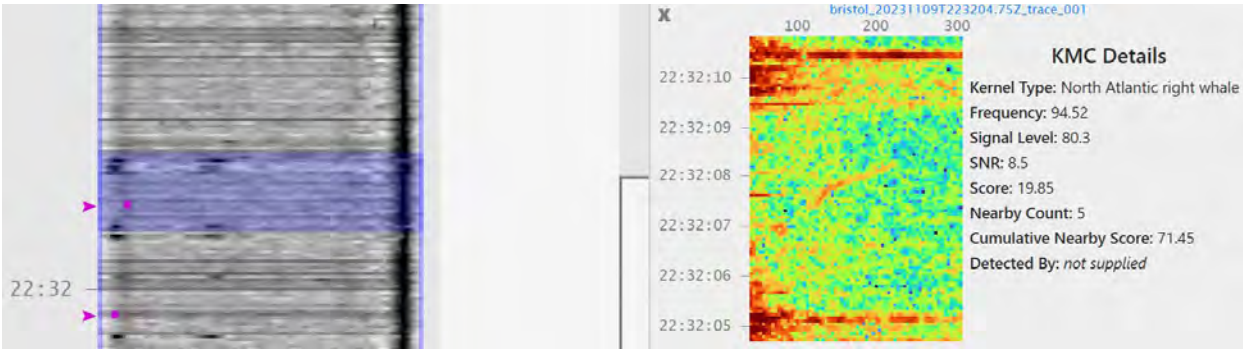


Figure 3 SeaPicket display excerpt showing broadband BTR (left) with contact report overlays (magenta squares) and supporting 6 s spectrogram snippet (right) for a NARW detection on a SeaPicket system from 9 November 2023.

We understand the ability of the SeaPicket system to estimate bearing to a detected animal. We are interested in seeing the additional data that will be collected from the deployed systems demonstrating the accuracy of bearing estimation, i.e., confidence interval (understanding that the accuracy of bearing estimation is frequency-dependent).

We have quantified the bearing accuracy of the SeaPicket system in the past but had not yet done so for the August 2023 J-9 source op at the time of the November 14 Teams video conference brief. We are working on this now and will make it available as soon as we have it. In the meantime, Figure 4 shows an estimate of bearing accuracy for the J-9 source ops conducted during the Spring 2022 SeaPicket demonstration. The reference track (orange) is not a GPS reconstruction for this case, but a moving average calculated from the contact report time series (not ideal, but a reasonable substitute in the absence of GPS reconstruction—we do have GPS reconstruction for the August 2023 J-9 operation). The bearing error from the instantaneous reports from the classifier show a mean error of 2° and a standard deviation of 9°. This is reasonable in the light of the fact that the bearing resolution of the 32-channel SeaPicket array with sensor spacing cut to 600 Hz ranges from 7°-15° over the frequency band of the right whale upcall.

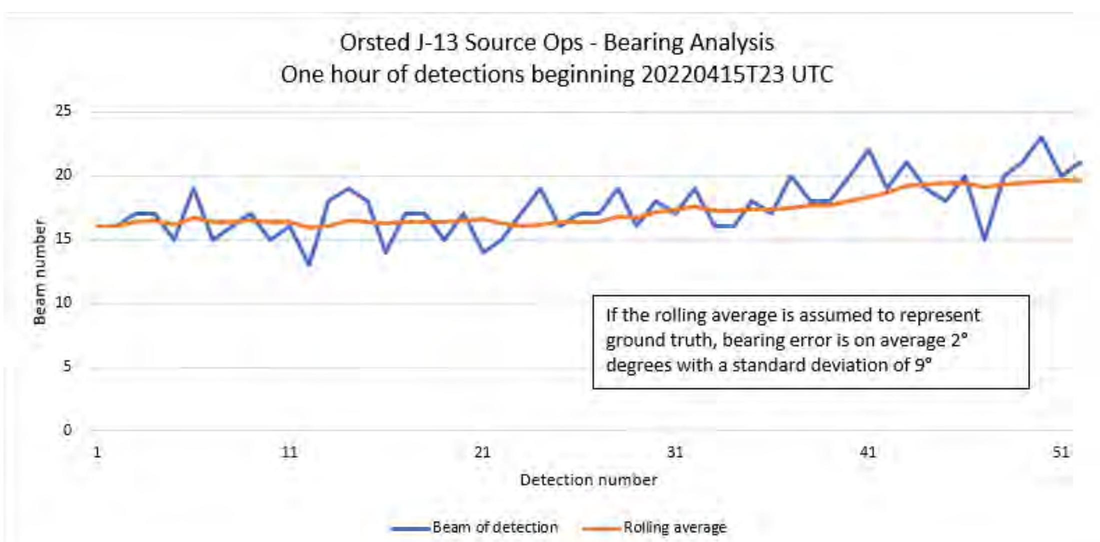


Figure 4 Bearing accuracy for J-9 source operations conducted on April 15, 2023.

We understand that localization is not being proposed as part of the Vineyard Wind transit lane monitoring scheme; however, we are interested in continuing to better understand how the orientation of the array influences effective and reliable monitoring of pile driving activities and transit lanes, and the interpretation of localization error. In addition, we are interested in seeing additional examples of acoustic detections that were localized using two or more systems from the ongoing/upcoming SeaPicket deployments. We also note that the orientation and location of the array will influence the detection range due to land masses and generally shallow water depths (< 50 m) including along the Vineyard Wind transit routes (and generally shallow waters where all lease areas are). We would appreciate it if messaging between ThayerMahan and wind developers about variable detection ranges that are site-dependent could occur early on. Thus far, the messaging has been that a 20-km detection range would be possible in all directions, but we know this cannot be entirely true due to sandbars, landmasses, etc.

Supplemental information cataloging localization results from the 2022 SeaPicket demonstration has been distributed to the NOAA/BOEM team. Figures 5 and 6 depict two new examples of localization solutions from concurrent humpback whale autodetections recorded on two SeaPicket arrays, Bristol (south of Martha's Vineyard) and Exeter (west of Martha's Vineyard) at 0936 and 0948 GMT, respectively, on January 9, 2024. ThayerMahan PAM analysts have reported humpback whale localization opportunities numbering in the 1000's on these two systems during the week of 8-12 January 2024.

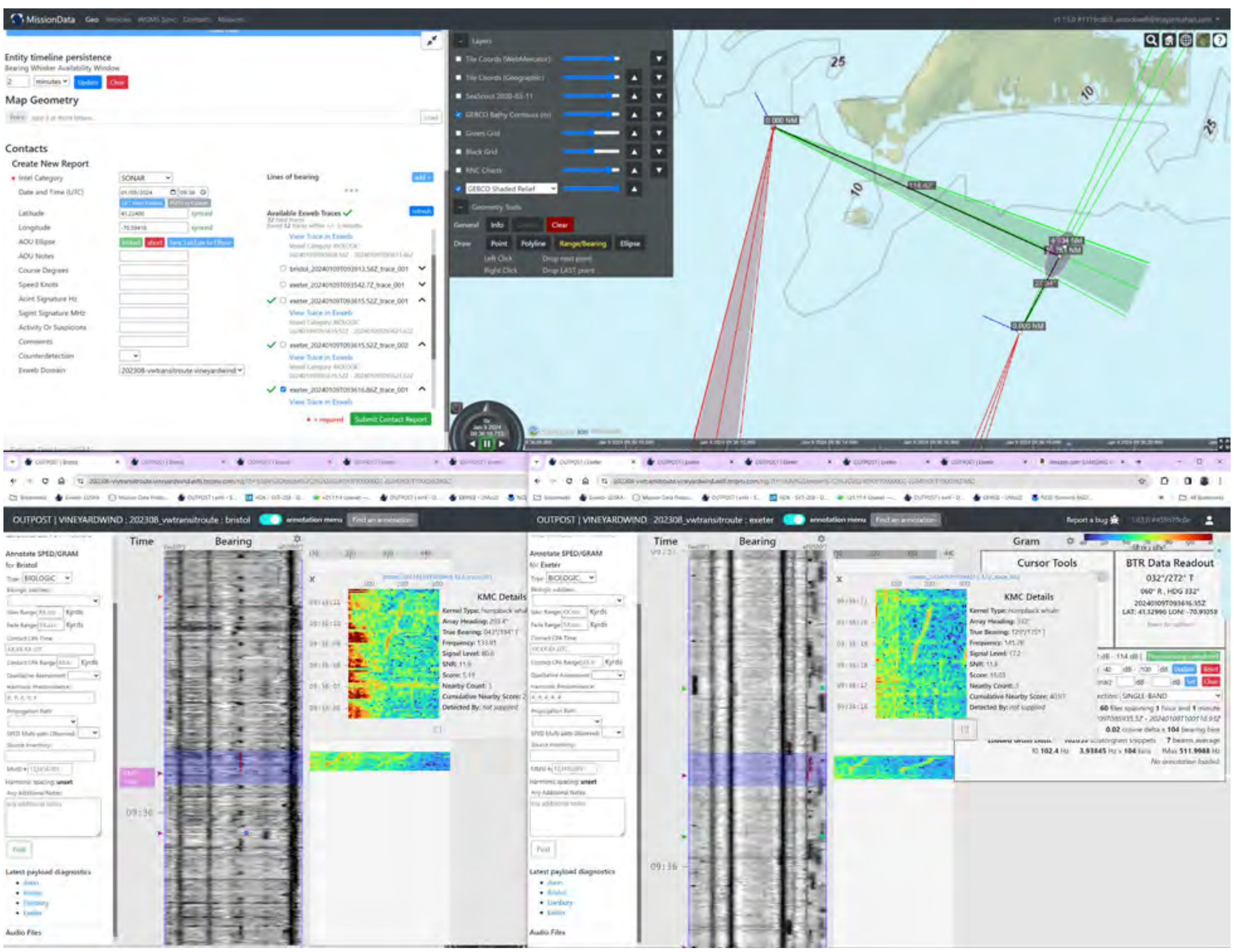


Figure 5 Concurrent humpback whale classifier detections supporting localization solution at 0936 GMT 9 January 2024.

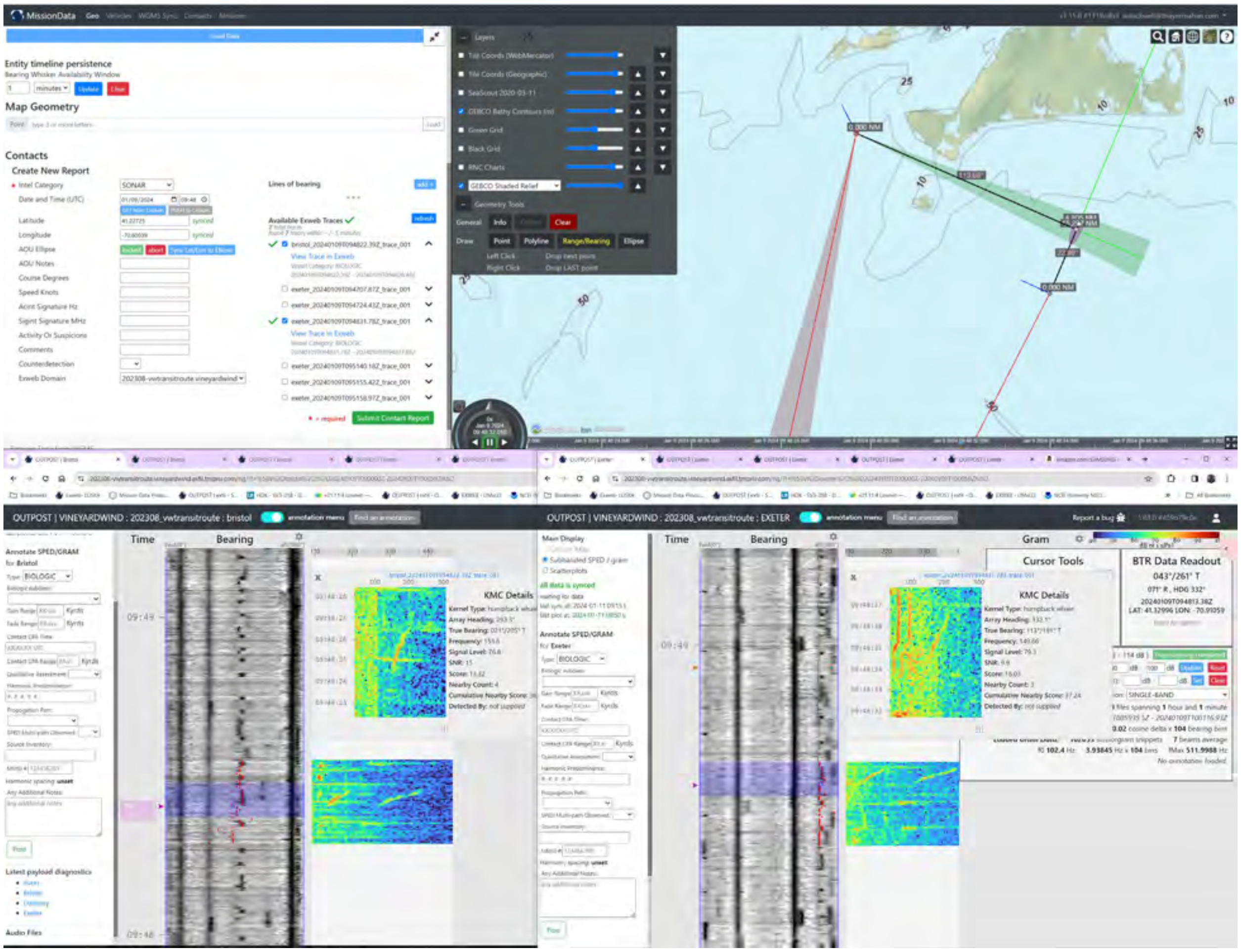


Figure 6 Concurrent humpback whale classifier detections supporting localization solution at 0948 GMT 9 January 2024.

The two examples yield consistent localization solutions to the south of Martha's Vineyard at a range of just over 15 NM from Exeter, and just under 5 NM from Bristol. The detection from Exeter is of particular interest as it suggests a line-of-sight (LOS) from the array that traverses the shoaling bathymetry between Nomans Land and the southwestern tip of Martha's Vineyard.

The detection range predictions in the form of detection contours (presentation slide 13) presented at the November 14 Teams video conference brief do indeed reflect the influence of bathymetry on azimuthal variation in detection performance. We could not agree more that the compression of detection range projections to a single number, such as 20 km, could be misinterpreted and is not generally desired. However, whenever such practice is adopted, the single number generally reflects a conservative estimate taken over all azimuths in a representative environment.[4] The results shown in presentation slide 15 of the November 14 Teams brief clearly support this (e.g., 17-40 km) assertion.

[4]The J-9 source transmissions were conducted so as to not exceed a source level of 150 dBrms re 1μPa @ 1m for any NARW upcall in the 5-minute wave file. The 27 upcalls comprising the 5-minute file were not of equal energy and no effort was made to equalize their levels. Of the 27 upcalls, 18 fell in the range of 140-150 dBrms source level; the remaining 9 were at a lower source level than 140 dBrms. This observation further reinforces the assertion that the single detection range estimate of 20 km is a conservative estimate of detection range in this environment for an actual upcall level of 170 dBrms.

Pile Driving Analysis Results from August 2023 Data Collection Event

V. Premus, P. Abbot, V. Kmelnitsky, J. Browning, A. Logan, T. Abbot, and J. Freise

23 February 2024

Executive Summary

Analysis of towed hydrophone array measurements of pile driving radiated noise collected in August 2023 during Orsted's South Fork Wind construction project is presented. Data was collected on a ThayerMahan Outpost system[1] comprised of a SeaTrac uncrewed surface vehicle (USV) instrumented with a Raytheon 32-channel towed hydrophone array. The principal finding is that while a 32-channel array can deliver 15 dB of array gain in isotropic noise conditions, this advantage rises to as much as 30 dB for highly anisotropic noise such as pile driving. This is further evidence that passive acoustic marine mammal monitoring systems that employ hydrophone arrays significantly outperform systems based on single omni-directional hydrophones in offshore construction areas and in the vicinity of shipping.

Approximately 48 hours of element data were recorded spanning two pile driving events. This report describes analysis performed on data collected during the August 1 pile driving event. As expected, the radiated noise from pile driving operations and the associated support vessels is significantly higher than normal ambient conditions. Median omni-directional hydrophone noise spectrum levels in the North Atlantic right whale frequency band during the strike measured roughly 30 dB higher than historical Wenz heavy shipping.[2] However, the beamformed data results show up to 30 dB of noise reduction in relative bearings pointed away from the pile driving operation. The acoustic masking effect of the pile driver noise also exhibits a strong frequency dependence within the NARW support band at the beamformer output relative to the single hydrophone, with beamformed noise levels decaying rapidly for frequencies above 100 Hz.

As North Atlantic right whales are not present in the Martha's Vineyard lease area during the month of August, to verify that the beamformed array can detect NARW in the presence of pile driving a signal injection analysis was performed using an audio wave file comprised of NARW upcalls excerpted from the 2013 DCLDE Workshop. *The results of the signal injection study show that the ThayerMahan beamformer and auto-detector software was able to detect and classify the NARW upcalls in pile driving noise at an element-level signal to noise ratio (SNR) for which the single hydrophone was completely masked.*

Using traditional passive sonar equation analysis, it was also shown that for a *NARW upcall emitted at a rms source level of 172 dB re 1 µPa, detection ranges of up to 15-25 km are predicted in the South Fork Wind lease area for up to two thirds of beamspace on a 32-channel towed hydrophone array in the presence of pile driving noise.* Depending on the range and source level of the NARW, a bearing sector of as much as 30°-60° centered on the pile driver bearing may be "blanked" or exhibit degraded classifier performance during the hammer strike. However, the analysis also shows that for this measurement geometry, the single hydrophone is completely obscured for NARW detection in the presence of pile driving for ranges to the animal greater than one kilometer.

The quantification of array performance in the presence of pile driving will continue—the next step is the analysis of similar measurements collected on bottom-mounted arrays. However, the findings on the performance of a beamformed towed array in the presence of pile driving presented herein are promising and further point to its credible use in support of marine mammal monitoring during offshore wind construction operations.

Introduction and Measurement Overview

The objective of this work is to measure and characterize pile driving noise at a fixed range on a high-spatial resolution, coherently beamformed towed array and assess its impact on the detection and classification of baleen whale vocalizations. The analyses performed to date include:

- Measurement of omni- and beam- noise levels and array gain vs. frequency
- Spatial distribution and in-band beam noise response
- Signal injection study for the evaluation of classifier performance
- Sonar equation analysis for bearing-dependent detection range predictions

In this report we summarize the data collection, the analysis methodology, and key findings to date. Given the calibrated acoustic measurements on a 32-channel towed array combined with the precise GPS ground-truth reconstruction of the vessels supporting the pile driving operation, the importance and utility of this pile driving noise dataset cannot be overstated.

Towed array measurements of pile driving operations were conducted with an Outpost system[1] on August 1, 2023, at a location roughly 15 NM southwest of Martha's Vineyard in Orsted's South Fork Wind lease area. The system was comprised of a SeaTrac USV instrumented with a 32-channel Raytheon hydrophone array and embedded digital signal processor (DSP). Element data were archived to a solid state hard drive. The array was towed at a depth of approximately 50' in water depths of approximately 100'.

Figure 1 depicts the GPS reconstruction for the USV, Lionfish, and several of the support vessels that were part of the pile driving operation on August 1, 2023. M/V Bokalift 2 was the pile driving vessel and M/V Bear was the vessel supporting bubble cloud operations. The Outpost system, delineated in green in the SW corner of Fig. 1, was programmed to follow a NW/SE racetrack at a range of approximately 5 NM from the pile driving activity to the NE.

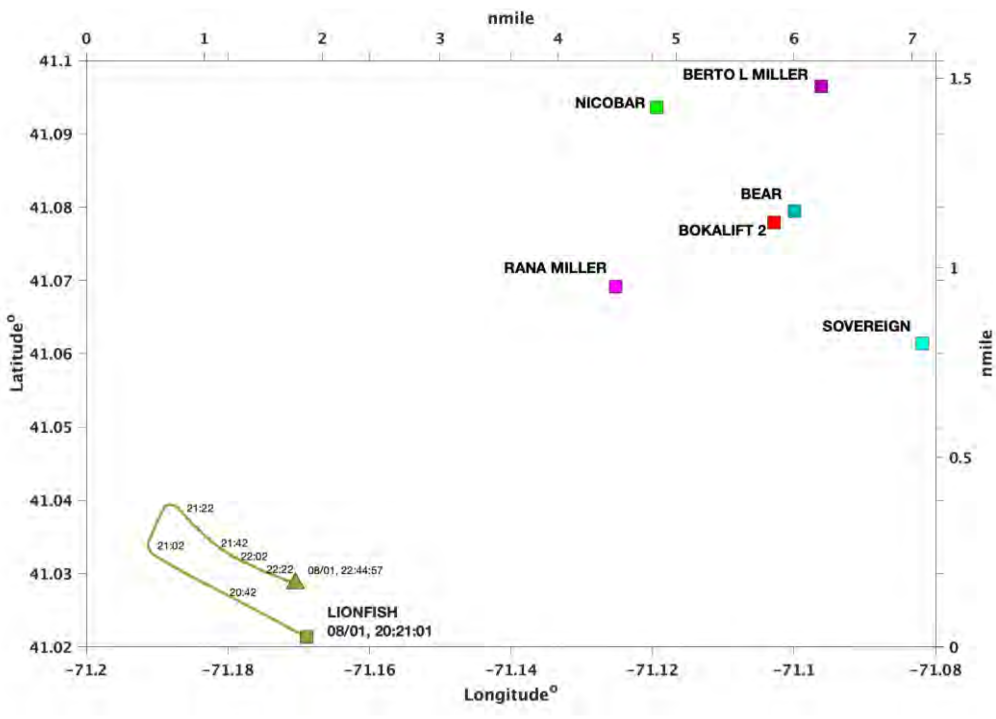


Figure 1 Measurement geometry and support vessel GPS positions.

Figure 2 (left) shows a sub-band peak energy detection (SPED) broadband detection surface in bearing-time record (BTR) format, with time on the y-axis and relative bearing on the x-axis. The DSP processing to generate this plot employed a 16k-point (6.5 s at the sample rate of 2520 Hz) Fast Fourier Transform (FFT) with 50% overlap and an incoherent integration interval, or scan rate, of 8 s, and an integration bandwidth of 40-625 Hz. This DSP configuration is typical of that used for vessel detection and tracking. The BTR plot illustrates the distribution of broadband ambient noise energy measured at the array during the roughly 2.4-hour pile driving event from 2020 to 2245 GMT on August 1. The color-coded overlay represents the vessel GPS reconstruction in bearing-time coordinates. Dark traces in the broadband display coincide with loud sources of broadband acoustic energy. It is clear from Fig. 2 that the ambient noise environment is dominated by support vessel radiated noise with at least six discernible vessel tracks. The agreement of the GPS reconstruction with the dark traces or tracks in the broadband display also provides some validation that the array and beamforming is accurately tracking the noise from the various ships involved in the operation. The righthand panel in Fig. 2 reports the range to some of the vessels shown in Fig. 1.

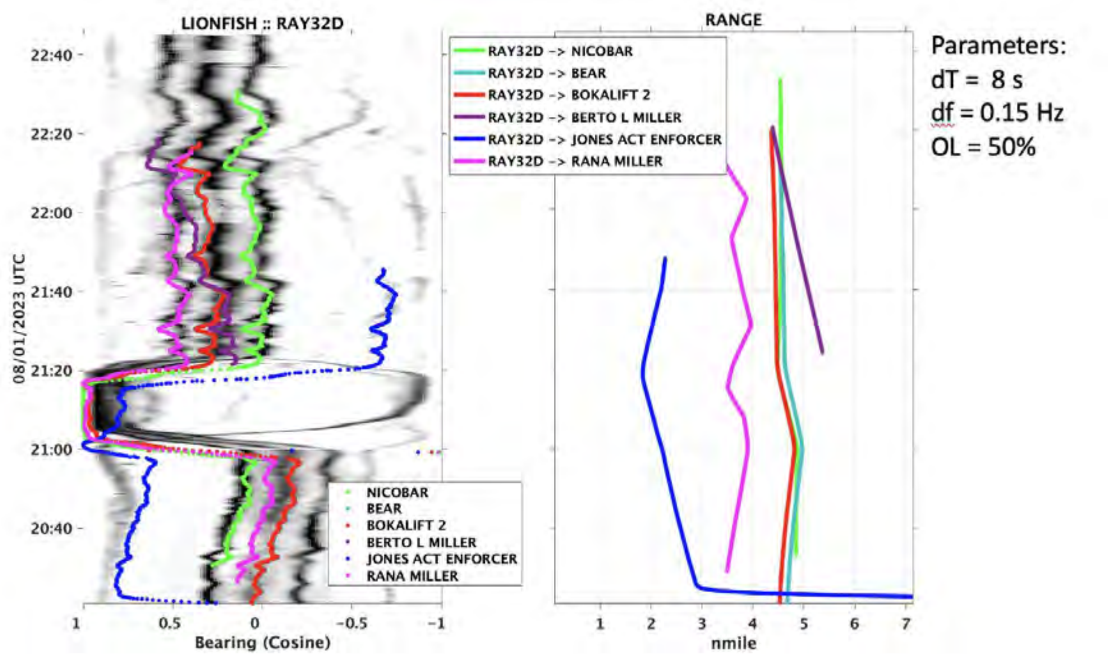


Figure 2 Detection surface in bearing-time record (BTR) format and range reconstruction from GPS.

Noise Analysis Processing Description

In order to assess the effect of pile driving noise on the performance of the North Atlantic right whale (NARW) detector-classifier using a passive sonar equation reconciliation, it is best to process the towed array data through the lens of the real-time, spectrogram-correlator algorithm. This means using a FFT length, percentage overlap, and update rate that support a temporal granularity capable of resolving short duration (~100 ms) broadband transient signals. Thus, the DSP processing parameters used for this analysis are: df = 3.938 Hz (effective noise bandwidth, ENBW = 5.89 Hz), OL = 75%, and dT = .0634 s.

Noise analysis results are first presented in the form of timeseries at the beamformer output and omni-averaged hydrophone level, and histograms of omni-noise and beam noise levels, as well as measured array gain. Sample support for noise and array gain statistics was also partitioned into strike and non-strike exemplars by explicitly detecting FFT frames associated with each strike event and inter-strike period. There was a total of 2,760 strikes performed on August 1, with reported strike energy increasing from approximately 200 kJ to 3100 kJ, during the course of the event. The strike rate was also variable ranging, from a rate of 3-5 per minute during “soft start” to more than 30-40 per minute for the majority of the operation.[3]

To facilitate comparison to Wenz historical observations, noise measurements are reported for the *median* frequency bin and *median* beam (in the case of beam noise) in each of 12 third-octave bands, *corrected to noise spectrum level* (i.e., units of dB re $1\mu Pa^2//Hz$).

Experimental Results

As a representative illustration of the method, Figure 3 (top) shows beam (yellow) and omni (purple) noise level timeseries in spectrum level corresponding to the third octave band centered at a frequency of 250 Hz for the **in-between** strike intervals of the 2.4-hour pile driving event. The histograms of Fig. 3 (bottom) characterize the noise variability and report the mean and standard deviation of beam and omni noise levels, as well as the measured array gain (AG).

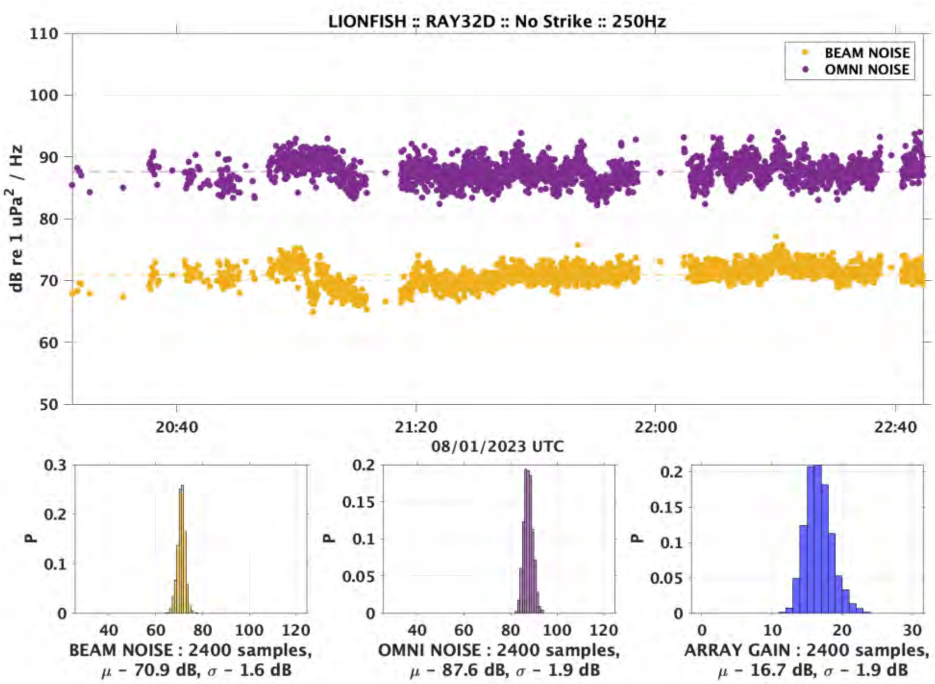


Figure 3 Array gain, omni-hydrophone, and beam noise timeseries and histograms measured in between strikes.

Array gain is a standard signal processing metric that compares the omni and beamformer output noise levels. In an isotropic noise environment, it can be shown that at the array cut frequency, the mean AG reduces to the array directivity index, or DI, which is equal to $10\log_{10} N$, where N is the number of channels in the array. The cut frequency is the frequency for which the array element spacing equates to one-half the acoustic wavelength—for frequencies below the cut frequency the spatial distribution of noise will be unambiguously resolved (i.e., no spatial aliasing is observed in the broadband detection surface). For the 32-channel Raytheon array cut to 625 Hz, the element spacing is 1.2 m, and DI is thus equal to 15 dB.

Notice that the mean omni noise level reported in Fig. 3 during the in-between strike periods measures 87.6 dB re 1 μPa^2//Hz. This level is quite high, very close to Wenz heavy shipping. At the beamformer output, the mean beam noise level is 70.9 dB re 1μPa^2//Hz, nearly 17 dB lower. This illustrates the degree of spatial noise rejection effected by the array beamformer in this ship noise dominated environment.

In environments dominated by anthropogenic noise from vessel traffic, pile driving, and bubble cloud generation, the noise distribution is said to be highly anisotropic, and the array gain is expected to be much greater than DI, reflecting the heavy tail content in the AG histogram. This is apparent in the mean AG of 16.7 dB reported in Fig. 3 (bottom, right). This value for AG is especially high for the subject array at 250 Hz given that the beamformer spatial resolution, and theoretical AG, degrades with decreasing frequency—AG decreases by 3 dB per octave below the cut frequency. Theory predicts the expected AG in isotropic noise at a frequency of 250 Hz to decrease from 15 to 11 dB. Thus, a value of 16.7 signifies a very high degree of anisotropy to the noise field. This is consistent with the appearance of multiple loud traces in the detection BTR of Fig. 2 associated with the numerous vessels supporting the pile driving operation. Keep in mind that this was only for the in-between strike periods.

Beam and omni noise level timeseries at a frequency of 250 Hz **during** the strike intervals over the 2.4-hour pile driving event are shown in Figure 4. During the strike, the mean measured omni noise level at 250 Hz increased to 98.2 dB re 1 μPa^2//Hz, almost 10 dB above Wenz heavy shipping—as will be seen in Figure 5, this is not even the worst case. The mean beam noise level at this frequency is reported as 72.7 dB re 1 μPa^2//Hz, revealing more than 25 dB of spatial noise rejection in the third octave band 224-282 Hz while the pile driving strikes are occurring.

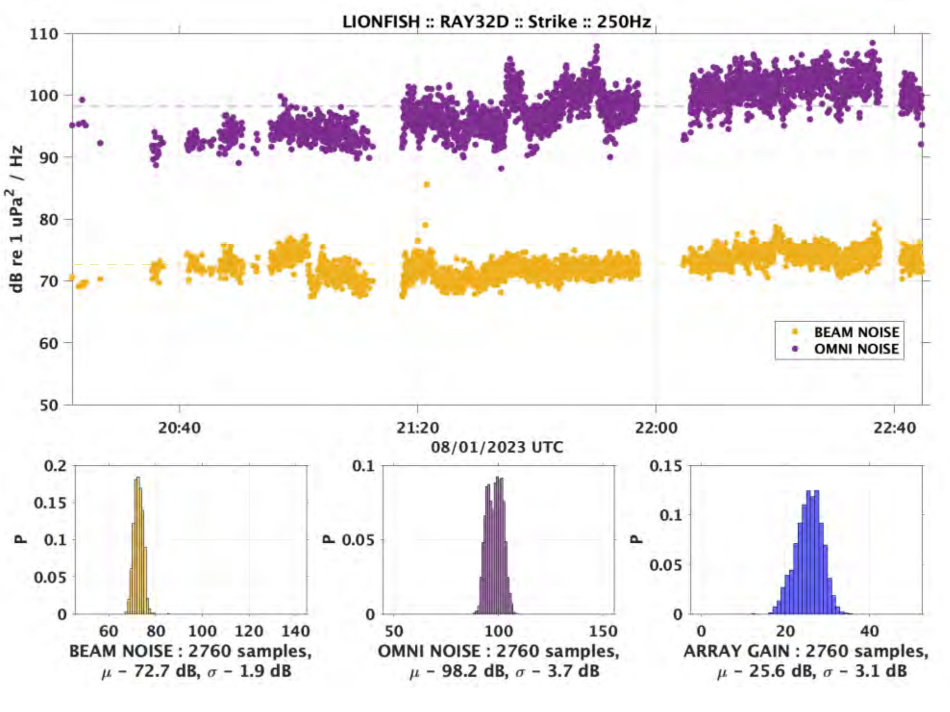


Figure 4 Array gain, omni-hydrophone, and beam noise timeseries and histograms during the strikes.

It is useful to point out that the standard deviation of the omni noise level during the strike is twice that of the between-strike periods, 3.7 dB vice 1.9 dB. This is attributable to the fact that the strike energy is steadily increasing as the pile is driven deeper into the seabed.[3] The trend of increasing noise level with time is clearly observed in the time series of Fig. 4, as the mean omni noise level increases from 92 dB re 1 μPa^2//Hz at 2030 GMT to 105 dB re 1 μPa^2//Hz near the end of the event at 2035 GMT.

The trend is much less apparent in the beam noise output—this is expected as the beam noise in Fig. 4 is not measured in the direction of the pile driving but rather for the median beam level, which captures the beamformer sidelobe leakage of this acoustic disturbance into relative bearings pointed away from the line of sight (LOS) to the pile driving. This is by design, to yield an efficient and representative measure of its contribution to the background noise in bearings where the spatial noise rejection by the array is realized. Note that for the relative bearing sector centered on the pile driving, no amount of array beamforming will provide spatial noise rejection, since in that case the disturbance is essentially a mainlobe interferer. For this reason, the angular sector centered on the pile driving operation is said to be acoustically "blanked." The empirical determination of the angular extent of this "blanked" bearing sector is discussed in more detail below.

Figure 5 summarizes the mean strike (red) and non-strike (blue) noise levels, corrected to spectrum level, as a function of frequency at third octave band intervals for the omni-averaged (solid) and median beam (dashed) output. Each curve represents an incoherent average over the entirety of the August 1 event, with a sample support of 2760 strike samples—the non-strike samples number slightly less, just 2400 samples, due to occasional difficulty in resolving a clean non-strike FFT frame due to sudden changes in strike rep rate. The vertical bars indicate $\pm\sigma$ intervals.

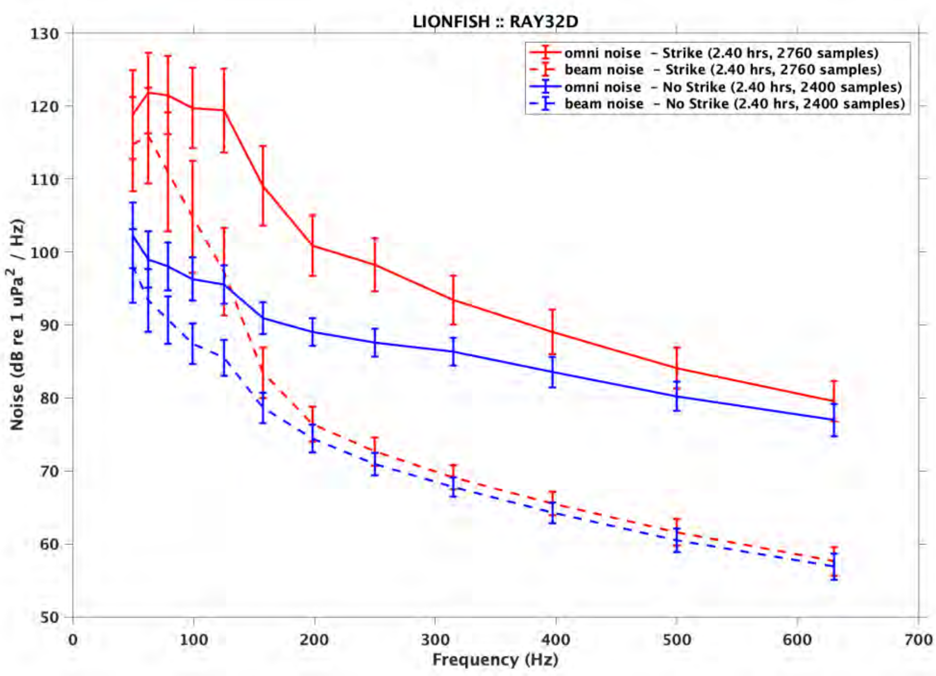


Figure 5 Power spectrum of during strike (red) and in-between strike (blue) intervals at the omni-averaged (solid) and beamformer output (dashed). Each curve is an incoherent average taken over the entire August 1 event. Noise levels are reported as median levels corresponding to each third octave band, and corrected to spectrum level (i.e., dB re 1 μPa2//Hz)

The average omni noise levels during the strike (red, solid) reported in Fig. 5 exhibit a strong frequency dependence over the NARW upcall support band. At a range of approximately 5 NM, the maximum omni noise spectrum level measures just over 120 dB re 1 μPa^2//Hz and remains nearly constant over the five third octave bands from 50-125 Hz. The strike noise level is then observed to rapidly decay in frequency, dipping below 100 dB re 1 μPa^2//Hz just one octave higher at a frequency of 250 Hz.

At the beamformer output, average beam noise levels during the strike (red, dashed) exhibit an even stronger frequency dependence over the upcall support band, with a steeper roll-off that starts earlier in frequency. The maximum beam noise level during the strike measures approximately 115 dB re 1 μPa^2//Hz at 63 Hz, but decays to 98 dB re 1 μPa^2//Hz at 125 Hz, and 72 dB re 1 μPa^2//Hz at 250 Hz, which is below Wenz heavy shipping. This steep roll-off in beam noise level with frequency relative to the omni-directional hydrophone is due to the beam response of the beamformer in directions pointed away from the pile driving line-of-sight (LOS). The strong frequency dependence suggests that optimization of post-beamformer NARW upcall auto-detector performance during the strike may be possible by focusing attention on that portion of the upcall support band above 100 Hz.

We must also not fail to recognize the significant performance benefit of the array beamforming revealed by Fig. 5 for the between strike intervals. The large number of vessels that support the pile driving and bubble cloud operations involve dozens of engines, generators, and compressors that conspire to elevate the quiescent, steady state ambient background, independent of the actual hammer impact. The average omni noise levels in between the strikes (blue, solid) remain quite high, e.g., 96 dB re 1 μPa^2//Hz at 125 Hz, which is well in excess of Wenz heavy shipping (86 dB re 1 μPa^2//Hz).[2] By comparison, the median beam noise at 125 Hz measures 87 dB re 1 μPa^2//Hz. Thus, for bearings pointed away from the pile driver LOS, the beamformed array returns the ambient noise environment to levels that are consistent with historical heavy shipping observations.

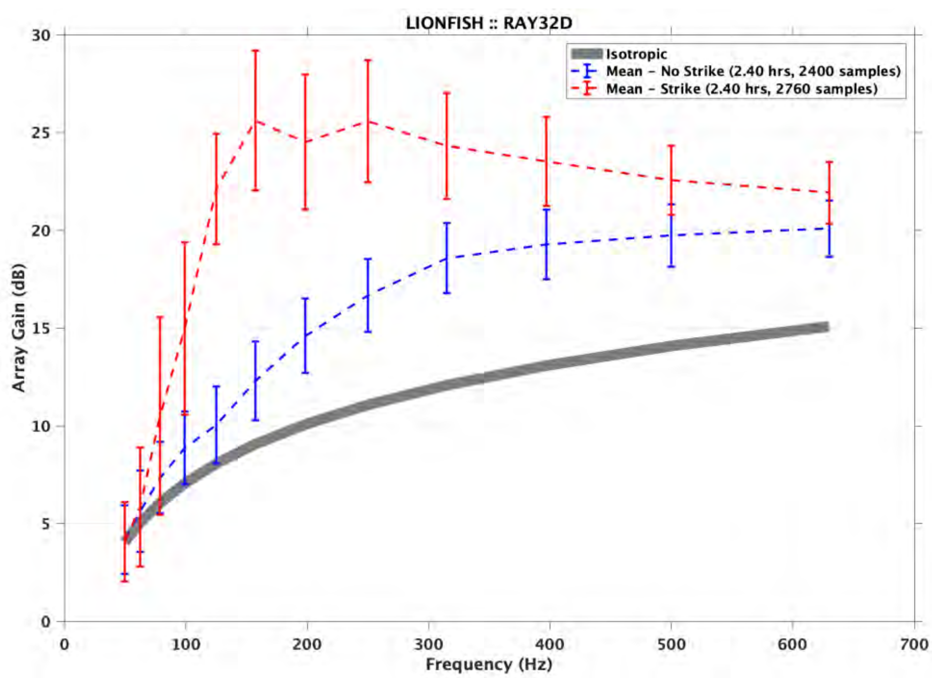


Figure 6 Measured array gain during strike (red) and in-between strike (blue) intervals relative to directivity index (gray).

Measurement of array gain vs. third octave band over the August 1 event is shown in Figure 6, again partitioned by during-strike (red) and between-strike (blue) intervals. As mentioned above, the AG metric is estimated by comparing the omni-averaged noise level to the median beam noise level. Vertical bars indicate $\pm\sigma$ intervals. For reference, directivity index, or theoretical AG in isotropic noise, as a function of frequency is overlaid in gray. Most notable from this result is the degree to which the measured AG exceeds theoretical DI prediction, with a sustained level of 22-25 dB observed over the much of the array operating band. This is due to the extremely anisotropic nature of the noise field for both the strike and between-strike intervals. Even during the between-strike periods, the measured AG significantly exceeds DI over most of the operating band of the array owing to the influence of the radiated noise from the many vessels supporting the pile driving operation.

Spatial Distribution of Pile Driving Noise

Next, we examine the spatial distribution of the pile driving noise operation both during and between strikes. It is best to do this with an instantaneous snapshot rather than incoherent average over the entire event as the relative bearing to the pile driving changes with time due to the motion of towed array. Figure 7 depicts a measurement of the third octave band beam response in polar coordinates for band 24 (224-282 Hz) in a single FFT frame at 2205 GMT for omni-average (orange) and beamformer output (blue). It should be emphasized that, unlike the results presented above, this result is a true third octave band measurement. The lefthand panel of Fig. 7 corresponds to the strike interval, and the righthand panel to the between-strike interval. This result is for just one third octave band; the NARW upcall support band spans seven third octave bands (bands 18 to 24, inclusive). The band 224-282 Hz is used here for illustration.

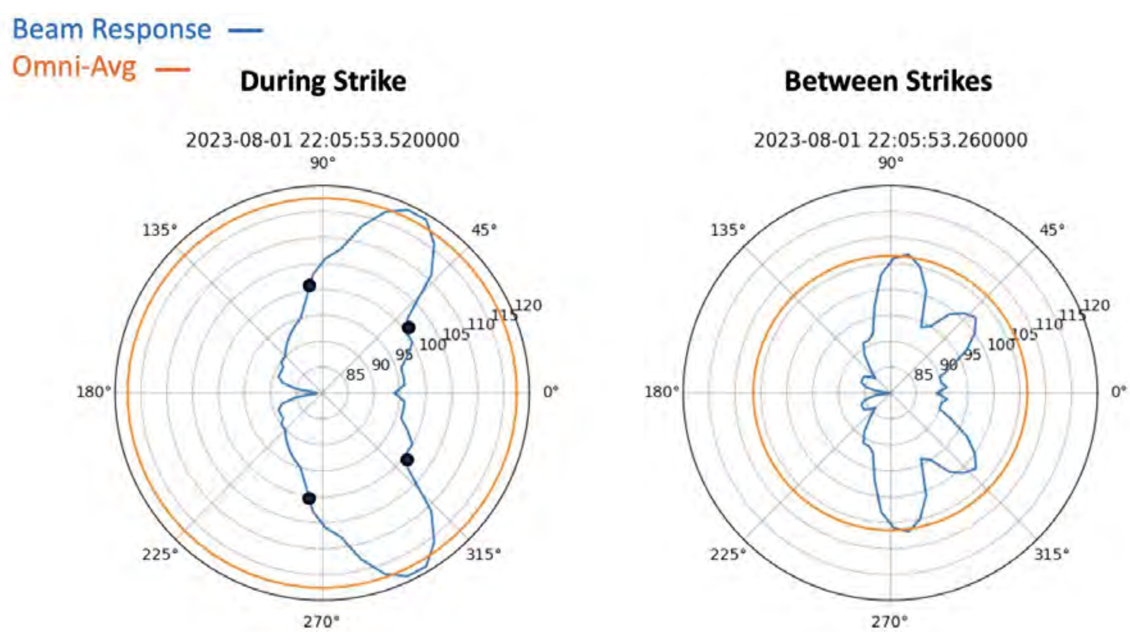


Figure 7 Third octave band spatial distribution of pile driving noise during strike and non-strike for band 24 (224—282 Hz) on August 1, 2023 at 2205 GMT: omni-average (orange), beamformer output (blue). Black dots denote estimated boundaries of blanking sector based on an in-band noise threshold of 101 re 1 μPa as reported in Ref. 4.

Consistent with the power spectrum level of 98 dB re 1 μPa^2//Hz reported in Fig. 5 for band 24 (center frequency 250 Hz), the peak third octave band level shown in Fig. 7 (left) at the bearing of the pile driving operation during the strike is approximately 120 dB re 1 μPa (e.g., 98 dB + $10\log_{10}\Delta f$). As a qualitative measure of the bearing extent of the beam response during the strike, black dots are used to denote the bearings for which the third octave band beam response crosses the threshold of 101 dB re 1Pa, which has been used in a previous sonar equation analysis as the in-band noise level that supports NARW upcall detectability—for details the reader is referred to Ref. 4. If this noise level is interpreted as the threshold in-band noise level below which desired detection performance is achievable, then the azimuthal sector circumscribed by the two dots in Fig. 7 (left) may be viewed as an estimate of the pile driving "blanking sector" within which detection performance is degraded. This stands in contrast to the omni-averaged case, for which detection is not supported at all due to the third octave band noise level exceeding the designated threshold in all bearings. More detailed discussion of the blanking sector and detection performance versus relative bearing in the presence of pile driving noise is presented below.

For the between-strike interval in Fig. 7 (right), the measured beam response takes on a completely different spatial dependence consistent with the distribution of support vessels in the op area. The peak third octave band level for band 24 is observed to decrease by nearly 15 dB to approximately 106 dB re 1 μPa absent the pile driving stimulus. While obviously much lower than the during the strike, the level associated with the operation's support vessels is still on the order of 10 dB above historical Wenz heavy shipping in this third octave band (e.g., 97 dB re 1 μPa).[3]

North Atlantic Right Whale Signal Injection Study

As North Atlantic right whales are not present in the Martha's Vineyard lease area during the month of August, to verify that the beamformed array can detect NARW in the presence of pile driving, a signal injection analysis was performed. This approach is often used in U. S. Navy tactical sensor performance assessment when data that combines the signal of interest with the relevant noise environment is sparse or unavailable. Of course, the most desirable condition is to employ at-sea array measurements of naturally-occurring NARW upcalls in the presence of pile driving noise. The next possible opportunity to collect and analyze such data will be when pile driving operations resume during the summer of 2024.

The signal injection implementation used herein draws upon actual, pre-recorded NARW upcalls excerpted from the St Andrews 2013 DCLDE Workshop database. In the first instance, a five-minute audio wave file comprised of a sequence of representative NARW upcalls was scaled to yield an average SNR of 20 dB at the beamformer output. The scaled wave file was then coherently added to the timeseries at each array element with an inter-element time delay programmed to emulate a right whale with a nominal degree of bearing rate. This enabled the assessment of performance as a function of relative bearing, and in particular, angular separation from the pile driving stimulus. This data was then reprocessed by the real-time beamforming and auto-detector software and results compared to the omni-directional hydrophone response. *The results show that the ThayerMahan beamformer and auto-detector software was able to detect and classify the NARW upcalls in pile driving noise at an element-level signal to noise ratio (SNR) for which the single hydrophone was completely masked.*

Figure 8 depicts a representative result from this process for a 60 s interval commencing at 2146 GMT on August 1. Fig. 8 (top) shows a narrowband display, or spectrogram, for the beamformer output in Beam 2 near aft endfire, while Fig. 8 (bottom) shows a representative single hydrophone spectrogram, channel 16. In this measurement geometry, as depicted in Fig. 1, the pile driving vessel, M/V Bokalift2, is slightly forward of array broadside and thus well-separated in relative bearing (nearly 60° away) from the injected upcall near forward endfire at this instant in time. From the measured received level of approximately 107 dB re 1 μPa in a 5.9 Hz band, it can be shown through transmission loss modeling of the South Fork Wind environment that the injected upcall may be associated with a right whale vocalizing at a source level of 172 dB from a range of 8-10 km.

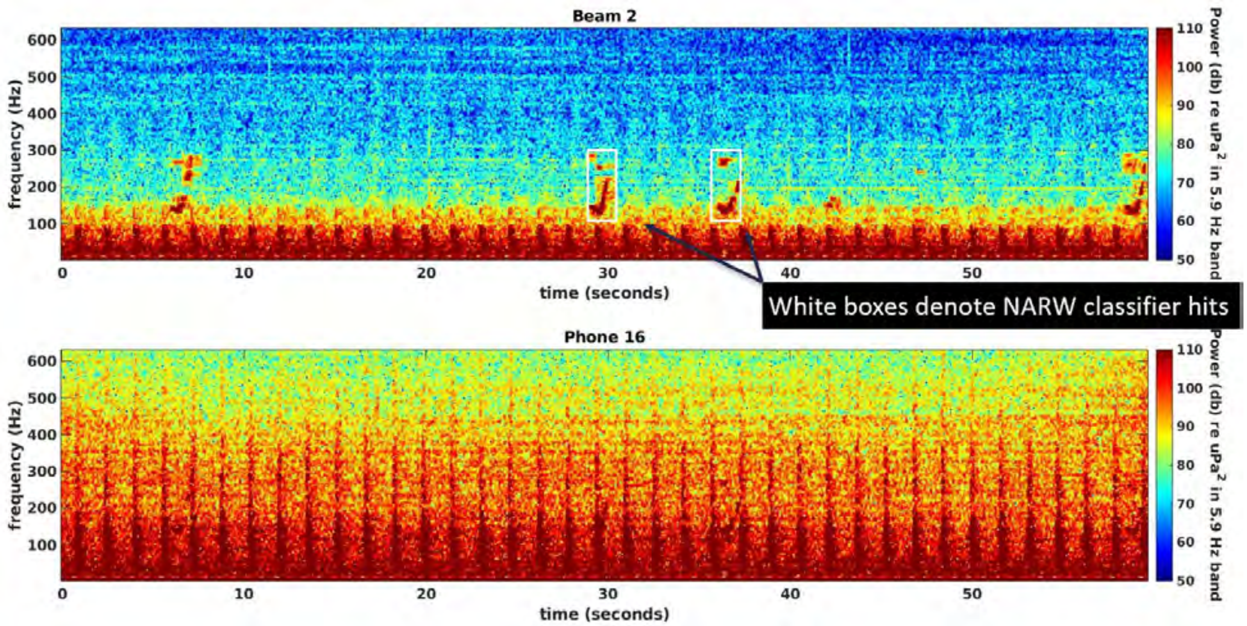


Figure 8 Results of recorded NARW upcalls injected at a post-beamformer SNR of 20 dB into August 1 pile driver array element data. Spectrograms show received level in units of dB re 1 µPa in a 5.9 Hz analysis band. Top shows the Beam 2 spectrogram, bottom shows single hydrophone. The white rectangle overlays depict NARW upcall classifier detections on the beamformer output—no such detections occurred for the single hydrophone at this injection level. The result illustrates the capacity of the array to spatially reject the pile driver interference relative to a single hydrophone and support autodetection of NARW upcalls in the presence of this noise source.

The advantage provided by the array beamformer is indisputable—the injected upcall is simply not detectable at the single hydrophone but is clearly apparent at the beamformer output. As the normalization of the beamformer filter coefficients is designed to yield unit gain through the beamformer, it is important to emphasize *that the observed received level of the injected upcall at the beamformer output is identical to that at the element level***.** The only difference in the two spectrograms depicted in Fig. 8 is the spatial noise rejection effected by the array beamformer. Four injected NARW upcalls are just barely discernible in the channel 16 spectrogram (bottom), at the 6 sec, 29 sec, 37 sec, and 59 sec marks, respectively. However, all four injected upcalls are very clearly seen in the beamformer output (top). Further, the white rectangles overlaid on the beamformed spectrogram signify that two of the four upcalls were detected by the spectrogram correlator classifier, at 29 sec and 37 sec, respectively. As one might expect from inspection of Fig. 8 (bottom), the autodetector processing of the single hydrophone data did not detect any of the injected upcalls.

Figure 9 shows the measured array gain in the forward endfire beam for the same 60 s interval of Fig. 8. Over much of the array operating band, array gain measures 20-25 dB due to the beamformer sidelobe response acting to spatially filter the noise from the pile driving stimulus. Notice that the injected right whale upcalls exhibit nearly 0 dB AG in this forward endfire beam. This is also expected, as they are essentially mainlobe interferers in this beam—the beamformer does not reject them because they match the plane wave signal model for this bearing—and thus report 0 dB array gain. Below 50 Hz or so, the AG decays to nearly 0 dB as the beam response approaches omni-directional several octaves below the array cut frequency of 600 Hz.

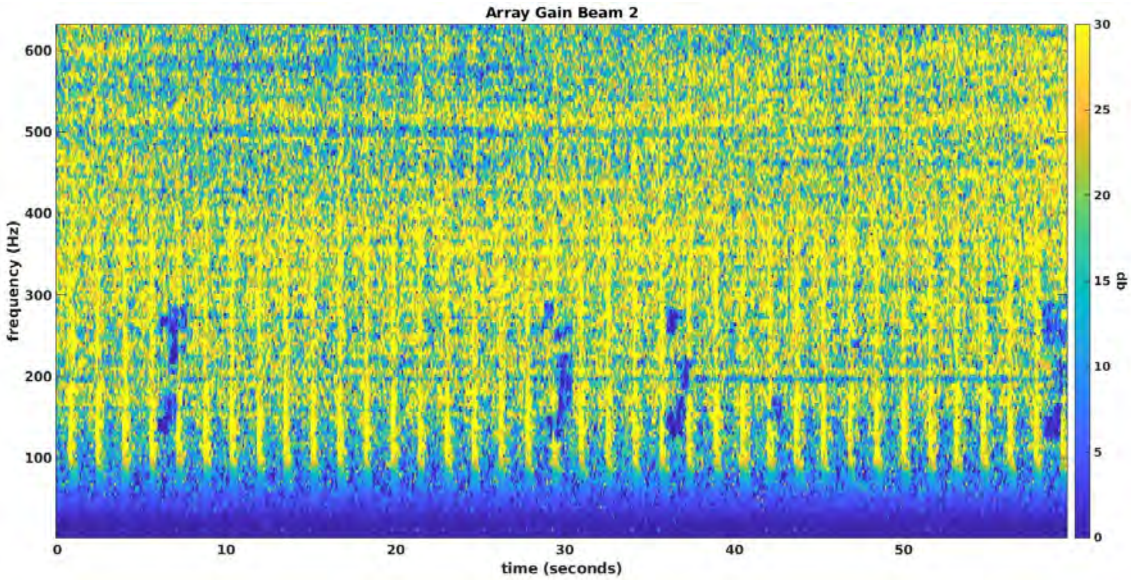


Figure 9 Measured array gain in Beam 2 corresponding to result in Figure 8. Demonstrates spatial noise rejection delivered by the array against pile driving noise. Note that the array gain exceeds the directivity index (DI), or 10logN, where N is equal to the number of array elements, due to the extreme anisotropy of the noise field.

Sonar Equation Analysis for Bearing-Dependent Detection Performance Prediction

In this section we employ a passive sonar equation treatment to the measured beam noise response to pile driving as a means for predicting NARW upcall detection performance as a function of bearing separation from the pile driving operation. The sonar equation can be written in terms a figure of merit (FOM) for a given environment as follows,

$$FOM \equiv TL = SL - (NL - AG) - NRD,$$

where TL represents the transmission loss, SL is the source level, (NL - AG) denotes ambient noise level measured at the beamformer output, and NRD is the system recognition differential, or SNR at the beamformer output required to yield a desired receiver operating point. The FOM can be interpreted as the maximum transmission loss that the system can tolerate for a given SL and NL and still meet the desired level of performance. For the current ThayerMahan system operating point of Pcc = 0.5 at a false alarm rate (FAR) of 1 per hour, NRD is equal to 5.5 dB.

For the scenario adopted herein, a NARW upcall rms source level of 172 dB re 1 μPa was assumed.[5] Transmission loss was computed using the Navy Standard Parabolic Equation (NSPE) transmission loss model using range dependent bathymetry, geoacoustic model, and historical sound speed data for the South Fork Wind lease area.

Beam noise response as a function of true bearing was computed from a 10-minute incoherent average of the pile driving noise data taken over the interval 2146-2156 GMT on August 1. In this case, no partitioning of the data into during-strike and between-strike intervals was done. Figure 10 depicts the beam noise (blue) in a 5.9 Hz analysis band and FOM (red) for both the beamformer output (left) and omni-hydrophone (right) rendered in polar coordinates. In both cases, the beam noise incoherent average is performed over the frequency band 98-248 Hz. The array orientation is SE-NW with an array heading of 135°. The pile driving support vessel, M/V Bokalift 2, is at a true bearing of 60° from the array.

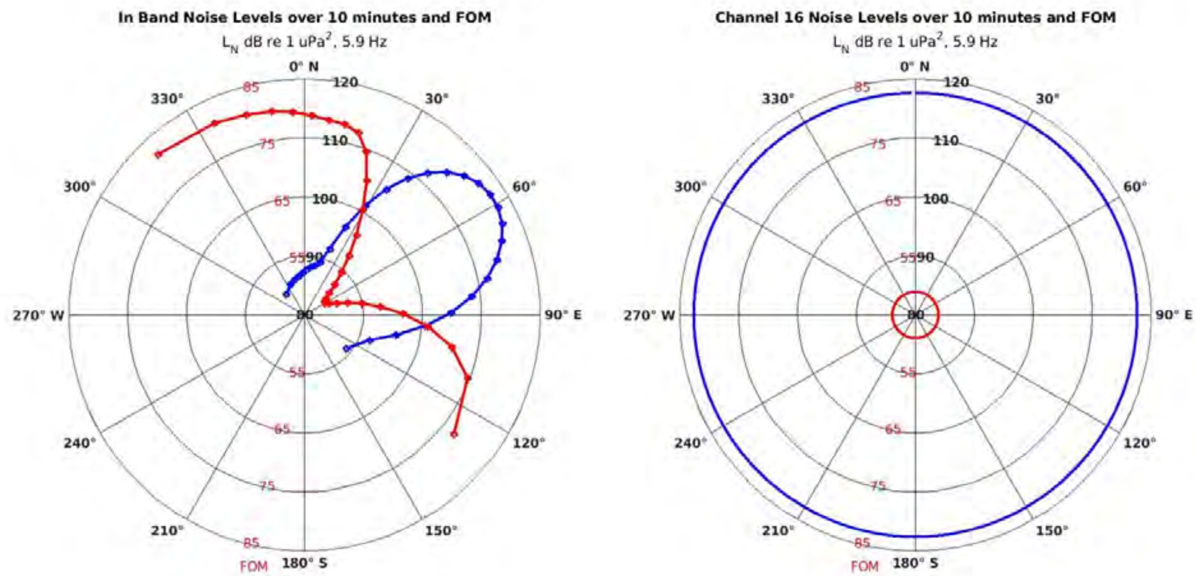


Figure 10 True bearing polar plots of beam noise response (blue) and figure of merit (red) over a 10-minute interval from 2146-2156 GMT for beamformer output (left) and omni-hydrophone (right). Beam and hydrophone noise response is reported in units of dB re 1 µPa in a 5.9 Hz analysis band. The array orientation is 135° during this time period and the true bearing to the pile driver, M/V Bokalift2, is 60°.

It should be noted that in the development of the beam noise response curves of Fig. 10, there are two important departures from earlier detection performance predictions.[1] The first is the definition of in-band noise level with respect to a 5.9 Hz analysis band, rather than the 200 Hz support frequency band (50-250 Hz) of the NARW upcall employed previously. The second is the use of the band 98-248 Hz to perform the incoherent average. These are justified as follows:

1) The modification to the definition of in-band noise level stems from the observation that, unlike coherent matched filtering of a known waveform as in the case of multi-static active sonar processing, *NARW upcall detection as implemented in the ThayerMahan spectrogram correlator detector-classifier is fundamentally a narrowband detection operation*. Narrowband spectrum features at the beamformer output are presented as candidates for upcall classification after an NRD threshold is applied in an analysis band of 5.9 Hz (ENBW). The set of pixels exceeding this NRD threshold (5.5 dB) are then forwarded for testing of a fingerprint match against individual members of the NARW upcall kernel library which is computed via a binarized inner product.[6]

2) The incoherent averaging band of 98-248 Hz was settled on empirically after the inspection of beamformed spectrograms of NARW upcalls injected into pile driving noise as shown in Fig. 8. These observations revealed that the frequency support for most NARW classifier decisions appears to occur at frequencies above 100 Hz, coincident with the steep roll-off in the pile driving noise spectrum at the beamformer output. Associating the incoherent average of noise level with that part of the frequency band below 100 Hz would have unduly penalized the FOM for pile driving noise spectrum content that does not factor into the performance of the auto-detector, potentially leading to underestimation of detection range performance.

The results of Fig.10 show that there is a strong bearing dependence to the beam noise response and FOM at the beamformer output. The array FOM exhibits a near dipole spatial response with some symmetry about the bearing to M/V Bokalift 2, the pile driver support vessel. On the other hand, the beam noise response and FOM of the single hydrophone is omni-directional with a FOM that is 30 dB less than that of the array for nearly two thirds of beam space.

To put the FOM calculations in the appropriate context to support the inference of detection range as a function of bearing, it is necessary to reconcile the FOM response with the TL model for the South Fork Wind lease area. Figure 11 depicts detection range contours corresponding to the array (red) and single hydrophone (blue) FOMs of 78 dB, and 64 dB, respectively, derived from previous sonar equation analysis.[1]

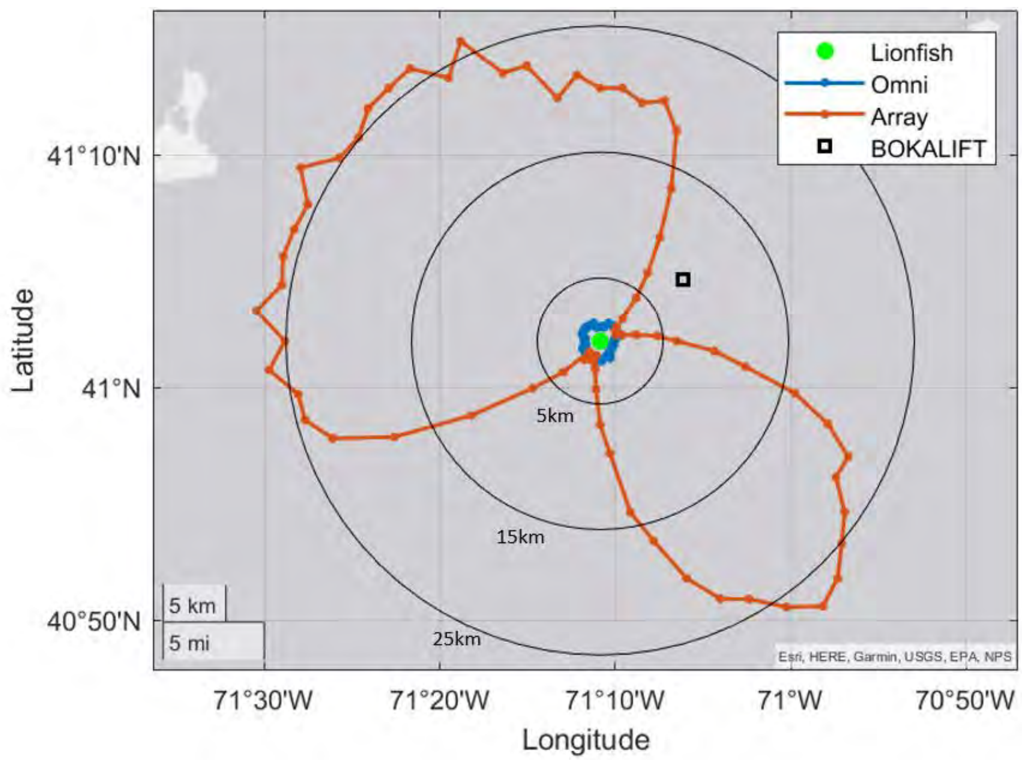


Figure 11 Detection range contours for array (red) and single hydrophone (blue) corresponding to the figure-of-merit calculations of Fig. 10. Receiver position denoted in green and the pile driving vessel, Bokalift 2, is denoted by black square.

The detection range contours depicted in Fig. 11 show that under an assumption of a NARW upcall emitted with a rms source level of 172 dB in the presence of the pile driving noise recorded at a distance of 5 NM on August 1, 2023, detection ranges of as much as 25 km are predicted at the beamformer output, with ranges of 15 km or more projected over approximately two thirds of beam space. This stands in contrast to the single hydrophone, which shows a detection range of less than 1 kilometer. The refinement of these detection performance predictions, with the development of confidence intervals to account for the uncertainty in modeled source level, transmission loss, and the assumptions invoked with regard to the in-band noise level, will the subject of continuing investigation.

Bearing Dependence of Classifier Performance

As a final exercise, the signal injection analysis was extended in an attempt to better quantify the bearing-dependence of the probability of correct classification (Pcc) at the beamformer output in the presence of pile driving operations. To improve experimental control in this scenario, the injected wave file was modified to be based on a *single representative upcall* from the St. Andrews 2013 DCLDE database, scaled as before to approximate a desired SNR at the beam output—in this case, we present auto-detector performance for two different SNR values: high (20-25 dB) and moderate (10-15 dB). For reference, these SNRs were measured for the aft endfire beam, furthest from the pile driving operation near array broadside. The upcall was repeated 12 times per minute at a uniform 5 s rep rate and coherently added to the element time series data as before, with inter-element time delay programmed to emulate a right whale with a bearing rate of roughly 3° per min, enough to support approximately 25-30 detection opportunities per beam over a 1-hour interval.

Figures 12 and 13 depict the measured Pcc vs bearing, plotted in polar coordinates, at SNRs of 20-25 dB and 10-15 dB, respectively. As noted earlier, the programmed false alarm rate operating point is 1 FA/hour, the same as that currently employed for the real-time ThayerMahan SeaPicket system. At the high SNR, Fig. 12 shows the spectrogram correlator reliably classifies the injected NARW upcall to within about 15° of the pile driver true bearing of 60°, resulting in a minimal "blanking sector" spanning about 30°. In fact, the classifier exhibits virtually perfect performance (Pcc = 1.0) to within 30° of the pile driver bearing. At moderate SNR, Fig. 13 shows the classifier maintains a Pcc of 0.5 to within about 30° of the pile driver true bearing, leaving a blanking sector that spans about 60° in bearing. Clearly the extent of the blanking region is driven by SNR, and thus the range and source level, of the calling animal. Note that there is no comparison reference for the single hydrophone case as the injected NARW upcalls were not detected for the omni-directional hydrophone at either high or moderate SNR.

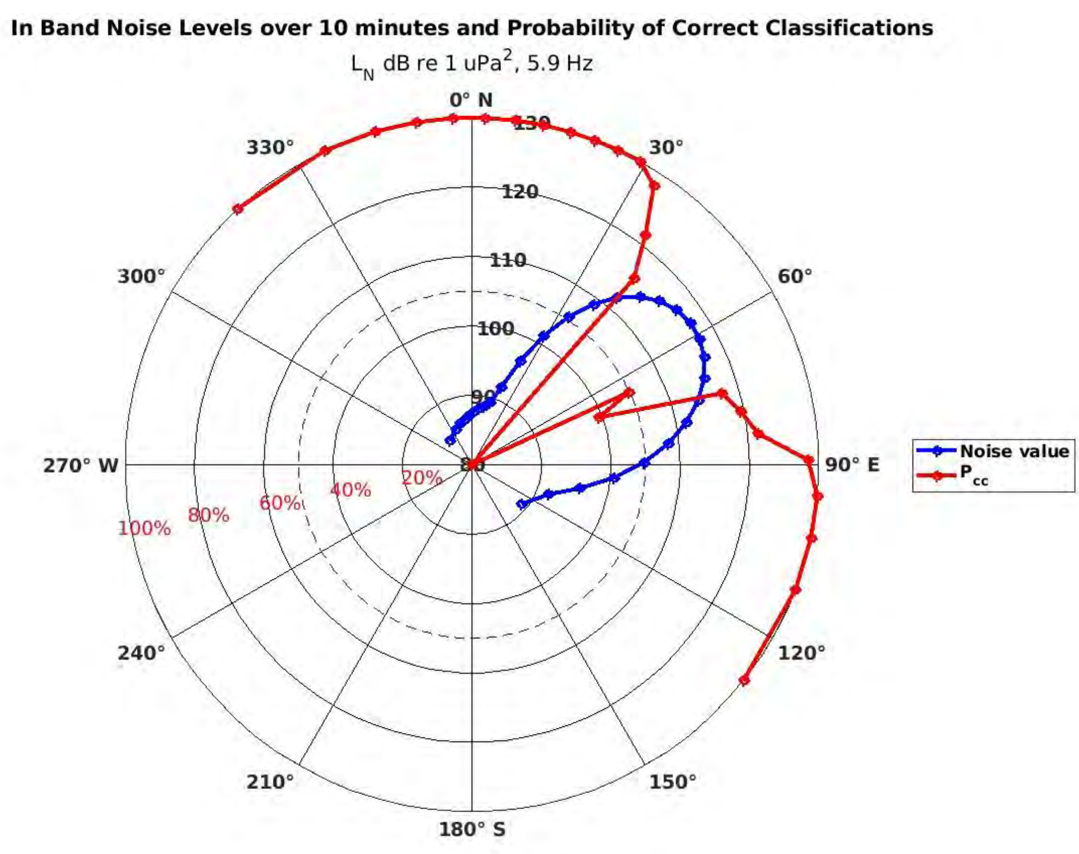


Figure 12 Pcc (red) and beam noise response (blue) vs. bearing in presence of pile driving noise for representative NARW upcall injected at high SNR (20-25 dB).

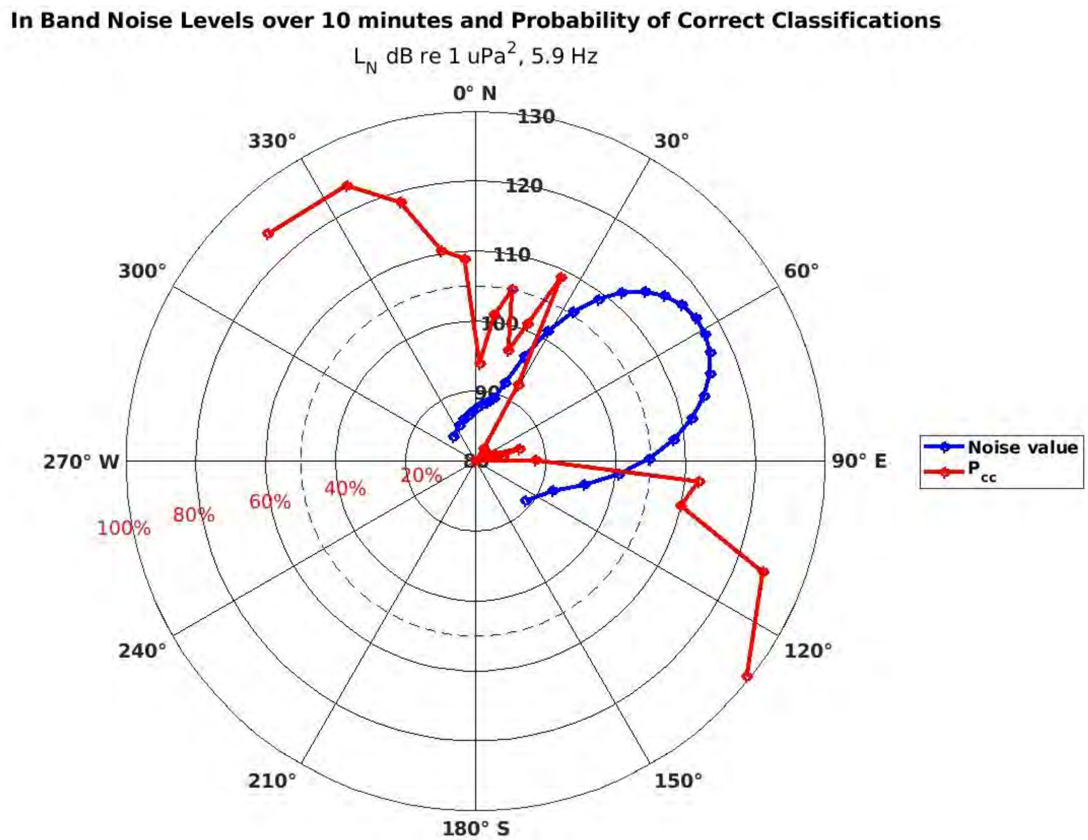


Figure 13 Pcc (red) and beam noise response (blue) vs. bearing in presence of pile driving noise for representative NARW upcall injected at moderate SNR (10-15 dB).

Summary

An analysis was performed of towed hydrophone array measurements of pile driving radiated noise collected between 1-3 August 2023 in Orsted's South Fork Wind lease area. Approximately 48 hours of element data were recorded spanning two pile driving events. This report describes analysis performed on data collected during the August 1 pile driving event.

The principal finding is that while a 32-channel array can deliver 15 dB of array gain in isotropic noise conditions, this advantage rises to as much as 30 dB for highly anisotropic noise such as pile driving. This has significant implications for passive acoustic marine mammal monitoring in the presence of anthropogenic noise sources and is further evidence as to why marine mammal monitoring systems with arrays outperform systems with single omni-directional hydrophones in offshore construction areas and in the vicinity of shipping.

As expected, the radiated noise from pile driving operations and the associated support vessels is significantly higher than normal ambient conditions. Median omni-directional hydrophone noise spectrum levels in the North Atlantic right whale frequency band during the strike measured roughly 30 dB higher than historical Wenz heavy shipping. However, the beamformed data results show up to 30 dB of noise reduction in relative bearings pointed away from the pile driving operation. The acoustic masking effect of the pile driver noise also exhibits a strong frequency dependence within the NARW support band at the

beamformer output relative to the single hydrophone, with beamformed noise levels decaying rapidly for frequencies above 100 Hz.
As North Atlantic right whales are not present in the Martha's Vineyard lease area during the month of August, to verify that the beamformed array can detect NARW in the presence of pile driving a signal injection analysis was performed. *The results of the signal injection study show that the ThayerMahan beamformer and auto-detector software was able to detect and classify the NARW upcalls in pile driving noise at an element-level signal to noise ratio (SNR) for which the single hydrophone was completely masked.*

Using traditional passive sonar equation analysis, it was shown that for a *NARW upcall emitted at a rms source level of 172 dB re 1 µPa, detection ranges of up to 15-25 km were predicted in the South Fork Wind lease area on a 32-channel towed hydrophone array in the presence of pile driving noise.* Depending on the range and source level of the NARW, a bearing sector of as much as 30°-60° centered on the pile driver bearing may be "blanked" or exhibit degraded classifier performance during the strike. However, the analysis also shows that the single hydrophone is completely obscured for NARW detection in the presence of pile driving at ranges beyond one kilometer.

It will be important to validate such detection performance predictions in the future using calibrated source operations with a J-13 acoustic projector, instrumented with a GPS receiver, transmitting pre-recorded NARW upcalls at the desired rms source level of 172 dB re 1 µPa in the presence of pile driving operations.

The quantification of array performance in the presence of pile driving will continue—the next step is the analysis of measurements collected on bottom-mounted arrays. Advanced signal processing methods for spatial noise rejection such as matched filtering, adaptive beamforming, and fixed nullspace projections are under investigation, as is the influence of array orientation on beam response to pile driving noise. However, the findings on the performance of a beamformed towed array in the presence of pile driving presented herein are promising and further point to its credible use in support of marine mammal monitoring during offshore wind construction operations.

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Acoustic Detection Performance Modeling of a 32-Channel Hydrophone Array in the Southern New England Offshore Wind Lease Area

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May 8, 2024

To assist with planning of asset allocation for the passive acoustic monitoring of marine mammals in the southern New England offshore wind lease area, model predictions of 32-channel hydrophone array detection performance are presented. Emphasis is on the North Atlantic right whale (NARW) upcall[1] using a parabolic equation (PE) transmission loss model[2] and range dependent bathymetry. Using standard passive sonar equation analysis, we can derive a figure of merit (FOM) for the environment as follows,[3]

$$FOM \equiv TL = SL - (NL - AG) - NRD, \qquad (1)$$

where *TL* represents transmission loss, *SL* is the root mean square source level of the upcall, *NL* is the in-band ambient noise level at the hydrophone, *AG* denotes the array gain, and *NRD* is the system recognition differential, or SNR at the beamformer output required to yield the desired receiver operating point. The FOM can be interpreted as the maximum transmission loss the system can tolerate under the given assumptions for SL and NL and still meet the desired level of detection performance.

FOMs were computed using (1) for both a 32-channel hydrophone array cut to a design frequency of 600 Hz, and a single hydrophone, based on the following assumptions and model inputs:

- North Atlantic right whale up-call rms source level of 160 dB re 1μPa @ 1 m.[4] The vocalizing animal is assumed to be in the upper water column.

- Ambient noise spectrum level at hydrophone of 80 dB re 1μPa/Hz corresponding to Wenz moderate shipping at 100 Hz.[5] This corresponds to a decidecade (third octave band) level of 93 dB re 1μPa at 100 Hz and is supported by recent data collections.[6]

- Noise bandwidth is 5.9 Hz due to the narrowband nature of the upcall detection algorithm, which compares each pixel in a pre-whitened spectrogram to an estimate of the local background noise in a 5.9 Hz effective noise bandwidth (ENBW), resulting in an in-band noise level of 88 dB re 1μPa.

- Noise is assumed to be spatially isotropic. Isotropic noise assumption implies a theoretical array gain of $10\log_{10} N$, or 15 dB, for a 32-channel array at the array design frequency. This is a significant underestimate of array gain in a highly anisotropic noise environment such as the southern New England lease area.

- Nominal amount of array signal gain degradation, ~1 dB, due to unmodelled array shape deviation from straight line yields a net array gain of 14 dB. Array is assumed to be bottom-mounted.

- In-band noise level at the array output is, therefore, NL - AG = (88-14) = 74 dB re 1μPa.

- Finally, an NRD of 5.5 dB is employed corresponding to the SNR threshold imposed on any feature in the pre-whitened spectrogram presented as a candidate to the NARW classifier to meet a false alarm operating point of 1 FA per hour.

Substituting these values into eq. (1) yields a FOM of 81 dB for the 32-channel hydrophone array, and 67 dB for the hydrophone. These FOM values are used in conjunction with the PE transmission loss model output to project 50% instantaneous probability of detection range contours for the array and hydrophone, respectively, as shown in Figure 1.

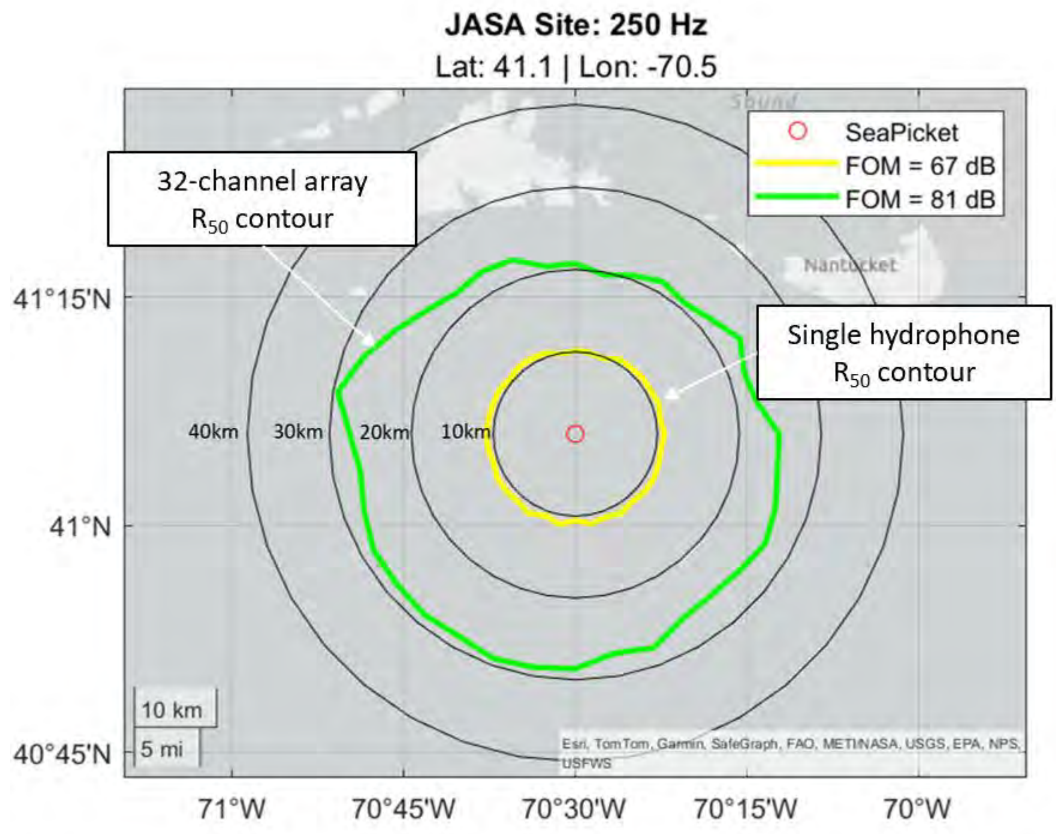

Figure 1 Detection range contours for 32-channel hydrophone array and single hydrophone in the southern New England offshore wind lease area

Figure 1 shows that in the subject environment 1) the array provides up to 3:1 detection range advantage, or nearly 10:1 area coverage advantage, over the single hydrophone, and 2) 20 km detection range for the 32-channel array is supported.

This sonar equation treatment, and assumptions invoked herein, is informed by on-going discussion between members of the NOAA and BOEM government teams and ThayerMahan/OASIS. The reader is referred to Refs. 7 and 8 for further details of that discussion.

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Appendix A: Geoacoustic Model Inputs

The sound speed profile employed in the PE model calculations, shown in Figure A-1, was a typical summertime downward refracting profile taken from the World Ocean Atlas.

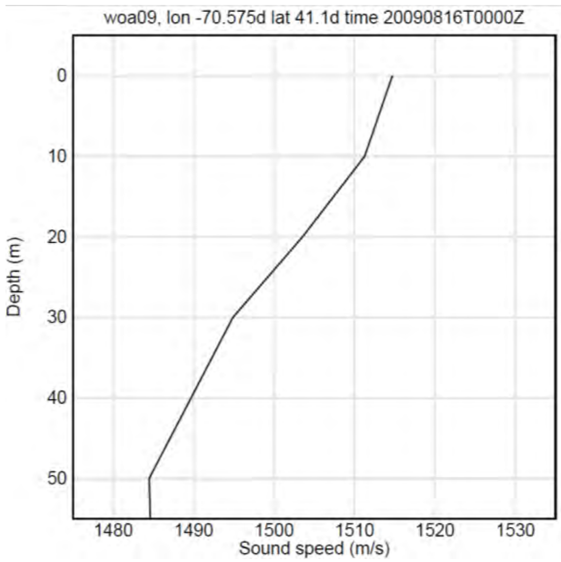

Figure A-2 Sound speed profile employed in the PE model calculations

Seabed geoacoustic properties used in the transmission loss model are listed in Figure A-2.

GEOACOUSTIC		usSEABED	
RB		0.0	
ZB	CB	0.0	1719.0
…	…	3.0	1800.0
-1	-1	-1	-1
ZR	RHO	0.0	1.946
…	…	3.0	2.03
-1	-1	-1	-1
ZA	ATTN	0.0	0.708
…	…	3.0	0.057
-1	-1	-1	-1

Figure A-3 PE seabed model parameters

The bathymetric data in the transit lane area was extracted from the GEBCO 2022 database, a bathymetry data set developed through the Nippon Foundation-GEBCO Seabed 2030 Project (https://www.gebco.net/data_and_products/historical_data_sets/). The GEBCO database provides bathymetric data, in meters, on a 15-arc-second interval grid.

Note that range dependence in the TL model is only represented via the bathymetric data. Sound speed profile, seabed description, and ambient noise values are assumed to be range independent and the same values are applied for each SeaPicket location.