NOAA Technical Memorandum NMFS-AFSC-490

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September 2024

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National Oceanic and Atmospheric Administration
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This document should be cited as follows:

Bassett, C., De Robertis, A., and Gallagher, M. 2024. A passive acoustic drifter for radiated noise measurements of NOAA Fisheries survey vessels. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-490, 116 p.

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A Passive Acoustic Drifter for Radiated Noise Measurements of NOAA Fisheries Survey Vessels

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Executive Summary

The National Oceanic and Atmospheric Administration's (NOAA) Fisheries Survey Vessel (FSV) fleet, beginning with the NOAA ship *Oscar Dyson*, was constructed to meet radiated noise recommendations for research vessels described by the International Council for the Exploration of the Sea (hereafter ICES recommendation, Mitson 1995). These recommendations apply over a broad frequency range to limit fish avoidance of vessels and reduce interference with active acoustic instrumentation commonly used in fisheries surveys. NOAA's Office of Marine and Aviation Operations (OMAO) developed an Acoustic Management Plan for the vessels to ensure that the design specifications for radiated noise were met. In addition to various physical surveys of components that contribute to a vessel's noise signature, this guidance recommended that newly constructed vessels undergo an acoustic trial at one of two certified U.S. Navy facilities. Such tests would verify that the new ship does not exceed the ICES recommendation and establish a baseline for the vessel. The guidance also recommends periodic visits to a certified range, generally after dry-docking, to ensure that the radiated noise signature of the vessel continues to comply with the noise recommendations.

The two certified range facilities suitable for acoustic noise trials are at the Atlantic Undersea Test and Evaluation Center (AUTEC) near Andros Island, Bahamas, and the Southeast Alaska Acoustic Measurement Facility (SEAFAC) near Ketchikan, Alaska. Testing at these Naval facilities is expensive and requires substantial transits to these facilities. To investigate the feasibility of using a lower-cost option to replicate the measurements of radiated noise from a NOAA FSV made by a certified range facility, De Robertis et al. (2011 and 2012) deployed a mooring near SEAFAC that replicated the physical configuration for measurements performed at the range and conducted radiated noise measurements the day after noise ranging. Low frequency (f < 500 Hz) noise measurements were similar to those observed at SEAFAC (average deviation < 1.4 dB, maximum deviation in any one-third octave bands < 2.5 dB). However, radiated noise at frequencies > 500 Hz was not directly comparable between these two consecutive days due to shaft-related vessel noise that was not present during the SEAFAC measurements which increased high-frequency noise levels by up to 12 dB. The results generally support the use of less expensive platforms for acoustic characterization of research vessel noise. Such measurements are not a direct replacement for certified range measurements, but they can provide for a lower cost alternative with fewer disruptions to vessel schedules if implemented during routine operations.

To satisfy existing standards for the measurement of radiated vessel noise described in ANSI (2009), hydrophones need to be deployed at fixed depths relative to the closest point of approach of the vessel being measured. While feasible, this requires a moored system that must be designed for the local bathymetry, thereby limiting conditions under which it can be properly deployed. To increase the flexibility of a mooring for measurements of radiated vessel noise, thereby reducing the costs associated with visits to test ranges and lost time for research activities, a passive acoustic drifter package has been designed to measure radiated vessel noise. This package, referred to as the Fisheries Survey Vessel Passive Acoustic Drifter (FSVPAD), complies with the ANSI standards for measuring vessel noise while reducing costs by allowing it to be deployed at sea during normal vessel operations in locations where bathymetry, meteorological, and oceanographic conditions are suitable. In addition to the FSVPAD, data acquisition and post-processing software packages have been written to facilitate the analysis of the passive acoustic measurements to ensure they comply with processing

standards. The FSVPAD, along with its software, are intended to be accessible not only to a well-informed scientist, but also by a technically proficient crew member on any NOAA ship or at a NOAA Fisheries science center. The FSVPAD system was deployed in June 2023 to measure the radiated noise levels of the NOAA ship *Oscar Dyson* with satisfactory results.

Detailed technical information is made available herein to allow other interested parties to build and deploy a similar system. In addition, this report contains the details necessary to operate the FSVPAD to meet measurement standards. To cover this information the document is divided into numerous sections belonging to five major categories:

- Background information and operational restrictions.
- Description of the FSVPAD.
- Data management and post-processing.
- Example detailing noise-ranging of NOAA ship *Oscar Dyson* in July 2023.
- Appendices.

The background information section provides a brief description of the overall system, summarizes its operational limitations, details relevant vessel operations, and describes the deployment/recovery procedures as they relate to the ship and crew. Instructions for assembling the FSVPAD, in addition to all relevant pre- and post-deployment requirements, are summarized in a single section. The data management and post-processing sections include detailed step-by-step instructions and screenshots to facilitate analysis by users unaccustomed to acoustic analysis. An example report resulting from an FSVPAD deployment to successfully measure radiated noise from a noise-reduced fisheries research vessel is provided. Supporting technical material including troubleshooting information, technical drawings, and other material are archived online with the processing scripts. Finally, the appendices include, but are not limited to, engineering details such as circuit diagrams; troubleshooting guides; descriptions of the mathematical operations performed by the processing scripts. These details should be sufficient for a user to either make use of the system on their own or to develop a similar system for their own use. Nevertheless, throughout this manual, references are made to the system as built and provided. Individuals using this document as a source of guidance for constructing their own system should disregard these comments.

Contents

I Background Information

Measurements of radiated noise levels from vessels that comply with measurement standards (ANSI 2009) require a specific set of vessel operations/maneuvers, have specified measurement geometries, and must adhere to basic processing procedures. The following sections provide a brief overview of the Fisheries Survey Vessel Passive Acoustic Drifter (FSVPAD), its ancillary components, and descriptions of the operational limitations and the vessel maneuvers required to meet the measurement standards. These details should be sufficient to determine if a site meets the basic requirements, whether the meteorological and oceanographic conditions are suitable for a deployment, and how the tests should be carried out. This section should be provided to the crew of the vessel well in advance of any deployment so that there is sufficient time to prepare for the vessel maneuvers and deployment/recovery procedures.

I.I Package Description

To measure radiated vessel noise and meet noise measurements standards without adjusting the deployment platforms for the specific water depth at the test site, a surface drifter is used. This drifter includes a surface expression to facilitate communications and tracking of the unit. GPS units on the vessel and drifter provide real time locations, range, and bearing measurements for the FSVPAD on a laptop computer on the bridge so that vessel maneuvers can be actively managed. All necessary hardware and programs are provided as part of the drifter package. A detailed description of all the system components is included in Section III. A repository containing the processing software, and additional technical documentation is provided at https://github.com/noaa-afsc-mace/FSVPAD-hydrophones.

A full test of radiated vessel noise is performed by deploying the drifter and following the operational instructions in the following sections. After the tests, the drifter is recovered and data from the instruments are downloaded to a laptop computer. A set of MATLAB scripts are provided to facilitate the post-processing of all relevant data. These codes require the Signal Processing Toolbox. User inputs to the post-processing scripts are then used to calculate the radiated noise levels produced by the vessel of interest.

I.II Operational Limitations and Site Selection

Various sources of ambient noise, non-acoustic noise, and self-noise can limit the ability of any passive acoustic system to detect radiated noise from any source. The proposed operational limitations of the FSVPAD are intended to limit the contributions of ambient noise sources, thereby increasing the signal-to-noise ratio, and maximizing the likelihood that high-quality noise measurements are obtained.

Wenz (1962) provides an overview of important sources of ambient noise. To the greatest extent possible, noise sources identified by Wenz (1962) and other researchers should be avoided. Noise-quieted vessels like the NOAA FSVs produce low radiated noise levels and are thus particularly susceptible to masking from ambient noise sources even at relatively short ranges.

Knudsen et al. (1948), Nystuen and Selsor (1997), and Ma et al. (2005) and the references therein have identified the impact contributions that wind and precipitation noise can make to ambient noise levels across the frequency bands relevant to the quantification of radiated noise levels from vessel. This noise, which is driven by the generation of bubbles at the ocean surface, has the potential to mask vessel noise across the relevant frequency range. Flow-noise is non-acoustic noise that is caused by strong currents, turbulence, or motion induced by surface waves (Strasberg 1985, Gobat and Grosenbaugh 1997, Bassett et al. 2014). This noise source is particularly challenging at low-frequencies ($f < 500$ Hz). Likewise, strong currents can mobilize fine- and coarse-grained sediment on the seabed, resulting in sediment generated noise at frequencies that can overlap with vessel signatures (Thorne 1986, 1990, Bassett et al. 2013). Lastly, vertical shear in the water column can cause vibrations, or cable strum, that can contaminate acoustic measurements. Minimizing interference from these noise sources can be accomplished by deploying the device in areas with relatively low currents and vertical shear in the water column. Anthropogenic noise, particularly radiated noise from vessel traffic, is a significant source of ambient noise (Ross 1976, Bassett et al. 2012, McKenna et al. 2012). This noise source is particularly important in this application as many vessels, especially modern commercial shipping vessels, produce much higher levels of radiated noise than NOAA's noise-reduced research vessels.

To avoid significant reductions in vessel signal-to-noise ratios relative to ambient noise from these sources the following conditions should be met when deploying the drifter:

Spatial limits: During the test the vessel will be required to transit to a range of at least 2 km from the drifter. Under ideal test conditions a total range of approximately 4 km, including some additional space to account for the drifter to move with the currents, should be available without interfering with shipping lanes or other maritime activities.

Water depth: The water depth should be at least 300 m or 3× the overall length of the ship, whichever is greater. If bathymetric constraints limit water depths to less than 300 m, then depth limits of the greater of 150 m or 1.5× the overall ship length can be used. This shallower depth corresponds to a lower precision measurement and should only be used when necessary. The depth should equal to or greater than 300 m or 150 m (whichever depth is used) within 1 km of the deployment in all directions. Drastic changes in bathymetry should be avoided where possible.

Spatial considerations: The deployment area should safely permit a closest point of approach (CPA) of 100 m.

Winds: Sustained winds of less than 15 knots.

Waves: Significant wave heights of less than 1 m.

Currents: Open ocean currents (e.g., < 15 cm/s throughout the water column) are ideal. In general, lower current velocities are better. For best results, do not deploy the FSVPAD in tidal channels or other areas with strong currents.

Precipitation: No precipitation is ideal. Light rainfall could result in low signal-to noise ratios, at frequencies greater than 10 kHz. Heavy rainfall and other forms of precipitation, except for snowfall, should be avoided.

Biological noise sources (marine mammals): If marine mammals are observed in the vicinity of the intended deployment location the FSVPAD should not be deployed. Their presence, including species and number, if possible, should be documented if observed during a deployment. Permanent and semi-permanent structures pose an entanglement risk. Avoid deployments where there is any known risk of entanglement.

Anthropogenic noise sources (ships or other structures): Noise from other vessels can easily interfere with the low radiated noise levels from the NOAA FSVs. Identify a location greater than 3 km from these sources. Moving farther away from noisy sources like shipping vessels, if possible, will improve measurement quality. As a rule, deploy the system in an otherwise suitable site as far from active vessel traffic and other maritime activities as is possible without compromising other research activities.

Endurance: The endurance of the system is approximately 3.5 hours and is limited by the rechargeable battery pack in the electronics assembly. Measurements should be accomplished within 3 hours of turning on the electronics.

I.III Vessel Operations

The vessel maneuvers replicate the procedures described in ANSI (2009) and should be adhered to whenever possible. Ideal operations are described, and alternative vessel maneuvers designed to meet lower standards for radiated noise characterization are included if geographic or temporal constraints do not allow for the full test. The following vessel operations describe the vessel's operational speed, how to approach and pass the drifter, and how the vessel should turn to satisfy the measurements standard.

I.III.I Vessel Speed/Shaft RPM/Generator Lineup

The vessel speed/shaft revolutions per minute (RPMs) during the radiated noise tests should be consistent with typical vessel operations. For example, if fisheries acoustic-trawl surveys on the vessel are ideally conducted with vessel speeds of 11 kts and shaft speeds of 96 RPMs, then those conditions should be used during testing except when the vessel is changing course. On NOAA FSVs, the same RPM and generator configuration used in previous tests should be used to ensure that the measurements are directly comparable to previous tests.

I.III.II Vessel Maneuvers - Description

This section provides a summary of the vessel maneuvers to maintain compliance with the standard (ANSI 2009). Section I.III.III provides a summary of the order of operations for the radiated noise tests that are sufficient for explanation to the vessel's crew without the technical details summarized below.

The vessel maneuvers during the radiated noise measurement tests are determined by the vessel speed and the closest point of approach (greater of 100 m [328 ft] or 1× the overall length of the ship; 100 m for NOAA FSVs). The critical range over which the radiated noise from the vessel is calculated is the data window length (DWL), which is measured in meters. The data window length is described by

$$\text{DWL} = 2\, d_{cpa} \tan(30°), \quad (1)$$

where d_{cpa} is the range at the closest point of approach. In most circumstances the targeted d_{cpa} is 100 m (0.054 nmi) so the DWL = 116 m (0.063 nmi). For a given pass on the starboard side of the vessel, the required geometry is described by Figure 1. The total distance past the drifter in the direction of travel over which a constant heading should be maintained, with minimal use of the helm, is described by 4×DWL (464 m; 0.25 nmi) for a targeted closest point of approach of 100 m. When using the graphical user interface (GUI) to locate the FSVPAD relative to the ship, the distance shown is its absolute range, not the distance along the vessel track. Therefore, the vessel should remain on course with minimal use of the helm whenever the distance to the FSVPAD is less than 420 m (0.23 nmi).

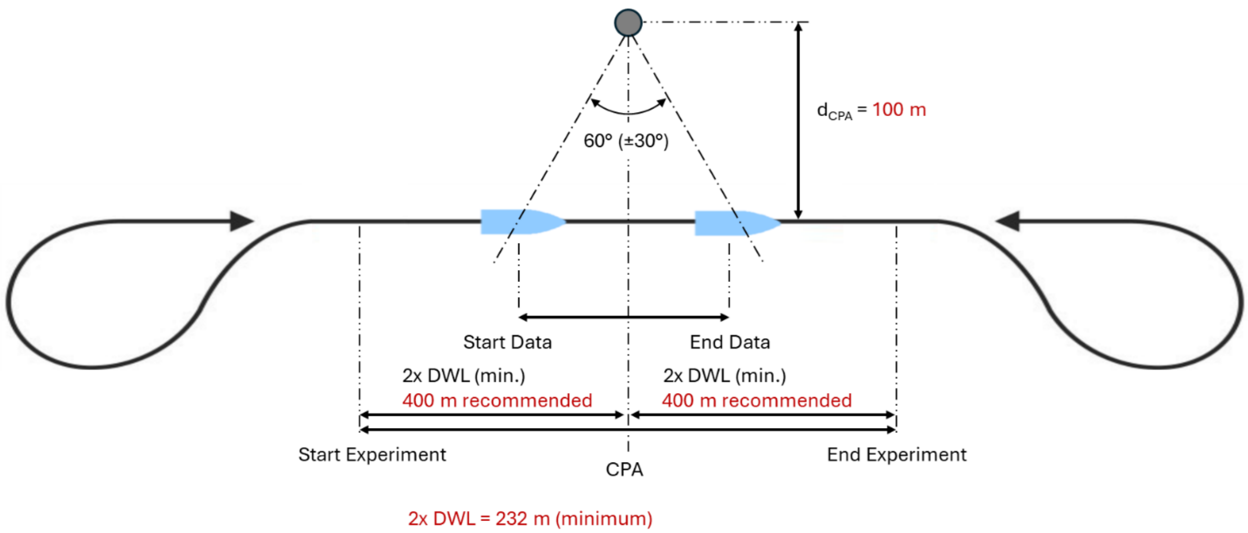


Figure 1. -- An example pass for a measurement of radiated noise. If the closest point of approach is 100 m, then DWL = 116 m, and the minimum distance over which a constant heading should be maintained is 464 m. The beginning and end of each transect are described by beginning and end of the experiments for a given transect (COMEX - commence exercise and FINEX -finish exercise), respectively. The red text highlights representative numbers for a 100 m CPA and recommended values for the ranges along the transect line following ANSI (2009).

I.III.III Vessel Maneuvers - Order of Operations

The order of operations for performing the radiated noise tests from the deployment through the recovery of the drifter is as follows:

(a) Before beginning the tests determine the direction that the drifter will move due to wind and currents. Vessel passes should be oriented along the path of the drift.

(b) Ensure that all propulsion systems and auxiliary machinery are operating as expected and continue to do so throughout the test.

(c) Deploy the FSVPAD as described in Section I.I.VI.

(d) Transit to a range of 2 km (1.08 nmi) or more from the FSVPAD. This location should be along the line of the passes thereby allowing the vessel to maintain a constant course as the vessel approaches the FSVPAD. At this location the shaft speed should be reduced to 0 RPM and the vessel should be allowed to drift for two minutes or more for an ambient noise measurement.

(e) After the 2-minute drift the vessel shaft speed should be increased to correspond to the test conditions and the vessel should begin the series of passes near the FSVPAD. Pass the FSVPAD with a targeted CPA of 100 m. As the vessel approaches COMEX location (approximately 400 m before the CPA) ensure that the vessel maintains a constant heading until the FINEX location (approximately 400 m after the CPA). At a speed of 11 knots, 400 m corresponds to approximately 71 seconds. Therefore, each pass from COMEX to FINEX lasts approximately 142 seconds. These values are the minimum to satisfy the standards and longer periods should be used if possible. Use either the vessel's chart plotting program or the software graphical user interface provided with the FSVPAD to estimate COMEX and FINEX to ensure the ship has transited a sufficient distance on a constant heading. Note that a range of 400 m along a constant heading from the CPA corresponds to approximately 412 m (0.22 nmi) read off of the GUI.

(f) Once the FINEX and any additional buffer distance is passed the vessel should perform a "Williamson" turn (Fig. 1), which will bring the drifter around to the opposite side of the vessel. A preferable approach is to transit a distance of at least 1 km (0.54 nmi) from the CPA before executing the Williamson turn. After turning, the vessel must be back on a constant speed and heading at least 10 seconds before passing the COMEX point.

(g) Repeat steps (e-f) until a minimum of 6 transects (3 on the port side and 3 on the starboard side) have been performed. If, and only if, temporal or other operational constraints limit the number of passes, a total of four total passes (two starboard and two port) can be used but only comply with lower precision standards. If any potential issues were noted during the experiment that could interfere with the noise measurements (e.g., the passing of another vessel), consider performing a total of eight to ten vessel passes. In post-processing the additional passes can be easily discarded. This approach maximizes the likelihood of obtaining high-quality measurements.

(h) If any transects passed either too close (d_{cpa} < 75 m [0.04 nmi]) or too far (d_{cpa} > 150 m [0.08 nmi]) from the FSVPAD, execute additional passes after the first six have been completed. Make note of these outliers for post-processing.

(i) After the final pass, transit out to a range of 2 km (1.08 nmi) and reduce the shaft speed to 0 RPMs. Allow the vessel to drift for 2 minutes.

(j) Recover the drifter as described in section I.I.V.

I.III.IV Deployment and Recovery Procedures

This section describes the methods that have previously been used to deploy and recover the FSVPAD from a NOAA FSV. These methods are recommended for future operations but an agreement on procedures should be reached with the vessel's commanding officer, chief boatswain, and other critical crew members. Deployment on other vessels should follow similar procedures but should be changed to reflect the availability of equipment. For example, on a smaller vessel with relatively little freeboard and a low gunwale, the FSVPAD can easily be deployed and recovered by hand.

I.III.V Deployment Procedures

Prior to setting up for deployment, construct the FSVPAD and confirm that the system is operating as expected (refer to Sections III-V). A minimum of three people, in addition to any individuals controlling the A-frame and winch, are required for the deployment. To prevent fouling the lines in the propeller, consider deploying the FSVPAD while the vessel is drifting. Throughout the following instructions care should be taken to ensure that lines do not get tangled around the FSVPAD's antenna, housing, or light. If any fouling of the lines occurs, carefully recover the system, untangle the lines, and re-deploy it.

(a) If operating on a NOAA FSV the equipment can be easily deployed from the hero deck on the starboard side of the vessel using the side-sampling A-frame.

(b) Prepare the hydrophones and lines. The deepest hydrophone will be deployed first. Carefully stage the lines and hydrophones, either on deck or in small crates, with the deepest hydrophone on the top to help with line management.

(c) Rig a line from the winch through a fairlead on the side-sampling A-frame and attach it on to the ring closest to the spar on the trailing float. The connection should be made using a mechanical release (e.g., a Sea Catch TR10). This will be used to lift and release the FSVPAD.

(d) Station at least two individuals on the hero deck. One will support the lifting and control of the spar and the other will pay out the lines, hydrophones, and heave plate.

(e) Set the line leading to the trailing float aside on the deck away from the line to the hydrophones. It will be the last object to leave the deck to allow for rapid recovery in case of a problem.

(f) Using the line led through the A-frame and attached to the oceanographic winch (section c above), lift the spar until it is standing roughly upright, but the bottom of the spar is still resting on the deck. One individual holds the spar standing upright on the deck.

(g) The other individual begins paying out the hydrophones and lines beginning with the weight below the deepest hydrophone. Once all three hydrophones are in the water, lift the spar over the starboard rails and use the A-frame to lower the drifter. As the spar is being lifted away from the vessel the lines leading to the hydrophones/heave plate should be continuously paid out. At this point confirm that the line to the trailing float is not wrapped around the spar, antenna, or any other part of the FSVPAD assembly.

(h) Hold the deployment of the spar once the bottom 6-12" is submerged. Continue to pay out the heave plate and hydrophones. When only a small amount of slack remains in the line to the hydrophones it can be released (a "soft release" using an extended boat hook is preferred). The weight of the hydrophones and drag from the heave plate will cause the lines to slowly become taut below the spar. Wait approximately 20 seconds after releasing the lines before lowering the spar into the water.

(i) Confirm that as the spar was lowered into the water the antenna was lifted from its pre-deployment height to approximately 1.5 m (5 ft) above the surface. If not, recover the instrument and verify that the antenna assembly is correctly installed and not binding prior to redeploying.

(j) Trigger the mechanical release to the FSVPAD.

(k) If the spar is floating upright then the trailing float/line can be deployed. The float should be released in the water such that it does not wrap around the drifter. If there are any problems the trailing float/line can be used to recover the system.

(l) Transit to the location where vessel noise tests will begin following the procedure in Section I.III.

I.III.VI Recovery Procedures

In preparation for the recovery the crew should prepare a grappling hook/line and two mooring hooks. Mooring hooks instead of standard boat hooks are preferred, but not necessary. Enough slack should be prepared in the winch line that is led through the side A-frame block before making it off to a cleat on the starboard rail. This line will be used to recover the spar using the winch and side A-frame. An additional line (referred to as the recovery line) at least 10 m long and ideally equipped with a mooring hook should also be prepared for use on the quarterdeck. A minimum of three people (crew or scientific staff), in addition to those managing the A-frame and winch, are recommended.

(a) The vessel should slowly approach the FSVPAD with it located on the starboard side of the vessel. Crew members should standby with a boat hook and grappling hook.

(b) As the vessel approaches the drifter, use the hooks to retrieve the trailing float line.

(c) Slowly pull the drifter towards the vessel using the trailing float line. Pull the drifter as high as is needed to either hook or make off the recovery line to one of the stainless-steel rings on the trailing float. The ring furthest from the spar makes the recovery easier but will allow the FSVPAD to swing more once it is removed from the water. In rough conditions the ring closer to the spar is recommended, but this requires lifting the FSVPAD further out of the water to make off the winch/recovery line.

(d) Once secured to the recovery line, release the FSVPAD, haul in the line and transfer the load from the recovery line to the winch line by placing another shackle on the ring before removing the recovery line.

(e) Use the winch to lift the FSVPAD out of the water, adjusting the A-frame as needed. Once the spar is out of the water use a boat hook to retrieve the lines below the base of the buoy. Manually retrieve the lines, heave plate, and hydrophones.

(f) After all components have been removed from the water, proceed with the recovery by adjusting the A-frame in and coming up on the winch as needed. In rough conditions it may be helpful to pass a tag line through one of the U-bolts low on the spar. The FSVPAD can be laid flat on the quarterdeck and at any point during the recovery process if needed.

(g) Once on board the FSVPAD should be laid flat on the deck with the trailing float. Recover the downline and the line and the hydrophones by hand.

(h) Detach the line to the heave plate/hydrophones from the bridle at the base of the spar. Pass the lines around the A-frame and stack the lines away from any equipment.

(i) Rinse all components with fresh water.

(j) Power down FSVPAD electronics (Section IV)

(k) Deconstruct the FSVPAD, coil lines, and set the equipment aside to dry.

(l) The physical recovery of the instrument is complete. Follow the data recovery and processing procedures (Sections IV and V).

II System Description

The FSVPAD includes a ship-based data logging and real-time visualization program in addition to the drifting platform. These combined components allow for redundancy in acquiring the GPS coordinates of the drifter while providing the ship's crew with real-time drifter locations if wind or currents cause the FSVPAD to drift considerably from the deployment location. The following sections provide information about each component of the system and how to assemble the system prior to deployment. To facilitate the assembly, Section III.I includes an itemized list of the system's components and a pre-deployment checklist with concise descriptions of the assembly process. In addition, the following sections include drawings or pictures of each of the components.

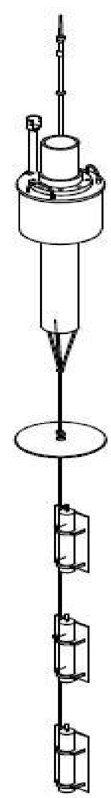


Figure 2. -- A drawing of the FSVPAD assembled for deployment (lines not to scale). The spar buoy contains batteries, a GPS, and communications electronics. A heave plate and the three hydrophones mounted on strongbacks are suspended below the drifter.

II.I FSVPAD Drifter

The FSVPAD drifter, which measures vessel-generated radiated noise with three hydrophones, is the largest component in the system (Fig. 2). A spar buoy, constructed from PVC and foam components that also include the electronics housing, allows the system to passively drift at the surface. Lines coupled to a heave plate (to dampen the motion of the lines relative to the spar) and three hydrophones mounted on strongbacks constitute the remainder of the package. A drawing of this system (individual components drawn to scale) is shown in Figure 3. To facilitate the shipment of the equipment, the system can be broken into individual components, the longest of which is 46” long. The following subsections describe the construction of each of components of the spar and Figure 3 shows multiple views of the spar, including labels, to help clarify the physical descriptions of the components.

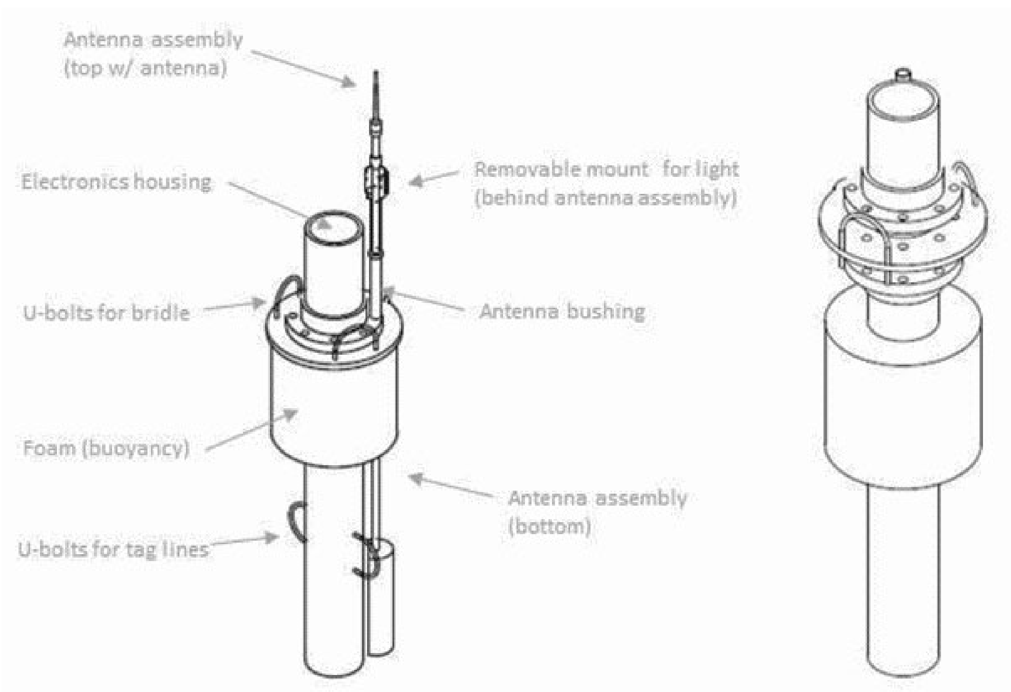


Figure 3: -- (Left) A diagram of the spar buoy with the critical parts labeled. Components of the system that are not included here are the cap for the electronics housing and the bridles. (Right) An exploded view of the spar buoy assembly including the upper and lower portions of the spar, the mounting plate, and the foam (without nuts, bolts, etc.). The light fixture and antenna assembly are not depicted.

II.I.I Spar Buoy

Assembling the Spar Buoy: The spar buoy portion of the FSVPAD system is shipped as eight separate components: the lower spar, upper spar, base plate, electronics housing and cap with attached antenna assembly, antenna lifter, light mount, trailing float assembly, and bridles. These components must all be assembled and attached to the lower portions of the FSVPAD prior to deployment. The construction and assembly of these components are described below.

Lower spar section: The spar buoy is constructed from a 5' section of 6" schedule 80 PVC pipe cut into two sections. The lower section, which provides buoyancy for the system and connects to the lines, strongbacks, and hydrophones, is 46" long. To facilitate deployment and recovery of the spar using tag lines, two 3⁄8"-16 thread, 4-1⁄2" ID stainless steel U-bolts are mounted through the lower spar. These can be used to control the spar during deployment and recovery operations. While placement of the U-bolts on opposite sides of the pipe facilitates deployment and recovery, there is no need to precisely position them. After mounting the U-bolts the area around the bolts/holes is sealed with PVC cement and epoxy to prevent water intrusion. The current design has the bottom of the U-bolts located 20-1⁄2" above the base of the lower PVC section. Twelve inches from the base of this lower spar section a 1⁄4" sheet of PVC, machined to match the inner diameter of the pipe, is mounted within the pipe to seal it. Two-part liquid polyurethane foam (e.g., FiberGlass Coatings, Inc., 2 lb/ft^3 density) is used to fill the lower section of the spar. A second 1⁄4" (or thinner) PVC sheet, mounted with PVC cement, is then used to seal the section at the upper end.

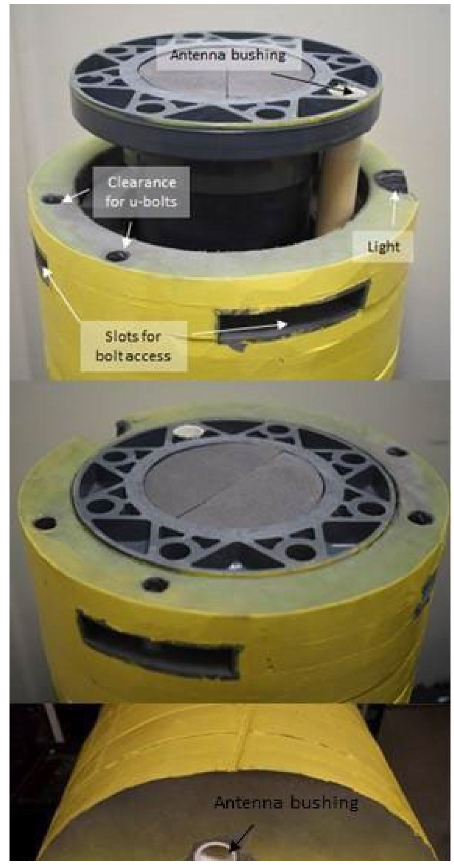


Figure 4. -- The Y20 foam with the lower spar. Alignment of the holes and slots is critical to assembly. It is easiest to add the holes and slots after preparing the other parts of the assembly.

To guide the antenna assembly (described below), a 14" long, 3⁄4" inner diameter PVC pipe is mounted to the pipe flange (Fig. 4). A 1" drill bit is used to increase the size of one of the eight holes in the pipe flange to support the antenna bushing. The bottom 1" of the 3⁄4" PVC pipe is then sanded before a combination of PVC cement and press fitting are used to connect the pipe to the flange. Care must be taken to ensure that the pipe is oriented vertically so that the buoyancy-driven antenna assembly can easily pass through the pipe without binding. PVC cement is used to mount the lower section of the spar to a 6" schedule 80 PVC flange. Note that prior to installing the flange, the outer rings of closed cell polyurethane foam should be machined, constructed, and installed as described below.

Closed cell, Y20, 1" thick polyurethane foam sheets (density of 2 lb/ft^3) cut into annuli provide additional buoyancy for the system. The added flotation here was constructed by cutting 12 annuli with outer diameters of 14" and inner diameters of 6-3⁄4". These twelve annuli fit snugly around the 6" schedule 80 pipe. Two additional annuli with outer diameters of 14" and inner diameters of 7.5" are cut to fit around the pipe flange. Slots should be cut into portions of the upper 2" of the foam assembly to allow access to the pipe flange bolts. Below the 14" diameter annuli additional six 10" diameter annuli, cut in half to surround only half of the spar, are placed to provide additional buoyancy, and counteract the buoyancy of the antenna assembly (see below).

A 1” schedule 40 PVC pipe runs from the base of the pipe flange through to the base of the flotation. These sections of Y20 are removed using a 1-⅜” hole saw. Additional material is removed from the upper sections to facilitate the mounting of the light and the lower sections of the U-bolts from the mounting plate, which are removed using either a mill or hole saws and drill bits during the final assembly. Pictures of the lower portion of the spar and the foam assembly, with labels, are included in Figure 4. Once all of the sections have been cut, the individual sheets are constructed into a single component using contact cement. To facilitate the process a segment of PVC pipe and a pipe flange can be used to properly align the holes in the annuli while the contact cement dries.

One inch from the base of the spar three holes (clearance for ⅝” shackles) separated at 120° angles are the anchor points for a three-point bridle. Once properly placed with shackles installed, additional holes for mounting lead ballast are drilled near the base of the lower spar. The total weight of the lead ballast is 6.8 kg. Four lead blocks (two 2.7 kg and 0.7 kg) were symmetrically mounted to the interior wall of the bottom of the lower spar section using ¼”-20 stainless steel bolt assemblies. The lead blocks used were locally available and do not reflect any specific design decisions. For proper buoyancy similar amounts of lead ballast should be used although the form factor is not critical. If different amounts of lead ballast are used the spar should be tested prior to a full radiated noise test to confirm that the spar remains upright when deployed.

Upper spar section: The shorter portion of the PVC pipe is used to construct the electronics housing. This section is 12” long and is sealed using a Delrin cap. The end cap forms the piston seal with the PVC pipe using two #253 (70A hardness) rubber O-rings. A CNC mill was used to machine the top 1” of the PVC pipe section to have an inner diameter of 5-⅝” to correspond to the tolerances necessary to get a good seal from the O-rings. The upper face of the short PVC section is also flattened and smoothed with a mill. This PVC pipe is also mounted within a 6” schedule PVC pipe flange that has been sealed internally at the base using a thin PVC plate. All PVC sections were connected and sealed using PVC cement.

As with the pipe flange on the lower section of the spar, the upper pipe flange also includes a bushing to guide the antenna lifter assembly. This section is constructed with a 10” long, ¾” PVC pipe mounted through one of the holes as with the lower pipe flange. Construction details are described in the section devoted to the lower section of the spar. A picture of the upper spar section including electronics housing, pipe flange, and antenna bushing is included in Figure 5. The upper spar is equipped with SOLAS reflective tape to increase visibility above the waterline.

Base plate: The upper and lower portions of the spar are connected through a base plate machined from a ¾” PVC sheet (Fig. 6). This plate is 15-½” diameter with a single, small bulge. Numerous holes in the plate are used for attaching the upper and lower sections of the spar, mounting U-bolts, and securing structural supports for a light fixture and the antenna. The size and spacing of these holes is driven by the bolt pattern of the PVC flanges, deployment and recovery procedures, and the location of sensitive components (e.g., the antenna and light). An additional 6” diameter section is removed from the center of the plate to reduce the weight of the plate. The outer edge of the base plate is equipped with SOLAS reflective tape.

Figure 5. -- The upper spar, which includes the electronics housing, pipe flange, and antenna bushing.

Two U-bolts are mounted to the base of the plate and are used, in conjunction with a two-point bridle and trailing line/float (both described below), to lift the FSVPAD during deployment and recovery. The placement of these bolts is asymmetric so that when the FSVPAD is lifted the light, antenna, and shorting plug tilt away from the line to prevent accidental fouling of these sensitive components.

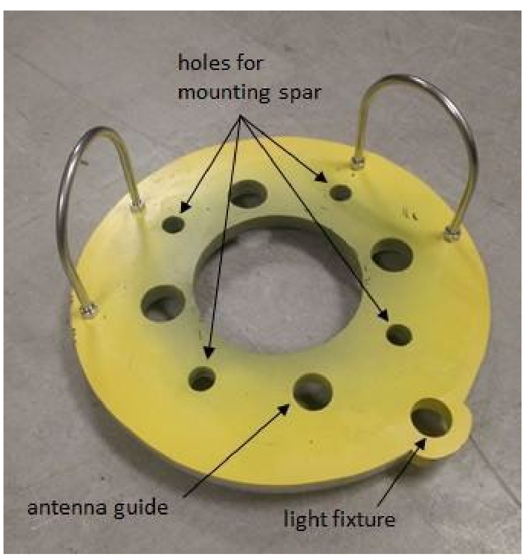


Figure 6. -- A picture of the base plate.

Antenna assembly: To communicate with the vessel at moderate ranges (i.e., > 1 km), the antenna is elevated to avoid interference patterns related to the height above the sea surface. Greater distances between the antenna and the sea surface will result in a larger effective communications range. On the other hand, a fixed antenna with the two U-bolts well above the waterline would result in a longer spar, thereby requiring more complicated deployment and recovery procedures. This problem is overcome using a buoyancy-driven system that lifts the antenna to approximately 5’ above the surface while in the water. While in air, the antenna “drops” downward so that the total height of the spar assembly is approximately 83” tall. This entire assembly, shown in Figure 7, is modular to facilitate the shipping of the entire system.

The antenna lifter assembly is constructed around a 68” long ½” diameter schedule 40 PVC pipe. The bottom of the pipe is sealed using a thin sheet of PVC (1” diameter) and then filled with 2-part liquid polyurethane foam for buoyancy. After filling the pipe with foam, the other end is also sealed with a thin PVC sheet no larger than the diameter of the pipe. Additional buoyancy for the system is provided by Y20 sections machined from scraps removed from the inside of the annuli used for the lower portion of the spar. The Y20 foam sections, with holes that allow it to fit snugly around the ½” PVC pipe, are connected into a single part using contact cement. This foam assembly is placed around the pipe, flush with the PVC cap used to seal the pipe (Fig. 7c). When placed in the water, this foam provides enough buoyancy to lift the full antenna assembly. The upper position is reached when the foam from the radio assembly comes in contact with the large foam annulus installed on the lower portion of the spar.

The upper portion of the antenna assembly is equipped with a “stopper” machined from ¾” thick PVC sheet from the mounting plate (Fig. 7b). This stopper is 1.5” diameter with a 1.1” diameter section removed from the middle so that it can be easily installed on the ½” PVC pipe. The two opposite sides are ground to have flat surfaces and a through hole for a 2”, 6-32 stainless steel bolt assembly is drilled through the stopper at the pipe. The stopper is installed 55” from the base of pipe. When installing the antenna assembly on the spar the stopper is removed and the pipe is slid up through the clearance hole in the foam annulus from the base of the spar. If the upper portion of the spar is attached, it also passes through the antenna bushing (Fig. 5). Installing the stopper will result in the antenna assembly resting on the upper spar bushing.

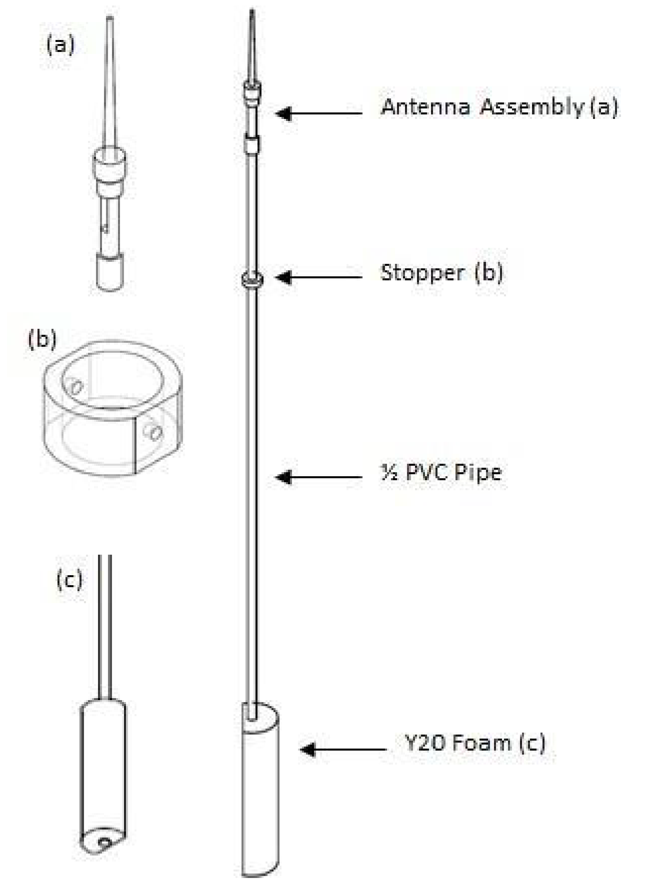


Figure 7. -- Drawings of the full buoyancy driven antenna assembly and individual components. For shipping this assembly can be removed. The upper portion of the antenna assembly (a) is removed and shipped with the electronics package.

The final component of the antenna assembly (Fig. 7a) serves as a coupling between the ¾” PVC pipe that forms the antenna lifter and the antenna assembly. This consists of a ½”-½” PVC pipe coupling; an additional 4.5” section of ½” PVC pipe with a 3” long, ¼” wide (or larger) slot for passing the antenna cable; and a ½”-¾” PVC pipe adapter. Through holes for a 2” long, 6-32 bolt assembly are drilled in the bottom of the ½”-½” coupling, which is permanently attached to the lower portion of the 4.5” section using PVC cement. A bulkhead SMA connector (joining the antenna cable to the antenna) is mounted to a 0.75” diameter thin PVC sheet, which is joined with the bottom of the larger portion of the adapter using PVC cement. The 900 MHz, half-wavelength, 2 dBi antenna is inexpensive and easily procured from numerous manufacturers. After the full system is confirmed to be working this upper section is potted with epoxy to waterproof the connection. The antenna cable is then attached to the bottom of the connector and passed through the slot in the PVC section before using PVC cement to join these final portions of the assembly. For deployment, this section, which is shipped with the electronics housing, is attached to the top of the long ½” antenna lifter assembly pipe using 6-32 stainless steel hardware.

Light assembly: For deployments during which the system may be used at night the FSVPAD can be equipped with a photoelectric cell activated Hi-liner Sea Light omni-directional waterproof strobe. Once powered on, the light blinks every 1.5 seconds if, and only if, the photoelectric cell registers low levels of light. The strobe has an endurance of 20 days using one D cell battery.

To elevate the light above the electronics housing a fixture was constructed using PVC components (Fig. 8). The total height of the light fixture, which elevates the light approximately 18” above the base plate, is 19”.

Two stoppers at the base allow the fixture to be installed when needed, or removed for daytime operations. A 16” long, 1” schedule 40 PVC pipe forms the core of the base structure. With the exception of the stopper at the base of the pipe, that allows the light fixture to be removed from the base plate, the components are combined using PVC cement. An 8-32 stainless steel bolt assembly passing through the bottom stopper and 1” pipe is used to secure the light fixture to the base plate. To secure the light two sets of cable ties are passed through the small flanges on the light and the two sets of holes near the top of the fixture.

Figure 8. -- (Left) A picture of the surface expression of the spar with the light fixture highlighted by the box. (Right) A drawing of the light fixture.

Trailing float and recovery line: To facilitate deployment and recovery of the FSVPAD, an 18’ line (½” Samson monofilament polypropylene) and trailing float are attached using a bowline knot and shackle to the two-point bridle on the spar base plate (Fig. 9). The float, a Polyform A-2 buoy (approximately 68 lbs of buoyancy), is secured at the opposite end of the line from the bridle. The line is equipped with two ⅜” x 3-¼” diameter stainless steel rings located approximately 12” and 48” from the two-point bridle. To maintain the line and stainless-steel rings at or near the surface while drifting the line is equipped with seine floats, held in position by overhand knots.

The recovery line connects to the U-bolts on the base plate via a two-point bridle. Each section of the bridle is 12” long and constructed from 5⁄16” 3-strand nylon. The ends of the lines are secured with stainless steel thimbles. Both ends of the bridle are attached to one of the U-bolts on the base plate with a stainless-steel shackle.

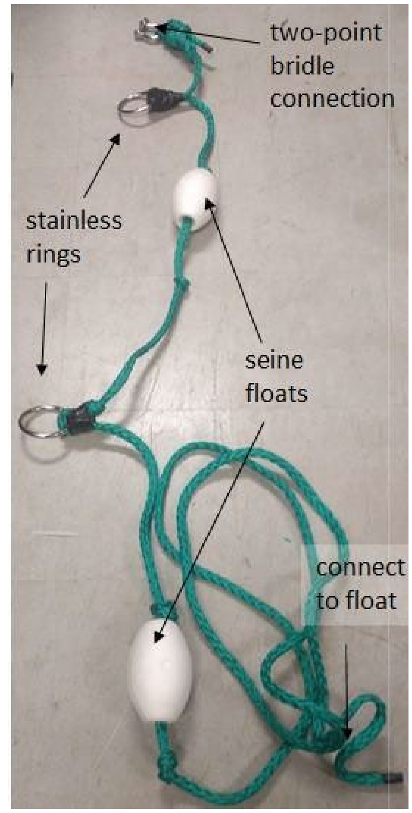


Figure 9. -- A labeled picture of the assembled trailing float line.

Heave Plate: To provide damping, thereby reducing self-noise in hydrophone measurements, a heave plate is located in-line between the spar and the hydrophones (Fig. 2). A shock cord leads to the lower spar section and the shortest of the three static lines leads to the upper shallow strongback/hydrophone assembly (see below). The 16” diameter heave plate was machined from a 1⁄4” Delrin sheet. Eight 1” holes were cut into the heave plate using a hole saw to reduce drag. The load from the spar to the lines is decoupled from the heave plate by using 1⁄2”-13, 316 stainless steel eye-bolts separated from the heave plate using two 1-1⁄2” x 1-1⁄2” x 3⁄4” standoffs machines from scrap Delrin. Figure 10 shows two views of the heave plate assembly.

Strongbacks: Each hydrophone is mounted on a strongback (Fig. 11) that is attached to the lines with shackles. The rectangular strongbacks are made from a thin Delrin sheet reinforced with thin stainless-steel sheets. These metal sheets are included primarily to increase the weight of the assembly in water, but they also provide additional structural integrity to the strongback in the event of an unanticipated load. Two 1⁄4”-20 stainless steel bolt assemblies mount these pieces together. Four holes in the Delrin sheet are used to mount the two clamps machined from 3⁄4” thick Delrin sheets. A back-up line is tied through the clearance hole at the base of the hydrophone and is attached to the hole equipped with a small shackle at the base of the strongback.

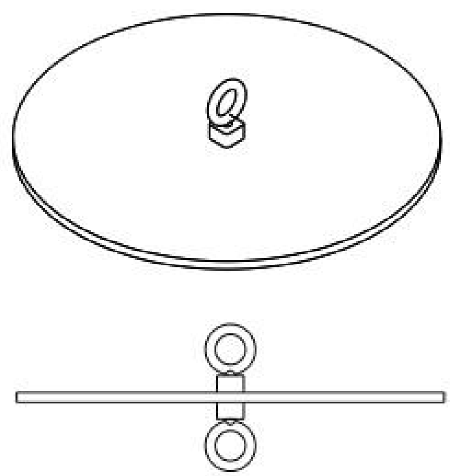


Figure 10. -- Drawing of the heave plate.

Hydrophone lines and three-point bridle: A three-point bridle is used to secure the lower portion (Fig. 4) of the spar to the lines leading to the heave plate and hydrophones (Fig. 12). Each section of the bridle is 12” in length, constructed of 5⁄16” three-strand nylon line, and includes stainless steel thimbles. On the spar side of the bridle the lines are connected directly to the spar using shackles. A single shackle connects the three points of the bridle to the lines leading to the heave plate. This section of line consists of two parallel sections: a three-meter 1⁄2” shock cord and a four-meter 5⁄16”, 3-strand nylon line.

Each end of the shock cord is fitted with stainless steel thimbles. Nylon thimbles are used for splices on the nylon line. The mounting points for both lines are the three-point bridle and heave plate. Extra length is provided in the static line so that it remains slack unless the shock cord fails. The nylon line, therefore, should be taped off, using electrical tape, at 1-2 ft intervals with equal amounts of slack between each section (Fig. 13).

Below the heave plate there are three additional sections of static line that are attached to the hydrophone strongbacks. The lines vary in length in order to satisfy the measurement standards, which dictate that for a closest point of approach the hydrophone should be at 26.8 m, 57.7 m, and 100 m. Both ends of lines are equipped with thimble splices using nylon thimbles. Each section of line is labeled at the thimble using colored electrical tape as an indicator of its length. Yellow tape denotes the 22.3 m line, blue tape the 27.4 m line, and white tape the 38.8 m line. The lines are to be installed such that the yellow line leads from the heave plate to the shallow hydrophone, blue leads from the shallow hydrophone to the middle hydrophone, and white leads from the middle to deep hydrophone. A five-pound lead weight should be suspended from the deep hydrophone's strongback.

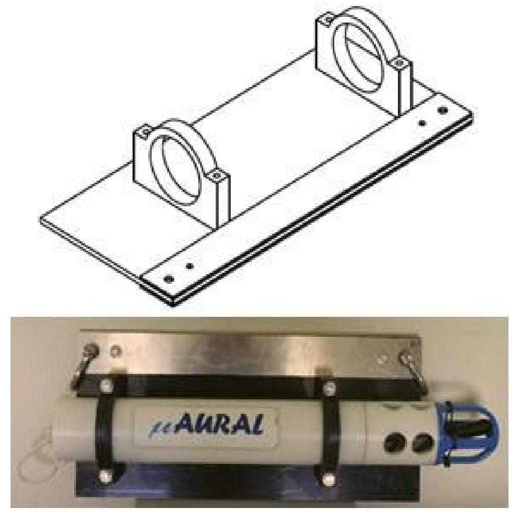


Figure 11. -- (Top) A drawing of the strongback assembly without hardware or a hydrophone. (Bottom) A strongback equipped with a hydrophone. When deployed the strongback should be oriented with the hydrophone towards the surface.

Figure 12. -- Three-point bridle assembly.

Figure 13. -- The shock cord/static line.

II.I.II Electronics Package Assembly

The electronics package for the drifter is housed in the upper section of the spar buoy. The electronics package includes batteries, a microcontroller, a radio, a GPS unit, and other circuitry. Detailed information about the electronics is included in Section III and Appendices. A. These components are mounted to 3D printed ABS sections designed to slide into the housing but fit snugly to prevent the components from rattling when the spar moves. FreeCAD, an open-source drafting program, was used to design these sections. Drawings were exported as .stl files, sliced using Simplify3D software, and printed using a LulzBot TAZ 6 3D printer. Except for the 12V battery, all of the electronics are housed in the upper portion of the housing.

The full electronics assembly, excluding the electronics, includes the 3D printed structures that are held together and mounted to a machined Delrin housing cap using four 10⅞” long, 6-32 threaded rods. These threaded rods pass through the holes in the 3D printed objects. Plastic standoffs (¼” and 1” long with clearance for 6-32 screws) and a Delrin disc are used to hold the assembly together and provide clearance within the housing for the GPS unit. Drawings, including three views of the structure supporting the electronics package, and labels, are included in Figure 14 and a picture of the full assembly with the electronics is included in Section III.VI.

When building the spar in preparation for deployment the electronics package is inserted into the upper portion of the spar assembly (Fig. 5) and pushed down until the bottom of the housing cap is flush with the end of top of PVC pipe. At this point the O-rings should be well within the housing, thereby sealing the electronics package and protecting it in case of submergence. If the assembly does not slide relatively easily into the housing it is most likely out of alignment and pinching an O-ring. Confirm this is not a problem by visual inspection of the cap.

Upon recovery the housing structure must be removed from the upper spar to download data and ship the electronics. It is removed by locating the two threaded holes in the top of the housing cap (Fig. 14a) and inserting a 1” 8-32 screw into each hole. By alternating between by turning the screws (inserting them further into the holes) the cap is gradually lifted. Once the seal of the first O-ring is broken, the package can be removed by carefully pulling on the cap.

Electronics Package: All the drifter electronics are housed in the upper portion of the spar as described in Section II.I.I, which provides a physical description of the housing. This section provides specific information about the components contained within or connected to the housing. Additional details are available in Appendix A. The electronics package includes a 12V battery, six AA batteries, an Arduino Uno microcontroller, a Freewave FGR2-P (board level) radio, an antenna, terminal strips, a Garmin 19X HVS GPS unit, and all necessary wiring. By default, the Garmin GPS units have a 10 Hz sampling rate. For these purposes, the sampling rate is reduced on units to 1 Hz using hardwired 2kΩ resistors wired as described in the unit’s user manual. The ship-based GPS unit is the same model and is also wired to reduce the sampling rate. In this configuration, the proper baud rate for sampling the output NMEA strings is 4800.

The micro-controller receives raw, unprocessed GPS strings (NMEA 0183) and writes them directly to ASCII log files on the SD card. The GPS filenames written follow the format

DGPSXXX.txt, where XXX is an integer from 000 to 999. When power is provided to the Arduino the program seeks the lowest integer value for which a log file does not already exist. It then creates and writes to a file with that name. Each time the unit loses power or is intentionally reset the Arduino will open a new file.

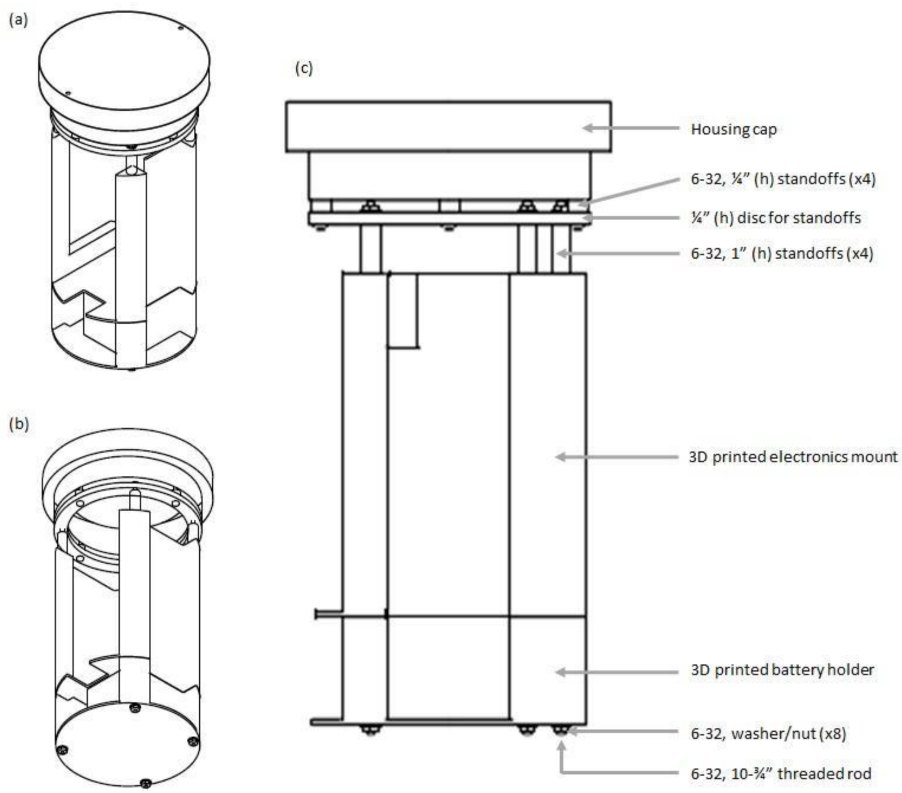


Figure 14. -- Drawings of the electronics assembly housed in the upper section of the spar (the bulkhead connector and cable gland in the cap and the O-rings are not included). (a) A projection from above. (b) A projection from below. (c) A labeled elevation view of the assembly.

The electronics, except for the microcontroller, are power cycled using a shorting plug equipped with a bi-color (red and green) LED. The housing cap is equipped with an 8-pin male SubConn MCIL bulkhead connector that mates with a female 8-pin SubConn MCIL connector. To provide power to the system the dummy plug is removed and replaced with the shorting plug (Fig. 15). Within the shorting plug, two pins, corresponding to the red and black leads, are wired together and are used to close the circuit thereby providing power to the GPS unit and Freewave radio. The LED is connected to pins on the microcontroller to provide real-time feedback using different blinking patterns. A circuit diagram for the shorting plug is included in Appendix A.

Figure 15. -- The FSVPAD shorting plug.

In addition to an 8-pin bulkhead connector for power cycling the electronics, the housing end cap is equipped with a 3⁄8” NPT stainless steel cable gland. The radio antenna cable, which terminates with a male SMA connector and 90° female to male adapter at the Freewave radio, passes through the cable gland but can be removed. Due to the rotational symmetry of the housing endcap, the precise locations of the cable gland and bulkhead connector are not critical so long as they do not interfere with the interior of the cap that supports the O-rings.

The Delrin end cap equipped with the cable gland and bulkhead connector are mounted to the assembly using standoffs with 6-32 stainless steel machine screws, a thin UHMW annulus and 8-32 galvanized steel threaded rods that pass through the 3D printed electronics chassis (Fig. 14).

The bolt pattern for the 8-32 stand-offs is determined by the geometry of the 3D printed chassis whereas the 6-32 threads are placed in the Delrin endcap with 90° rotational symmetry.

II.II Hydrophones

Noise measurements are made using three Multi-Electronique *μ*AURAL autonomous hydrophone packages, hereafter referred to as *μ*AURALs. These compact systems are 18” long, have a 3” diameter, and weigh 6 lb in air and 2 lb in water. Each *μ*AURAL consists of an HTI-96-MIN hydrophone with a 3-pin MCIL SubConn connector and a pressure housing containing a rechargeable NiMH battery pack, signal conditioning board, and data acquisition electronics. These programmable units can log data on a schedule or continuously with sampling rates from 8 to 96 kHz. Analog signals from the hydrophone are amplified by 9 dB, 12 dB, 15 dB, or 18 dB depending on the jumper settings on the board. The hydrophones are pre-set for 18 dB gain, which is an appropriate setting for a routine deployment of the system. Maximum signals of ±5V are written as .wav files to an SD card. The bit-depth of the recorded signals varies depending on the sampling rate with 24-bit signals recorded for all sampling rates except 96 kHz, for which 16-bit signals are recorded. Each system is independently programmed by opening the pressure housing and connecting a USB to micro-USB cable from a Laptop computer to the unit. Data are downloaded from the unit via USB from a PC using vendor-provided software. A magnet (provided with the units) is used to power the systems after the units have been programmed and the pressure housings are sealed. LEDs visible within the pressure housings provide confirmation that the systems are operational.

II.III Ship-Based Components

The acquisition software is built using Python 2.7 with a PyQT4-based graphical user interface. The software requires a connection to a ship-based GPS unit for monitoring and data acquisition. A Garmin 19X HVS with the 2 kΩ resistor installed (this limits data rate to 1 Hz) is provided with the other vessel-based equipment. A 10 m cable connects the GPS unit to the laptop computer. A serial connector has been added to the end of the cable and a short serial to USB cable allows the GPS unit to be plugged into the laptop for monitoring and data acquisition. An AC-DC adapter has been spliced on the end of the GPS cable so that the GPS can be powered from a standard 120 VAC receptacle.

The remaining components of the ship-based system support the radio communications with the FSVPAD. The receive radio is a Freewave FGR-PE-U unit. Radio communications with the FSVPAD require an antenna and cable leading from the antenna installation location outside of the vessel to the data acquisition system on the bridge. The antenna is an 8” tall, 900 MHz, half wavelength antenna with an SMA connector. A 50-foot LMR-400 coaxial cable with an N type connector runs from the Freewave radio to the antenna. Other suitable, higher gain antenna options and shorter cables exist, but are not necessary, due to the limited required communications ranges and the operational constraints imposed by having an antenna located near the sea surface. Depending on the configuration various SMA, N-type, and UHF connectors may be required to connect the antenna, cable, and radio. Communications between the Freewave radio and the laptop require an RJ-45 (ethernet) to serial cable that ships with the Freewave unit and a serial to USB cable for connecting to the laptop. The Freewave unit comes with a power cord for 120 VAC power.

A photograph of the ship-based components is included in Section III.V, where configuration details for the system are described.

II.IV Visualization and Data Acquisition Software

During radiated noise tests, radio transmissions from a Freewave radio carrying GPS coordinates from the GPS unit on the FSVPAD are received by the antenna and Freewave radio on the vessel. A Python script running on the laptop computer receives and processes both sets of GPS strings. Relevant GPS strings from both units are written as text files for post-processing. At the same time, a GUI presents the range and bearing to the FSVPAD from the vessel in addition to regularly updating speed-over-ground and coordinates. Finally, the interface provides a window warning the user if the coordinates are synchronized to within a few seconds. When GPS signals from the FSVPAD are lost, the distances presented by the interface are based on the last received coordinates of the FSVPAD and the current vessel location. When new GPS signals from the vessel are received the interface automatically updates and no longer indicates asynchronous timestamps. GPS signals from the FSVPAD are occasionally lost when the direct path for communication between the antennas is lost because the line-of-sight is lost (e.g., when the vessel is executing turns) or if the distance between the antennas is too great. Details about starting the data acquisition and visualization software are included in the deployment instructions (Section III).

II.V Post-Processing and Data Analysis Software

All post-processing of the data is performed using custom MATLAB scripts (see Section II.VII for details). Following a deployment of the system the user must place the required data sets into the proper directory structure. Data post-processing is made manageable for users with limited MATLAB experience by breaking the analysis into small tasks (see Section V for step-by-step instructions). When performing each processing step, the user's primary interactions are with well-documented graphical user interfaces that walk users through the necessary inputs. Most of the processing occurs using scripts with which the user does not interact, but that provide the user with status updates. Final products take the form of .mat files for data storage, figures (.png) and a .csv file summarizing the results, which are directly compared to the ICES recommendations for noise quieted research vessels (Mitson 1995).

II.VI Packing and Shipping

The FSVPAD and ship-based components were designed so that, if needed, they can be shipped on a single pallet or within a pallet-size tote. When constructed, the length of the FSVPAD exceeds this size and must be broken down for shipment in this form. The larger components of the FSVPAD, including the spar sections, base plate, and heave plate are best shipped loose because they do not fit well in cases. For this reason, a tote is preferable. The other components, once broken down, can be readily placed in cases for shipment. When packing, care should be taken to protect sensitive components (e.g., electronics, antennas). Recommended disassembly and packing procedures are included in Section IV.IV.

II.VII Additional Information

Addition information related to the design, fabrication, and assembly of various components described in this section is included on the project page (https://github.com/noaa-afsc-mace/FSVPAD-hydrophones) under Technical Documentation.

III Preparing for Deployment

The process of preparing and deploying the instrumentation takes at least three hours for an experienced user. The following sections provide equipment checklists for the ship-based components and FSVPAD, and detailed deployment instructions. A full lab test, minus the releasing of the FSVPAD into the water, is recommended prior to any deployment to familiarize oneself with the procedures. This process will also allow users to identify steps that can be performed well in advance of deployment as opposed to those that cannot.

Prior to constructing and deploying the system, the hydrophone batteries and electronics battery pack should be charged, and the checklists should be used to gather all the equipment. Section II can be referenced to help identify the system components identified in the checklists. If one of the instruments does not appear to be properly configured, and the following sections still provide an inadequate description, the Appendices include troubleshooting information and instructions for reprogramming the instruments. The following sections are presented based on the recommended order of operations.

III.I Equipment Checklists

Ship-based equipment: The best approach to deploying the entire system is to set up all ship-based components prior to using the FSVPAD.

Laptop computer
Garmin 19X HVS GPS unit with white cable
Antenna cable
Antenna
Freewave radio and power supply
Labeled serial to USB cables (×2)
Power strip
Cable ties and/or hose clamps for antenna and GPS installation

FSVPAD: The following list includes all components of the FSVPAD as they are shipped. Individual components should be verified using the descriptions in Section II. Prior to constructing the FSVPAD the hydrophones should be programmed and calibrated (see Section III).

Lower spar section with foam
Lead ballast (may be installed in lower spar section)
Base plate for connecting spar sections
Upper spar (electronics housing)
End cap with dummy plug and electronics chassis
Shorting plug (packed with ship-based electronics)
Two-point bridle
Three-point bridle
Trailing float
Trailing float line with seine floats and stainless-steel rings
Antenna lifting assembly
Antenna assembly

Light fixture (if applicable)
Light (if applicable)
Shock cord and attached static line
Heave plate assembly
Hydrophone strongback assembly (×3)
Hydrophone lines (×3)
Hydrophones (×3)
Shackles
Cable ties
Spar stainless steel hardware (e.g., ¼-20 bolts)

Tools and Miscellaneous:

Small Phillips head screwdriver
Large flathead screwdriver
7/16” wrenches (×2), one ratchet preferred
1-⅛” wrenches (×2), one ratchet preferred
Small adjustable wrench
Snips
Cable ties (various sizes)
Electrical tape
Steel wire (18 ga. optional)
Twine or other small (< ¼”) line
Multimeter
Kimwipes or similar
O-ring grease (Molykote 55 or similar)

III.II Create a Deck Log

Open Notepad or another text editor and save a file titled YYYYMMDD Notes.txt to the Desktop. Once the experiment has been completed and data are being post-processed this file should be moved to the directory used for the tests results as is explained in Section V. The purpose of this log is to record all information that could be relevant to processing or interpreting the results. As a result, the file should be written such that it could be easily understood by a reader that is unfamiliar with the project and was not present at the time of the tests. The beginning of the deck log file should contain all the important information related to the date, time, location, and other operational information in addition to notes about the hydrophone serial numbers at the depths at which they were deployed. All of the suggested information should be included and the recommended formatting is as follows (some notes placed in square brackets highlight additional information that could be included as clarifying comments):

Radiated Noise Drifter Test:
Date: 14 July 2023

Deployment Time (UTC): 17:14

Test location (brief description): Gulf of Alaska shelf break, ~60 nmi south of Kodiak
Anticipated deployment coordinates: 56.20° N, 152.93° W
Approximate Depth: 1300 m

Metocean conditions:
Patchy fog, overcast.
Waves: Small wind waves, approx. 1-2 ft (sea state 1)
Wind: light S winds, ~6 kt
Precipitation: None

[**Note if any changes are anticipated during the test. If they are observed document them as with a time later in the deck log.**]

Hydrophone serial numbers:
- Shallow: 382293
- Midwater: 382295
- Deep: 382299

Drifter aspect [**first pass on port or starboard side?**]:
During the first pass the drifter will be on the starboard side.

GPS Location [**where is the GPS located on the vessel?**]:
Description: Mounted on flying bridge aft rail, 30.5 cm directly aft of amidships benchmark.

GPS position relative to midway between the engine room and propeller:
Alongship position (+ is forward of this point): +7.65 m
Athwartship position (+ is starboard of this point): +0 m
[The positions were computed from the GPS location and the ship's as-built drawings]

Other notes:

For proper post-processing it is critical that the proper hydrophone serial numbers are associated with the drift depths (i.e., shallow, middle, deep). Two other important notes required for post-processing are the GPS location offsets and the aspect of the first pass. Throughout the drift, additional notes should be kept to aid in the interpretation of the data in the event that there are any problems during the deployment. These notes should include comments as the drifter is prepared for deployment and details about the drifts during the measurements. Each comment should include a timestamp (UTC). For example:

Test Notes:

[**Notes should be taken in chronological order. Include dates if measurements were made on over multiple days.**]

14 July, 2023 – FSVPAD assembled and all components tested the previous day in preparation for opportunistic deployment under favorable conditions.

1630 UTC: Hydrophone 382293 turned on, pistonphone measurements started

1637 UTC: Hydrophone 382295 turned on, pistonphone measurements started

1639 UTC: Hydrophone 382299 turned on, pistonphone measurements started

1650 UTC: Electronics all operating. Radio communications confirmed. Laptop logging GPS data.

1700 UTC: On station, prepared for deployment.

1714 UTC: FSVPAD in water. Transiting to 2 km N of drifter. All echosounders off, ship is operating on generators 2, 4. Ship RPM limited to 85-88 RPM by power limitations on generators. These limitations are newly imposed on the power system and Dyson cannot achieve the 93 RPM used in previous ~ 11 knot tests using these generators. Proceeded with maximum available RPM (~87) using generators 2, 4 so that the test results will be most comparable with previous tests.

1750 1973 m away. Passive measurement

1802 UTC: Beginning pass 1 (starboard pass)

1804 UTC: Pass 1 CPA of approximately 98 m, 88 RPM at time of CPA, 9.4 knots over ground

1807 UTC: Finish pass 1, turning for pass 2

Beginning Pass 2 (port pass)*...*

[**Note anything relevant that happens during the tests, including issues that could affect ambient noise. Add notes for every pass and times for recovery and power cycling the instruments post-recovery.**]

Continue taking notes throughout the setup, experiment, and recovery. Do not delete this file at any point. These notes are required for proper post-processing of noise measurements.

III.III Hydrophones and Pistonphone Measurements

The laptop computer provided for data visualization and logging of the ship and FSVPAD GPS data are also used to program and setup the hydrophones. Programming and "calibration" of the hydrophones should therefore be performed prior to setting up any additional equipment. The purpose of processing the pistonphone data is not to calibrate the data, but rather to ensure that the hydrophone is not damaged and that results derived are consistent with the hydrophone's specified sensitivity. Nonetheless, calibration is used to describe this process throughout this document. This section provides procedures to conduct the calibration, see section V.I for data processing instructions.

Our experience is that pistonphone calibrations can be finicky: if pistonphone results differ by > 3 dB from expectations, the pistonphone calibration should be repeated. If results deviate strongly from the expected signal, it is a sign that the hydrophone may be either damaged or in need of calibration. It is recommended that the hydrophones be calibrated with the pistonphone prior to use in the field to 1) familiarize the user with their operation and 2) verify that the hydrophones are working as expected.

To expedite the deployment and calibration of the hydrophones, begin by gathering the following equipment and supplies from the hydrophone case(s):

- three hydrophones
- the magnetic switch (described later in this section)
- a USB cable
- three cable ties
- the laptop computer
- the pistonphone, and the pistonphone adapter;
- a small wire cutter (for cable ties).

Once everything has been gathered, proceed with the hydrophone setup and calibration process. The following instructions detail the steps necessary to properly deploy and calibrate the devices. Additional details are also available in the μAURAL user guide. It is best to deploy/calibrate one hydrophone at a time before proceeding to the next. For reference during the deployment process Figures 16 and 21 highlight features of the electronics, the configuration window, and LED codes that are mentioned during some of the steps.

III.III.I Preparing for Calibration

(a) Take the pistonphone (Fig. 16) out of its case, remove the standard coupler, and replace it with the hydrophone coupler. Of the two available couplers the one for the hydrophone is larger and has a wider diameter.

(b) Unscrew and remove the back cover of the pistonphone using a flathead screwdriver or coin and insert the AA batteries. Close and secure the cover.

(c) Confirm that the coupler is operating by turning it on. The LED is green if operating properly. If the light is red, there is a problem. The most likely solution is that the batteries need to be replaced. If the batteries are new and the light remains red the pistonphone may be damaged. Proceed but note in the deck log that the pistonphone measurements are questionable.

(d) Proper post-processing will require additional information. Record, in the deck log, the barometric pressure and calibration offset values using the barometer in the pistonphone case.

(e) Set the prepared pistonphone where you will be setting up the hydrophones. It will be used immediately after each hydrophone is powered on.

Figure 16. – Pistonphone.

III.III.II Hydrophone Setup and Calibration

(a) Confirm that the hydrophone is powered off (no LEDs blinking near the start/stop switch labeled **S** near the base of the cap, Fig. 17). **Confirm the computer time is in UTC and that the computer has been synchronized with the internet.** (Note: The GPS units will have the proper time in UTC. If any drift resulting from an unsynchronized clock is introduced in the hydrophone measurements it will not be possible to properly account for the range to the vessel thereby requiring the tests be repeated.

- To sync the time an internet connection is required. Right click on the clock in lower right corner of the computer screen. Choose the “Adjust date/time”. At the top of the window click the “Internet Time” tab. Click the “Change Settings” button in the “Internet Time” tab. This opens a separate “Internet Time Settings” window with an “Update Now”. Click the “Update now” tab to update the time. Click “OK” and then close all of the date and time related windows.

(b) Remove the cap to access the electronics section (Fig. 17). Do this by using the Delrin cap (not the blue hydrophone protection cage) as a handle to twist counterclockwise while an assistant holds the pressure case steady.

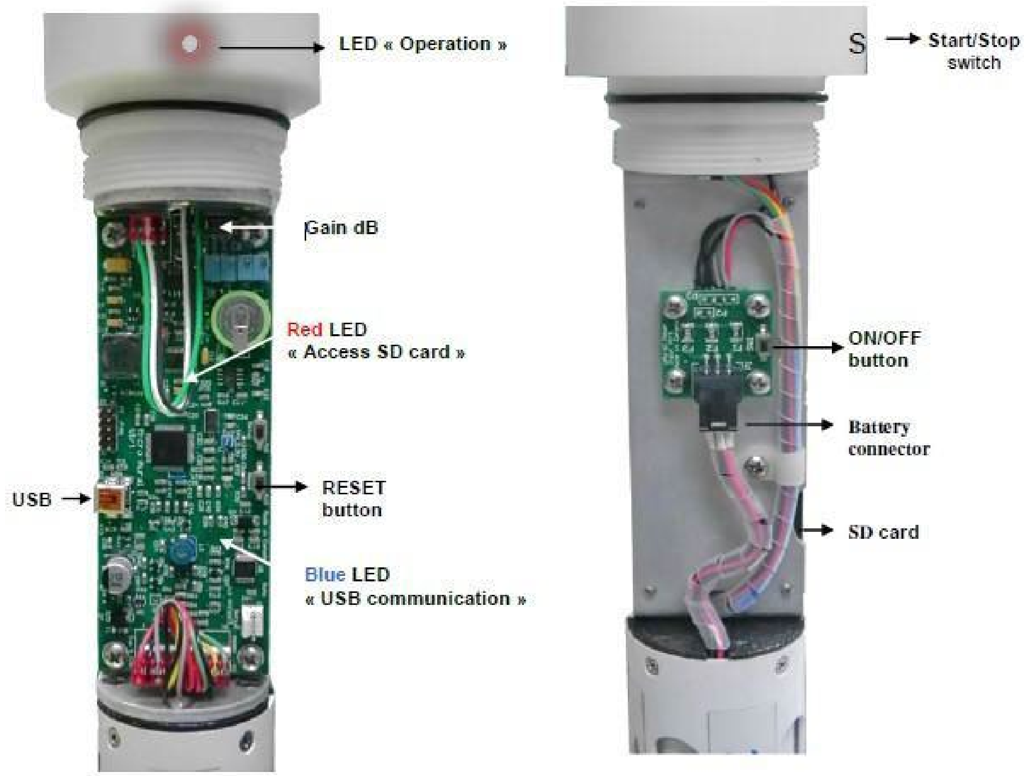


Figure 17. -- The electronics in the μAURAL housings. See μAURAL manual for details.

(c) Remove the SD card and insert it directly into the laptop computer or use an SD card adapter. Delete any files remaining in the “Data” directory on the SD card. Leave all other files on the flash card. Put the flash card back in the hydrophone.

(d) Connect the USB cable to the μAURAL and the laptop computer and launch the μAURAL software. The software should only be started after the USB connection to the device has been made and LEDs on the μAURAL indicate that the device is communicating with the computer. Once launched the configuration window (Fig. 18) should appear.

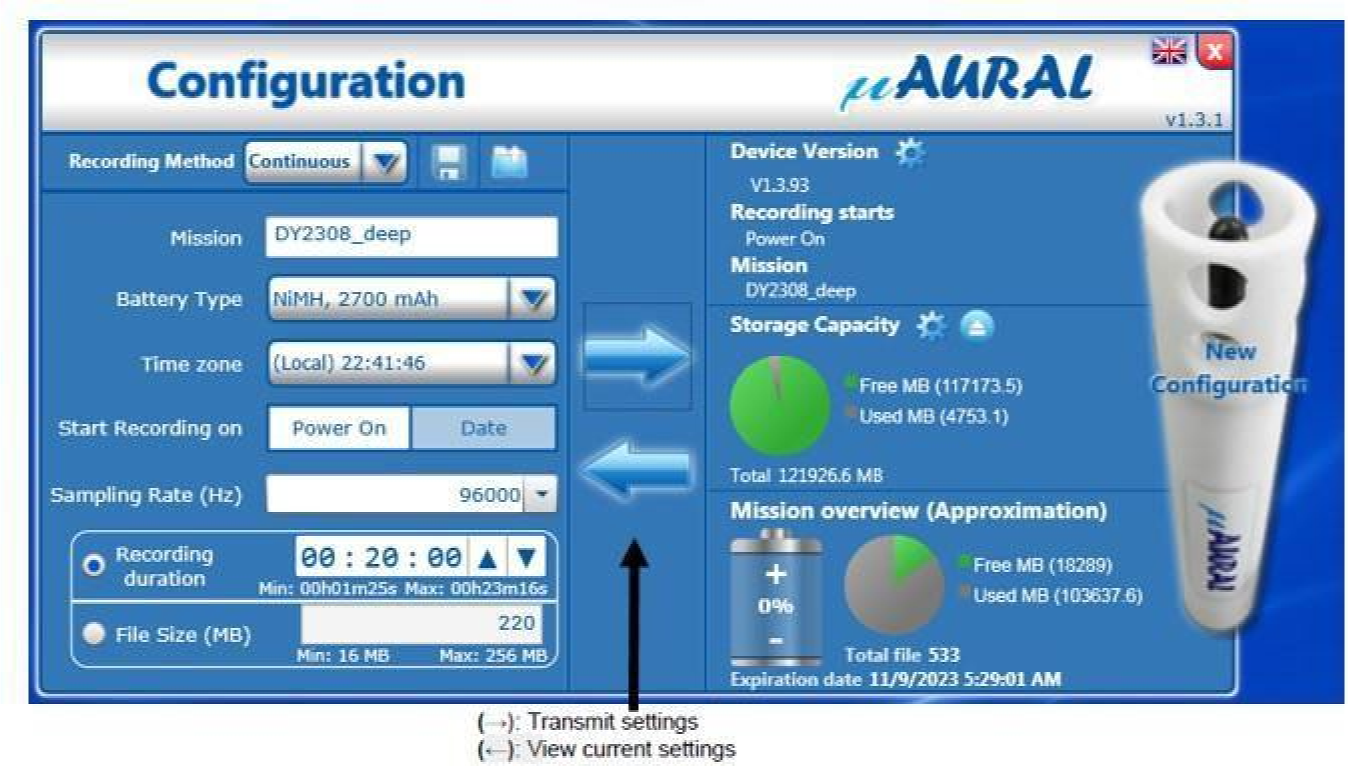


Figure 18. -- The µAURAL configuration window.

(e) Configure the hydrophone using the following settings (pg. 17-21 of the µAURAL manual; MTE 2015):

- Recording Method: Continuous
- Mission: "Cruise_Depth", where "Cruise" is the cruise name and should not include spaces (e.g., DY 2308 becomes DY2308_) and "Depth" is the depth at which that hydrophone will be deployed (i.e., Shallow, Middle, or Deep).
- Time Zone: UTC
- Start Recording on: Power On
- Sampling Rate (Hz): 96000 (Different sampling rate options can be selected and are compatible with the post-processing software. Users should only change the sampling rate if they understand the implications for the measurements and results).
- Recording Duration: 00:02:00 (this should correspond to a 22 MB file with the 96 kHz sampling rate
- Click the ⇨ button to send the configuration to the device.
- Click the eject button (⏏) near the "Storage Capacity" heading
- Disconnect the USB cable from both the hydrophone and the laptop

(f) Before closing the configuration window save the configuration file into the proper raw data directory for the hydrophone as described in Section IV (i.e., ...\Hydrophones\SN). The save button is the disk icon located near the upper right corner of the configuration interface.

(g) Confirm that the battery cable is connected to the electronics board. Ensure that the O-rings are in good shape, free of contamination, and properly lubricated. Apply o-ring grease (e.g., Molykote 55) from the kit if necessary. Seal the housing by twisting clockwise but do not hold it by the blue protection cages which are fragile. *The housing should only be hand-tightened*.

(h) Attached to the blue hydrophone protection cage are four O-rings held together by a cable tie which holds the hydrophone in place (Fig. 20a). Remove the cable tie and carefully adjust the position of the hydrophone so that it is outside of the cage but most of the cable is still within the cap (Fig. 20b). Pulling too much cable out can make it difficult to replace the hydrophone within the cage.

(i) Turn on the hydrophone using the following steps (additional start-up procedure information is on pages 22-23 of the *μ*AURAL manual):

- Locate the start/stop switch (the **S**) on the base of the cap.
- Move the magnet (Fig. 19) near the S switch until the red LED begins blinking. After blinking for a couple of seconds, the red LED remains on without blinking (this means the system is reviewing the configuration).
- Remove the magnet. At this point the LED will turn off.
- Check the LED status. For continuous recording the red LED will blink slowly (every few seconds). The LED will continue to blink as long as the hydrophone is operating.
- In the deck log record the serial number and the time that the hydrophone started
- If the LED pattern is anything but slowly blinking red, the configuration is incorrect. Review the LED codes (Fig. 21) to determine the problem and reconfigure the hydrophone.

Figure 19. -- The *μ*AURAL magnet.

(j) Immediately after the hydrophone is turned on the hydrophone should be calibrated. To simplify post-processing the entire calibration procedure should be completed within the first two minutes after the hydrophone has been turned on. Insert the hydrophone securely into the pistonphone coupler (Fig. 20b) and set the pistonphone on a piece of foam (taken from cases in which the hydrophones were shipped) on a flat surface with the power switch facing up. Turn the pistonphone on and make sure the LED is green. Allow the pistonphone to operate for 20-30 seconds. Turn the pistonphone off for an additional 15 seconds before turning it on a second time for an additional 20-30 seconds.

(k) Pistonphone measurements are complete. Remove the hydrophone from the pistonphone and secure the hydrophone by replacing the cable tie holding the hydrophone inside of the blue cage (Fig. 20a).

(l) Use the magnet to turn off the hydrophones until the full system is prepared for the deployment. To do this move the magnet adjacent to the S switch until the red LED remains lit. Remove the magnet and the system powers down. When properly powered down the red LED no longer blinks. Monitor the hydrophone for 15 seconds to ensure it is not running.

Repeat the previous steps for the other hydrophones. After completing the pistonphone measurements on all hydrophones, secure the pistonphone and coupler back in the case after removing the batteries from the pistonphone. Place the hydrophones back in the center of the cage and secure it with a cable tie (Fig. 20a). Mount the hydrophones on their strongback/clamp assemblies (Fig. 13). Note in the deck log the hydrophone serial numbers (printed on the hydrophone), gains (if known or changed), and deployment depths (i.e., shallow, middle, and deep).

Figure 20. -- (a) Hydrophone protection cage. The arrow points to the cable tie that must be removed for calibration. (b) The hydrophone configuration during calibration. After removing the cable tie the hydrophone cable is mostly within the cap.

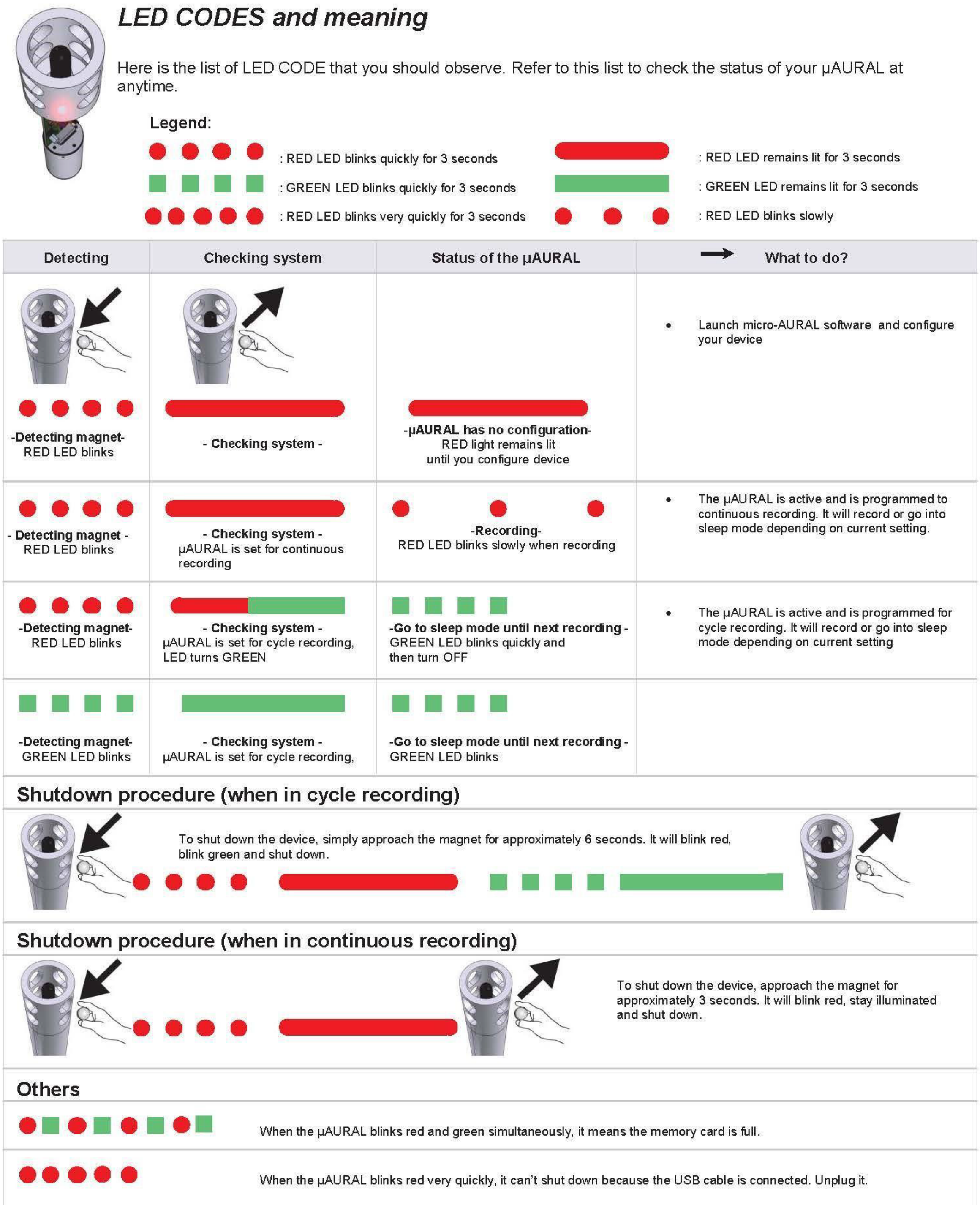


Figure 21. -- LED codes and interpretation for the *µ*AURAL units (MTE 2015).

III.IV Preparing the Electronics

In advance of final preparations for deploying the FSVPAD the batteries in the hydrophones and the electronics package should be charged and the electronics package should be confirmed to be fully prepared for deployment by testing radio communications on deck. The Arduino Uno microcontroller, Garmin GPS unit, Freewave radio, and bulkhead LED are all driven by a single circuit and code stored on the microcontroller. Prior to setting up the electronics, the battery voltages should be checked. A 12V NiMH battery mounted in the lower portion of the electronics chassis powers the radio and GPS unit. Using a voltmeter, check the voltage across the two-pin Molex connector leading to the lower chassis. A fully charged battery will read greater than 12V. If not fully charged a full test of the system should be delayed until the battery can be recharged. Also confirm that the voltage across the barrel connector leading to the AA battery reads approximately 9V. The AA batteries should be replaced if not fully charged (i.e., reading greater than 1.5V each).

The Freewave radios should not require further configuration. To prepare for the deployment, simply connect the 12V battery to the circuit by connecting the labeled, white, two-pin Molex connector from the lower electronics chassis to upper components. Simply connecting these batteries will not power up the units because the circuit is closed by the shorting plug (Fig. 15) on the housing end cap. The shorting plug should only be inserted once the ship-board equipment has been configured and the user is familiar with the steps required to confirm the system is operating as expected.

III.V Setup of Ship-Based Components

The ship-based components listed in Section III.I should be gathered and taken to the bridge. Both the radio antenna and GPS units should be installed outside in a location that facilitates cable runs into the bridge for easy communications during vessel tests. When choosing the placement of the shipboard GPS unit it is important to know the relative location of the propeller because calculations of the ship's range from the drifter are calculated relative to the propeller. Therefore, determine a good, unobstructed location whose distance from the propeller and is easily calculable. Once placed, record the relative location of the GPS following the coordinate system relative to the engine room and propeller defined in Figure 22. Previous installations on NOAA FSVs have used the handrail at the aft area of the flying bridge above a benchmark denoting the ship's centerline. Mount the GPS units, radio antenna, and cables and run them to the desired setup location on the bridge.

Next, gather the laptop computer, Freewave radio, USB cables, and power cords. The end of the white cable leading to the GPS unit has a serial connector that may already be connected to a serial to USB adapter labeled "SHIP GPS COM19." Once these two cables are connected the USB connector is plugged into the port on the right-hand side of the laptop. A power cable terminated with a green Phoenix connector provides the Freewave radio power. A red cable with an RJ-45 (Ethernet) connector on one end and a serial connector on the other is plugged into the COM1 port of the radio. A serial to USB cable labeled "COM11 - DRIFTER" attached to the red cable is plugged into the USB port on the back of the laptop. During operations the laptop should be plugged to wall power. A picture of the prepared ship-based components, with labels, are shown in Figure 23.

At this point the FSVPAD electronics are not powered up so communications with the FSVPAD GPS (COM11) cannot be verified. Proper operations are confirmed after the FSVPAD is constructed prior to deployment of the system.

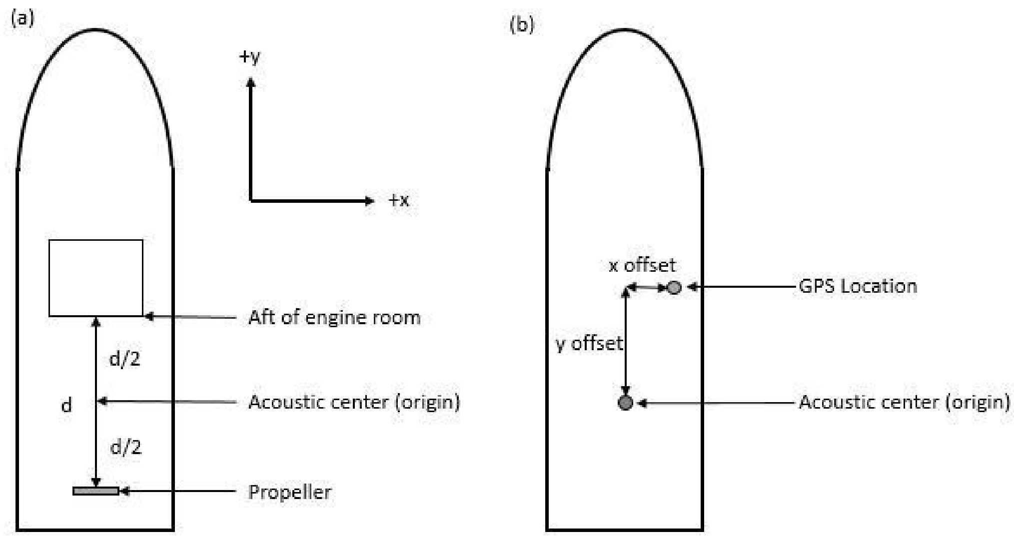


Figure 22. -- Critical measurements for the placement of the GPS. (a) The vessel's acoustic center is defined as the mid-way point between the engine room and the propeller. This serves as the origin of the coordinate system used to calculate the vessel's source levels. (b) Drawing showing the x- and y-offsets for the GPS given an arbitrary location on the vessel. Forward and starboard of the acoustic center corresponds to positive x- and y-values.

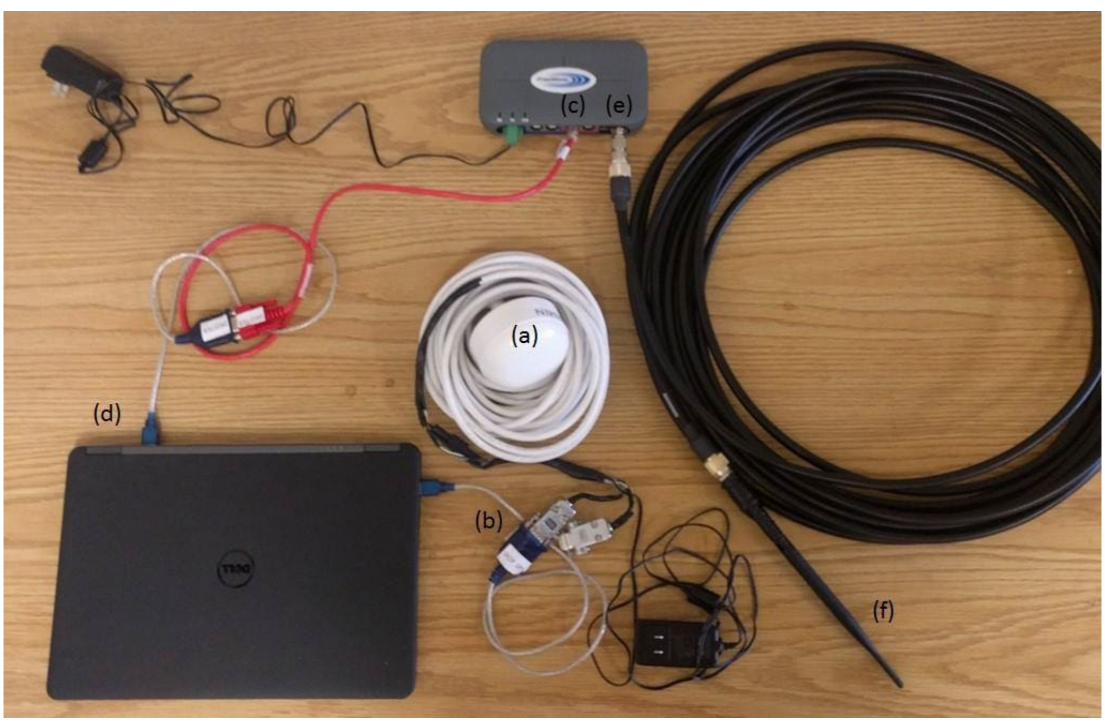


Figure 23. -- The ship-based electronics package for tracking and logging data from the FSVPAD. (a) The GPS unit and cable. (b) Serial to USB connection for ship GPS data. (c) Freewave radio RJ-45 to USB connection for FSVPAD GPS. (d) USB connection for FSVPAD GPS. (e) Freewave radio antenna connection. (f) Antenna and cable.

III.VI Assembling the FSVPAD

The following steps should be used to construct the FSVPAD in preparation for a deployment. Once fully deployed, the system actively consumes the limited energy budget supported by the battery (~ 3.5 hours). Therefore, the system has been designed such that it can be physically constructed well in advance of any operations with relatively simple steps to power the instruments immediately before deployment. To understand the physical construction users are encouraged to familiarize themselves with the individual components and deployment logistics well in advance of operations. Figures 2-15 (Section II) include figures and drawings of the full assembly and should be referenced during the construction process.

The instructions for the FSVPAD construction are broken into three stages. The first, and most detailed, describes the construction of the spar components excluding the electronics. The second section describes the lower portions of the FSVPAD, which are most easily secured to the spar on deck where the system will be deployed. Installation of the electronics housing and starting the hydrophones is the final stage. All shackles should be seized using either an appropriately sized cable tie or wire.

Stage 1: The FSVPAD should be constructed in an open space inside of the ship so that the interior of the electronics housing remains dry

(1-a) Attach the upper and lower spar sections, sandwiching the base plate between them. When properly oriented, the hole for the light fixture aligns with a cut-out in the foam and allows for the antenna lifter assembly to pass through both PVC flanges. The sections and base plate are secured using the ¾” stainless bolt assemblies. Tighten all four bolts using either 1⅛” or adjustable wrenches.

(1-b) Secure the two-point bridle using the provide shackles. One line connects to each of the U-bolts mounted on the base plate. The ends of each short line are shackled together to form the bridle.

(1-c) Remove the stopper from the top of the antenna assembly (Fig. 7) and slide the rest of the assembly from the bottom of the foam, through the bushings on the lower and upper spar sections and re-install the stopper. If the spar is vertically oriented the stopper should now rest on the antenna bushing (the PVC attachment mounted to the PVC flange that forms the base of the electronics housing). The smooth (non-rounded) portion of the foam at the base of the antenna assembly should face inward towards the spar.

(1-d) If needed, install the light fixture. First, put a new D battery into the light. Then, remove the PVC stopper at the base of the light fixture after unscrewing the stainless bolt assembly. Slide the light fixture through the base plate from the top. Using the bolt assembly, re-attach the stopper to the light fixture. Secure the light to the fixture using two cable ties passing through holes near the top of assembly (Fig. 8). These holes line up with two pass-through points on the light to hold it in place throughout the deployment.

(1-e) A small flag has been provided. It can be mounted to the light fixture using cable ties and electrical tape. This requires that the light fixture is installed even if a light is not used.

(1-f) Secure the three-point bridle to the base of the spar using shackles. Three holes, symmetrically spaced and located at the base of the spar, are sized so that the shackles fit tightly. The threaded ear of the shackles should be on the interior lower spar (i.e., the shoulder/flange of the shackle should face outward).

(1-h) If desired and available, attach a radar reflector below the flag using cable ties. A 12” aluminum radar reflector was found to greatly increase the ability to detect the drifter from the ship.

Stage 2: Constructing the strongbacks, heave plate

(2-a) Identify the three strongbacks and their proper deployment locations. The strongbacks are labeled ‘1’, ‘2’, and ‘3’ for shallow, mid-water, and deep, respectively. In addition, ‘U’ and ‘D’ denote the orientation of the strongbacks where the ‘U’ identifies the portion of the strongback that should face towards the surface. Two clamps are installed on each strongback. Labels on each clamp identify the strongback on which they should be installed and their proper orientation (‘U’ vs. ‘D’).

(2-b) Attach the hydrophone clamps to the strongbacks using the ¼”-20 hardware and 9⁄16” wrenches.

(2-c) Mount the hydrophone pressure housings in the clamps. In the deck log note the six-digit serial number printed on each hydrophone, and associate it with the shallow, middle, or deep hydrophone as appropriate.

(2-d) Using bowline knots secure each hydrophone to its strongback using the small, white safety lines. At the pressure housing the bowline should pass through the clearance hole. The other end of the line is tied onto a small shackle placed on the clearance hole at the base (centered) of the strongback.

(2-e) Gather one to two plastic totes (or similar containers) to stage the lines and set them aside adjacent to the strongback/hydrophone assemblies.

(2-f) Place the heave plate assembly adjacent to the baskets and strongback assemblies.

(2-g) Gather the three static lines used to attach the heave plate and strongbacks. The three lines have different colors of tape near the thimbles to denote their lengths. The short line (yellow tape) connects the bottom of the heave plate to the top of strongback 1 [shallow]. Blue tape denotes the line connecting the bottom of strongback 1 to the top of strongback 2 [middle]. The final color (white) attaches the bottom of strongback 2 to the top of strongback 3 [deep]. In order to keep the hydrophone array vertical in the water column, a lead weight (5 to 10 lb) is attached to the down side of strongback 3 with a short piece of line.

(2-h) Attach the lines to their respective strongbacks/heave plate. During deployment the deeper components of the system enter the water first, beginning with the weight and strongback 3 [deep]. Therefore, the system should be rigged starting with the heave plate and working towards the deep strongback. Connect the heave plate to strongback 1 and ‘flake’ the line (ensuring that line going out first is on top) into the basket/tote. When the line gets to the strongback, place it in the tote/basket.

(2-i) Secure the line from strongback 1 to strongback 2, flaking the line and strongback into the tote/basket.

(2-j) Secure the line from strongback 2 to strongback 3, flaking the line and placing the strongback int the tote/basket.

(2-k) All of the lines, strongbacks, and the heave plate are now rigged for deployment. Note that the heave plate has not yet been secured to the spar/three-point bridle. This final step is carried out immediately before deployment (after the electronics have been turned on [Stage 3]).

Stage 3: Installing the electronics housing and powering up the instruments

Ship-based components are not subject to the same power limitations as the FSVPAD electronics. The ship-based components should therefore be set up before completing the following steps (see Section III.V). Before proceeding the ship-based GPS and radio should be operating but not logging data.

In addition, the following steps should only be carried out once the crew is prepared for deployment and the vessel nearing the position of the test (e.g., within 30 minutes of deployment).

(3-a) Remove the shorting plug, electronics chassis mounted to the FSVPAD end cap, and the antenna from the shipping case.

(3-b) Clean the two O-rings on the cap of the electronics housing. Also wipe the surface on the upper portion of the inside of the electronics housing where the O-rings make contact. Lubricate the O-rings using Molykote 55 (or similar) O-ring grease.

(3-c) Use a voltmeter to check the voltage across the leads on the 12V battery in the base of the chassis. If it reads less than 12.5V the battery must be recharged before deployment. The voltage across the barrel connector to the microcontroller should read greater than 9V. If voltage is lower, replace the 6 AA batteries prior to deployment.

(3-d) Prior to installing the electronics housing make sure that all the electronics have been re-connected with the exception of the barrel connector to the microcontroller.

(3-f) Remove the dummy plug installed on the housing end cap and replace it with the shorting plug. This provides power to the GPS and radio. Verify that the LEDs on the Freewave radio are on.

(3-g) Insert the loose barrel connector from the AA batteries into the Arduino microcontroller and verify that the lights on the board power up. The LED on the shorting plug should begin to blink within 15 seconds.

(3-h) Do not proceed until the LEDs on the Arduino, the Freewave radio, and the shorting plug are all blinking. If any LEDs are not working unplug the shorting plug and barrel connector to stop drawing power from the batteries. Review the troubleshooting guides (Appendix B) to identify the problem before re-installing the connectors and proceeding.

(3-i) Insert the electronics package and housing cap into the housing. When properly installed the bottom of the end cap should be flush with the top surface of the upper spar section. The cable gland on top of the electronics housing should be oriented such that it is as close as possible to the antenna lifter assembly.

(3-j) Mount the antenna to the antenna lifter assembly using the 6-32 hardware.

(3-k) Move the FSVPAD to the deck where the instruments will be deployed. Move the strongbacks and heave plate to the deck adjacent to the spar. The location of the FSVPAD at this time should result in a direct line-of-sight to the ship-based Freewave antenna. This is required in order to verify communications prior to deployment (see 3-m below).

(3-l) Secure the shock cord and static line leading to the heave plate to the base of the spar using the three-point bridle. Seize the shackle.

(3-m) At this point the FSVPAD should be communicating with the ship-based electronics. Confirm this by opening Parallax on the laptop driving the ship-based components. If both systems are operating properly, regularly updated NMEA strings should appear on both COM11 and COM19 when viewed using Parallax (see Fig. 24). It may take a few minutes for the GPS units to provide updated coordinates or time stamps. Carry on with the deployment since the GPS units will eventually update and this can be verified later using the data acquisition program. One thing to try if there are issues is to send a carriage return (enter key) using Parallax on the shipboard PC. Sections III.VIII.III and III.VIII.V focus on verifying that the GPS units are functioning properly and should be referred to for additional details.

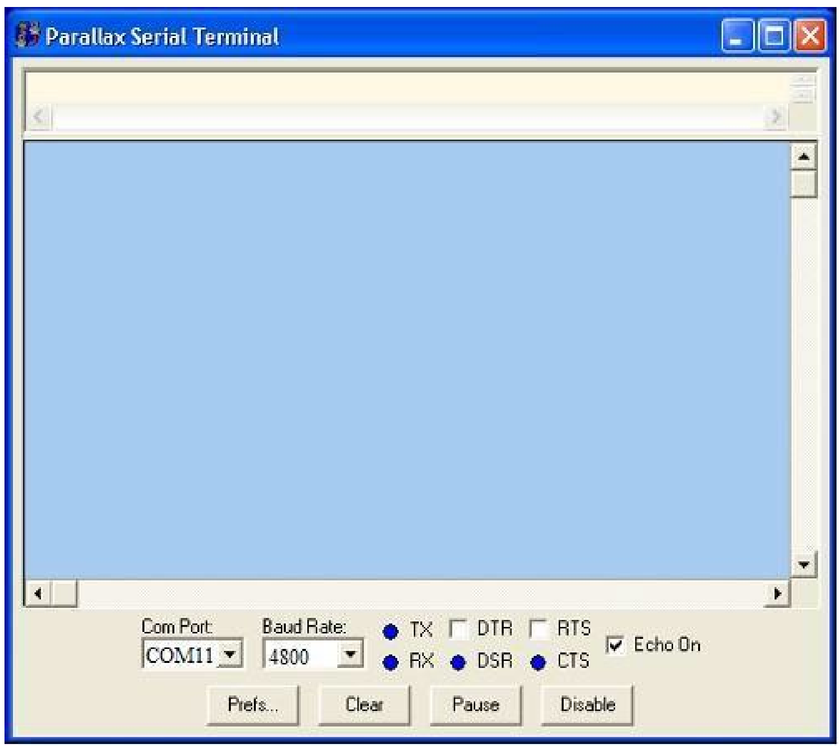


Figure 24. -- The Parallax interface. For viewing NMEA strings from GPS units the correct COM port must be selected and the baud rate should be set to 4800.

III.VII Arduino/Data Logger

As described in the previous section, deploying and confirming the operation of the Arduino data/logger microcontroller should only require that the power to the unit be turned on and the LED output on 8-pin SubConn bulkhead connector be monitored. This connector also provides power to the drifter GPS unit and Freewave radio so this step is performed immediately before deploying the drifter (as described in Section III.VI). Once powered, the bulkhead connector with the LED will flash in one of three configurations that conveys the operational state of the microcontroller/data logger. These states include:

(1) Green blink (fast; timing depends on received signals):

The LED will blink green if the serial software connection on the microcontroller is receiving GPS data and functioning as expected. Therefore, a green blinking light is an indication that the GPS unit is receiving power and providing data strings to the microcontroller (and presumably the radio). Note: This green blinking light does not indicate a current GPS fix. Verifying that GPS data are being received must be performed separately on the computer.

(2) Red blink (fast; twice per second):

The SD card failed to initialize. It is necessary to access the electronics in the housing to further investigate the source of the failure. The most likely source of the error is that the card was not properly inserted. Another possibility is that the card has failed.

(3) Red blink (slow; three seconds on and one second off):

The SD card is present, but a file is not being written. Wait for a short period in case this problem is related to the Arduino not receiving GPS strings. If the LED does not transition to blinking green within a couple of minutes, there is a problem. Confirm that the card is not in “read only” mode. Check that the 12 V battery is charged. Refer to the Appendix for additional troubleshooting options.

If the LED fails to operate as expected, refer to Appendix B.III for more troubleshooting information.

III.VIII GPS Units

This section focuses specifically on GPS units. Issues identified during FSVPAD setup are most likely attributable to improper configuration and setup during verification. Without proper configuration the data acquisition and real-time visualization programs will not function properly. To simplify the troubleshooting process during configuration all required cables are labeled. Both GPS systems should be set up well in advance of the deployment. The drifter GPS/radio within the spar, as previously mentioned, should not be switched on until just before deployment to save power. Figure 22 includes a labeled picture of the data acquisition and tracking laptop properly wired for the deployment. When configuring the equipment for deployment, care should be taken to replicate the COM port configuration summarized in the caption. If the COM ports are improperly configured, the real-time tracking program will improperly calculate the bearing to and coordinates of the drifter. After configuring the equipment according to Figure 22, proceed to the following sections to confirm proper operation of the GPS units and radio communications.

III.VIII.I Ship GPS

Once the shipboard GPS unit has been mounted and the location recorded, provide power to the unit using the provided AC to 12-volt DC power supply. The DB-9 serial connectors should be attached to the USB adapter with the matching label. The unit can be powered on by plugging in the power supply.

To confirm that the GPS unit is operating and transmitting data, open the Parallax Serial Terminal. Make sure that no other USB devices with connections to the GPS units are plugged into the computer. Change the COM port to COM19 (lower left corner) and the Baud Rate to 4800 (in the lower right corner). If the COM port is not COM19 it is acceptable to proceed; however, make note of the port on which the data are being received. It will be necessary to make changes to the data acquisition configuration file. Before identifying the COM port for the ship's GPS, confirm that USB port going to the drifter is disconnected.

If properly configured the display should begin to stream NMEA strings within a few seconds. This confirms that the GPS unit is powered up and sending data. Also confirm that the GPS unit has a fix by viewing an RMC (recommended minimum) string. An RMC string begins with `$GPRMC` and is followed by a series of alphanumeric values separated by commas. An example RMC string is shown below:

```
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A
```

where the second entry is the time (UTC) and fourth through eighth entries (highlighted by the red box) are the coordinates of the fix. If the time and coordinates are consistent with the current time and location, then the unit has a valid GPS fix.

III.VIII.II FSVPAD GPS

The FSVPAD's GPS unit and radio are pre-configured and, in the absence of problems that require troubleshooting, should require little attention beyond confirming its operation. First, remove the 8-pin SubConn dummy plug and replace it with the shorting plug. Next, ensure that the Arduino Uno is connected by inserting the barrel connector and checking that its switch is installed. If operating, lights appear on the microcontroller. No direct connection is available within the electronics housing to directly monitor the GPS unit's signal so prior to the deployment proper operation of the GPS unit must be confirmed via radio communications. If the GPS is operating and attempting to send signals, the bulkhead LED should blink green. If the bulkhead connector is blinking red see Section III.VI and Appendix B.III for troubleshooting procedures.

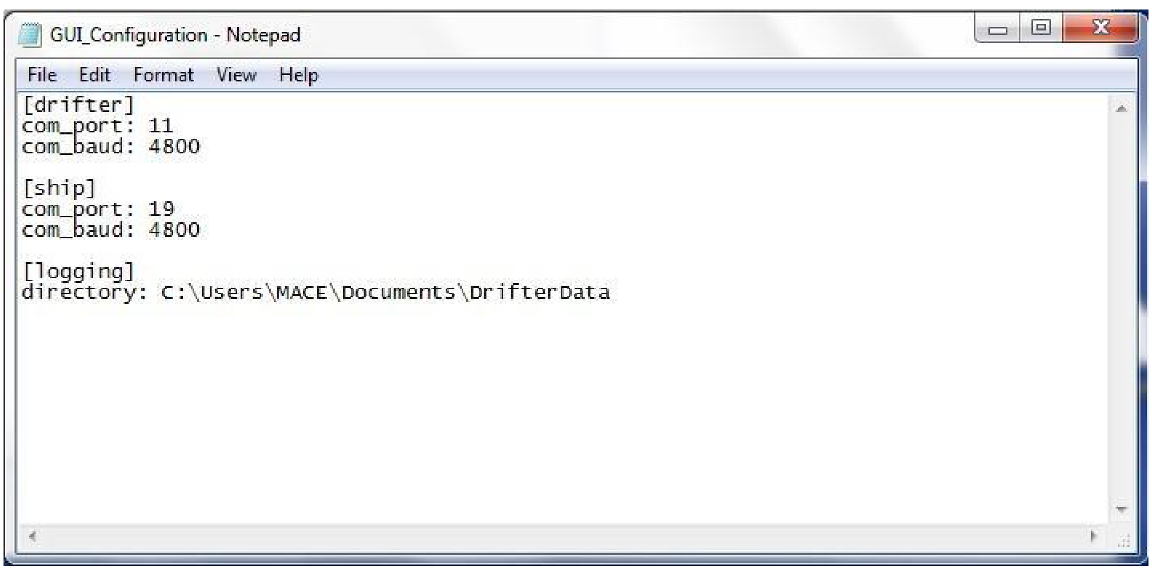
III.VIII.III Confirming Radio Communications

The default serial communications ports on the data collection laptop are COM11 for drifter GPS signals and COM19 for the ship-based GPS. A configuration file is referenced by the Python data acquisition and real-time drifter tracking script which automatically configures the program to perform the calculations and write the GPS data to the proper files. If the GPS units are not using these ports, the configuration files should be edited to reflect the current COM ports.

To verify the COM ports being used, first, unplug all of the USB connections from the laptop and then open the Parallax Serial Terminal program on the Desktop (Fig. 24). Next, plug in the DB-9 to the USB converter that leads to the Freewave radio (the FSVPAD GPS) into the USB port on the right side of the computer. Use Parallax to confirm the COM port providing the GPS stream and note the port number (e.g., COM9). Repeat the process for the other DB-9 to USB converter but use the USB port on the back, left corner of the screen (Fig. 22).

The COM port configuration file must be updated with the current information. The configuration file is located in the ...\Documents\FSVPAD Programs\winPython-x64\ FSVPAD Logger directory. This configuration file is packaged with the winPython installation to facilitate use of the program by users unfamiliar with Python. The configuration file for the script is called GUI_ Configuration.txt. Open the file in a text editor. An example of what this file contains is shown in Figure 25. For the program to properly parse the data the headings must be identical to those shown in the figure. In this case, the FSVPAD GPS is running on COM port 11 and the ship GPS uses COM port 19. Both units must use a baud rate of 4800. The output directory, which can be edited, is ...\Documents\DrifterData. After editing the COM ports or output data directory save them to the same location.

If any errors related to missing COM ports or improper formatting of the configuration file occur when the program is executed, a dialog window with an error will appear specifying the source. Three examples are shown in Figure 26. The first error appears if no COM port exists that matches the specified COM port for the ship-based GPS in the configuration file. The second error is the same but notes that the spar (FSVPAD) COM port is incorrect. The third error appears if a mistake has been made in formatting of the heading dictating a specific directory. To fix these errors edit the headings to match those shown in Figure 25. Without proper formatting the script cannot identify the proper COM ports or output data directory.


GUI_Configuration - Notepad

File Edit Format View Help

```
[drifter]
com_port: 11
com_baud: 4800

[ship]
com_port: 19
com_baud: 4800

[logging]
directory: C:\Users\MACE\Documents\DrifterData
```

Figure 25. -- The GPS_Configuration.txt file. This file is called by the FSVPAD Python script to identify the proper COM ports for the ship and FSVPAD GPS data in addition to the desired data directory. The headings in closed brackets must be identical to this file. COM ports should reflect the known COM ports for the respective GPS strings.

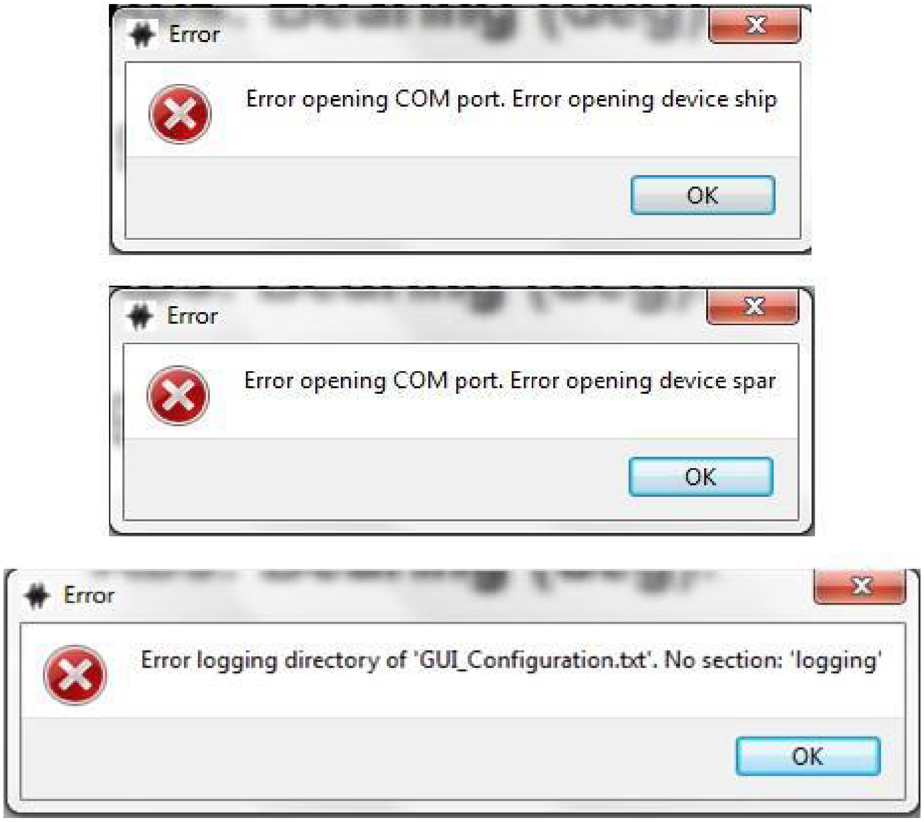


Figure 26. -- Example dialog windows that appear if there are any COM port or output data directory issues when executing the Python script. These errors can occur due to improper configuration file formatting or the absence of the COM ports specified in the file.

III.VIII.IV Saving Ship and FSVPAD GPS Data to File

When operating, the system will be writing three different output files to the FSVPAD laptop. These files are found in the parent directory specified in the configuration file (by default: ...\Documents\Drifter Data\GPS Files YMD _XXXXXX). The first file is written to the ...\Drifter Data\Distance sub-directory and has the filename GPS Calcs YYMMDD nnn.txt where YYMMDD is the date and nnn is a file number, which iterates up from 000. The file contains a timestamp, range, bearing, drifter speed-over-ground, and the last recorded coordinates of the drifter. Two additional files are located in the ...\RawGPS subdirectory. These file names have the formats ShipGPS YYYYMMDD nnn.txt and DrifterGPS YYYYMMDD nnn.txt. These files contain a series of GPRMC NMEA strings in addition to timestamps appended to these strings by the Python script. As long as GPS data are being received by the Python script/laptop, the systems will continue to write these files.

III.VIII.V Visualizing GPS Data During Radiated Noise Testing

This description of the real-time monitoring program assumes that proper GPS and radio operations have been confirmed. A Python script with a graphical user interface has been developed for real-time monitoring of the vessel. In addition, this program writes files with the FSVPAD positions and the ship GPS files for post-processing. To start the program, click the

FSVPAD Logger icon on the desktop (Fig. 27). This icon is a shortcut to the program executable saved with the winPython package that is located in the ...Documents\FSVPAD Programs\winPython-x64 directory. Once started, a GUI will appear as shown in Figure 28. To begin data acquisition press the “Start” button. Following a delay of approximately five seconds the program will automatically fill the white boxes with data. Throughout operation, the program will update the values in the range, bearing, drifter speed over ground (SOG), coordinates, and status boxes. Although the GUI is only updated every few seconds, the program calculates and records the range, bearing, FSVPAD SOG, and FSVPAD coordinates once per second. This file, which may be used for comparison to post-processed GPS data, is stored in the directory highlighted in the GUI. Note that while the ship-based GPS provides a data point once per second, the data from the drifter are received only once the Freewave radio buffer is filled (several seconds). Therefore, the data points used in range and bearing calculations are not synchronized. They are, however, based on GPS observations with no more than a few seconds between them so they are accurate to within 10s of meters unless the system is not receiving signals from the FSVPAD.

If, based on the results in the GUI, it is unclear that the GPS data are current, the underlying Python script is programmed to print received GPS strings to the command prompt window so that the user can verify the receipt of GPS strings in real time. Once acquiring data, a command prompt window will open in the background and can be viewed by moving windows on the computer screen. Each time a relevant NMEA string is received by the data acquisition system it is printed to the command prompt window with a timestamp and text string noting the source. This format is always as follows:

Source: Datetime NMEA,

where Source is either “Ship” or “Spar” to identify the origin of the printed GPS string. When the system is properly communicating, ship and spar strings are alternately printed in the command prompt window. When the FSVPAD and ship are not communicating by radio, only ship strings are printed to the screen. If GPS strings are not being printed for the FSVPAD, the most likely explanation is that the package is either too far away from the ship for communications, the line-of-sight signal between the radio is blocked, or the electronics package in the FSVPAD is not operating correctly. Communications are most likely to fail near the ends of each vessel pass or when the vessel is executing turns. So long as communications are reestablished as the vessel approaches the FSVPAD this is not a concern.

Figure 27. -- Desktop icons.

The GUI will continue to run until the “Stop” button in the upper-right corner is clicked. When pressed this button will trigger the program to close down. After approximately 30 seconds the GUI will automatically close down. If the user would like to view the drifter coordinates at the time of the final transmission, the log file can be opened and reviewed. This file is in the parent directory specified in the configuration file and the sub-directory is ...\RawGPS. The format of the comma delimited .txt file is:

time (UTC), range, bearing, drifter SOG, drifter coordinates, received time differential

The received time differential simply calculates the number of seconds between the ship-based and drifter GPS coordinates used to calculate the range and bearing observations. These time differences are again attributed to either the buffer on the FSVPAD Freewave radio or delays in communication between the radios as opposed to problems with the connection to the ship-based components.

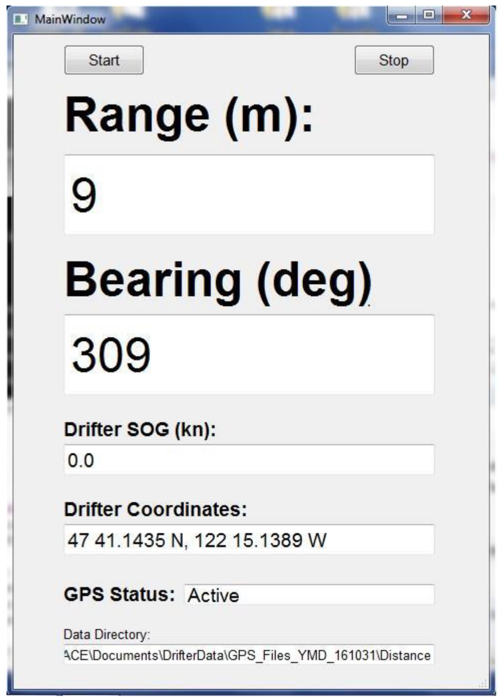


Figure 28. -- The GUI for real-time tracking of the drifter.

IV Post-Recovery and Data Management

Upon physical recovery of the drifter it is necessary to shut down all of the instruments and download all of the GPS and hydrophone data. The following sections describe the process of properly shutting down the instruments, backing up data, and creating the proper set of directories to facilitate the post-processing. Users should enter the times at which instruments are powered off in the deck log.

IV.I Instrument Shut-Down

In preparation for the recovery of the FSVPAD gather the tools and switches needed to power cycle the instruments and remove any necessary electronics from the housings. These tools include the bulkhead dummy plug for the FSVPAD electronics, the *μ*AURAL magnet (Fig. 19), and a small Phillips-head screwdriver.

IV.I.I Ship-Based Components

It is safe to power down the ship-based GPS units once the drifter passes have been completed. The crew of the vessel, however, may prefer that the visualization interface remains active until the drifter is fully recovered. Regardless, once permission has been received to close the interface the user can stop the data logging and close the interface in two steps. First, click the "Stop" button in the upper-right-hand corner of the GUI (Fig. 28). At this point the Python script is no longer logging, and the user may click the [x] to close the interface. Failure to properly stop the script will not result in a loss of data, but may result in incomplete strings written at the end of the file. This may cause subsequent processing errors if not manually removed. The USB connections and power supplies can be disconnected at any point. Ship-based components should now be broken down and properly secured as shipped (see details below).

IV.I.II FSVPAD

After recovery the primary power supply to the FSVPAD electronics can be powered down as soon as the instrument is on the deck. To do this simply remove the shorting plug and replace it with the dummy plug. The hydrophones should also be turned off as soon as the entire system has been recovered and is resting on deck. The hydrophones are turned off by placing the *μ*AURAL magnet (Fig. 19) near the "**S**" power switch on the hydrophone housing (also used to turn the instrument on during deployment). As the switch is approached, the red LED will blink quickly for three seconds before staying illuminated (red). The unit powers down once the magnet is removed.

Before opening any of the housings to extract that electronics/data all the instruments should be rinsed with fresh water, dried, and taken to the interior of the vessel. The hydrophones should be removed from their clamps and set aside. The end cap of the electronics housing is removed from the FSVPAD by locating the 8-32 Phillips head screws. Turn the screws clockwise. Each screw should be rotated only one to two revolutions per screw before switching to the other. If too many turns are taken on an individual screw before switching to the other the end cap will bind in the housing and the process will need to be reversed. Once the heads of the screws are level with the surface of the end cap the chassis can be removed by pulling directly upwards on the end cap and carefully sliding the unit out of the housing. Once removed, the FSVPAD electronics can be fully powered down by removing the barrel connector from the Arduino microcontroller.

At this point, all ship-based and FSVPAD electronics should be powered down. If the ship-based equipment has not been powered down return to the bridge and shutdown the equipment.

IV.II Create a Directory for Data and Results

During post-processing a MATLAB script (Make_Test_Directories.m) will create the required data and results directory structure. These steps are described in the first few paragraphs of Section V. This process will require users to have available the information about the hydrophone serial numbers and depths at which they were deployed, which should be recorded in the deck log. Once the proper directory structure exists, users can proceed with the data recovery steps discussed in the following sections.

IV.III Data Recovery

The data files necessary to properly process the radiated noise measurements from the vessel are located in three locations: the laptop computer, the FSVPAD microcontroller, and the hydrophones (Table 1). An external SD card reader is needed to transfer the data from the hydrophones and microcontroller if the laptop does not have one.

Table 1. --Data to be copied to the data processing computer ...\ represents the source directory created for processing in section V.

Instrument	Data type	Sample filename	Target directory	Source
Drifter GPS	GPS fixes	DGPS000.TXT	…\GPS_Files_YMD\20230714\Arduino GPS	From drifter SD card (section IV.III.I)
GPS from laptop	GPS fixes	DrifterGPS_YYYYMMMDD_001.txt ShipGPS__YYYYMMMDD _001.txt	...\GPS_Files_YMD\RawGPS	Downloaded from bridge laptop (section IV.III.I)
Hydrophone data	*.wav file	HHMMSS_ YYYYMMMDD _96Khz_DY2308_deep.wav	...\Hydrophones\XXXXXX	Downloaded from hydrophones (section IV.III.II)

IV.III.IGPS Data

Three different sets of GPS data must be moved into the proper processing folders. The ship-based and FSVPAD GPS strings are currently located in the directory dictated by the configuration file (default: ...\Documents\Drifter Data\GPS Files YMD XXXXXX). Creation of the processing directories discussed in the previous sections will result in the following subdirectories associated with the parent directory (test name) dictated by the user:

...\GPS Files YMD _XXXXXXXX\RawGPS

...\GPS Files YMD _XXXXXXXX\Arduino GPS

The ShipGPS and DrifterGPS files should be copied from the data directory in the configuration file to the ...\RawGPS directory. The last GPS file(s) to be copied are those located on the SD card in the Arduino. Remove the SD card from the microcontroller, insert it into the laptop, and transfer the files to the ...\Arduino GPS directory. These GPS data on the SD card have file names formatted as "DGPSnnn.txt," where nnn is a three-digit number that counts up from 000 each time a new file is created. Additional information about the proper directory structure is included in Section V.

IV.III.II Hydrophone Data

If the proper directory structure has already been created, directories for the hydrophone data are already present. Once prepared to download the data from the hydrophone, open the housings, disconnect the battery, and remove the SD card (the micro USB connection can be used to transfer data but it is slower). For each hydrophone, copy the data from the SD card's data directory into the proper drift directory. For example, if the hydrophone serial number is 382293 then the proper project directory is ...\TestName\Hydrophones\382293, where TestName is the user-specified parent directory that also includes the GPS subdirectories. There is no need to transfer data that is not associated with the radiated noise test or the pistonphone measurements. A good rule of thumb would be to transfer data between 30 minutes before and after the official beginning of the test passes in addition to the timestamps associated with the pistonphone data. After downloading the data, insert the SD cards back into the *μ*AURAL from which it was taken. Before resealing the housing, recharge the battery using the charger in the hydrophone case (see the following section for additional details). Store the hydrophone without re-establishing the electrical connection between the battery and the electronics.

IV.IV Packing the Instruments

IV.IV.I Recharging Batteries

There are four batteries that should be recharged after each deployment. These batteries include the three batteries in the *μ*AURAL units and the 12V in the drifter housing. The batteries should be recharged as soon as possible to ensure that the batteries are prepared for the next deployment. When the units are fully charged the LEDs on the recharger are all solid green. Depending on the state of the battery the recharging process may take a couple of hours.

Finally, the Arduino unit is driven by 6 AA batteries. Use a voltmeter to check the voltage at the barrel connector and ensure that it exceeds 9V. If the voltage is less than 9V or no voltmeter is available, then the AA batteries should be replaced.

IV.IV.II Ship-based GPS

A Pelican should be provided for safe storage and shipment of the ship-based instrumentation in addition to the electronics chassis and end cap for the FSVPAD. The foam inserts in the Pelican case have been cut so that the different components can be stored in an organized fashion. To store the FSVPAD electronics leave all components mounted and connected, including the bulkhead dummy plug. This assembly should be placed in the Pelican case with the ship-based components. The cable for the ship-based GPS unit should be unplugged from the unit and tightly coiled with the unit itself placed in the middle. The other ship-based cables and power supplies should be coiled and placed with the components of the GPS unit. Finally, the shorting plug and Freewave radio should be placed in the remaining space within the case. This case should also include the battery charger for the 12V battery installed in the electronics chassis. The antenna cable provided with the system is too large to fit inside the Pelican case. Instead, it should be placed in a large plastic bag for shipment with the other equipment.

IV.IV.III FSVPAD

In preparation for shipping or storage, the FSVPAD must be broken down into its major components. When broken down these include the upper spar assembly, lower spar assembly, base plate, light fixture, antenna lifter, strongbacks, heave plate, trailing float/line, and lines and bridles. The recommended order for disassembly of FSVPAD is as follows:

- First, remove the antenna lifter and light fixture assemblies.
- All the loose components (e.g., stoppers, bolt assemblies) should be re-installed and shipped/stored together.
- Remove the ¾” bolts connecting the upper spar, base plate, and lower spar. These bolts are best shipped attached to the lower spar assembly.
- Remove the base plate and upper spar. All lines and bridles should be removed, dried, and shipped together.
- Storage and shipping of the strongbacks is most efficient with the clamps removed and placed in bags with their hardware.
- Other loose hardware (e.g., shackles, spar hardware) should be placed in a bag and placed with the lines/bridles.

If stored and shipped in a tote, the most efficient use of space is using the various cases to form a platform for the lower spar section, whose dimensions vary along the length due to the foam. Remaining loose components such as the upper spar, trailing float, base plate, and heave plate can then be packed in the remaining space around the other cases.

V Data Processing

The following sections highlight, in detail, how to post-process all the data obtained during a test. Before starting, users will want to have the deck log at hand since various notes that should be in the log are required. Results of the radiated noise levels for the vessel are obtained by following all the processing steps, which are contained within a MATLAB script called FSVPAD_Master_Script.m (Fig. 29). All processing of the data is performed using MATLAB scripts, most of which were written specifically for this application. A series of user interfaces are used to help the user navigate the processing. When a new dialog window appears it will include instructions, sometimes written in the upper left-hand corner, to guide the user through the process. The directory structure used for the processing and data outputs are hard coded with references to the parent directory created by user entries. As a result, MATLAB skills are helpful, but not necessary, for processing the data.

Processing of the data, which is described in detail below, proceeds as follows. First, the proper directory structure to store the raw and post-processed data are created. Next, pistonphone measurements are processed to verify the hydrophones are functioning as expected. Then, initial postprocessing of the GPS and hydrophone data is performed. Finally, a single script requiring user input aligns GPS and hydrophone time stamps to back-calculate the radiated noise levels and print figures and a summary text file for reporting purposes.

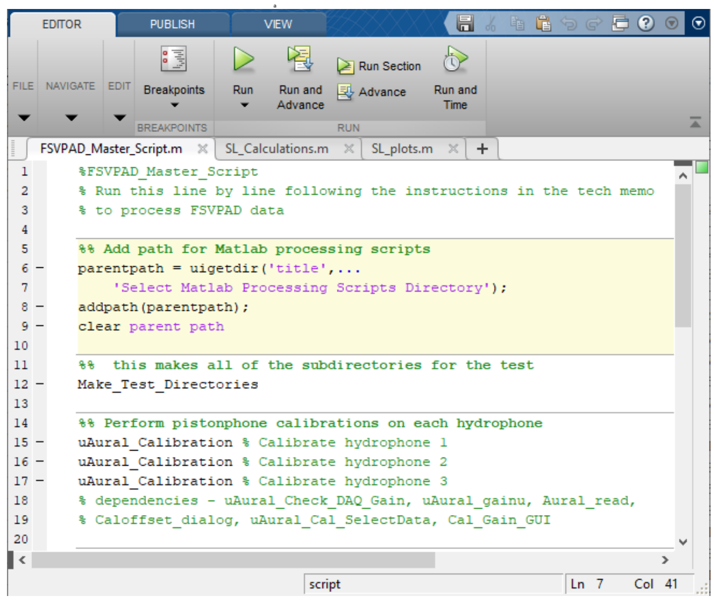


Figure 29. -- The FSVPAD master script.

To begin, identify the location where the processing scripts have been downloaded. Navigate to this directory and double click the FSVPAD Master Script.m script to open the code in MATLAB (Fig. 29). The green text preceded by % symbols indicate comments, which do not have to be run. For example, a user could right click anywhere on lines 6-9 and select the “Evaluate Selection” and MATLAB will only execute lines 6-9 (Fig. 30).

Processing the data by running sections in the order that they appear ensures that users will be able to fully process the data set without any errors associated with the codes. After running the first section (lines 6-9), which tells MATLAB where to look for the processing functions, users will run the next section which will create the proper data and results directories for the test. Right click and run the section associated with line 12 to open up the script in the editor. This executes the script, which will prompt users to first “Select Parent Directory for Radiated Noise Test Data.” This is the main directory for the entire experiment and will be empty unless data have already been placed in the folder according to the proper directory structure (Fig. 31). Select the directory and click the “Select Folder” button. Next, a series of dialog windows will ask the user to enter information related to the vessel tested, the date of the test, and the hydrophone serial numbers. Enter this information carefully (entering an incorrect hydrophone serial number could result in errors or improper processing at later steps) before clicking “OK” in the dialog boxes. Once all of the dialog boxes close all of the proper directories should exist in the parent directory. Confirm this is the case before proceeding. At this point, data should be downloaded into the proper data directory (Section IV).

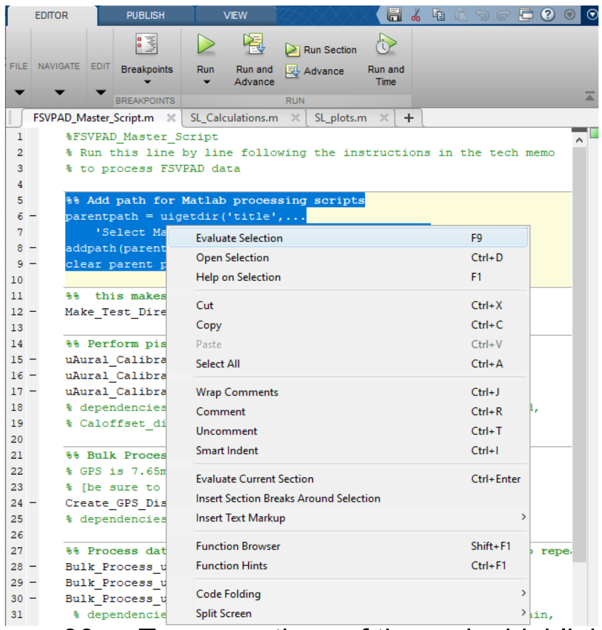


Figure 30. -- To run sections of the code, highlight the code with the mouse and then right-click and select ‘Evaluate Selection’.

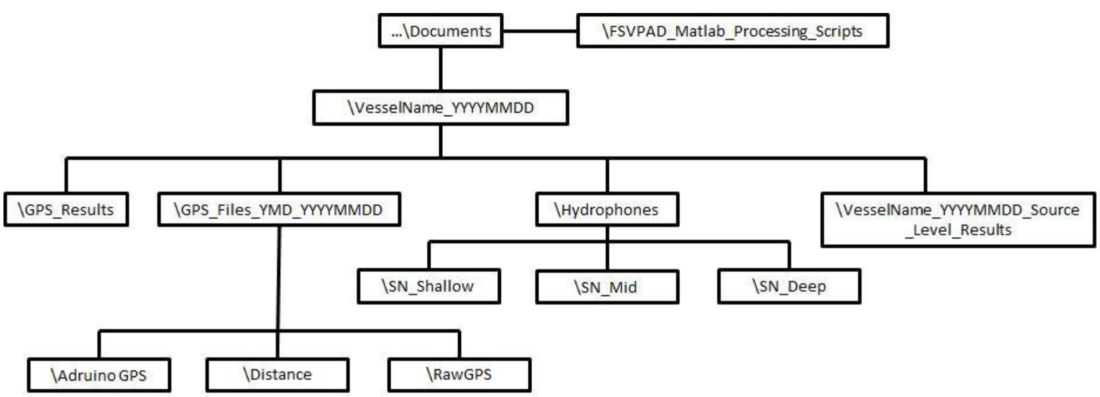


Figure 31. -- A schematic of the directory structure used for post-processing of the GPS and hydrophone data. Except for the parent directory (here ...\Documents), the directories are created in post-processing using the Make_Test_Directories.m script. Here the “SN_Shallow” etc. directories for the hydrophones represent the serial number.

V.I Processing Pistonphone Measurements

The following steps are used to process the time series measurements with the pistonphone. Results are written to a text file with manufacturer-specified calibration data that can be easily reviewed, particularly if radiated noise measurements diverge from expectations or if there are strong disagreements between individual hydrophones.

The GRAS 42AA pistonphone used for calibration measurements produces a 250 Hz, 140 dB re 1 μPa signal. A coupler specifically designed for the HTI-96 hydrophones adds 4.2 ± 0.5 dB to the 140 dB re a μPa signal for a total expected SPL of 144.2 dB re a 1 μPa. When calibrating, this value, in addition to an offset accounting for the atmospheric pressure, is what one expects to observe assuming that the specified hydrophone sensitivity is correct. When processing the signal, a bandpass filter from 100-400 Hz is applied to filter out-of-band ambient noise including 60 Hz AC interference. The results of these pistonphone measurements are currently not used in calculating the radiated noise levels; however, a scalar offset based on the differences between the measured signal during pistonphone measurements and the manufacturer specified value could easily applied.

If the system was properly deployed, pistonphone measurements should exist for each of the three hydrophones. The following paragraphs discuss the processing for an individual file and should be repeated for the full set of measurements. To begin the processing navigate to the directory containing all of the processing scripts. Using the master script (lines 15-17) open and run the uAural Calibration.m code. A dialog opens immediately prompting the user to select the .wav file associated with the pistonphone measurements. Navigate to the proper directory based on the serial number that is being processed. If calibration was performed immediately after the hydrophone was turned on the pistonphone measurements should be in the first .wav file in the directory. Select the first .wav file and click “Add” (Fig. 32).

Next, a dialog will ask if the DAQ gain is 18 dB. This is the default setting and the answer is “Yes” unless the data acquisition gain has been changed by moving the jumper on the data acquisition board. If this has been changed click “No” and use the drop-down menu that appears to select the current gain settings on the board.

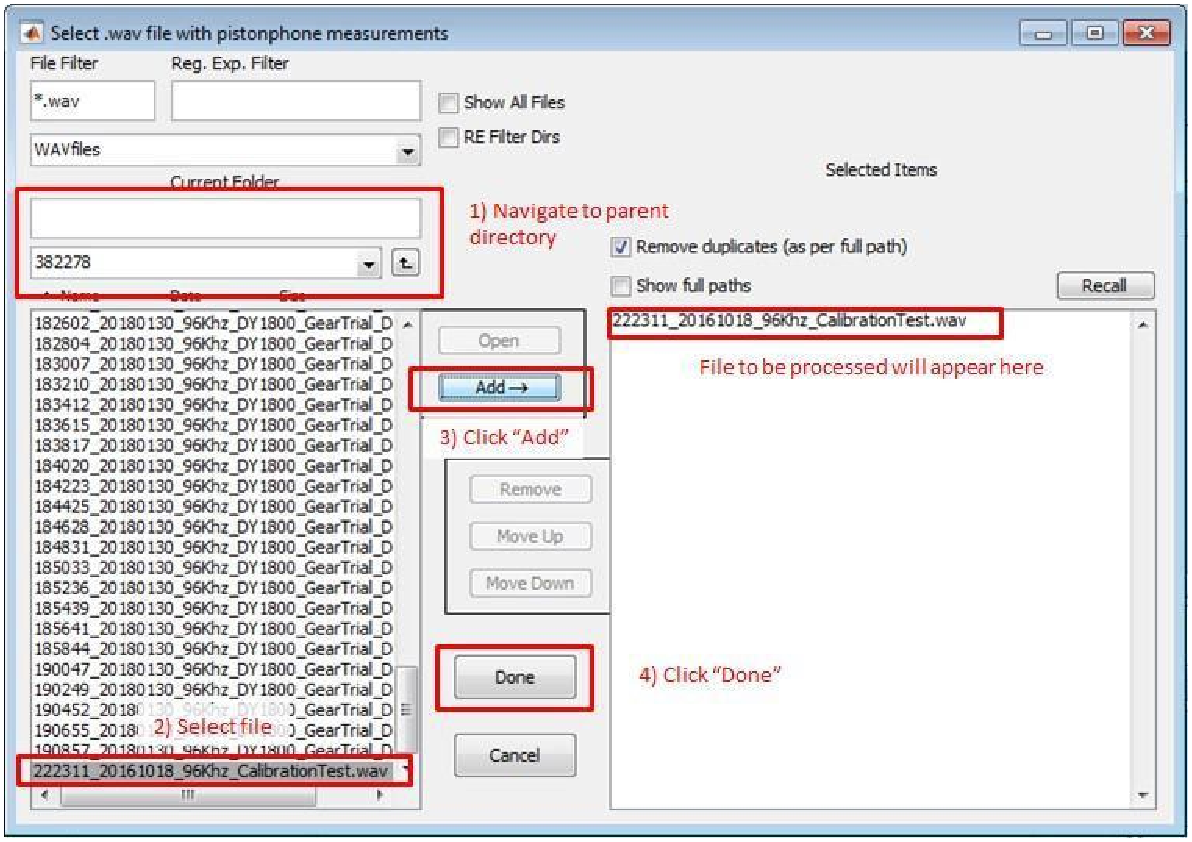


Figure 32. -- Window prompting user to select the hydrophone data for the pistonphone measurements. Navigate to the proper directory, "Add" the file, and click the "Done" button to begin with the processing of the time series.

During pistonphone measurements the atmospheric pressure and calibration offset should have been recorded in the deck log. A dialog now appears (Fig. 33) that asks for the calibration offset (this value will fall within the range of +0.3 to -0.5 dB at sea level even under extreme atmospheric conditions). Enter the value rounded to one decimal place and press the "OK" button. Make sure to include the sign. If the GUI is closed or the "Cancel" button is pressed without entering a value a default value of 0.0 dB is used.

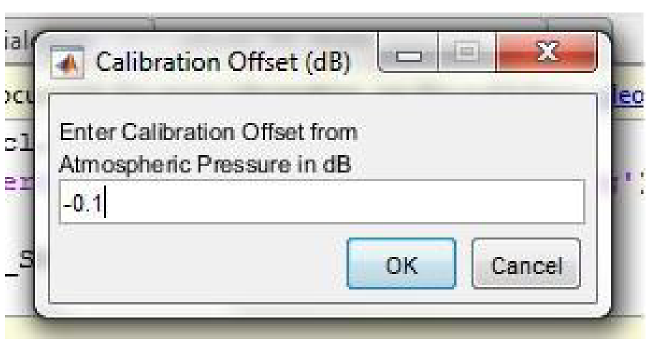


Figure 33. -- Pistonphone offset dialog window.

A window will appear with the bandpass-filtered time series. The user is prompted to select a portion of the signal that is 10 seconds or longer and is relatively loud and flat (Fig. 34). Crosshairs show the location of the mouse and the user should click two points, in chronological order, corresponding to the start and end points of the portion of the signal that will be analyzed (Fig. 34). After the two points have been selected press “Enter” on the keyboard. A figure will now appear that plots the filtered signal, the selected portion of the signal (Fig. 35), and the measured and expected SPLs of the signal. An additional dialog appears asking whether the user approves of the data or not.

If “No” is clicked the user will be asked to again select the portion of the time series to be analyzed. If the user clicks “Yes” the code will automatically complete the processing, write a results file to CalibrationResults.txt file, and print a figure with the approved time series and measured SPL. These files are written to the Processed Hydrophone Data directory associated with the test. MATLAB’s command window will print “The calibration script is done running...” once the code is no longer running. An example of the processed pistonphone data figure printed to the results directory is shown in Figure 35. Repeat this process for all hydrophones.

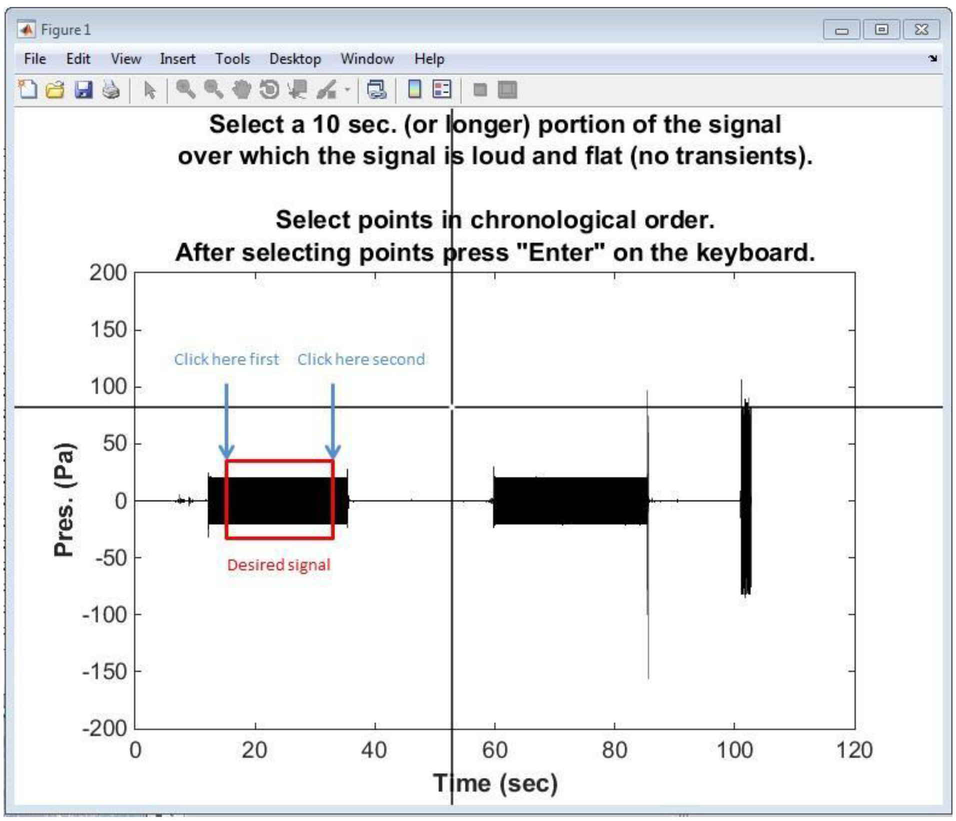


Figure 34. -- Window that prompts the user to select a portion of the recordings for the pistonphone measurements. An example of an appropriate signal is shown in the red box. The blue arrows highlight places that a user would click to select that portion of the signal. High amplitude transient signals may occur, especially when the pistonphone is turned on/off (e.g., the spike around 85 seconds). Such transients should be avoided.

V.II GPS Processing

First ensure that all the GPS files associated with the test are in the proper directory. Remove any GPS files from other tests if they are present in the data directory. If the date (in UTC, not local) changed during the tests and the system was restarted a second directory with a new date will have been created. If this occurred, move the additional files to the first date and edit the date and file numbers so they occur chronologically after the files from the first date. For example, if the files named ShipGPS_20180127_000.txt and ShipGPS_20180128_000.txt were created for a single test, rename the second file ShipGPS_20180127_001.txt and place it in the directory for 20170127. Do this for both the drifter and ship GPS files.

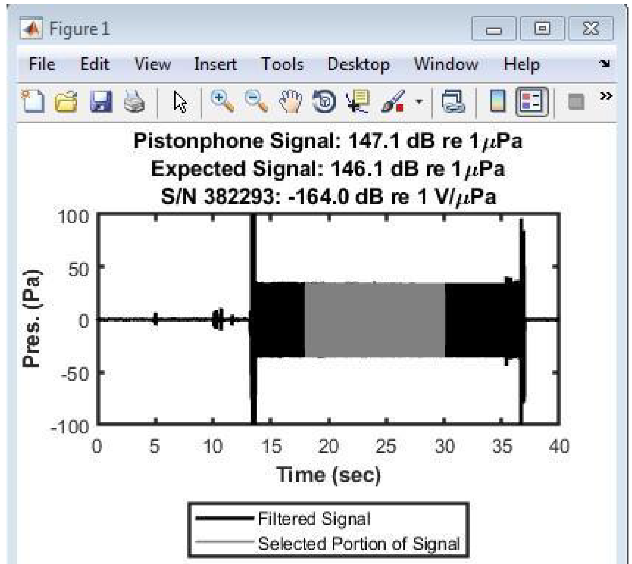


Figure 35. -- Pistonphone results showing the measured signal, the expected signal based on the gain and the hydrophone sensitivity.

Running the Create GPS_Distances.m file (line 24 of the master script) will process both the ship and drifter GPS data. Fewer points are likely to be missing using the data from the microcontroller. As such, the processing uses the drifter GPS data stored on the Arduino by default.

Since data points may have been dropped, the Create_GPS_Distances.m takes the sampling rate of the GPS units (1 Hz), and linearly interpolates all the recorded data (this generally only applies to a small fraction of the data). To begin, specify the start and end times of the tests in UTC on lines 24 and 25 of the Create_GPS_Distances.m code. For example, if a test began at 23:10:00 UTC on January 27, 2023 and ends on 00:43:00 UTC on January 28, 2023 then the lines of code should read as follows:

```
starttime = datenum(2023,1,27,23,10,0);

endtime   = datenum(2023,1,28,0,43,0);
```

After editing the lines click the green "Run" arrow in MATLAB run the code. This code calls functions (GPS_interp.m, GPS_parse.m, and GPS_distance.m) that are located in the processing functions directory. When the code is executed, it produces two dialog windows that ask the user to select a ship GPS file and a drifter GPS file (the directions are located in the upper left corners of the windows). This is used to identify the directory from which the GPS data are derived so it is only necessary to pick a single file of the type dictated by the dialog box. Given the start and end times the code reads in all GPS files associated with tests. GPS_interp.m will interpolate and provide all of the data with 1 Hz resolution. Distances and bearings between the drifter and vessel are calculated using GP_distance.m function. Note that slight errors in the bearing attributed to not accounting for the GPS offsets are introduced at this stage but are not relevant to further processing. Other data that are saved for the entire time series includes timestamps, latitudes, longitudes, speed over ground, and course over ground for both the drifter and ship. The data are automatically written to a .mat file. This output will be used with processed hydrophone data to identify the appropriate data from each pass to calculate the radiated noise levels from the vessel. Both files are saved to the results directory for the text and have the following file name format: YYYYMMDDThhmmss_Processed GPS.mat, where YYYY, MM, DD, hh, mm, ss, and ext refer to the year, month, day, hour, minute, second, and file extension (.mat or .png), respectively. These files are saved in the ...\GPS Results directory. A figure showing the range and bearing to the FSVPAD as a function of time is also printed to the \GPS Results directory (e.g., see Fig. 36). Before proceeding, review the figure to verify that the results are consistent with the expectations based on the experiment. If they are not, review the raw GPS data to ensure that the right data were selected and that the proper time periods were selected for processing in the processing script. Given that all units operate on time stamps from the GPS units, the most likely sources of errors are selecting the wrong data or using a GPS that did not establish a GPS fix.

V.III Hydrophone Processing

Processing of the radiated noise data recorded by the hydrophones is carried out in two steps. The first step is to read and process the data from each of the hydrophones individually. This results in three .mat files that contain time stamps and all of the relevant processed acoustic data for the individual recordings. The second step of processing, which is described in the next section, involves loading the processed hydrophone data into MATLAB, combining the results with the GPS to identify the relevant portions to analyze on each vessel pass, and calculating the range-corrected radiated noise levels.

To process the noise measurements in bulk, sequentially execute the Bulk Process uAural.m code on lines 28-30 of the master script. The code raises a dialog window (Fig. 37) that prompts the user to “Select All Files in Chronological Order.” Navigate to the proper directory for the experiment and the proper hydrophone serial number. By default, the hydrophone recordings (.wav files) from a given day will appear in chronological order. However, if files from multiple days were recorded or are present in the data directory these need to be sorted. Best practice is to sort the files by date by clicking “Date” right below that portion of the GUI that is used to select the proper directory. Select all the relevant files (the formal test period in addition to 30 minutes before and after the test) and press the “Add →” button. All selected files should then appear in the window on the right-hand-side of the box. If all files appear in the window below the “Selected Items” heading then press the “Done” button in the center of the GUI.

After selecting the hydrophone data a new dialog will open asking the user to provide the signal processing parameters for the hydrophone data. This dialog window, shown in Figure 38, appears with default values that are driven by the sampling frequency of the data. These default values satisfy the basic requirements for processing the acoustic data and should not be modified unless the user specifically wants to process the data differently or if the jumper to modify the hydrophone gain has been changed. Once processing parameters have been selected press the “Done” button in the GUI. The Bulk Process uAural.m then starts to process the selected hydrophone data.

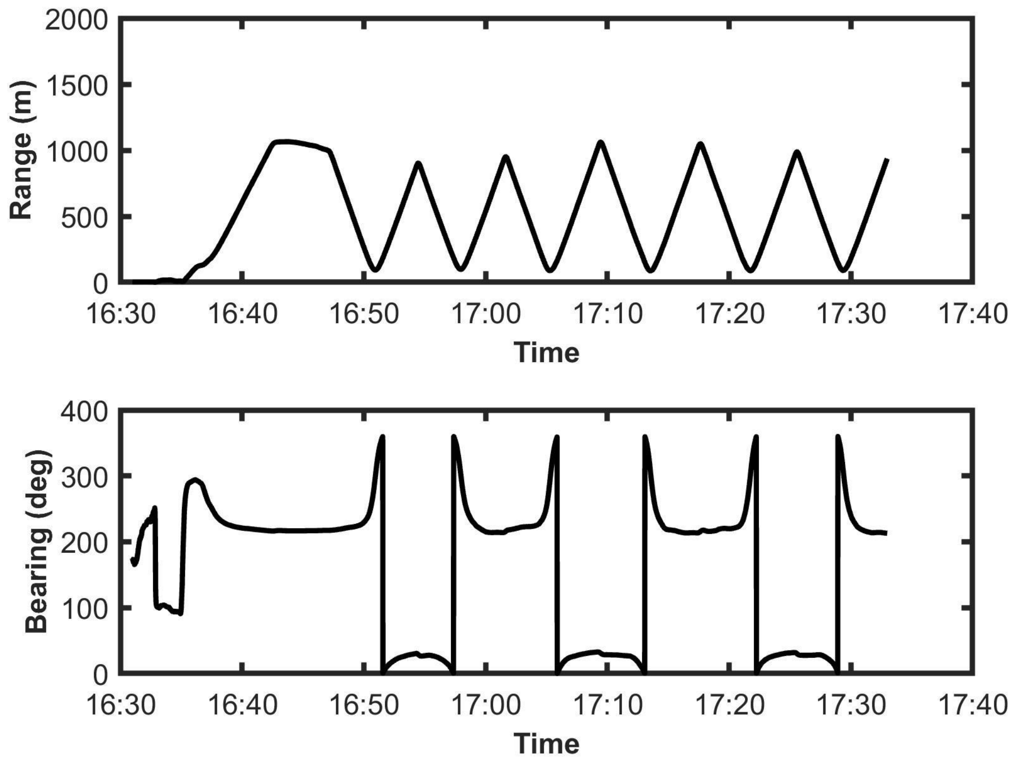


Figure 36. -- Example of processed GPS data. The top panel shows the range between the FSVPAD and vessel-based GPS as a function of time. The bottom panel shows the bearing as a function of time.

The code then proceeds to process all the data in the directory. While processing, the command window will print the number of files that have been processed. When all files have been processed, the following text will appear in the command window: “PROCESSING OF HYDROPHONE XXXXXX IS COMPLETE.” Once completed two .mat files containing the timestamps, frequency vectors, the one-third octave band sound pressure levels, broadband sound pressure levels (calculated by integrating the one-third octave and sound pressure levels), the sound pressure level spectra calculated in 1 Hz bands, and information about the serial numbers and deployment depth will be saved. The .mat files are saved in the respective hydrophone directories with the following filename formats: Hydrophone_XXXXXX_TOL and Hydrophone_XXXXXX_PSD. A figure including a spectrogram of the one-third octave band sound pressure levels and the broadband sound pressure levels is also saved in the directory.

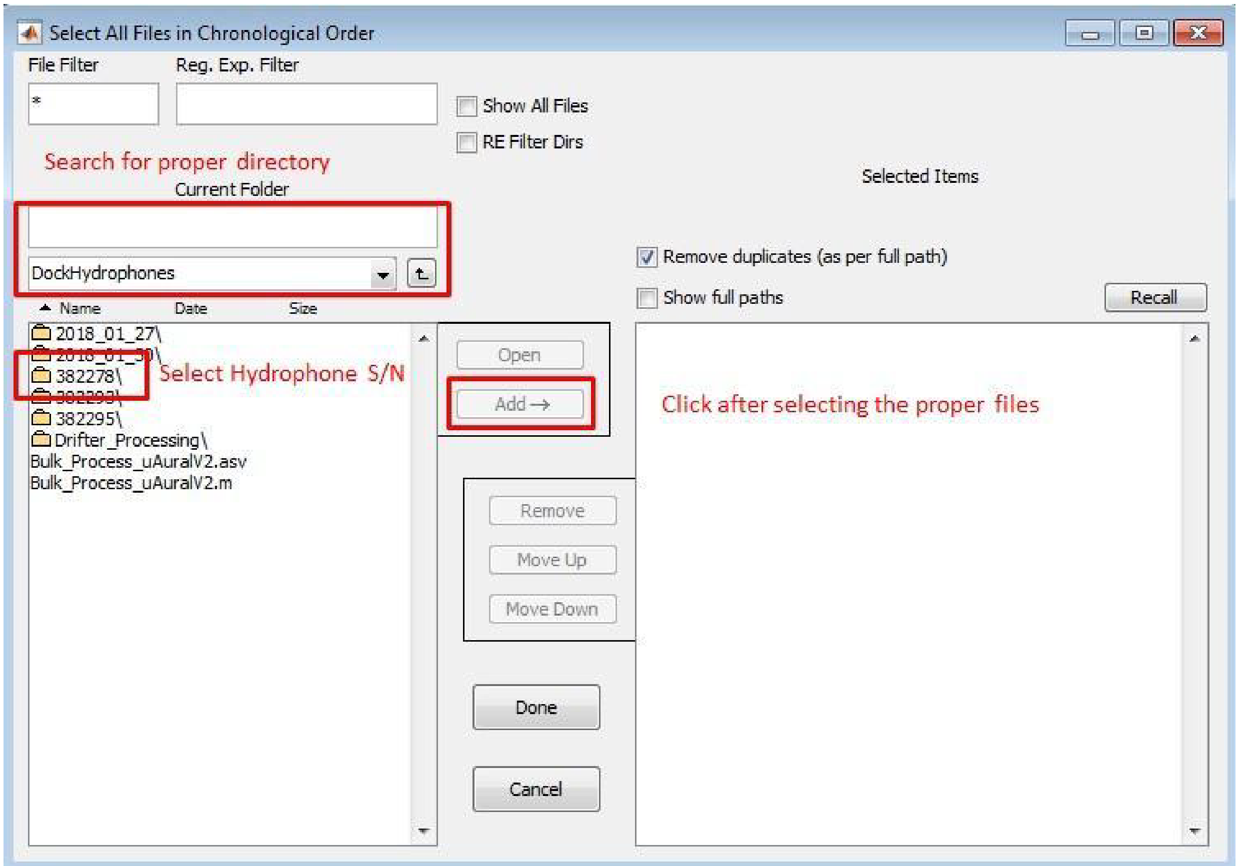


Figure 37. -- The data selection dialog box for bulk processing of the hydrophone measurements. Search the directories to identify the proper data. Double click on the proper hydrophone serial number and select all of the .wav files in the directory.

This process should be repeated for all three hydrophones at which point six .mat files and three .png files should be stored in the ...\Hydrophones\Processed_Hydrophone_Data directory. Figure 39 shows an annotated example of one-third octave band and broadband sound pressure level data from a radiated noise experiment. In the processed acoustic data the six vessel passes should be clear for at least some frequencies. Times associated with increases in noise should correspond to the known times of the vessel passes (check deck log). A period of relatively low-noise prior to beginning the passes (i.e., when the vessel was away from the FSVPAD in neutral) should also be clear. If neither of these is true, then only a few explanations exist:

1. The ambient noise conditions were too noisy for a successful test.
2. The hydrophones did not operate properly.
3. The ship was not noisy enough to be measured.

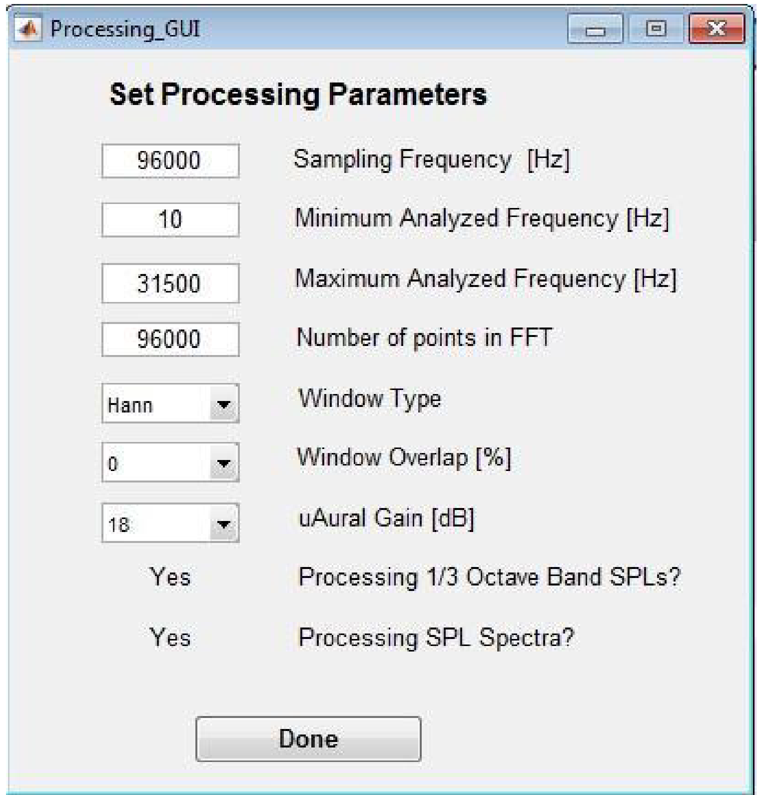


Figure 38. -- Graphical user interface for the input of processing parameters. When the GUI opens it loads default parameters based on the sampling rate of the hydrophones. No changes should be made to the default parameters unless the gain settings have been changed on the *μ*AURAL data acquisition boards or the user desires specific output formats.

If measurements of one-third octave band (TOL) sound pressure levels, (Fig. 39; top panel) regularly exceed values of 100 dB re 1 *μ*Pa across a range of frequencies even when the ship was known to be far (e.g., 1 km) from the FSVPAD, ambient noise is likely the problem. Wind, precipitation, or anthropogenic noise (e.g., ships even at ranges exceeding 1 km if large) could all be interfering with the test. If measured noise levels generally fall into the range of those shown in the top panel of Figure 39 hydrophone problems are not likely to be the explanation, but the contrary is true of values that are always similar to upper and lower bounds of the colorbar. Regardless of any concerns, continue processing the data given that most of the processing has been completed and the results will help to identify any problems or lack thereof.

V.IV Radiated Noise Level Calculations

Radiated noise is calculated by executing the SL_Calculation.m script (line 36 of the master script). To produce these results, this code combines the GPS and acoustic data sets, aligns the timestamps, calculates ranges between the FSVPAD and ship by including the GPS offsets from the acoustic center of the vessel, and accounts for the effects spreading and attenuation and the measured noise levels. In addition to plotting the radiated noise, results are also compared to the noise recommendations for research vessels (Mitson 1995).

When the SL_Calculation.m is executed, it will first ask the user to link to the directory with all of the MATLAB processing functions. Next, a window will open and prompt the user to select the processed GPS data .mat file. This file is located in the project's GPS Results directory and has the name YYYYMMDD_THHMMSS_Processed_GPS.mat.

As with previous processed data (e.g., the calibration data; Fig. 32), select the proper file, click the "Add" button, and press "Done". Once selected, the code immediately calls a dialog window (Fig. 40) that asks for the user to input the GPS offsets from the acoustic center of the vessel. This offset can be entered in units of either meters or feet and the drop-down menu should be used to specify the units. Once entered, press "Return." The GUI will briefly produce a dialog stating the GPS offsets. If they were entered incorrectly the code should be closed and restarted. To stop the code and restart click in the MATLAB command window and press Ctrl+C.

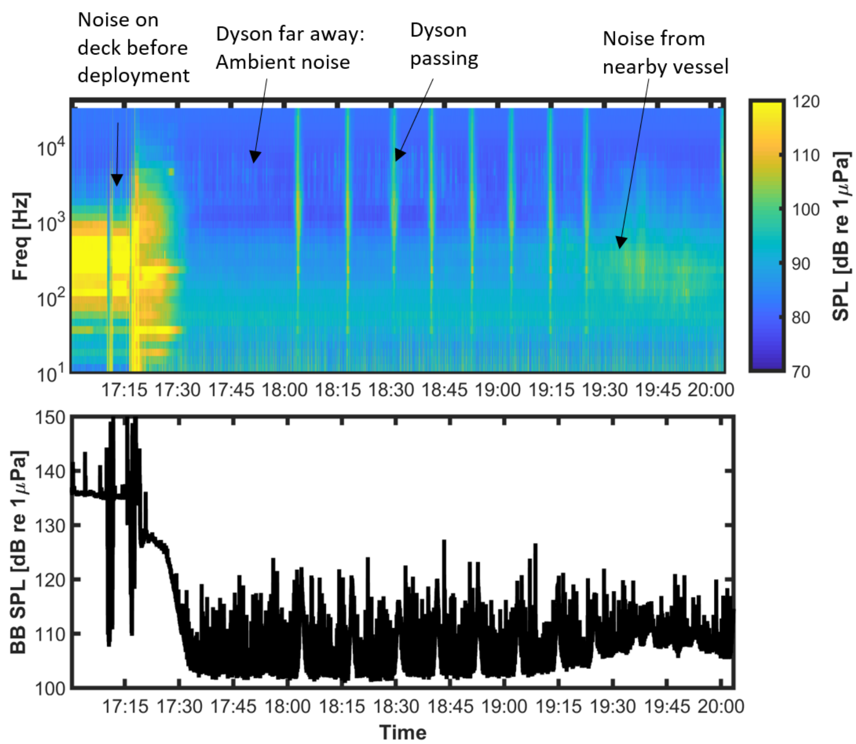


Figure 39. -- Annotated example of noise data from a single hydrophone during radiated noise tests of the NOAA ship *Oscar Dyson*.

After the GPS offsets and test configuration are entered into the window, a new user interface opens (Fig. 41a). Click the "Plot GPS" button in the upper right corner of the interface and a new dialog window appears. This dialog window (not shown) asks the user "Was the first pass on the port or starboard side of the vessel?" Select the correct option and the dialog will close. By entering the proper GPS offsets and the aspect of the first pass the additional processing functions recalculate the distance to FSVPAD from the vessel for the entire GPS time series. Going forward, whenever the distance between the vessel and the FSVPAD appears the calculations will have accounted for the horizontal distance from the FSVPAD to the acoustic center of the vessel.

To proceed with processing, the user selects relevant portions of the GPS time series. The user is required to identify data points before and after each pass by clicking on the “Select Data for Pass X” buttons and following the instructions. For example, when the user selects the “Select Data for Pass 1” button the interface prompts the user to select data before and after the relevant CPA. Points should be selected in chronological order. That is, the point where the vessel is approaching the FSVPAD should be selected prior to the point where the vessel is moving away from the FSVPAD. The underlying code will use the data points to automatically identify the minimum range near the selection and identify the relevant data windows. Therefore, the user selections should include periods both before and after the successive CPAs during which the range to the drifter is greater than 300 m but less than 600 m to ensure that the minimization functions only search data associated with that pass. Once the two data points have been selected, the code will identify the times associated with the processing window and calculate the range at the CPA. The interface and plot are then updated to include this information.

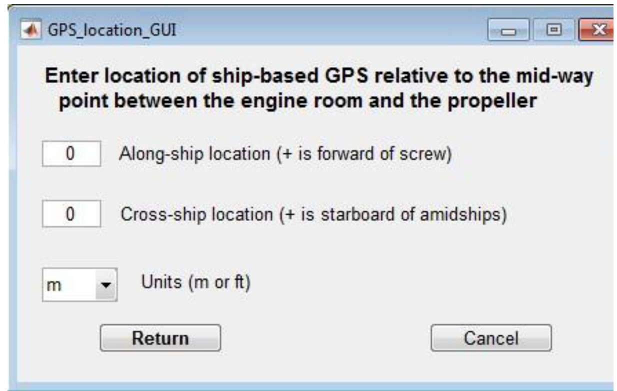


Figure 40. -- The graphical user interface for entering the distance offset between the ship-based GPS unit and the ship’s propellor. Default values for along- and cross-ship offsets are 0 m. Input values in feet are converted to meters before passing the data to the processing code.

The user should progressively enter data for all of the passes using the buttons. If the cross-hairs revert to an arrow while selecting individual passes proceed anyway. The arrow itself can still be used to select data. Once all of the passes have been entered, or if a mistake is made, press the “Finished Selecting Data.” This button will trigger a dialog box asking the user if the results look good. Click either “Yes” or “No.” Clicking “Yes” allows the code to proceed whereas “No” resets the GUI and allows the user to re-select the relevant data.

If more than six passes are available, the user should select the six best passes (three per aspect) in chronological order. An example of how the GUI appears following the manual entry of data points is shown in Figure 41b. At this point the GPS data will be saved to the workspace to be used for post-processing of the radiated noise data. The code will also create a dialog box noting that the CPA timestamps have been exported. A file, PassNumber CPA Time Data.mat, is saved to the GPS Results and can be manually reviewed later, if desired, by users familiar with MATLAB. A figure similar to Figure 41b with the range and bearing data is also saved to the GPS Results directory.

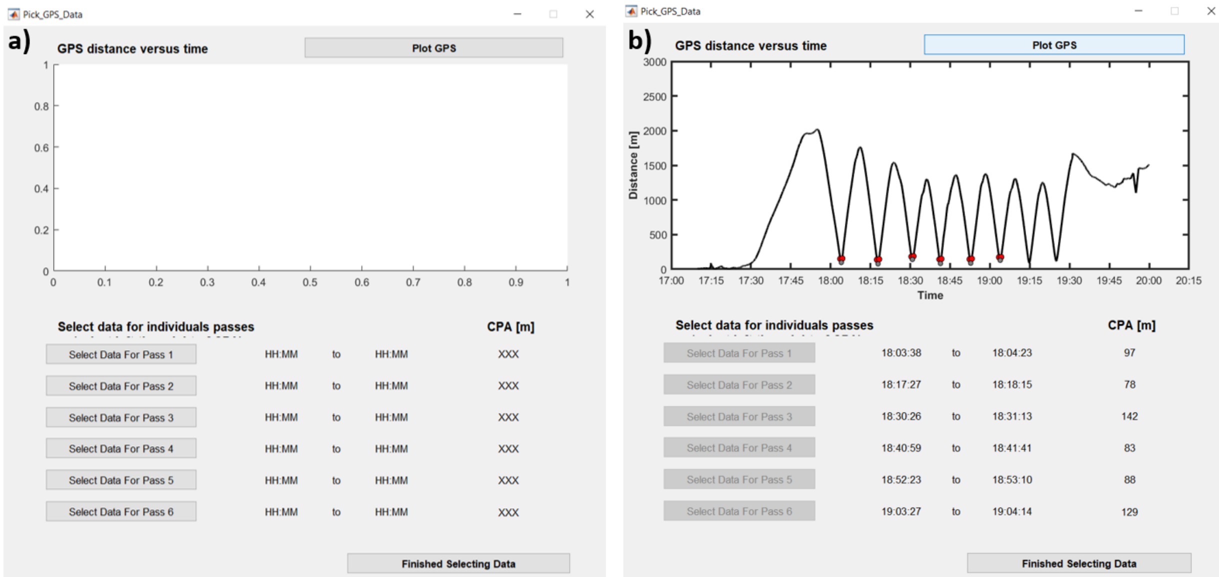


Figure 41. -- (a) GUI for selection of the GPS data for the closest points of approach during the passes. The “Plot GPS” button in the upper right corner loads and plots the GPS data with distance on the y-axis and time on the x-axis. The user can select the data associated with each pass by pressing the “Selected Data for Pass X” buttons. Once completed, the “Finished Selecting Data” button triggers a series of dialog windows that are used to confirm that the user is happy with the data. (b) An example showing the interface after GPS data has been processed. The CPAs shown in the interface account for the entered GPS offsets in addition to the aspect of the vessel during the passes.

At this point post-processing of the GPS data is complete and the code moves on to analyzing the hydrophone data. The user is prompted to load in the processed data from the shallow hydrophone first. The relevant .mat file (e.g., Hydrophone 283393 TOL.mat) is in the \Hydrophones\Processed _Hydrophone Data directory. Add the file corresponding to the shallow hydrophone data by selecting the proper serial number and click done. A few dialog windows appear, prompting the user to “select a 2 min. period when the vessel was in neutral and far from the ship.” Click “OK” to close the dialog window. A period representing the ambient noise conditions during the radiated noise tests will be determined. Review the two-panel figure that includes the range to the FSVPAD as a function of time and a spectrogram (noise levels as a function of time and frequency) in the lower panel. Use the lower panel of the figure to select a period when the vessel was far from the FSVPAD and noise levels were low (darker colors). Reviewing the deck log will remind the user when the vessel was in neutral and far from the FSVPAD if it is not immediately obvious from the figure. An example of this figure and where to click to select a relevant period is shown in Figure 42.

Once the ambient noise period has been selected the code prompts the user to select the proper .mat file for the middle hydrophone. Once again, navigate to the hydrophone results directory, select the data associated with the middle hydrophone serial number, press “Add,” then “Done.” Another dialog window prompts the same for the deep hydrophone. At this point the code proceeds to process data from all the hydrophones and calculate the ambient and radiated noise parameters.

The next step is to execute SL_plots.m on line 43 of the master script which prints numerous figures. The final step is to run SL_text_output.m on line 46 which produces text files summarizing the data and CPA distances. These figures and files will be used for quality control purposes and to write a report about the measured radiated noise. Descriptions of these figure files and how to use them are described in the next section.

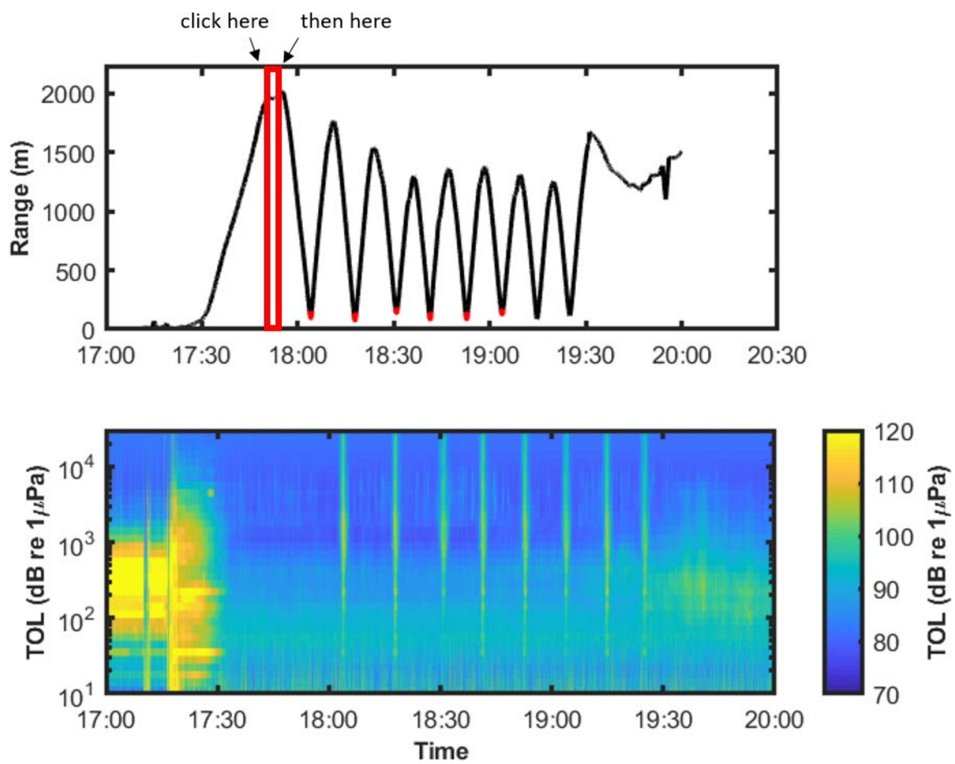


Figure 42. -- (Top panel) Range between the acoustic center of the ship and the FSVPAD as a function of time. (Bottom panel) Spectrogram of the measured noise from the shallow hydrophone. The top panel shows an example of where to click (red box and arrows) when selecting a relevant ambient noise measurement.

VI Reviewing Results and Reporting

This section discusses the results produced by the post-processing scripts and how to review the results with an emphasis on quality control. The purpose of this quality control is to identify any issues with the results while there may still be time to perform another test, if necessary. In addition, this section discusses the important results that should be included in a report. In quality control and reporting it is important to identify the operational conditions and any potential problems or suspect results. Adequately conveying these concerns ensures that those not involved with the experiment will be able to understand the data that they are reviewing.

Noise-reduced vessels are very quiet, and it is important to make sure that sufficient quality control is conducted to ensure that sources of noise other than the vessel are excluded. In many cases, a noise-reduced vessel is likely to be undetectable due to noise levels in some frequency bands, particularly at low frequencies. To facilitate an unbiased analysis, the post-processing scripts produce figures that help flag potential problems and text files summarizing the results.

VI.I Results and Quality Control

This section discusses the figures and .txt files that are created to summarize the results of the radiated noise tests. These files are derived from tests on the NOAA ship *Oscar Dyson*, a noise-reduced fisheries survey vessel. The tests were performed off Kodiak, Alaska, in July 2023.

The name of each output file is noted and the information it contains is described. The files are presented in a logical order (as opposed to alphabetically) to facilitate the review for quality control purposes.

The key considerations for data quality control are given in each case. Under good conditions the results will be qualitatively similar to those presented here. Regardless of whether a measured vessel is noise quieted or relatively noisy, concerns should arise when patterns observed vary considerably from the results presented here. The descriptions in this section should help users identify potential problems.

CPA and TOL.png: This figure (Fig. 43) contains two panels. In the top panel the range from the ship to the FSVPAD is plotted as a function of time. The black line shows the entire deployment period, the red values highlight the times near the closest-point-of-approach that are used in the radiated noise levels calculations, and the gray highlights the period used for ambient noise measurements. The bottom panel shows a spectrogram of the one-third octave band sound pressure levels associated with the same times as the ranges in the top panel. In this case, there are clear increases in noise levels are associated with the vessel CPAs above ~30 Hz.

Review both panels of the figure. If the ranges and noise levels as a function of time are consistent with expectations (e.g., Fig. 43) continue reviewing the results. If the ranges in the top panel are not consistent with what was known to have occurred during the experiment incorrect times may have been selected for processing. If the lower panel does not show clear increases in noise levels associated with vessel CPAs there are a number of possible problems. (1) The radiated noise from the vessel could be of low amplitude (particularly on a noise-quieted vessel). (2) Levels of ambient noise may have been too high. (3) The hydrophone timestamps may have been out of alignment. The most likely reason for this would be that the computer was not synced with an Internet time server prior to programming the hydrophones. Nothing can be done to fix the problem if points (1) or (3) were the source - repeating the test is necessary. However, further investigation of the results figures should reveal if ambient noise levels were problematic (point 2).

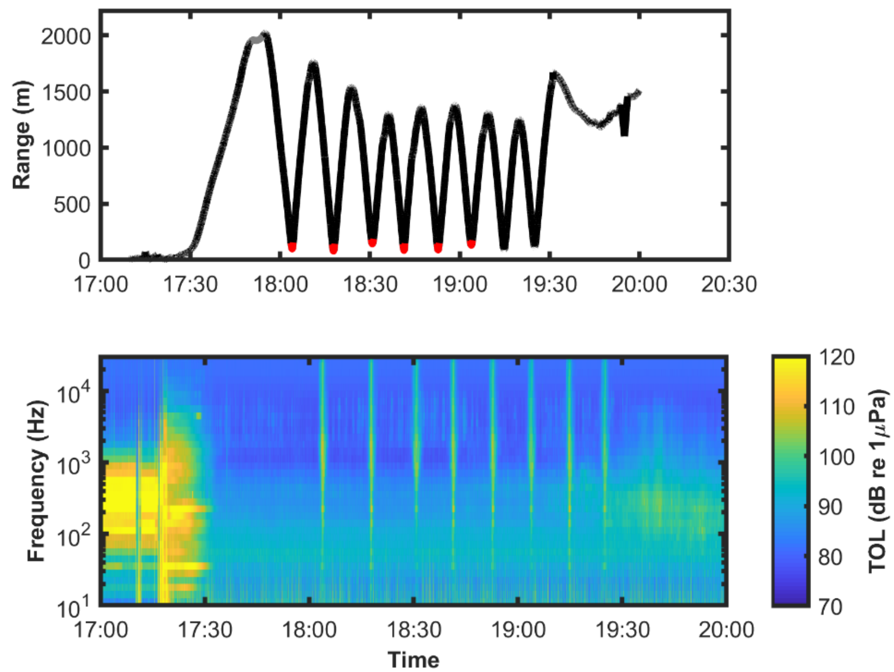


Figure 43. -- CPA and TOL. The gray shading on the top panel shows when ambient levels were measured. The first 6 passes were analyzed.

Ambient_vs_CPA.png: This figure (Fig. 44) is useful for comparing ambient noise to the one-third octave band sound pressure levels (TOL) during one of the CPAs using each hydrophone. The black line shows the ambient noise levels and the gray lines show one second averages of the measured radiated noise (i.e., not corrected for range) from the vessel.

This figure primarily serves to provide an early indication of whether the signal-to-noise ratios might be a problem at some frequencies. The ambient noise curve provides a context for knowledgeable users but is not strictly necessary. If vessel passes were clear in the CPA and TOL figure some portion of the gray line should be well above the black line.

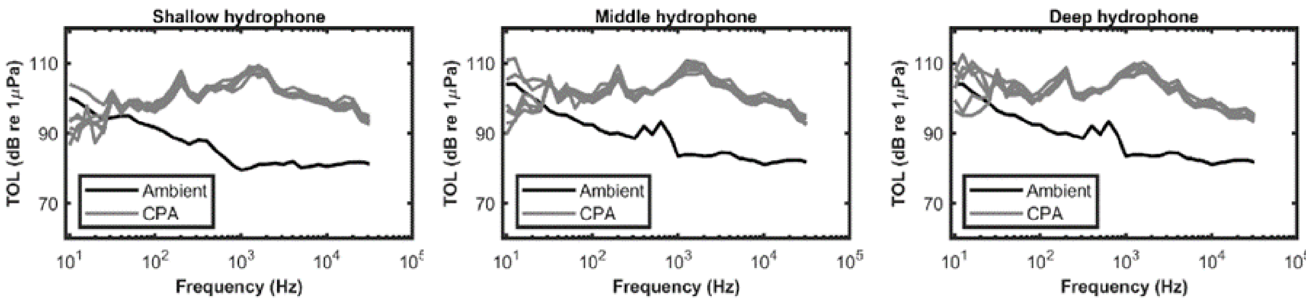


Figure 44. -- Ambient noise and CPA.

Noise Test SNRs.png: This figure (Fig. 45) shows the signal to noise ratios for the radiated noise tests for the averages derived from each hydrophone. The y-axis is the one-third octave band sound pressure level, which is plotted against the one-third octave and center frequency. The radiated noise measurement standard (ANSI 2009) notes that frequencies where SNRs are less than 3 dB should be excluded from analysis because these are effectively measurements of ambient noise and no substantive conclusions can be drawn about vessel noise at these frequencies. For SNRs between 3-10 dB an ambient noise correction is applied. For SNRs >10 dB radiated vessel noise is dominant and no correction is applied.

Given the requirements laid out in the standards, the SNR curves are plotted over “patches” with a “stoplight” color scheme. Values falling into the red area are not suitable for analysis. Areas falling within the yellow area (SNRs between 3-6 dB) are considered suspect, but are corrected and retained. Portions falling within the green area are corrected as dictated by the standard but are considered high quality measurements of the radiated vessel noise. In this case, test frequencies below 30 Hz had SNRs that were below 3 dB whereas the higher frequencies all had sufficient SNRs to qualify as “good” measurements.

Review this figure to determine the SNRs of the radiated noise measurements at different frequencies. Proper interpretation of the final results is dependent on adequately flagging results with low SNRs. Different vessels will have unique acoustic signatures and SNRs will vary with frequency based on the vessel and ambient noise conditions. Having some data points with low SNRs (typically clustered at similar frequencies) is not itself problematic. However, if most or all the frequencies fall into the “orange” or “red” categories the tests should be repeated. One exception to this would be in the case of measurements of a vessel known to be extremely low noise. In those cases, low SNRs may be expected. Cases like this, where the radiated noise levels still fall below the ICES quite vessel guidelines (Mitson, 1995), are flagged in other result summaries (see the RadiatedNoise_vs_ICES_Spec figure and Radiated Noise Results.txt file discussions for details). The report should specifically note that any measurements are corrected for noise at any frequency where the SNRs are between 3-10 dB.

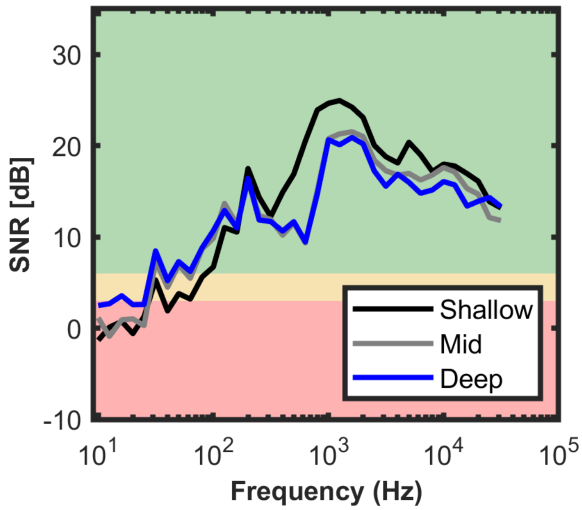


Figure 45. -- Noise Test SNRs.

FORMAL Noise Test SNRs.png: This graph (which is not shown as a figure in this document) is identical to Figure 45 except the “stoplight” colored patches have been removed. This figure is printed strictly as an alternative version of the Noise Test SNRs figure that could be used in a more formal setting (e.g., a technical report or publication). No further quality control review is needed since the relevant information is contained in the Noise Test SNRs figure.

Radiated Noise All Passes.png: This figure (Fig. 46) includes three panels plotting the average radiated noise levels as a function of frequency, accounting for losses based on the range to the FSVPAD, for all passes and hydrophone depths. Note that this figure has not been filtered for low-signal-to noise cases (i.e., cases where noise rather than the vessel is the primary contributor to the observations). Each panel includes multiple lines that correspond to individual passes. Where no significant variability is observed between passes, distinguishing between these lines is difficult (a positive result). Easily identifiable outliers suggest a problem with an individual pass and these issues will be flagged in the Radiated Noise Results.csv file and the Range of Radiated Noise Measurements by Depth figure described below.

Quality control of this figure should focus on outliers. If no outliers exist, the unique lines in each of the panels should be relatively difficult to distinguish. Where one or more lines are clearly identifiable, this suggests that problems (e.g., changes in ambient noise or vessel operating conditions) likely exist. The figure alone cannot be used to identify the outlying pass. This information is automatically generated and included in the Radiated Noise Results.txt file. Where SNRs are sufficient across a broad range of frequencies and no outliers are present, good radiated noise curves are generally expected.

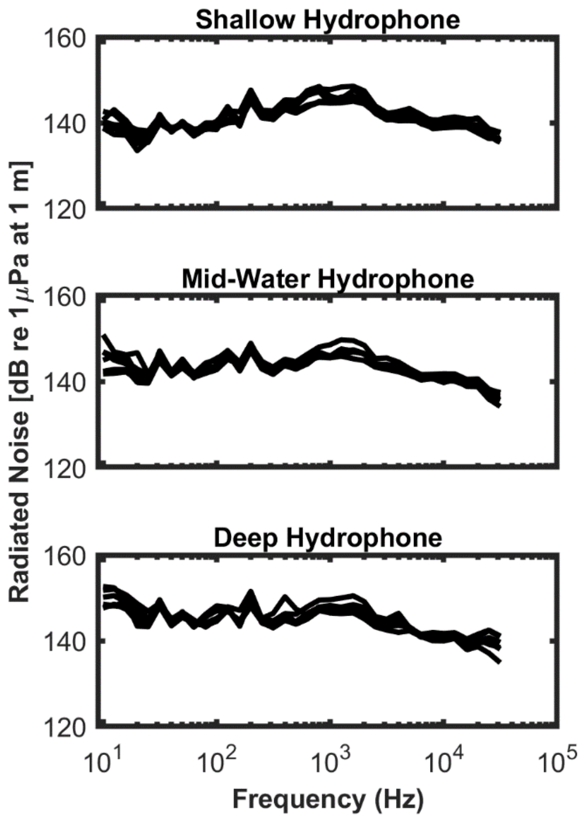


Figure 46. -- Radiated Noise All Passes.

Range of Noise.png: This figure (Fig. 47) plots the range of the radiated noise curves for all passes as a function of the one-third octave band center frequencies. Here the range is defined as Range = $|TOL_{max} - TOL_{min}|$, where TOL_{max} and TOL_{min} are the maximum and minimum values observed during any of the passes for a hydrophone at a given depth. No signal to noise ratio exclusion criteria have been applied. This figure is included because the ANSI radiated noise standard requires the reporting of individual measurements where the range varies by more than 3 dB. Further information is available in the Radiated Noise Results.csv file.

As with other figures, quality control review of this figure should focus on cases with outliers (frequencies where the range is greater than 3 dB). These outliers will appear above the dashed line in the figure. Note, however, that outliers greater than 3 dB are only relevant when they correspond to measurements with sufficient SNR for inclusion in the radiated noise curves (reference figures with “stoplight” presentation). If outliers are retained in the analysis, the justification should be included in the report. An example where this approach might be used is when there are relatively small outliers (< 6 dB) but the radiated noise curve still meets noise quieted vessel recommendations. In these cases, discuss the outlier in the report but note the measurements were still below specification.

If questionable or invalid data exist, there are multiple potential solutions:

- Identify the outlying pass and reprocess the data using a different pass with the same vessel aspect (if more than six were performed during testing).
- Identify the pass that produced the outlier and reprocess the data excluding this pass.

The report should include the total number of passes included for each vessel aspect (i.e., starboard and port) and identify any passes that have been excluded. Using fewer than six passes increases the uncertainty in the radiated noise curve and does not fully comply with the measurement standard.

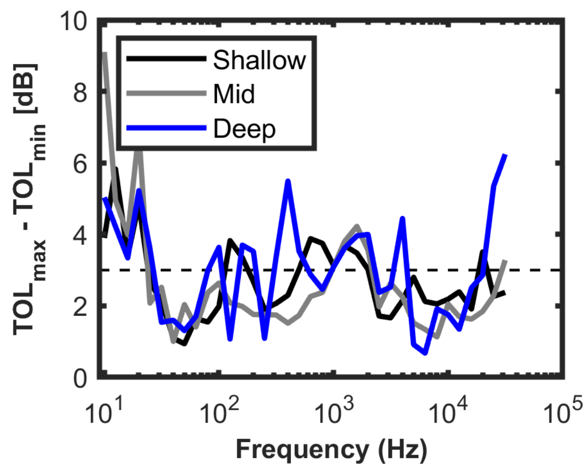


Figure 47. -- Range of Radiated Noise.

RadiatedNoise vs ICES spec.png: This overview figure (Figure 48) shows the observations color coded by SNR in relation to the ICES recommendation. Measurements with < 3 dB signal to noise ratio are invalid and represent the upper bound for ship-generated noise (as vessel noise is not detectable above ambient noise levels). Note that levels are one-third octave levels corrected to a 1 Hz bandwidth as per the ICES recommendation.

The Radiated Noise figure should be considered in the context of ambient noise and SNR. This is because noise levels can vary considerably based on vessel type, vessel design, operating conditions, and other variables. As such, the amplitude of the radiated noise level curve alone is not a powerful indicator of good results from the experiment. If frequencies are plotted in red or orange, SNRs were low. If users can identify any obvious reason for low SNRs (e.g., wind, breaking waves, anthropogenic noise sources, or precipitation) users should consider repeating the test. The one exception is if the SNRs are low but the vessel meets the ICES recommendation. In those cases, SNRs may be low, but the vessel does not produce high amounts of radiated noise, thereby resulting in the low SNRs.

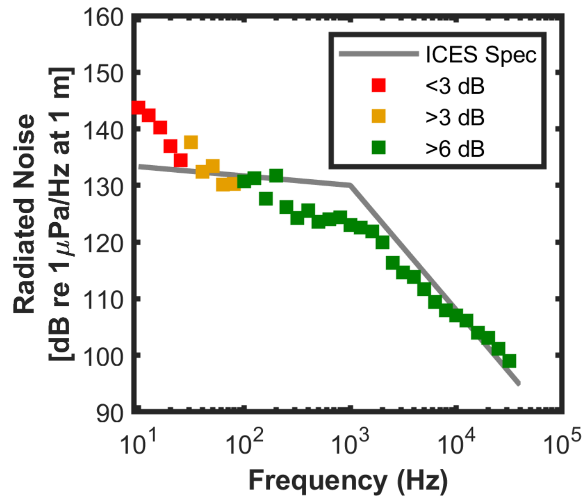


Figure 48. -- Radiated Noise versus ICES spec.

Formal Radiated Noise.png: This figure (Fig. 49) shows the average radiated noise curve in one-third octave band sound pressure levels calculated (correcting for ambient noise) from all valid passes and all hydrophone depths. Frequencies where all hydrophones are > 3 dB SNR are included. In cases where two of the hydrophones have an SNR > 3 dB, only those hydrophones are averaged. For example, in the case of the 2023 Dyson measurement described below, at 40 Hz, the shallow hydrophone was excluded (e.g., see Fig. 49 as well as the summary text file described below). No further quality control review is needed since the relevant information is contained in the RadiatedNoise_vs_ICES_Spec figure.

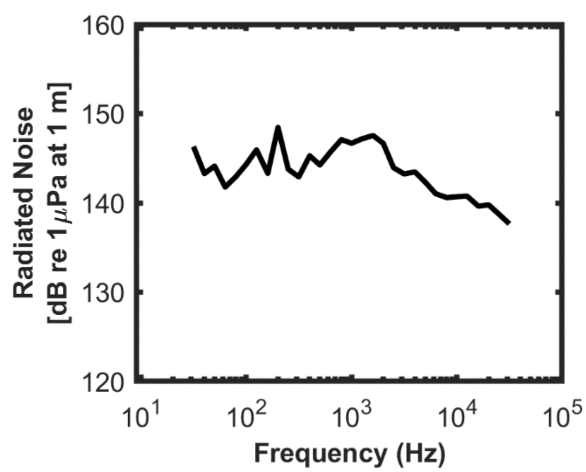


Figure 49. -- Formal Radiated Noise.

Formal Radiated Noise vs ICES Spec.png: This figure (Fig. 50) shows the final radiated noise results with the ICES recommendation drawn on the figure. Note that levels are one-third octave levels corrected to a 1 Hz bandwidth as per the ICES recommendation. No further quality control review is needed since the relevant information is contained in the Radiated Noise_vs_ICES_Spec figure.

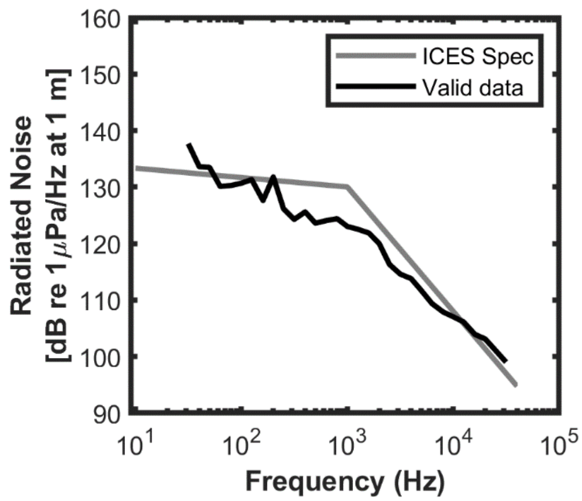


Figure 50. -- Formal radiated noise vs ICES Spec.

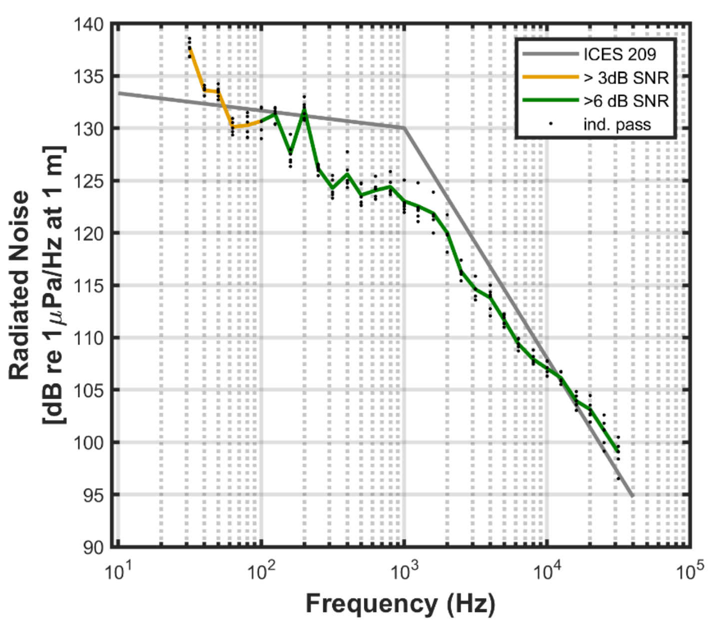


Figure 51. -- Result overview versus ICES Spec.

Result_overview_vs_ICES_Spec.png: This overview figure (Fig. 51) shows the final radiated noise results with the ICES recommendation drawn on the figure. Results are color-coded by SNR and the observations from each pass are shown by the dots. Note that levels are one-third octave levels corrected to a 1 Hz bandwidth as per the ICES recommendation. Quality control review should focus on identifying whether individual passes are outliers.

Radiated_Noise_Results.csv: This text file is written to the ...\Results directory and provides quantitative information that can be archived as a quantities record of the results, and used for additional analyses. This file should be provided with the report and used to investigate any potential issues identified during quality control. All sound pressure levels are in units of dB re 1 μ Pa Hz^{-1} to be consistent with the ICES recommendation.

The results file has the following columns:

Frequency – Center frequency of each third octave band
ICES_209_SL – Sound pressure level of ICES 209
Bandwith – Bandwith of third octave band in Hz
TOL_SPL_RAW – Raw sound pressure level averaged over all hydrophones (no filtering, includes invalid data)
TOL_SPL_3dB_SNR – Sound pressure level averaged over all hydrophones with SNR > 3 [i.e. valid data]. Results are averaged over all passes and represent the final noise measurement result.
SL_relative_to_ICES – observed deviation relative to the ICES reccomedation (i.e., ICES_209_SL subtracted from TOL_SPL_3dB_SNR).
SNR_shallow – Signal to noise level in dB relative at the shallow hydrophone
SNR_middle - Signal to noise level in dB relative at the middle hydrophone
SNR_deep - Signal to noise level in dB relative at the deep hydrophone
num_hyds_used_SNR3dB – Number of hydrophones averaged when calculating TOL_SPL_3dB_SNR
index_all_hyds_SNR6dB – index for high-quality data: 1 if 3 hydrophones with SNR > 6 dB were averaged to compute TOL_SPL_3dB_SNR, 0 otherwise
SPL_passx – results for individual pass x (Sound pressure level averaged over all hydrophones with SNR > 3 for a given pass)

CPA_distances.txt: This text file is written to the ...\Results directory and provides a list of distances between the FSVPAD and the vessel at the closest point of approach (CPA). If any CPAs are less than 80 m but more than 120 m, the data should be reprocessed without those passes or the experiment should be performed again. Should users choose to present the data using more variable CPAs, it should be noted in the report.

CalibrationResults.txt: This file is written to the ...\Processed Hydrophone Data directory and contains the results of the processed pistonphone measurements. Each line is associated with a specific hydrophone. The following line shows an example:

GOOD CAL, Hydrophone 382293 (-164.0 dB re 1V/uPa);
Pistonphone Signal 147.1 dB re 1 uPa, Expected: 146.1 dB.

The first comment will highlight whether or not the measurements suggest the pistonphone may be damaged or some other factor resulted in a poor measurement. Therefore, the line starts by stating either “GOOD CAL” or “BAD CAL.” Next, the hydrophone serial number and manufacturer-specified sensitivity are noted. The “Pistonphone signal ...” portion of the line notes the measured sound pressure level, which is then compared to the expected sound pressure level given the pistonphone and atmospheric pressure offset. Where “good calibrations” are noted, there are no identifiable concerns. Where a bad measurement is logged this should be reported. If bad measurements are reported in this, but the test results are broadly consistent across the hydrophones, it is an indication that there was an issue with the pistonphone measurements

VI.II Reporting Results

A report describing ship radiated noise tests with the FSVPAD should include information about the vessel and its operations, conditions under which it was tested, any notes regarding events that could influence the measurements (e.g., another vessel in the area), and issues flagged by the analysis software. Given the number of factors that could affect the results, it is not possible to cite all of the possible factors that should be reported if they occur. If the user has information regarding the test that could be potentially useful in interpreting the results they should be included in the report. If previous radiated noise measurements are available for this vessel, the new results can be compared to the previous measurements to provide context and an understanding of temporal changes in radiated noise. This section briefly highlights examples of the information that should be reported for FSV measurements, and the following section includes an example report that can be referenced for clarification. Where measurements are made on vessels other than NOAA FSVs the user will need to make the decision about what information should be included.

Vessel and vessel characteristics: If the tests were performed on an FSV, note the name and that it was an FSV. If a non-FSV is being tested, note as much relevant information about it as possible. Critical characteristics include the vessel type (e.g., research vessel), vessel dimensions (beam and length overall), draft, motor/engine characteristics, and weight. Note the original design and purpose of the vessel if its current use varies from that of the original design (e.g., a fishing vessel re-purposed as a research vessel).

Test Conditions: Environmental conditions and the operational status of the vessel during the test should be reported. Relevant environmental test conditions include the water depth in the test area, wind speed (as quantitative as possible), waves (estimated wave height or sea state) with a qualitative description of wave breaking or foam, and precipitation (type and rate). In addition, any potential sources of incidental noise should also be noted. Examples include, but are not limited to, human activity such as vessels or marine mammals. Since many vessels are noisy, the presence of any visually identified vessels should be noted. Any AIS transmitting vessel within 5 km should be recorded, including the type of vessel (e.g., tug, fishing, shipping), if possible.

The operational state of the vessel should also be noted in as much detail as possible. Record which vessel aspect was measured during each of the individual passes (e.g., starboard first then alternating throughout the test). The engine RPM, the generator configuration, and speed-over-ground should be reported. If the crew is aware of any operational issues that might result in an identifiable signature, this should be noted (e.g., a noisy bearing producing sound related to the propeller rotation rate).

GPS Location and Offsets: Provide a description of the position at which the GPS was secured on the vessel. In addition, describe the method used to calculate the offset between the GPS and the acoustic center of the vessel (i.e., distance between the GPS location and half-way between the engine room and propeller).

Hydrophone Depths: If standard procedures were followed then the depths of the hydrophones are estimated as 27 m, 58 m, and 100 m, respectively. Record any changes and resulting hydrophone depths that resulted from any non-standard configuration of the FSVPAD.

Radiated Noise Measurements: A summary of the radiated noise measurements and any concerns flagged in the output constitutes the largest portion of the report. The following itemized list summarizes the results and discussions that should be included.

- Vessel pass ranges: The calculated ranges written to the Radiated Noise Results.txt file should be reported as follows: The CPAs during the passes in chronological order, were XX, XX, XX, XX, XX, XX m.
- Signal-to-noise ratios: The SNR figure should be included in the text. For purposes of the report the figure with the "stoplight" patches (Fig. 43) should be included. A discussion of the SNRs should include the frequencies at which SNRs were adequate (i.e., SNR > 10 dB), marginal (i.e., 3 dB < SNR < 10 dB), and insufficient (SNR < 3 dB) under the test conditions.
- Radiated noise results: The radiated noise overview measurement figure (i.e., Fig. 51) should be included in the report. This figure includes the flags noting the SNRs under test conditions. Radiated noise levels (values of y-axis) and frequencies (x-axis) of all measurements with suitable SNRs (the orange and green portions of the line) as well as any outliers should be discussed. The results should be discussed in the context of the ICES recommendation and any previous radiated noise measurements.
- Flagged Concerns: If outliers exist and are included in the files they should be noted in the report. Even if passes were excluded from the analysis because of their status as outliers the number of passes falling into this category and their reason for exclusion should be reported.

CalibrationResults.txt: Reporting should discuss whether pistonphone measurements were consistent with expectations. Where "bad" results were identified for only one or two hydrophones, the results figures should be reviewed for consistency between the hydrophones. If hydrophone(s) associated with bad pistonphone measurements generally agree with the other measurements this indicates potential problems with the processed pistonphone data. The bad calibration should still be reported but should include the caveat that measurements were otherwise consistent.

At a minimum, the following figures (or similar) should also be included in the report:

- CPA and TOL,
- Noise Test SNRs, and
- Radiated Noise Overview.

Where specific problems were flagged other figures should be included. For example, if SNRs were low, the Ambient vs CPA figure provides evidence to support the assertion that the test was performed properly but background noise conditions prevented radiated noise measurements at some frequencies. Additional plots can be made from the data in radiated_noise_results.csv as needed.

VI.III Example Radiated Noise Test and Report

This section includes an example report on the radiated noise measurements. In this case, the report covers measurements of the NOAA ship *Oscar Dyson*, a noise-reduced fisheries survey vessel. The figures included in this report were included and described in previous sections, but are included again to present a complete example of a radiated noise report.

Radiated noise measurements of NOAA ship *Oscar Dyson* - July 14, 2023

Summary

The underwater radiated noise of the NOAA ship *Oscar Dyson* was measured on 14 July 2023. One-third octave band (TOL) source levels are provided in a single configuration (86 RPM using generators 2, 4) at an average ship speed of ~10.4 knots. Radiated noise is compared with the 'ICES 209 recommendations for research vessel radiated noise' criteria to which the vessel was designed, and to previous measurements of radiated noise at U.S. Navy ranges. *Dyson's* radiated noise level was found to be consistently above previous measurements made under similar conditions at U.S. Navy noise ranges. The ship exceeded the ICES design recommendation both at low frequencies relevant to fish avoidance and high frequencies relevant to sonar performance.

Description of the test

Radiated noise measurements were performed on the NOAA ship *Oscar Dyson* on 14 July 2023 in the Gulf of Alaska during an acoustic-trawl survey. NOAA ship *Oscar Dyso*n is a diesel-electric noise-reduced stern trawler (63.6 m LOA, 15 m beam, full load displacement 2749 tons) designed to meet the ICES recommendation for research vessel radiated noise. These recommendations include limits for low-frequency noise emission in the range of fish hearing (< 1 kHz) to minimize fish reactions, and higher-frequency limits to maximize sonar performance (Mitson 1995). Although the vessel was regularly tested at U.S. Navy range facilities in the past, the last observations were conducted in 2011 due to the cost of measurement at the test facility and impacts on the ship schedule. Given the current noise signature is unknown, radiated noise was measured to establish current levels of radiated noise to inform maintenance, particularly as plans for an upcoming midlife-refit are being developed.

Underwater radiated noise was measured with a portable GPS-tracked free-drifting spar buoy (FSVPAD) equipped with three battery-powered µAural loggers with HTI-96 min hydrophones during an acoustic-trawl survey. The ship's position was tracked using a GPS unit attached to the centerline of the vessel on the aft rail of the flying bridge. CAD drawings of the ship were used to compute an offset between the GPS location and the midpoint between the engine room and propeller. Measurements were made in deep water (1,300 m) off the shelf break in calm sea conditions (swell 1-2 feet, wind < 8 knots). There was no precipitation or vessel traffic in the vicinity of the hydrophones during the test.

The measurements follow established practice that produce results comparable to Naval noise ranges (De Robertis et al. 2013). The measurements reported here comply with grade A of the American National Standards Institute's standard for radiated noise measurement of ships (ANSI 2009) unless stated otherwise. The hydrophones were positioned at depths of 27, 58, and 100 m. Beam aspect radiated noise was measured at a nominal range of 100 m to the array while transiting at 88 RPM using generators 2 and 4. Tests at 93 RPM (the ship condition used as a nominal 11 knot benchmark in previous measurements) were attempted to allow a direct comparison, but these could not be performed with generators 2 and 4 as they exceeded power limits that have been established since the last visit to a Naval noise range in 2011. Tests were thus carried out at the highest speed that could be sustained with generators 2 and 4, which was 85-88 RPM, with an average of 86 RPM. Passes alternated between starboard side (odd numbered passes), and to port side (even numbered passes). Ship speed over ground averaged ~10.4 knots (9.6 knots on even numbered passes, and 11.1 knots on odd numbered passes which used the reciprocal course) in this configuration.

Calibration measurements with a G.R.A.S. 42AA pistonphone with a HTI-96 coupler were used to verify that the hydrophones functioned properly and as a 'reality test' of the complete sequence of data acquisition and processing methods used. After accounting for the offset for atmospheric pressure, the hydrophones were in agreement with the manufacturer-provided hydrophone sensitivities within (0.3, 0.4, 1.4 dB for the shallow, middle and deep hydrophones respectively). Although this calibration is at a single frequency (250 Hz), previous calibrations of hydrophones of the same model at Navy facilities have shown that the sensitivities over the range of 10-750 Hz are within ~0.5 dB of those at 250 kHz, and within ~1.5 dB at frequencies up to 10,000 Hz (see De Robertis et al. 2011, their Fig. 3). In post-processing, the gains were not adjusted for the measured sensitivities as the pistonphones are treated as a system check. Results would have been similar (~0.7 dB higher) if this correction had been applied.

Data were processed and range-corrected as per ANSI (2009), and six vessel passes were averaged. Data at the closest point of approach (CPA) are averaged while the vessel is within an angle of ±30 degrees of the FSVPAD. The measured one-third octave noise levels were compared to ambient noise estimated with the ship at a distance of 1,900 m. Data < 3 dB above ambient levels were discarded. For data 3 to 10 dB above ambient levels, the ambient noise was subtracted from the data. Results are reported as third octave band levels, but when comparisons to the ICES recommendation are made, third octave levels are adjusted to 1 Hz bandwidth (i.e., third octave band level $+10\log_{10}$(bandwidth) as per Urick [1983]).

Radiated noise results

At the closest point of approach, the distances between the *Dyson* and the FSVPAD listed in chronological order were 97, 78, 142, 83, 88 and 129 m (Fig. 52). Some of these separation distances differ from the ANSI standard of 80-120 m CPAs, but outliers were retained as there was no consistent relationship with estimated radiated noise levels and the CPA distance. The hydrophone records are consistent among passes and with the expectation that most third octave bands showed increased levels relative to ambient associated with ship passage (Fig. 53). A comparison between ambient noise levels and the sound pressure levels observed at CPA suggested that, below 30 Hz, vessel noise did not exceed measured background ambient noise (Fig. 54). At 40 Hz, the shallow hydrophone exhibited an SNR of < 3 dB, and only the middle and deep hydrophones were averaged. The range of observations at a given hydrophone exceeded 3 dB in some cases (Fig. 55), particularly for low frequencies where the vessel could not be reliably detected above the noise floor (e.g., Figs. 53-54), and frequencies between 400-1500 Hz which were dominated by shaft-related noise (described below), which may be temporally variable.

Converting the radiated noise values from Figure 53 into equivalent 1 Hz bands (1 Hz bandwidth [i.e., third octave band level +10log$_{10}$(bandwidth)] allows for results to be directly compared to the ICES recommendation (Fig. 55). *Dyson* exceeded the ICES noise recommendation at both the lowest frequencies (by 5.1 dB at 31.5 Hz, 1.3 dB at 40 Hz and 50 Hz, and 0.6 dB at 200 Hz) and the highest frequencies (by 0.3-2 dB at 12,500-31,500 Hz). The observations suggest that *Dyson* is substantially louder than previous measurements (Fig. 57). Although operating 5-8 RPM slower than previous measurements, which will result in lower noise levels, the radiated noise is substantially higher than previous observations at most frequency bands, and similar to elevated noise levels observed in 2006/2007 at low frequencies (e.g., look at 30 Hz in Fig. 57) before work was done on the generator resilient mounts. Given the lower RPM of these tests, the increases reported here should be taken as a minimum estimate of the changes in radiated noise.

Low-frequency noise emission overlaps broadly with that of fish hearing, and the primary concern is that increased noise levels may result in altered fish avoidance and bias acoustic-trawl abundance estimates (Mitson 2009). Dyson's low-frequency (< ~500 kHz) radiated noise is dominated by diesel generator noise (Thomas and Bradley 2005), and investigating whether there have been changes in the levels from the diesel generator or degradation of the resilient generator mounts is a logical next step.

The increases in radiated noise are highest at > 500 Hz. Radiated noise at these frequencies is typically related to propeller cavitation and is likely associated with the known 'shaft modulated noise' that is periodically observed on *Dyson* and results in reduced performance of the EK80 fisheries echosounder used in acoustic-trawl surveys. This noise caused degraded sonar performance in summer 2023 and was clearly audible in the recordings from these noise tests. A similar noise was observed during noise ranging in 2010 where it was absent for much of this test but initiated suddenly and was captured during some recordings. This noise level produced similar levels and frequency-dependence to those observed in this test (Fig. 58). This noise source is associated with poor sonar performance, limiting the effectiveness of the vessel for acoustic-trawl surveys, and requires correction. In recent years (e.g., 2021 and 2023), this has degraded data quality and reduced the effective range of the EK80 sonar used for acoustic-trawl surveys to the point that *Dyson* must slow down on deep-water transects.

Recommendations and Remediation

When released, this report recommended that remediation should be attempted by inspecting and servicing the shaft and propeller components during *Dyson's* winter 2023 repair period.

1) Inspect and collect mount height measurements on all resilient mounts dockside

2) Investigate machinery spaces for sound shorts

3) Collect structure-borne vibration data on rotating machinery while underway

4) Evaluate sonar performance after the winter 2023 repair period

5) Develop a plan to remediate increased noise levels during *Dyson’s* mid-life refit

6) Measure *Dyson’s* radiated noise after the mid-life refit

The elevated high-frequency noise documented here was traced to noise produced by the shaft-line bearing. The bearing was opened, inspected, and repaired while the vessel was in drydock in winter 2023. Subsequent sonar-self noise tests indicated that this shaft-related noise was absent and sonar self-noise improved to normal/acceptable levels similar to those experienced in the past.

Data availability Radiated noise levels and signal-to-noise ratios by pass and hydrophone are provided in the attached radiated_noise_results.txt file [Provide this file along with the report].

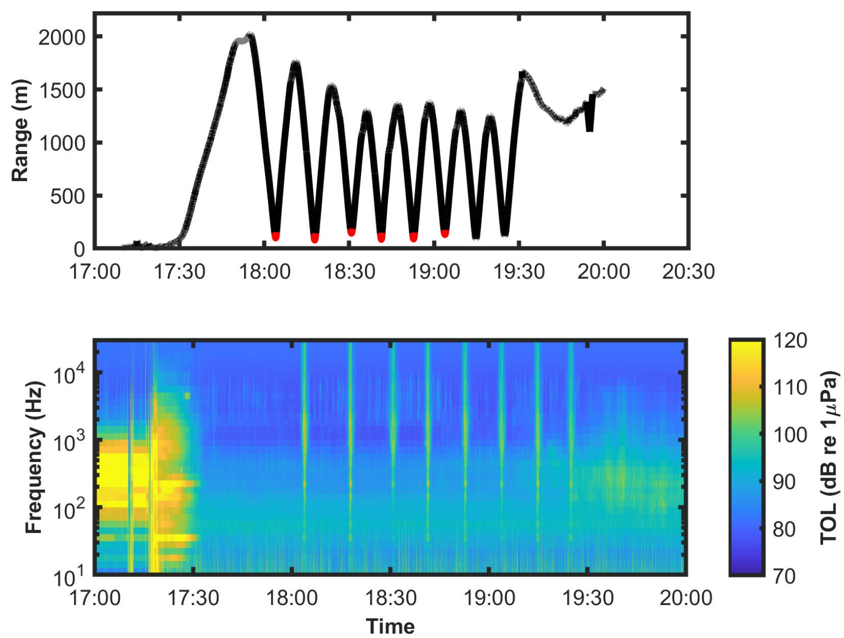


Figure 52. -- Top panel: distance between the NOAA ship *Oscar Dyson* and the FSVPAD as a function of time. The red portions of the line highlight the times used for radiated noise calculations and the gray shows the time used for ambient noise calculations. Bottom panel: one-third octave band SPLs as a function of time during the tests. Changes in measured noise from the vessel based on the range to the FSVPAD are clear throughout the test period.

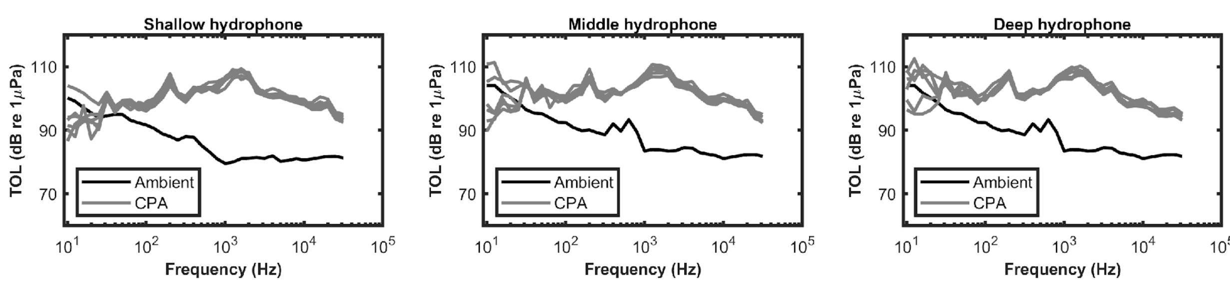


Figure 53. -- Comparison of third octave band radiated noise near CPA and ambient noise at each hydrophone. Noise levels at CPA are similar to ambient at < 30 Hz, indicating that valid measurements of radiated noise are not possible from these data.

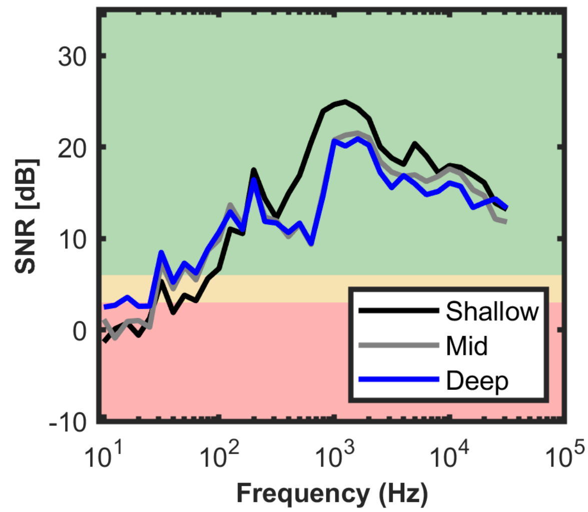


Figure 54. -- Signal-to-noise ratios (SNR) for all hydrophones. The red, orange and green shading denote areas with insufficient (SNR < 3 dB), acceptable (3 dB < SNR < 6 dB), and good (SNR > 6 dB) signal to noise ratios.

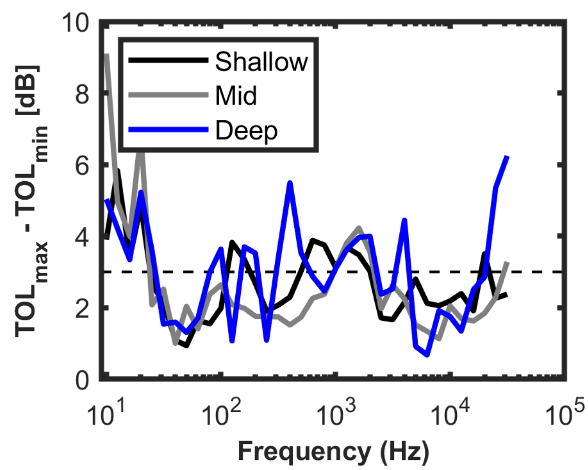


Figure 55. -- Range of estimated radiated noise (i.e., highest-lowest) observed over the 6 passes. A range of 3 dB is indicated by a dotted line. High variability was consistently observed at low frequencies where SNR was low.

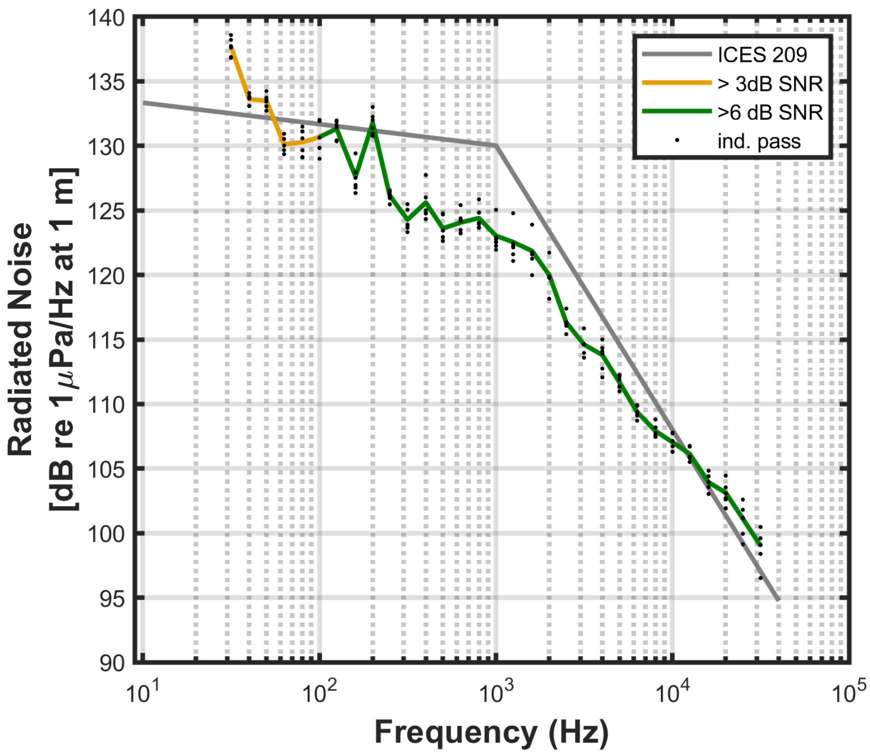


Figure 56. -- Comparison of radiated noise levels from *Oscar Dyson* with the ICES recommendation. Orange denotes SNR between 3-6 dB for at least 1 hydrophone, and green indicates > 6 dB at all hydrophones. Black points indicate measurements on individual passes. In this instance, third octave bands < 30 Hz are not reported as they were excluded due to low signal-to-noise ratios and for the 40 Hz band only the middle and deep hydrophones are averaged as the shallow hydrophone has a SNR < 3.

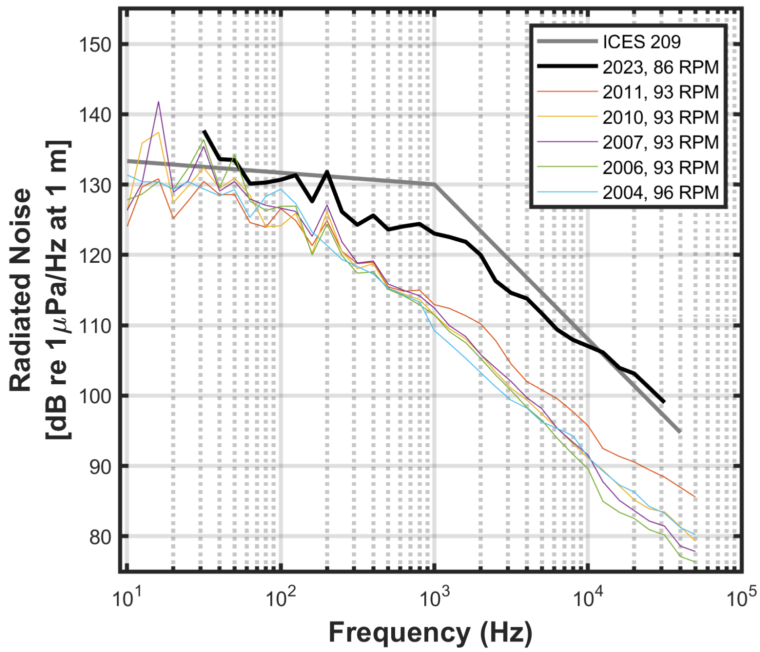


Figure 57. -- Comparison of radiated noise levels from *Oscar Dyson* with previous results at Naval noise ranges and the ICES recommendation. All previous measurements are nominal 11 knot measurements using generators 2 and 4.

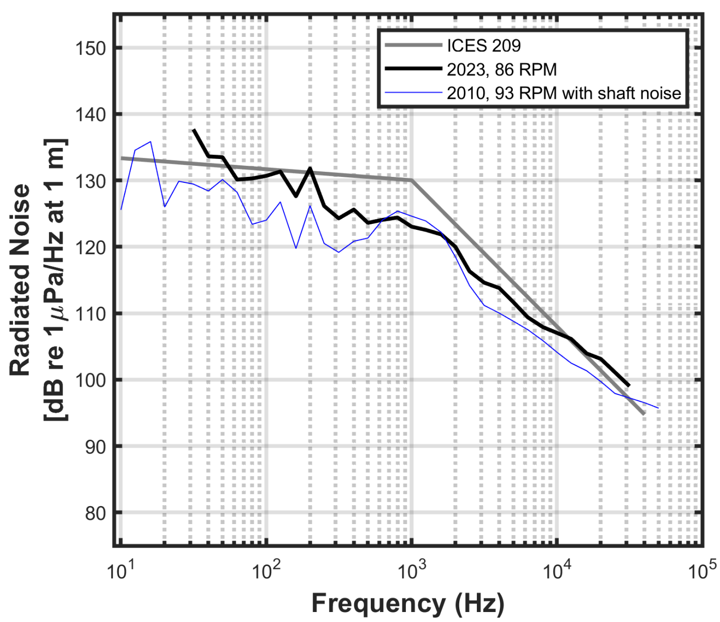


Figure 58. -- Radiated noise in 2023 compared to an observation in 2010 when the 'shaft noise' was observed.

Acknowledgements

This project was funded by NOAA's Office of Science and Technology and the Alaska Fisheries Science Center and was instigated by Chris Wilson. We are grateful to Robert Levine, K. C. Wilson, Sandy Parker-Stetter and Jim Lee for their improvements to manuscript drafts. The crew of the NOAA ship Oscar Dyson made the field deployments possible. Finally, Scott Furnish saved the day when he re-wired a battery to exclude some shorted cells that were discovered immediately before deployment.

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Appendices

Appendix A Troubleshooting

To the greatest extent possible, the FSVPAD and ship-based electronics packages have been configured to be “plug-and-play.” Nonetheless, the following sections provide troubleshooting recommendations for cases in which individual components in the system are not operating as expected.

A.I GPS and Communications Troubleshooting

If all of the equipment has been started, but proper GPS communications cannot be confirmed there are a number of possible explanations. First, consider the possibility that the units are operating and communicating but that the scripts are not calling the proper COM ports (see Sec. B.I.I). If this is not the source of GPS or communications issues consider the options described in this section.

Check all USB connections on the laptop: Verify that the ship-based GPS unit is properly connected to the laptop. Use Parallax Serial Terminal to check data streams on the relevant serial ports if there are any questions (Sec. III.VIII.III). Use this information to investigate the source of the failure of communication (e.g., is the problem clearly related to the FSVPAD because ship-based signals are being received?).

No ship-based GPS signals: If no ship-based signals are received, verify that the GPS power supply is plugged in, the cable is properly attached to the GPS unit, and the serial to USB cable is properly inserted into the laptop. If the GPS unit is properly set up but no signals are received there are only four possibilities: the cable is bad, the GPS unit is not working, the outlet is not providing power, or the computer's USB port is bad. A voltmeter can be used to confirm wall power is being provided and that signals are being set by the GPS Unit (look for fluctuating voltages across Pins 2 and 5 of the DB-9 connector). If proper wall power is being provided and fluctuating voltages are measured on the DB-9 connector then the laptop computer is likely the source of the problem. Try another USB port and another serial to USB adapter.

No FSVPAD GPS signals: First verify that the Freewave radio is plugged in and operating. If it is communicating with the FSVPAD, the LEDs adjacent to the Ethernet port being used will blink green when data are received. If the port is receiving data, either the cable from the radio to the computer or the laptop itself are the likely sources of the problem. Try an alternative USB port or alternative cable.

If no radio signals are being received, first verify that FSVPAD has been properly powered on. If the bulkhead connector is blinking, the GPS unit is operational. Next, verify that the ship-based and FSVPAD antennas are not obstructed. There should be a direct line of sight between the antennas for communication to occur. Consider standing the FSVPAD upright and securing it if necessary. Check again for communications. If FSVPAD GPS signals are still not being received, move antennas such that the receiver antennas are adjacent to the FSVPAD with no obstructions. If GPS signals are still not received check the battery voltage within the FSVPAD electronics housing. If the voltage does not exceed 12 V, recharge it before testing and deploying. Also verify that when the bulkhead connector is installed that the LEDs on the radio in the housing blink. Search for loose connections in the electronics house. Verify that the FSVPAD GPS unit is operating by removing it from the electronics housing and installing it on the cable for the ship-based GPS. Use the steps described above in **No ship-based GPS signals section** to verify the GPS unit is operational. Finally, it may be necessary to reconfigure the FSVPAD radio (Appendix C).

If none of these are identified as the source of the problem, consider consulting with the ship's electronics technician or other qualified person.

A.II Arduino Issues

If the barrel connector from the battery is connected to the microcontroller but there is concern about whether or not the Arduino is logging data, then the following steps should be followed to troubleshoot the unit. The status of the unit should be verified by observing the LED on the bulkhead connector. As follows is a description of the LED status and how to interpret it.

LED is blinking green: The unit is writing NMEA strings to the SD card and there are no errors.

LED is blinking red: If the LED is blinking red there are two possible errors that are identifiable by the blinking pattern.

Blinks red; 3 seconds on and 1 second off: A card initialization error. The most likely problem is that an SD card has not been properly inserted into the microcontroller. If it is properly inserted but the same error continues, check to ensure the card is working by inserting it into the laptop to see if the SD card is recognized. If not, try replacing it with another card. If the card is recognized but is not working properly in the Arduino, reformat the card to FAT32 (for partitions 32 GB or smaller) or exFAT for larger partitions. To do this with the card connected on a windows PC, open a window to the "Computer." Right-click on the Removable Storage device labeled "Arduino" and select "Format" from the menu options. In the window that appears, change the "File system" to "FAT32" or "exFAT" and click "Quick Format" under the "Format options." Press start. Once the card has been reformatted, eject it from the computer. Re-insert the card into the micro-controller and attempt to redeploy the units. To power cycle/restart the unit press the button on the microcontroller (Fig. A1).

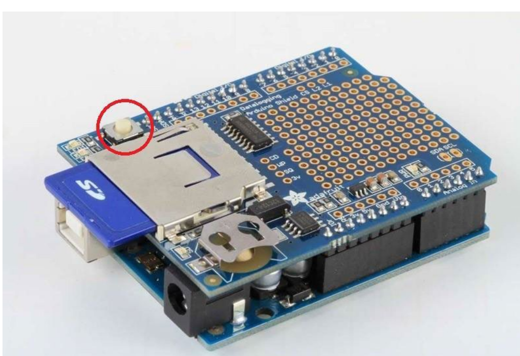

Figure A1. -- An Arduino micro-controller equipped with a data logging shield. To reset the unit press the button highlighted by the red circle.

Blinks red twice per second: The SD card is properly installed but the micro-controller cannot create a file and write data. Remove the card and make sure that the read only switch on the flash card is not engaged. Re-insert the card and test it again.

LED is not blinking: If no LED appears the most likely problem is that the bulkhead switch is not properly connected or the 12V battery is not charged, therefore the GPS unit will not power up and provide NMEA strings to the microcontroller. If NMEA strings are not received, then the LED will not blink green. If the 12V battery is charged and the bulkhead switch is connected, another possibility is that the 6 AA batteries providing power to the microcontroller are low or the barrel connector to the microcontroller is not properly connected. If the batteries are new and the barrel connector is connected, then the next step is to connect the laptop to the Arduino to upload the code to the unit (see below). After solving the problem and/or disconnecting the microcontroller, power-cycle the unit (Fig. A1).

Connecting the Arduino to the laptop to reload the micro-controller code: Find the USB Type B cable and connect it to the Arduino unit. Connect the other end to the computer. Open the Arduino software. When properly connected to the FSVPAD computer the microcontroller should be automatically identified on COM port 6. Next, open the code (referred to as a “Sketch”) that needs to be uploaded to the unit. This can be done using the same approach as is done using any other software package (i.e., File → Open...). Select the “DrifterGPSLogger” code. Next, identify the right-facing arrow in Arduino GUI (Fig. A2). Press the button and the sketch will be uploaded to the unit. If an error occurs orange text will appear in the black space at the bottom of the GUI beneath the sketch. If no errors occur the white text will appear and document the memory used by the sketch. Once the unit has been properly loaded the Arduino software can be closed. At this point the unit should operate as expected as long as there are no other problems with the deployment.

Figure A2. -- The Arduino graphical user interface. In this case the “DrifterGPSLogger” sketch is open. The right facing arrow button under the “Edit” drop-down menu is used to upload the sketch to the microcontroller.

Appendix B Codes

This section briefly summarizes the library of codes used to acquire and process data from the FSVPAD. This includes a script written to operate the microcontroller (Arduino), a Python script to acquire and process GPS data during tests, and the set of MATLAB scripts used to perform all of the data post-processing. The entire set of codes is available at https://github.com/noaa-afsc-mace/FSVPAD-hydrophones. Note that the scripts have, in general, not been optimized for efficiency since data processing and storage are not generally limitations in this application. Thus, well-commented codes that would be easy to follow and modify were written. Below is a brief summary of all of the codes available online and what role they play in FSVPAD data acquisition and processing. Further information is available in the comments included in each script.

Arduino

A single script to operate the Arduino (DrifterGPSLogger.ino) is included in the repository. Once properly programmed using this script, the shorting plug will trigger operations and data acquisition.

Python

The only Python script is FSVPAD_Logger.py. This script is used to both log the FSVPAD and ship GPS signals and to run the data visualization program. When installed on the provided laptop setup for FSVPAD processing, the script is run by double-clicking the FSVPAD Logger shortcut on the desktop.

MATLAB Functions and Processing Scripts

Processing is achieved by following the FSVPAD_Master_Script.m. This is the master script used to manage and run the codes required to process all the FSVPAD data in the proper order. Analysis is performed by opening this script and running sections of this code as described in section V.

Below is a list of the functions called during the processing. As functions, information is passed to these scripts by the primary processing codes, but the user is not required to directly interact with them. The scripts are included in alphabetical order. Some additional utility functions called by the scripts (uipickfiles.m, sw_svel.m) that were not written specifically for this application were downloaded from the MATLAB File Exchange (www.mathworks.com/matlabcentral/fileexchange).

alpha_sea.m: Attenuation, as a function of frequency, is calculated using this code. In general, it requires multiple inputs that include depth, temperature, salinity, pH, and frequency. In this set of codes, this code is called using a fixed set of reasonable oceanographic parameters. Since the ranges are limited to around 100 m, the impact of this assumption is small.

Bulk_Process_uAural.m: Bulk processing script for the hydrophone measurements. It reads the .wav files and produces the various acoustic outputs of interest.

Cal_Gain_GUI.m: When processing the audio of pistonphone measurements, the user is prompted to confirm that the DAQ gain is set at the default (18 dB) level. This code produces a GUI with a drop down menu for the user to select from the different DAQ gain options.

Caloffset_dialog.m: Creates a dialog box for the user to input the expected difference in the signal produced by the pistonphone that can be attributed to the atmospheric pressure. This code is called by the uAural_Calibration.m code.

Create_GPS_Distances.m: This code uses the raw GPS strings from the vessel and drifter and processes the data to calculate the range and bearing to the drifter from the vessel. It does not account for the offsets from the acoustic center to the GPS unit or the aspect of the vessel during the drift tests. It calls three related processing codes: GPS_distance.m.

GPS_interp.m, and GPS_parse.m: After processing the data, these functions store a .mat file containing the GPS data and save a figure showing the distance and bearing as a function of time.

ginputax.m: This code was sourced from the MATLAB file exchange. It is called on multiple occasions to allow users to select inputs from the graphical user interface when figures are plotted.

GPS_distance.m: A function called by Create_GPS_Distances.m. The code takes the time series data for the coordinates of the ship and drifter and converts them to ranges and bearings.

GPS_interp.m: This function is called by Create_GPS_Distances.m. The processed GPS data, in addition to the start and end times of interest, are passed to the function. The time series is then linearly interpolated so that the data are available with a sampling frequency of 1 Hz.

GPS_location_GUI.m: The underlying code for the GUI that takes user input for the distance offset between the ship-board GPS unit and the “acoustic center” of the vessel. By definition the acoustic center is halfway between the engine room and the propeller. This function works in conjunction with GPS_location_GUI.fig. The code is called during processing and distance outputs are passed to the MATLAB workspace in the units of meters. By default, positive offsets are reserved for locations forward and starboard of the acoustic center.

GPS_parse.m: A function called by Create_GPS_Distance.m. It prompts the user to identify the parent directory for the GPS files associated with the acoustic measurements. It then processes the data and returns a single structure called “GPS” that contains the latitudes, longitudes, dates/times, speed over ground, and course over ground for the fields “ship” and “drifter.”

hydrophone_info.m: This code takes the input files names, parses them, and passes the serial numbers back to other variables. It is used primarily to track the serial number.

ICES_spec.m: Produces frequency and SPL vectors that represent the recommendations for radiated noise levels from research vessels (Mitson, 1995).

Make_Test_Directories.m: Prompts user to identify information about the vessel test and then uses that information to create the proper directory structure of the raw data, post-processed data, and final results.

Pick_GPS_Data.m: Calls various dialogs and asks for the user to select data from the time versus range between the vessel and the drifter. Using GPS offsets and the aspect of the vessel during each pass the range between the acoustic center of the vessel and the drifter is calculated. It also calculates the ranges as times associated with the passage of the vessel within the 30 degree aperture called for in the radiated noise measurement specifications. A set of variables is returned in a structure called DWT, which represents the data window time) that includes a field for each pass entered by the user. These times and ranges are later called along with the noise measurements to apply range corrections to the noise measurements. Prior to calling this code, the raw GPS data should be processed and saved to a .mat file using the Create_GPS_Distances.m code.

Process_Pass.m: This function takes a number of important inputs and uses them to calculate signal-to-noise ratios, and radiated noise levels (at 1 m) for each pass. To process the data, the code requires the hydrophone data structure produced by the Bulk_Process_uAural.m file, the processed GPS results produced while running the SL_calculation.m code, the ambient noise calculations produced while running the SL_calculation.m script, and relies on attenuation values in each third octave band calculated by alpha_sea.m. With these inputs, the script aligns all of the GPS and hydrophone timestamps, calculates slant ranges between the hydrophones and the acoustic center of the ship, corrects for noise, and accounts for transmission losses. The final product is multiple acoustic products in 1-second samples throughout the relevant window of the pass and averaged values for the pass.

Processing_GUI.m: Calls Processing_GUI.fig and allows users to edit the default processing signal processing parameters. The defaults are automatically adjusted based on the sampling rate of the hydrophone data.

SL_Calculations.m: This is the code used to do the final radiated noise calculations. Users are required to select GPS data associated with closest points of approach and identify a period suitable for ambient noise. The MATLAB environment is saved in the /results directory at this point in case it needs to be referred to in the future.

SL_Plots.m: This code generates the figures described in section VI.II.

SL_text_output: This code generates the summary text files described in section VI.II

sw_svel.m: This code calculates the sound speed in sea water using the UNESCO (1028) polynomial. It was sourced from the MATLAB File Exchange.

uAural_band_merge.m: Hydrophone data are processed in 1-second data windows. Rather than saving the entire spectrum for each data window, variable band merging is applied to considerably decrease the data volume. Depending on the frequency, the resolution of the spectrum varies from 1-20 Hz. The details are described in the comments at the beginning of the function. The band merging is performed by taking the average (linear) of a set of values from the spectrum and replacing them with a single data point. A new frequency array is also written so that the band-merged spectrum can be easily plotted or integrated to obtain the broadband SPL from 10 Hz (the lower limit) to the Nyquist frequency.

uAural_Cal_SelectData.m: This code is called during processing of the pistonphone data using uAural_Calibration.m. It produces a figure and prompts the user to select two points in time that correspond to the beginning and end of the signals from the pistonphone measurements. These points are then used to process the SPL produced by the pistonphone.

uAural_Calibration.m: This script is used to process .wav files that contain measurements of the signal produced by the pistonphone during “calibrations.” It walks the user through the steps of loading, selecting, and processing data. Results are indexed to the hydrophone serial number and written to a calibration text file.

uAural_Check_DAQ_Gain.m: This code produces a dialog asking the user to confirm the DAQ gain. If the user specifies that the default gain is incorrect, a different interface is called that allows the user to select the gain from a drop-down menu.

uAural_gain.m: Takes the hydrophone serial number and provides the manufacturer specified gain. If the hydrophone serial number is not in the list it exits the code and provides an error in the command window with instructions.

uAural_Processing_para.m: Creates global variables for the default processing parameters for the hydrophone data. These parameters are passed to a GUI where they can be modified.

uAural_read.m: Reads .wav files from uAURAL given their filename.

uAural_Spec.m: Calculates the sound pressure level spectra based on parameters called from the primary processing functions. A detailed description of the calculations is included in Appendix E.

uAural_TOBs.m: A table of potential one-third octave bands that is called by Bulk_Process_uAural.

uAural_YN_dialog.m: A dialog that is called by the uAural_Calibration.m code that asks the user to approve of the pistonphone time series that was selected. If the user does not approve of the time series, the code returns to the main script and prompts the user to select a new portion of the time series.

Appendix C Radio Configuration

The radios provided with the existing FSVPAD system are pre-configured for operation. The following instructions are only necessary to aid in troubleshooting if the radios are not communicating with each other or if new radios need to be configured. In that case the user should connect to the radios and confirm the settings included below following these instructions. First, the systems shipped with a blue Ethernet cable (RJ45 connectors on each end). Connect one end to the laptop computer's Ethernet port and the other end to one of the two Ethernet ports on the Freewave radio. These ports are labeled "Ethernet" in blue to differentiate them from the serial ports labeled in red.

There are two Freewave radios. The ship-based (receive) Freewave radio (model FGR2-PE-U) is in a gray enclosure. Its counterpart for the FSVPAD is a Freewave FGR2-P board level radio. By default, the IP addresses for the radios are 192.168.111.100. To work with this system the IP addresses have been changed. If attempting to connect to the radios using the IP addresses described below fails, try connecting to the devices using the default IPs.

Connecting to the radios to configure them (this should not be necessary unless new radios are being used):

(1) Change the static IP of the laptop to the following: 192.168.111.99

(a) Follow the following path to make the changes:
Control Panel → Network and Sharing Center → Change adapter settings → [right click on] Local Area Connection → Properties → select Internet Protocol Version 4 (TCP/IPv4) and select the "Properties" button

(2) Attach the provided blue Ethernet cable to one of the blue connections on the radio, connect the other end to the laptop.

(3) Once the static IP is changed you can sign on to the individual radios one at a time.

(a) Open an Internet browser and type the IP of the desired radio in the address bar

(b) The user and password: "admin"

(4) Change the settings to match those in the "Radio Configuration" section below.

(5) Save the settings and reboot the radio using the buttons on the program.

(6) Now, change the settings on the other radio. The first time you will need to connect using the Ethernet cable. Once the radios can communicate you will be able to change the settings for both radios by connecting to a single one.

NOTE: If you are unable to connect to the radio directly using the Ethernet port, the IP address has probably been changed. Follow these instructions instead.

(1) Connect to the Red "Com 1" port on Freewave to the computer using the red DB-9 to RJ-45 connector cable. Do not connect the power to the radio.

(2) Open Freewave Tool Suite and Select the "Setup Terminal" Option. Choose the port (COM1 by default). If using the USB port on the right side of the provided laptop then the COM port is 9.

(3) Connect power to the Freewave but continue paying attention to the screen. After approximately 10 seconds it will ask you to Press "Y" to enter the configuration menu. Press either Y or y within a few seconds and you will be prompted to provide a login and password.

(4) The login and password are both "admin"

(5) Use the menu to set the parameters as described in the "Radio Configuration" section below. Please note if any settings are different than below. The configuration of the windows

and the accessible settings are mostly the same with a slightly different interface. All relevant configuration settings with the exception of the Call Book can be directly accessed in this manner. If the Call Book needs to be edited then reconnect using the Ethernet cable after properly configuring the IP addresses.

(6) Once the changes have been made save and exit the menu. Power cycle the units to reboot them with the new settings.

Radio Configuration:

The following sections highlight the settings for the transmit and receive radios. For radio communications the settings must match. If the radios will not communicate, double check the settings. Below is a summary of the important settings and screen shots (Figs. A3-A10) of the settings as they appear through the Ethernet connection using an Internet browser.

Transmit (not in enclosure) radio for the FSVPAD:

IP: 192.168.111.100 (note, this is the default)

IP Setup:

IP Address: 192.168.111.100
Subnet Mask: 255.255.255.0
Default Gateway: 192.169.111.111
Web Page Port: 80

Serial Setup 1 (configure Serial Setup 2 the same way):

TCP Client Settings: Enable
TCP Client Settings Port: 7001 (this should be 7000 in Serial Setup 2)
Baud Rate: 4800 (this is the baud rate for 1 Hz GPS data)
Interface: RS232
Runtime Serial Setup 'U': Enable

Radio Setup:

Network Type: Point-To-Point
Modem Mode: Gateway
Frequency Key: 5
Zones: Check all
Max Packet Size: 9
Min Packet Size: 1
Transmit Power: 10
Retry Timeout: 255
RF Data Rate: 115 kbps
Transmit Rate: Normal
Call Book: 9470992 (in column 1 [Endpoint], row 1 [Entry 0]); Everything else is 0. This is the serial number of the receive radio (change if necessary).
Network ID: 255
Repeaters: Disabled
Subnet ID (RX): 0
Subnet ID (TX): 0

Receive (in enclosure) radio for the vessel: IP: 192.168.111.101 (note, this is the default)

IP Setup:

IP Address: 192.168.111.101
Subnet Mask: 255.255.255.0

Default Gateway: 192.169.111.111
Web Page Port: 80

Serial Setup 1 (configure Serial Setup 2 the same way):

TCP Client Settings: Enable
TCP Client Settings IP Address: 192.168.111.100
TCP Client Settings Port: 7000
Baud Rate: 4800 (this is baud rate for 1 Hz GPS data)
Interface: RS232
Runtime Serial Setup 'U': Enable

Radio Setup:

Network Type: Point-To-Point
Modem Mode: EndPoint
Frequency Key: 5
Zones: Check all
Max Packet Size: 9
Min Packet Size: 1
Transmit Power: 10
Retry Timeout: 255
RF Data Rate: 115 kbps
Transmit Rate: Normal
Call Book: 9458179 (in column 1 [Endpoint], row 1 [Entry 0]); Everything else is 0. This is the serial number of the transmit radio (change if necessary).
Network ID: 255
Repeaters: Disabled
Subnet ID (RX): 0
Subnet ID (TX): F

Other configuration notes:

- The Default RF Data rate is 154 kbps, which is higher than the 115 kbps. The lower setting is used as it is recommended for better communications in situations with relatively low data rates. This setting can be changed if needed but should be changed in both the transmit and receive configurations.
- The radios are configured for Point-To-Point transmissions. This requires Network ID number 255.

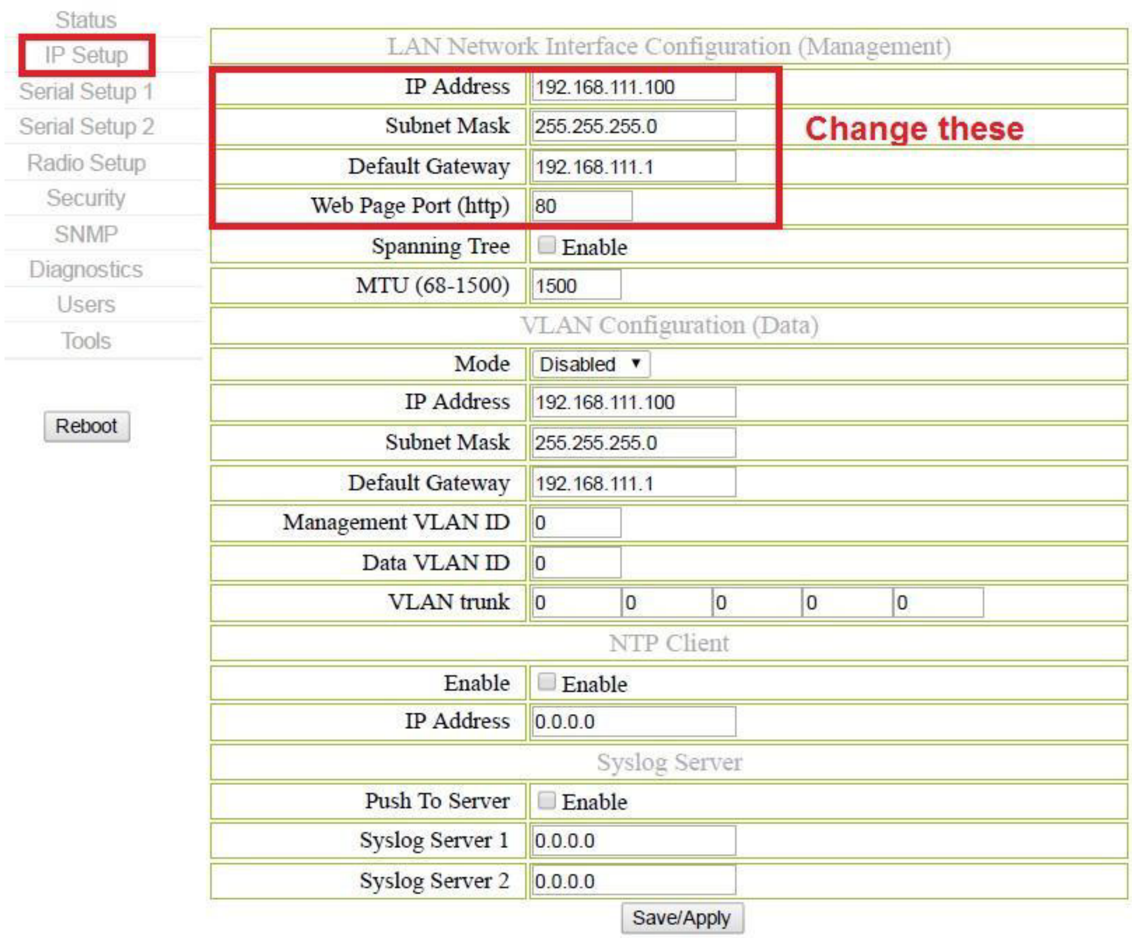

Figure A3. -- Transmit (FSVPAD) radio IP configuration.

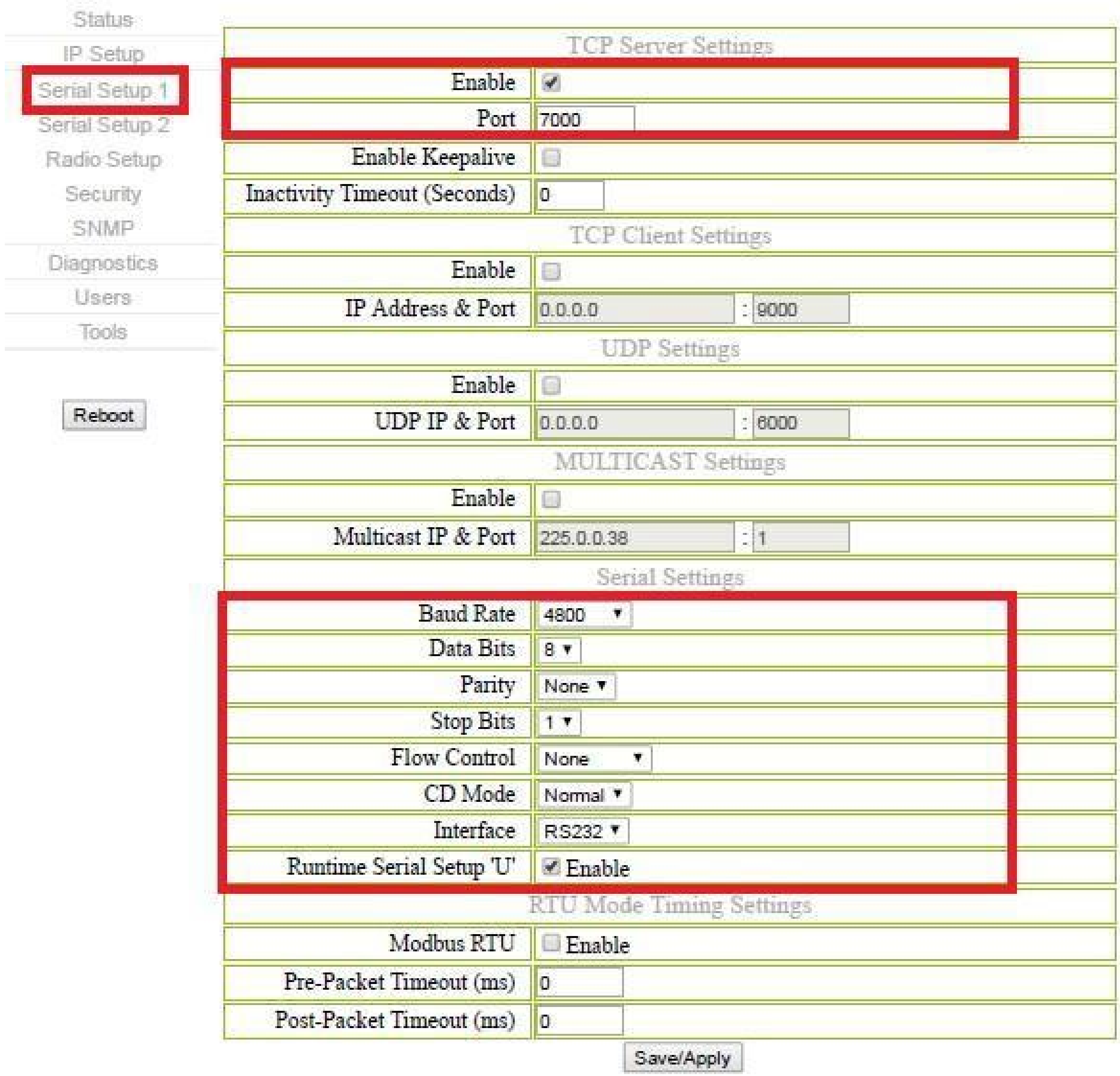

Figure A4. -- Transmit (FSVPAD) radio's Serial Setup 1 configuration. Serial Setup 2 configuration should also be changed to match Serial Setup 1.

Figure A5. -- Transmit (FSVPAD) radio's Radio Setup settings.

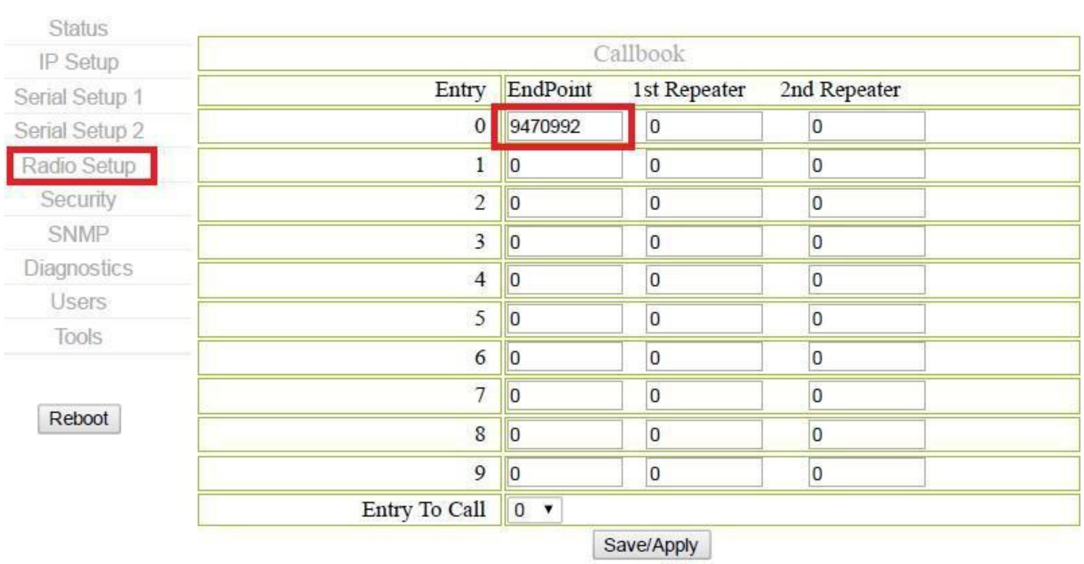

Figure A6. -- Transmit (FSVPAD) radio's Call Book settings.

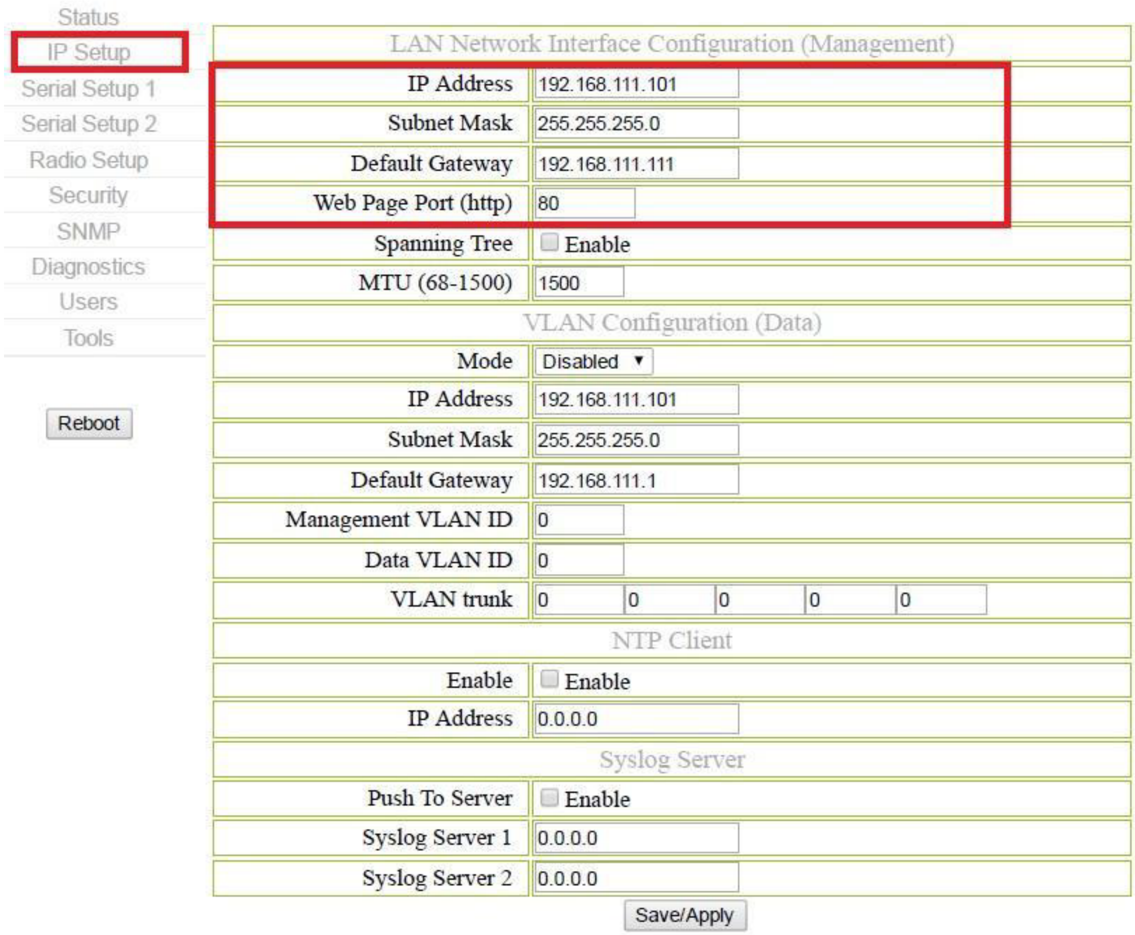

Figure A7. -- Receive (ship) radio's IP configuration.

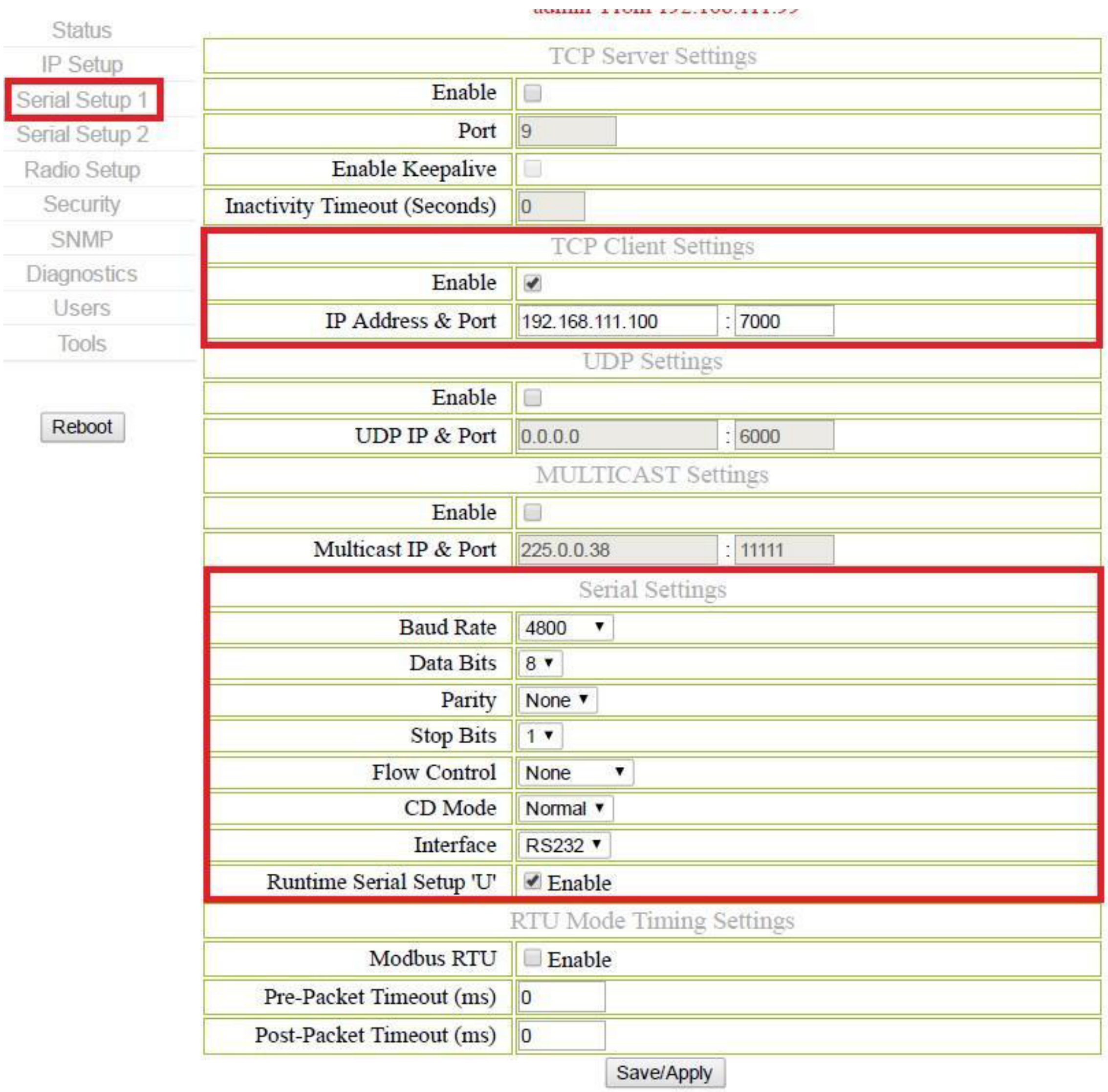

Figure A8. -- Receive (ship) radio's Serial Setup 1 configuration. Serial Setup 2 configuration should also be configured to match Serial Setup 1.

Figure A9. -- Receive (ship) radio's Radio Setup settings.

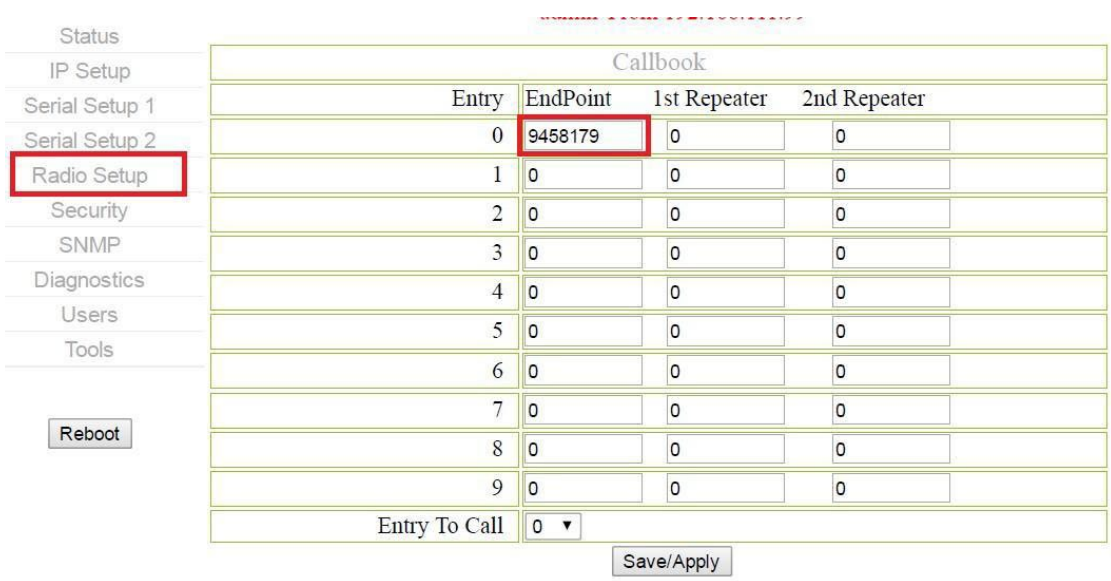

Figure A10: -- Receive (ship) radio call book settings.

Appendix D Calculations

When operating, the graphical user interface of the Python program running on the ship calculates the distance and bearing between the vessel and the drifter in real-time. The following sections briefly describe the calculations built into the Python scripts. These same equations are used in calculations made during post-processing.

D.I Distance Calculations from GPS Coordinates

The distance between two points in both the real-time data acquisition stream (Python) and the post-processing results (MATLAB) are calculated using the Haversine Formula because it remains accurate at small distances. So that the program is suitable at different latitudes the programs first calculate the earth's radius (r) as a function of latitude. Here,

$$r = \sqrt{\frac{\left(\left(r_{eq}^2 \cos(\phi)\right)^2 + \left(r_{pol}^2 \sin(\phi)\right)^2\right)}{\left(\left(r_{eq} \cos(\phi)\right)^2 + \left(r_{pol} \sin(\phi)\right)^2\right)}}, \tag{1}$$

where r_{eq} is the equatorial radius of the earth (6378.137 km), r_{pol} is the polar radius of the earth (6356.7425 km), and φ is the latitude. Given the relatively short ranges over which the system operates the radius is calculated at the latitude of the ship for each distance calculation.

The radius is then combined with the ship and drifter coordinates in the Haversine formula according to the following set of equations:

$$\Delta\phi = \phi_2 - \phi_1 \tag{2}$$

$$\Delta\lambda = \lambda_2 - \lambda_1 \tag{3}$$

$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_2)\cos(\phi_1)\sin^2\left(\frac{\Delta\lambda}{2}\right) \tag{4}$$

$$d = 2r\tan^{-1}\left(\frac{a}{1-a}\right), \tag{5}$$

where ϕ is the latitude, λ is the longitude, the indices 1 and 2 correspond to the FSVPAD and vessel, d is the final distance between the ship and the FSVPAD and $\tan^{-1}$ is the four-quadrant inverse tangent. All calculations are performed by first converting the latitude and longitude to radians.

D.II Bearing Calculations from GPS Coordinates

The bearing between the ship and drifter is calculated for both the real-time data acquisition stream (Python) and the post-processing results (MATLAB). Using the same variables as the distance calculations (Appendix E.I) the bearing is calculated according to

$$x = \sin(\Delta\lambda)\cos(\phi_2) \quad (6)$$
$$y = \cos(\phi_1)\sin(\phi_2) - \sin(\phi_1)\cos(\phi_2)\cos(\Delta\lambda) \quad (7)$$
$$b = \tan^{-1}\left(\frac{x}{y}\right), \quad (8)$$

where *b* is the bearing and $\tan^{-1}$ is the four-quadrant inverse tangent. All calculations are performed in radians and converted from degrees for real-time and post-processed data. To limit the bearing to values from 0-360 degrees the compass bearing is calculated by

$$b = \text{rem}\left(\frac{b + 360}{360}\right), \quad (9)$$

where rem indicates that the compass bearing is taken as the remainder.

D.III Conversion from .wav Data

Prior to calculating basic acoustic quantities, it is necessary to convert the format of the recorded audio into a time series using physically meaningful units. In processing of acoustics data this is typically volts and pressure. The steps outlined below are coded into the processing functions.

When read into MATLAB in its native format, the signed integer values stored in a .wav file have maximum and minimum values of $-\frac{2^m}{2} \leq y \leq \frac{2^m}{2} - 1$ where *y* is the time series in the .wav file and *m* is determined by the bit-depth (here *m* = 16 for 96 kHz sampling rates; otherwise *m* = 32). Before converting the signal to voltage. The time series *y* is converted to a signal with minimum and maximum values of -1 to 1 according to

$$z(t) = \frac{y(t)}{\left(\frac{2^m}{2}\right)}, \quad (10)$$

where $z(t)$ represents the normalized time series. By default, the maximum values of *z* are -1 to 1, but the voltage limits may be different for other systems (e.g., the Multi-Electronique has a maximum voltage of 5V). A voltage time series is then calculated according to $v(t) = z(t)V_{max}$, where V_{max} is the maximum voltage.

The time series $v(t)$ is the voltage recorded by the data acquisition system after accounting for the hydrophone's sensitivity and any additional gains or losses, which may be frequency dependent. These terms, however, can be accounted for after calculating the sound pressure level spectrum. For conversion of $v(t)$ to a received pressure time series the total gain is determined by

$$G = G_{\text{sens}} + G_{\text{DAQ}} \text{ [dB]}, \quad (11)$$

where G_{sens} is the hydrophone sensitivity [dB re 1V/μPa] and G_{DAQ} [in dB] is the gain of the data acquisition system. In all calculations performed here gains are applied in frequency space using *G* following the processing of the voltage time series.

It is, however, possible to apply linear gains and process acoustic quantities using a pressure time series assuming that gains and sensitivities do not exhibit any strong frequency dependence. To do this, the gain is applied directly to the voltage time series. The linear gains are first determined according to

$$g = 1e6 \cdot 10^{((G_{sens}+G_{DAQ})/20))} \text{ [V/Pa]}, \quad (12)$$

where g is the total gain in linear space and the 1e6 term accounts for the units of μPa in the hydrophone sensitivity. The pressure time series is then

$$p(t) = v(t)/g \quad [Pa], \quad (13)$$

which can be used for calculation of basic acoustic quantities such as one-third octave band sound pressure levels, broadband sound pressure levels, and pressure spectral densities.

Stored .wav files contain recorded hydrophone data in the form of a single time series for the duration of the recording (in this case greater than 2 minutes). The acoustic quantities of interest, however, are calculated on shorter time scales. Therefore, following the steps outlined above each file is truncated into a series of 1-second data windows. Each of these individual data windows is processed independently as described in the following sections to calculate the power spectral densities, one-third octave band sound pressure levels, and the broadband sound pressure levels.

D.IV One-Third Octave Band Sound Pressure Levels

One-third octave band sound pressure levels are calculated by processing each subsample of the recorded audio using a series of one-third octave band filters consistent with acoustic standards (ANSI 2004). By convention, the calculation of one-third octave bands is based on a center frequency of 1 kHz for the first band. Exact center frequencies of other bands are calculated according to

$$f_c = 1000 * 2^{\frac{n}{3}}, \quad (14)$$

where n is an integer. For nominal center frequencies between 10 Hz-20 kHz the range of integer values of n is -20 to 15. The upper and lower limits for the one-third octave bands are defined as

$$\begin{aligned} f_l &= f_c * 2^{-\frac{1}{6}} \text{ and} \\ f_u &= f_c * 2^{\frac{1}{6}}, \end{aligned} \quad (15)(16)$$

where f_u and f_l are the upper and lower frequency limits of the band with the given center frequency. Calculations based on these equations calculate the exact center frequency and bandpass frequencies for each one-third octave band. Nonetheless, these bands are usually referred to by their nominal values. By default, if the hydrophone sampling rate is 96 kHz than the nominal values for which the measured one-third octave band sound pressure levels are calculated is:

f_c = 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000, 10000 12500, 16000, 20000, 25000, 31500 [Hz].

Based on user input during processing these upper and lower limits can be modified so long as the upper band limit is below the Nyquist frequency (f_s/2). The one-third octave band sound pressure levels are calculated by passing the voltage time series to the filter bank and accounting for the gain according to

$$L_p(f_c) = L_v(f_c) + G(f), \quad (17)$$

where $L_v(f_c)$ is the calculated one-third octave band SPL based on the voltage time series without accounting for the frequency-dependent gains (G) and $L_p(f_c)$ is the final value with units of dB re 1μPa.

Appendix E File Formats

This section describes key outputs stored in the post-processed data outputs that are created during the different calculation steps. Due to the structure of the processing scripts, users should not, in general, need to review data at this level. Nonetheless, summaries of important variables stored in the saved file formats are included in case users more familiar with MATLAB would like to further review the results or produce their own figures or analyses based on the calculated data.

E.I Raw GPS Data

The GPS units produce a time series of NMEA strings. To reduce the storage of unnecessary time strings, the data acquisition scripts, both PYTHON and Arduino, strip all messages except the GPRMC strings. GPRMC strings contain the recommended minimum specific GPS data and include the time in UTC, date, coordinates, speed over ground [knots], course over ground [knots], and other information not relevant to the processing. When processed using the Create_GPS_Distances.m script, the outputs include the following variable saved in the *...*TESTNAME\Results directory:

- YYYYMMDDTHHMMSS_Processed_GPS.mat: All processing GPS data
- GPS.fnpath: File path for the raw GPS files
- GPS.shipfn: Names of the files in the ship GPS time series
- GPS.shiplat: Time series of ship latitudes
- GPS.shiplon: Time series of ship longitudes
- GPS.shiptime: Time series of time (UTC) for ship GPS strings
- GPS.shipSOG: Time series of ship speed over ground
- GPS.shipCOG: Time series of ship course over ground
- GPS.drift_fnpath: File path for the drifter GPS files
- GPS.drifterfn: Names of the files in the drifter GPS files included in time series
- GPS.drifterlat: Time series of FSVPAD latitudes
- GPS.drifterlon: Time series of FSVPAD longitudes
- GPS.driftertime: Time series of time (UTC) for FSVPAD GPS strings
- GPS.drifterSOG: Time series of FSVPAD speed over ground
- GPS.drifterCOG: Time series of FSVPAD course over ground
- GPS.time: Time series of combined (ship and FSVPAD) GPS data
- GPS.range: Time series of the ranges from the vessel to the FSVPAD

- GPS.bearing: Time series of the bearing from the ship to the FSVPAD

The GPS.time, GPS.range, and GPS.bearing variables are used in additional postprocessing and are interpolated to have 1 Hz data.

E.II Post-Processed GPS Data

Post-processing of the GPS strings using the CPA_GPS_data.m results in creation of additional variables that are directly related to each of the user-selected vessel passes. This file (PassNumber_CPA_Time_Data.mat) contains data stored in a MATLAB structure called DWT (data window time) are included in a separate substructure for each vessel pass. DWT data outputs are structured as described below.

- CPA_GPS_data.mat: All data within the critical sampling window (data window period; DWP) between COMEX and FINEX during each pass GPS.P1.ts: MATLAB datenum for the start time of the DWP
- GPS.P1.te: MATLAB datenum for the end time of the DWP
- GPS.P1.t: Time series of MATLAB datenums for data within the DWP (sampled at 1 Hz)
- GPS.P1.CPA: Closest point of approach within the DWP for the pass
- GPS.P1.DWT_ds: Range to the vessel at the start of the DWP
- GPS.P1.DWT_de: Range to the vessel at the end of the DWP
- GPS.P1.d: Time series of ranges from the vessel to the FSVPAD for the data within the DWP (samples at 1 Hz)
- GPS.P1.aspect: String noting the vessel aspect (closest to FSVPAD) during the DWP (either Port or Starboard)

These data are saved for each vessel pass such that if there are six passes, DWT contains six substructures (DWT.P1, DWT.P2, ..., DWT.P6).

E.III Raw Hydrophone Data

Raw hydrophone data, as stored by the *μ*AURAL hydrophones, as .wav files. A MATLAB function included in the processing package (uAural_read.m) reads the native .wav files and stores the recorded time series, the sampling frequency, and the bit-depth. Depending on the sampling frequency the *μ*AURAL hydrophones will have bit depths of either 16 or 24. The variables are passed between functions during processing to ensure that any changes in bit-depth or sampling rate are properly accounted for in calculations.

E.IV Post-Processed Hydrophone Data

Two files for the post-processed data are saved as .mat files with the hydrophone serial number stored in the file names. For example, for hydrophone 382295, the following files contain vectors for the frequency arrays, one-third octave band sound pressure levels, and sound pressure spectra with 1 Hz frequency resolution. The file formats are as follows:

- Hydrophone_382295_TOL.mat: All data are stored in a structure called TOL
- TOL.time: A vector of the timestamps (total number: *m*) associated with the one-third -octave band sound pressure levels
- TOL.fTOL: A vector (total number: *n*) of the one-third octave band center frequencies sound pressure levels
- TOL.TOL: An array (*n* x *m*) of the one-third octave band sound pressure levels where *n* is the number of one-third octave bands and *m* is the number of 1-second samples
- TOL.SN: The hydrophone serial number
- TOL.Depth: A string noting the hydrophone depth (either “Deep”, “Mid”, or “Shallow”)
- Hydrophone_382295_PSD.mat: All data are stored in a structure called PSD
- PSD.time: A vector of the timestamps (total number: *m*) associated with the one-third octave band sound pressure levels
- PSD.f: A vector (total number: *n*) of the one-third octave band center frequencies sound pressure levels
- PSD.PSD: An array (*n* x *m*) of the sound pressure spectrum where *n* is the number of frequency bands and *m* is the number of 1-second samples.
- PSD.SN: The hydrophone serial number
- PSD.Depth: A string noting the hydrophone depth (either “Deep”, “Mid”, or “Shallow”)

Appendix F Definitions and Symbols

F.I Definitions

Acoustic center: Position on the ship where it is assumed that all of the noise sources are co-located as a single point source (ANSI standard). Here it is assumed to be half way between the propeller and the engine room.

COMEX (commence exercise): start test range location; position of the vessel under two times (2x) the “start data” distance ahead of the CPA

CPA: closest point of approach

DAQ: data acquisition system

DWL (data window length): distance between the start data location and end data location

data window period (DWP): time it takes the vessel to travel the data window length at a given speed

data window time (DWT): time during which the vessel is between the COMEX and FINEX positions during each vessel pass

FINEX (finish exercise): end test range location; position of the vessel under two times (2x) the “start data” distance past of the CPA

FSV: Fisheries Survey Vessel

GUI: Graphical user interface

Pistonphone: An acoustic calibrator that produces precise sound pressure within a closed coupling volume. A pistonphone uses a mechanically oscillating piston at a specified frequency.

F.II Symbols

ΔL_i: Signal-to-noise ratio between observed radiated noise levels and ambient noise conditions in the i^{th} frequency band during the radiated noise test [dB]

$\Delta\lambda$: Difference in longitude between vessel and drifter

$\Delta\varphi$: Difference in latitude between vessel and drifter

Δf: Frequency response of resulting acoustic spectra [Hz]

λ: Longitude

Ω: Ohms (resistance)

ϕ: Latitude

d_{cps}: The range in meters at the closest point of approach

d_{hor}: Horizontal distance between the hydrophones and the acoustic center of the vessel

d_{tot}: Total distance between the hydrophones and the acoustic center of the vessel

d_{ver}: Vertical distance between the hydrophones and the acoustic center of the vessel

f_1: Maximum frequency used in band-merging operations

f_2: Minimum frequency used in band-merging operations

f_c: Center frequency of acoustic of acoustic band

f_l: Low-frequency limit of one-third octave band

f_s: Sampling frequency

f_u: High-frequency limit of one-third octave band

$fft(x)$: Represents the Fast Fourier Transform of x

g: Hydrophone sensitivity [V/Pa]

G: System sensitivity accounting for hydrophone sensitivity and pre-amplifier gain [dB re 1 V/μPa]

G_{DAQ}: Data acquisition system pre-amplifier gain [dB]

G_{sens}: Hydrophone sensitivity [dB re 1 V/μPa]

L_p: One-third octave band sound pressure level [dB re 1 μPa]

$L_{p,n,i}$: One-third octave band sound pressure level associated with background noise in the i^{th} frequency band [dB re 1 μPa]

$L_{p,s+n,i}$: One-third octave band sound pressure level associated with the combination of radiated vessel noise and background noise in the i^{th} frequency band [dB re 1 μPa]

$\overline{L'_{pi}}$: One-third octave band attributed to radiated vessel noise in the i^{th} frequency band [dB re 1 μPa]

L_s: One-third octave band source level calculated by averaging the measurements from all hydrophones for a given vessel pass [dB re 1 μPa]

$L_{s,d,i}$: One-third octave band source level as a function of range in the i^{th} frequency band calculated from measured one-third octave band noise measurements after accounting for spherical spreading (transmission losses) based on the total distance between the acoustic center of the vessel and the hydrophones [dB re 1 μPa]

$L_{s,i}$: Average source level for each pass as a function of the hydrophone index. The value is calculated as the arithmetic mean of individual samples associated with each pass. It has the dimensions of [a x b], where a is the number of passes and b is the number of one-third octave bands. [dB re 1 μPa]

$L_{s,l}$: One-third octave band source level averaged from all $L_{s,d,i}$ values calculated during a vessel pass [dB re 1 μPa]

m: Bit-depth of digitized hydrophone recordings

n: Exponent (integer values from -20 to 15) used in calculating the center frequencies of one-third octave bands

N: Number of data points in Fast Fourier Transform

p: Acoustic pressure [Pa]

p_o: Reference pressure [1 μPa]

PSD: Power spectral density or pressure spectral density

r: Earth radius as a function of latitude and longitude [m]

rms: Root-mean-squared

T: Length of recording in the temporal domain that is used in Fast Fourier Transforms [sec.]

TOL: One-third octave band sound pressure level

v: Vessel speed over ground in meters/second

$v(t)$: Voltage as a function of time [V]

V_{max}: Maximum output voltage of data acquisition system [V]

$w(t)$: Window function (e.g., Hann) applied to raw voltage time series [V]

w_{cf}: Scalar weighting function applied to tapered time series to correct for the change of variance introduced by the window, $w(t)$

y: Recorded time series in hydrophone (values -1 to 1)

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September 2024

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