

Passive Portable Detection and Localization of Beaked Whales

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Award Number: N0001409WX21206

LONG-TERM GOALS

The long-term goal of this program is to develop passive-portable tools for the detection of marine mammal vocalizations including those from deep diving Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales from ships of opportunity including small observer vessels.

OBJECTIVES

The two primary objectives of this program are ; 1) to develop a 53F GPS-modified sonobuoy multiple-sensor, wide-baseline system and 2) to develop a portable bearing array, capable of deployment from an observer vessel.

APPROACH

Sonbuoy-Based System

The sonobuoy-based system extends to the field the capabilities of the Marine Mammal Monitoring on Navy Range (M3R) program's passive acoustic Detection, Classification, and Localization (DCL) tools, which are presently available at the Atlantic Undersea Test and Evaluation Center (AUTEC) and Southern California Offshore Range (SCORE). The system was designed to provide real-time feedback from multiple sonobuoys, to be highly portable, easily deployable, and cost efficient.

The prototype system is based on GPS-modified 53F Underwater Sensor Systems Incorporated (USSI) sonobuoys. These buoys provide a bandwidth of 10 Hz – 40 kHz and transmit acoustic and GPS position data via a standard sonobuoy RF link. The buoys are battery-powered and will last up to 8 hours. The units are expendable and scuttle at the end of their usable life. They are light-weight and easily deployed from a ship or a Rigid Hull Inflatable Boat (RHIB). A central receiver is used with a separate GPS demodulator and the GPS data are modulated on a sub-carrier and converted to an RS-232 serial signal at the receiver. A single buoy costs \$1,500. Existing M3R software was modified to read dynamic GPS hydrophone positions telemetered from the 53F buoys. These positions are used in the localization software and which was also modified to dynamically update buoy locations as they were received over the RF link.

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Passive Portable Detection And Localization Of Beaked Whales				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NUWC,Code 70T, Building 1351,Newport,RI,02841				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The long-term goal of this program is to develop passive-portable tools for the detection of marine mammal vocalizations including those from deep diving Blainville?s (Mesoplodon densirostris) and Cuvier?s (Ziphius cavirostris) beaked whales from ships of opportunity including small observer vessels					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

The sonobuoys were tested for their ability to detect Blainville's beaked whale at AUTECH from 25-31 January, 2009. The modified sonobuoys were deployed on the range in areas of known beaked whale populations. Whale vocal activity and positions of vocalizing groups were recorded using the sonobuoys and compared to those detected on the AUTECH hydrophones by the existing M3R system.

A prototype system was also fielded during the Behavioral Response Study in the Mediterranean 29 July – 6 September, 2009, during which whale vocal activity and location of vocalizing groups were compared to visual observations and acoustic whale detections from towed arrays.

Tetrahedral Bearing Array

On Navy ranges, marine mammal observers are directed to an area of vocalizing beaked whales detected by M3R passive acoustics used in conjunction with range hydrophones (DiMarzio, *et al.*, 2008). However, when clicks are detected from beaked whales, the animals are foraging at depth (Johnson, *et al.*, 2006). A simple 4-sensor bearing array deployed from the RHIB will provide the ability to detect vocalizing animals from the surface and to derive a bearing to the animals. This increases the probability of finding animals when they surface, especially in marginal sighting conditions, by allowing the surface observers to refine their position relative to the animals. The detection range to a surface deployed sensor in a downward refracting acoustic environment is limited to those cases where the animal's beam pattern is pointed upward (Figs. 1 and 2). However, by combining detections from widely spaced bottom-mounted or surface-deployed sensors such as sonobuoys with a local bearing array, the probability of sighting animals on the surface is greatly increased.

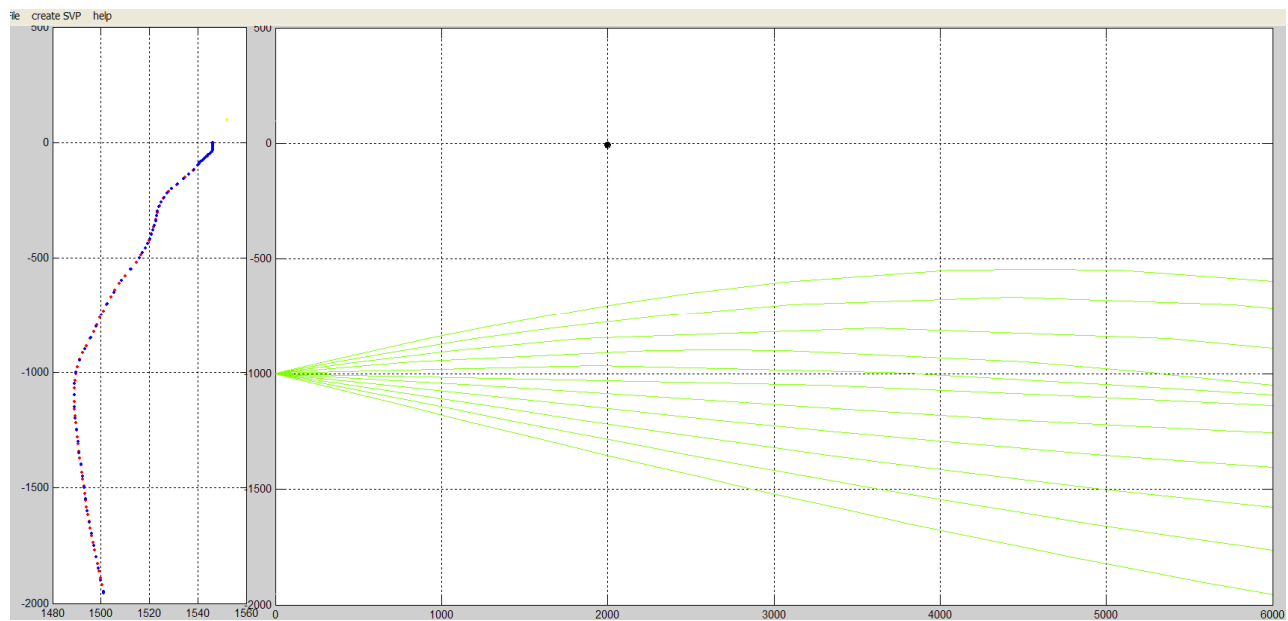


Figure 1. Raytrace for source at 1000 m with a 20 degree beam width, pointed at 0 degrees along the horizontal, calculated with an AUTECH August sound velocity profile

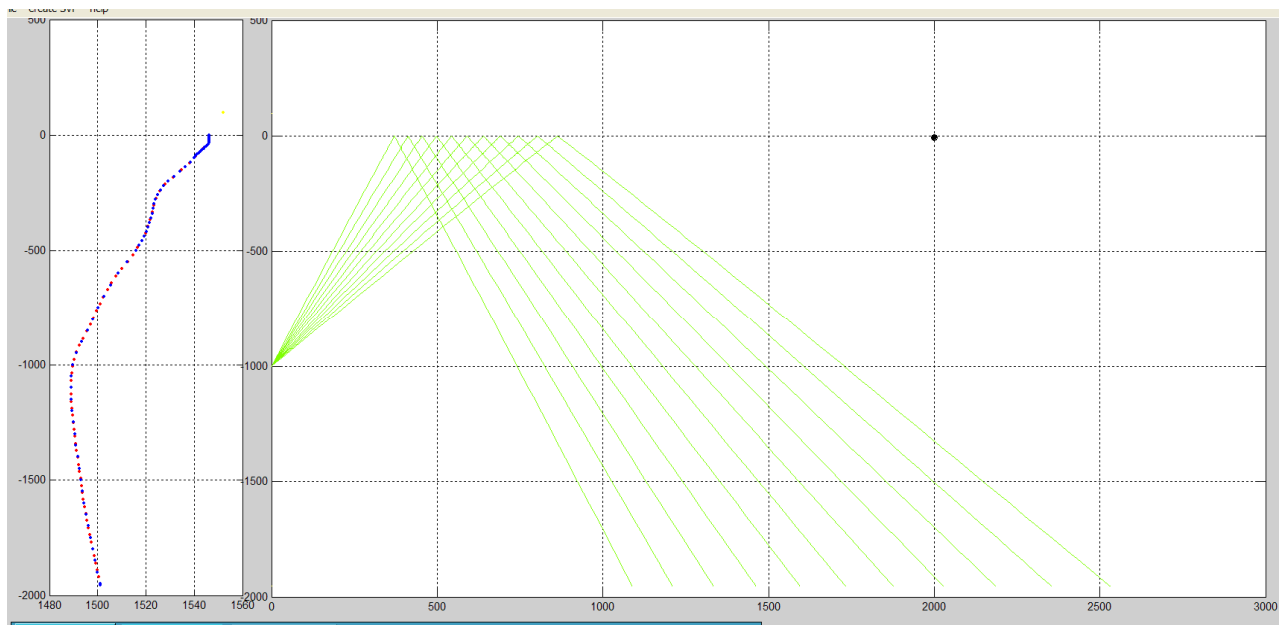


Figure 2. Raytrace for source at 1000 m with a 20 degree beam width, pointed up at 60 degrees, calculated with an AUTECH August sound velocity profile

A prototype unit was built by Applied Physical Sciences Incorporated and includes a 4-element high frequency bearing array with pre-amplification and an integrated magnetic sensor (heading, roll, pitch, depth). Each element is transmitted as a differential analog signal to the surface on a separate twisted pair of wires along with the compass and 3-axis accelerometer data. The prototype array is small, rugged, and intended for easy deployment from a RHIB.



Figure 3. Bearing array sensors before potting (left) with final unit (right)

This program provided funds to develop the topside signal processing for the bearing array. A transient bearing algorithm was designed and implemented. Software that reads the orientation data from the RS-232 link and produces the relative bearing to the detected marine mammal transients was designed and implemented. Graphical user displays for the detection, bearing, and localization data were created. The user displays are currently running in JAVA and are compatible with a ruggedized laptop when a small portable deck set becomes available.

WORK COMPLETED

Multiple items were completed as part of this program including:

- Portable Sonobuoys System
 - Real-time ship-based signal processor
 - GPS demodulator reader software
 - Localization software for dynamically updated positions
 - GPS-Demodulator modifications for 40kHz BW 53F sonobuoys
 - GPS position server software
 - M3R localization and click count server software
 - Tested prototype system at AUTEC during January 2009
 - Fielded a ship-based system for Med 09 July-Sept 2009
- Bearing Array
 - Prototype tetrahedral bearing array
 - Real-time multi-channel detection algorithm
 - Real-time multi-channel bearing algorithm
 - Bearing array archive software
 - Graphical user displays for bearing display provided
 - Ship-based processor
 - Tested prototype system at AUTEC during January 2009
 - Fielded a ship-based system for Med 09 July-Sept 2009

RESULTS

AUTEC Field Trials

An initial test to document the efficacy of sonobuoys and the prototype bearing array for beaked whale detection was conducted at AUTEC 25-31 January, 2009 under the auspice of The Technical Cooperative Program (TTCP) and in collaboration with Defense Research and Development Canada (DRDC). The sonobuoys were provided by DRDC and deployed off the DRDC's vessel CFAV "Quest" (Fig. 4). A field-ready multi-channel signal processor was designed by NUWC and installed on the Quest and received signals from DRDC sonobuoy receivers and all 4 elements of the prototype bearing array. These data, along with a GPS-IRIG encoded time were recorded on an Alesis recorder and detections from the ship-based signal processor were archived.

The shore-based M3R system was used to identify areas of beaked whale vocal activity and sonobuoys were then deployed in those areas. Blainville's beaked whale vocalizations were successfully detected using on multiple sonobuoys and then compared to the vocal activity and locations identified by the M3R system. (Fig. 5)



Figure 4. DRDC research vessel “Quest” and ship-board marine mammal visual observer (Charlotte Dunn)

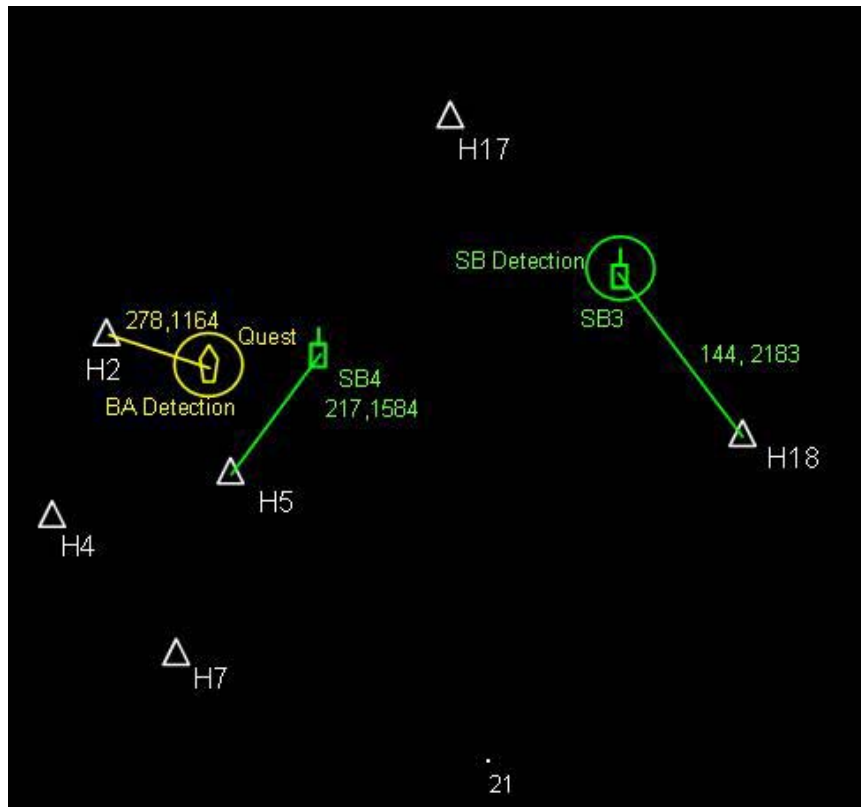


Figure 5. Track display of “Quest” with bearing array (yellow) and a GPS-modified 53F sonobuoy (green) against phones with active beaked whale detections (triangles). Ranges and bearings are indicated. The circles indicate beaked whale click detections.

The prototype bearing array was also deployed in areas of vocalizing animals and was used successfully to detect Blainville’s beaked whale vocalizations. The time delays were measured and bearings were calculated for these detections (Fig. 6).

The detection ranges for both the sonobuoys and the bearing array were also calculated. The maximum range recorded for the bearing array deployed to a depth of 30 meters was estimated to be 1235 meters. , Detections were limited to cases when the ship was able to come to a stop when in proximity to foraging beaked whales. For the sonobuoys with the hydrophone at a depth of 300 meters, the maximum range was estimated to be 2183 meters (Table 1). The test at AUTECH also included the use of other passive acoustic technologies including DRDC's underwater glider and TNO's Delphinus towed array, both of which successfully detected Blainville's beaked whale vocalizations.

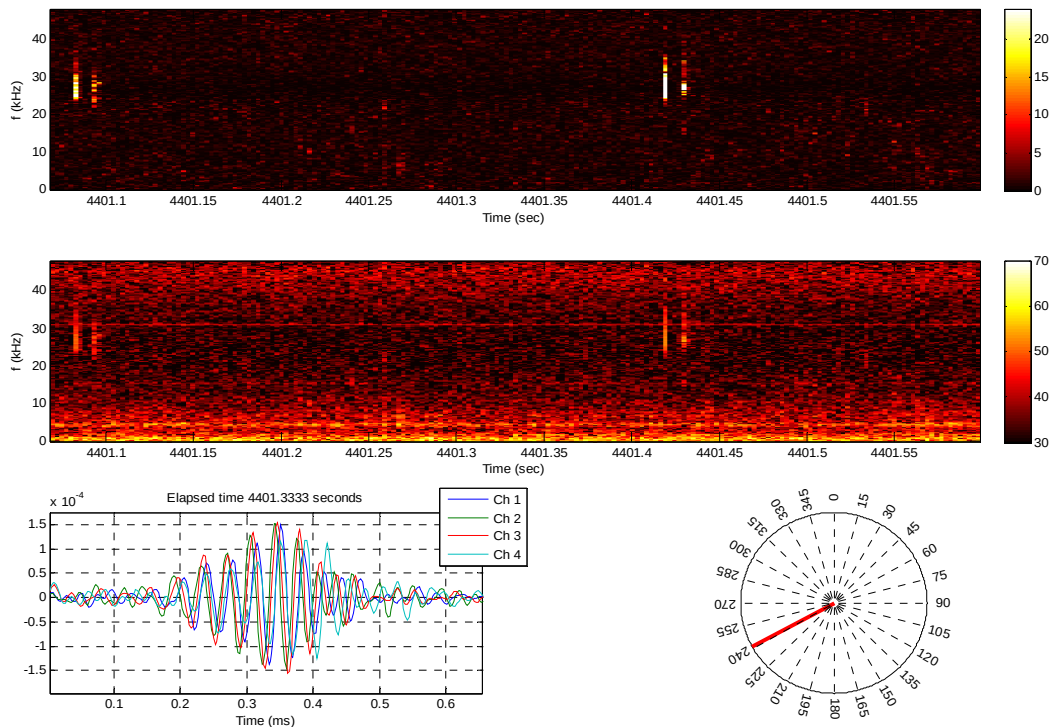


Figure 6. Spectrograms from Blainville's beaked whale clicks and time domain plots from 4 bearing array elements and calculated bearing.

Device	# Detections	Average Range (m)	Max Range (m)	Min Range (m)	Stand. Dev.
Delphinus	13	2261.923	5127	315	103.1055
BA	3	963.6667	1235	492	410.015
SB10	0	0	0	0	0
SB6	0	0	0	0	0
SB8	1	2183	2183	2183	-----
SB4	2	169	169	169	-----
SB3	0	0	0	0	0
SB5	0	0	0	0	0

Table 1. Summary Blainville's beaked whale detection ranges from sonobuoys and bearing array during January 2009 test in the Bahamas

Med09 Field Trials

Both sonobouy and bearing array systems were tested on board the NATO Undersea Research Center research vessel "Alliance". NUWC's 3-channel Flightline receiver was combined with a 4-channel NURC sonobuoy receiver. A 16-channel Undersea Sensor Systems Incorporated (USSI) GPS demodulator was used to extract buoy positions from the receiver channels' outputs. The buoys successfully detected marine mammal vocalizations including dolphins (Fig. 7) and Cuvier's beaked whales (Fig. 8).

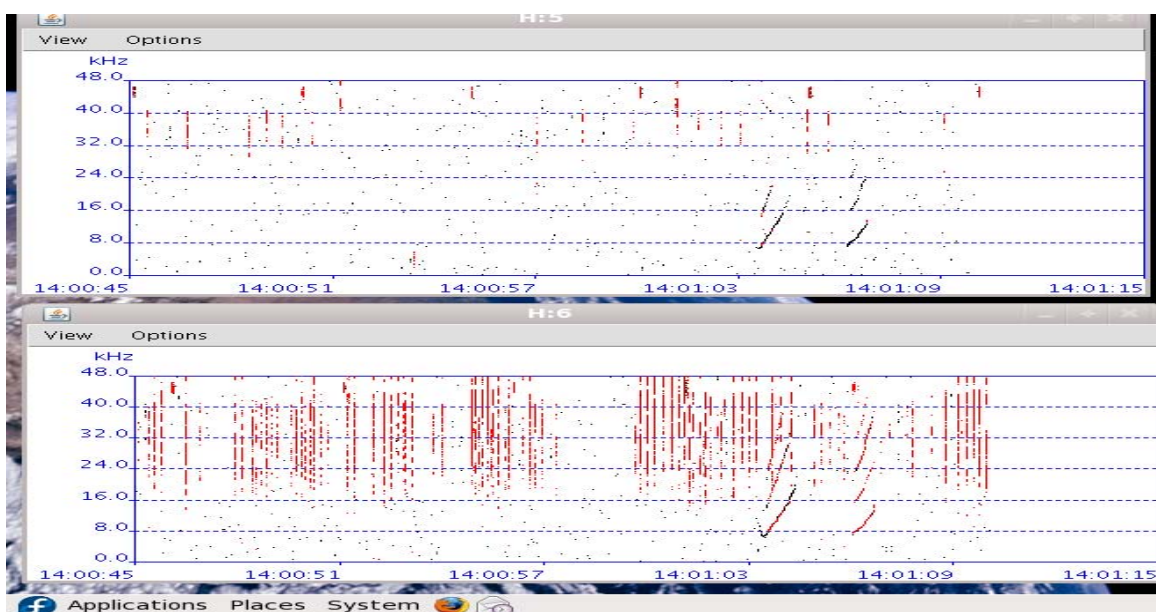


Figure 7. M3R 2D spectrogram display of dolphin vocalizations (clicks AND whistles?) detected on 2 GPS-modified 53F sonobuoys deployed off the NURC "Alliance" 24 August 2009.

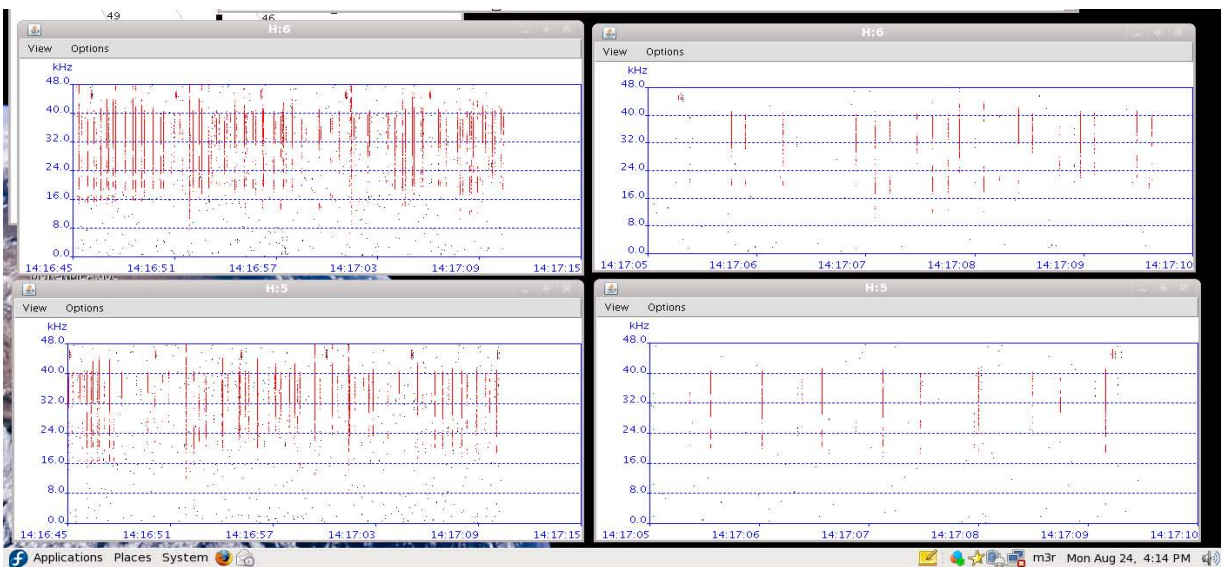


Figure 8. M3R 2D spectrogram display of Cuvier's beaked whale clicks detected on 2 GPS-modified 53F sonobuoys deployed off the NURC "Alliance" 24 August 2009. Left panel show detections on 2 buoys with zoom on right.

Several issues mainly with the casting of GPS data via a network to the ship-board GIS displays were uncovered during the test and rectified. It was also noted that the USSI demodulator multiplexes through the 16 receiver inputs. The GPS data are transmitted from the buoy at a 5 second repetition rate. If a buoy's RF carrier is present, the receiver will wait up to 5 seconds for a packet before moving to the next channel. If 16 buoys are deployed, minimally 1 in every 16 packets will be demodulated while 15 of the 16 transmitted packets will be missed. It was further noted that if a buoy does not have GPS lock, a null packet with no position information will be transmitted. Under the lossy GPS conditions that occurred at times during the experiment, such multiplexing compromises the system's ability to receive valid GPS positions. Implementing a software-based demodulator which dedicates a channel to each active sonobuoy would eliminate packet loss and potentially improve the system's ability to track individual sonobuoys.

The bearing array was also fielded during the Med 09 cruise. The intent of the array is to be easily deployed from observer RHIBs. During Med09, the array was ship deployed from the Alliance. It was to be deployed during a playback while the "Alliance" was stopped in the water and the playback source was deployed. Thus, it was hoped that the array would provide an additional sensor during playback and be combined with detections from surrounding sonobuoys. Because no playbacks were executed and because the ship was required to come to a stop to deploy the array, only one opportunity to test the array against vocalizing beaked whales occurred. However, no detections were recorded in the raw elemental data which indicated that there were no clicks of sufficient SNR to register either a detection or a bearing.

A number of tests were conducted using a playback source deployed off the "Alliance". During the second week of the cruise, the bearing array was successfully used to detect and calculate bearings to a 38 kHz source set at a 0.5 msec duration. The source was placed at the bow and the array at the stern of the vessel. The bearing of the ship and that calculated by the array were found to be within +/- 5 degrees.

During the second half of the cruise, 4 light bulbs were dropped. The implosions were detected and bearings calculated. (Fig. 9). The deployment RHIB was positioned at the 4 cardinal angles relative to the ship. Bulbs were dropped with the RHIB aligned with the bow, stern, and sides of the Alliance and the ship's heading was noted. The actual position of the RHIB upon bulb drop was estimated relative to the ship. The calculated bearings were consistently in the correct direction and the average error relative to the ship's heading assuming a perfectly aligned drop position was 15.57 degrees. Given the source characteristics (imploding light bulb) and the error related to the drop position, these results are within the design goals for the system.

During the 6th week of the cruise, the source test was repeated with mixed results. A small source was again positioned near the ship's bow and the array near the stern. The source was used to generate test signals. Bearings to the source were calculated but showed a bi-modal bearing distribution, one at the correct bearing but more readings at an incorrect bearing. Preliminary analysis suggests the threshold setting provided to the bearing array software was incorrect and should have been adjusted. This threshold sensitivity is an issue that needs to be addressed in the RHIB based system.

Minor engineering issues were isolated during the Med09 cruise. The RS-232 link required improvement and the start-up threshold conditions should be handled without operator intervention. The current prototype array processor is fieldable on a ship with power and space sufficient for a small rack-mounted computer. However, for use onboard a RHIB, the processor must be designed in a small form-factor capable of running off 12V D.C.

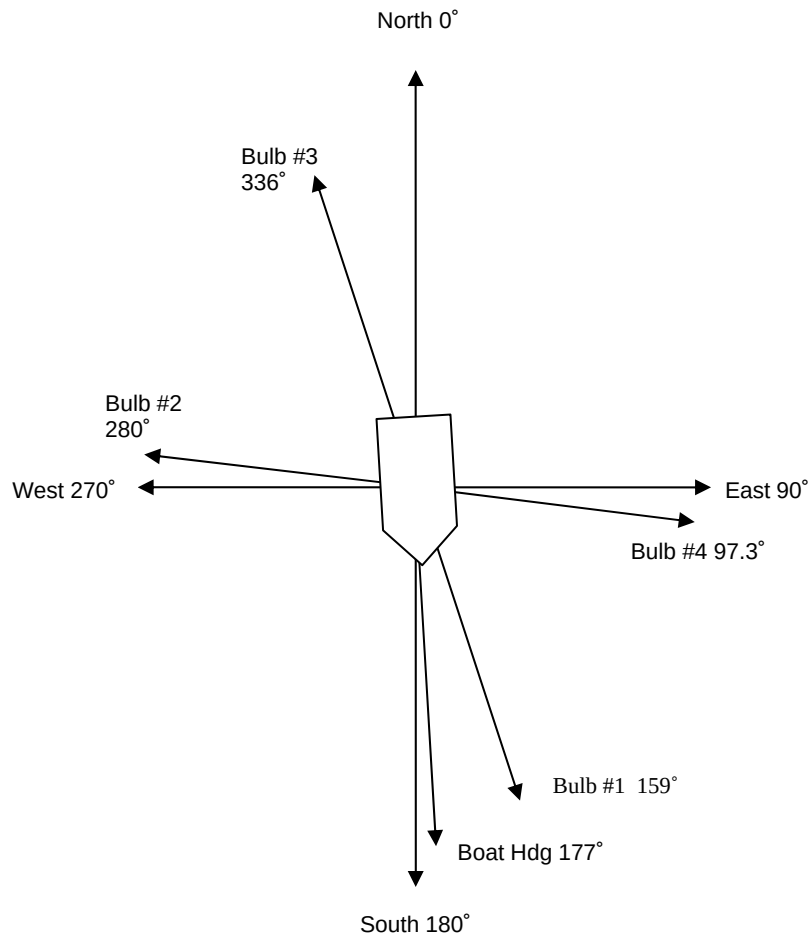


Figure 9. Results from a “light bulb” test with estimated bearing to the drop points and actual real-time calculated bearings.

IMPACT/APPLICATIONS

Both the sonobouys and the bearing array successfully detected deep foraging Blainville’s and Cuvier’s beaked whales. For open ocean operations, these devices are capable of monitoring without the need for extensive infrastructure (as on an instrumented Navy range) and at a low cost. The bearing array is particularly valuable for tests involving small boats. For instance, during M3R species verification tests on Navy ranges, an observer RHIB is vectored to vocalizing beaked whales. Animals vocalizations are detected using bottom-mounted Navy range hydrophones. While the animals are vocalizing and being detected by the M3R system, they are on a deep foraging dive and are not visible on the surface (Tyack, *et al.*, 2006). When the animals surface, they may be up to 1500 meters from where they were detected ref. If visual observers are equipped with a small bearing array, they could detect vocalizations and verify that they are in the correct position. Moreover, obtaining a bearing to the animals reduces the size of the area observers must search. This would result in a significant improvement in their ability to locate animals when they surface especially in marginal sea-state conditions. As both Cuvier’s and Blainville’s beaked whale spend little time on the surface and visually present a small profile, such an advantage would greatly improve our capacity to locate and subsequently tag these animals.

The bearing array should prove useful at SCORE as well, where current practice dictates that observers stop the RHIB in an area of beaked whale activity and are cued by the M3R team for the start and stop of vocalizations. Observers then listen and look for the blow of the surfacing animal. This technique has been used successfully in very calm conditions but breaks down quickly as the conditions deteriorate. The ability to verify location and reduce the search area in this scenario becomes extremely important.

TRANSITIONS

The most immediate application for these new technologies relates to the proposed SOCAL-10 playback effort scheduled to begin in the summer of 2010. This program is designed to isolate and tag marine mammals and expose the animals to a known signal at a known distance and source level. The program is utilizing a “fast and light” approach which means a RHIB will be used for tagging and observation while a small ship with a limited crew will be used for source deployment and playback.

When targeting beaked whales, most likely Cuvier’s, the RHIB will operate off San Clemente Island on the Southern California Antisubmarine Warfare Range (SOAR). Use of a small array deployed from the observer RHIB will provide a distinct advantage in visually locating animals when they surface.

During playbacks off range, in the absence of the Navy’s permanent hydrophone array, the use of sonobuoys and the bearing array would allow the source vessel to monitor for vocalizing animals. This is especially important for verifying unseen animals are not in the area and are therefore not unintentionally exposed during the playback.

RELATED PROJECTS

M3R is a closely related project with a need for portable passive monitoring especially on observer RHIBs. As stated earlier, observers are routinely vectored to vocalizing Blainville’s and Cuvier’s beaked whales, but it is difficult to detect these animals even in the best of conditions. The ability to acoustically determine the location of animals and to narrow the search area by receiving a bearing to the animals would be extremely helpful.

The marine mammal survey carried out by the Bahamas by the Bahamas Marine Mammal Research Organization (BMMRO) is an ongoing project. The use of the bearing array for both the survey and BMMRO’s ongoing photo-ID work off Abaco and in the Tongue Of The Ocean (TOTO) would greatly enhance their ability to find animals and document their vocalizations. This is particularly important given recent sightings by BMMRO of Gervais’ beaked whale (*Mesoplodon europeaus*) in the TOTO.

Observations and tagging of beaked whales by Cascadia Research Collective on both the SCORE Range and in Hawaii continues. As these efforts focus on small boat observations, use of the array and sonobuoys would be advantageous..

Dr. Patrick Miller, University of St. Andrews, has requested a prototype array for his ongoing tagging work. This request is contingent on the array being in a form-factor compatible with deployment from a small observer boat.

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