Final Report

Acoustic Monitoring of Dolphin Occurrence and Activity in the VACAPES MINEX W-50 Range

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Prepared by

Marc O. Lammers[1], Lisa Munger[1], Eden Zang[1], Marian Howe[1], and Eva Nosal[2]

[1] Oceanwide Science Institute

P.O. Box 61692
Honolulu, HI 96839

[2] Abakai International, LLC
2579 Lai Road
Honolulu, HI 96816

Submitted by:

HDR

Virginia Beach, VA

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Ecological Acoustic Recorders. Photos courtesy of Dan Engelhaupt and Marc Lammers (left to right).

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Executive Summary

Mine neutralization exercise (MINEX) activities that utilize underwater detonations (UNDET) have the potential to injure or kill marine mammals occurring in close proximity. To better understand the impact of MINEX training on marine mammals, an effort was begun in August 2012 to monitor odontocete activity at the Virginia Capes (VACAPES) Range Complex MINEX site using passive acoustic methods as part of the United States Navy's Integrated Comprehensive Monitoring Program. The initial objectives of the project were to establish the daily and seasonal patterns of occurrence of dolphins in the VACAPES W-50 MINEX training range, to detect explosions related to MINEX activities, and to determine whether dolphins in the area show evidence of a response to MINEX events.

Between 2012 and 2016, Ecological Acoustic Recorders (EARs) programmed to achieve continuous monitoring were deployed and refurbished approximately every 2 months. The data were analyzed manually for the daily presence/absence of dolphins, and their acoustic activity was quantified in detail for the period prior to, during, and after MINEX training events, which can occur on the range multiple times per month. The results indicated that dolphins occur near the training area year-round, with approximately 97 percent of monitored days containing some dolphin acoustic signals. However, there is clear seasonal variability, with a consistent period of low occurrence or reduced acoustic activity during winter months, and the lowest levels occurring in February. The data also revealed that dolphins exhibit an acoustic or behavioral response following an UNDET event. Acoustic activity levels approximately 1 kilometer (km) from the "epicenter" of training exercises were lower during both the daytime hours of the day of an exercise and the day following the exercise, suggesting that animals either left the area, reduced their signaling, or both. Conversely, dolphin acoustic activity levels during the second day following an exercise were higher than the day before an exercise. Perhaps because training events often occur over multiple days, dolphins may anticipate additional UNDETs beyond the final day of a training event, which could explain the reduced acoustic activity observed during the first day following the training event. In other words, dolphins may hedge against potential future exposure to an UNDET by avoiding the area.

A second phase of the project began in September 2013 to determine whether the responses observed at 1 km from the epicenter also occur at greater distances and whether a spatial redistribution of animals takes place. In addition, a localization array was implemented to examine the spatial distribution of dolphins near the epicenter shortly before and after UNDETs. Alternating 2-month deployments in 2013, 2014, and 2015 consisted of two different EAR configurations. In the first configuration, four EARs were arranged in a linear array at distances of 1 km, 3 km, 6 km, and 12 km from the primary MINEX training epicenter in order to examine whether animals are responding and/or redistributing along the coast or offshore during training events. In the second configuration, EARs were arranged in a localization array to measure the distances that animals occur from MINEX training activities.

The data obtained from the seven linear-array deployments between September 2013 and March 2016 were examined to determine the acoustic activity of dolphins at the EAR locations during the days before, during, and after MINEX training events in order to determine the range

at which an acoustic response by dolphins could be observed. A significant decrease in dolphin acoustic activity was observed between the day before and the day of the training event during the daytime hours in the data obtained 3 km from the epicenter. No significant differences were found in the acoustic activity recorded 6 km from the epicenter. These results suggest that the radius of potential active avoidance by dolphins during MINEX training events is between 3 km and 6 km. Notably, however, a reduction in acoustic activity on the day of an UNDET was also observed during daytime hours between the day before and the day of the training event at the two 12 km sites towards the north and south of the epicenter, which suggests that animals may respond to UNDETs occurring relatively far away. It is unclear why this is or what the response represents, but one possibility is that the animals are moving toward the epicenter from more distant areas to exploit prey fauna killed by the UNDET, perhaps during the nighttime hours in between or after training days.

Four EAR arrays with localization capability were deployed in 2013–2016. The first deployment was from 16 November 2013 to 23 January 2014, but time-alignment of recordings in order to localize signals was not possible using the UNDET explosion pulse as planned. The time-alignment of recordings from the array was later made possible by adding a pinger to one of the EAR moorings in subsequent deployments. The second localization array was deployed between 16 August 2014 and 7 November 2014, and provided 10 days of recordings from three instruments (data from the fourth unit were unusable due to electronic noise), during which no explosions were detected. The third localization array was deployed from 25 June 2015 to 21 August 2015. One EAR stopped recording 1 week into the deployment, and the remaining three EARs recorded until the end. Five explosions were detected, two on 7 July 2015 and three on 14 July 2015. In total, 22 candidate dolphin whistles for localization were detected in the 4 hours surrounding the first explosion on 7 July. However, due to low sample size and low signal-to-noise ratio of more than half of these whistles, reliable localizations could not be accomplished. In addition, the UNDET event itself could not be localized, as it was detected in a recording lacking time-synchronization pings. Dolphin signals were also detected within minutes of an UNDET event on 14 July 2015, suggesting that dolphins were present within 1.0–1.5 km of the UNDET, but these signals were detected in recordings lacking time-synchronization pings and therefore could not be localized. The fourth localization array was deployed on 13 June 2016 and recorded until 8 July 2016. EAR and pinger schedules were modified for the final localization array, such that EARs recorded for 30 minutes with no "off" interval and each recording contained synchronization pings. EAR B was inadvertently recovered early in the deployment so only data from three EARs were available for localization. Two UNDET events were detected, on 16 June and 24 June, with sufficient dolphin whistles available for localization and analysis for several hours before and after the first of these events. The results suggest potential movement of dolphin groups relative to the EAR array in the hours before and after the explosion, but no significant differences were found in distance or direction to dolphin localizations between the "before" and "after" periods.

In general, due to small sample sizes of both UNDET events and whistles, and other limitations in the ability to time-align EAR recordings, distances of dolphin groups to UNDET sources could not be determined within the first three localization-array deployments. Although the fourth deployment was successful in terms of localizing dolphin signals, the small sample size of explosions with co-occurring whistles continued to limit the ability to make statistically robust inferences.

Beginning in 2015, a supplemental effort was undertaken to field-test the micro Marine Autonomous Recording System (microMARS) recorder, a new type of low-cost acoustic recorder, with the objective of comparing its performance relative to the EAR. Although some initial problems were encountered during the first deployment of these instruments, the manufacturer corrected the problems in time for the second deployment. A seven-day subset of the microMARS data from the deployment surrounding the 7 July 2015 MINEX training event was analyzed and compared with the results obtained using an EAR at the same location. The subset of data was manually analyzed using a bandwidth of 25 kilohertz (kHz) (the same bandwidth recorded by the EARs) and also using a 50-kHz bandwidth to determine whether a broader recording bandwidth influenced the results obtained. One of the microMARS tested had a low-gain hydrophone (MH33-1), which did not have sufficient sensitivity to capture the majority of dolphin signals present. However, the unit with the high-gain hydrophone (MH33-2) produced results that did not differ significantly from those obtained using the EAR, with slightly better agreement at the higher microMARS analysis bandwidth. The data showed that a recording bandwidth greater than the EAR's 25 kHz did not appreciably change the results obtained, indicating that this bandwidth was sufficient to investigate the trends and behavioral responses documented in this study. In general, the microMARS was found to be well suited for the passive acoustic monitoring work conducted during this project. However, the long-term performance of this recorder over multiple consecutive deployments and over time frames of many months or multiple years was not tested here. Therefore, the failure rate of individual recorders due to malfunction and/or ordinary wear and tear remains unknown.

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Appendix A: EAR Deployment Details

Acronyms and Abbreviations

BP	burst pulses
EAR	Ecological Acoustic Recorder
EST	Eastern Standard Time
GPS	Global Positioning System
ICMP	Integrated Comprehensive Monitoring Program
kHz	kilohertz
km	kilometer(s)
m	meter(s)
microMARS	micro Marine Autonomous Recording System
MINEX	Mine Neutralization Exercise
SNR	signal-to-noise ratio
U.S.	United States
UNDET	underwater detonation
VACAPES	Virginia Capes

1. Introduction

The United States (U.S.) Navy is required to comply with federal laws designed to protect marine species, including the Endangered Species Act and the Marine Mammal Protection Act. As part of the regulatory process, the U.S. Navy must monitor and report on certain activities that have the potential to kill, injure, or otherwise harassmarine mammals, such as sonar and underwater detonations (UNDETs). The U.S. Navy's Integrated Comprehensive Monitoring Program (ICMP) was established in 2009 as a planning tool to focus the U.S. Navy's monitoring priorities pursuant to Endangered Species Act and Marine Mammal Protection Act requirements (DoN 2010). Two of the principal monitoring objectives identified in the ICMP are:

A. Increase understanding of how many marine mammals are likely to be exposed to stimuli (e.g., sonar and underwater detonations) associated with adverse impacts, such as behavioral harassment and hearing threshold shifts (temporary or permanent).

B. Increase understanding of how marine mammals respond (behaviorally or physiologically) to sonar, underwater detonations, or other stimuli at specific received levels that result in the anticipated take of individual animals.

In order to help meet these objectives for the Virginia Capes (VACAPES) W-50 mine neutralization exercise (MINEX) training range (**Figure 1**), a long-term passive acoustic monitoring study was begun in August 2012, in conjunction with a separate vessel-based visual survey, to document the spatial and temporal occurrence of cetaceans in the W-50 area and adjacent coastal waters, and to examine their behavioral responses to UNDETs. To this end, the objectives of the first year of the study (August 2012–July 2013) were:

1. Detail the daily and seasonal occurrence of bottlenose dolphins (*Tursiops truncatus*) near the primary location of MINEX activities.
2. Detect UNDETs associated with training events.
3. Quantify the acoustic activity of dolphins in response to UNDETs.

In Years 2–4 of the study (August 2013–July 2016), these objectives were expanded to also address the following questions:

4. At what distance from the explosion site is an acoustic response observable?
5. Do dolphins show evidence of re-distribution as a result of MINEX activities?
6. At what distance from MINEX explosions do dolphins occur?

In Year 3 an effort was also undertaken to field-test the micro Marine Autonomous Recording System (microMARS) recorder, a new type of low-cost acoustic recorder with promise for future monitoring applications. The objective was to field test four microMARS units and compare their performance relative to Ecological Acoustic Recorders (EARs). This report describes the methods employed in the study, presents the results from 4 years of monitoring, and discusses the implications of the findings.

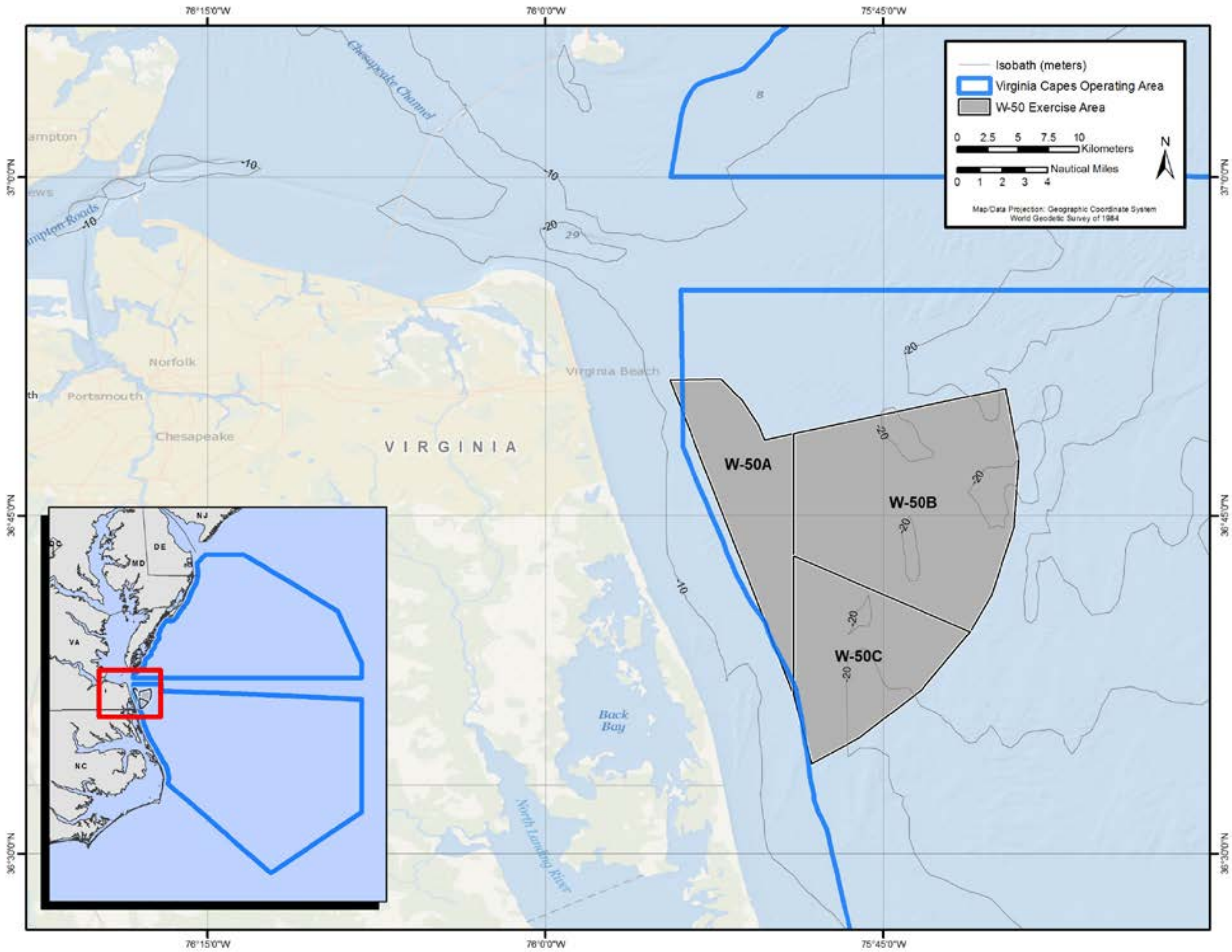


Figure 1. Map of the VACAPES Range Complex displaying an expanded view of the W-50 MINEX training range.

2. Methods

2.1 EAR Monitoring

Passive acoustic monitoring was initiated in the MINEX W-50 training area in August 2012, using bottom-moored EARs (**Figure 2**). The EAR (Oceanwide Science Institute, Honolulu, Hawaii) is a microprocessor-based autonomous recorder that samples the ambient sound field on a programmable duty cycle (Lammers et al. 2008). Four EARs were programmed to sample at a rate of 50 kilohertz (kHz) for 180 seconds (3 minutes) every 360 seconds (6 minutes), providing a recording bandwidth of approximately 25 kHz at a 50 percent duty cycle (**Appendix A, Table A-1**). This bandwidth is sufficient to detect signals (whistles and the low-frequency end of clicks) from bottlenose dolphins and other delphinid species potentially occurring in the VACAPES area, which produce signals at frequencies below 25 kHz. Harbor porpoise (*Phocoena phocoena*) clicks, with center and peak frequencies of 130 to 140 kHz (Goodson and Sturtivant 1996), are above the recording range of these EARs. EAR clocks were set to local time (either Eastern Standard Time or Eastern Daylight Savings Time depending on time of year) prior to each deployment; all times given in this report are in local time.

Figure 2. Images of an EAR prior to deployment and while deployed.

During the first deployment, the four EARs were paired and co-located approximately 1 kilometer (km) apart, and their recording periods were offset so that one unit was recording while the other was off. As a result, one of the paired units was always "on" in order to detect any nearby UNDETs. Two of the EARs (units A and B) were placed in 13-meter (m) and 14-m water depths (respectively) approximately 1 km from a site that was considered to be the "epicenter" of MINEX training activity. This is a search field location where the majority (approximately 95 percent) of MINEX detonations were expected to occur each year. The other two EARs (units C and D) were deployed in 15-m and 16-m water depths (respectively) approximately 5 km to the south-southeast of EARs A and B near another mine search field area. The recording parameters and deployment specifics are presented in **Appendix A**.

Of the four EARs initially deployed in August 2012, two were lost due to a malfunction in the anchoring system. As a result, monitoring at sites C and D was discontinued. However, sites A and B were both maintained through four additional deployments, after which site A was discontinued (see below). The EARs were recovered, refurbished, and re-deployed by staff from HDR approximately every 2 months, or as weather conditions and logistics allowed.

An experienced acoustic technician manually scanned recordings from sites A and B for the presence of MINEX explosion events, and from site B for dolphin signals, using the MATLAB™ program Triton (Wiggins 2003) and/or the program CoolEdit™ (now Adobe Audition; formerly Syntrillium, Inc.). Recordings containing dolphin whistles, echolocation clicks, or burst pulses were considered a "detection" of dolphins in the area. Dolphin presence/absence was quantified on a recording-by-recording (file-by-file) basis at site B for the entire deployment period in order to establish the daily, monthly, and seasonal patterns of occurrence of dolphins in the area. This analysis was performed for the twelve deployments that occurred between August 2012 and August 2015. For periods when explosions were detected on either EAR, a detailed assessment was made of the dolphin acoustic activity on unit B the day before, the day of, and the 2 days after each training exercise. Some training events occurred over multiple days, so the “day of” the event was the day when the first UNDET was detected and the “day after” and the “second day after” were the days following the final UNDET of the training event. For these four days, an acoustic activity index, representing the sum of the index values for the various sounds detected (**Table 1**), was assigned for each 3-minute recording to quantify acoustic activity. Activity indices were then used to quantitatively compare the acoustic activity of dolphins during the hours before and after an UNDET and the days surrounding the training event. Beginning with deployment #13, an automated MATLAB™ script was used to identify UNDET events by searching recordings for short, high-energy events.

Beginning in September 2013, EAR deployments were modified to address questions 4, 5, and 6 in **Section 1**. Two EARs were added to replace the units that were lost in 2012, and the deployment configurations were modified. To address questions 4 and 5, the four EARs were placed in a “linear-array” configuration, which was oriented to the south, east, or north during alternating EAR redeployments (**Figure 3; Appendix A, Tables A-2 and A-3**). EAR units were spaced at distances of 1 km (site B), 3 km (site E, H, or K), 6 km (site F, I, or L), and 12 km (site G, J, or M) from the primary MINEX epicenter. The EARs at 1 and 3 km were programmed at offsetting duty cycles in order to ensure the capture of all UNDETS, as in the previous year. Site B was maintained as the 1-km location for this and all subsequent linear-array deployments to ensure the continuation of the data time-series obtained during the previous year. The data obtained from linear-array deployments were used to examine the acoustic activity of dolphins at the four distances from the UNDET epicenter the day before, during, and after MINEX training events to determine the range at which an acoustic response by dolphins can be observed. Data were also used to assess whether or not there is a re-distribution of animals following MINEX training activities.

Table 1. Index values used to quantify dolphin acoustic activity for each 3-minute recording made the day before, during, and after detected explosions, based on the abundance of dolphin whistles, burst pulses (BP), and echolocation.

Acoustic Category	Index Value
1–20 whistles	1
BP only < 10	1
Echolocation only < 2 clicks/second	1
21–40 whistles	1.5
Echolocation only > 2 clicks/second	1.5
BP only > 10	1.5
Echolocation & BP < 10	1.5
1–20 whistles & echolocation or BP	2
> 41 whistles	2.5
Echolocation & BP > 10	2.5
1–20 whistles, echolocation, & BP	3

21–40 whistles & echolocation or BP	3
21–40 whistles, echolocation, & BP	3.5
> 41 whistles & echolocation or BP	3.5
> 41 whistles, echolocation, & BP	4

2.2 EAR localization array

Question 6 was addressed by placing the EARs in a localization-array configuration during alternating deployments beginning with deployment #6, with the units separated by approximately 150 m (**Figure 4**). This array configuration was designed for the capability to localize dolphins during periods of MINEX training using time-of-arrival differences of dolphin signals recorded on the four EAR units. A Trimble high-accuracy Global Positioning System (GPS) receiver was used to precisely record EAR deployment locations. For the first three localization array deployments (deployments #6, 9, and 12), the EAR units were programmed to record simultaneously at a 50 percent duty cycle of 3 minutes “on” every 6 minutes, allowing them to record the same dolphin signals and explosions. It should be noted that using a simultaneous 50 percent duty cycle resulted in half of the deployment period being unmonitored, potentially resulting in undetected explosions if these occurred when the recorders were off. During the fourth and final localization array deployment (deployment #15), EARs were programmed to record continuously (100 percent duty cycle) for 30 minutes at a time with no gap between recordings.

In order to accurately localize signals during post-processing, the EAR recordings must be precisely time-aligned. To accomplish this, an ARS-100 pinger (RJE International, Inc., Irvine, California) was co-deployed with one of the moorings beginning with the second localization-array deployment (An unsuccessful attempt was made to use the UNDET as a synchronization pulse during the first deployment). The pinger produced a short series of five 1-second tonal frequency sweeps (4 to 7 kHz) once every 30 minutes, therefore in every fifth EAR recording in the second and third deployments, and in every recording in the fourth deployment. The known location of the pinger was used to calculate the time-delay between EARs in order to time-align the recordings.

To time-align EAR recordings, a “pinger template” was created using a 0.5-second linear chirp from 4 to 7 kHz. The pinger template was cross-correlated with the recorded pings on each EAR to give pinger arrival times at each phone. These actual ping arrival times were compared to the expected ping arrival times modeled using the known EAR positions and sound speed, and EAR timing was corrected accordingly (**Figure 5**).

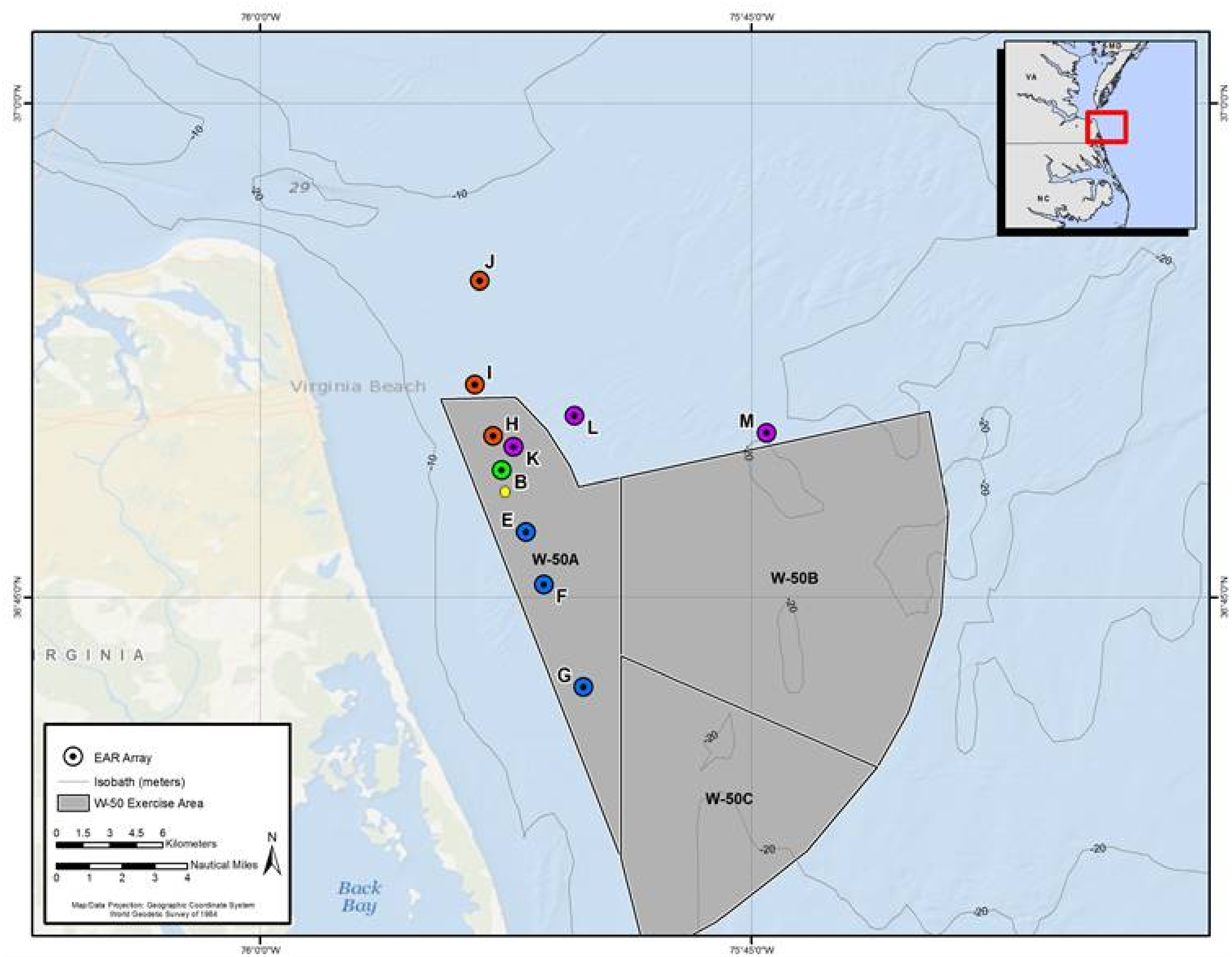


Figure 3. Spatial configuration of three linear EAR arrays deployed during the second and third years of the project. Site B remained constant and north is shown as red (B–H–I–J), east as purple (B–K–L–M), and south as blue (B–E–F–G). The yellow dot represents the position of the "epicenter."

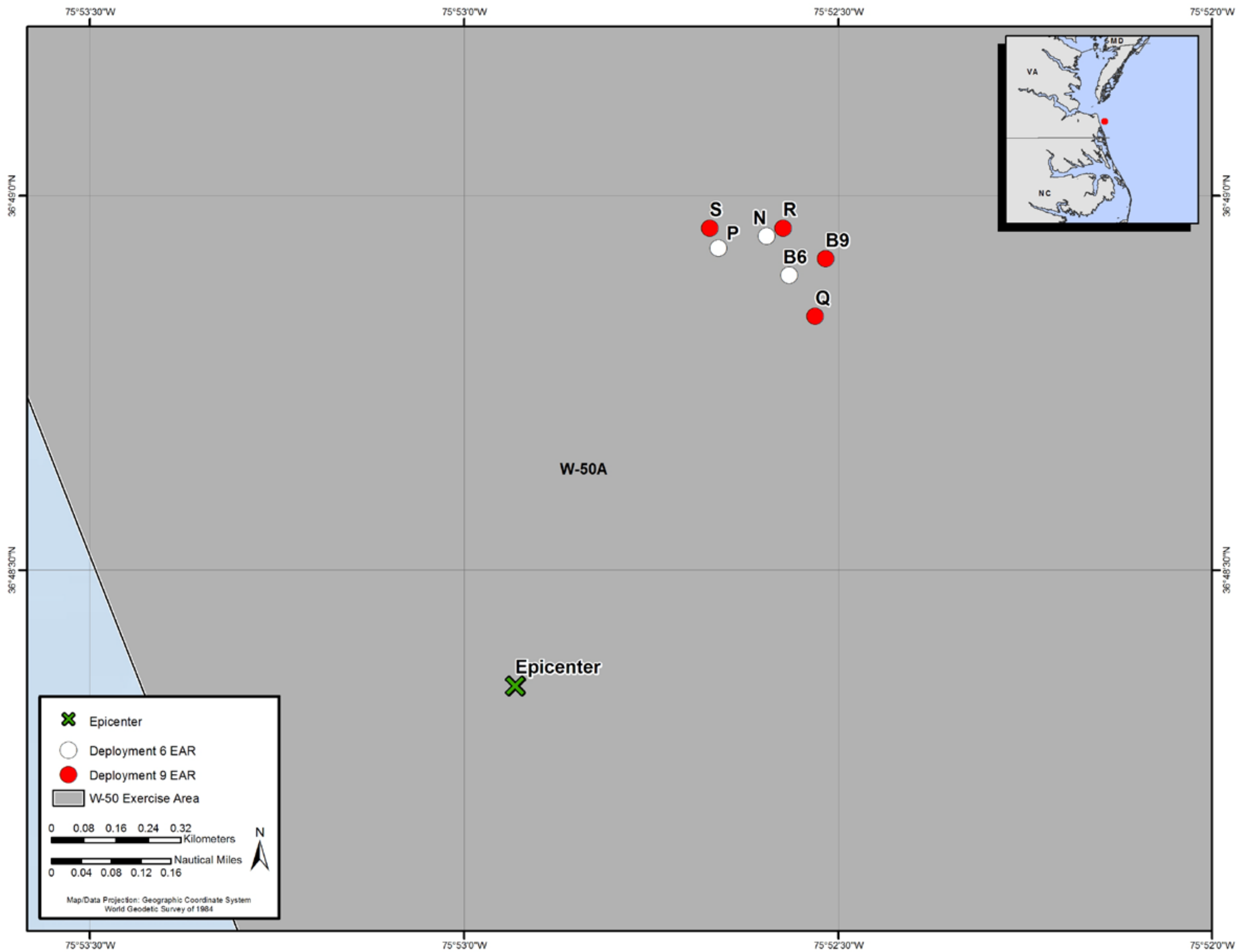


Figure 4. Spatial configuration of the two localization EAR arrays relative to the location of the epicenter of MINEX training activities. The white markers represent deployment 6 and the red markers represent deployment 9. Configurations in deployments 12 and 15 remained the same as deployment 9.

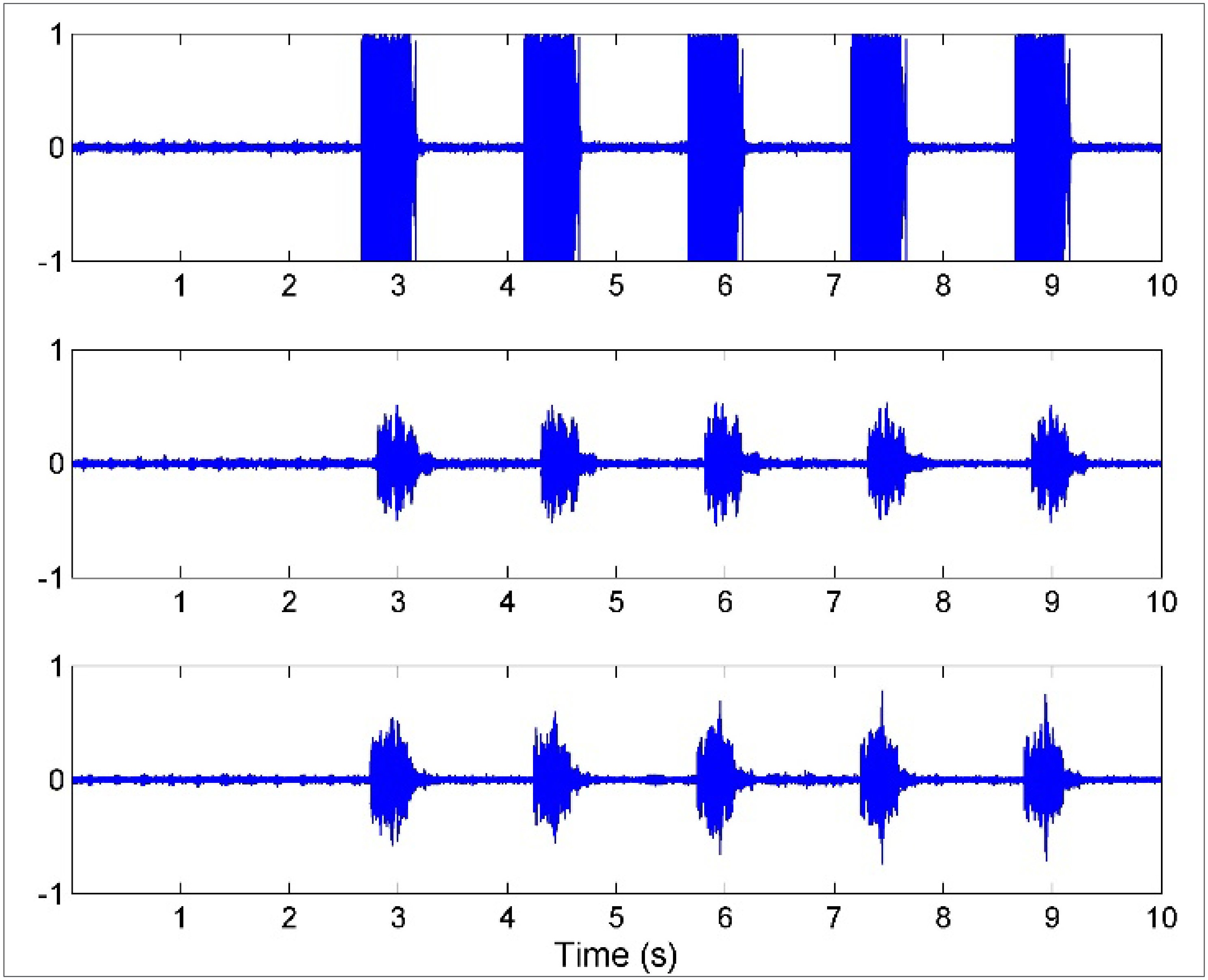


Figure 5. Example of the time-aligned pinger source signal as it was received at EARs B (top), Q (middle), and R (bottom). Y-axis values represent volts.

To demonstrate the feasibility of this approach, a few selected files were analyzed from the second localization array. EAR recordings were time-aligned as described in the previous paragraph and then band-pass filtered between 5 and 10 kHz (the band with most dolphin whistle energy for these recordings). Recordings were then divided into overlapping 1-second segments (50 percent overlap). Segments were cross-correlated for each receiver pair, and a threshold function was used to flag "sound present" segments. Time-differences of arrival between hydrophone pairs for "sound present" segments were estimated by picking the peak in the cross-correlation function for each hydrophone pair. Finally, the estimated time-of-arrival differences were fed into a hyperbolic localization algorithm to produce position estimates for each sound (**Figure 6**). For recordings with multiple high-signal-to-noise-ratio (SNR) whistles (**Figure 7a**), localization tracklines could be produced and potential errors could be identified (**Figure 7b**).

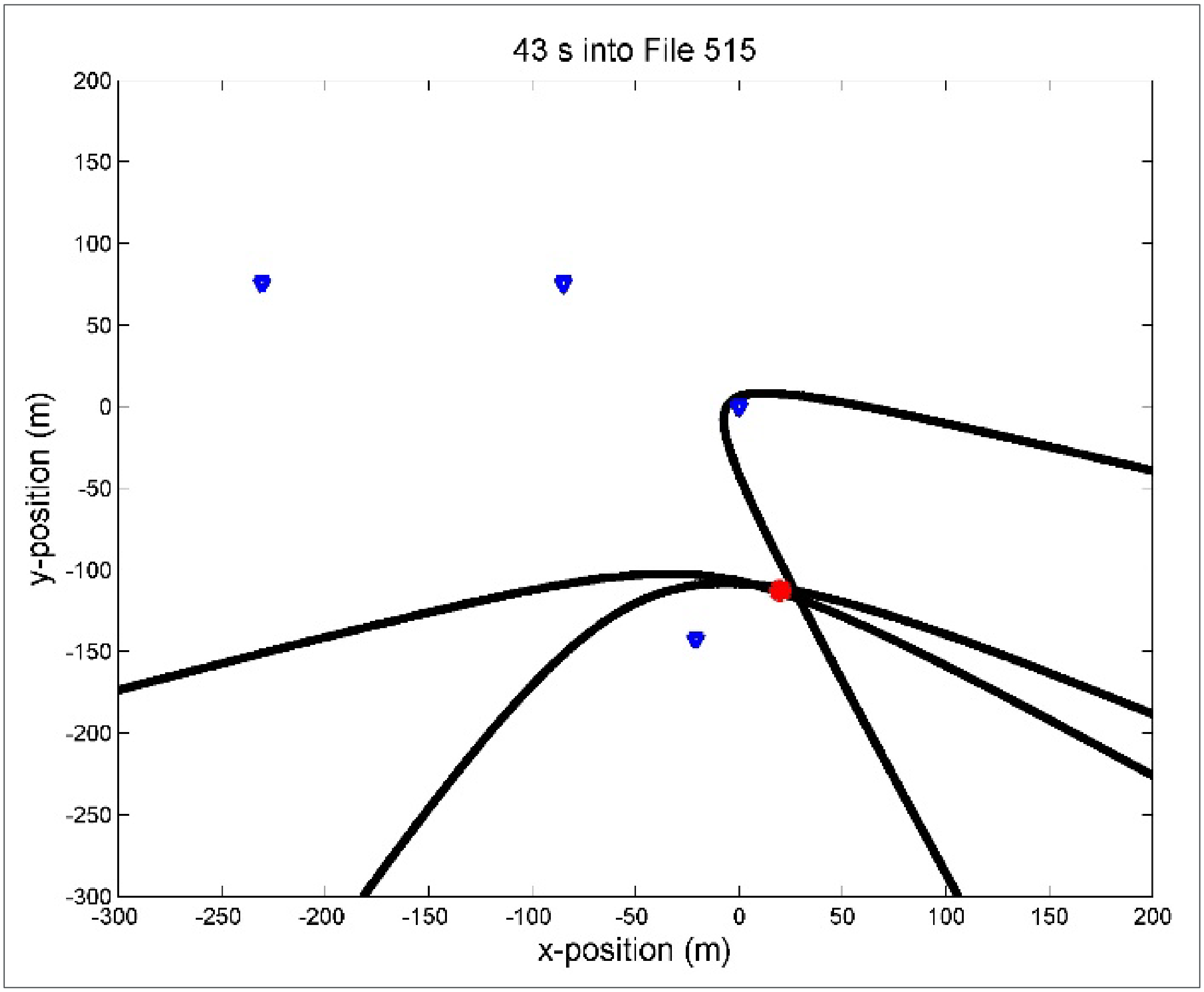
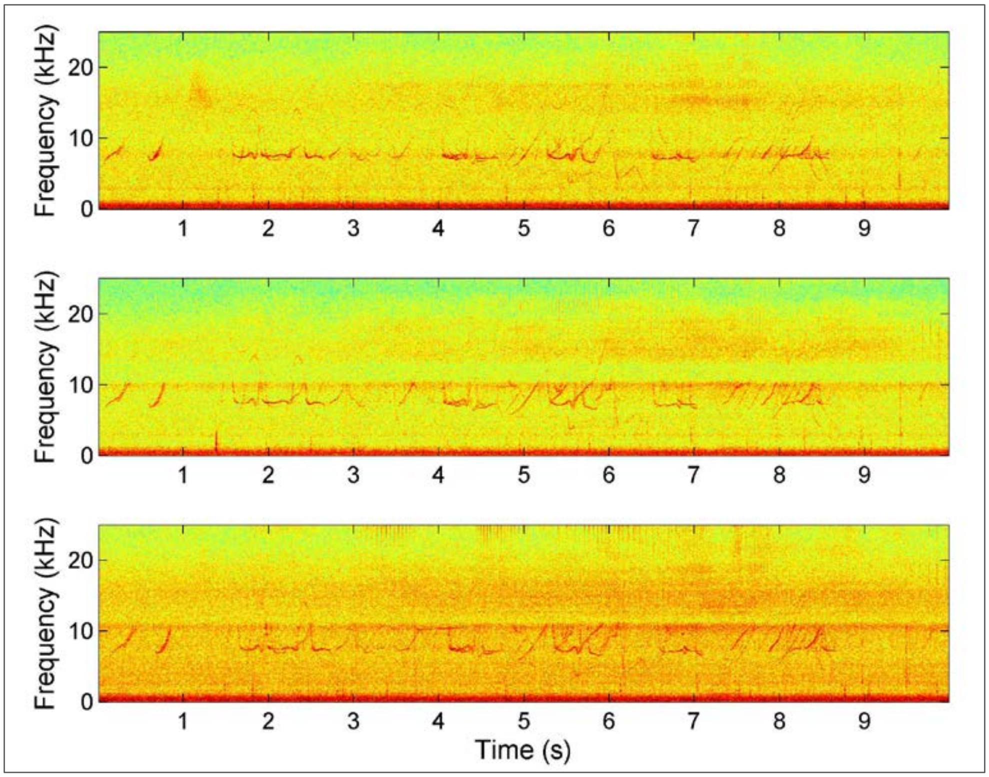
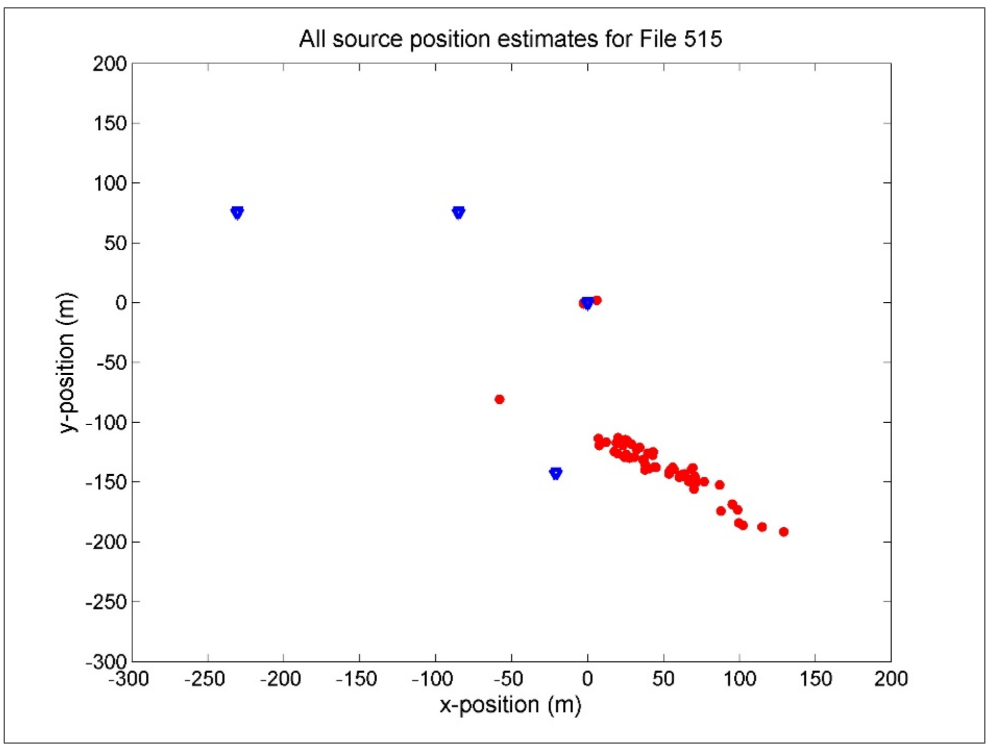


Figure 6. Example of a localized dolphin whistle. The blue marks indicate the positions of the four EARs. The red dot is the position of the signaling dolphin inferred by the convergence of the three hyperbolae.



(A)



(B)

Figure 7. (A) Spectrograms of a time-aligned sequence of whistles occurring in recording 515 from three EARs during the second localization-array deployment. (B) Localizations of dolphin whistles from recording 515. The blue marks indicate the position of the EARs and the red circles indicate localization of all source positions, including whistles, pings, and potential errors.

Only files containing pings could be accurately time-aligned. EAR clock offsets in recordings lacking pings were not predictable with enough precision across all instruments to allow for accurate interpolation and time-alignment. Therefore, dolphin signals were only candidates for localization if they occurred within pinger files.

Localization array deployments #3 and 4 were the only two deployments that both were instrumented with the time-synchronization pinger and recorded at least one UNDET event. In deployment #3, candidate dolphin whistles were identified in files containing pings (every fifth recording) in the 4-hour time period around explosions (2 hours before and 2 hours after). This 4-hour period was chosen as a preliminary approach, given the limitations of the pinger/recording schedule, to investigate potential changes in dolphin distribution immediately around an explosion. In deployment #4, the amount of data potentially available for localization increased as a result of the change in recording schedule to continuous recording (no gaps between files) and synchronization pings in every recording. Therefore, a longer search period of 12 hours before and 12 hours after an explosion was chosen for identifying candidate whistles for localization. Quality criteria for whistles included the following: 1) sufficient SNR for an analyst to visually detect whistle spectrograms from all three EARs, 2) minimal or no overlap with other whistles in time or frequency, and 3) a minimum of at least five such whistles in a given 0.5-hour recording.

EAR recordings were time-aligned using the synchronization pings as described previously in **Section 2.2**. An analyst extracted dolphin whistles of sufficient quality by drawing a box around the portion of the spectrogram containing the whistle. These box boundaries determined the window duration (usually < 2 seconds) and band-pass filter edges (rounded down and up to the nearest kHz for the low and high end, respectively). Data segments containing whistles were then passed through the localization algorithm described previously, which calculated time difference of arrival based on peaks in the cross-correlation function between hydrophone pairs and estimated positions using hyperbolic fixing.

Dolphin whistle location estimates (hereafter referred to as “localizations”) were plotted and analyzed relative to EAR R as a reference point. Whistle segments less than 0.25 seconds in time from neighboring segments were excluded from analyses in order to minimize duplication of location estimates. In addition, location estimates greater than 2 km from the EAR array were excluded from analyses due to high probability of error on distances more than approximately 10 times the array aperture. All computations were performed using Universal Transverse Mercator coordinates (i.e. northing and easting).

3. Results

3.1 Work Completed

HDR staff performed 15 rounds of deployments and recoveries from August 2012 through July 2016for a total of 53 individual EAR deployments (**Table 2**). In total, 42 deployments were successful and produced high-quality data (**Appendix A, Tables A-2 and A-3**). Four instruments were lost during the study period and seven instruments stopped recording prematurely, malfunctioned, or were erroneously recovered prematurely. In total, 609,584 individual recordings were made between all EARs, totaling 30,479 hours of data.

Table 2. EAR deployment summary.

EAR Deployment	EAR Configuration	Deployment Date(s)	Recovery Date(s)	EAR Sites
1	Two paired EARs	8/15/2012	10/15/2012	A, B, C, D
2	Paired EARs	12/7/2012	3/3/2013 & 3/15/2013	A, B
3	Paired EARs	3/15/2013	5/31/2013	A, B
4	Paired EARs	5/31/2013 & 6/9/2013	8/19/2013	A, B
5	Linear array	9/20/2013	11/11/2013	B, E, F, G
6	Localization array	11/16/2013	1/23/2014	B, N, P
7	Linear array	2/16/2014	4/27/2014	B, K, L, M
8	Linear array	5/18/2014	8/3/2014	B, I, H, J
9	Localization array	8/15/2014	10/27/2014	B, Q, R, S
10	Linear array	11/9/2014	1/23/2015	B, E, F, G
11	Linear array	3/9/2015	5/29/2015	B, H, I, J
12	Localization array	6/24/2015	8/30/2015	B, Q, R, S
13	Linear array	10/13/2015	12/16/2015	B, K, L, M
14	Linear array	2/1/2016	3/23/2016	B, E, F, G
15	Localization array	6/13/2016	7/8/2016	B, Q, R, S

3.1.1 EAR deployments at Site B

The EAR at site B obtained the most comprehensive data set over the duration of the study, at a consistent location within 1 km of the presumed MINEX training epicenter. In total, 213,176 recordings representing 10,659 hours of data were made at site B in August 2012 - July 2016. All deployments except #7 and #14 successfully obtained data from this location. The hard disk drive from deployment #7 malfunctioned, preventing recovery of the on-board data. The EAR from deployment #14 was not recovered and is presumed lost. For deployments #1–12 all recordings obtained from site B were manually examined for the presence/absence of dolphins to establish daily and monthly trends in dolphin occurrence near the epicenter of MINEX training. For deployment #7, data from EAR K were used instead as a proxy of dolphin occurrence in the area. The data from all deployments made at site B were also analyzed manually or using a custom automated MATLAB™ script to establish the presence of UNDETs in recordings. Lastly, the recordings corresponding to the day before, day of, and the two days following an UNDET were examined in detail and each recording was given an acoustic activity index value based on the criteria in **Table 1**.

3.1.2 Linear-array EAR deployments

The initial linear array (EARs B-E-F-G) was deployed towards the south of the epicenter on 20 September 2013, and was retrieved on 11 November 2013. However, only three of the units were successfully retrieved. EAR F, located 6 km from the epicenter, did not respond to release commands from the surface transponder and was therefore presumed lost. The most likely explanation is that it was moved or picked up by a fishing trawler. The lost EAR was replaced with a new unit, and on 16 February 2014, four EARs were redeployed in an eastern orientation (sites B-K-L-M) (**Appendix A, Tables A-2 and A-3**). These were recovered on 27 April 2014. The north-oriented array (B-H-I-J) was deployed on 18 May 2014, and retrieved on 3 August 2014 (**Appendix A, Table A-2**). A second southward linear array was deployed 9 November 2014 and recovered 23 January 2015, the second northward array was deployed from 9 March 2015 to 29 May 2015, the second eastward array was deployed from 13 October 2015 to 16 December 2015, and a third southward array was deployed from 1 February 2016 to 23 March 2016 (**Appendix A, Table A-2**). EAR B from the latter deployment did not respond to commands from the surface transponder. U.S. Navy divers searched the location, but they were not able to locate the unit, so it is also presumed lost.

The data obtained from the seven linear-array deployments between September 2013 and March 2016 were examined to establish the presence of UNDETs in the recordings and to assess dolphin acoustic activity before, during, and after MINEX training events. Data from EAR B continued to be analyzed for the presence of dolphin signals to maintain consistency with the data time series. Results of these analyses are reported in **Section 3.2**. Data from the four distances for each linear array were also used to determine whether or not there was a re-distribution of animals following MINEX training activities. The acoustic activity index was averaged by EAR location and pooled by the distance from the epicenter of training exercises for the days before, during and after an UNDET event. This allowed an examination of animal presence at each distance from the epicenter following MINEX events irrespective of the direction of the linear array. These results are reported in **Section 3.3.**

3.1.3 Localization-array EAR deployments

The first localization-array deployment took place between 16 November 2013 and 23 January 2014. It included only three EARs because EAR F was lost during the previous deployment. An attempt was made to synchronize the EAR clocks using the low-frequency precursor of the impulse from recorded UNDETs. However, this approach was ultimately unsuccessful because the characteristics of the precursor pulse were inconsistent. As a result, localizations of dolphin signals could not be attempted for this deployment. The second localization-array deployment (with the pinger at EAR B for time-aligning recordings) was made between 16 August 2014 and 7 November 2014. EARs B and Q recorded successfully during the entire deployment. EAR R recorded for 10 days and then unexpectedly stopped. EAR S recorded during the entire deployment, but the resulting data were contaminated by electronic noise, most likely due to instrument malfunction. No explosions were detected during the 10-day period with three operational EARs, and therefore no data were available for localization of signals surrounding any UNDET events.

The third localization array was deployed between 25 June 2015 and 21 August 2015, with the pinger co-located with EAR R. EAR R again unexpectedly stopped recording after 7 days, but the pinger continued to operate. The other three EARs recorded throughout the deployment, but as of 29 July 2015 (approximately 1 month into the deployment), EAR clocks had drifted to the extent that data were no longer being recorded simultaneously. Five explosions were detected within the first month when EARs were recording concurrently; two occurred on 7 July 2015 approximately 2 hours apart, and three occurred within a 7-hour span on 14 July 2015. Dolphin whistles were also detected on both days of the explosions, but candidate whistles for localization were only available in the 4-hour period surrounding the first explosion on 7 July. Although dolphin whistles were detected in multiple other recordings on days with explosions, most did not co-occur with pings and therefore localization in relation to these other events was not possible.

Whistle detections surrounding the first explosion event on 7 July 2015 are tabulated in **Table 2**. Whistles were detected in three files co-occurring with pings: two files before the explosion (at approximately 1.5 hour and 1 hour before, respectively) and one 6 minutes after the explosion. There were 12 total whistles available for localization in the two files before the explosion, half of which were subjectively rated as having "poor" SNR, i.e., not visible or barely visible in the spectrogram on one or more hydrophones (e.g., **Figure 8**). In the file following the explosion, there were approximately 10 whistles detected, six of which received "poor" SNR ratings (**Figure 8**). Realistic position estimates were not obtained for these whistles. In addition, the explosion itself occurred in a file without pings, which precluded time-alignment and localization of the explosion using EAR data. It may still be possible to estimate distances of dolphins to the explosion if the location of the UNDET is known, but due to the limited sample size of suitable files for localization and whistles within those files, further analyses are unlikely to provide additional statistical power.

Table 3. Whistle detections in recordings containing pings used for time-alignment before and after an UNDET event in July 2015.

File name	File time	Number of whistles suitable for localization	Signal-to-Noise Ratio rating
File 2990	7/7/15 11:00 (1.5 hour before explosion)	10	5 poor, 5 moderate
File 2995	7/7/15 11:30 (1 hour before explosion)	2	1 poor, 1 moderate
File 3005	7/7/15 12:30 (6 minutes after explosion)	10	6 poor, 4 moderate

The fourth and final localization array was deployed between 13 June 2016 and 8 July 2016, with the pinger co-located with EAR R. EAR B was prematurely recovered by U.S. Navy divers searching for the EAR that had been lost during the previous deployment, such that only three EARs (R, Q, and S) were recording during the two UNDET events detected on 16 June 2016 and 24 June 2016. The first recorded explosion on 16 June 2016 occurred at approximately 11:00 local time, and took place south of the EAR array (exact location to be determined). In the 24 hours surrounding this explosion (12 hours before and 12 hours after), a total of 11 files contained dolphin signals suitable for localization. These included 7 files within a 10-hour period prior to the explosion, the 1 file during which the explosion occurred, and 3 files in the 6 hours after the explosion. The second recorded explosion was on 24 June 2016 at approximately 10:00. However, only two files in the 24-hour period surrounding this explosion contained whistles suitable for localization, and of these, one file also contained the explosion. Due to the limited sample size of dolphin signals recorded before and after the second explosion, analysis efforts focused on only the first explosion.

Dolphin localizations before and after the explosion on 16 June 2016 are plotted in **Figures 9 and 10**. The distances from EAR R to dolphin localizations in the 10-hour “before” period ranged from 0 to 1.3 km (**Figures 9, 10**). Most of the "before" localizations (>80 percent) were within 400 m of EAR R (**Figure 11**), with one cluster of localizations roughly 1.2 to 1.4 km southwest of the array (**Figures 9, 10**). During the “after“ period, approximately 73 percent of localizations were again within 400 m of EAR R (**Figure 11**), but there were at least three clusters (and two single localizations) farther than 400 m from the EAR (**Figures 9, 10**). The farthest localized cluster after the explosion was approximately 1 km due west of EAR R (**Figures 9, 10**). However, distances to dolphin localizations from EAR R were not significantly different after the explosion compared to before the explosion (Mann-Whitney U-test, p=0.8). In addition, there was no significant difference before and after the explosion in the direction (compass bearing angle) of dolphin localizations from EAR R (**Figure 12**, Mann-Whitney U-test, p=0.2).

Upon deploying the array on 13 June 2016, the science team used a transducer aboard the small vessel to send out sequences of pings to aid in ground-truthing array localizations. Two minutes of transducer pinging data were recorded by all three EARs and available to localize using the methods described previously. The results of the ping localizations compared to the recorded GPS position of the boat/transducer are displayed in **Figure 13**. The errors in distances ranged between 40 and 90 m, and averaged 73 m. The error appeared to be systematically biased toward overestimating the north-south distance (southward in this case), but the east-west position was within approximately 10 m of the east-west coordinate of the boat (**Figure 13**). This may be related to array geometry, as the EAR array had a slightly larger east-west spread than north-south spread and therefore better accuracy in this dimension, but other factors may also contribute to this bias. The small sample size of available ground-truth data (i.e., sounds from known sources at known locations) limits further comparisons.

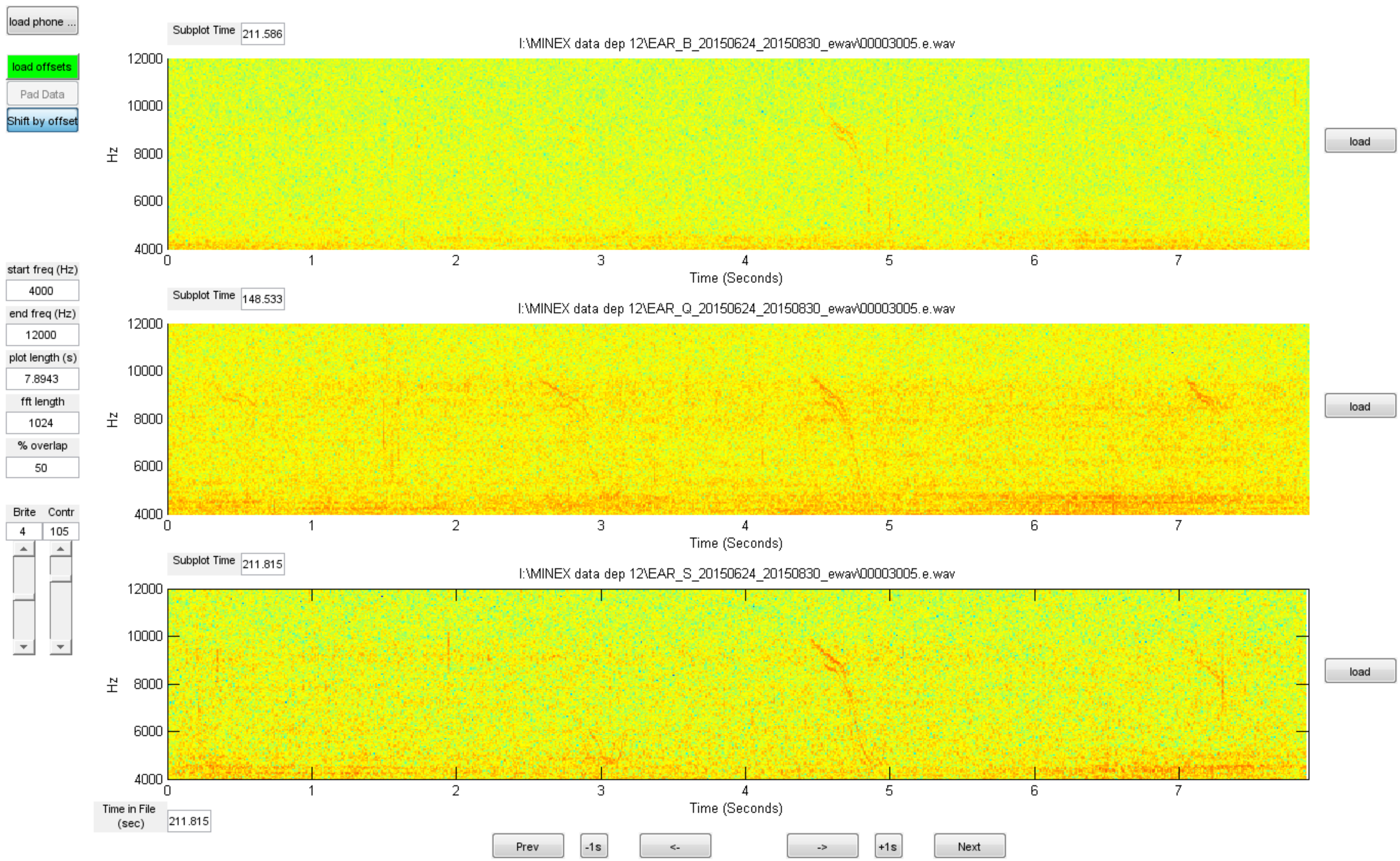


Figure 8. Time-aligned spectrograms from three EARs in file 3005, following an explosion detected in file 3004 6 minutes earlier. Note the low SNR of the whistles at 0.5 second and 2.7 seconds on EARs B (top panel) and S (bottom panel).

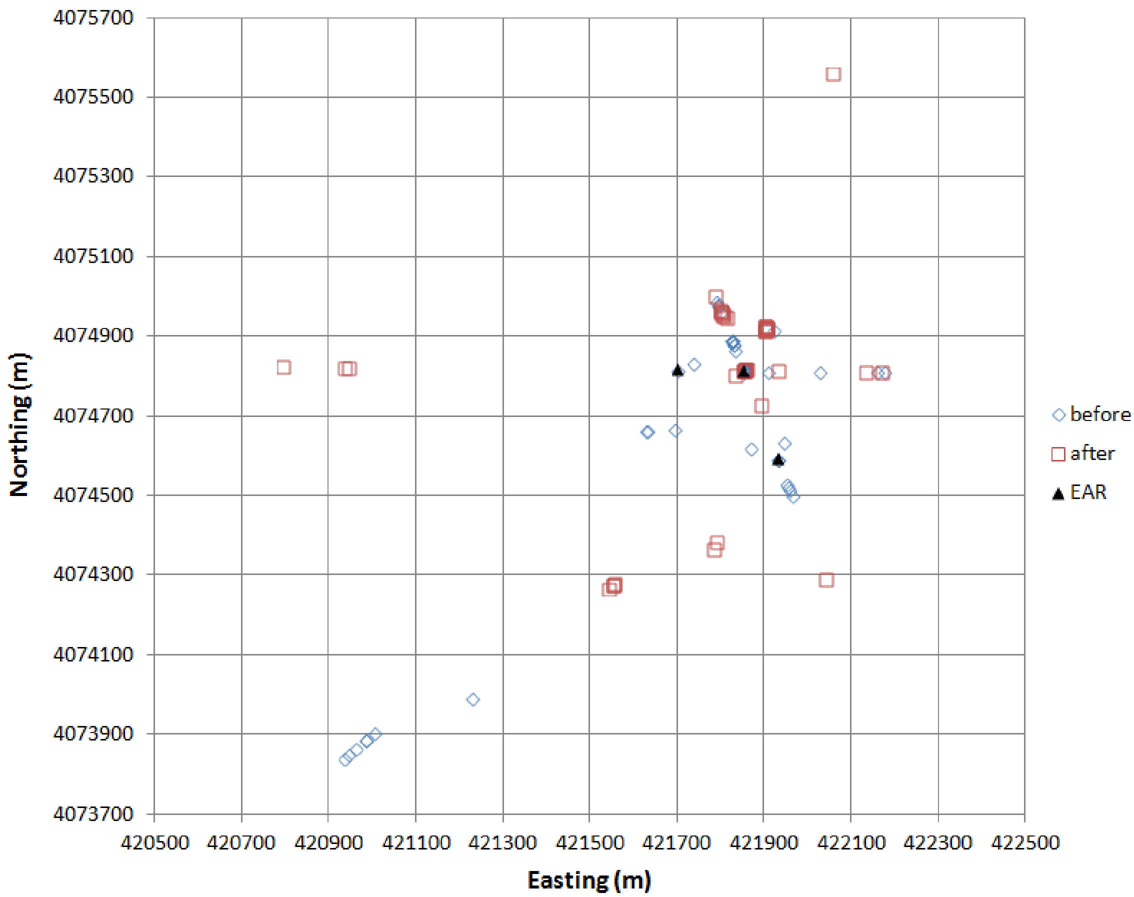


Figure 9. Map of dolphin location estimates before and after the explosion on 16 June 2016.

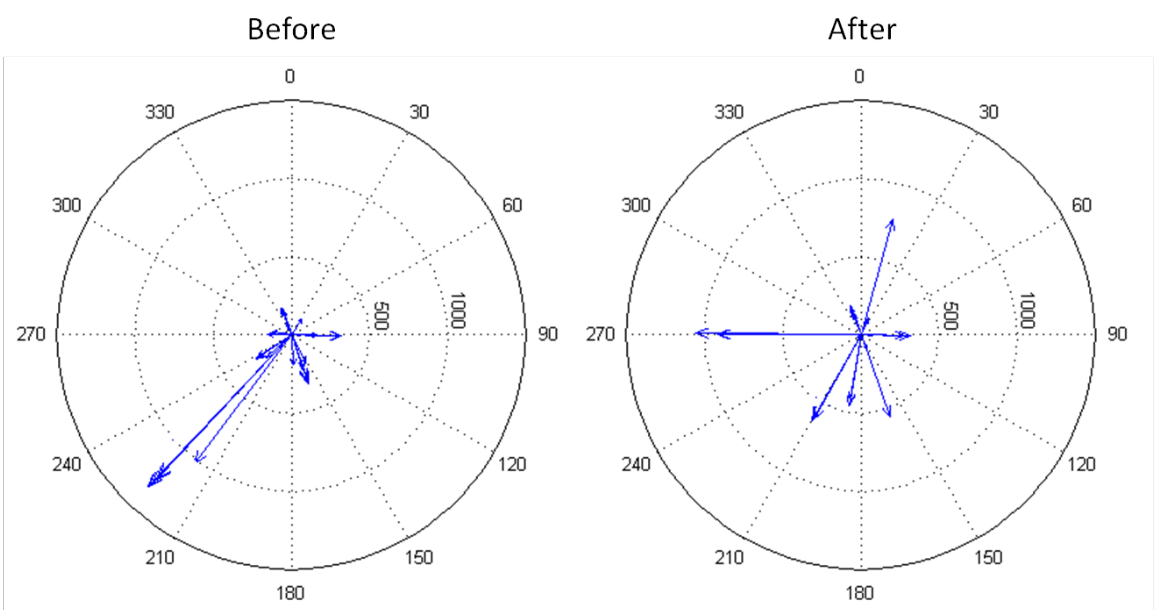


Figure 10. Compass plots of dolphin localizations relative to EAR R before and after the explosion. Distances in meters (along radii of circle) and bearing angles in degrees, with EAR R at center/origin.

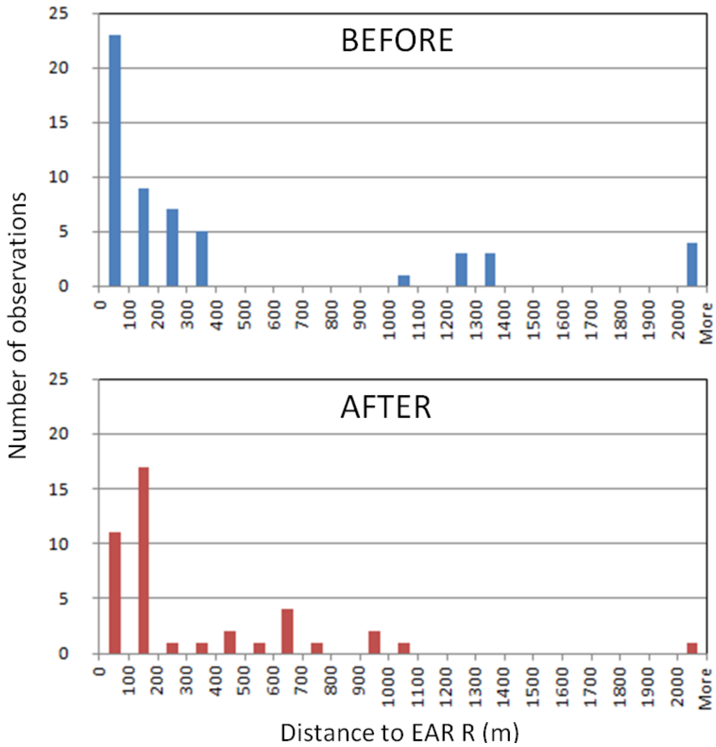


Figure 11. Histogram of distances of dolphin location estimates to EAR R before and after the explosion (upper and lower panels, respectively).

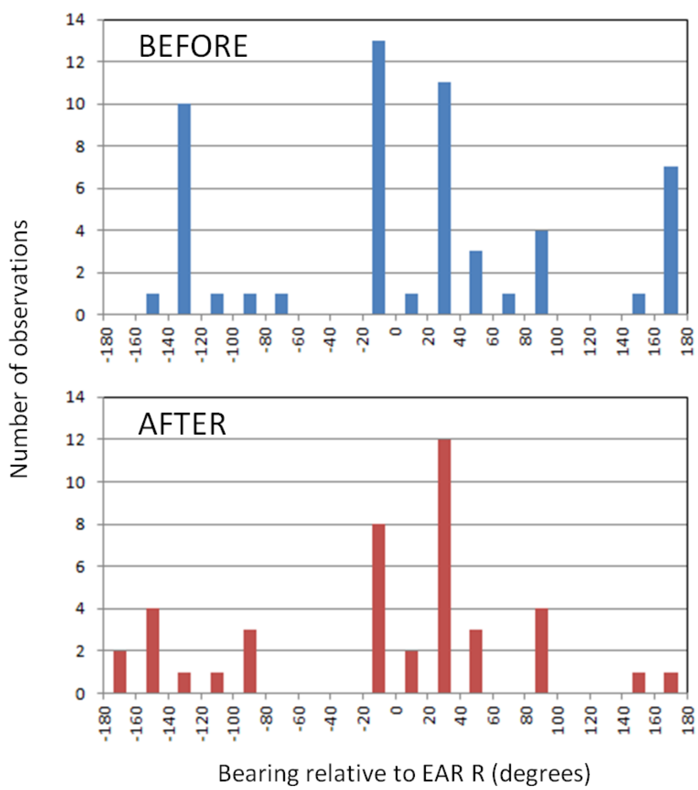


Figure 12. Histogram of localization bearing angles relative to EAR R before and after the explosion (upper and lower panels, respectively).

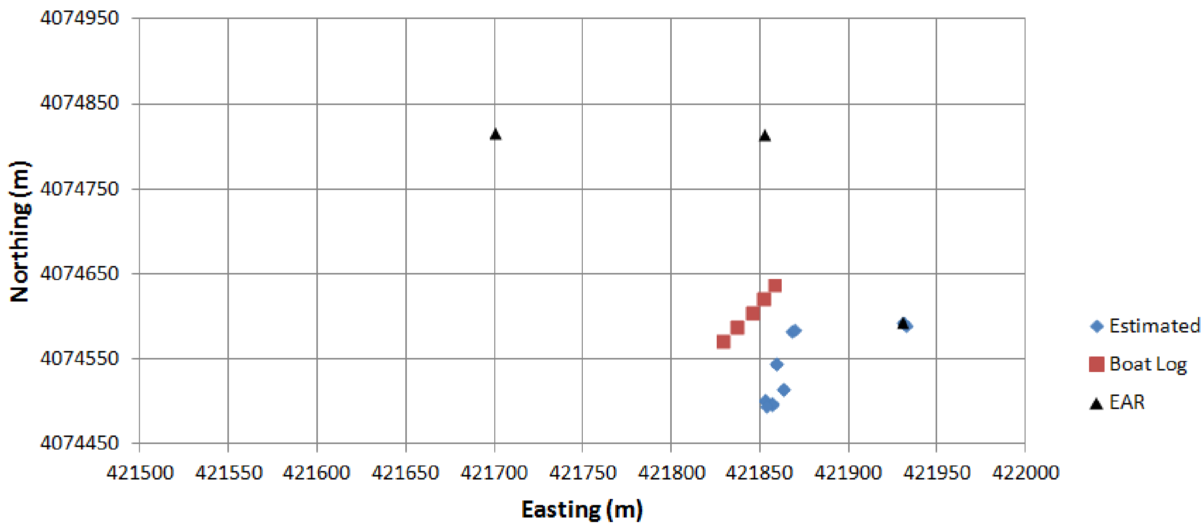


Figure 13. Locations of pings from HDR boat estimated using EAR data (blue diamonds) and recorded from on-board GPS receiver into the boat log (red squares).

3.1.4 microMARS deployments

A total of 52,349 microMARS recordings (3418 hours) was collected from four units co-located with EARs during deployments #11 and 12 between March and July 2015 (**Table 4**). Deployment #11 was a linear array to the north of the epicenter. Deployment #12 was a localization array, so all microMARS/EAR moorings were deployed at site B within 150–300 m of each other. The microMARS were programmed to have different recording schedules (duty cycled or continuous), sampling rates (100 kHz or 250 kHz), and file lengths (3 min or 5 min) in order to test functionality. They were deployed with one of two hydrophone models (MH33-1 and MH33-2), which had different gains and therefore sensitivities. The units from deployment #11 all stopped recording much earlier than expected. Two units (47 and 68) recorded for less than one day. It is unclear why these units failed and the manufacturer (Desert Star Systems, LLC) could not re-create the problem during testing. Units 77 and 69 recorded for approximately five and ten days, respectively. These recording durations were also shorter than expected and were likely due to greater power consumption than anticipated.

The units from deployment #12 were outfitted with additional batteries and were programmed to record continuously at either 100 kHz or 250 kHz sampling rates. These units recorded for periods ranging between 30 and 38 days, which matched the anticipated recording periods. The units stopped recording because they either ran out of battery power or storage space.

Other than the two instrument failures from deployment #11, two additional complications were encountered with the microMARS. The first problem was the long duration of data downloads. The download rate was approximately 1 minute per file for a 5-minute file sampled at 250 kHz. Thus, multiple days were required to download the data from each microMARS unit, unless multiple computers were used in parallel. Secondly, the start times from duty-cycled recordings were not consistent. A time gap of several seconds was introduced between the end of one recording and the beginning of the next. The accumulation of these gaps resulted in progressively later start times for each recording. As a result, EAR recordings and microMARS recordings were not time-aligned. The manufacturer was made aware of these problems and is developing software solutions to resolve both issues.

A seven-day subset of the microMARS (MM) data from deployment #12 surrounding the 7 July 2015 MINEX training event was analyzed and compared with the results obtained using an EAR at the same location (site B). The data were selected from MM69, which was fitted with a high-gain hydrophone (MH33-2), and from MM77, which had a low-gain hydrophone (MH33-1). According to the manufacturer's specifications, there is a 20 dB re 1 µPa gain difference between the two models. Each subset of data was manually analyzed file-by-file using a bandwidth of 25 kHz (the same bandwidth recorded by the EARs) and also using a 50-kHz bandwidth to determine whether a broader recording bandwidth influenced the results obtained. The data were examined for the presence/absence of dolphin signals. In addition, dolphin signaling occurring during the day before, day of, day after and second day after the training event was quantified using the same acoustic activity metrics presented in **Table 1**. A quantitative comparison of the two microMARS and the EAR data streams is presented in **Section 3.5**.

Table 4. Summary of microMars recording dates and data quantity. The "MM/EAR" column identifies both the microMARS and the EAR with which it was co-deployed.

Deployment	MM/EAR	Dates of recording	# of files	Duty Cycle	Sampling rate (kHz)
11	MM47_EAR_B	03/09/2015	14	Contin	100
11	MM68_EAR_H	03/09/2015	111	3 on/3 off	100
11	MM69_EAR_J	03/08/2015–03/17/2015	6061	3 on/3 off	250
11	MM76_EAR_I	03/08/2015–03/12/2015	4094	Contin	250
12	MM68_EAR_Q	06/23/2015–07/30/2015	17098	Contin	100
12	MM69_EAR_S	06/23/2015–07/24/2015	14161	Contin	250
12	MM77_EAR_R	06/23/2015–07/23/2015	8495	Contin	250
12	MM47_EAR_B	06/23/2015–07/31/2015	10810	Contin	100
		Total	**52349**		

3.2 Dolphin Occurrence near "epicenter" area of W-50

The analysis of recordings from site B for the presence/absence of dolphin signals covers the period from 15 August 2012 to 30 August 2015, totaling 799 days of recordings. Dolphins were present almost daily in or near the MINEX range, with detections (as defined in **Section 2.1**) made on 97 percent of recording days (**Figure 14**). The species identity cannot be confirmed without the use of classification algorithms, but it is assumed that the majority of detections are from bottlenose dolphins, based on sighting data from recent visual surveys in the area (Engelhaupt et al. 2014, 2015).

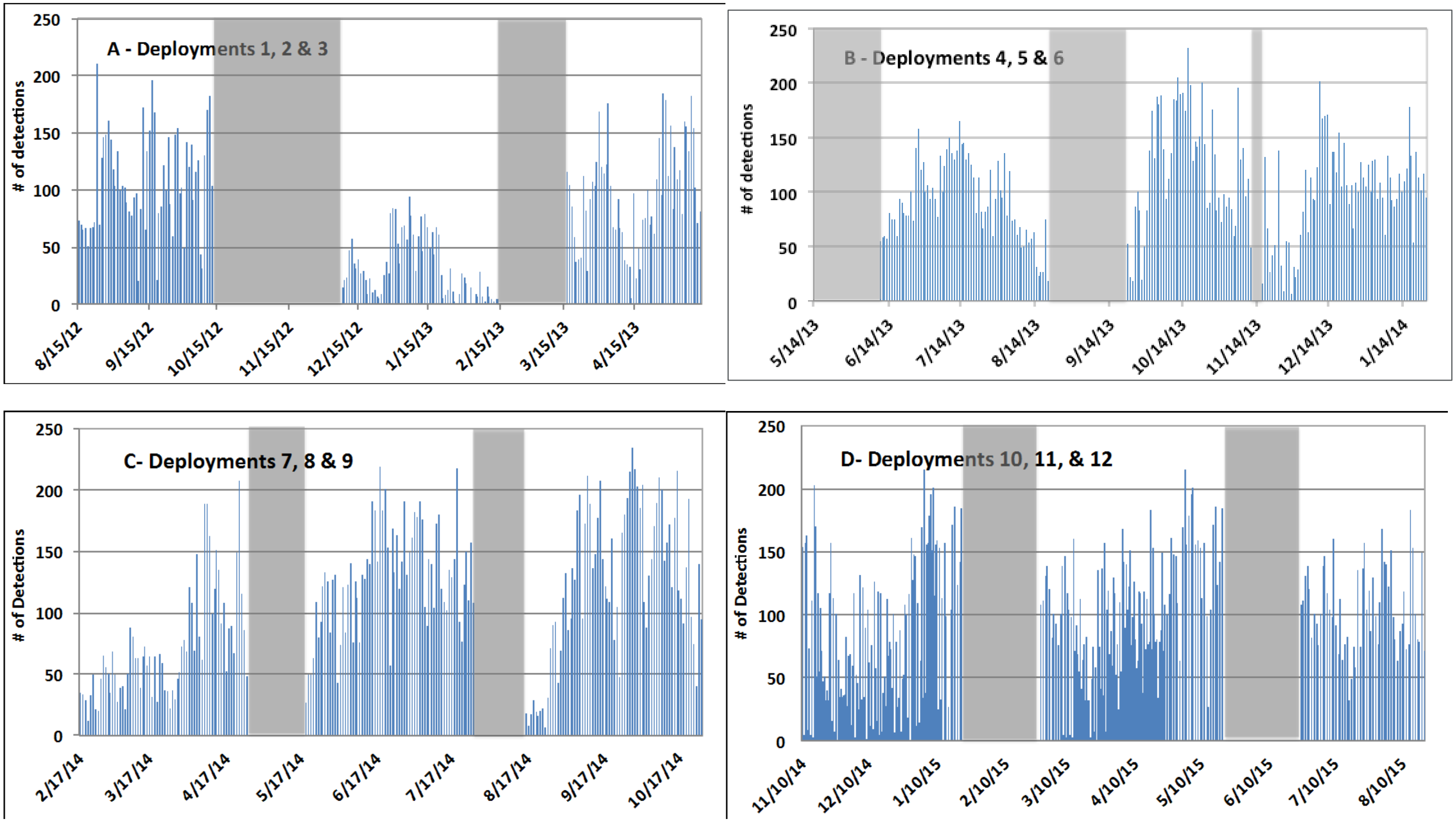


Figure 14. Daily numbers of dolphin detections near the epicenter of UNDET activity in MINEX W-50 between 15 August 2012 and 30 August 2015 for deployments 1–12. All detections are from site B, except during deployment 7 (16 February–27 April 2014), which came from site K. Grayed areas represent periods when the EAR was either not deployed or not recording.

During the 3 years of monitoring analyzed, a clear seasonal trend was observed in the mean number of daily detections each month (**Figure 15**). Dolphins were most commonly detected between the months of April and October. Detection rates dropped substantially between November and March and were lowest during the month of February. However, it should be noted that although the number of daily detections decreased during winter months, dolphins were still detected in the area nearly daily throughout the year.

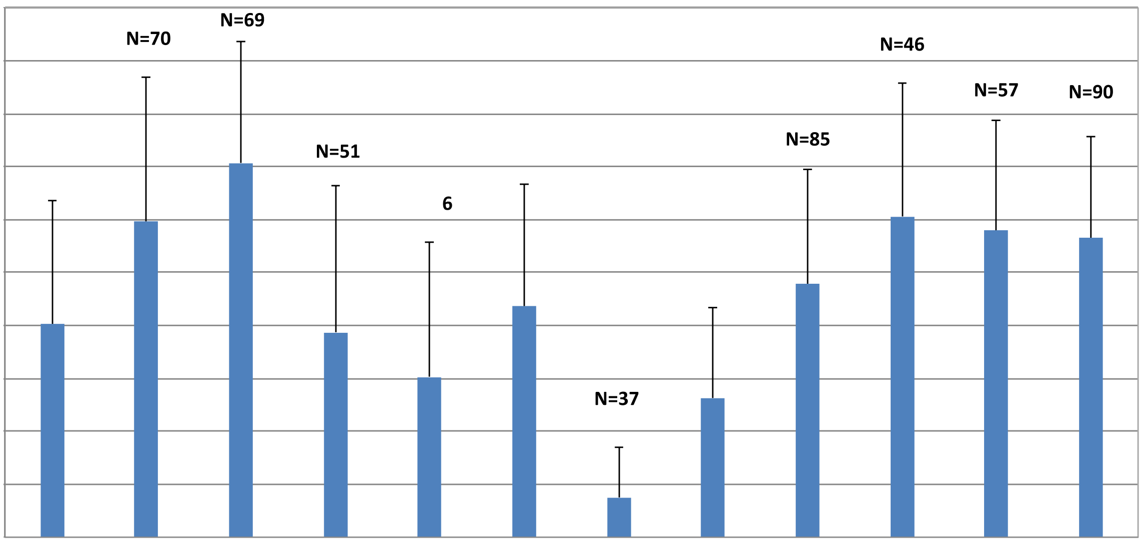


Figure 15. Mean number of daily dolphin detections at site B averaged by month for the three years of data collection between 15 August 2012 and 30 August 2015. Error bars represent one standard deviation. N values give the total number of days that were monitored during each month.

3.3 Dolphin Acoustic Response to MINEX training events

In total, 74 UNDETs were detected in the data between 15 August 2012 and 8 July 2016 (**Table 4**) representing 38 MINEX training events. Of the 74 UNDETs recorded, 49 were detected at the EARs located 1 km away from the epicenter (A, B, and Q), 22 were detected on the EARs placed 3 km away (B, K and H), 2 were detected on the EARs located 6 km away (F and L), and 1 was detected at an EAR 12 km away (G). Of the 38 training events recorded across all EARs, 31 coincided with data successfully obtained from site B (1 km from the epicenter). Of these 31 training events, all included baseline data recorded from the day before and the day of the event, 30 included data from the day after the event, and 29 included data from the second day after the event. The differences in the number of days recorded are due to the timing of EAR recovery and recording duration relative to two training events.

Table 5. UNDETs detected during deployments 1–15, including the site at which it was detected, the date and time of the explosion, and whether dolphin signals were observed in the same recording (Y = yes, N = no).

Deployment	EAR	Recording #	Explosion Date & Time (local time)	Dolphins present?
1	B	5163	9/5/12 12:21	Y
1	B	5208	9/5/12 16:51	Y
1	B	5214	9/5/12 17:27	Y
1	B	6590	9/11/12 11:03	N
1	B	6591	9/11/12 11:09	Y
1	B	6641	9/11/12 16:09	Y
1	B	6822	9/12/12 10:15	Y
1	B	8031	9/17/12 11:09	N
1	B	10715	9/28/12 15:33	Y
1	B	12126	10/4/12 12:39	Y
2	A	633	12/10/12 19:09	N
2	B	631	12/10/12 15:09	N
2	B	8591	1/12/13 19:09	Y
3	B	3247	3/29/13 12:45	Y
3	B	4448	4/3/13 12:53	Y
4	A	4433	6/19/13 11:20	Y
4	B	371	6/11/13 13:10	N
4	B	12129	7/30/13 12:57	N
4	B	12385	7/31/13 14:33	Y
4	B	12871	8/2/13 15:09	N
5	G	8279	10/25/13 11:58	N
6	B	1420	11/22/13 10:31	N
6	B	1429	11/22/13 11:24	N
6	B	1431	11/22/13 11:37	N
6	B	1460	11/22/13 14:32	N
6	B	5985	12/11/13 11:02	N
6	B	5999	12/11/13 12:25	N
6	B	14895	1/17/14 14:00	N
6	B	14899	1/17/14 14:24	N
7	K	4938	3/9/14 13:51	Y
7	K	4945	3/9/14 14:35	Y
7	K	12364	4/9/14 12:28	Y
7	K	12395	4/9/14 15:33	N
7	K	15894	4/24/14 14:46	Y
8	B	403	5/20/14 16:20	Y
8	B	423	5/20/14 18:20	Y
8	B	4426	6/6/14 10:38	Y
8	B	4437	6/6/14 11:44	N

Deployment	EAR	Recording #	Explosion Date & Time (local time)	Dolphins present?
8	B	13794	7/15/14 11:25	Y
8	B	14546	7/18/14 14:38	Y
8	H	647	5/21/14 16:45	N
8	H	654	5/21/14 17:27	Y
8	H	659	5/21/14 17:57	Y
8	H	662	5/21/14 18:17	N
8	H	2778	5/30/14 13:51	Y
8	H	12365	7/9/14 12:33	N
8	H	12381	7/9/14 14:09	N
8	H	14289	7/17/14 12:59	Y
8	H	14299	7/17/14 13:58	Y
8	H	14528	7/18/14 12:51	Y
8	H	15247	7/21/14 12:45	Y
9	B	9093	9/22/14 21:19	N
9	B	9110	9/22/14 23:01	Y
9	B	16452	10/23/14 13:13	N
9	B	16460	10/23/14 14:01	N
10	B	14043	1/7/15 12:19	Y
11	B	17406	5/20/15 12:36	Y
11	B	17414	5/20/15 13:26	Y
11	H	17170	5/19/15 13:03	Y
12	B	3004	7/7/15 12:24	N
12	B	3027	7/7/15 14:43	N
12	B	4659	7/14/15 9:56	Y
12	B	4682	7/14/15 12:14	N
12	B	4730	7/14/15 17:01	N
13	B	5450	11/4/15 17:01	Y
13	L	5450	11/4/15 17:00	Y
14	E	4346	2/19/16 14:40	N
14	E	6941	3/1/16 10:11	N
14	E	7181	3/2/16 10:10	Y
14	E	11026	3/18/16 10:45	N
14	E	11027	3/18/16 10:45	N
14	F	5995	2/26/16 11:33	N
15	Q	141	6/16/16 10:54	N
15	Q	524	6/24/16 10:12	Y

The mean hourly acoustic activity indices of dolphins during the day prior, the day of, and the two days after the 31 analyzed training events at site B are shown in **Figure 16**. During the day prior to an event, dolphins were most active during mid-day and nighttime hours. On the day of MINEX training and the following day, the daytime peak in activity was reduced or absent. In contrast, the nighttime peak persisted following MINEX training events, suggesting that the animals in the area resumed normal activity during these hours. During the second day following a training event the hourly acoustic activity levels were significantly higher than the levels observed during the day before the event (see next paragraph), suggesting that animals were more active and/or abundant in the area during this time than during the baseline period (the day before an exercise).

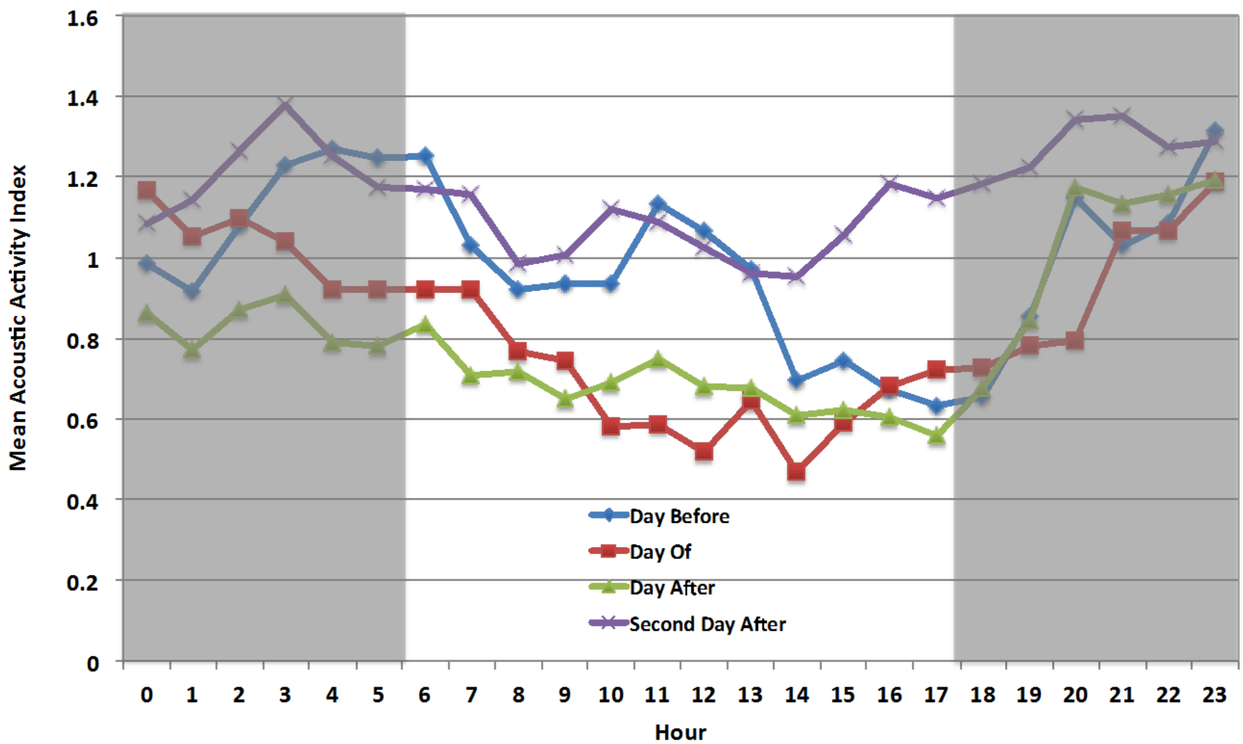


Figure 16. The mean hourly dolphin acoustic activity observed over the 24-hour period of the days before (N = 31), the days of (N = 31), and the first (N = 30) and second (N = 29) days after a MINEX training event at site B. Shaded periods represent approximate twilight/nighttime hours.

To determine whether the observed differences are statistically significant, the hourly indices for each “day before”, “day of”, “day after” and “second day after” were averaged for 12-hour approximate daytime (06:00–17:59) and nighttime (18:00–05:59) periods. The “day before” values were then matched with the corresponding “day of”, “day after” and “second day after” values and either a parametric paired t-test or a non-parametric Wilcoxon matched pairs test was performed, depending on the outcome of a normality test. For the daytime hours, the “day before” acoustic indices were significantly higher than the “day of” (Wilcoxon matched pairs test, $N=31$, $Z=3.46$, $p<0.001$) and the “day after” (Wilcoxon matched pairs test, $N=30$, $Z=2.15$, $p=0.032$), but significantly lower that the “second day after” (Wilcoxon matched pairs test, $N=28$, $Z=2.07$, $p=0.038$). For the nighttime hours, the “day before” acoustic indices were not significantly different from the "day of" (paired t-test, t=1.092, DF=30, p=0.283), "day after" (paired t-test, t=0.692, DF=30, p=0.494) or "second day after" (paired t-test, t=1.642, DF=27, p=0.112).

Figure 17 presents the average hourly dolphin acoustic activity observed on the linear-array EARs as a function of the three additional monitored distances (3 km, 6 km, and 12 km) from the epicenter of MINEX training for the days before, of, and after a training event. The data are pooled among array orientations (north, south, and east) for each distance from the epicenter.

To statistically infer whether training events influenced dolphin acoustic activity at these distances from the epicenter, the hourly indices for each "day before," "day of," and "day after" were averaged for the daytime and nighttime. Because more than 90 percent of recorded UNDETs occurred between 10:00 and 17:59, the hypothesis was tested that daytime effects would more likely be observed between these hours at distances farther away from the epicenter on the "day of" the training event. The "day before" values were then matched with the corresponding "day of" and "day after" values and either a parametric paired t-test or a non-parametric Wilcoxon matched pairs test was performed.

For the pooled 3-km data (N=15 MINEX training events recorded), a significant decrease occurred in the mean daytime dolphin acoustic activity between the day before and the day of the training event (paired t-test, t=2.26, DF=14, p=0.040). No significant differences were found between the daytime hours of the "day before" and the "day after," or between the nighttime hours of the "day before" and either the "day of" or "day after." Similarly for the pooled acoustic activity recorded 6 km from the epicenter (N=10 MINEX training events recorded), no significant differences were found between the "day before" and either the "day of" or "day after" for either the daytime or nighttime periods. Lastly, for the pooled 12-km data (N=14 MINEX training events recorded), a significant decrease occurred in the mean daytime dolphin acoustic activity between the day before and the day of the training event (Wilcoxon matched pairs test, N=14, Z=2.41, p=0.016). However, no significant differences were found between the daytime hours of the "day before" and the "day after," or between the nighttime hours of the "day before" and either the "day of" or "day after."

To further explore the significantly lower acoustic activity observed between the "day before" and "day of" daytime periods in the 12-km data, the data were grouped according to the linear array orientation (north, south, and east). **Figure 18** shows the mean acoustic activity observed during the "day before" and the "day of" for the northern (J), southern (G), and eastern (M) sites. The northern site had more than three times the baseline dolphin acoustic activity of the southern site and more than 18 times the activity observed at the eastern site. At both the northern and southern sites, mean daytime dolphin acoustic activity dropped by nearly half during the day of a training event. At the eastern site activity levels remained low and unchanged.

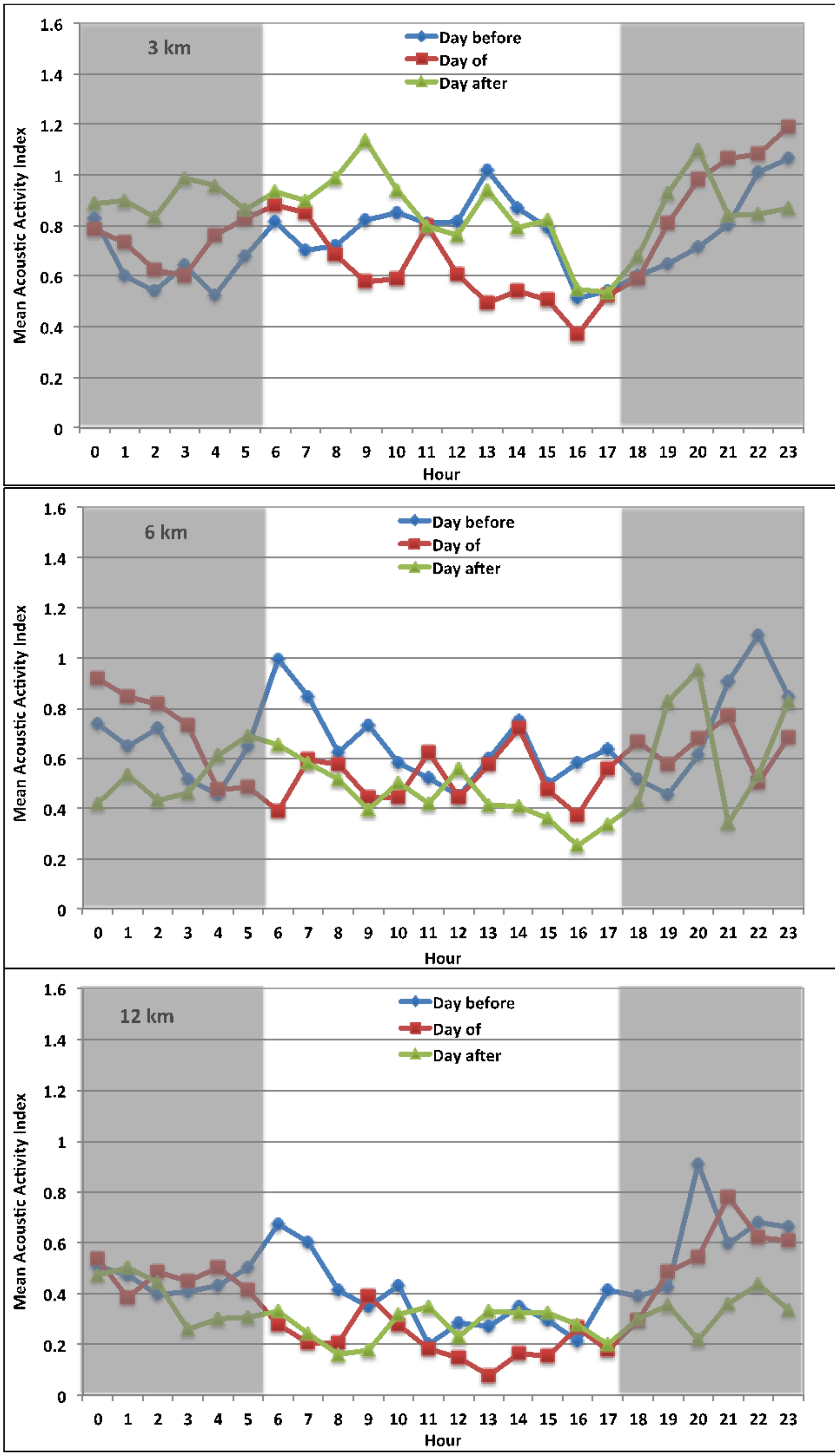


Figure 17. The mean hourly dolphin acoustic activity observed over the 24-hour period of the days before, the days of, and the days after a MINEX training event pooled across sites 3 km (top, N=15), 6 km (middle, N=10) and 12 km (bottom, N=14) from the epicenter of training activities, regardless of directional orientation of array.

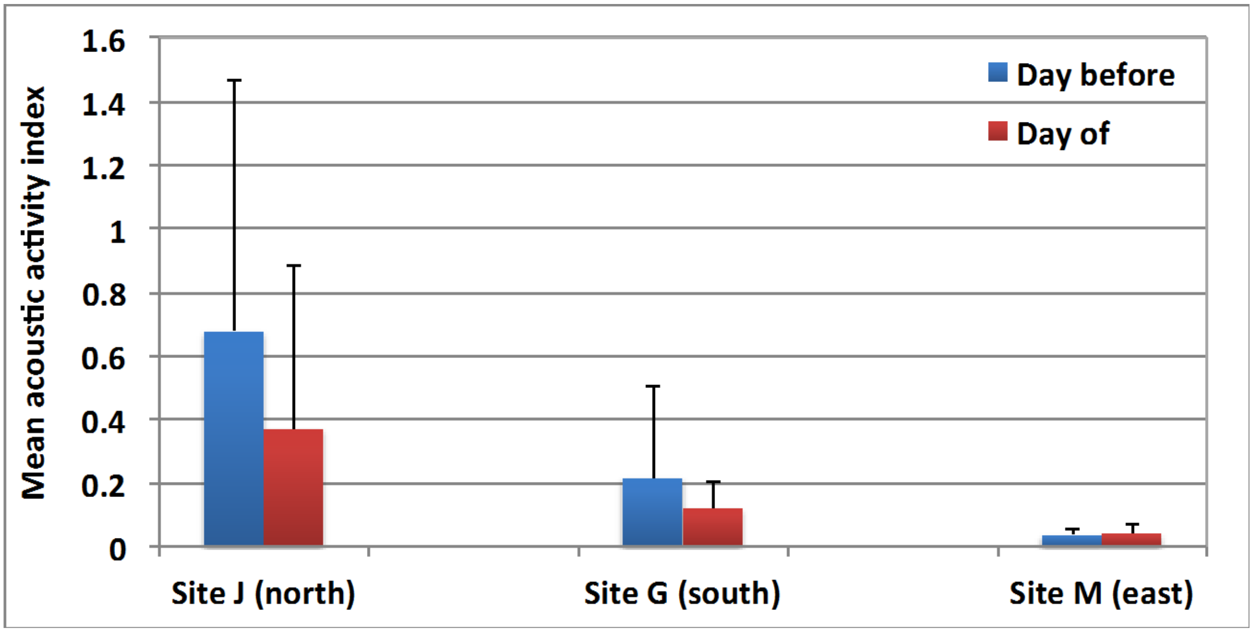


Figure 18. The mean acoustic activity index observed at sites J (N=6), G (N=5) and M (N=3) during the day before and the day of a MINEX training event.

3.4 Summary of Localization Work

Each of the four localization-array deployments resulted in useful lessons learned for subsequent deployments. Data from the first array demonstrated that the UNDET pulse could not be used to synchronize EAR clocks as planned, so a pinger was added to subsequent deployments to allow EAR clock offsets to be determined. The feasibility of using a pinger to time-align EAR recordings and subsequently estimate dolphin positions using time-of-arrival differences was successfully demonstrated using dolphin recordings from the second localization array; however, no UNDET events were recorded during this deployment. During the third deployment, UNDETs were detected on two days, and dolphin whistles were recorded on both of these days. However, it was discovered that only recordings containing pings were useful for localization, due to unpredictable EAR clock drift in files between pinger files. Therefore, the EAR recording duty cycle (3 minutes on every 6 minutes, or 50 percent), in combination with the pinger schedule (every 30 minutes, or in every 5th EAR file) limited the amount of potentially usable data for localizing dolphins to 3-minute recordings every 30 minutes, effectively a 10 percent duty cycle. A small number of dolphin signals (N=22) were identified as candidates for localization in association with one explosion event detected on 7 July 2015. Unfortunately, these signals could not be reliably localized, likely due to low SNR of whistles. In addition, this deployment revealed that EAR clocks drifted apart from each other over time, such that after approximately one month of recording, they were no longer recording simultaneously.

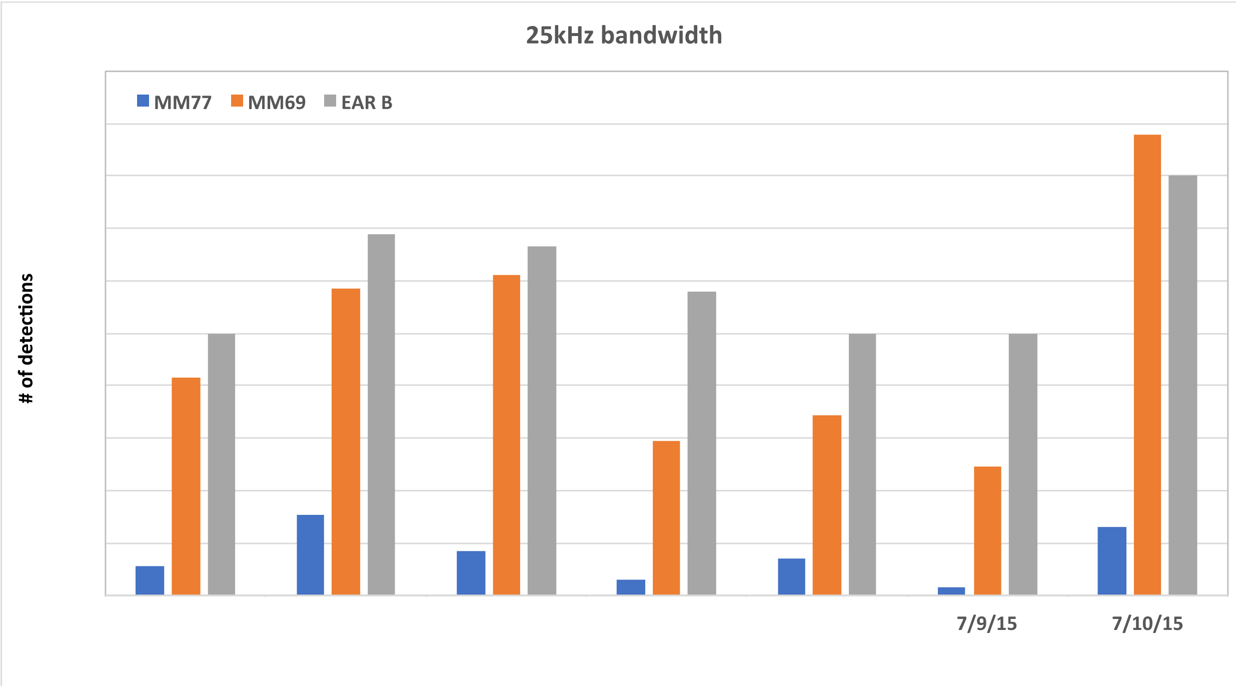
To address some of the duty cycle and clock alignment issues, the EAR recording schedule was modified for the fourth and final localization array, such that 30-minute files were recorded consecutively (with no “off” time) and synchronization pings were available in every file. As a result, this array yielded a near-continuous stream of potentially usable data. The sample size was still limited by the number and timing of training exercises, with only two UNDET events recorded during this deployment. The first of these events provided the best opportunity to localize animals in the hours before and after an explosion, and results show that locations of dolphin groups did change relative to the EAR array over this time period. However, differences in dolphin locations (distance and direction to EAR array) were not significantly different before and after the explosion. A larger sample size (of both UNDET events and dolphin whistles) is needed in order to observe and quantify any patterns or trends.

The error in location estimates was examined for the fourth deployment using ground-truth data from the EAR deployment vessel pinging at a known location, three days before the first UNDET event. Localizations made using the EAR array were within 40–90 m (on average 73 m) of the boat's recorded location. A larger number of receivers in the array would reduce errors in distances, and indeed three of the four localization-array deployments included four EARs originally. Unfortunately, due to instrumentation issues (electronic noise, early cessation of recording) and an inadvertent early recovery, data from only three EARs were usable in all of the localization array deployments. Another factor that may affect error in estimated distances is EAR clock drift/jitter within a single recording, such that accuracy of localizations decreases with increasing elapsed time between the signals of interest and the synchronization pings. Future studies would benefit from more frequent ground-truthing (i.e., sending out acoustic signals from known locations) throughout the array deployment period.

3.5 Comparison of microMARS vs. EAR data

Figure 19 shows a comparison of the presence/absence of dolphins detected manually at site B by the two microMARS and EAR B during the seven days between 4 July and 10 July 2015. The microMARS data were analyzed at bandwidths of both 25 kHz and 50 kHz in order to determine whether greater bandwidth appreciably influences the results. The EAR data bandwidth was limited by the sampling rate used (50 kHz), so it remained constant at 25 kHz for all analyses. MM77, which had a low-gain hydrophone (MH33-1), had between 50 and 97 percent fewer daily detections compared with MM69 (with the high-gain MH33-2 hydrophone) and EAR B. This was true at both bandwidths, but especially at 25 kHz where the MM77 had on average 88 percent fewer detections than the EAR. At a data bandwidth of 25 kHz, MM69 had fewer dolphin detections than EAR B on 6 of the 7 days, and for the entire period had 33% fewer detections than the EAR. However, at a data bandwidth of 50 kHz, MM69 had more dolphin detections than the EAR on 4 of the 7 days and 5.6 percent more detections that the EAR overall.

An analysis was also conducted to determine whether dolphin acoustic activity observed during the “day before,” “day of,” “day after,” and “second day after” the MINEX training event that took place on 7 July 2015 was different among the three instruments. **Figure 20** shows a comparison of the results for the instruments at both the 25-kHz and-50 kHz bandwidths. Indices are averaged for the 24-hour period between 00:00 and 23:59. Mean acoustic indices were mostly lower on MM69 than on EAR B for the four days at both bandwidths and were much lower on MM77. However, the overall relative trends in acoustic activity across the four days were very similar between MM77, MM69, and EAR B at both bandwidths.



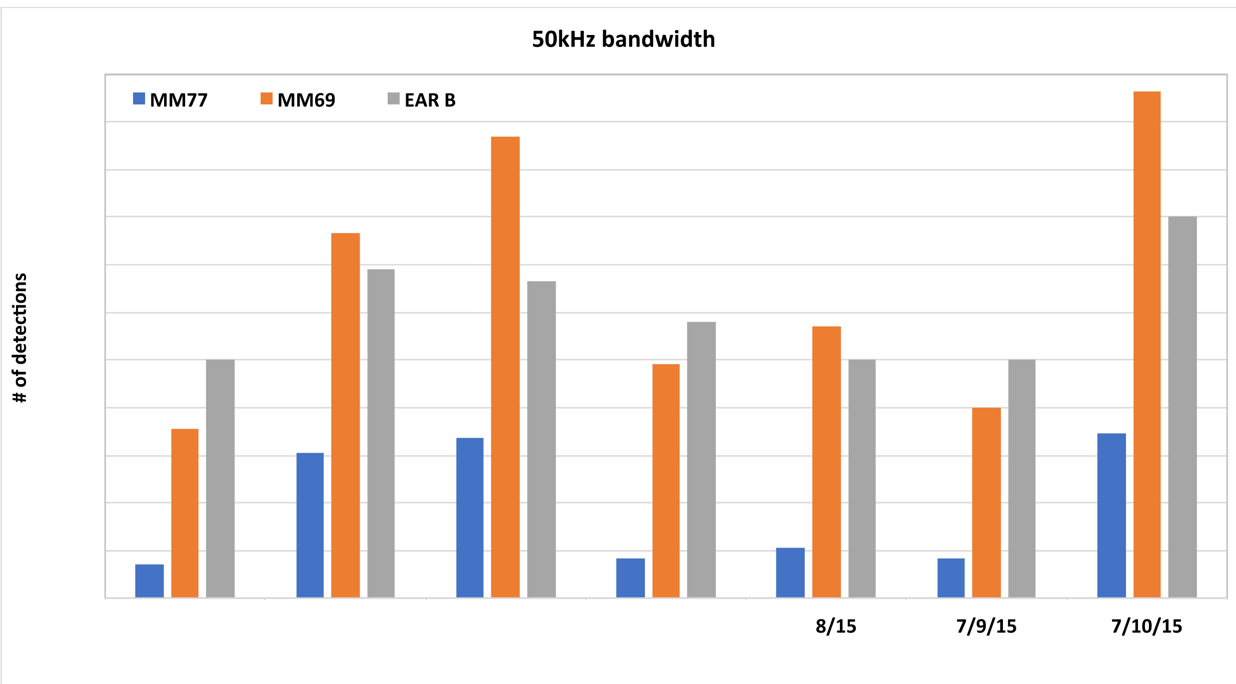
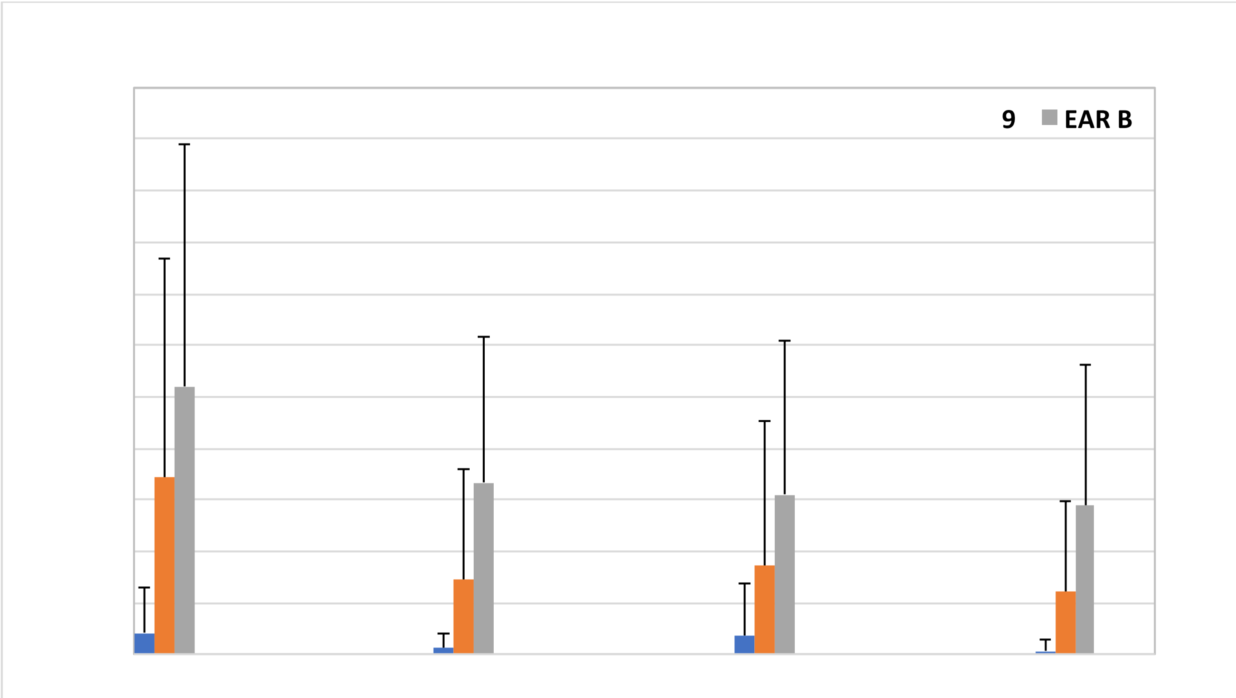


Figure 19. The number of dolphin detections made at site B by microMARS 77, microMARS 69, and EAR B during the seven days between 4 July and 10 July 2015. The top panel shows detections made using both microMARS and the EAR recordings with a 25-kHz bandwidth. The bottom panel shows results using 50-kHz bandwidth data for microMARS and 25-kHz bandwidth data for the EAR.



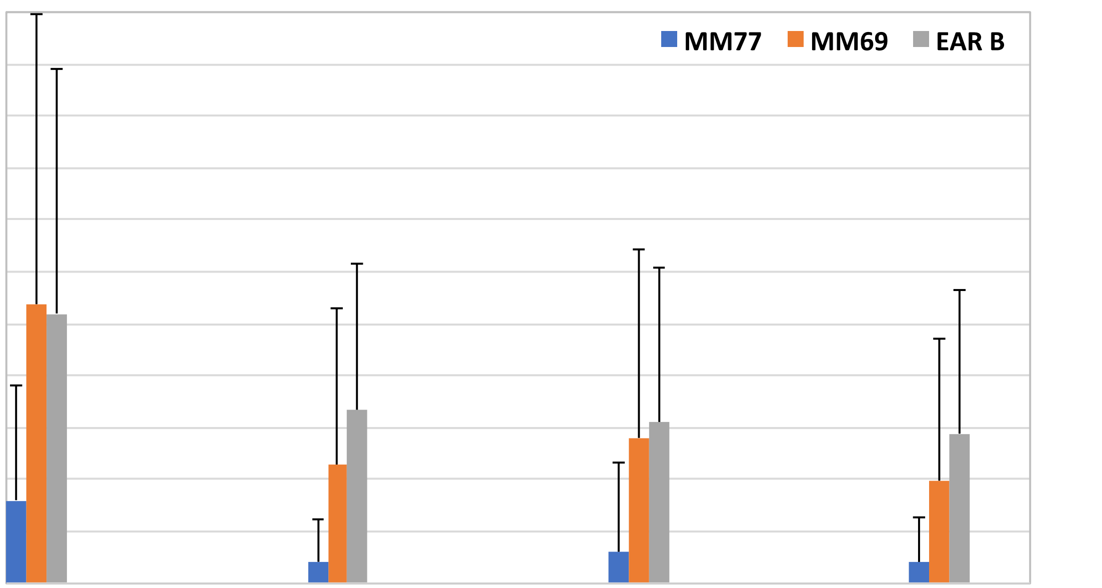


Figure 20. The dolphin acoustic activity observed at site B by microMARS 77, microMARS 69, and EAR B during the "day before," "day of," "day after," and "second day after" the MINEX training event that occurred on 7 July, 2015. The top panel shows the mean acoustic activity indices and standard deviation bars for both microMARS and the EAR recordings with a 25-kHz bandwidth. The bottom panel shows results using 50-kHz bandwidth data for microMARS and 25-kHz bandwidth data for the EAR.

4. Discussion of Findings

After overcoming some initial complications related to the logistics of mooring EARs in the shallow waters off Virginia Beach, this monitoring project yielded high-quality information about the occurrence of odontocetes in the MINEX W-50 training area and the behavioral response of dolphins to UNDETs. The data show that dolphins are present in the training area nearly daily. These findings indicate that dolphins are periodically exposed to noise from UNDETs, although it is not clear at what range most exposures occur. Seasonally, there is a consistent period of low occurrence or reduced acoustic activity during the winter months with a minimum in February. This finding is consistent with reported seasonal trends in bottlenose dolphin abundance off Virginia Beach (Barco et al. 1999; Engelhaupt et al. 2014, 2015). From year to year, differences were observed between a few of the same months, suggesting some inter-annual variability of the occurrence of dolphins in the area immediately around the epicenter.

There is strong evidence that dolphins respond behaviourally to MINEX training events. The data from site B, comprising 31 monitored training events in 4 years of data collection, paint a clear picture: dolphins either moved away or became less acoustically active during the daytime hours of a day with one or more UNDETs. Dolphin acoustic activity returned to baseline levels in the evening and night-time hours of that day. However, during the daytime hours of the following day, acoustic activity was again reduced compared to baseline levels, but activity normalised again in the evening and at night. It cannot be determined with certainty from these data whether the decrease in acoustic activity represents individuals moving away from the area, a change in acoustic signaling behavior, or both. In captive animals, stressful events can lead to periods of reduced or no acoustic activity lasting hours or even days (Sidorova et al. 1990, Castellote and Fossa 2006). Studies of free-ranging delphinids provided some evidence that individuals alter their whistle production rates and other parameters after exposure to simulated MFAS (and in some cases mimic MFAS signals), but effects varied depending on species and behavioral state (DeRuiter et al. 2013). Dolphins may also alter their whistle production rates in response to stressful events, as in a study that found increased signature whistle rates after brief capture-and-releases (Esch et al. 2009). Interestingly, during daytime hours of the second day following a training event, dolphin acoustic activity at site B was generally higher than the baseline period. The higher acoustic activity levels observed two days after a training event could indicate more frequent signalling by individual dolphins, perhaps reflecting increased social cohesion, cautiousness, exploratory behavior, stress, or other differences in behavioral state compared to the baseline.

If the assumption is made that reduced acoustic activity is indicative of fewer dolphins occurring in an area, then the patterns observed suggest that dolphins temporarily move away from the epicenter during the day of the training event, but return during nighttime hours. Perhaps because training events often occur over multiple days, dolphins may anticipate additional UNDETs beyond the final day of the training event, which could explain the reduced acoustic activity observed during the first day following the final UNDET. In other words, dolphins may hedge against potential future exposure to an UNDET by avoiding the area. The fact that dolphin activity near the epicenter is higher during the second day following the training event than during the baseline period could also indicate that dolphins occupy the area in greater numbers, perhaps to exploit prey fauna killed during the training event by the blast wave of UNDETs (however, no evidence for or against this explanation presently exists).

The data obtained from the EARs located 3 km, 6 km, and 12 km away from the epicenter further help inform the response by dolphins to MINEX training events. There is evidence that dolphin acoustic activity is reduced 3 km away from the epicenter during the day of an UNDET, but not 6 km away, suggesting that the radius of potential avoidance by dolphins is between 3 km and 6 km. Of note, however, is that a significant reduction in acoustic activity on the day of an UNDET was also observed at the two 12-km sites towards the north and south of the epicenter. This suggests that animals occurring near the 12-km sites responded to UNDETs occurring relatively far away. It is unclear why this is or what the response represents, but one possibility is that the animals may be moving from more distant areas toward the epicenter to exploit prey fauna killed by the UNDET, perhaps during the nighttime hours in between or after training days. Another possibility is that habituation to UNDETs exists among animals typically occurring ~6 km away, but not among those substantially further away, which may be exposed to training events less frequently.

Data from the localization-array deployments (and other deployments) indicate that dolphins were sometimes present in the minutes surrounding an UNDET event within the EAR detection area, which is likely within 1 or 2 kilometers of the UNDET source. Unfortunately, data from the first three localization-array deployments were insufficient to more accurately answer research Question 6 (At what distance from MINEX explosions do dolphins occur?). Some of the reasons for this were instrument-related, including unexpected early cessation of recording, instrument noise, and low precision and accuracy of internal EAR clocks. Some limitations were also related to the recording parameters, including the EAR recording duty cycle and the pinger schedule, which reduced the amount of usable data for localization. Finally, some of the limitations were inherent in the data themselves: only a small number of UNDET events were detected, and dolphin signals with the potential to be localized were limited by low sample size and challenging to work with due to low SNR and overlapping/distorted whistle contours.

Some of these issues were addressed in the fourth and final localization array by altering the EAR recording schedule, such that recording was continuous and for 30 minutes in each cycle. This ensured that each recording would contain pings for time-synchronization, and that any explosion during the deployment period would also be recorded.

The fourth and final deployment of the localization array yielded usable data for localizing dolphin groups relative to explosions. Two explosions were recorded during this array deployment, but only the first was associated with sufficient quantity and quality of dolphin whistles available for localization. The resulting dolphin localizations suggest potential movement of dolphin groups relative to the EAR array during the time period from 10 hours before the explosion to about 6 hours afterward, but do not demonstrate any significant differences in distance or direction of dolphin localizations before and after the explosion. A larger sample size of explosions (and dolphin signals) would be needed to statistically analyze whether dolphin movements show any pattern or trend in response to UNDET events.

Lastly, the field tests of the microMARS recorders reveal that these instruments are generally well-suited for the kind of passive acoustic monitoring work conducted during this project.

Although some initial problems were encountered during the first deployment of these instruments, the manufacturer corrected the problems by the second deployment. The microMARS with the low-gain hydrophone (MH33-1) did not have sufficient sensitivity to capture the majority of dolphin signals present, but the unit with the high-gain hydrophone (MH33-2) produced results that closely matched those obtained using the EAR, particularly at the higher analysis bandwidth. The data also showed that a bandwidth greater than the EAR's 25 kHz did not appreciably change the results obtained, indicating that the 25 kHz bandwidth was sufficient to investigate the trends and behavioral responses documented in this study. It should be noted that the long-term performance of microMARS recorders over multiple consecutive deployments and over time frames of many months or multiple years was not tested here. Therefore, the failure rate of individual recorders due to malfunction and/or ordinary wear and tear remains un-quantified. In addition, the microMARS tested in this study were co-located on moorings designed and tested for EARs, which are more rugged than microMARS. The functionality and rate of instrument loss for moorings customized for the microMARS in the shallow waters off Virginia Beach, Virginia, are therefore also presently unknown.

5. Acknowledgements

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A

EAR Deployment Details

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Appendix A: EAR Deployment Details

Table A-1. Recording parameters of the MINEX EARs, deployments 1-14. For deployment 15, recording time increased to 1800 seconds (30 minutes) and recording period was also 1800 seconds (30 minutes) for no "off" time between recordings; other parameters remained the same.

Sampling Rate	50 kHz
Recording Time (duration)	180 seconds (3 minutes)
Recording Period (how often)	360 seconds (6 minutes)
Anti-Aliasing Filter	90%
Hydrophone Sensitivity	Approx. -193 dB re 1μPa
Clock	Local Time
Disk Space	320 GB maximum
Energy Detection	Disabled

Table A-2. EAR deployment/recovery information and outcomes.

EAR Deployment	EAR Configuration	Deployment Date(s)	Recovery Date(s)	EAR Sites	EAR ID #s Deployed	EARs Recovered	# of Recordings on EAR B	# of Explosions Detected
1	Two paired EARs	8/15/2012	10/15/2012	A, B, C, D	27, 54, 61, 63	61, 63	14,296	10
2	Paired EARs	12/7/2012	3/3/2013 & 3/15/2013	A, B	61, 63	61, 63	16,594	3
3	Paired EARs	3/15/2013	5/31/2013	A, B	61, 63	61, 63	16,400	2
4	Paired EARs	5/31/2013 & 6/9/2013	8/19/2013	A, B	61, 63	61, 63	17,051	5
5	Linear array	9/20/2013	11/11/2013	B, E, F, G	2, 4, 61, 63	2, 61, 63	12,633	1
6	Localization array	11/16/2013	1/23/2014	B, N, P	2, 61, 63	2, 61, 63	16,808	6
7	Linear array	2/16/2014	4/27/2014	B, K, L, M	2, 61, 63, 797	2, 61, 63, 797	16,293 (EAR K)	5
8	Linear array	5/18/2014	8/3/2014	B, I, H, J	2, 61, 63, 797	2, 61, 63, 797	17,153	15
9	Localization array	8/15/2014	10/27/2014	B, Q, R, S	2, 61, 63, 797	2, 61, 63, 797	17,536	4
10	Linear array	11/9/2014	1/23/2015	B, E, F, G	2, 61, 63, 797	2, 61, 63, 797	16,939	1
11	Linear array	3/9/2015	5/29/2015	B, H, I, J	17, 18, 20, 19	17, 18, 20, 19	17,719	2
12	Localization array	6/24/2015	8/30/2015	B, Q, R, S	17, 18, 20, 19	17, 18, 20, 19	13,839	5
13	Linear array	10/13/2015	12/16/2015	B, K, L, M	17, 18, 20, 19	17, 18, 20, 19	8,154	1
14	Linear array	2/1/2016	3/23/2016	B, E, F, G	17, 18, 20, 19	18, 20, 19	0	6
15	Localization array	6/13/2016	7/8/2016	B, Q, R, S	18, 19, 20, 14	18, 19, 20, 14	0	2

Table A-3. EAR deployment coordinates by deployment site (A through S) and deployment number (1–15). For any given site, only the deployment numbers where an EAR was deployed at that site are included.

EAR Site	Deployment	Latitude	Longitude
A	1	36° 48.914'N	75° 53.199'W
A	2	36° 48.887'N	75° 53.163'W
A	3	36° 48.962'N	75° 53.224'W
A	4	36° 49.023'N	75° 53.154'W
B	1	36° 48.904'N	75° 52.525'W
B	2	36° 48.850'N	75° 52.465'W
B	3	36° 49.914'N	75° 52.485'W
B	4	36° 48.922'N	75° 52.600'W
B	5	36° 48.858'N	75° 52.620'W
B	6	36° 48.894'N	75° 52.566'W
B	7	36° 48.838'N	75° 52.529'W
B	8	36° 48.820'N	75° 52.537'W
B	9	36° 49.053'N	75° 53.147'W
B	10	36° 48.892'N	75° 52.511'W
B	11	36° 48.886'N	75° 52.483'W
B	12	36° 48.917'N	75° 52.516'W
B	13	36° 48.881'N	75° 52.543'W
B	14	36° 48.919'N	75° 52.522'W
B	15	36° 48.915'N	75° 52.222'W
C	1	36° 46.570'N	75° 49.684'W
D	1	36° 46.564'N	75° 48.994'W
E	5	36° 46.985'N	75° 51.890'W
E	10	36° 46.930'N	75° 51.795'W
E	14	36° 46.986'N	75° 51.009' W
F	5	36° 45.388'N	75° 51.336'W
F	10	36° 45.381'N	75° 51.279'W
F	14	35° 45.372'N	75° 51.247'W
G	5	36° 42.271'N	75° 50.124'W
G	10	36° 42.258'N	75° 50.129'W
G	14	36° 42.253'N	75° 50.105' W
H	8	36° 49.900'N	75° 52.881'W
H	11	36° 49.900'N	75° 52.874'W
I	8	36° 51.468'N	75° 53.436'W
I	11	36° 51.512'N	75° 53.433'W
J	8	36° 54.621'N	75° 53.292'W
J	11	36° 54.614'N	75° 53.238'W
K	7	36° 49.563'N	75° 52.256'W
K	13	36° 49.569'N	75° 52.262'W
L	7	36° 50.513'N	75° 50.395'W
L	13	36° 50.531'N	75° 50.427'W

EAR Site	Deployment	Latitude	Longitude
M	7	36° 49.993’N	75° 44.528’W
M	13	36° 50.091’N	75° 44.524’W
N	6	36° 48.946’N	75° 52.596’W
P	6	36° 48.930’N	74° 52.660’W
Q	9	36° 48.930’N	74° 52.500’W
Q	12	36° 48.838'N	75° 52.521'W
Q	15	36° 48.838’N	75° 52.517’W
R	9	36° 48.850'N	75° 52.417'W
R	12	36° 48.958'N	75° 52.571'W
R	15	36° 48.957’N	75° 52.571’W
S	9	36° 48.833’N	75° 52.550’W
S	12	36° 48.955’N	75° 52.668’W
S	15	36° 48.957’N	75° 52.673’W

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