Acoustic Monitoring of Dolphin Occurrence and Activity in the VACAPES MINEX W-50 Range 2015 Annual Progress Report

Submitted to:

Naval Facilities Engineering Command Atlantic under Contract No. N62470-10-D-3011, Task Orders 03, 43, and 57, issued to HDR, Inc.

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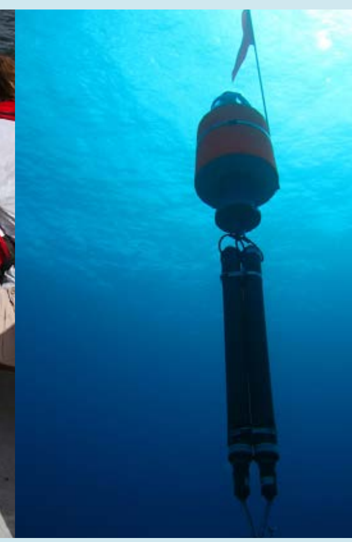

Submitted by:

HDR

Virginia Beach, VA

December 2016

Suggested Citation:

Lammers, M.O., L. Munger, E. Zang, M. Howe, and E. Nosal. 2016. *Acoustic Monitoring of Dolphin Occurrence and Activity in the Virginia Capes MINEX W-50 Range: 2015 Annual Progress Report.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Orders 03, 43, and 57, issued to HDR Inc., Virginia Beach, Virginia. 15 February 2016.

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

This project is funded by U.S. Fleet Forces Command and managed by Naval Facilities Engineering Command Atlantic as part of the US Navy's marine species monitoring program.

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 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 Virginia Capes W-50 MINEX training area, 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 2013, two 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 km from the 'epicenter' of training exercises were on average lower during both the day of an exercise and the day following the exercise, suggesting that animals either reduced their signaling, left the area, or both. Conversely, dolphin acoustic activity levels during the second day following an exercise were higher than either the day before, the day of or the first day after an exercise. It is still unclear how long the observed responses persist until typical baseline (day before an exercise) behavior is re-established.

A second phase of the project began in September 2013 to determine whether the responses observed represent a shift in acoustic behavior or a spatial redistribution of animals. Alternating 2-month deployments in 2013, 2014, and 2015 consisted of two different EAR array configurations. In the first configuration, four EARs were arranged in a linear array at distances of 1 kilometer (km), 3 km, 6 km, and 12 km from the primary MINEX training epicenter in order to examine whether or not animals are redistributing along the coast or offshore in response to training events. In the second configuration, EARs were arranged in a localization array in an effort to establish the distances that animals occur from MINEX training activities. The data from the third year of work (August 2014 - July 2015) generally confirmed the findings previously reported for the first 2 years of the study (Lammers et al. 2015).

The data obtained from the five linear-array deployments between September 2013 and May 2015 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. Although sample sizes were still

limited, evidence did not suggest that dolphins exhibit the same behavioral response at 3, 6, or 12 km that had been observed at 1 km. However, the data examined to date do suggest that dolphins may follow a pattern of re-distribution away from the epicenter after a MINEX training event. There is evidence that dolphins may be more acoustically active or abundant 3 km from the epicenter during the day of and the day after an exercise, but additional data must be obtained and analyzed to increase sample sizes.

Three EAR arrays with localization capability have been deployed since 2013. 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 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 unti 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. EAR 'R' 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. A total of 22 candidate dolphin whistles for localization was detected surrounding the first explosion on 7 July; 12 whistles were detected in the 1.5 hour before the explosion and 10 in the 6 minutes following the explosion. However, due to low sample size and low signal-to-noise ratio of more than half of these whistles, reliable localizations could not be determined. 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. 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 from existing data from the first three localization-array deployments.

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Appendix A - EAR Deployment Details

Acronyms and Abbreviations

BP	burst pulses
EAR	Ecological Acoustic Recorder
EST	Eastern Standard Time
ICMP	Integrated Comprehensive Monitoring Program
khz	kilohertz
km	kilometer(s)
m	meter(s)
MINEX	Mine Neutralization Exercise
SNR	signal to noise ratio
U.S.	United States
UNDET	underwater detonation
VACAPES	Virginia Capes

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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 injure or kill marine 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 (U.S. Navy, 2010). Two of the principal monitoring goals identified in the ICMP are as follows:

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 goals 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 to:

1. Detail the daily and seasonal occurrence of resident 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.

Beginning in the second year of the study (August 2013–July 2014), 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 researchers also undertook an effort to field-test the 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 with the existing moorings and compare their performance relative to Ecological Acoustic Recorders (EARs). This report presents the methods employed in the study and the results from the first 3 years of monitoring. This report also explains the implications of the findings and describes data-collection efforts to meet the remaining research objectives for 2016.

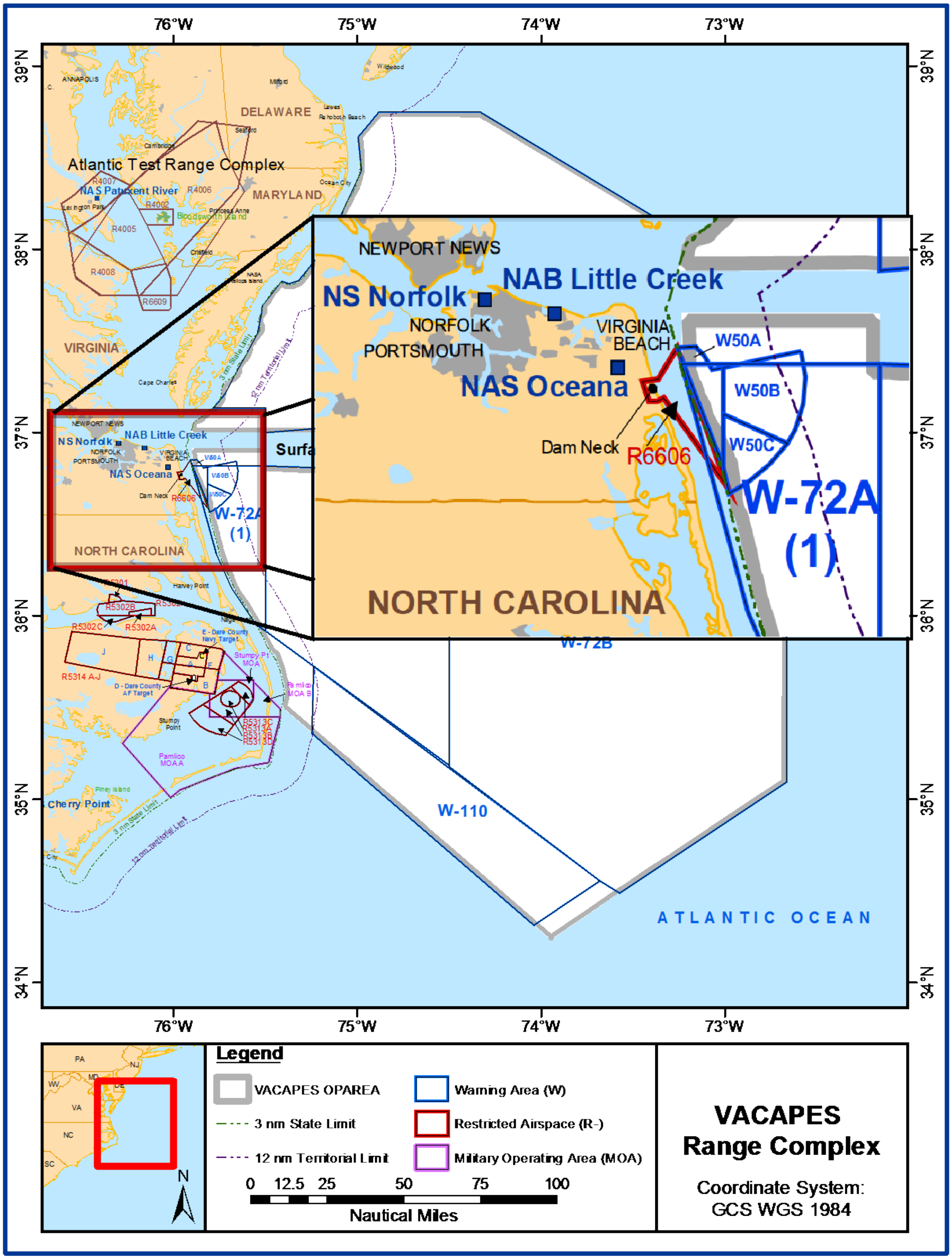


Figure 1. Map of the VACAPES Range Complex displaying an expanded view of the W-50 MINEX training range.

2. Methods

2.1 2012–2013 EAR Monitoring

Passive acoustic monitoring was initiated in the MINEX W-50 training area on 15 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**). 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 130–140 kHz (Goodson and Sturtivant 1996), are above the recording range of these EARs.

The 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 explosions. 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. For all subsequent deployments, 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 only 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. 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. 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 on three different time scales: minutes after an UNDET, hours after an UNDET, and days surrounding an UNDET (i.e. the day before, day of, and two days after). In addition to quantifying dolphin acoustic activity during periods associated with MINEX exercises, dolphin presence/absence was quantified on a recording-by-recording (file-by-file) basis at site B for the entire deployment period.

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

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/sec	1
21-40 whistles	1.5
Echolocation only > 2 clicks/sec	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 2013—2015 EAR Monitoring

Beginning in September of 2013, EAR deployments were modified to address questions 4, 5, and 6 in the introduction (**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 shifted to the south, east and north during alternating EAR redeployments (**Figure 3, Appendix A**). 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 before, during, and after MINEX training events to determine the range at which an acoustic response by dolphins is observed. Data were also used to assess whether or not there is a re-distribution of animals following MINEX training activities.

Question 6 was addressed by placing the EARs in a localization-array configuration during alternating deployments, 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 was used to precisely record EAR deployment locations. The four 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.

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 (4–7 kHz) once every 30 minutes, therefore in every fifth EAR recording. 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 kHz 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**).

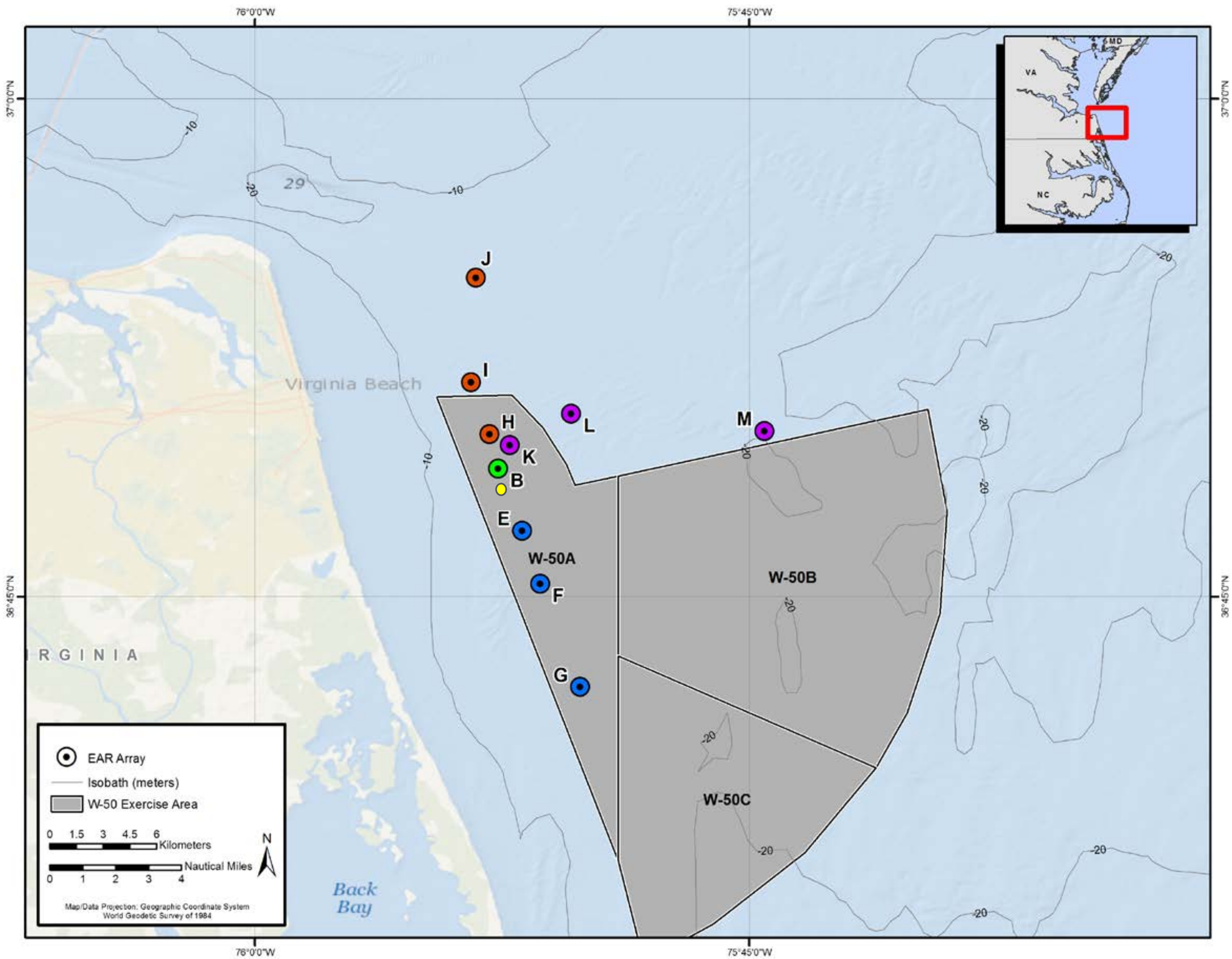


Figure 3. Spatial configuration of three linear EAR arrays deployed during the second and third years of the project. Site B remained constant and north is shown as red (B–H–I–J), east as purple (B–K–L–M), and south as blue (B–E–F–G). The yellow dot represents the position of the 'epicenter'.

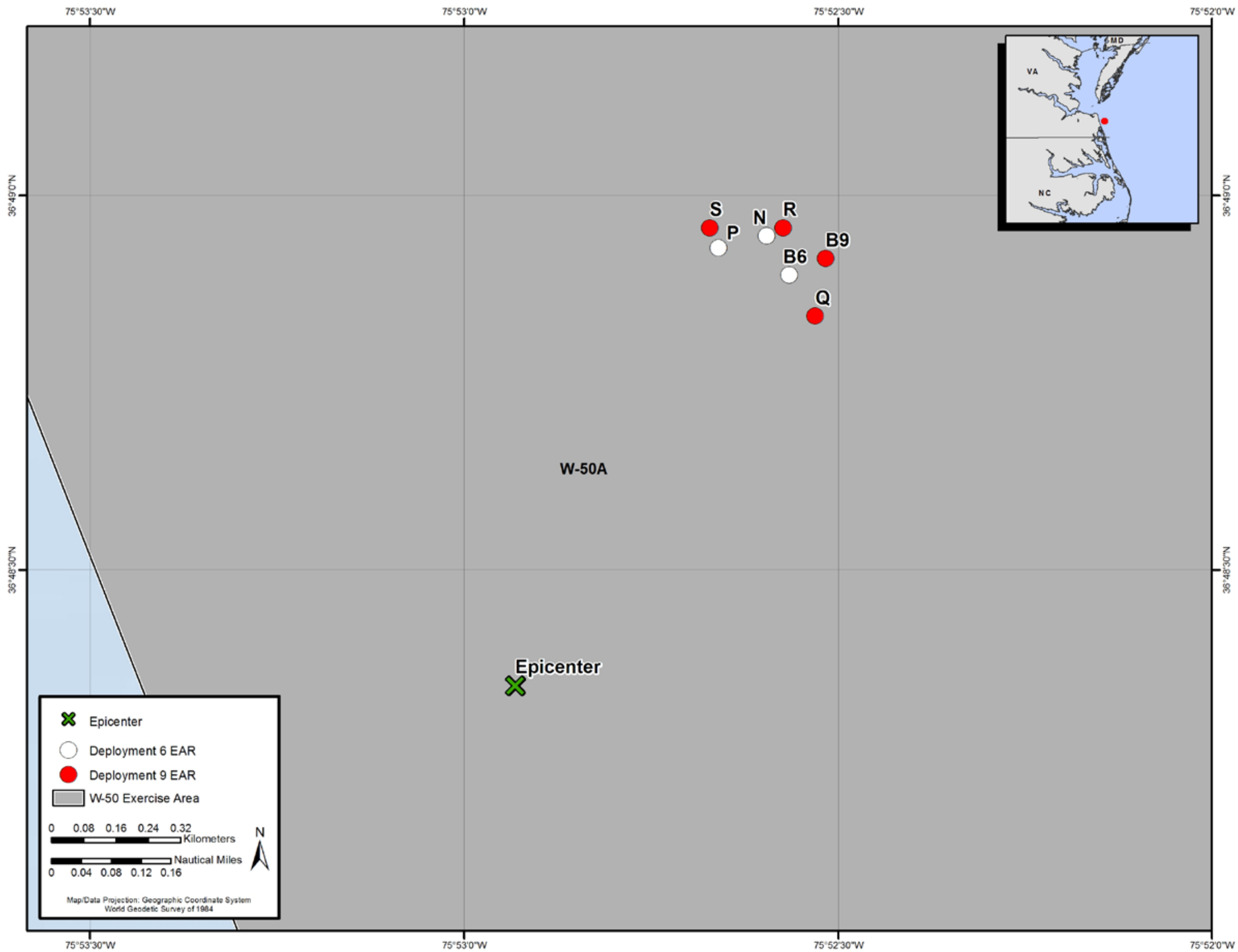


Figure 4. Spatial configuration of the two localization EAR arrays relative to the location of the epicenter of MINEX training activities. The white markers represent deployment 6 and the red markers represent deployment 9.

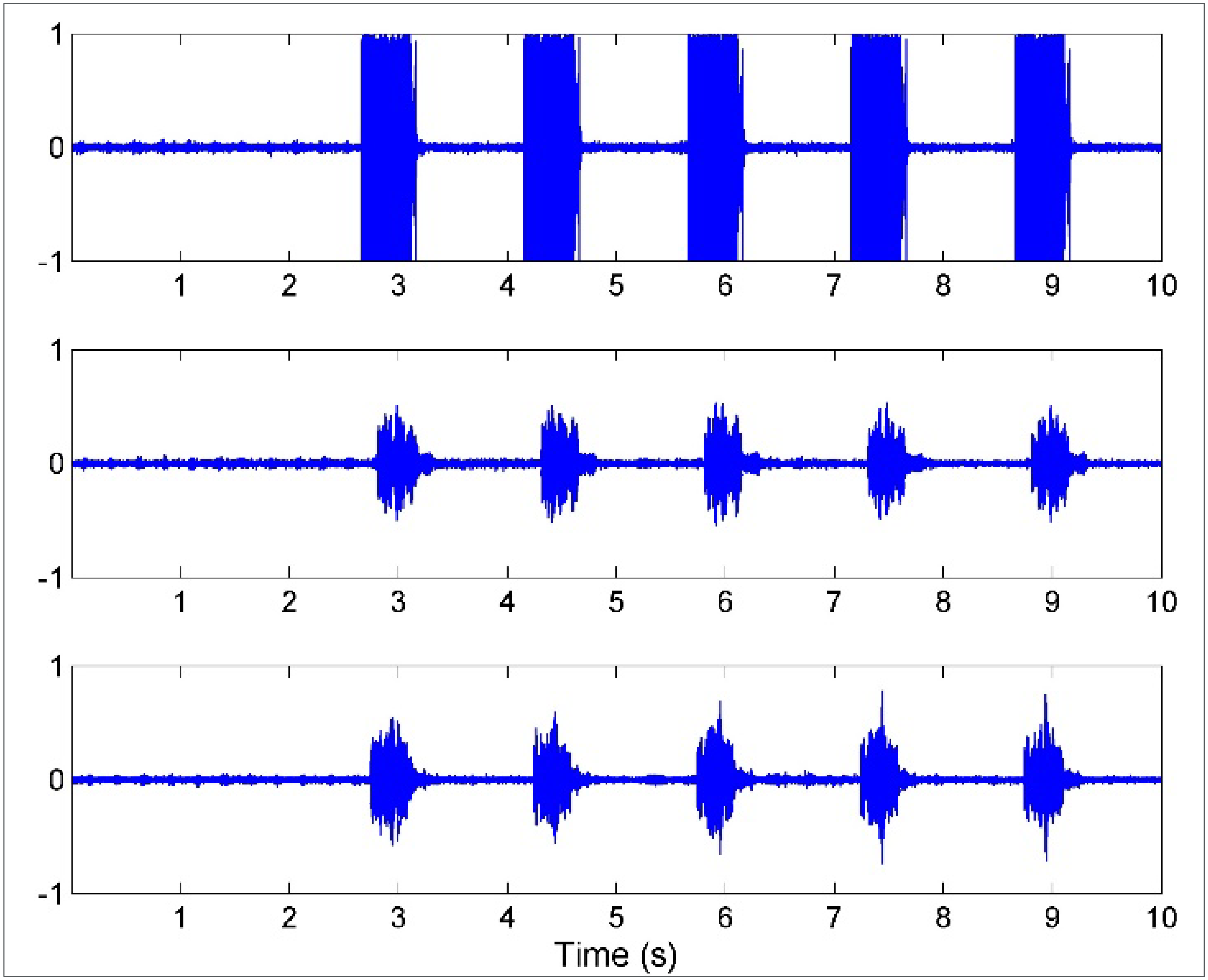


Figure 5. Example of the time-aligned pinger source signal as it was received at EARs B (top), Q (middle), and R (bottom). Y-axis values represent volts.

Once the EARs were time-aligned, each recording was 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**). The feasibility of these methods for time-aligning and localizing dolphin signals was demonstrated using data from the second localization array. 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**).

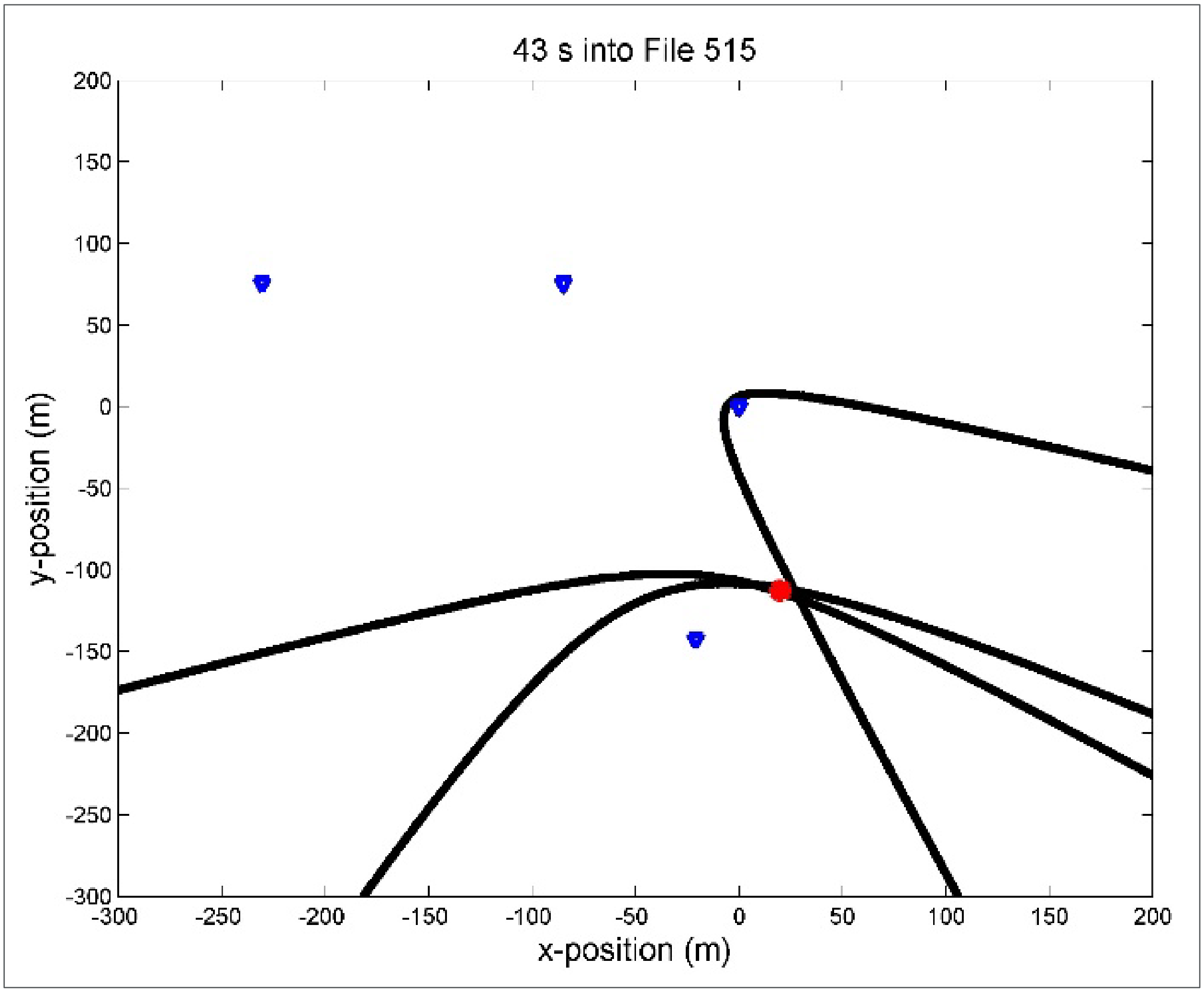
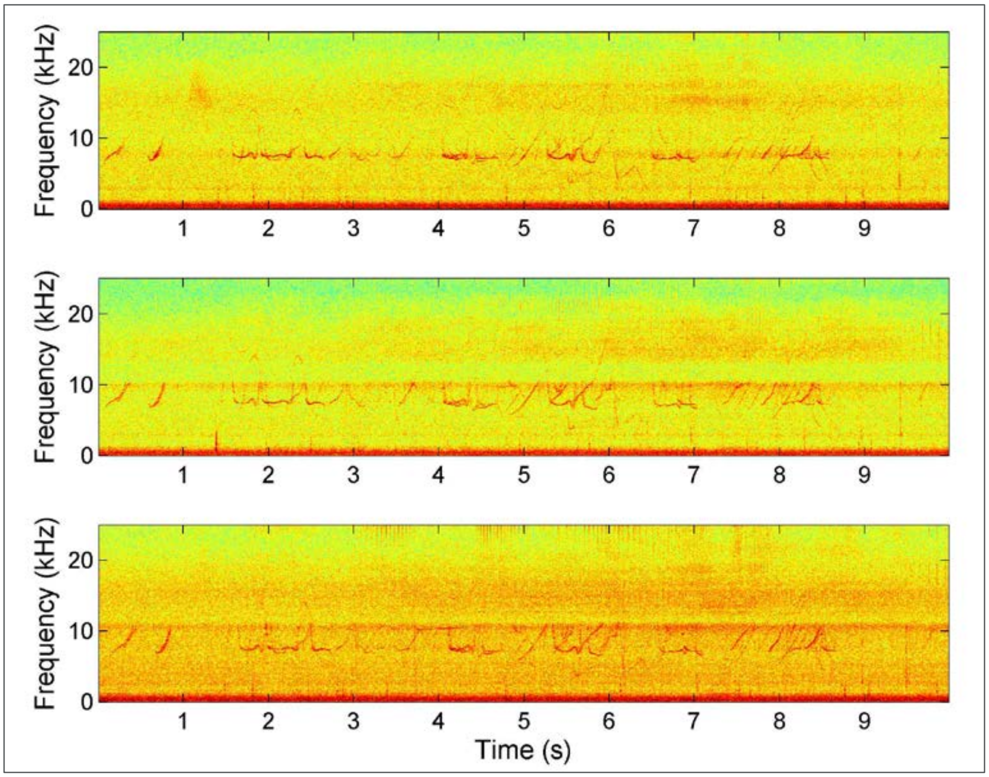
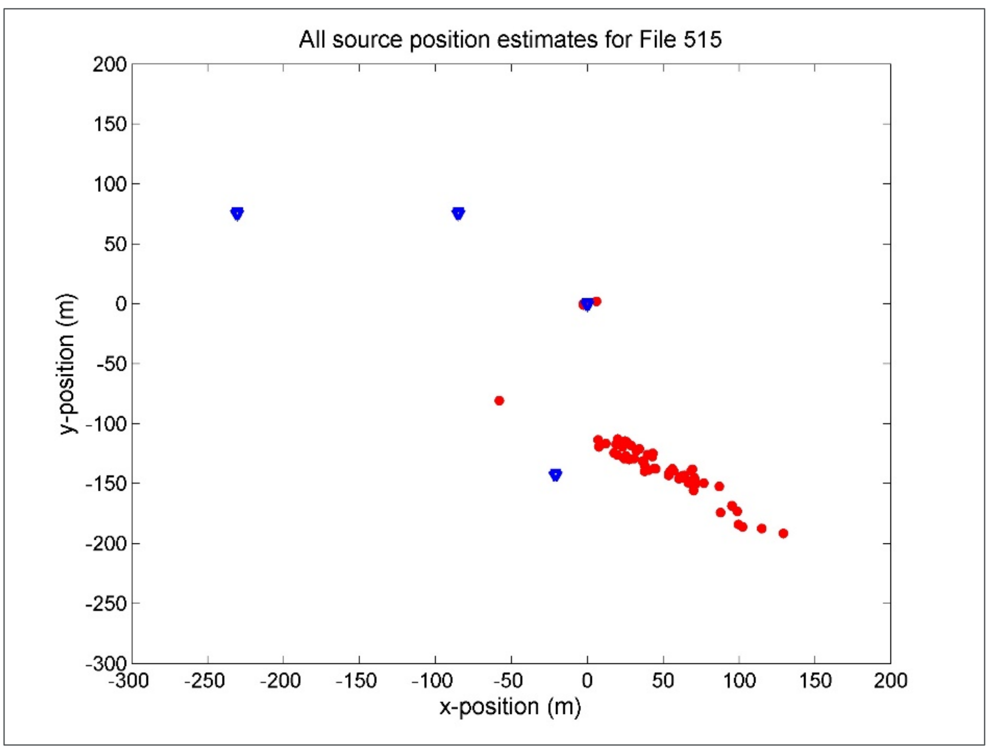


Figure 6. Example of a localized dolphin whistle. The blue marks indicate the positions of the four EARs. The red dot is the position of the signaling dolphin inferred by the convergence of the three hyperbolae.



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 without pings were not consistent enough 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. Upon recovery, files with pings were time-aligned and candidate dolphin signals recorded within pinger files during the 4 hours surrounding UNDETs (2 hours before and 2 hours after) were localized using time-of-arrival differences. The 2-hours 'before' and 'after' periods were chosen to investigate whether any changes in dolphin distribution 1) were detectable or 2) could be indicative of a response to the explosion.

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3. Results

3.1 Work Completed to Date

HDR staff performed fourteen deployments and thirteen recoveries since the beginning of the project on 15 August 2012 (**Appendix A**). Three instruments have been lost during this time. To date, 32 out of 42 EAR deployments (31 out of 38 after the initial deployments) were successful and produced high-quality data. Six instruments stopped recording prematurely or malfunctioned. In total, 344,510 3-minute recordings have been made, totaling 17,225 hours of data.

3.1.1 EAR deployments at Site B

In total, 201,388 recordings representing 10,069 hours of data have been made at site B since the beginning of the study. All deployments except #7 successfully obtained data from this location. The hard disk drive from deployment #7 malfunctioned, preventing recovery of the on-board data. For deployment #7, data from EAR K were used instead as a proxy of dolphin activity near the epicenter of MINEX training. The data from site B (and K) have been analyzed through 21 August 2015, by manually examining individual recordings for the presence/absence of dolphin signals and UNDETs. In total, 27 UNDETs were recorded at this location.

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 (B-K-L-M) (Tables A-2 and A-3). They 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 (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 1 February 2016 and is currently still collecting data (Table A-2).

The data obtained from the five linear-array deployments between September 2013 and May 2015 were examined to assess dolphin acoustic activity before, during, and after MINEX training events. Data from the two linear-array deployments in October–December 2015 and February 2016 have not yet been analyzed. Data from unit B continued to be analyzed for the presence of dolphin signals to maintain consistency with the data time series. Results of these analyses to date 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 stopped recording unexpectedly 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 and all were during 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 four-hour period surrounding one 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 was not possible, and potential dolphin distribution during both the 2-hour before and 2-hour after periods for other explosions could not be determined.

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, e.g. 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 a "poor" SNR rating (**Figure 8**). Realistic position estimates were not obtained for these whistles; investigation is ongoing to determine possible causes for the lack of convergent position estimates (including poor signal quality and low SNR) and alternative localization techniques. Presently, no solid inference can yet be drawn about dolphin movement in response to an explosion. In addition, the explosion occurred in a file without pings, which precluded time-alignment and localization of the explosion itself; therefore the distance of dolphins to the explosion cannot be estimated.

Table 2. Whistle detections in recordings containing pings before and after an UNDET event at 12:24 on 7/7/15.

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

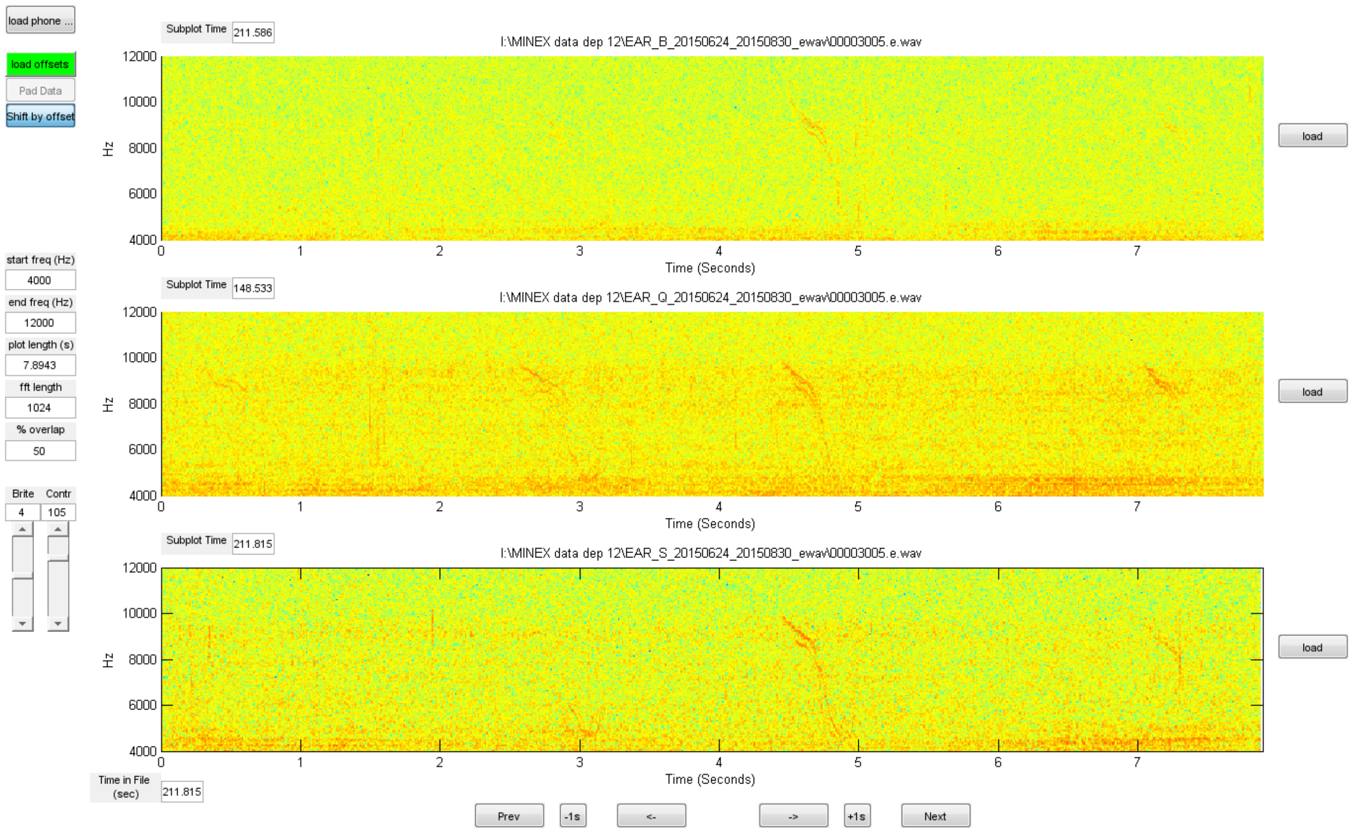

Figure 8. Time-aligned spectrograms from three EARs in file 3005, following an explosion detected in file 3004 6 minutes earlier. Note the low SNR of the whistles at 0.5 second and 2.7 seconds on EARs B (top panel) and S (bottom panel).

3.1.4 microMARS deployments

A total of 52,349 microMARS recordings were collected from four units co-located with EARs during deployments 11 and 12 between March-July 2015 (**Table 3**). 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 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 76 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.

Beside 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 min file sampled at 250kHz. 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 has been made aware of these problems and is developing software solutions to resolve both issues.

Efforts are still ongoing to analyze the microMARS data and compare subsets of these data with results obtained using EARs. A quantitative comparison of the two data streams will be presented in a final project report available in 2017.

Table 3. Summary of MicroMars recording dates and data quantity.

Deployment	MM/EAR	Dates of recording	# of files
11	MM47_EAR_B	03/09/2015	14
11	MM68_EAR_H	03/09/2015	111
11	MM69_EAR_J	03/08/2015 - 03/17/2015	6061
11	MM76_EAR_I	03/08/2015 - 03/12/2015	4094
12	MM68_EAR_Q	06/23/2015 - 07/30/2015	17098
12	MM69_EAR_S	06/23/2015 - 07/24/2015	14161
12	MM76_EAR_R	06/23/2015 - 07/23/2015	8495
12	MM47_EAR_B	06/23/2015 - 07/31/2015	10810
		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 has been completed for the period from 15 August 2012 to 30 August 2015, totaling 799 days of recordings. Dolphins are present daily in or near the MINEX range, with detections (as defined in **Section 2.1**) made on 97 percent of recording days (**Figure 9**). The species identity cannot be confirmed without the use of classification algorithms (not planned under the present contract), but it is assumed that the majority of detections are from bottlenose dolphins (*Tursiops truncatus*), given the presence of a resident population in the area (Barco et al. 1999).

During the 3 years of monitoring analyzed to date, a clear seasonal trend was observed in the mean number of daily detections each month (**Figure 10**). Dolphins were most commonly detected between the months of April and October. Detections dropped substantially between November and March and were the 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.

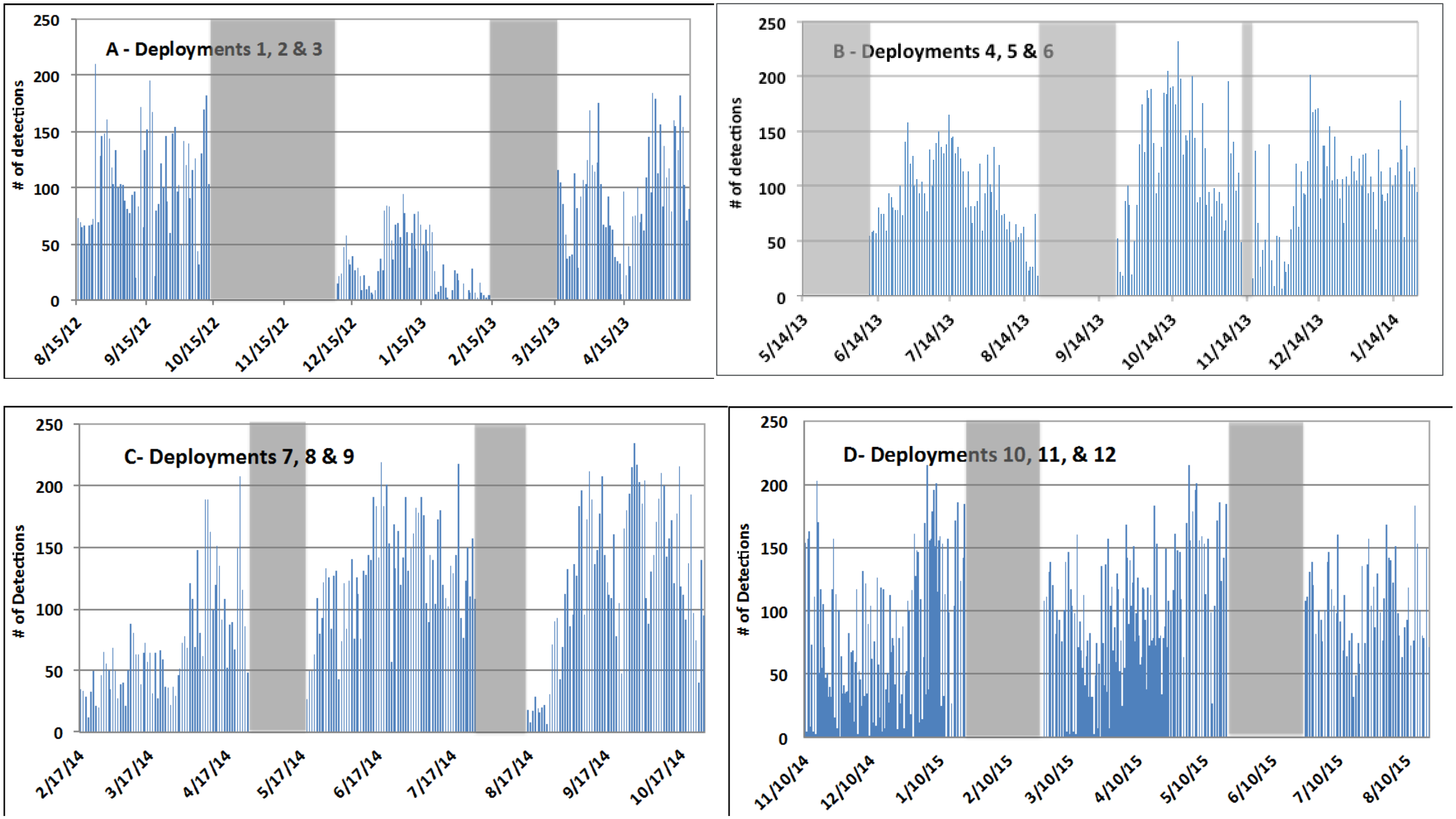

Figure 9. Daily numbers of dolphin detections near the epicenter of UNDET activity in MINEX W-50 between 15 August 2012 and 28 July 2014 for deployments 1–12. All detections are from site B, except during deployment 7 (16 February–27 April 2014), which came from site K. Greyed areas represent periods when the EAR was either not deployed or not recording.

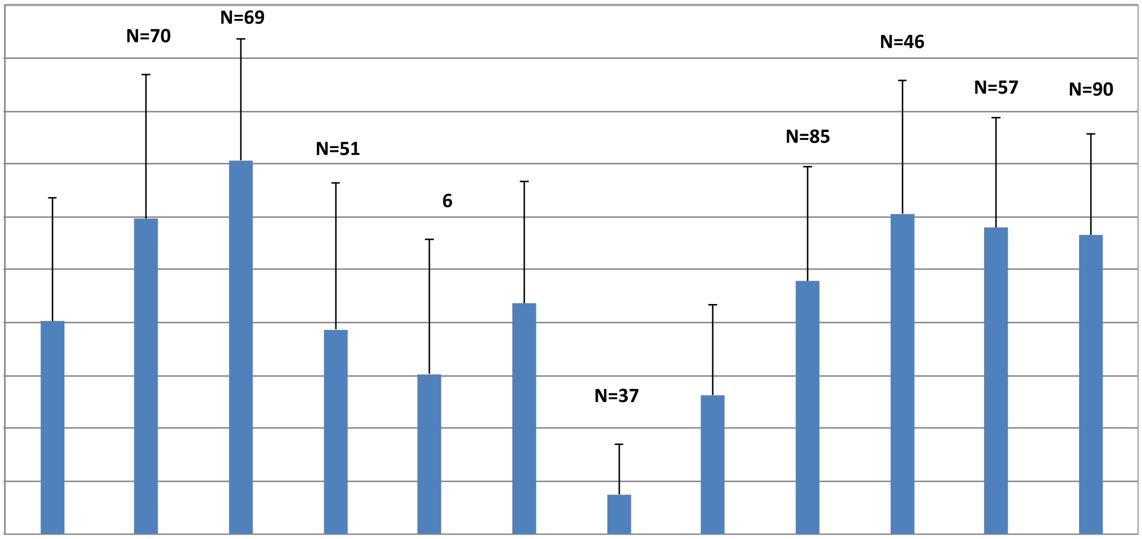

Figure 10. Mean number of daily dolphin detections at site B averaged by month for the three years of data collection. Error bars represent one standard deviation. ‘N’ values give the total number of days that were monitored during each month.

3.3 Dolphin Acoustic Response to Explosions

In total, 63 explosions were detected in the data analyzed between 15 August 2012 and 30 August 2015 (**Table 3**) representing 34 MINEX training events. The hourly sums of acoustic activity of dolphins the day prior, the day of, and the 2 days after training events are shown in **Figure 11**. During the day prior to an event, dolphins were most active during mid-day (11:00–12:00 EST) and nighttime hours (19:00–04:00 EST). On the day of MINEX training and the following day, the daytime peak in activity was reduced or absent, although the nighttime peak persisted. A paired t-test comparison of the averaged 24 hourly bins of the day before and the day of the exercise revealed a significant difference ($t = 2.798$, $DF = 23$, $p = 0.010$). Conversely, a paired t-test comparison of the averaged 24 hourly bins of the day of the exercise and first day after the exercise was not significant ($t = 0.328$, $DF = 23$, $p = 0.746$). In contrast to the reduced or absent daytime peak, the nighttime peak in activity persisted following MINEX training events, suggesting that the animals in the area resumed normal activity during these hours. This trend also suggests that the decreased activity observed during daylight hours of the following day might represent avoidance of the area. During the second day following a training event the acoustic activity levels were significantly higher than the levels observed during the day before the event (Paired t-test, $t = 6.904$, $DF = 23$, $p < 0.001$), 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).

Table 4. Explosions detected during deployments 1–12, 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	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	B	631	12/10/12 15:09	N
2	A	633	12/10/12 19:09	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	B	371	6/11/13 13:10	N
4	A	4433	6/19/13 11:20	Y
4	B	12129	7/30/13 12:57	N
4	B	12385	7/31/13 14:33	Y
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	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	B	4426	6/6/14 10:38	Y
8	B	4437	6/6/14 11:44	N
8	H	12365	7/9/14 12:33	N
8	H	12381	7/9/14 14:09	N
8	B	13794	7/15/14 11:25	Y
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	B	14546	7/18/14 14:38	Y
8	H	15247	7/21/14 12:45	Y

Table 3 (continued).

Deployment	EAR	Recording #	Explosion Date & Time	Dolphins present?
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 13:24	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 14:42	N
12	B	4659	7/14/15 9:54	Y
12	B	4682	7/14/15 12:12	N
12	B	4730	7/14/15 17:00	N

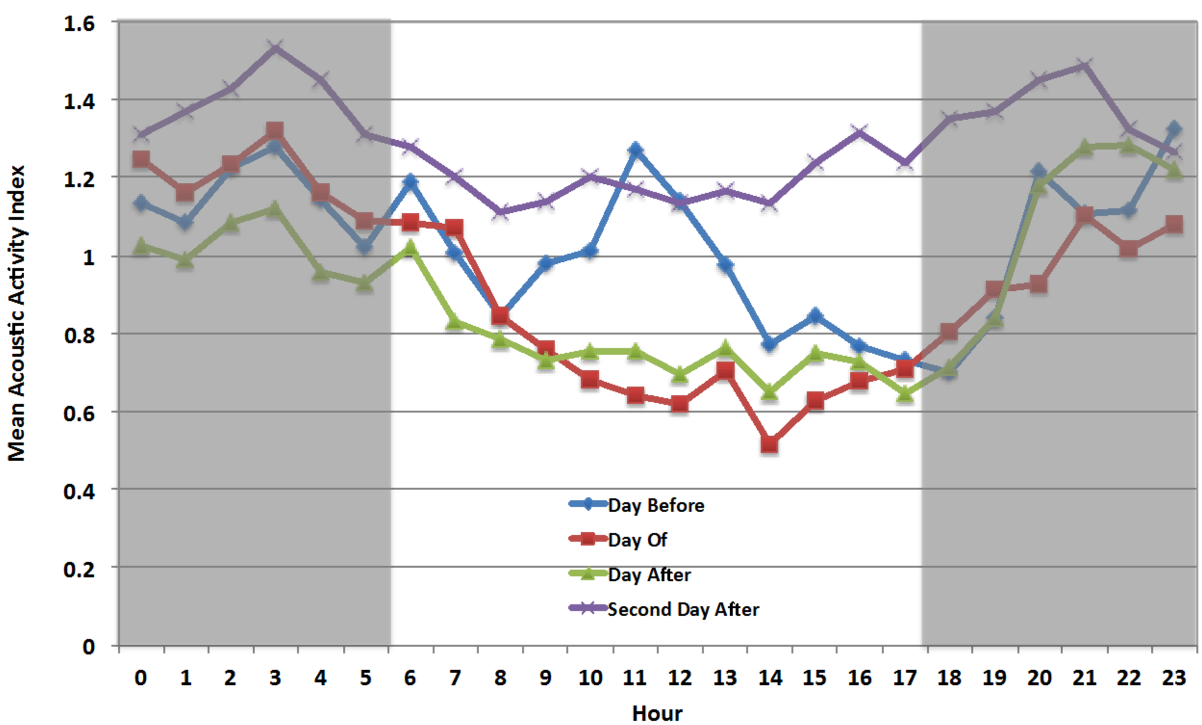

Figure 11. The hourly dolphin acoustic activity observed over the 24-hour period of the days before (N = 25), the days of (N = 31), and the first (N = 27) and second (N = 23) days after a MINEX training event at site B. Shaded periods represent twilight/nighttime hours.

Figure 12 presents the 24-hour dolphin acoustic activity observed on the linear-array EARs as a function of the distance from the epicenter of MINEX training for the days before, of, and after a MINEX training event. For the pooled 3-km data (N = 13 MINEX events), an increase was noted in the acoustic activity between the day before and both the day of and the day after a MINEX event (paired t-test of mean hourly bins, $p = 0.009$ and $p < 0.001$, respectively). No inference was attempted on the pooled data from the 6-km sites because of the small sample size (N = 4) due to instrument problems at this site during two deployments. For the pooled data from 12 km away (N = 10), no statistically significant differences were found between the day before, day of, and day after an exercise.

3.4 Summary of Localization Work

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 data from the second localization array. However, the data available to localize dolphins in proximity to UNDET events were limited. A small number of dolphin signals (N = 22) were detected in recordings suitable for localization (i.e., also containing time-synchronization pings) surrounding only one explosion event detected on 7 July 2015. These signals could not be localized with confidence, likely due in part to low SNR of whistles. The explosion source itself could not be localized because the explosion occurred in a file without pings that could not be time-aligned.

Several factors limited the amount of data available from localization array deployments to investigate Question 6 (At what distance from MINEX explosions do dolphins occur?). First, the sample size of detected explosions was small to begin with. No explosions were detected during the second localization-array deployment when 3 EARs were operational, and in the third deployment, only five explosions were detected on two days. Second, although the introduction of the pinger allowed time-alignment of recordings with pings, these represented only 20 percent of the data collected (one in every five files), further reducing the probability of detecting dolphin signals that would be candidates for localization. Finally, EAR clock drift over time resulted in offset recording times after approximately 1 month during the third deployment, and although no UNDET events were detected in the second month of deployment, this indicates clock drift as an issue to consider for future deployments.

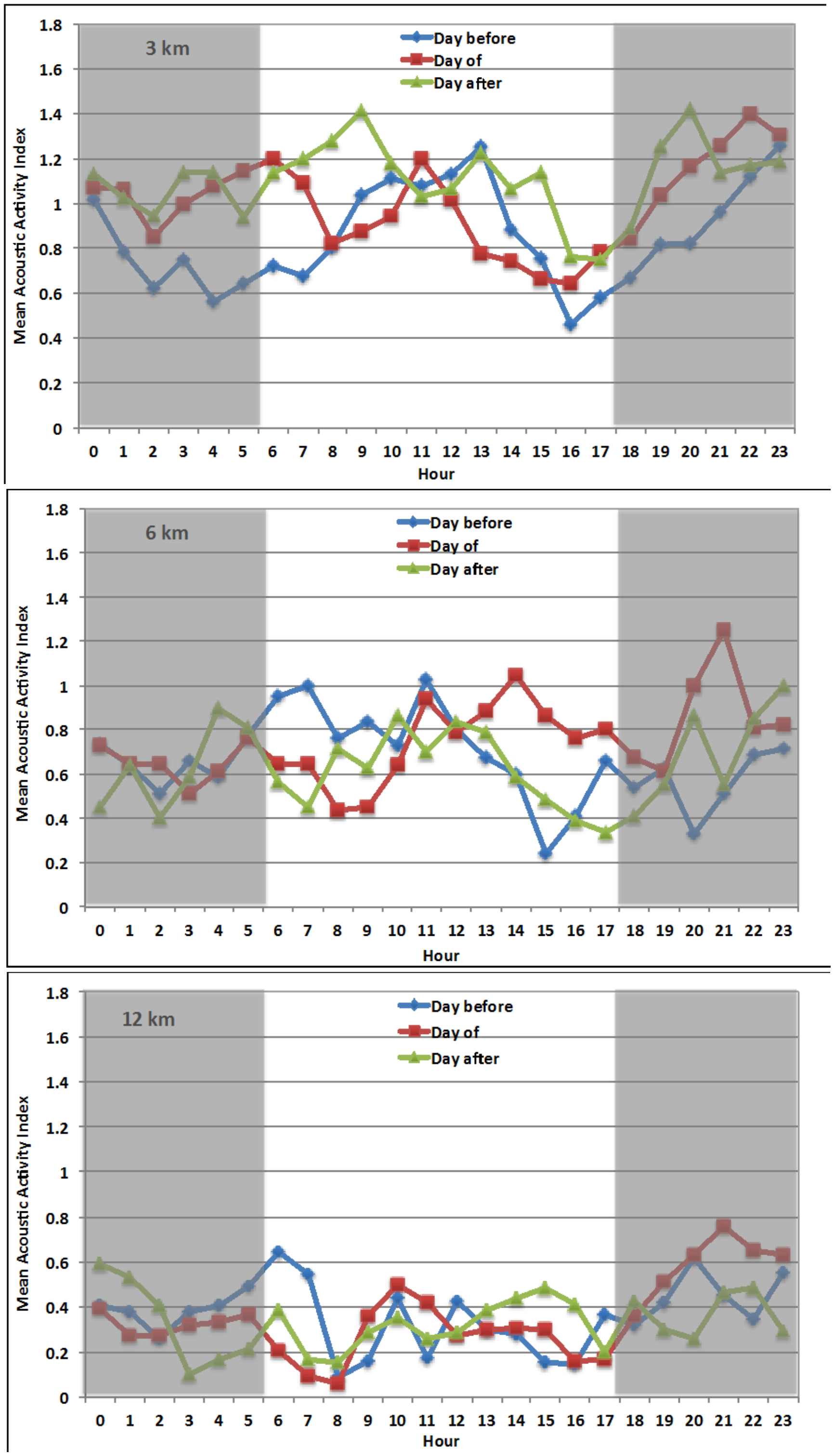

Figure 12. The hourly dolphin acoustic activity observed over the 24-hour period of the days before, the days of, and the days after a MINEX training event pooled across sites 3 km (N = 13), 6 km (N = 4) and 12 km (N = 8) from the epicenter of training activities, regardless of directional orientation of array.

4. Discussion of Findings and Future Work

After overcoming some initial complications related to the logistics of mooring EARs in the shallow waters off Virginia Beach, this monitoring project continues to yield 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. Seasonally, there appears to be a consistent period of low occurrence or reduced acoustic activity during the winter months with a minimum in February. This finding is consistent with seasonal trends in bottlenose dolphin abundance off Virginia Beach reported by Barco et al. 1999 and Engelhaupt et al. 2014, 2015. 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.

These findings suggest that dolphins are periodically exposed to noise from UNDETs, although it is not clear yet at what range. Based on 3 years of monitoring data, there is strong evidence that dolphins respond behaviorally to MINEX training events. Following an UNDET, acoustic activity decreases during the subsequent hours. It is still not clear whether this represents a suppression of acoustic activity by the animals, individuals moving away from the area, 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). It is not known whether free-ranging animals respond similarly. However, the data produced by the linear EAR array deployments are beginning to shed some light on this question. The sample sizes are still too small to draw any clear conclusions, but the data examined to date do suggest that dolphins may follow a pattern of re-distribution away from the epicenter after a MINEX training event. There is some evidence that dolphins are more acoustically active or abundant 3 km from the epicenter during the day of and the day after an exercise, but additional data must be obtained and analyzed to increase the available sample size. One additional linear-array is presently deployed that will hopefully add additional sample points for the analyses presented here and also allow a more detailed examination of the occurrence of dolphins in relation to direction from the epicenter (i.e., north, south, and east).

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 three localization-array deployments to date have been 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 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 the instrument and duty-cycle related issues could be addressed by 1) having more redundancy in case of EAR failure by deploying additional EARs in the localization array, and 2) modifying the duty cycle of recordings and the pinger. To be able to localize signals in each recording, time-synchronization pings would be required in every file, which would require altering the recording schedule or recording continuously (either is possible with the EAR2). However, these considerations need to be weighed against the likelihood of detecting an UNDET event. Modifying the recording schedule such that 'on' and 'off' periods are longer in duration may reduce the probability of detecting explosions, which are already rare/infrequently detected. Alternatively, the EARs could be programmed to record continuously to ensure the capture of both the pinger and all UNDETs, but this approach would limit the recording duration possible during a deployment. For either approach, the chance of success would be maximized if the EAR array could be deployed during a known period of anticipated MINEX training events.

One final round of EAR deployments will take place in 2016, which is planned as a localization array. However, based on the lessons learned from the three previous localization-array deployments, it is clear that the success of another deployment will depend on timing it to occur during a forecasted period of multiple MINEX events and also modifying the EAR recording schedule as discussed above.

5. Acknowledgements

We are very grateful to Amy Engelhaupt, Jessica Aschettino, Michael Richlen, and Dan Engelhaupt at HDR for their invaluable role in the deployment, recovery, and refurbishing of EARs and also in overall project management. At OSI, Maegan Kraus and Mattie Cifuentes contributed greatly to the analysis of the data and preparation of this report. We thank U.S. Fleet Forces Command and Joel Bell at NAVFAC Atlantic for support of this project.

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A

EAR Deployment Details

Table A-1. Recording parameters of the MINEX EARs.

Sampling Rate	50 kHz
Recording Time (duration)	180 s (3 min)
Recording Period (how often)	360 s (6 min)
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	14296	10
2	Paired EARs	12/7/2012	3/3 & 3/15/13	A,B	61,63	61,63	16594	3
3	Paired EARs	3/15/2013	5/31/2013	A,B	61,63	61,63	16400	2
4	Paired EARs	5/31 & 6/9/13	8/19/2013	A,B	61,63	61,63	17051	5
5	Linear array	9/20/2013	11/11/2013	B,E,F,G	2,4,61,63	2,61,63	12633	1
6	Localization array	11/16/2013	1/23/2014	B,N,P	2,61,63	2,61,63	16808	6
7	Linear array	2/16/2014	4/27/2014	B,K,L,M	2,61,63,797	2,61,63,797	16293 (EAR K)	5
8	Linear array	5/18/2014	8/3/2014	B,I,H,J	2,61,63,797	2,61,63,797	17153	15
9	Localization array	8/15/2014	10/27/2014	B,Q,R,S	2,61,63,797	2,61,63,797	17536	4
10	Linear array	11/9/2014	1/23/2015	B,E,F,G	2,61,63,797	2,61,63,797	16939	1
11	Linear array	3/9/2015	5/29/2015	B, H, I, J	17, 18, 20, 19	17, 18, 20, 19	17719	2
12	Localization array	6/24/2015	8/30/2015	B,Q,R,S	17, 18, 20, 19	17, 18, 20, 19	13839	5
13	Linear array	10/13/2015	12/16/2015	B,K,L,M	17, 18, 20, 19	17, 18, 20, 19	8154	TBD
14	Linear array	2/1/2016	still deployed	B,E,F,G	17, 18, 20, 19	TBD	TBD	TBD

Table A-3. EAR deployment coordinates by deployment site (A through S) and deployment number (1–14). 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^{o} 48.914'N	75^{o} 53.199'W
A	2	36^{o} 48.887'N	75^{o} 53.163'W
A	3	36^{o} 48.962'N	75^{o} 53.224'W
A	4	36^{o} 49.023'N	75^{o} 53.154'W
B	1	36^{o} 48.904'N	75^{o} 52.525'W
B	2	36^{o} 48.850'N	75^{o} 52.465'W
B	3	36^{o} 49.914'N	75^{o} 52.485'W
B	4	36^{o} 48.922'N	75^{o} 52.600'W
B	5	36^{o} 48.858'N	75^{o} 52.620'W
B	6	36^{o} 48.894'N	75^{o} 52.566'W
B	7	36^{o} 48.838'N	75^{o} 52.529'W
B	8	36^{o} 48.820'N	75^{o} 52.537'W
B	9	36^{o} 49.053'N	75^{o} 53.147'W
B	10	36^{o} 48.892'N	75^{o} 52.511'W
B	11	36^{o} 48.886'N	75^{o} 52.483'W
B	12	36^{o} 48.917'N	75^{o} 52.516'W
B	13	36° 48.881'N	75° 52.543'W
B	14	36° 48.919'N	75° 52.522'W
C	1	36^{o} 46.570'N	75^{o} 49.684'W
D	1	36^{o} 46.564'N	75^{o} 48.994'W
E	5	36^{o} 46.985'N	75^{o} 51.890'W
E	10	36^{o} 46.930'N	75^{o} 51.795'W
E	14	36° 46.986'N	75° 51.009' W
F	5	36^{o} 45.388'N	75^{o} 51.336'W
F	10	36^{o} 45.381'N	75^{o} 51.279'W
F	14	35° 45.372'N	75° 51.247'W
G	5	36^{o} 42.271'N	75^{o} 50.124'W
G	10	36^{o} 42.258'N	75^{o} 50.129'W
G	14	36° 42.253'N	75° 50.105' W
H	8	36^{o} 49.900'N	75^{o} 52.881'W
H	11	36^{o} 49.900'N	75^{o} 52.874'W
I	8	36^{o} 51.468'N	75^{o} 53.436'W
I	11	36^{o} 51.512'N	75^{o} 53.433'W
J	8	36^{o} 54.621'N	75^{o} 53.292'W
J	11	36^{o} 54.614'N	75^{o} 53.238'W

Table A-3 (continued)

EAR site	Deployment	Latitude	Longitude
K	7	36º 49.563'N	75º 52.256'W
K	13	36° 49.569'N	75° 52.262'W
L	7	36º 50.513'N	75º 50.395'W
L	13	36° 50.531'N	75° 50.427'W
M	7	36º 49.993'N	75º 44.528'W
M	13	36° 50.091'N	75° 44.524'W
N	6	36º 48.946'N	75º 52.596'W
P	6	36º 48.930'N	74º 52.660'W
Q	9	36º 48.930'N	74º 52.500'W
Q	12	36º 48.838'N	75º 52.521'W
R	9	36º 48.850'N	75º 52.417'W
R	12	36º 48.958'N	75º 52.571'W
S	9	36º 48.833'N	75º 52.550'W
S	12	36º 48.955'N	75º 52.668'W