Atlantic Behavioral Response Study (BRS): 2017 Annual Progress Report

Submitted to:

Naval Facilities Engineering Command Atlantic under Contract No. N62470-15-D-8006, Task Order 50, Issued to HDR, Inc.

Prepared by

Southall Environmental Associates

Duke University

Cascadia Research Collective

CREEM – University of St. Andrews

Submitted by:

Virginia Beach, VA

March 2018

Suggested Citation:

Southall, B.L, R.W. Baird, M. Bowers, W. Cioffi, C. Harris, J. Joseph, N. Quick, T. Margolina, D. Nowacek, A. Read, R. Schick, J. Shearer, and D.L. Webster. 2018. *Atlantic Behavioral Response Study (BRS) – 2017 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 50, issued to HDR Inc., Virginia Beach, Virginia. March 2018. Draft Report.

Cover Photo Credits:

Cuvier's beaked whale (*Ziphius cavirostris*) off Cape Hatteras. Photographed by Danielle Waples, taken under National Marine Fisheries Service Scientific Research Permit No. 19903 issued to Andy Read / Duke University.

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

Table of Contents

Figures

Tables

Acronyms and Abbreviations

BRS	Behavioral Response Study
CEE	Controlled Exposure Experiment
CRC	Cascadia Research Collective
EEZ	Exclusive Economic Zone
hr	hour(s)
km	kilometer(s)
LIMPET	Low-Impact Minimally-Percutaneous External-electronics Transmitter
m	meter(s)
min	minute(s)
photo-ID	photo-identification
SD	standard deviation
SPOT	Smart Position and Temperature
U.S.	United States

Executive Summary

Different programs within the U.S. Navy have supported the development of behavioral response studies (BRS) with marine mammals and military sonar over the past decade. The Atlantic-BRS project (supported by the U.S. Navy's marine species monitoring program under this contract) was conceived, designed, and initiated through a collaboration of researchers involved in several of these previous studies and in previous baseline marine mammal monitoring of key species including (Cuvier's beaked whales (*Ziphius cavirostris*) and short-finned pilot whales (*Globicephala macrorhynchus*) off Cape Hatteras, NC. The current project was designed to transition and advance approaches from previous BRS work to examine the behavioral responses of priority marine mammal species to military sonar off the Atlantic coast for the first time. The Atlantic-BRS project was designed through collaborative planning process in order to develop a prioritized experimental design. The approach employs both short-term, high-resolution acoustic tags and longer-term, coarser resolution location and behavior tags to study responses at different temporal and spatial scales. This first field phase of this multi-year study, completed in 2017, represents a successful response to the complex challenges of field conditions (weather, animal distribution) and coordination with ongoing Navy training operations, that are required for success.

Some 2017 field operations were limited by weather (especially during the fall field season due to multiple hurricanes) and mechanical issues and operational schedules with Navy ships that precluded coordination with experiments on multiple occasions. However, major accomplishments were made in terms of both data acquisition and analytical methods. Twenty-six satellite-linked, depth-transmitting tags were deployed on both focal species (14 on beaked whales, 12 on pilot whales), which resulted in thousands of hours of movement and diving behavior before and following CEEs. Ten of these individuals (7 beaked whales, 3 pilot whales) were monitored during a successful CEE sequence conducted with the USS MACFAUL using full-scale 53C sonar. Additionally, a simulated sonar CEE was conducted with seven beaked whales and four pilot whales when a Navy ship was unavailable; this total included mostly satellite-tagged animals but also individual focal beaked and pilot whales tagged with high-resolution acoustic tags (DTAGs). While the number of successful CEE sequences was smaller than expected, this was more than offset by the large number of individuals involved. During 2017, more beaked whale CEEs were conducted than in all previous BRS efforts using simulated or actual military sonar combined. This clearly illustrates the strength of this approach and validates the species and site location for the study. Existing analytical approaches are now being applied to these data, with novel integration on different time/space scales. In addition, a new paradigm of spatial analysis has been developed to address errors associated with position estimates from the satellite tags and consequent implications for modeling received noise during CEEs. In total, considerable effort has been expended in advancing analytical methods.

Extensive analyses of the 2017 data are ongoing and, although some results are presented here, additional data from subsequent field effort are clearly required. From analyses conducted thus far, all exposed individuals continued to utilize the study area following CEEs (*i.e.*, there was no obvious large-scale avoidance or abandonment of habitat). We are analyzing potential responses using several methods to investigate subtler potential responses, to the extent

possible given the resolution of available data. Further evaluations and conclusions on these data in terms of potential responses during CEEs will be presented and discussed at the marine species monitoring program review meeting in March 2018, although some broad conclusions regarding response probability and contextual factors (e.g., source-animal range, behavioral state) will require additional data collection in subsequent field phases. A number of methodological and analytical lessons learned from 2017 are described here, together with the initial results, as they relate to the experimental plans for the 2018 field effort.

1. Overview

1.1 Overall project design and objectives

Beginning with planning discussions at the Navy marine species monitoring meeting in Norfolk in March 2015 and extending over the subsequent two years, a research collaboration of scientists from Duke University, Southall Environmental Associates (SEA), Cascadia Research, and the University of St. Andrews evaluated potential marine mammal behavioral response studies (BRS) within several key regions of the Atlantic coast. These planning discussions and research priorities were developed in coordination with representatives from Navy monitoring and research programs and considered research sites off Virginia, Florida, and North Carolina with a number of potential focal species. Based on a combination of specified Navy research and monitoring priorities, identified species priorities, existing baseline data, and the probability of success given recent work in each location, a prioritized research plan focusing on beaked and pilot whales was developed to leverage the existing capabilities and relatively high probability of success in locating and tagging these species off Cape Hatteras, NC.

Most previous studies have either used short-term, high-resolution tag sensors to measure fine-scale behavior in response to calibrated metrics of experimental noise exposure from acoustic tags or coarser-scale, longer-term measurements of movement and diving during incidental exposures during sonar training operations. This study is unique in bringing both approaches together, building on previous experience with both tag types on these species in this location. Specifically, the overall design involves expanding the temporal and spatial scales of previous BRS efforts by combining short-term, high-resolution acoustic archival tags (DTAGs) and satellite-linked, time-depth recording tags (SLTDRs) simultaneously deployed on multiple individuals of focal species in the same controlled exposure experiments (CEEs). Furthermore, this experimental context will build from simulated mid-frequency active sonar (MFAS) signals to include full-scale, operational military sonar (e.g. SQS-53C-equipped combat vessels) systems positioned according to experimental objectives.

The overall research objective is to provide direct, quantitative measurements of marine mammal behavior before, during, and after known exposures to MFAS signals in order to better describe behavioral response probability in relation to key exposure variables (received sound level, proximity, animal behavioral state). These measurements will have direct implications for and contributions to more informed assessments of the probability and magnitude of potential behavioral responses of these species. They will be directly applicable to the Navy in meeting their mandated requirements to understand the impacts of their MFAS training operations on protected species and to the regulatory agencies in evaluating potential responses within regulatory contexts.

Several key categories of potential behavioral responses are being evaluated, including potential avoidance of sound sources that influence habitat usage, changes in foraging behavior, and changes in social behavior. While the overall experimental approach using CEEs and comparing exposure among conditions before, during, and after noise exposure is common, several methodological differences (e.g., tag set-up, nominal target exposure levels) differ slightly among species given the known differences in their life history, baseline behavior, and susceptibility to noise exposure. As in previous studies, explicit monitoring and mitigation protocols have been established in conducting and evaluating CEEs in order to meet experimental objectives while ensuring that studies are conducted according to both permit authorizations and ethical standards. Further, these research objectives, field dates, and outcomes of these studies thus far have been communicated transparently to a variety of interested stakeholders.

1.2 Experimental Design

As discussed within the experimental coordination and planning regarding overall design and statistical analysis and integration with other studies, there was considerable value identified in maintaining consistency with other BRS projects. Such consistency was seen as critical to allow comparisons to be drawn among studies and support the meta-analyses needed to derive dose-response probabilistic functions. The resulting overall design thus involved a number of different kinds of monitoring methodologies and platforms. These included quantitative measurements of individual behavior using tags of several types attached to animals, small-boat-based individual and group focal follow observations, targeted collection of individual tissue biopsy samples and photo-identification, and remote passive acoustic monitoring from archival recorders deployed in the general area in conjunction with companion studies supported by the Navy.

Given that the coordination required with Navy combat vessels equipped with SQS-53C sonar systems for BRS efforts off Hatteras, the overall experimental design was based on the methods employed in SOCAL-BRS using CEEs with both simulated MFAS and operational vessel-based 53C systems (see: Southall et al., 2012; 2016). This design includes a period during which baseline behavioral data are collected prior to the CEE. Baseline data are then collected during a minimum of 60 minutes for animals with DTAGs. A 24-hour minimum period of baseline data collection was employed for animals equipped with satellite tags, although most baseline data periods were in practice much longer for this tag type. Pre-exposure baseline behavioral data collection primarily involved data from tag sensors, supplemented by focal follows of tagged animals by observers in small boats where possible using methods consistent with those employed in SOCAL.

Sonar transmissions during CEEs occurred in the same manner as in SOCAL-BRS. Simulated MFAS sources (as in Southall et al., 2012) were operated from a stationary source deployed to 20m depth for a total of 30-min at output source levels of 212 dB (RMS) re 1 μPa, positioned at ranges from subjects that met experimental objectives (described below). Full scale sources included transmission of full power (235 dB (RMS) re 1 μPa) signals of a constant nominal 53-C waveform type (single ping sequence using two sequential CP/CW waveforms 0.5 sec duration each with 0.1s separation for total ping series 1.1 sec duration). Signals were transmitted with a 25-s repetition rate, using surface duct sector search mode, and 3°downward vertical steering. Transmissions occurred for a total duration of 60 min with the transmitting ship transiting in a direct course at a net (over ground) speed of 8 kt. Based on the position of a focal animal, the starting position and course for the transmitting vessel was determined using custom *in situ* propagation modeling tools using the Navy-consistent models and unclassified databases in software developed and provided by the Naval Postgraduate School (NPS). The course of the vessel was designed to result in an escalation in received levels at the presumed location of focal individuals based on their movement, to the extent it is known. This was designed to be generally but not directly toward individuals. Given the relatively large number of tagged individuals exposed during CEEs, individuals had varied MFAS exposure conditions during CEEs in terms of exposure range and received level. Target received levels for the focal animals ranged from 110-160 dB RMS, depending upon species and the aggregate location of focal individuals (110-130 dB for beaked whales 120-160 dB for pilot whales). The experimental design allows for positioning of MFAS sources to result in target received levels at focal individuals, but resulted in a diversity of received levels for other individuals at positions and ranges that were not controlled, but were known (with error) from positions derived from satellite tags.

Following exposure cessation, monitoring of experimental subjects was maintained. Satellite tags were programmed to continue to collect data consistently for days or weeks following CEEs. Focal animals (particularly for DTAG individuals) were monitored for a further 60-min, employing the same focal animal sampling protocol. At the end of this sampling period post CEEs, attempts to obtain biopsy sample were made for focal individuals as well as potentially other animals in the group. Biopsy samples will be used to determine the sex and reproductive status of the whales and to potentially measure the level stress hormones in exposed whales.

To maximize the chances of successful coordination with Navy ships engaged in training exercises in areas that are several tens to ~100 miles from the study site, the experimental design called for a single CEE within each week. This schedule also addressed the potential for habituation or sensitization of animals within the relatively small area and the relatively infrequent sonar transmissions here, compared other studies which have occurred in training ranges where sonar is used more intensively. The clear priority for the Hatteras-BRS was to conduct CEEs using actual SQS-53C sonar systems. There are potential confounding issues with the use of an experimental simulated sonar source, although the majority of CEEs in other projects (e.g., SOCAL-BRS) have employed similar “scaled” versions of real sources. Given these confounding issues and the need to focus on actual tactical sonar systems, simulated sonar CEEs were clearly identified as secondary priority and were reserved for instances where tagged animals are available, weather conditions support CEEs, and Navy ships were not available.

1.3 Overall Analytical Approach

Behavioral response analyses focus on how beaked and pilot whales change their behavior from baseline conditions during periods of MFAS exposure in known contexts during CEEs. The analytical methods being used directly transition and apply successful methods developed in other BRS studies (with these and related species), with specific questions and methods derived for differences in the nature available data (tag type) and species in questions. Broadly speaking, analyses are designed to consider to address questions of: (a) potential avoidance behavior; (b) potential changes in behavioral state; and (c) potential changes in social behavior. Short- and longer-term consequences of disturbance are initially being evaluated separately using established analytical methods for short- and medium-term tags. However, this study offers a unique opportunity to explore how these methods may complement one another and how high-resolution, short-term response data may inform methods used for longer-term monitoring. The specific data streams collected from different research platforms are given in **Table 1**, with their use in specific ongoing analyses relating to those questions addressed in **Tables 2 and 3** for pilot and beaked whales specifically (below).

Analyses of short-term changes in movement, foraging and social interactions primarily involve analyses of DTAG data, supplemented with focal follow observations where possible, using different methods based on species type. Additional analyses of DTAG data are being conducted to construct informative priors to determine states and inform state-switching analysis of the longer-term satellite-linked tag records within a Bayesian framework. State-switching analysis in beaked whales is more straightforward than in pilot whales, because pilot whales possess a greater suite of behavioral states, making analysis more computationally intense and requiring a hierarchical approach. Analysis of longer term movement patterns from the satellite tags provide information on the probability of longer term avoidance (e.g., habitat abandonment) following exposure using metrics such as linearity of movement and residence time. Measures of social cohesion are being conducted in a more limited set of tag deployments where multiple individuals were tagged within a group.

Response variables, such as changes in heading or vocal behavior, are being evaluated with several regression models, including generalized linear (or additive) mixed-effects models and generalized estimating equations (GEEs). Exposure contextual variables include: received noise exposure level, range to source, time since exposure, animal behavioral state, and relative movement. Change-point analyses and metrics of response intensities are being considered using individual-based analyses with methods including GEEs, Mahalanobis distance, or more univariate statistical analyses of individual behaviors. State switching models, are being used to examine the probability of changes in behavioral state following exposure (e.g., from foraging to other states).

Different response questions and methods are being applied based on tag type and associated data for both tagged pilot and beaked whales (**Tables 2 and 3**, respectively).

Table 1. Data streams collected as part of the Atlantic BRS experiment and their intended products (see Table 2 below for response analysis categories)

Data Stream	Task(s)	Product(s)	Where Used?
DTAGs *In-field processing*	Tag set-up, test files, cal files	Data Archive Summary Sheets	Metadata; Reporting
	Tag deployment/summary sheet with tag lat/long on/off, determine tag duration	Data Archive Summary Sheets	Metadata; Reporting
	Download tag; backup and archive tag data	Raw .dtg files	Raw data
	Create prh file; line up to acoustics	Processed .prh files	Processed data
	Photos of all DTAG animals archived and referenced for future deployments	Photo archives	Photo ID; field recognition, **SI response**
	Quick look acoustic audit – vocalizations	Audit files	Quick look analysis
DTAGs *Post-field processing and analysis*	CEE RL analysis (different metrics) and flow noise file generation	Processed RL and noise files	RLs covariate in **all analyses**; flow noise for speed calculations
	Uncorrected and corrected Pseudotracks	Raw ptrack; corrected ptrack	**HA response**
	Tag deployment quick look reports with dive profiles, pseudotrack, RLs	Data Archive Summary Sheets	Metadata; Reporting
	Full acoustic audit – vocalizations	Audit files	**FB response** **SI response**
	Call counts pre, during and post CEE	Audit files	**SI response**
	Click durations for focal individuals	Audit files	**FB response**
	Acoustic transitions between pre-defined foraging phases	Audit files	**FB response**
	Accelerometry data: depth, pitch, heading, MSA, turning angle pre, during and post CEE, during dives and during phases of dives	Processed prh data (by-dive)	**HA response** **FB response**
	Metrics for dive by dive analysis including: dive depth, dive duration, surface duration, number of buzzes, ascent and descent rates and durations	Processed dive data (by-dive)	**HA response** **FB response**
SAT TAGS *In field processing*	Summary sheets for each tag with all settings and deployment conditions	Data Archive Summary Sheets	Metadata; Reporting
	Archive photos of each sat tagged animal.	Photo archives	Photo ID; field recognition, **SI response**
	Quick look summaries/plots of locations ahead of CEE days to coordinate planning and positioning of Navy ships	Data Archive Summary Sheets	Quick-look analysis Metadata; Reporting

Data Stream	Task(s)	Product(s)	Where Used?
SAT TAGS *Post processing and analysis*	Smoothed X-Y track	Tracks and ARC-GIS plots	Metadata; Reporting **HA response**
	Movement reaction based on source-whale range (avoidance)	Analysis	**HA response**
	Horizontal speed calculations and analysis	Analysis	**HA response**
	Metrics for dive by dive analysis, max depth, duration.	By-individual summary files	Metadata; Reporting; FB analysis
	Time series analysis within and across individuals, state switching	Analysis	**HA response**
	Modelled RL and Acoustic range (source to whale)	Modelled RL and calculated positions	RLs covariate in **all analyses**
Overall Synthesis and Metadata *In field*	Daily across-project log during CEE-possible days, including coordination with ships	Daily Log	Metadata; Reporting
	Synthesis of known or estimated animal positions and planning for CEE locations/coordination	Pre-CEE summary	Metadata; Reporting
	Archive and back-up model runs and parameters used to estimate RLs	Data Archive Summary Sheets	Metadata; Reporting
	Ship tracks and transmission schedule (source log if scaled source)	Data Archive Summary Sheets	Metadata; Reporting
Overall Synthesis and Metadata *Post-processing*	Metadata summary of all CEEs with animal locations and ship tracks	Tracks and ARC-GIS plots	Metadata; Reporting
	Summary of modelled vs. actual RLs for DTAGS; model results for sat tags	RL Summary	Metadata; Reporting; **Response analyses**
FOCAL FOLLOW *In field*	Download data, scribe any spoken tracks, archive field vis obs and vessel track logs	Daily log files	Metadata; Reporting;
	Quick look reports and QA/QC; provide for integration with DTAG data for corrected pseudotracks	Quick look reports	Quick look analysis; Metadata; Reporting;

Data Stream	Task(s)	Product(s)	Where Used?
FOCAL FOLLOW *Post processing and analysis*	GPS data, location/habitat use	GIS maps; data analysis	Metadata; Reporting;
	Bin FF data into time samples	Data analysis	**SI response**
	Movement reaction based on source-whale range	Data analysis	**HA response**
	Metrics for analysis in binned samples: Social behaviour category, group size, distance to nearest other group, defined behaviour categories (spyhop, logging etc…), cohesion	Data analysis	**SI response**
	Covariates for analysis, integrate from other data sources	Data analysis	**SI response**
BIOPSY SAMPLES *In field*	Labelling and storage	Field data	Post Processing
BIOPSY SAMPLES *Post processing and analysis*	Sex id	Data summary	Potential use in **all response analyses**
	Hormones	Data summary	Separate analyses
	Stress, levels pre, and post	Data summary	Separate analyses
PHOTO ID *In field processing*	Compiling, naming, archiving photos	Archived data	Field recognition **SI response**
PHOTO ID *Post processing and analysis*	Grading and matching to existing catalogue	Catalog	Subsequent field recognition
	Group size estimate from photos	Data summary	**SI response**
	Group composition from photos	Data summary	**SI response**
	Individual sighting information	Catalog	Subsequent field recognition

Table 2. Response Questions and Analytical Methods: Pilot Whale Response Analyses

Behavioral Response Questions	Data Collection Method	Specific Metrics	Analytical Methods
Horizontal Avoidance (**HA**)	**DTAGs**	* *Velocity* (vert, horizontal) * *Heading differential* * *Heading variance*	1. **General Estimating Equations** (GEEs); exposure as predictor variable and these response metrics. 2. **Mahalanobis Distance** with these as input variables
	Focal Follows	* Location (range/bearing) to derive *source-animal range*	
	SAT TAGs	* X-Y positions to derive: *source-animal range* *spatial movements*	1. **Behavioral change-point analysis** (BCPA) of spatial movement 2. **Attraction/repulsion analytics** 3. **Spatial point-process methods**
Changes in Foraging Behavior (FB)	**DTAGs**	* *Depth* * *Buzzes* * *MSA*	1. **State-switching models** 2. **GEEs**; exposure as predictor variable and these response metrics
	SAT TAGs	* *Depth* * *Duration* * *Shape*	1. **GEEs**; exposure as predictor variable and these response metrics 2. **State-switching models**
Changes in Social Interactions (SI)	**DTAGs**	* *Call rates*	1. **General Linear Models** (GLM) 2. **GEEs**; exposure as predictor variable and these response metrics
	Focal Follows	* *Lat/lon position* * *Focal animal speed* * *Group size* * *Group spread* * *Surface synchrony* * *Heading synchrony* * *Behavioral state/activity*	
	SAT TAGs	* *Inter-animal distance*; only for animals tagged in same group	1. **Group Dynamic Movement Models** (Langrock et al., Hanks et al.)

Table 3. Response Questions and Analytical Methods: Beaked Whale Response Analyses

Behavioral Response Questions	Data Collection Method	Specific Metrics	Analytical Methods
Horizontal Avoidance (HA)	**DTAGs**	* *Velocity* (vert, horizontal) * *Heading differential* * *Heading variance*	1. **General Estimating Equations** (GEEs); exposure as predictor variable and these response metrics. 2. **Mahalanobis Distance** with these as input variables
	Focal Follows	* Location (range/bearing) to derive *source-animal range*	
	SAT TAGs	* X-Y positions to derive: *source-animal range* *spatial movements*	1. **Behavioral change-point analysis** (BCPA) of spatial movement 2. **Attraction/repulsion analytics** 3. **Spatial point-process methods**
Changes in Foraging Behavior (FB)	**DTAGs**	* *Depth* * *Clicks* * *MSA*	1. **State-switching models** 2. **GEEs**; exposure as predictor variable and these response metrics
	SAT TAGs	* *Depth* * *Duration* * *Shape*	1. **GEEs**; exposure as predictor variable and these response metrics 2. **State-switching models**
Changes in Social Interactions (SI)	**Focal Follows**	* *Lat/lon positions* * *Group size* * *Diving synchrony*	1. **General Linear Models** (GLM) 2. **GEEs**; exposure as predictor variable and these response metrics
	SAT TAGs	* *Inter-animal distance*; animals tagged in group	1. **Group Dynamic Movement Models**

1.4 2017 Field Logistics and Configuration (vessels, personnel, tags)

The 2017 Atlantic-BRS field effort consisted of both a spring (May) and fall (Aug-Sept) field effort. Each field period had an initial phase focusing on advance deployment of satellite tags followed by a more intensive, larger team effort during periods when Navy ships were potentially available during which deployment of either satellite tags or DTAGs were attempted and CEEs were conducted.

Satellite tags were deployed from the R/V *Barber* during two weeks prior to the onset of CEE efforts during both phases. The field team for this portion of the project included four individuals from Duke and Cascadia, who collectively located animals, positioned the boat for tagging, deployed the tags, and collected photo ID and other data from groups. The *R/V Barber* is an 8-

m aluminum-hulled SAFE boat capable of handling relatively heavy seas and it ran in and out of Oregon Inlet on a daily basis on days when sea conditions were suitable for locating and tagging animals.

During periods in which DTAG deployments and CEEs were attempted, the following vessel configuration and research crew of 10 individuals was involved. The field team worked from three vessels: (1) the R/V *Barber* (with an identical crew of four); (2) a second (6-m) RHIB (R/V *Exocetus*) with a crew of three (driver, tagger, and visual observer) that either ran out from Oregon Inlet or was based from an offshore vessel; and (3) a third offshore research platform (M/V *Tiki* based out of Ocean City, MA for spring and F/V Kahuna based out of Manteo, NC for fall) that served as the base of operations for the *Exocetus*, housed the simulated sound source, provided and additional tracking and vidual observation platform, and supported three additional personnel (chief scientist, visual observer/radio tracker, and a DTAG field technician that served as an additional visual observer and conducted DTAG tracking/recovery).

In terms of tag sensors, two types were deployed, short-term, high resolution archival acoustic and movement tags (DTAGs) and depth-transmitting satellite tags. Five version 3 DTAGs from the University of Michigan were obtained through a lease agreement for each period of Navy ship availability and were returned for servicing between each of the two field periods. A total of 30 Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) satellite-linked tags were available to Atlantic-BRS for 2017, with a target of 15 deployed in each of the two field periods. While several SPOT6 location-only tags were among those available, priority was placed (given the interest in feeding and diving behavior) in the use of SPLASH10-A depth transmitting tags in the LIMPET configuration; almost all tags available were of this type. The initial tagging priority was on beaked whales as this species is of high Navy interest, but is more challenging to tag. Pilot whales were tagged with a secondary priority and nearer to the beginning of the first CEE period. Efforts were made to deploy two tags in social groups of either species, in order to evaluate potential changes in social associations as a response metric during CEEs.

Considerable advance planning and coordination was conducted to ensure effective communication between the Atlantic-BRS field team conducting tagging operations and planning CEEs with Navy field operations. This included extensive planning discussions over the past two years between the Atlantic-BRS team and Navy representatives, evaluating and applying lessons-learned in terms of field communications and coordination from previous research and operational experience. These unclassified discussions have included logistical planning to coordinate research objectives and plans, as well as opportunities for the use of Navy sonar sources in CEEs from operational ships engaged in ongoing training exercises. Communication protocols with redundancies and regular contact periods were developed with designated Navy representatives, with logistical, operational, and communication approaches leveraging protocols developed in the SOCAL-BRS project. The Atlantic-BRS team coordinated before, during, and after the field effort through designated representatives, including regular updates and communication, as well as quick look summaries following field operations.

Finally, the Atlantic-BRS team undertook several measures to openly and transparently communicate research plans and objectives externally. This included presentations of research objectives and experimental and monitoring protocols at the U.S. Navy marine species monitoring program technical review meetings held in Norfolk in spring 2015 and 2016 and a scientific presentation at the SEAMAMMS conference in April 2016. Duke also provided direct regarding research plans and established lines of communication in the unlikely event of any marine mammal stranding occurring during operations with representatives from the Mid-Atlantic Marine Mammal Stranding Network. We provided summary information during and following research activities, as appropriate, through participating research organizations. Results will continue to be presented in open scientific and public meetings, as well as peer-review publications.

This page intentionally left blank.

2. Field Effort

2.1 Field Dates, Overall Accomplishments, Assessment of Field Effort

PHASE I (SPRING)

Field dates:

- **1-13 May 2017**: Shore-based satellite tag deployment effort (two field days with suitable conditions for tagging) from *Barber.*
- **14-19 May**: Sat tag and DTAG effort (*USS Bainbridge* was scheduled but cancelled; decision made to extend sat tagging efforts, deploy DTAGs if possible, and test offshore BRS configuration with *Tiki.*
- **22-26 May**: DTAG and CEE effort planned with *USS Bulkely*. Conditions were unsuitable for small-boat tagging efforts the entire week; efforts to coordinate CEEs focusing on satellite tags that had been deployed were not realized as ship returned to port based on rough seas.

Overall accomplishments:

- Successful deployment of 14 of a possible 15 satellite tags (5 beaked whales; 9 pilot whales).
- No DTAGs deployed, but options belayed in good conditions when no Navy ship to prioritize satellite tag deployments.
- Able to relocate sate-tagged animals in the field using goniometer; significantly increases chances of subsequent tag deployments.
- Important lessons-learned in terms of vessel configurations.

Assessment of field approach:

- Weather was below-average overall for May; several excellent periods, many workable days, some blown out days.
- Animal sightings: Very good; many groups of both focal species in target areas
- RHIB operations worked reasonably well and as expected.
- Lessons-learned in terms of future operations: *M/V Tiki* was not a good fit for this project given challenges/inability to house and deploy *Exocetus* at sea and based on very slow transit speed.
- Navy ship availability was limiting factor with both scheduled ships unavailable for CEEs; simulated source was not fielded in spring and precluded back-up option of secondary objective.

PHASE II (FALL)

Field dates:

- **16-21 August 2017**: Shore-based satellite tag deployment effort (two field days with suitable conditions for tagging) from *Barber.*
- **20-24 August**: Sat tag and DTAG effort; *USS GRAVELY* was scheduled and deployed with BRS coordination. Both satellite tags and DTAGs on both species were deployed and available for a real ship CEE on 22 Aug but *GRAVELY* was unable to support given mechanical issues recovering RHIBs. The decision was made to conduct a simulated sonar CEE, which was accomplished from *Kahuna* (although the source terminated due to a false leak alarm halfway through the sequence).
- **27 August-1 Sept**: Field teams were mobilized, but conditions unsuitable for small boat operations and no Navy vessel available for CEE with the 12 satellite tagged whales.
- **10-12 September**: Multiple hurricanes affecting overall Atlantic region precluded small-boat operations and additional tagging. *USS MACFAUL* deployed as scheduled for training operations with Atlantic-BRS coordination. Remote coordination with MACFAUL to successfully conduct full-scale CEE according to operational protocols for multiple individuals of both species on 12 September.

Overall accomplishments:

- Successful deployment of 12 of a possible 15 satellite tags (9 beaked whales; 3 pilot whales).
- Successful deployment and recovery of two DTAGs (one beaked whale, one pilot whale).
- Successful completion of scaled source CEE involving 7 beaked whales (6 satellite tags, one focal DTAG individual) and four pilot whales (3 satellite tags, one focal DTAG individual) at different physical ranges and received level contexts.
- Successful completion of full-scale 53C MFAS CEE involving 7 beaked whales and 3 pilot whales (all satellite tags) at different physical ranges and received level contexts.
- Continued ability from two platforms to relocate sate-tagged animals in the field using goniometer; significantly increases chances of subsequent tag deployments and tracking tagged individuals.
- Important lessons-learned in terms of vessel configurations.

Assessment of field approach:

- Although several excellent days allowed many of the accomplishments, the weather overall was significantly limiting with multiple tropical storm/hurricane systems that affected both small boat and Navy ship operations. Future field efforts should aim to avoid fall (September) periods to the extent possible.
- Continued high degree of success with locating and tagging beaked whales. Thanks to the combination of relatively high density of animals and proven and skilled field teams, very high rates of tag deployments per field day continue to be achieved

- The missed opportunity for real ship CEE with *GRAVELY* was very unfortunate. The spatial configuration of tagged individuals (with ARGOS error acknowledged) was ideal in terms of the experimental objectives, had we been able to position the ship according to the nominal plan developed in the field (**Figure 1**).
- Having scaled sound source provided secondary option in conditions where Navy ship mechanical issues rendered it unavailable to support
- Having satellite tags deployed ahead of available Navy ships even during periods when small boat operations were not possible and the ability to monitor remotely and coordinate with Navy ship remotely allowed for the successful completion of a real source CEE with a large number of tagged individuals.

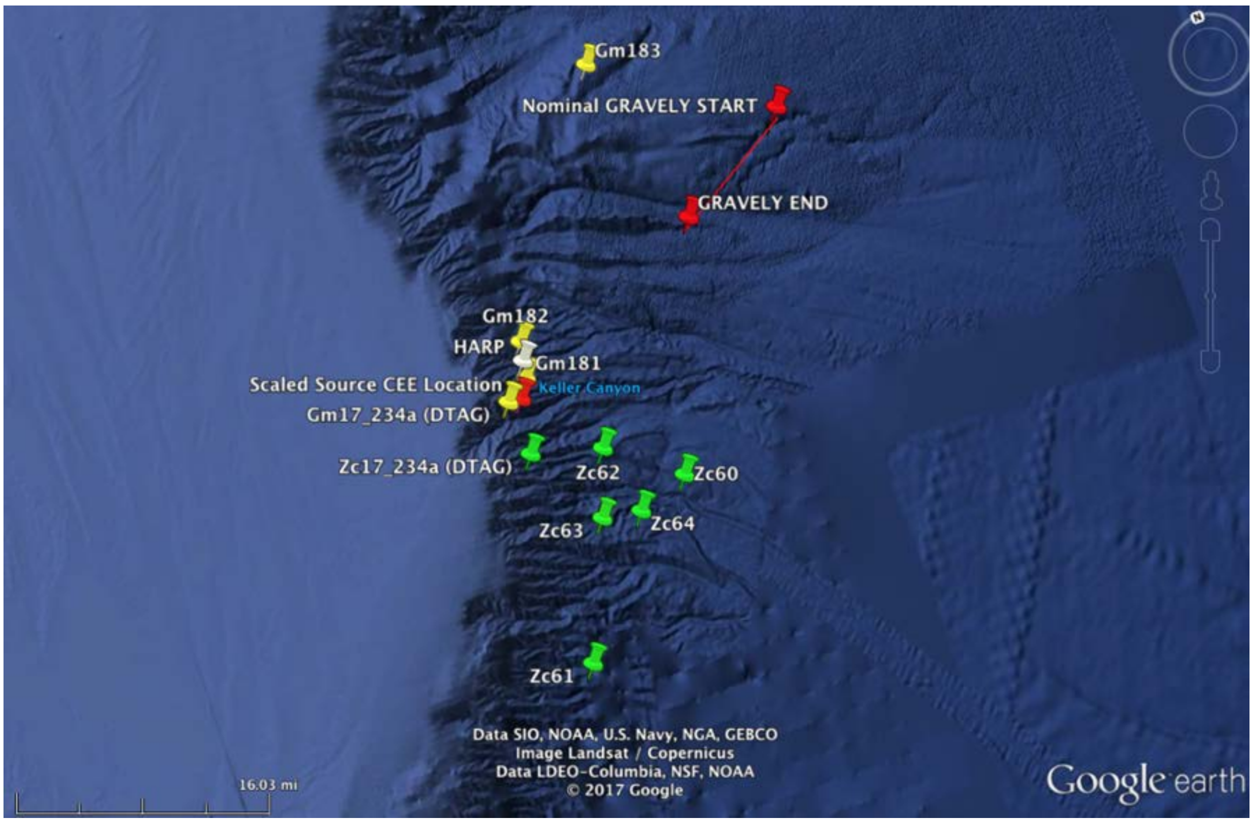

Figure 1. Approximate locations (most recent raw ARGOS position of class code 0 or higher for satellite-tagged individuals and known focal-follow positions for DTAG-ed individuals) for tagged beaked whales (green) and pilot whales (yellow) relative to requested ship track derived *in situ* for *USS GRAVELY* on 22 August 2017.

2.2 Tag deployments

Satellite tag deployments were conducted by researchers from Cascadia and were coordinated and in part supported through a separate research project led by Cascadia, which was coordinated with the Atlantic-BRS. More details regarding the tag configurations, deployments, and baseline data collected from these tags is provided in a companion annual report submitted separately by Cascadia. A simple summary of the tag deployments completed during the periods within the overall Atlantic-BRS effort is provided here for individuals of both species. Overall, 26 satellite tags were deployed, 12 on pilot whales and 14 on beaked whales (**Table 4**). Additional details regarding satellite tag results and analyses specific to CEEs are provided in **Section 3** (below).

Table 4. 2017 satellite tag deployments during Atlantic-BRS field efforts for pilot and beaked whales

Tag ID	Deployment Date	Sighting #	Deployment Latitude (°N)	Deployment Longitude (°W)	Depth at tagging location (m)	Tag duration (days)	CEE (scaled source or ship)
GmTag172	5/10/2017	3	35.54	-74.73	1,488	32.61	none
GmTag173	5/11/2017	4	35.72	-74.83	223	23.93	none
GmTag174	5/11/2017	4	35.72	-74.83	234	31.5	none
GmTag175	5/16/2017	7	35.65	-74.69	1,657	25.69	none
GmTag176	5/16/2017	7	35.64	-74.69	1,724	14.33	none
GmTag177	5/17/2017	2	35.8	-74.78	1,103	28.29	none
GmTag178	5/17/2017	6	35.7	-74.79	624	18.75	none
GmTag179	5/17/2017	6	35.7	-74.80	578	0.37	none
GmTag180	5/17/2017	6	35.7	-74.80	539	32.68	none
GmTag181	8/20/2017	5	35.58	-74.77	775	30.94	both
GmTag182	8/20/2017	5	35.56	-74.77	822	29.49	both
GmTag183	8/20/2017	8	35.6	-74.72	1,522	32.29	both
ZcTag054	5/10/2017	5	35.58	-74.71	1,500	18.12	none
ZcTag055	5/10/2017	5	35.57	-74.71	1,546	52.89	none
ZcTag056	5/10/2017	5	35.53	-74.70	1,705	47.87	none
ZcTag057	5/16/2017	6	35.64	-74.70	1,737	49.35	none
ZcTag058	5/16/2017	9	35.58	-74.71	1,514	39.11	none
ZcTag060	8/17/2017	7	35.59	-74.76	1,058	34.67	both
ZcTag061	8/17/2017	7	35.61	-74.73	1,425	44.44	both
ZcTag062	8/17/2017	9	35.64	-74.71	1,631	12.16	scaled source
ZcTag063	8/20/2017	7	35.54	-74.72	1,566	30.68	both
ZcTag064	8/20/2017	7	35.53	-74.71	1,599	49.63	both
ZcTag065	8/22/2017	5	35.53	-74.79	546	12.78	scaled source
ZcTag066	9/4/2017	3	35.59	-74.75	1,210	38.38	ship
ZcTag067	9/4/2017	4	35.6	-74.73	1,449	42.31	ship
ZcTag068	9/4/2017	4	35.58	-74.75	1,085	39.98	ship

As noted, two (version 3) DTAGs also were successfully deployed during the fall field effort. This included a successful full deployment on one beaked whale (**Zc17_234a**) for a total on-animal duration of 7h and a successful full deployment on one pilot whale (**Gm17_234a**) for a total on-animal duration of 4.5h. Both deployments occurred on 22 August and each was a focal individual for the simulated MFAS CEE conducted on that day. High-resolution movement and calibrated acoustic data were obtained for both individuals over the full deployment interval, which including the full experimental CEE sequences (before, during, after noise exposure) for CEE #2017-01 with the simulated MFAS source (described below).

2.3 CEEs Conducted

During the Atlantic-BRS 2017 field effort, two CEEs sequences were conducted. The first (**CEE #2017-01**) was conducted with the simulated sonar MFAS source on 22 August 2017 after it was known that the *USS GRAVELY* was unavailable for the planned real ship CEE. A total of seven beaked whales and four pilot whales were monitored with different combinations of tags and focal follow monitoring during this sequence. configuration and metadata. The second (**CEE #2017-02**) was conducted in coordination with the *USS MACFAUL* on 12 September 2017. A total of seven beaked whales and three pilot whales were monitored using just satellite tag sensors (no on-water focal follow monitoring) during this sequence. The overall configuration, associated *in situ* model results used in field planning, and quick look results of individual movement/diving summaries are provided below for both CEE #2017-01 (II.C.1.) and #2017-02 (II.C.2).

2.3.1 CEE #2017-01 - Simulated Sonar CEE

Date: 22 August 2017

MFAS source: 15-element vertical line array projecting simulated 53C MFAS deployed to 20m depth from *F/V Kahuna* (stationary)

MFAS signal parameters: Three-segment, 1.2s duration pings; 25s repetition rate (as in Southall et al. (2012) for SOCAL-BRS)

MFAS source level: 212 dB re 1 μPa (RMS) sound pressure level (hereafter dB SPL)

CEE transmission START time and location: 1441 EDT (1841Z) at 35.548; -74.770

CEE transmission END time and location: 1445 EDT (1855Z) at 35.564; -74.791

Tagged individuals being monitored during CEE (monitoring method)

<u>*Beaked whales*</u>:

Zc60 (SPLASH-10A satellite tag)

Zc61 (SPLASH-10A satellite tag)

Zc62 (SPLASH-10A satellite tag)

Zc63 (SPLASH-10A satellite tag)

Zc64 (SPLASH-10A satellite tag)

Zc65 (SPLASH-10A satellite tag; deployed on 22 Aug ~1.5h prior to CEE)

Zc17_234a (focal individual with DTAG3 deployed 1110 EDT (1510Z); focal follow during CEE)

<u>*Pilot whales*</u>:

Gm181 (SPLASH-10A satellite tag)

Gm182 (SPLASH-10A satellite tag; focal follow during CEE – in group with DTAGed Gm17_234a)

Gm183 (SPLASH-10A satellite tag)

Gm17_234a (focal individual with DTAG3 deployed 1148 EDT (1548Z); focal follow during CEE within same group as Gm182)

Once the decision was made to switch from the potential real sonar MFAS CEE with the USS GRAVELY to a simulated sonar CEE, propagation modeling was conducted in situ based on real time focal follow positions of Zc17_234a and Gm17_234a. The objective was to achieve RLs from a stationary position relative to both individuals that met the received level (RL) objectives of up to 130 dB SPL for beaked whales and up to 160 dB SPL for pilot whales. Given the dynamic nature of the focal individuals and with cognizance of the presence of the additional nine tagged individuals (one being Gm182 who was in the same focal group of six total pilot whales along with Gm17_234a), RL modeling was conducted using the acoustic propagation planning tool developed by the Naval Postgraduate School (NPS) for the SOCAL-BRS project and adapted for the Atlantic-BRS. Several received depths were modeled to evaluate potential variability in the sound field as a function of vertical movement. The resulting propagation results for 100m (which indicated maximum RL values of those modeled) that were used in determining the position of the *F/V Kahuna* with the sound source are shown below for Zc17_234a (**Figure 2**) and Gm17_234a (**Figure 3**).

The propagation model results predicted that for the source location selected for the *F/V Kahuna*, received levels would vary as a function of depth, but maximum values would be ~131 dB SPL for Zc17_234a and ~146 dB SPL for Gm17_234a. This location was selected as a reasonable balance between the two focal individuals and with cognizance of the estimated recent locations of the satellite tagged animals. Clearly these have associated error (discussed more in detail below) as evidenced by the presumed location of Gm182 relative to Gm17_234a at the time of the CEE. These animals were within several body lengths of one another but using the available most recent ARGOS position, it would have been presumed to be ~10 km to the north. The available information at the time of the CEE regarding the location of tagged areas in the nearby area where this CEE was likely audible are shown below (**Figure 4**).

Once the DTAGs were recovered and analyzed, pseudotracks of the movement of both focal animals were derived using a Bayesian melding method that integrates the tag movement sensor data with fixed known surface positions from focal follow observations from the following RHIB. These tracks are shown for periods before, during, and after the CEE occurred for both Zc17_234a and Gm17_234a relative to the sound source location (**Figure 5**).

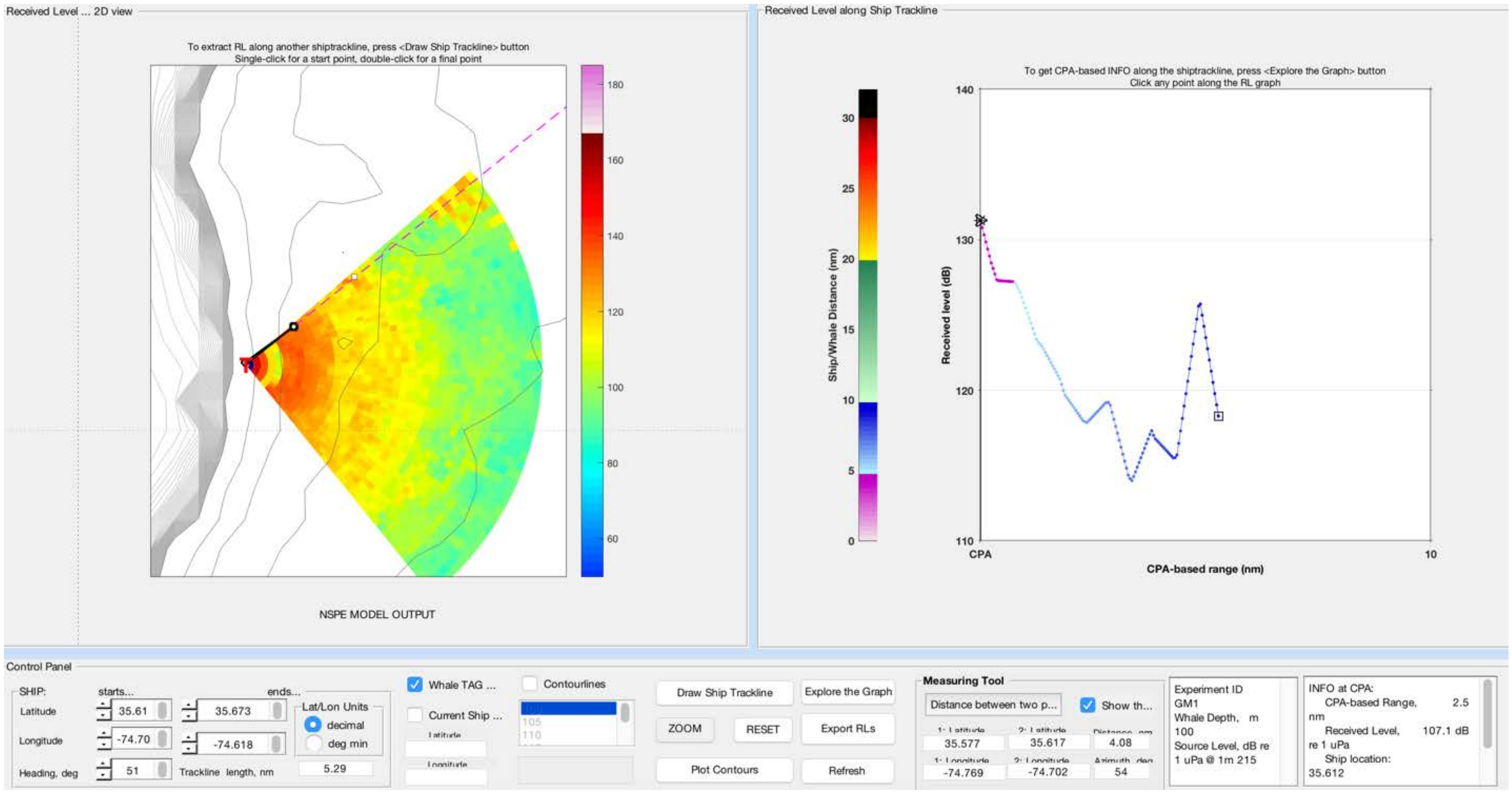

Figure 2. Modeled received levels for Zc17_234a (at location indicated by T) at 100m depth from *in situ* acoustic propagation assuming the *F/V Kahuna* at starting source location selected for CEE#2017-01 (35.548; -74.770).

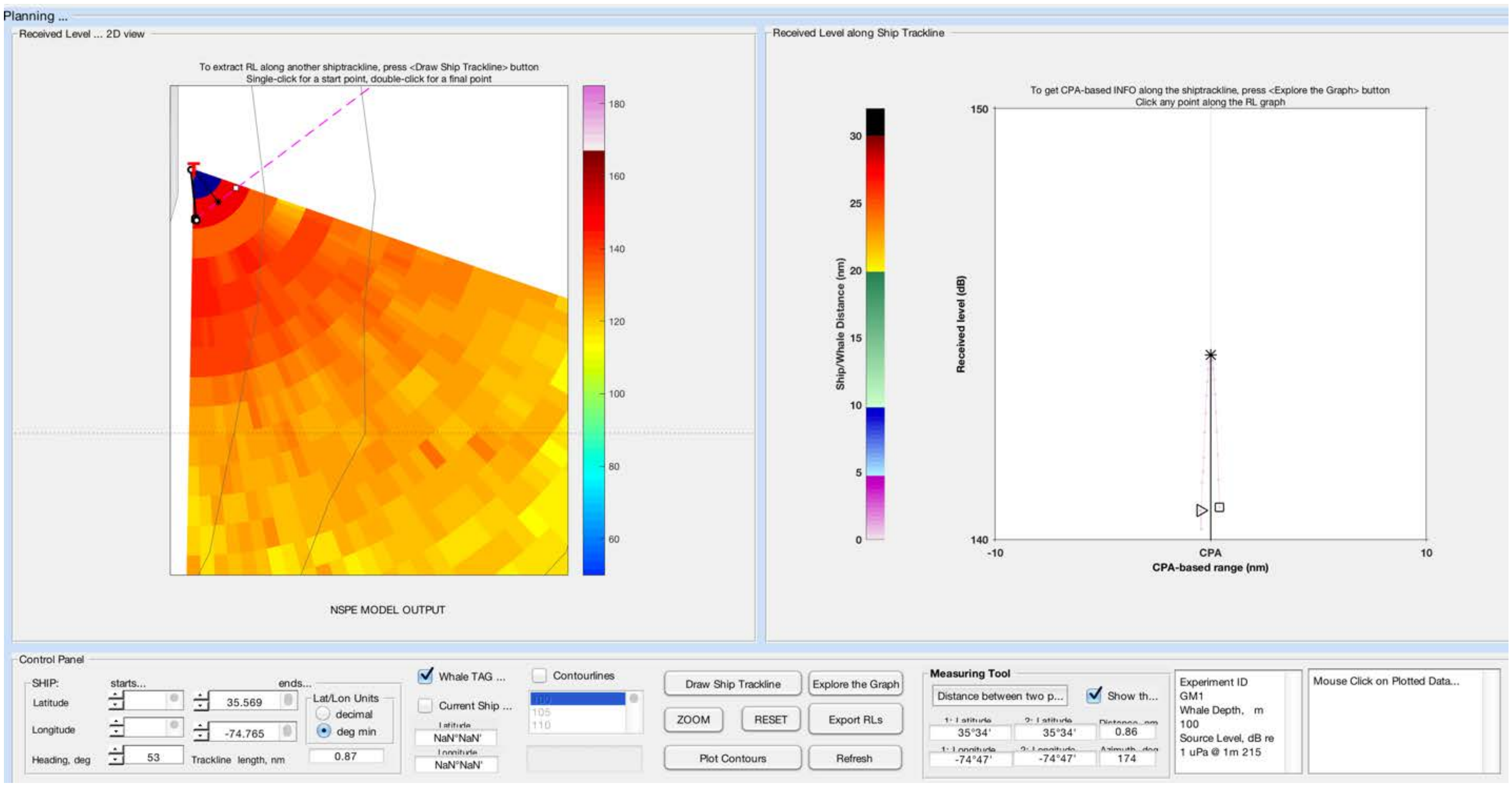

Figure 3. Modeled received levels for Gm17_234a (at location indicated by T) from *in situ* acoustic propagation assuming the *F/V Kahuna* at starting source location selected for CEE#2017-01 (35.548; -74.770).

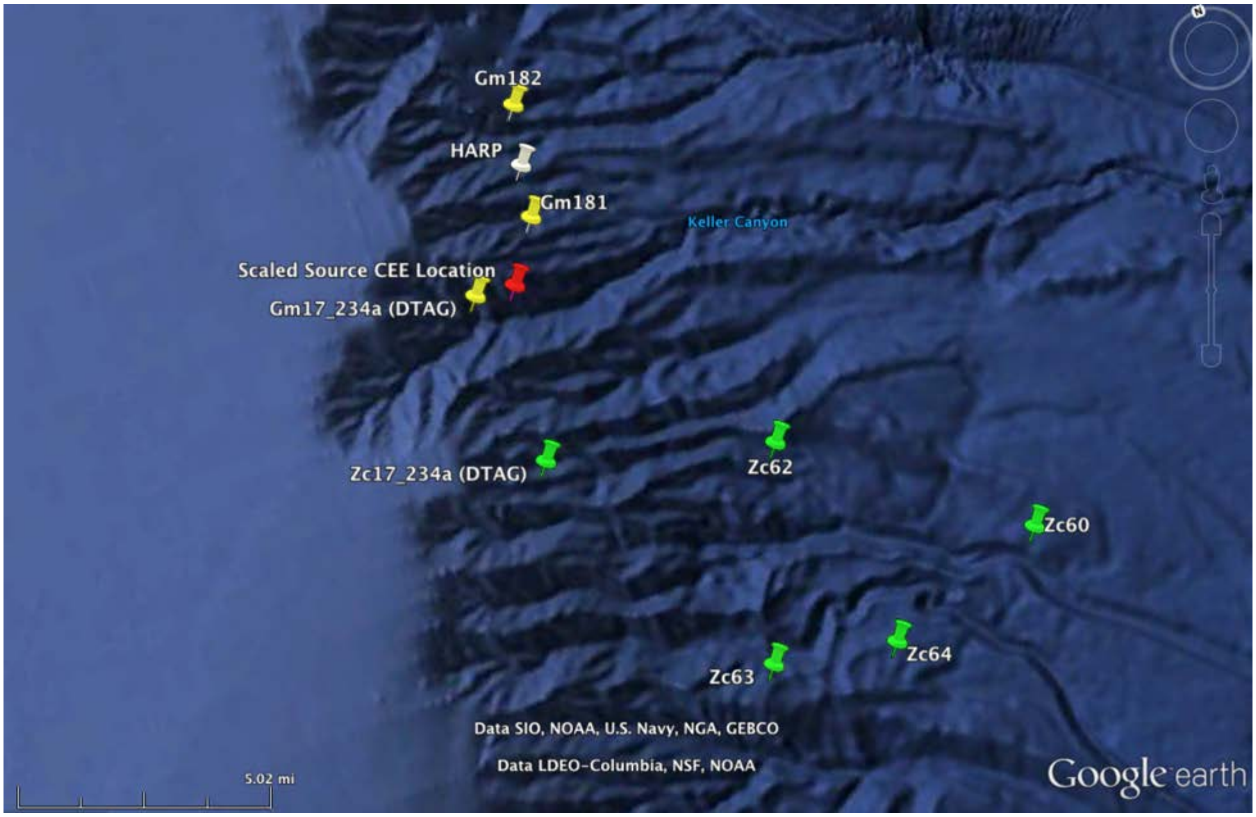

Figure 4. Approximate locations (most recent raw ARGOS position of class code 0 or higher for satellite-tagged individuals and known focal-follow positions for DTAG-ed individuals) for tagged beaked whales (green) and pilot whales (yellow) relative to simulated (scaled) MFAS experimental source during Atlantic-BRS CEE #2017-01 conducted on 22 August 2017.

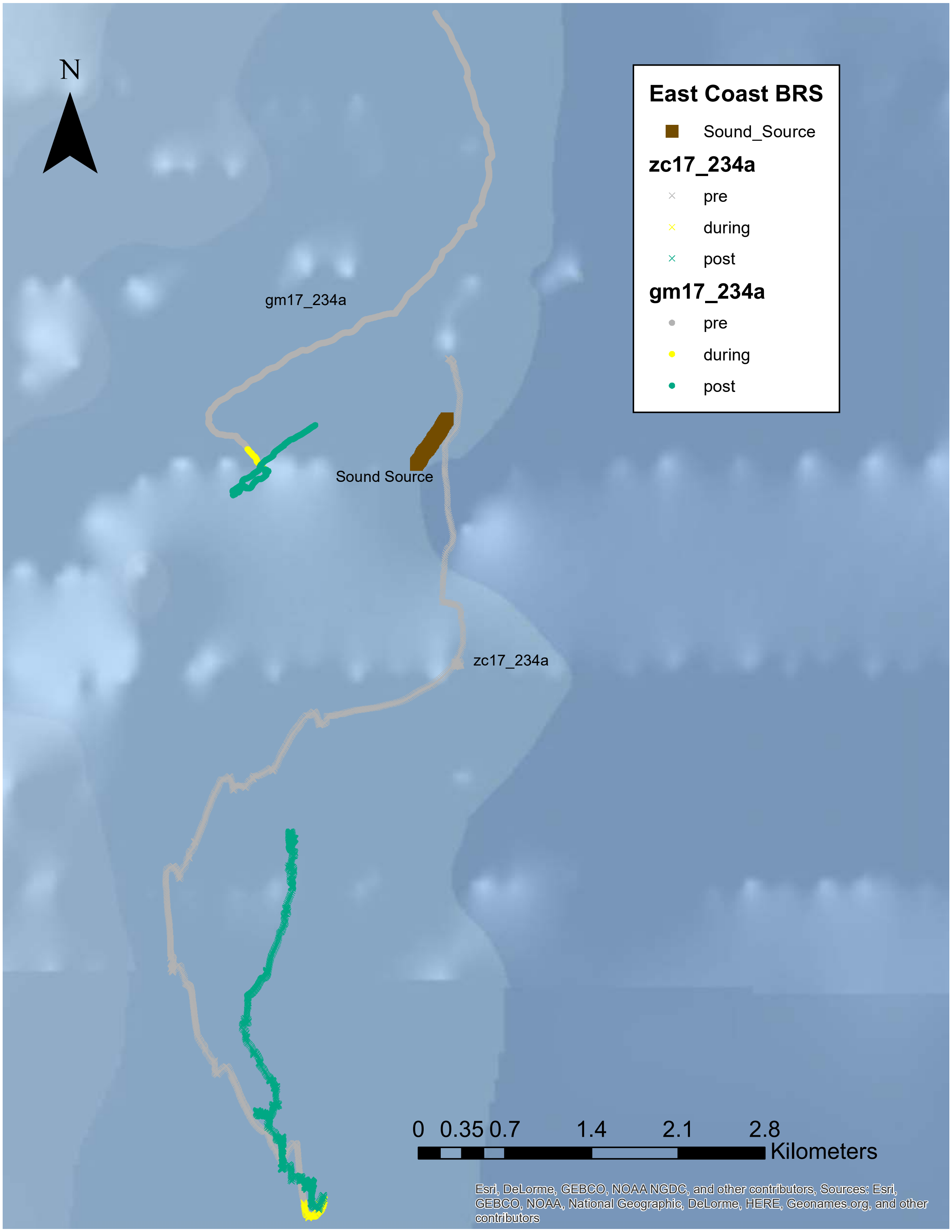

Figure 5. Corrected pseudotracks of beaked whale Zc17_234a and pilot whale Gm17_234a tagged beaked whales before (pre: gray), during (yellow), and after (post: green) during Atlantic-BRS CEE #2017-01 conducted on 22 August 2017.

Three-dimensional movement and received acoustic data from the DTAGs were analyzed to describe diving behavior of individuals and calibrated RLs at the focal animals. There were 32 pings identified on both tag records during the ~14 min transmission). Received levels (3.4 kHz center frequency) are given (**Figures 6-11** and **Table 5** for Gm17_234a and **Figures 12-17** and **Table 6** for Zc17_234a) as dB (RMS) SPL, dB peak SPL, signal-to-noise ratio SNR) within the 3.4 kHz center frequency 1/3rd-oct band containing the exposure stimulus), peak SPL RLs, and sound exposure levels (SEL in dB re 1µPa2-s) for each individual.

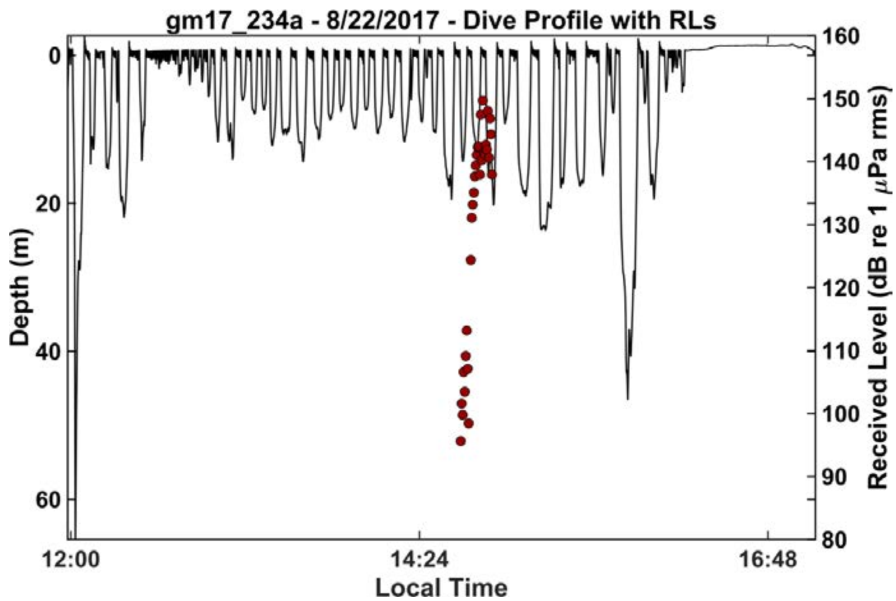

Figure 6. Dive profile with received MFAS signal levels (dB SPL) for pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01.

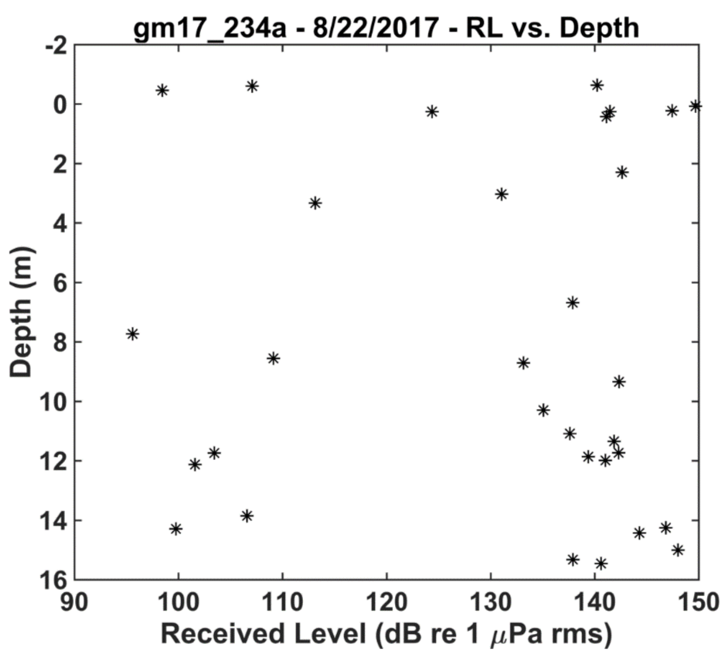

Figure 7. Received MFAS signal levels (dB SPL) as a function of depth for pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01.

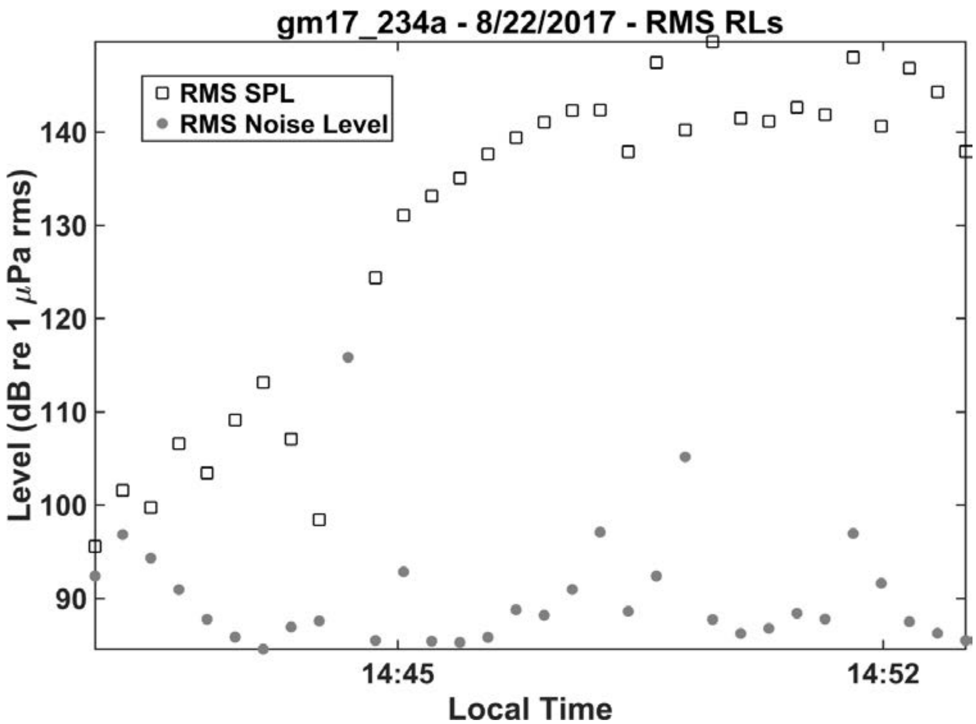

Figure 8. Received MFAS signal levels (dB SPL) relative to 1/3rd-oct band noise levels for pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01.

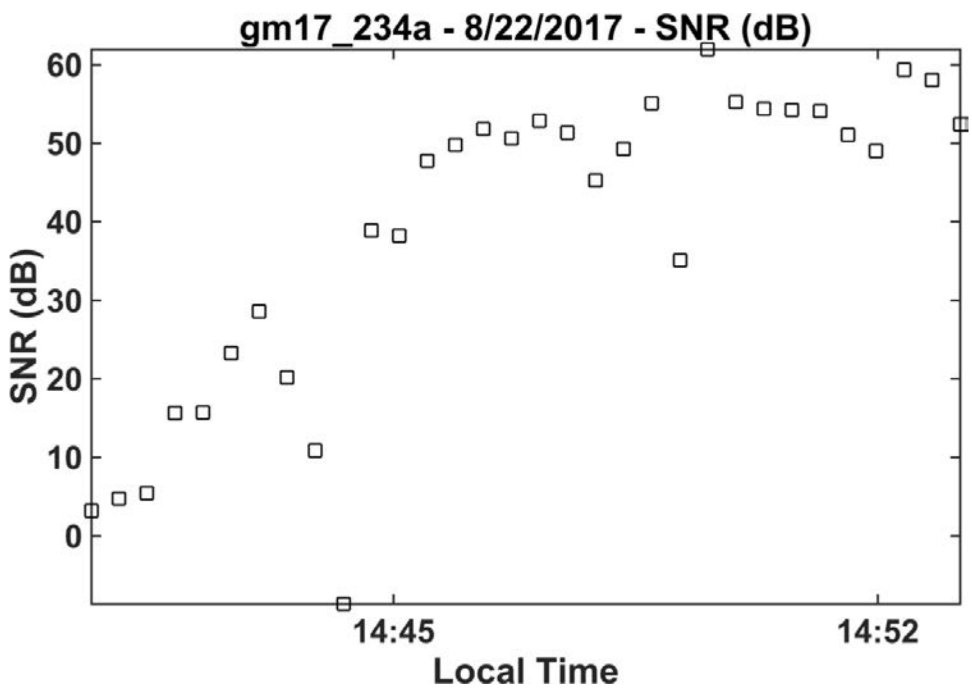

Figure 9. Signal-to-noise ratios (SNR) for each MFAS exposure for pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01.

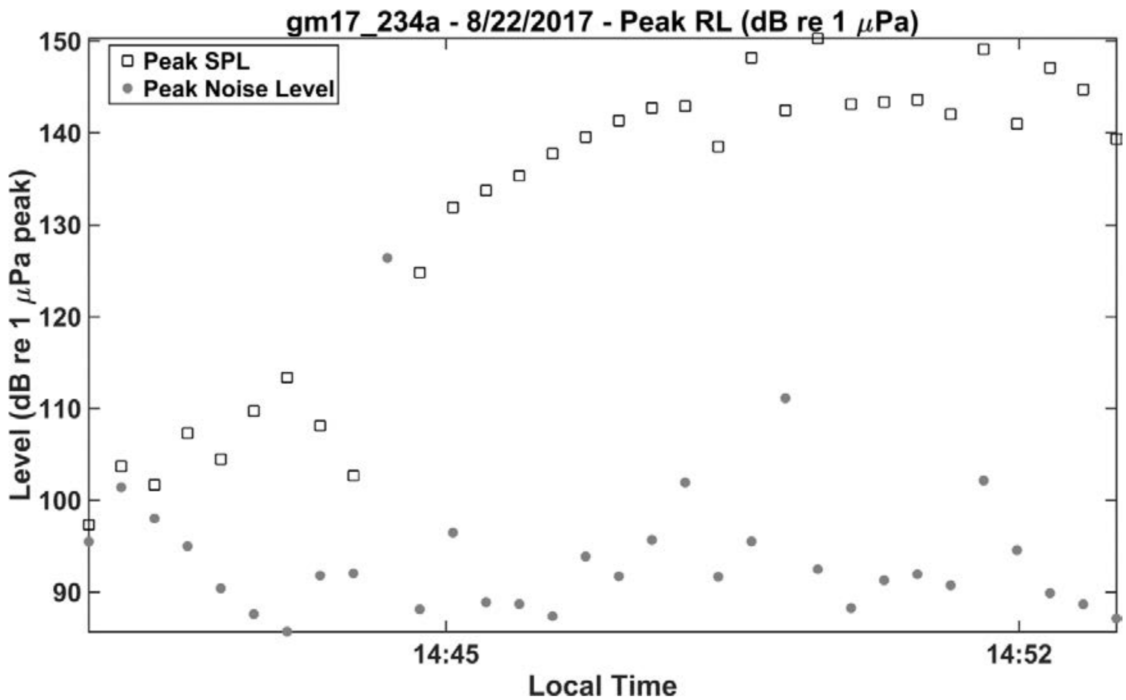

Figure 10. Received MFAS signal levels (peak SPL) for pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01.

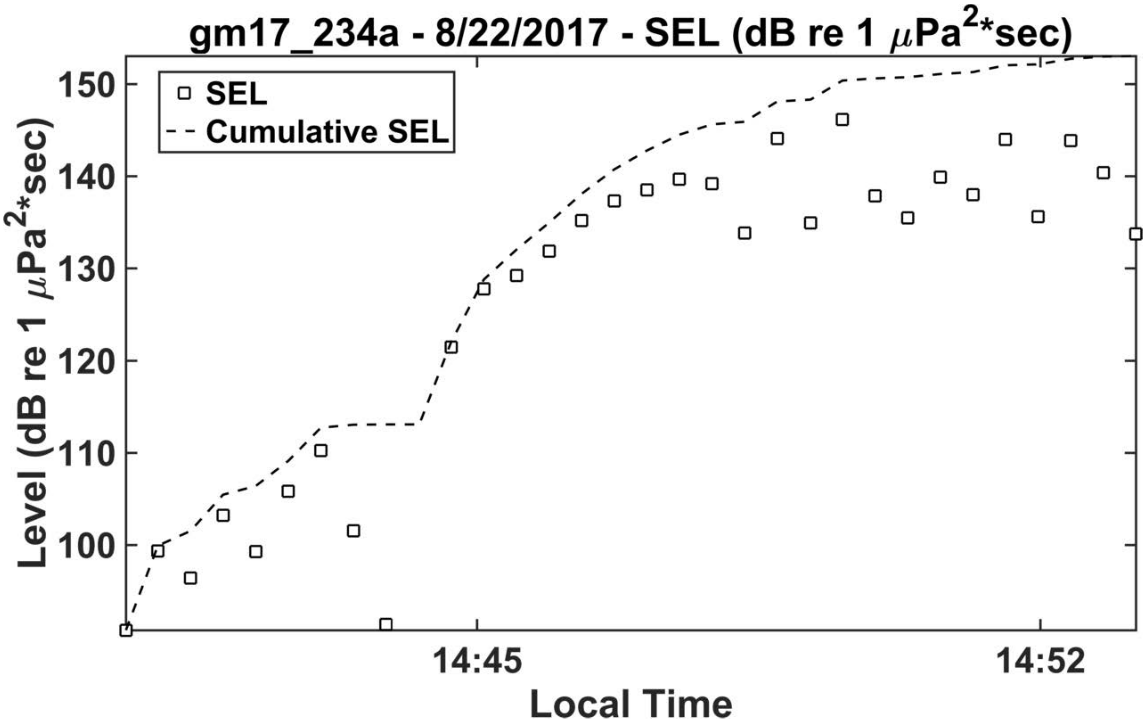

Figure 11. Received MFAS signal levels (per ping and cumulative sound exposure level (SEL)) for pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01.

Table 5. Measured received levels for each MFAS ping received by pilot whale Gm17_234a during Atlantic-BRS CEE #2017-01. Note: the maximum RL predicted from *a priori* propagation modeling conducted in situ was ~146 dB SPL, compared with the calibrated maximum value of 149.6 dB SPL measured on the tag.

SPL_rms	SPL_Peak	SNR
95.59045	97.34617	3.195524
101.5811	103.7108	4.733275
99.75697	101.663	5.432059
106.5796	107.2852	15.61552
103.4531	104.4718	15.68476
109.1377	109.7292	23.27478
113.1507	113.3585	28.59546
107.0822	108.1245	20.14735
98.43571	102.6718	10.85123
NaN	NaN	-8.64383
124.3744	124.797	38.87956
131.0612	131.9045	38.19584
133.1645	133.7176	47.74794
135.0711	135.3164	49.77125
137.6234	137.7363	51.79757
139.3815	139.5191	50.59995
141.0273	141.3423	52.83235
142.296	142.7213	51.32022
142.351	142.9112	45.24833
137.886	138.4961	49.27061
147.4466	148.1829	55.04477
140.2406	142.4552	35.08357
149.6984	150.2725	61.95469
141.4674	143.1163	55.22508
141.1436	143.3668	54.35569
142.6382	143.5904	54.22586
141.8671	142.0256	54.08538
148.0147	149.104	51.06477
140.6202	140.9834	48.99923
146.8423	147.1021	59.32941
144.2996	144.7139	58.0278
137.9141	139.3175	52.41667

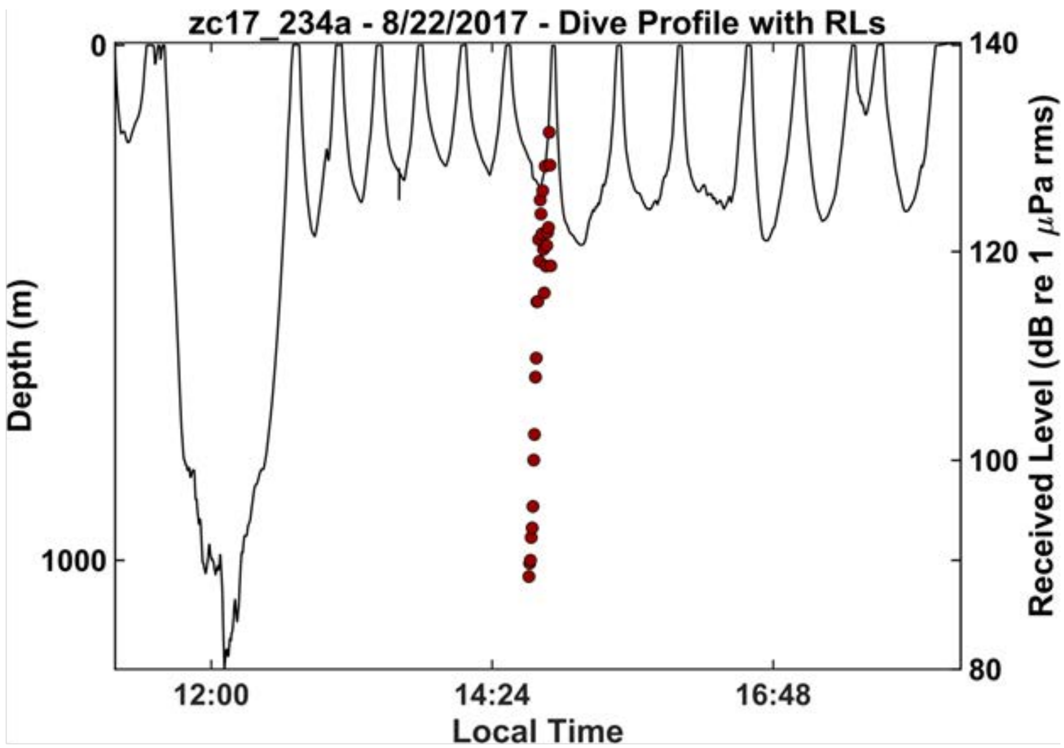

Figure 12. Dive profile with received MFAS signal levels (dB SPL) for beaked whale Zc17_234a during Atlantic-BRS CEE #2017-01.

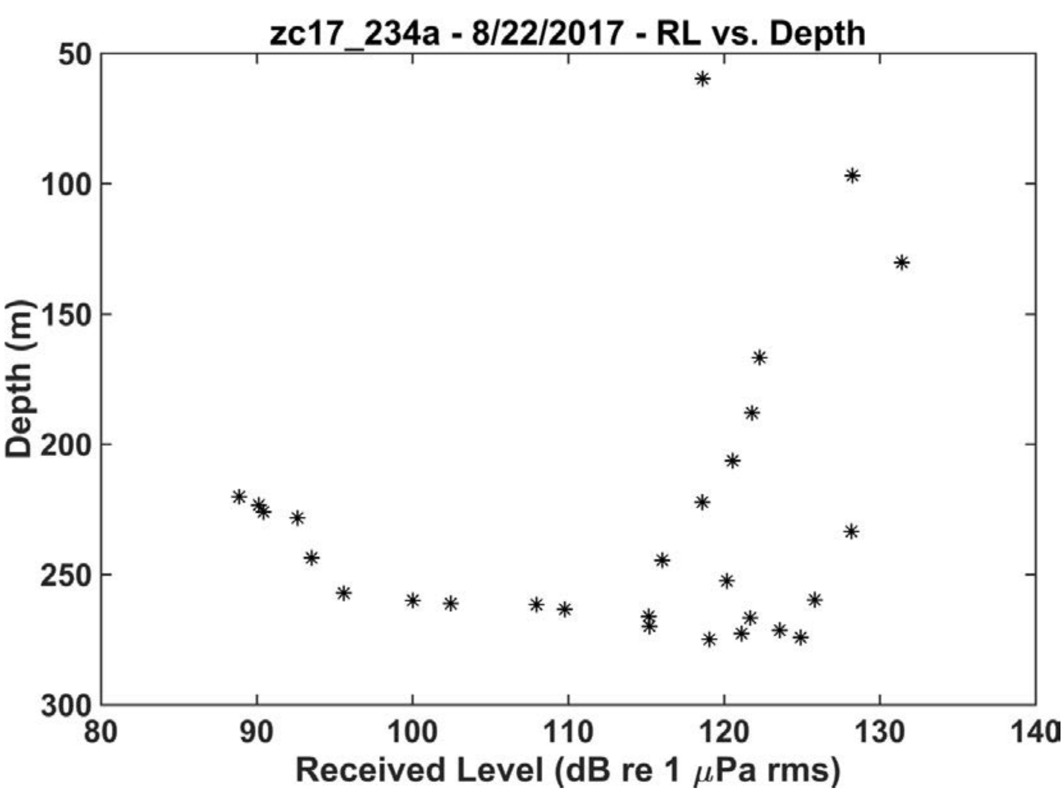

Figure 13. Received MFAS signal levels (dB SPL) as a function of depth for pilot whale Zc17_234a during Atlantic-BRS CEE #2017-01.

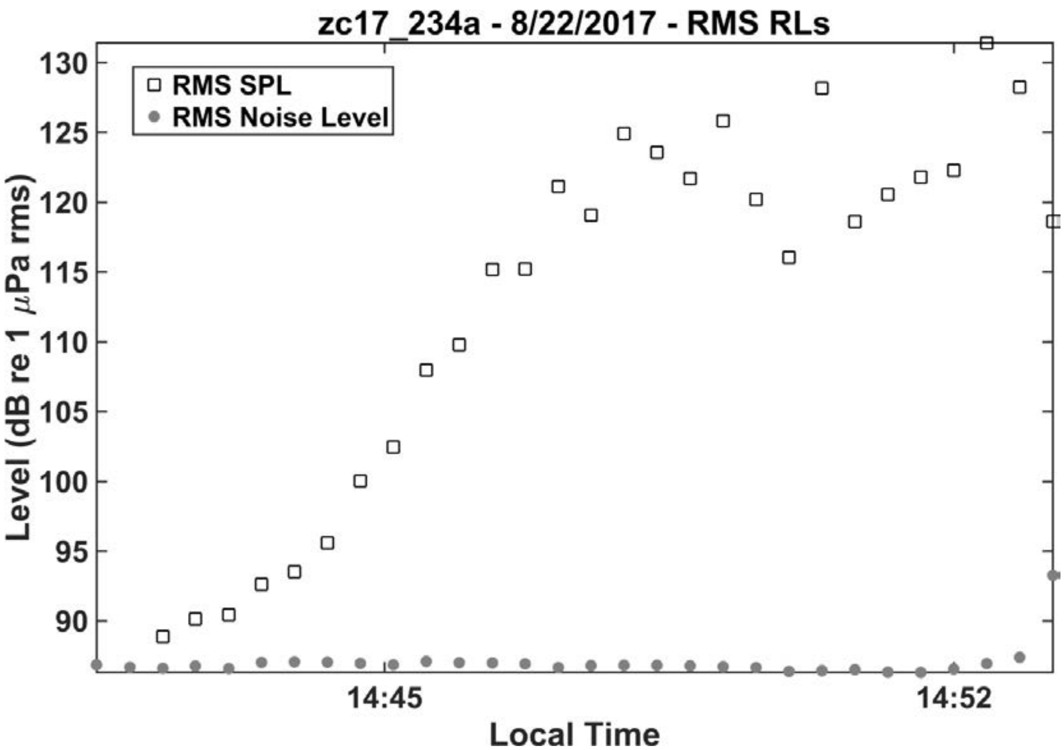

Figure 14. Received MFAS signal levels (dB SPL) relative to 1/3rd-oct band noise levels for pilot whale Zc17_234a during Atlantic-BRS CEE #2017-01.

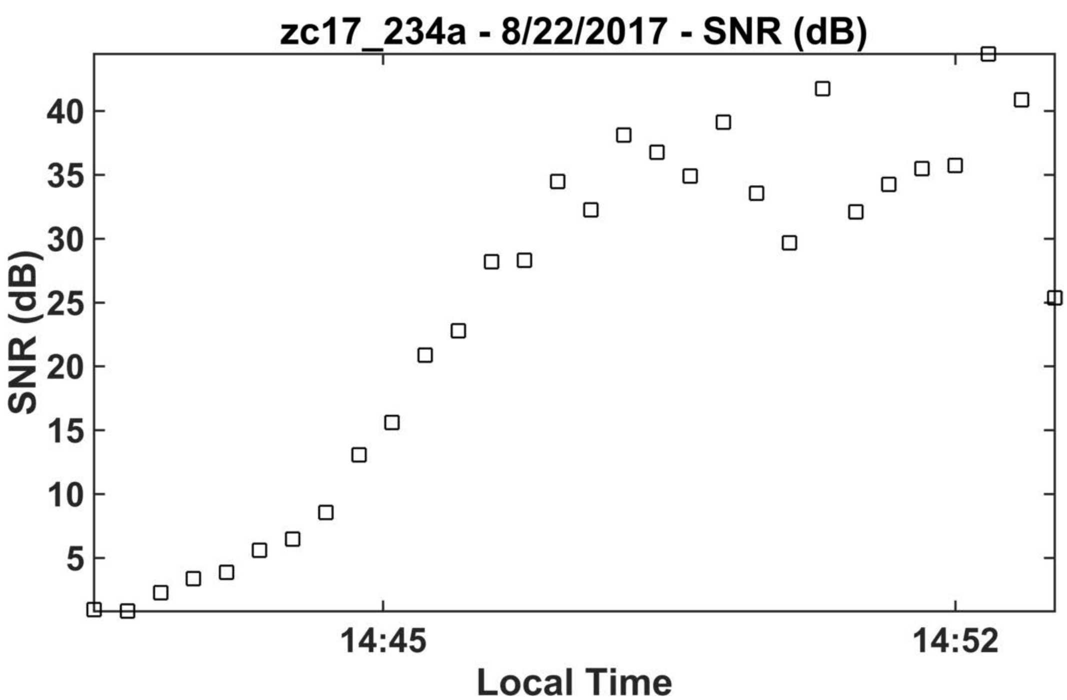

Figure 15. Signal-to-noise ratios (SNR) for each MFAS exposure for pilot whale Zc17_234a during Atlantic-BRS CEE #2017-01.

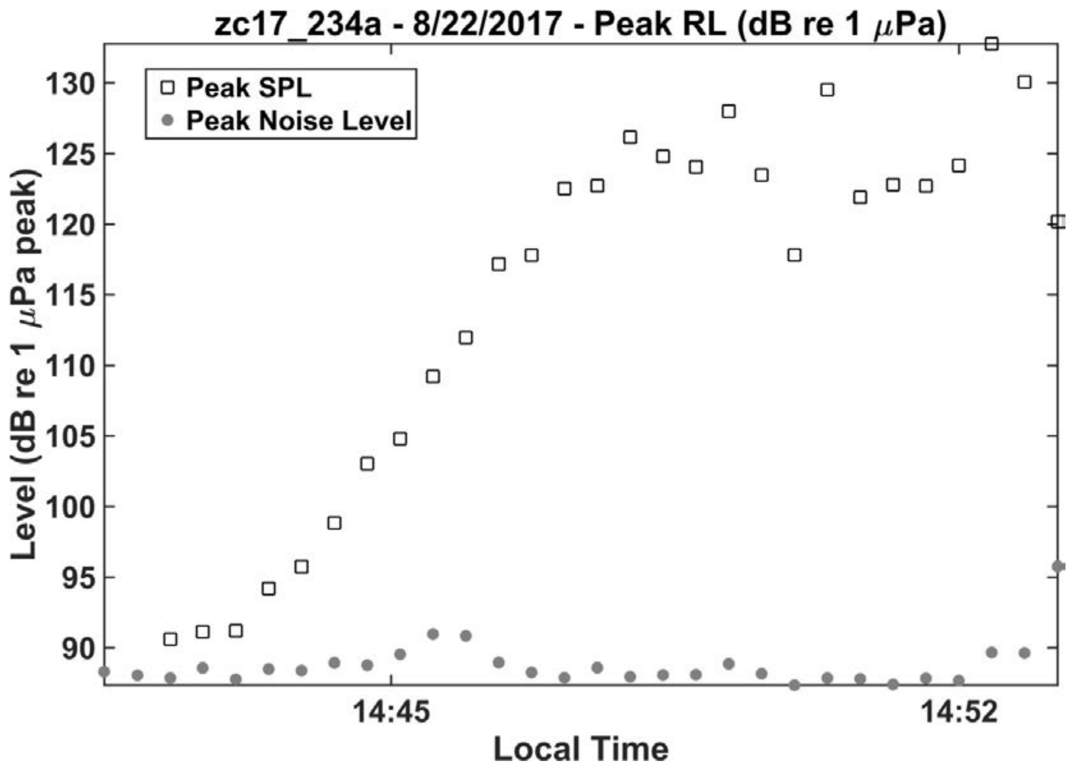

Figure 16. Received MFAS signal levels (peak SPL) for pilot whale Zc17_234a during Atlantic-BRS CEE #2017-01.

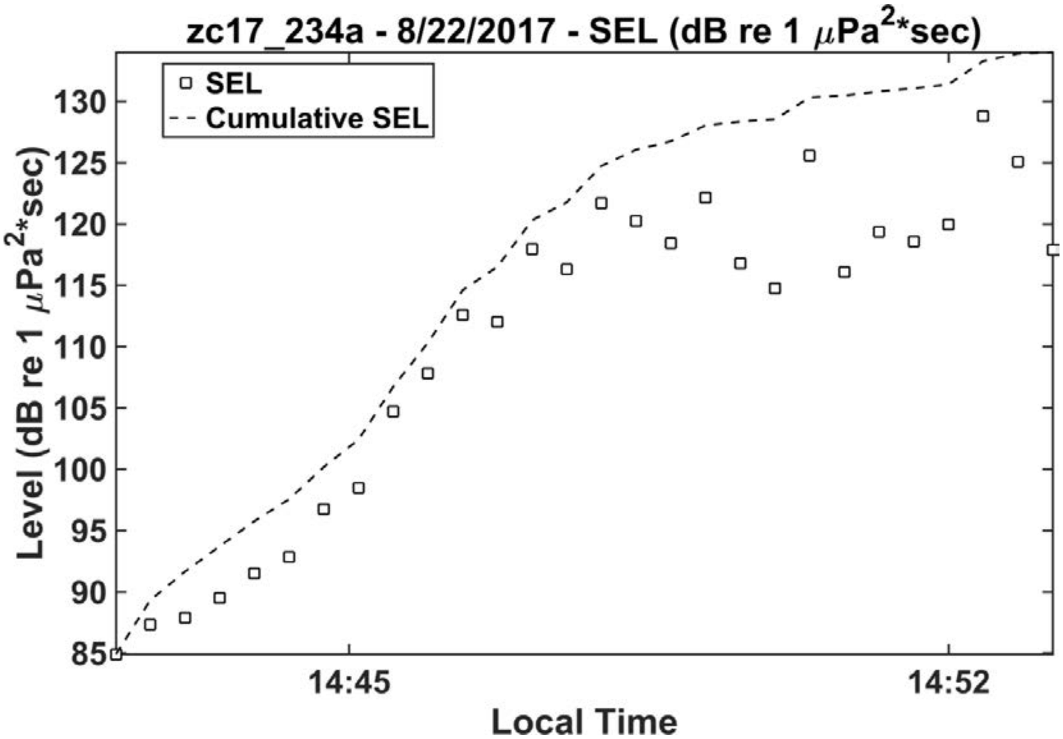

Figure 17. Received MFAS signal levels (per ping and cumulative sound exposure level (SEL)) for pilot whale Zc17_234a during Atlantic-BRS CEE #2017-01.

Table 6. Measured received levels for each MFAS ping received by beaked whale Zc17_234a during Atlantic-BRS CEE #2017-01. Note: the maximum RL predicted from *a priori* propagation modeling conducted in situ was ~131 dB SPL, compared with the calibrated maximum value of 131.4 dB SPL measured on the tag.

SPL_rms	SPL_Peak	SNR
NaN	NaN	0.941466
NaN	NaN	0.823685
88.86682	90.60222	2.279934
90.13648	91.12174	3.377947
90.42565	91.20559	3.853222
92.60798	94.18077	5.589983
93.51776	95.73056	6.466367
95.59203	98.83739	8.552909
100.0276	103.021	13.07151
102.458	104.7912	15.60794
107.9592	109.208	20.86649
109.7768	111.9642	22.77856
115.1702	117.1649	28.18738
115.2163	117.7851	28.29376
121.1198	122.5103	34.47938
119.0541	122.7084	32.25669
124.9116	126.1559	38.10538
123.5698	124.7869	36.76635
121.672	124.0424	34.90735
125.8158	127.9868	39.11178
120.1891	123.4728	33.54943
116.0327	117.8053	29.66238
128.1724	129.5245	41.73665
118.5955	121.8863	32.09342
120.552	122.7918	34.23837
121.7913	122.6862	35.47775
122.2739	124.1534	35.73194
131.4078	132.7652	44.4675
128.2462	130.0715	40.86931
118.6197	120.1832	25.35505

For individual pilot and beaked whales monitored with satellite tags during CEE #2017-01, maps showing Douglas-filtered ARGOS positions relative to the location of the simulated (scaled) MFAS source on 22 August 2017 are provided below (**Figures 18-22**). We are currently conducting more detailed animal movement modeling based on these filtered positions that accounts for positional error in providing many potential tracks. This process and the associated RL modeling for the satellite tagged whales is described in greater detail below (**Section 3**). For several individuals (e.g., Gm183, Zc63), there were no filtered ARGOS positions for 22 August. They are consequently not shown in the simple maps here, but they will be ultimately considered separately in terms of potential broad-scale responses using the more robust geospatial analyses using movement models.

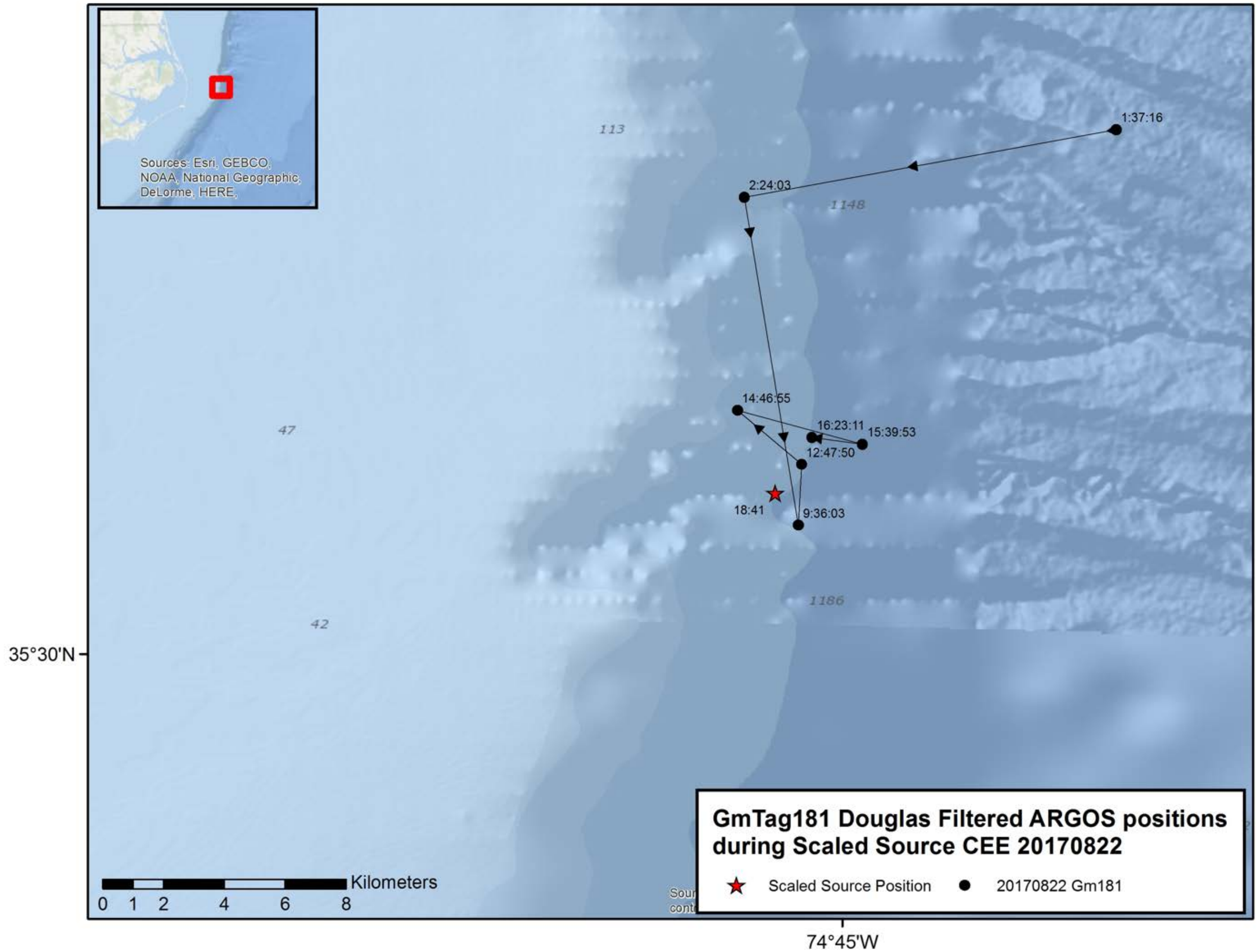

Figure 18. Map showing Douglas-filtered ARGOS positions for pilot whale Gm181 on 22 August relative to simulated (scaled) MFAS source location for Atlantic-BRS CEE #2017-01.

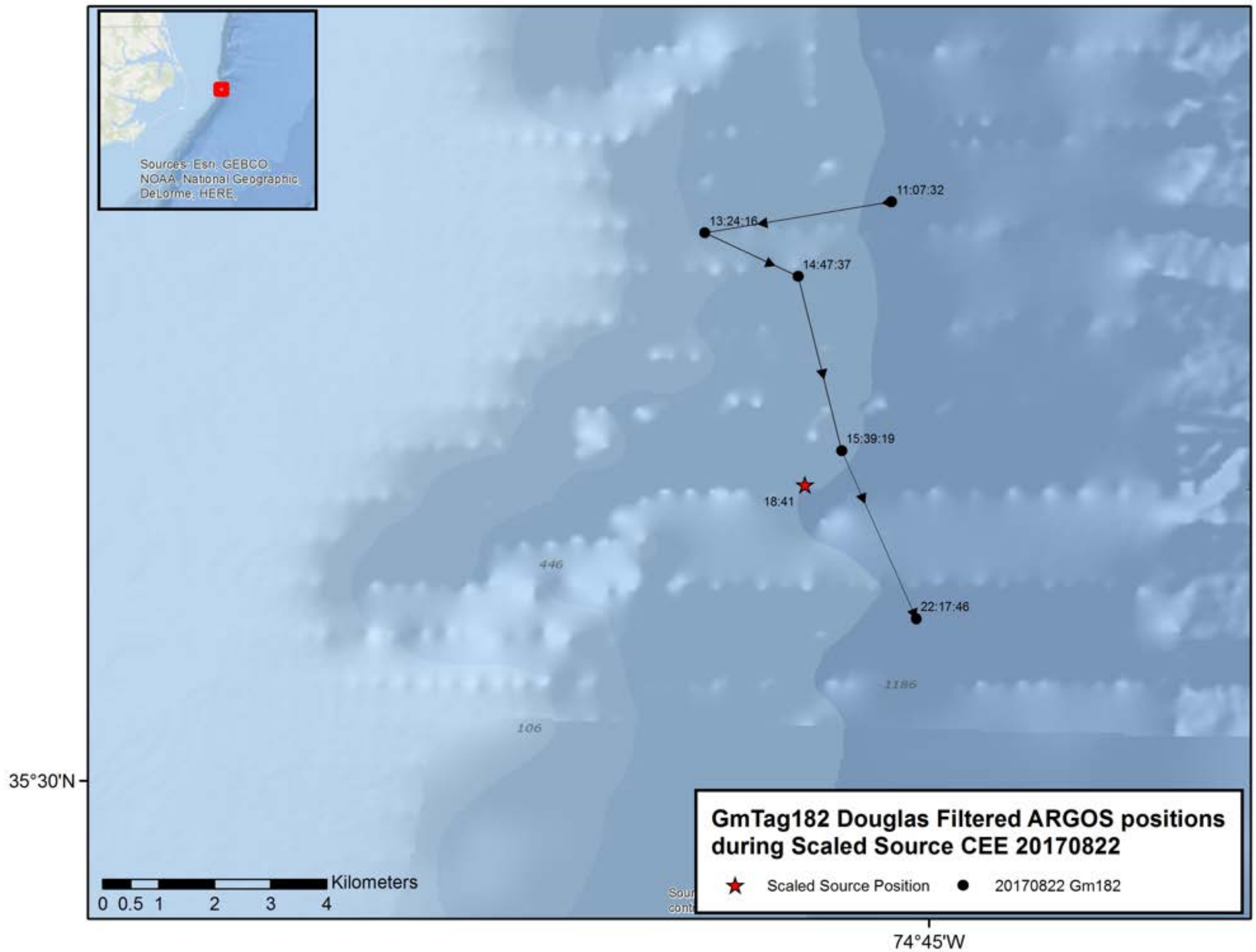

Figure 19. Map showing Douglas-filtered ARGOS positions for pilot whale Gm182 on 22 August relative to simulated (scaled) MFAS source location for Atlantic-BRS CEE #2017-01.

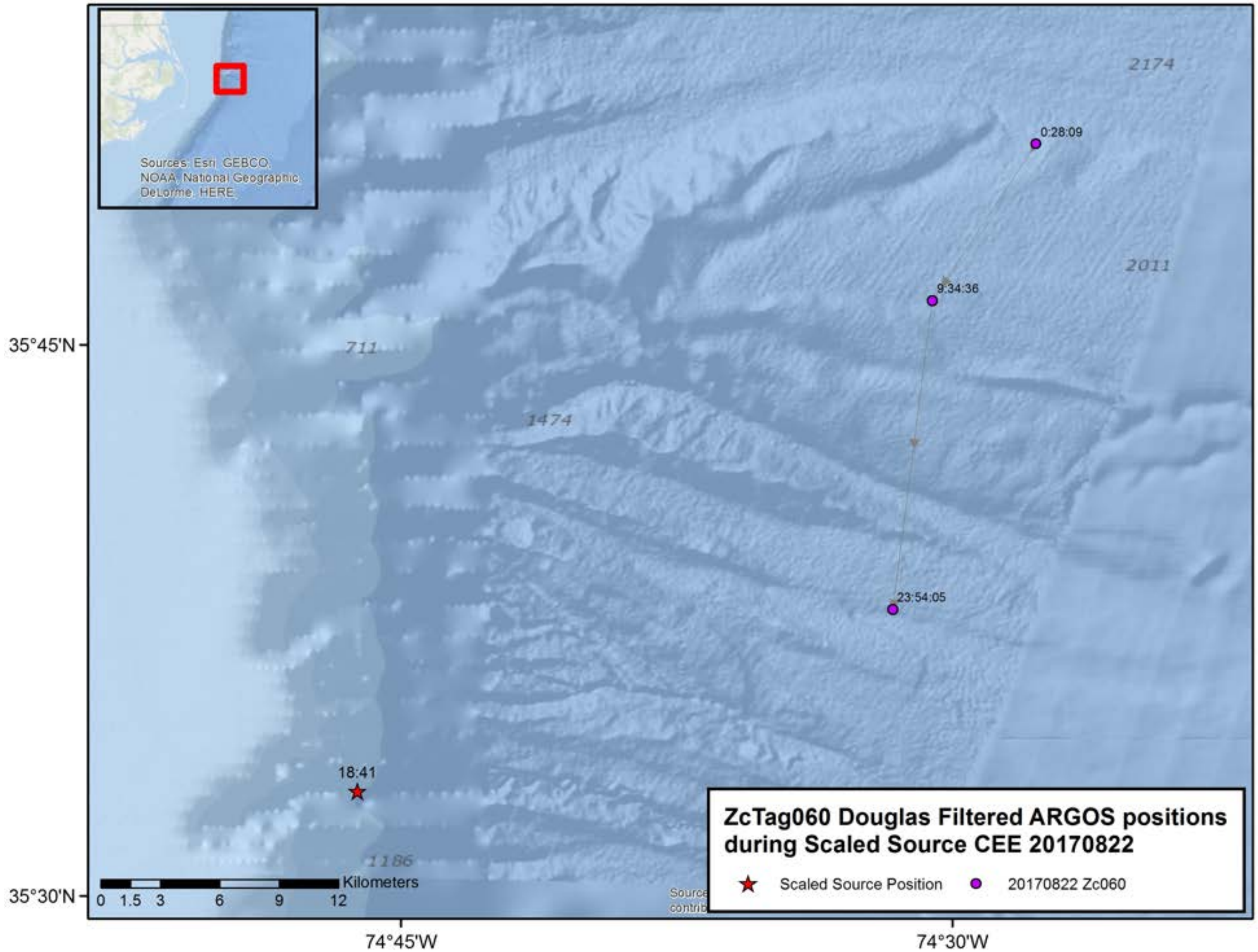

Figure 20. Map showing Douglas-filtered ARGOS positions for pilot whale Zc60 on 22 August relative to simulated (scaled) MFAS source location for Atlantic-BRS CEE #2017-01.

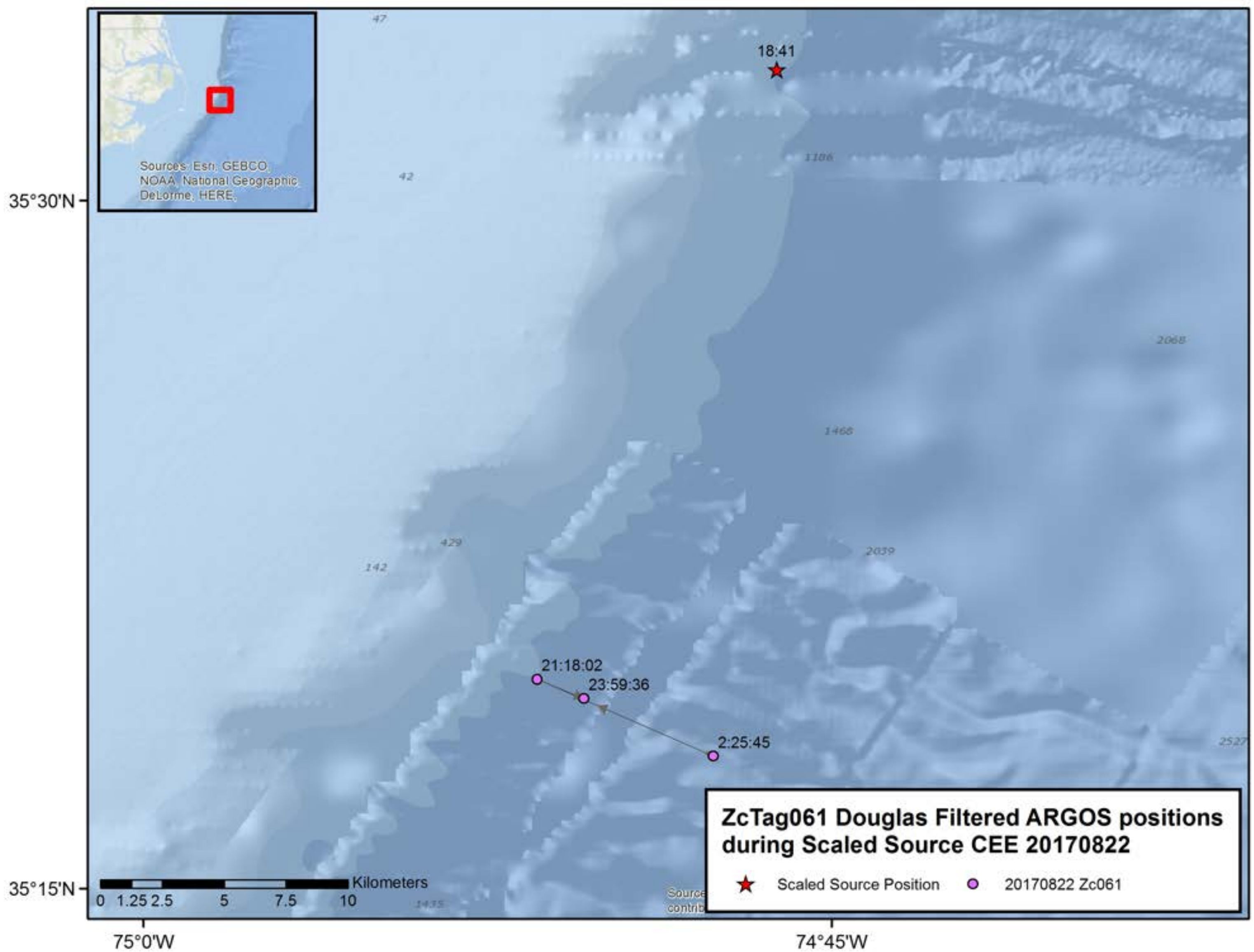

Figure 21. Map showing Douglas-filtered ARGOS positions for pilot whale Zc61 on 22 August relative to simulated (scaled) MFAS source location for Atlantic-BRS CEE #2017-01.

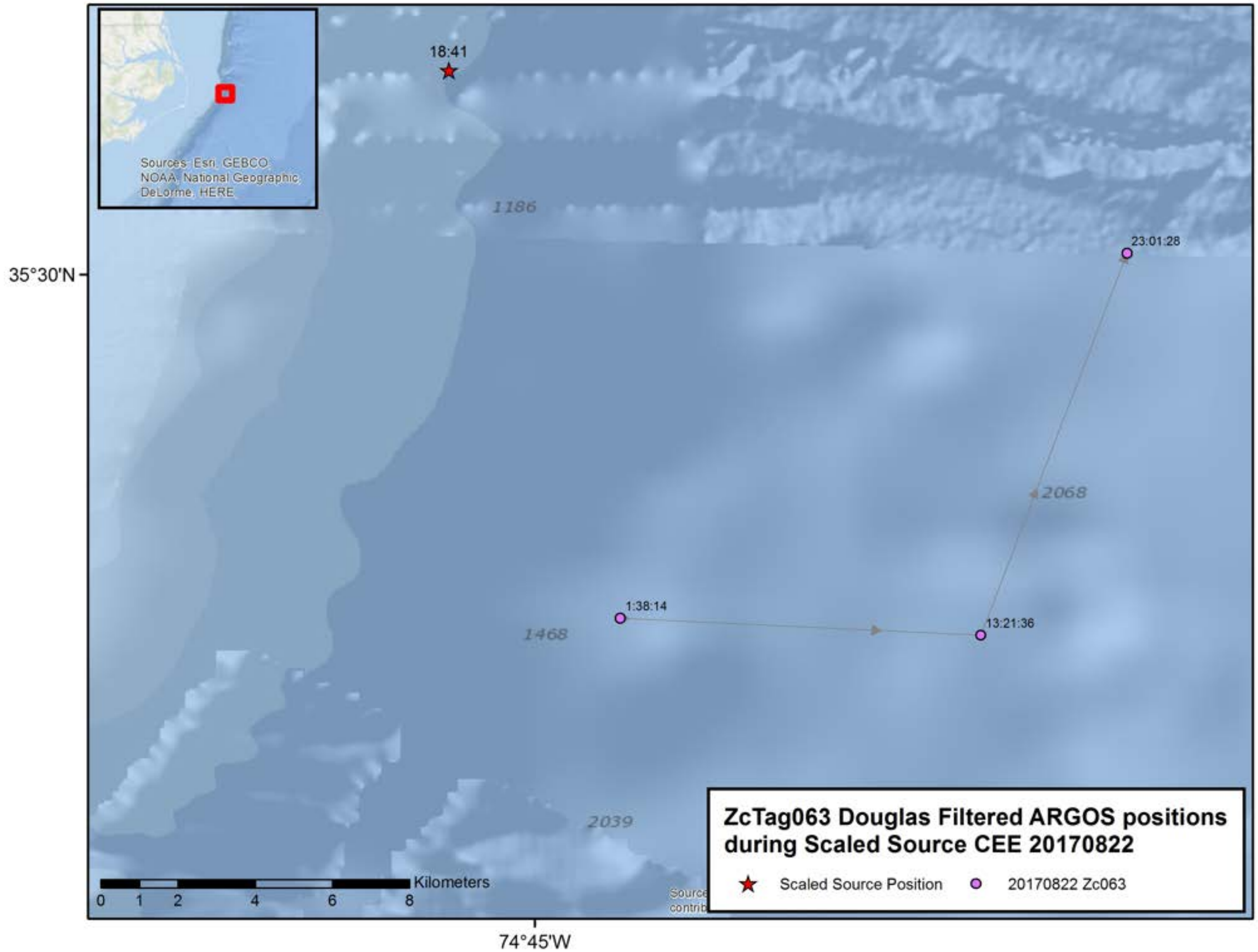

Figure 22. Map showing Douglas-filtered ARGOS positions for pilot whale Gm181 on 22 August relative to simulated (scaled) MFAS source location for Atlantic-BRS CEE #2017-01.

2.3.2 CEE #2017-02 – Full-scale 53C CEE (USS MACFAUL)

Date: 12 September 2017

MFAS source: Full-scale 53C MFAS operated by *USS MACFAUL* transiting on prescribed straight-line course at speed of 12 kt through water (8 kt over ground given measured 4 kt surface current experienced *in situ*)

MFAS signal parameters: Nominal 53C F-3 waveform, 1.5s duration pings; 25s repetition rate

MFAS source level: Nominally 235 dB re 1 µPa dB SPL

CEE transmission START time and location: 1203 EDT (1603Z) at 36.075; -74.260

CEE transmission END time and location: 1303 EDT (1703Z) at 35.950; -74.347

Tagged individuals being monitored during CEE (monitoring method)

Beaked whales:

Zc60* (SPLASH-10A satellite tag)

Zc61* (SPLASH-10A satellite tag)

Zc63* (SPLASH-10A satellite tag)

Zc64* (SPLASH-10A satellite tag)

Zc66 (SPLASH-10A satellite tag)

Zc67 (SPLASH-10A satellite tag, but transducer issues with depth data)

Zc68 (SPLASH-10A satellite tag)

Pilot whales:

Gm181* (SPLASH-10A satellite tag)

Gm182* (SPLASH-10A satellite tag)

Gm183* (SPLASH-10A satellite tag)

* Individuals also exposed to MFAS during scaled source CEE#2017-01

As noted above, field conditions during late August and September periods were negatively affected by multiple tropical storm and hurricane systems that affected large areas along the Atlantic coast. While these systems precluded small boat operations for DTAG and focal follow operations, based on the large number of satellite tagged individuals of both focal species, we pursued CEE options using these individuals. The *USS MACFAUL* was available as planned during the week of 11 September and was available to coordinate with the Atlantic-BRS project on 12 September. Extensive acoustic propagation modeling was conducted using ARGOS positions of satellite tagged individuals available on 10-12 September in order to determine an appropriate course and heading for the *MACFAUL*. Because the ship was conducting training operations to the north of the location of most of the tagged individuals off Cape Hatteras, nominal starting locations were explored to the north of the constellation of most of the tagged individuals. Modeling was conducted for all individuals, but most extensively in terms of depth differences for the individuals of each focal species (Gm182 and Zc68) that were believed (from the most recent ARGOS locations) to be closest to the nominal starting location. These individuals were considered the 'focal' individuals for this experiment in that the selection of the vessel starting location was determined most directly to attempt to achieve the experimental objectives for each species in balancing the ship location relative to their estimated positions as close to the start of the CEE as was possible. An initial nominal location for the *MACFAUL* was determined based on preliminary modeling for all individuals (**Figure 23**)

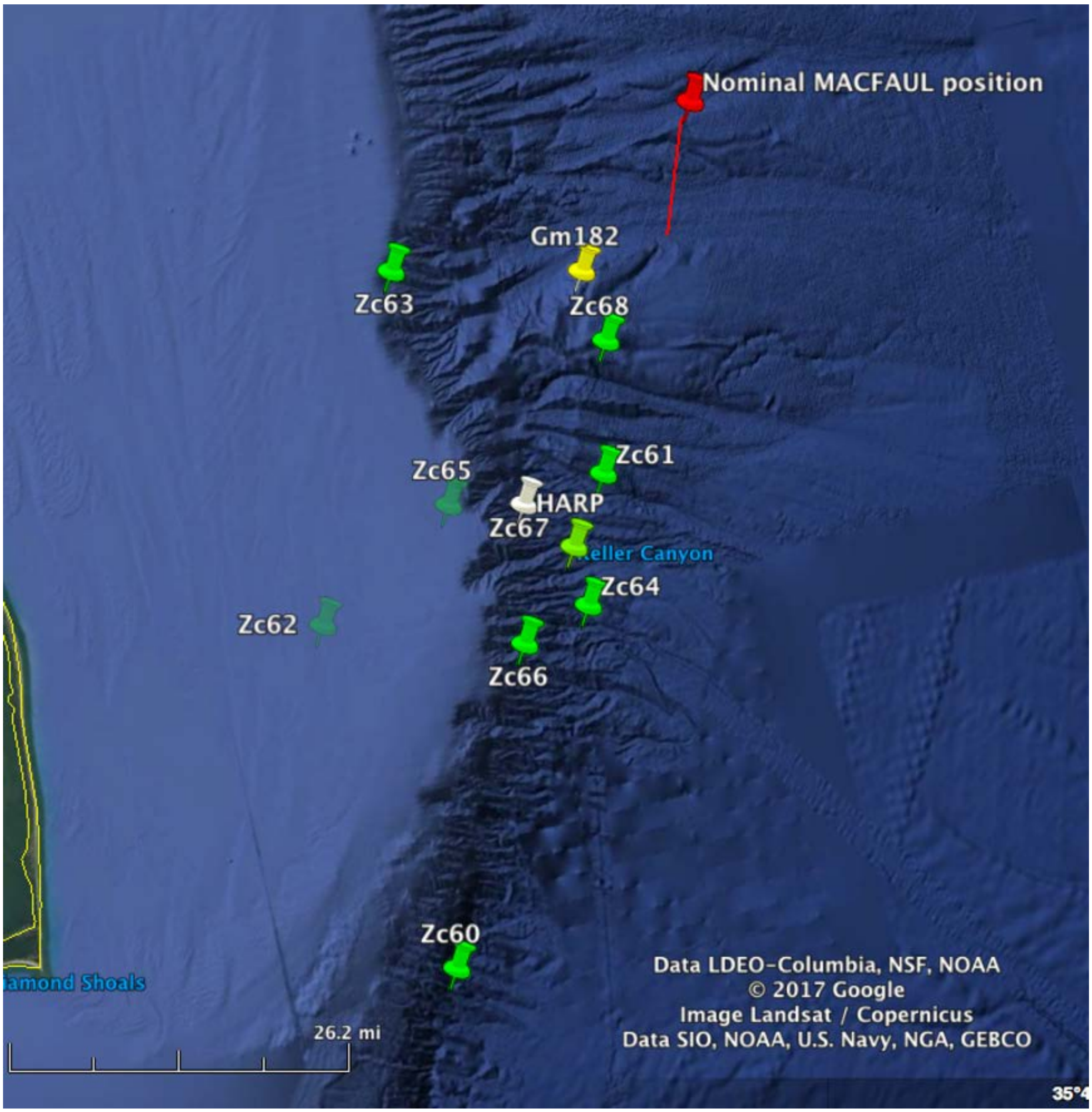

Figure 23. Initial location selected for *USS MACFAUL* position for 12 September CEE #2017-02 shown relative to most recent ARGOS locations for focal beaked whales (green) and pilot whales (yellow) in areas off Cape Hatteras.

Using these locations on 11 September, additional modeling was conducted using the NPS acoustic propagation tools. An important development of this tool from the initial version derived for the SOCAL-BRS model was the ability to access and utilize recent sound velocity profile data from a variety of observing platforms and forecast models available via the NAVSEA HYCOM database. Given the extremely dynamic nature of oceanographic conditions along the continental shelf break off Cape Hatteras where this study is occurring, this is a critical consideration, as evidenced by the modeling conducted in preparation for CEE #2017-02. Utilizing the 11 September HYCOM data within the NPS modeling tool, much higher RLs were predicted near the surface (10m) than at the depths to which the focal whales had been diving in recent dives. This is illustrated for the 'focal' individuals believed to be nearest the nominal MACFAUL start location for the CEE. This included the 'focal' pilot whale (Gm182 – see **Figures 24 and 25**) and 'focal' beaked whale (Zc68 – see **Figures 26 and 27**). Comparable patterns were observed in other individuals in other locations.

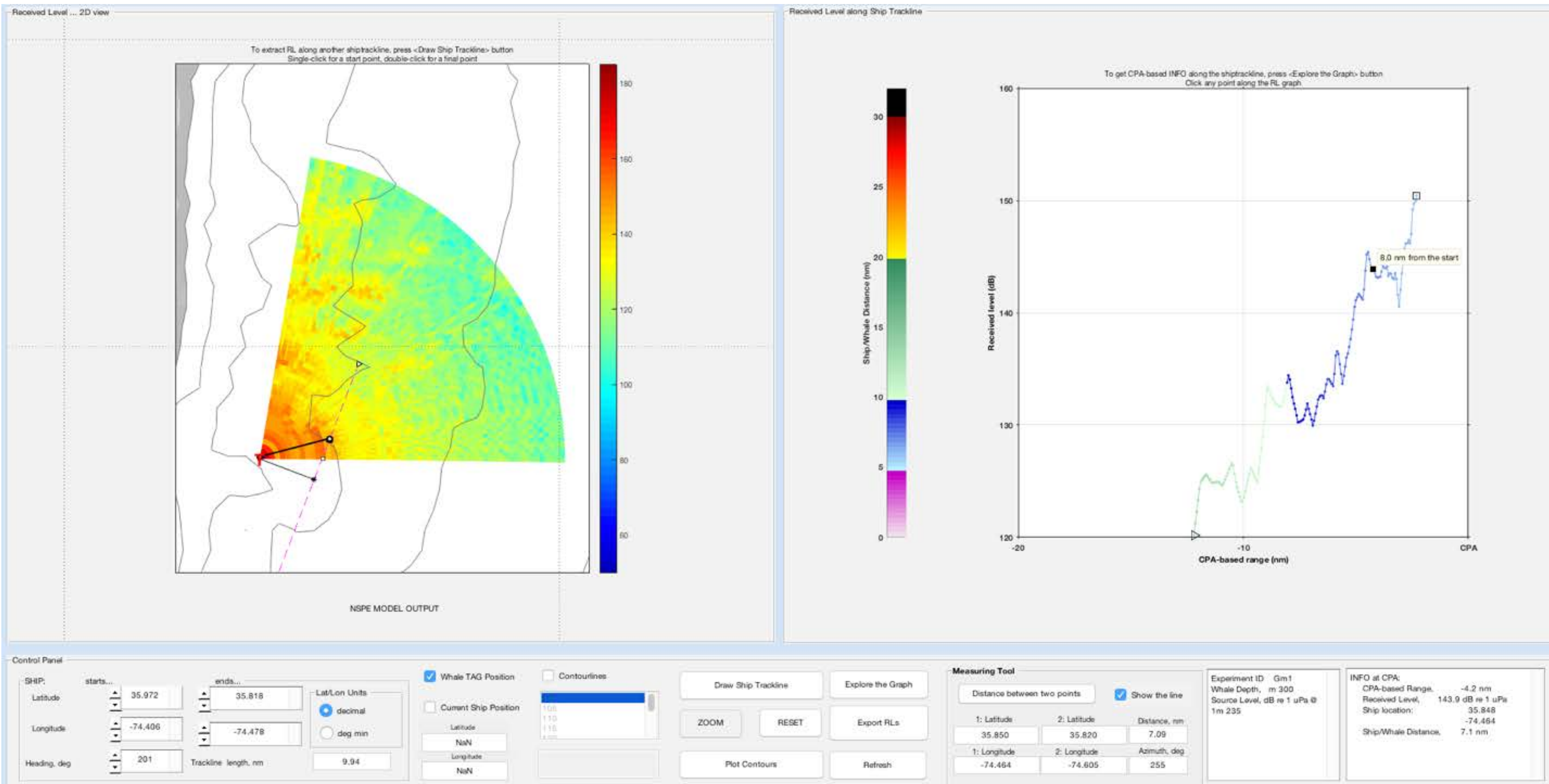

Figure 24. Modeled RLs at for Gm182 at location "T" and a depth of 300m assuming initial nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL at the closest point of approach is ~143 dB SPL.

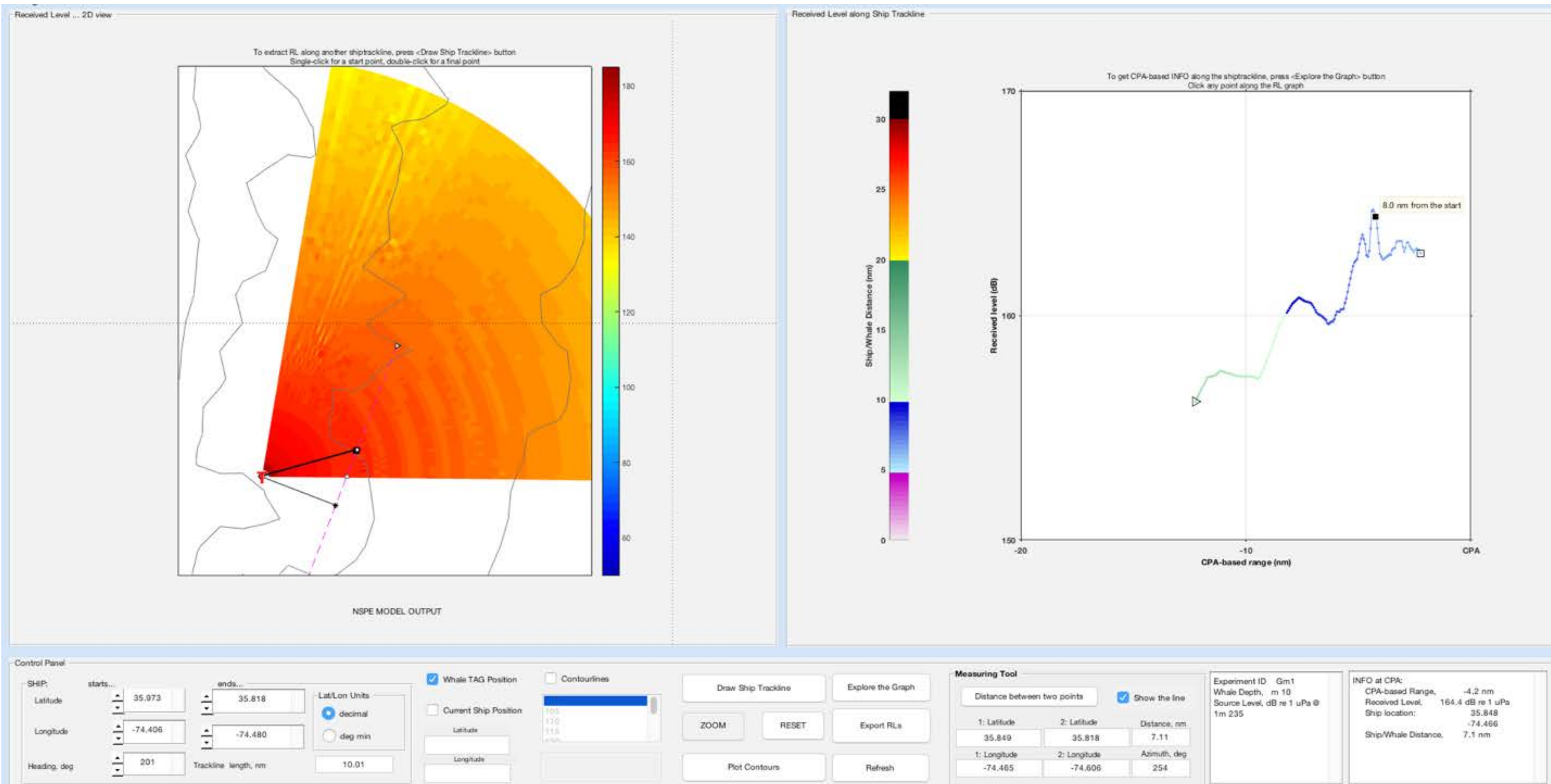

Figure 25. Modeled RLs at for Gm182 at location "T" and a depth of 10m assuming initial nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL at the closest point of approach is ~164 dB SPL.

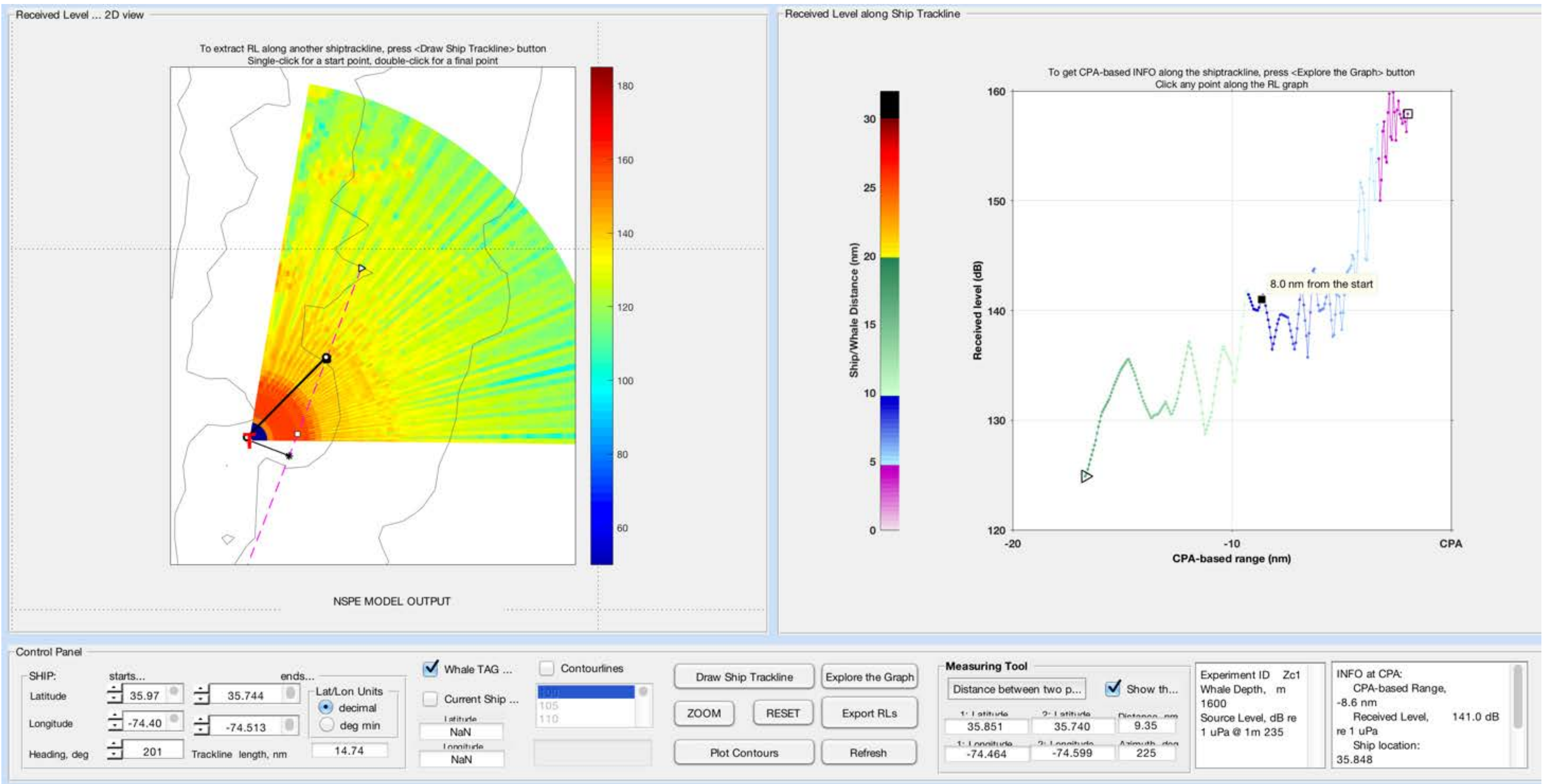

Figure 26. Modeled RLs at for Zc68 at location "T" and a depth of 1600m along initial nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL at the closest point of approach is ~141 dB SPL.

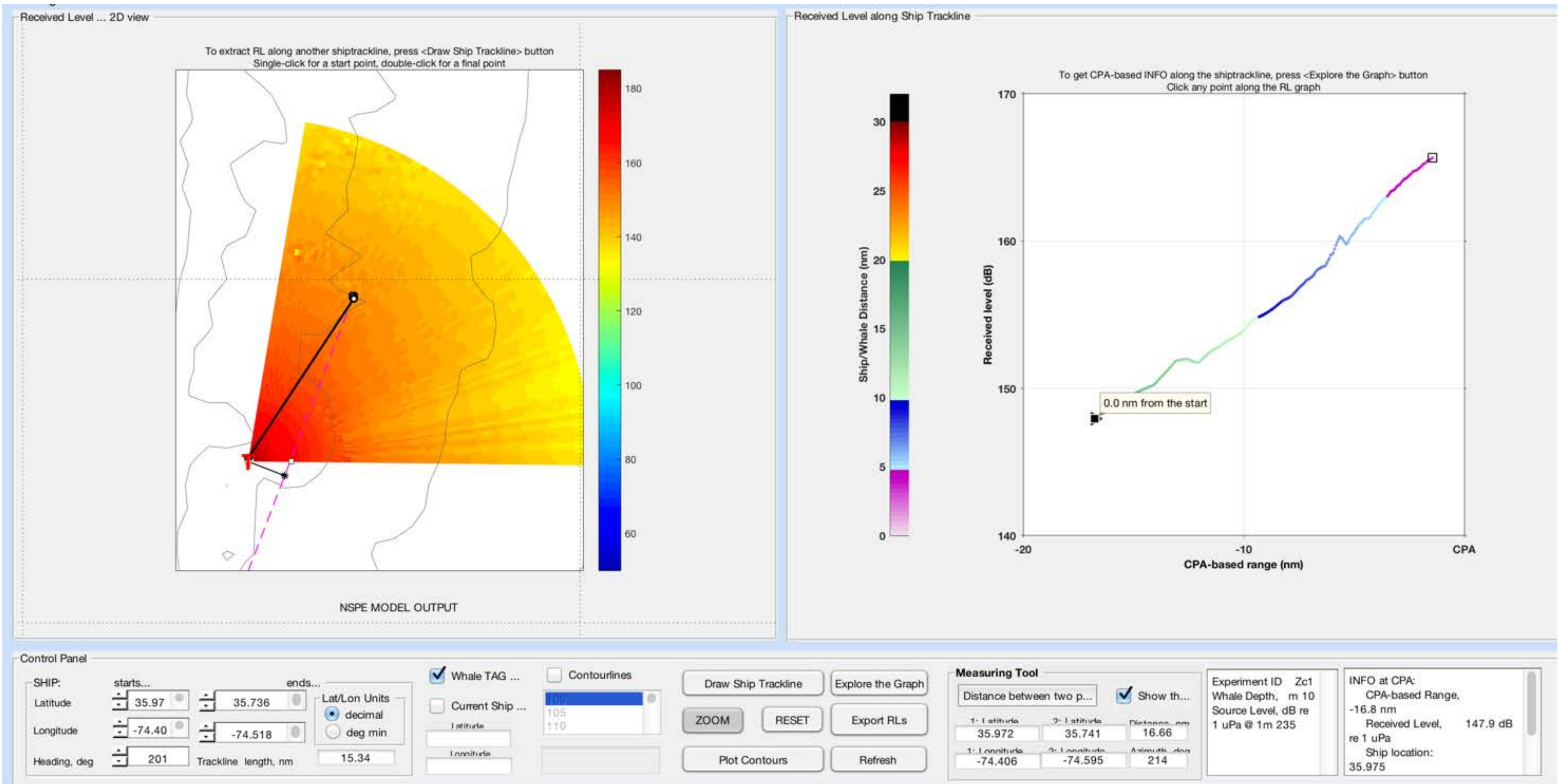

Figure 27. Modeled RLs at for Zc68 at location “T” and a depth of 10m along initial nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL at the closest point of approach is ~156 dB SPL.

These observations were consistent with a subsequent ray-tracing propagation model (**Figure 28**) conducted along a transect from the nominal *MACFAUL* start position to the estimated location of Zc68 using *in situ* XBT data (from the *MACFAUL*) available through the HYCOM database for 11 September. This model verifies the presence of strong surface ducting conditions at that time, which was likely the result of extensive surface mixing associated with recent storm systems. Notice relatively low propagation loss indicated by warm colors in the surface layers).

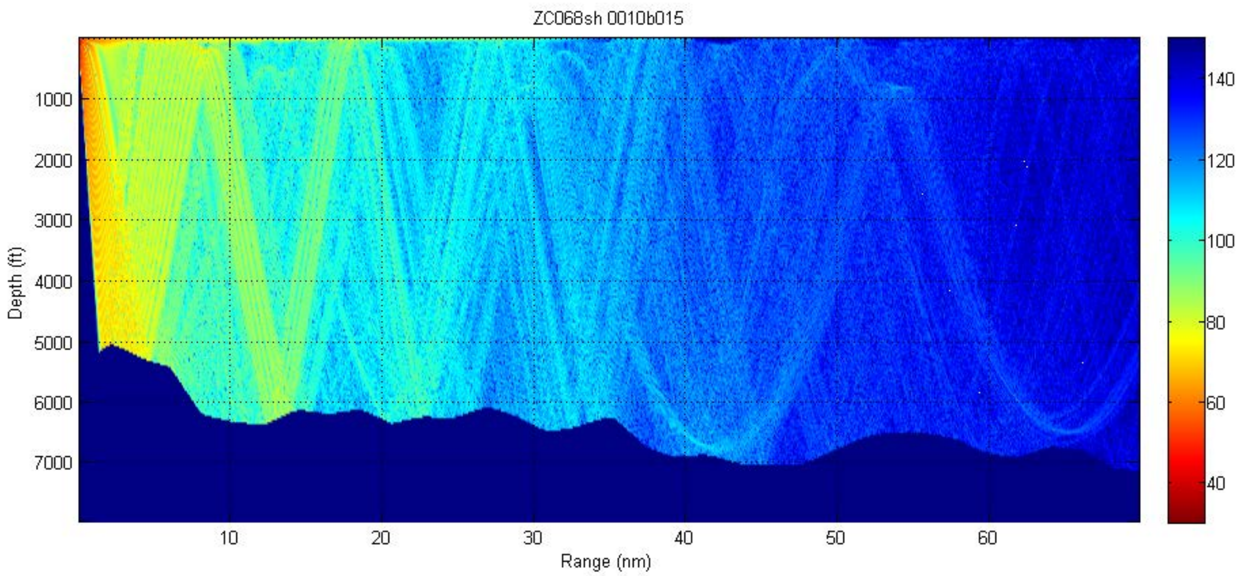

Figure 28. Sound propagation model showing relative transmission loss at different depths along a transect from nominal start position of *USS MACFAUL* through predicted location of Zc68 on 11 Sept 2017 in preparation for CEE #2017-02.

Given these clear results and in order to attempt to prevent knowingly exposing tagged animals to received levels well above target ranges, a modified location for the MACFAUL course (16 km further to the NNE) was determined (**Figure 29**).

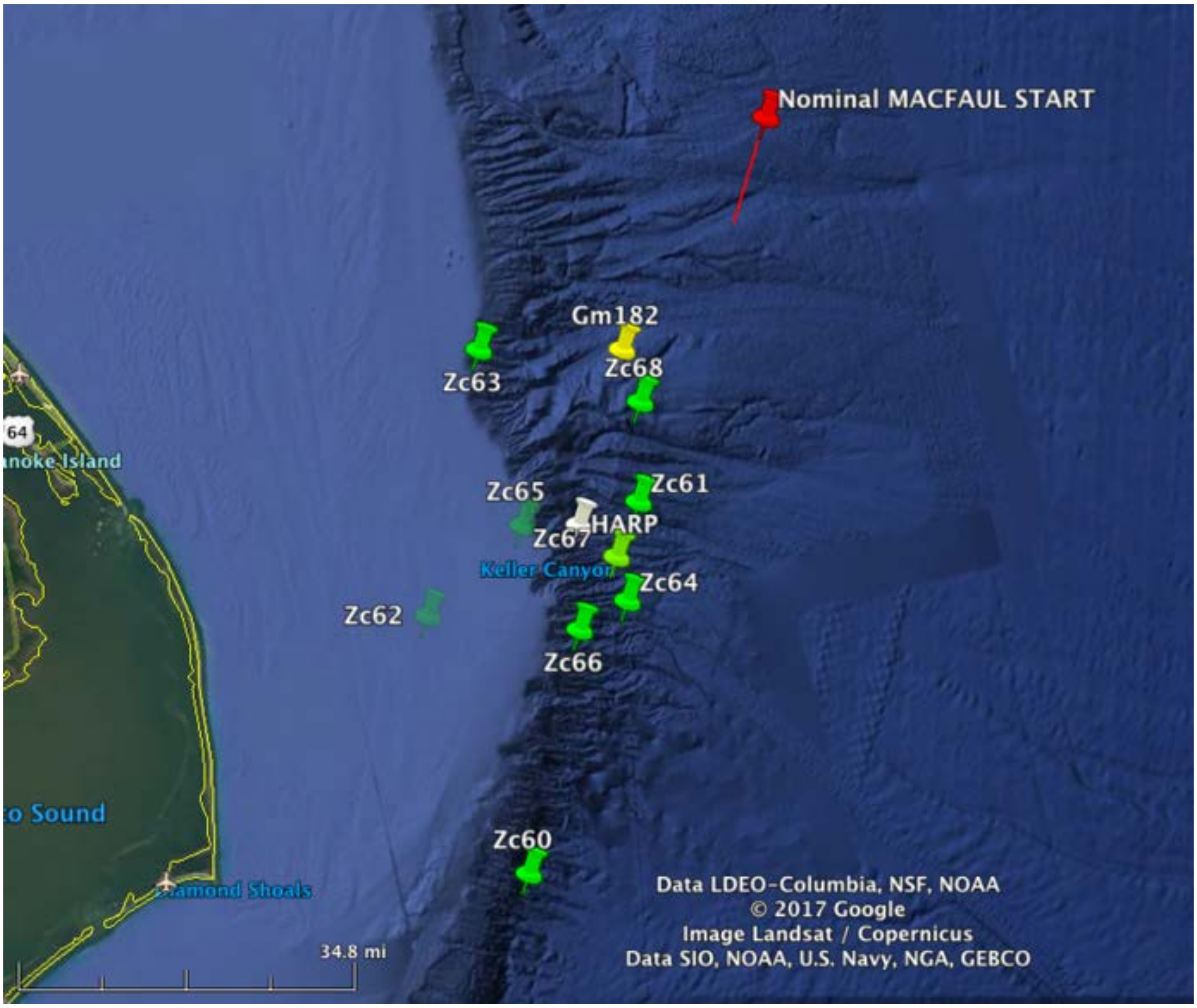

Figure 29. Modified location (based on propagation model results) selected for *USS MACFAUL* position for 12 September CEE #2017-02 shown relative to most recent ARGOS locations for focal beaked whales (green) and pilot whales (yellow) in areas off Cape Hatteras.

Additional propagation modeling was conducted overnight through the morning of 12 Sept in order to evaluate modeled RLs at both shallow and deeper-diving depths for the revised *MACFAUL* course for both Gm182 (**Figures 30 and 31**) and Zc68 (**Figures. 32 and 33**)

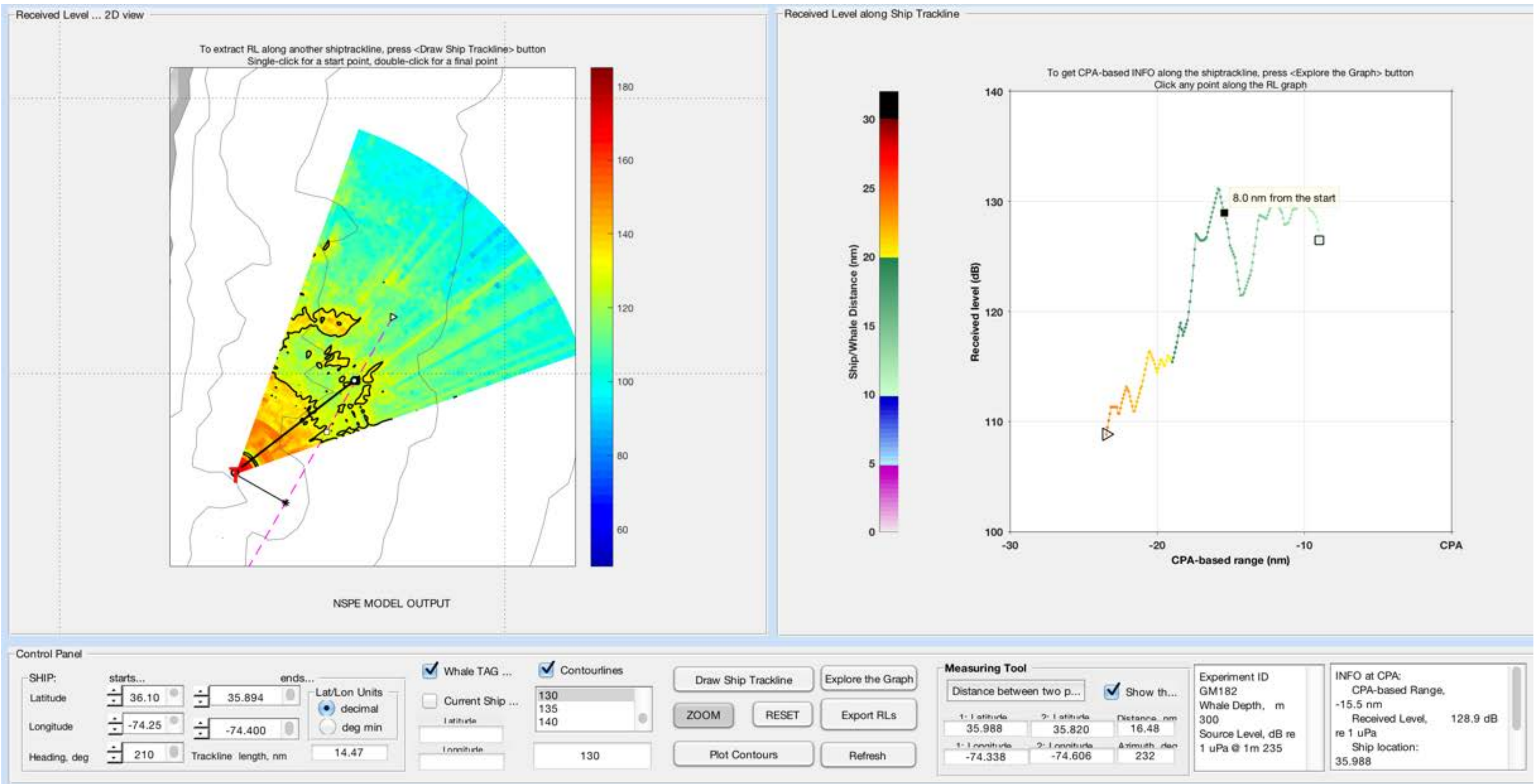

Figure 30. Modeled RLs at for Gm182 at location "T" and a depth of 300m assuming the modified (and executed) nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL at the closest point of approach is ~129 dB SPL.

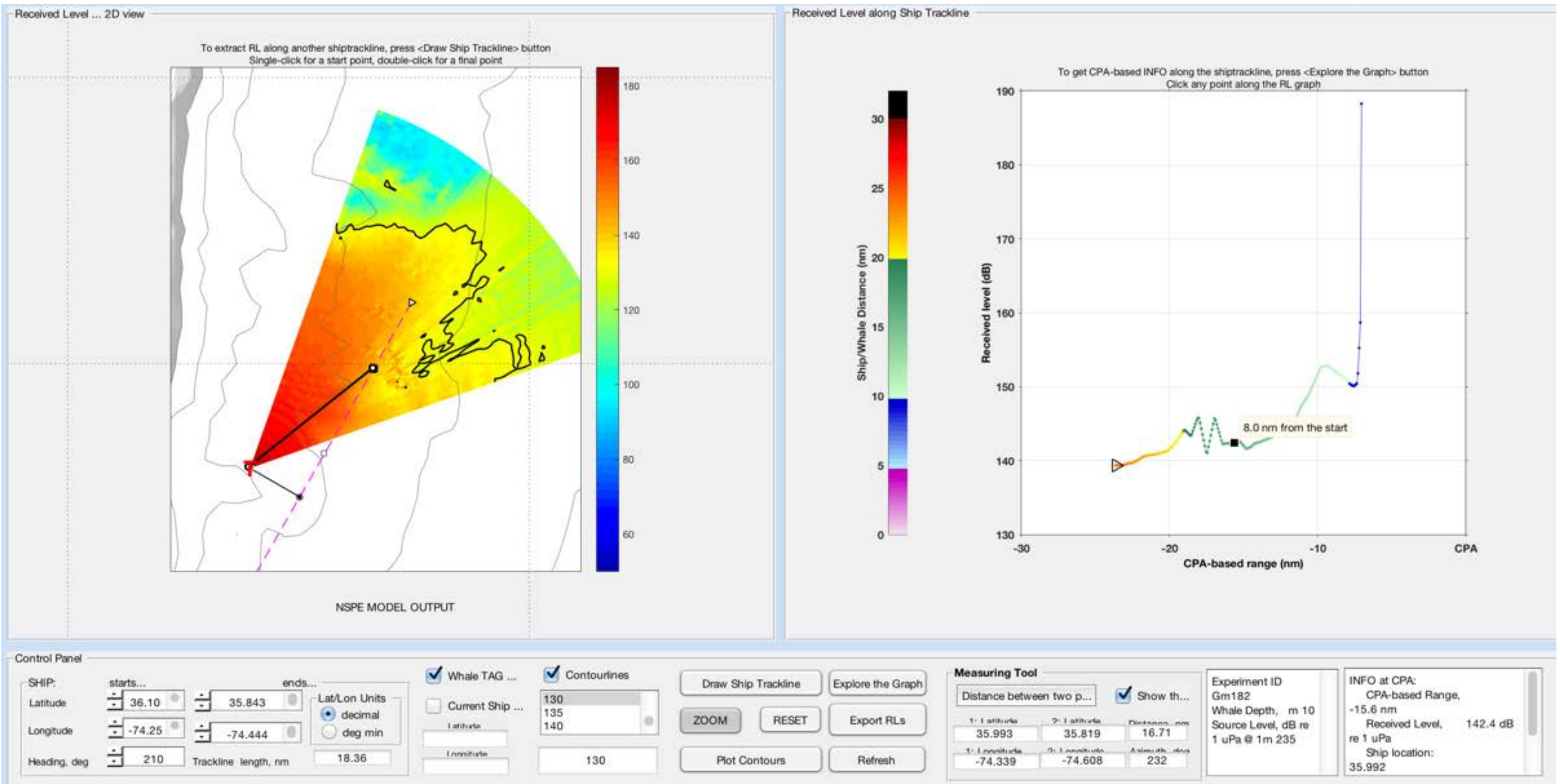

Figure 31. Modeled RLs at for Gm182 at location "T" and a depth of 10m assuming the modified (and executed) nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL occurs prior to the closest point of approach and is ~146 dB SPL.

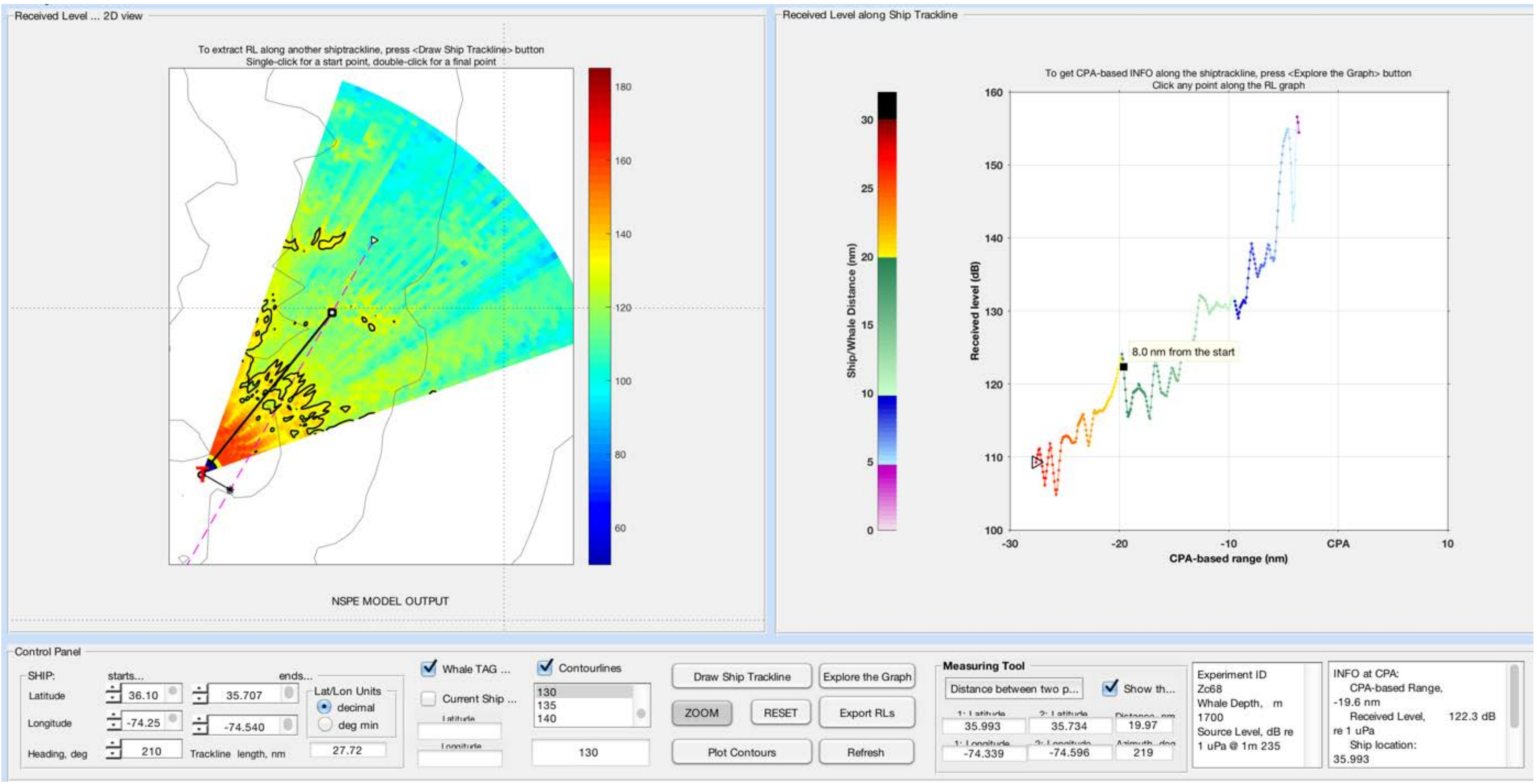

Figure 32. Modeled RLs at for Zc68at location "T" and a depth of 1700m assuming the modified (and executed) nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL occurs prior to the closest point of approach and is ~124 dB SPL.

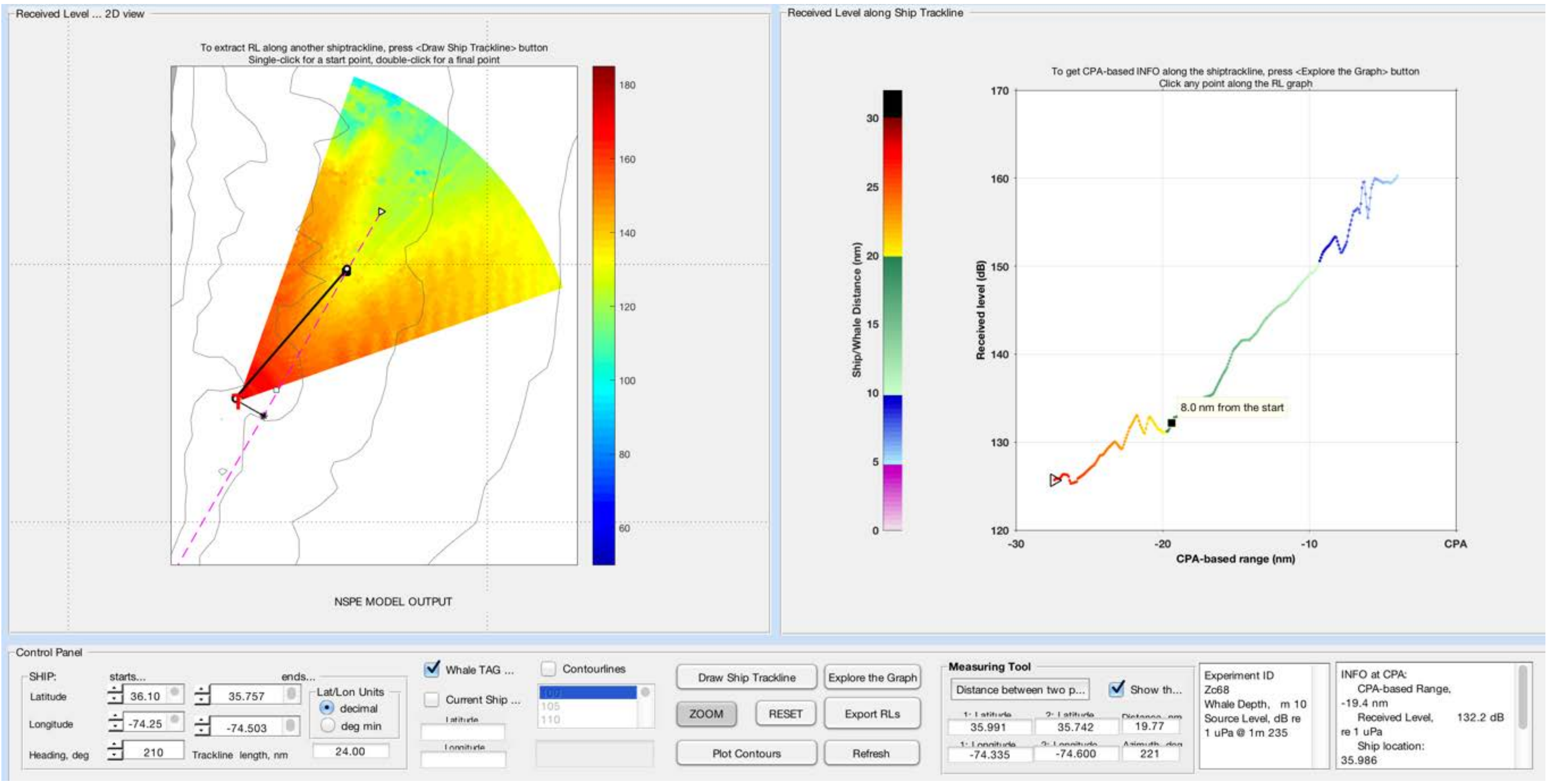

Figure 33. Modeled RLs at for Zc68at location "T" and a depth of 10m assuming the modified (and executed) nominal track of *USS MACFAUL* position for 12 September CEE #2017-02. Maximum RL occurs prior to the closest point of approach and is ~133 dB SPL.

Using the 12 September HYCOM data, propagation modeling for all animals off the Cape Hatteras areas was conducted using estimated ranges to the *MACFAUL* to derive preliminary RLs using the relative simplistic point estimate approach for several nominal depths (**Table 7**).

Table 7. Estimated ranges from satellite tagged animals off Cape Hatteras to the USS MACFAUL during Atlantic-BRS CEE #2017-02 and associated ranges of estimated RLs.

Animal ID	Estimated Range to *USS MACFAUL* at START CEE (km)	Estimated Range to *USS MACFAUL* at END CEE (km)	Estimated PRELIMINARY Received Levels (dB SPL)
Gm182	44	31.5	105 – 146
Zc68	51	36.5	100 – 133
Zc63	61	49.5	85 – 110
Zc61	66	51.5	90 – 122
Zc67	76.5	61.5	85 – 117
Zc64	83.5	68	<80 – 115
Zc66	91.5	76	<80 – 115
Zc60	132	117	<80 – 95

For individual pilot and beaked whales monitored with satellite tags during CEE #2017-02, maps showing Douglas-filtered ARGOS positions relative to the USS MACFAUL track on 12 September 2017 are provided below (**Figures 34-42**). We are currently conducting more detailed animal movement modeling based on these filtered positions that accounts for positional error in providing many potential tracks. This process and the associated RL modeling for the satellite tagged whales is described in greater detail below (**Section 3**). For several individuals (e.g., Gm183, Zc63), there were no filtered ARGOS positions for 12 September. They are consequently not shown in the simple maps here, but they will be ultimately considered separately in terms of potential broad-scale responses using the more robust geospatial analyses using movement models.

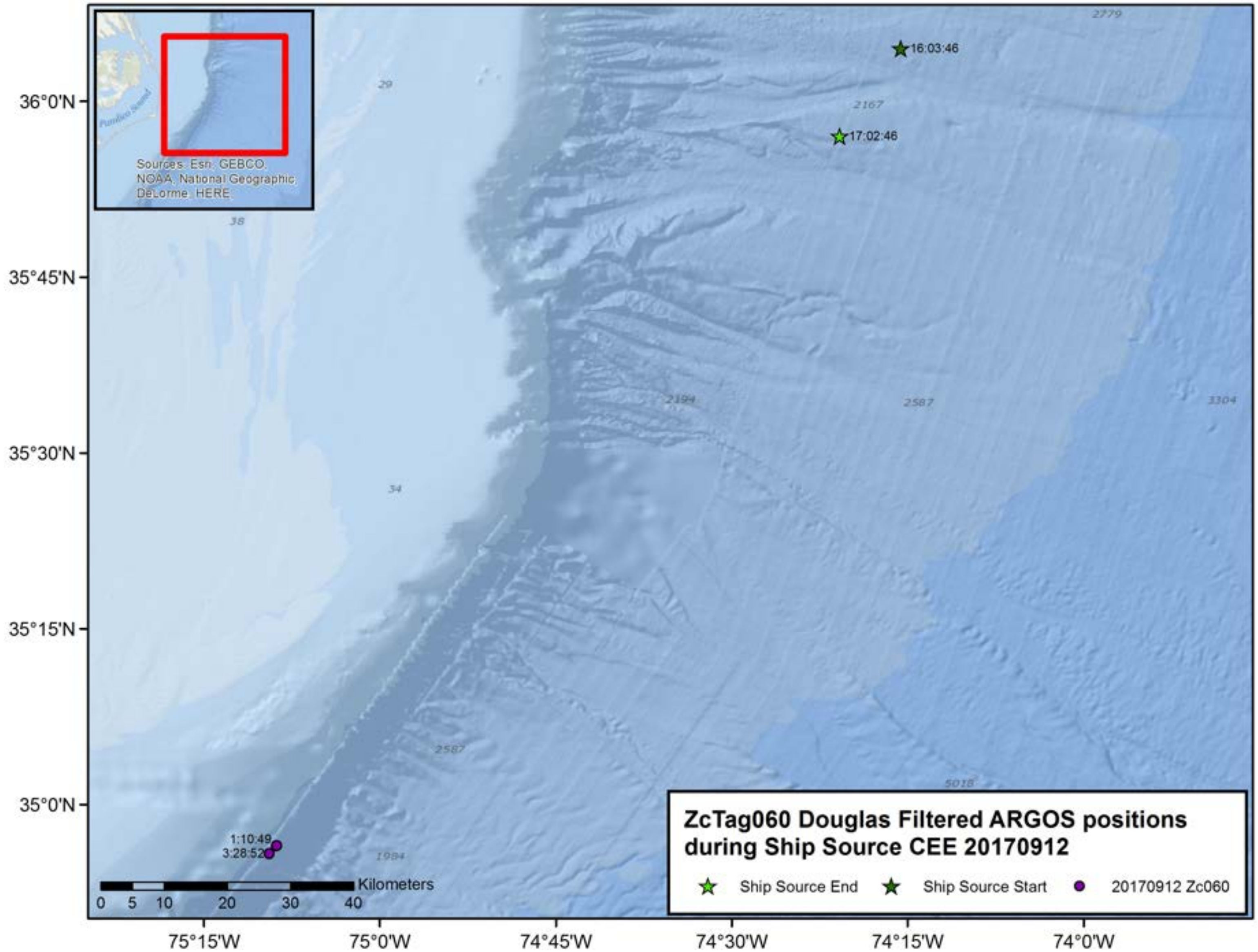

Figure 34. Map showing Douglas-filtered ARGOS positions for beaked whale Zc60 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

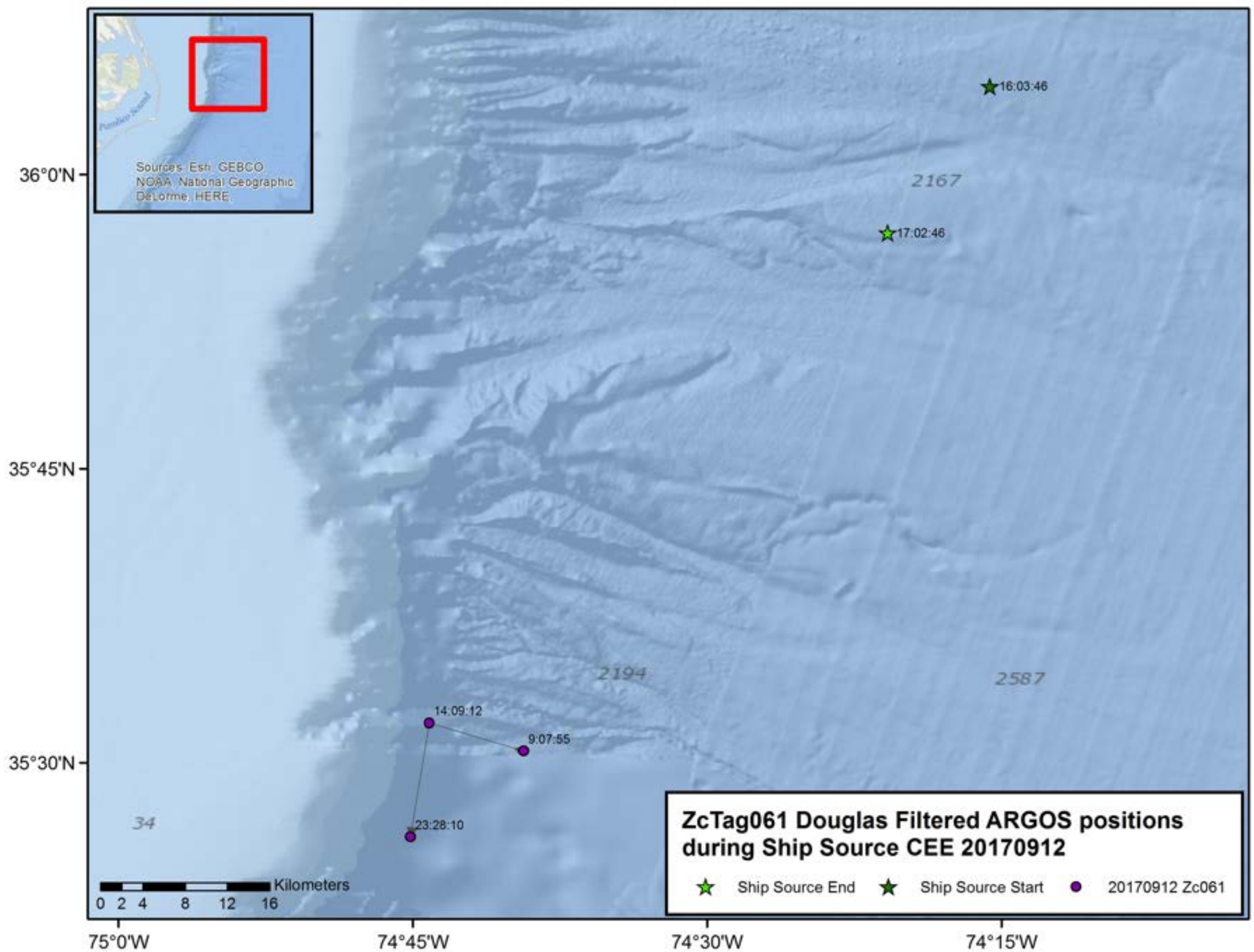

Figure 35. Map showing Douglas-filtered ARGOS positions for beaked whale Zc61 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

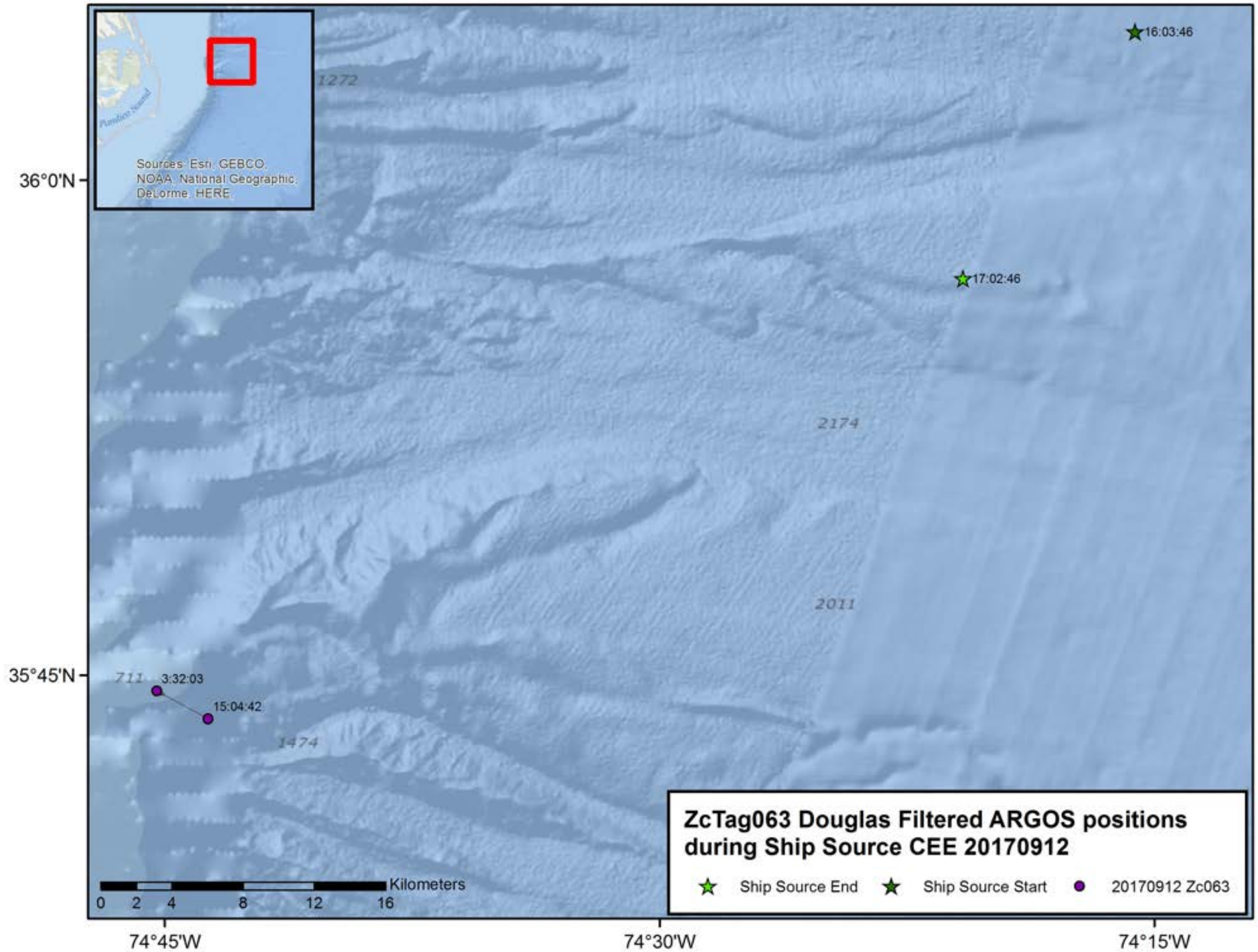

Figure 36. Map showing Douglas-filtered ARGOS positions for beaked whale Zc63 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

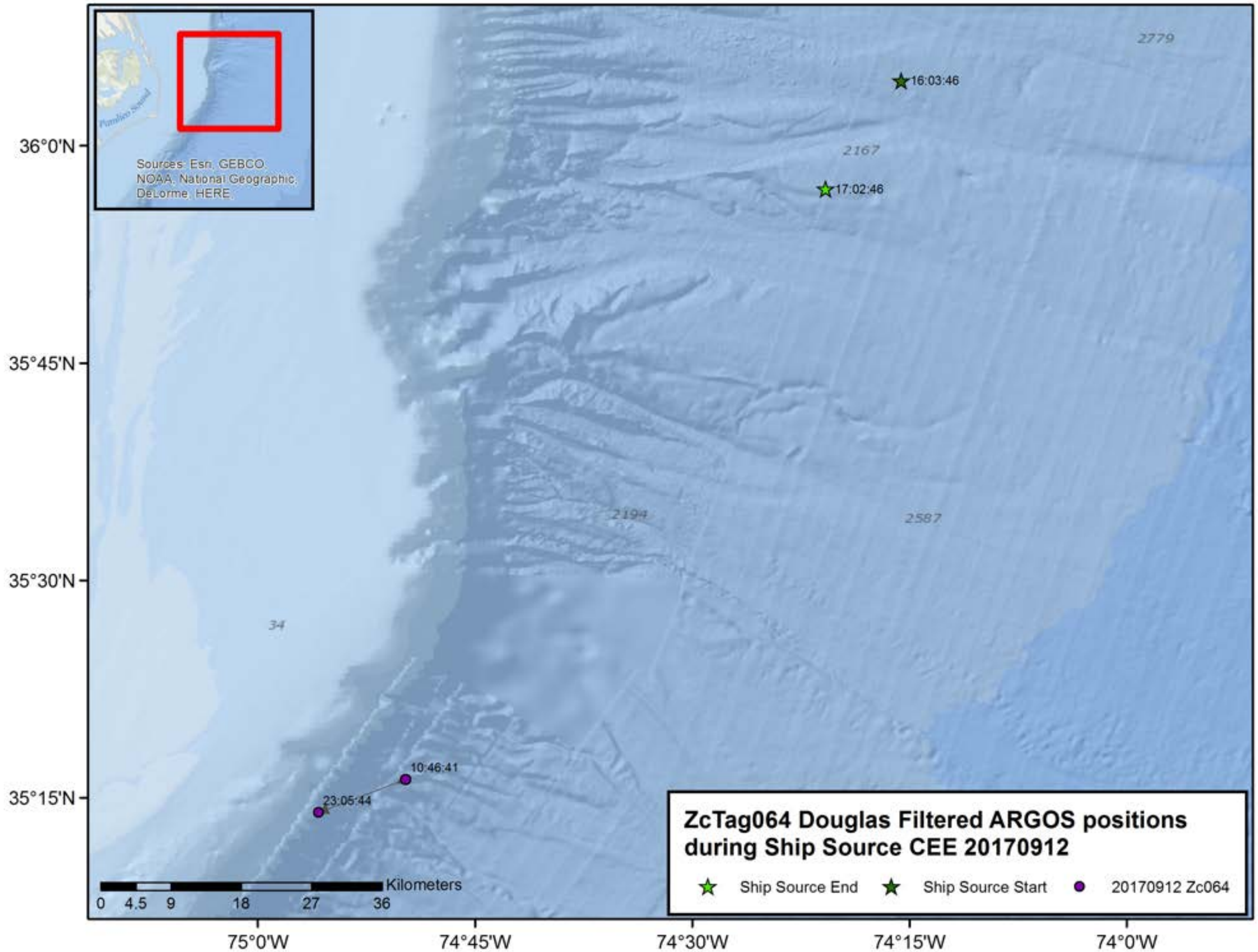

Figure 37. Map showing Douglas-filtered ARGOS positions for beaked whale Zc64 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

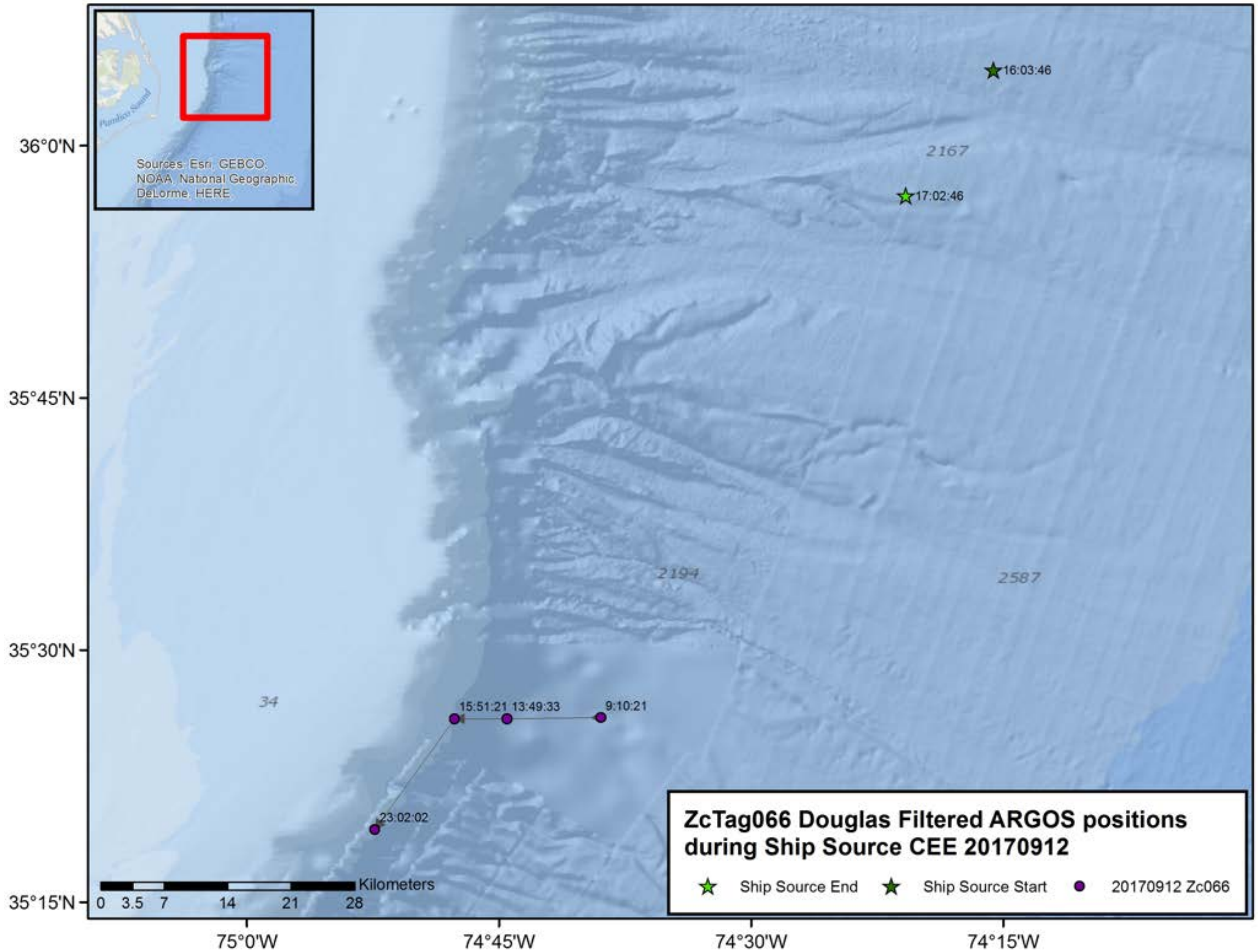

Figure 38. Map showing Douglas-filtered ARGOS positions for beaked whale Zc66 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

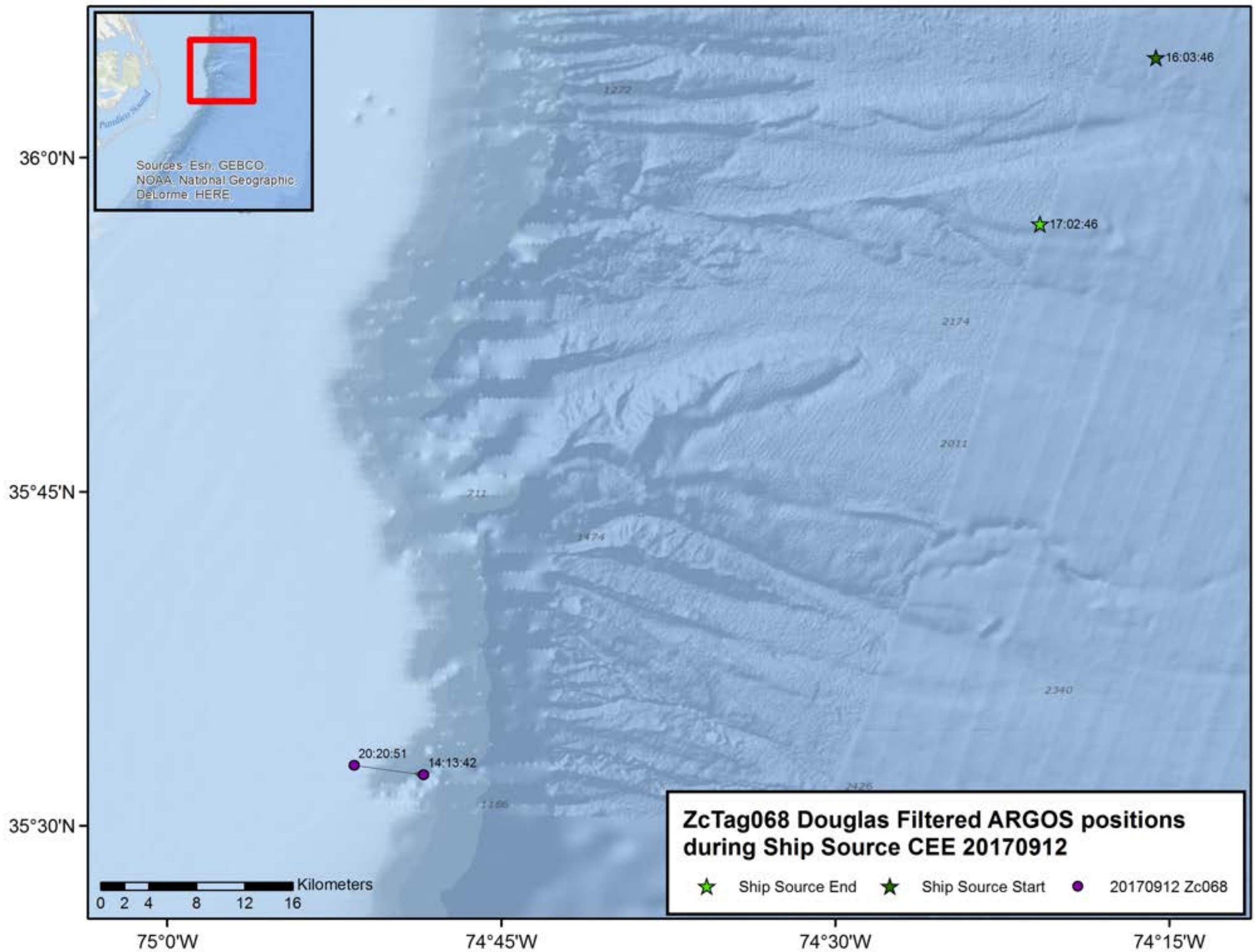

Figure 39. Map showing Douglas-filtered ARGOS positions for beaked whale Zc68 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

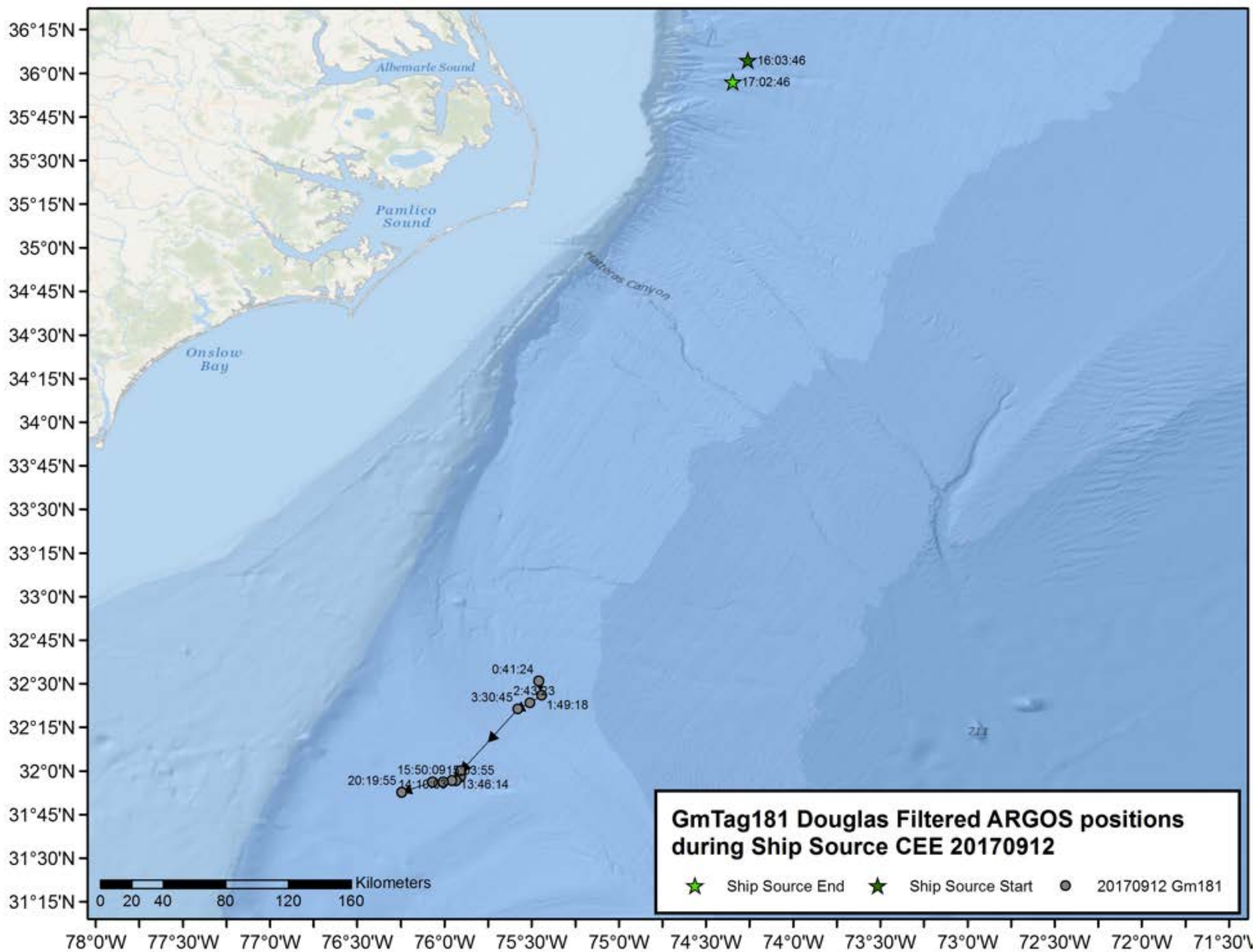

Figure 40. Map showing Douglas-filtered ARGOS positions for pilot whale Gm181 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

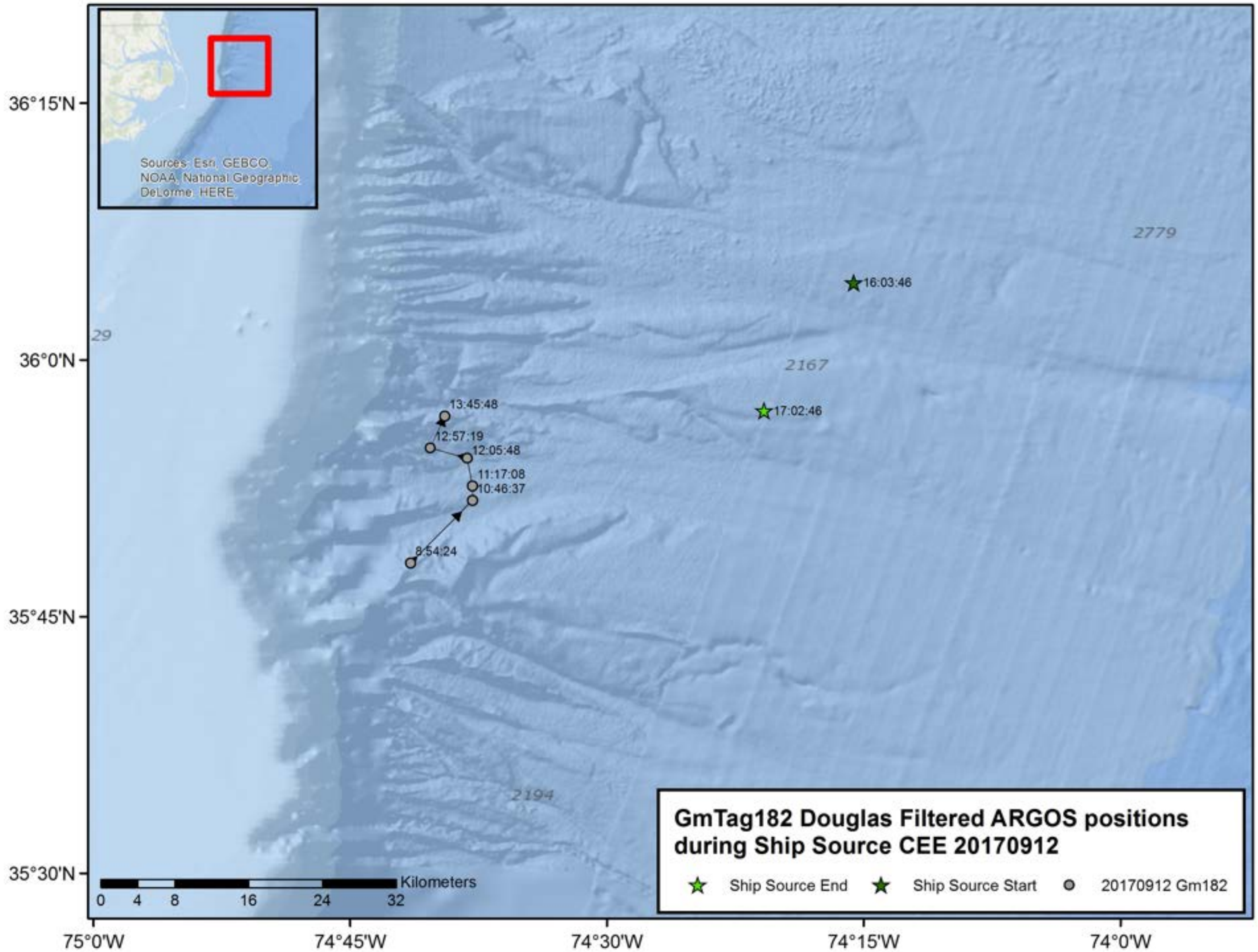

Figure 41. Map showing Douglas-filtered ARGOS positions for pilot whale Gm182 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

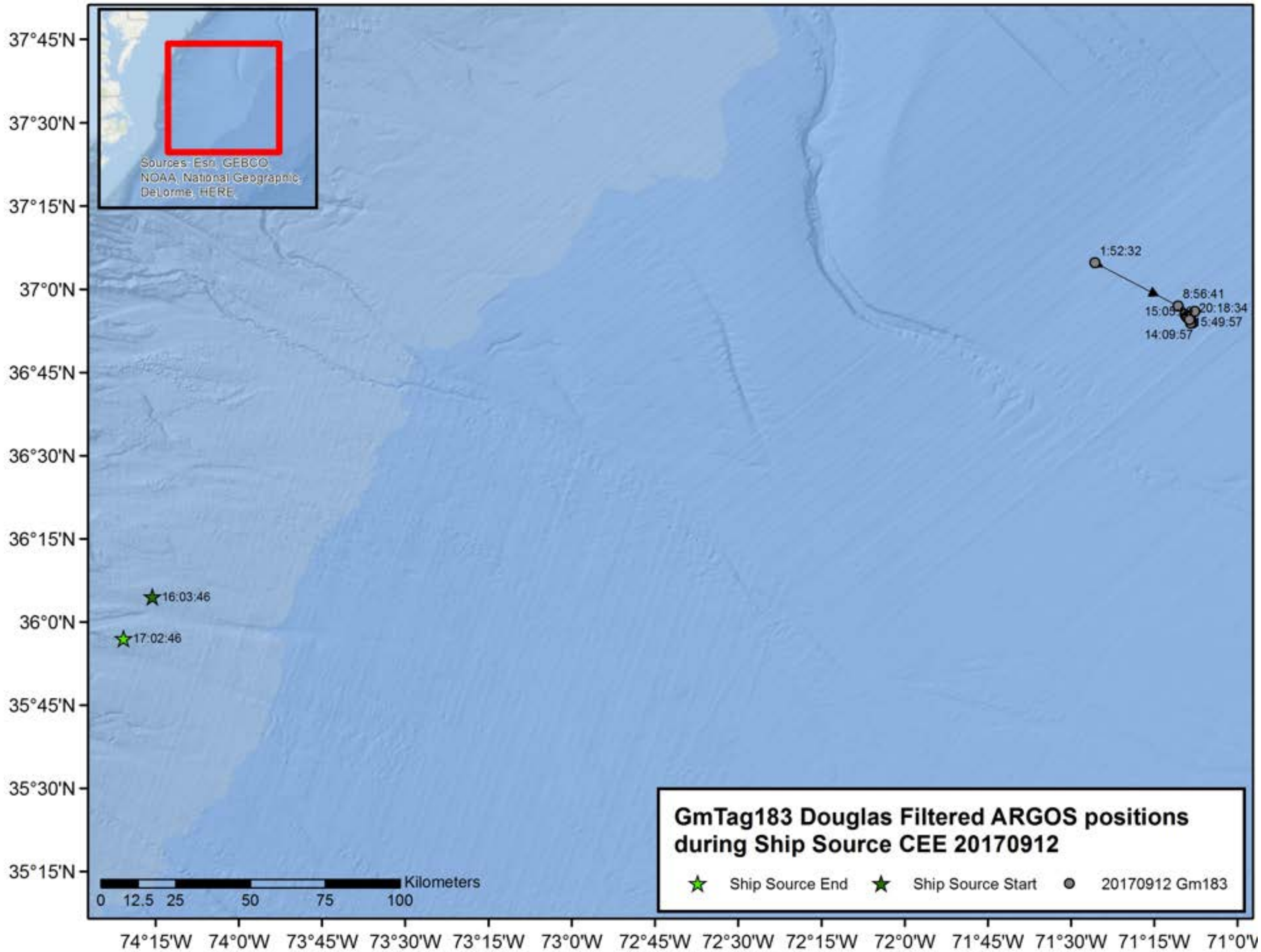

Figure 42. Map showing Douglas-filtered ARGOS positions for pilot whale Gm183 on 12 September relative to *USS MACFAUL* MFAS source location for Atlantic-BRS CEE #2017-02.

3. CEE Exposure-Response Analyses: Status and Preliminary Results

3.1 Baseline Animal Movement and Diving Data

As shown in **Table 4** above, the 26 satellite tags deployed on (14) beaked whales and (12) pilot whales recorded individual movement and diving data for many hundreds of total days. This includes thousands of hours of data both prior to and following either of the CEEs conducted. The extent to which any potential response as a function of exposure persisted is a matter of ongoing analysis (see below). But even if responses were to last several days, many tags recorded for weeks after CEEs. Additional high-resolution kinematic and acoustic data were also recorded from the two DTAGs deployed, with the beaked whale DTAG deployment being the first successfully recovered data of this type for this high priority species off the east coast.

These tag deployments that occurred during the Atlantic-BRS field effort extend and contribute to a fairly extensive baseline database for these species off Cape Hatteras that have been collected through several related and ongoing collaborations. For instance, Duke has deployed a large number of DTAGs on pilot whales in several ongoing studies to monitor behavior and behavioral responses to predator sounds and active acoustic echosounders in these areas through support from both the range monitoring program and SERDP. Further, Cascadia has been partnering with Duke University for several years preceding the Atlantic-BRS effort to successfully deploy dozens of satellite-transmitting tags of different types on these species. More details regarding baseline analyses of movement and diving behavior for the satellite tags deployed during the Atlantic-BRS effort are provided in the parallel Cascadia annual report about their tagging effort. While these data provide critical additional understanding of the baseline behavior of beaked and pilot whales off Cape Hatteras that are both generally and specifically useful to the analysis and interpretation of potential responses during CEEs, the details about these baseline data are provided separately in that report and we focus here on the specific analysis of CEE results using different methods.

It is noted that there are two ongoing analyses being led by Duke that apply some of the baseline behavioral and diving satellite tag data collected in the Atlantic-BRS project. One of these focused on better describe basic aspects of diving and feeding behavior and habitat usage of beaked whales in this area (although using relatively few Atlantic-BRS deployments to augment a larger sample size obtained in preceding efforts). The second analysis utilizes satellite tag data collected entirely during this project on several beaked whales tagged in the same social group to investigate potential behavioral synchrony and cohesion in this species. This investigation of beaked whale social interactions will provide some of the first-ever such insight of what is a likely a key factor in mediating potential responses to disturbance in this key species and will lay the foundation for more informed and detailed future analyses of changes in social interactions as a function of exposure to sonar.

3.2 CEE Analysis Progress and Status

As described above, at the outset of the first year of the Atlantic-BRS effort quite specific analytical questions and approaches were identified (see **Table 2**). These relate to potential avoidance responses (movement away from sound sources) and potential changes in foraging and social behavior. It was also identified that substantially different approaches would be required for analysis of high-resolution, but short-duration DTAG kinematic and acoustic data relative to the much longer-duration coarser resolution movement and diving summary data from the satellite tags. Ultimately, insights and analyses from both tag sensor types to animals exposed to the same or similar CEEs will provide a unique insight into potential response types and probabilities on different scales of spatial and temporal resolution. As clearly acknowledged ahead of the 2017 field effort, this will be a multi-year effort in order to obtain sufficient exposure-response samples to fully evaluate these issues.

Major advances were made in 2017 and despite their being just two CEEs conducted, these involved nearly 20 instances of tagged individuals exposed to MFAS during controlled scenarios under various contexts of distance, RL, and other factors. This includes over a dozen individual exposure-response sequences with high priority beaked whales which, in just this first year and two CEEs, exceeds the combined CEE sample size of all controlled, experimental results published to date across all beaked whale species (see Southall et al., 2017). Initial data processing of movement and diving data from all tags was completed by late fall for all individuals involved in each CEE.

Following the initial analyses of data acquired during the Atlantic-BRS spring field effort, it was clear that extensive additional development of analytical methods regarding tag data (notably related to characterizing and accounting for spatial error in ARGOS data in relation to RL modeling and horizontal movement analyses) would be required. Given the lack of CEE data from the spring period, and following discussions with the Navy regarding analytical plans and progress, analysis plans were focused on the use of tag data acquired to test potential responses during “mock” CEE sequences in the data where simulated exposures were assumed. These analyses enabled the Atlantic-BRS team to apply and derive analytical approaches from previous efforts within the teams and individuals working in this project. This also included the development of an extensive and secure data archive accessible to all team members via the Open Science Framework in order to store and analyze data of different types. Much of this data archive is available and accessible within the team and to the Navy, but sections are strategically password protected and limited to key personnel working on specific analyses to prevent any unintended changes or deletions of data.

Most of the mock analyses have been completed and are described below; these results have proven extremely valuable in terms of informing and enabling the real CEE response analyses. Extensive effort has occurred in terms of CEE response analyses for both the simulated and real sonar CEEs as well, although this includes a number of ongoing analyses that remain in progress at this time. Limited definitive conclusions regarding potential responses, or lack of responses, are provided in the draft annual report here out of caution given the ongoing nature of analyses. Additional resolution and detail of 2017 CEEs is expected to be completed at a major analysis meeting in Beaufort in late February, the outcomes of which will be presented at the U.S. Navy fleet monitoring meeting in San Diego in March. Results obtained to date and a summary of the current status of CEE analyses in progress are provided here, first for those CEE analyses related to DTAG data followed by analyses of satellite tag data.

3.2.1 DTAG Analysis - Progress and Status

MOCK CEE DTAG ANALYSIS

In order to and evaluate and improve CEE analytical methods for DTAG data in preparation for subsequent exposure-response analyses, we evaluated potential responses during mock CEE periods from previously obtained DTAG data off Cape Hatteras. Baseline behavioral DTAG records from pilot whales tagged in earlier, related projects that were at least 3-h in duration and occurred at approximately at the same time of day were selected for the mock CEE analyses (**Table 8**). Two of the records were concurrent deployments and occurred as part of a separate CEE, although only data obtained prior to the playback experiment were evaluated during the mock CEE. The 'baseline' period for each of record began 15 minutes after the tag was placed on the animal, to account for any effects from tagging, and continued until 1-h prior to the nominal CEE period. The pre-exposure, mock exposure, and exposure periods then consisted of 1-h of data each.

Table 8. Nine DTAG records from previously tagged pilot whales off Cape Hatteras used for mock CEE analyses. Tag on and tag off times (local EDT) and total duration of the tag record are provided. * indicates DTAG records were part of another playback experiment, although data used here all preceded exposure during that study.

Animal ID	Time On (local)	Time Off (local)	Total Time (hh:mm)
Gm10_185b	14:30	20:20	5:50
Gm10_209c	13:19	20:09	6:50
Gm11_149b	10:33	14:24	3:50
Gm11_150b	11:11	14:46	3:34
Gm11_156a	12:11	16:29	4:17
Gm12_163b	11:20	14:49	3:29
Gm14_279a	12:42	16:09	3:27
*Gm14_178a	12:09	16:38	4:29
*Gm14_178b	12:22	15:53	3:31

The position of a presumed full-scale 53C MFAS exposure was selected based on a known focal follow location and a similar modeling procedure as was used in the field to determine the start and end location of the "ship." This was done for all subjects to generate modeled "RLs" within the nominal experimental range of 140-160 dB; an example for Gm11_149b using a known focal follow position for the location of the focal animal (at position "T") is given below (**Figure 43**). This enabled both a simulated RL, as well as the determination of instantaneous distance (range) from the source vessel to the focal animal.

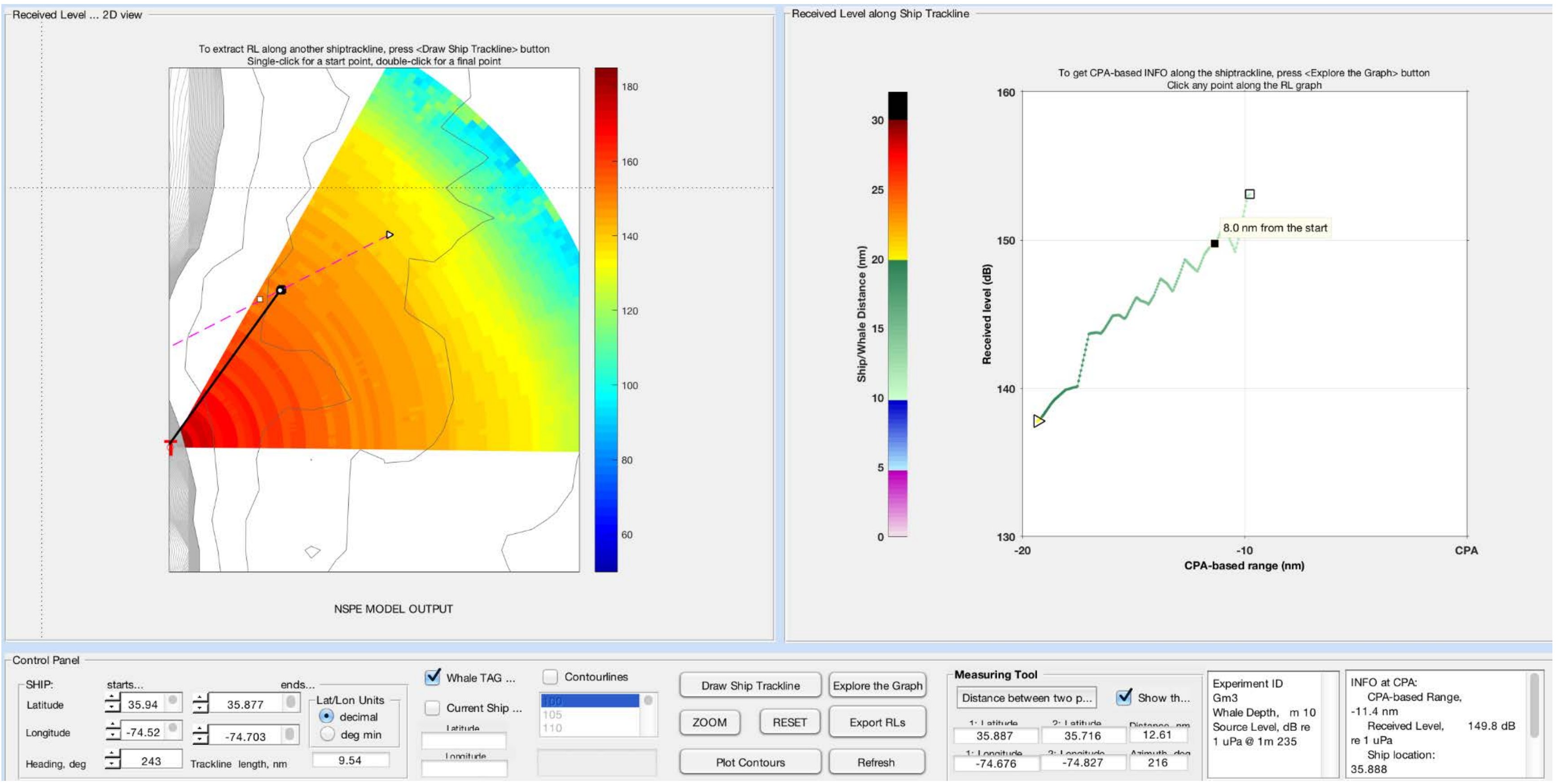

Figure 43. Modeled received levels for pilot whale Gm11_149b using a simulated position of a real ship 53C sonar for mock CEE analysis.

To determine change-points in the behavior of the focal animal, we employed Mahalanobis distance (MD) analysis to investigate potential statistical outliers in several key behavioral metrics from the DTAG record (as in DeRuiter *et al*., 2013). The non-dimensional MD metric is calculated over a sliding time window and enables the compression of multiple metrics of 'distance' from the baseline condition for each variable into a single metric of difference. This approach also accounts for the variance of a variable and the covariance between variables.

This metric enables the measurement of how similar a set of experimental conditions is to a known set of baseline conditions, using the following relationship:

$$D^2 = (x - m)^T C^{-1} (x - m)$$

where:

D^2 is the Mahalanobis Distance

x is the vector of data

m is the vector of mean values of the baseline data

C^{-1} is the inverse covariance matrix of the baseline data

For DTAG data, we computed MD across all mock experimental phases using the following variables: depth, overall dynamic body acceleration (ODBA), maximum specific acceleration (MSA), vertical velocity, horizontal velocity, heading variance and horizontal distance from source vessel.

We then used MD as a potential response variable and evaluated it against four treatments: baseline, before (pre) exposure, during exposure and post exposure periods using a Gaussian General Estimating Equation (GEE) with the geepack package (Højsgaard et al., 2006) in R statistical software (R Core Team 2015). To account for the repeated measures in the experimental design a blocking unit (Animal ID) was specified, which allowed for within-subject correlation of residuals, but assumes independence between blocking units. Data from two concurrently tagged animals (Gm14_178a & b) were placed in the same blocking unit and were not assumed to be independent. All other tags were treated as independent observation periods. We then ran models with an independent and autoregressive correlation structure and used the ANOVA method to compare each model by Wald tests. In each case the independent correlation structure was determined to be a better model. Each treatment was compared to the baseline using 95% confidence intervals derived from a parametric bootstrap of 10,000 iterations on the fit parameters of the GEE. For the bootstrap, we assumed a multivariate normal distribution with means equal to the estimated parameters from the model and the variance-covariance matrix from the fit model. Utilizing these methods, the MD levels determined before, during and following the mock CEE were not significantly different than baseline levels across all nine animals (**Figure 44**).

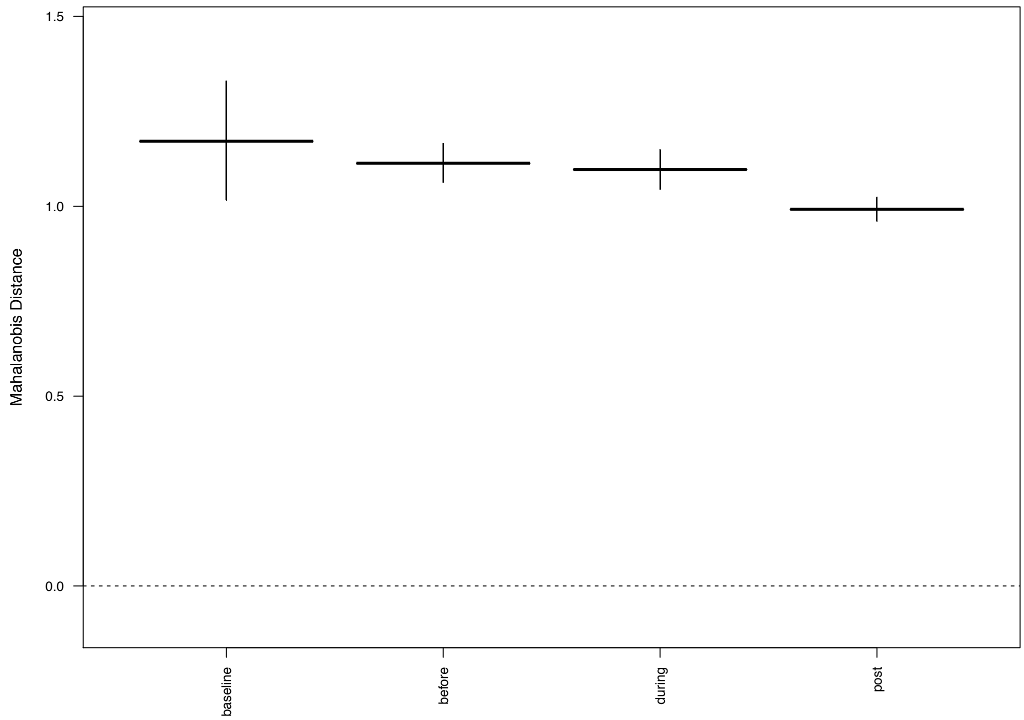

Figure 44. Parameter estimates, together with 95% confidence intervals (CI) of GLM for MD for before (pre) exposure, during exposure, and nine DTAG pilot whales. Horizontal lines represent parameter estimates and vertical lines represent the 95% CI derived from parametric bootstrap of the fit parameters of the GLM. MD levels before, during and post CEE were found to not be significantly different than baseline levels.

SIMULATED SONAR CEE DTAG ANALYSES – PRELIMINARY RESULTS

We used the same analytical approaches for the calculation of MD metrics and the evaluation of MD results using GEEs described for mock CEEs in the initial analysis of simulated sonar CEEs. As in the mock CEE analysis, we thus included depth, ODBA, MSA, vertical velocity, horizontal velocity, heading variance and horizontal distance from source vessel in the computation of MD. For Zc17_234a began after an initial foraging dive (approximately 90 minutes into the record) up until 1 hour before the CEE. We excluded the foraging dive from the baseline to properly measure the MD of the shallow non-foraging dives that occurred during and post CEE (as in DeRuiter et al. 2013). The baseline period for Gm17_234a began 15 minutes after the tag was placed on the animal, to account for any effects from tagging, and continued up until 1 hour before the CEE. The MD calculation was measured at 5 minute windows with a 50 percent overlap for both Zc17_234a (**Figure 45**) and Gm17_234a (**Figure 46**).

Figure 45. Mahalanobis distance measured in 5-min. windows with 50% overlap for Zc17_234a. The color of the lines and points indicate the phase of the exposure (baseline, before (pre-) exposure, during exposure, and post-exposure).

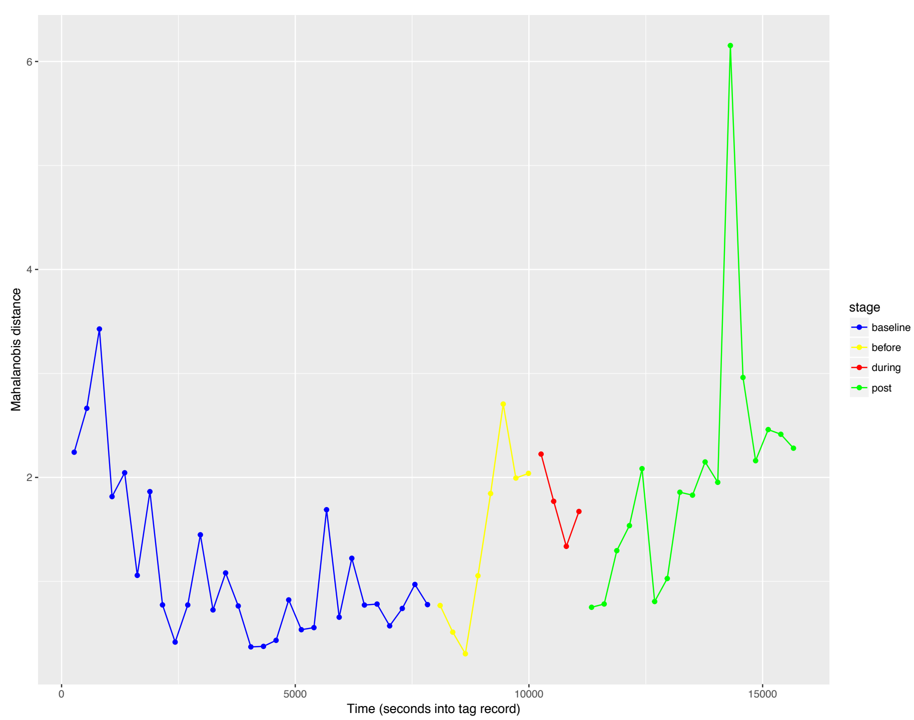

Figure 46. Mahalanobis distance measured in 5-min. windows with 50% overlap for Gm17_234a. The color of the lines and points indicate the phase of the exposure (baseline, before (pre-) exposure, during exposure, and post-exposure).

To evaluate potential differences in behavioral metrics, we evaluated MD values against four treatments: baseline, before, during and post CEE with generalized linear model (GLM) for both zc17_234a and gm17_234a. Each treatment was compared to the baseline using 95% confidence intervals derived from a parametric bootstrap of 10,000 iterations on the fit parameters of the GLM. For the bootstrap, we assumed a multivariate normal distribution with means equal to the estimated parameters from the model and the variance-covariance matrix from the fit model. All analysis and figures were computed using R statistical software (R Core Team 2015). The MD levels before, during and post exposure were not significantly different than baseline levels for either animal (**Figures 47 and 48**), although the post exposure period for Gm17_234a approached significance (**Figure 48**, p=0.06).

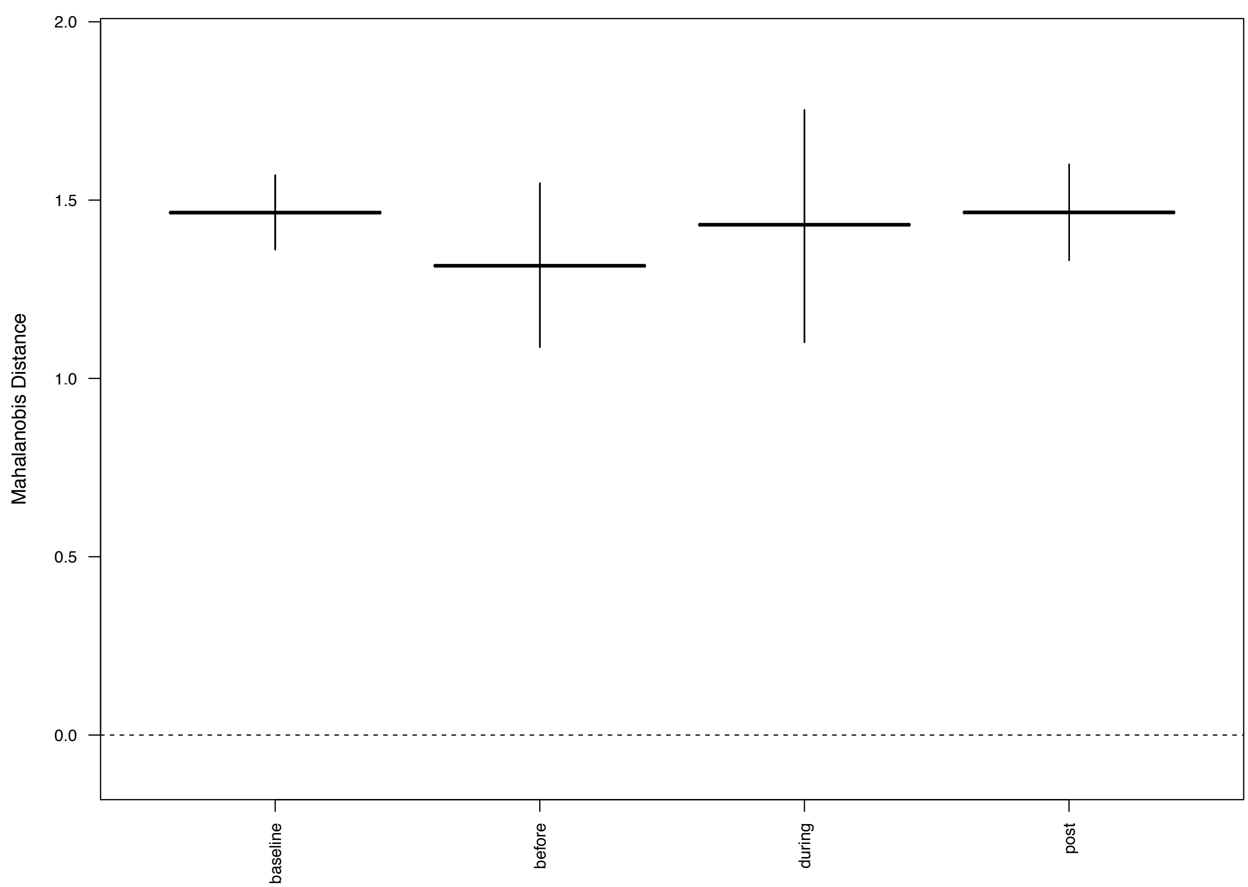

Figure 47. Parameter estimates, together with 95% confidence intervals (CI) of GLM for MD for before (pre-) exposure, during exposure, and post exposure for Zc17_234a. Horizontal lines represent parameter estimates and vertical lines represent the 95% CI derived from parametric bootstrap of the fit parameters of the GLM. MD levels before, during and post exposure were found to not be significantly different than baseline levels.

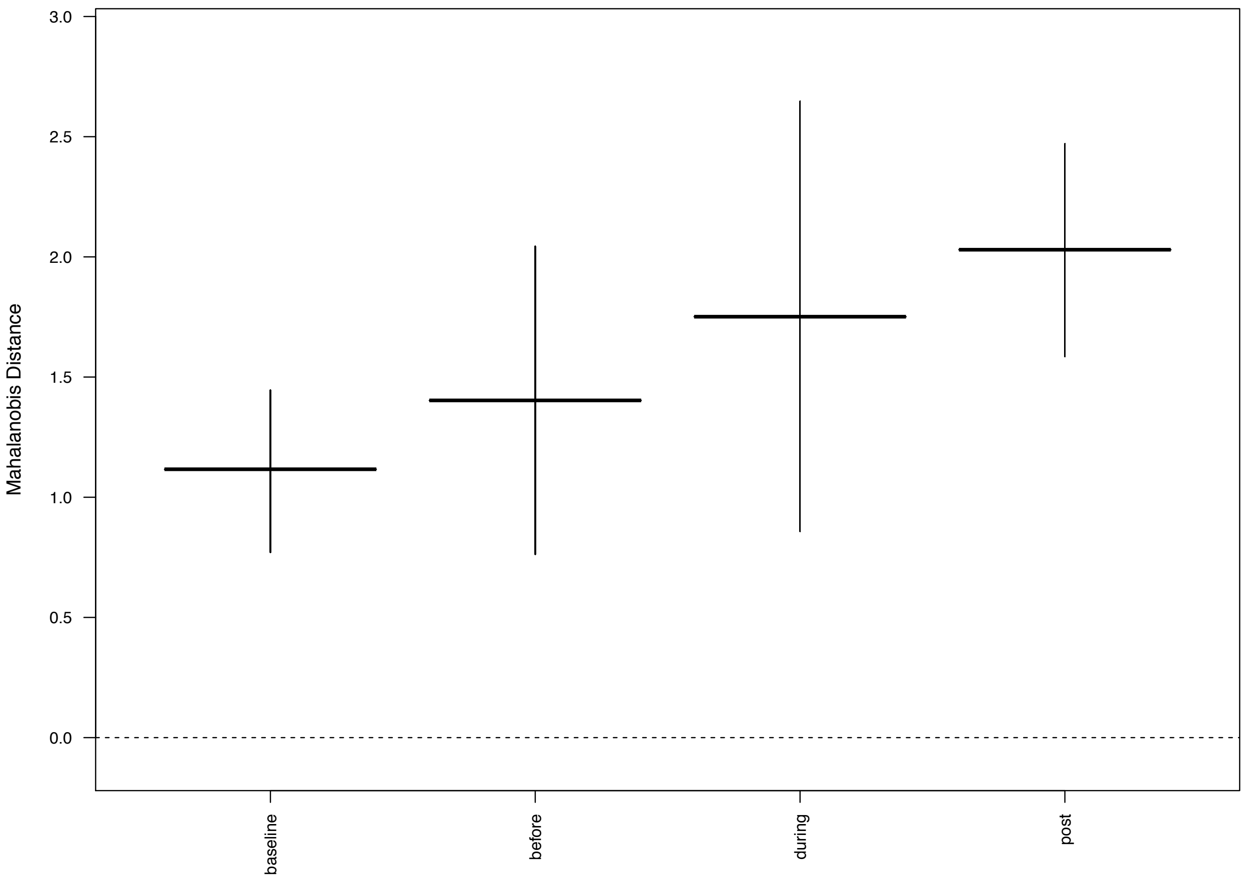

Figure 48. Parameter estimates, together with 95% confidence intervals (CI) of GLM for MD for before (pre-) exposure, during exposure, and post exposure for Gm17_234a. Horizontal lines represent parameter estimates and vertical lines represent the 95% CI derived from parametric bootstrap of the fit parameters of the GLM. MD levels before, during and post exposure were found to not be significantly different than baseline levels.

3.2.2 Satellite Tag Analysis - Progress and Status

MOCK CEE SATELLITE TAG ANALYSIS – SPATIAL MOVEMENT AND RL MODELING

Among the most challenging and extensive analyses conducted thus far relates to evaluating and appropriately characterizing individual animal surface locations, given the large uncertainty in these locations typically associated with ARGOS positions. This is a critical aspect of the CEE analysis in relation to both the evaluation of potential avoidance responses to sound sources and in the estimation of received levels associated with MFAS transmissions from known locations. Building and expanding on several related Navy-funded research and monitoring efforts to evaluate movement and acoustic exposure during noise exposure, several advanced geospatial modeling methods were implemented. The objective in these modeling efforts was to: (1) more fully and fairly characterize potential animal positions given often sparse ARGOS positional data with associated error for periods (hours-days) before, during, and after CEEs for satellite tagged animals, and (2) use this more robust characterization of potential locations with derived noise propagation analyses to model RLs for defined MFAS exposure periods given known location of CEE sources. The development of this approach began with a mock CEE scenario using a pilot whale tagged during the spring Atlantic-BRS field effort (Gm175) during a defined period on 23 May 2017.

As a first step that is similar to several previous such estimates of location and associated RL, an initial characterization of surface positions was based on the Douglas-filtered ARGOS locations (such as those shown within CEE days in **Section 2** above). A simple characterization of location and positional error relative to a known position of interest (e.g., ship start/end position along a specified transmission track) is to use the Douglas-filtered ARGOS location as the “best” estimate of position at a fixed time with “near” and “far” bounds of potential location error defined by the ARGOS error associated with the corresponding “best” position class code (**Figure 49**).

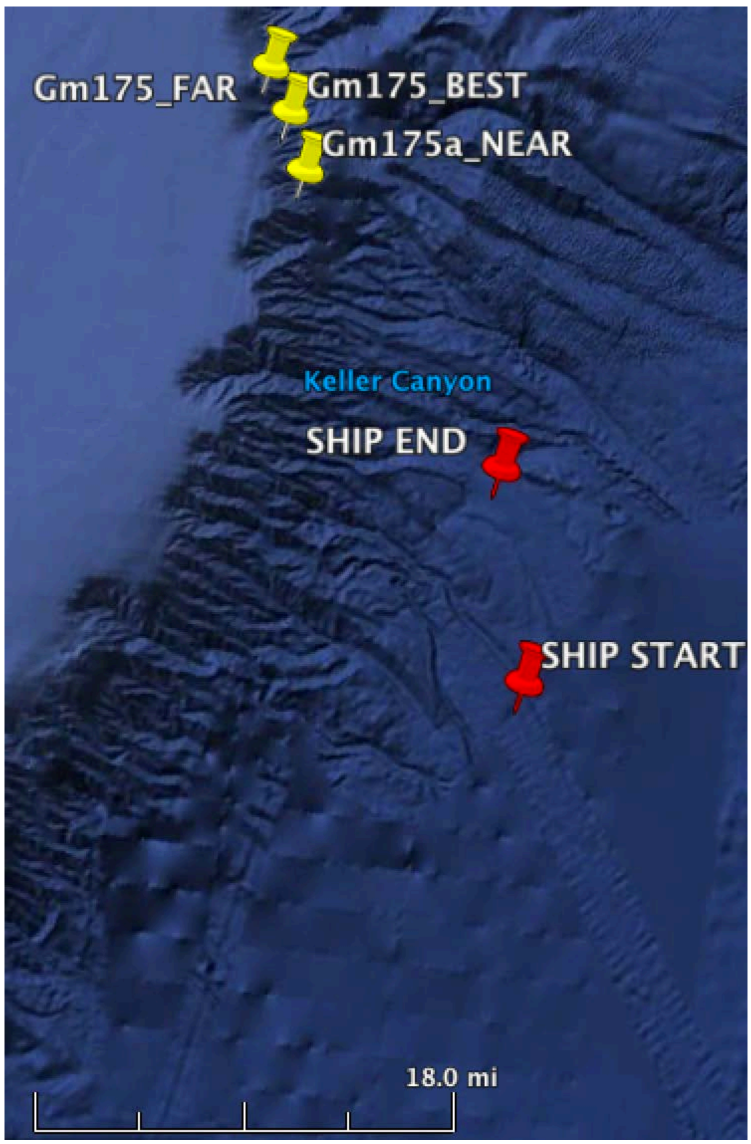

Figure 49. Simple characterization of “best” spatial position of pilot whale Gm175 at Douglas-filtered ARGOS location point relative to a nominal start and end locations of a ship operating a MFAS source. “Near” and “Far” locations represent potential positional error for distances closer to and further from the best location determined by the ARGOS error class code.

By defining these points in an attempt to characterize spatial error, potential RLs associated with MFAS transmissions along the prescribed ship track can then be modeled for different potential locations. To illustrate this method, we conducted propagation modeling at the “near” “best” and “far” locations for Gm175 for both potential shallow (10m) and deep (300m = maximum dive depth reported from the tag closest to the surface location) vertical position. Sound propagation profiles and predicted RLs for locations along the ship course for the deep (300m) positions are shown below for the “near” (**Figure 50**), “best” (**Figure 51**), and “far” (**Figure 52**) locations.

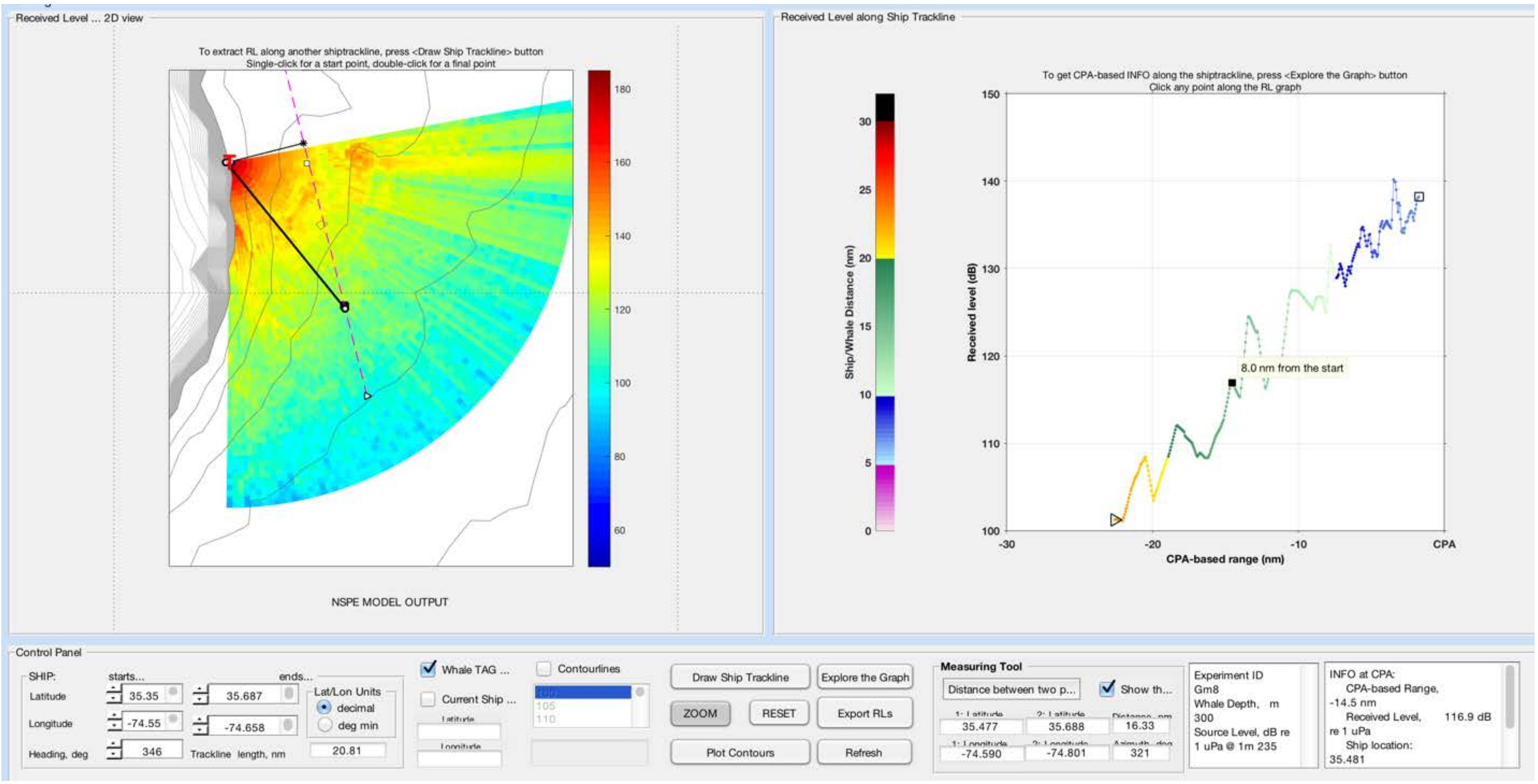

Figure 50. Modeled received levels for pilot whale Gm175 at "near" surface position (300m depth) using a simulated position of a real ship 53C sonar for mock CEE analysis.

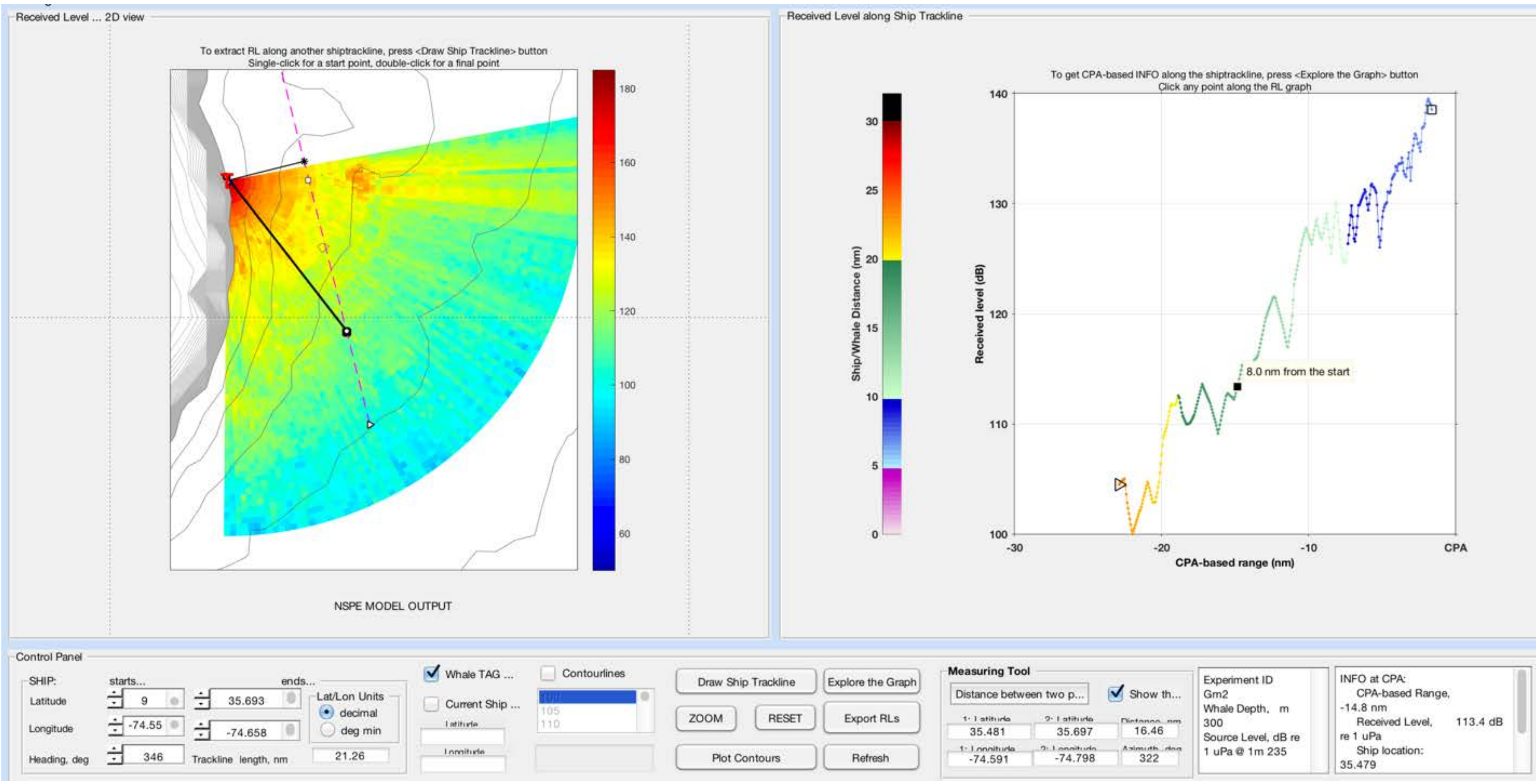

Figure 51. Modeled received levels for pilot whale Gm175 at "best" surface position (300m depth) using a simulated position of a real ship 53C sonar for mock CEE analysis.

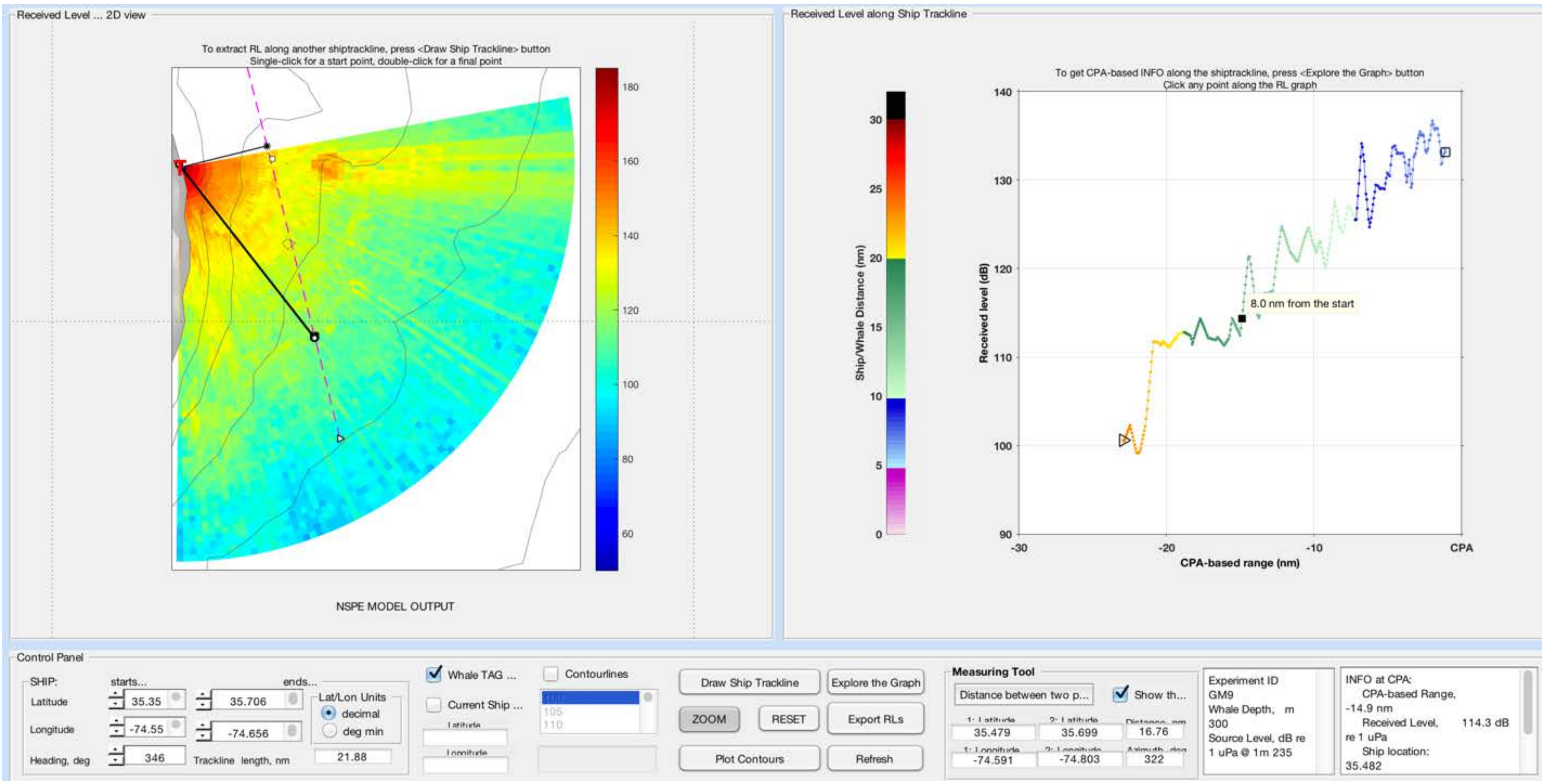

Figure 52. Modeled received levels for pilot whale Gm175 at “far” surface position (300m depth) using a simulated position of a real ship 53C sonar for mock CEE analysis.

This procedure conducted for all locations at 300m was then repeated for each location at shallow (10m) depth. This was done in an attempt to bound the depth region in which the animal was thought to likely occur, based on the maximum div recorded during this period and the fact that multiple surface events took place during this period. This resulted in modeled RLs at six defined points (i.e., 'near', 'best', 'far' locations for each of two depths) along a bearing from the vessel starting position, the horizontal location of which was defined by the reported ARGOS location (as the 'best' position) and the associated positional error (to determine the symmetrical range to the 'near' and 'far' positions. This process yields an estimate of RLs within this two-dimensional space that ranges from ~95-130 dB SPL assuming a 2-h MFAS transmission time along a 16-nm segment of the specified track of the ship (red dashed line in plots); slightly longer transmissions times were used for the mock CEE than in actual exposure experiments.

In an effort to improve on this coarse, two-dimensional characterization of potential positions of the animal and the associated RLs at these positions, we applied a more robust modeling approach to evaluate the same scenario for Gm175. We then joined the ARGOS error ellipse data to each Douglas-filtered track for each individual. We then fit a continuous-time correlated random walk (CRAWL) model to these data to estimate many (100) potential individual tracks that could occur based on the locations for the filtered track. In two-stage movement analyses, these are referred to as imputation distributions (Scharf et al., 2017). The resulting 100 potential tracks from the output of the CRAWL model are shown below (**Figure 53**) relative to the same nominal ship course modeled in the example above.

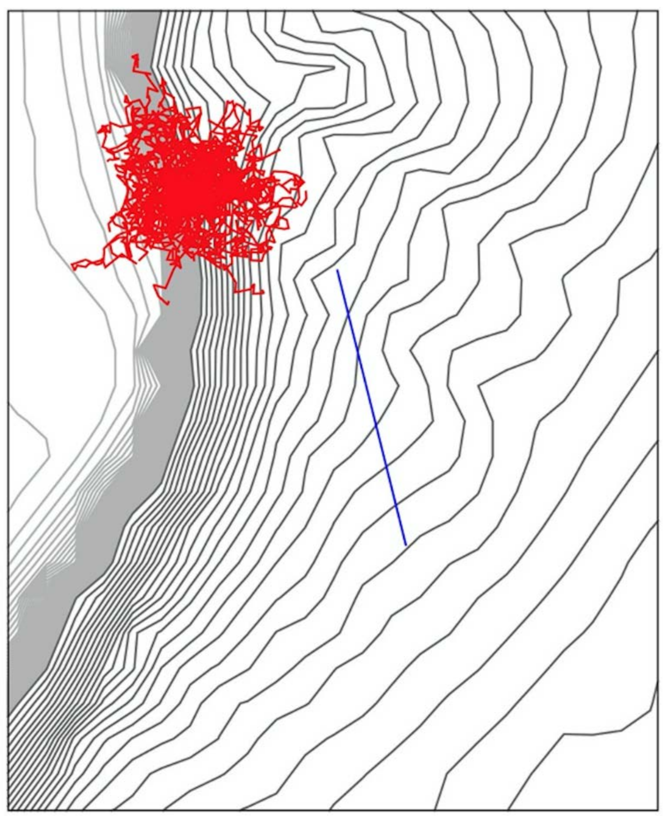

Figure 53. 100 individual potential tracks determined using CRAWL modeling of Douglas-filtered ARGOS track locations for Gm175 (red) during a 2-h period. Tracks are shown in relation to the presumed transit of a ship transmitting MFAS (blue line) during a mock CEE.

During the CEE when the ship is actively pinging, we need to calculate the RL for the animal for each ping. Though the ship is pinging every 25 seconds, we chose to model the RL on the animal every 5 minutes. (This resolution represents a compromise between the frequency of pings (25s) and the frequency of observed locations for the animal (3-4/day).) At each 5-minute interval, we traced a ray line (or whatever this is called) from the ship to the corresponding position of the animal at that time (grey lines in **Figure 54**). Using the same model assumptions as before, and updating the HYCOM component to be for 23 May 2017, we estimated the RL for each depth in the water column. To capture the effect of positional uncertainty in the animal's location, we repeated this process for each of 100 predicted movement tracks.

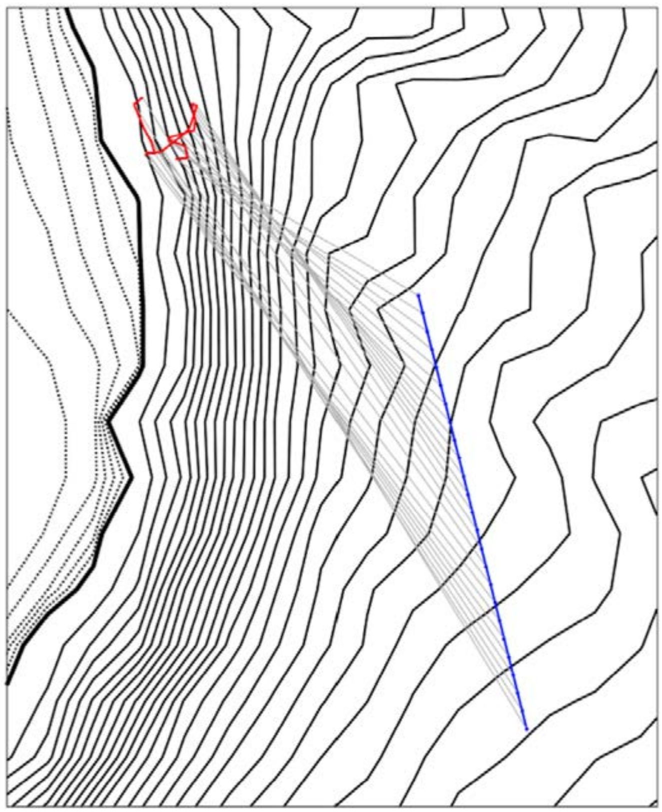

Figure 54. Illustration of a single potential track for Gm175 (red) determined using CRAWL modeling of Douglas-filtered ARGOS track locations shown in relation to the presumed transit of a ship transmitting MFAS (blue line) during a mock CEE. Gray lines illustrate ray-tracing model bearings for points along the ship track corresponding to 5-min increments along its course. RLs were modeled for each corresponding location on this track at each increment. This procedure was replicated for all other modeled tracks at each ship location.

Using this method for each ship location and for all 100 potential modeled animal tracks, a more robust representation of animal position and associated RLs may be determined; that is, we fully characterize the uncertainty inherent in this system. Movement behavior of Gm175 as represented by all 100 track imputations is show below (**Figure 55**), both for the entire deployment (left) and during a 6-h period spanning before, during, and after the mock CEE (right); see figure caption for specific details.

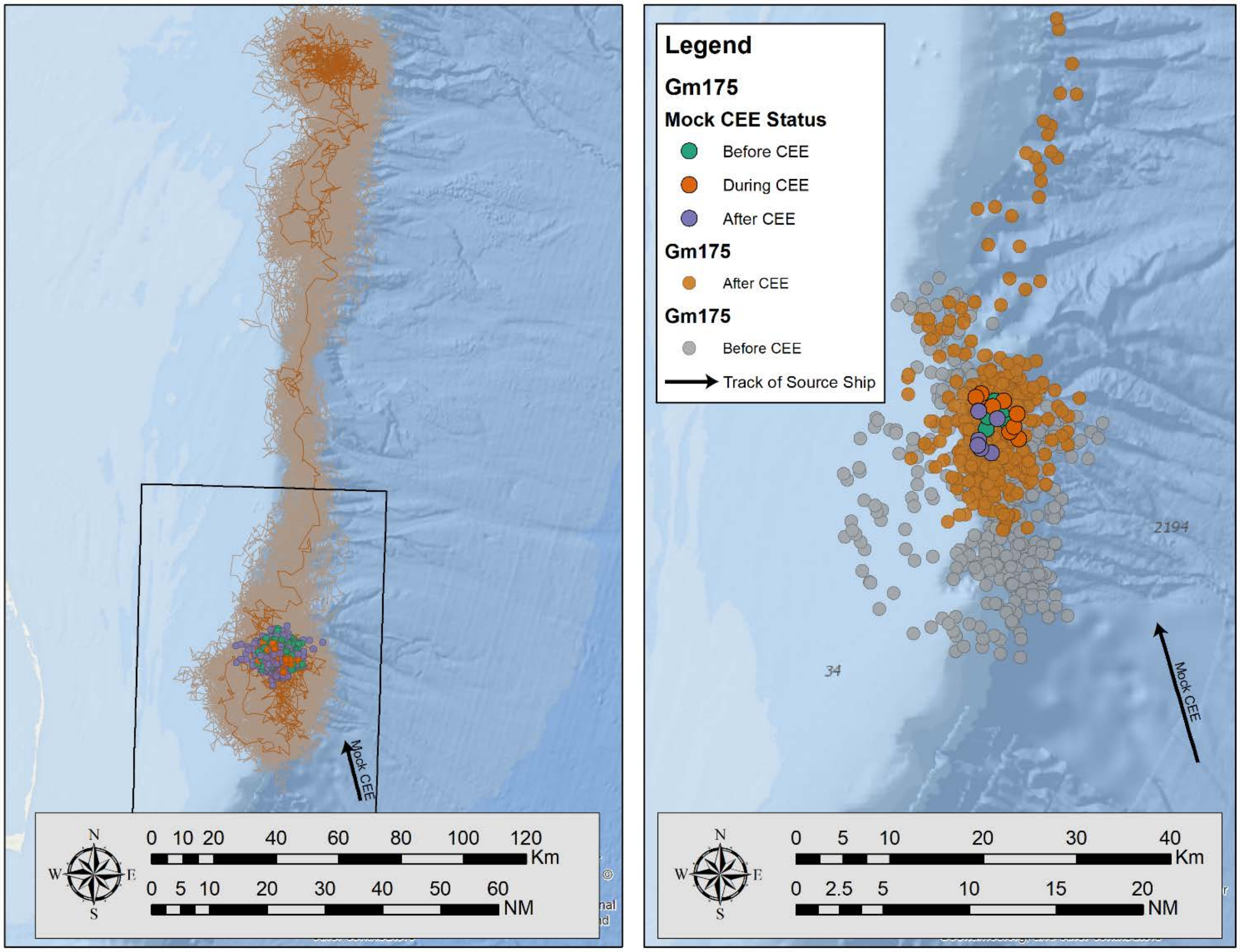

Figure 55. Individual potential tracks for Gm175 determined using CRAWL modeling of Douglas-filtered ARGOS track locations shown in relation to the known transit of a Navy ship during a mock CEE period on 23 May 2017. The left panel shows all positions of all 100 tracks (light orange), all positions for a randomly selected single track highlighted in dark orange. Positions for all 100 tracks are highlighted for a 2-h period before the CEE (green), the 1-h exposure period (red), and a 2-h period after the CEE (purple). The right panel focuses on a single randomly selected track (same track in left panel) relative to the ship's course, showing individual locations >2h before the CEE (grey), locations during a 2-h period before the CEE (green), the 1-h exposure period (red), a 2-h period after the CEE (purple), and locations > 2h after the CEE (orange).

For each animal position at each 5-min interval, RLs were modeled for all depths, providing the ability to characterize the predicted noise exposure in three-dimensions (volumetrically) in a manner that more fully accounts for the positional error associated with the ARGOS locations. Where the water depth at the modeled location was shallower than the presumed animal depth, values were excluded. To illustrate this, modeled RLs at discrete depth layers (10m, 100m and 300m) are presented to demonstrate the associated variability in RLs at positions along the ship track (**Figure 56**). Boxplots show the median and quartile values of the RLs on the animal, for each 5-min interval during the ship's CEE. Box whiskers represent two standard deviations from median values; red crosses indicate outlier values (> 2.7 SD from median values).

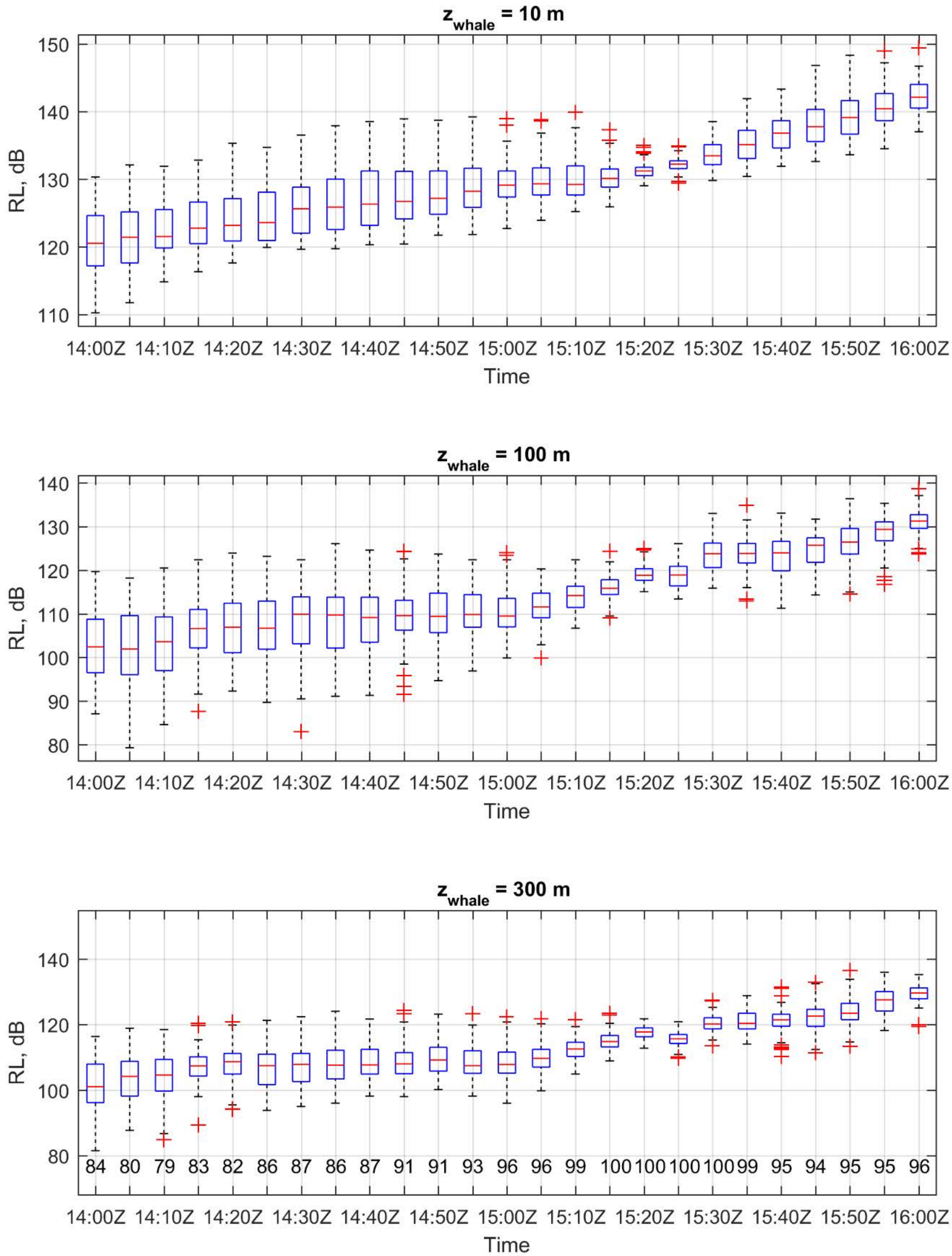

Figure 56. Box plots show the median and quartile values for modeled RLs at 100 potential locations of Gm175 during a mock CEE with a ship transmitting MFAS from 1400-1600Z. Box whiskers represent two standard deviations from median values; red crosses indicate outlier values (> 2 SD from median values). Numerical values below each box plot on the 300m depth layer indicate the number of tracks at each location (out of 100) that were used; modeled locations shallower than the depth layer were excluded.

REAL SHIP (53C) CEE SATELLITE TAG ANALYSIS – SPATIAL MOVEMENT AND RL MODELING

We are currently applying the spatial movement modeling and RL modeling methods developed in the mock CEE analysis described for Gm175 for all satellite-tagged individuals during both the simulated sonar CEE (#2017-01) and the *USS MACFAUL* 53C sonar CEE (#2017-02). These analyses are extensive and ongoing, but initial spatial movement and modeled RL results are presented here for an individual pilot whale (Gm182) and an individual beaked whale (Zc68) that were considered 'focal' during this CEE. As described above (**Section 2**) neither individual was visually focal-followed during this CEE, however these were the individuals assumed to be closest to the *MACFAUL* during the CEE—the CEE for which we conducted the most extensive *in situ* RL modeling. Results presented for Gm182 here should be compared to **Figures 30** and **31**. Results presented here for Zc68 should be compared to **Figures 32** and **33**.

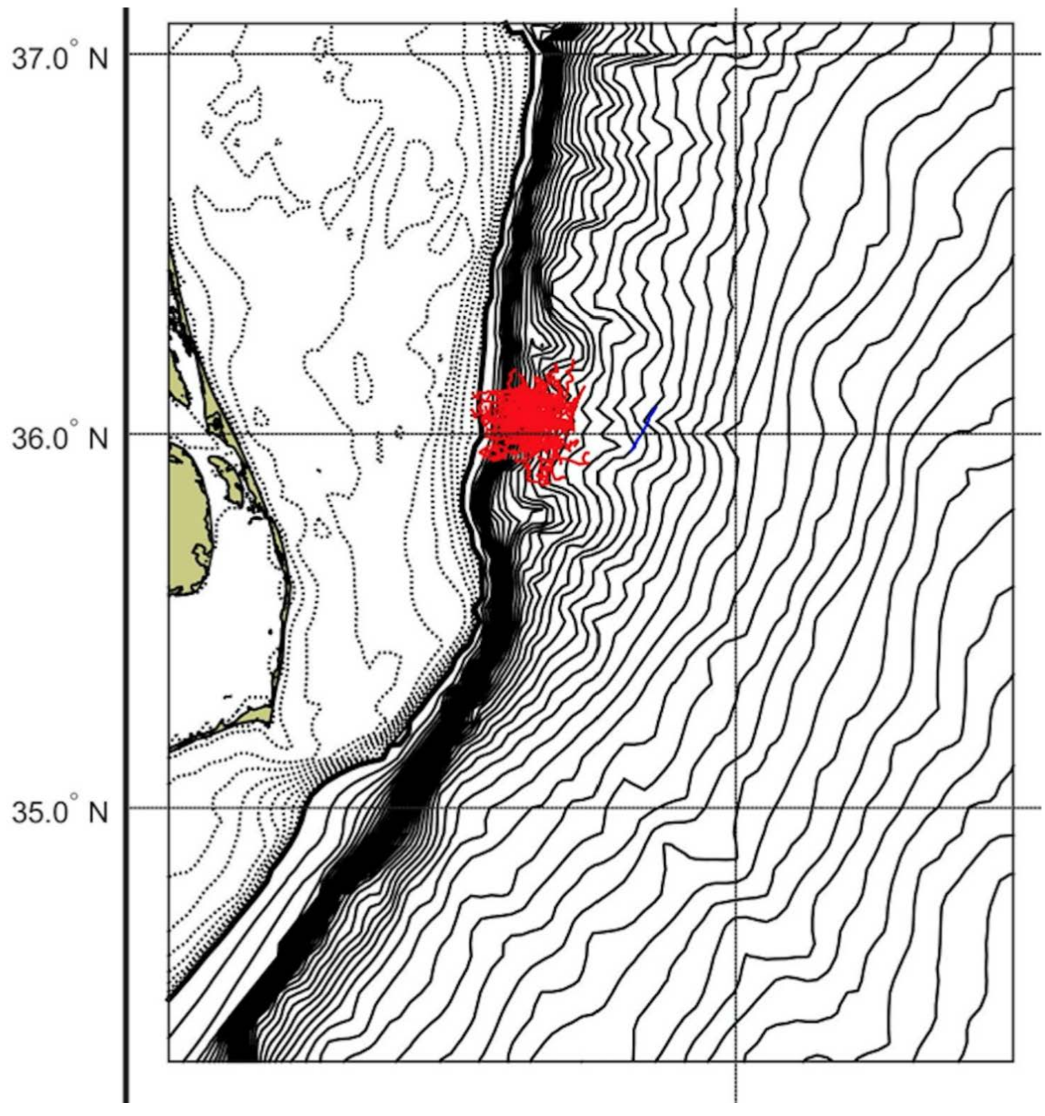

Figure 57. 100 individual potential tracks determined using CRAWL modeling of Douglas-filtered ARGOS track locations for Gm182 (red) during a 1-h period of 12 September in relation to the known transit of *USS MACFAUL* transmitting MFAS (blue line) during CEE #2017-02.

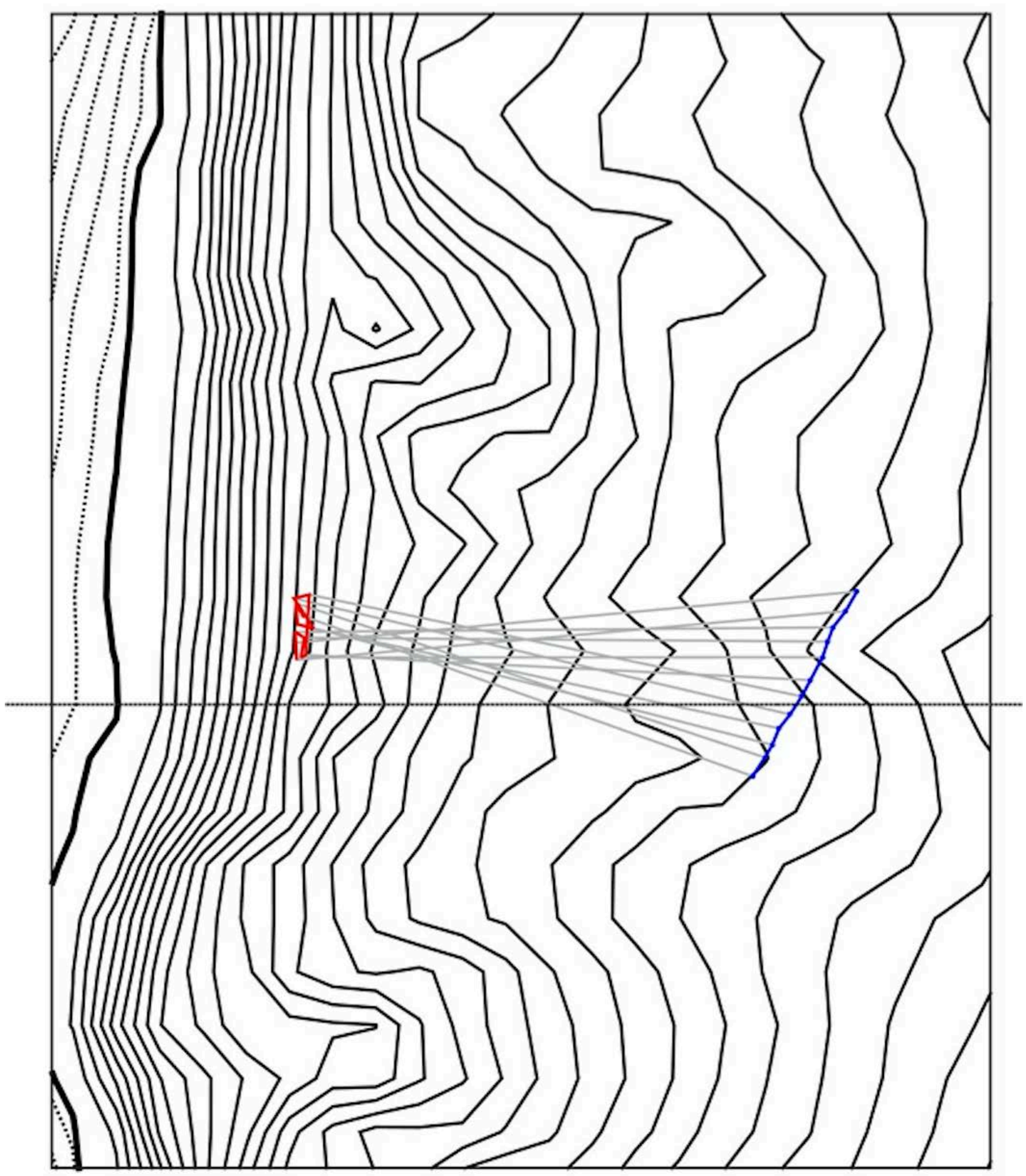

Figure 58. Single modeled track for Gm182 (red) determined using CRAWL modeling of Douglas-filtered ARGOS track locations shown in relation to the known transit of *USS MACFAUL* transmitting MFAS (blue line) during CEE #2017-02. Gray lines illustrate ray-tracing model bearings for points along the ship track corresponding to 5-min increments along its known course. RLs were modeled for each corresponding location on this track at each increment. This procedure was replicated for all other modeled tracks at each ship location.

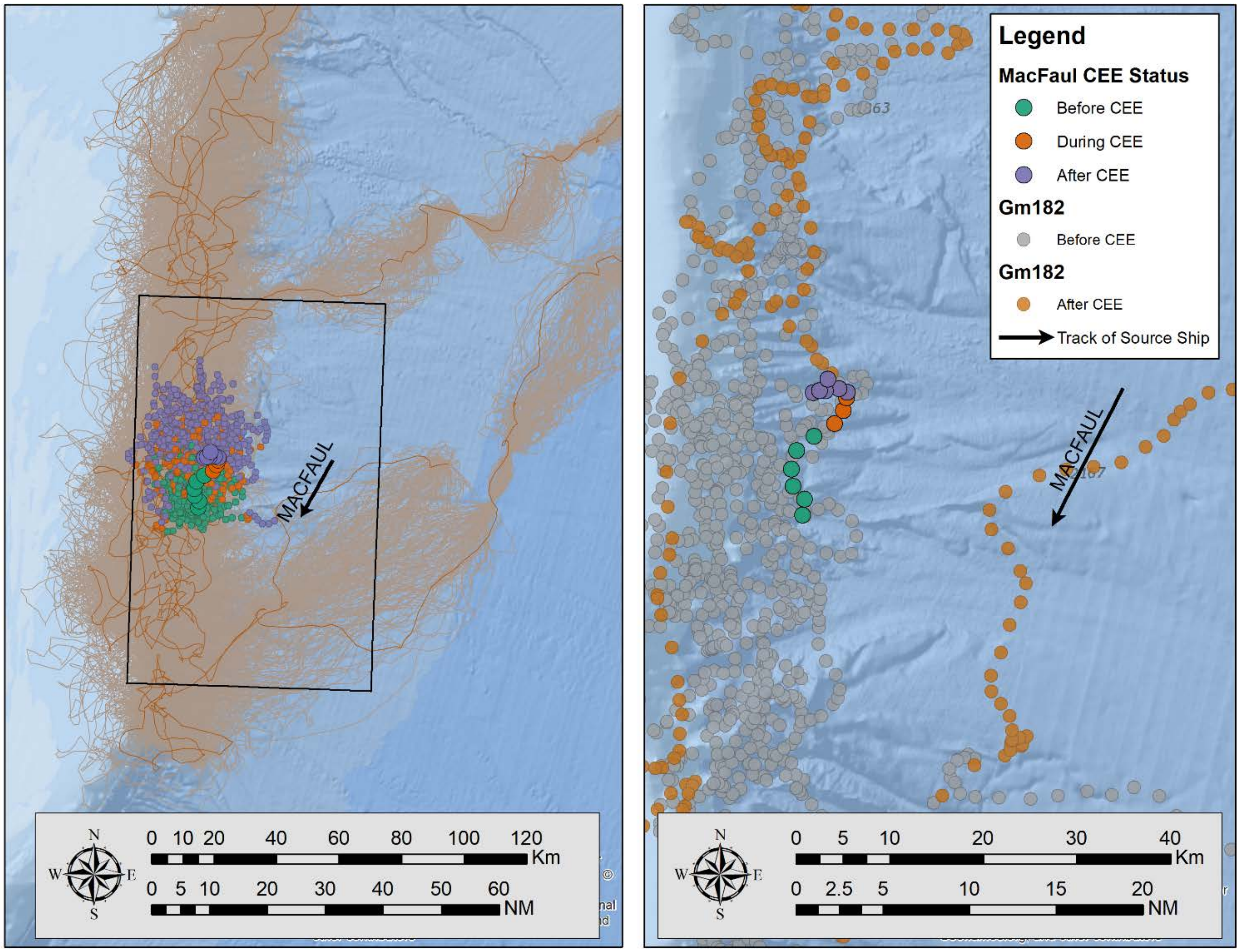

Figure 59. Individual potential tracks for Gm182 determined using CRAWL modeling of Douglas-filtered ARGOS track locations shown in relation to the known transit of *USS MACFAUL* transmitting MFAS during CEE #2017-02 on 12 September 2017. The left panel shows all positions of all 100 tracks (light orange), all positions for a randomly selected single track highlighted in dark orange. Positions for all 100 tracks are highlighted for a 2-h period before the CEE (green), the 1-h exposure period (red), and a 2-h period after the CEE (purple). The right panel focuses on a single randomly selected track (same track in left panel) relative to the *MACFAUL* course, showing individual locations >2h before the CEE (grey), locations during a 2-h period before the CEE (green), the 1-h exposure period (red), a 2-h period after the CEE (purple), and locations > 2h after the CEE (orange).

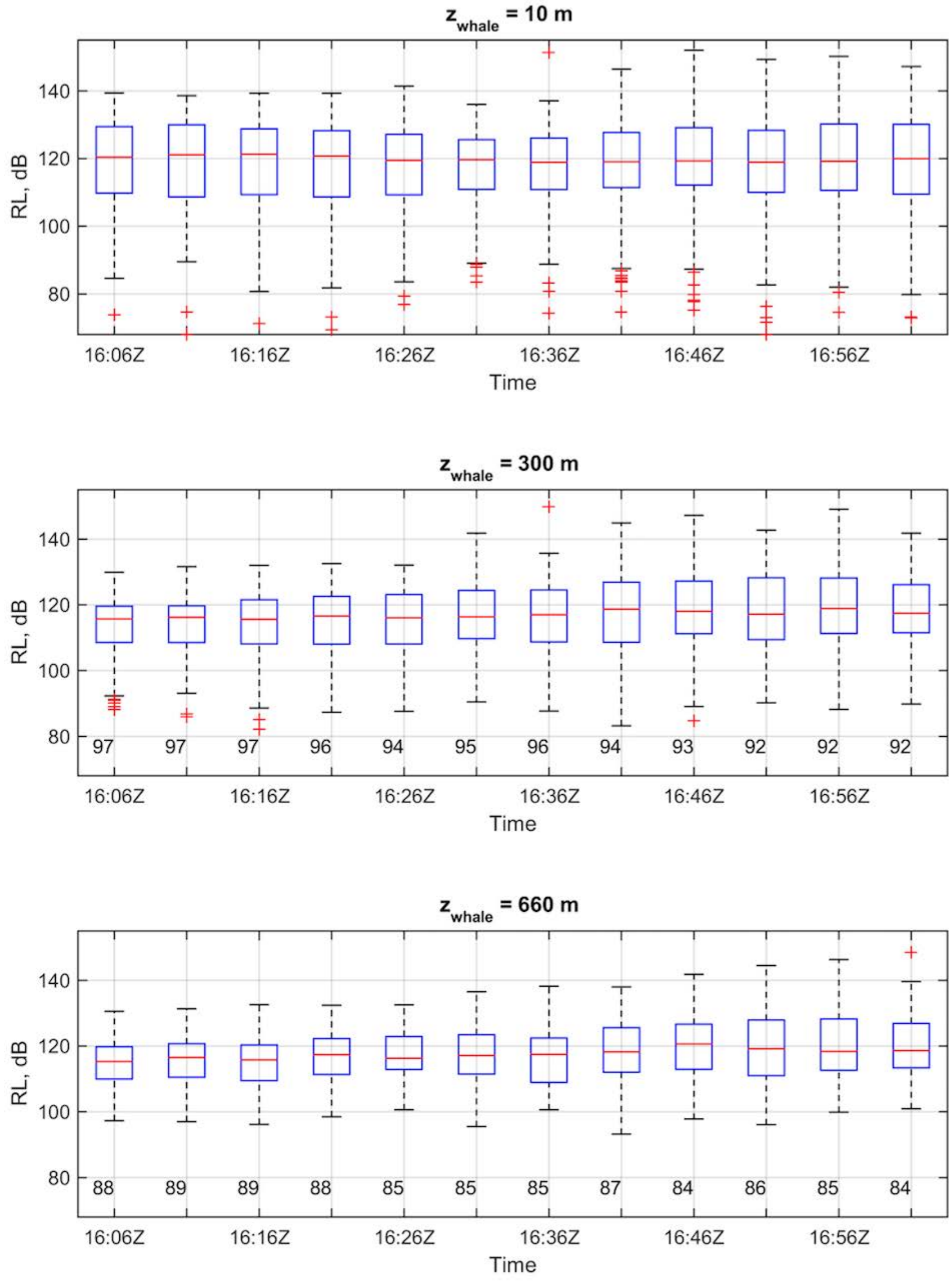

Figure 60. Box plots show the median and quartile values for modeled RLs at 100 potential locations of Gm182 during CEE #2017-02 from 1603-1703Z on 12 September 2017. Modeled RL results are presented for a shallow depth (10m), a mid-water depth (300m) and a depth corresponding to the maximum dive reported from the tagged individual closest to the CEE period (660m). Box whiskers represent two standard deviations from median values; red crosses indicate outlier values (> 2 SD from median values). Numerical values below box plots indicate the number of tracks at each location (out of 100) that were used; modeled locations shallower than the depth layer were excluded.

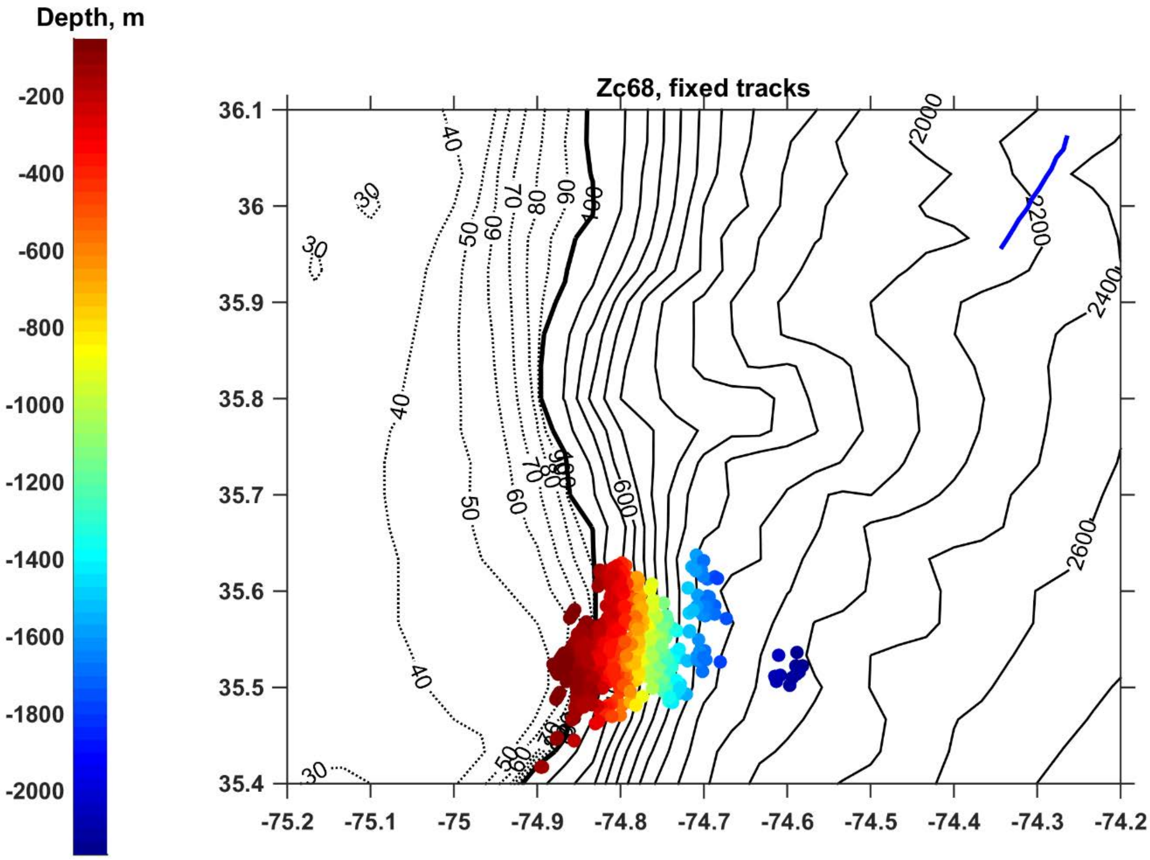

Figure 61. 100 individual potential tracks determined using CRAWL modeling of Douglas-filtered ARGOS track locations for Zc68 during a 1-h period of 12 September in relation to the known transit of *USS MACFAUL* transmitting MFAS (blue line) during CEE #2017-02. Points of the animal are color coded according to depth of the ocean floor.

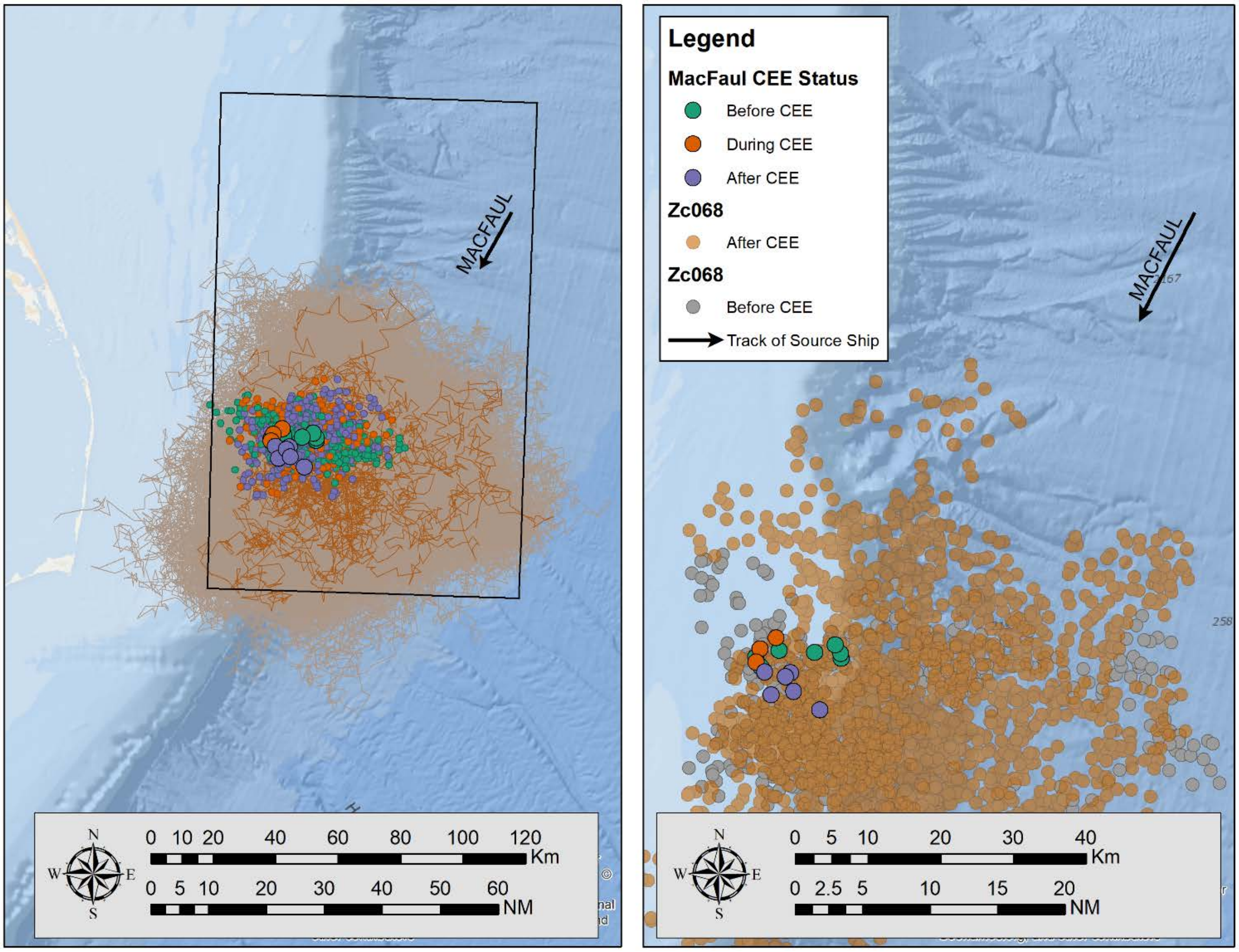

Figure 62. Individual potential tracks for Zc68 determined using CRAWL modeling of Douglas-filtered ARGOS track locations shown in relation to the known transit of *USS MACFAUL* transmitting MFAS during CEE #2017-02 on 12 September 2017. The left panel shows all positions of all 100 tracks (light orange), all positions for a single randomly selected track highlighted in dark orange, and positions for all 100 tracks for a 2-h period before the CEE (green), the 1-h exposure period (red), and a 2-h period after the CEE (purple). The right panel focuses on a single randomly selected track relative to the *MACFAUL* course, showing individual locations >2h before the CEE (grey), locations during a 2-h period before the CEE (green), the 1-h exposure period (red), a 2-h period after the CEE (purple), and locations > 2h after the CEE (orange).

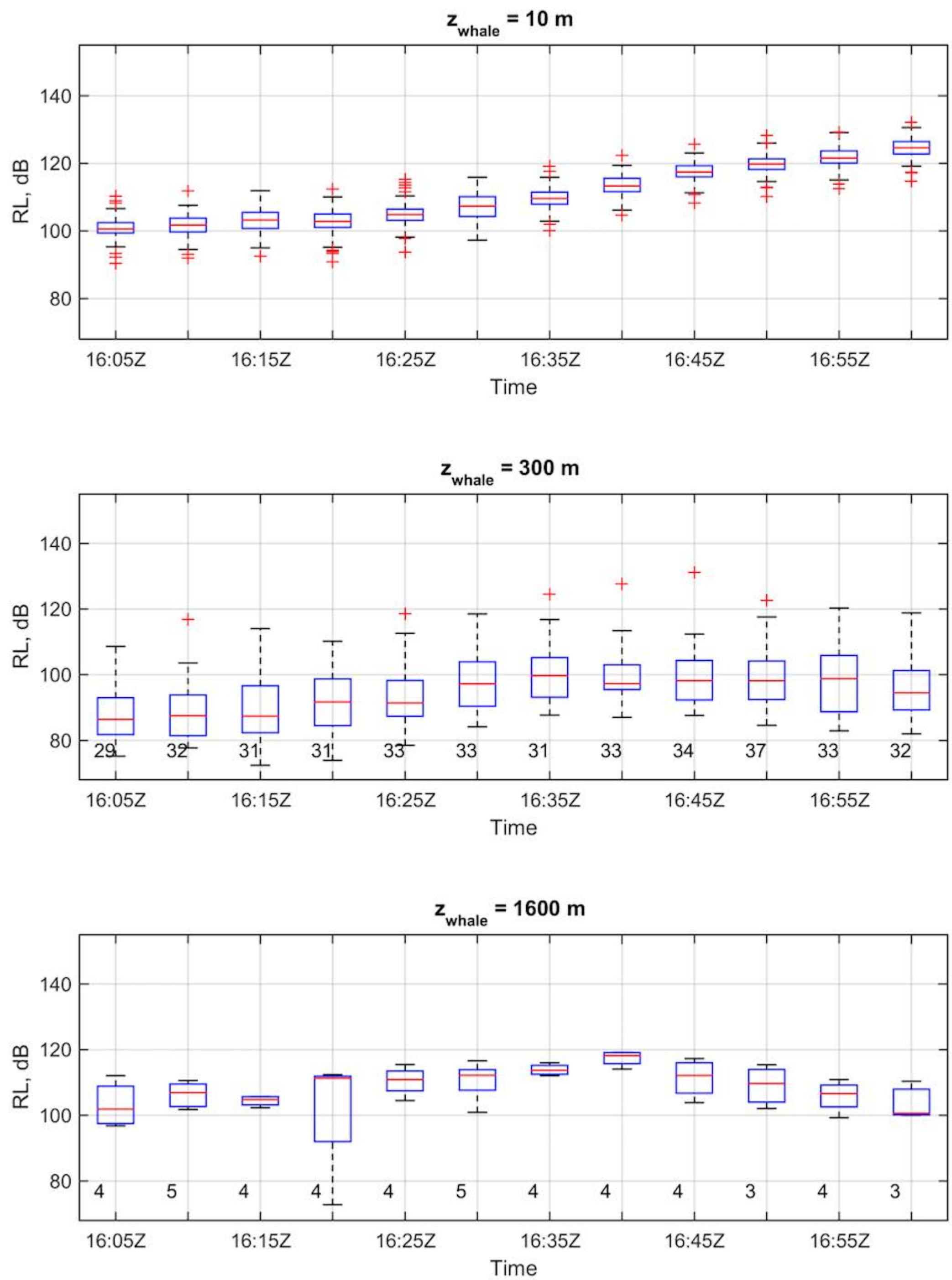

Figure 63. Box plots show the median and quartile values for modeled RLs at 100 potential locations of Zc68 during CEE #2017-02 from 1603-1703Z on 12 September 2017. Modeled RL results are presented for a shallow depth (10m), a mid-water depth (300m) and a depth corresponding to the maximum dive reported from the tagged individual closest to the CEE period (1600m). Box whiskers represent two standard deviations from median values; red crosses indicate outlier values (> 2 SD from median values). Numerical values below box plots indicate the number of tracks at each location (out of 100) that were used; modeled locations shallower than the depth layer were excluded.

REAL SHIP (53C) CEE SATELLITE TAG ANALYSIS – DIVING AND FORAGING ANALYSIS

Regression analysis of dive parameters across all individuals

Regression models (Generalized Estimating Equations, GEEs) were used in an initial evaluation of potential differences in dive behavior across all tagged whales. Specifically, GEEs estimate the average response over the population. The data utilized thusfar includes 14 satellite tagged *Ziphius*, five from the spring field season and nine from the fall field season. Of those nine from the Fall, two were exposed only to the simulated MFAS source (CEE #2017-01), three only to the MACFAUL CEE (#2017-02), and four were exposed to both. Response variables of interest include dive depth, dive duration and inter deep dive interval. Explanatory variables include exposure status (before or after exposure), time since exposure event, dive shape ("U", "V" or "Square), age and sex class.

Initial steps included extensive checking of data and preliminary models. In particular, we evaluated the presence of influential individuals and time periods. Due to varying tag durations, data were truncated to one week after the last exposure event (either CEE depending on tag). This limited the influence of a few tags with long durations. Initially one week was felt to be a reasonable compromise between the expected duration of any response, and looking for longer term responses (beyond the duration of a DTAG). However, these analyses will be rerun with a shorter truncation time following the results from the Mahalanobis distance analysis (see below). In particular, this should help limit the influence of behavioral changes that occur due to a change in circumstances (e.g., environment or prey availability) long after the baseline period that are highly unlikely to be related to the exposure event.

Models were initially fit to the dive depth and inter deep dive interval for all dives (up to one week post exposure) for all whales, and results were examined carefully. Following this we carried out the analysis described below to determine whether there were any underlying differences in the behavior of animals between the spring and fall deployments.

Given our uncertainty regarding an appropriate post-exposure duration to include in the analysis, and the functional form of any decay in response over time, it was agreed to prioritize the individual-based Mahalanobis distance analysis to obtain a better understanding of the probable scale of any responses to either the scaled or CEE exposure. It was felt that gaining a better understanding of individual responses would aid interpretation of the "population-average" results from the GEEs.

The next steps for this analysis are to reduce the post-exposure time-scale included in the analysis, investigate the role of a range of environmental covariates (see seasonal influences below), and test different functional forms for the "time since exposure" covariate.

Regression analysis of seasonal differences in foraging behavior

Following examination of output from the initial set of regression models fitted to the dive variables (described above in **Section 1**), we added a time period covariate to the models to assess any differences in the behavior of animals tagged during the two field seasons – Spring and Fall. We compared the baseline dive data from all of the tagged animals in Spring with the pre-exposure data from all of the tagged animals in Fall. We found evidence of a small, but significant, difference in the overall dive depth and duration of animals tagged in Spring and the animals tagged in August. In particular, “V”-shaped dives (thought to be related to foraging) appear to be slightly shallower and longer in duration in the Fall compared with “V”-shaped dives in the Spring. There could be many reasons for this, and the next step is to look to see whether this difference can be explained by environmental covariates. If we can establish a reason for the difference then it will be possible to combine the data for the purposes of response analysis. A range of environmental covariates have been extracted for these tags (from sampling the output of the CRAWL model) to allow us to investigate this further. Covariates include depth of ocean, distance to 300m isobath and distance to major canyons.

Mahalanobis Distance analysis – individual based analysis

Mahalanobis distance analysis was used to evaluate whale’s behavior on a dive-by-dive basis by comparing all dives in an individual’s time-series of dives with its’ own average baseline dive behavior (following DeRuiter et al. 2013). The goal of this analysis was to assess whether specific exposure and post-exposure dives were unusual (in multi-variate space). Baseline was defined as pre-exposure. As this analysis was carried out on the satellite tag data it focused on three variables – dive depth, dive duration and inter deep dive interval.

The first step in the analysis was to evaluate different dive types as distances should only be calculated between dives within the same dive type. We conducted K-means cluster analysis on all of the baseline and pre-exposure dives from the fall field season. Using silhouette analysis, there was little evidence for more than one dive type and therefore we proceeded on the basis that all dives belong to the same dive type. This does not seem an unreasonable conclusion given that the data were already filtered to include only dives over 33 minutes.

To ensure reasonable estimates of the variance-covariance matrix we included all of the data from the Aug/Sept tags (pre- and post-exposure). Including the exposure and post-exposure period in the calculation is conservative in that it will reduce the apparent distance between truly unusual behavior and the average. The same variance-covariance matrix was used for all analyses (i.e., each individual comparison with its own baseline).

Each dive was categorized as either baseline, during or post-exposure as follows. We initially evaluated at those tags that were coincident with the scaled exposure. For these, baseline dives were defined as all dives before the scaled exposure event for an individual. We then compared all baseline dives, the exposure dive (during scaled) and 24 hours of post-exposure dives with the average baseline dive for that individual. We then fitted a GLM (or GEE if evidence of autocorrelation) to the distance values with exposure status (baseline, during, post), time since exposure and dive shape as explanatory variables. On the basis that there were no responses to the scaled exposure that lasted more than 24-h post-exposure (see results below), we used all data up to the CEE exposure as baseline, minus the dive during the scaled exposure and 24 hours post scaled exposure, to assess any effect of the CEE exposure. We then compared all baseline dives, the exposure dive (during CEE) and 24 hours of post-exposure dives with the average baseline dive for that individual. We then fitted a GLM (or GEE if evidence of autocorrelation) to the distance values with exposure status (baseline, during, post), time since exposure and dive shape as explanatory variables. Tag Zc65 was excluded from this analysis because of insufficient baseline data (1 dive prior to scaled exposure).

Preliminary results indicate that one of five tagged whales exposed to the scaled exposure had a significantly higher Mahalanobis distance value for the dive during exposure compared to the average baseline dive. For no whales was there a significant difference in Mahalanobis distance values between baseline and the 24-h post scaled exposure period.

Two of the seven whales exposed to the CEE had a significantly higher Mahalanobis distance value for the dive during exposure compared to the average baseline dive. For no whales was there a significant difference in Mahalanobis distance values between baseline and the 24-h post CEE exposure period. However, for two whales there was a significant effect of "time since exposure" indicating a decrease in the distance value post exposure. This remains a subject of current and further investigation, as is underlying driver of the higher Mahalanobis distance in the cases where there was a significant difference from baseline (*i.e.*, was the dive deeper, or longer, or have a longer inter deep dive interval than the average baseline dive?).

In addition, these results need to be examined in the context of where the tagged whales were relative to the exposures as well as their environmental context. This may help explain why some individuals appear to have carried out unusual dives during exposure whilst others did not. It can also be seen in the example figures below (Figs 64 & 65) that there are other "unusual" dives in the time-series for some individuals and that some of these fall in the baseline periods. We would like to better understand these unusual dives and the environment in which they occur. A range of environmental and exposure covariates have been extracted for these tags (from sampling the output of the CRAWL model), which will allow this next step to be conducted. Finally, additional simulations will be conducted to evaluate the power to detect responses given the levels of variability in dive behavior, even within an individual. Example results to date for individual-based Mahalanobis distance analysis are provided for the two focal individuals for CEE #2017-02 with the *USS MACFAUL* on 12 September 2017.

In this analysis, each dive within the time-series for ZcTag68 was compared (in multivariate space) with the average baseline dive for this individual. Time-series of Mahalanobis distances for Zc68, truncated at 24-h post CEE exposure are shown below (**Figure 64**). It can be seen that there was a peak in Mahalanobis distance at dive 81, which was the third dive after the exposure event, and started 47 minutes after the end of the exposure event. **Figure 65** shows a density plot for the distances, demonstrating that the exposure dive itself was not particularly unusual but that the highest distance value was attributable to a post-exposure dive (#81). **Figure 65** shows the time-series of Mahalanobis distances below time-series plots for the variables included in the calculation. On visual inspection, dive 79, which was the exposure dive, did not appear to be unusual in terms of MDist and the individual variables. Dive 80 was a short, shallow dive with a short inter-deep dive interval following the dive, but was not flagged as being particularly unusual in multivariate space. Dive 81 was within normal limits for depth and dive duration, but had an unusually long inter-deep dive interval of >15,000secs (>4 hours).

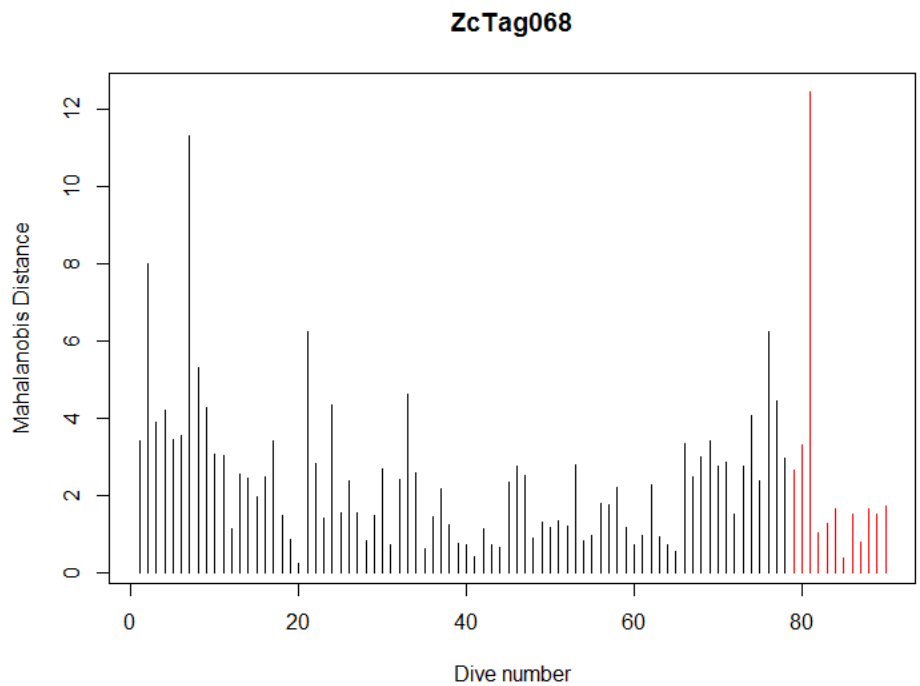

Figure 64. Time series of dives for individual Zc68 with the height of each line representing the distance (in multivariate space) of each dive from the average baseline dive for this individual. Baseline dives are in black, during and post CEE exposure dives are in red. The dive coincident with exposure, i.e. the during dive, was dive 79 and is the first dive shown in red. The time-series has been truncated 24 hours after the exposure event.

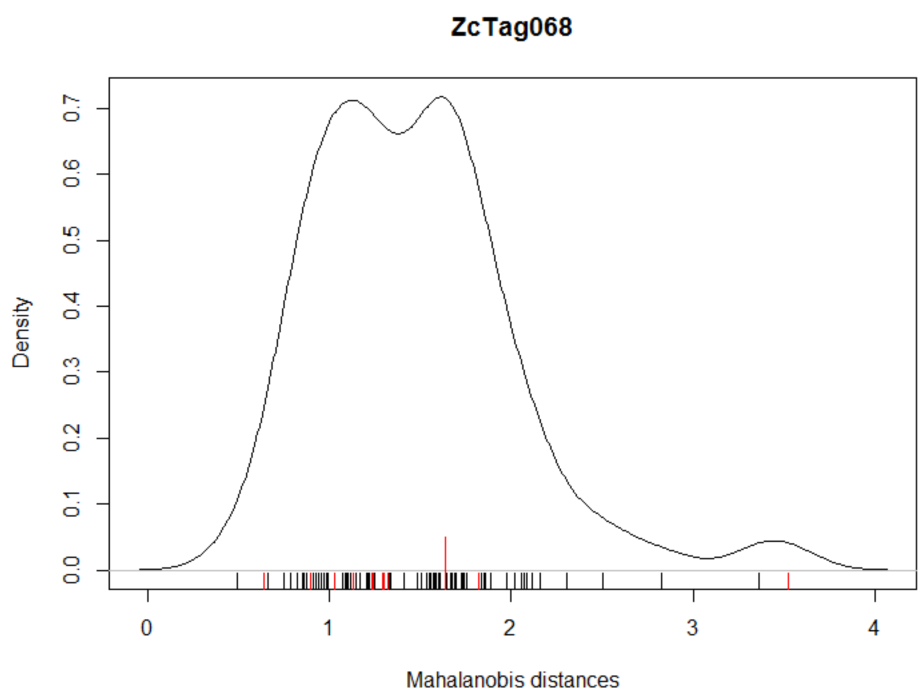

Figure 65. Density plot of Mahalanobis distances (shown as square root of distance). The black curve shows the proportion of observations at each distance. At the bottom of the plot, along the x-axis, the black tick marks indicate distances for baseline dives, and red ticks are during and post CEE. The taller tick mark indicates the dive cycle that included the exposure event.

We fitted a GEE to the Mahalanobis distances with dive shape, exposure status and time since exposure as variables. Only time since exposure was retained during model selection. There was a significant negative relationship between time since exposure and Mahalanobis distance, indicating that as time since the exposure event increased the Mahalanobis distance decreased. This can be attributed to the high Mahalanobis distance shortly after exposure (associated with dive 81 – see **Figure 66**) and then the return to much lower distance values immediately after.

An initial analysis of time-series of environmental covariates were conducted for Zc68, including bathymetry, distance to shelf, distance to canyons and distance to MACFAUL. In evaluating these covariates (**Figure 67**) the exposure dive is highlighted in red. Each of these covariates is plotted against the Mahalanobis distance values (**Figure 68**).

We refitted the above GEE model on Mahalanobis distance values and included bathymetry, distance to shelf, distance to canyons and distance to the CEE ship as well as dive shape, exposure status and time since exposure as variables. The selected model was identical to the previous model, with only time since exposure retained. None of the additional environmental/exposure covariates were retained during model selection.

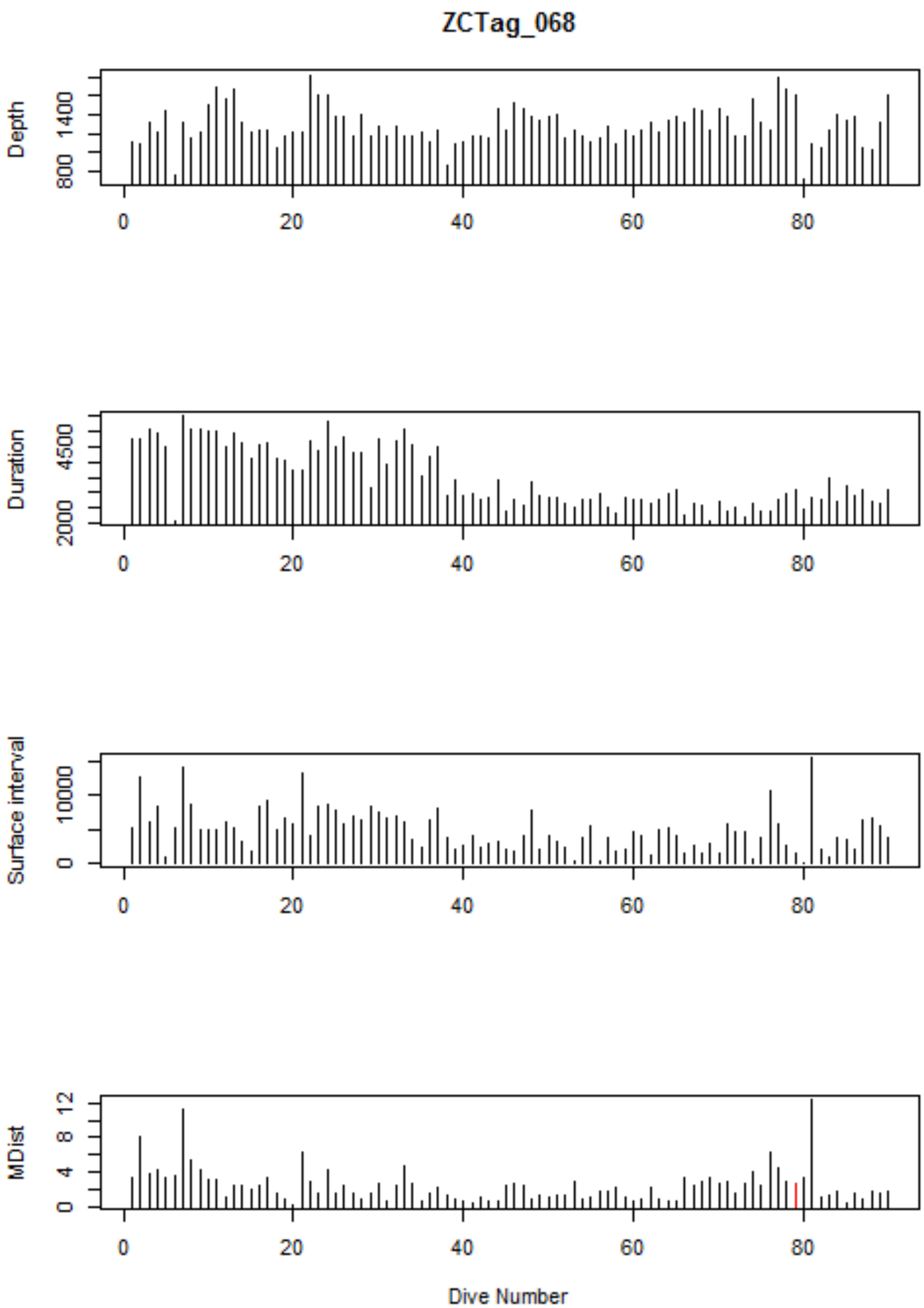

Figure 66. Panel of time-series plots with dive depth (top plot), dive duration (2nd from the top), inter-deep dive interval (2nd from bottom) and Mahalanobis distance (bottom). On the bottom plot the exposure dive (dive 79) is indicated in red. The time-series has been truncated 24 hours after the exposure event.

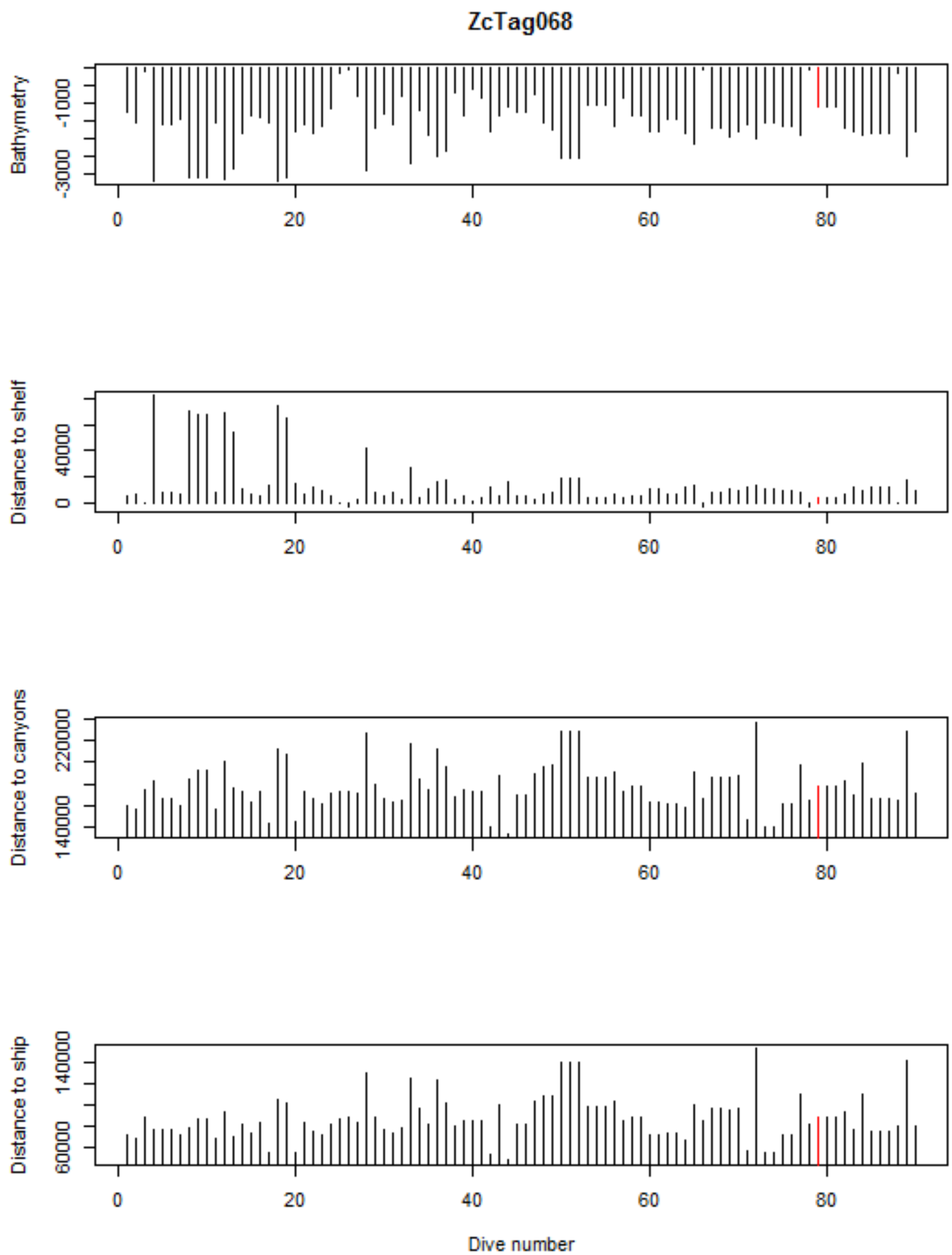

Figure 67. Time-series plots of environmental and exposure covariates. Top plot shows bathymetry, 2nd top plot shows distance to shelf, 2nd bottom plot shows distance to canyons and bottom plot shows distance to exposure ship. In each plot the exposure dive is indicated in red. The time-series has been truncated 24 hours after the exposure event.

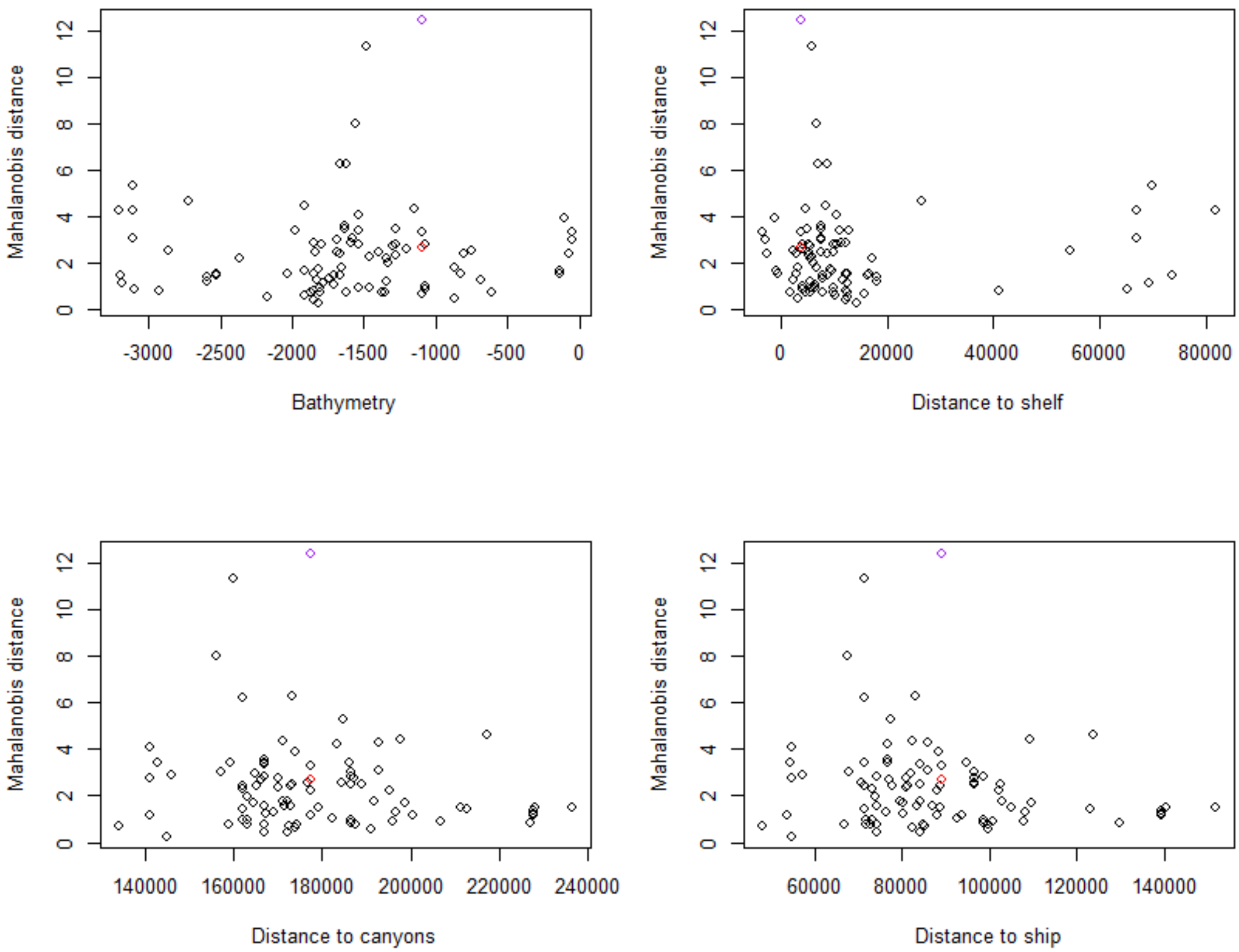

Figure 68: Mahalanobis distance against each of the environmental/exposure covariates. In each panel the exposure dive (dive 79) is indicated in red and the dive with the highest Mahalanobis distance value (dive 81) is indicated in purple. The plots only include data up to 24-h post exposure.

For the pilot whale tags, the first step in the analysis was to check for different dive types as distances should only be calculated between dives within the same dive type. We conducted k-means cluster analysis on all of the pre-exposure dives from the fall field season. Using silhouette analysis, there was only weak evidence for more than one dive type and therefore we proceeded on the basis that all dives belong to the same dive type.

To ensure reasonable estimates of the variance-covariance matrix we included all of the data from the three tags (pre- and post-exposure). By including the exposure and post-exposure period in the calculation is conservative in that it will reduce the apparent distance between truly unusual behavior and the average. The same variance-covariance matrix was used for all analyses (i.e., each individual comparison with its own baseline).

In this analysis, each dive within the time-series for Gm182 was compared (in multivariate space) with the average baseline dive for this individual; the time-series of Mahalanobis distances for Gm182, was truncated at 24-h post scaled exposure (**Figure 69**). It can be seen that there was a peak in Mahalanobis distance at dive 127, which was the last dive within 24 hours of the scaled exposure event. This is being driven by an unusually long inter deep dive interval following this dive. It is not thought likely that this high Mahalanobis distance value is directly related to the exposure event given the apparently “normal” diving behavior prior to this dive. We therefore truncated the time-series at 18 hours post scaled exposure, which omitted this dive cycle, prior to regression analysis of the Mahalanobis distance values (**Figure 69**).

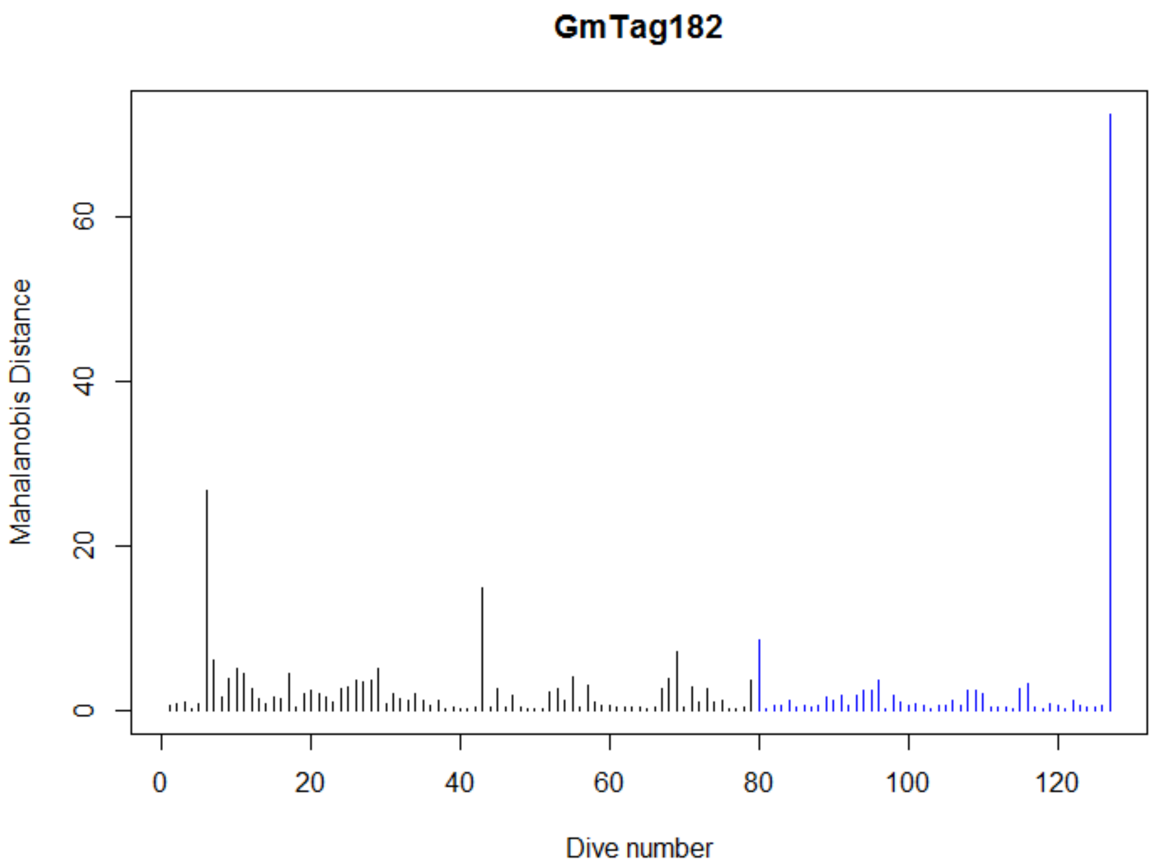

Figure 69. Time series of dives for individual Gm182 with the height of each line representing the distance (in multivariate space) of each dive from the average baseline dive for this individual. Baseline dives are in black, during and post scaled exposure dives are in blue. The dive coincident with exposure, i.e. the during dive, was dive 80 and is the first dive shown in blue. The time-series has been truncated 24-h after the exposure event.

We fitted a GEE to the Mahalanobis distances with dive shape, exposure status and time since exposure as variables. Only exposure status was retained during model selection. There were significant differences between each of the three factor levels – baseline, during and post exposure. The Mahalanobis distance value for the during scaled exposure dive was significantly higher than both baseline and post exposure, and baseline was significantly higher than post exposure (**Figure 70**).

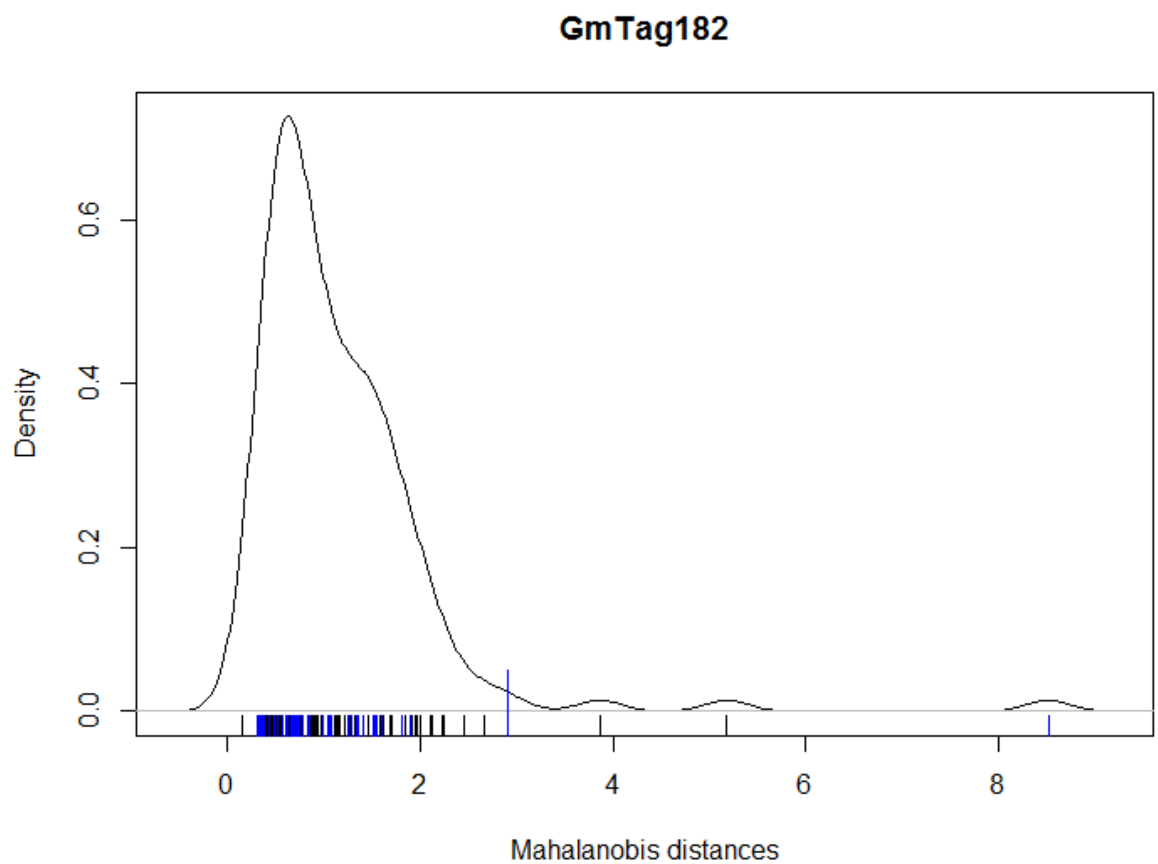

Figure 70. Density plot of Mahalanobis distances (shown as square root of distance). The black curve shows the proportion of observations at each distance. At the bottom of the plot, along the x-axis, the black tick marks indicate distances for baseline dives, and blue ticks are during and post scaled exposure. The taller tick mark indicates the dive cycle that included the exposure event.

We then used all data up to the CEE exposure as baseline, minus the dive during the scaled exposure and 24 hours post scaled exposure, to assess any effect of the CEE exposure. We ran the Mahalanobis distance analysis on this dataset and the time-series of distances (**Figures 71, 72, and 73**) and a density plot (**Figure 74**). On visual inspection, the two dives coincident with the CEE do not appear to be unusual. There does appear to be a peak in Mahalanobis distance in the post exposure period, at dive 865, which started more than four hours after the exposure event ended (**Figure 74**). However, there are peaks of a similar magnitude in the baseline period (**Figure 75**).

We fitted a GEE to the Mahalanobis distances with dive shape, exposure status and time since exposure as variables. Only exposure status was retained during model selection. There was no significant difference between baseline and post CEE exposure, but the Mahalanobis distance values for during CEE exposure were lower than both baseline and post exposure. This is presumably due to the peaks in Mahalanobis distance in both the baseline and post exposure periods.

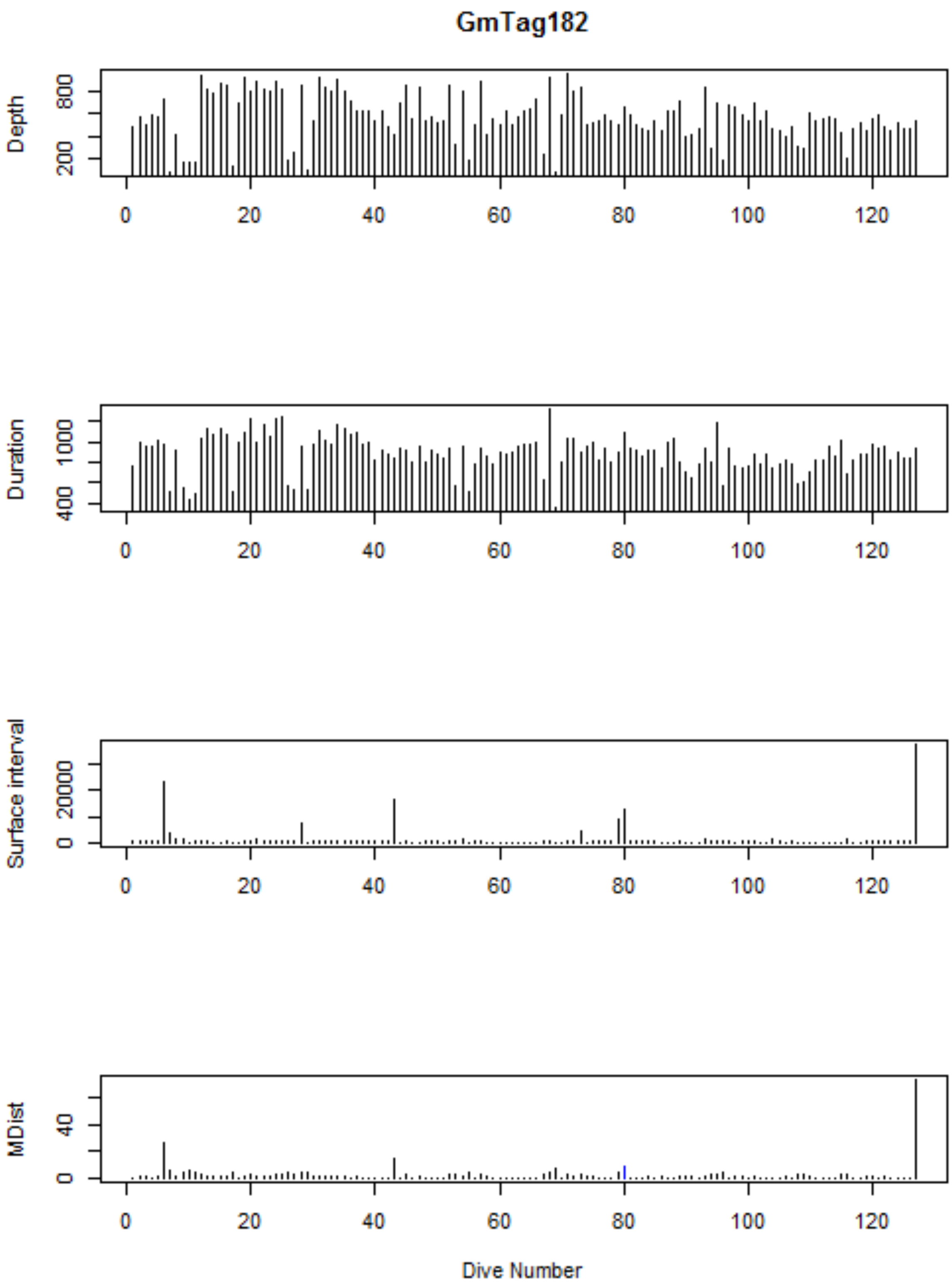

Figure 71. Panel of time-series plots with dive depth (top plot), dive duration (2nd from the top), inter-deep dive interval (2nd from bottom) and Mahalanobis distance (bottom). On the bottom plot the exposure dive (#80) is indicated in blue. The time-series has been truncated 24 hours after the exposure event.

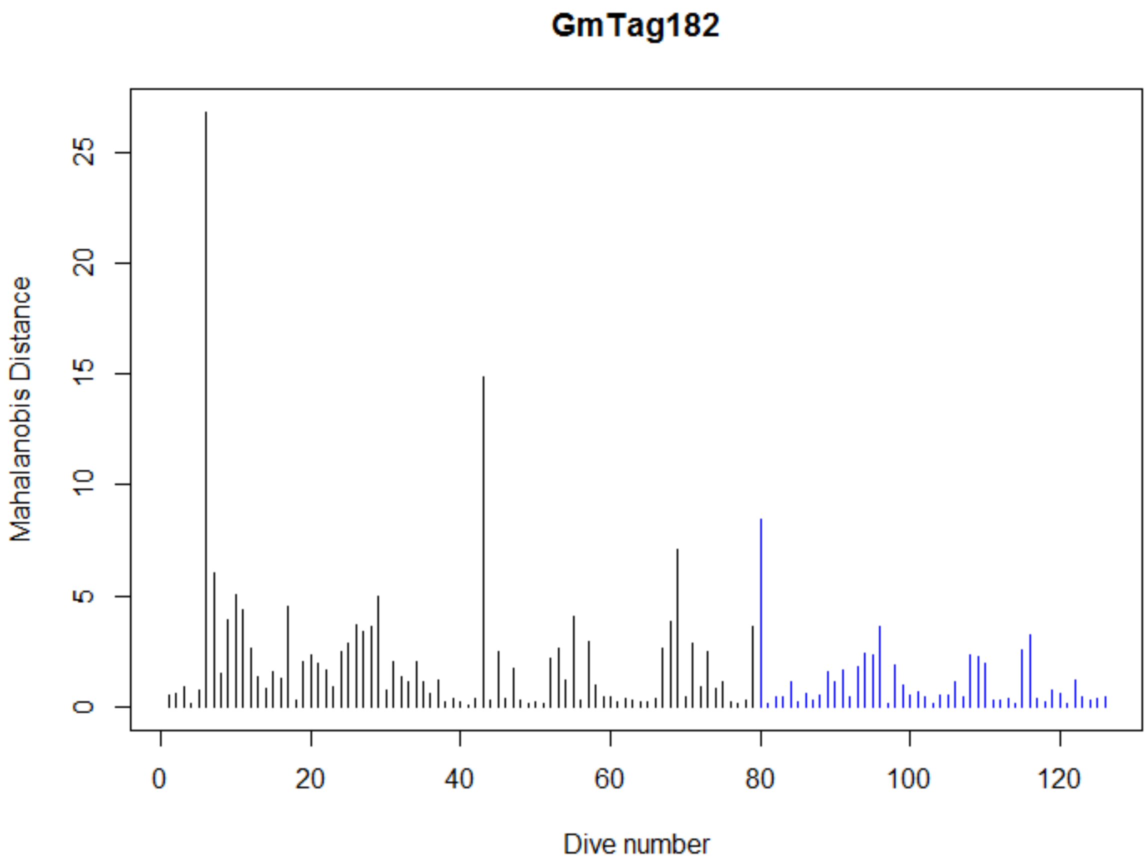

Figure 72: Time series of dives for individual GmTag_182 with the height of each line representing the distance (in multivariate space) of each dive from the average baseline dive for this individual. Baseline dives are in black, during and post scaled exposure dives are in blue. The dive coincident with exposure, i.e. the during dive, was dive 80 and is the first dive shown in blue. The time-series has been truncated 18 hours after the exposure event.

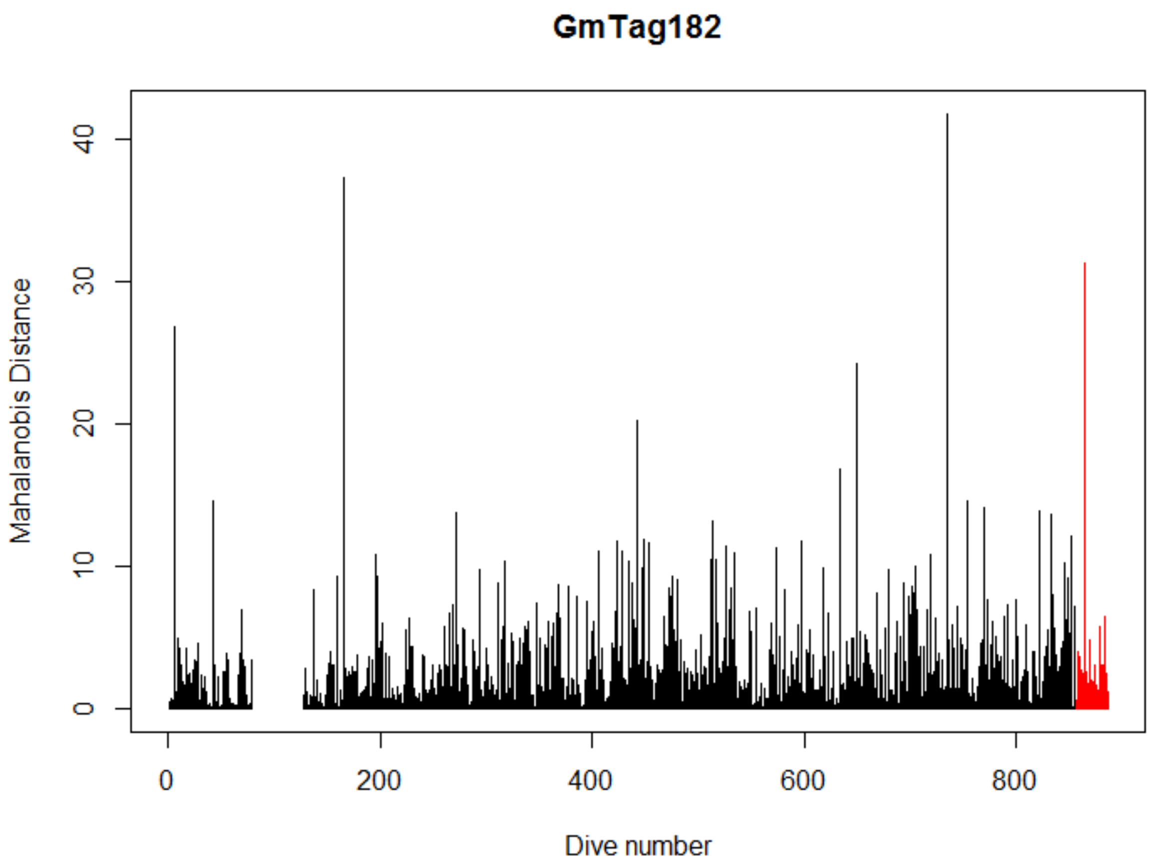

Figure 73: Time series of dives for individual GmTag182 with the height of each line representing the distance (in multivariate space) of each dive from the average baseline dive for this individual. Baseline dives are in black, during and post CEE exposure dives are in red. The dives coincident with exposure, i.e. the during dives, were dive 856 and 857 and are the first dives shown in red. The time-series has been truncated 24 hours after the CEE exposure event. Note the gap in the time-series reflects the 24hours after the scaled exposure event, which was removed from the baseline time-series prior to analysis of the CEE exposure event.

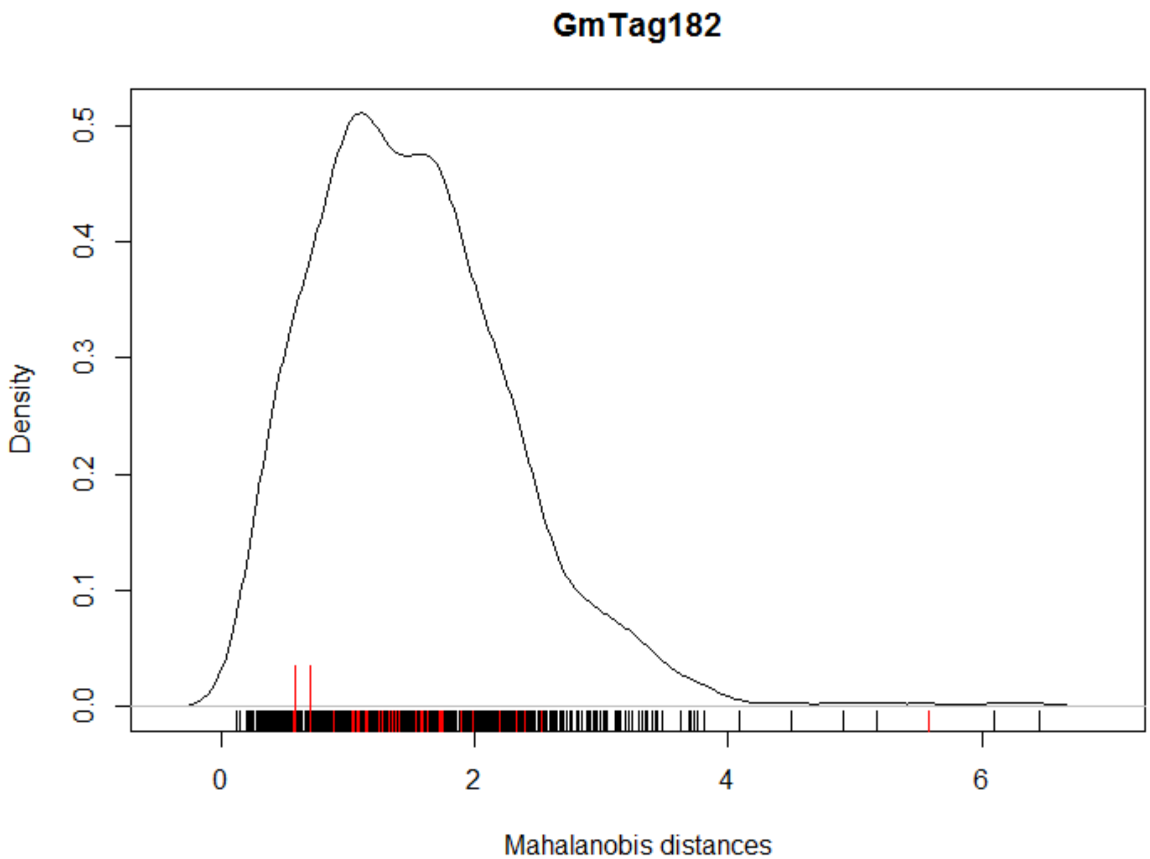

Figure 74. Density plot of Mahalanobis distances (shown as square root of distance). The black curve shows the proportion of observations at each distance. At the bottom of the plot, along the x-axis, the black tick marks indicate distances for baseline dives, and red ticks are during and post CEE exposure. The taller tick marks indicate the dive cycles that included the exposure event.

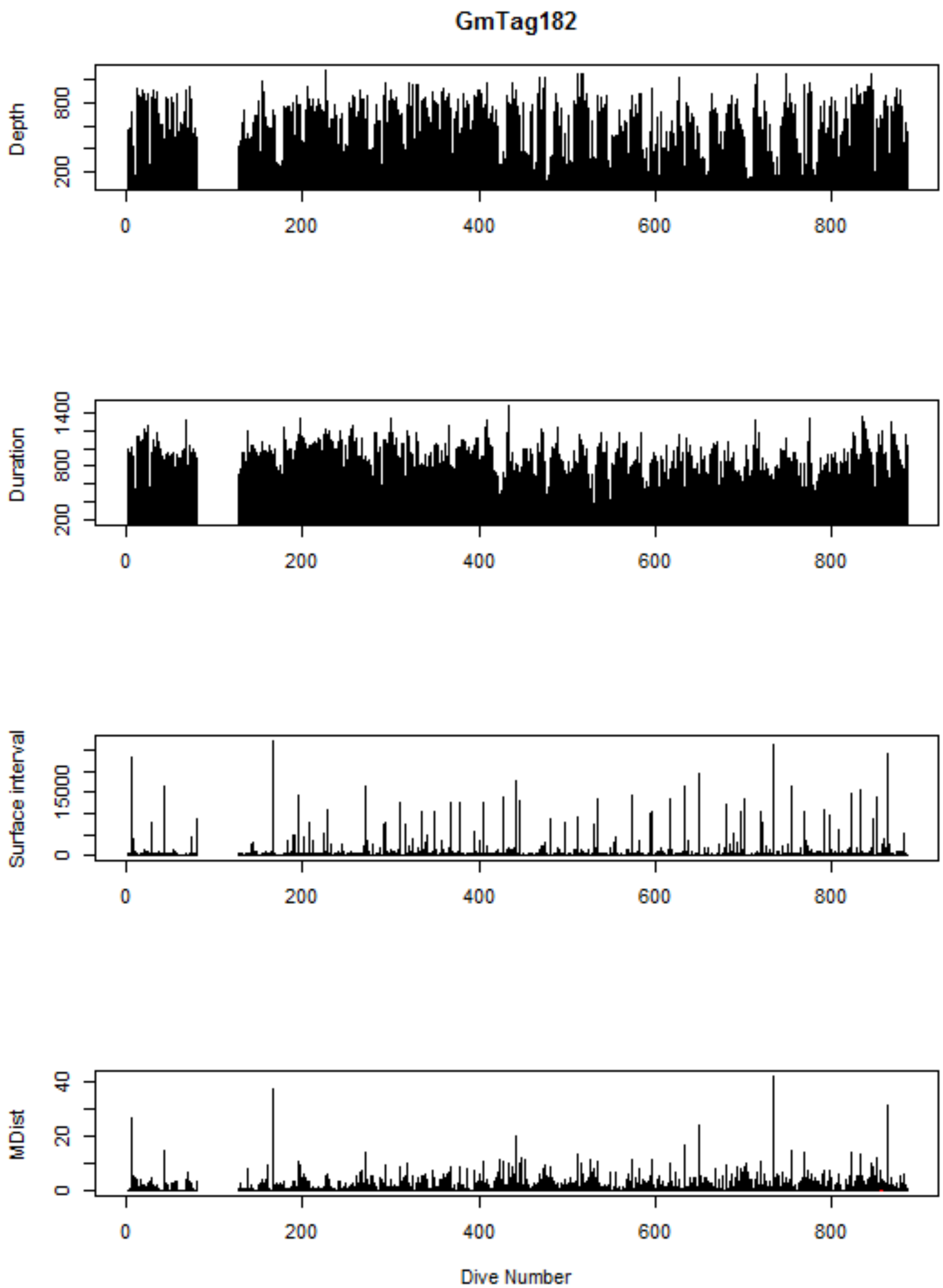

Figure 75. Panel of time-series plots with dive depth (top plot), dive duration (2nd from the top), inter-deep dive interval (2nd from bottom) and Mahalanobis distance (bottom). On the bottom plot the exposure dives (dive 856 and 857) are indicated in red. The time-series has been truncated 24 hours after the CEE exposure event. Note the gap in the time-series reflects the 24hours after the scaled exposure event, which was removed from the baseline time-series prior to analysis of the CEE exposure event.

HIDDEN MARKOV MODEL (HMM) ANALYSIS OF ZC BASELINE DATA

We have begun to use Hidden Markov Models to explore the baseline data from the satellite tagged Ziphius. We have looked only at the baseline data to establish if more than one state is present. Due to the strict sampling regime on dive duration, we have not sampled any dives of less than 33-min. duration, effectively removing the non-foraging diving state from the time-series.

Initial analyses are focused on four of the five baseline animals tagged in May that had no data gaps in their time series. Time series analysis using HMM's are able to accommodate gaps in data, but subsequent biological interpretation of behavioral state transitions will be problematic if data gaps are long enough to miss entire transition events. Dive start and end times were taken from each tag and a data frame where each row contained a diving cycle was created. This included a single dive greater than 33-min. duration and the following inter deep dive interval. Each diving cycle was considered as one sampling unit within a time series for each whale. We calculated three dive parameters for each dive: *Dive duration*, the time between the start of descent and the end of ascent (seconds); *Maximum depth*, the maximum depth reached during the dive (meters); *Inter-deep dive interval*, the time between the end of the dive to the start of the next dive of greater than 33-min. duration (seconds)

We used a multivariate hidden Markov model (HMM) as a framework for the analysis. The HMM allows unsupervised classification of dives into the most likely underlying, or 'hidden', state sequences that gave rise to our observations.

The model involved an observed state-dependent process and an unobserved first-order N-state Markov chain that assumed the probability of being in the current state is determined only by the previous state (Rabiner 1989, Zucchinni and MacDonald 2009). The three dive parameters were specified as the observable series and were each assumed a distribution with state-dependent mean and variance parameters. The multi-state HMM considered the three observed dive variables as independent of each other, conditional on the 1st order sequence of hidden states (Langrock et al 2012, Altman 2007). All parameters were assumed Gamma distributions as they were continuous positive values. Models were constructed based on two underlying non-observable behavioral states and that the observations were conditionally independent given the states, i.e., contemporaneous conditional independence was assumed (Altman 2007). We did not consider any higher state models at this time.

We did not consider individual random effects, and assumed all whales shared common distribution parameters for all variables (Langrock et al 2012). We will consider individual random effects for future analysis. We assumed a transition matrix where all state transitions were possible and we included all dives from all individuals in the models.

We fitted the models via numerical maximum likelihood estimation using moveHMM (Michelot et al., 2016) in R (R core development team 2014). To improve confidence that the global maximum was found during the maximization process, we specified different initial values and investigated the likelihood surface prior to maximization in multiple model runs. We used the inbuilt moveHMM tools to apply the Viterbi algorithm (Forney 1973) to each individual animal and used it to find the most likely sequence of hidden states given the likelihood of the three observed variables under the estimated state-dependent distributions and the transition probabilities between states.

Initial results suggest that there may be some relationship between longer duration dives and longer inter deep dive intervals, across individuals. However high levels of individual variation distort distributions for all the variables with many model runs allocating all but one diving cycle to a single state and then the outlying cycle to a state in isolation. This individual variability needs to be assessed further as does any erroneous records on the tags that may be producing misleading results.

4. Overall Assessment and Recommendations for 2018 Effort

4.1 General Assessment of Atlantic-BRS 2017 Accomplishments

- We were extremely successful in deploying satellite tags (26 of 30 available), especially for Cuvier's beaked whales (14 satellite-linked dive tags deployed), collecting thousands of hours of baseline data.
- The advance deployments of satellite tags provided multiple CEE options for both species.
- Opportunities to coordinate with Navy ships were much more limited than expected (only 1 of 6 possible weeks) due to scheduling changes and mechanical issues.
- Weather conditions were relatively poor, especially during fall, when multiple tropical systems precluded small boat operations and affected Navy ship operations.
- Despite these challenges, we achieved the most challenging of all possible scenarios (satellite tags and DTAGs deployed on individuals of both focal species, with focal follow monitoring). Unfortunately, the Navy ship was unavailable, but we successfully conducted a simulated MFAS CEE.
- Over the entire field period, a total of 21 unique CEE events occurred for 10 individual beaked whales and four pilot whales (7 individuals were exposed to both CEEs at different levels/ranges). Each of these events will be analyzed separately.
- We achieved one real ship 53c MFAS CEE with satellite-tagged whales, when weather conditions precluded small-boat operations
- We deployed fewer DTAG than expected, due to a combination of poor weather and cost-benefit decisions to not deploy tags when Navy ships were unavailable.
- After some modifications, our final field configuration of vessels proved to be very effective. We employed a primary large RHIB on all field days and, when conditions allowed, a smaller tagging RHIB, paired with another research platform that housed the simulated sound source and provided an additional tracking platform.
- We were able to receive signals from satellite tag using the ARGOS goniometer. This system allowed us to track and relocate tagged individuals and to deploy a DTAG in a group of pilot whales that contained a satellite tagged individual.
- The satellite tag settings we employed proved very effective in reducing gaps in behavioral data, especially for beaked whales. There are trade-offs in these decisions, however, and our emphasis on transmitting data from foraging dives precluded, as expected, the collection of information on shallow dives.

- The limited number of surface positions, and the large errors associated with these estimates generated by Service ARGOS, has complicated our analysis of horizontal avoidance during CEEs and modeling of RLs. The latter is especially complex off Cape Hatteras, where even modest positional errors relative to the shelf break can have major consequences for modeled RLs.
- We have conducted an extensive analysis effort to address our research questions, including a robust geospatial modeling approach to evaluate horizontal movements and to model RLs.
- Our analyses of horizontal avoidance, disruption of foraging behavior, and modification of social interactions are ongoing. As expected for pilot whales, but somewhat surprisingly for beaked whales, there was a relatively high degree of inter-individual variability in baseline behavior. We are employing within-individual change-point methods to evaluate individual responses.
- Our analyses are ongoing and final results of the 2017 CEES are not yet available. We believe that additional field efforts will be required before we are in a position to draw firm conclusions about the type, magnitude, and probability of responses under different exposure contexts.
- Nevertheless, neither the simulated MFAS CEE, nor the real ship 53C CEE, resulted in any large-scale avoidance of the study area by either focal species. All individuals monitored continued to use these areas and display typical movement and diving behavior in the days and weeks following CEEs.

4.2 Recommendations for 2018

- We recommend that the research approach we employed in 2017 be continued to increase sample sizes for CEEs for both species, with some modifications based on lessons learned.
- Cape Hatteras offers an excellent study site, which offers the potential to locate, tag, and track individuals of several species, including Cuvier’s beaked whales, a species of high priority to the Navy. The study site should be maintained.
- Given our success in 2017, we should maintain beaked whales as a clear priority species for tagging and CEEs, as conditions allow.
- The timing of the fall field season should be shifted earlier to avoid tropical storm systems.
- As many weeks of Navy ship coordination should be scheduled as possible, given the expected attrition due to scheduling and maintenance issues.
- The basic vessel configuration, with shore-based RHIBs and a sound source/tracking platform (as we used in the fall of 2017) should be maintained.
- The combination of satellite tags and DTAG deployments should be continued. We expect additional DTAG deployments with better weather conditions and additional availability of sound source options.

- The simulated sound source should be retained for 2018 as a secondary priority. It should be refurbished and repaired to preclude operational failure due to a false detection of leak alarm that occurred in 2017.
- We should consider small increases in target RL range for CEEs, guided by results from ongoing analyses.
- The analyses required to determine potential response are complex and time-consuming. Development of the protocols for processing and analyzing data from the 2017 field effort will prove extremely useful for future analysis, but we anticipate that a comparable amount of work will be required. We emphasize that the extent of this individual-based analysis depends more upon the *total number of individuals tagged than the number of CEEs conducted*.
- Extensive planning and coordination discussions among the team and in coordination with the Navy will be necessary to ensure continued success in 2018.

This page intentionally left blank.

5. References

Altman, R. Mixed hidden Markov models: an extension of the hidden Markov model to the longitudinal data setting. *J. Am. Stat. Assoc.* **102**, 201 –210 (2007).

DeRuiter, S. L., Southall, B. L., Calambokidis, J., Zimmer, W. M. X., Sadykova, D., Falcone, E. A., Friedlaender, A. S., Joseph, J. E., Moretti, D., Schorr, G. S., et al. (2013). First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar. *Bio. Lett.* 9, 20130223–20130223.

Forney, G. D. The Viterbi algorithm. *Proc. IEEE.* **61**, 268-278 (1973).

Højsgaard, S., Halekoh, U. and Yan, J. (2006). Geepack: The R package geepack for Generalized Estimating Equations. *J. Stat. Soft.* 15, 1–11.

Langrock, R. *et al*. Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions. *Ecology*. **93**, 2336-2342 (2012).

Michelot, T., Langrock, R., Patterson, T.A. (2016). moveHMM: an R package for the statistical modelling of animal movement data using hidden Markov models. Methods in Ecology and Evolution, 7 (11), pp. 1308-1315.

R Core Development Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria (2014).

Scharf, Henry, Mevin B. Hooten, and Devin S. Johnson. 2017. “Imputation Approaches for Animal Movement Modeling.” *Journal of Agricultural, Biological and Environmental Statistics* 22 (3). Springer US:335–52.

Southall, B. L., Nowacek, D.P., Miller, P.J.O., and Tyack, P.L.T. (2016). Synthesis of Experimental Behavioral Response Studies Using Human Sonar and Marine Mammals. *Endangered Species Research 31*, 291-313. doi: 10.3354/esr00764

Southall, B.L., D. Moretti, B. Abraham, J. Calambokidis, P.L. Tyack. (2012). Marine Mammal Behavioral Response Studies in Southern California: Advances in Technology and Experimental Methods. Marine Technology Society Journal 46, 46-59.

Rabiner, L. R. A tutorial on hidden Markov models and selected applications in speech recognition. *Proceedings of the IEEE*. **77**, 257-285 (1989).

Zucchini, W. & MacDonald, I. L. Hidden Markov models for time series: an introduction using R. London. Chapman & Hall (2009).

This page intentionally left blank.