Atlantic Behavioral Response Study (Atlantic-BRS): 2019 Annual Progress Report

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

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Acronyms and Abbreviations

BRS	Behavioral Response Study
CEE	controlled exposure experiment
DAF	Douglas ARGOS filtered
dB re 1 µPa	decibel(s) referenced to 1 micro Pascal
GEE	generalized estimating equation
km	kilohertz
m	meter(s)
MFAS	mid-frequency active sonar
min	minute(s)
NPS	Naval Postgraduate School
ONR	Office of Naval Research
photo-ID	photo-identification
RL	received level
RHIB	rigid-hulled inflatable boat
RMS	root mean square
SD	standard deviation
sec	second(s)
SEL	sound exposure level
SNR	signal-to-noise ratio
SEA	Southall Environmental Associates
SOCAL	Southern California
SPOT	Smart Position and Temperature
U.S.	United States

Executive Summary

The Atlantic Behavioral Response Study (Atlantic-BRS) was conceived, designed, and initiated through a collaboration building on recent studies under the U.S. Navy's Marine Species Monitoring Program, including baseline monitoring of key marine mammal species (Cuvier's beaked whales (*Ziphius cavirostris*) and short-finned pilot whales (*Globicephala macrorhynchus*)) off the coast of Cape Hatteras, North Carolina. The project transitions and advances approaches developed from previous BRS work supported by the Navy's Living Marine Resources program and Office of Naval Research. It is the first systematic effort to quantify sonar exposure and behavioral responses of priority marine mammal species to military sonar using controlled exposure experiments (CEEs) off the U.S. Atlantic coast. The Atlantic-BRS was designed through collaborative planning and has evolved based on systematic evaluation of three years of field experience. We have applied CEE methods involving mid-frequency active sonar (MFAS) - both full-scale operational SQS-53C and a simulated sound source - using a variety of strategically-deployed tag sensors on many individuals simultaneously. The approach employs both short-term, high-resolution acoustic tags and longer-term, coarser resolution satellite-linked location and behavior tags to study responses at multiple temporal and spatial scales. While the project is ongoing, we have already produced the largest and most comprehensive data set available for sonar exposure and response for one of the highest-priority marine mammal species for the Navy.

Building on the first two field seasons of this project (see: Southall et. al 2018; 2019), Atlantic-BRS field operations in 2019 included some of our most notable advances to date. We modified our field approaches and satellite-transmitting tag programming strategy such that each tag deployment would include two weeks of relatively fine-scale time series dive data, with a single CEE sequence focused within each of two tagging periods in each of two field seasons (spring and summer). This was extremely successful in 2019 - four CEEs were conducted as planned, two each within the spring and summer field efforts, and all including multiple high-priority beaked whales and a smaller number of secondary-priority pilot whales. Additionally, we accomplished the first-ever CEE with a short-term high-resolution acoustic tag on one individual beaked whale and a satellite-transmitting tag on another in the same group, achieving the multi-scale design within a MFAS CEE. Further, we were successful in tagging multiple animals within the same social group on multiple occasions, providing insights into both social structure and behavioral coordination. This level of resolution and insight into high-priority, but difficult to study beaked whales is unprecedented. Although coordination of CEEs with Navy vessels operating SQS-53C sonar (highest priority source) was limited due to conflicts with their training and maintenance schedules, all CEEs were successfully completed using a simulated MFAS source at ranges of several to many tens of km, spanning the full range of target received levels.

We have continued individual-based analyses of diving behavior, potential horizontal avoidance, and social behavior for data collected from tagged beaked whales in 2017 and 2018 using existing and newly developed quantitative metrics. Multiple manuscripts on baseline behavior and analytical methods were submitted and published in peer-reviewed journals in 2019 supporting these analyses. Clear behavioral changes including some of the strongest observed avoidance responses and new insights into possible effects on social interactions observed in

this project were documented during 2019 simulated MFAS source CEEs in a number of focal and other tagged individuals. Response analyses are ongoing for all CEEs conducted through 2019 and will be incorporated with additional requisite data from subsequent field efforts. Both logistical and analytical lessons learned will be incorporated into our planning and methods as we prepare for field effort in 2020.

1. Overview

1.1 Overall project design and objectives

The Atlantic Behavioral Response Study (Atlantic-BRS) was initiated following extensive planning discussions with researchers and U.S. Navy personnel to transition experimental methods previously developed under the Southern California Behavioral Response Study (SOCAL-BRS), funded primarily by the U.S. Navy's Living Marine Resources (LMR) program, as well as the Office of Naval Research (ONR). For the past three years, a research collaboration of scientists from Duke University, Southall Environmental Associates (SEA), Cascadia Research, and the University of St. Andrews has conducted strategic tag deployments and controlled exposure experiments (CEEs) on beaked and pilot whales off the coast of Cape Hatteras, North Carolina. This collaboration has had unprecedented success in tagging high-priority beaked whales and conducting CEEs with both operational mid-frequency active sonar (MFAS) systems from Navy surface vessels (e.g. SQS-53C-equipped combat vessels) as well as experimental sound sources simulating these systems. This report describes the objectives, field methods and results, and analyses conducted to date. Most focus here is on accomplishments from the 2019 field season and response analyses largely conducted on data collected in 2017 and 2018 (Southall et al 2018; 2019) as detailed analyses of the 2019 field data are still ongoing.

Most previous studies have either used short-term, high-resolution acoustic tag sensors to measure fine-scale behavior in response to calibrated metrics of experimental noise exposure, or coarser-scale, longer-term measurements of movement and diving behavior associated with incidental exposures during sonar training operations. This study is unique in bringing both approaches together and building on previous experience with both tag types for focal species within the same area. 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) providing short-term (hours) but very high-resolution movement and calibrated acoustic data, and satellite-linked, time-depth recording tags (SLTRDs, i.e. "sat tags") providing much longer-term (weeks-months) data on movement and increasingly better resolution dive data, simultaneously deployed on multiple individuals of focal species in the same CEEs.

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 (e.g. 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. Results will be directly applicable to the Navy in meeting their mandated requirements to understand the impacts of training and testing activities on protected species, as well as to regulatory agencies in evaluating potential responses within regulatory contexts.

Several key categories of 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 not uncommon, several methodological parameters (e.g., tag types and configuration settings, nominal target exposure levels) differ slightly among species given known variability in their life history, baseline behavior, and presumed (from previous observations and studies in other areas) sensitivity to noise exposure. As in previous studies, explicit monitoring and mitigation protocols have been established and followed in conducting CEEs in order to meet experimental objectives and ensure compliance with both permit authorizations and ethical standards. Further, experimental objectives, field work accomplishments, and planned effort are regularly communicated transparently to interested stakeholders through periodic compliance reporting, progress updates, and presentations and discussions in scientific and general audience fora.

1.2 Experimental Design

Considerable value was identified during extensive advanced planning in maintaining consistency with other BRS projects in the initial experimental design of this project. Given this, and the success in deploying many tags and successfully conducting both real ship MFAS and simulated MFAS CEEs in 2017 and 2018, minimal changes were made to the field approach prior to 2019 effort. Differences were largely in field configurations, timing of effort, tag settings, etc., rather than changes in overall experimental design. Such consistency is 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 involves multiple different kinds of monitoring methodologies and platforms, incorporating lessons learned from a variety of research and monitoring programs funded by the Navy. These included quantitative measurements of individual behavior using tags of several types, small-boat-based individual and group focal follow observations, targeted collection of individual tissue biopsy samples and photo-identification (photo-ID), and remote passive acoustic monitoring from archival recorders deployed in the general area.

Given the coordination required with Navy combat vessels equipped with SQS-53C sonar systems for BRS efforts off the coast of Cape Hatteras, the overall experimental design was based on the methods employed in the SOCAL BRS using CEEs with both simulated MFAS and operational vessel-based 53C systems (Southall et al. 2012; 2016; 2019. This approach includes a period during which baseline behavioral data are collected prior to the CEE - a minimum of 60 minutes for animals with DTAGs, and a 24-hour minimum for animals equipped with satellite tags; most baseline data periods were much longer in practice for satellite tags. 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 (see Southall et al. 2012). Simulated MFAS sources were deployed to a 20-meter (m) depth from a drifting (not under power) vessel and operated for a total of 30 minutes (min) at output source levels from 160 to a maximum of 212 decibels (root mean square) referenced to 1 microPascal (dB [RMS] re 1 µPa). Vessels were positioned at ranges from subjects that met experimental objectives for received levels (RL; 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-second (sec) duration each with 0.1 sec separation for total ping series 1.1 sec duration). Signals were transmitted with a 25 sec 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 knots. 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 supported by the Naval Postgraduate School (NPS). The experimental design allows for positioning of MFAS sources to result in target received levels at focal individuals based on their position and accounting for local bathymetry and dynamic oceanographic conditions. However, other individuals were incidentally exposed at a variety of received levels that were not explicitly controlled but were estimated (with error) from positions derived from either satellite tags or observations in the field. The course of the vessel (or drift of the simulated MFAS source) was designed to result in an escalation in RL at the presumed location of focal individuals based on their movement, to the extent it is known. Movement of the source was designed to be generally, but not directly, toward individuals. Given the large number of tagged individuals exposed during CEEs, individuals have had (by design) varied MFAS exposure conditions in terms of range and received level. Target received levels for the focal animals ranged from 120 to 160 dB RMS, depending upon species and the aggregate location of focal individuals (120 to 140 dB for beaked whales, 135 to 160 dB for pilot whales). These target levels represent an incremental increase from 2017 and 2018 based on the limited responses observed from initial analyses, and are consistent with more detailed analyses conducted subsequently.

Monitoring of experimental subjects was maintained following completion of an exposure sequence, both visually and by the tags. Satellite tags were programmed to continue collecting data consistently for days or weeks following CEEs. Focal animals (particularly for DTAG individuals) were visually monitored for a further 60 min, employing the same focal animal sampling protocol. Attempts to obtain biopsy samples were made for focal individuals as well as other animals in the group following the post-exposure monitoring period. 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 approximately 100 killometers (km) 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 to other studies which have occurred in training ranges where sonar is used more routinely. For 2019, we specifically set up satellite-transmitting tags to provide approximately two weeks of continuous, relatively high duration (5-min time series) dive data, with ARGOS positional data being collected for several weeks longer. This was done to increase the resolution during a focal period when Navy ships were expected to be available or simulated MFAS CEEs could otherwise be conducted. For all these reasons, the objective was to conduct one CEE within each ~2 week window following satellite tag deployments. Given that there were two tag deployment windows in each the spring and summer, the goal was thus to conduct 4 CEEs, each with multiple tagged individuals and ideally with both tag types. The clear priority was to conduct CEEs using operational SQS-53C MFAS sonar systems from actual Navy vessels. The simulated MFAS sonar source is more comparable to operational systems such as helicopter dipping sonars (AN/AQS-13) and is thus more appropriate for comparison with those kinds of systems in terms of response. It was thus clearly identified as a secondary priority and reserved for instances where tagged animals are available, weather conditions support CEEs, but Navy ships were unavailable.

1.3 Overall Analytical Approach

Behavioral response analyses focus on how animals, in this case 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 of available data (tag type) and species in questions. Analyses of behavior and behavioral response for the Atlantic-BRS are designed to consider 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 are summarized in **Table 1**, with their use in specific ongoing analyses addressed in **Tables 2 and 3** for pilot and beaked whales respectively. We developed these tables based on the overall data processing and analytical objectives established at the start of the project in 2017 and retained slightly modified versions in this report as they still have relevance in the overall analytical approach. We also provide a detailed depiction of the data processing and analytical modules.

Analyses of short-term changes in movement, foraging and social interactions primarily rely on the 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. Analyses of broader 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 applied based on tag type and associated data for both pilot and beaked whales (**Tables 2 and 3**, respectively). Building on these data processing and analysis descriptions, we subsequently developed a series of flow chart diagrams (called 'modules') to better illustrate the complex and inter-related processes being utilized in the Atlantic-BRS project. These include an overall depiction of the data processing and analysis procedures (**Figure 1**), as well as a field data processing module (**Figure 2**), satellite tag data processing module (**Figure 3**), DTAG data processing module (**Figure 4**), and a diving behavioral response module (**Figure 5**).

Table 1. Data streams collected as part of the Atlantic-BRS and their intended products or application (see Tables 2 and 3 for response analysis categories, FB – foraging behavior, HA – horizontal avoidance, SI – social interaction)

Data Stream	Task(s)	Output(s)	Product/Application
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**

Data Stream	Task(s)	Output(s)	Product/Application
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
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**

Data Stream	Task(s)	Output(s)	Product/Application
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;
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

1 **Table 2. Response types and analytical methods: Pilot whale response analyses**

Behavioral Response Type	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** 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 types and analytical methods: Beaked whale response analyses

Behavioral Response Type	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** 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**

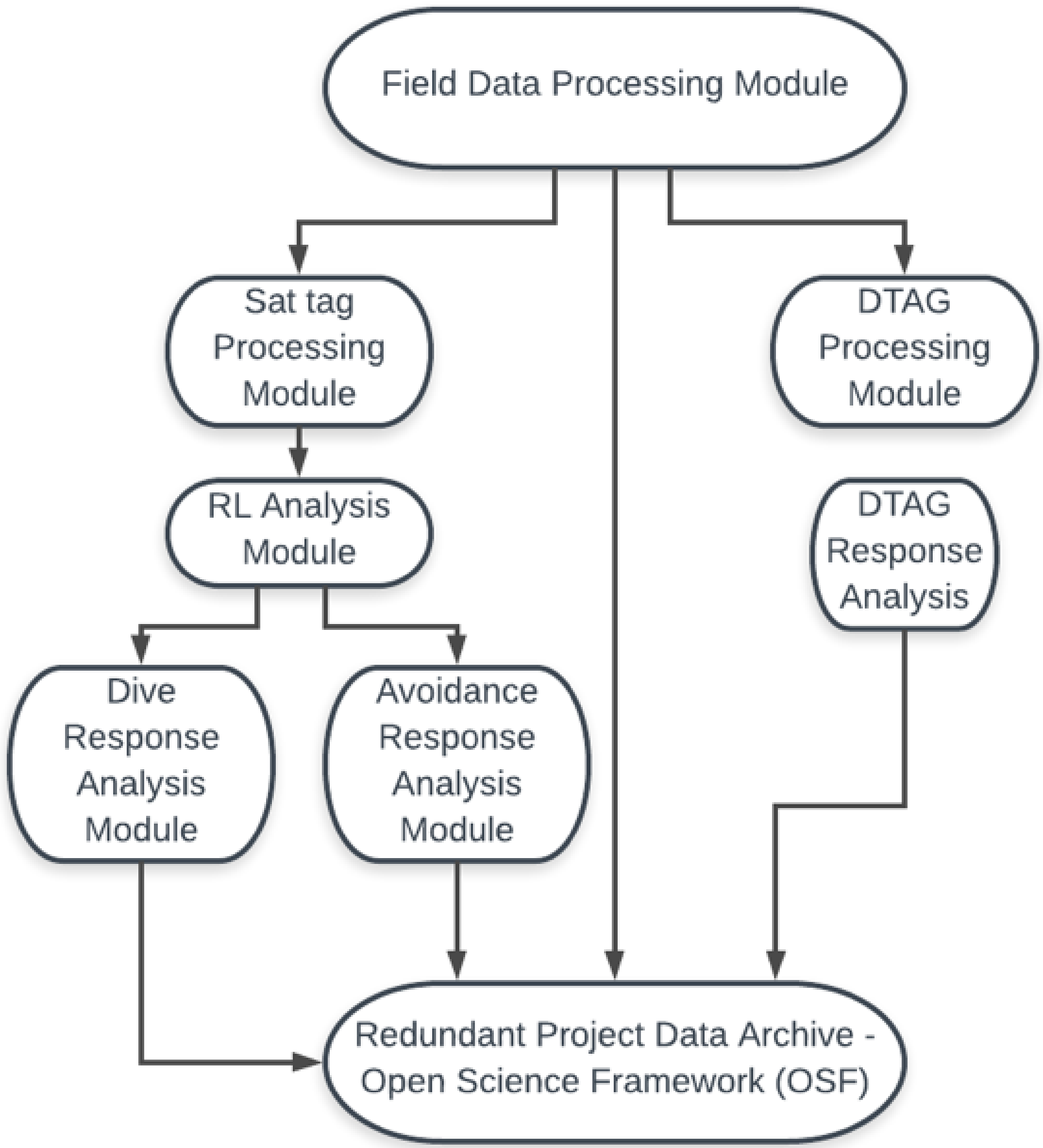

Figure 1. Overall flowchart of Atlantic-BRS data processing and analysis procedures

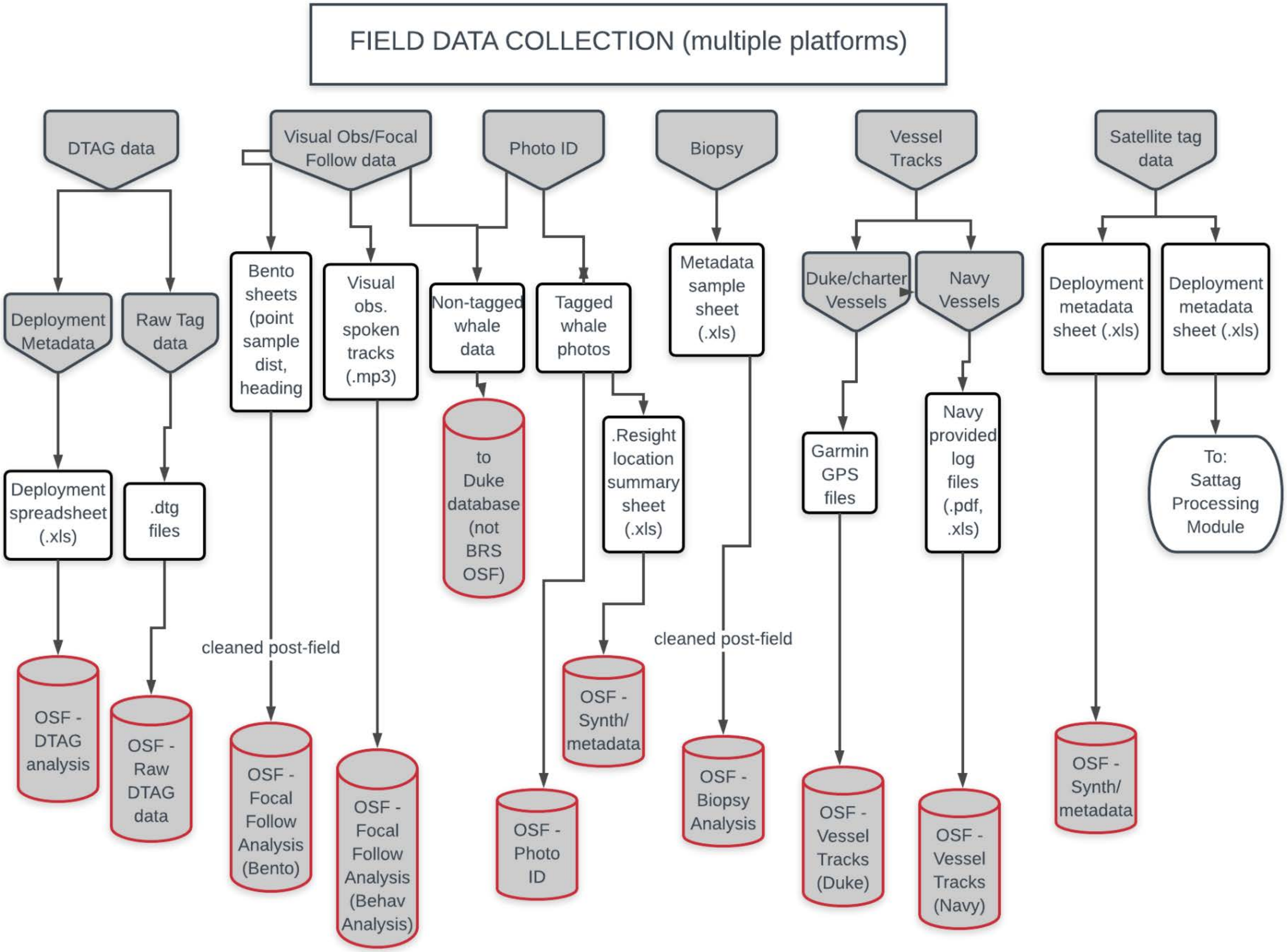

Figure 2. Atlantic-BRS field data processing module

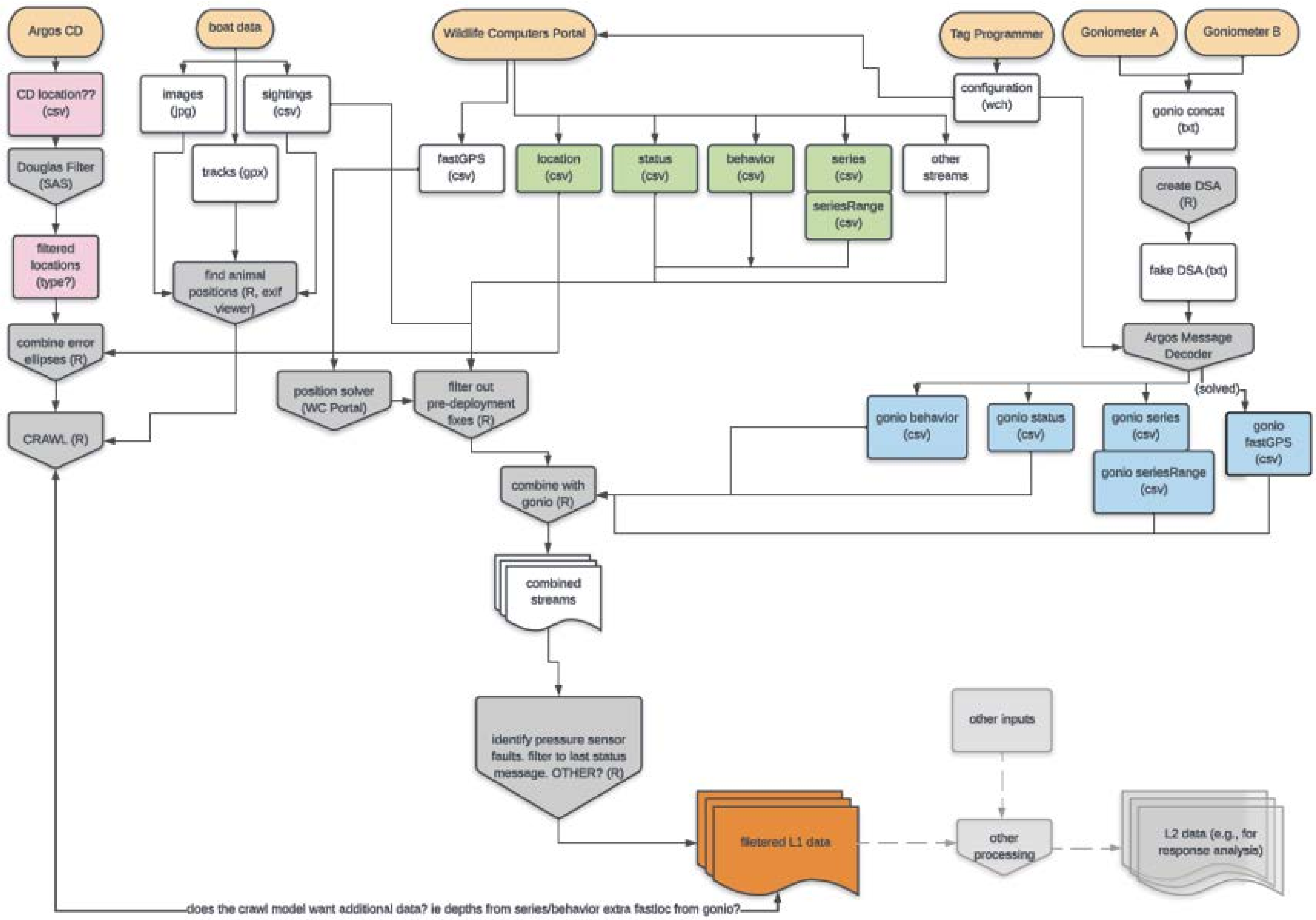

Figure 3. Atlantic-BRS sat tag data processing module

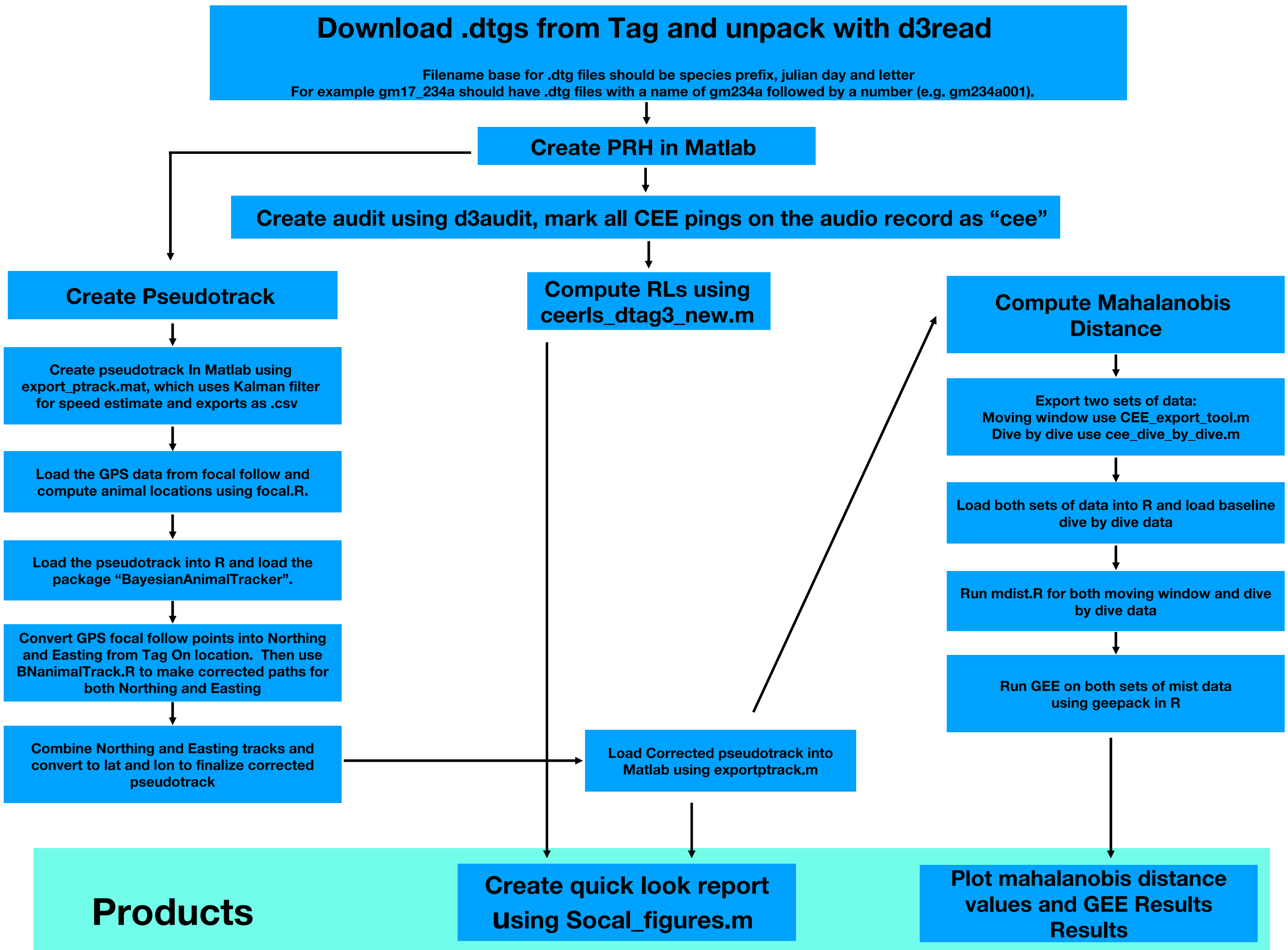

Figure 4. Atlantic-BRS DTAG data processing module

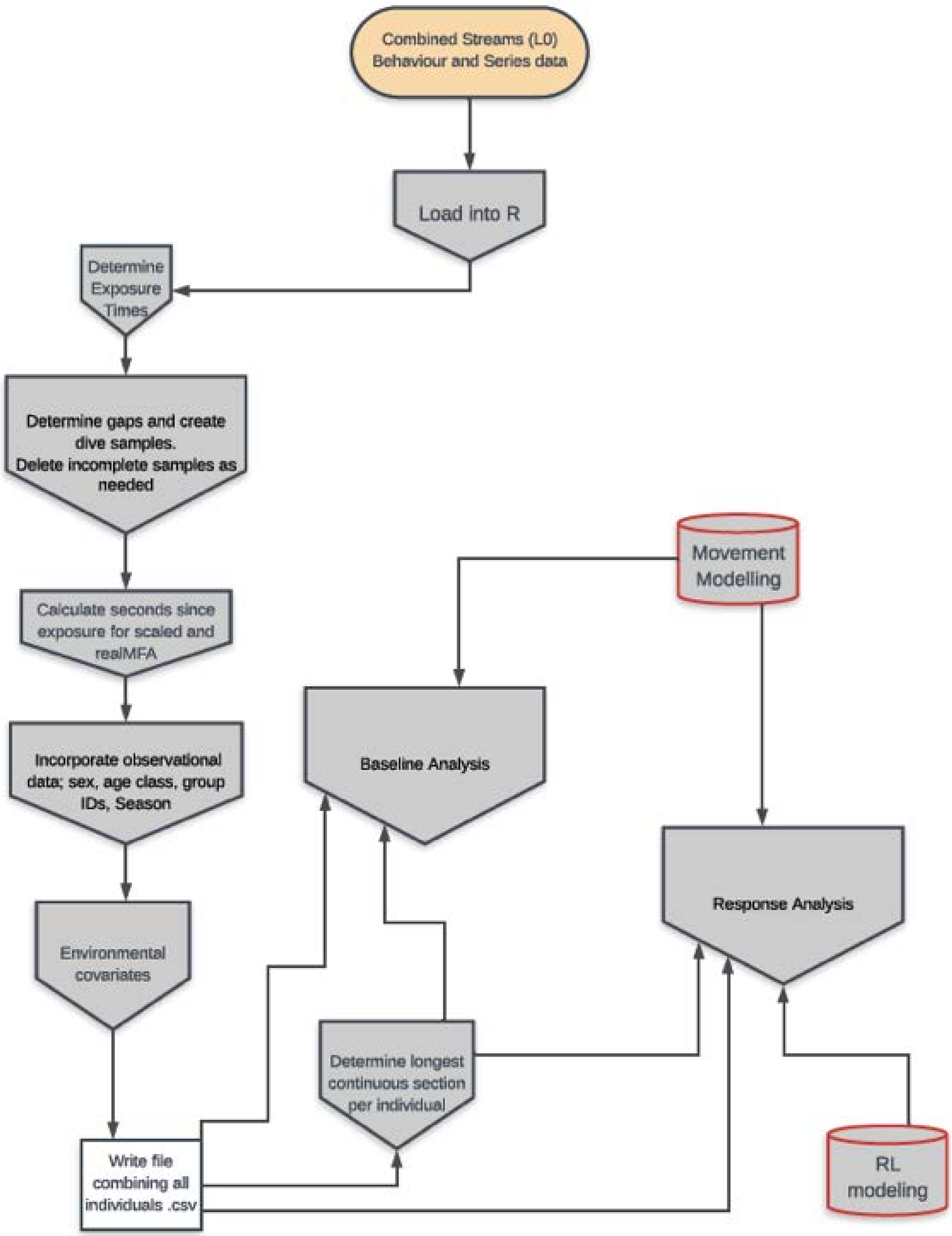

Figure 5. Atlantic-BRS diving behavioral response module

1.4 Field Logistics and Configuration

The 2019 Atlantic-BRS field effort retained the overall approach from 2018 in terms of a spring (May-June) and summer (August) field campaign. The second period was scheduled earlier in the year given lessons learned regarding fall tropical storm/hurricanes from earlier field efforts. This again proved effective, although relatively poor field conditions in early May again in 2019 will likely influence target windows for 2020. Based on lessons-learned from earlier tag deployments and the data analyses, the 2019 field effort was built around the objective of two phases of tag deployments within each field campaign, each with a corresponding CEE (i.e., four targeted advance tagging windows and four CEEs).

Each field window thus had an initial phase focusing a small RHIB-based team on advance deployment of satellite tags followed by a more intensive, larger team effort with multiple vessels during which DTAG deployments were attempted and CEEs were conducted. Satellite tags were deployed by a small team (n= 4-5) aboard the R/V *Barber*, an 8-m aluminum-hulled SAFE boat capable of handling heavy seas, during several weeks prior to the onset of CEE efforts. The field crew transited offshore on a daily basis when sea conditions were suitable, located animals, deployed tags, and collected photo-ID and other data from groups.

During periods in which DTAG deployments and CEEs were attempted, a research crew of ~10 individuals was involved and worked from three vessels: (1) the R/V *Barber* (with an identical crew of 4-5 as above); (2) a 6-m rigid-hulled inflatable boat (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) an offshore research platform (predominately the *F/V Kahuna* but in some instances the *F/V Hog Wild* or other charter boats based out of Manteo, North Carolina that housed the simulated sound source, provided an additional tracking and visual observation platform, and supported three additional personnel (chief scientist, visual observer/radio tracker, and DTAG field technician that served as an additional visual observer and conducted DTAG tracking/recovery).

Five version 3 DTAGs from the University of Michigan were obtained through a lease agreement 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, with a target of deploying 15 in each of the two field periods. Priority was placed (given the interest in feeding and diving behavior) on the use of SPLASH10-A depth transmitting tags; almost all tags available were of this type. A small number of SPLASH-10F tags that incorporate fastloc GPS were available but not deployed. The highest tagging priority was on Cuvier's beaked whales as this species is of high Navy interest (see Southall et al., 2016) 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 multiple tags in social groups of either species, in order to evaluate potential changes in social associations as a response metric during CEEs. Substantial progress was made in this regard (discussed below).

Considerable advance planning and coordination occurred within the field team and with the Navy sponsors and coordination team. This ensured effective communication between the field team conducting tagging operations and planning CEEs with Navy field operations. This included extensive and sustained planning discussions between the Atlantic-BRS team and

Navy representatives, beginning months in advance of field operations. Open discussions between the field team and Navy evaluated and applied lessons-learned in terms of field communications and coordination from previous research and operational experience. 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 research 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. While 2019 was disappointing in that all (six) ships originally identified to coordinate with BRS operations were ultimately unavailable to serve as CEE sources, regular updates and coordination enabled the field team to plan accordingly and successfully complete CEEs with multiple high-priority beaked whales during all four intended CEE windows using the simulated MFAS source.

Finally, the research team undertook several measures to openly and transparently communicate research plans and objectives externally. This included presentations of research objectives, experimental and monitoring protocols, and initial results from 2017-18 at the U.S. Navy's marine species monitoring program Atlantic technical review meeting held in Virginia Beach, VA in spring 2019, and a project overview scientific presentation by chief scientist B. Southall as well as multiple related scientific presentations at the World Marine Mammal Conference in December 2019. The Duke University Marine Laboratory also provided direction 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.

2. Field Effort

2.1 Summary of 2019 Field Effort: Accomplishments and Assessment

PHASE I (SPRING 2019)

Field dates:

- **1–14 May 2019**: Window for first shore-based satellite tag deployment effort (three field days with suitable conditions for tagging; tags deployed on two days) from R/V *Barber.*
- **14–16 May**: Navy ship scheduled for CEE coordination with first wave of tags deployed. Ship was unavailable but conditions were suitable to conduct CEE with back-up simulated MFAS source (15 May; CEE #2019_01).
- **18 May – 2 June:** Second wave of spring satellite tag deployments, as well as post-exposure and photo-ID re-sight data collection on previously tagged animals. Poor conditions occurred in the first week of this period, but many tags deployed over four days later in this period.
- **4-6 June**: Second Navy ship scheduled for CEE coordination but also ultimately unavailable. Field team again selected period with suitable conditions and portion of focal tagged whales in best configuration and successfully conducted simulated MFAS CEE with simulated source (7 June; CEE #2019_02).
- **7-15 June:** Follow-up re-sights for satellite tag data acquisition and photo-ID on tagged whales exposed in CEEs.

Accomplishments:

- Successful deployment of 9 of satellite tags (8 beaked whales; 1 pilot whale).
- Two successful CEEs with simulated MFAS CEEs. Both were conducted at or near higher target RLs specified for 2019.
- Novel observations of potential social group disruption in beaked whales with individuals with known sighting history in same social group subsequently sighted apart following CEE.
- Sustained efforts to relocate sat-tagged animals in the field using goniometer detections. This significantly increases chances of subsequent tag deployments, improves animal pseudotracks by providing high confidence surface locations, and results in many photo-ID resights to evaluate group composition and social interactions. These developments proved very important on multiple levels.
- Greatly improved satellite-transmitting tag dive data thanks to earlier progress in tag deployment strategies to reduce/eliminate gaps in satellite tag data and to improve temporal resolution on diving and behavioral data. We successfully collected continuous dive data for two-week periods, strategically covering CEE periods, as designed.

Assessment of field approach:

- Weather was typical overall for May-June. This included several excellent periods, many workable days, some blown out days, and a number of marginal condition days where just relocation of previously tagged animals was possible. The first half of May was again quite poor in terms of conditions – subsequent efforts are likely to look to start slightly later.
- Animal sightings: Generally good with groups of both focal species in target areas, although almost all effort was focused on beaked whales.
- RHIB operations worked well and as expected. Multiple goniometers from RHIB and charter boats.
- No DTAGs were deployed, mainly given conditions during CEE periods although several close approaches occurred on beaked whales. Considerable time and effort was spent in evaluating several different configurations of VHF transmitters in tags, which resulted in conclusions of best approaches to use that were effective in the summer.
- Problems with the simulated MFAS source experienced in 2018 were completely resolved and both CEEs were conducted without incident in terms of source performance. CEE #2019_01 was terminated early but this was a function of other animals (bottlenose dolphins) coming within the requisite 200m protective shutdown zone.
- Navy ship availability was a limiting factor, but the field team adapted and conducted simulated MFAS CEEs during the periods in which tags were deployed and ready.

PHASE II (SUMMER 2019)

Field dates:

- **27 July – 4 August 2019**: Window for first shore-based satellite tag deployment effort of summer BRS phase (four field days with suitable conditions for tagging; tags deployed on three days) from R/V *Barber.*
- **6–8 Aug**: Navy ship scheduled for CEE coordination with first wave of summer tags deployed. Ship was unavailable but conditions were suitable to conduct CEE with back-up simulated MFAS source (6 Aug; CEE #2019_03).
- **9-18 Aug:** Window for second shore-based satellite tag deployment effort of summer BRS phase (two field days with suitable conditions for tagging; tags deployed on one days) from R/V *Barber.*
- **20-22 Aug**: Second Navy ship scheduled for CEE coordination but also ultimately unavailable. Field team again selected period with suitable conditions and portion of focal tagged whales in best configuration and successfully conducted simulated MFAS CEE with simulated source (19 Aug; CEE #2019_04).
- **20-30 Aug:** Follow-up re-sights for satellite tag data acquisition and photo-ID on tagged whales exposed in CEEs.

Accomplishments:

- Successful deployment of 12 satellite tags (8 beaked whales; 4 pilot whales).
- Successful deployment and recovery of two DTAGs (both beaked whales; 1 very short).
- First successful deployment of DTAG on beaked whale in a group with long-term satellite tag reporting position and continuous dive data. Numerous methodological implications including first-ever CEE on animals together and being measured on multiple temporal, spatial scales of resolution.
- Successful completion of two full-duration simulated MFAS source CEEs.
- Sustained success in relocating tagged whales for resights, photo-ID, and group composition.
- Sustained success in collecting continuous, full time series dive data at 5-min resolution
- Significant new insights into social behavior of Cuvier's beaked whales, with CEE conducted on group with three (!) simultaneously tagged beaked whales. Major implications for response analyses and also novel observations of potential social responses to MFAS exposure.

Assessment of field approach:

- Decisions to move summer effort earlier to avoid September were vindicated by several tropical systems in the broader area in early fall. Very good conditions occurred during several windows with workable weather at least for re-sight detections on most days in August. Major storms were experienced in the area in September.
- Continued high degree of success with locating and tagging beaked whales. Thanks to a high density of animals and skilled field teams, very high rates of tag deployments per field day continue to be achieved, including the most productive string of days ever for this species.
- The lack of ship availability with 53C sonar during periods with many tagged whales, including multiple individuals and both tag types, was unfortunate. However, simulated source MFAS CEEs were again successfully conducted during targeted periods, providing novel insights and increasing sample sizes.

2.2 Tag deployments

Satellite tag deployments were conducted by researchers from Bridger Consulting in coordination with the Atlantic-BRS team aboard Duke University vessels. A summary of tag deployments for 2019 is provided below for individuals of both species (**Tables 4, 5**). Overall, 21 satellite tags were deployed - 16 on Cuvier's beaked whales and 5 on short-finned pilot whales. Maps showing Douglas-filtered ARGOS positions for all beaked and pilot whales tagged in 2019 are given below (**Figures 6** and **7** respectively). Individual (by-animal) plots of Douglas-filtered ARGOS positions are also given for the entire satellite tag deployment periods for beaked (**Figures 8-23**) and pilot whales (**Figures 24-27**) below. For whales that were tagged during CEEs, the start and end location of the respective CEEs are indicated on the individual plots.

Two DTAGs were also deployed on pilot whales during the 2019 field effort (**Table 6**). One was very brief, but the second included one of the most important accomplishments of this project to date a Cuvier's beaked whale (Zc19_219a) was successfully tagged with a DTAG in a group of four animals, one of which (Zc93) had been monitored already for over a week with a satellite tag. This was thus, the first successful full (~6h by design) DTAG deployment on a beaked whale in a group with other tagged individuals. Quick look summaries of DTAG results during successful CEEs are provided within respective sub-sections of Section 2.3.

Table 4. Satellite tag deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2019

Species[1]/ Tag ID	Deployment date	Sighting #	Deployment latitude (°N)	Deployment longitude (°W)	Dive data streams	Tag duration (days)
ZcTag082	05/11/19	7	35.5216	-74.7619	5-min time series	53
ZcTag083	05/11/19	11a	35.5734	-74.7486	5-min time series	40
ZcTag084	05/23/19	1	35.5318	-74.7276	5-min time series	44
ZcTag085	05/27/19	1	35.6928	-74.7463	5-min time series	41
ZcTag086	05/28/19	3	35.5956	-74.7300	5-min time series	14
ZcTag087	06/02/19	2	35.6000	-74.7255	5-min time series	21
ZcTag088	06/02/19	3	35.6090	-74.7233	5-min time series	44
ZcTag089	06/02/19	6	35.5780	-74.7342	5-min time series	28
ZcTag090	07/29/19	2	35.5932	-74.7468	5-min time series	16
ZcTag091	07/29/19	5	35.6193	-74.7493	5-min time series	14
ZcTag092	07/30/19	1	35.5359	-74.7258	5-min time series	41
ZcTag093	07/30/19	1	35.5398	-74.7283	5-min time series	25
ZcTag094	07/30/19	7	35.5909	-74.7411	5-min time series	3
ZcTag095	08/12/19	4	35.6509	-74.7384	5-min time series	38
ZcTag096	08/12/19	4	35.6473	-74.7357	5-min time series	44
ZcTag097	08/12/19	4	35.6301	-74.7411	5-min time series	37

[1]Zc = *Ziphius cavirostris*

Table 5. Satellite tag deployments for pilot whales during Atlantic-BRS field efforts in 2019

Species[1]/ Tag ID	Deployment date	Sighting #	Deployment latitude (°N)	Deployment longitude (°W)	Dive data streams	Tag duration (days)
GmTag223	5/8/19	6	35.68755	-74.77493	Behavior categorical	1
GmTag224	7/28/19	3	35.83640	-74.83162	Behavior categorical	32
GmTag225	7/28/19	5	35.85322	-74.81622	Behavior categorical	11
GmTag226	7/28/19	6	35.84785	-74.81029	Behavior categorical	25
GmTag227	7/28/19	6	35.85607	-74.81084	Behavior categorical	10

[1]Gm = *Globicephala macrorhynchus*

Table 6. DTAG deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2019

Tag ID	Deployment date	Deployment latitude (°N)	Deployment longitude (°W)	Baseline or CEE number	Tag duration	Recovered?
n/a (short deployment)	8/6/19	35.69	-74.75	Baseline	n/a (minutes)	YES
Zc19_219a*	8/6/19	35.83	-74.83	CEE #2019-03	6 hours	YES

* In group with satellite tagged Zc93 during CEE #2019-03

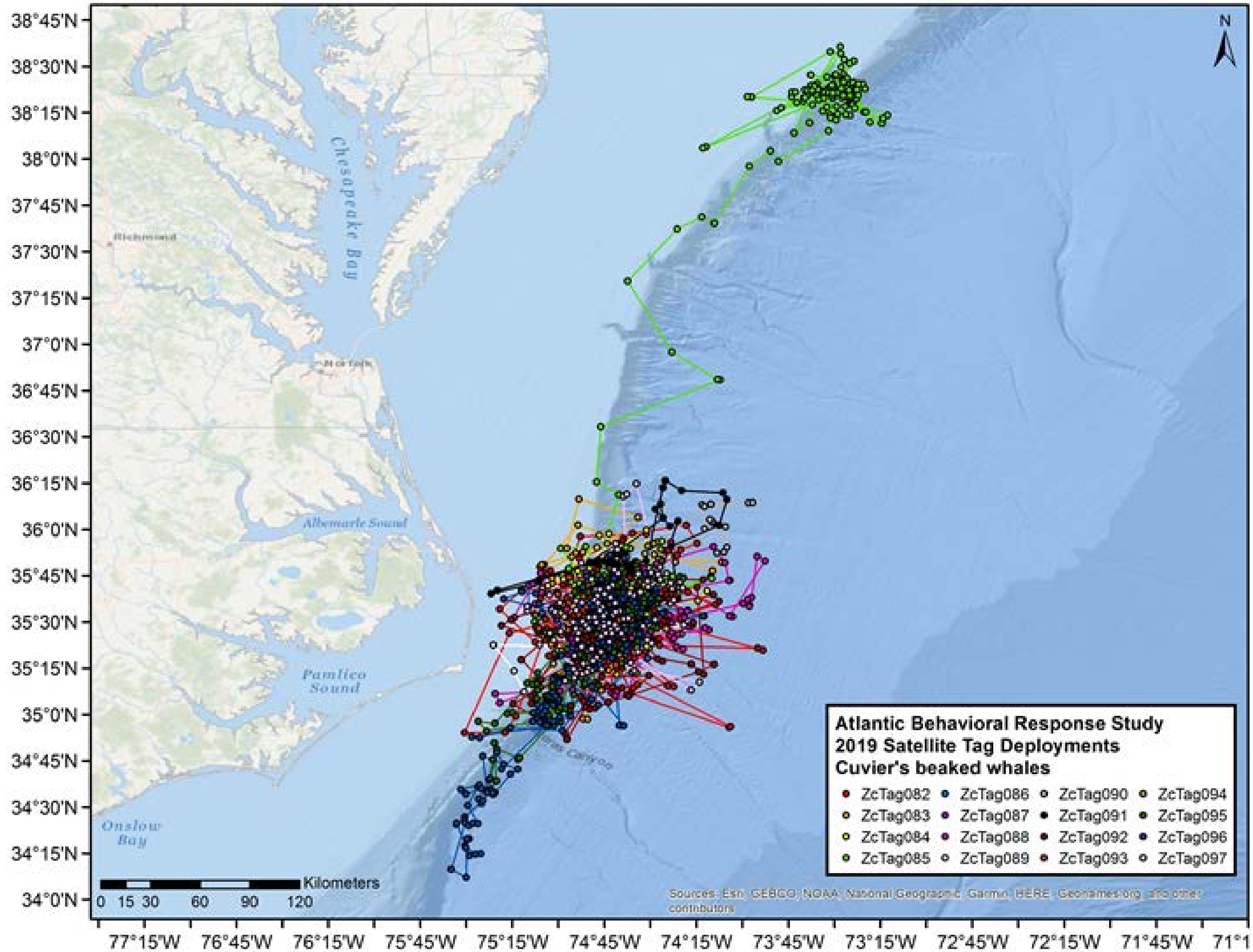

Figure 6. Douglas-filtered ARGOS positions for all Cuvier's beaked whales tagged during Atlantic-BRS field efforts in 2019

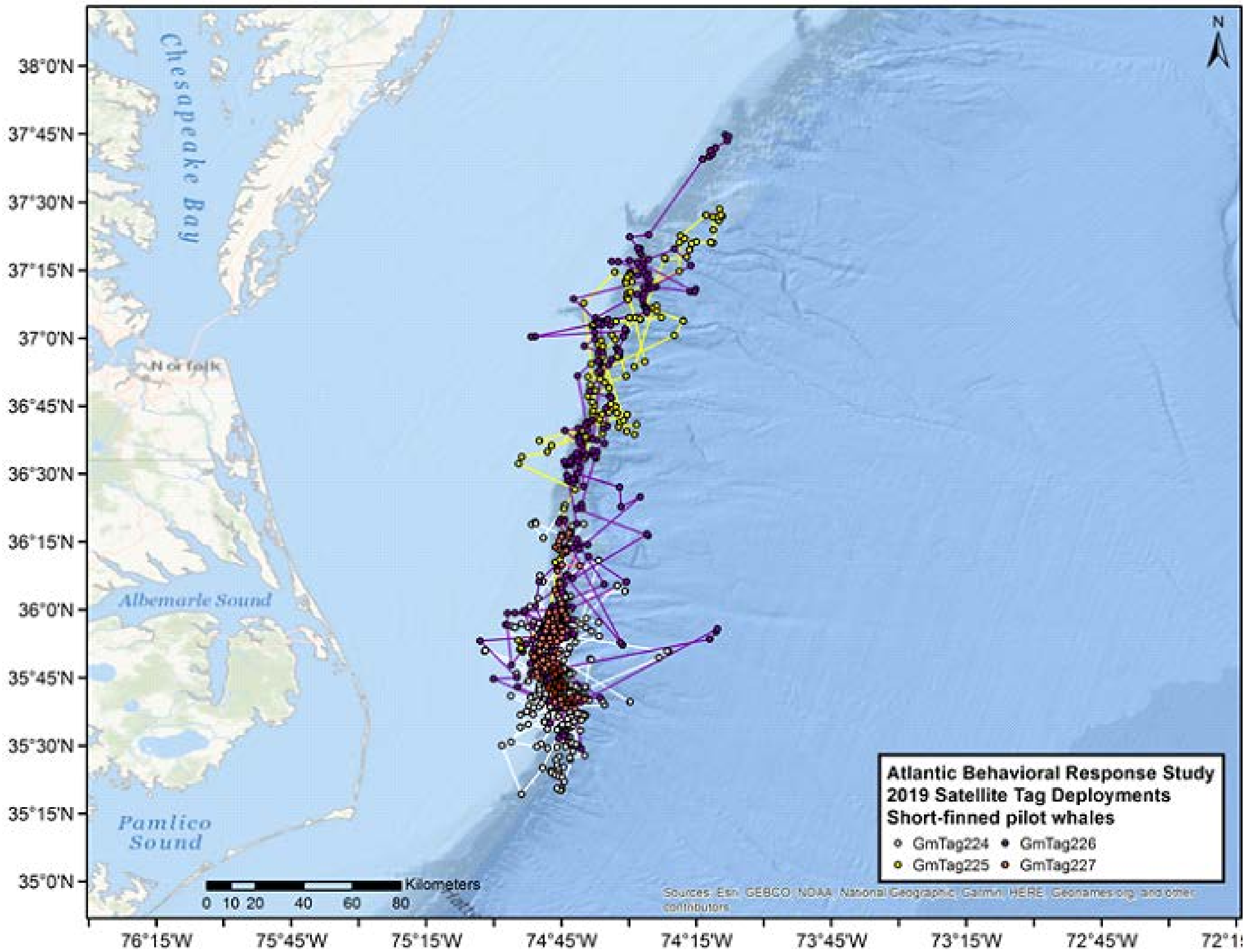

Figure 7. Douglas-filtered ARGOS positions for all short-finned pilot whales tagged during Atlantic-BRS field efforts in 2019

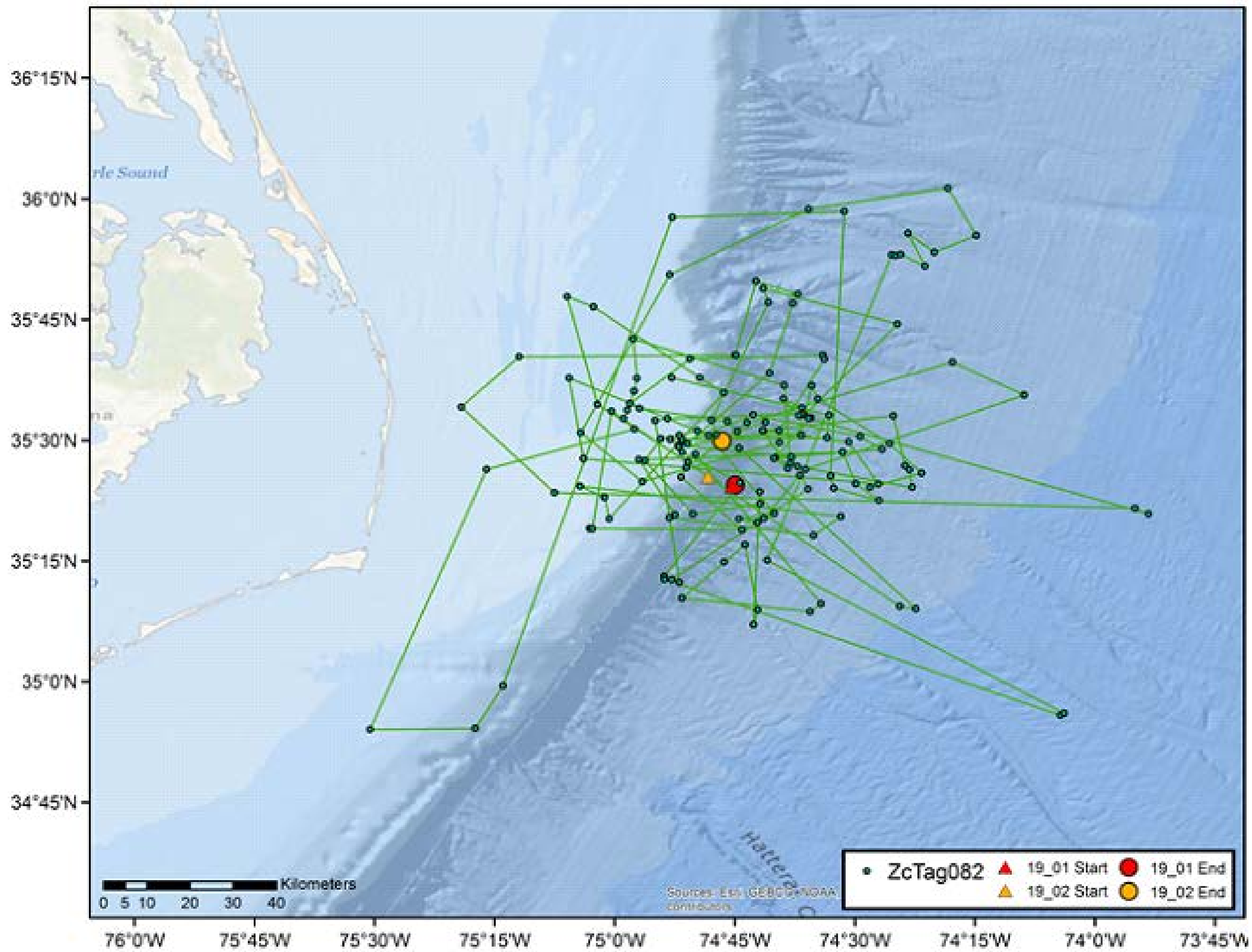

Figure 8. Douglas-filtered ARGOS positions for entire track of ZcTag82 showing positions of CEEs conducted while tag was deployed.

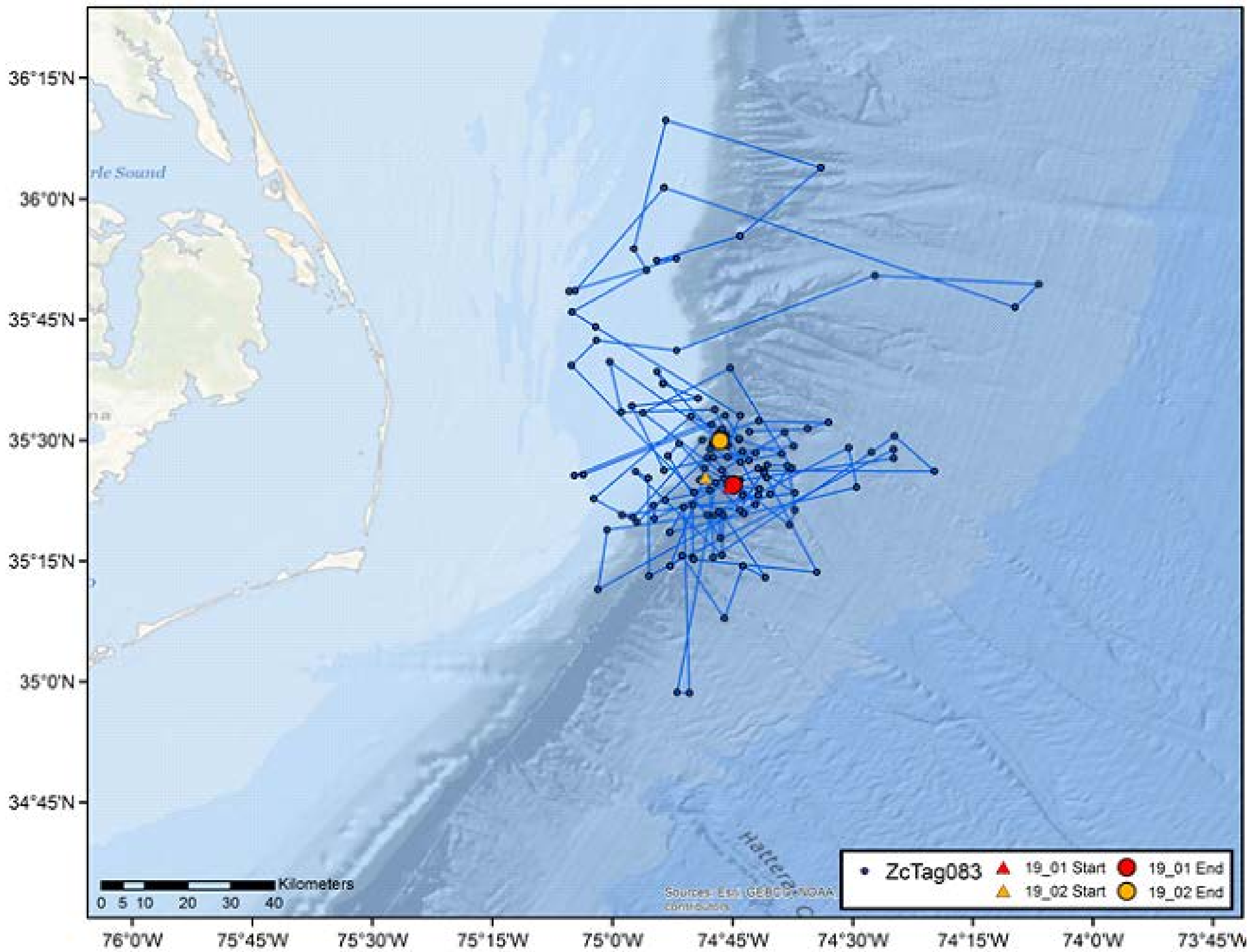

Figure 9. Douglas-filtered ARGOS positions for entire track of ZcTag83 showing positions of CEEs conducted while tag was deployed.

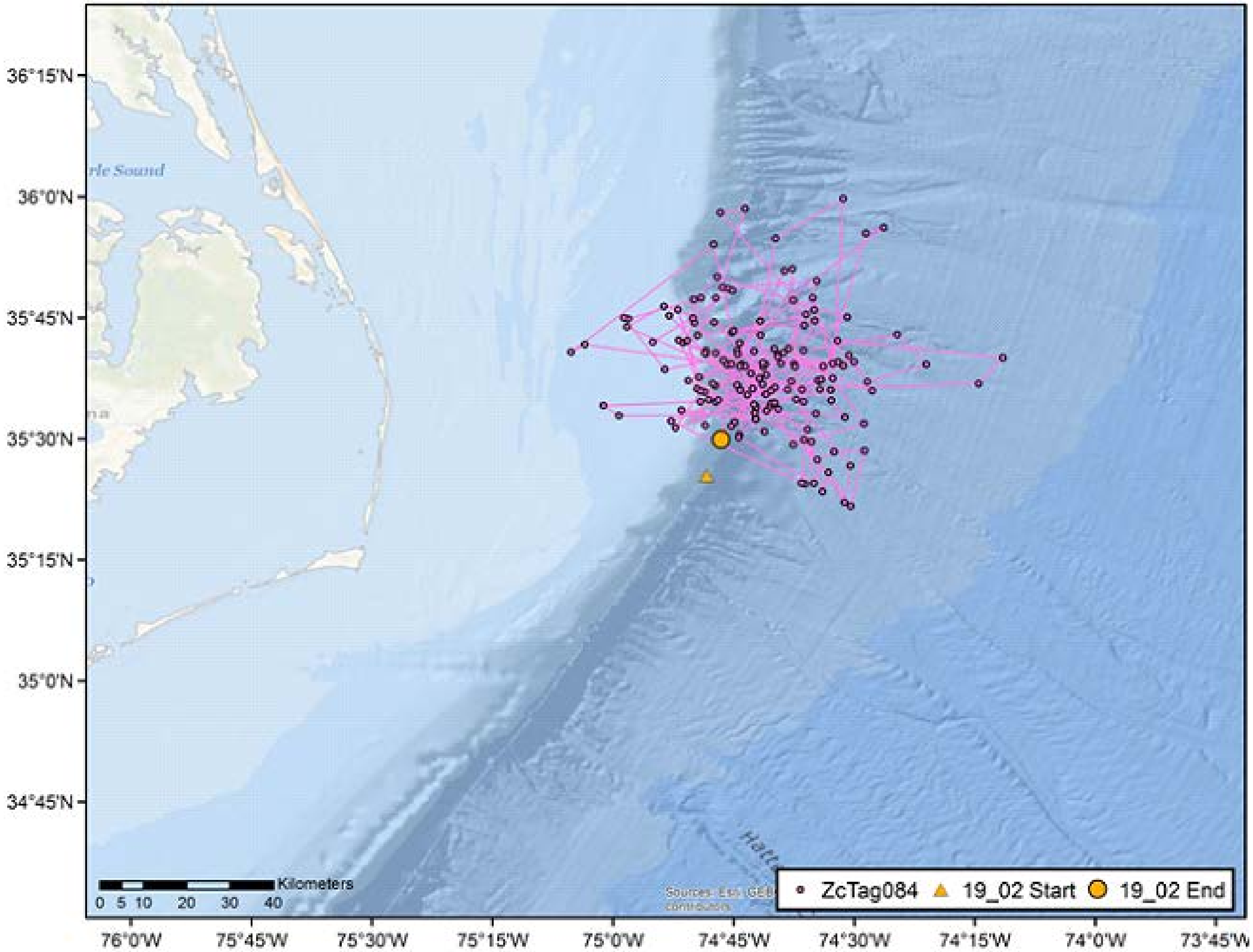

Figure 10. Douglas-filtered ARGOS positions for entire track of ZcTag84 showing positions of CEEs conducted while tag was deployed.

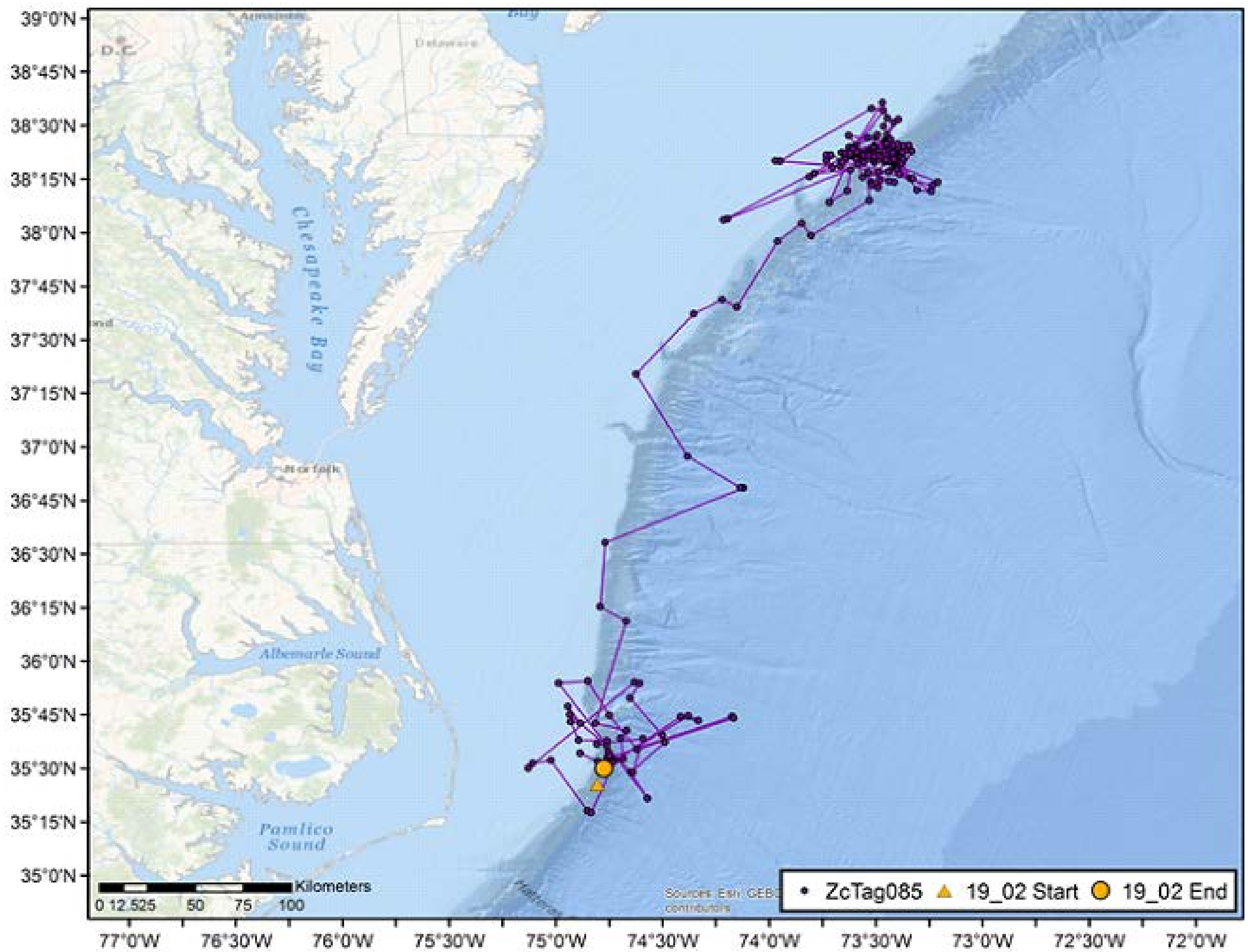

Figure 11. Douglas-filtered ARGOS positions for entire track of ZcTag85 showing positions of CEEs conducted while tag was deployed.

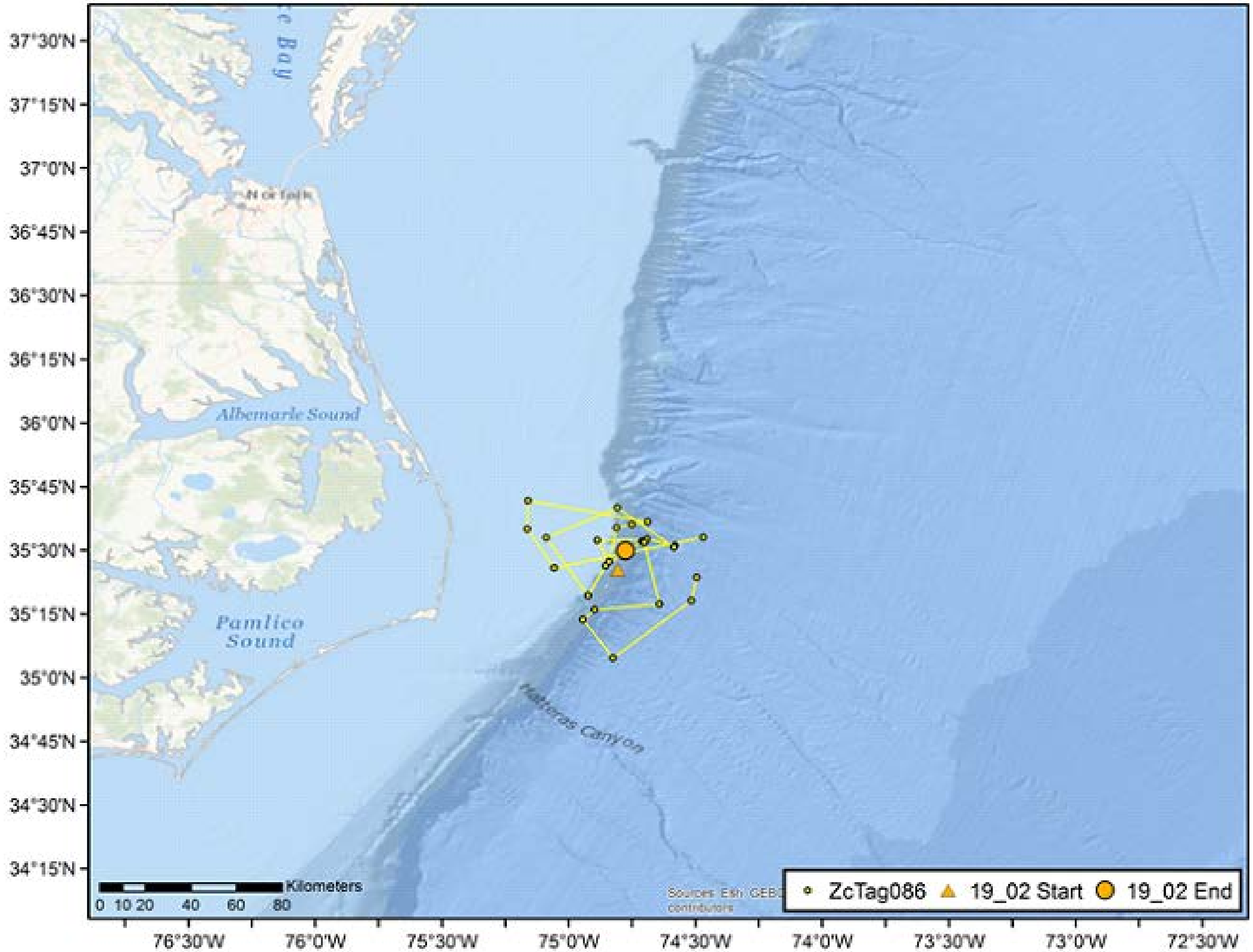

Figure 12. Douglas-filtered ARGOS positions for entire track of ZcTag86 showing positions of CEEs conducted while tag was deployed.

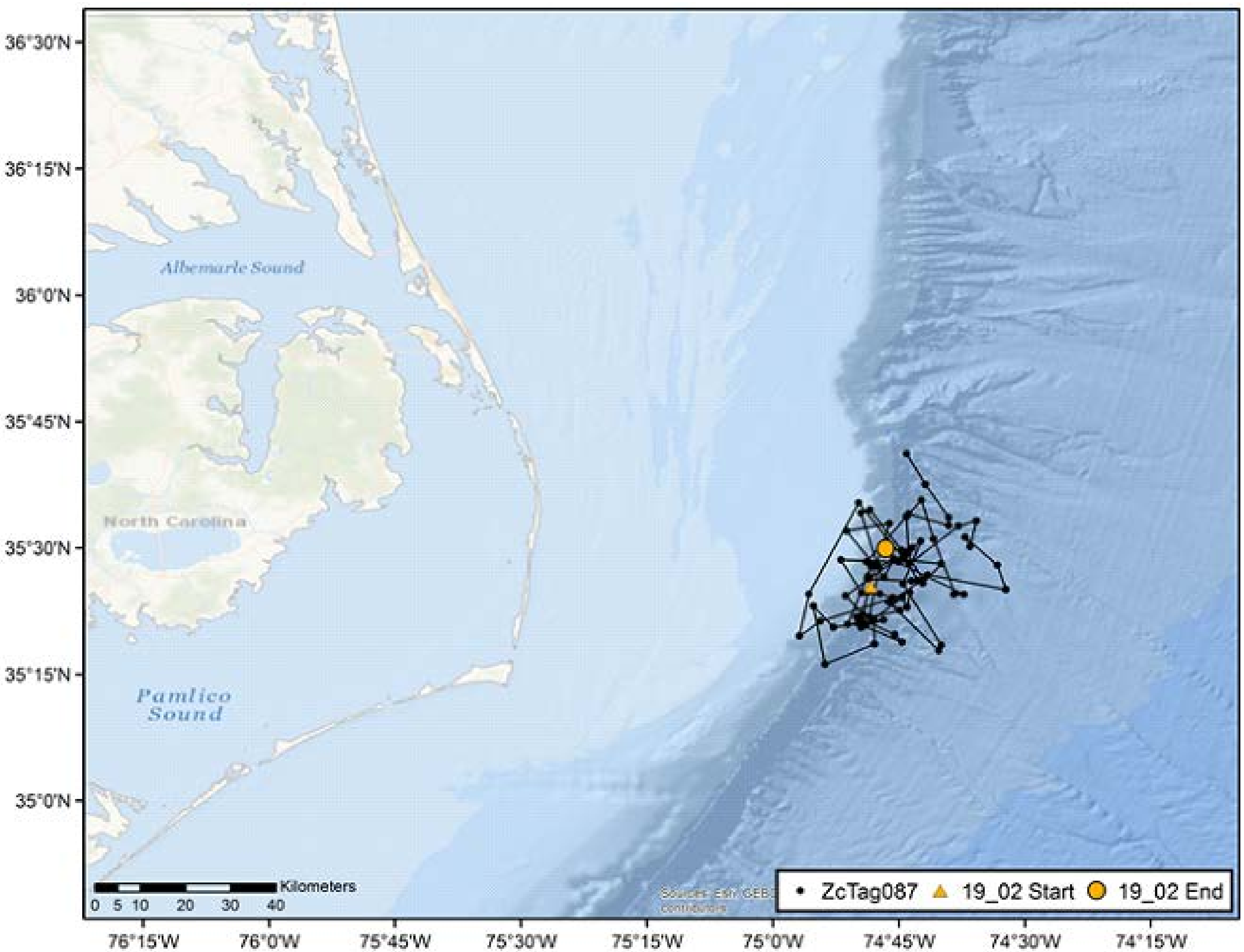

Figure 13. Douglas-filtered ARGOS positions for entire track of ZcTag87 showing positions of CEEs conducted while tag was deployed.

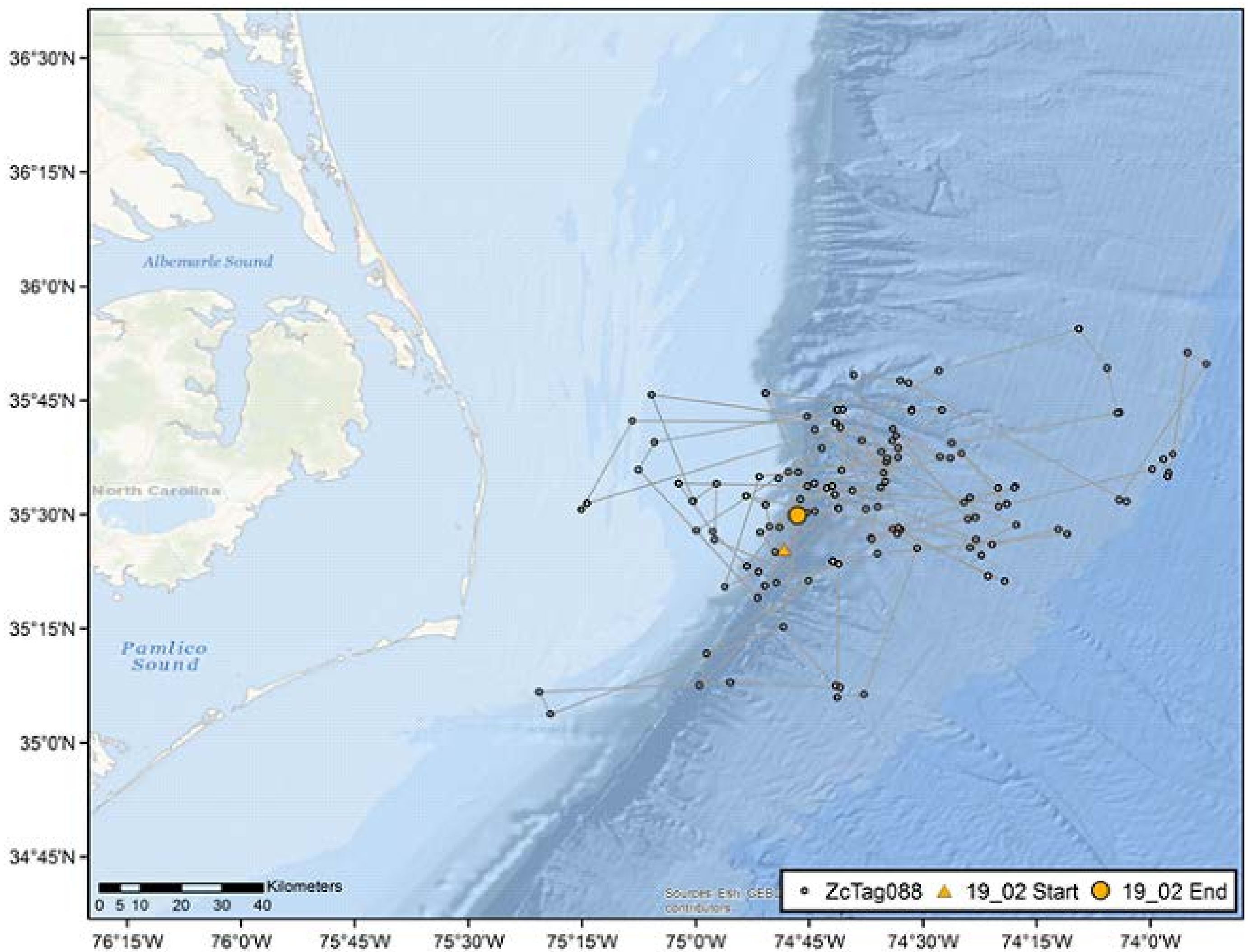

Figure 14. Douglas-filtered ARGOS positions for entire track of ZcTag88 showing positions of CEEs conducted while tag was deployed.

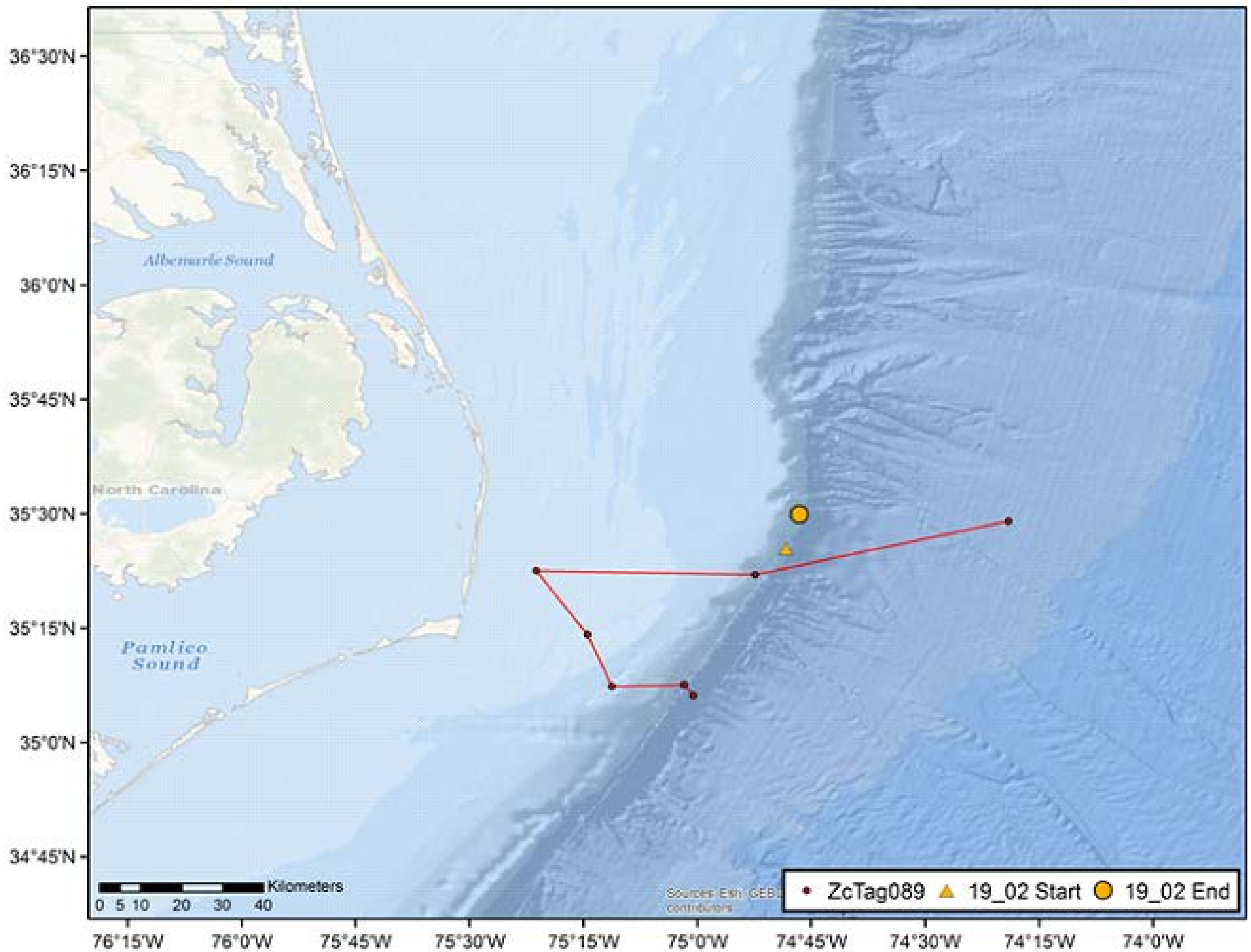

Figure 15. Douglas-filtered ARGOS positions for entire track of ZcTag89 showing positions of CEEs conducted while tag was deployed.

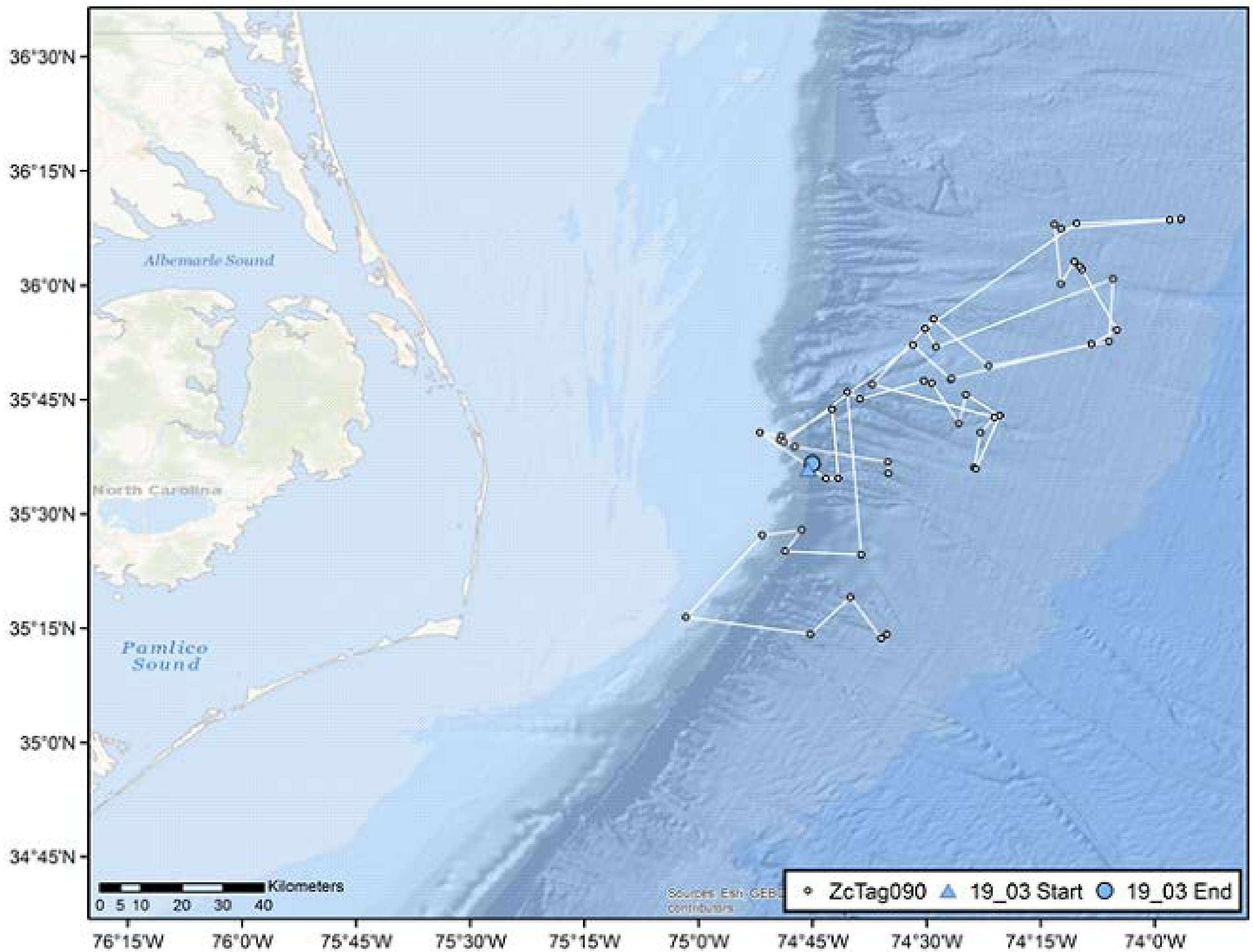

Figure 16. Douglas-filtered ARGOS positions for entire track of ZcTag90 showing positions of CEEs conducted while tag was deployed.

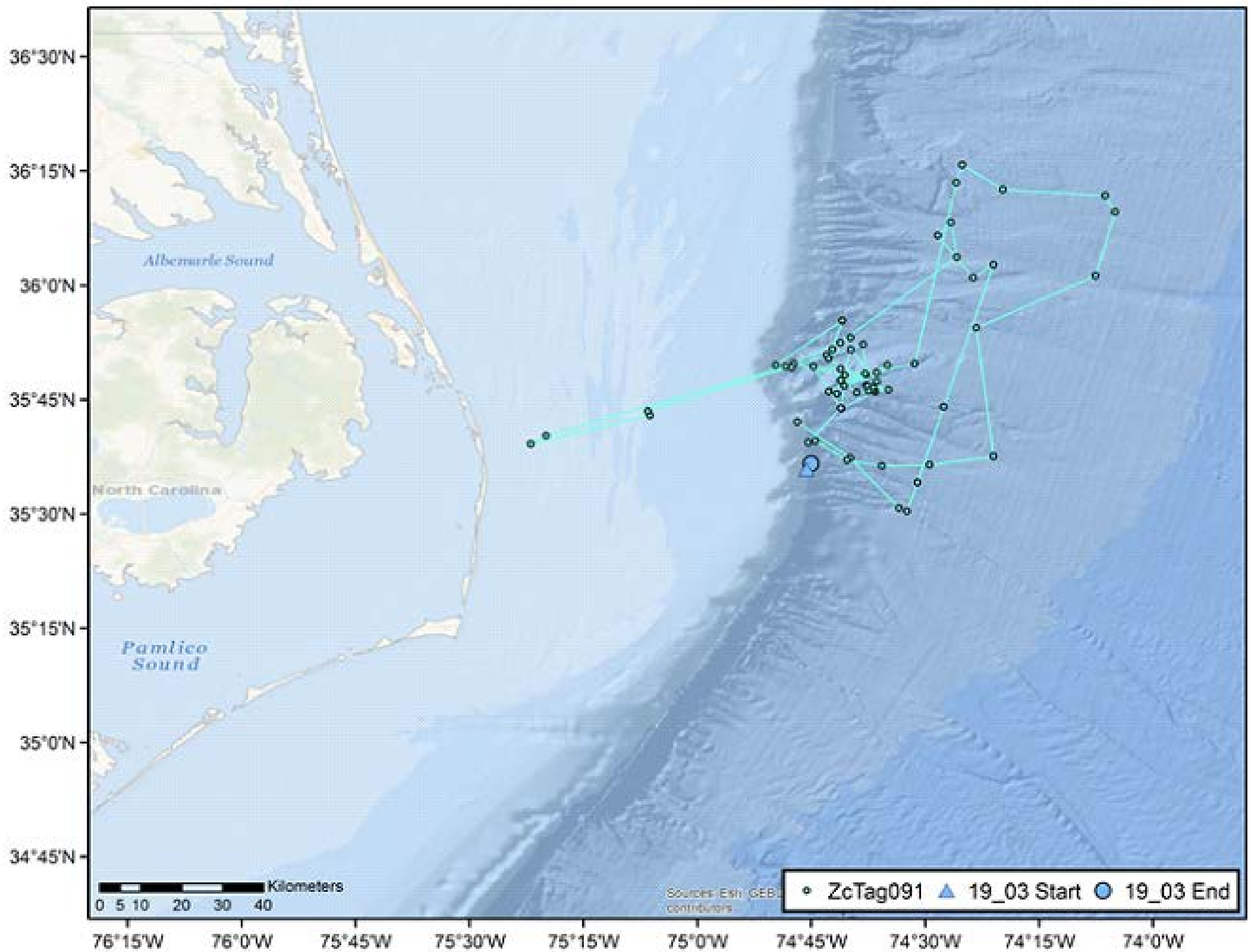

Figure 17. Douglas-filtered ARGOS positions for entire track of ZcTag91 showing positions of CEEs conducted while tag was deployed.

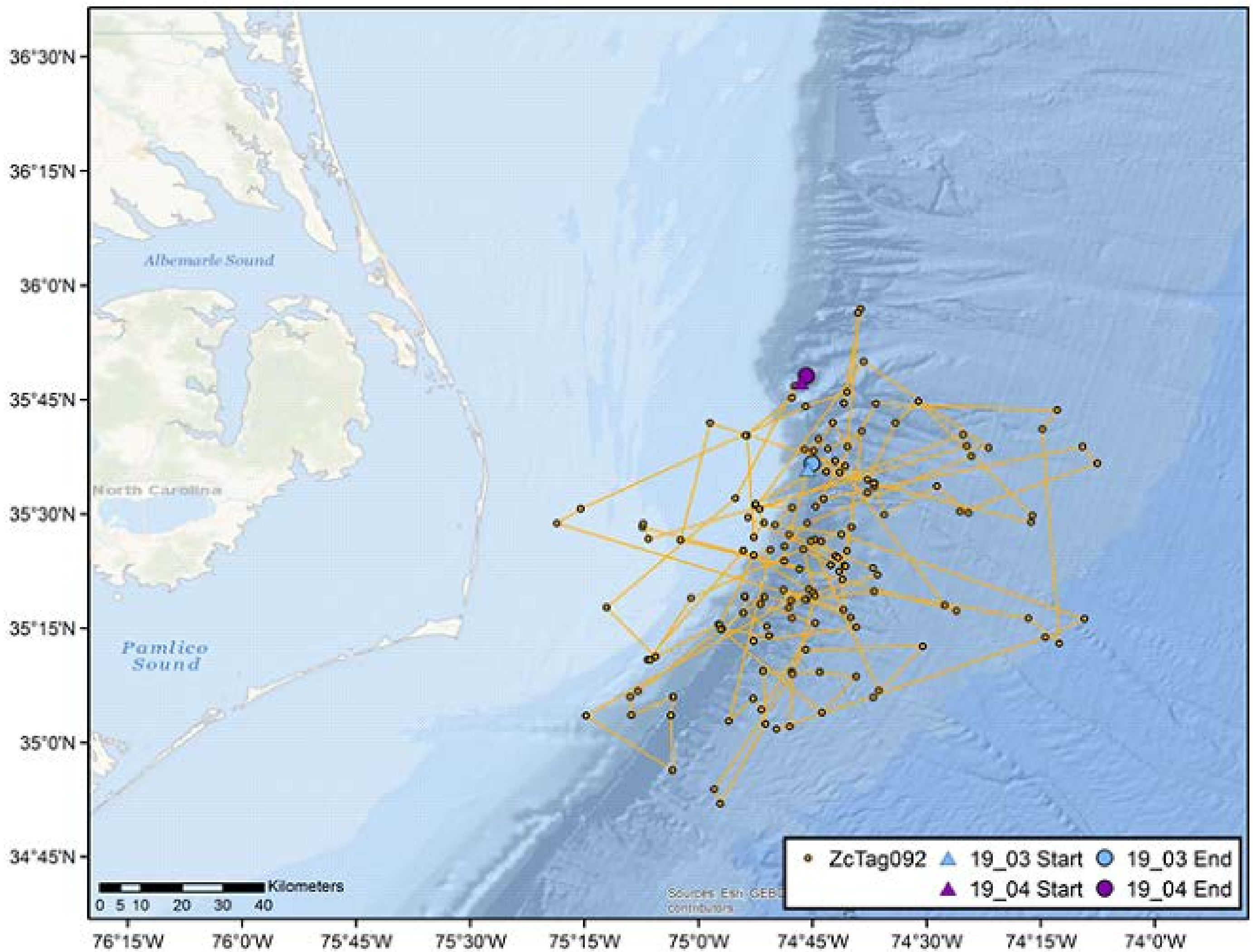

Figure 18. Douglas-filtered ARGOS positions for entire track of ZcTag92 showing positions of CEEs conducted while tag was deployed.

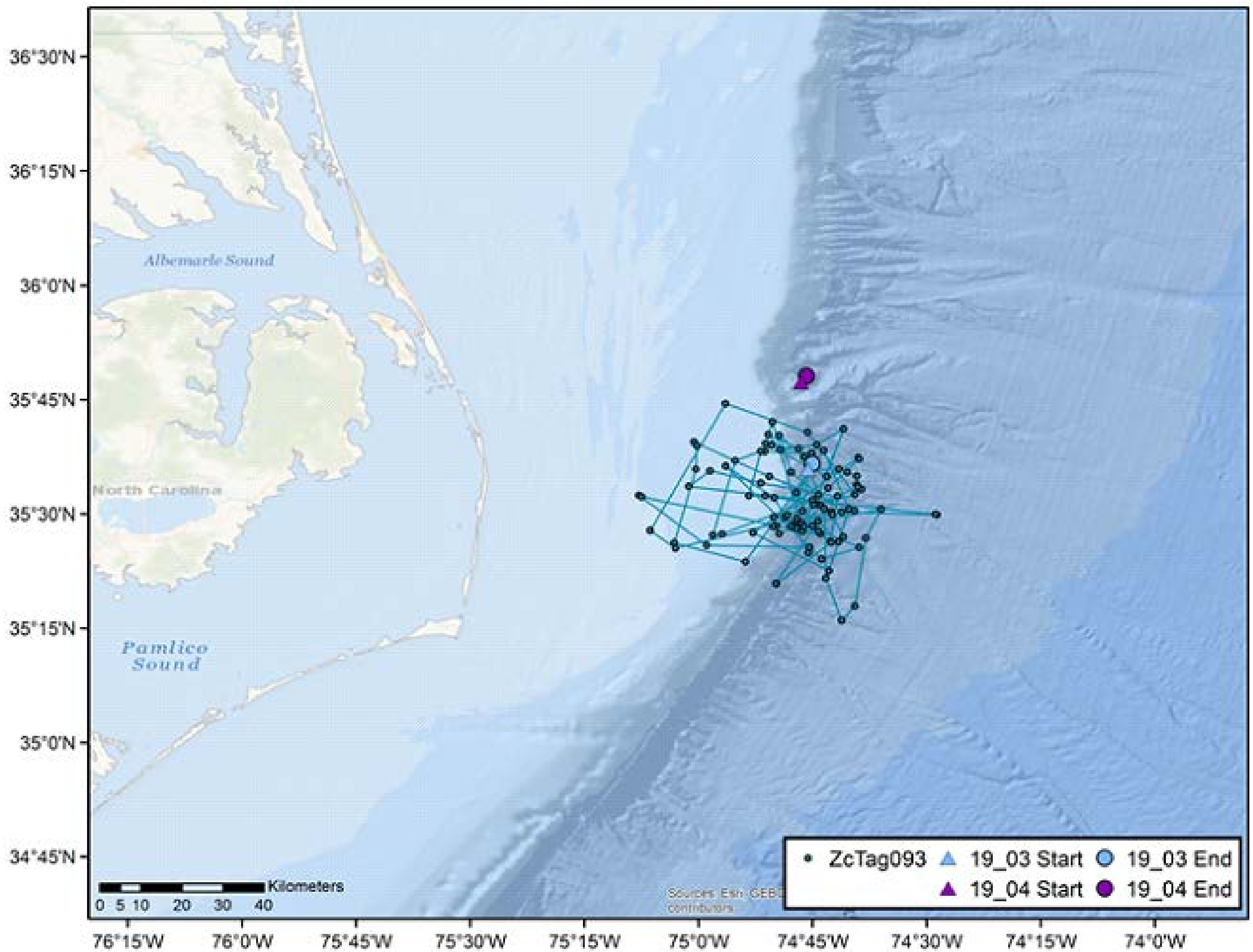

Figure 19. Douglas-filtered ARGOS positions for entire track of ZcTag93 showing positions of CEEs conducted while tag was deployed.

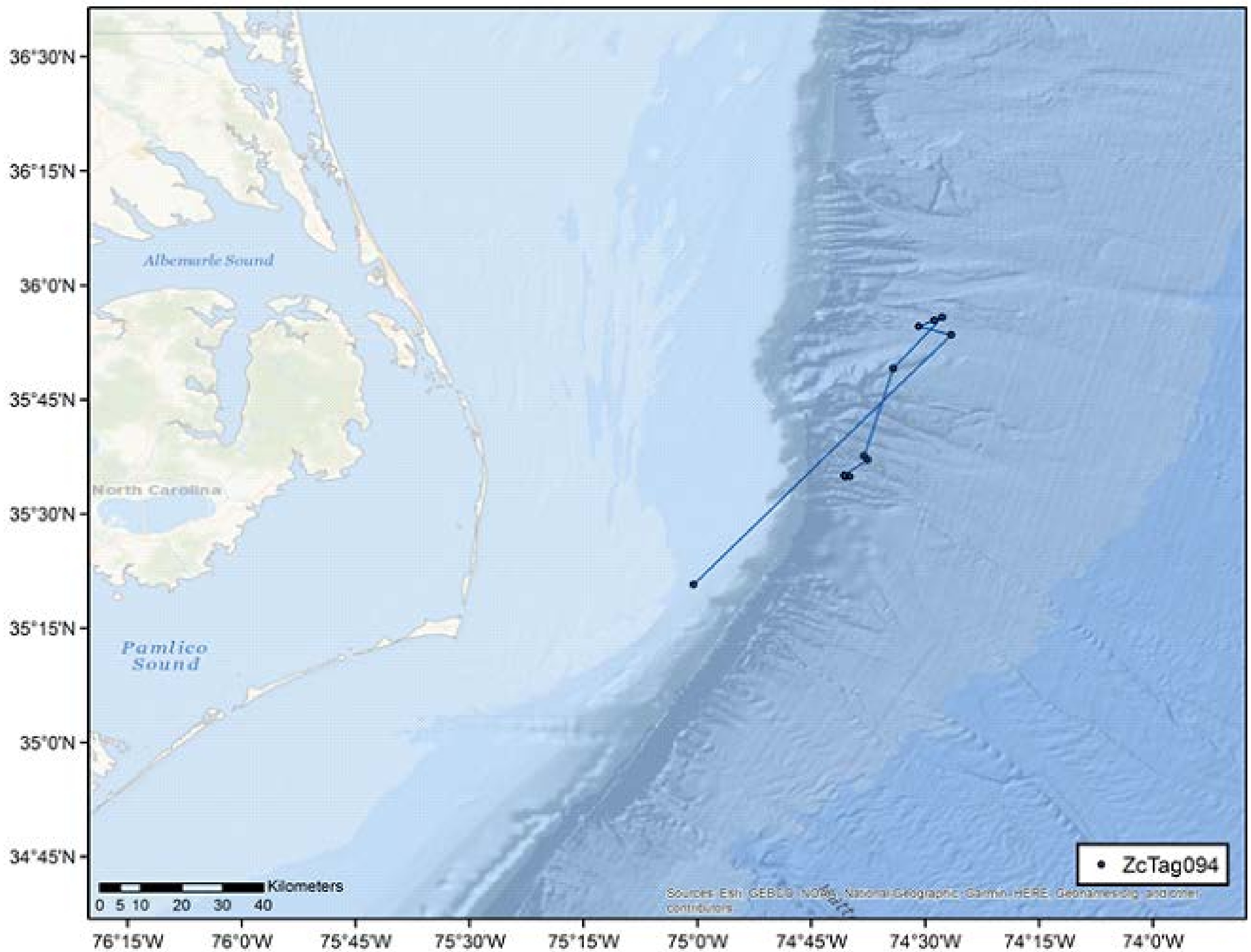

Figure 20. Douglas-filtered ARGOS positions for entire track of ZTagc94.

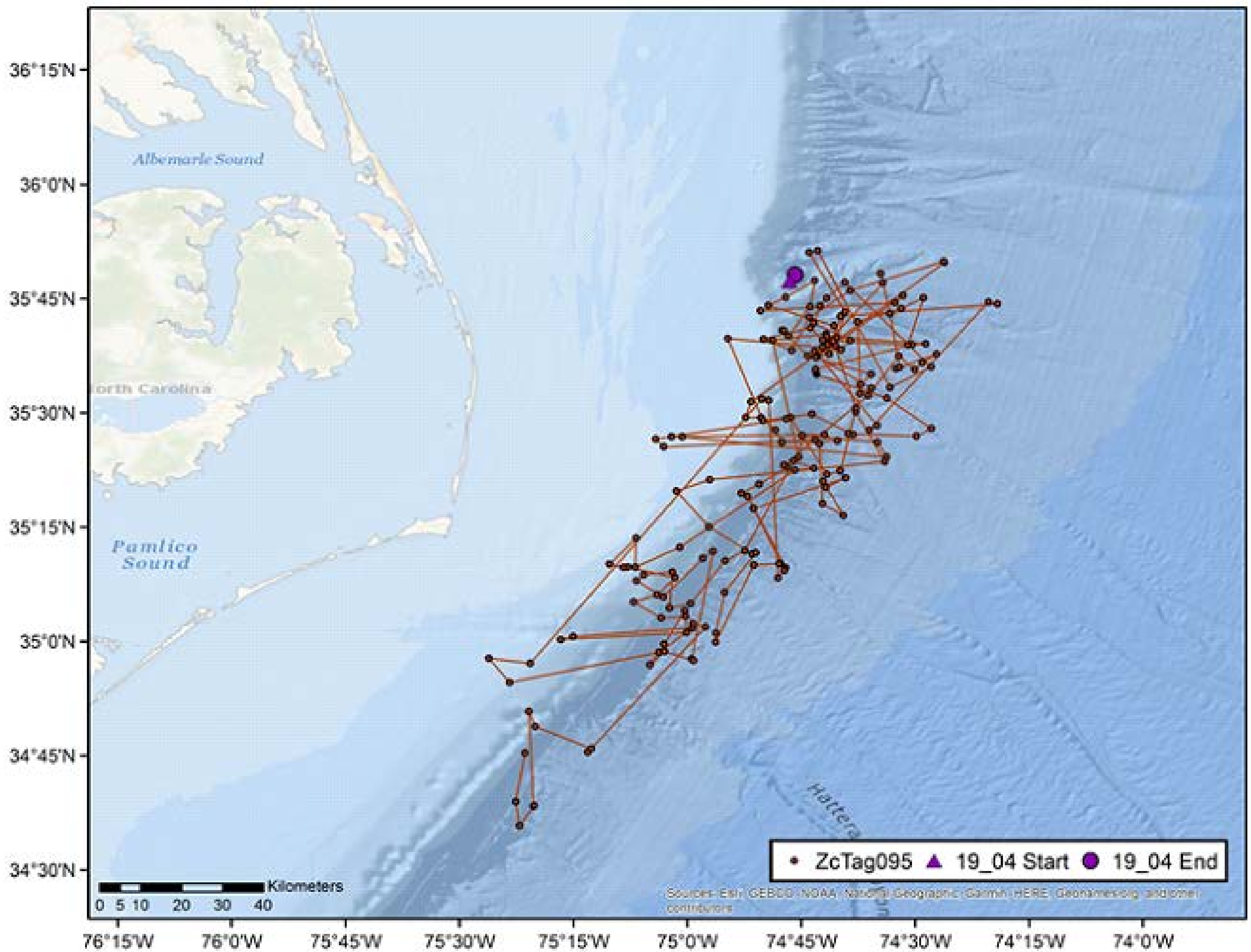

Figure 21. Douglas-filtered ARGOS positions for entire track of ZcTag95 showing positions of CEEs conducted while tag was deployed.

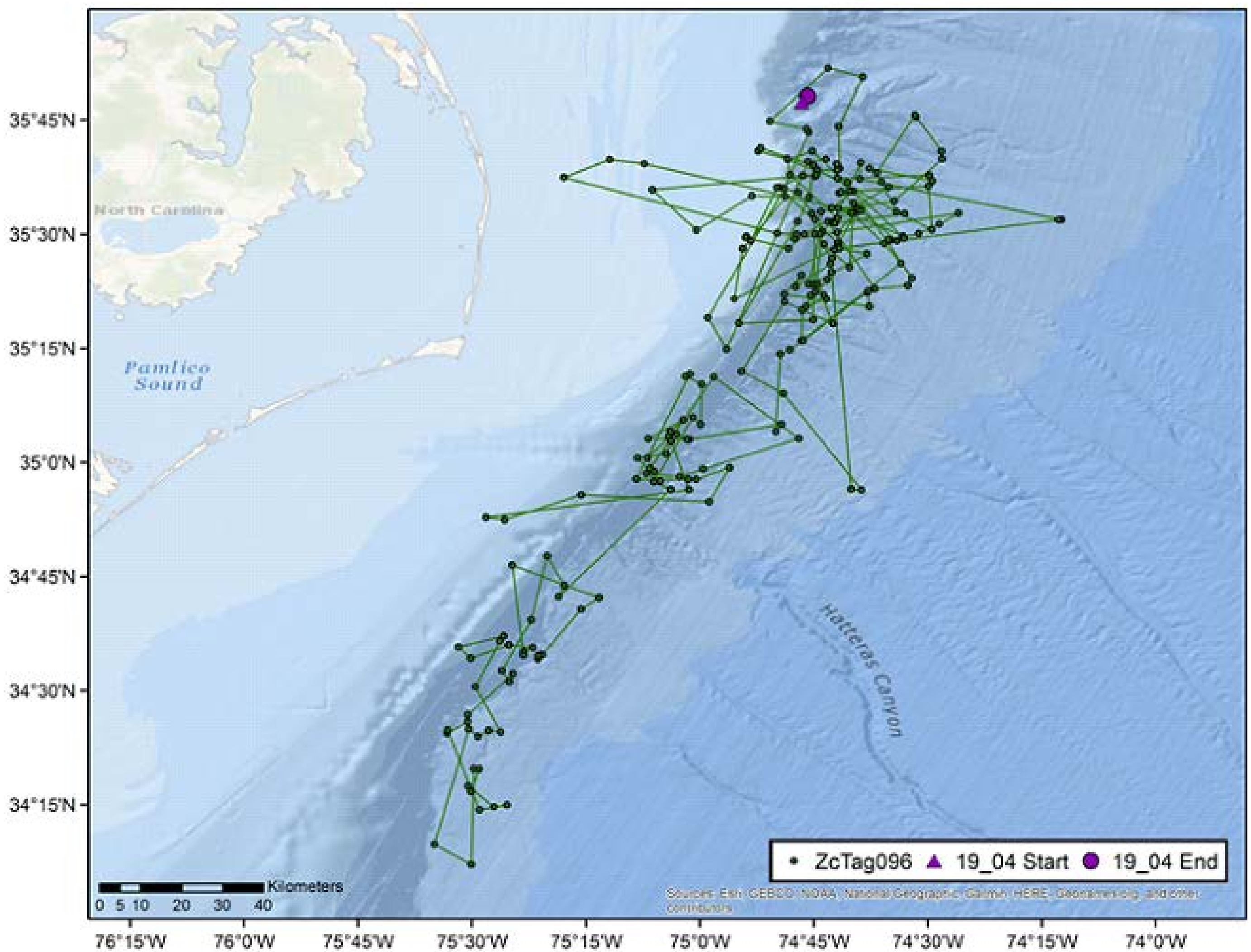

Figure 22. Douglas-filtered ARGOS positions for entire track of ZcTag96 showing positions of CEEs conducted while tag was deployed.

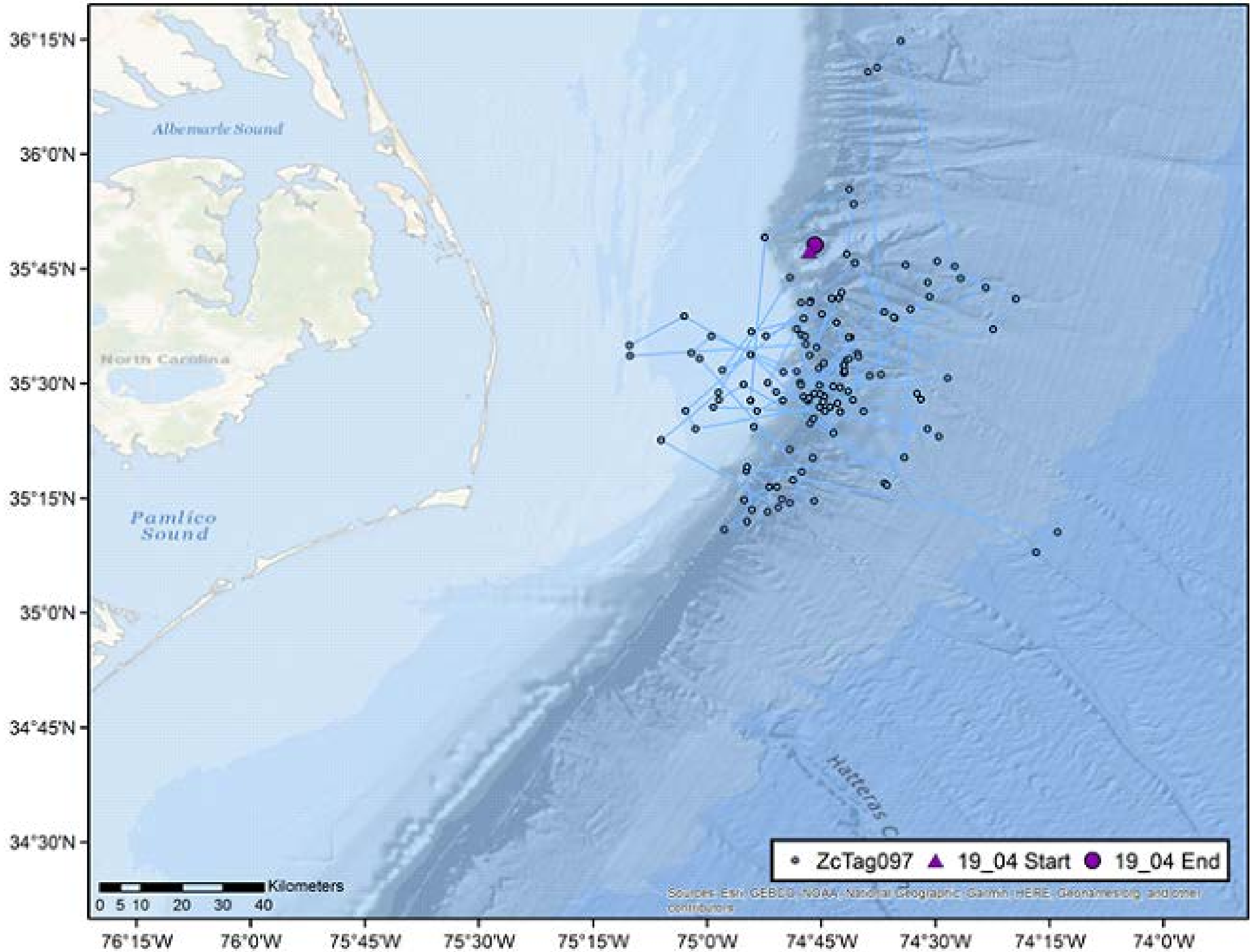

Figure 23. Douglas-filtered ARGOS positions for entire track of ZcTag97 showing positions of CEEs conducted while tag was deployed.

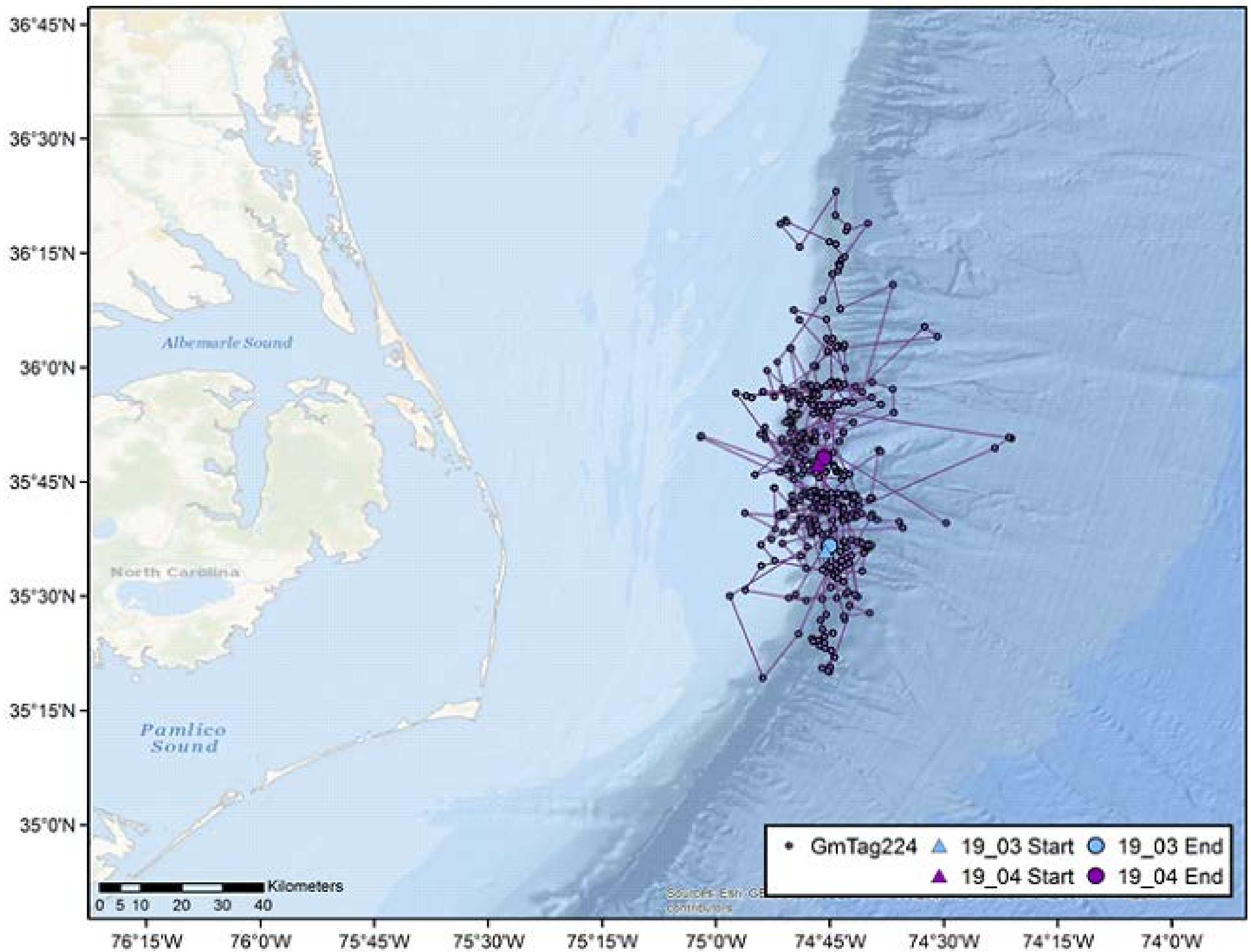

Figure 24. Douglas-filtered ARGOS positions for entire track of GmTag224 showing positions of CEEs conducted while tag was deployed.

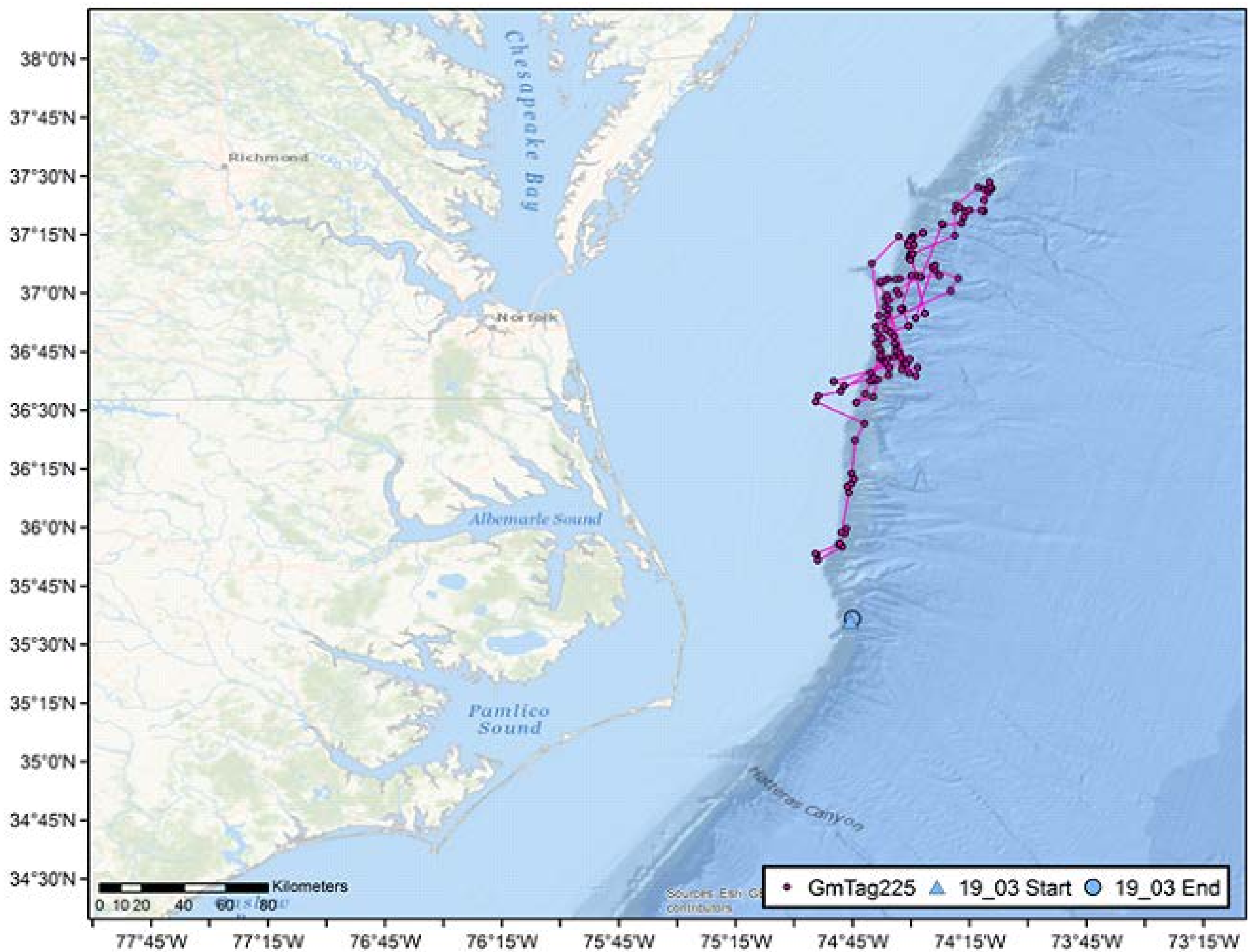

Figure 25. Douglas-filtered ARGOS positions for entire track of GmTag225 showing positions of CEEs conducted while tag was deployed.

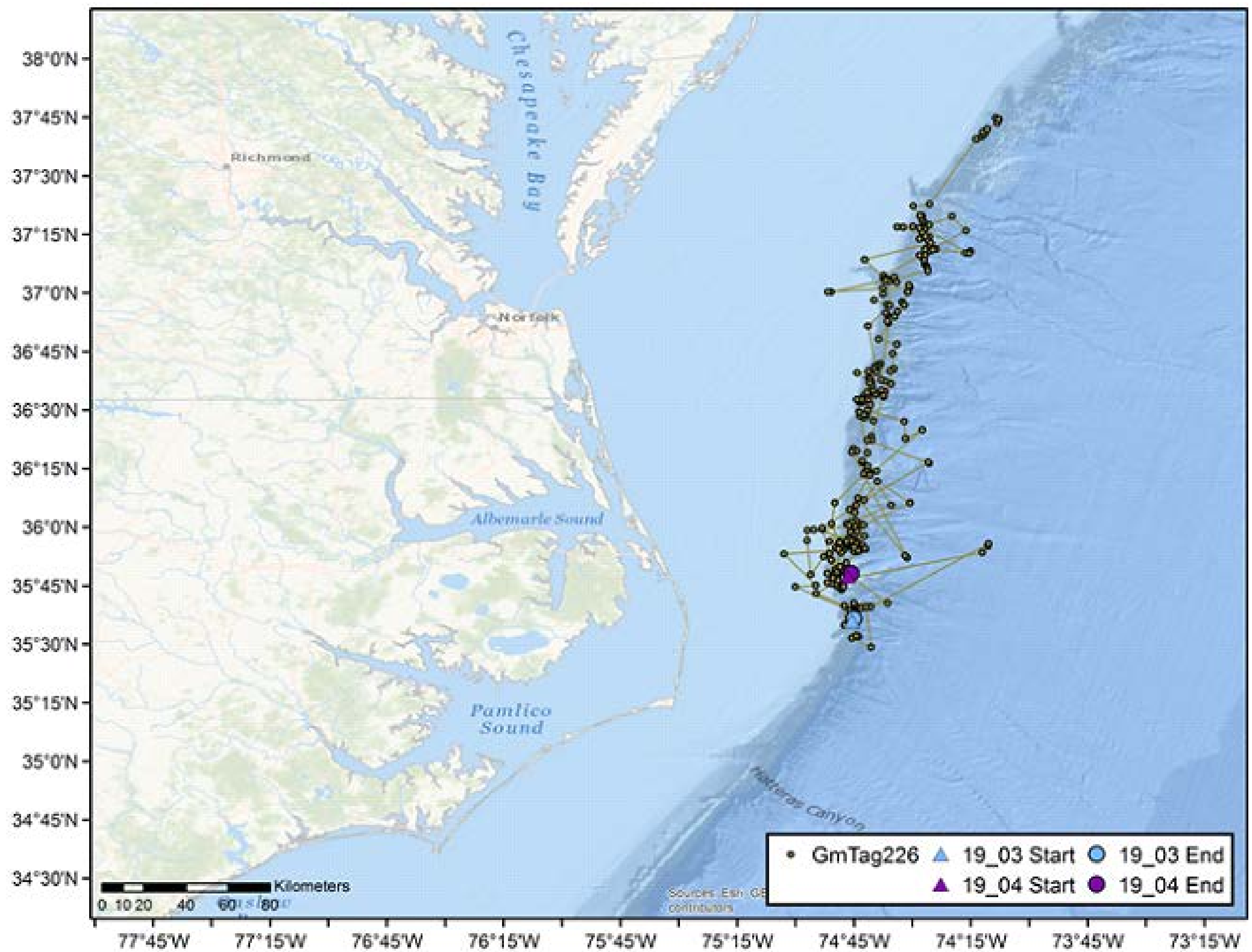

Figure 26. Douglas-filtered ARGOS positions for entire track of GmTag226 showing positions of CEEs conducted while tag was deployed.

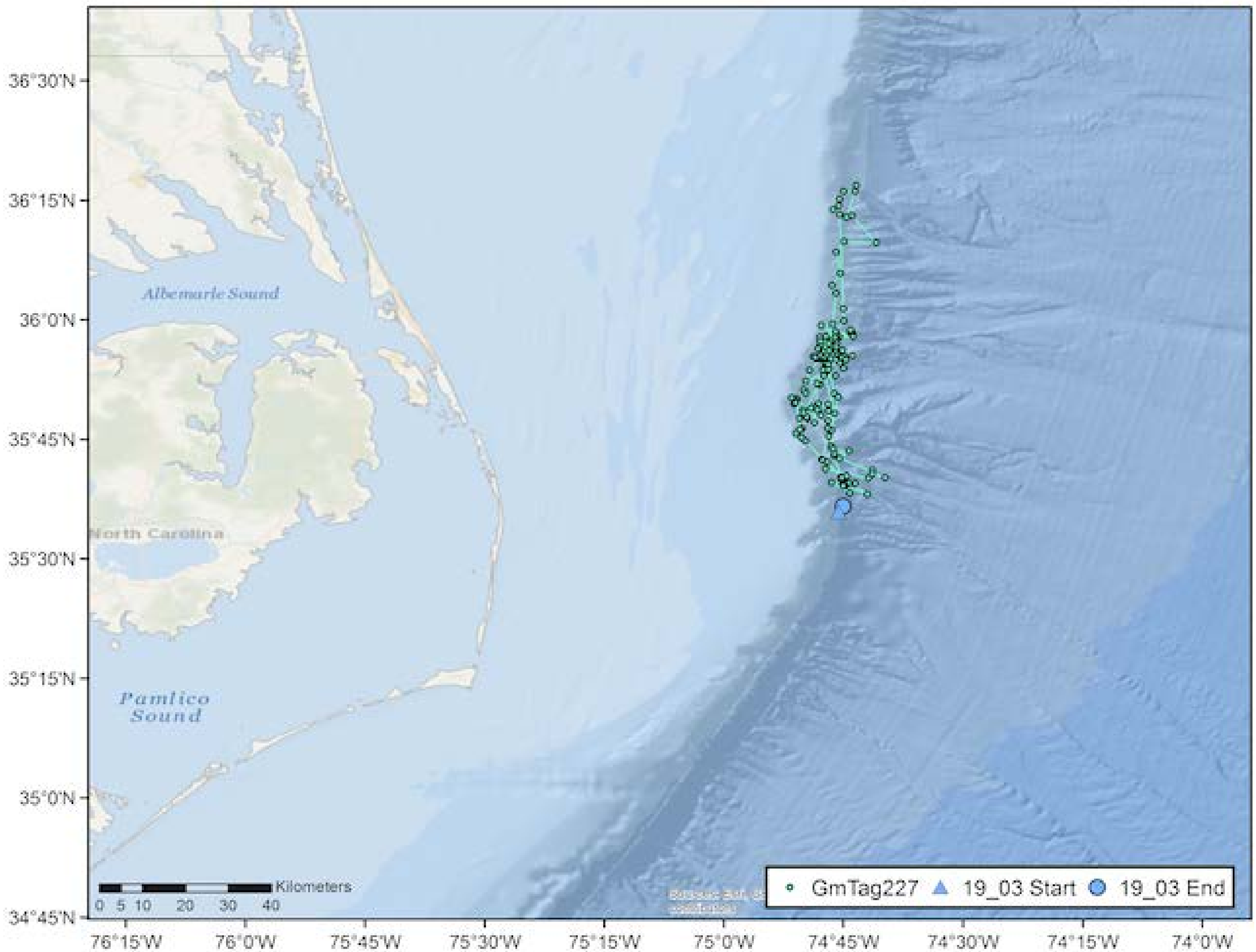

Figure 27. Douglas-filtered ARGOS positions for entire track of GmTag227 showing positions of CEEs conducted while tag was deployed.

2.3 CEEs Conducted

Four CEE sequences were conducted during the Atlantic-BRS 2019 field effort. This included one active exposure sequence for each of the effective tagging period windows as discussed above (i.e., two each in the spring and summer field efforts). No Navy ships were available to participate during either field period, so all CEEs were successfully conducted with the simulated MFAS source (**Table 7)**.

Table 7. CEEs conducted during 2019 Atlantic-BRS field efforts

CEE ID	Date	CEE Type	Focal whales	CEE duration (min)	Initial CEE source latitude (°N)	Initial CEE source longitude (°W)
#2019-01	5/15/19	Simulated MFAS	Zc82; Zc83	7*	35.40	74.76
#2019-02	6/7/19	Simulated MFAS	Zc89; Zc86	30	35.42	74.81
#2019-03	8/6/19	Simulated MFAS	Zc19_218a; Zc93 (in same group)	30	35.60	74.76
#2019-04	8/19/19	Simulated MFAS	Zc95; Zc96; Zc97 (in same group)	30	35.79	74.78

* Preliminary shut-down of simulated MFAS source due to permit requirements for marine mammals (Atlantic bottlenose dolphins) swimming within 200m of active source at near full power

Subsequently, we provide a summary synthesis of each CEE conducted with standardized tables and figures including: (1) metadata summaries; (2) planning RL modeling (where applicable), (3) modeled positions from satellite tag locations for individuals exposed during each CEE using several methods; and (4) dive records for satellite tagged whales during CEEs; and (5) DTAG quick-look summaries for applicable CEEs (Sections 2.3.1 through 2.3.8). A brief description of each standardized figure type is provided within Section 2.3.1, which is applicable for all subsequent figures of the same type. Figures are provided for all individuals where tags reported sufficient data during CEE periods. In some instances, gaps in data reporting occurred or tags had ceased to report data of a particular type (e.g., dive data) but were still reporting other types (e.g., ARGOS positions) dependent on how tags were strategically set up based on expectations of CEE timing.

2.3.1 CEE #2019-01: Simulated MFAS

Table 8. Metadata summary for Atlantic-BRS CEE #2019-01

CEE # 2019_01	
Date:	21 May 2019
Type:	Simulated MFAS (deployed from *F/V Hog Wild*)
Signal parameters:	Three-segment (1.2 s total duration) pings (3.5–4 kilohertz [kHz]); 212 dB re 1 µPa (RMS) @ source; 25 s rep rate; TERMINATED CEE after 15 pings (mandated shut-down)
Start time (UTC):	15:04:50
Start lat/lon (source):	35.40247; -74.755902
End time (UTC):	15:11:15
End lat/lon (source):	35.40688; -74.748435
Beaked whales tagged during CEE:	(n=2) – Zc82 (focal sat tag animal); Zc83 (was in nearby vicinity)
Pilot whales tagged during CEE:	None
Estimated Range (start CEE):	5.4 km (2.1 nm) @ start; drift was ~1nm to the NE during CEE
Modeled Max RL:	139.5 dB RMS @ 1000m initial posit. 148-140 dB RMS at start location (@10, 1000m).

CEE #2019_01 - Narrative Summary
Our first CEE of 2019 was set up well initially with focal follow on Zc82 and Zc83 in the relatively nearby area. Conditions were not ideal and we were focusing on only sat tagged whales with no DTAG effort and no *R/V Barber*. We were in measured 4.4 kt current to ENE and drifted about that rate and direction during the stationary period with source deployed. CEE was underway and we were nearly through the ramp-up when a small group of bottlenose dolphins came directly over to the *Hog Wild* with the simulated source at near full power. Once they came inside 200m (they eventually came to the side of the boat), we terminated MFAS transmissions as per the mandated requirements of our NMFS permit. This resulted in less than 7 min of transmissions (15 total pings) prior to termination. Zc82 was not re-located visually after this short CEE (focal was detected by goniometer as was Zc83) but this was likely more of a function of the relatively poor sighting conditions than a major horizontal avoidance. This was the first and only CEE from this platform (*Hog Wild*) which worked fine generally speaking.

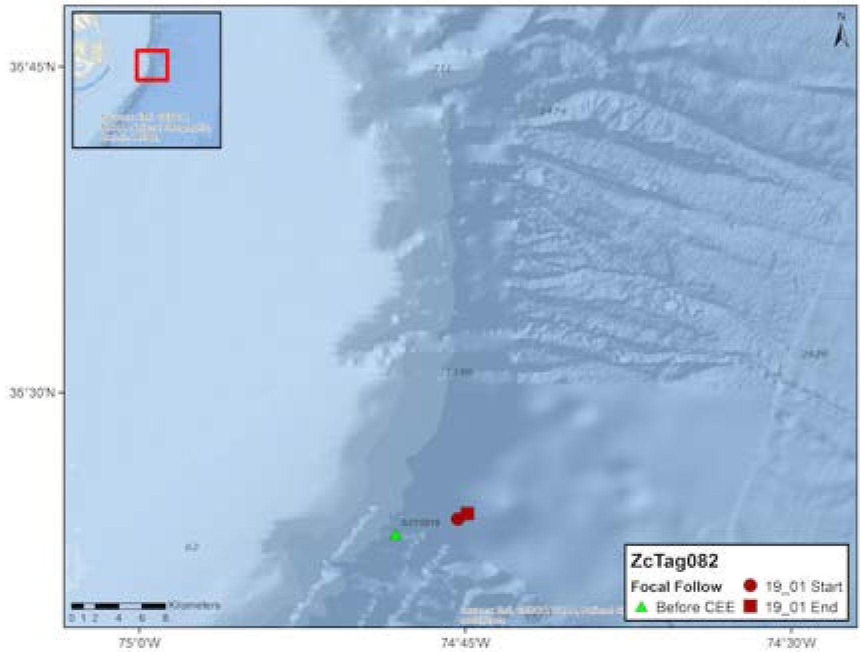

Figure 28. Overview map of source and focal follow locations for CEE #2019-01

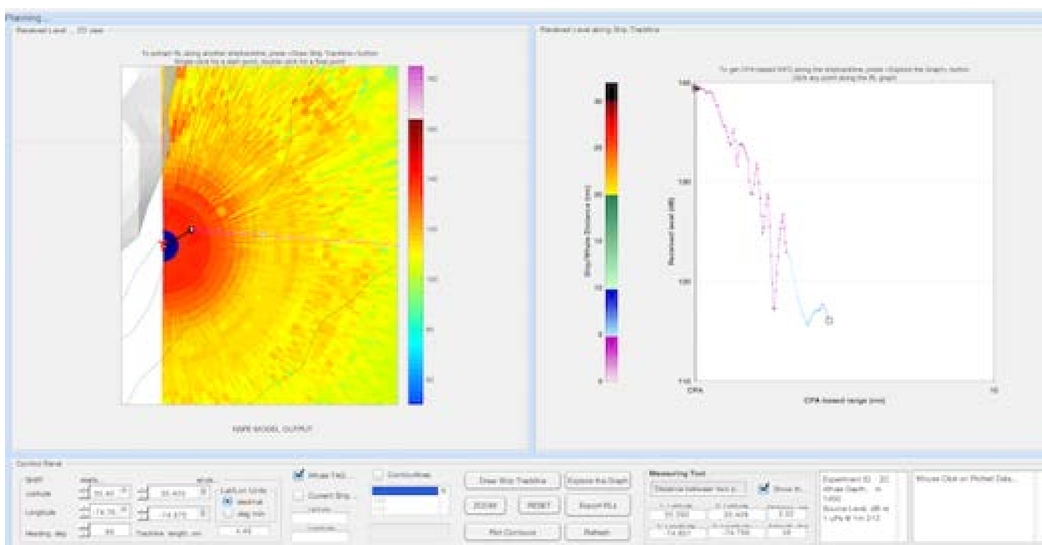

Figure 29. RL model prediction at 1000 m depth for focal whale ZcTag82 for initial position used for *in situ* modeling of Atlantic-BRS CEE #2019-01. Modeled RL at this depth and estimated position was: 139.5 dB RMS.

NOTE: These RL model prediction plots were generated using the Naval Postgraduate School (NPS) sound propagation tool used in the field to estimate received levels for animals at known/estimated tag location (T) with a MFAS source positioned at a strategic location (small white circle in left plots). Right panels show modeled RLs at different positions along tracks. For simulated MFAS CEEs (as here) where the source is not moving under power (drifting), this is indicated as the closest point of approach for the model estimate. Model runs are shown for different focal animals (where appropriate) and different animal depths in the water column, based on species and location differences.

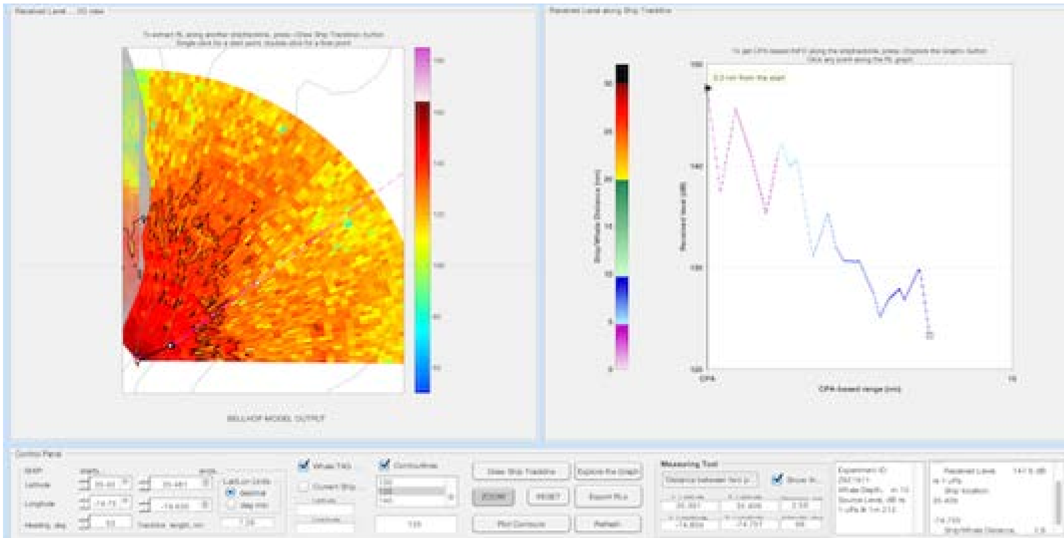

Figure 30. RL model prediction at 10 m depth for focal whale ZcTag82 for estimated start position of Atlantic-BRS CEE #2019-01. Modeled RL at this depth and estimated position was: 147.6 dB RMS.

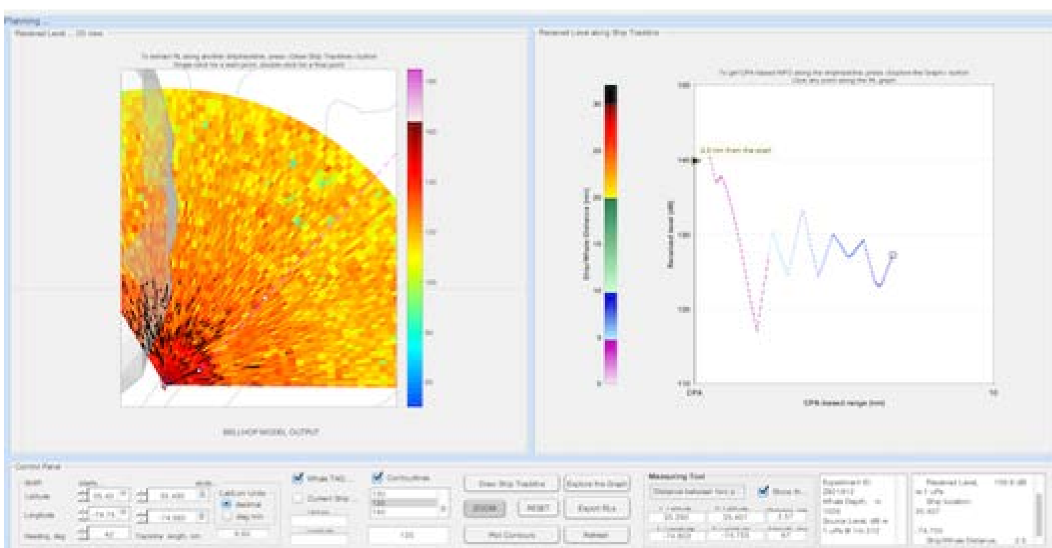

Figure 31. RL model prediction at 1000 m depth for focal whale ZcTag82 for estimated start position of Atlantic-BRS CEE #2019-01. Modeled RL at this depth and estimated position was: 139.9 dB RMS.

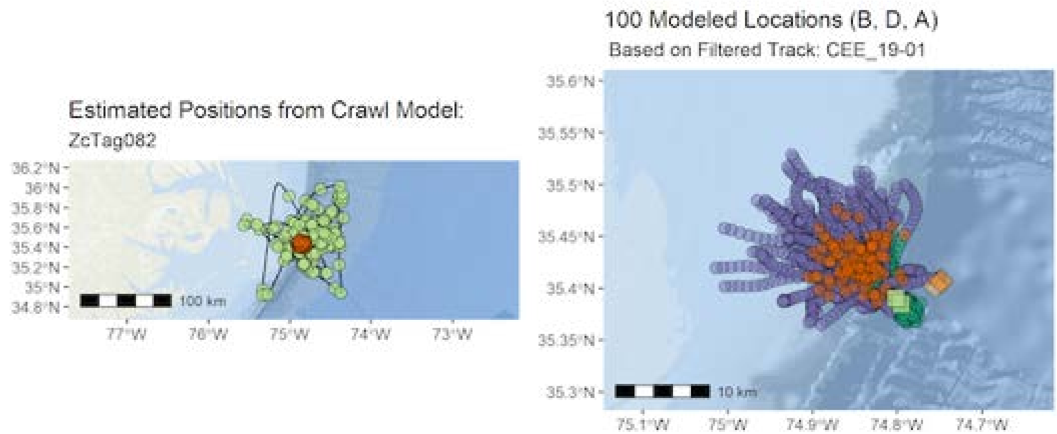

Figure 32. Estimated surface positions for focal whale ZcTag82 before, during, and after Atlantic-BRS CEE#2019-01

NOTE: These plots have two panels for each individual specific to each CEE. Left panels show modeled animal locations from both Douglas ARGOS filtered (DAF) tracks with the location along the entire track (in green squares) during the respective CEE indicated with track imputations during the CEE indicated along this track shown as orange dots. Right panels show modeled locations from 100 imputed tracks based upon the simple DAF track corrected with surface locations to better account for spatial error in the underlying data. Locations of the MFAS sound source are shown as diamonds, with pale blue representing locations at the start of CEEs and darker blue indicating ending locations. The 100 positions for each imputed track are shown one hour before CEEs (green dots), at the start of CEEs (red dots), and one hour after CEEs (purple dots); yellow squares indicate the single DAF track location during each respective phase.

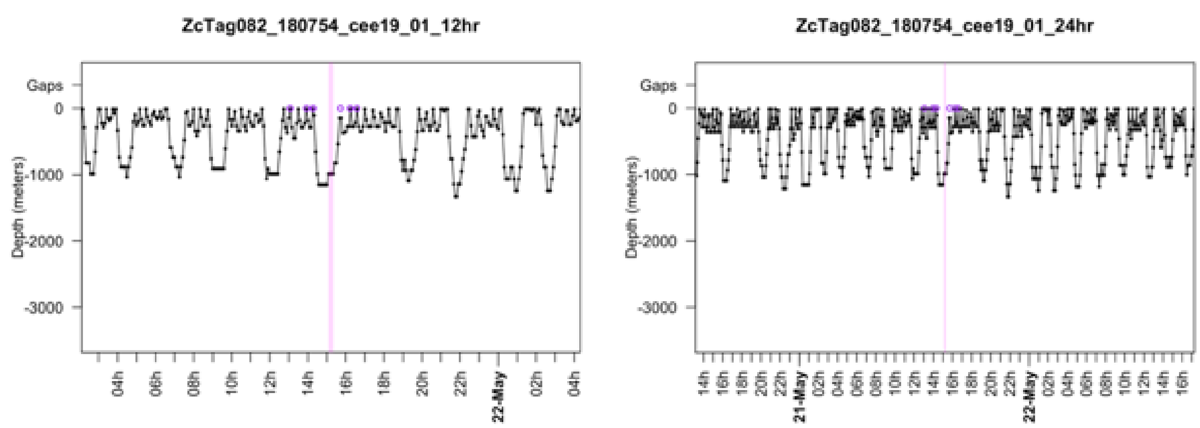

Figure 33. Available dive data for focal whale Zc82 before, during, and after Atlantic-BRS CEE #2019-01

NOTE: These plots illustrate dive data for days during which CEEs occurred. Time (in GMT, which is +4 hours from EDT during CEE periods) is indicated on the x-axis, with depth indicated on the y-axis). CEE periods are indicated as pink bars. Figures are provided for each animal for periods spanning both 12-h before and after each CEE (left panels) and 24-h before and after each CEE (right panels). It should be noted that based on satellite-tag (time series) settings, some tags ceased reporting dive data during some CEEs but were still reporting ARGOS position estimates. Thus, some individuals for which tag location maps are provide, dive data during CEE periods may be absent.

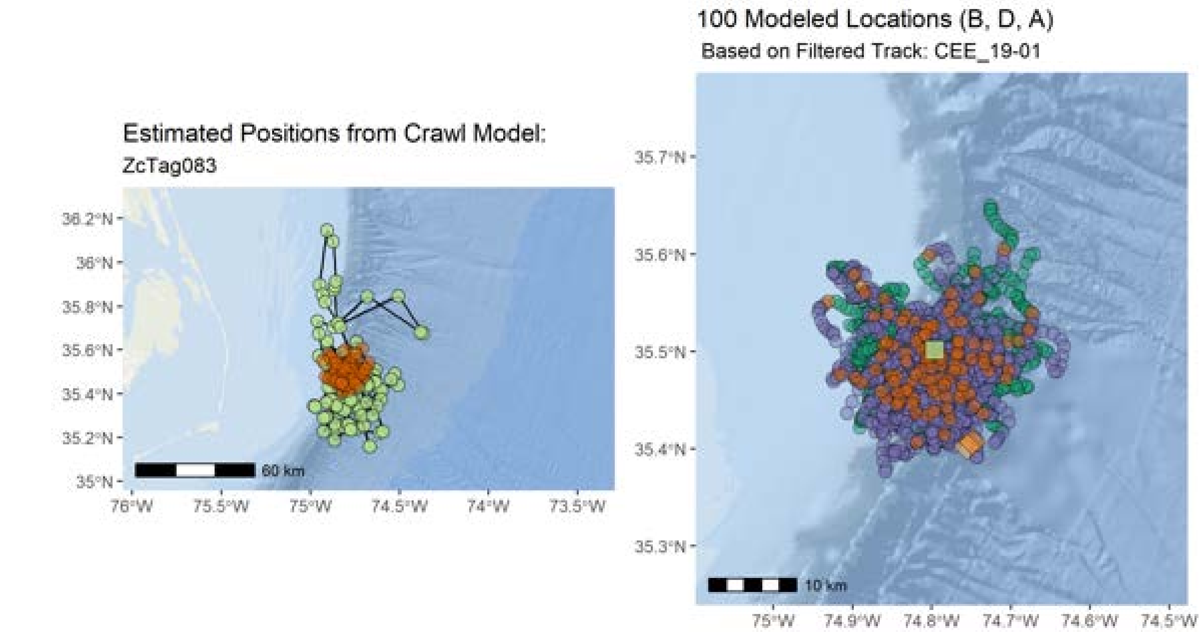

Figure 34. Estimated surface positions for tagged whale Zc 83 before, during, and after Atlantic-BRS CEE #2019-01

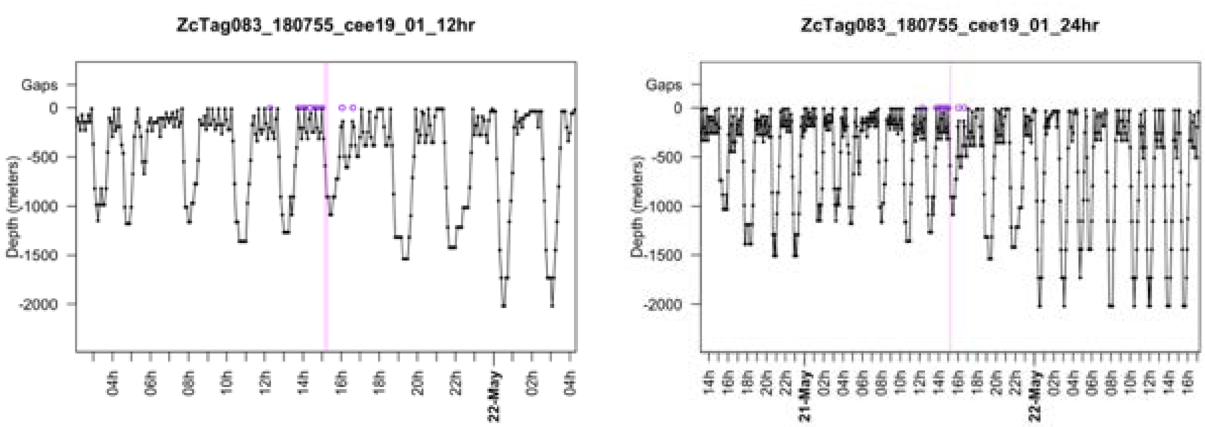

Figure 35. Available dive data for tagged whale Zc83 before, during, and after Atlantic-BRS CEE #2019-01

2.3.2 CEE #2019-02: Simulated MFAS

Table 9. Metadata summary for Atlantic-BRS CEE #2019-02

CEE # 2019_02	
Date:	7 June 2019
Type:	Simulated MFAS (deployed from *F/V Kahuna*)
Signal parameters:	Three-segment (1.2 s total duration) pings (3.5–4 kilohertz [kHz]); 212 dB re 1 µPa (RMS) @ source; 25 s rep rate; 72 pings
Start time (UTC):	15:13:09
Start lat/lon (source):	35.42307; -74.80614
End time (UTC):	15:43:09
End lat/lon (source):	35.49813; -74.77607
Beaked whales tagged during CEE:	(n=8) – Zc89 (focal sat tag animal in group of 4); Zc86 (was in nearby vicinity); Zc88; Zc82, Zc83, Zc84, Zc87 (XY only)
Pilot whales tagged during CEE:	None
Estimated Range (start CEE):	7.6 km (4.1 nm) @ start; drift was ~3.5nm to the NNE during CEE
Modeled Max RL:	135 dB RMS @ 700m initial posit. 142-133 dB RMS at start location (@10, 700m). Also modeled for end location as source was in ~ 5kt current; 142-151 dB RMS (@10, 700m).

CEE #2019_02 - Narrative Summary
A somewhat challenging CEE given the spatial context, which appeared in the field and on quick look analysis to have included several clear responses. The complexity in the field was the result of the focal whale (Zc89) being in an area of very strong current at the time of the CEE. Kahuna was reading almost 5 kt current to the ENE before the CEE but drifted more NNE and went almost 3.5 nm during the CEE. The focal group had not been moving a lot before the CEE and goal was to drift by at ~2 nm range during CEE, but with different direction we may have drifted closer to or over the focal group. While more detailed analysis remains to be conducted, Zc89 appeared to have exhibited an extended deep dive (nearly two hours), spatial avoidance (though most strongly evident well after the CEE), and potentially a change in social structure of the focal group it was in. This would represent something novel in our observations. Before the CEE the animal was in a group with three other individuals, but when the field team managed to get visual on it (on the fourth surface series after the CEE) it was alone. We observed some apparent switching of animals between other groups that day (and other days) so this may have not been that atypical though it was timed just after the CEE and following the focal animal moving rapidly away from the CEE area. The ability to interpret and evaluate these aspects of potential social responses is only possible given our efforts to tag multiple whales and to have re-sights and photo ID on non-CEE and follow up days using the goniometer in relocation.

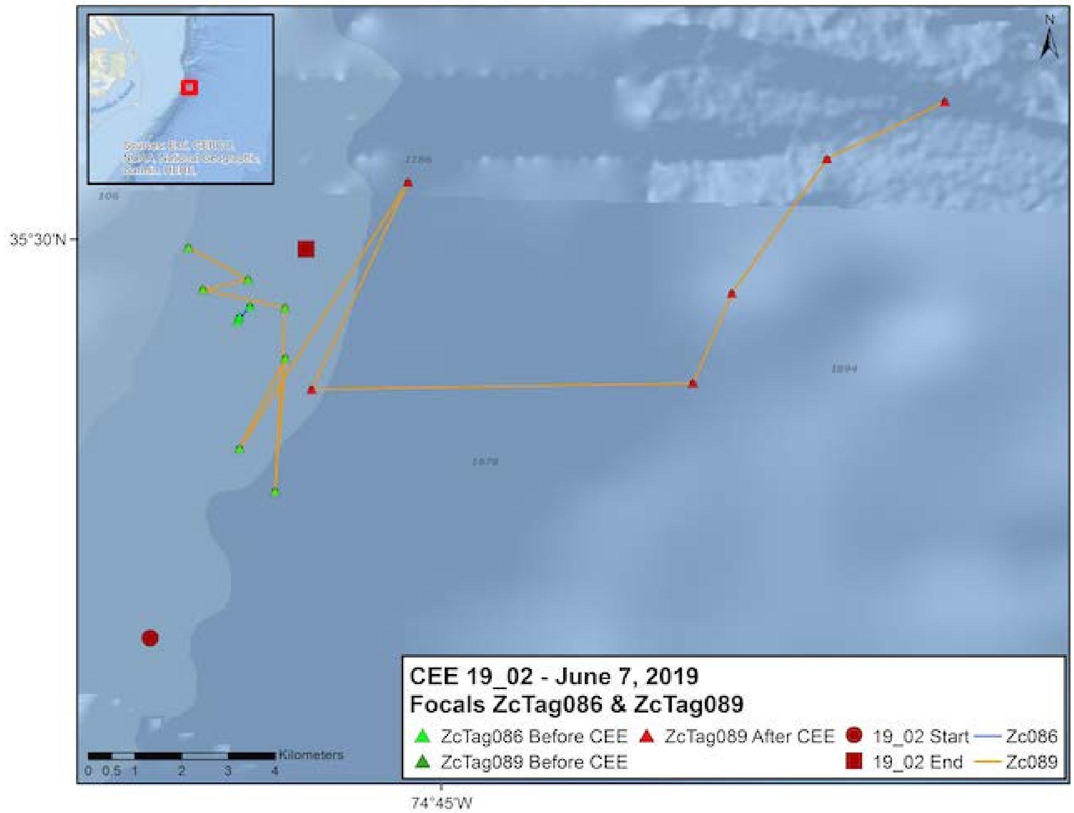

Figure 36. Overview map of source and ZcTag89 group focal follow locations for CEE #2019-02.

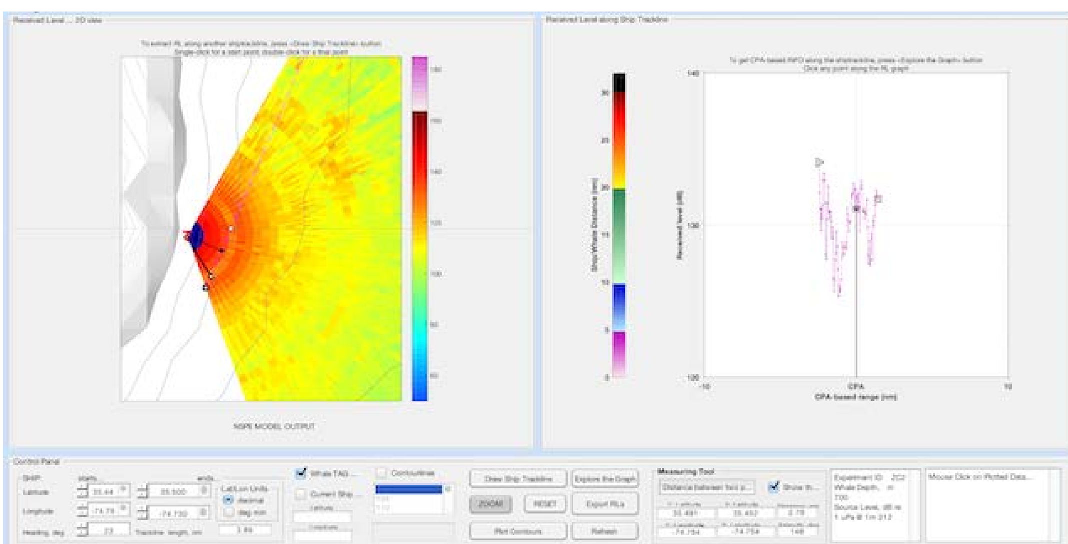

Figure 37. RL model prediction at 700 m depth for focal whale ZcTag89 for initial position used for *in situ* modeling of Atlantic-BRS CEE #2019-02. Modeled RL at this depth and estimated position was: 134.5 dB RMS.

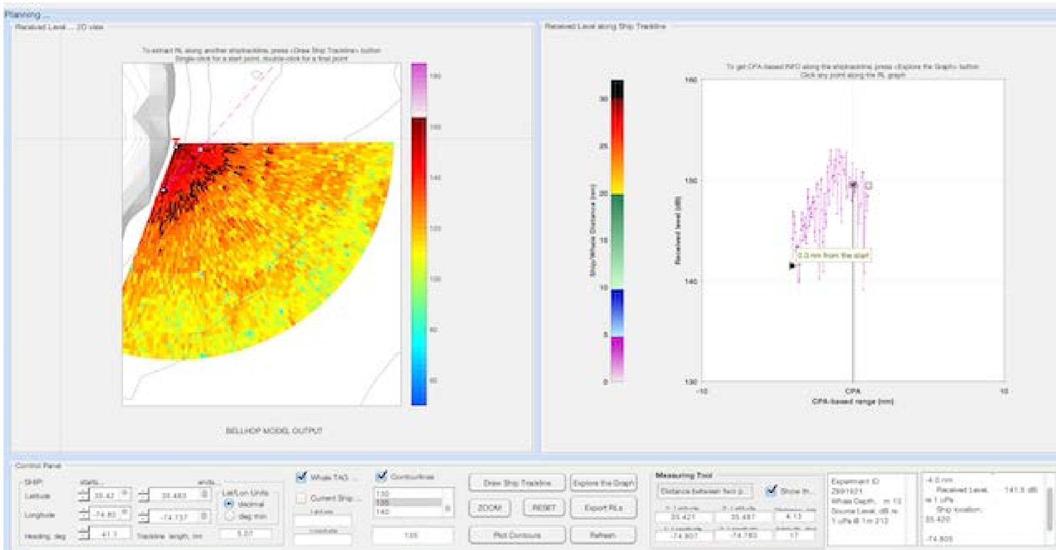

Figure 38. RL model prediction at 10 m depth for focal whale ZcTag89 for estimated start position of Atlantic-BRS CEE #2019-02. Modeled RL at this depth and estimated position was: 141.5 dB RMS.

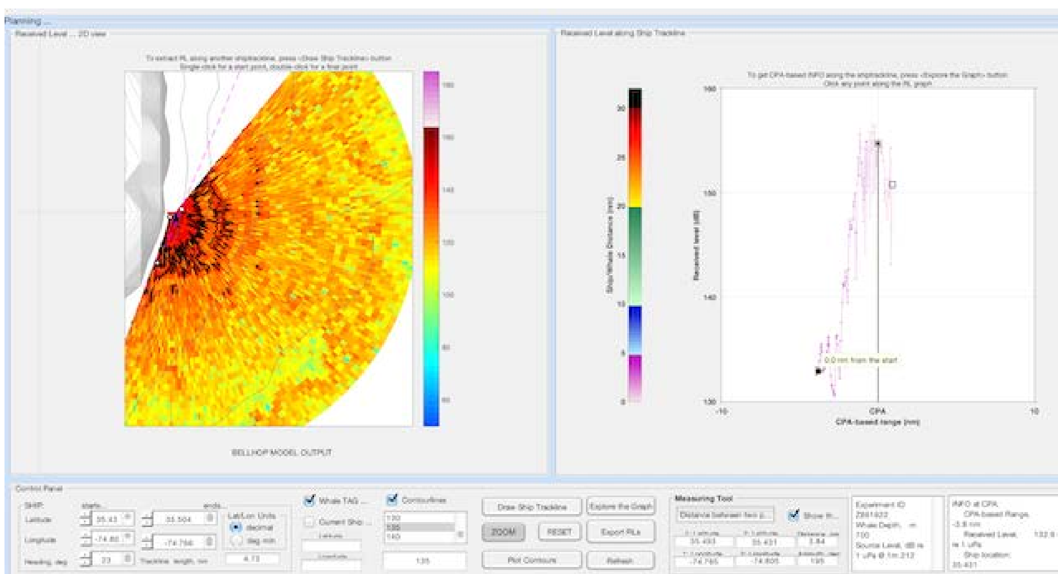

Figure 39. RL model prediction at 700 m depth for focal whale ZcTag89 for estimated start position of Atlantic-BRS CEE #2019-02. Modeled RL at this depth and estimated position was: 132.9 dB RMS.

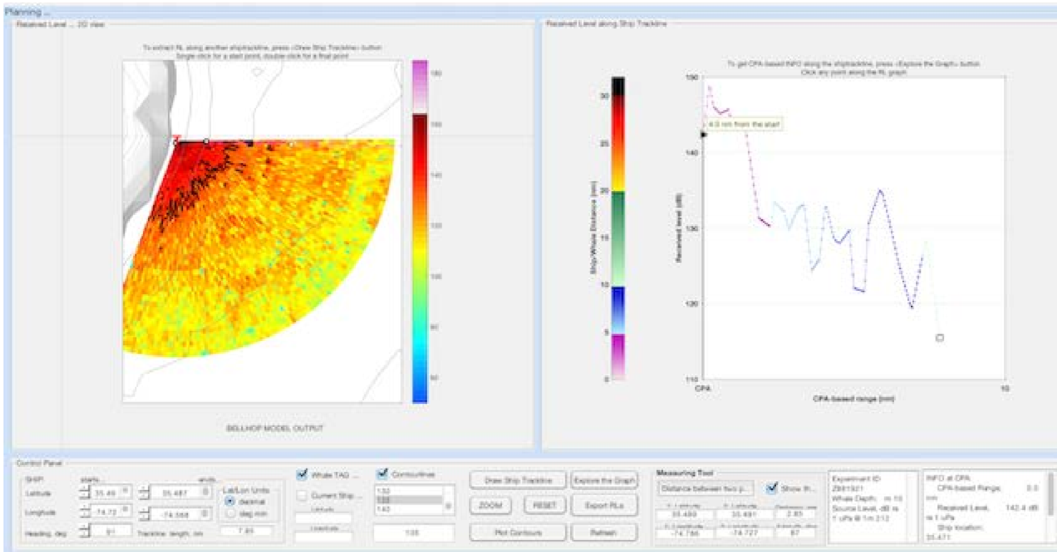

Figure 40. RL model prediction at 10 m depth for focal whale ZcTag89 for estimated end position of Atlantic-BRS CEE #2019-02. Modeled RL at this depth and estimated position was: 142.4 dB RMS.

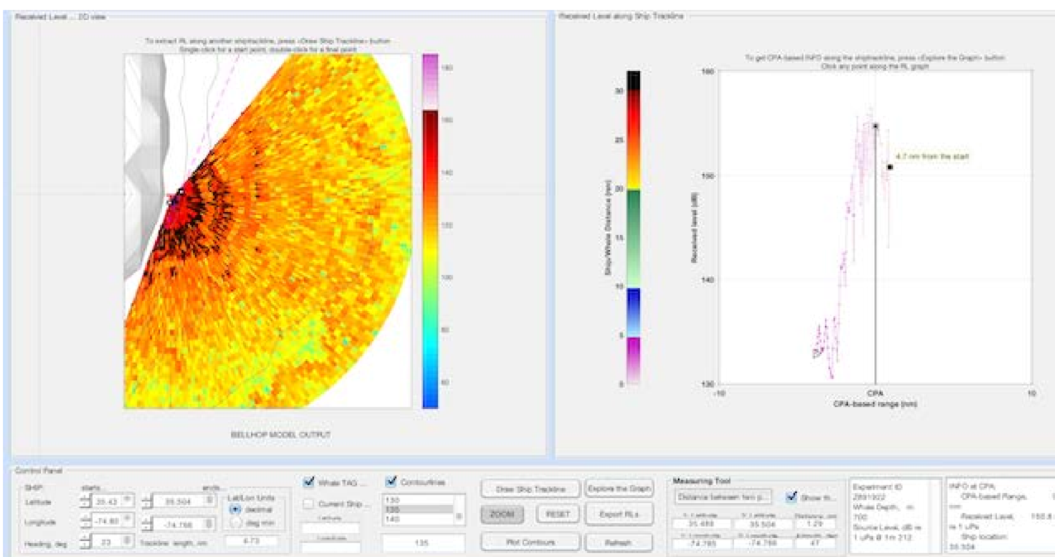

Figure 41. RL model prediction at 700 m depth for focal whale ZcTag89 for estimated end position of Atlantic-BRS CEE #2019-02. Modeled RL at this depth and estimated position was: 150.8 dB RMS.

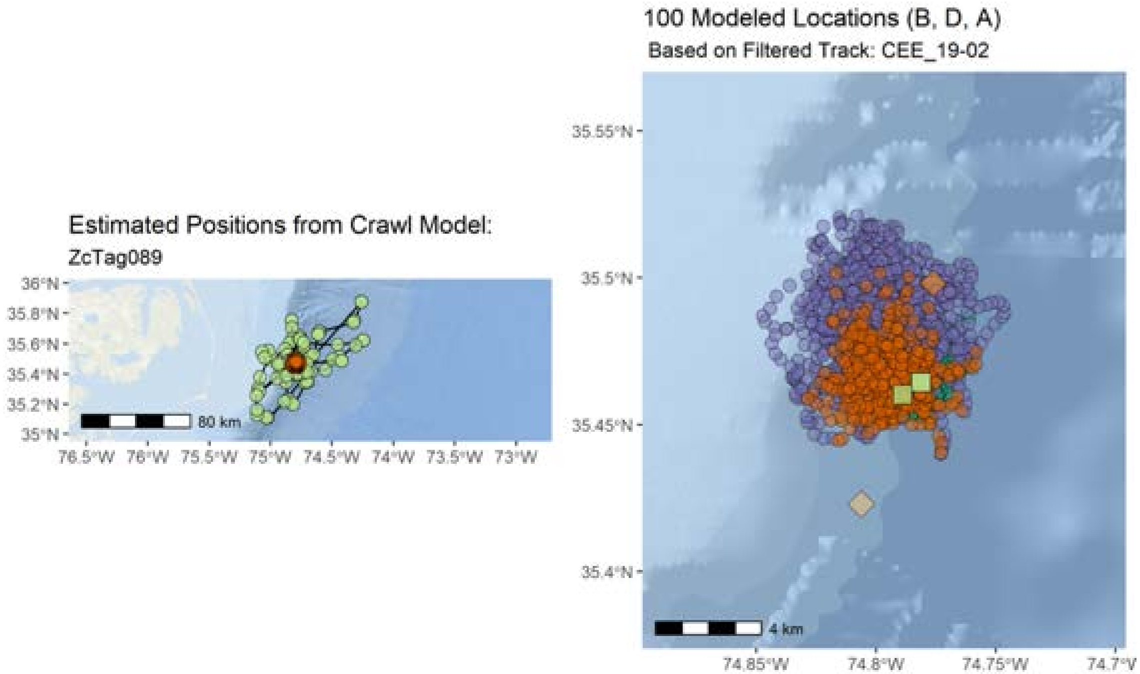

Figure 42. Estimated surface positions for whale ZcTag89 before, during, and after Atlantic-BRS CEE #2019-02.

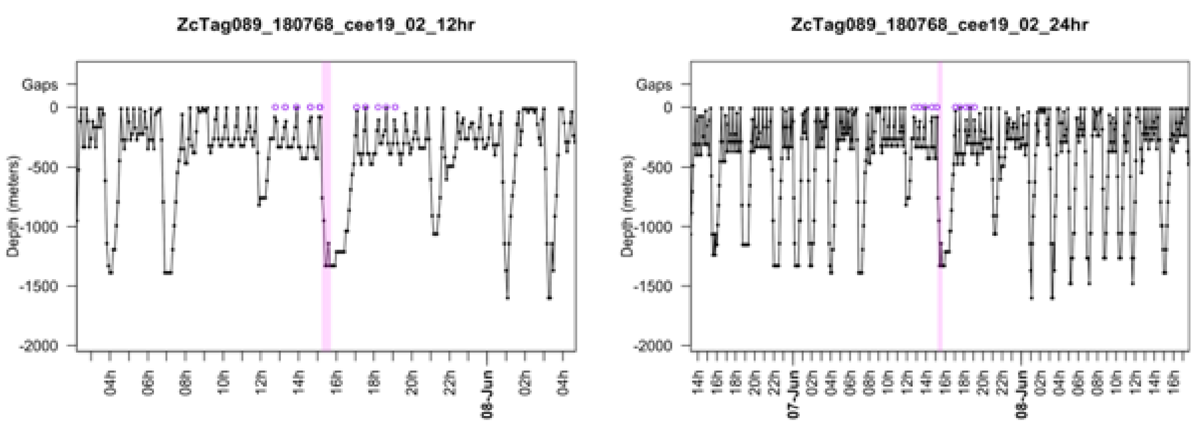

Figure 43. Available dive data for whale ZcTag89 before, during, and after Atlantic-BRS CEE #2019-02.

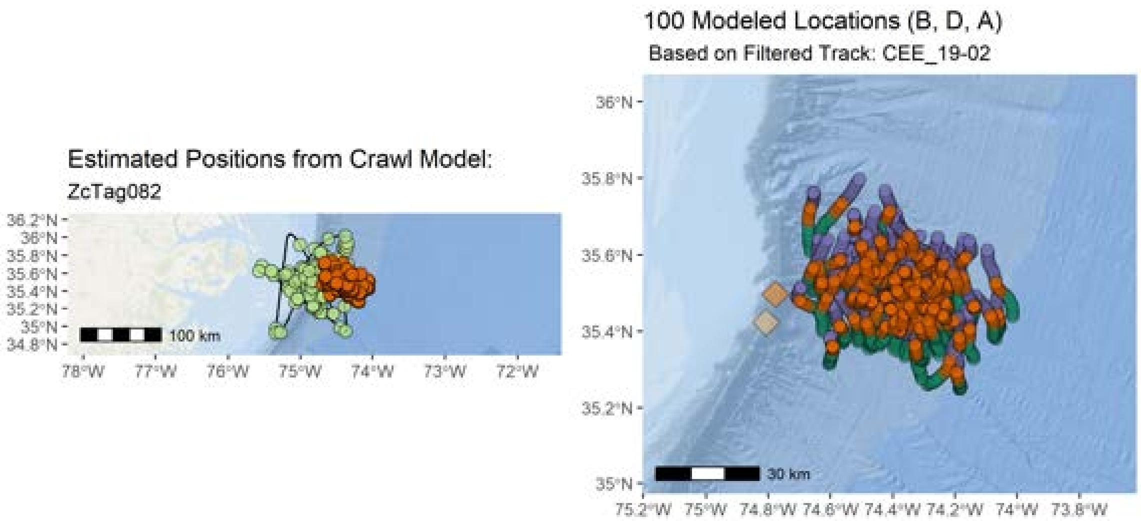

Figure 44. Estimated surface positions for tagged whale ZcTag82 before, during, and after Atlantic-BRS CEE #2019-02.

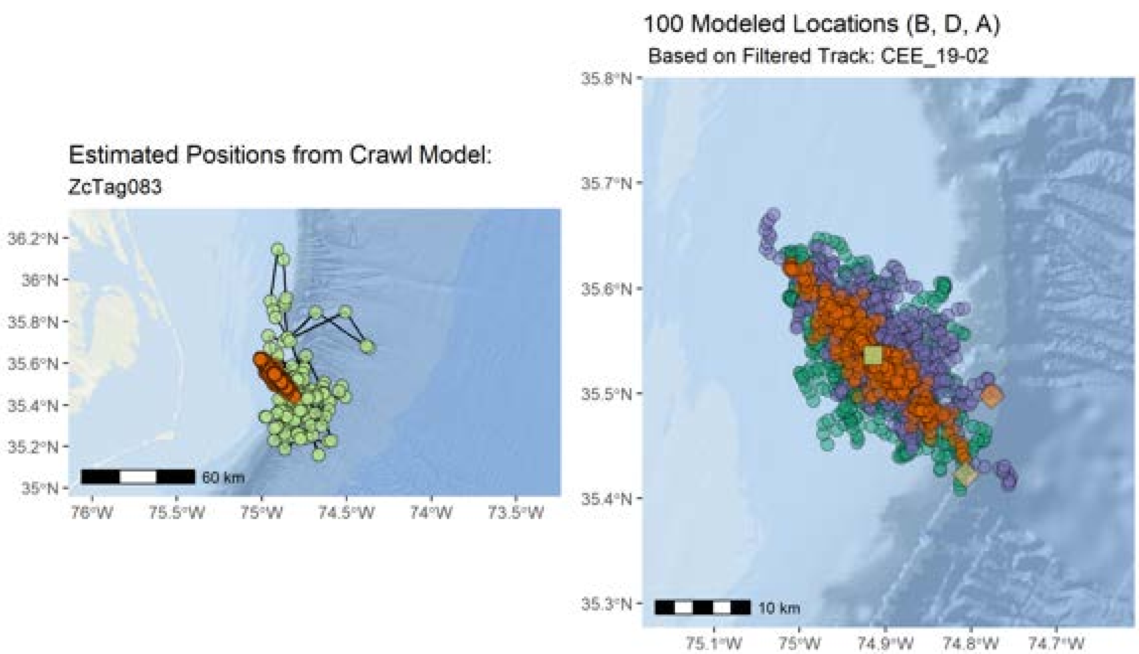

Figure 45. Estimated surface positions for tagged whale ZcTag83 before, during, and after Atlantic-BRS CEE #2019-02.

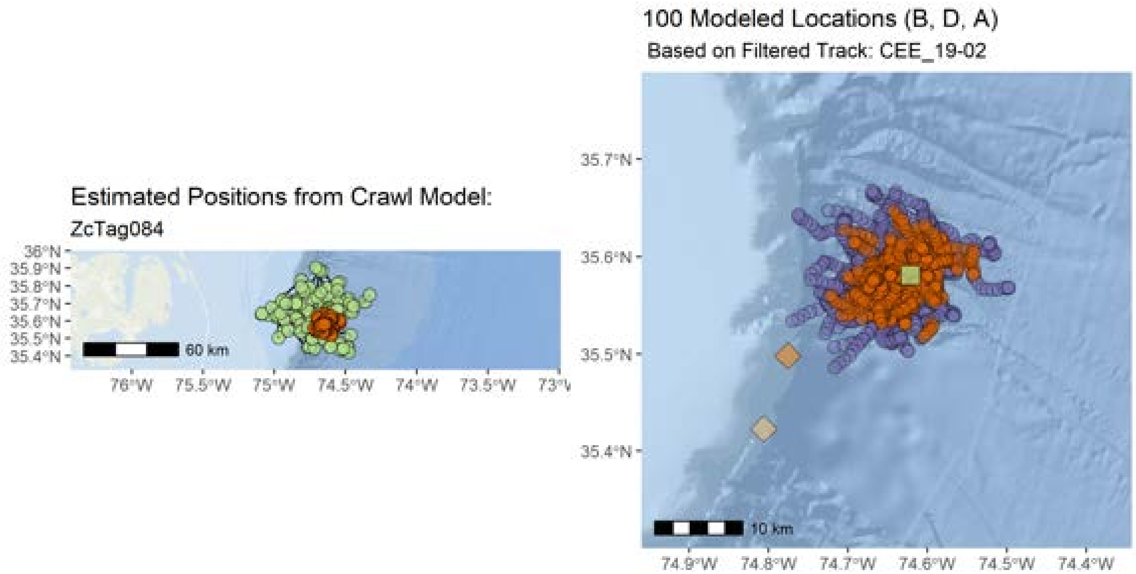

Figure 46. Estimated surface positions for tagged whale ZcTag84 before, during, and after Atlantic-BRS CEE #2019-02.

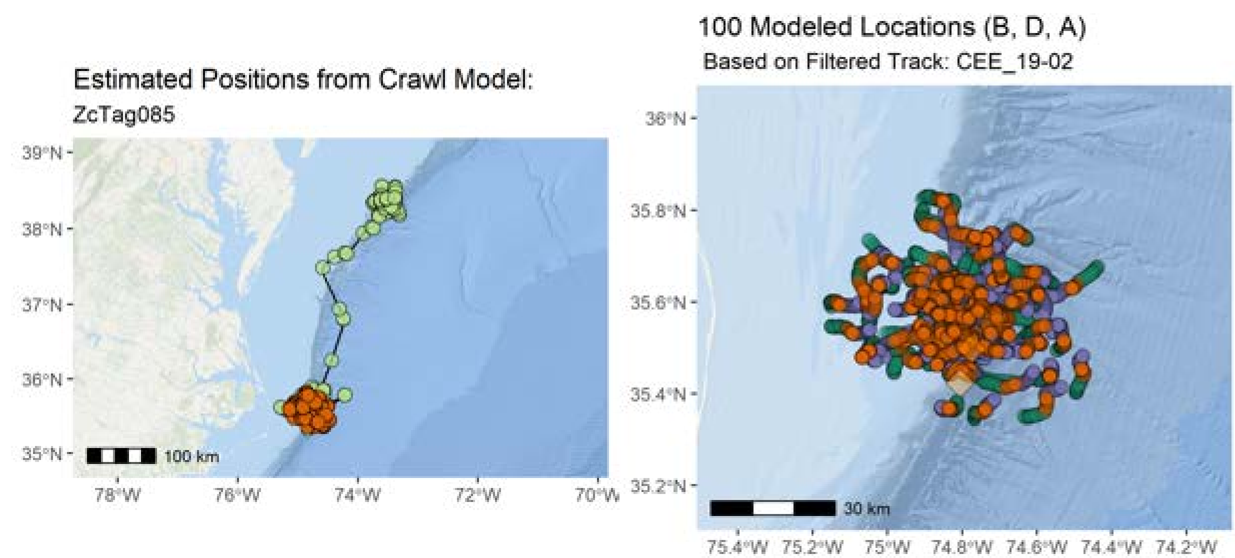

Figure 47. Estimated surface positions for tagged whale ZcTag85 before, during, and after Atlantic-BRS CEE #2019-02.

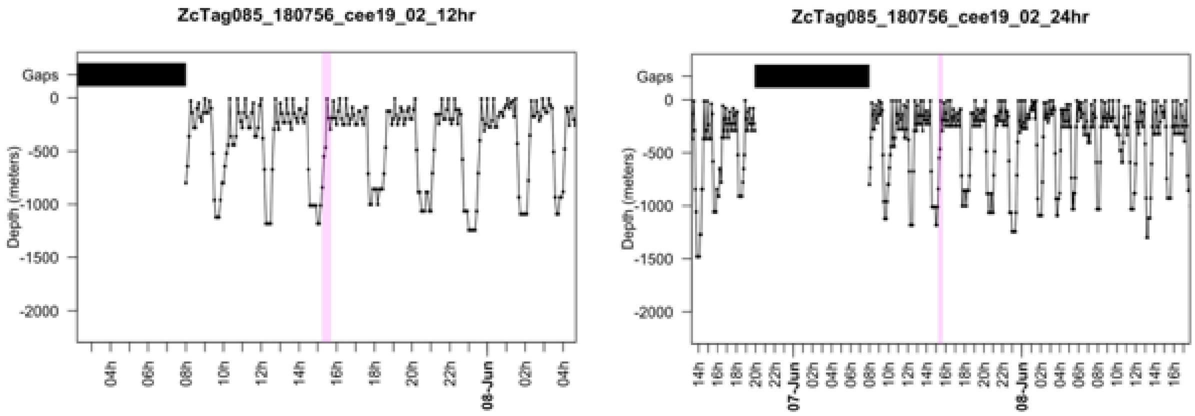

Figure 48. Available dive data for tagged whale ZcTag85 before, during, and after Atlantic-BRS CEE #2019-02.

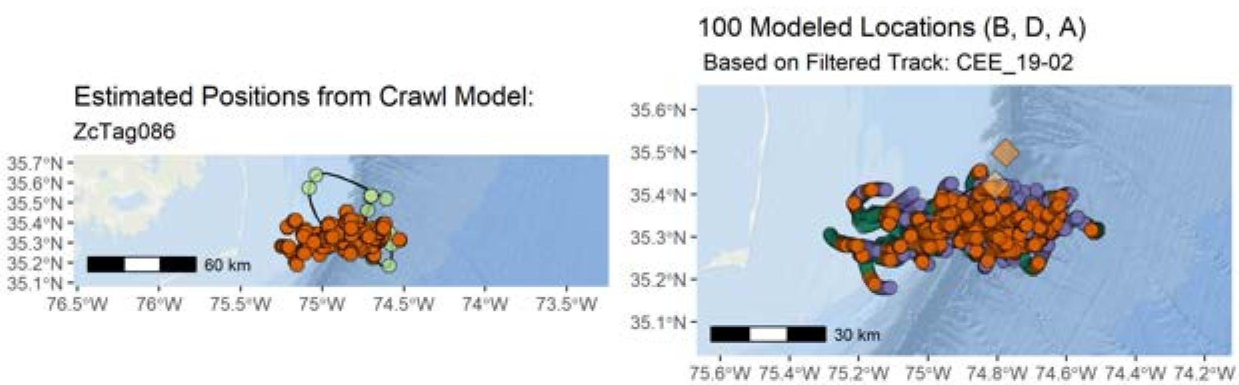

Figure 49. Estimated surface positions for tagged whale ZcTag86 before, during, and after Atlantic-BRS CEE #2019-02.

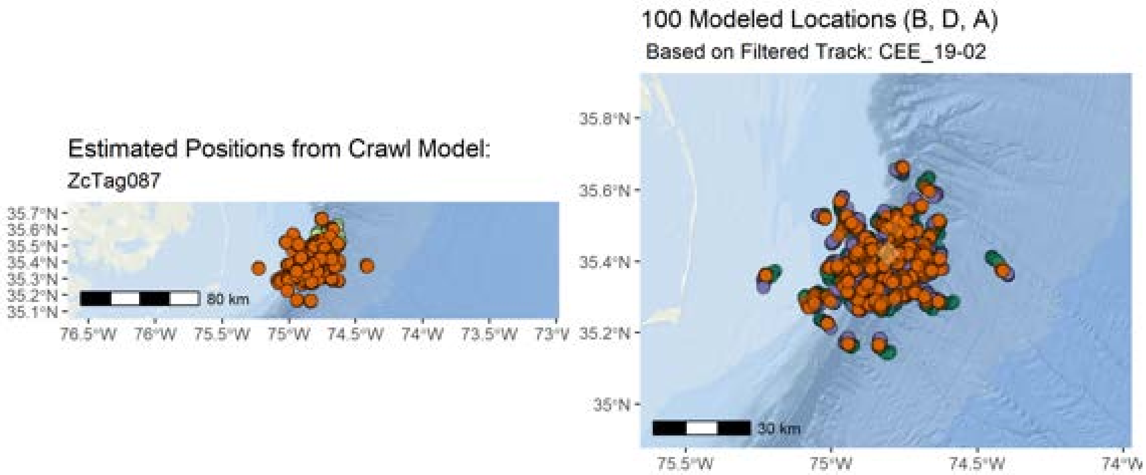

Figure 50. Estimated surface positions for tagged whale ZcTag87 before, during, and after Atlantic-BRS CE E#2019-02.

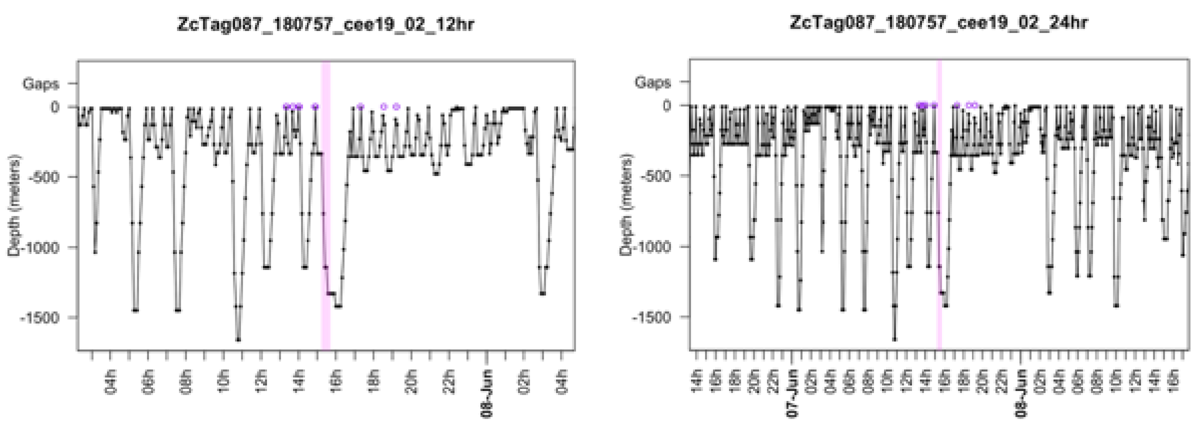

Figure 51. Available dive data for tagged whale ZcTag87 before, during, and after Atlantic-BRS CEE #2019-02.

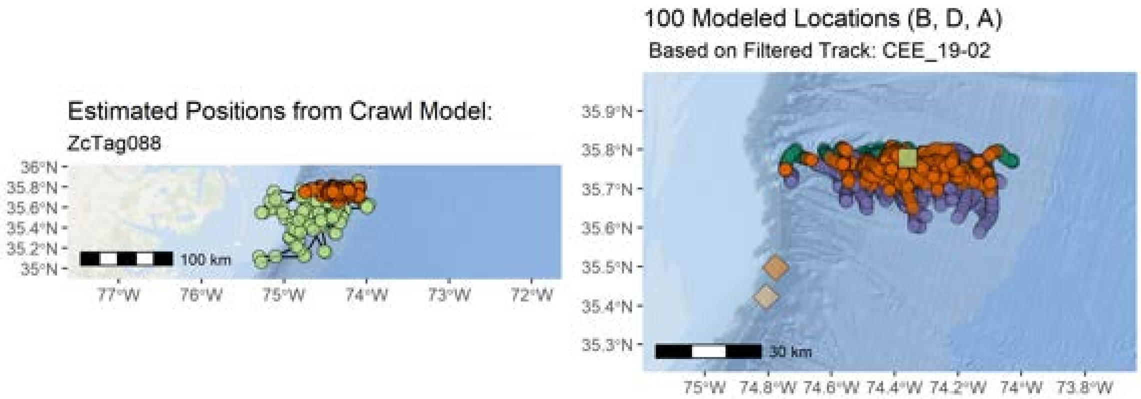

Figure 52. Estimated surface positions for tagged whale ZcTag88 before, during, and after Atlantic-BRS CEE #2019-02.

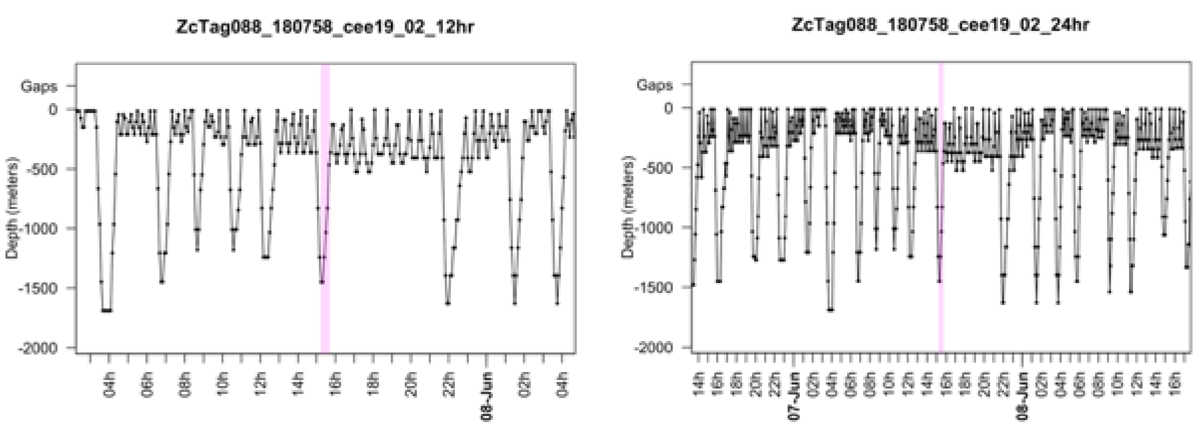

Figure 53. Available dive data for tagged whale ZcTag88 before, during, and after Atlantic-BRS CEE #2019-02.

2.3.3 CEE #2019-03: Simulated MFAS

Table 10. Metadata summary for Atlantic-BRS CEE #2019-03.

CEE # 2019_03	
Date:	6 August 2019
Type:	Simulated MFAS (deployed from *F/V Kahuna*)
Signal parameters:	Three-segment (1.2 s total duration) pings (3.5–4 kilohertz [kHz]); 212 dB re 1 µPa (RMS) @ source; 25 s rep rate; 72 pings
Start time (UTC):	17:37:43
Start lat/lon (source):	35.5973; -74.76018
End time (UTC):	18:07:43
End lat/lon (source):	35.60955; -74.75063
Beaked whales tagged during CEE:	(n=5) - Zc93, Zc19_218a (focal sat tag and DTAG whales within same group); Zc90 (dive data errors); Zc91, Zc92 (XY only)
DTAG tag metadata (Zc19_218a)	Tag recording start: 15:38:09 (UTC); total deployment: 5.33h Tag on: 35.57552; -74.75181 - recovered: 35.48829; -74.77375
Pilot whales tagged during CEE:	(n=4) - Gm224, Gm225, Gm226, Gm227
Estimated Range (start CEE):	3.3 km (1.8 nm)
Modeled Max RL:	137-139 dB RMS (10, 300, 1400m). Measured RL on DTAG was 136 dB RMS (@ 300 m)

CEE #2019_03 - Narrative Summary
Novel accomplishment in having a satellite-tagged Cuvier's within the same group as a DTAG Ziphius, both of which returned complete and complementary data on multiple scales. This provides not only important data to compare diving behavior using different resolution tags, but also the ability to consider behavioral synchrony before, during, and after MFAS exposure. From initial field and quick look assessments of focal follow and tag sensor data, there appears to be strong responses in both focal individuals. They were tightly coordinated in dive behavior and the high-resolution calibrated DTAG depth data are very well-characterized within the time-series dive data from Zc93. Both animals appear to have been on a 'shallow/bounce' dive at the onset of the CEE and shortly thereafter initiated a deep and relatively long dive followed by a relatively long series of bounce dives. Additionally, the animals moved initially toward deep water away from the source and then directly away for a period of several hours at an average horizontal speed exceeding 10 knots. The maximum received RMS SPL measured on the DTAG was 136 dB; the in situ modeled max received level using real-time field locations and anticipated positions was 137.5 dB.

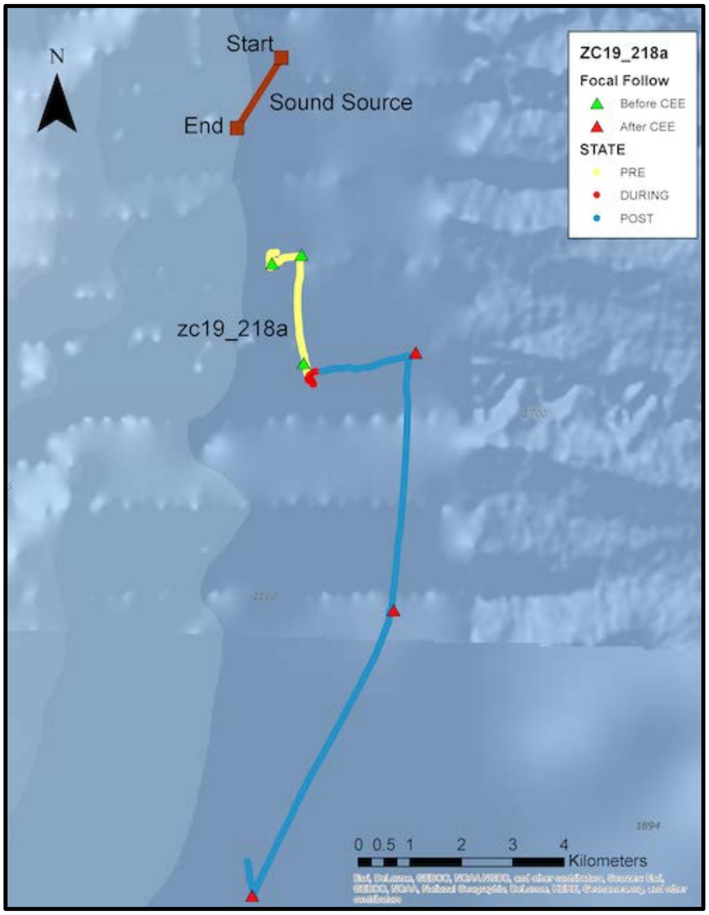

Figure 54. Overview map of source and Zc19_218a (in group with ZcTag93) focal follow locations for CEE #2019-03.

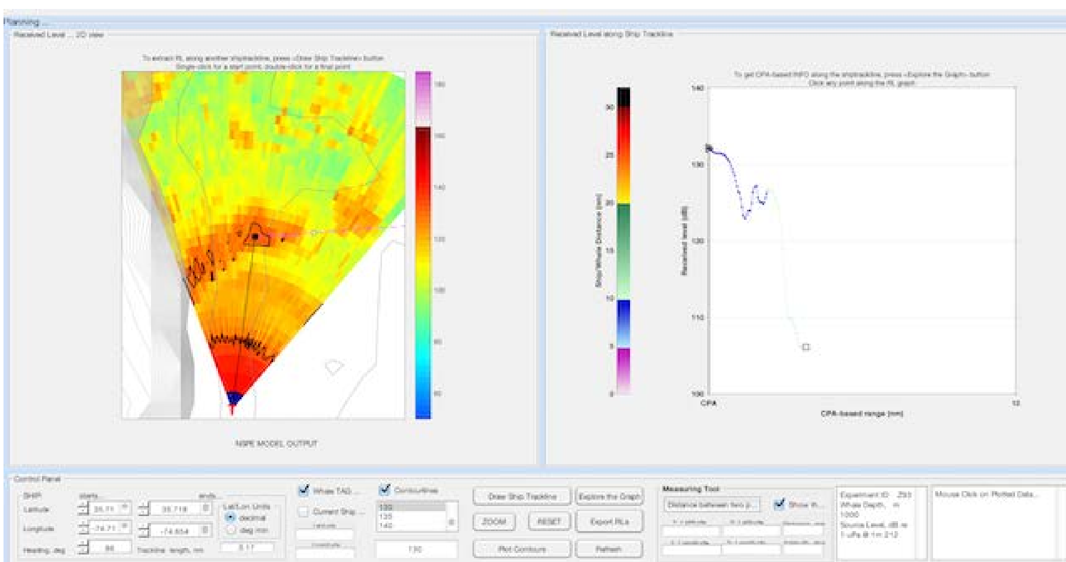

Figure 55. RL model prediction at 1000 m depth for focal whales Zc19_218a and ZcTag93 for initial position used for *in situ* modeling of Atlantic-BRS CEE #2019-03. Modeled RL at this depth and estimated position was: 132.0 dB RMS.

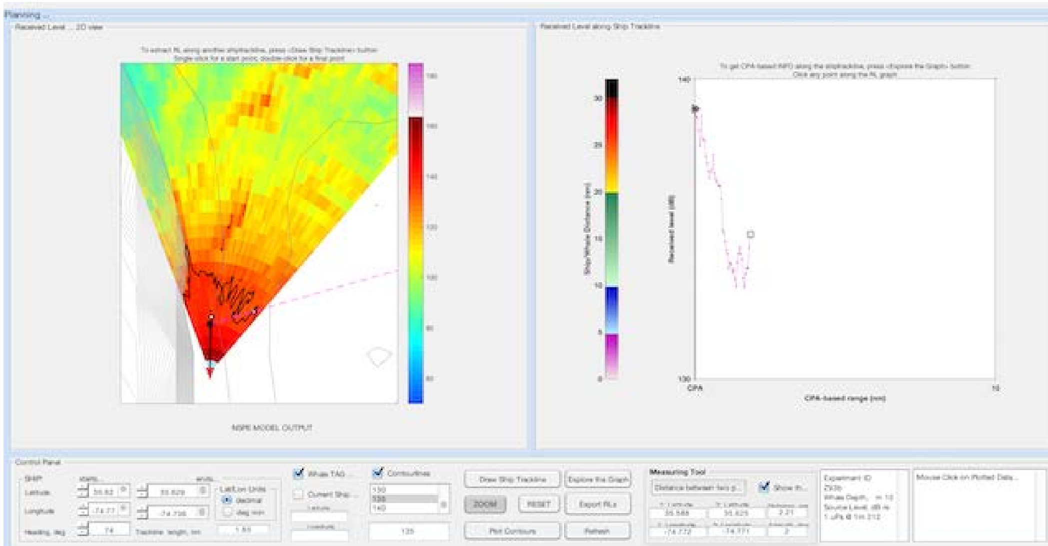

Figure 56. RL model prediction at 10 m depth for focal whales Zc19_218a and ZcTag93 for estimated start position of Atlantic-BRS CEE #2019-03. Modeled RL at this depth and estimated position was: 138.0 dB RMS.

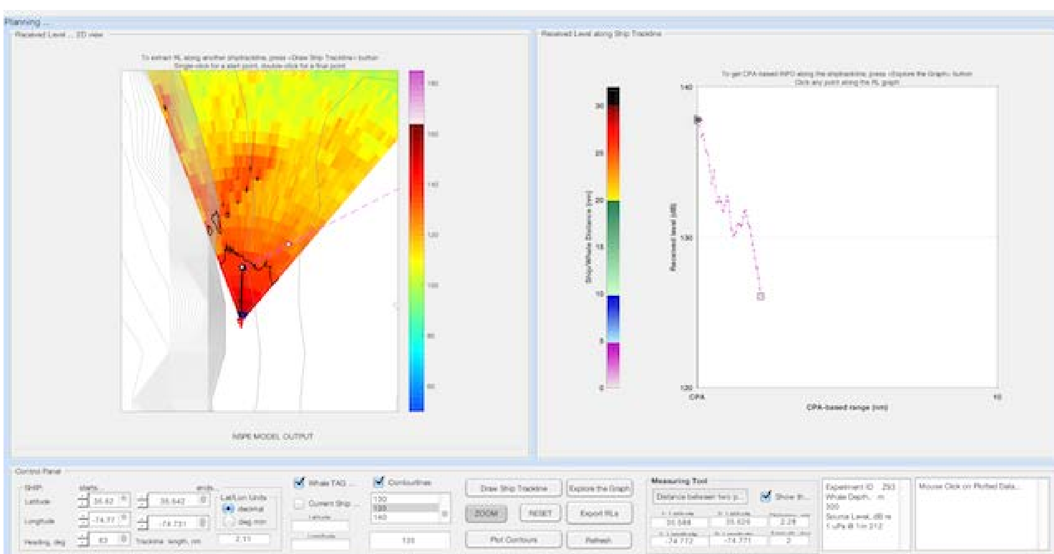

Figure 57. RL model prediction at 300 m depth for focal whale Zc19_218a (actual depth at start CEE from DTAG measurements) for estimated start position of Atlantic-BRS CEE #2019-03. Modeled RL at this depth and estimated position was: 137.5 dB RMS.

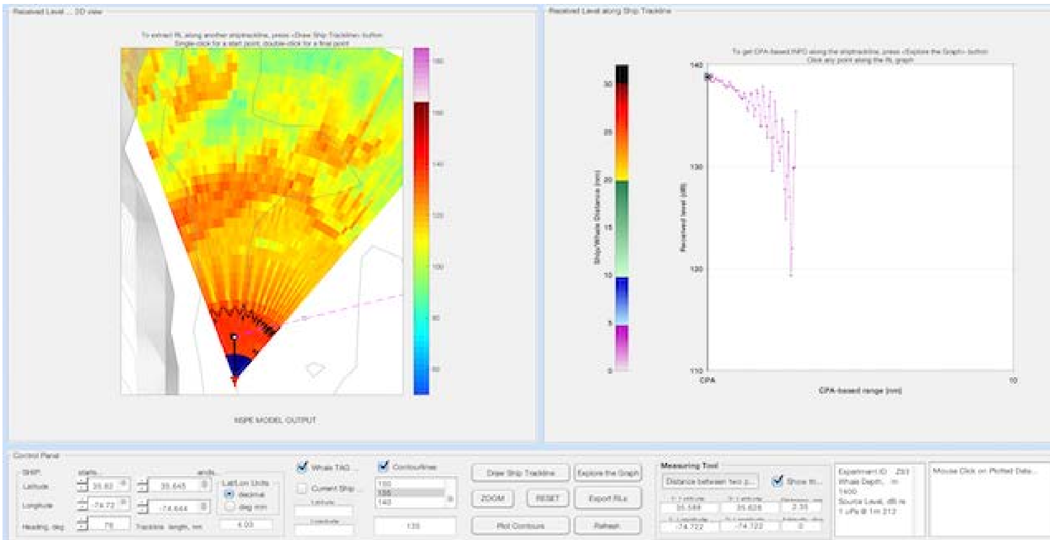

Figure 58. RL model prediction at 1400 m depth for focal whales Zc19_218a and ZcTag93 for estimated start position of Atlantic-BRS CEE #2019-03. Modeled RL at this depth and estimated position was: 139.0 dB RMS.

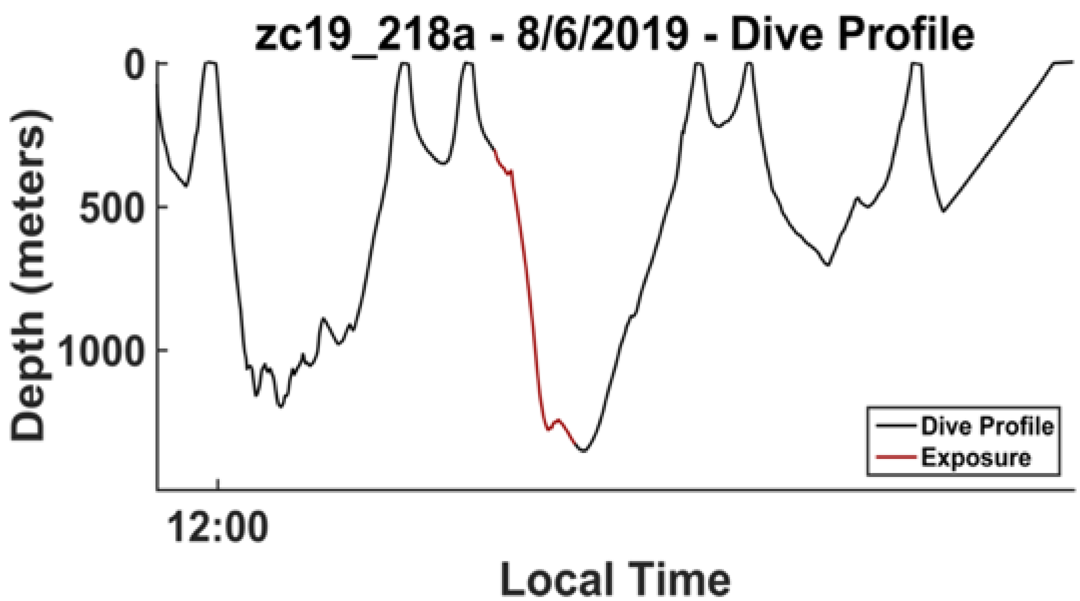

Figure 59. Dive data (from DTAG) for focal whale Zc19_218a before, during, and after Atlantic-BRS CEE #2019-03.

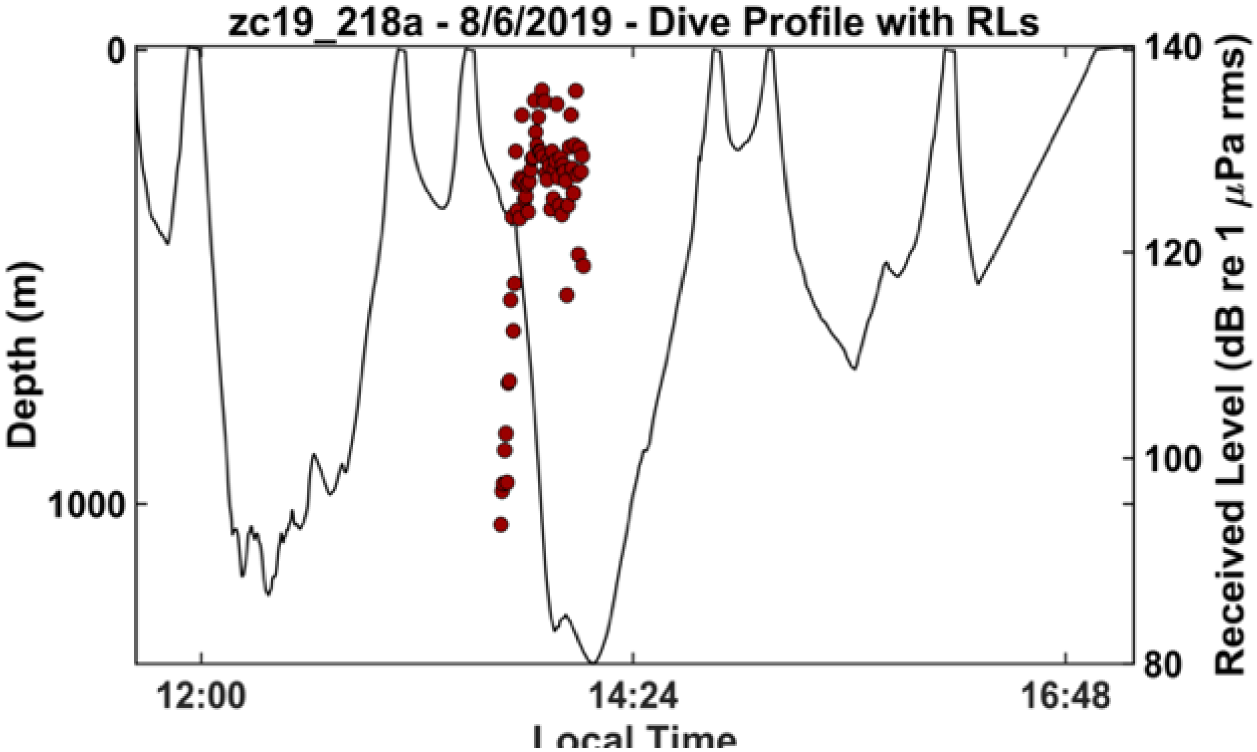

Figure 60. Dive data (from DTAG) with received levels (RLs) for focal whale Zc19_218a before, during, and after Atlantic-BRS CEE #2019-03.

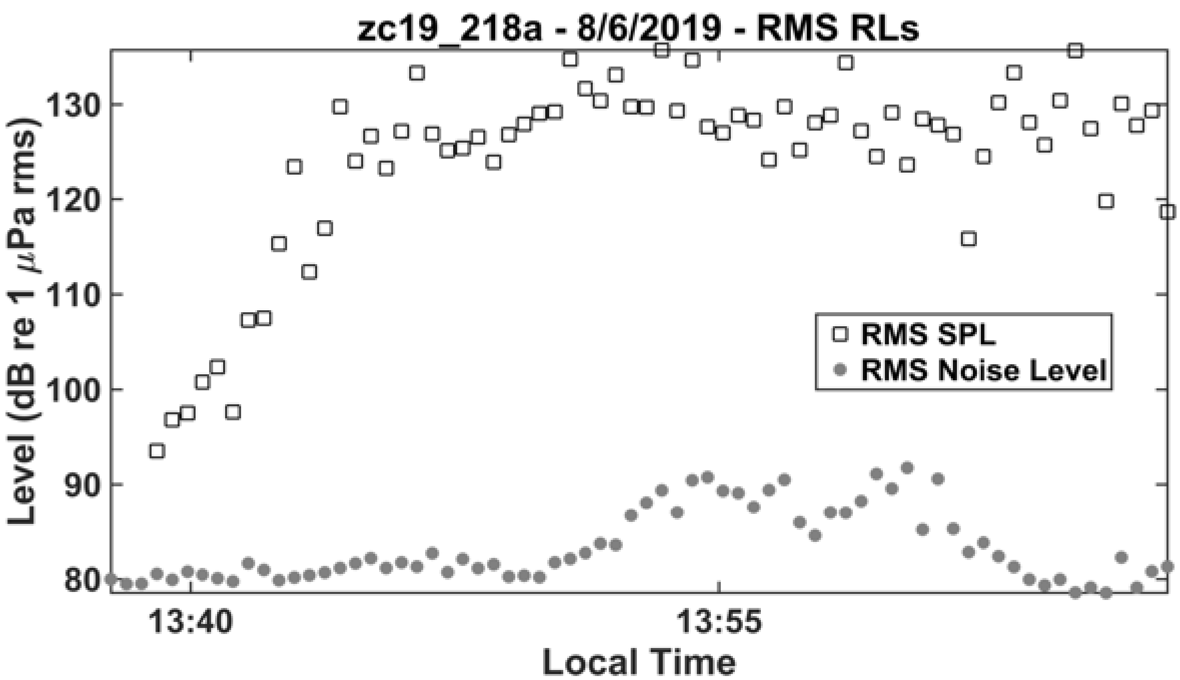

Figure 61. Received MFAS exposure levels relative to RMS ambient noise levels for focal whale Zc19_218a during Atlantic-BRS CEE #2019-03.

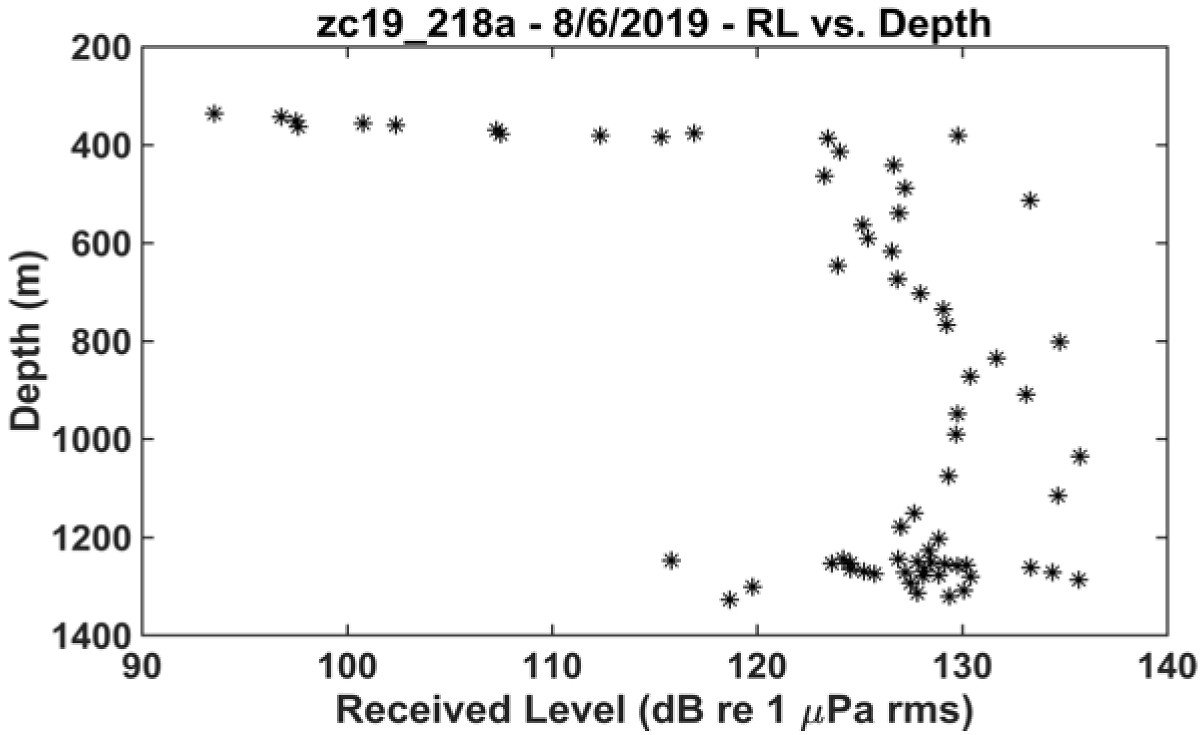

Figure 62. Received MFAS exposure levels (dB RMS) relative to whale depth for focal whale Zc19_218a during Atlantic-BRS CEE #2019-03.

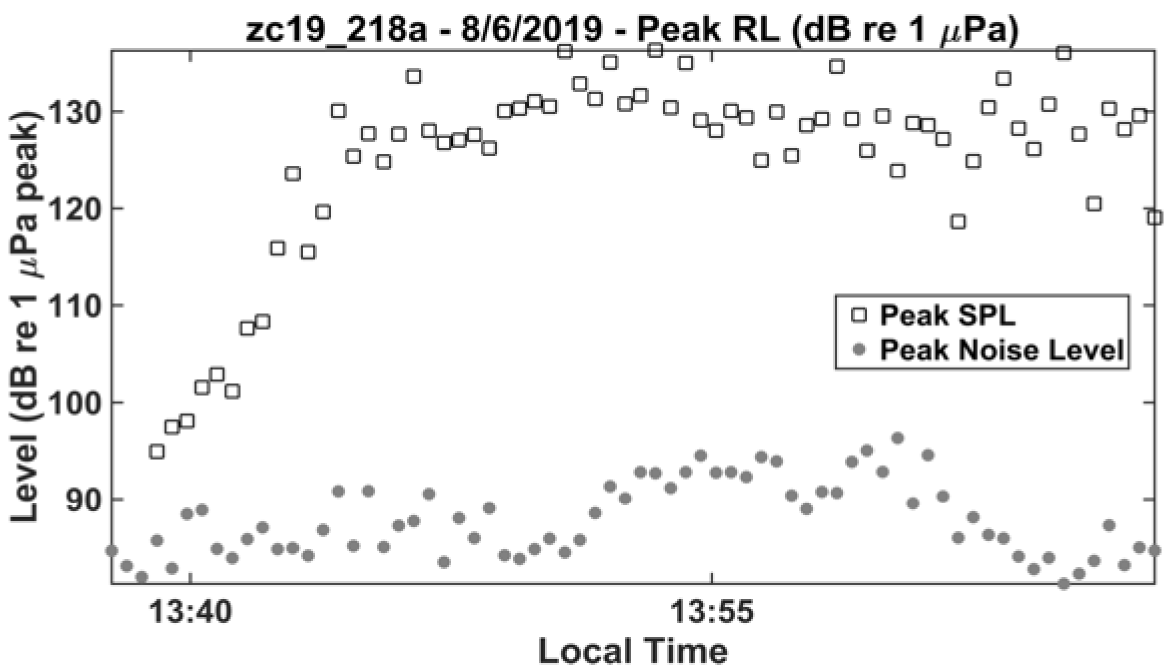

Figure 63. Received MFAS exposure levels (peak SPL) relative to ambient noise for focal whale Zc19_218a during Atlantic-BRS CEE #2019-03.

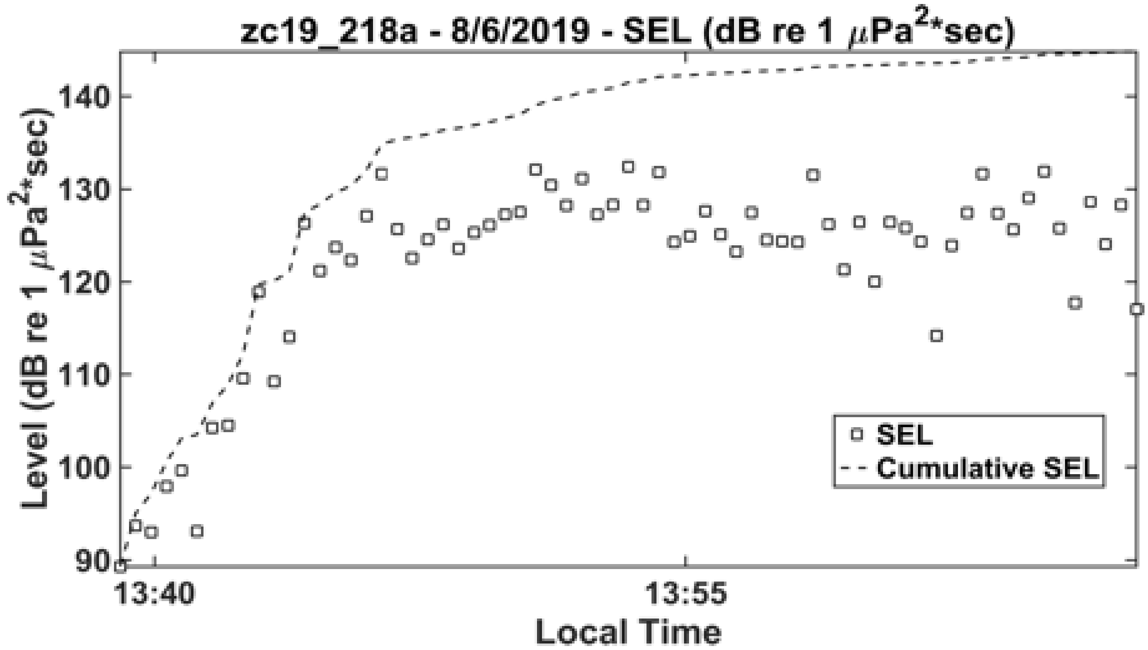

Figure 64. Received MFAS exposure levels (per ping and cumulative sound exposure level (SEL)) for focal whale Zc19_218a during Atlantic-BRS CEE #2019-03.

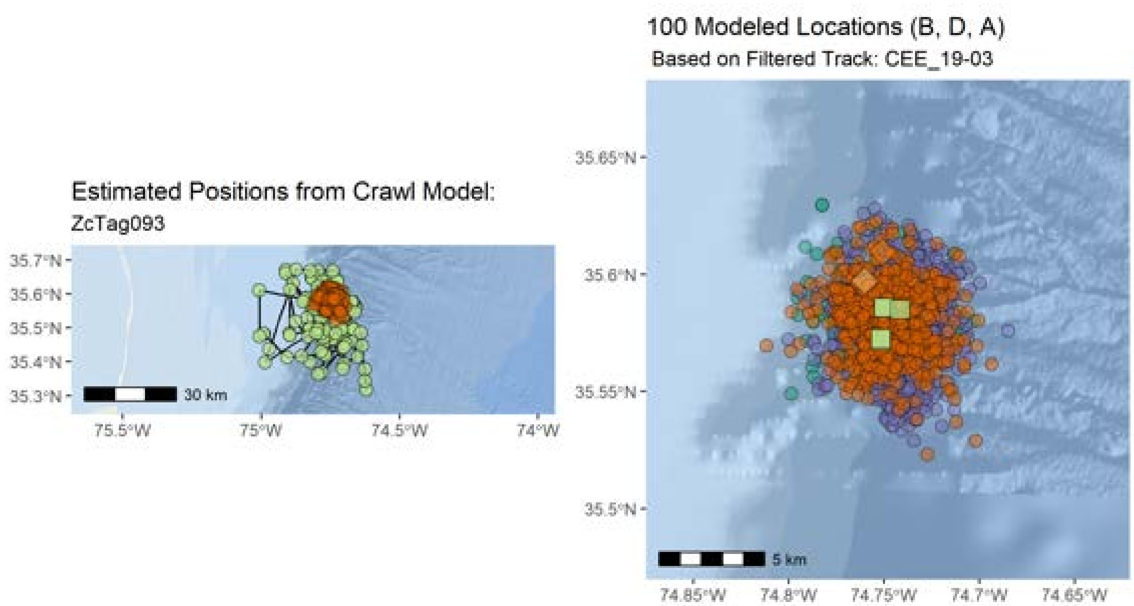

Figure 65. Estimated surface positions for focal whale ZcTag93 before, during, and after Atlantic-BRS CEE #2019-03.

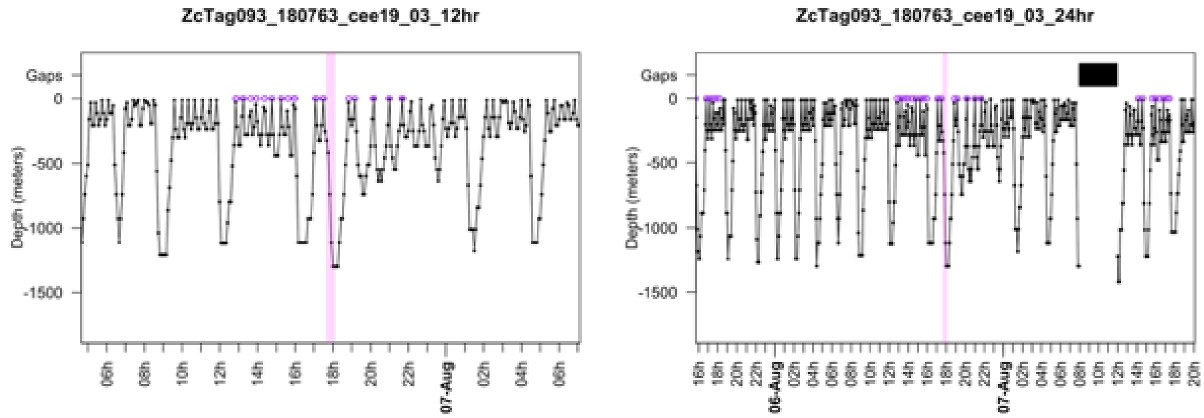

Figure 66. Available dive data for whale ZcTag93 before, during, and after Atlantic-BRS CEE #2019-03.

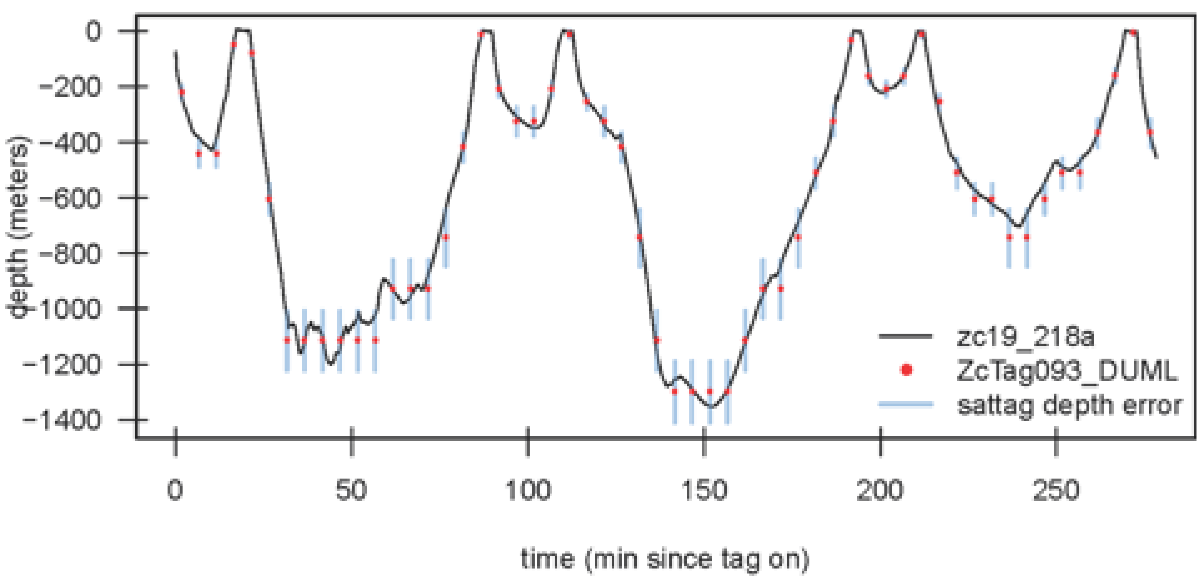

Figure 67. Dive profile (black) for focal DTAG whale (Zc19_219a) shown for same period with time series depths (red; depth error bars in blue) for satellite-transmitting tag on focal whale ZcTag93 (within same focal group) before, during, and after Atlantic-BRS CEE #2019-03.

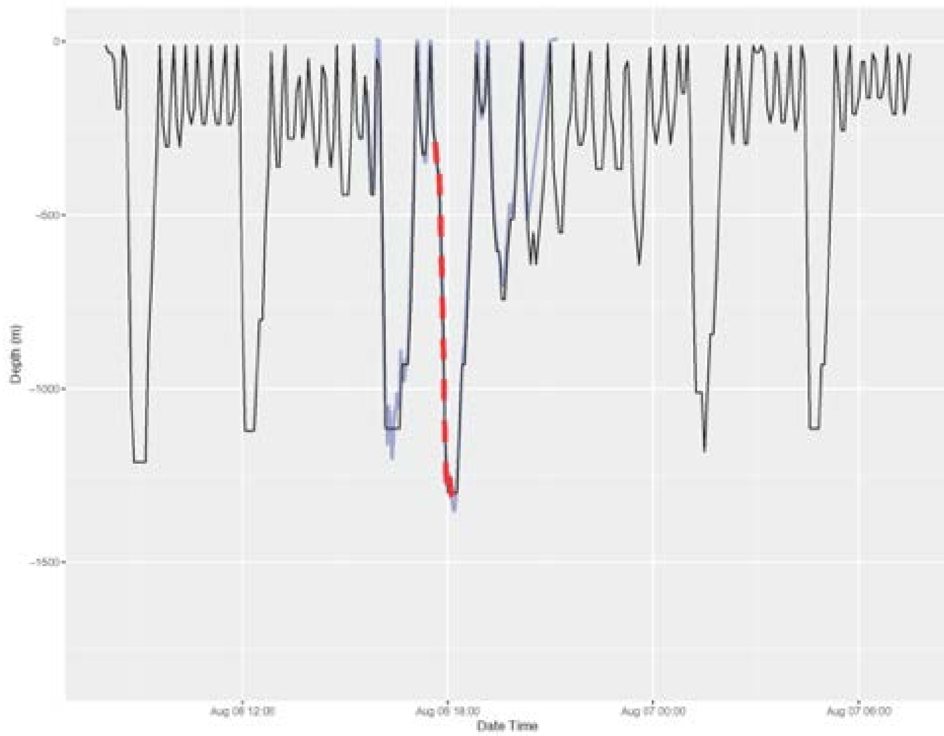

Figure 68. Dive profile (black) for focal whale (ZcTag93) for 24h period centered on Atlantic-BRS CEE #2019-03 (exposure period highlighted in red). DTAG Zc19_219a dive data is overlaid (blue) for the period of deployment.

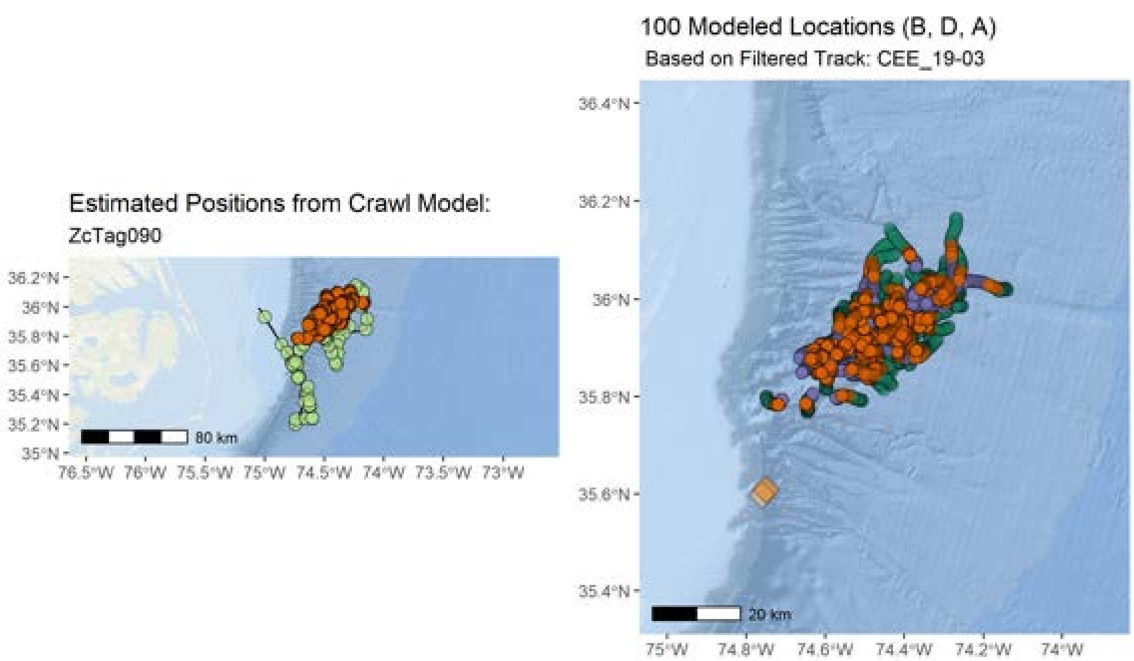

Figure 69. Estimated surface positions for tagged whale ZcTag90 before, during, and after Atlantic-BRS CEE #2019-03.

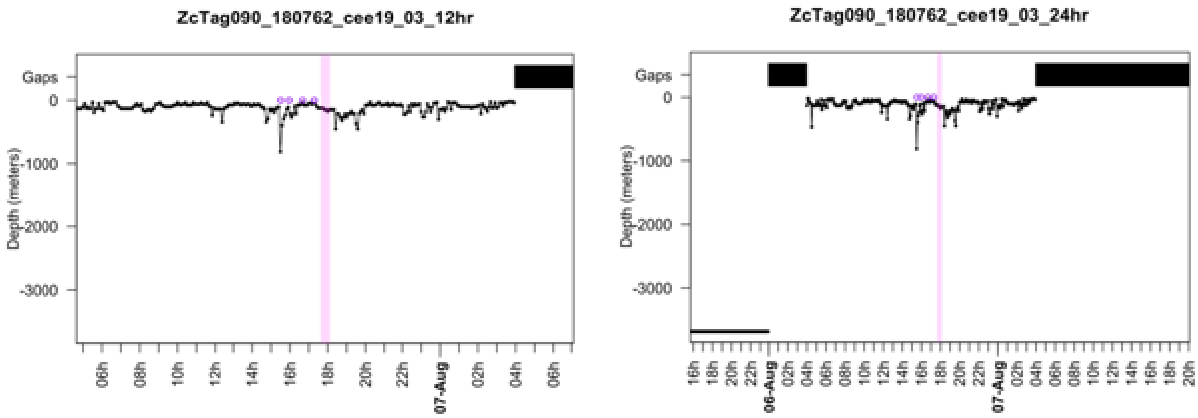

Figure 70. Available dive data for tagged whale ZcTag90 before, during, and after Atlantic-BRS CEE #2019-03.

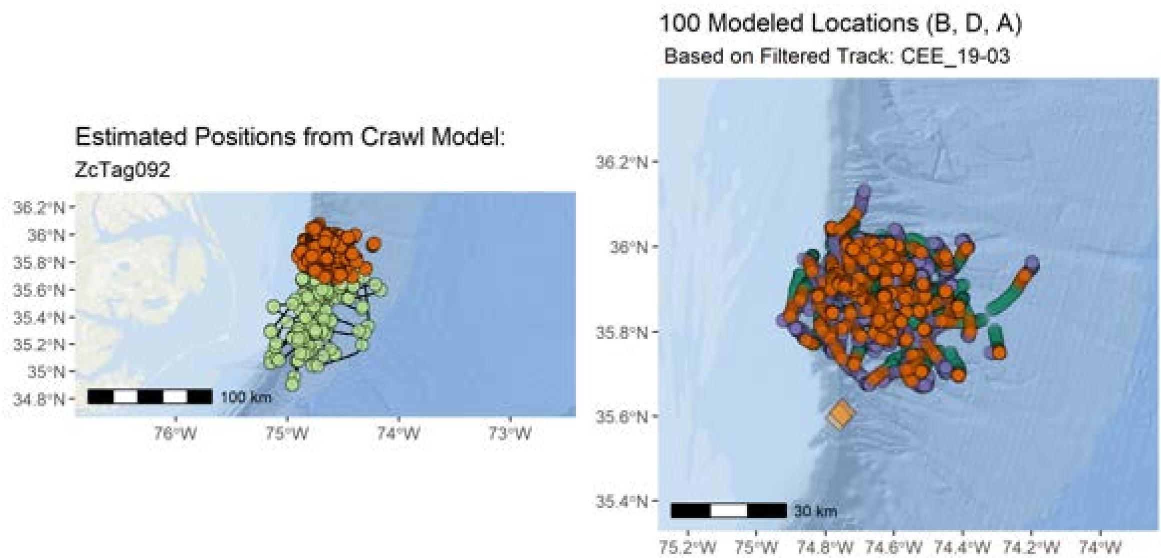

Figure 71. Estimated surface positions for tagged whale ZcTag92 before, during, and after Atlantic-BRS CEE #2019-03.

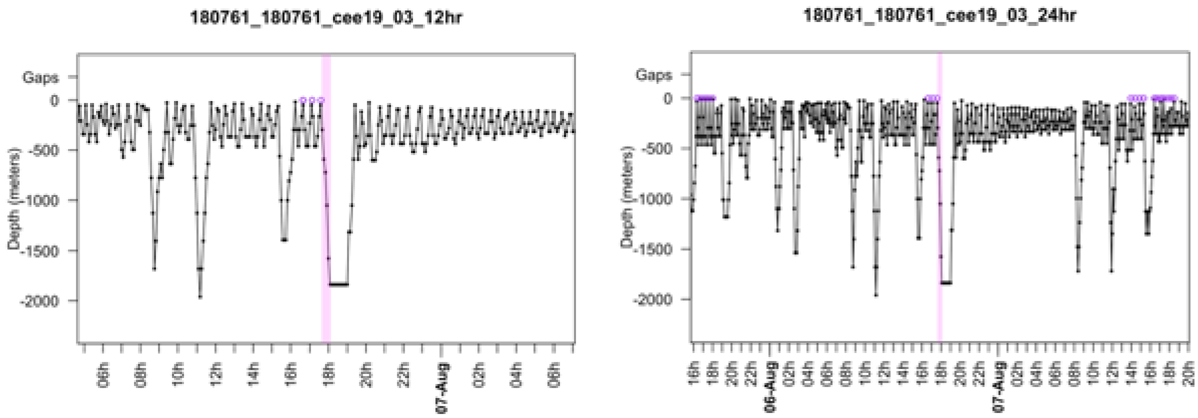

Figure 72. Available dive data for tagged whale ZcTag92 before, during, and after Atlantic-BRS CEE #2019-03.

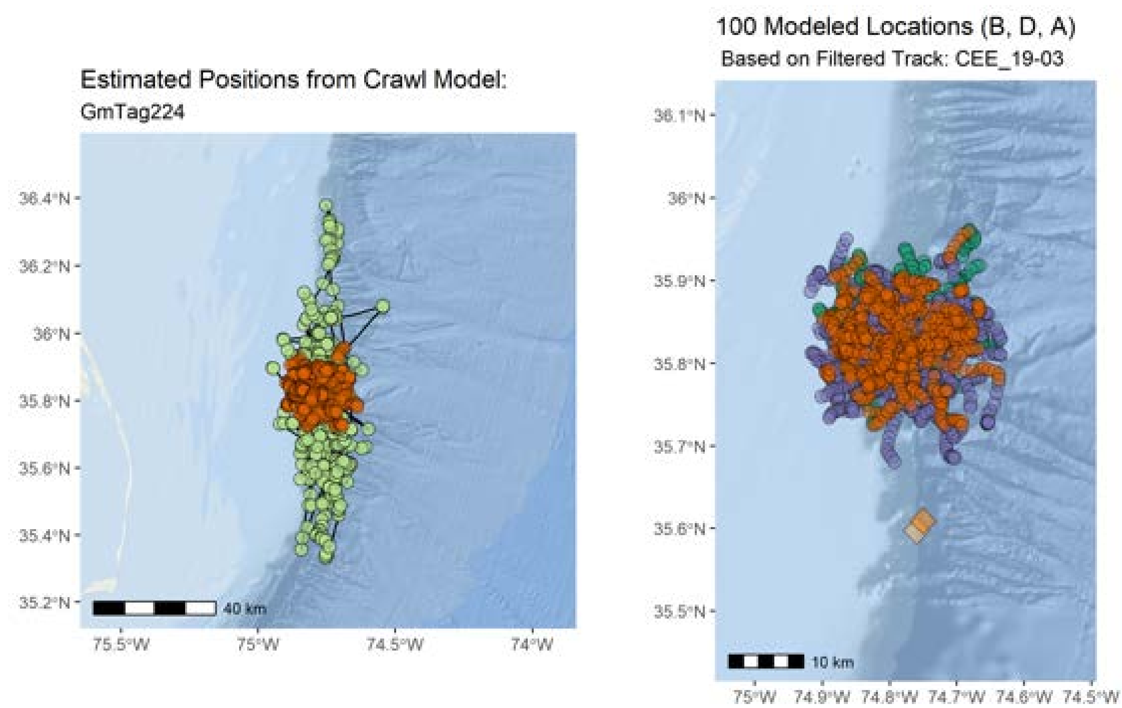

Figure 73. Estimated surface positions for tagged whale GmTag224 before, during, and after Atlantic-BRS CEE #2019-03.

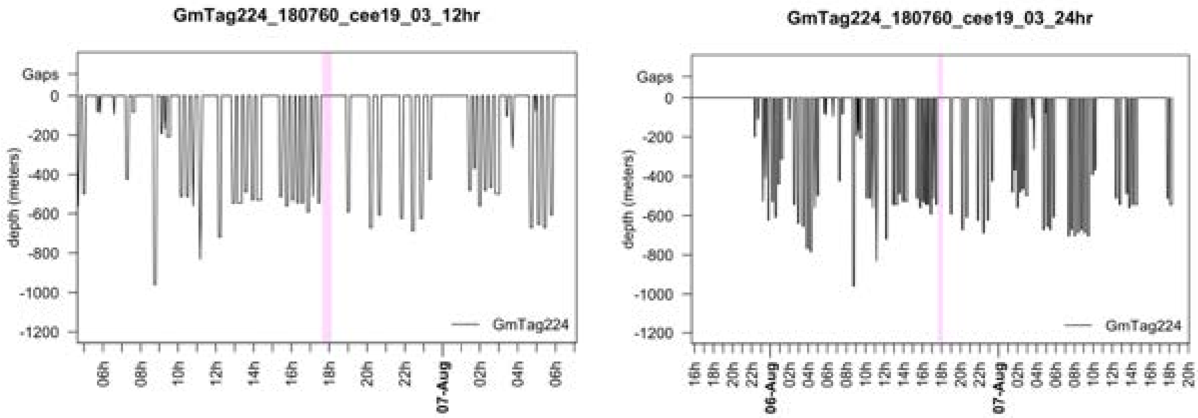

Figure 74. Available dive data for tagged whale GmTag224 before, during, and after Atlantic-BRS CEE #2019-03.

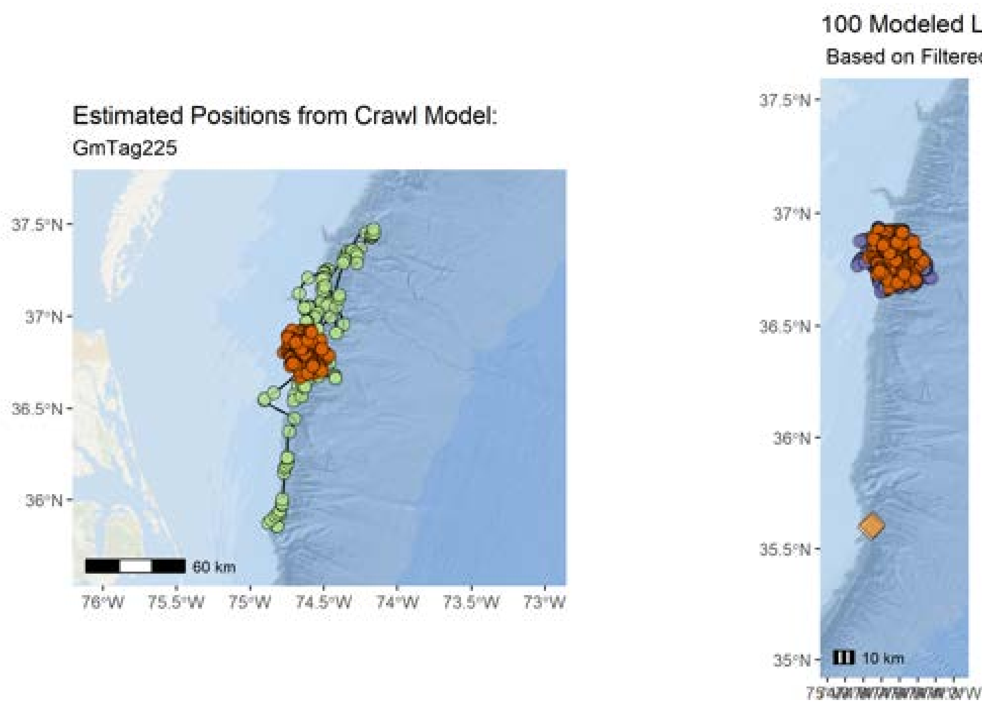

Figure 75. Estimated surface positions for tagged whale GmTag225 before, during, and after Atlantic-BRS CEE #2019-03

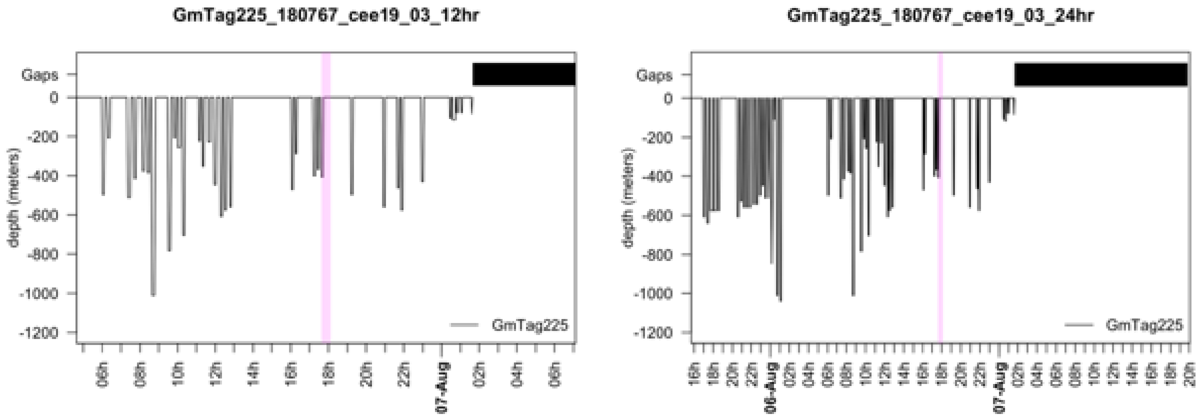

Figure 76. Available dive data for tagged whale GmTag225 before, during, and after Atlantic-BRS CEE #2019-03.

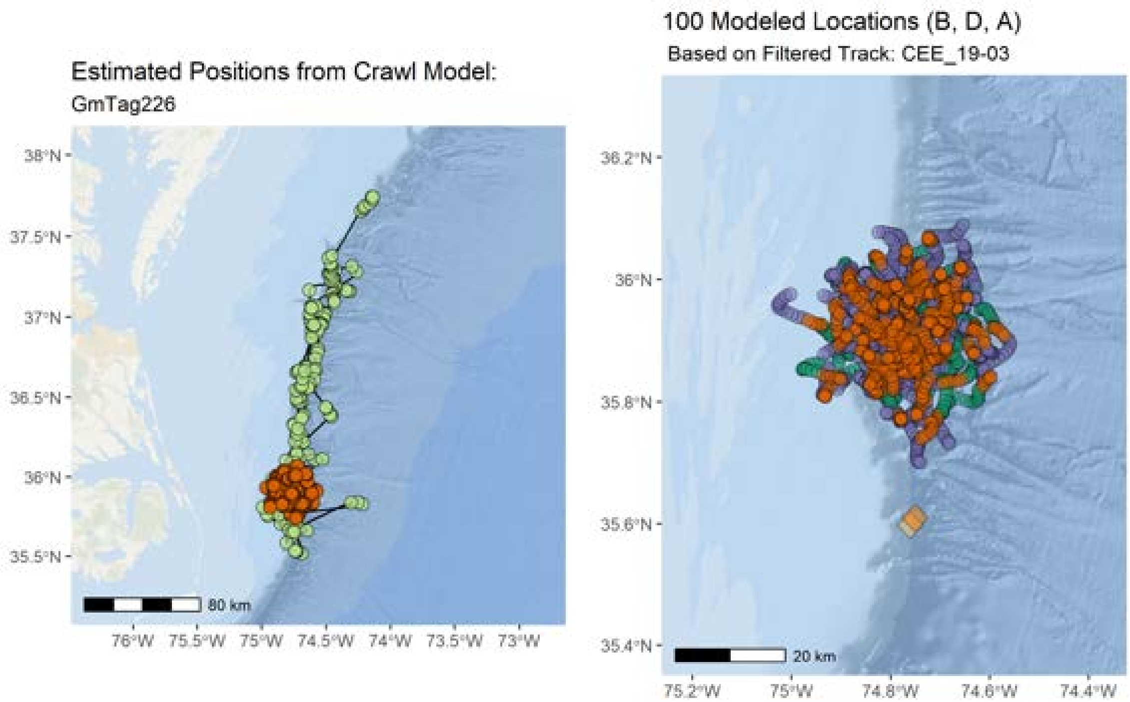

Figure 77. Estimated surface positions for tagged whale GmTag226 before, during, and after Atlantic-BRS CEE #2019-03.

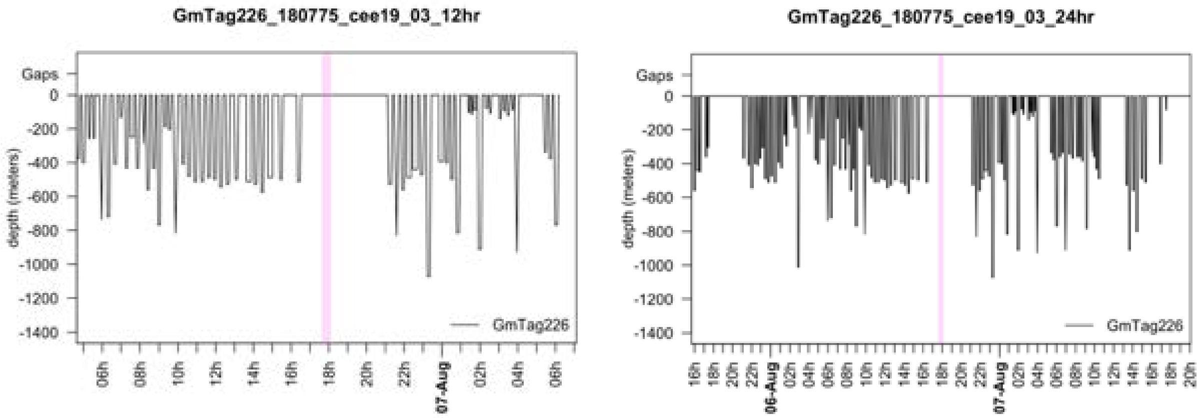

Figure 78. Available dive data for tagged whale GmTag226 before, during, and after Atlantic-BRS CEE #2019-03.

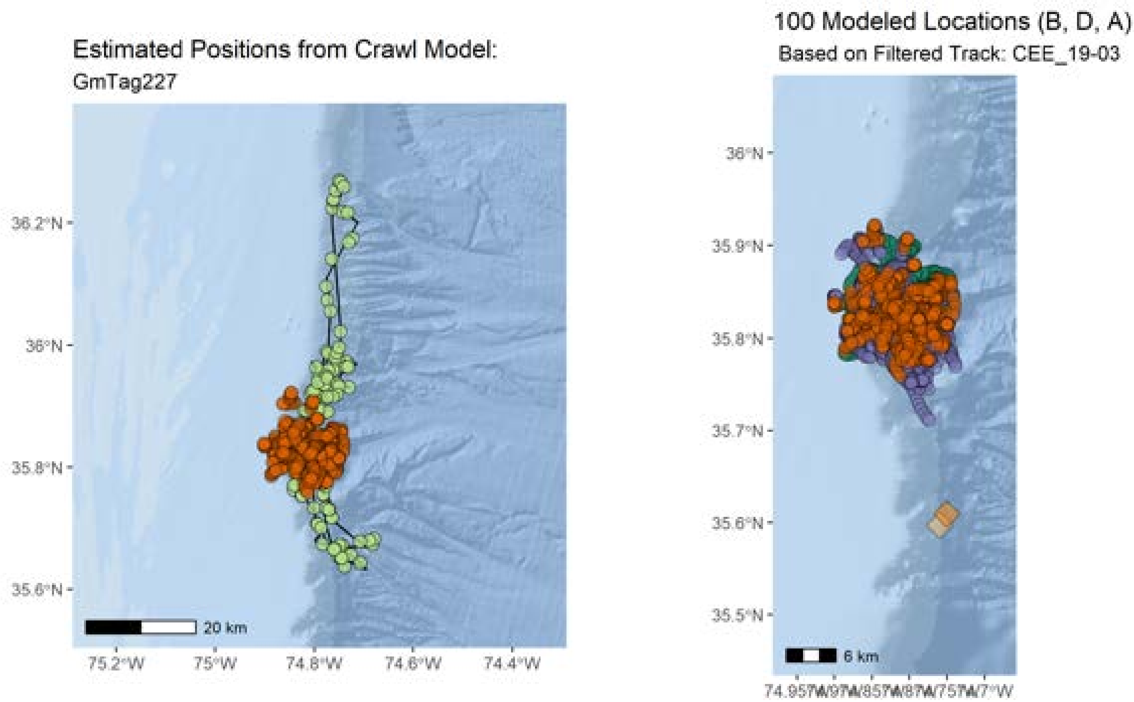

Figure 79. Estimated surface positions for tagged whale GmTag227 before, during, and after Atlantic-BRS CEE #2019-03

2.3.4 CEE #2019-04: Simulated MFAS

Table 11. Metadata summary for Atlantic-BRS CEE #2019-04.

CEE # 2019_04	
Date:	19 August 2019
Type:	Simulated MFAS (deployed from F/V Kahuna)
Signal parameters:	Three-segment (1.2 s total duration) pings (3.5–4 kilohertz [kHz]); 212 dB re 1 µPa (RMS) @ source; 25 s rep rate; 72 pings
Start time (UTC):	19:11:00
Start lat/lon (source):	35.80173; -74.763427
End time (UTC):	19:41:00
End lat/lon (source):	35.80173; -74.763427
Beaked whales tagged during CEE:	(n=5) - Zc95, Zc96, Zc97 (all focal sat tag whales within same group); Zc92 (XY data only); Zc93 (XY only)
Pilot whales tagged during CEE:	(n=2) - Gm224; Gm226
Estimated Range (start CEE):	3.4 km (2 nm)
Modeled Max RL:	138-141 dB RMS (300-1000m)

CEE #2019_04 - Narrative Summary
Novel accomplishment in having multiple (3) satellite-tagged Cuvier's within the same group all with complete and complementary relatively high-resolution time series data. This provides important data to compare diving behavior to consider behavioral synchrony before, during, and after MFAS exposure. While the dive data are of less resolution than with the DTAG in CEE 2019_03, they also suggest similar kinds of dive responses and, particularly considering the focal follow data, horizontal avoidance response. These three whales were tightly coordinated in dive behavior before, during, and after the CEE and in the two post-CEE locations were moving away from the source location (well after the CEE) swimming at a high rate of speed (observed directly in final post-CEE focal follow observations

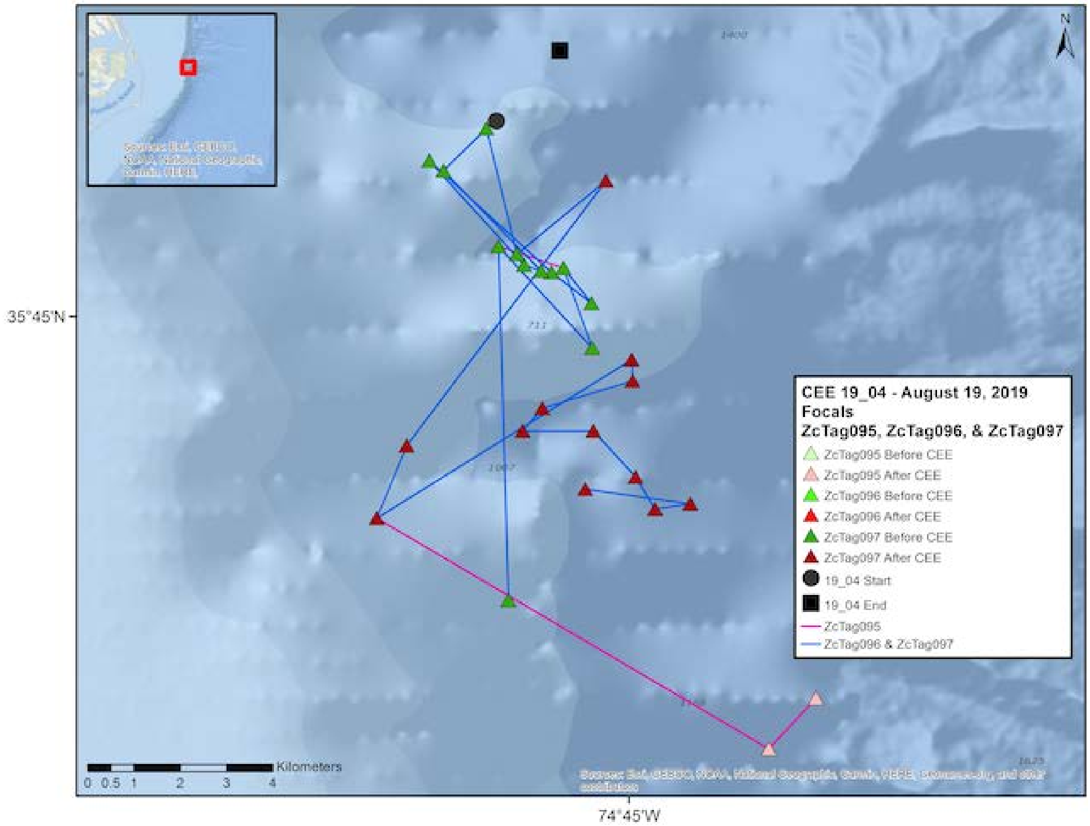

Figure 80. Overview map of source and ZcTag95, ZcTag96, and ZcTag97 group focal follow locations for CEE #2019-04.

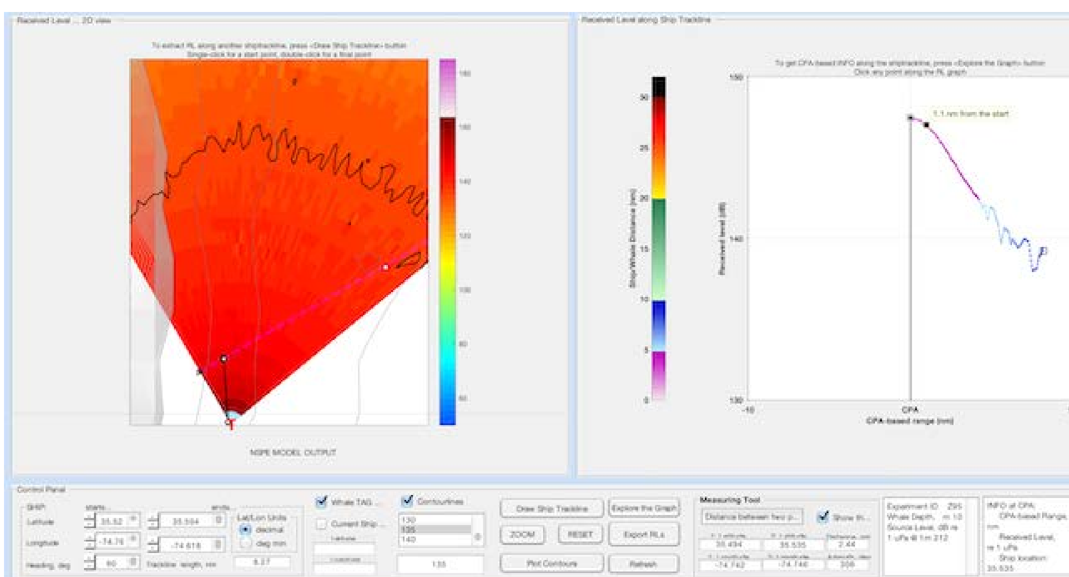

Figure 81. RL model prediction at 10 m depth for focal whales ZcTag95, ZcTag96, and ZcTag97 for initial position used for *in situ* modeling of Atlantic-BRS CEE #2019-04. Modeled RL at this depth and estimated position was: 147.0 dB RMS.

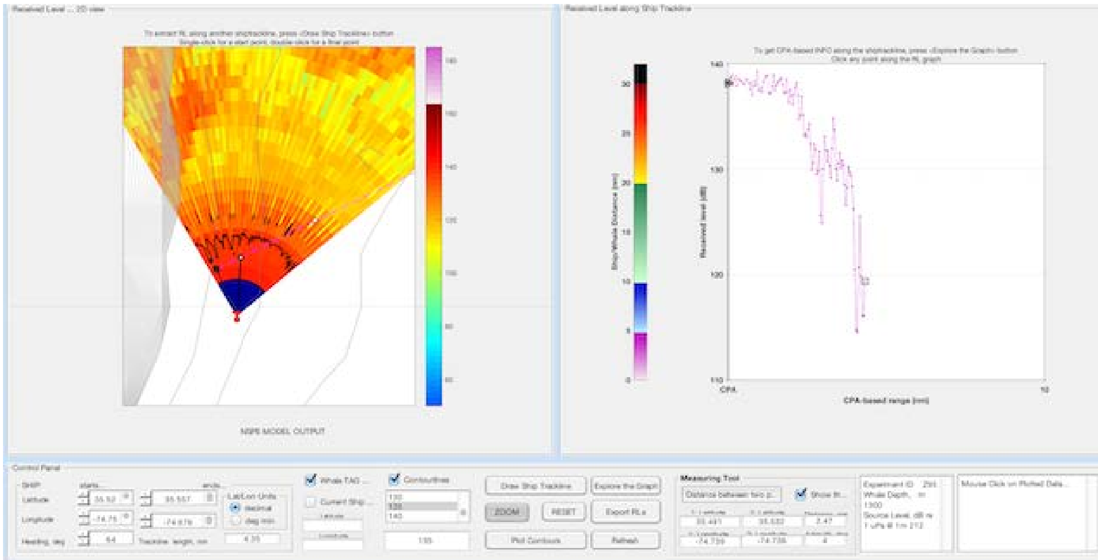

Figure 82. RL model prediction at 1300 m depth for focal whales ZcTag95, ZcTag96, ZcTag97 for initial position used for *in situ* modeling of Atlantic-BRS CEE #2019-04. Modeled RL at this depth and estimated position was: 138.2 dB RMS.

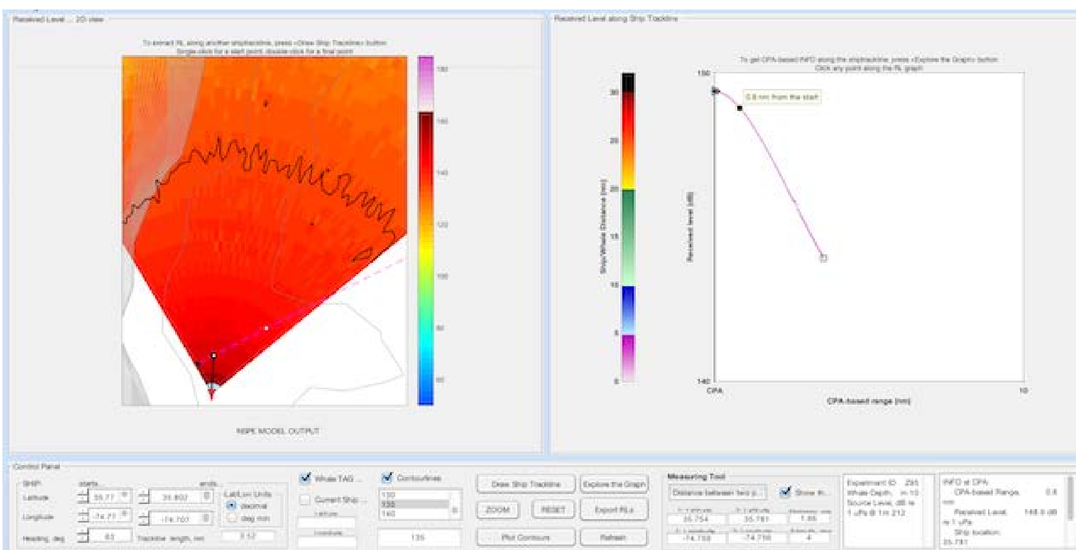

Figure 83. RL model prediction at 10 m depth for focal whales ZcTag95, ZcTag96, and ZcTag97 for estimated start position of Atlantic-BRS CEE #2019-04. Modeled RL at this depth and estimated position was: 148.9 dB RMS.

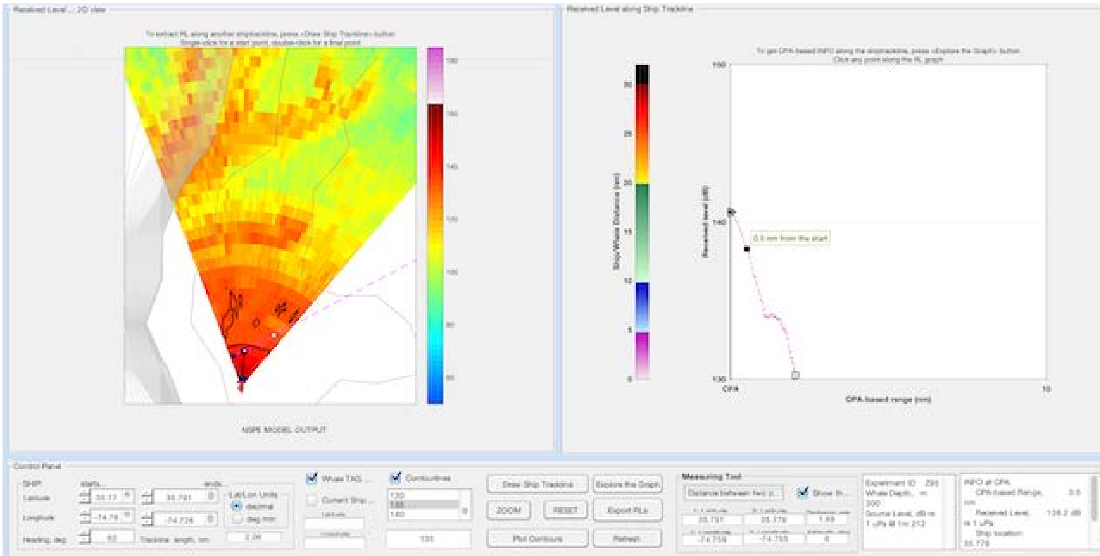

Figure 84. RL model prediction at 300 m depth for focal whales ZcTag95, ZcTag96, and ZcTag97 for estimated start position of Atlantic-BRS CEE #2019-04. Modeled RL at this depth and estimated position was: 138.2 dB RMS.

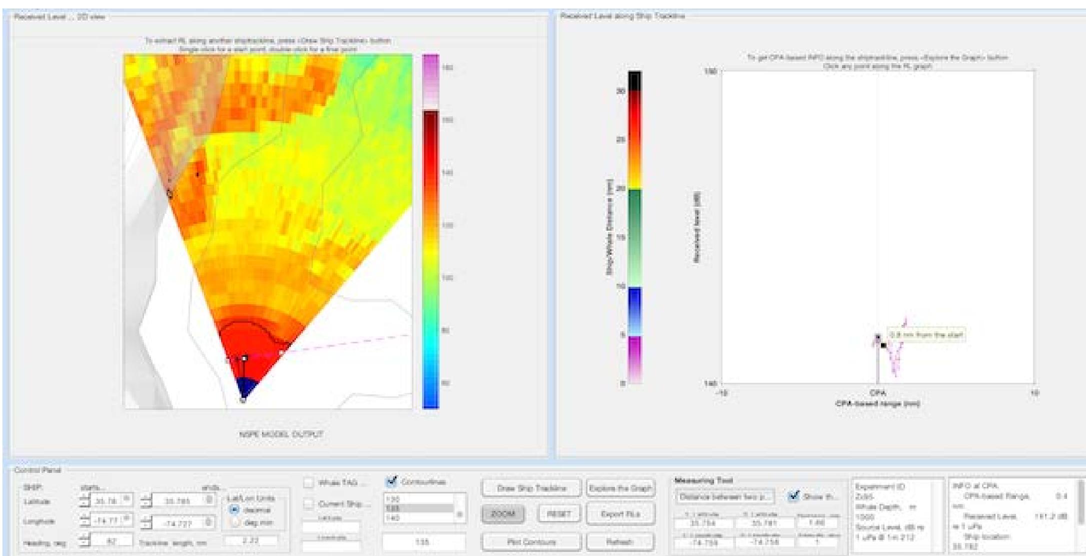

Figure 85. RL model prediction at 1000 m depth for focal whales ZcTag95, ZcTag96, and ZcTag97 for estimated start position of Atlantic-BRS CEE #2019-04. Modeled RL at this depth and estimated position was: 141.2 dB RMS.

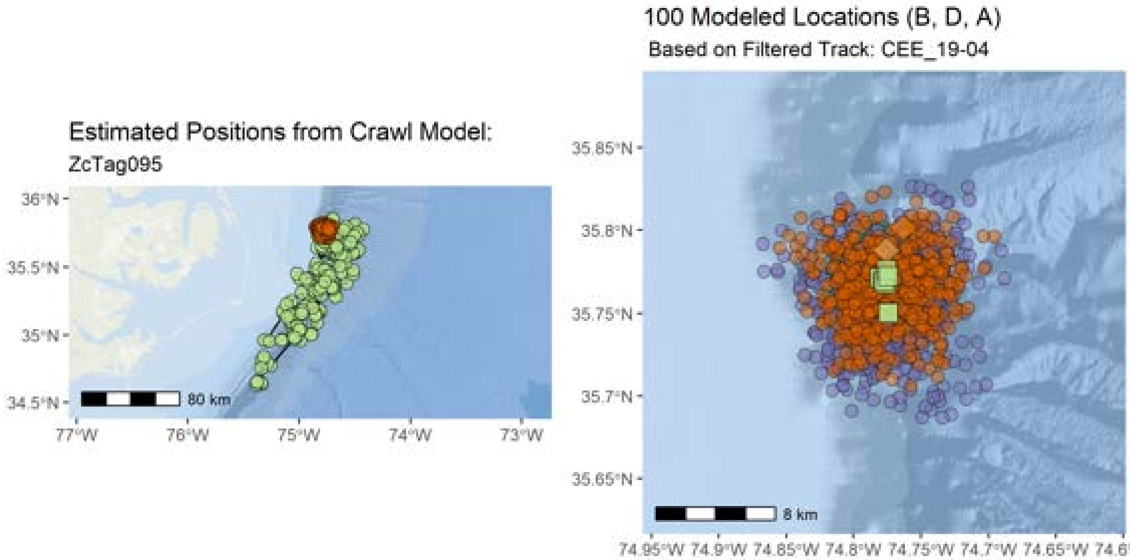

Figure 86. Estimated surface positions for whale ZcTag95 before, during, and after Atlantic-BRS CEE #2019-04.

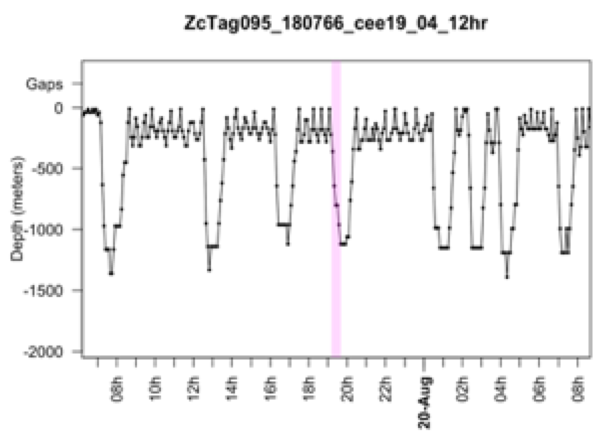

Figure 87. Available dive data for whale ZcTag95 before, during, and after Atlantic-BRS CEE #2019-04.

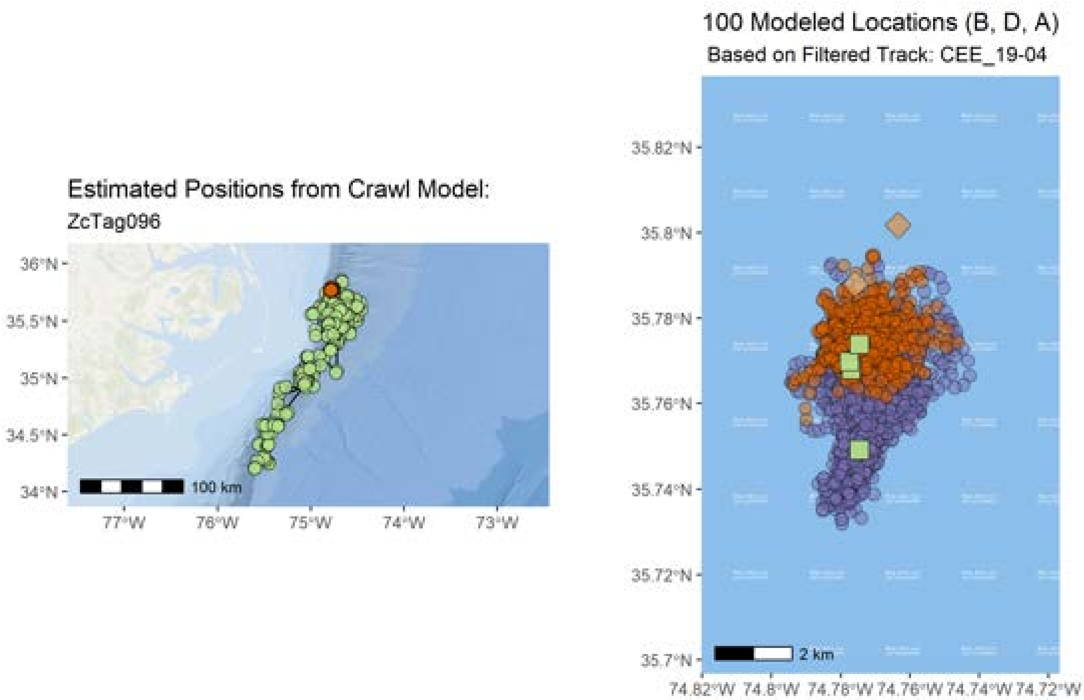

Figure 88. Estimated surface positions for tagged whale ZcTag96 before, during, and after Atlantic-BRS CEE #2019-04.

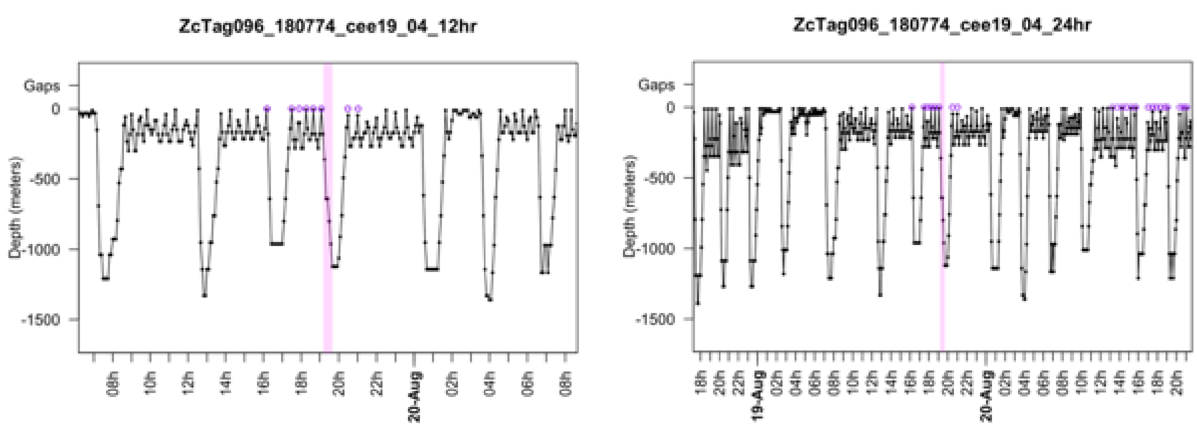

Figure 89. Available dive data for tagged whale ZcTag96 before, during, and after Atlantic-BRS CEE #2019-04.

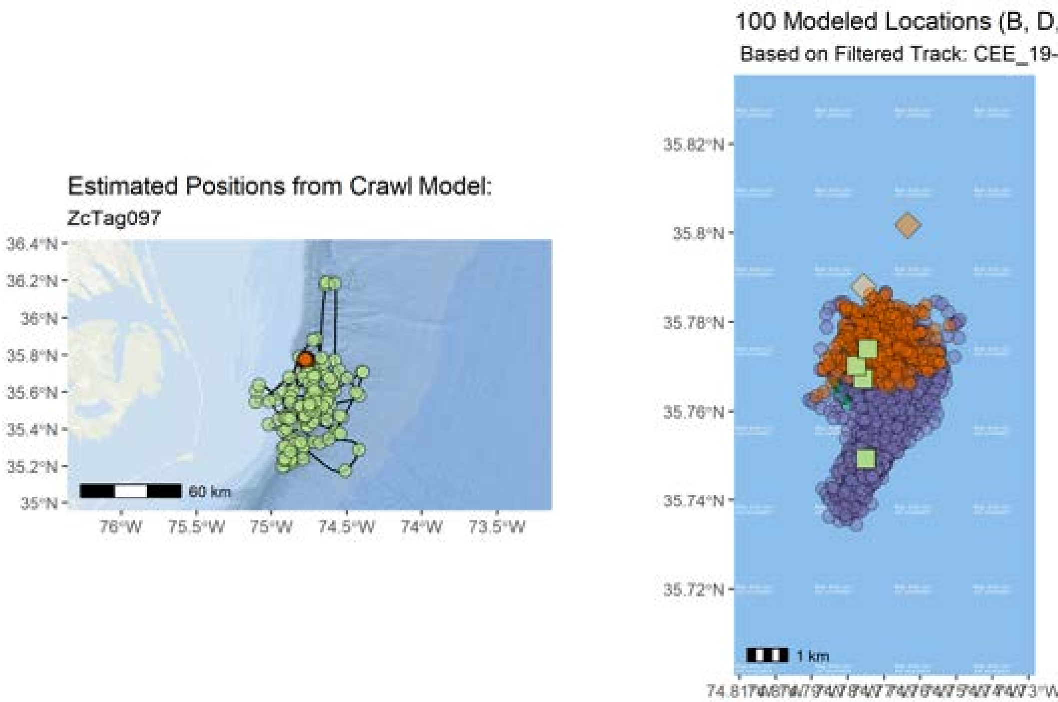

Figure 90. Estimated surface positions for tagged whale ZcTag97 before, during, and after Atlantic-BRS CEE #2019-04.

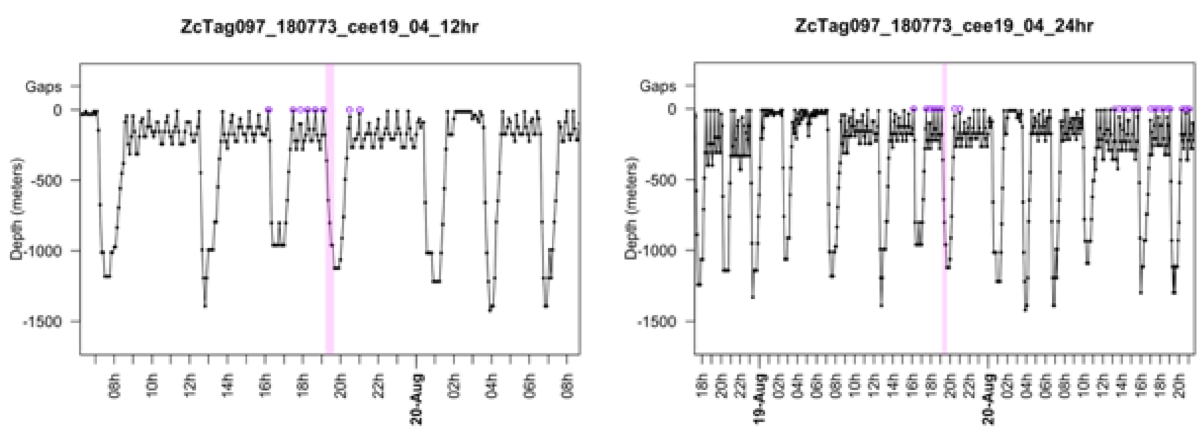

Figure 91. Available dive data for tagged whale ZcTag97 before, during, and after Atlantic-BRS CEE #2019-04.

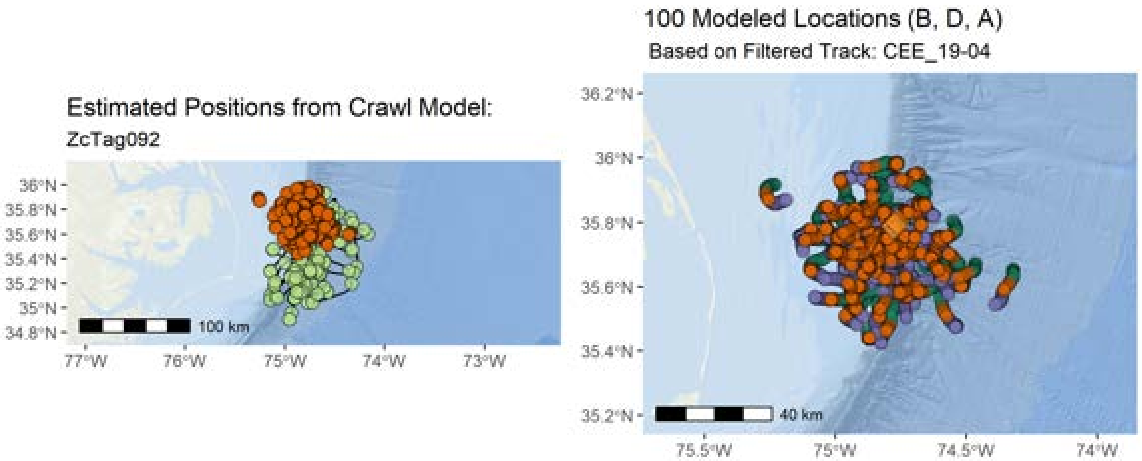

Figure 92. Estimated surface positions for tagged whale ZcTag92 before, during, and after Atlantic-BRS CEE #2019-04.

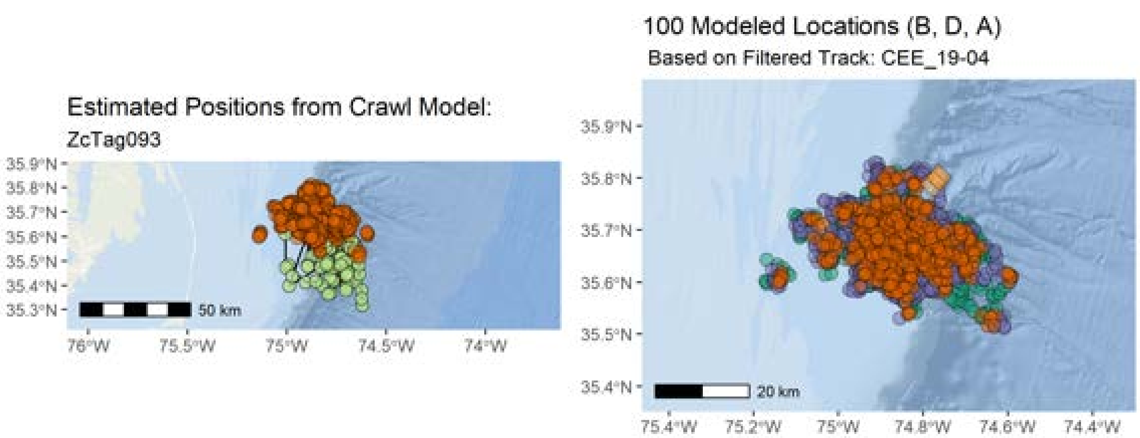

Figure 93. Estimated surface positions for tagged whale ZcTag93 before, during, and after Atlantic-BRS CEE #2019-04.

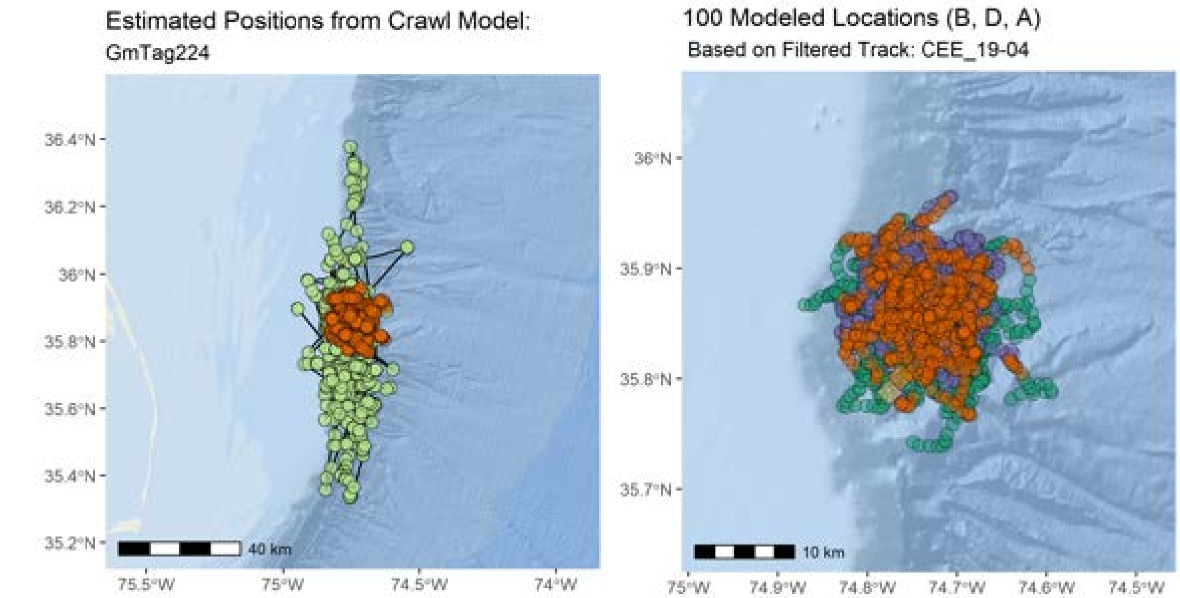

Figure 94. Estimated surface positions for tagged whale GmTag224 before, during, and after Atlantic-BRS CEE #2019-04.

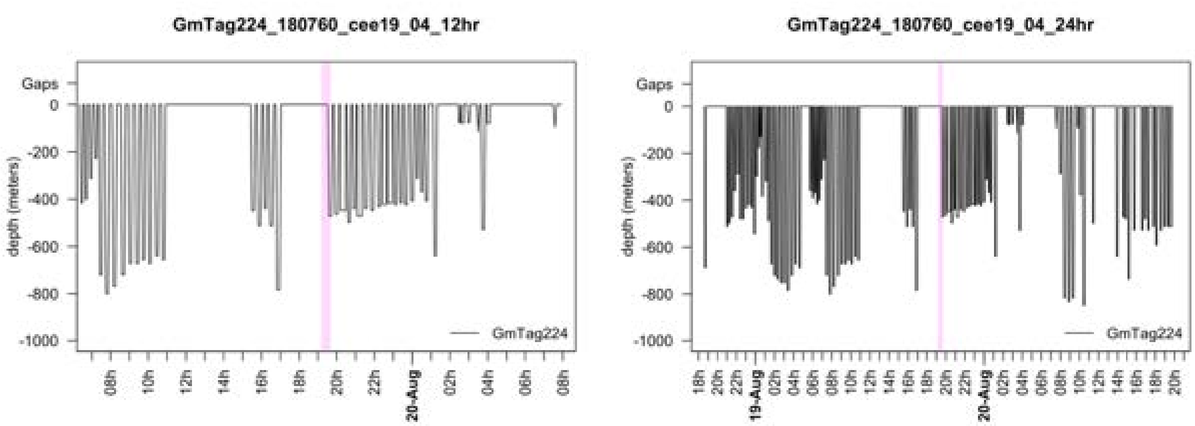

Figure 95. Available dive data for tagged whale GmTag224 before, during, and after Atlantic-BRS CEE #2019-04

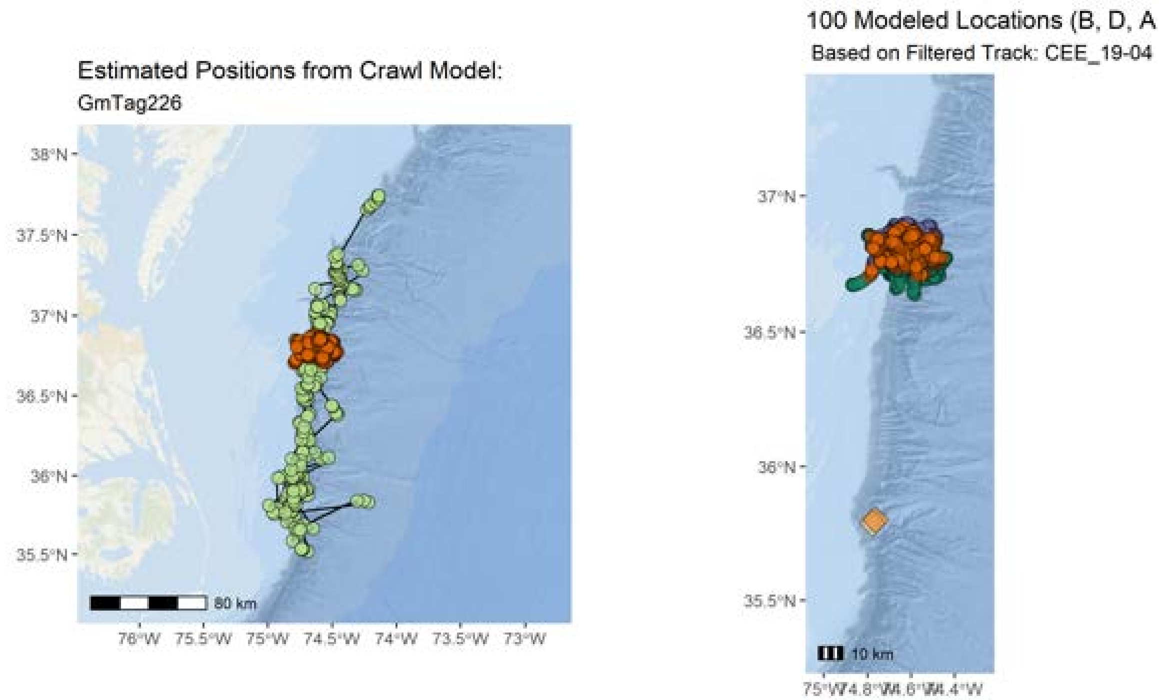

Figure 96. Estimated surface positions for tagged whale GmTaq226 before, during, and after Atlantic-BRS CEE #2019-04.

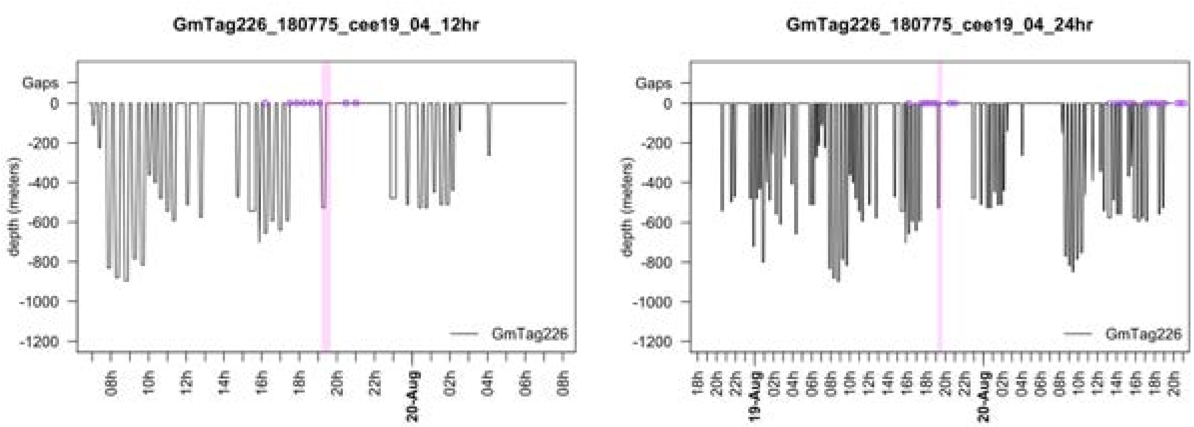

Figure 97. Available dive data for tagged whale GmTag226 before, during, and after Atlantic-BRS CEE #2019-04.

3. Analytical Developments, Preliminary Results, and Publications & Presentations

3.1 Analytical Developments

3.1.1 Progress on RL modeling for animal exposure events

We previously reported on extensive progress made by NPS, Duke, and SEA colleagues regarding the use of propagation models from known MFAS source locations to quantitatively predict which animals would have received exposures during CEEs at audible levels (See Southall et al. 2019). Additional progress and customization of this process has occurred subsequently, many of the details of which are now published in Schick et al., 2019. Elements of this process are explained briefly here, which include some improvements and modifications since our previous report. The overall objective of this approach is to use a systematic, quantitative and site-specific means of evaluating exposure in order to determine which tagged animals should be included within the more complex RL exposure and all response analyses.

In the below example using the USS NITZE (3 June 18; CEE with Zc69 discussed below), the radiated noise field in was modeled in 360-deg radials at 10m depth bins. The plots below show these noise fields at a discrete depth (0-10m) for each (NITZE top; RAMAGE below) in terms of modeled RL (left) as well as in the 1/3rd-oct ambient noise level that would have to exist at each location in order to mask detection of the signal.

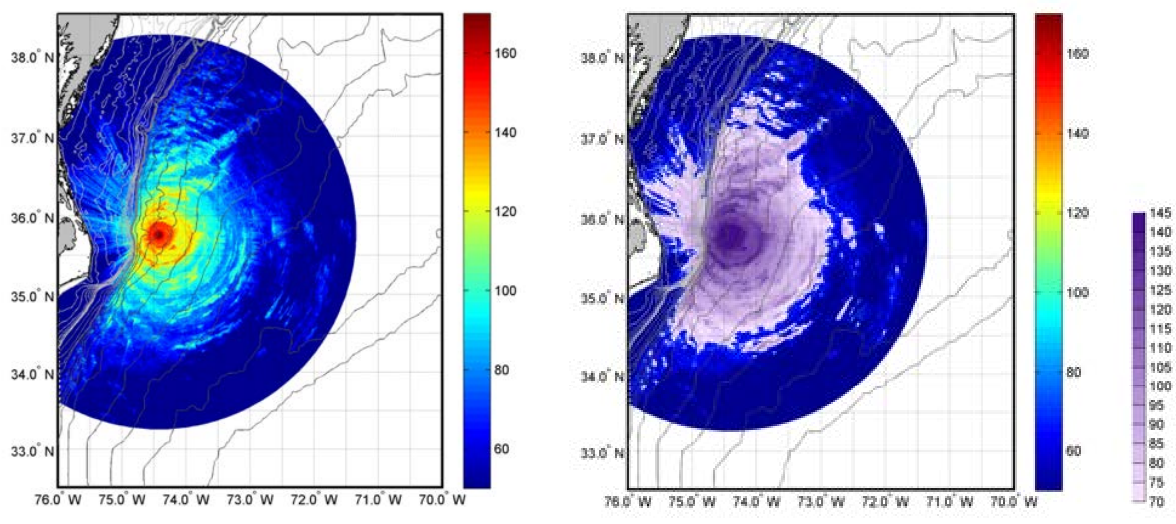

Figure 98. Modeled 360-deg sound fields from *USS NITZE* at end location of 3 June 18 CEE. The left panel shows modeled RLs (in dB re: 1μPa), while the right panel shows ambient noise levels within the 3.5 kHz 1/3-oct band that would be required to mask detection of the signal.

An iterative approach with underlying assumptions was developed, which is conducted separately for each CEE. This process has the following steps:

(i) Calculate these noise footprints for each depth bin (10m resolution) at defined time intervals within CEEs (start, middle, end) based on known location of source at these times

(ii) Convolve RL footprints across all depths to give a maximum RL along any radial across all depths (note: this could be interpreted as overly conservative for pilot whales) – this provides an effective “footprint” of the exposure at 5-min intervals along the known track of the source during transmissions (greater resolution than done previously);

(iii) Determine the predicted 1/3rd-oct ambient noise level for 3.5 kHz center frequency band at that time (based on wind speed using predictive atmospheric models);

(iv) Define the region of the noise footprint where the 1/3-oct (RMS) MFAS level exceeds the 1/3rd-oct ambient noise level (SNR>0);

(v) For each individual, each of the 100 imputed track points are evaluated at these defined times from movement modeling and overlaid onto the corresponding noise footprint where SNR>0.

(vi) For individuals where more than 5 of these 100 locations fall within this defined footprint for any time step, the more complex and time consuming individual-based RL model determination and subsequent response analysis will be conducted. Whales with five or fewer points within this footprint will not be evaluated further for this exposure.

3.1.2 Ongoing development of analytical methods

Extensive effort has been invested in the application of existing analytical methods, as demonstrated in the CEE analyses and quick-look assessments provided here. Additional development and enhancement of analytical approaches is ongoing as well, to improve and systematize analyses of behavioral response. A detailed evaluation of the Mahalanobis distance method for identifying behavioural change has been a focus over the last year with regard to application to both DTAG data and satellite tag data. Many studies, including Atlantic BRS, have used Mahalanobis distance methods to collapse multiple data streams, recorded from animal movement tags, into one variable that quantifies behaviour change over time; however, there is little information on how well Mahalanobis distance can detect behaviour changes or how the different ways to implement the method affect performance. A simulation study is being conducted to assess how Mahalanobis distance methods perform with different species, different tags, and under different implementations. From this, we can provide recommendations on how best to use these methods in future analyses. The simulation study aims to quantify both the false positive rate of detecting a behavioural change, and the statistical power of this method. Results so far (based on application to simulated DTAG data) indicate that the Mahalanobis distance method has high power to detect responses, but can also have a high false positive rate when baseline data is sparse.

In parallel, we have been developing and evaluating alternative change-point analysis methods. One approach which we are pursuing is a Continuous Time Markov Chain (CTMC) method. The CTMC approach allows for joint modelling of dive and surface durations and allows for covariates (such as dive depth, distance to shelf edge, or distance to source vessel to affect dive and surface durations differently). This approach can capture cyclical/non-linear correlation in the baseline data and look at deviations from any underlying patterns in behaviour during exposure. Generalised Linear Models (GLM) and Generalised Additive Models (GAM) of dive duration or surface duration alone are similar to the above approach but they cannot model both processes together. Once both the Mahalanobis distance and CTMC approaches have been applied to a sample of satellite tag data, we will evaluate the strengths and weaknesses of both approaches.

The Atlantic-BRS efforts are also coordinating with and benefiting from analytical development from the ONR-funded Double MOCHA project. A number of these are directly relevant to the Atlantic-BRS and will benefit and influence future analysis efforts. The St Andrews and Duke Double MOCHA teams are pursuing a number of different approaches for analysing data from both DTAGs and satellite tags, prioritising baseline data analysis for methodological development with the aim of then incorporating exposure data. Currently the St Andrews team are developing a flexible statistical framework to model patterns in the acceleration of whales (development based on beaked whales). The method describes the level of activity of a whale, as measured by its acceleration and postural changes, through the different phases of its dives. Estimates are obtained for the trend and variability in the movement of the animal, which provides a flexible description of its behaviour through time. In the context of CEEs, sound exposure can be included as a covariate on the level of activity of the animal, to measure deviations from the baseline model and detect behavioural responses.

The Duke team is focussing on developing methods to analyse dive trajectories recorded by satellite tags. These data records are considerably coarser in time than DTAG data but allow baseline behaviours to be studied over longer periods of time. Satellite tags record depth as a discretized interval measurement once every five minutes (e.g., “depth is between 50m and 100m”). Depths cannot be known precisely because the depth intervals recorded on the tags are 20m for the shallowest depths, and 200m for the deepest depths. The limited depth and time resolution in satellite tag data makes applying existing models for dive behaviour challenging because these models generally assume depth is known precisely at all points in time. The Duke team is developing a hierarchical Bayesian statistical model and computational method to analyse the discretized depth data collected for all dives collected in a satellite tag record. The method estimates diving rates and durations in addition to the depth intervals that are visited between observations. The model is flexible enough that it can be extended to include sound exposure data as a covariate after a model for baseline behaviour is established.

3.2 Preliminary Results

3.2.1 Baseline Animal Movement and Diving Data

As shown in **Tables 4 and 5**, the 21 satellite tags deployed on (16) beaked whales and (5) pilot whales recorded individual movement and diving data for many hundreds of days in total. This is in addition to 57 tags (27 beaked whales; 30 pilot whales) previously deployed in 2017 and 2018, making the collective effort off Cape Hatteras, including the baseline satellite tag deployments conducted in years preceding the Atlantic-BRS project, the largest set of baseline data on Cuvier's beaked whales currently available anywhere in the world. The collective dataset now includes many tens of thousands of hours of data both prior to and following either of the CEEs conducted. These data augment previously collected baseline data in serving as the foundation against which potential fine-scale behavioral responses are analyzed.

3.2.2 Summary of Responses Observed in the Field

While analyses are ongoing and will include assessments across many exposures, including those obtained from the three years of fieldwork to date and subsequent efforts, responses observed in 2019 CEEs were among the clearest and strongest documented within some individuals. These included avoidance responses, changes in diving behavior, and some of the first indications of changes in social interactions as a function of MFAS exposure.

Avoidance responses of focal individuals on the order of 10 or more km from pre-CEE areas over periods of hours were apparent in the field within multiple CEEs (#2019-02, #2019-03, and #2019-04). Individuals at greater ranges than focal whales generally remained and focal individuals eventually returned to the core areas where they were observed before CEEs, notably beaked whales tagged and observed in what are clearly high-use areas off Cape Hatteras near the HARP deployment sites. Changes in diving behavior included what appear to be extended dive durations during MFAS CEEs (e.g., nearly 2h dive in #2019-02 focal individual (ZcTag89) and shallower ascent phases were observed; these are consistent with some previous CEEs with Cuvier's beaked whales in the SOCAL-BRS effort. Additionally, because of the simultaneous DTAG (Zc19_218a) and satellite tag (ZcTag93) deployments within the same social group, we are able to quantify fine-scale aspects of movement and energetic responses during the strong avoidance responses seen during and following the CEE (#2019-03). Finally, given our success in tagging multiple individuals within the same social groups and following, photographing, and tracking individuals and groups over time, we now have some initial insights into possible disruption of social interactions during and following CEEs. We observed both what appear to be splitting of social groups during or just following MFAS exposure (CEE#2019-02) and apparent changes in multi-individual diving synchrony over hours and days following another CEE (#2019-04). It is important to note that sample sizes are limited at this point and that these should be seen as preliminary findings requiring both additional analysis and additional replication.

Quantitative analyses of behavioral changes within and between animals are underway and definitive conclusions about the nature and magnitude of avoidance, diving/foraging, and social responses to simulated and (especially) actual MFAS sources will require additional analyses and exposure-response data collection. However, our CEE results from 2019 are some of the most notable to date and provide some of the clearest and strongest kinds of response data obtained thus far in this or any prior sonar-related BRS. These strong responses are guiding our future field planning efforts and objectives, as described below.

3.2.3 Example Detailed Analysis Results – Zc69

As discussed, we are progressing with both horizontal avoidance and dive response analyses for beaked and pilot whales looking at responses within and across many individuals. We are approaching these analyses first from the perspective of the simulated MFAS sources given that so many more individuals have been included, and at more representative/higher RLs, than for CEEs with real ships. While those are clearly the priority as stated, an additional number of real ship CEEs (with an objective of four including 4-6 beaked whales and some smaller number of pilot whales) will need to be conducted to advance those analyses. While we would like to retain the option for additional CEEs with simulated MFAS for the 2020 field season, we have begun to develop a response paper for at least beaked whales using existing analytical methods. These analyses are ongoing, and will be influenced to some degree by the ongoing developments described above. However, considerable progress has been made in the individual analytical approaches.

We have also conducted additional detailed analysis for the individual exposed during the most successful real Navy ship CEE (Zc69) conducted in 2018 using these existing methods. Examples of these analyses, as a means of demonstrating the kinds of results being generated and also an interesting possible larger-scale avoidance response, are provided below.

Beaked whale Zc69 was one of the first individuals for which series tag settings and relatively high-resolution (5-min) dive data were obtained continuously for a focused two-week period (see Southall et al., 2019). During this period, spanning 25 May to 7 June 2018, this whale was tracked, resighted multiple times, and was being monitored during four CEEs.

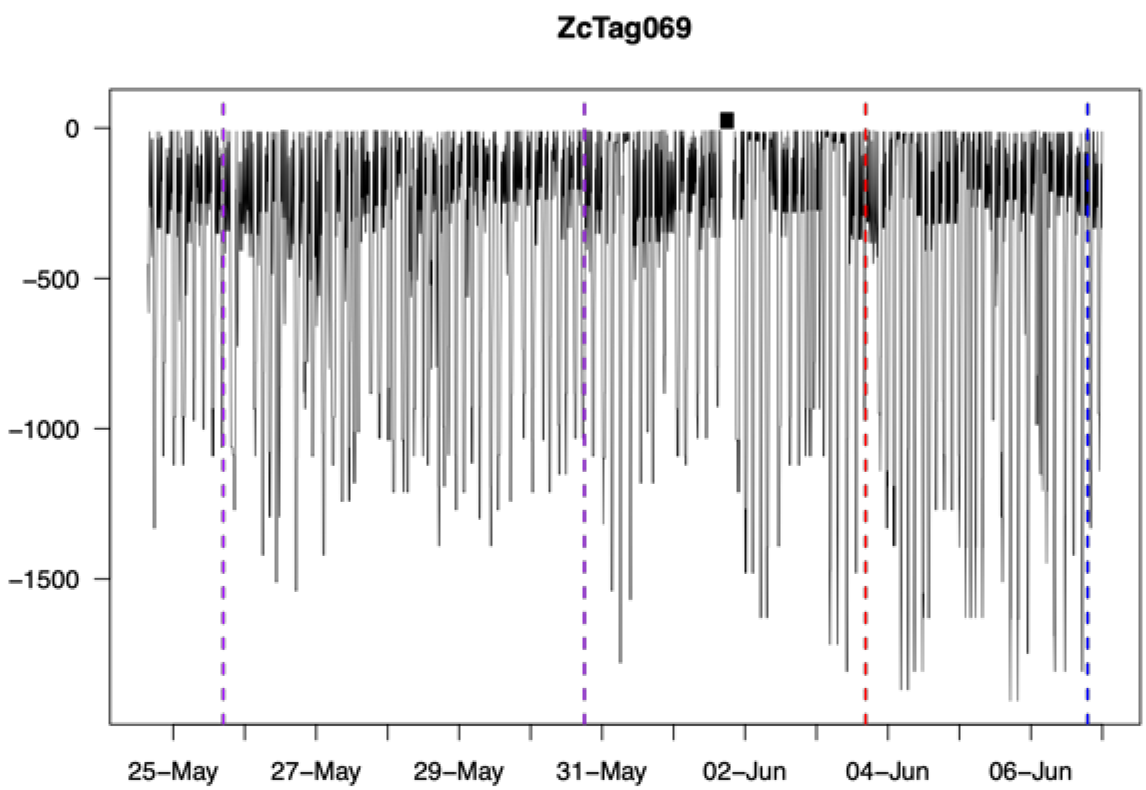

Figure 99. Complete dive record for ZcTag69. Purple lines denote exposure during a simulated MFAS CEEs (#s 2018_02 and 2018_03), the red line denotes an exposure to a real Navy vessel (USS NITZE) CEE (#2019_04), and the blue line denotes a control CEE (#2018-05).

Mahalanobis Distance analyses to evaluate potential changes in overall diving and foraging behavior do not suggest a strong immediate response during or just following CEE 2018_04 with the USS NITZE (see first highlighted red dive in **Figure 100** series below; dive 84). However, subsequent dives (#s 86-87) indicate a substantial spike in this integrated metric of differences in aspects of diving behavior from baseline conditions.

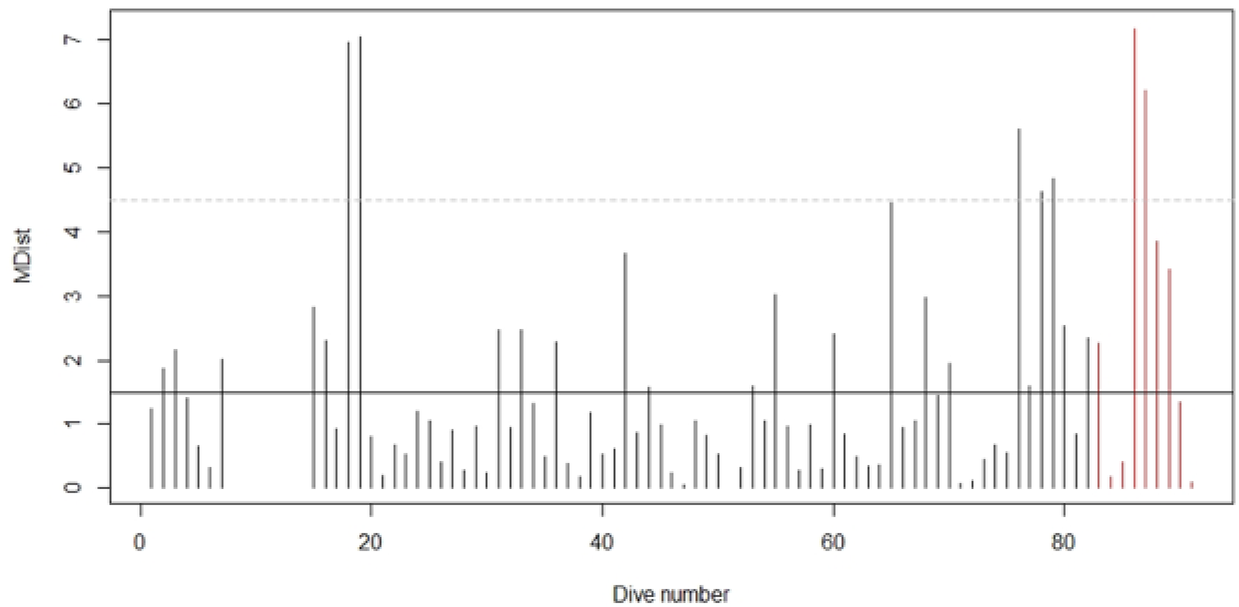

Figure 100. Mahalanobis distance analyses for ZcTag69 for all dives leading up to CEE #2018-04, which occurs coincident with the first red highlighted dive (#84).

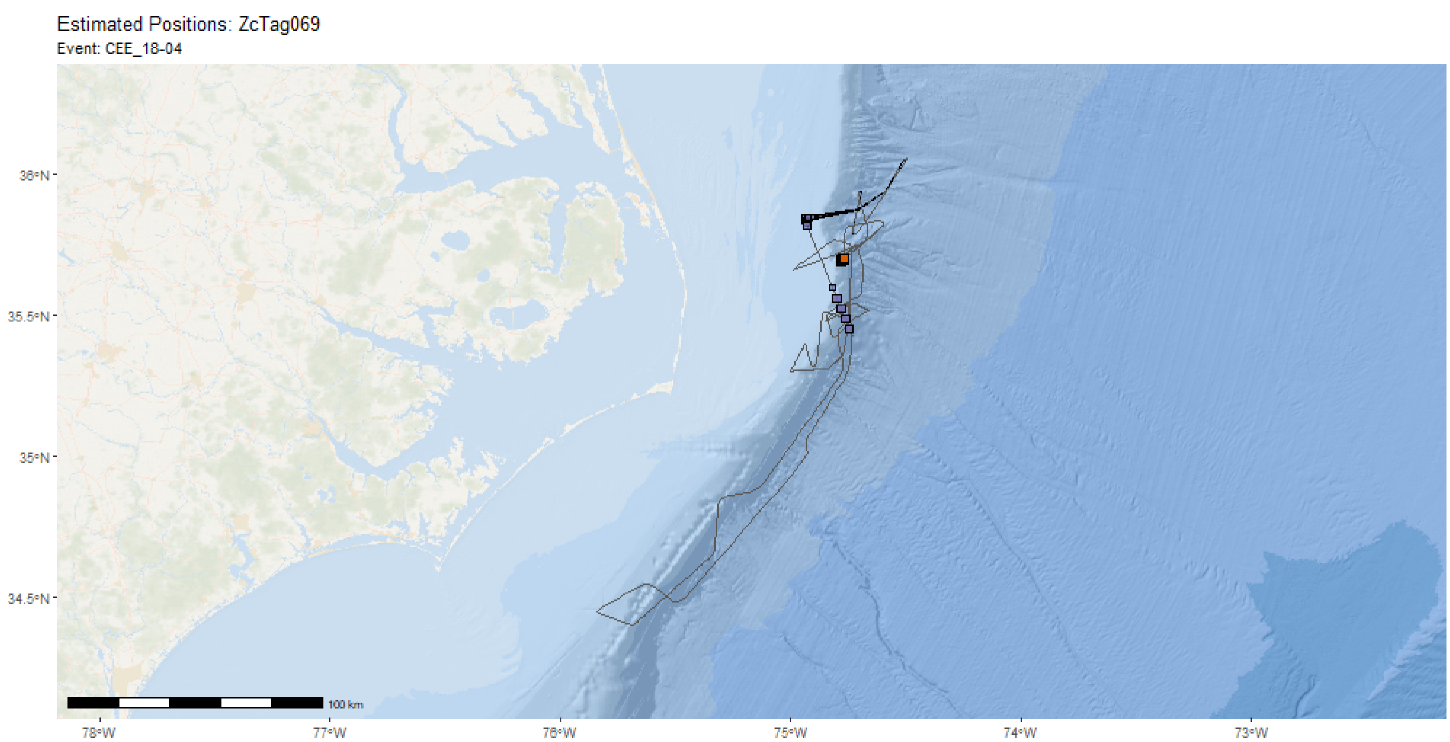

Figure 101. Horizontal movement data for ZcTag69 before and following CEE #2018-04 (orange square). The relatively large southwestward movement occurred just following this exposure, with the whale not returning for nearly a week to the core area (bounded by other highlighted sectors of the track) it had used for many days prior.

Satellite-tag positions also indicate that just following CEE #2018_04 and the exposure to the USS NITZE, Zc69 continued moving south but continued tens of miles outside the core area it had been utilizing during periods prior to this exposure. Based on a time-varying horizontal avoidance analysis (using the method of Hanks et al., 2015), this was a statistically-significant response, indicating strong and sustained movement away from the area followed by an attraction several days later back to the same core area (see **Figure 102** below). It should be noted that the whale was already moving away from the core area prior to CEE #2018_04 with the USS NITZE, but this movement away was sustained, strong, and unlike any movement during any of the pre-exposure period for this CEE (which included several other simulated MFAS CEEs at relatively lower RLs).

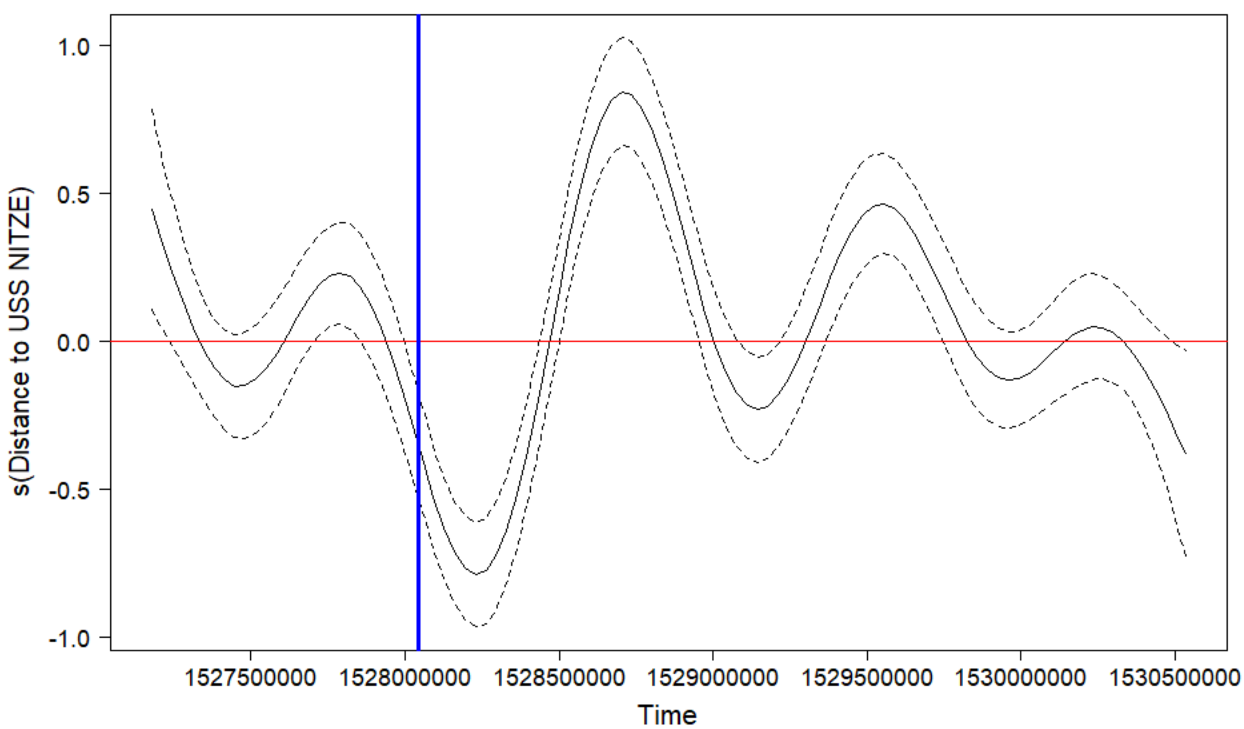

Figure 102. Horizontal avoidance analysis for ZcTag69 before demonstrating strong avoidance of the core habitat area during and just following CEE #2018-04 with the USS NITZE (indicated by the blue line).

3.3 Publications and Presentations

As the Atlantic-BRS project has progressed into its third year, we have increasingly begun to generate peer-reviewed publications and to give technical presentations of results in different venues. Below we provide a complete summary of papers that are either published, in review, or in advanced stages of development (**Table 12**), as well as technical presentations given during 2019 (**Table 13**). Direct links to publications and presentations are provided where available.

Table 12. Atlantic-BRS publications and manuscripts in review and development.

Category	Nominal Title/Subject	Lead Author (Institution)	Status
Baseline behavior	Diving Behavior of Cuvier's Beaked Whales (Ziphius cavirostris) off Cape Hatteras, North Carolina	Shearer (Duke)	**PUBLISHED**
Methodology - Technology	Mind the gap - Optimising satellite tag settings for time series analysis of foraging dives in Cuvier's beaked whales	Quick (Duke)	**PUBLISHED**
Methodology - Technology	Accounting for Positional Uncertainty When Modeling Received Levels for Tagged Cetaceans Exposed to Sonar	Schick (Duke)	**PUBLISHED**
Baseline behavior	Extreme Synchrony in Diving Behaviour of Cuvier's Beaked Whales (Ziphius cavirostris) off Cape Hatteras, North Carolina.	Cioffi (Duke)	In review
Baseline behavior	More than metronomes: variation in diving behaviour of Cuvier's Beaked Whales (Ziphius cavirostris)	Quick (Duke)	In review
Baseline behavior	Aerobic dive limits in Cuvier's beaked whales	Quick (Duke)	In preparation
Baseline behavior	Shallow night intervals in Ziphius cavirostris	Cioffi (Duke)	In preparation
Baseline physiology	Baseline variation of steroid hormones in short-finned pilot whales (Globicephala macrorhynchus)	Wisse (Duke)	In preparation
Methodology - Technology	Continuous time series data programming regime	Cioffi (Duke)	In preparation
Methodology - Technology	Estimating RLs and horizontal avoidance with dynamic covariates in exposed animals	Schick (Duke)	In preparation
CEE Exposure-Response	Meta-analysis of context of beaked whale response to sonar exposure	Quick (Duke)	In preparation
CEE Exposure-Response	Behavioral responses of Cuvier's beaked whales to simulated mid-frequency active military sonar off Cape Hatteras, NC	Southall (SEA; Duke)	In preparation
Disturbance Exposure-Response	Measuring stress responses in short-finned pilot whale biopsies: are field methods confounding our data?	Wisse (Duke)	In preparation

1 **Table 13. Atlantic-BRS presentations during 2019.**

Presenter	Date	Presentation Title	Venue
Southall	March (2019)	Atlantic behavioral response study	2019 Monitoring program review meeting (Norfolk)
Southall	Dec (2019)	Noise exposure criteria - emergent conclusions for auditory thresholds to broader issues	World Marine Mammal Conference (Society for Marine Mammalogy SMM) Barcelona (exposure-response workshop)
Quick	Dec (2019)	Next generation framework for modeling marine mammal responses to noise	SMM Barcelona (exposure-response workshop)
Wisse	Dec (2019)	Measuring stress responses in short-finned pilot whale biopsies: are field methods confounding our data?	SMM Barcelona (endocrinology workshop)
Quick	Dec (2019)	More than metronomes: variation in diving behavior of Cuvier's Beaked Whales (Ziphius cavirostris)	SMM Barcelona
Schick	Dec (2019)	Accounting for positional uncertainty when modeling received levels for tagged cetaceans exposed to sonar	SMM Barcelona
Cioffi	Dec (2019)	Extreme synchrony in diving behavior of Cuvier's Beaked Whales (Ziphius cavirostris) off Cape Hatteras, North Carolina.	SMM Barcelona
Wisse	Dec (2019)	Baseline variation of steroid hormones in short-finned pilot whales (Globicephala macrorhynchus)	SMM Barcelona
Southall	Dec (2019)	Atlantic behavioral response study – Responses of Cuvier's beaked whales and short-finned pilot whales to military sonar off Cape Hatteras, North Carolina, USA	SMM Barcelona

4. Overall Assessment and Recommendations for 2020 Effort

4.1 General Assessment of Atlantic-BRS 2019 Accomplishments

- We were extremely successful in deploying satellite tags (n=21, including 16 highest priority beaked whales). Further, these deployments occurred within focused tagging windows preceding designated CEE windows and included relatively high-resolution dive data from series tag settings. This resulted in concentrate periods of high quality, gapless movement and dive data centered on experimental windows. These strategic deployments meant that there were focal beaked whales (and in some cases pilot whales) available for inclusion in CEEs during focal periods, and that each individual was generally included and exposed for a single CEE. These modifications, and continued success in re-locating previously tagged whales for data acquisition and focal follow, were substantial improvements using lessons-learned identified in previous field efforts.

- Overall we had fewer DTAG deployments (n=2) than in previous field efforts. Although notably, both tags were recovered and we had much better success in tracking and recovering tags given some modifications to the VHF transmitters, again based on lessons learned from evaluating tag failures in 2018. Both DTAG deployments were on high-priority beaked whales and most notably one deployment was on a beaked whale that was in the same social group with a satellite-tagged beaked whale. This enabled us to fully achieve the multi-scale design of this experiment within a MFAS CEE for the highest-priority species. The results from this deployment have many important implications. Because the two tagged whales remained closely coordinated with one another (based on surface observations and from their underwater dive record), they enable several methodological assessments and comparisons of the data coming from the different tag sensors, and how to analyze them. Further, from the perspective of response analysis, we are able within this CEE to consider the apparent avoidance and highly energetic associated responses observed using the fine-scale, high-resolution sensor (DTAG) with those obtained during this period for the satellite-transmitting tag. It also allows us to put into context and perspective, those relatively strong but immediate responses with the two-week dive record of the satellite-transmitting tagged whale.

- Opportunities to coordinate with Navy ships during 2019 were ultimately unavailable. Ships were identified for at least two windows of each field period (spring and summer), but changes in their operational schedules and maintenance issues resulted in them unfortunately being unavailable. As planned for within our experimental design, the secondary option simulated MFAS source was successfully used (without any operational issues thanks to prior maintenance conducted) for CEEs during all scheduled periods.

- A total of four CEEs were conducted during the 2019 field season, a smaller number conducted than during 2018. However, because of the strategic approach to tag deployments ahead of specified CEE periods, maximizing the amount of higher-resolution dive data, and seeking to maximize the number of tagged whales included in each CEE, we effectively had as much or more high-quality data during CEEs than in either of the two previous field seasons. Further, given our efforts to relocate previously tagged whales, we were able to satellite-tag multiple individuals within the same group and also relocate tagged individuals to either re-tag the same individual with a different tag type or to tag other individuals in the same group.

- Target RLs for beaked whales were increased to 140 dB RMS for 2019 based on assessment of results from previous years. We achieved these target levels for all four CEEs based on directly measured and/or high confidence RL modeling methods and known locations of animals. As described in section 3.3.2, quite strong responses were observed in a number of focal animals at these RLs. These were strong enough that we do not recommend increasing target RLs for subsequent CEEs, but rather adding to the sample size at these RLs both for the simulated MFAS and especially for real ship CEEs.

- We continued to apply and improve methods of receiving and signals from satellite tags using the ARGOS goniometer. This allows us to track and relocate tagged individuals many times to obtain photos, biopsy samples, and locate other individuals for tagging attempts. Our ability to begin evaluating potential effects of MFAS exposure on social interactions and group composition is only possible because of these developments.

- Satellite tag settings we employed continued to prove very effective in reducing gaps in behavioral data. Further, we increasingly employed programming strategies that provided greatly enhanced resolution in dive data during specified periods. There are trade-offs in these decisions, however, including the fact that these approaches result in a limited period in which dive data are received. This was strategically determined based on anticipated Navy ship availability, which was effective in several conditions and not so in others.

- Multiple papers were published, submitted for review, or are in progress. These have focused on aspects of baseline behavior and methodological advances, including tag settings and RL modeling methods, which have both major implications and improvements in our underlying data and analyses but also are directly contributing to other Navy-funded efforts.

- Our detailed analyses of horizontal avoidance, disruption of foraging behavior, and modification of social interactions are ongoing, but we have begun to develop integrated response analyses for several publications, focusing initially on the simulated MFAS CEEs, given that substantially more data are needed and expected using real ship MFAS CEEs.

- As discussed above (3.2.2), responses observed in 2019 CEEs were among the clearest and strongest documented within some individuals.

4.2 Recommendations for 2020

- We recommend that the modified and improved field methods concentrating on fewer CEEs with more tagged individuals developed for 2019 be continued for CEEs in focused periods for both species. Of greatest priority is to obtain additional operational Navy vessel CEEs for target RLs similar to those evoking strong responses in simulated MFAS CEEs.

- Cape Hatteras offers an excellent study site, with the potential to locate, tag, and track individuals of several species, including Cuvier's beaked whales, with an incredible 24 whales tagged in two years. Given that this species is of high priority to the Navy and the site offers a unique condition of being occasionally exposed to MFAS but not being in the heart of a training range like other areas in the Bahamas, California, and Hawaii (and thus subject to criticisms of the generalizability of the data by testing habituated animals), the study site should certainly be maintained.

- Beaked whales should be maintained as a high priority species for tagging and CEEs, as conditions allow. Where possible, additional deployments of tags of both types on multiple individuals within the same species group should be tagged. Repeat sightings to confirm surface locations, obtain satellite tag data, and obtain photo ID should be sustained. Photos obtained should continue to be coordinated with other Navy-funded efforts (e.g., Waples and Read, 2020).

- Navy ship coordination should consider identification of potential windows of coordination with BRS efforts, an informed evaluation of which kinds of scheduled operations and other aspects of ship schedules are most likely to result in successful coordination, and then increased coordination effort to see that highest likelihood vessels are ultimately available.

- Duke has recently acquired a new fast-catamaran style research platform that could offer a superior platform of operation and coordination for offshore operations. Whether and how this platform could be used and would improve logistical operations (e.g., by being able to house a portion of the research team offshore rather than running in and out) should be explored. This will likely augment and interface with the charter boat and RHIB configuration used previously as opposed to completely replacing it.

- The combination of satellite tags (with series settings for beaked whales) and DTAG deployments should be maintained, with additional effort to simultaneously deploy DTAGs within groups with satellite tagged individuals.

- Based on the subjectively obvious responses observed in some focal beaked whales in 2019 at the higher RLs, no further escalation in target RLs are recommended, at least for beaked whales.

- Extensive planning and coordination discussions among the team and in coordination with the Navy will continue to be required, given the complexity and magnitude of logistical planning, field effort, and many simultaneous ongoing analyses.

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