Spatial Use by Cuvier's Beaked Whales and Short-finned Pilot Whales Satellite Tagged off Cape Hatteras, North Carolina:

2017 Annual Progress Report

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Cuvier's beaked whale (*Ziphius cavirostris*) off Cape Hatteras. Photographed by Andrew J. Read, Duke University, taken under NOAA Scientific Permit No. 14809 (Douglas Nowacek) and NOAA General Authorization Letter of Confirmation 19903 held by Duke University.

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Acronyms and Abbreviations

BRS	Behavioral Response Study
CEE	Controlled Exposure Experiment
CRC	Cascadia Research Collective
km	kilometer(s)
km^2	square kilometer(s)
LIMPET	Low-Impact Minimally Percutaneous External-electronics Transmitter
m	meter(s)
min	minute(s)
photo-ID	photo-identification
SD	standard deviation
sec	second(s)
U.S.	United States

1. Introduction

In 2014 a collaborative study between Cascadia Research Collective (CRC) and Duke University was initiated off the coast of Cape Hatteras, North Carolina, to examine the spatial use and diving behavior of a number of species of odontocetes using remotely deployed Low-Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) satellite tags. This work builds upon and complements longer-term studies of movements and site fidelity of both Cuvier's beaked whales (*Ziphius cavirostris*) and short-finned pilot whales (*Globicephala macrorhynchus*) off the North Carolina coast using photo-identification (photo-ID) (Swaim et al. 2014, Foley et al. 2015b, 2016, 2017a). While the primary focus has been on Cuvier's beaked whales and short-finned pilot whales, in the first three years a number of other species have been tagged as well. From 2014 through 2016, satellite-tag data were obtained from 70 individuals of 7 species: 15 Cuvier's beaked whales, 40 short-finned pilot whales, 10 common bottlenose dolphins (*Tursiops truncatus*), 2 common dolphins (*Delphinus delphis*), 1 Risso's dolphin (*Grampus griseus*), 1 Clymene dolphin (*Stenella clymene*), and 1 sperm whale (*Physeter microcephalus*), ranging over periods from 1.3 to 354 days (Baird et al. 2015, 2016, 2017; Foley et al. 2015a; Thorne et al. 2017).

In 2017, additional field efforts were undertaken focusing on the two primary species in May, August, and September as part of the Atlantic Behavioral Response Study (BRS), a collaborative effort between Duke University, Southall Environmental Associates, the University of St. Andrews, and CRC. Satellite tags were deployed on both Cuvier's beaked whales and short-finned pilot whales in each of the three periods, prior to scheduled controlled exposure experiments (CEEs), although CEEs were only undertaken in August and September 2017. Given the CEEs and their potential influence on small-scale movements and diving behavior, this report summarizes results from satellite tagging, focusing on large-scale spatial use by tagged individuals as well as diving behavior prior to the CEEs. Detailed analyses of small-scale movements and diving behavior in relation to the CEEs can be found in Southall et al. 2018.

2. Methods

During the 2017 field efforts, location and depth SPLASH10 tags (produced by Wildlife Computers, Redmond, Washington) with the extended-depth-range option were used in the LIMPET configuration (Andrews et al. 2008). Given the unique requirements of the BRS, the tags were programmed differently than in previous efforts, with continuous information on deep foraging dives prioritized over maximizing the longevity of the tag battery or obtaining information on all (i.e., both deep and shallow) dives. The unique tag programming for each species was based on the average number of respirations per hour from previous tagging studies, and how this affects the ability to transmit dive data to the satellite. Tags deployed on both species were set to transmit every day, 21 hours per day for Cuvier's beaked whales and 17 hours per day for short-finned pilot whales, with a theoretical battery life of 37 and 25 days, respectively. These tags were programmed to provide dive statistics (e.g., start and end time, maximum depth, and duration) for any dives that exceeded predetermined species-specific depth or time thresholds. For the purposes of the 2017 field effort, the thresholds were defined as: Cuvier's beaked whale: 150 meters (m) and 33 minutes (min), and short-finned pilot whales:

75 m and 30 seconds (sec). These thresholds are deeper and, in the case of Cuvier's beaked whales longer, than in previous years, to reduce gaps in the behavioral record, as tags were being deployed prior to CEEs and deep foraging dives were the primary parameter of interest. Prior to each field effort, satellite pass predictions were executed using the Argos website to determine the best hours of the day for transmissions given satellite overpasses for the approximate 2-month period starting at the beginning of each deployment period.

Tags were remotely deployed using a DAN-INJECT JM 25 pneumatic projector (DanWild LLC, Austin, Texas), and were attached with two 6.8-centimeter surgical-grade titanium darts with backward-facing petals. The target area for tag attachment was the dorsal fin or base of the fin. In some encounters, after deploying the first tag in a group of Cuvier's beaked whales, an Argos Goniometer[1] (CLS America, Lanham, MD) was used to help re-locate the tagged individual after a long dive, allowing us to deploy additional tags on other members of the group.

Photographs were taken of target and companion individuals prior to and at the time of tagging for contribution to the long-term Duke University photo-ID catalogs. Age class (i.e., adult, sub-adult) and sex were noted in the field based on body size and morphology, and photographs were also used to confirm sex for Cuvier's beaked whales based on the presence of erupted teeth and scarring patterns (see McSweeney et al. 2007).

Locations of tagged individuals were estimated by the Argos system using the least-squares method and were assessed for plausibility using the Douglas Argos-filter version 8.5 to remove unrealistic locations, following protocols previously used (Schorr et al. 2009; Baird et al. 2010). Filtered location data were processed with R 3.2.2 (packages *sp* 1.2-2, *rgeos* 0.3-15, *raster* 2.5-2) to determine depth, distance from shore, and distance from the 200-m isobath. Depth values were generated from 3 arc-second data from the United States (U.S.) Coastal Relief Model for regions off the U.S. Atlantic coast (Northeast Atlantic, Southeast Atlantic) where available, and with 30 arc-second data from the General Bathymetric Chart of the Oceans 2014 (www.gebco.net/) in other areas. The 200-m isobath dataset used was from the "Data Basin" on-line mapping tool (databasin.org). Given the inherent lack of precision associated with Argos-derived locations, combined with the steep continental shelf-edge and slope topography, we report median and maximum depths of tagged animal locations. Maximum depths are less likely to be influenced by Argos location quality or the steep slope given that the deepest locations of most tagged individuals were well seaward of the continental shelf (see **Section 3, Results**).

Probability-density maps were generated using all filtered satellite-tag data for all individuals of each species, with data from all four years (2014–2017) incorporated. Kernel-density polygons corresponding to the 50, 95, and 99 percent densities were generated using the R package *adehabitatHR* version 0.4.11[2]. Bandwidth (h) values used were h=41831 for short-finned pilot whales and h=10742 for Cuvier's beaked whales. Polygons were plotted in Google Earth Pro version 7.1.2.2041.

When more than one tag was deployed on the same species during the same time periods, we assessed whether individuals were acting in concert during the period of overlap by measuring

[1] https://www.clsamerica.com/argos-goniometer
[2] https://www.movebank.org/node/14620

the straight-line distances between pairs of individuals when locations were obtained during a single satellite overpass (approximately 10 min). We used both the mean distances between pairs of individuals and the maximum distance between pairs to assess whether individuals were acting independently, following protocols described by Schorr et al. (2009) and Baird et al. (2010). For Cuvier's beaked whales, given the relatively low quality of Argos locations received from this species, individuals were thought to be remaining associated if the mean distance apart was less than 15 kilometers (km) and the maximum distance apart was less than 30 km. For short-finned pilot whales, since a greater proportion of high-quality Argos locations are obtained (cf. Costa et al. 2010), we used mean distances apart of 5 km as a cutoff for individuals remaining associated.

To assess whether potential pressure transducer issues may have influenced dive depth recordings, we examined the status file from each tag deployment. The depth value noted in a status message represents the last value recorded immediately prior to the tag transmitting, so it is typically within 1 to 2 m of zero, although in extreme cases of linear drift, values within 10 m of zero have been observed and may be considered to be within an acceptable range (R.D. Andrews, pers. comm.). We considered cases where more than one value exceeded +/- 10 m as indicative of potential transducer failure issues. It is not possible to determine whether such transducer issues reflect a simple baseline shift, which should be corrected with the zero offset correction feature of the tags, or represent a change in the linearity of depth readings and therefore prevent an accurate estimate of the actual dive depth. In addition, the manufacturer of the pressure transducers notes that the transducers may fail if subject to depths exceeding 3,000 m, so for any tags with depths exceeding this we also assessed minimum rates of ascent and descent, by dividing twice the dive depth by the dive duration. Rates of descent and ascent for deep (>800 m) dives from time-depth recorder deployments on Cuvier's beaked whales are less than 2 m/sec and 1 m/sec, respectively (Baird et al. 2008), so we used an average of 2 m/sec as an indicator of pressure transducer issues. We also compared the estimated bottom depth (from the analyses noted above) for locations available spanning dive depths in excess of 3,000 m to determine whether the tagged individuals were in areas deep enough to allow for such deep dives.

For those tags with potential pressure transducer issues, we only present dive data for the period prior to evidence of the potential issues. In addition, since a number of the tagged individuals were subjects of the controlled exposure experiments (see Southall et al. 2018), we only present dive data prior to CEEs.

3. Results

Field efforts were undertaken for tagging in May, August, and September 2017. Twenty-six tags were deployed, and one tag was lost during a deployment attempt (**Table 1**). Of the 14 tags deployed on Cuvier's beaked whales, 12 were deployed in the dorsal fin or at the base of the dorsal fin, and two were deployed below the base of the fin. Tag attachment durations (based on the time of the last locations received) ranged from 12.1 to 52.9 days, with the median attachment duration (39.5 days) exceeding the expected battery life (37 days). Of the 12 tags deployed on short-finned pilot whales, all were deployed on the fin or at the base of the fin. One

tag (GmTag179) transmitted for less than one day, but the others transmitted from 14.3 to 32.6 days, with the median (28.9 days) exceeding the expected battery life (25 days).

Tags were deployed on more than one individual in the same encounter on a number of different days (**Table 2, 3**). For Cuvier's beaked whales, information on distance between individuals, combined with synchrony in dive behavior (unpublished data), indicated that the three adult males tagged together in a group of seven individuals in May 2017 (ZcTag054, ZcTag055, and ZcTag056) remained associated for an extended period. Two other males tagged together in the same group (ZcTag067 and ZcTag068) had evidence of synchronous dive behavior (unpublished data) for six days. While average distances apart were quite large over the entire period of tag overlap (**Table 4**), based on pairs of locations received in the first 10 days the individuals were likely associated for that period (range = 8.9 to 11.8 km).

Movement patterns of the Cuvier's beaked whales varied, with 11 of the 14 individuals remaining within 100 km of the location where they were tagged (**Table 4).** Most of the tagged individuals remained in small areas on the continental slope near the tagging locations (**Figures 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, and 14; Table 5**), with only occasional movements off the slope (e.g., **Figures 6, 8, 10, and 14**). Three individuals (ZcTag057, ZcTag066, and ZcTag067) showed greater ranges of movements than those previously documented. One individual moved as far as 260 km offshore (ZcTag057; **Figure 4, Table 5**), one moved 288 km along the shelf break to the south of the tagging location (off the North Carolina/South Carolina border) (ZcTag066, **Figure 12, Table 4**), and one moved 236 km along the shelf break north of the tagging location (off Maryland) (ZcTag067, **Figure 13**). Both ZcTag066 and ZcTag067 were subjects of a CEE, but the timing of these large-scale movements appeared unrelated to the CEE (i.e., the individuals left the Hatteras area more than two weeks after the CEE). These three individuals extended the known range of individuals tagged off Hatteras to the north, south, and offshore, when compared to individuals tagged in previous years (**Figures 15, 16**). A probability-density distribution from tag data obtained from all four years suggests that the core range for individuals tagged off the coast of Cape Hatteras is relatively small (50 percent core area = 1,682 square kilometers [km^2]; **Figure 17**).

While 14 location-depth satellite tags were deployed on Cuvier's beaked whales, four tags had pressure transducer issues partway through the deployments. Repeated transducer readings exceeding 10 m started for ZcTag057 on 15 June 2017, for ZcTag066 after 29 September 2017, and for ZcTag067 starting on 8 September 2017. For ZcTag055, the combined ascent/descent rates for dives through 18 June 2017 were within the normal range (mean = 0.85 m/sec, max = 1.28 m/sec), but subsequent dive data indicated a transducer failure, with multiple rates exceeding 2 m/sec (mean = 1.70 m/sec, max = 2.39 m/sec). The maximum dive depths recorded during this period of anomalously high ascent/descent rates were 3,759.5 m. While there were few locations of the tagged animal available for the periods with dives >3,000 m, bottom depths from these locations ranged from 1,901 to 2,308 m, providing support for the use of anomalous ascent/descent rates in identifying potential pressure transducer issues. For these four tags, dive data were not considered after the dates of onset of transducer issues. One additional tag had one dive >3,000 m (ZcTag060, max = 3,183.5 m, occurring in between the two CEEs), but combined ascent/descent rates for this dive were in the normal range (1.19

m/sec) and bottom depths at all five locations obtained that day exceeded 3,000 m (max = 3,218 m), suggesting that the dive depth was consistent with proper transducer function.

After excluding data once there was evidence of transducer failure, as well as periods post-CEEs, 205 days of behavior data were obtained from Cuvier's beaked whale tags. Programming tags to only record (and thus transmit) deep and long dives resulted in few gaps in the behavior data. Behavior data coverage ranged from 34.5 to 100 percent of the period (median = 100 percent; **Table 6**).

Maximum dive depths documented for individual Cuvier's beaked whales that either were not subjects of the CEEs or for individuals prior to CEE exposure were between 1,743 and 2,543 m, and maximum dive durations ranged from 65 to 114 min (**Table 6**). Median depths at locations of these tagged individuals ranged from 1,222 to 2,440 m (maximum = 2,363–3,497 m; **Table 5**), suggesting that many of the dives were likely to, or close to, the sea floor.

Twelve satellite tags were deployed on short-finned pilot whales (**Table 1**). The tags were deployed during seven different encounters. The pairs of individuals in two of these encounters (GmTag173 & GmTag174, and GmTag181 & GmTag182) acted independently, while those tagged together in other encounters appeared to remain closely associated during the period of tag overlap (**Table 3)**.

Mean and maximum distances moved varied considerably among individual short-finned pilot whales (**Table 4)**, as did the typical depths used (**Table 5**), suggesting considerable variability in movement patterns and habitat use among short-finned pilot whale groups off the U.S. Atlantic coast. Several individuals remained strongly associated with the shelf edge and shelf break over the entire duration of tag attachment (GmTag172 through GmTag177, **Figures 18-23**), while others had excursions off the shelf (GmTag178 and GmTag180, **Figures 24, 25,** GmTag182, **Figure 27**). Two individuals tagged on the same day in August 2017 but in different groups (GmTag181, **Figure 26**; GmTag183, **Figure 28**) initially spent most of their time seaward of the slope, before moving almost 900 km (GmTag181) and over 750 km (GmTag183) to the south. While the two tracks to the south were generally similar, the two whales moved south independently of each other, with GmTag181 leaving the Hatteras area on 9 September 2017 and GmTag182 leaving the area on 15 September 2017. These individuals moved into an area with a broad slope off northern Florida, overlapping an area where pilot whales tagged off Jacksonville, Florida in 2016 spent considerable time (**Figure 30**). The timing of movement of these individuals far to the south appeared to be unrelated to the CEEs.

A map showing combined track and location data from all short-finned pilot whales tagged off North Carolina in 2014 (*n*=17), 2015 (*n*=19), 2016 (*n*=5), and 2017 (n=11), as well as individuals tagged off Jacksonville, Florida, in 2016 (*n*=4) is shown in **Figure 30**. While the 99 percent probability-density based on all four years covers a broad area (794,680 km^2), ranging from Florida to New York and into Canadian and international waters, the 50 percent core range of these individuals is small (25,360 km^2; **Figure 31**) and centered off Cape Hatteras, North Carolina. It should be noted that the 95 and 99 percent probability polygons include considerable areas not known to be habitat for short-finned pilot whales (i.e., shallow-water shelf and even some estuarine habitats). This inclusion of shallow shelf and estuarine habitats in the probability density maps is an artifact of the preference for this species to use the very

steep slope waters adjacent to a broad shelf area along much of the east coast of the United States, combined with uncertainty associated with Argos locations and the bandwidth used in the probability density calculations.

4. Discussion

This study provides additional information on the movements and habitat use of two species of odontocetes along the eastern coast of the United States building upon work begun in 2014 (Baird et al. 2015, 2016, 2017). The combined efforts represent the first dedicated satellite tagging on free-ranging medium-sized odontocetes off the U.S. Atlantic coast. Tag deployments have provided additional long-distance movement information for Cuvier's beaked whales off the U.S. Atlantic coast, as well as long-distance movements of short-finned pilot whales in the area, information that prior to 2014 had only been obtained from previously stranded individuals released off Florida (Wells et al. 2013). Importantly, tag deployments of both species have also allowed for examining behavioral responses as part of the Atlantic BRS (Southall et al. 2018).

With 14 Cuvier's beaked whales satellite tagged in 2017, the sample size of movement data for this species off the U.S. east coast has been effectively doubled, and the combined sample of location data now represents 1,150 days of locations, the largest collection of satellite-tag data for this species anywhere in the world. The large number of tags deployed in 2017 reflects in part the high density of Cuvier's beaked whales off Cape Hatteras (McLellan et al. in press). The primary factor limiting an even greater number of tag deployments on Cuvier's beaked whales off Cape Hatteras is suitable sea conditions for finding, approaching, and tagging this species.

While most of the tagged Cuvier's beaked whales remained in or near the core area of the animals tagged in previous years, staying near the continental slope off Cape Hatteras, individuals tagged in 2017 extended the known range of this population to the north (**Figure 13**), to the south (**Figure 12**), and offshore (**Figure 4**). While these longer-distance movements were all from tags that transmitted for long periods (38 to 49 days, **Table 4**), they were similar in attachment durations (40 to 53 days) to tags on individuals that remained closely associated with the core area off Cape Hatteras (e.g., ZcTag055, ZcTag064, ZcTag068). Consequently, they reflect variability in movement patterns more than the influence of attachment duration.

While the photo-ID work suggests that short-finned pilot whales display a high degree of site fidelity off Cape Hatteras, satellite tagging demonstrates that these animals cover a significant range north and south along the continental slope, and occasionally into offshore waters (**Figure 24**). Importantly, in 2017 individuals moved far to the south of Cape Hatteras, to an area off northern Florida where pilot whales tagged off Jacksonville in 2016 spent considerable time (Foley et al. 2017b) (**Figures 26, 28**). The considerable variability in movement patterns and habitat use likely reflects patterns that vary by social group and by responses to ephemeral oceanographic conditions (Thorne et al. 2017). Understanding site fidelity and association patterns determined through photo-ID will help in interpreting such variability.

Even though short-finned pilot whales cover a much larger range, their core range (**Figure 31**) appears to be centered in the same area as Cuvier's beaked whales (**Figure 17**), although it is approximately 15 times larger than that of Cuvier's beaked whales. Even though more study is

necessary to determine the structure and habitat use of these stocks, the importance of the continental slope to the east of Cape Hatteras (North Carolina) is becoming increasingly apparent as sample sizes increase.

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Figures

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Figure 1. All filtered locations of Cuvier's beaked whale ZcTag054 over the 18.1-day tag-attachment duration, 10–28 May 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. ZcTag054 was tagged in the same encounter as ZcTag055 (Figure 2) and ZcTag056 (Figure 3).

Figure 2. All filtered locations of Cuvier's beaked whale ZcTag055 over the 52.9-day tag-attachment duration, 10 May–2 July 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. ZcTag055 was tagged in the same encounter as ZcTag054 (Figure 1) and ZcTag056 (Figure 3).

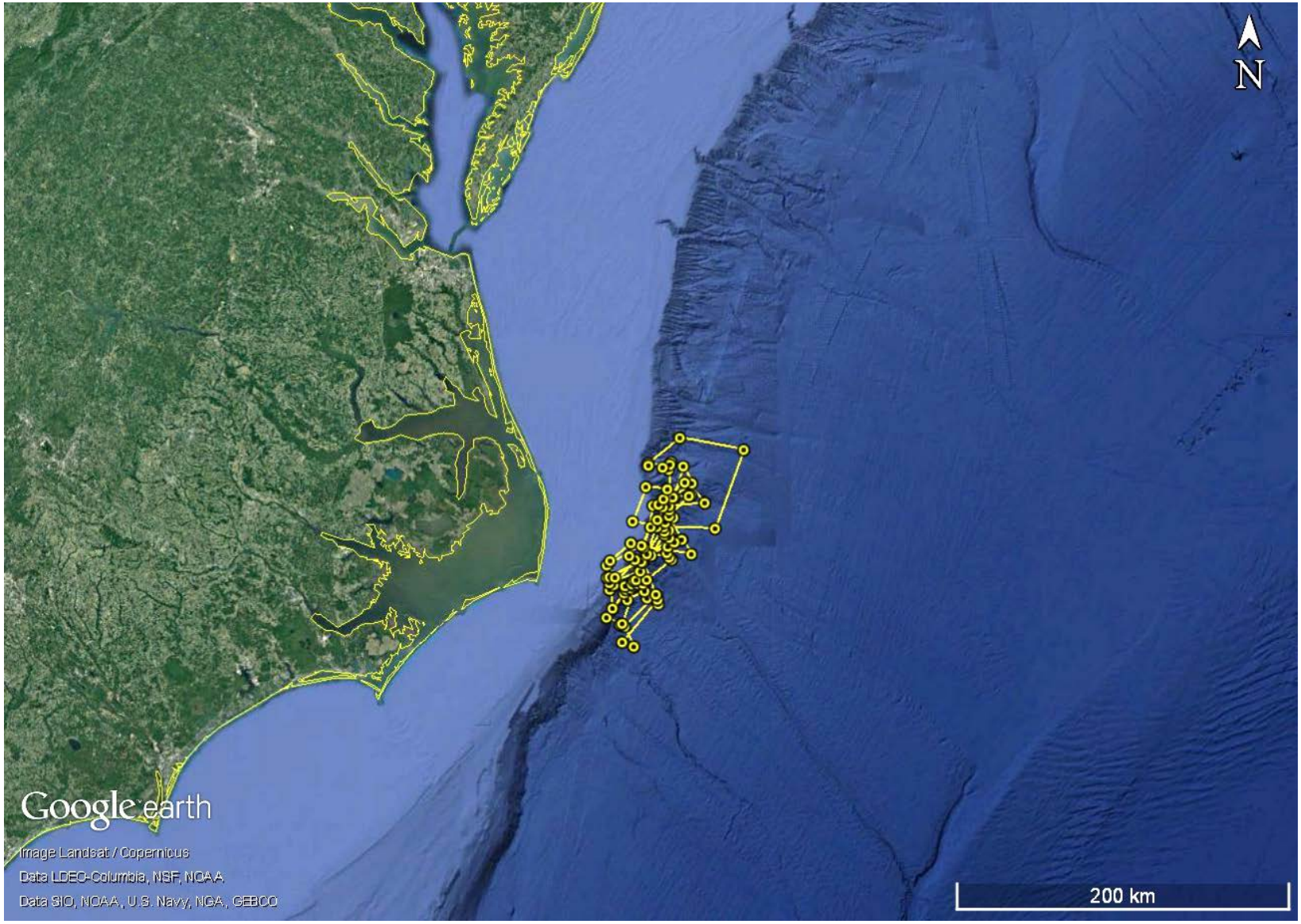

Figure 3. All filtered locations of Cuvier's beaked whale ZcTag056 over the 47.8-day tag-attachment duration, 10 May–27 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. ZcTag056 was tagged in the same encounter as ZcTag054 (Figure 1) and ZcTag055 (Figure 2).

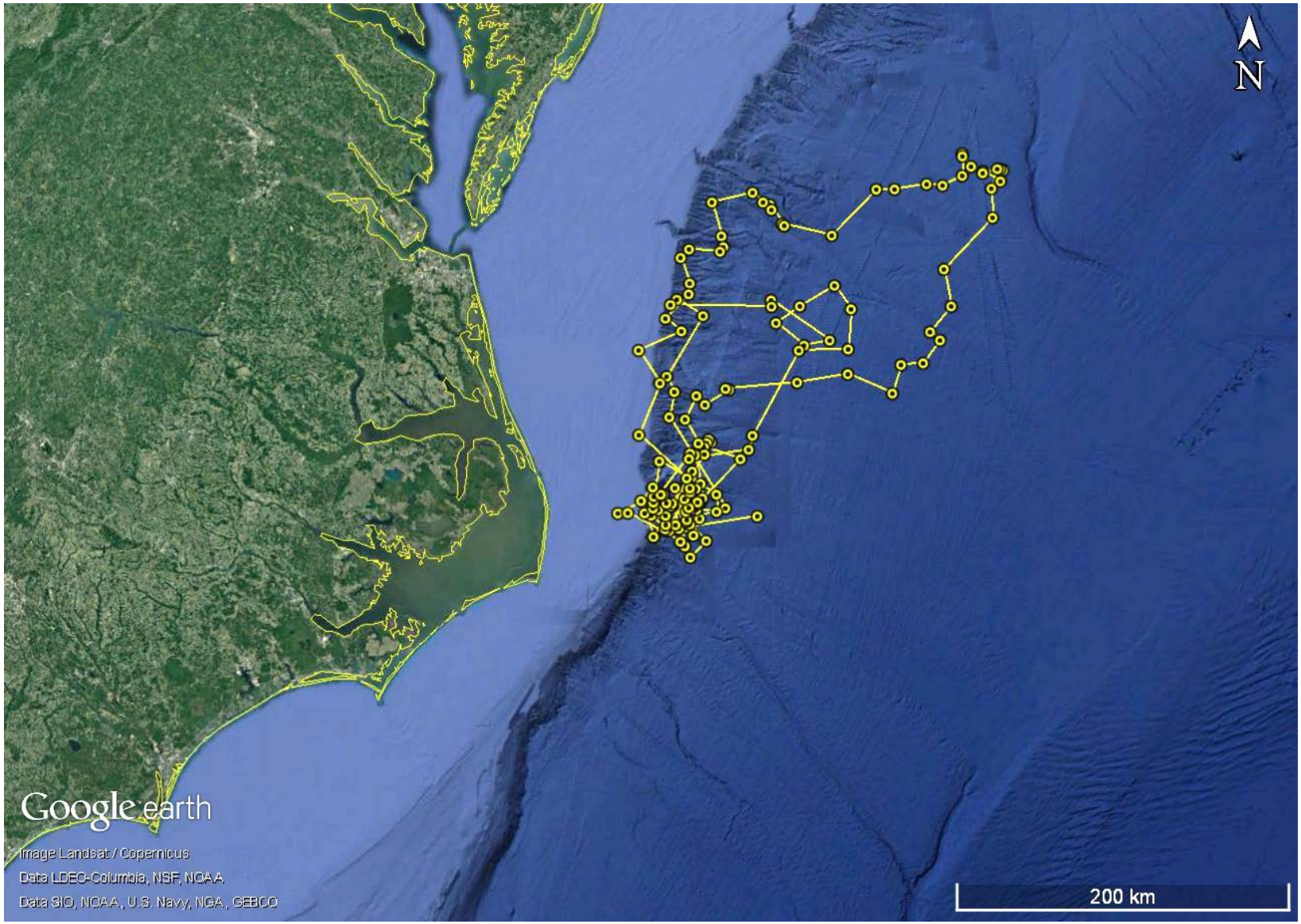

Figure 4. All filtered locations of Cuvier's beaked whale ZcTag057 over the 49.3-day tag-attachment duration, 16 May–5 July 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments.

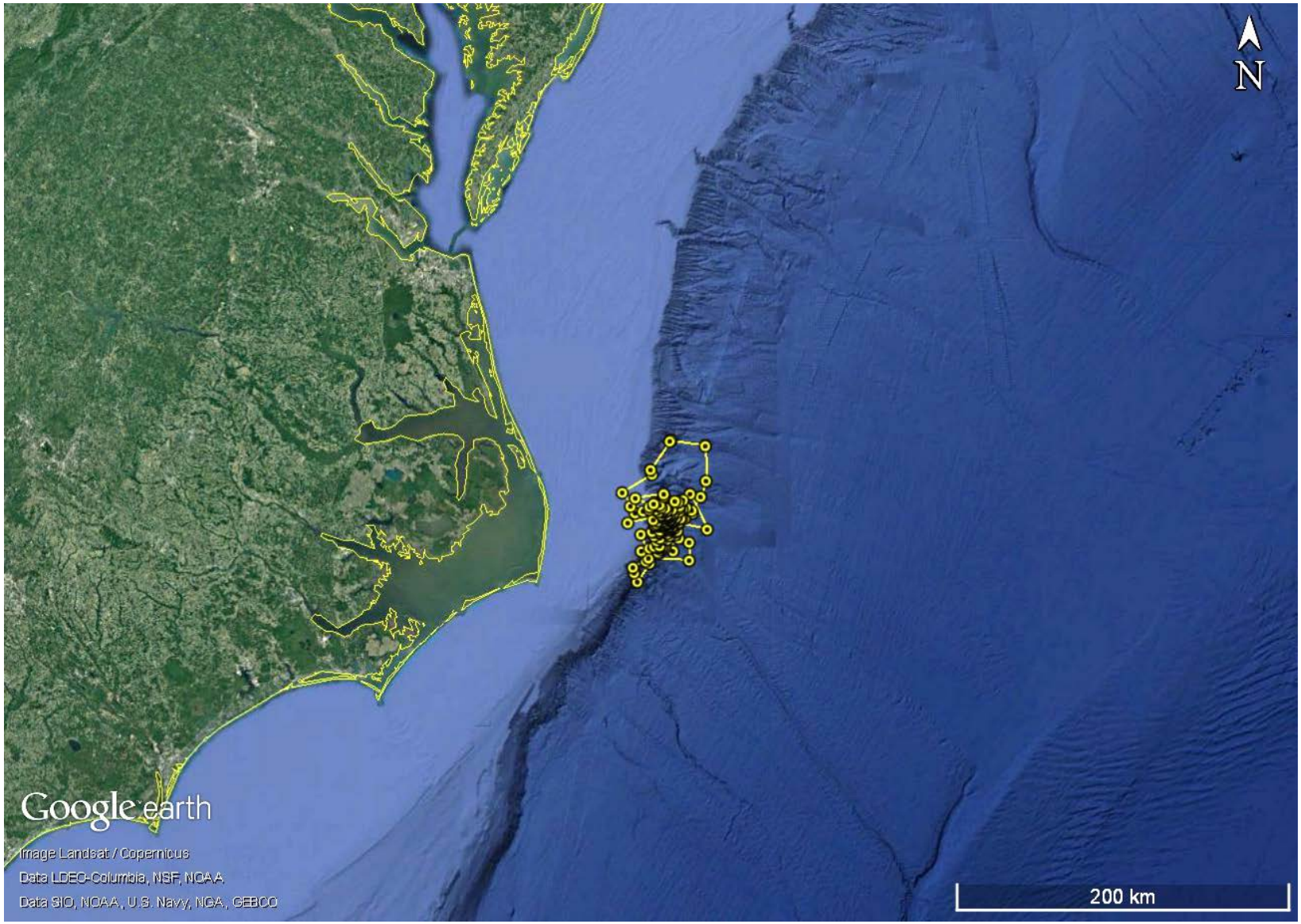

Figure 5. All filtered locations of Cuvier's beaked whale ZcTag058 over the 39.1-day tag-attachment duration, 16 May–24 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments.

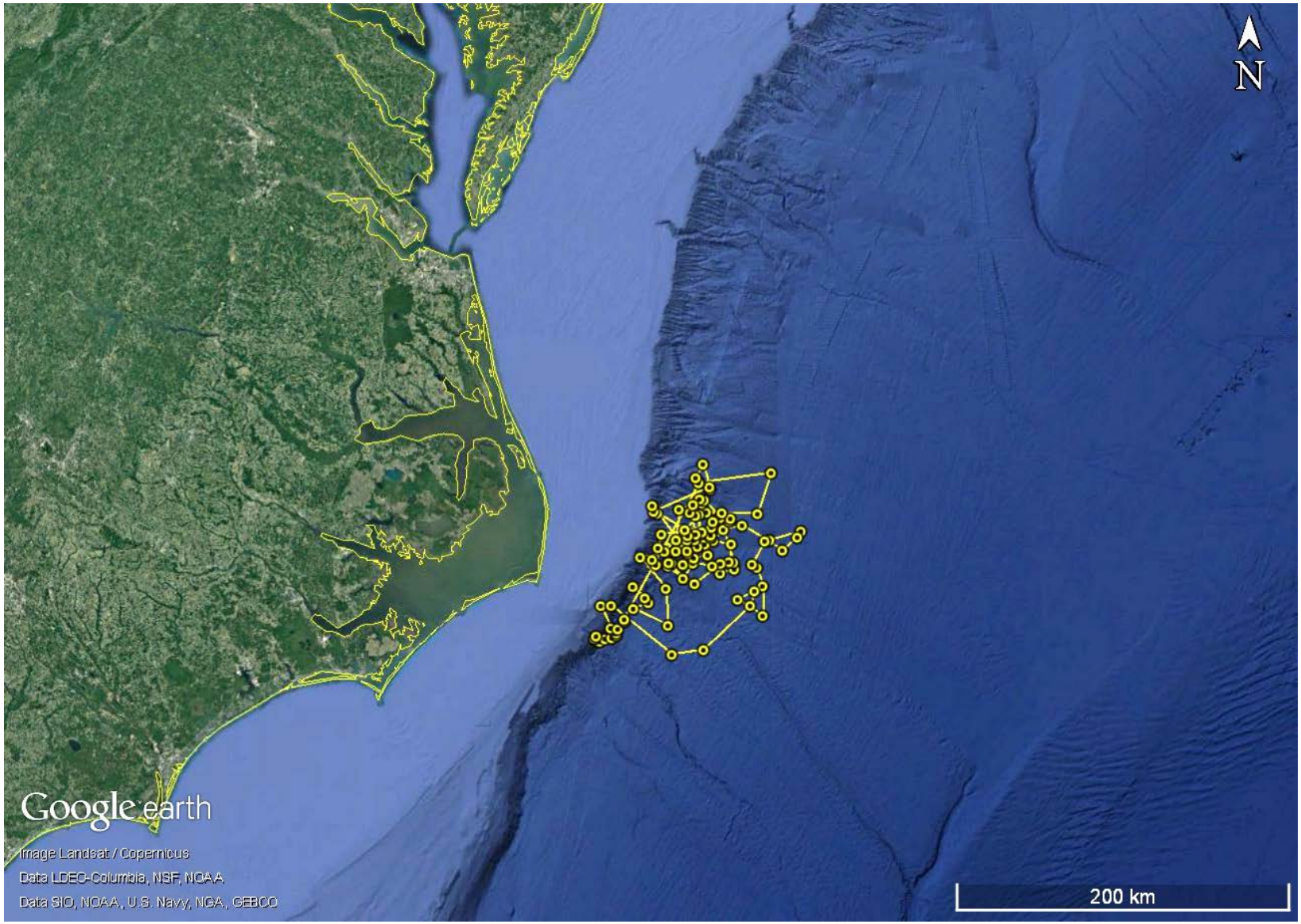

Figure 6. All filtered locations of Cuvier's beaked whale ZcTag060 over the 34.7-day tag-attachment duration, 17 August–21 September 2017, with consecutive locations joined by a line. This individual was a subject in both of the controlled exposure experiments (22 August and 12 September 2017). ZcTag060 was tagged in the same encounter as ZcTag061 (Figure 7).

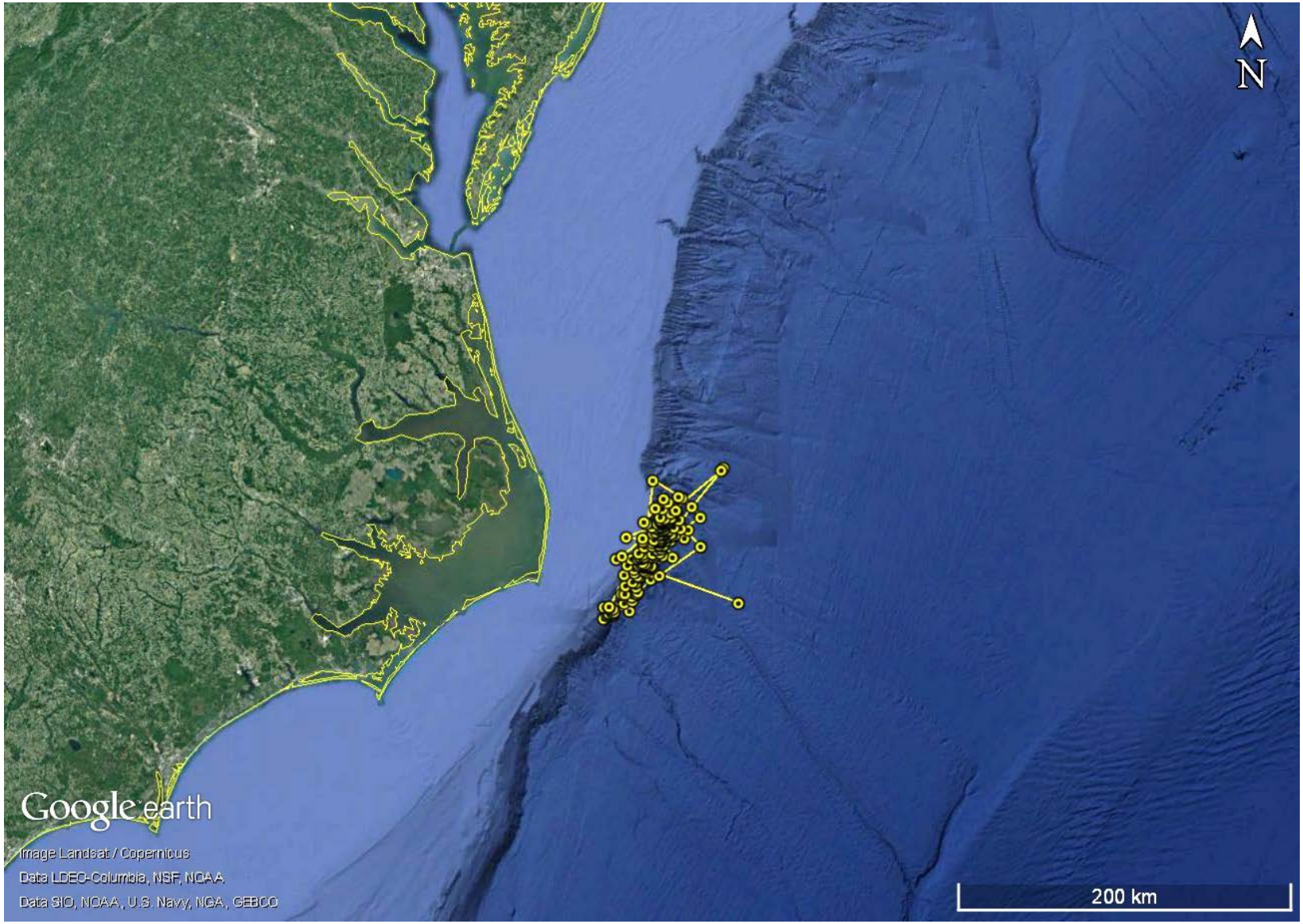

Figure 7. All filtered locations of Cuvier's beaked whale ZcTag061 over the 44.4-day tag-attachment duration, from 17 August–1 October 2017, with consecutive locations joined by a line. This individual was a subject in both of the controlled exposure experiments (22 August and 12 September 2017). ZcTag061 was tagged in the same encounter as ZcTag060 (Figure 6).

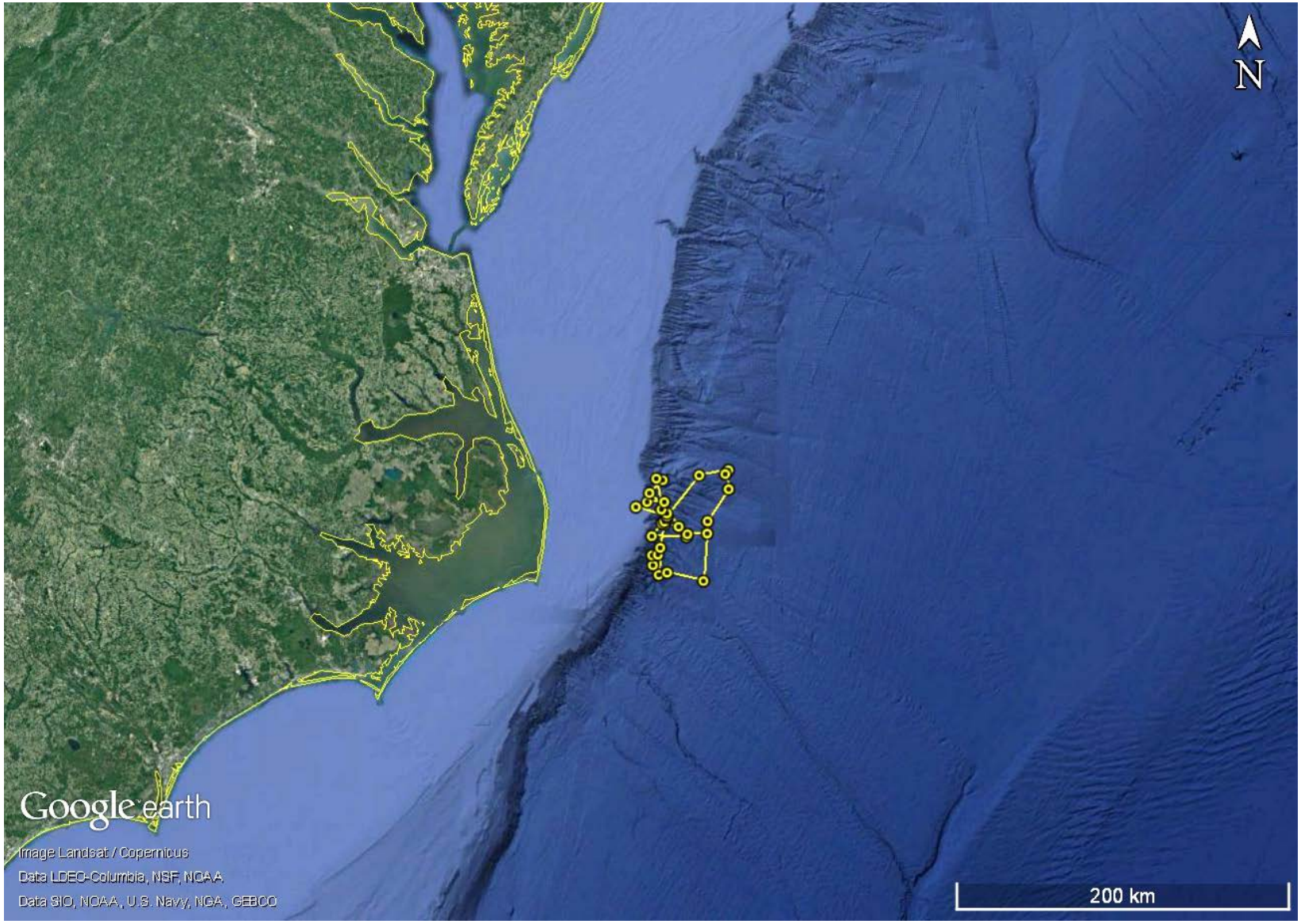

Figure 8. All filtered locations of a Cuvier's beaked whale ZcTag062 over the 12.2-day tag-attachment duration, 17–29 August 2017, with consecutive locations joined by a line. This individual was a subject in the first controlled exposure experiments, on 22 August 2017.

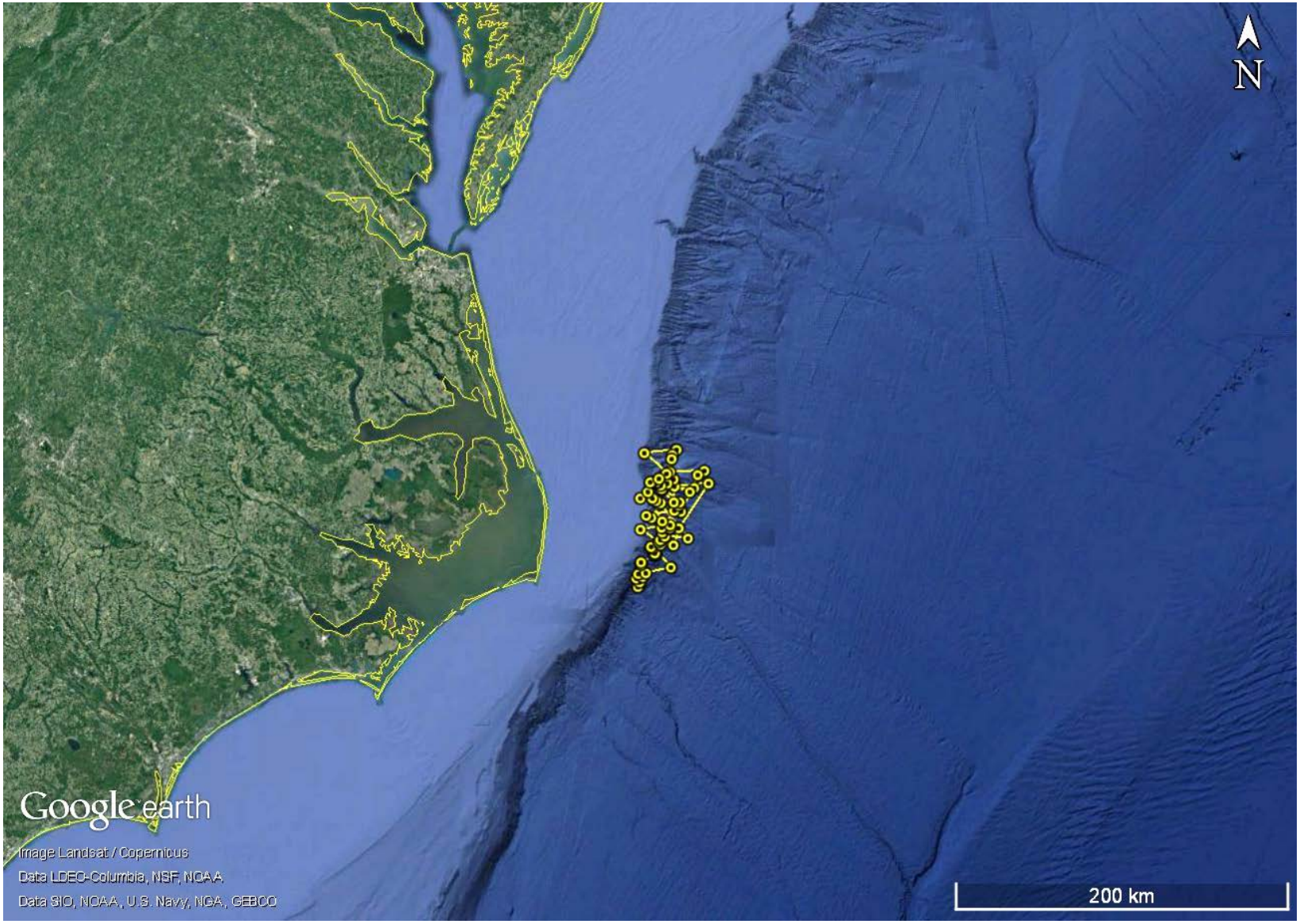

Figure 9. All filtered locations of Cuvier's beaked whale ZcTag063 over the 30.7-day tag-attachment duration, 20 August–20 September 2017, with consecutive locations joined by a line. This individual was a subject in both of the controlled exposure experiments (22 August and 12 September 2017). ZcTag063 was tagged in the same group as ZcTag064 (Figure 10).

Figure 10. All filtered locations of Cuvier's beaked whale ZcTag064 over the 49.6-day tag-attachment duration, 20 August–9 October 2017, with consecutive locations joined by a line. This individual was a subject in both of the controlled exposure experiments (22 August and 12 September 2017). ZcTag064 was tagged in the same group as ZcTag063 (Figure 9).

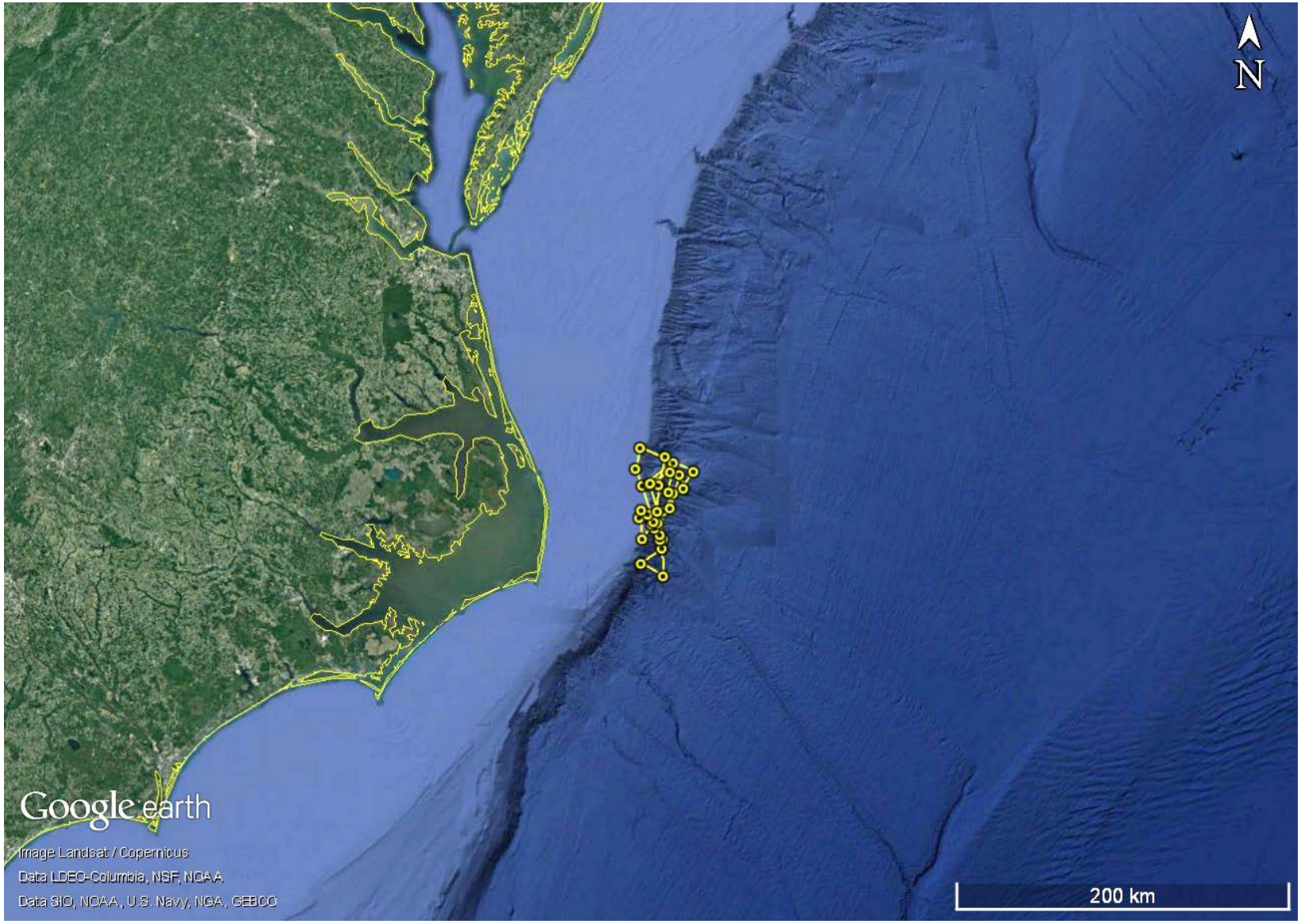

Figure 11. All filtered locations of Cuvier's beaked whale ZcTg065 over the 12.8-day tag-attachment duration, 22 August–4 September 2017, with consecutive locations joined by a line. This individual was a subject in the first controlled exposure experiment, on 22 August 2017.

Figure 12. All filtered locations of Cuvier's beaked whale ZcTag066 over the 38.4-day tag-attachment duration, 4 September–12 October 2017, with consecutive locations joined by a line. This individual was a subject in the second controlled exposure experiment, on 12 September 2017. The large-scale movement to the south did not begin until 1 October 2017.

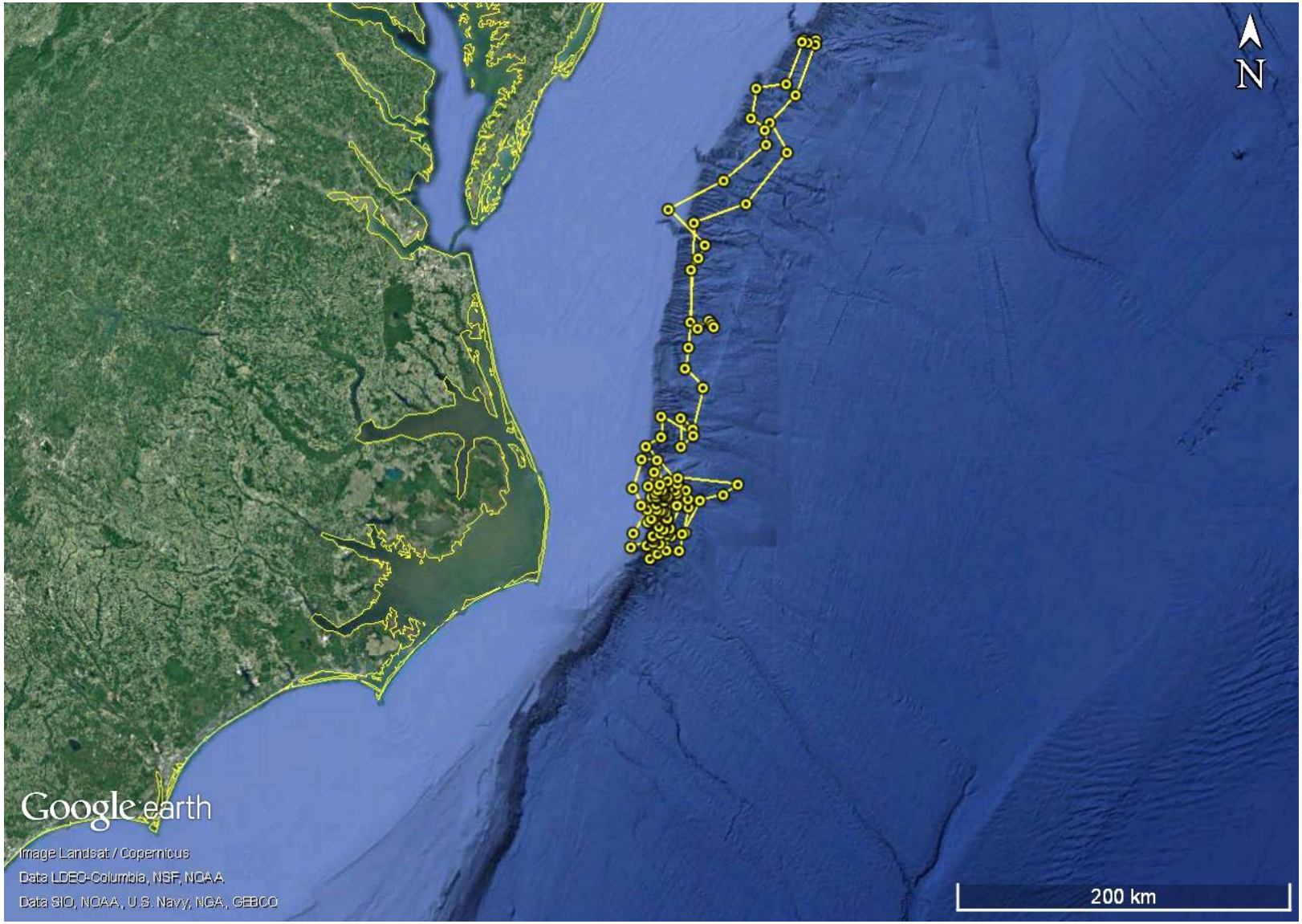

Figure 13. All filtered locations of Cuvier's beaked whale ZcTag067 over the 42.3-day tag-attachment duration, 4 September–17 October 2017, with consecutive locations joined by a line. This individual was a subject in the second controlled exposure experiment, on 12 September 2017. The large-scale movement to the north did not begin until 30 September 2017. ZcTag067 was tagged in the same group as ZcTag068 (Figure 14).

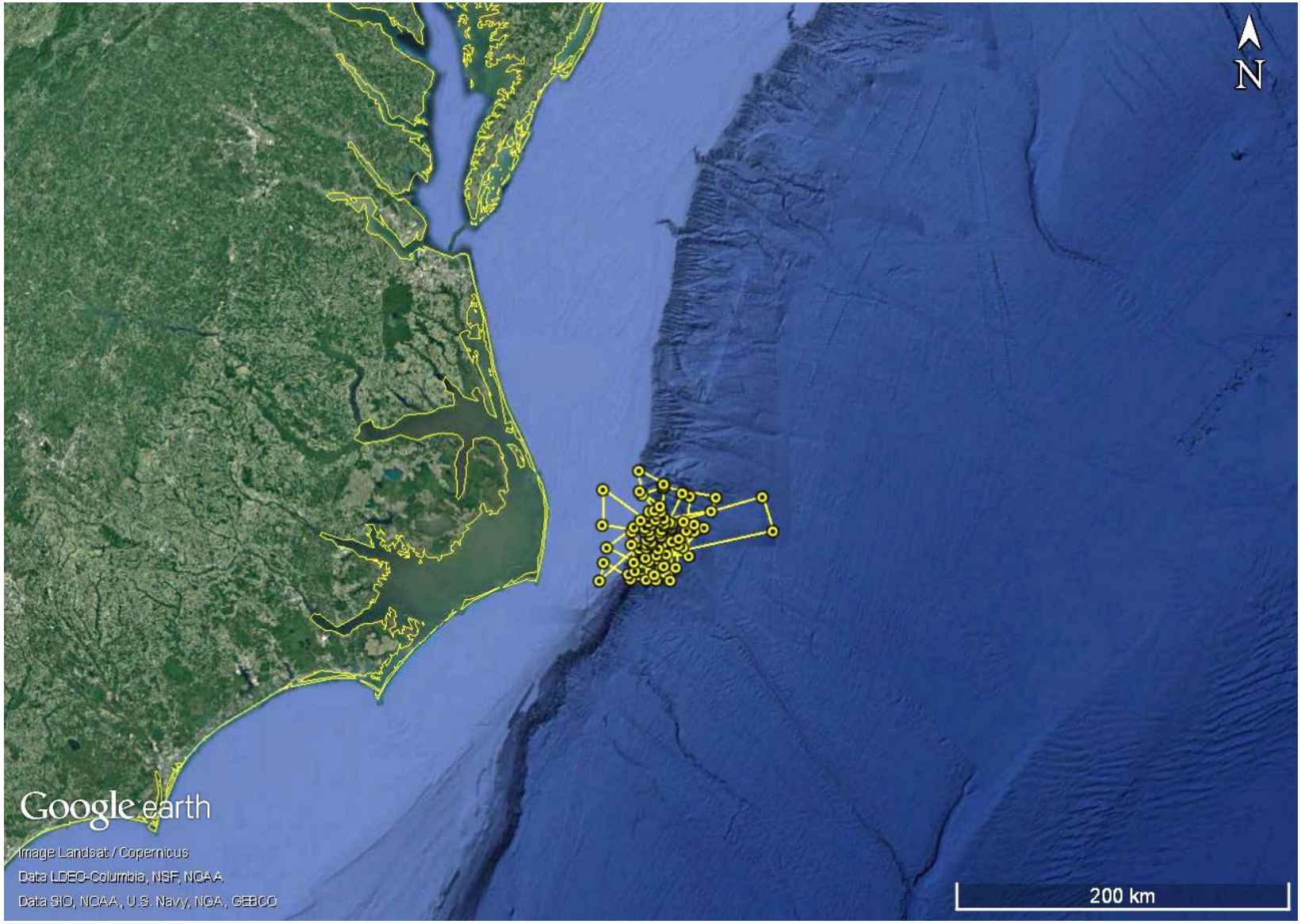

Figure 14. All filtered locations of Cuvier's beaked whale ZcTag068 over the 39.9-day tag-attachment duration, 4 September–14 October 2017, with consecutive locations joined by a line. This individual was a subject in the second controlled exposure experiment, on 12 September 2017. ZcTag068 was tagged in the same group as ZcTag067 (Figure 13).

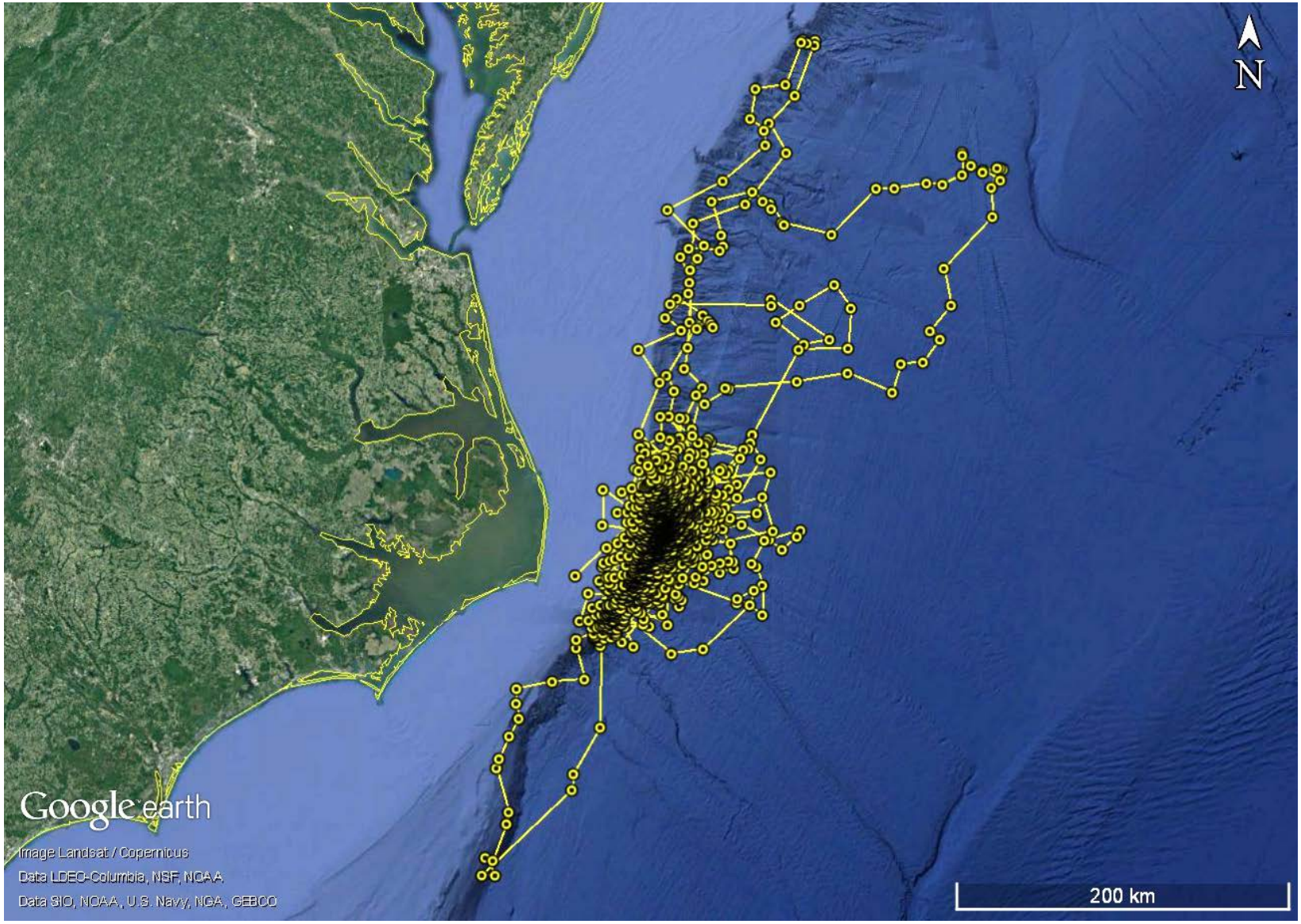

Figure 15. All filtered locations of Cuvier's beaked whales tagged in 2017 (*n*=14), with consecutive locations joined by a line.

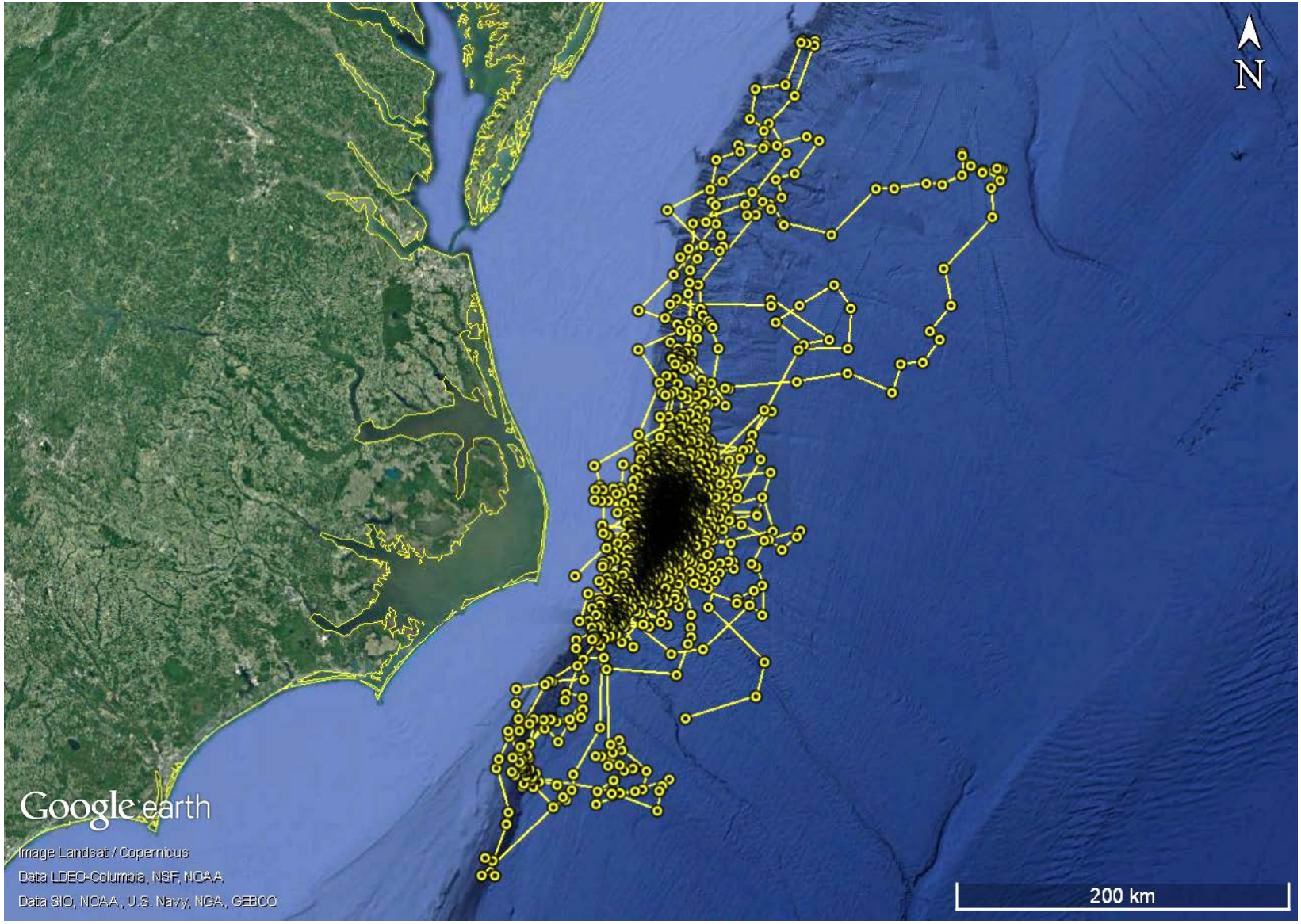

Figure 16. All filtered locations of Cuvier's beaked whales tagged in 2014 (*n*=3), 2015 (*n*=6), 2016 (*n*=6), and 2017 (*n*=14), with consecutive locations joined by a line.

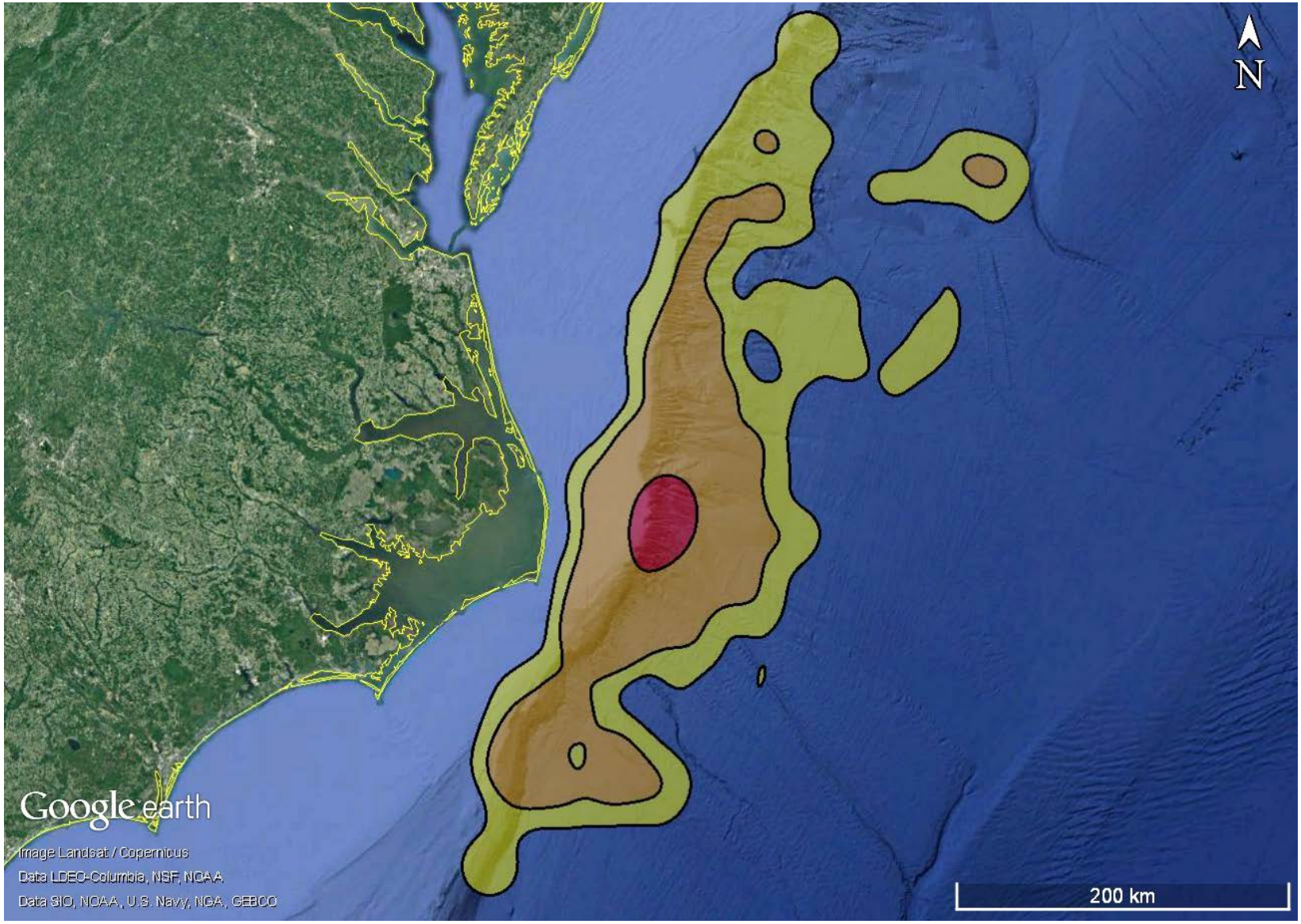

Figure 17. A probability-density representation of Cuvier's beaked whale location data from 29 individuals tagged off North Carolina in 2014 (*n*=3), 2015 (*n*=6), 2016 (*n*=6), and 2017 (*n*=14). The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95 percent polygon, and the yellow represents the 99 percent polygon.

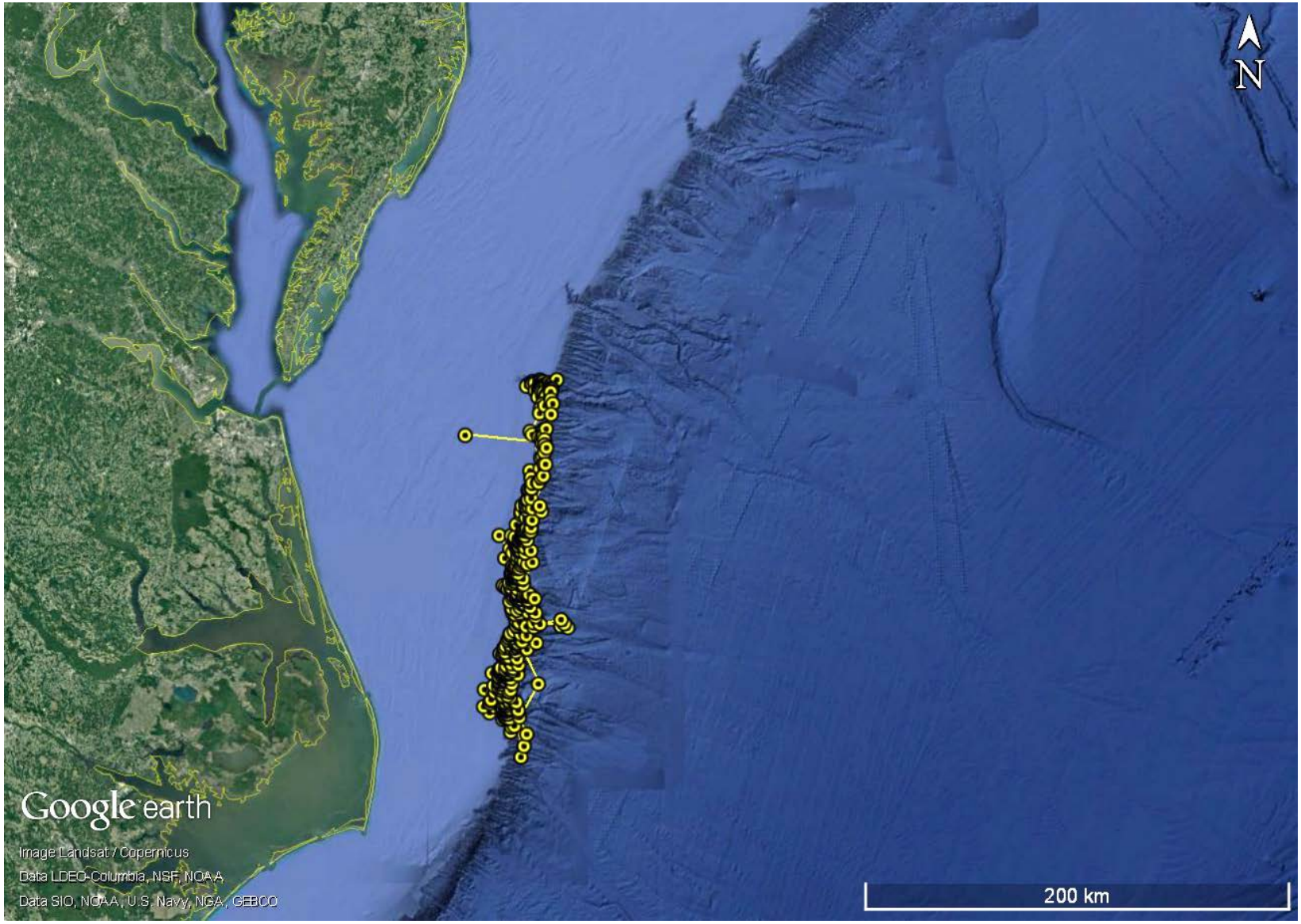

Figure 18. All filtered locations of short-finned pilot whale GmTag172 tagged off North Carolina over a 32.6-day period, 10 May–12 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments.

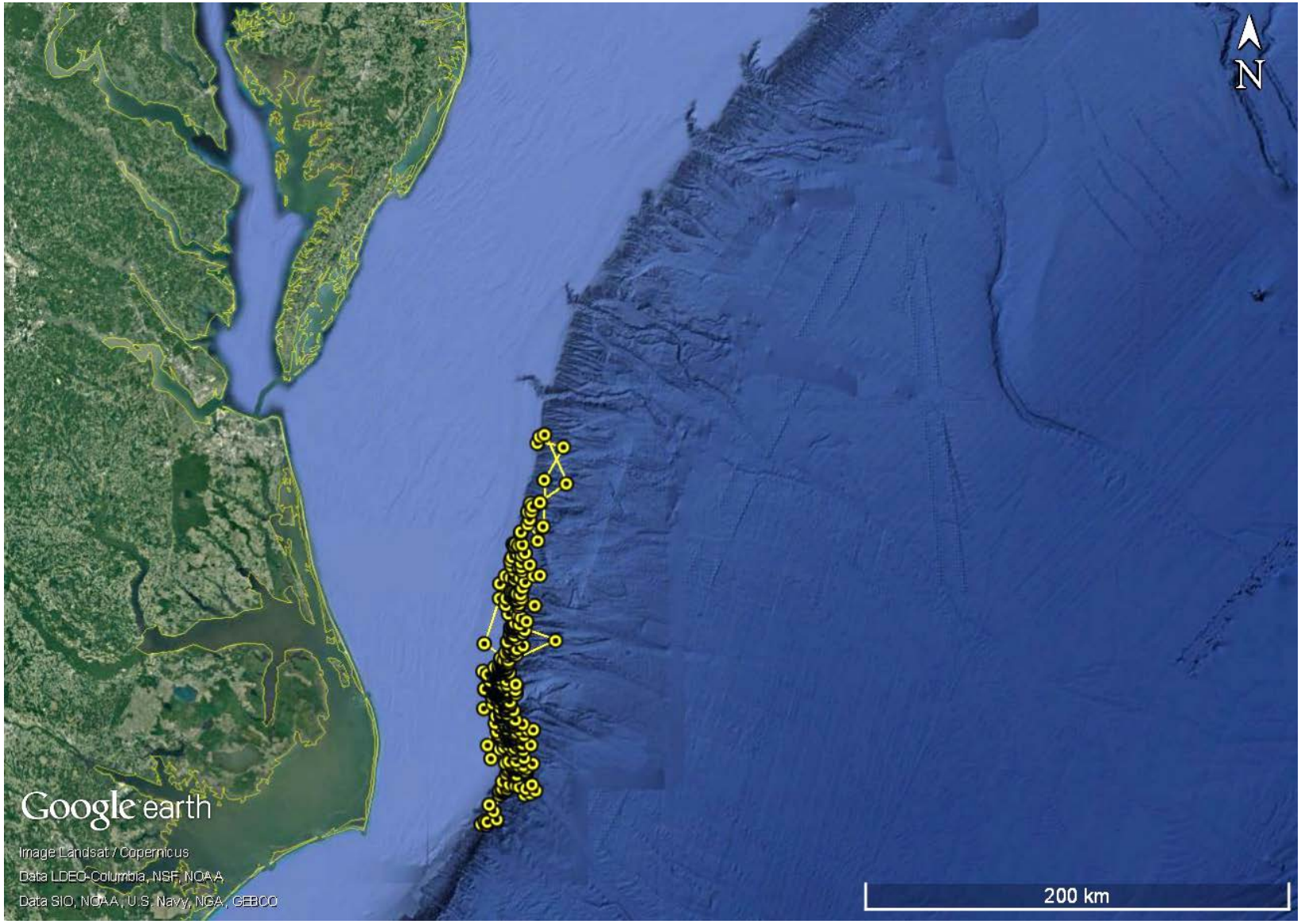

Figure 19. All filtered locations of short-finned pilot whale GmTag173 tagged off North Carolina over a 23.9-day period, 11 May–4 June 017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. GmTag173 was tagged in the same group as GmTag174 (Figure 20).

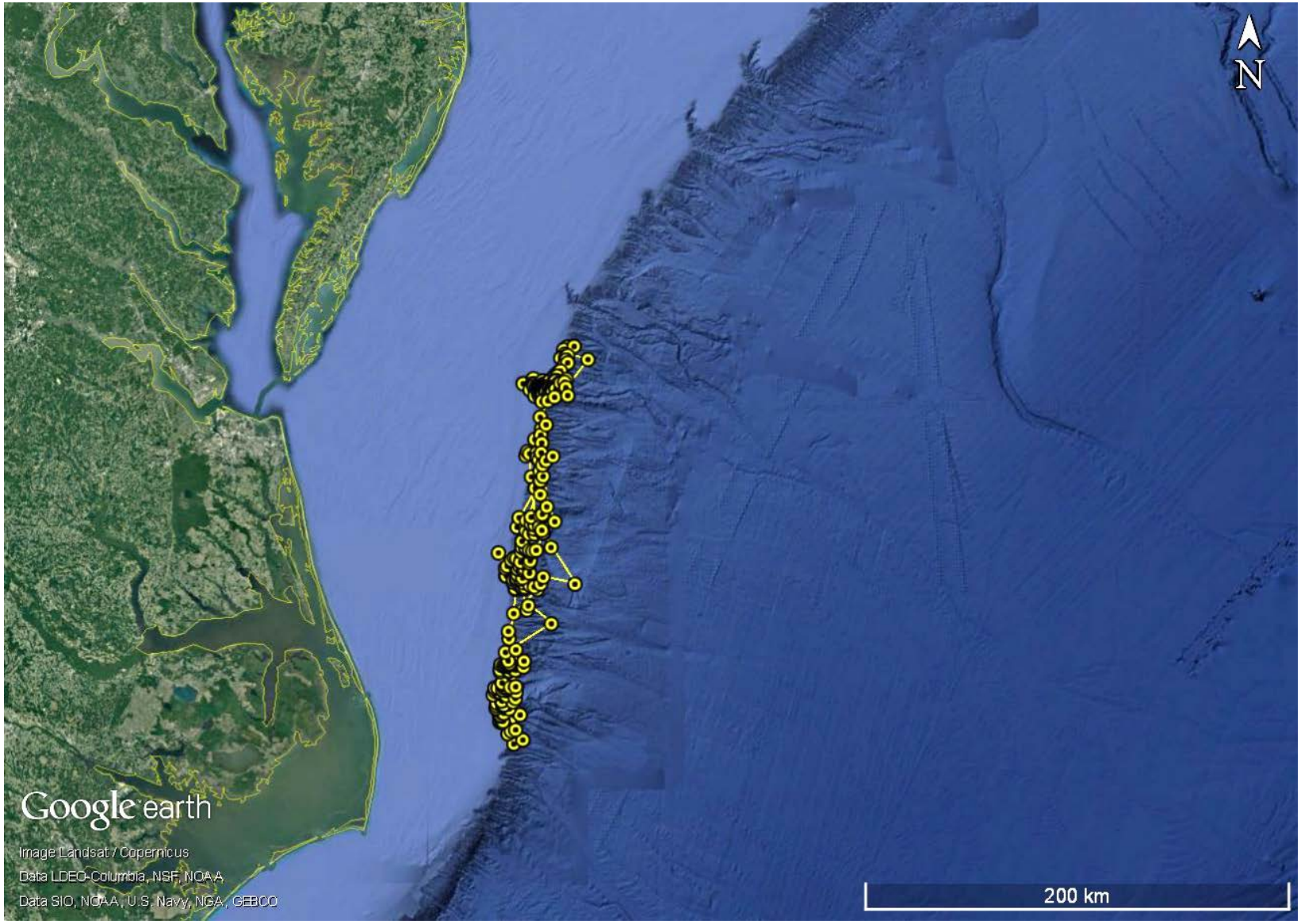

Figure 20. All filtered locations of short-finned pilot whale GmTag174 tagged off North Carolina over a 31.5-day period, 11 May–12 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. GmTag174 was tagged in the same group as GmTag173 (Figure 19).

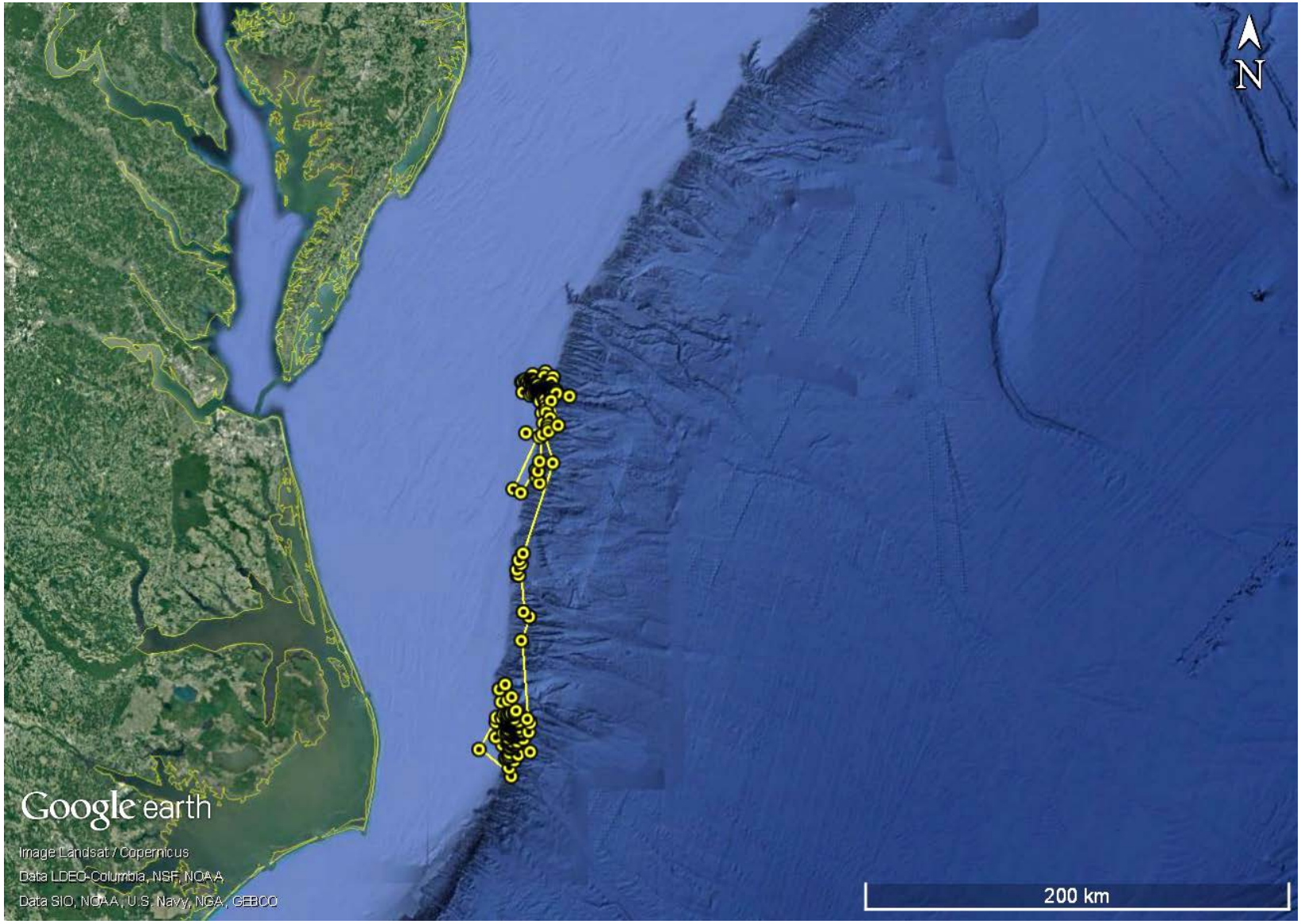

Figure 21. All filtered locations of short-finned pilot whale GmTag175 tagged off North Carolina over a 25.7-day period, 16 May–11 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. GmTag175 was tagged in the same group as GmTag176 (Figure 22).

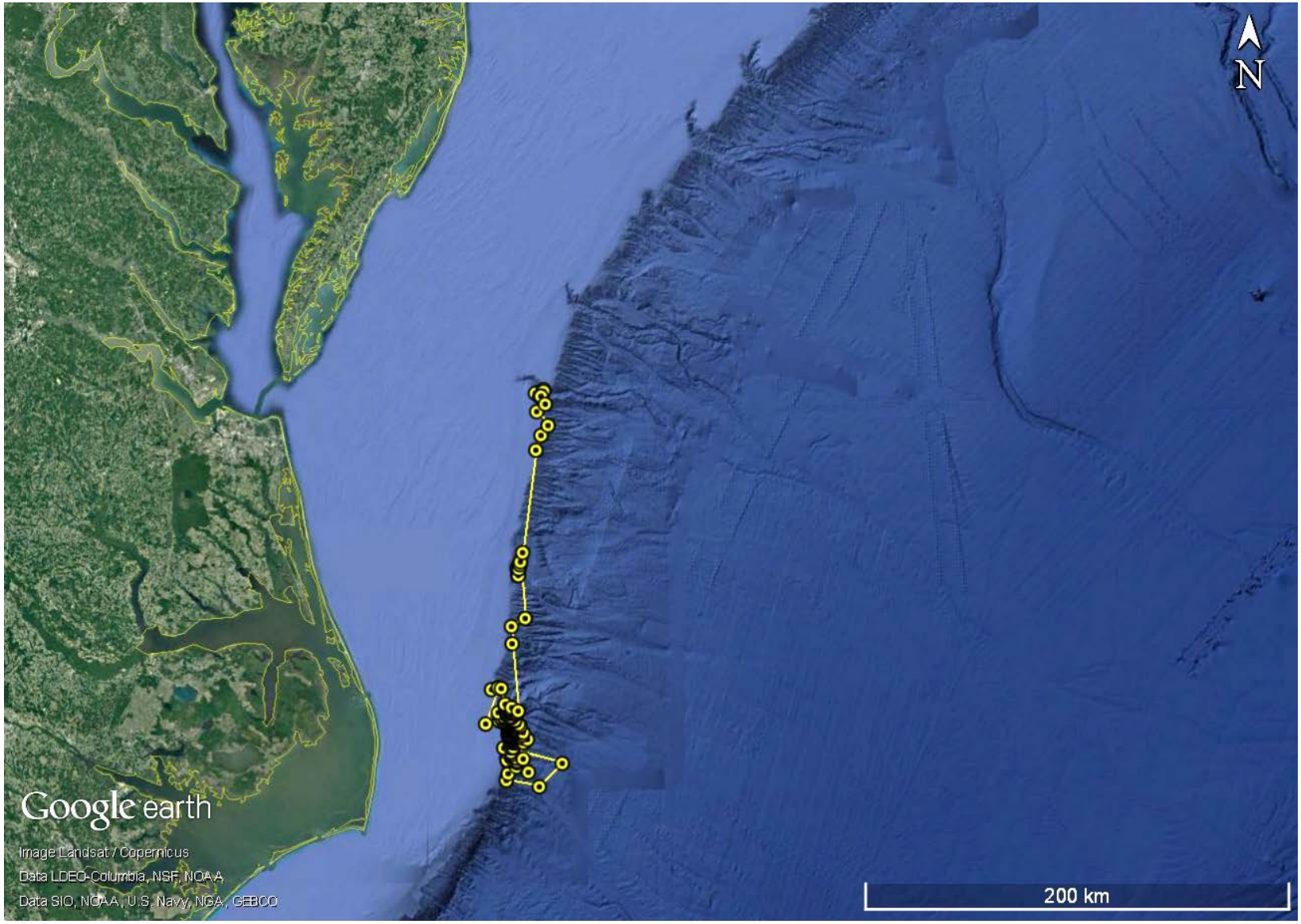

Figure 22. All filtered locations of short-finned pilot whale GmTag176 tagged off North Carolina over a 14.3-day period, 16–31 May 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. GmTag176 was tagged in the same group as GmTag175 (Figure 21).

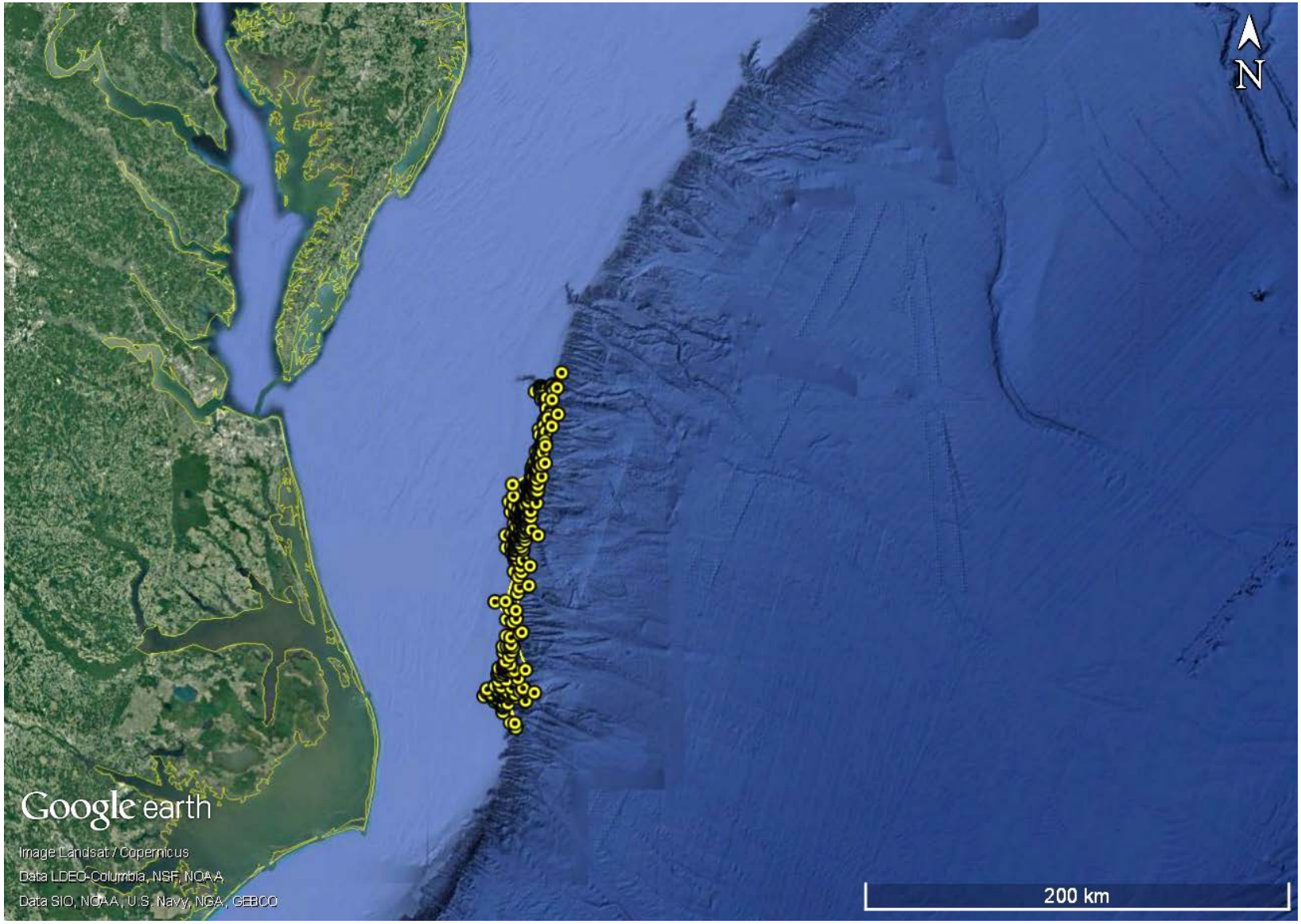

Figure 23. All filtered locations of short-finned pilot whale GmTag177 tagged off North Carolina over a 28.3-day period, 17 May–14 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments.

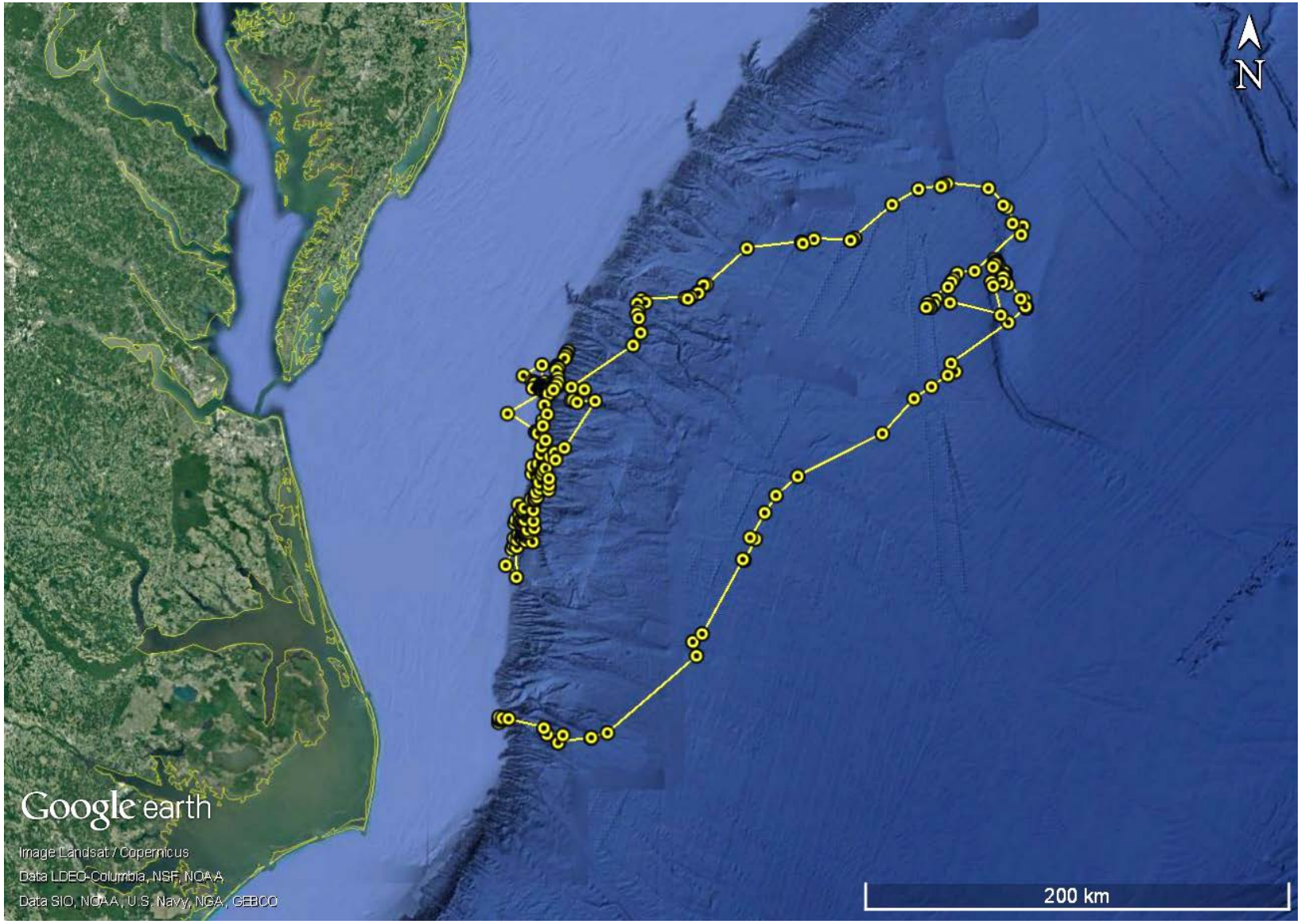

Figure 24. All filtered locations of short-finned pilot whale GmTag178 tagged off North Carolina over a 18.7-day period, 16 May–5 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. GmTag178 was tagged in the same group as GmTag179 (which only transmitted for <1 day, not shown) and GmTag180 (Figure 25).

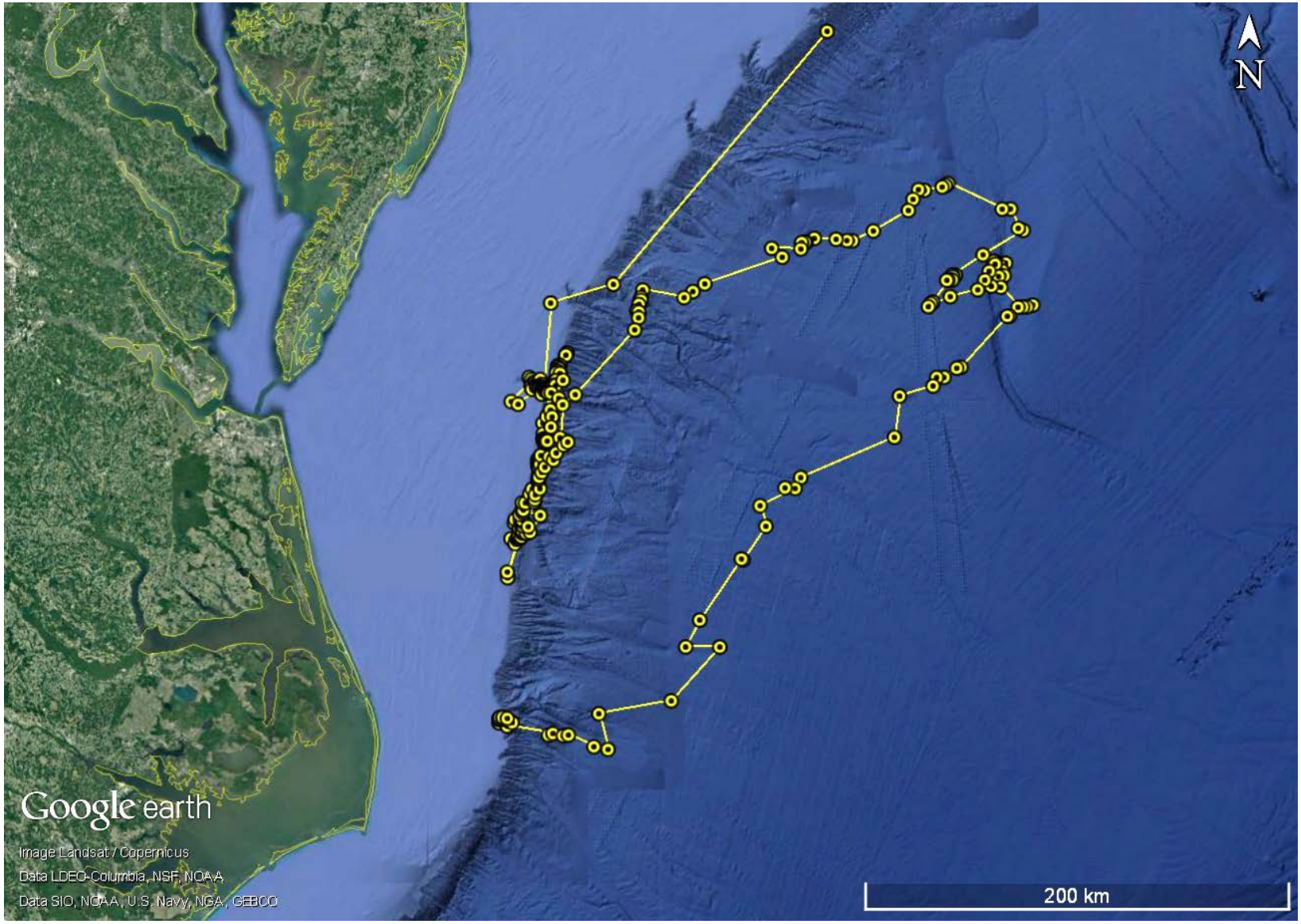

Figure 25. All filtered locations of short-finned pilot whale GmTag180 tagged off North Carolina over a 32.7-day period, 17 May–19 June 2017, with consecutive locations joined by a line. This individual was not one of the subjects of the controlled exposure experiments. GmTag180 was tagged in the same group as GmTag178 (Figure 24) and GmTag179 (not shown).

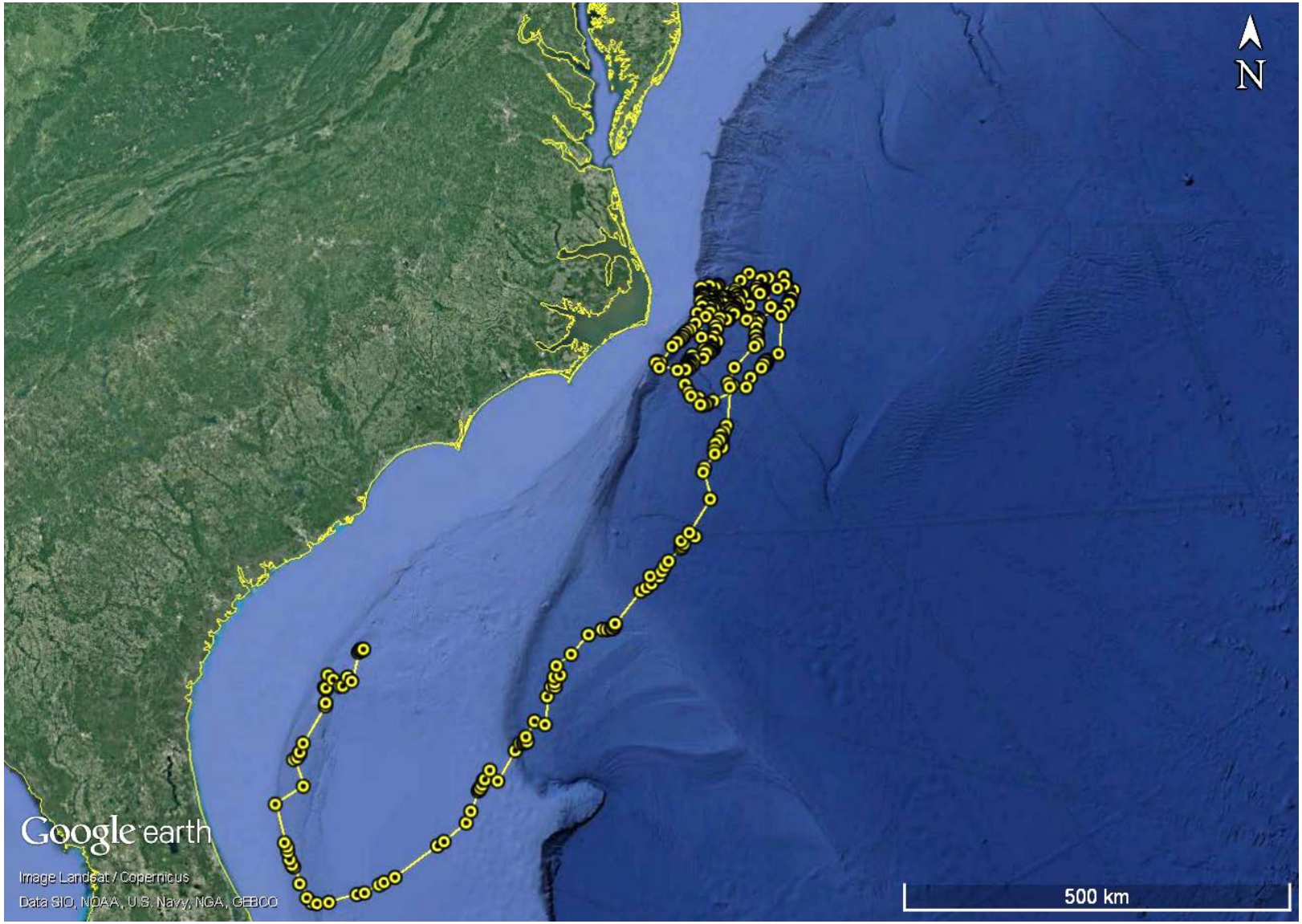

Figure 26. All filtered locations of short-finned pilot whale GmTag181 tagged off North Carolina over a 30.9-day period, 20 August– 20 September 2017, with consecutive locations joined by a line. This individual was a subject for the first controlled exposure experiment, on 22 August 2017. The large-scale movement to the south began on 10 September 2017, two days prior to the second CEE. GmTag181 was tagged in the same group as GmTag182 (Figure 27).

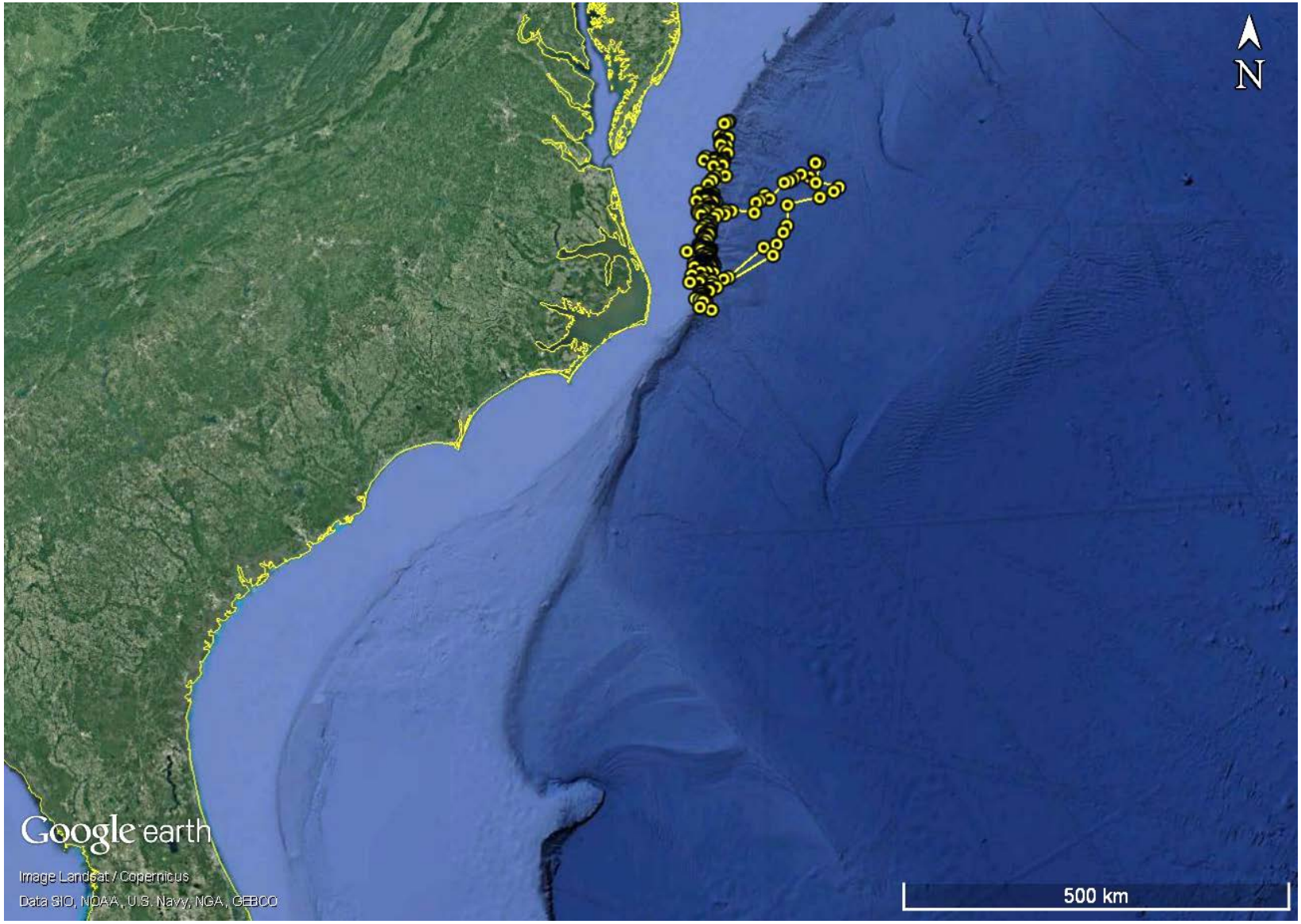

Figure 27. All filtered locations of short-finned pilot whale GmTag182 tagged off North Carolina over a 29.5-day period, 20 August–18 September 2017, with consecutive locations joined by a line. This individual was a subject for both of the controlled exposure experiments (22 August and 12 September 2017). GmTag182 was tagged in the same group as GmTag181 (Figure 26).

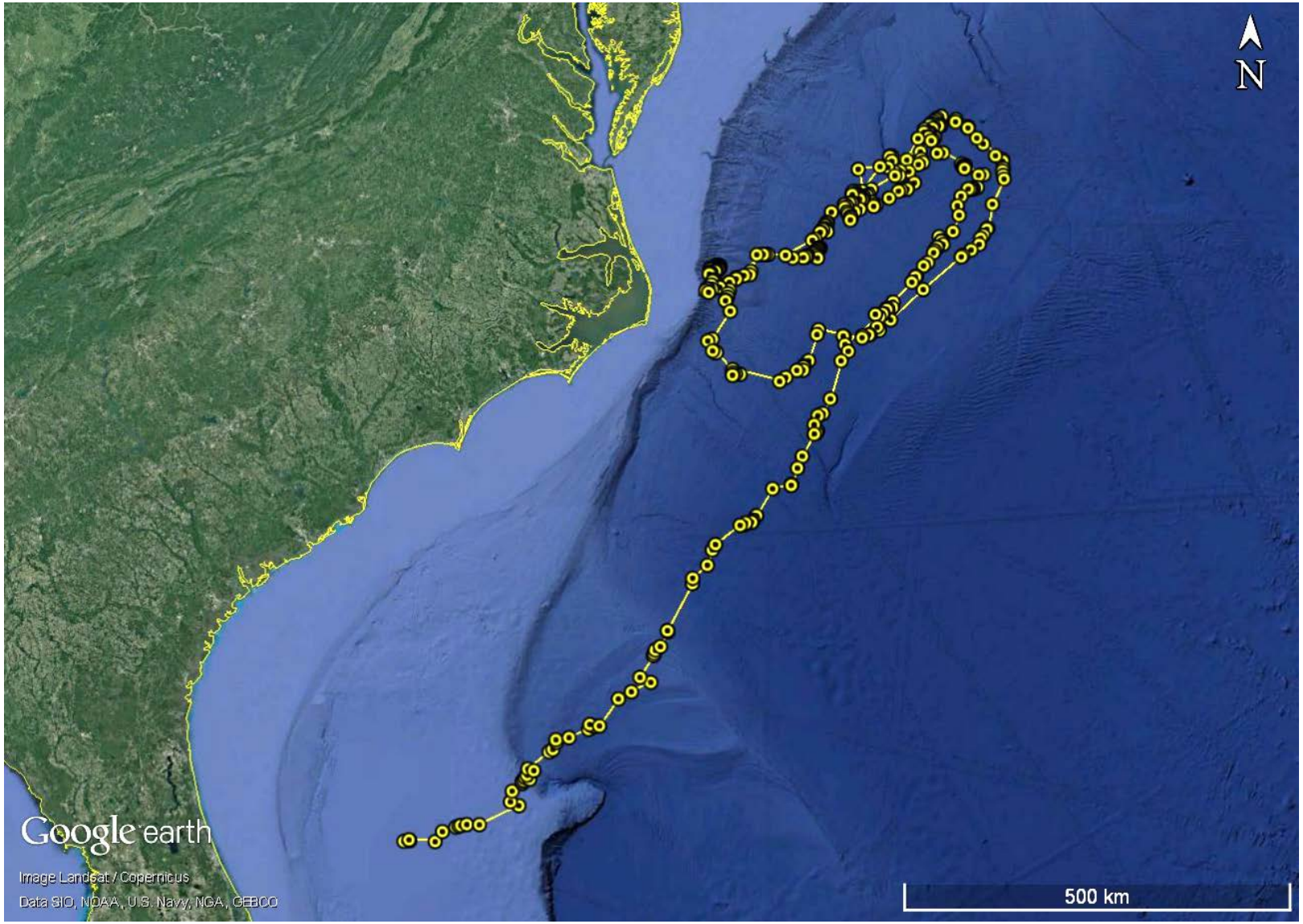

Figure 28. All filtered locations of short-finned pilot whale GmTag183 tagged off North Carolina over a 32.3-day period, 20 August–21 September 2017, with consecutive locations joined by a line. This individual was not a subject for the controlled exposure experiments. The large-scale movement to the south began on 16 September 2017.

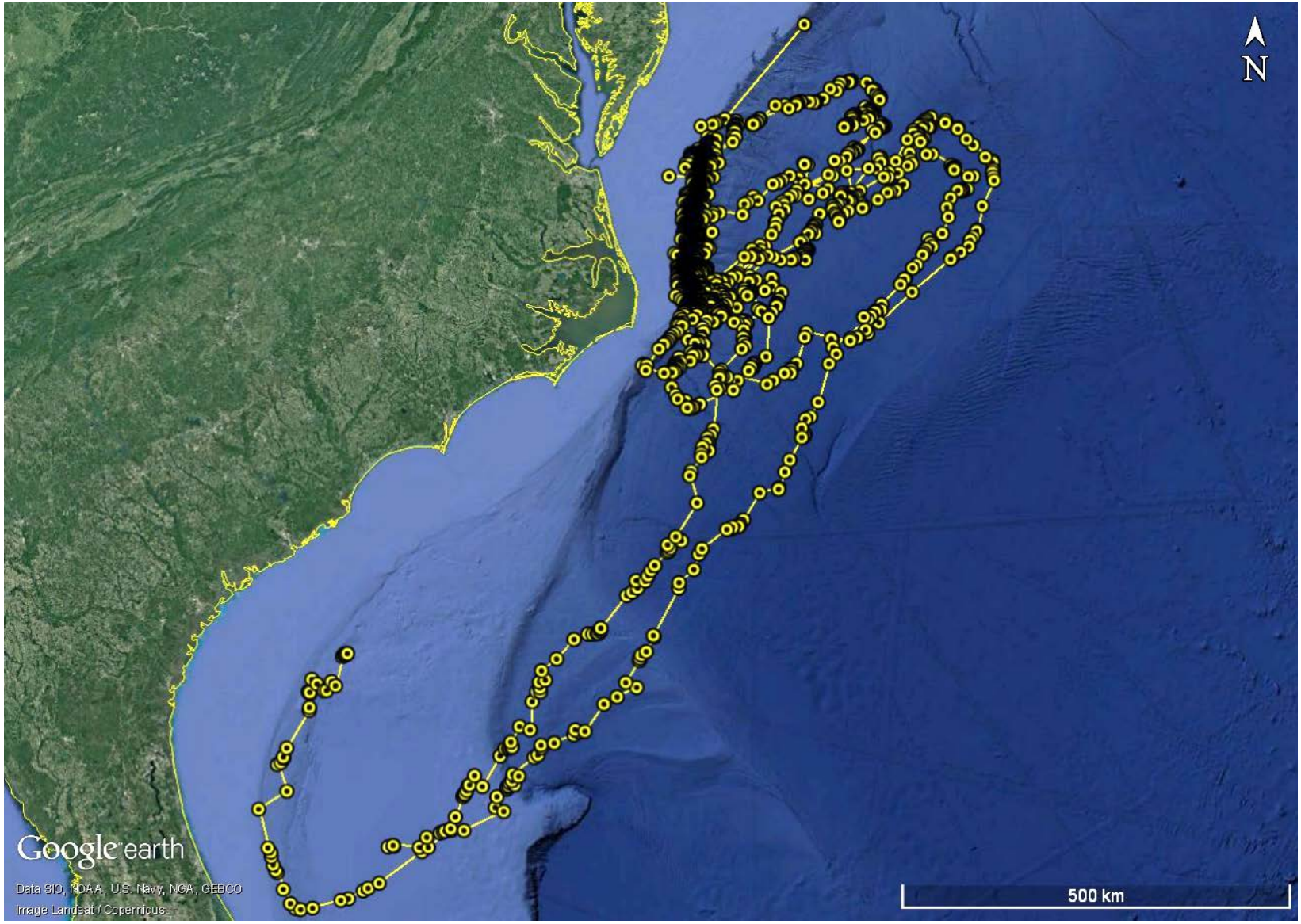

Figure 29. All filtered locations of short-finned pilot whales tagged off North Carolina in 2017, with consecutive locations joined by a line.

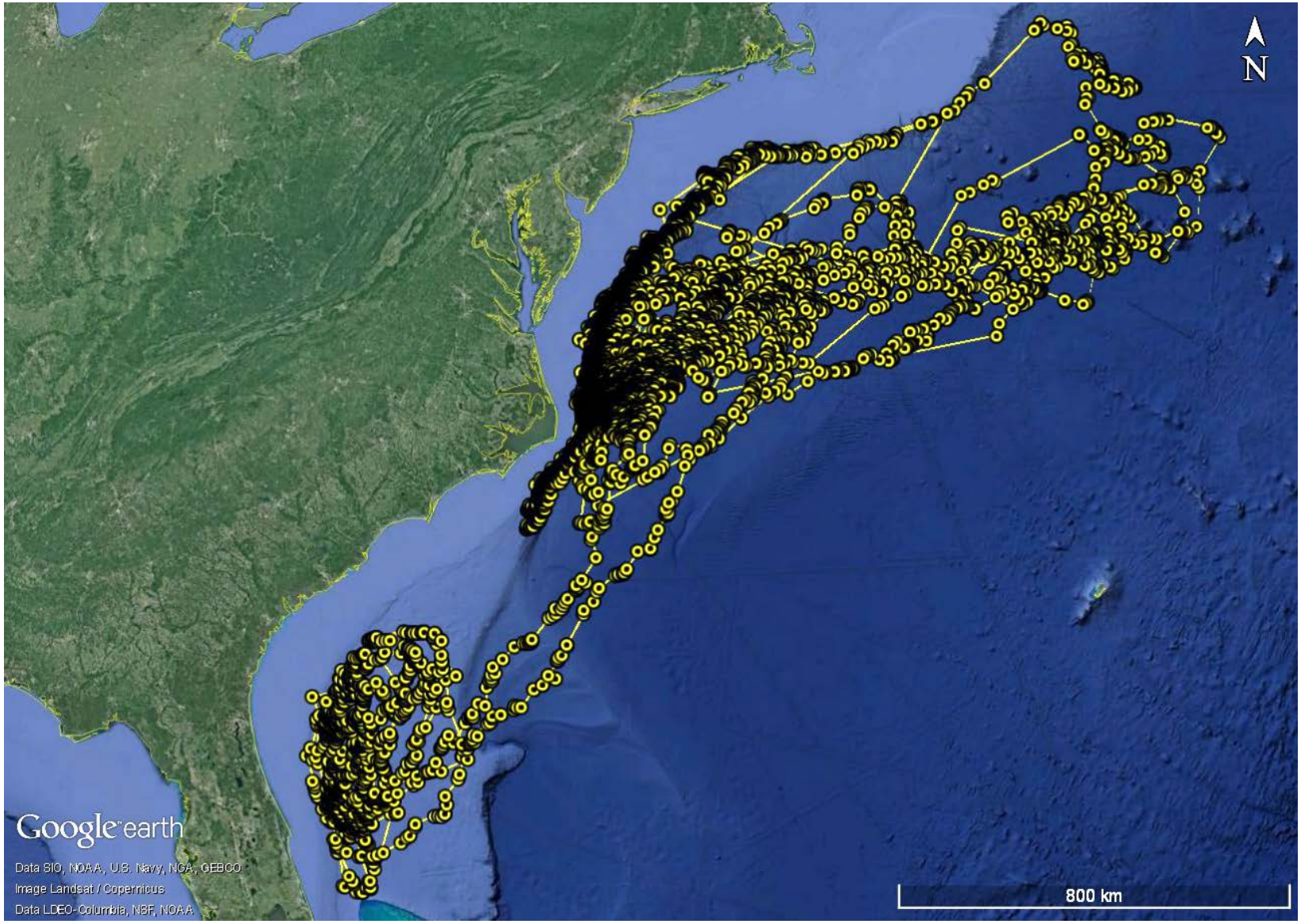

Figure 30. All filtered locations of short-finned pilot whales tagged off North Carolina in 2014 (*n*=17), 2015 (*n*=19), 2016 (*n*=9), and 2017 (*n*=11), and off Jacksonville, Florida, in 2016 (*n*=4), with consecutive locations joined by a line. Only tag attachment durations of >1 day are shown.

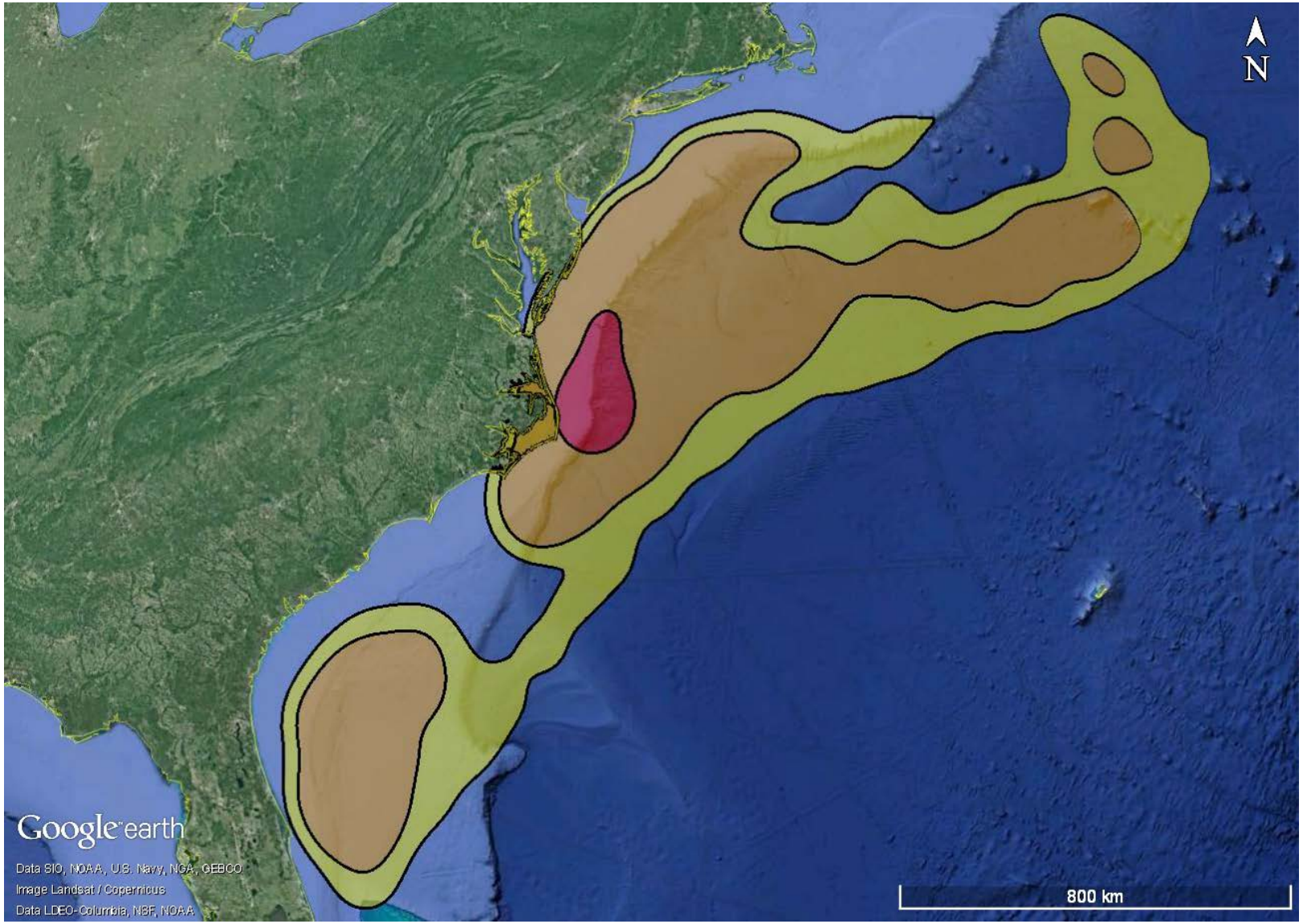

Figure 31. A probability-density representation of short-finned pilot whale location data from 56 individuals tagged off North Carolina in 2014 (*n*=17), 2015 (*n*=19), 2016 (*n*=9), and 2017 (*n*=11), as well as Jacksonville, Florida, in 2016 (*n*=4). The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95 percent polygon, and the yellow represents the 99 percent polygon. Only tag attachment durations of >1 day are included.

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B

Tables

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Table 1. Summary details of satellite tag deployments off Cape Hatteras, North Carolina, during 2017

Species[1]/ Tag ID	Sex/age class	Deployment Date	Sighting #	Deployment Latitude (°N)	Deployment Longitude (°W)	Depth at tagging location (m)	Tag duration (days)
GmTag172	Adult Female	5/10/2017	3	35.54	74.73	1,488	32.61
GmTag173	Adult Male	5/11/2017	4	35.72	74.83	223	23.93
GmTag174	Adult Male	5/11/2017	4	35.72	74.83	234	31.50
GmTag175	Adult Male	5/16/2017	7	35.65	74.69	1,657	25.69
GmTag176	Adult Male	5/16/2017	7	35.64	74.69	1,724	14.33
GmTag177	Adult Female	5/17/2017	2	35.80	74.78	1,103	28.29
GmTag178	Sub-adult Male	5/17/2017	6	35.70	74.79	624	18.75
GmTag179	Adult Male	5/17/2017	6	35.70	74.80	578	0.37
GmTag180	Adult Male	5/17/2017	6	35.70	74.80	539	32.68
GmTag181*	Adult Male	8/20/2017	5	35.58	74.77	775	30.94
GmTag182*	Adult Male	8/20/2017	5	35.56	74.77	822	29.49
GmTag183	Adult Male	8/20/2017	8	35.60	74.72	1,522	32.29
ZcTag054	Adult Male	5/10/2017	5	35.58	74.71	1,500	18.12
ZcTag055	Adult Male	5/10/2017	5	35.57	74.71	1,546	52.89
ZcTag056	Adult Male	5/10/2017	5	35.53	74.70	1,705	47.87
ZcTag057	Adult Unknown	5/16/2017	6	35.64	74.70	1,737	49.35
ZcTag058	Sub-adult Unknown	5/16/2017	9	35.58	74.71	1,514	39.11
ZcTag060*	Adult Male	8/17/2017	7	35.59	74.76	1,058	34.67
ZcTag061*	Adult Unknown	8/17/2017	7	35.61	74.73	1,425	44.44
ZcTag062*	Adult Unknown	8/17/2017	9	35.64	74.71	1,631	12.16
ZcTag063*	Adult Male	8/20/2017	7	35.54	74.72	1,566	30.68
ZcTag064*	Sub-adult Unknown	8/20/2017	7	35.53	74.71	1,599	49.63
ZcTag065*	Adult Male	8/22/2017	5	35.53	74.79	546	12.78
ZcTag066*	Sub-adult Male	9/4/2017	3	35.59	74.75	1,210	38.38
ZcTag067*	Adult Male	9/4/2017	4	35.60	74.73	1,449	42.31
ZcTag068*	Adult Male	9/4/2017	4	35.58	74.75	1,085	39.98

Gm = *Globicephala macrorhynchus*; Zc = *Ziphius cavirostris*, *Individuals that were subjects of the controlled exposure experiments. m=meter(s)

Table 2. Distances between pairs of Cuvier's beaked whales with temporally overlapping tag data. Distances are calculated when locations are received during the same satellite overpass. List is ordered based on the timing of tagging for comparison purposes.

Pair	Age/Sex of pair	Timing of tagging	Mean distance apart (km)	Max distance apart (km)
ZcTag063-064	Adult Male/Sub-Adult Unknown	same group	34.24	62.8
ZcTag060-061	Adult Male/Adult Unknown	same group	37.37	75.41
ZcTag067-068	Adult Male/Adult Male	same group	73.03	310.19
ZcTag055-056	Adult Male/Adult Male	same group	14.6	28.6
ZcTag054-056	Adult Male/Adult Male	same group	13.1	27.4
ZcTag054-055	Adult Male/Adult Male	same group	14	24.3
ZcTag057-058	Adult Unknown/Sub-Adult Unknown	same day	130.7	279.7
ZcTag061-062	Adult Unknown/Adult Unknown	same day	13.3	21.64
ZcTag060-062	Adult Male/Adult Unknown	same day	23.12	41.73
ZcTag066-068	Adult Male/Adult Male	same day	51.96	206.16
ZcTag066-067	Adult Male/Adult Male	same day	108.03	395.23
ZcTag064-067	Sub-Adult Unknown/Adult Male	different day	54.43	66.28
ZcTag064-066	Sub-Adult Unknown/Adult Male	different day	15.53	32.07
ZcTag064-065	Sub-Adult Unknown/Adult Male	different day	41.07	78.25
ZcTag062-064	Adult Unknown/Sub-Adult Unknown	different day	35.94	42.18
ZcTag061-064	Adult Unknown/Sub-Adult Unknown	different day	23.92	75.55
ZcTag062-065	Adult Unknown/Adult Male	different day	27.78	45.35
ZcTag062-063	Adult Unknown/Adult Male	different day	33.6	44.63
ZcTag061-068	Adult Unknown/Adult Male	different day	27.15	57.62
ZcTag061-067	Adult Unknown/Adult Male	different day	25.67	70.05
ZcTag061-066	Adult Unknown/Adult Male	different day	13.79	80.24
ZcTag061-063	Adult Unknown/Adult Male	different day	19.56	55.12
ZcTag068-064	Adult Male/Sub-Adult Unknown	different day	33.79	49.9
ZcTag060-064	Adult Male/Sub-Adult Unknown	different day	30.5	74.3
ZcTag056-058	Adult Male/Sub-Adult Unknown	different day	26.5	49.9
ZcTag055-058	Adult Male/Sub-Adult Unknown	different day	21.3	63.2
ZcTag054-058	Adult Male/Sub-Adult Unknown	different day	33	52.7

Pair	Age/Sex of pair	Timing of tagging	Mean distance apart (km)	Max distance apart (km)
ZcTag065-061	Adult Male/Adult Unknown	different day	28.18	53.14
ZcTag056-057	Adult Male/Adult Unknown	different day	158.5	263.8
ZcTag055-057	Adult Male/Adult Unknown	different day	131.9	216.2
ZcTag054-057	Adult Male/Adult Unknown	different day	157.3	292.4
ZcTag065-060	Adult Male/Adult Male	different day	39.18	51.44
ZcTag063-068	Adult Male/Adult Male	different day	45.25	73.02
ZcTag063-067	Adult Male/Adult Male	different day	28	42.03
ZcTag063-066	Adult Male/Adult Male	different day	37.1	60.61
ZcTag063-065	Adult Male/Adult Male	different day	22.65	45.37
ZcTag060-068	Adult Male/Adult Male	different day	41.3	77.37
ZcTag060-067	Adult Male/Adult Male	different day	42.86	89.33
ZcTag060-066	Adult Male/Adult Male	different day	31.34	71.26
ZcTag060-063	Adult Male/Adult Male	different day	62.09	99.23

Key. Zc = *Ziphius cavirostris* (Cuvier's beaked whale); km = kilometer(s)

Table 3. Distances between pairs of short-finned pilot whales with temporally overlapping tag data. Distances are calculated when locations are received during the same satellite overpass.

Pair	Age/Sex of pair	Timing of tagging	Mean distance apart (km)	Max distance apart (km)
GmTag173-174	Adult Male\Adult Male	same group	78.8	162.2
GmTag175-176	Adult Male\Adult Male	same group	3	25.1
GmTag178-179	Sub-Adult Male\Adult Male	same group	2.4	4.2
GmTag178-180	Sub-Adult Male\Adult Male	same group	2.4	16.6
GmTag179-176	Adult Male\Adult Male	same group	6.1	7.9
GmTag179-180	Adult Male\Adult Male	same group	2.3	3.9
GmTag181-182	Adult Male\Adult Male	same group	270.6	983.2
GmTag177-178	Adult Female\Sub-Adult Male	same day	89.4	308.2
GmTag177-179	Adult Female\Adult Male	same day	14.5	16
GmTag177-180	Adult Female\Adult Male	same day	84.9	308.4
GmTag181-183	Adult Male\Adult Male	same day	339	798.9
GmTag182-183	Adult Male\Adult Male	same day	246.6	570.5
GmTag172-173	Adult Female\Adult Male	different day	59.9	200.9
GmTag172-174	Adult Female\Adult Male	different day	50	138.1
GmTag172-175	Adult Female\Adult Male	different day	54.5	123
GmTag172-176	Adult Female\Adult Male	different day	55.8	120.9
GmTag172-177	Adult Female\Adult Female	different day	40.5	130.3
GmTag172-178	Adult Female\Sub-Adult Male	different day	104.5	311.3
GmTag172-179	Adult Female\Adult Male	different day	2.5	4.6
GmTag172-180	Adult Female\Adult Male	different day	98	311.5
GmTag173-175	Adult Male\Adult Male	different day	75.4	203
GmTag173-176	Adult Male\Adult Male	different day	29	133.5
GmTag173-177	Adult Male\Adult Female	different day	68.2	144
GmTag173-178	Adult Male\Sub-Adult Male	different day	149.3	331.2
GmTag173-179	Adult Male\Adult Male	different day	9.8	10.7
GmTag173-180	Adult Male\Adult Male	different day	143.2	325.6
GmTag174-175	Adult Male\Adult Male	different day	68.9	179.2

Pair	Age/Sex of pair	Timing of tagging	Mean distance apart (km)	Max distance apart (km)
GmTag174-176	Adult Male\Adult Male	different day	93.5	176.9
GmTag174-177	Adult Male\Adult Female	different day	37.1	84.5
GmTag174-178	Adult Male\Sub-Adult Male	different day	108.6	313.3
GmTag174-179	Adult Male\Adult Male	different day	97	97.3
GmTag174-180	Adult Male\Adult Male	different day	113.2	313.1
GmTag175-177	Adult Male\Adult Female	different day	72.7	162.3
GmTag175-178	Adult Male\Sub-Adult Male	different day	122.7	326.3
GmTag175-179	Adult Male\Adult Male	different day	3.5	3.5
GmTag175-180	Adult Male\Adult Male	different day	116.2	321.8
GmTag176-177	Adult Male\Adult Female	different day	76	163.1
GmTag176-178	Adult Male\Sub-Adult Male	different day	173.2	331.3
GmTag176-180	Adult Male\Adult Male	different day	181.5	330

Table 4. Characteristics of movements in relation to tagging distance for satellite-tagged odontocetes tagged off North Carolina in 2017

Tag ID	Number of locations after filtering	Mean (SD) distance from tagging location (km)	Maximum distance from tagging location (km)	Total distance traveled (km)
GmTag172	357	83.7 (46.2)	173.9	2,078.9
GmTag173	355	29.9 (25.1)	129.1	1,914.7
GmTag174	259	95.2 (55.9)	171.2	1,368.8
GmTag175	228	86.4 (70.3)	165.2	1,096.2
GmTag176	131	26.4 (39.8)	160.7	665.2
GmTag177	299	69.7 (42.7)	149.6	1,452.3
GmTag178	223	167.4 (86.1)	329.7	1,461.3
GmTag179	9	3.2 (2)	7.9	26.3
GmTag180	240	165.1 (84.6)	349.1	1,715.7
GmTag181	312	224.3 (261.8)	888.0	2,939.5
GmTag182	227	88.4 (60.9)	215.3	2,112.5
GmTag183	332	261.8 (168.6)	763.5	3,431.9
ZcTag054	63	38.1 (18.1)	74.4	502.6
ZcTag055	52	27.8 (17.7)	78.8	671.8
ZcTag056	87	30.4 (17.8)	74.4	1,219.2
ZcTag057	133	91.4 (85.3)	277.3	2,274.0
ZcTag058	131	12.7 (9.6)	46.8	1,100.6
ZcTag060	100	45.3 (21.9)	85.5	1,409.1
ZcTag061	148	27 (18.1)	72.2	1,362.1
ZcTag062	30	22.6 (13.2)	51.2	356.9
ZcTag063	65	20.5 (10.4)	42.2	637.2
ZcTag064	60	30 (17.5)	71.2	857.8
ZcTag065	32	19.1 (12.3)	44.7	465.1
ZcTag066	134	56.6 (51.7)	236.0	1,359.0
ZcTag067	103	64.3 (85.4)	288.6	1,337.7
ZcTag068	80	21 (13.2)	68.1	1,279.8

Key: Gm = *Globicephala macrorhynchus*; Zc = *Ziphius cavirostris*); km = kilometer(s);

Table 5. Depths and distances from shore and the 200-m isobath from GIS analysis of filtered satellite-tag locations.

Tag ID	Depth (m)		Distance from shore (km)			Distance from 200-m isobath (km)	
	Median	Max	Min	Median	Max	Median	Max
GmTag172	530.5	1,892.7	51.2	85.5	114.7	3.1	32.9
GmTag173	559.2	2,179.0	50.9	64.1	122.6	3.5	25.8
GmTag174	522.3	1,907.6	56.6	99.7	118.3	2.9	31.7
GmTag175	605.8	1,764.3	47.0	92.8	118.0	2.1	16.5
GmTag176	752.6	2,430.4	50.7	63.1	110.2	2.0	22.3
GmTag177	413.3	1,445.4	52.3	97.4	114.5	2.3	11.5
GmTag178	918.2	3,573.2	56.9	108.2	281.9	5.9	161.4
GmTag179	249.8	1,505.0	58.1	59.3	66.9	5.0	6.4
GmTag180	713.6	3,452.7	56.9	107.6	284.2	4.2	162.4
GmTag181	2,711.3	4,236.6	41.5	121.2	344.6	41.6	244.8
GmTag182	1,133.0	3,338.4	50.0	91.5	253.6	8.2	155.5
GmTag183	3,622.3	4,673.2	67.2	278.4	432.6	196.6	335.4
ZcTag054	1,789.9	2,620.4	38.2	62.2	76.4	6.6	19.5
ZcTag055	1,946.7	2,749.6	31.1	67.8	96.9	11.5	33.0
ZcTag056	1,653.1	2,844.5	38.2	64.0	118.5	8.0	54.4
ZcTag057	2,064.5	3,497.2	40.9	98.7	260.5	25.3	161.7
ZcTag058	1,695.1	2,553.6	44.6	69.1	97.5	7.0	33.7
ZcTag060	2,440.0	3,283.3	39.9	87.8	147.8	24.9	84.0
ZcTag061	1,558.4	3,109.7	41.5	64.2	117.0	4.7	61.4
ZcTag062	1,707.9	2,814.5	51.7	69.2	107.9	7.7	43.3
ZcTag063	1,660.3	2,364.1	54.9	67.6	95.4	7.1	31.1
ZcTag064	2,077.4	2,832.1	36.3	71.5	127.4	13.1	62.9
ZcTag065	1,222.7	2,376.0	53.5	66.3	87.6	7.3	23.2
ZcTag066	1,348.7	3,044.7	21.6	57.6	122.7	5.6	51.4
ZcTag067	1,428.6	2,527.9	50.5	71.2	133.2	7.9	47.2
ZcTag068	1,410.6	3,038.4	32.5	65.8	131.7	7.4	68.0

Key Gm = *Globicephala macrorhynchus*; km = kilometer(s); m = meter(s); Zc = *Ziphius cavirostris*

Table 6. Summary of diving behavior data from location-depth tags, restricted to time periods prior to controlled exposure experiments or to transducer failure. For short-finned pilot whales, dives that exceeded 75 m and 30 sec were recorded, while for Cuvier's beaked whales dives that exceeded 150 m and 33 min were recorded.

Tag ID	Number of days of behavior data	Percent of total record	Number of dives	Max dive depth (m)	Max dive duration (min)
GmTag172	32.3	99.6	1,303	1,047.8	23.2
GmTag173	23.2	97.6	988	1,079.8	21.6
GmTag174	30.6	99.1	1,468	1,079.8	22.6
GmTag175	25.1	98.7	901	999.8	22.2
GmTag176	11.6	92.6	335	1,111.8	23.1
GmTag177	24.1	89.9	1,152	871.8	18.4
GmTag178	17.6	95.4	675	1,047.8	20.1
GmTag179	0.4	100.0	19	711.8	18.6
GmTag180	19.7	64.8	831	1,143.8	19.1
GmTag181*	1.4	94.4	47	903.8	20.5
GmTag182*	1.4	100.0	45	927.5	20.9
GmTag183	30.0	94.3	1,060	1,263.5	22.8
ZcTag054	17.9	100.0	193	2,415.5	76.2
ZcTag055^	13.4	34.5	149	2,287.5	106.7
ZcTag056	47.5	100.0	524	2,415.5	88.4
ZcTag057^	48.7	100.0	303	2,479.5	89.5
ZcTag058	39.2	100.0	352	2,223.5	92.0
ZcTag060*	4.3	100.0	38	2,543.5	95.2
ZcTag061*	5.2	100.0	64	2,223.5	85.1
ZcTag062*	4.9	100.0	41	2,159.5	113.3
ZcTag063*	2.3	100.0	23	2,287.5	99.6
ZcTag064*	2.3	100.0	21	2,287.5	85.8
ZcTag065*	0.3	100.0	3	1,231.5	65.1
ZcTag066*^	7.4	95.4	71	1,871.5	114.2
ZcTag067*^	4.3	87.9	29	1,743.5	92.2
ZcTag068*	7.3	95.7	71	1,807.5	91.5

Key: m = meter(s); min = minute(s); Gm = *Globicephala macrorhynchus*; Zc = *Ziphius cavirostris*; *Individuals that were subject to CEEs. ^Tags with potential pressure transducer issues part way through tag attachment period.