Density Model for Clymene Dolphin (*Stenella clymene*) for the U.S. Navy Atlantic Fleet Testing and Training (AFTT) Study Area: Supplementary Report

Model Version 3

Duke University Marine Geospatial Ecology Laboratory*

2022-06-20

Citation

When referencing our methodology or results generally, please cite Roberts et al. (2023), which documented the modeling cycle we completed in the 2022 for the U.S. Navy AFTT Phase IV Environmental Impact Statement, and Mannocci et al. (2017), which developed the original methodology and models upon which the 2022 models were based. The full citations appear in the References section at the end of this document.

To independently reference this specific model or Supplementary Report, please cite:

Roberts JJ, Yack TM, Halpin PN (2022) Density Model for Clymene Dolphin (*Stenella clymene*) for the U.S. Navy's AFTT Phase IV Study Area, Version 3, 2022-06-20, and Supplementary Report. Marine Geospatial Ecology Laboratory, Duke University, Durham, North Carolina.

Copyright and License

Model Version History

Version	Date	Description
2	2015-01-23	First publicly-released version of this model, released in 2015 as part of the final delivery of the U.S. Navy Marine Species Density Database (NMSDD) for the Atlantic Fleet Testing and Training (AFTT) Phase III Environmental Impact Statement.
3	2022-06-20	Updated the AFTT Phase III model with many additional surveys contributed since that time. Please see Roberts et al. (2022, 2023) for details. This update was released as part of the final delivery of the NMSDD for the AFTT Phase IV Environmental Impact Statement.

*For questions or to offer feedback please contact Jason Roberts (jason.roberts@duke.edu) and Tina Yack (tina.yack@duke.edu)

1 Survey Data

The goal of this project was to build, for the U.S. Navy's AFTT Phase IV Environmental Impact Statement (EIS), an update to the model we developed for the AFTT Phase III EIS. The Phase III model was developed using the methodology of Mannocci et al. (2017) by L. Mannocci but not included in the 2017 publication. Following the approach taken by that model, we built this update from data collected in the east coast, Gulf of Mexico, and Caribbean regions. We also included segments south of 50 °N from trans-Atlantic surveys by R/V Song of the Whale, which reported a sighting in tropical eastern Atlantic waters, but were not available for the Phase III model. We excluded surveys that did not target small cetaceans or were otherwise problematic for modeling them. We restricted the model to aerial survey transects with sea states of Beaufort 4 or less (for a few surveys we used Beaufort 3 or less) and shipboard transects with Beaufort 5 or less (for a few we used Beaufort 4 or less). We also excluded transects with poor weather or visibility for surveys that reported those conditions. Table 1 summarizes the survey effort and sightings available for the model after most exclusions were applied. Figure 1 shows the data actually used to fit the model.

Table 1: Survey effort and observations considered for this model. Effort is tallied as the cumulative length of on-effort transects. Observations are the number of groups and individuals encountered while on effort. Off effort observations and those lacking an estimate of group size or distance to the group were excluded.

			Effort	Observations		
Institution	Program	Period	1000s km	Groups	Individuals	Mean Group Size
Aerial Surveys						
HDR	Navy Norfolk Canyon	2018-2019	10	0	0	
NEFSC	AMAPPS	2010-2019	83	0	0	
NEFSC	NARWSS	2003-2016	380	0	0	
NEFSC	Pre-AMAPPS	1999-2008	45	0	0	
SEFSC	AMAPPS	2010-2020	112	0	0	
SEFSC	GOMEX92-96	1992-1996	27	0	0	
SEFSC	GulfCet I	1992-1994	50	7	413	59.0
SEFSC	GulfCet II	1996-1998	22	5	487	97.4
SEFSC	GulfSCAT 2007	2007-2007	18	0	0	
SEFSC	MATS	2002-2005	27	0	0	
UNCW	MidA Bottlenose	2002-2002	15	0	0	
UNCW	Navy Cape Hatteras	2011-2017	34	10	1,519	151.9
UNCW	Navy Jacksonville	2009-2017	92	0	0	
UNCW	Navy Norfolk Canyon	2015-2017	14	1	20	20.0
UNCW	Navy Onslow Bay	2007-2011	49	0	0	
UNCW	SEUS NARW EWS	2005-2008	106	0	0	
VAMSC	MD DNR WEA	2013-2015	15	0	0	
VAMSC	Navy VACAPES	2016-2017	18	0	0	
VAMSC	VA CZM WEA	2012-2015	19	0	0	
		Total	**1,136**	**23**	**2,439**	**106.0**
Shipboard Surveys						
MCR	SOTW Visual	2005-2019	23	3	92	30.7
NEFSC	AMAPPS	2011-2016	15	1	25	25.0
NEFSC	Pre-AMAPPS	1995-2007	17	0	0	
NJDEP	NJEBS	2008-2009	14	0	0	
SEFSC	AMAPPS	2011-2016	16	3	325	108.3
SEFSC	GOM Oceanic CetShip	1992-2001	49	46	3,757	81.7
SEFSC	GOM Shelf CetShip	1994-2001	10	1	9	9.0
SEFSC	Pre-AMAPPS	1992-2006	33	10	1,808	180.8
SEFSC	Pre-GoMMAPPS	2003-2009	19	17	1,049	61.7
SEFSC	SEFSC Caribbean	1995-2000	8	0	0	
		Total	**204**	**81**	**7,065**	**87.2**
		Grand Total	**1,340**	**104**	**9,504**	**91.4**

Table 2: Institutions that contributed surveys used in this model.

Institution	Full Name
HDR	HDR, Inc.
MCR	Marine Conservation Research
NEFSC	NOAA Northeast Fisheries Science Center
NJDEP	New Jersey Department of Environmental Protection
SEFSC	NOAA Southeast Fisheries Science Center
UNCW	University of North Carolina Wilmington
VAMSC	Virginia Aquarium & Marine Science Center

Table 3: Descriptions and references for survey programs used in this model.

Program	Description	References
AMAPPS	Atlantic Marine Assessment Program for Protected Species	Palka et al. (2017), Palka et al. (2021)
GOM Oceanic CetShip	Gulf of Mexico Oceanic CetShip Surveys	Mullin and Fulling (2004)
GOM Shelf CetShip	Gulf of Mexico Shelf CetShip Surveys	Fulling et al. (2003)
GOMEX92-96	GOMEX 1992-1996 Aerial Surveys	Blaylock and Hoggard (1994)
GulfCet I	GulfCet I Aerial Surveys	Davis and Fargion (1996)
GulfCet II	GulfCet II Aerial Surveys	Davis et al. (2000)
GulfSCAT 2007	GulfSCAT 2007 Aerial Surveys	
MATS	Mid-Atlantic Tursiops Surveys	
MD DNR WEA	Aerial Surveys of the Maryland Wind Energy Area	Barco et al. (2015)
MidA Bottlenose	Mid-Atlantic Onshore/Offshore Bottlenose Dolphin Surveys	Torres et al. (2005)
NARWSS	North Atlantic Right Whale Sighting Surveys	Cole et al. (2007)
Navy Cape Hatteras	Aerial Surveys of the Navy's Cape Hatteras Study Area	McLellan et al. (2018)
Navy Jacksonville	Aerial Surveys of the Navy's Jacksonville Study Area	Foley et al. (2019)
Navy Norfolk Canyon	Aerial Surveys of the Navy's Norfolk Canyon Study Area	Cotter (2019), McAlarney et al. (2018)
Navy Onslow Bay	Aerial Surveys of the Navy's Onslow Bay Study Area	Read et al. (2014)
Navy VACAPES	Aerial Survey Baseline Monitoring in the Continental Shelf Region of the VACAPES OPAREA	Mallette et al. (2017)
NJEBS	New Jersey Ecological Baseline Study	Geo-Marine, Inc. (2010), Whitt et al. (2015)
Pre-AMAPPS	Pre-AMAPPS Marine Mammal Abundance Surveys	Mullin and Fulling (2003), Garrison et al. (2010), Palka (2006)
Pre-GoMMAPPS	Pre-GoMMAPPS Marine Mammal Abundance Surveys	Mullin (2007)
SEFSC Caribbean	SEFSC Surveys of the Caribbean Sea	Mullin (1995), Swartz and Burks (2000)
SEUS NARW EWS	Southeast U.S. Right Whale Early Warning System Surveys	
SOTW Visual	R/V Song of the Whale Visual Surveys	Ryan et al. (2013)
VA CZM WEA	Virginia CZM Wind Energy Area Surveys	Mallette et al. (2014), Mallette et al. (2015)

2 Density Model

Our objective was to update the Phase III model with new data without repeating the covariate selection exercise performed during its development. We therefore fitted a year-round model that included sea surface temperature as the only covariate, as done for the prior model. The resulting relationship (Figure 2) strongly resembled that of the prior model. Model predictions are shown in Section 3. Extrapolation analyses displayed geographic patterns very similar to the environmental envelope estimated for the prior model (Figure 6). The necessity for environmental extrapolation was driven mainly by a lack of sampling in waters with very low sea surface temperatures, as occurred of northern Newfoundland, Labrador, and west Greenland in non-summer months.

2.1 Final Model

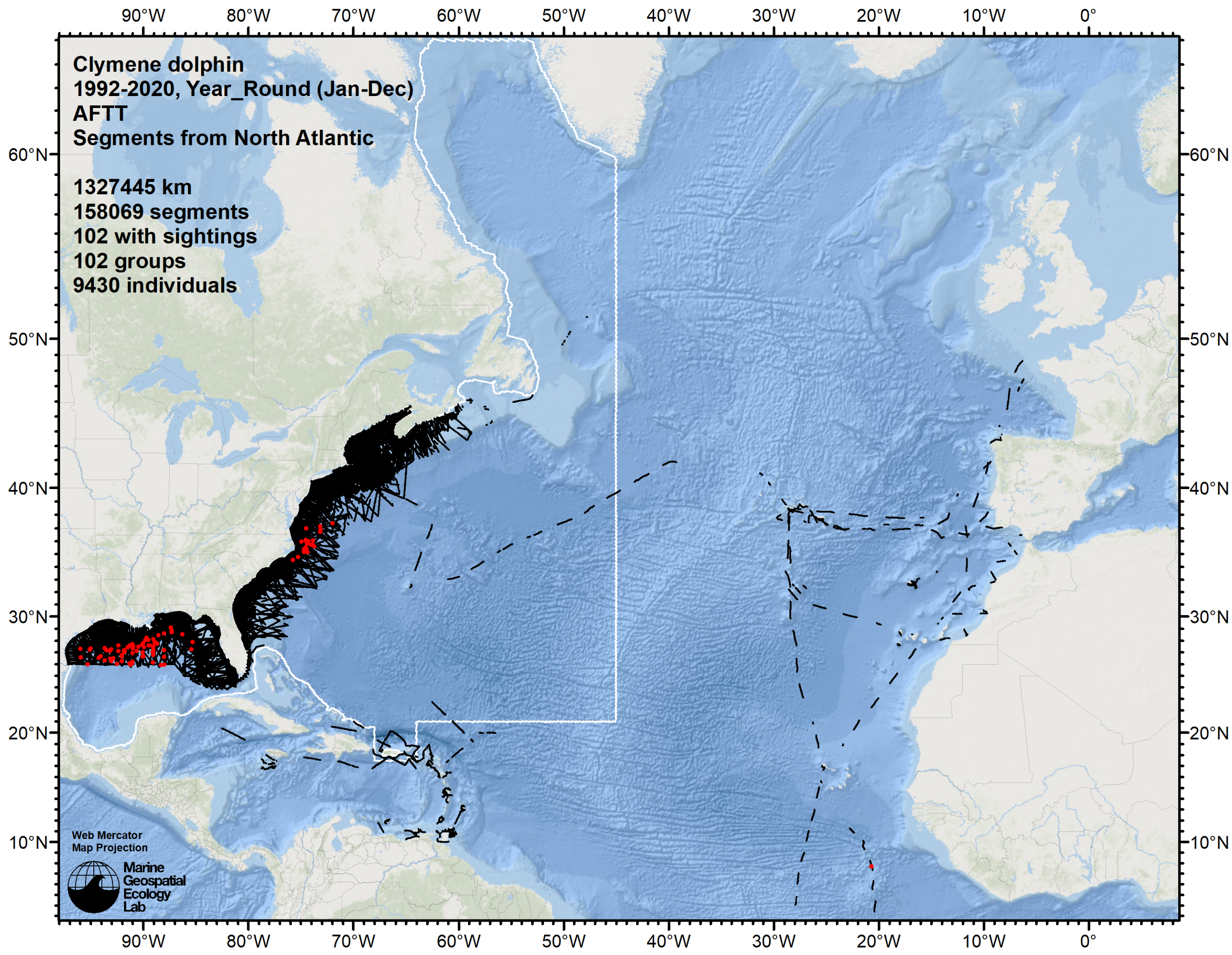


Figure 1: Survey segments (black lines) used to fit the model. Red points indicate segments with observations. This map uses a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

Statistical output for this model:

```
Family: Tweedie(p=1.497)
Link function: log

Formula:
IndividualsCorrected ~ offset(log(SegmentArea)) + s(SST, bs = "ts",
```

```
    k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -21.9307     0.9691  -22.63   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
         edf Ref.df     F p-value
s(SST) 2.348      3 13.69  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.000621   Deviance explained = 22.4%
-REML = 1472.7  Scale est. = 968.93    n = 157971

Method: REML   Optimizer: outer newton
full convergence after 13 iterations.
Gradient range [-2.130091e-06,1.561198e-06]
(score 1472.673 & scale 968.9295).
Hessian positive definite, eigenvalue range [1.057191,312.6959].
Model rank =  4 / 4

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

         k'  edf k-index p-value
s(SST) 3.00 2.35     0.6  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

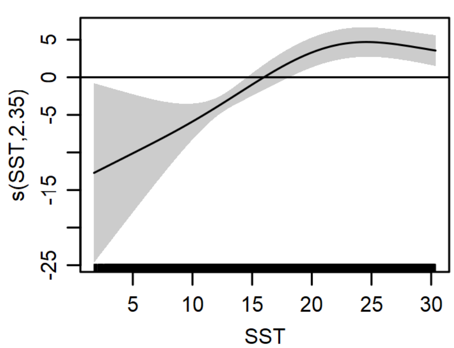


Figure 2: Functional plots for the final model. Transforms and other treatments are indicated in axis labels. *log10* indicates the covariate was $\log_{10}$ transformed. *sqrt* indicates the covariate was square-root transformed. */1000* indicates meters were transformed to kilometers for interpretation convenience.

Table 4: Covariates used in the final model.

Covariate	Description
SST	Climatological monthly mean sea surface temperature (°C) from GHRSST Level 4 CMC0.2deg (Brasnett (2008); Canada Meteorological Center (2012))

2.2 Diagnostic Plots

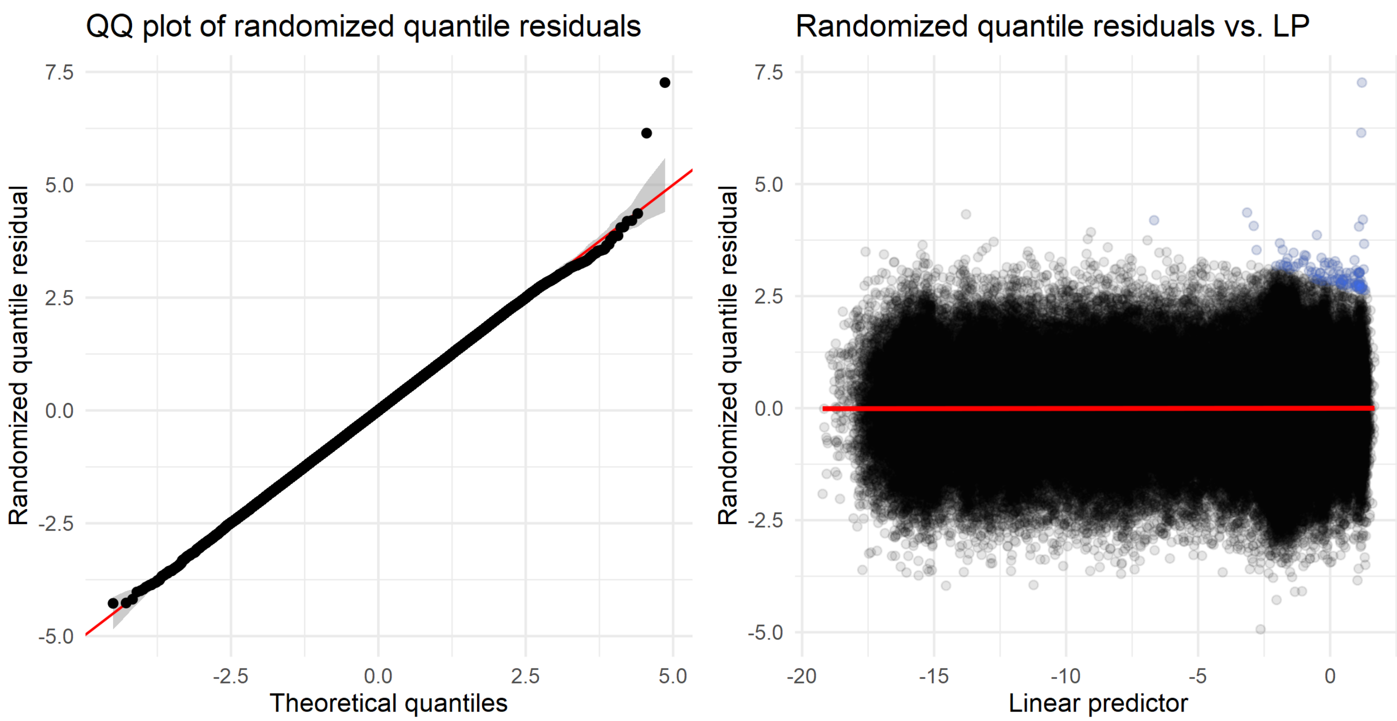


Figure 3: Residual plots for the final model.

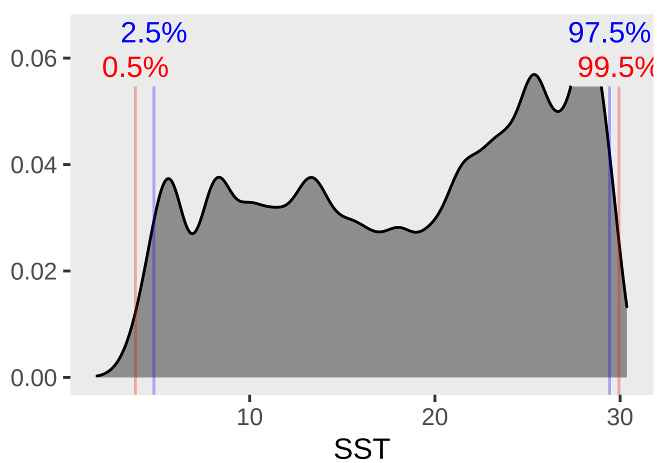


Figure 4: Density histograms showing the distributions of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Red and blue lines enclose 99% and 95% of the distributions, respectively. Transforms and other treatments are indicated in axis labels. *log10* indicates the covariate was $\log_{10}$ transformed. */1000* indicates meters were transformed to kilometers for interpretation convenience.

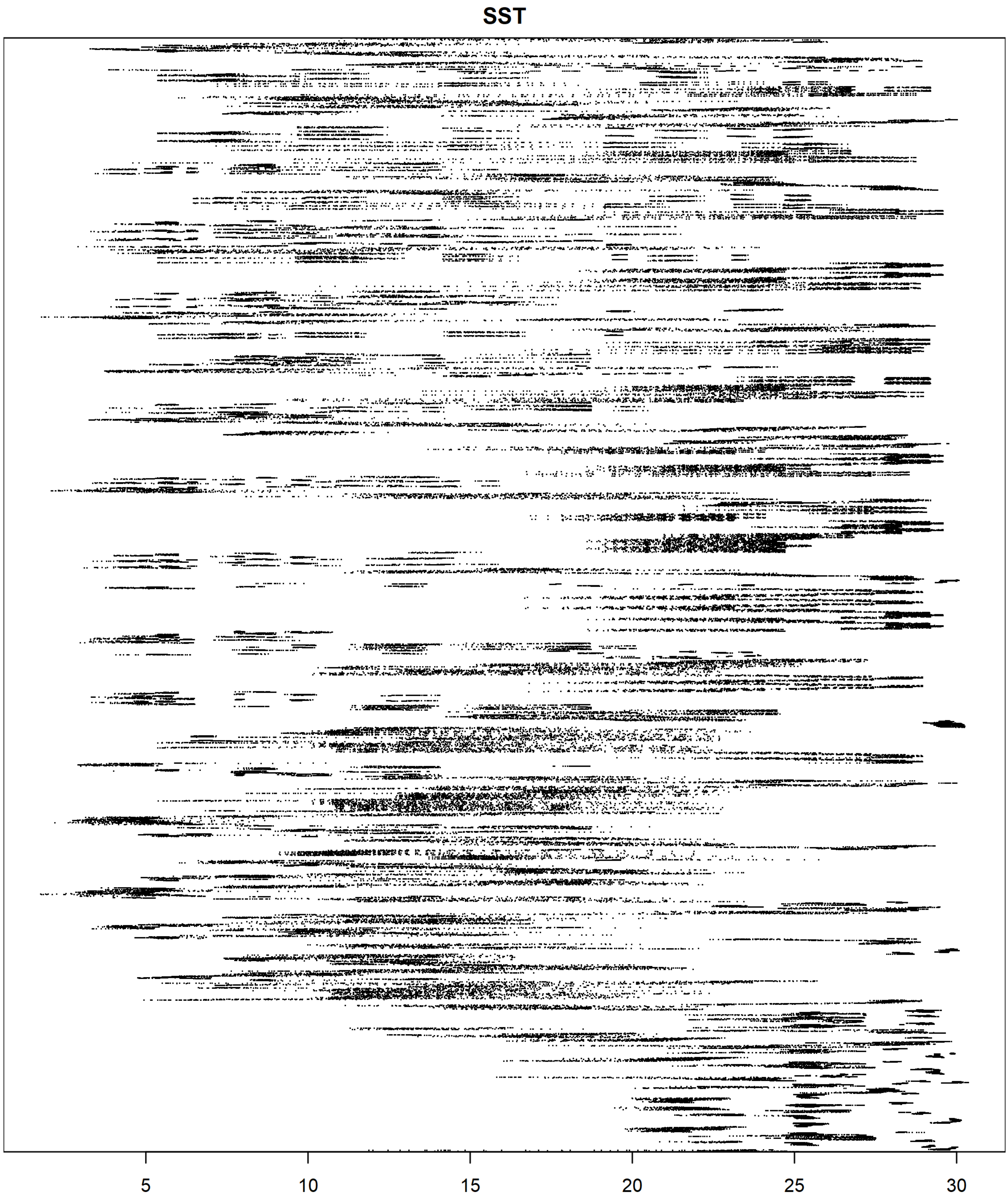
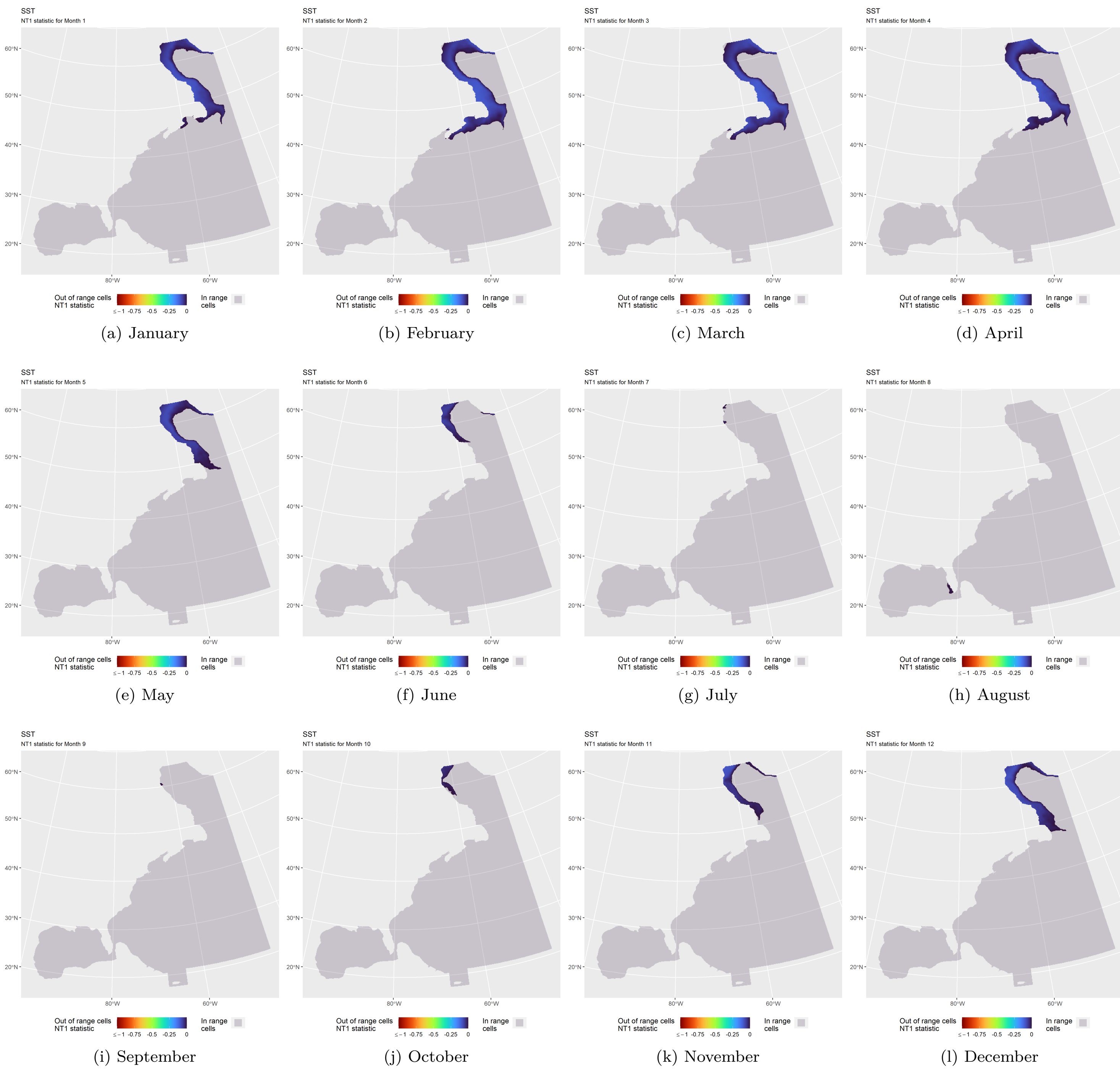


Figure 5: Dotplot of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed as shown in Figure 4. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by segment ID, sequentially in time.

2.3 Extrapolation Diagnostics



(a) January (b) February (c) March (d) April

(e) May (f) June (g) July (h) August

(i) September (j) October (k) November (l) December

Figure 6: NT1 statistic (Mesgaran et al. (2014)) for the SST covariate in the model. Areas outside the sampled range of a covariate appear in color, indicating univariate extrapolation of that covariate occurred there during the month. Areas within the sampled range appear in gray, indicating it did not occur.

3 Predictions

3.1 Summarized Predictions

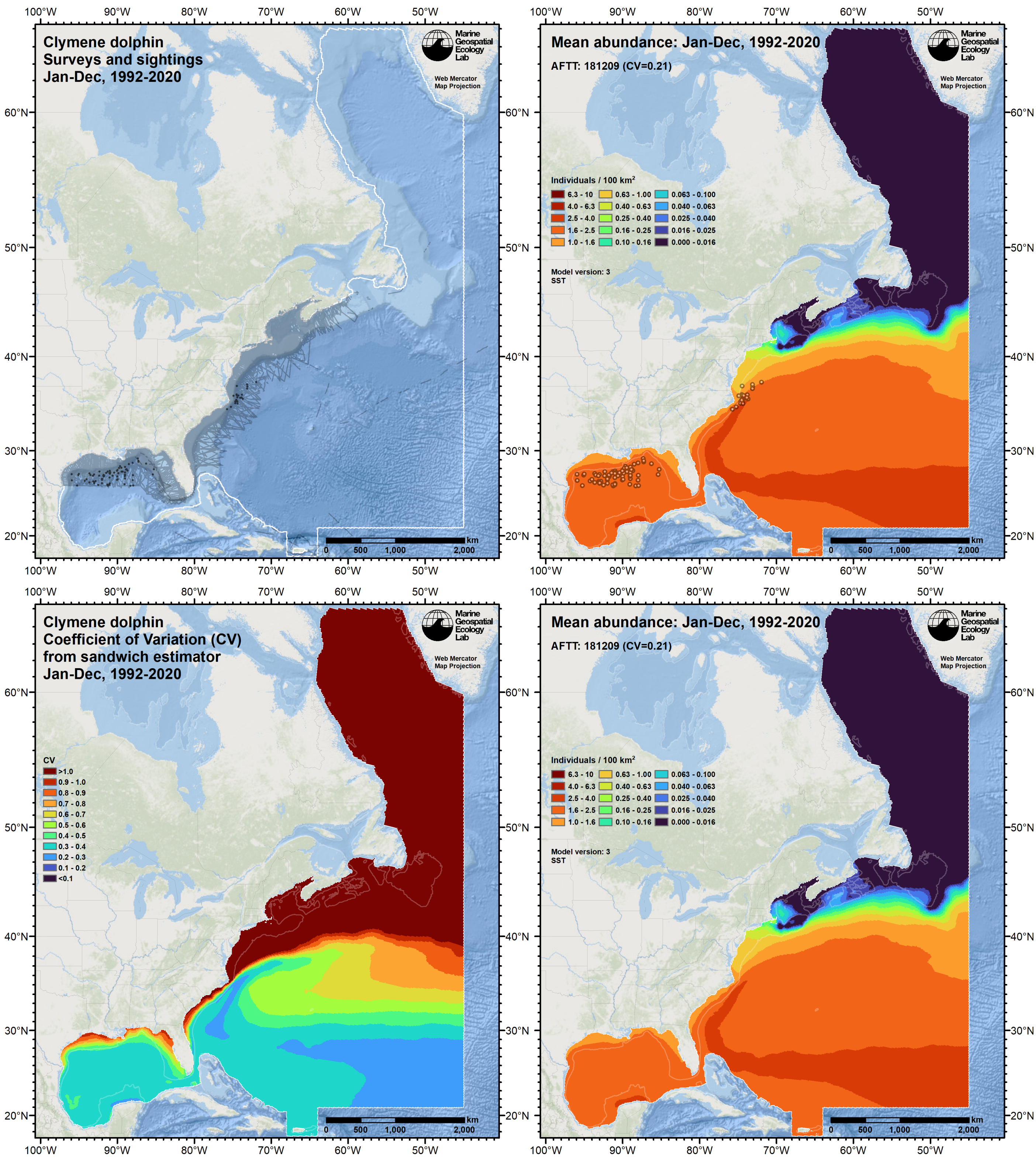


Figure 7: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the given era. Variance was estimated with the analytic approach given by Miller et al. (2022), Appendix S1, and accounts both for uncertainty in model parameter estimates and for temporal variability in dynamic covariates. These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

3.2 Comparison to Previous Density Model

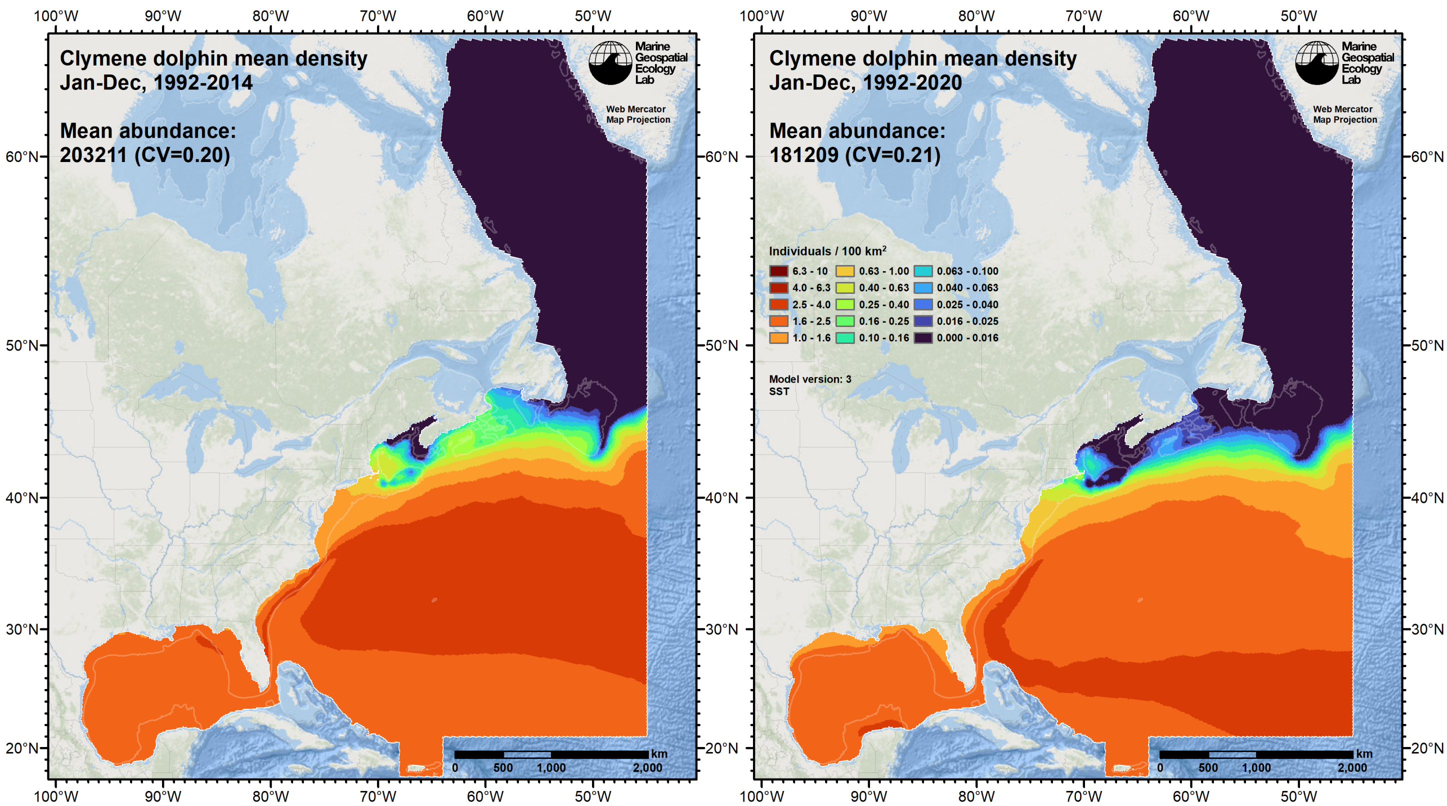


Figure 8: Comparison of the mean density predictions from the previous model (left) to those from this model (right). These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4 Discussion

Following what was done for the prior model, we summarized this updated model into a single year-round mean density surface (Figure 7). Although our figures show predictions for the entire AFTT study area, we recommend that the regional East Coast (EC) and Gulf of Mexico (GOM) models be used for the waters they cover, and that the AFTT model be used only for waters outside those regions. Those models accounted for the species' preference for deep, offshore waters, while this model did not. Also, in the EC region, all of the sightings have been reported around the Cape Hatteras area (Figure 1); the EC regional model accounts for this. Please see the regional model reports for more details, and Roberts et al. (2023) for overall descriptions of the regional models.

This model's predictions strongly resembled the prior model's predictions (Figure 8). Mean abundance predicted by the new model was about 11% lower than the old model but was not significantly different statistically.

Extrapolation analysis (Figure 6) showed that environmental extrapolation was necessary off northern Newfoundland, Labrador, and west Greenland in non-summer months, driven by the low sea surface temperatures there during those months. However, the Clymene dolphin, a tropical, subtropical, and warm-temperate species, is considered absent in these areas, so we do not find this extrapolation as cause for concern.

5 References

Barco SG, Burt L, DePerte A, Digiovanni R Jr. (2015) Marine Mammal and Sea Turtle Sightings in the Vicinity of the Maryland Wind Energy Area July 2013-June 2015, VAQF Scientific Report #2015-06. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Blaylock RA, Hoggard W (1994) Preliminary Estimates of Bottlenose Dolphin Abundance in Southern U.S. Atlantic and Gulf of Mexico Continental Shelf Waters: NOAA Technical Memorandum NMFS-SEFSC-356. NOAA National Marine

Fisheries Service, Southeast Fisheries Science Center, Miami, FL

Brasnett B (2008) The impact of satellite retrievals in a global sea-surface-temperature analysis. Quarterly Journal of the Royal Meteorological Society 134:1745–1760. doi: 10.1002/qj.319

Canada Meteorological Center (2012) GHRSST Level 4 CMC0.2deg Global Foundation Sea Surface Temperature Analysis Version 2.0. PODAAC, CA, USA. doi: 10.5067/GHCMC-4FM02

Cole T, Gerrior P, Merrick RL (2007) Methodologies of the NOAA National Marine Fisheries Service Aerial Survey Program for Right Whales (Eubalaena glacialis) in the Northeast U.S., 1998-2006. U.S. Department of Commerce, Woods Hole, MA

Cotter MP (2019) Aerial Surveys for Protected Marine Species in the Norfolk Canyon Region: 2018–2019 Final Report. HDR, Inc., Virginia Beach, VA

Davis R, Fargion G (1996) Distribution and Abundance of Cetaceans in the North-Central and Western Gulf of Mexico, Final Report Volume II: Technical Report. OCS Study MMS 96-0027. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA

Davis RW, Evans WE, Würsig B (2000) Cetaceans, Sea Turtles and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance and Habitat Associations. Volume II: Technical Report. OCS Study MMS 2000-003. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BED/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA

Foley HJ, Paxton CGM, McAlarney RJ, Pabst DA, Read AJ (2019) Occurrence, Distribution, and Density of Protected Species in the Jacksonville, Florida, Atlantic Fleet Training and Testing (AFTT) Study Area. Duke University Marine Lab, Beaufort, NC

Fulling GL, Mullin KD, Hubard CW (2003) Abundance and distribution of cetaceans in outer continental shelf waters of the US Gulf of Mexico. Fishery Bulletin 101:923–932.

Garrison LP, Martinez A, Maze-Foley K (2010) Habitat and abundance of cetaceans in Atlantic Ocean continental slope waters off the eastern USA. Journal of Cetacean Research and Management 11:267–277.

Geo-Marine, Inc. (2010) New Jersey Department of Environmental Protection Baseline Studies Final Report Volume III: Marine Mammal and Sea Turtle Studies. Geo-Marine, Inc., Plano, TX

Mallette SD, Lockhart GG, McAlarney RJ, Cummings EW, McLellan WA, Pabst DA, Barco SG (2014) Documenting Whale Migration off Virginia's Coast for Use in Marine Spatial Planning: Aerial and Vessel Surveys in the Proximity of the Virginia Wind Energy Area (VA WEA), VAQF Scientific Report 2014-08. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Mallette SD, Lockhart GG, McAlarney RJ, Cummings EW, McLellan WA, Pabst DA, Barco SG (2015) Documenting Whale Migration off Virginia's Coast for Use in Marine Spatial Planning: Aerial Surveys in the Proximity of the Virginia Wind Energy Area (VA WEA) Survey/Reporting Period: May 2014 - December 2014, VAQF Scientific Report 2015-02. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Mallette SD, McAlarney RJ, Lockhart GG, Cummings EW, Pabst DA, McLellan WA, Barco SG (2017) Aerial Survey Baseline Monitoring in the Continental Shelf Region of the VACAPES OPAREA: 2016 Annual Progress Report. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Mannocci L, Roberts JJ, Miller DL, Halpin PN (2017) Extrapolating cetacean densities to quantitatively assess human impacts on populations in the high seas. Conservation Biology 31:601–614. doi: 10.1111/cobi.12856

McAlarney R, Cummings E, McLellan W, Pabst A (2018) Aerial Surveys for Protected Marine Species in the Norfolk Canyon Region: 2017 Annual Progress Report. University of North Carolina Wilmington, Wilmington, NC

McLellan WA, McAlarney RJ, Cummings EW, Read AJ, Paxton CGM, Bell JT, Pabst DA (2018) Distribution and abundance of beaked whales (Family Ziphiidae) Off Cape Hatteras, North Carolina, U.S.A. Marine Mammal Science. doi: 10.1111/mms.12500

Mesgaran MB, Cousens RD, Webber BL (2014) Here be dragons: A tool for quantifying novelty due to covariate range and correlation change when projecting species distribution models. Diversity Distrib 20:1147–1159. doi: 10.1111/ddi.12209

Miller DL, Becker EA, Forney KA, Roberts JJ, Cañadas A, Schick RS (2022) Estimating uncertainty in density surface models. PeerJ 10:e13950. doi: 10.7717/peerj.13950

Mullin KD (1995) Cruise Report: Oregon II Cruise 215 (95-01): 26 January - 11 March 1995. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula, MS

Mullin KD (2007) Abundance of Cetaceans in the Oceanic Northern Gulf of Mexico from 2003 and 2004 Ship Surveys. Southeast Fisheries Science Center Reference Document PRBD-2016-03. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula, MS

Mullin KD, Fulling GL (2003) Abundance of cetaceans in the southern U.S. North Atlantic Ocean during summer 1998. Fishery Bulletin 101:603–613.

Mullin KD, Fulling GL (2004) Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996–2001. Marine Mammal Science 20:787–807. doi: 10.1111/j.1748-7692.2004.tb01193.x

Palka D, Aichinger Dias L, Broughton E, Chavez-Rosales S, Cholewiak D, Davis G, DeAngelis A, Garrison L, Haas H, Hatch J, Hyde K, Jech M, Josephson E, Mueller-Brennan L, Orphanides C, Pegg N, Sasso C, Sigourney D, Soldevilla M, Walsh H (2021) Atlantic Marine Assessment Program for Protected Species: FY15 – FY19 (OCS Study BOEM 2021-051). U.S. Deptartment of the Interior, Bureau of Ocean Energy Management, Washington, DC

Palka DL (2006) Summer abundance estimates of cetaceans in US North Atlantic navy operating areas (NEFSC Reference Document 06-03). U.S. Department of Commerce, Northeast Fisheries Science Center, Woods Hole, MA

Palka DL, Chavez-Rosales S, Josephson E, Cholewiak D, Haas HL, Garrison L, Jones M, Sigourney D, Waring G, Jech M, Broughton E, Soldevilla M, Davis G, DeAngelis A, Sasso CR, Winton MV, Smolowitz RJ, Fay G, LaBrecque E, Leiness JB, Dettloff K, Warden M, Murray K, Orphanides C (2017) Atlantic Marine Assessment Program for Protected Species: 2010-2014 (OCS Study BOEM 2017-071). U.S. Deptartment of the Interior, Bureau of Ocean Energy Management, Washington, DC

Read AJ, Barco S, Bell J, Borchers DL, Burt ML, Cummings EW, Dunn J, Fougeres EM, Hazen L, Hodge LEW, Laura A-M, McAlarney RJ, Peter N, Pabst DA, Paxton CGM, Schneider SZ, Urian KW, Waples DM, McLellan WA (2014) Occurrence, distribution and abundance of cetaceans in Onslow Bay, North Carolina, USA. Journal of Cetacean Research and Management 14:23–35.

Roberts JJ, Yack TM, Halpin PN (2023) Marine mammal density models for the U.S. Navy Atlantic Fleet Training and Testing (AFTT) study area for the Phase IV Navy Marine Species Density Database (NMSDD), Document Version 1.3. Duke University Marine Geospatial Ecology Lab, Durham, NC

Ryan C, Boisseau O, Cucknell A, Romagosa M, Moscrop A, McLanaghan R (2013) Final report for trans-Atlantic research passages between the UK and USA via the Azores and Iceland, conducted from R/V Song of the Whale 26 March to 28 September 2012. Marine Conservation Research International, Essex, UK

Swartz SL, Burks C (2000) Cruise Results: Windwards Humpback (Megaptera novaeangliae) Survey: NOAA Ship Gordon Gunter Cruise GU-00-01: 9 February to 3 April 2000 (NOAA Technical Memorandum NMFS-SEFSC-438). NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL

Torres LG, Mclellan WA, Meagher E, Pabst DA (2005) Seasonal distribution and relative abundance of bottlenose dolphins, Tursiops truncatus, along the US mid-Atlantic coast. Journal of Cetacean Research and Management 7:153.

Whitt AD, Powell JA, Richardson AG, Bosyk JR (2015) Abundance and distribution of marine mammals in nearshore waters off New Jersey, USA. Journal of Cetacean Research and Management 15:45–59.