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Risk Assessment for Marine Vessel Traffic and Wind Energy Development in the Atlantic

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Prepared for Bureau of Ocean Energy Management, Herndon VA

November 2013

¹Maritime Consultant



Pacific Northwest
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1.0 Introduction

The Bureau of Ocean Energy Management (BOEM) is initiating leasing of the seabed for offshore wind energy development on the outer continental shelf (OCS) in the Atlantic from Maine to Florida, with initial development planned for a series of Wind Energy Areas (WEAs) designated by the Department of Interior. Additional wind areas are under development and are currently considered to be Wind Call Areas (WCAs), leasing areas, and other set asides. Some of the proposed sites are located at or near the entrances to major ports, others are located at the seaward terminus of existing Traffic Separation Schemes (TSS), and many of the wind areas occupy locations along historical shipping routes. The siting of offshore wind farms has the potential to affect existing shipping along the Atlantic Coast; modifications to safe-access routes may be required.

The United States Coast Guard (USCG) has the authority to ensure navigational safety in U.S. waters. The USCG has undertaken the Atlantic Coast Port Access Study (ACPARS) to assess future port access and navigation needs for the Atlantic coast, at a time when the mix of shipping routes and vessels are likely to change due to factors such as the widening of the Panama Canal and opening of the Arctic Ocean to shipping. The presence of wind turbines off the Atlantic coast has the potential to affect shipping routes and activities. In order to safely incorporate the presence of offshore wind farms into ACPARS, the USCG requires information on the following: the effects of offshore renewable energy infrastructure on potential traffic density; the impacts of offshore wind infrastructure on shipping traffic including rerouting, funneling, and obstructions to navigation; and whether changes to safe access routes for vessels are needed with the installation of offshore wind farms, including modifications to fairways or TSSs.

BOEM entered into an Interagency Agreement in August 2012 with the US Department of Energy (DOE) to provide risk assessment expertise to the USCG development of ACPARS and BOEM's OCS leasing. DOE assigned Pacific Northwest National Laboratory (PNNL) to provide an assessment of navigational safety risks (including collision, contact, grounding, and stranding). PNNL structured the project around several activities: 1) acquisition and processing of Automated Identification System (AIS) data; 2) geospatial analysis to elucidate historical shipping routes; 3) development of a data-driven numerical model to predict vessel movements in the presence of offshore wind farms; 4) enlisting expertise in navigation from an experts' panel; 5) assessment of navigational risks from the presence of offshore wind farms; and 6) recommendations for changes to the navigation system to accommodate those changes.

This report focuses on the activities carried out by PNNL, in close coordination with BOEM and USCG, from August 2012 to November 2013, and indicates the priority actions for additional enhancement to the modeling system to be carried out from December 2013 through November 2014. The body of the report briefly introduces each step of the process, and reports on notable outcomes. Detailed descriptions, computations, and figures that represent each step are included in ten technical appendices.

1.1 Structure of the Navigation Risk Project

The process for estimating the risk of offshore wind development off the Atlantic coast using AIS data, developing a data-driven model, comparing existing (“base case”) shipping routes to future routes determined by the presence of wind farms (“scenarios”), and estimating risk is summarized in Figure 1.

The steps in the process are discussed in subsequent sections of this report.

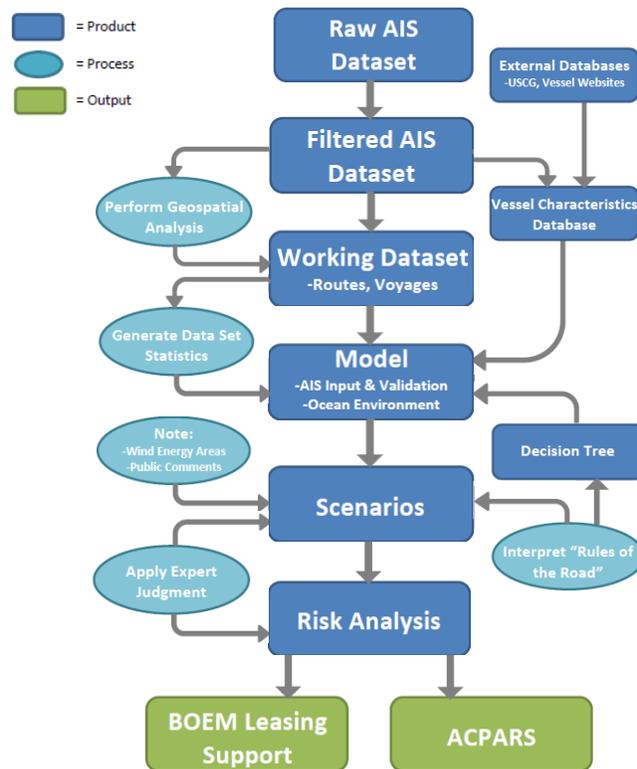


Figure 1: Process for acquiring, processing and applying AIS data for numerical modeling of navigation risk from offshore wind farms. The modeling critical path follows the center darker blue rectangles. Inputs processes provide further inputs (lighter blue ovals) and products (other dark blue rectangles) that build in a stepwise fashion. The green output rectangles represent to decision processes that the analyses will support.

2.0 AIS Data Processing

The USCG provided AIS datasets to PNNL covering a total of four years: 2009, 2010, 2011, and 2012. The datasets contained relatively raw AIS data for the entire US; the only processing that took place from the AIS receivers was to remove signals from military vessels and other unspecified processes. PNNL staff filtered the AIS data to retain only the domain of interest: the Atlantic coast from the Canadian border to the Florida Straits, and from the seaward extent of AIS coverage to mouths of Atlantic ports. Vessel movements in port (or landward of a port mouth) were not considered in our analyses because they were not considered to be affected by the development of wind farms offshore. Although AIS signals may be broadcast every few seconds to every few minutes, a one-minute interval was chosen (or less if the minimum broadcast period was greater than one minute). The results of the filtering process was a dataset that focused in the domain of interest, with a manageable size for data manipulation and storage.

The 2009 AIS dataset was found to have several flaws and it was decided that three years' of AIS data (2010, 2011, 2012) best represented the current state of Atlantic vessel traffic. The original dataset for 2010-2012 contained over 25 billion (25×10^9) points; the resulting filtered AIS dataset included approximately 1.1 billion (1.1×10^9) points.

The AIS dataset was used to draw tracks (repeated AIS data points over time) for each vessel voyage. From the AIS tracks, data discovery processes were enlisted to identify routes that are used by commercial vessels along the Atlantic coast. Processing of the AIS data also led to the generation of input files for use in the numerical model. These routes are further detailed in the next section. Details of the acquisition, processing, filtering, and application of the AIS data can be found in Appendix A.

3.0 Geospatial Analysis

The purpose of the geospatial analysis was to help with visualization of the 2010-2012 AIS tracks and to discover vessel routes. Based on methodologies developed in the UK (DTI 2005), routes were delineated for each vessel type (cargo, tanker, towing) that correspond to 95% of the vessel tracks. For historical routes that did not contain sufficient data to delineate 95% of the tracks, a delineation with 90% of the tracks were also created. At the request of the USCG, individual routes representing travel between each pair of ports along the Atlantic coast were determined, which provides a visual description of key routes, and include track densities as "heat maps." An example of a port to port route is shown in Figure 2. Details of the geospatial analysis and route discovery methods and outcomes are in Appendix B.

The geospatial database containing all the data layers that supports the analysis is delivered to BOEM as a separate attachment. These layers include:

- Tracks of filtered AIS data;
- Port to port routes for cargo, tanker and towing between ports along the Atlantic coast;

- Wind development areas designated by BOEM, including Wind Energy Areas (WEAs), Wind Call Areas, Lease Areas, and the planned Atlantic Wind Connection cable route and substation locations; and
- Location of buoys, beacons, and lights for the Atlantic coast.

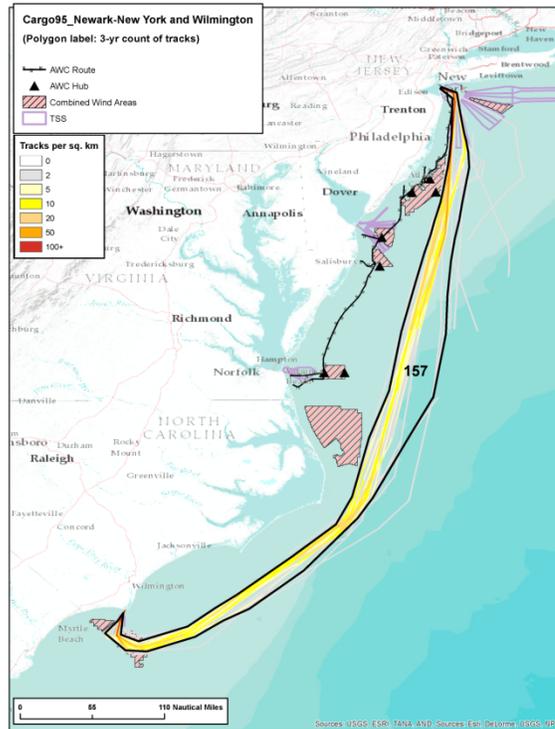


Figure 2: Map showing a polygon that represents the 95% boundary of cargo traffic between the ports of Newark-NY and Wilmington from 2010-2012.

4.0 Vessel Characteristics Database

Using the filtered AIS datasets, PNNL identified each vessel that appeared along the Atlantic coast for the years 2010, 2011, and 2012. A database of vessel characteristics was developed from these data that includes a subset of the AIS data types (identifier such as MMSI; vessel type such as cargo, tanker, towing; dimensions including length, width, and draft). AIS information was found to be missing or incorrect for some vessels; these data were added or corrected using the USCG AVIS database as a reference. Other information was obtained from online public databases. Other confounding factors to ensuring that the vessel database was correct and complete included several instances of ships changing name within the three year period 2010-2012; the most recent name for the ship was used in the vessel characteristics database.

Information from the vessel characteristics database was used as an input to developing and validating the numerical model for vessel movement. More details on the vessel characteristics database can be found in Appendix C.

5.0 Model Development

A numerical model was developed to simulate the movement of vessels along the Atlantic coast, driven by the AIS data. The model, dubbed the Marine Vessel Traffic (MVT) model, simulates the voyages of all vessels that ply the routes over a two week period. The vessels, 1,100 in all, match those found in the vessel characteristic database, and move based on the ocean conditions, capabilities of each vessel, and interact with one another using the rules of the road. The model includes probabilistic and stochastic (randomized) movements that simulate the natural variation of a vessel from a straight line between destinations. Like the AIS data, the model domain covers the Atlantic from the Canadian border to the Florida Straits, and from the mouth of the port entrances to the seaward extent of the AIS receivers (or the EEZ).

Output of the model can be mapped as vessel tracks and/or animations of ship movement. Output is also generated for use in model input debugging and risk analyses. The details of the model development and outputs are described in Appendix D.

6.0 Model Validation

Numerical models are simulations of the world and must be validated against real world data to ensure that the simulations are close to reality. The MVT model is based on AIS data, yet is driven by rules described through mathematical functions. Most commonly, data-driven models are validated by the collection of additional data against which they can be tested. However, the 2010-2012 AIS dataset upon which the model was based is very extensive; use of portions of the data to validate the model do not risk self-perpetuation of bias that might be contained in validating with a small dataset.

Three different types of validation were carried out under this project:

- Validating the movement of modeled vessels against real vessels from the vessel characteristics database;
- Validating the speed at which the model moves ships against speeds observed in the AIS data; and
- Validating the total distance traveled by any modeled vessel on a single voyage, against that which a comparable vessel would travel.

The movement of vessels was validated by choosing a subset of 41 cargo, tanker and towing vessels, that touched upon every port in the Atlantic, and using all TSSs, precautionary zones and other routing measures. AIS track data were plotted against the equivalent modeled tracks and any discrepancies noted. Extremely close correlation was found between the model tracks and the AIS tracks for the three vessel types and along all routes.

The speed and distance traveled by vessels in the model were checked against their AIS data counterparts, using a variety of techniques. Both attributes were well represented by the model. The detailed methods and results of the model validation can be found in Appendix E.

7.0 Base Case and Scenario Development

Understanding the increased risk to vessel movement from the presence of wind farms offshore requires a thorough understanding of the risk of casualties that occur before the development of wind farms – a situation called a base case. The risk of casualties for vessels navigating around wind farms in future can then be compared to the base case casualty rate to determine what increase (if any) will occur due to the presence of the wind farms; these future cases are called scenarios.

Two base cases were developed using the MVT model, simulating a two week period of vessel traffic in the Atlantic in July (summer, good weather), and in March (winter, poor weather). For each base case, future scenarios were developed that include the presence of wind farms. Additional scenarios can introduce further challenges to shipping, such as fog and high seas.

Table 1 summarizes the two base cases and four scenarios examined during this study period.

Table 1: Situations modeled for base cases and scenarios for vessel movement and wind farms.

Scenario	Base Case	Domain	Sub Domain	Additional Inputs
Base Case	July	Atlantic coast	none	Wind for July 2011
Base Case	March	Atlantic coast	none	Wind for March 2011
1	July	Atlantic coast, all wind areas	none	Wind for July 2011
2	March	Atlantic coast, all wind areas	none	Wind for March 2011
3	July	All Atlantic, all wind areas	Divide north/south	Add additional high wind speeds to simulate foul weather
4	March	All Atlantic, all wind areas	Divide north/south	Add additional high wind speeds to simulate foul weather

Details on the development and modeling of the base cases and scenarios can be found in Appendix F.

8.0 Risk Analysis

Vessel traffic has an inherent risk of collisions, allisions, and groundings. Those numbers are very low for any year, and are reported to the USCG as they occur. This project investigates the potential for additional risk to vessel traffic due to the presence of wind farms off the Atlantic coast. By modeling future scenarios that include wind farms, the marginal increase in risk can be calculated. By complicating future scenarios, for example by adding fog or inclement weather, additional potential risk can be evaluated.

8.1 Determining Risk

The model outputs for the two base cases (July and March) and for subsequent scenarios are compared to understand the increase in risk to vessel traffic from the presence of offshore wind farms; scenarios 1 and 3 are compared to base case A (July) and scenarios 2 and 4 are compared to base case B (March). Comparing each scenario against the appropriate base case, any additional encounters between vessels that appear for the scenario, is considered to potentially increase the risk to vessel traffic.

The USCG maintains the Marine Information for Safety and Law Enforcement (MISLE) casualty database for reported collisions, allisions, and groundings by vessel type, event and location. Using data for the Atlantic from this database for the period 2001 – 2011, PNNL staff determined the number of collisions, allisions and groundings per vessel voyage and per 1000 km travelled.

From the normalized casualty rates (derived from the MISLE database), a baseline number of collisions, allisions, and groundings were calculated for each base case. The additional encounters observed from the scenarios were also normalized to the casualty data. The increase in casualties from the scenarios (due to the presence of wind farms) can then be expressed as an increased risk to vessel traffic. A detailed description of the process of calculating risk from the model output and the casualty data is in Appendix I.

8.2 Outcome of Risk Calculations

Using the MISLE casualty data, and calculating the marginal increased risk to vessels from wind farms shows a moderate increase in collisions (~12%), and a small increase in groundings (~0.4%) over a year of vessel traffic along the Atlantic coast. While a risk of additional allisions (interactions with stationary objects like buoys and towers) can be calculated, it is generally considered that these interactions are seldom reported as casualties; underreporting allisions makes any baseline estimate of risk (and hence any marginal increase) suspect.

It is important to note that enhancements and refinements to the numerical model planned for 2014 may change the overall estimates of risk to vessel traffic from wind farms.

9.0 Experts' Panel

Working with the maritime consultant on the project team, Gregory Shelton, PNNL identified a group of experts in maritime shipping, navigation, and offshore wind development to work with the project team to provide input on specific areas of interest. The panel includes representatives from the major shipping associations for the major vessel types (cargo, tankers, towing and tugs) as well as former ships' captains, mariners, and pilots. Federal agency staff from BOEM and USCG also regularly participated with the panel, as did representatives of the offshore wind industry. Personnel from other sectors were invited to join but were not active in the process, including: fishers, recreational boaters, federal staff from NOAA and the US Army Corps of engineers. A full listing of the panel members and their affiliations, as well as a listing of the dates of the webinars and other meetings can be found in Appendix G.

The PNNL project team engaged the experts' panel through a series of planned webinars, through one-on-one contacts, and by reaching out to active mariners through association representatives. The main purpose of the webinars was to share specifics of the project and the progress being made, to provide a forum for the experts to ask questions, and for the PNNL team to ask for input on specific issues needed to inform the modeling and risk assessment effort.

Examples of the questions that were asked of the panel include:

- How do vessels select one TSS lane over another at Newark-New York, Delaware Bay, and Chesapeake?
- What is typical response to crossing situations? Course change, speed reduction, or both?
- What are typical vessel speeds in TSSs, coastal zone, and open ocean?
- What are typical maximum rudder angle of vessels?
- Pusher tugs appear to utilize TSSs similarly to cargo and tanker (Delaware). Why?
- What is a typical size (length, width, maximum draft) of barges using Atlantic coastal waters?
- What is typical size of vessel safety zones (fore/aft and abeam)? What is typical minimum distance between vessels = overtaking, head on, or in TSS?
- Do vessels typically follow line astern in TSSs? When would they not?
- How would you define "adequate sea room" for vessels, (for example if they were to pass landward of a wind farm)?
- How much room is needed for vessels to pass near shoals?
- Under poor weather conditions (fog), how much additional distance would you want between vessels before some evasion action might be needed? (this is our "encounter distance")
- Same question under high seas/high winds: how much additional encounter distance is needed?
- For towing, we have assumed each tug has a barge (or set of barges) that total 91 meters in length. Is this a reasonable assumption?
- Is the project team's interpretation of the rules of the road (to be used to train the model to allow ships to interact appropriately) properly defined by the following figure (
- Figure 3):

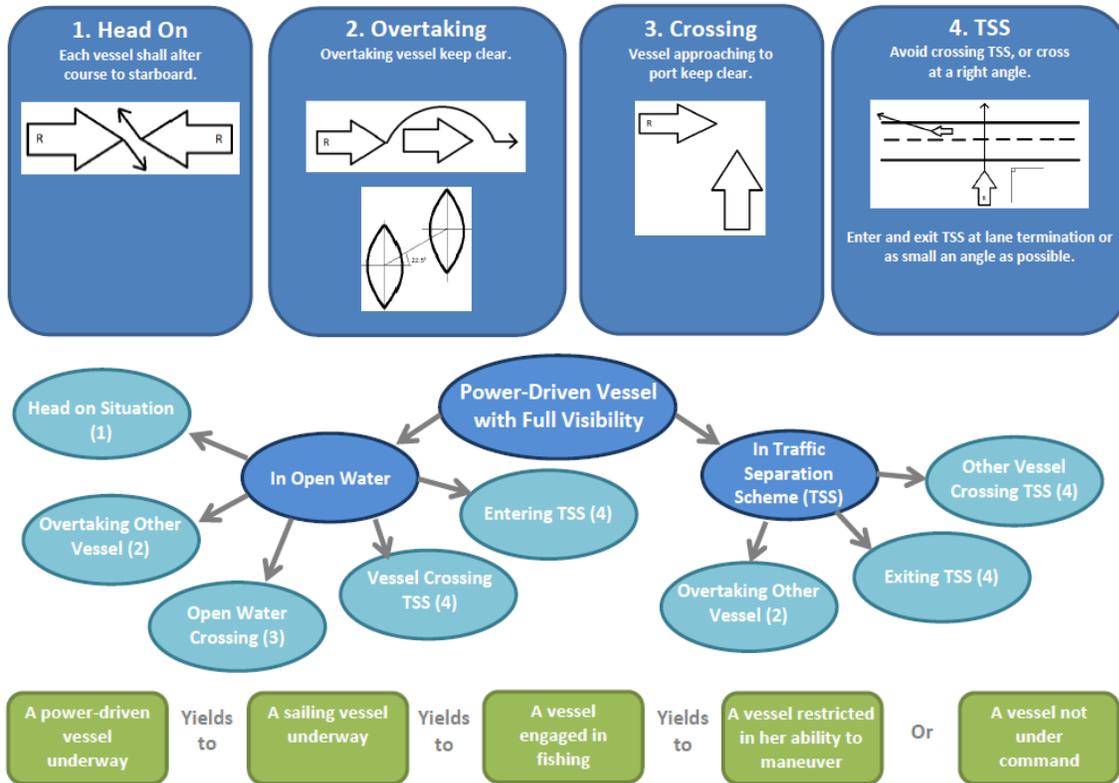


Figure 3: Graphical depiction of rules of the road, as presented to the experts’ panel for review, to be used to train the numerical model.

10.0 Technical Committee

Throughout the course of the project, a subset of PNNL, BOEM and USCG staff have met periodically as a technical committee to discuss technical issues associated with the AIS data, vessel characteristics, model development and validation, base case and scenario development, risk calculations, and outcomes of the project. The committee met by online meeting generally at a two week interval and twice while PNNL staff were in the Washington DC area. The technical committee played a valuable role in keeping the various project participants current on the state of the project, and was an excellent sounding board and source of advice for PNNL staff. A listing of technical committee participants and meeting dates can be found in Appendix H.

11.0 Users’ Manual

A users’ manual is under development to ensure that the process for applying the numerical model will be well understood by those who wish to use it. Appendix J contains the initial version of the users’ manual for the beta version of the model. As needed, additional detail may be added to include AIS data processing, model validation, and risk calculations.

12.0 References

The Department of Trade and industry (DTI). 2005. Guidance on the Assessment of the Impact of Offshore Wind Farms: Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms.

Appendix A - AIS Data Processing

A.1 Introduction

In recent years the use of Automatic Identification Systems (AIS) has become widespread in the shipping industry for commercial vessels of a specified tonnage as mandated by USCG regulations (IMO 2000). AIS data are recorded at time intervals that depend on the speed of the vessel (IALA 2004), with update frequencies ranging from as small as 2 seconds to several minutes. With the large number of vessels that traverse the waters of the Atlantic Coast of the US, AIS data for each year results in an accumulation of very large data set of the AIS records. For the purpose modeling analysis, these data need to be thinned and organized into a more usable form. This appendix describes the processing of the AIS data including rectification of problems identified during data processing.

A.2 Received Data

The U.S. Coast Guard (USCG) provided raw AIS data for the years 2010-2012 as comma-delimited files (CSV) with all military vessels removed. AIS data from 2010 and 2011 were provided as monthly data with vessel types mapped to seven types (cargo, tanker, towing, passenger, fishing, other, and unknown). However, AIS data from 2012 were provided as daily data with unmapped vessel types. Some attempts were also made to process AIS data from 2009, though the datasets were found to be problematic and ultimately not included in the AIS data analyses.

To create a more workable dataset, the first step was to reduce the size of the data by eliminating points either outside the spatial domain or at small time intervals. The spatial domain was chosen to extend from the southern tip of Florida to the U.S.-Canada border. AIS records were kept at a minimum of one-minute intervals, chosen because these points would be frequent enough to accurately represent vessel motion. Table A - 1 shows the exact counts of points during each of these reduction stages per year.

Table A - 1: Number of AIS Records at Various Stages of Reduction.

Points	2010	2011	2012
Original AIS Records	1,848,562,761	4,568,660,156	18,808,522,457
AIS Records within the spatial domain	340,070,249	895,388,637	4,250,335,733
AIS Records with minimum time interval of 1 minute	340,009,933	403,756,251	405,063,468

This data extraction (reduction) produced a set of track files partitioned by type. Within each file, the data are organized by vessel MMSI, and individual records sorted by time of recording.

A.3 Data Organization

The following fields were included in the raw AIS data: MMSI, coordinates, time, rate of turn, speed over ground, course over ground, heading, IMO number, call sign, name, length, width, draft, and vessel type. It was found that a few vessels had names that included commas, which caused the data to misalign in the CSV files. Additional processing was used to identify and remove the commas. Table A - 2 shows a list of these vessel names for reference.

Table A - 2: A list of names requiring comma correction.

Year	MMSI	Original Name	Corrected Name
2010	338669000	M,V GEYSIR	M V GEYSIR
2010	367241000	R,V_ATLANTIS	R V_ATLANTIS
2010	1193046	CAPT.W.A.BISSO,JR	CAPT.W.A.BISSO JR
2010	366820370	PILOTN0,4	PILOTN04
2010	219148000	ALICE,THERERA P	ALICE THERERA P
2010	259898000	KRISTIN,KNUTSEN	KRISTIN KNUTSEN
2011	319017800	G,020	G020
2011	366820370	PILOTN0,4	PILOTN04
2011	338669000	M,V GEYSIR	M V GEYSIR
2012	338045035	BETTYE-M,JENKINS	BETTYE-M JENKINS
2012	338669000	M,V GEYSIR	M V GEYSIR
2012	366963050	DALE A, HELLER	DALE A HELLER
2012	366963280	CAPT, O A FRANKS	CAPT O A FRANKS
2012	366988930	M,V MCNEIL	M V MCNEIL
2012	366995990	W.C.BINION JR,	W.C.BINION JR
2012	367057420	WILLIAM C, NORMAN	WILLIAM C NORMAN
2012	367158180	INTERN,L DISCOVERER	INTERN L DISCOVERER
2012	367365630	BARANOF,WIND	BARANOF WIND
2012	367371610	ARTHUR E, SNIDER	ARTHUR E SNIDER
2012	367505090	CAPT, DAN PRICE	CAPT DAN PRICE
2012	432685000	FUKUICHIMARU NO,83	FUKUICHIMARU NO 83
2012	495270931	PILOTN0,4	PILOTN04
2012	735059037	HCEG,B,E GUAYAS	HCEG B E GUAYAS

As previously stated, the AIS data were separated into files by type and ordered by MMSI and time so that the sequence of individual AIS records would represent the track of each individual vessel. In cases where there was a gap in the record that lasted more than one hour or extended more than 0.1 degrees, a space was added to the track indicating the lack of data. This ensured that when the tracks were plotted geospatially, the lines would represent tracks with clearly identifiable motion. The end result was a set of data representing all vessel motion on the Atlantic Coast of the United States for the periods 2010-2012.

A.4 Intersection Files

For further data reduction and ease of analysis of vessel voyages, transects were created. The first transects were placed across entrances to waterbodies containing major ports with more transects radiating concentrically away from these entrances. Designated entrances sometimes contained multiple ports, though all traffic on inland waterbodies were not included in the domain modeled, so the designated entrances was the destination for the purposes of AIS data analysis. Transects out at sea were drawn so as to be perpendicular to vessel travel direction in order to better distribute the points and capture widths of the commonly traveled routes. Figure A - 1 shows all the drawn transects along the entire Atlantic Coast, zooming in on the concentric transects around the Chesapeake entrance.

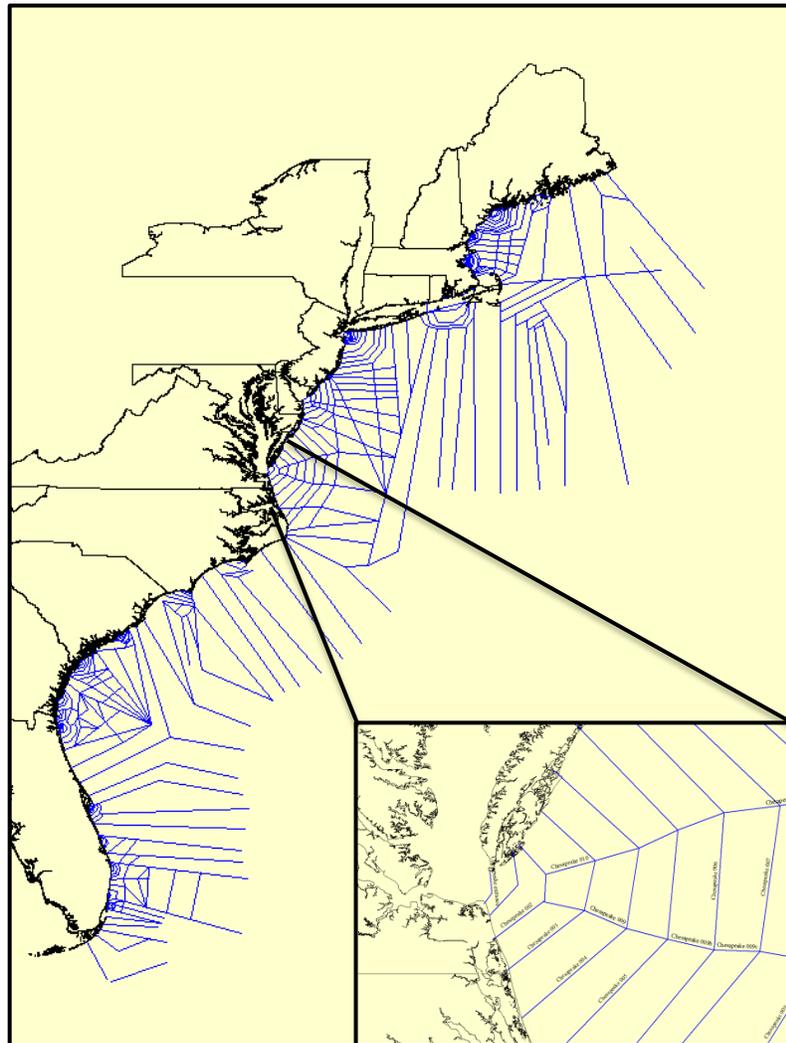


Figure A - 1: Transects drawn along the Atlantic Coast.

Points of intersection of the vessel tracks were then computed for all transects. Each of the intersection points included the following fields: MMSI, transect name, coordinates, time, vessel type,

vessel name, heading, speed, and vessel dimensions. The heading and speed were calculated based on AIS records bounding the intersection point. The resulting intersection file sizes were decreased by at least 100 times in comparison with the track file sizes. The inclusion of transect names to ease identification of the intersection point location, and keywords such as “entrance” were used to assist in the subsequent analyses. Figure A - 2 shows an example of the creation of transect points for a cargo vessel called the Atlanta Express.

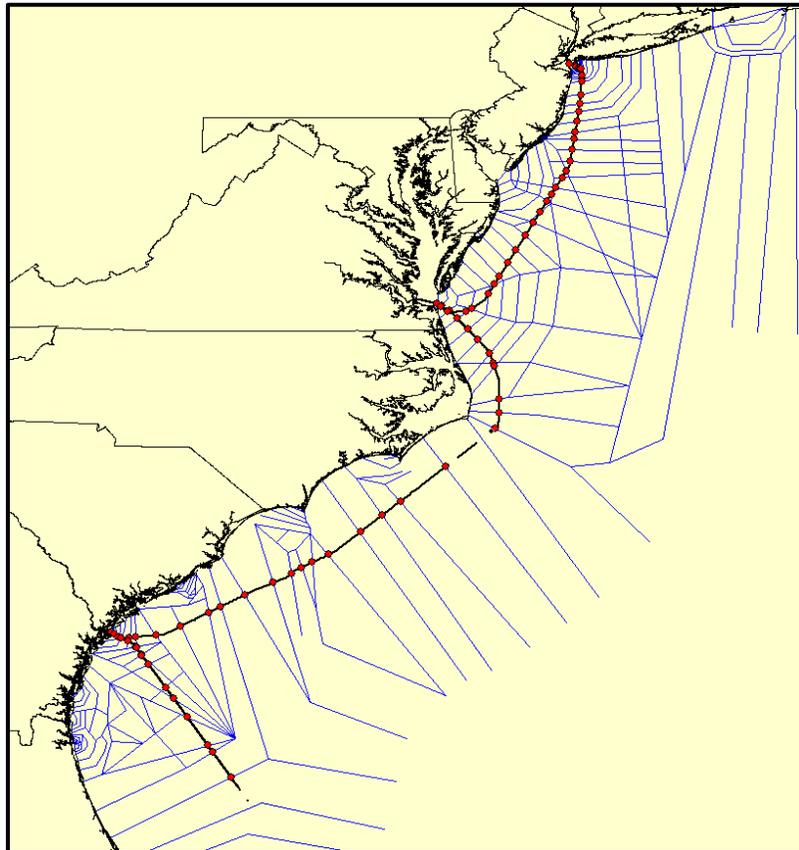


Figure A - 2: An example of intersections generated for the Atlanta Express vessel.

During this intersection analysis process, a few additional changes were made to clean up the data set. The intersection files were separated by all seven types, so when some vessels were found to have a different type than found in the vessel characteristics database (Appendix A), these points need to be moved to the respective files. Furthermore, situations existed where an MMSI was less than the required 9 digits. It was assumed that the last digits were simply being dropped; the 0s were added to the truncated MMSI to give 9 digits. The result was compare against the vessel characteristics database to determine that a real vessel was being represented. If no match in the vessel characteristics database was found, then the AIS-based vessel entries were removed from the dataset. Table A - 3 lists the deleted vessels.

Table A - 3: Vessels deleted due to MMSI errors.

2010		2011		2012	
MMSI	Type	MMSI	Type	MMSI	Type
1195	Cargo	2157100	Cargo	1193046	Cargo
7718175	Cargo	3041300	Cargo	8656952	Cargo
8913710	Cargo	9036002	Cargo	9036002	Cargo
9245677	Cargo	21846000	Cargo	25874000	Cargo
36376000	Cargo	23814000	Cargo	37067700	Cargo
36676000	Cargo	36376000	Cargo	1023636	Towing
37067700	Cargo	53890215	Cargo	1193046	Towing
9263942	Tanker	98765	Towing		
46809	Towing	290907	Towing		
528453	Towing	298716	Towing		
572329	Towing	528453	Towing		
587370	Towing	587370	Towing		
608097	Towing				
693559	Towing				

After the intersection files were combined into an annual data set, they were sorted by vessel MMSI and time, thus generating points representing a line that represents the vessel movement.

A.5 Voyage Discovery

Examination of the intersection files revealed large time gaps in the voyages due to vessels leaving the domain, turning off their AIS system, entering a port, or losing signal with a receiver. To differentiate between a gap in the middle of a voyage and an entirely new voyage, iterative tests were conducted with several time intervals before settling on a gap greater than 24 hours as designating as a new voyage. Special handling identified cases of anchoring to prevent them from causing breaks in voyages if a vessel spends longer than 24 hours at anchor. These identified voyages were used directly as input to the marine vessel traffic model discussed in Appendix D.

Intersection files analyzed and voyages parsed into three categories: (1) two port, (2) one port, and (3) no port. A two-port voyage was determined by whether entrance transects were found at the endpoints of each voyage, as seen in Figure A - 3. A one-port voyage was assigned if the voyage began or terminated at a port. A no-port voyage was assigned if voyage began and ended without being at a port. Using these designations, the voyages were also utilized for geospatial analysis (Appendix B) making this use of voyage data a parallel activity to that for the modeling analyses.

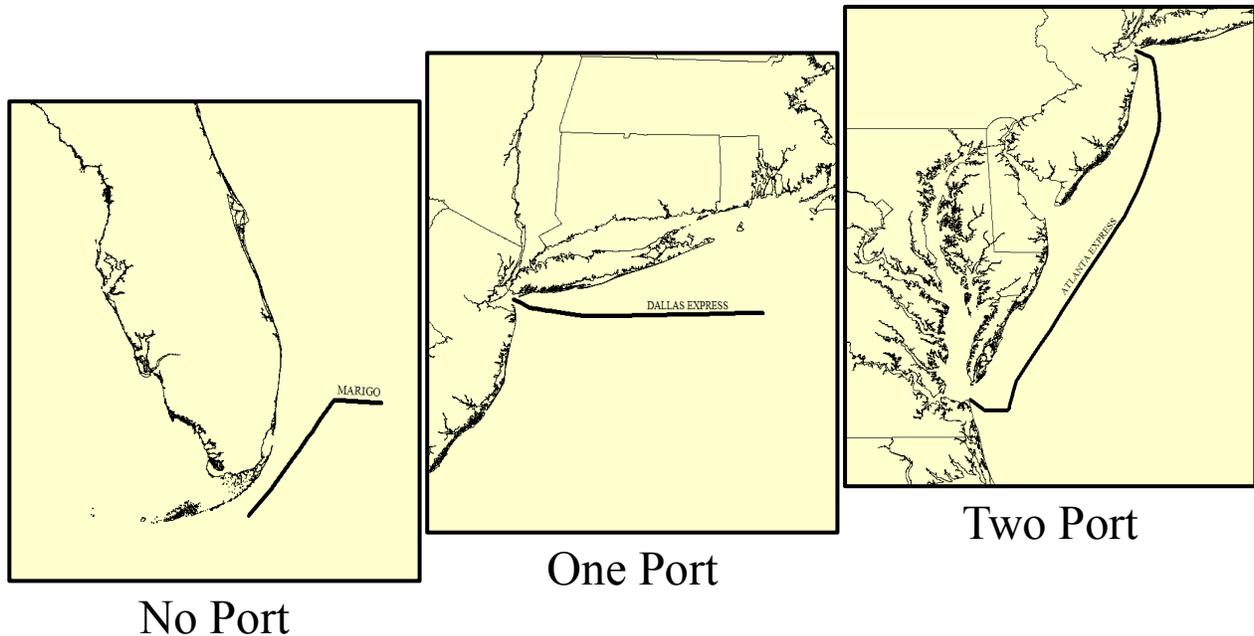


Figure A - 3: The three categories created during the Voyage Discovery.

Statistics were also gathered for validation purposes. Voyage counts were tracked by vessel type and for each combination of entrances. Travel time in days and travel distance in kilometers were also computed for all voyages excluding time at ports and outside the domain. These were also organized by vessel type and voyage categorization, for use in model validation. Table A - 4, Table A - 5, Table A - 6, and Table A - 7 show statistics gathered from all three years of available AIS data.

Table A - 4: Voyage counts arranged by voyage category, obtained from available AIS data.

	Cargo	Tanker	Towing
2010 – Two Port	8,721	1,447	10,616
2010 – One Port	24,757	7,125	3,979
2010 – No Port	5,847	4,773	2,269
2011 – Two Port	9,514	1,487	13,212
2011 – One Port	25,623	7,391	4,457
2011 – No Port	6,016	4,739	2,357
2012 – Two Port	8,520	1,336	14,923
2012 – One Port	24,190	5,918	4,673
2012 – No Port	6,943	4,523	4,178

Table A - 5: Voyage counts obtained from available AIS data.

Voyages	Cargo	Tanker	Towing	Total Voyages
2010	39,325	13,345	16,864	69,534
2011	41,153	13,617	20,026	74,796
2012	39,653	11,777	23,774	75,204
Annual Average	40,044	12,913	20,221	73,178

Table A - 6: Travel time (days) obtained from available AIS data.

Travel Time (days)	Cargo	Tanker	Towing	Total Travel Time
2010	22,543	6,940	8,508	37,991
2011	23,769	7,296	9,374	40,439
2012	22,218	6,234	9,044	37,496
Annual Average	22,843	6,823	8,975	38,642

Table A - 7: Travel distance (km) obtained from available AIS data.

Travel Distance (km)	Cargo	Tanker	Towing	Total Travel distance
2010	13,407,718	3,45,810	2,816,417	16,224,135
2011	14,000,235	3,552,080	3,015,530	20,567,845
2012	12,858,635	3,005,243	2,881,440	18,745,318
Annual Average	13,422,196	3,278,662	2,904,462	18,512,433

A.6 Creating Model Inputs

Two files were to be generated from AIS preprocessing for use as model inputs, a vessel file and a voyage file. The vessel file is a list of vessels, detailing all the necessary physical characteristics required by the model. The voyage file is a list waypoints by vessel meant to designate when to start moving and to what route is followed during a voyage. File formats were a combination of comma-delimited and specific headers to signal different operations in the model.

Figure A - 4 shows one example from the vessel file; the first three fields are vessel identifiers, followed by physical characteristics, and then followed by default model inputs. While most of the physical vessel traits existed in the vessel characteristics database (Appendix C), maximum speed and average speed were taken directly from the intersection files so that they are based on AIS data. The pilot is a random name assigned to vessels, with each pilot assigned different maneuvering skill and reaction times, allowing vessels to respond differently to the same situation. The use of these variables is discussed in Model Development (Appendix D).

```
//Vessel
Type = Cargo-Bulk Carrier
Name = UBC TARRAGONA
MMSI = 209017000
Pilot = Steve
Width = 28.6 m
Length = 182.59 m
Draft = 10.85 m
BlockCoefficient = 0.825
Displacement = 47912692.14 kg
Horsepower = 10697 hp
MaxSpeed = 9.153096 m/s
AverageSpeed = 6.569321 m/s
MaxRudderAngle = 35.0°
Navigation = TBD
Detection = v
DetectionZone = TBD
SafetyZone = TBD
VesselDriftDragCoefScaleFactor = 1.0
VesselDriftLiftCoefScaleFactor = 0.6
RudderAreaScaleFactor = 1.0
DragCoefDuringRotation = 1.3
MaxRudderApplicationRate = 3.0
EffectiveRudderWakeFraction = 0.4
WakeEffectExponent = 1.7
```

Figure A - 4: Example from the vessel file.

Before a voyage file can be generated, voyage endpoints need to be determined from a process similar to the voyage discovery. Vessel heading is considered when crossing an entrance transect and an entrance crossing is estimated for situations where a vessel leaves a port without ever having entered the port or vice versa. Special handling occurs for ships at anchor for more than 24 hours outside an entrance; the time is counted as time spent within the closest port to the anchoring. The voyages are also cleaned by deleting “voyages” involving only one isolated point and removing the middle entrance transects when many are found in a row. The latter is indicative of a vessel traveling parallel and repeatedly crossing a transect. The result was a list of points designating voyage endpoints as seen in Figure A - 5.

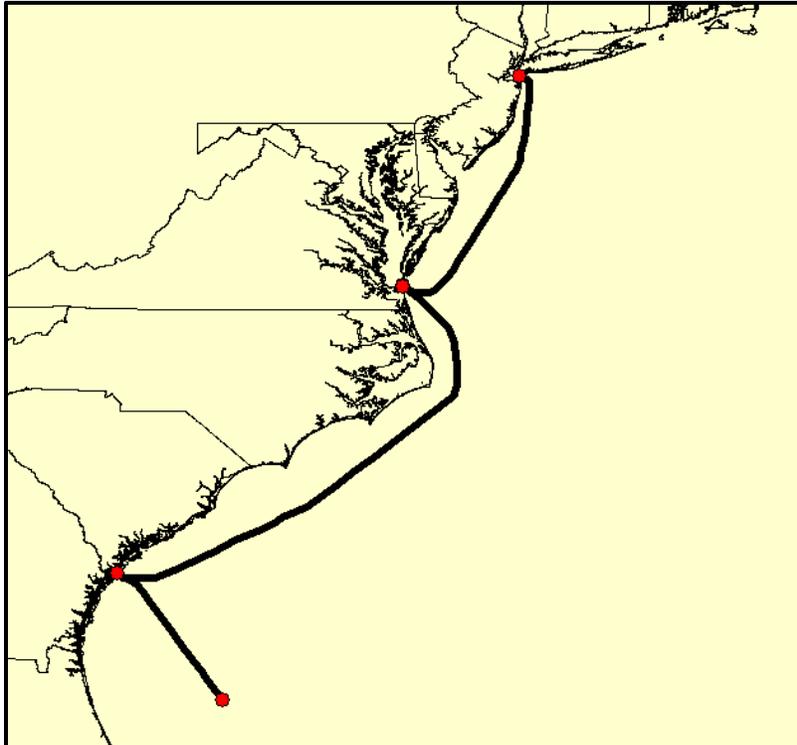


Figure A - 5: Endpoints used to guide the creation of the voyage file.

These endpoints are then assigned one of four point identifiers: (1) DomainIn, (2) DomainOut, (3) PortIn, or (4) PortOut. A DomainIn will always include starting coordinates, date, heading, and speed. A PortIn will include coordinates and the number of days spent in port. A PortOut will include coordinates, heading, and speed. A DomainOut only requires coordinates. For the PortIn, duration in port is used because voyages in scenarios involving windfarms and routing measures may need to alter their course, so the simulation relies only on starting times and durations to determine schedules. Identifiers are always paired in order to designate the two endpoints of each voyage. Waypoints are added from the intersection file to fill in voyage information between endpoints. Figure A - 6 shows one example from the voyage file; the vessel is seen entering the domain, entering the Wilmington port, and then leaving the domain.

```

//Voyage
VesselName=UBC TARRAGONA
VesselMMSI=209017000
NumberOfNavigationPoints=17
DomainIn=South Atlantic 036,-77.8556326261,33.2849978906,2011-07-12 07:40:53.503333,320.190489,7.382978
WayPoint=Wilmington 007c,-77.9750203986,33.4032012866
WayPoint=Wilmington 005,-78.1235571388,33.5605714515
WayPoint=Wilmington 004,-78.0959364543,33.6565398516
WayPoint=Wilmington 003,-78.0769318135,33.7339559785
WayPoint=Wilmington 002,-78.0446530858,33.7876133588
WayPoint=Wilmington 001,-78.0216121991,33.8589998218
PortIn=Wilmington entrance,-78.0067664306,33.8807578815,2.316959,2011-07-12
PortOut=Wilmington entrance,-78.0068959552,33.8808478227,190.050229,6.571125
WayPoint=Wilmington 001,-78.0223514576,33.8592859102
WayPoint=Wilmington 002,-78.0457598898,33.7881905387
WayPoint=Wilmington 003,-78.1059134262,33.7439994266
WayPoint=Wilmington 004,-78.1753325400,33.6777466066
WayPoint=Wilmington 005,-78.2628824880,33.5851866979
WayPoint=Wilmington 006,-78.3003379977,33.4634460171
WayPoint=Wilmington 007,-78.3181467066,33.3308867035
DomainOut=South Atlantic 033,-78.4176733242,32.7638864355

```

Figure A - 6: Example from the voyage file.

A.7 References

International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA). 2004. IALA Guideline No. 1028 on the Automatic Identification (AIS).

International Maritime Organization. 2000. The International Convention for the Safety of Life at Sea, Amendment.

Appendix B - Geospatial Analysis

B.1 Introduction

As outlined in the scope of the project, PNNL was tasked to perform numerous geospatial operations on the raw and filtered AIS data. These analyses were critical for visualizing the nature of the raw AIS data and products synthesized from the raw data. The geospatial activity relied heavily on the output of voyage discovery process outlined in - AIS Data Processing Appendix A.

An early investigation of the density of ship traffic for the eastern seaboard led to a request from BOEM and the United States Coast Guard (USCG) to create a GIS database of port-to-port routes. The port-to-port route polygons represent the boundary that encompasses 95% of the voyages between port combinations. These geospatial derivatives from the AIS data can be used to provide an understanding of ship traffic without having to load millions of AIS points.

When port-to-port route polygons are overlaid on Wind Energy Areas the resulting map reveals areas that may require special attention during model simulations. An example set of these maps can be seen in Figure B - 4 to Figure B - 9 at the end of this document.

B.2 Voyage Discovery

Examination of the intersection files revealed large time gaps in the voyages that would result due to vessels leaving the domain, turning off their AIS system, entering a port, or losing signal with a receiver. In order to differentiate between a gap in the middle of a voyage and an entirely new voyage, iterative tests were conducted using several time steps. Based on this analysis, we determined that for a single vessel, any gap greater than 24 hours would be designated as a new voyage. Special handling identified cases of anchoring to prevent them from causing breaks in voyages if a vessel spent longer than 24 hours at anchor.

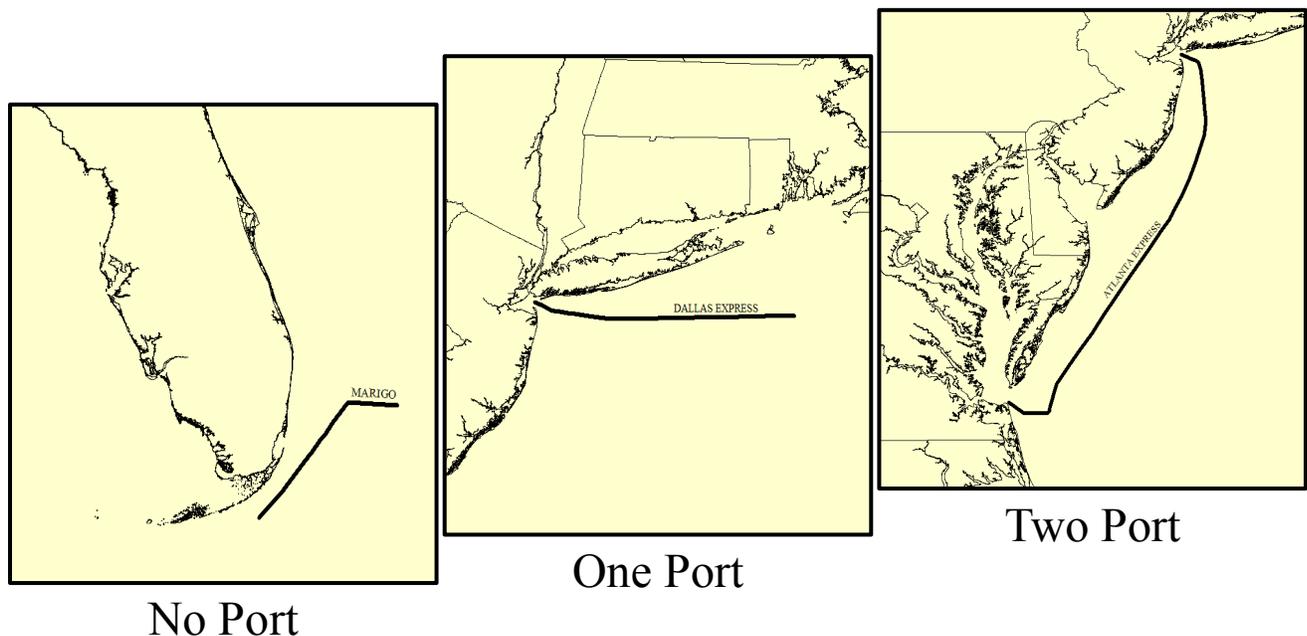


Figure B - 1: The Three Categories Created during the Voyage Discovery.

Intersection files were parsed into three categories: (1) two port, (2) one port, and (3) no port. This was determined by whether entrance transects were found at the endpoints of each voyage, as seen in Figure B - 1. Only the two port category was utilized during the geospatial analysis, as these represented voyages that defined routes between ports. Files were organized by bi-directional port combination for cargo, tanker, and towing vessels separately.

B.3 Route Density Rasters

The intersection points on transects were isolated for each vessel that transited between two ports. The route points were connected to create a line for each for each identified transit between the two ports. The lines were converted to density rasters (heat maps) via ArcGIS 10.0 LINEDENSITY function. This function calculates the density of linear features in the neighborhood of the output raster pixel. The function was parameterized to calculate the density in units of tracks per square kilometer and the output was stored as Tagged Image Format (TIF).

B.4 Port-to-port Polygon Route Delineation

According to Guidance on the Assessment of the Impact of Offshore Wind Farms (DTI 2005), “As a minimum the route width should accommodate 95% of all traffic transiting each route.” Using the AIS data we isolated all voyage points that indicated travel between two ports. The voyage lines represented by the points were intersected with transects and the intersection points along each transect were ordered and counted in order to calculate points along each transect that bounded 95% of all traffic moving between ports. Because of AIS drop outs (AIS signal loss resulting in a gap in the data stream) that often would occur away from ports, a different number of points would be found on each transect. If more than a quarter of transects had fewer than 20 trips during the 3-year period, the 90% boundary was calculated instead. However, if more than a quarter of those transects had fewer than 10 intersections, then the port-to-port route was eliminated. The intersection points were tallied for each transect and we identified points outside the 95th (or 90th) percentile count. For example if there were 80 voyage tracks crossing a transect, our count would be 80 intersection points on that transect. To identify the locations of the 95th percentile boundaries, we removed 2 points (2.5% of 80=2) from either side, leaving the two outer-most points as the 95th percentile bounds. In cases where the 95% (or 90%) limit was an odd value, we dropped the odd voyage line furthest from the mean voyage location.

The points resulting from this transect analysis were then connected via concave hull function to create the port-to-port boundary polygon for every port-to-port route combination. In some cases the concave hull function contained artifacts that were hand edited to create a more realistic representation of the boundary (~15% of port-to-port polygons). An example of the polygon overlaid with lines and density raster can be seen in Figure B - 2.

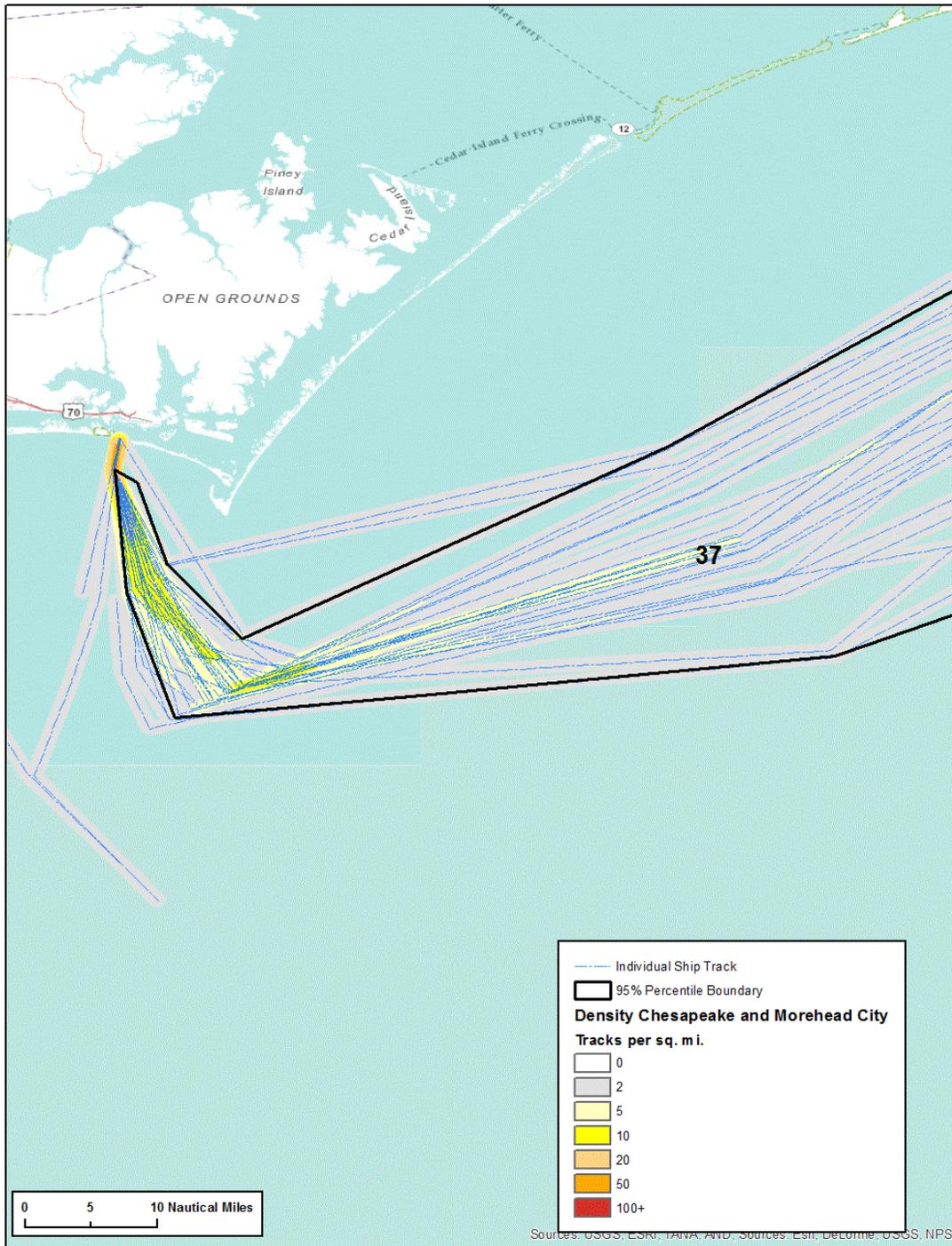


Figure B - 2: Example of the three GIS representations of port-to-port route polygons: lines, density raster and resulting polygon.

B.5 Geodatabase Development

A GIS database was created to house the geospatial derivatives of the AIS data. Voyage lines, track density and bounding polygons are intended to provide various levels of representation of the cargo, tanker and towing voyages from 2010-2012. Lines representing individual voyages show the routes transited by individual vessels between 2 ports. Density rasters created from lines is a further refinement of the data showing numbers of overlapping tracks during the period of analysis. The polygon data represent the highest level of geospatial synthesis of the AIS data and represent the statistical bounds of the traffic between 2 ports over the period of analysis (Table B - 1).

The polygon routes were attributed with traffic type (cargo, tanker or towing), port 1, port 2 (no particular order), area and count of voyages between two ports over the three years of AIS data.

Table B - 1: GIS layers and their attribution.

Layer Type	Attribution
Line	Traffic type, Length, Port 1, Port 2
Density Raster	None (pixel value represents number of voyages per square kilometer)
Polygon	Traffic type, Area, Port1, Port2, Count of voyage between ports 2010-2012

The line, density raster and polygon files were added as features to an ArcGIS 10.1 feature database. To rapidly locate and select particular port-to-port GIS data layers, we created a tool in the Geodatabase that allows a user to query by port (Figure B - 3).

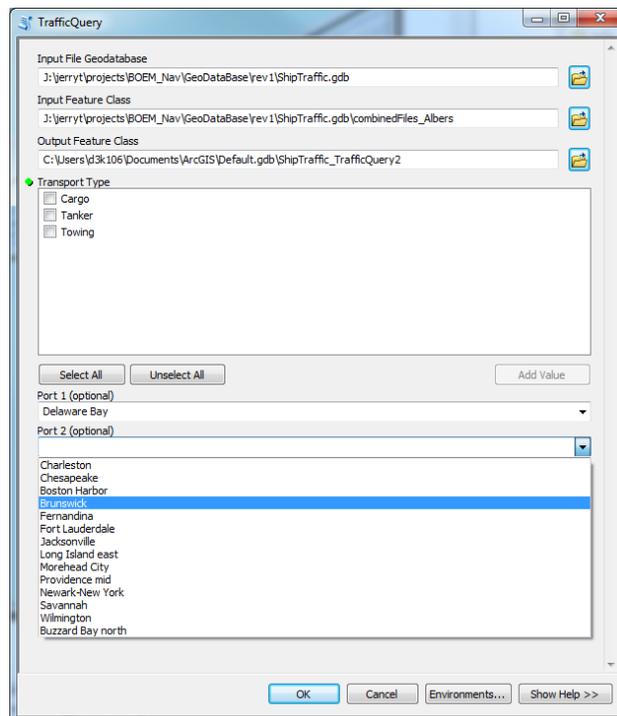


Figure B - 3: Interface for GIS query tool.

B.6 Example Maps

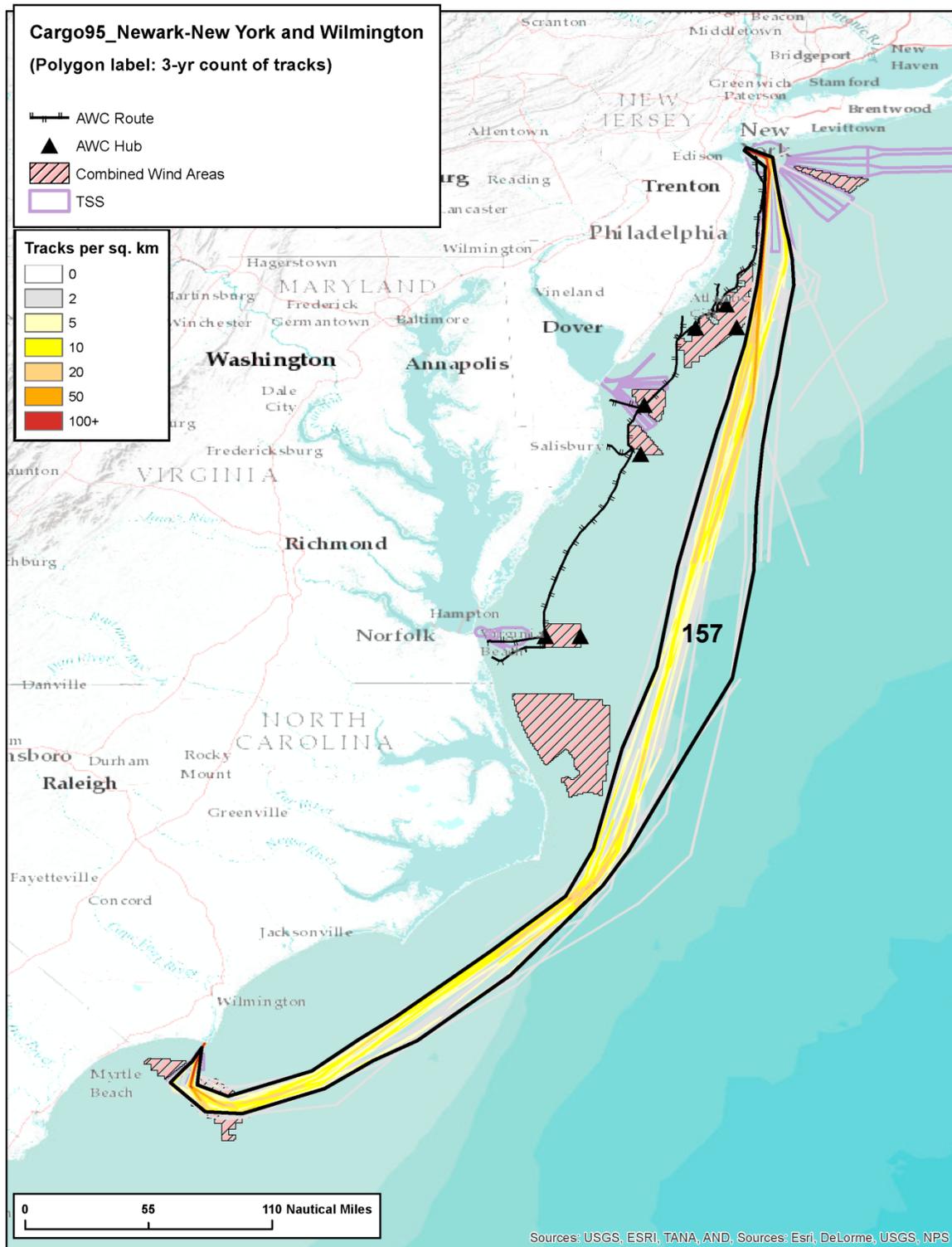


Figure B - 4: Port-to-port polygon showing the 95% boundary of cargo traffic between Newark-NY and Wilmington from 2010-2012.

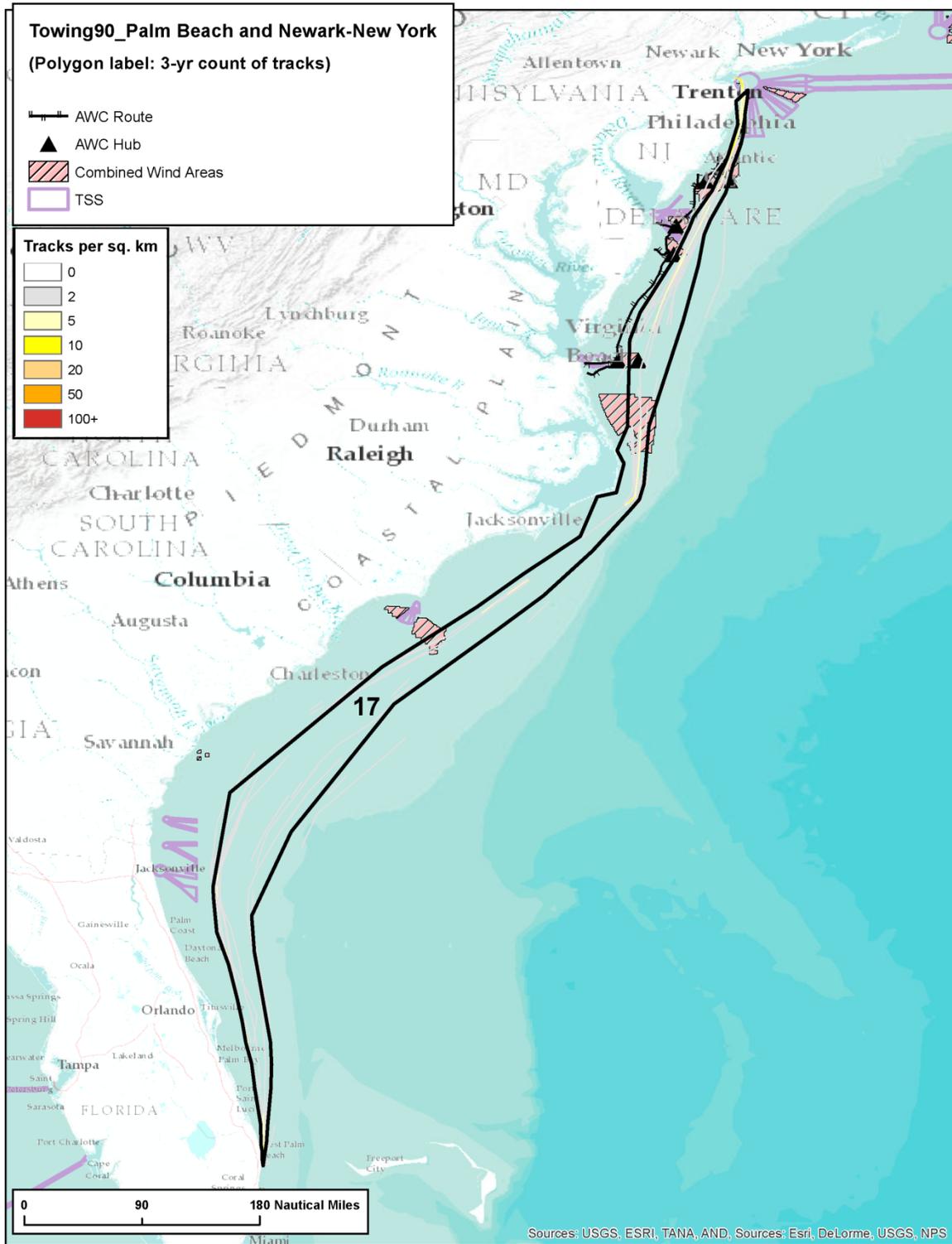


Figure B - 5: Port-to-port polygon showing the 90% boundary of cargo traffic between Palm Beach and Newark-NY from 2010-2012.

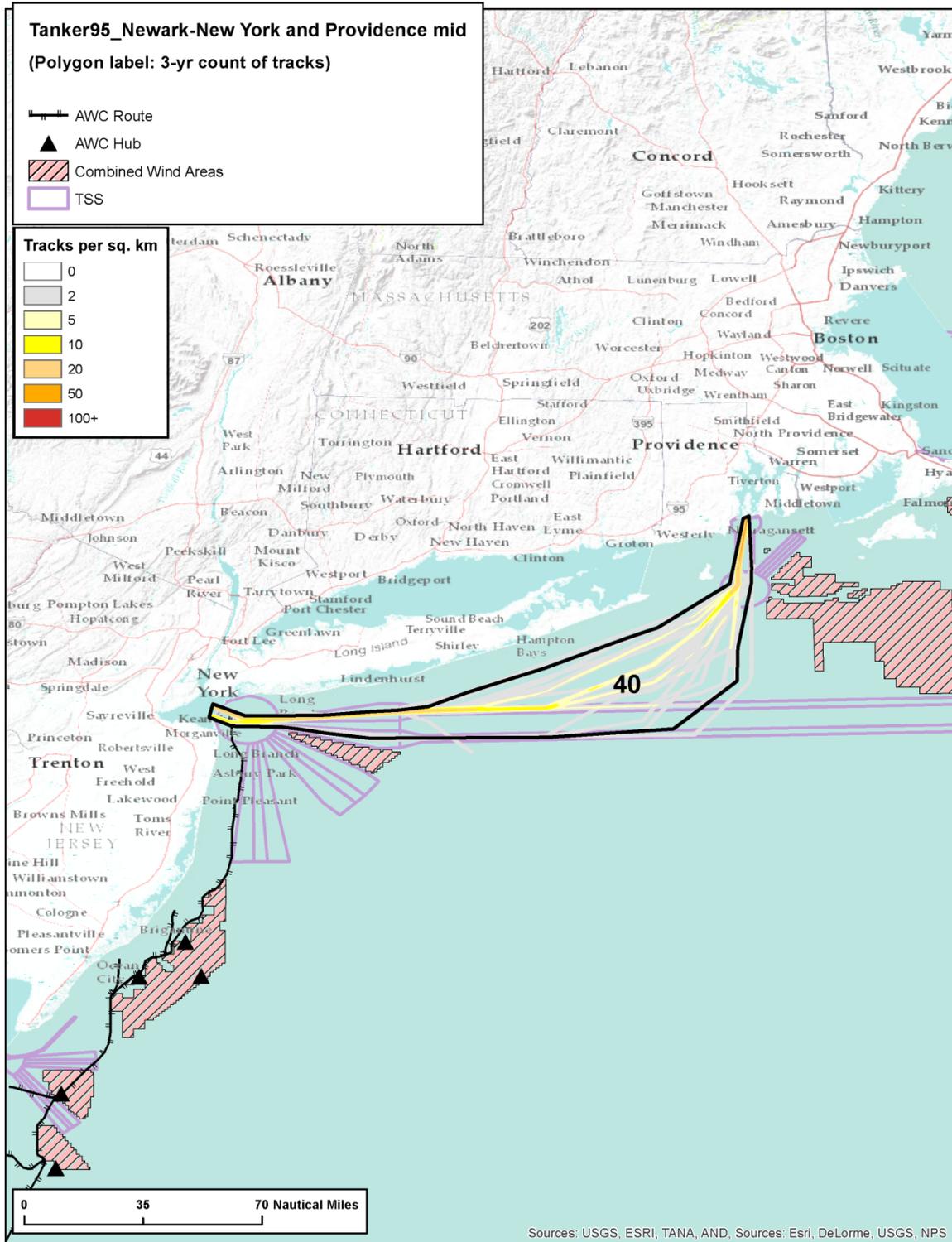


Figure B - 6: Port-to-port polygon showing the 95% boundary of cargo traffic between Newark-NY and Providence from 2010-2012.

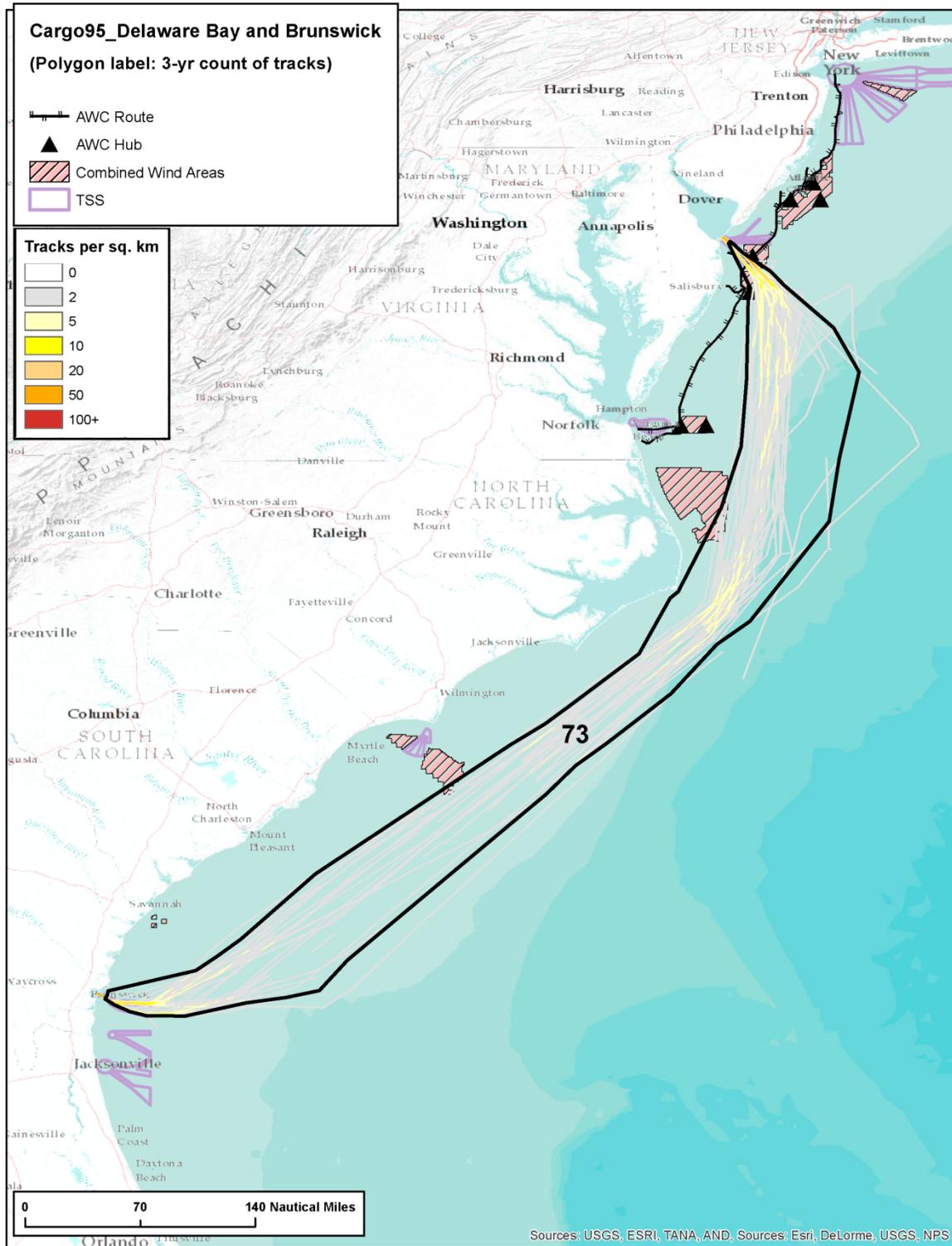


Figure B - 7: Port-to-port polygon showing the 95% boundary of cargo traffic between Delaware Bay and Brunswick from 2010-2012.

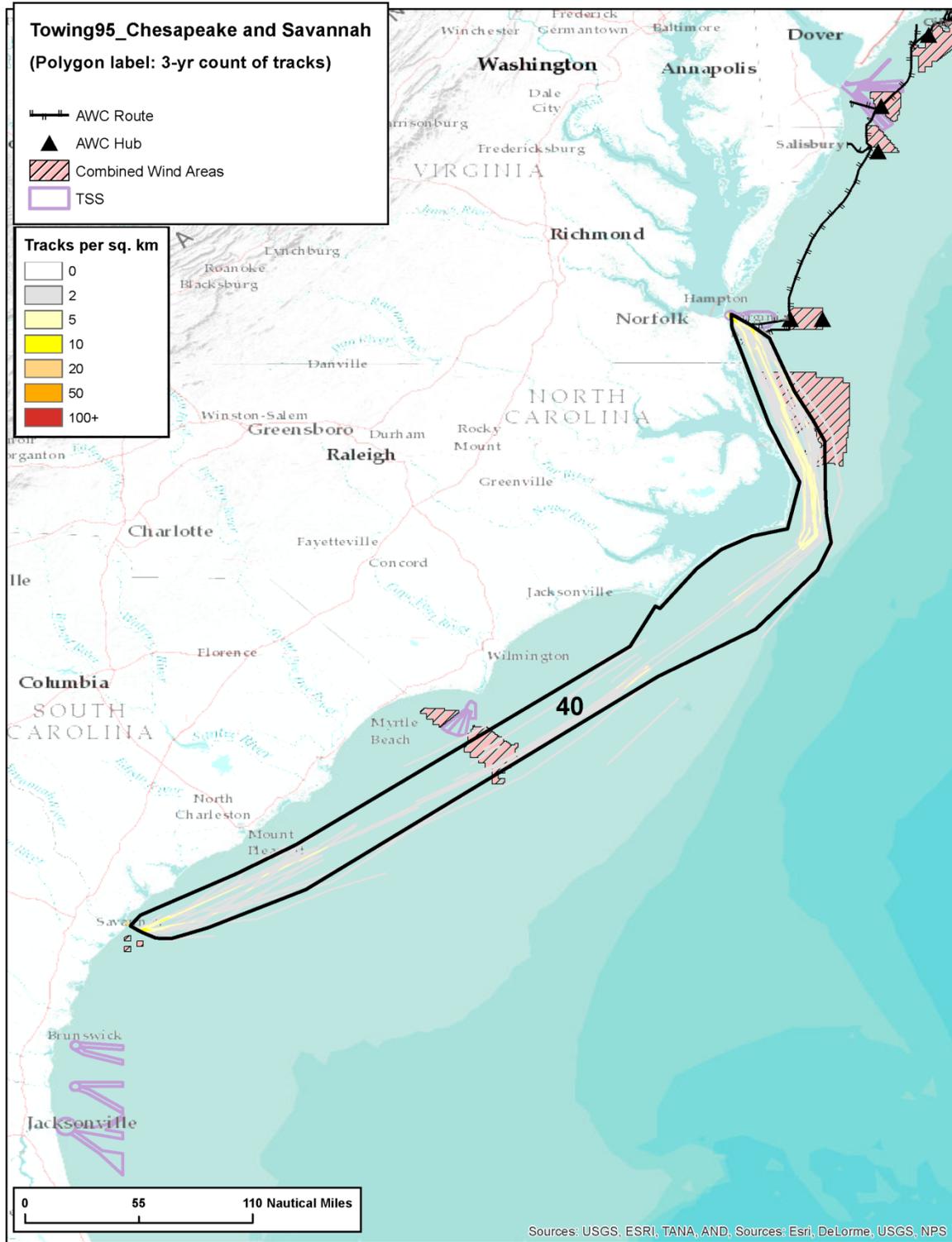


Figure B - 8: Port-to-port polygon showing the 95% boundary of cargo traffic between Chesapeake Bay and Savannah from 2010-2012.

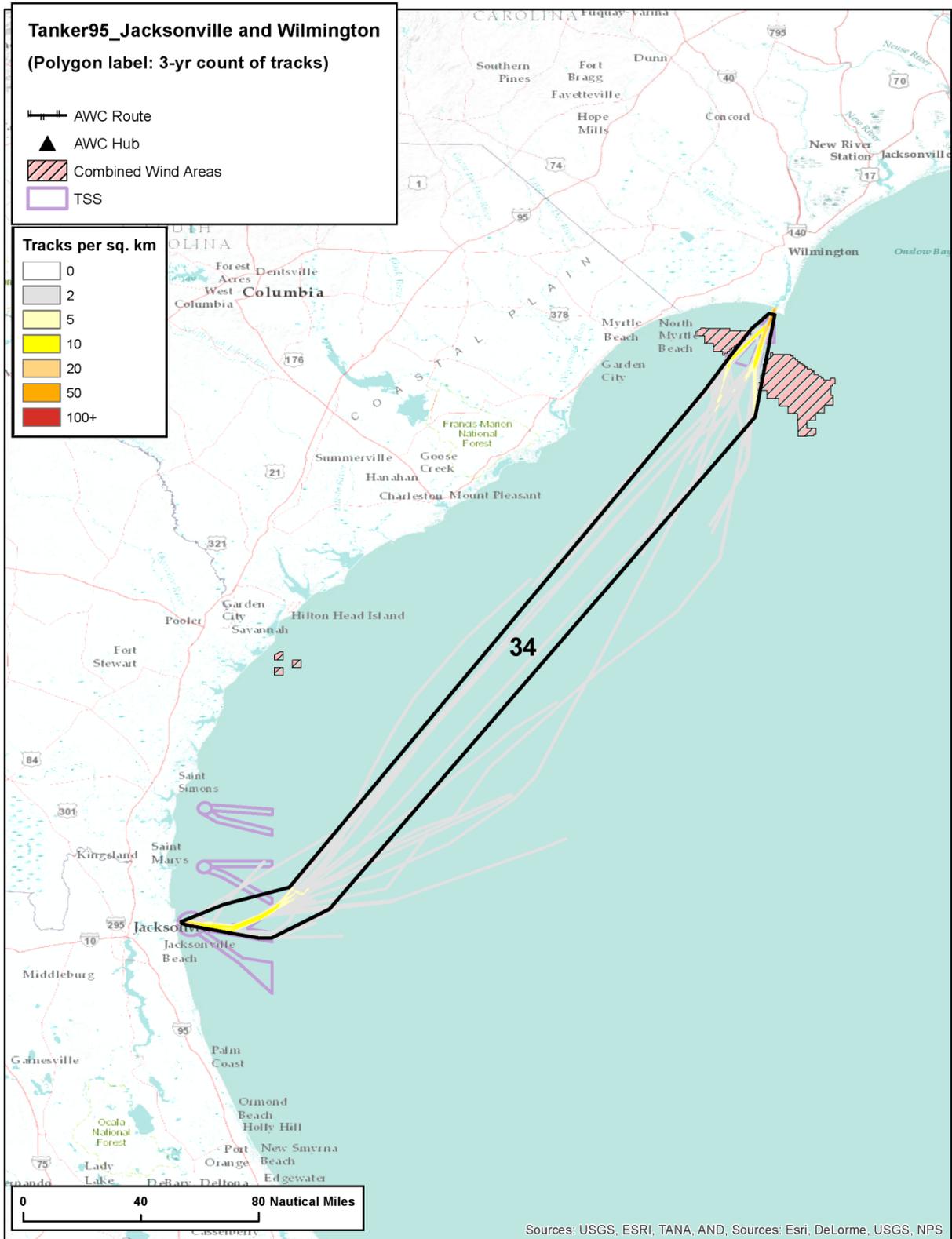


Figure B - 9: Port-to-port polygon showing the 95% boundary of cargo traffic between Jacksonville and Wilmington from 2010-2012.

B.7 References

The Department of Trade Industry (DTI). 2005. Guidance on the Assessment of the Impact of Offshore Wind Farms: Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms.

Appendix C - Vessel Characteristics Database

C.1 Introduction

Physical characteristics of the vessels are used in the simulation of vessels transiting the Atlantic Coast. A simplified set of hydrodynamic equations used to solve vessel surge (forward motion), vessel sway (lateral motion), and yaw (rotation about the vertical axis) include terms accounting for vessel momentum, drag, and mass inertia. To include those physical processes, the physical characteristics of each vessel are needed: length, width, draft, engine horse power, hull's block coefficient, wetted-area drag coefficient, vessel displacement (mass), radar height, maximum speed, and average speed. Several of these characteristics (such as length, width, and draft) are readily available but others (such as block coefficient) are not. For any vessel, there is no single information source, so it has been necessary to combine these data from multiple sources based on several ship identifiers. These include: (1) MMSI – a Maritime Mobile Service Identity (MMSI) number unique to each AIS transponder, (2) IMO Number – an identification number provided by the International Maritime Organization (IMO), (3) call sign – a unique designation for the broadcasting station on the vessel, and (4) the vessel name.

C.2 Information Sources

Initial physical characteristics were obtained directly from the raw AIS data. When a ship first installs the AIS system details such as type, name, IMO, call sign, length, width, and draft are input manually. This creates significant observed inconsistencies in the vessel data, either lacking the information entirely or providing clearly erroneous data (i.e. call sign of “1234”). For the extraction of vessel characteristic from the monthly AIS data, the first instance that each vessel appeared in the domain from 2010-2012 was stored. All these monthly vessel appearances were merged to eliminate duplicates, keeping the most recent appearance because it most accurately represented changes in vessel identification with time. MMSI was chosen as the primary unique identifier during this entire process, though a few situations existed where the same MMSI applied to multiple ships; these were identified and handled to keep the vessels separate.

In order to validate the inherent errors with the AIS vessel inputs, The United States Coast Guard (USCG) has created an Authoritative Vessel Information Service (AVIS) database containing a list of nearly 45,000 vessels known to transit United States waters. AVIS incorporates a novel composite vessel identifier combined with a tiered validation process employing both enhanced computer matching algorithms and improved data validation processes by experienced MDA analysts (USCG 2011). In order to clearly identify each vessel, the AVIS database assigns a vessel ID unique to this database. The AVIS database also includes MMSI, name, IMO number, call sign, length, width, draft, gross tonnage, horsepower, type, and a more specific type. Vessels in the AIS and AVIS data were matched when the MMSI and one other identification numbers matched (IMO number, call sign, or name). The physical characteristics from the AVIS database were used and took priority over the AIS data because the data were more reliable.

A tertiary validation effort involved manually looking up vessel characteristics from several online sources. Because of the large number of vessels, this correction was only performed for vessels lacking data from both the AIS and AVIS datasets. The first website was a tugboat website (TBI Group 2013) created by an interested group of individuals, while the other was hosted by the National Oceanic and Atmospheric Administration (NOAA) Fisheries on behalf of the USCG (NOAA 2013). Length, width, and draft were gathered in feet and then converted to meters. This source was the lowest priority because it was the least reliable, and only filled in for information that was absent elsewhere.

For the three years of AIS data (2010-2012) spanning the US Atlantic Coast, 20,603 unique vessels were identified for inclusion in the vessel characteristics database. The distribution between the vessel types and years are seen in Table C - 1. Table C - 2 shows a breakdown of the contribution each source made to the creation of the vessel characteristics database. The calculated values are explained in the next section.

Table C - 1: Total vessel counts per year and vessel type.

	2010	2011	2012
Cargo	4563	4243	4178
Tanker	2188	2136	2073
Towing	738	789	751
Passenger	351	417	452
Fishing	220	315	464
Other	2687	3433	4331
Unknown	534	583	1090
Total	11,281	11,916	13,339

Table C - 2: Contributions from all sources, priority denoted by the superscript.

	AVIS Database	AIS Data	Online Sources	Ratio Discovery
Type	9.2% ²	90.8% ¹	N/A	N/A
Length	72.8% ¹	20.5% ²	1.4% ³	5.3% ⁴
Width	71.3% ¹	21.7% ²	1.4% ³	5.6% ⁴
Draft	55.8% ¹	13.9% ²	2.9% ³	27.3% ⁴
Horsepower	61.9% ¹	N/A	N/A	38.1% ²

C.3 Calculations

A few additional checks were conducted after merging all data sources. The length, width, and draft values were compared to the largest known vessels. Values that exceeded these maximums were assumed to be accidentally input as feet and were instead converted to meters. Vessels were also discarded if the MMSI number was not nine digits long.

However, even after combining all these data sources, there were some vessels for which physical characteristics could not be obtained. The last column in Table C - 2 shows the percentages for which data was missing and needed to be artificially generated. A ratio discovery process began with averaging length per type and filling in the blanks with these averages. The same process could not be repeated for the other characteristics because there were some cases where a vessel only had a length recorded. If this length was very small then the average width per type could potentially be larger than the length, an implausible situation. Instead, the average multiplier from length to width was determined per type. Since the previous step ensured that all length had values, either real or calculated, these average multipliers could be assigned to calculate a width for every ship. The ratio discovery was then repeated for draft and horsepower. All ratios used were as follows:

$$\begin{aligned} & \textit{Length} \rightarrow \textit{Width} \\ & \textit{Length} * \textit{Width} \rightarrow \textit{Draft} \\ & \textit{Length} * \textit{Width} * \textit{Draft} \rightarrow \textit{Horsepower} \end{aligned}$$

During the ratio discovery, multipliers were determined and applied for each vessel type, though the unknown category was an aggregate of all other types.

After the ratio discovery, the physical characteristics gathered from the three sources were complete for each vessel. However, the maximum displacement was also needed for input into the model. Block coefficients were determined from MAN Diesel (2011) for all but towing, for which online sources indicated a value of 0.91 due to the shape of a typical barge. After that, the following two equations were used to calculate the max displacement:

$$\textit{Block Volume} (m^3) = \textit{Length} (m) * \textit{Width} (m) * \textit{Draft} (m)$$

$$\textit{Maximum Displacement} (kg) = 1025 \left(\frac{kg}{m^3} \right) * \textit{Block Coefficient} * \textit{Block Volume} (m^3)$$

C.4 Annotations

Once the database was compiled, the values were referenced to each source and annotated accordingly. Figure C - 1 shows a sample from the vessel characteristics database with annotations:

- AVIS Database (a)
- AIS Database (b)
- Online Sources (c)
- Ratio Discovery (d)

MMSI	Name	Type	Specific Type	Length(m)	Beam(m)	Draught(m)	GT	HP	Block Co	Max Displacement (kg)
310040000	ENDURANCE	Cargo	b	222.00 a	32.21 a	10.00 b	31062.2	29805.2 d	0.65	47641005.8
310043000	AURORA B	Other	b	43.00 a	9.50 a	3.00 b	532.6	7356.7 d	0.6	753682.5
310051000	TALITHA	Unknown	b	10.66 c	3.54 c	1.54 c	24.5	85.6 d	0.6	35829.0
310056000	MORNING GLORY	Other	b	43.00 a	9.20 a	5.83 d	1002.2	13844.5 d	0.6	1418356.2
310065000	GOLDEN ODYSSEY	Other	a Yacht	80.45 a	12.82 a	4.05 a	1864.0	11474.0 a	0.6	2568882.3
310085000	GOLDEN OSPREY	Other	b	30.00 b	8.00 b	2.40 b	250.3	3457.7 d	0.6	354240.0
310094000	GOLDEN SHADOW	Other	a Yacht	66.75 a	12.21 a	4.30 a	1293.0	10616.0 a	0.6	2155313.8
310107000	NELSON STAR	Cargo	b	151.00 a	20.33 a	7.50 b	10001.5	12500.0 a	0.65	15339556.8
310109000	NAPIER STAR	Cargo	b	151.00 a	20.33 a	8.00 b	10668.2	16756.0 a	0.65	16362193.9
310111000	FAITHFUL	Towing	b Tug	31.01 a	9.74 a	4.17 a	302.0	6305.0 a	0.91	1174794.9
310125000	BAD GIRL	Other	b Yacht	56.74 a	9.85 a	2.08 a	709.0	6720.0 a	0.6	714930.8
310132000	LISBON EXPRESS	Cargo	b Container Ship (Fully Cellular)	216.13 a	32.26 a	10.78 a	33735.0	56112.0 a	0.65	50076665.2
310133000	VALENCIA EXPRESS	Cargo	b Container Ship (Fully Cellular)	216.13 a	32.26 a	10.78 a	33735.0	56112.0 a	0.65	50076665.2
310141000	POWER	Cargo	b	223.00 a	32.26 a	9.40 b	29375.5	28186.8 d	0.65	45054098.2
310142000	TIMARU STAR	Cargo	b Refrigerated Cargo Ship	151.00 a	20.33 a	9.60 a	8665.0	33512.0 a	0.65	19634632.7
310150000	A V KASTNER	Cargo	b Bulk Carrier Self-discharging	158.63 a	23.04 a	9.64 a	12702.0	15144.0 a	0.65	23473727.3
310174000	LICORNE	Other	b	28.00 b	6.00 b	2.48 d	180.7	2496.8 d	0.6	255794.6
310200000	ERICA XI OF HAMILTON	Other	b Yacht (Sailing)	27.00 a	6.80 a	1.80 a	106.0	286.0 a	0.6	203245.2
310205000	HERO	Cargo	b	243.00 a	32.26 a	11.20 b	38139.7	33060.0 a	0.65	58495961.2
310210000	FERNIE	Cargo	b Bulk Carrier	266.00 a	40.56 a	15.42 a	63153.0	15961.0 a	0.825	140683048.5
310216000	LEANDER G	Other	b Yacht	74.65 a	12.80 a	4.00 a	1930.0	14155.0 a	0.6	2350579.2
310245000	PREDICTION	Other	b Yacht	43.60 a	8.80 a	2.80 b	489.0	3099.0 a	0.6	660697.0
310253000	LNG LAGOS	Tanker	b LNG Tanker	275.01 a	42.09 a	11.80 a	81472.0	31549.0 a	0.825	115501395.9
310261000	QUORN	Cargo	b Bulk Carrier	290.00 a	46.00 a	18.33 a	92194.0	21050.0 a	0.825	206774085.4
310263000	SNOWDON	Cargo	b Bulk Carrier	292.00 a	46.00 a	17.30 a	85848.0	21705.0 a	0.825	196500925.5
310265000	RUTLAND	Cargo	b Bulk Carrier	291.00 a	46.00 a	17.30 a	85848.0	21705.0 a	0.825	195827977.1
310273000	M/Y-SENSES	Passenger	b	99.73 d	23.18 d	5.00 b	9721.2	86275.4 d	0.6	7108475.7
310279000	CAPE CARMEL	Cargo	b Bulk Carrier	290.00 a	46.00 a	18.33 a	92194.0	21048.0 a	0.825	206774085.4
310290600	SKULPTOR TOMSKIY	Cargo	b	138.00 b	21.00 b	8.00 b	10071.1	9663.6 d	0.65	15446340.0
310323000	TENO	Cargo	b Refrigerated Cargo Ship	145.50 a	22.64 a	9.26 a	10298.0	10520.0 a	0.65	20322991.0
310324000	TALCA	Cargo	b Refrigerated Cargo Ship	145.52 a	22.64 a	9.22 a	10298.0	10520.0 a	0.65	20237984.2
310327000	GRAND PRINCESS	Passenger	b Passenger/Cruise	289.52 a	36.03 a	8.50 a	107517.0	562198.0 a	0.6	54530172.8
310340000	S/Y TIMONEER	Other	b	44.00 b	10.00 b	4.00 b	764.8	10565.3 d	0.6	1082400.0
310346000	GYPSUM CENTENNIAL	Cargo	b Bulk Carrier Self-discharging	197.10 a	32.21 a	9.75 a	32881.0	15140.0 a	0.65	41240050.3
310348000	HELIOS	Other	b Yacht	59.07 a	10.50 a	3.51 a	969.0	6595.0 a	0.6	1338870.3
310361000	STAR PRINCESS	Passenger	b Passenger/Cruise	289.51 a	36.03 a	8.45 a	108977.0	509597.0 a	0.6	54207534.7
310376000	CORAL PRINCESS	Passenger	a Passenger/Cruise	294.00 a	32.31 a	8.30 a	91627.0	252076.0 a	0.6	48488360.1

Figure C - 1: Annotated sample from the Vessel Characteristics Database.

C.5 References

MAN Diesel & Turbo. 2011. Basic Principles of Ship Propulsion.

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Appendix D - Model Development

D.1 Introduction

The Marine Vessel Traffic (MVT) model developed for this risk analysis is based on vessel characteristics used for the simulation of vessel motion, rules for TSS utilization based on analysis of AIS data, and rules of the road from traditional rules dealing with approaching vessels and the guidance developed from those rules. The model includes probabilistic and stochastic capabilities that can result in a ship's deviation from a direct line route. The rules of the road are compiled into a decision tree that provides the functional logic defining the operator's responses. The geographic area making up the model domain covers the Atlantic Coastal Waters and Atlantic Ocean from Maine to Florida and extends beyond the EEZ (200 miles) and encompasses the spatial distribution of commercial shipping movements in the Atlantic Coastal Region as identified in the AIS data. This appendix documents the development of the model.

D.2 General Structure of the MVT Model

The MVT model simulates the navigation of marine vessels between ports along the Atlantic Coast and between ports and the vessels transiting Atlantic Ocean waters off the eastern seaboard of the US. The simulation code endeavors to incorporate the primary functionality required for navigation in the Atlantic coastal waters. The MVT model simulation is made dynamically, meaning that the solution of equations and application of rules is made sequentially through a simulated time period, which is handled with the computer code as the time marching loop (Figure D - 1). Each turn through the time marching loop is called a time step.

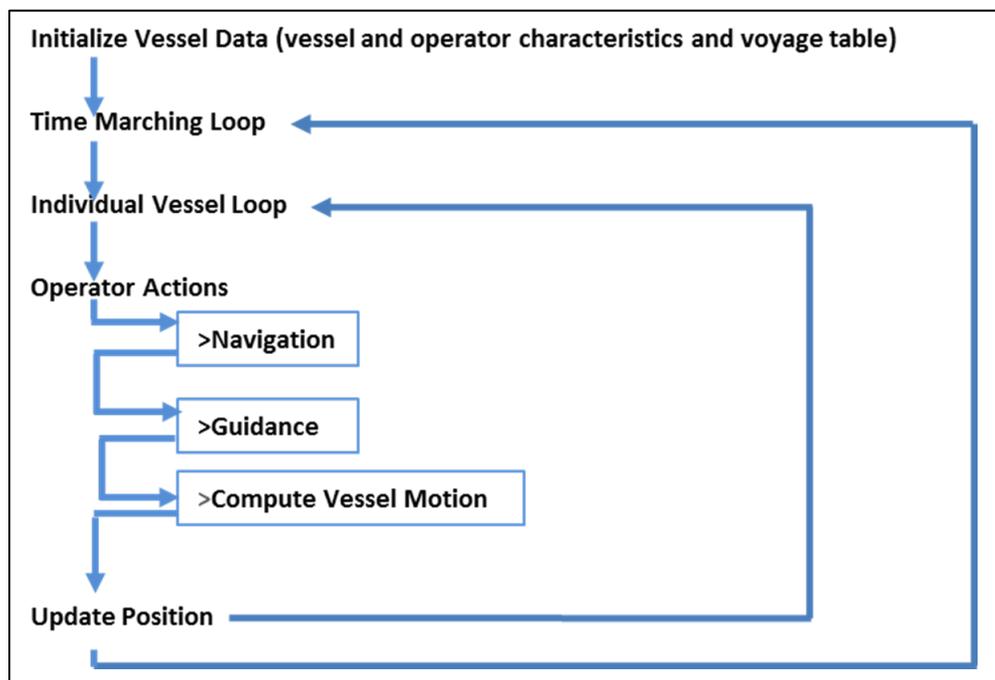


Figure D - 1: General computer code structure of MVT model for the solution navigation, guidance, and motion of marine vessels. Results from model computations are output at the end of each turn through the time marching loop.

The simulation of the marine vessel traffic system means that the actions of many vessels are simulated simultaneously. On the order of 1000 vessels are being handled at any one time during a MVT model time step. Within the time marching loop is a vessel loop that sequentially steps through the list of active vessels and calls the vessel operator function to monitor the conditions surrounding the vessel, apply rules appropriate to the conditions, and log any relevant information for use in analyses (Figure D - 1). Once the operator is called, a sequence of functions is called that are generally grouped in to the following three categories: navigation, guidance, and vessel motion (Figure D - 1).

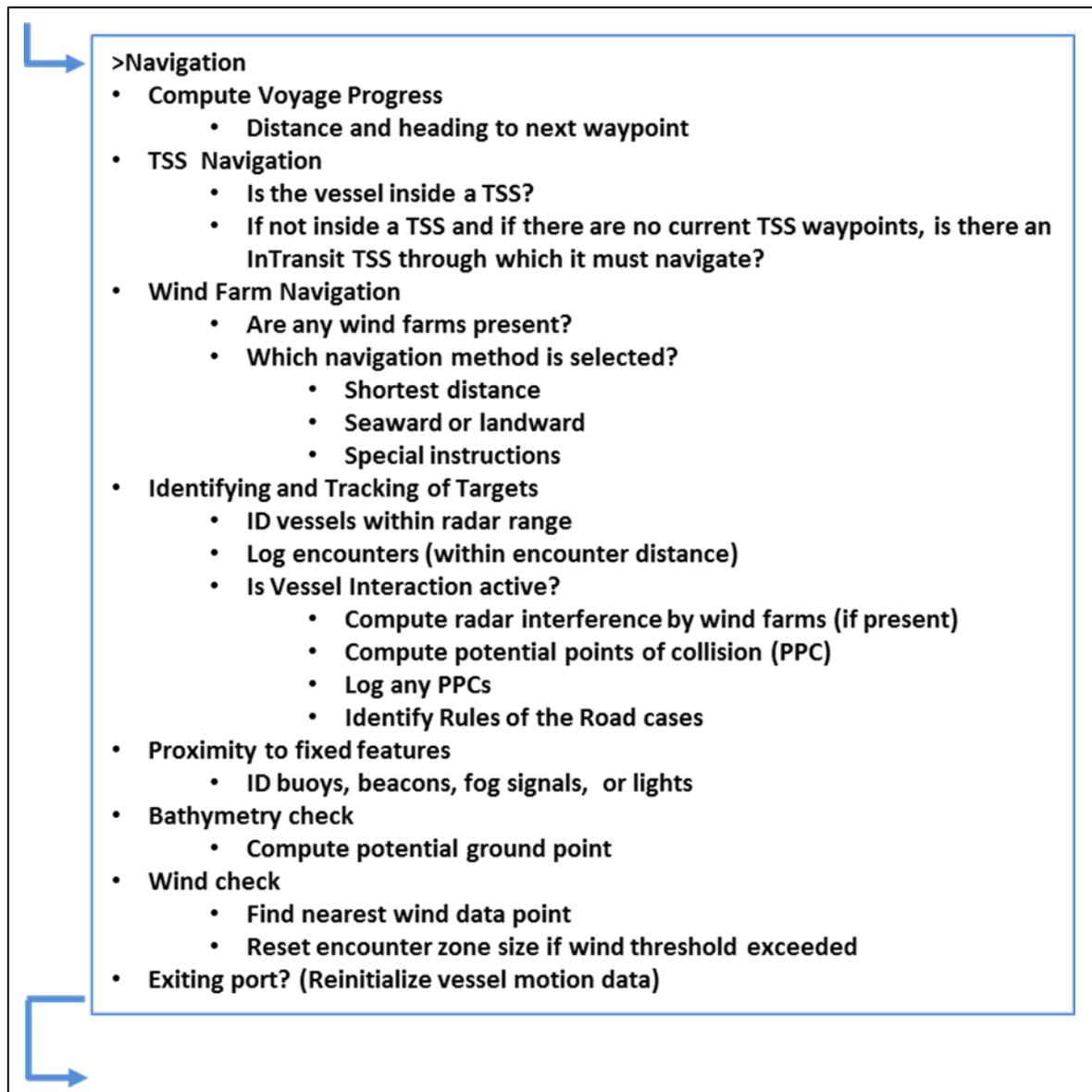


Figure D - 2: Navigation functionality in the MVT model computer code. Arrows indicate the navigational functionality is connected to a sequence of operations implemented to carry out vessel voyages.

The navigational functionality monitors the surrounding environment and used to assess and indicate what is needed to sail from one waypoint to another (Figure D - 2). (The MVT model framework is centered on waypoint navigation.) The navigational functions implemented include the following:

- Compute the voyage progress
- Ascertain the presence of traffic separation schemes (TSSs) to be used to enter or exit a port
- Ascertain the presence of a combined wind area
- Identify and track vessels (targets) within the radar and visual range of your (own) vessel. If the target is within radar range, potential points of collision are computed as are applicable rules of the road
- Identify and compute the proximity to fixed features, particularly buoys, beacons, lights, and fog signals
- Compute proximity to bathymetry above own vessel's maximum draft
- Ascertain the wind and current velocities
- Reinitialize vessel motion data, at the initiation of exiting a port

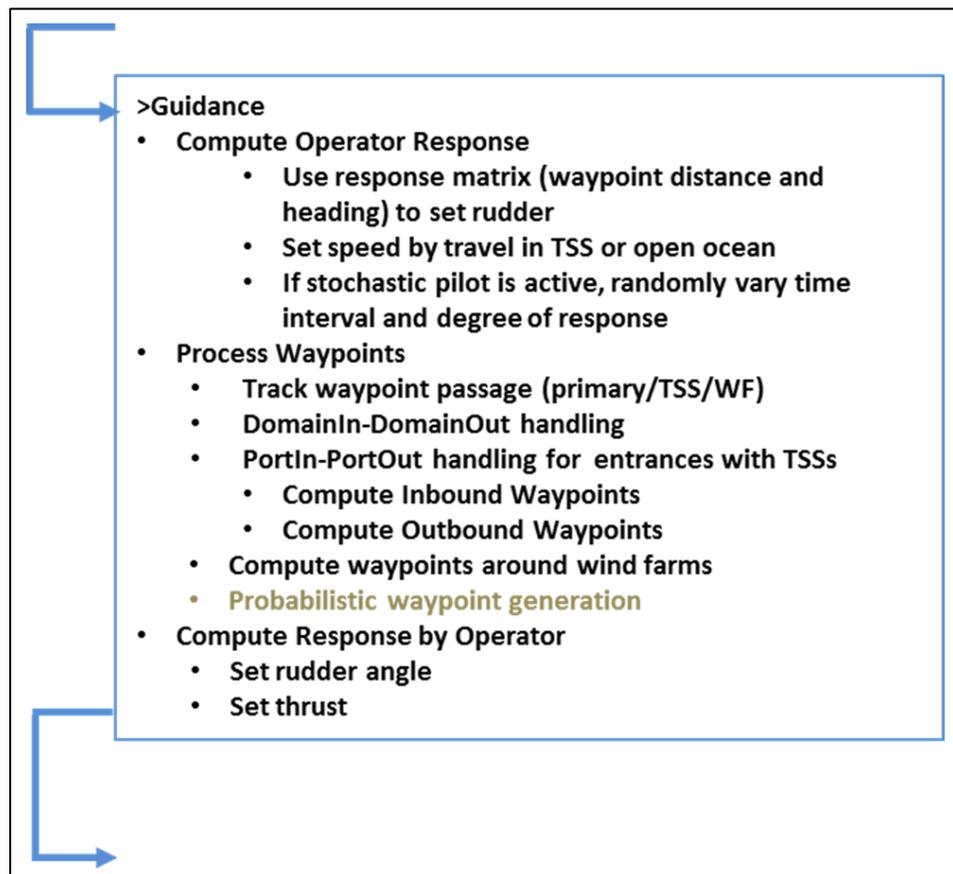


Figure D - 3: Guidance functionality in the MVT model computer code. The greyed text is functionality not yet fully implemented at the time of writing.

Guidance functionality uses the navigational information to ascertain steps needed for own vessel to proceed and complete its current voyage (Figure D - 3). The implemented guidance functions include the following:

- Compute how the operator responds to the navigational information to set heading and speed
- Process waypoint data to ascertain passage of waypoints and potentially the generation of new waypoints
- Set rudder angle and speeds

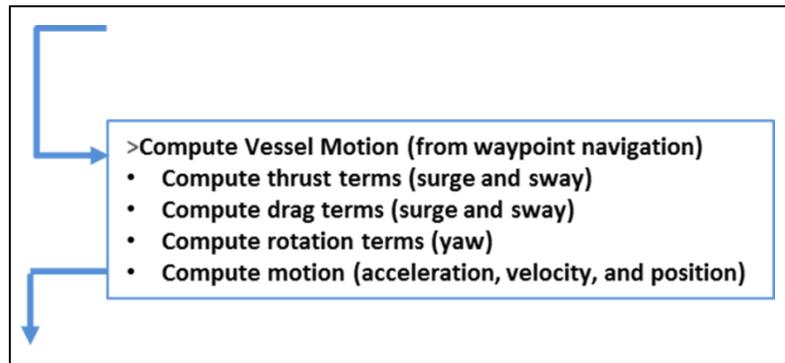


Figure D - 4: Vessel motion functionality in the MVT model computer code.

Finally, the computed navigational information and guidance settings are used in the calculation of vessel motion (Figure D - 4). The implemented vessel motion functions include the following:

- Compute thrust terms for surge and sway motions
- Compute drag terms from surge and sway motions
- Compute rotational terms for vessel yaw
- Compute motion (change in position) considering vessel acceleration and velocity

The following sections describe the implementations in greater detail.

D.3 Equations of Motion

Because of the large spatial domain and the potential for simulations of long duration, the number of vessels involved is on the order 1000s. As discovered early in the development process, the model must be run with time steps of 1 second. To keep the model run times reasonable (< 24 hours), the MVT model utilizes simplified equations of motion to account for vessel propulsion and maneuvering. Three types of hydrodynamic equations are computed to account for basic vessel motions of surge, sway, and yaw (Crane et al 1989; Perez and Clemente 2007). Surge is a forward motion, sway is a lateral motion, and yaw is a rotational motion. The equations account for the propulsion or thrust of the vessel (surge), the skin-drag of the vessel (surge), the form drag of the rudder (surge), the lift force on the rudder from its angle of attack during application of the rudder (yaw), the rotation of the vessel from the rudder's lift force during application of the rudder (yaw), and the lift force on the vessel due to its rotation during rudder application (sway). Drag and inertial forces are applied in the opposite direction of accelerations due to thrust (surge), lift (sway), and rotation (yaw).

D.3.1 Equations For Surge And Sway

The mass, thrust, and drag forces on the vessel are used to compute its acceleration and deceleration rates via Newton's 2nd Law, that is, $F = Ma$, in which F is a force in Newtons (N, $kg \frac{m}{s^2}$), M is the mass (kg), and a is acceleration (m/s^2). The acceleration is defined by as the rate of change in velocity (V , m/s) of the vessel, which gives the following:

$$a = \frac{dV}{dt}$$

Combining the 2nd Law with the definition of acceleration and noting acceleration occurs due to the balance of forces (called the net force (F_N)) gives the following:

$$F_N = M \frac{dV}{dt}$$

To satisfy the 2nd Law, it is necessary that there be a balance of forces, which for the equations for surge and sway means defining the net forces as follows:

$$F_{N,surge} = T - D - D_R$$

$$F_{N,sway} = L_v - D_v$$

For the surge equation, the balance of forces includes the engine thrust (T), vessel drag (D), and the rudder drag (D_R). For the sway equations, the balance of forces includes the lateral lift force (L_v) due to the hull's drift angle from applying the rudder and the drag (D_v) associated with the hull's drift angle. Details of these force and drag terms are provided in the following paragraphs.

Thrust is computed based on the definition of horsepower (Hp) as follows:

$$Hp = TV$$

indicating that Hp varies with thrust and speed. For the purposes of the modeling, Hp is a model input obtained from the vessel characteristics database, the maximum observed velocity input to the model comes from the AIS data, and thrust is computed from the two inputs. Because the maximum observed velocity is used, the computed thrust is actually the maximum thrust the vessel is capable of. Thrust is adjusted up to the maximum to vary the speed of the vessel.

For the surge equation, the thrust originates solely from forward propulsion, while the drag originates from skin friction on the vessel hull and rudder and from drag on the rudder at an angle of attack with respect to the vessel's course during application of the rudder. The amount of propulsive thrust (T) applied on the vessel is determined by the speed that the vessel operator is trying to maintain. The speed is the one of the primary inputs from the operator within solution, and the other primary input is rudder angle. The speed and rudder angle are determined by the navigational and maneuvering requirements needed by the vessel during the simulation. Note that the maximum thrust is limited by the horsepower of the vessel's engines.

For the sway equation, lift is produced on the vessel during turning, which forces the vessel to move laterally. When superimposed on the vessel's forward motion, this induces a turn. Drag in the sway equation originates from drag on the vessel as it rotates during turning (producing a drift angle with respect to the vessel's course).

The vessel area and its drag coefficients are used to compute drag forces on the vessel from skin friction during motion using standard fluid dynamics equations of the following form:

$$D = \frac{1}{2} C_d \rho V^2 A_w$$

in which D is the drag force, C_d is the drag coefficient (unit less), ρ is the density of the fluid ($\frac{kg}{m^3}$), V is the forward velocity of the vessel, and A_w is the wetted surface area of the vessel's hull (m^2). C_d is computed assuming that at the maximum speed, D equals the maximum thrust as follows:

$$C_d = \frac{2T_{max}}{\rho V_{max}^2 A_w}$$

The drag on the rudder (D_R) occurs on during forward motion of the vessel is given by Tupper (2004) as follows:

$$D_R = 577 A_R V^2 \sin(\alpha)$$

As the rudder is applied, the angle of attack (α , (radians)) is positive if the rudder is pushed to initiate a starboard. The angle is negative when pushed to initiate a port. The angle of attack is with respect to the vessel when facing to the stern.

With application of the rudder, the heading of a vessel diverges from its course; the difference between the heading and course is the drift angle. That is, drift places the vessel at an angle to the direction of motion, which results in a lift force (L_v) being produce lateral to the direction of motion of the vessel. This causes the vessel to turn. The equation of the lift force is as follows:

$$L_v = \frac{1}{2} C_L A_S \cos(\alpha_d) \rho V^2$$

The lift is generated on the vessel's sideward projected area ($A_S \cos(\alpha_d)$), as determined by the drift angle, α_d . The lift coefficient, C_L , is taken from information in Tiara et al (2007); it also varies with drift angle. A scale factor is input to the model to adjust the lift coefficient to better approximate turning characteristics.

In concert with the lift produced by the vessel's drift angle is an increase in drag produced by the drift as follows:

$$D_v = \frac{1}{2} C_D A_S \sin(\alpha_d) \rho V^2$$

The drag coefficient due to the vessel's drift angle, C_D , is taken from information in Tiara et al (2007); it varies with drift angle. A scale factor is input to the model to adjust the drag coefficient to

better approximate turning characteristics. For this drag component, the equation uses the forward projected area of the turning vessel.

D.3.2 Equations for Yaw

Newton's 2nd Law with respect to rotational motion (yaw) is as follows:

$$\tau_{net} = I a_{\omega}$$

in which τ_{net} = the sum of the torques (force times the length of the lever arm, $(kg \frac{m^2}{s^2})$) acting on the rotating vessel. I is the mass moment of inertia $(kg \ m^2)$, and a_{ω} is the angular acceleration (*rotations/s²*). The balance of torques comes from the torque (τ_R) induced by the rudder force times the lever arm over the half length of the vessel and the fluid resistance (τ_{RD}) on the vessel as it rotates.

$$\tau_{net} = \tau_R - \tau_{RD}$$

The angular acceleration is defined by the angular velocity (ω , rotations per second), which in turn is defined by the rotation (θ , rotations) as follows:

$$a = \frac{d\omega}{dt} = \frac{d}{dt} \left(\frac{d\theta}{dt} \right)$$

Assuming a prismatic form for the vessel, the mass moment of inertia about the vertical axis at the center of the vessel is as follows (Beer and Johnston 1972):

$$I = \frac{1}{12} M (B^2 + L^2)$$

in which B is the vessel width (m), and L is the vessel length (m).

The rudder force (R) is the lift for a theoretical foil (rudder) given as follows by Roberson and Crowe (1980):

$$R = \frac{1}{2} C_R A_R \rho V^2$$

The rudder force (R) is lateral to the vessel's direction of motion and is applied at the aft end of the vessel, which induces a rotation of the vessel. The rotational motion is handled in the equations for yaw. The lift coefficient (C_R) for the rudder is derived from using NACA 0015 lift coefficients (Lazauskas 2013). The rudder area (A_R) is not available from the vessel characteristics database, so it needed to be estimated. Tupper (2004) provides an approximate estimate of rudder area as 1/60 or 1/70 of the product of length and draft of the vessel. A scale factor of 1/65 is used for the MVT model..

The torque from rudder force is as follows:

$$\tau_R = \frac{L}{2} R$$

The torque for the rudder force (τ_R) is the product of the lever arm (half the vessel length assuming the vertical axis of rotation is at the vessel center) and rudder lift force (R).

The torque produced by drag from the rotation of the vessel, τ_{RD} , through the water is found by integrating from the vertical axis of rotation (assumed at the center of the vessel) outward to the bow/stern as follows:

$$\tau_{RD} = 2 \int_0^{\frac{L}{2}} \left(\frac{1}{2} C_{rd} \rho \frac{A_s}{2} (l\omega)^2 \right) dl$$

Multiplying by 2 provides for torque due to drag from both ends. The rotational drag coefficient, C_{rd} , is assumed to be similar to that for a flat plate perpendicular to the flow. Solving the integral and multiplying through by 2 gives the total torque due to drag as follows:

$$\tau_{RD} = C_{rd} \rho \frac{A_s}{2} \omega^2 \frac{(L/2)^3}{3}$$

D.4 Numerical Methods for Solution of the Equations of Motion

Numerical methods are generally used to solve ordinary differential equations, which the Newton's 2nd Law and the related equation for rotation. The following subsections outline the numeric methods used to solve these differential equations. Fundamentally, these numeric equations form the basis for the solution of marine vessel traffic model.

D.4.1 Equations for Surge and Sway

In the case of translational motion, it was previously noted that Newton's 2nd Law includes the balance of forces (called the net force (F_N)) as follows:

$$F_N = M \frac{dV}{dt}$$

For application in the model, the equation is solved numerically, which is accomplished by applying explicit and implicit forms of Euler's method. The explicit form of Euler's method is generally stated as

$$x_1 = x_0 + \Delta t \left(\frac{\Delta x}{\Delta t} \right)_0$$

with the rate of variable, x , known at time zero and Δt is the time interval from t_0 to t_1 . The implicit form of Euler's method is generally stated as

$$x_1 = x_0 + \Delta t \left(\frac{\Delta x}{\Delta t} \right)_1$$

with the rate of variable, x , known at time one.

Applying the explicit Euler equation to approximate the time derivative of velocity gives the following:

$$F_{N,0} = M \left(\frac{V_1 - V_0}{\Delta t} \right)$$

in which V_0 is the velocity at time zero, V_1 is the velocity at time one, and $F_{N,0}$ is net force at time zero. Rearranging the terms gives the more familiar form of the explicit Euler equation as follows:

$$V_1 = V_0 + \Delta t(F_{N,0}/M)$$

The explicit Euler equation provides a means of computing the vessel's velocity, but it is also necessary to compute the location (position, P (m)) of the vessel and how the position changes over time. The definition of the rate of change of position of the vessel is given as follows:

$$V = \frac{dP}{dt}$$

Applying the implicit Euler equation to approximate the derivative, with P_0 the position at time zero and P_1 the position at time one, gives the following:

$$V_1 = \frac{P_1 - P_0}{\Delta t}$$

Rearranging the terms gives the more familiar form of the implicit Euler equation as follows:

$$P_1 = P_0 + \Delta t V_1$$

Substituting the explicit Euler equation for velocity into the position equation gives the general form of the explicit Euler equation used to solve the vessel's equation of motion for surge and sway:

$$P_1 = P_0 + \Delta t \left(V_0 + \Delta t(F_{N,0}/M) \right)$$

Motion of the vessels is assumed to occur in two-dimensional space representing the surface of the ocean. To solve the equation in the local x and y Cartesian directions, the general equation is split into the two direction components giving following equations of motion for surge and sway:

$$P_{1,x} = P_{0,x} + \Delta t \left(V_{0,x} + \Delta t(F_{N,x,0}/M) \right) \quad (1)$$

$$P_{1,y} = P_{0,y} + \Delta t \left(V_{0,y} + \Delta t(F_{N,y,0}/M) \right) \quad (2)$$

Because the vessel motion occurs on the surface of the ocean and the spatial domain includes the whole of the Atlantic Coast, it is necessary to transform the local x and y coordinate motion to the global coordinate system (latitude and longitude). At each time step, the distance traveled and azimuth of travel is transformed using the methods of Vincenty (1975) as implemented by the USNGS compute codes Forward and Inverse (USNGS 2012). The methods are applied in the ellipsoidal domain and provide accuracy on the order of centimeters over large distances (1000s of NM). These codes were implemented

in the MVT model to handle the transformations between local and global positions. Because the distance traveled per time step (1 second) is small (5 to 10 m), any errors in transforming the local solution to the global system are negligible.

The terms for $F_{N,surge}$ and $F_{N,sway}$ presented previously are substituted into $F_{N,0}$, with all component terms of surge and sway computed at time zero in the numerical scheme. This leads to the numerical method being explicit.

D.4.2 Equations for Yaw

In the case of rotational motion, a balance of torques is described using Newton's 2nd Law, with the angular acceleration representing the rate of change of rotation rate (ω) as follows:

$$\tau_{net} = I \frac{d\omega}{dt}$$

Applying the explicit Euler equation to approximate the time derivative of rotation rate gives the following:

$$\tau_{net,0} = I \left(\frac{\omega_1 - \omega_0}{\Delta t} \right)$$

in which ω_0 is the velocity at time zero, ω_1 is the velocity at time one, and $\tau_{net,0}$ is net torque at time zero. Rearranging the terms gives the more familiar form of the explicit Euler equation as follows:

$$\omega_1 = \omega_0 + \Delta t (\tau_{net,0}/I) \quad (3)$$

The explicit Euler equation provides a means of computing the vessel's rotation rate, but it is also necessary to compute the heading (θ (*radians*)) of the vessel and how the heading changes over time. The definition of the rate of change of heading of the vessel is given as follows:

$$\omega = \frac{d\theta}{dt}$$

Applying the implicit Euler equation to approximate the derivative, with θ_0 the heading at time zero and θ_1 the heading at time one, gives the following:

$$\omega_1 = \frac{\theta_1 - \theta_0}{\Delta t}$$

Rearranging the terms gives the more familiar form of the implicit Euler equation as follows:

$$\theta_1 = \Delta t \omega_1 + \theta_0 \quad (4)$$

D.5 The Atlantic Coast Domain

For the current study, the model domain lies to the east of the eastern seaboard of the United States (Figure D - 5). The domain extends from the Florida Keys to the south to the US-Canadian border to the north. To the east, the domain extends to longitude 64° W. To the west, the domain extends to the land boundary of the Atlantic Coast. For ports along the coast, the domain does not extend into bays where those ports are located but rather is limited to the entrances of those bays. (The port entrances that are included in the current analysis are provided in the section Selection of Traffic Separation Schemes by Vessels.)

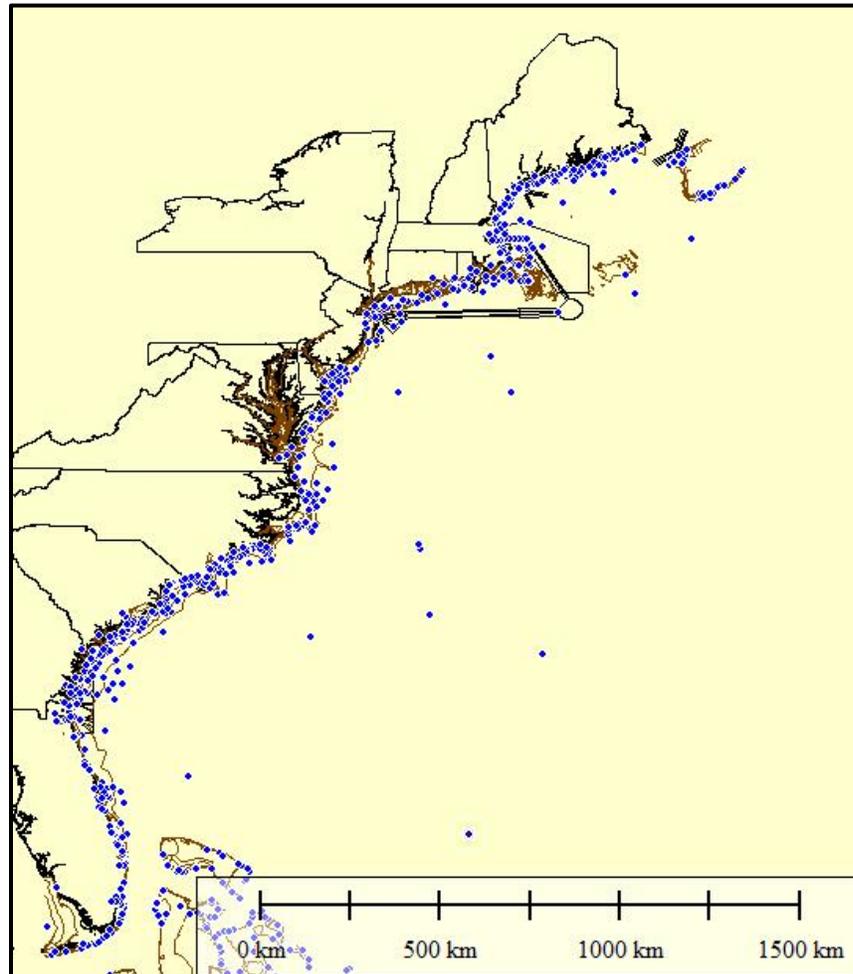


Figure D - 5: Model domain along the US Atlantic Seaboard including the Atlantic Coastal land boundary (black lines) NGMC (2009), buoys, beacons, lights, and fog signals (blue dots) NOAA (2012), and bathymetry (brown lines) NOAA (2012).

The Atlantic Coast land boundary utilized by the model was obtained from NGMC (2009) (Figure D - 5). Electronic navigational charts of Atlantic Coastal waters were obtained from NOAA (2012). Data layers, used for MVT model input, were extracted from the electronic navigational charts for locations of fixed features (buoys, beacons, lights, and fog signals) and for bathymetry contour lines (Figure D - 5).

D.6 Navigational Method

As discussed in the previous section, the MVT model uses a set of equations to simulate the motion of vessels using fundamental physical principles. The route that a vessel takes is governed by the methods for navigating between points.

The MVT model utilizes sequence of waypoints derived from AIS data (Appendix A), and the set of waypoints constitute a voyage or a set of voyages. (Voyages are defined three ways: (1) from one port to another, (2) from a point in the ocean to a port, and (3) from a port to a point in the ocean.) At the start of a simulation, the initial positions of vessels and their starting times are provided. These initial points are considered as entries into the model domain (called DomainIn). From this first point to all subsequent waypoints, the vessel determines the azimuth and distance from the vessel to the next waypoint.

The azimuth and distance are computed using computer codes derived from USNGS (2012) for forward and inverse calculations. These codes compute the geodetic azimuth and distance on an ellipsoid using the methods described by Vincenty (1975). The forward calculation uses the position, azimuth, and heading to compute a new position. The inverse calculation uses two positions and computes the azimuth and heading from the first position to the second position. For the purpose of navigation to the next waypoint, the inverse calculation is used.

D.7 Vessel Operator Methods

The operational characteristics for each vessel are provided through three primary means: a rudder response matrix, a frequency interval at which the operator monitors and responds, and the range of potential response frequencies that are computed stochastically. Different operator responses can be simulated for different vessels. That is, each vessel has its own designated operator, though each type of operator can be utilized by multiple vessels. The level of rudder response is computed at frequency intervals depending on the specified operator characteristics (Table D - 1). As a vessel travels towards a waypoint, the distance and azimuth to that waypoint is monitored. The deviation of the course from the computed azimuth to the waypoint is used to determine the level of rudder that needs to be applied. The distance from the waypoint is also used in determining the level of rudder that needs to be applied. The matrix values are used to scale the maximum rudder response as provided in the MVT model input.

Table D - 1: Example operator response matrix for a moderate level of response. The matrix values are used to scale the maximum rudder response as provided in the MVT model input.

	Distance (ship lengths)			
Course Deviation (degrees)	4	40	160	640
5	0.05	0.10	0.10	0.10
10	0.05	0.10	0.10	0.10
25	0.05	0.05	0.10	0.10
180	0.05	0.05	0.05	0.05

As the solution proceeds through time, the operator monitors and processes the navigation, guidance, and vessel motion functions of the MVT model. However, monitoring and processing does not happen at every solution time interval but may be skipped depending on the operator's monitoring interval. Intervals of 2 to 4 seconds mean that monitoring and processing happens every second or every fourth time step, if the solution time interval is 1 second. In addition, stochastic variation can be specified. Stochastic variation in intervals of monitoring and processing means that the duration for the next interval is reset each time that monitoring and processing occur.

One other stochastic process that is included is variation of the rudder response. This is specified as percent of variation in the computed rudder response.

D.8 Selection of Traffic Separation Schemes by Vessels

Cargo and tanker traffic make extensive use of traffic separation schemes (TSSs) that are specified in the Code of Federal Regulations (CFR) Title 33 Part 167 (CFR 2012). As found in the AIS data, most towing and tug vessel do not utilize TSSs, though there is an exception for the TSS identified as "Delaware Bay Northeastern Approach, Two-Way". Articulated-pusher tugs also use the TSSs on the southeastern and eastern approaches to Delaware Bay.

The selection of a TSS route into a port entrance depends on whether a vessel is inbound or outbound. For inbound, a vessel selects the closest TSS route into its port of call (PortIn). For outbound the TSS route away from the port depends on the next waypoint (Waypoint, PortIn, or DomainOut). Generally, waypoint generation occurs in three steps:

- Compute a set of TSS waypoint associated with a particular port
- Eliminate unnecessary waypoints based on rules for specific ports
- Adjust specific waypoints (especially those for precautionary areas) for specific TSS type at specific por

Table D - 2: Port Entrances and the Outbound TSS Routes. Inbound TSS routes are the reverse of outbound.

Port Name	Decision	TSS Route	
Boston Harbor entrance	Next waypoint is south of current location, but next entrance is not Cape Cod	1	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Boston Harbor, • Traffic Lane + Boston Harbor Traffic Lane, Outbound • Precautionary Area-eCFR + New York: Precautionary Areas - Eastern
	Next waypoint is south of current location and next entrance is Cape Cod	2	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Boston Harbor • Traffic Lane + Massachusetts Bay to Cape Cod Bay, Two-Way • Precautionary Area + Massachusetts Bay
	Next waypoint is north of current location	3	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Boston Harbor
Brunswick entrance	Next waypoint is north of current location	1	<ul style="list-style-type: none"> • Precautionary Area + Brunswick Georgia • Traffic Lane + Brunswick Georgia North Approach, Two-Way
	Next waypoint is south of current location	2	<ul style="list-style-type: none"> • Precautionary Area + Brunswick Georgia • Traffic Lane + Brunswick Georgia South Approach, Two-Way
Buzzards Bay north entrance	All	1	<ul style="list-style-type: none"> • Additional Routing Area + Buzzards Bay Route, Two-Way • Traffic Lane + Buzzards Bay, Outbound • Precautionary Area-eCFR + Narragansett and Buzzards Bay
Cape Cod Bay entrance	None		-
Charleston entrance	None		-

Port Name	Decision	TSS Route	
Chesapeake Entrance	Next waypoint is north of current location	1	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Chesapeake Bay Approaches – West • Traffic Lane + Chesapeake Eastern Approach, Outbound
	If vessel draft is greater than the 90 th percentile or next waypoint is south of current location	2	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Chesapeake Bay Approaches – West • Traffic Lane + Chesapeake Southern Approach, Outbound
Delaware Bay entrance	Next waypoint is north of 38.7° N	1	<ul style="list-style-type: none"> • Precautionary Area + Delaware Bay: Precautionary Area • Traffic Lane + Delaware Bay Eastern Approach, Outbound
	Next waypoint is south of 38.7° N	2	<ul style="list-style-type: none"> • Precautionary Area + Delaware Bay: Precautionary Area • Traffic Lane + Delaware Bay Southeastern Approach, Outbound
	Vessel type is towing and going to New York	3	<ul style="list-style-type: none"> • Traffic Lane + Delaware Bay Northeastern Approach, Two-Way
Fernandina entrance	Next waypoint is north of current location	1	<ul style="list-style-type: none"> • Precautionary Area + St. Marys River • Traffic Lane + St Marys River North Approach, Two-Way
	Next waypoint is south of current location	2	<ul style="list-style-type: none"> • Precautionary Area + St. Marys River • Traffic Lane + St Marys River South Approach, Two-Way
Fort Lauderdale entrance	All	1	<ul style="list-style-type: none"> • Precautionary Area + Fort Lauderdale
Fort Pierce entrance	None		-

Gloucester entrance	None		-
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Port Name	Decision	TSS Route	
Jacksonville entrance	Next waypoint is north of current location	1	<ul style="list-style-type: none"> • Precautionary Area + St. Johns River • Traffic Lane + St Johns River North Approach, Two-Way - South Branch 2 • Traffic Lane + St Johns River North Approach, Two-Way - North Branch
	Next waypoint is south of current location, but north of South Approach route waypoint	2	<ul style="list-style-type: none"> • Precautionary Area + St. Johns River • Traffic Lane + St Johns River North Approach, Two-Way - South Branch 2 • Traffic Lane + St Johns River North Approach, Two-Way - South Branch 1
	Next waypoint is south of current location	3	<ul style="list-style-type: none"> • Precautionary Area + St. Johns River • Traffic Lane + St Johns River South Approach, Two-Way
Long Island east entrance	All	1	<ul style="list-style-type: none"> • Additional Routing Area + Long Island East Entrance Route, Two-Way • Precautionary Area-eCFR + Narragansett and Buzzards Bay
Miami entrance	All	1	<ul style="list-style-type: none"> • Precautionary Area + Miami, FL
Morehead City entrance	None		-

New Bedford entrance	All	1	<ul style="list-style-type: none"> • Additional Routing Area + Buzzards Bay Route, Two-Way • Traffic Lane + Buzzards Bay, Outbound • Precautionary Area-eCFR + Narragansett and Buzzards Bay
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Port Name	Decision	TSS Route	
Newark-New York entrance	Next waypoint is north of 40.35° N or east of -68.5° W	1	<ul style="list-style-type: none"> • Precautionary Area-eCFR + New York: Precautionary Areas – Western • Traffic Lane + New York Eastern Approach: Ambrose to Nantucket, Outbound – West • Shipping Safety Fairway + Nantucket Ambrose Safety Fairway • Traffic Lane + New York Eastern Approach: Ambrose to Nantucket, Outbound – East • Precautionary Area-eCFR + New York: Precautionary Areas - Eastern
	Next waypoint is south of current location, but north of 39.8° N	2	<ul style="list-style-type: none"> • Precautionary Area-eCFR + New York: Precautionary Areas – Western • Traffic Lane + New York Southeastern Approach: Ambrose Hudson Canyon, Outbound
	Next waypoint is south of 39.8° N	3	<ul style="list-style-type: none"> • Precautionary Area-eCFR + New York: Precautionary Areas – Western • Traffic Lane + New York Southern Approach: Ambrose to Barnegat, Outbound
Palm Beach entrance	All	1	<ul style="list-style-type: none"> • Additional Routing Area + Buzzards Bay Route, Two-Way • Traffic Lane + Buzzards Bay, Outbound • Precautionary Area-eCFR + Narragansett and Buzzards Bay

Port Canaveral entrance	None		-
Portland entrance	Next waypoint is south of current location, but north of 43.2° N	1	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Portland Maine • Traffic Lane + Portland Maine Eastern Approach, Outbound
	Next waypoint is south of 43.2° N	2	<ul style="list-style-type: none"> • Precautionary Area-eCFR + Portland Maine • Traffic Lane + Portland Southern Approach, Outbound
	Next waypoint is north of 43.6° N, vessel does not use TSS	3	<ul style="list-style-type: none"> • None

Port Name	Decision	TSS Route	
Portsmouth entrance	All	1	<ul style="list-style-type: none"> Traffic Lane + Boston Harbor Traffic lane, Outbound Precautionary Area-eCFR + New York: Precautionary Areas
Providence East entrance	None		-
Providence Mid entrance	All	1	<ul style="list-style-type: none"> Precautionary Area-eCFR + Narragansett Bay Traffic Lane + Narragansett Bay, Outbound Precautionary Area-eCFR + Narragansett and Buzzards Bay
Providence West entrance	All vessels not headed to Long Island East Entrance, New Bedford Entrance, or Buzzards Bay North Entrance	1	<ul style="list-style-type: none"> Precautionary Area-eCFR + Narragansett Bay Traffic Lane + Narragansett Bay, Outbound Precautionary Area-eCFR + Narragansett and Buzzards Bay
Salem entrance	Next waypoint is north of 42.0° N	1	<ul style="list-style-type: none"> Additional Routing Area + Salem entrance, Two-Way
	Next waypoint is south of 42.0° N	2	<ul style="list-style-type: none"> Additional Routing Area + Salem entrance, Two-Way Traffic Lane + Boston Harbor Traffic Lane, Outbound
Sandy Point-Searsport entrance	None		-
Savannah entrance	None		-
Wilmington entrance	All	1	<ul style="list-style-type: none"> Precautionary Area + Cape Fear Traffic Lane + Cape Fear Approach, Outbound
Newark-New York entrance	Going to Long Island East Entrance, New Bedford Entrance, Providence Mid Entrance, Providence West Entrance, or Buzzards Bay North Entrance	1	<ul style="list-style-type: none"> Eliminate TSS Waypoints east of next waypoint
Portsmouth	Headed north	1	<ul style="list-style-type: none"> Eliminate TSS Waypoints south of next waypoint
Providence Mid entrance	Headed to Long Island East Entrance, New Bedford Entrance, or Buzzards Bay North Entrance	1	<ul style="list-style-type: none"> Eliminate all TSS except for Precautionary Area-eCFR + Narragansett Bay

Twenty-eight port entrances were identified and included in the MVT model. For each port entrance, Table D - 2 provides rules that are applied to select an outbound TSS. (As stated previously, inbound TSS selection is based on closest distance.) Rules for selection are needed because of the variety of potential routes a vessel could take to get to its next destination. Of course, port entrances without TSSs have no rules to be applied.

Table D - 3: Outbound TSS Waypoint Elimination to Account for Initial Vessel Locations within TSSs.

Port Name	Route	Eliminated Waypoints
Newark-New York entrance	Going to Long Island East Entrance, New Bedford Entrance, Providence Mid Entrance, Providence West Entrance, or Buzzards Bay North Entrance	Eliminate TSS Waypoints east of next waypoint
Portsmouth	Headed north	Eliminate TSS Waypoints south of next waypoint
Providence Mid entrance	Headed to Long Island East Entrance, New Bedford Entrance, or Buzzards Bay North Entrance	Eliminate all TSS except for Precautionary Area-eCFR + Narragansett Bay

Table D - 4: Inbound TSS Waypoint Elimination to Account for Irregular Entries into TSSs and for Initial Vessel Locations within TSSs.

Port Name	Route	Eliminated Waypoints
Boston Harbor entrance	If TSS route contains at New York Precautionary Area- Eastern, but vessel is north or west of precautionary area	Eliminate TSS Waypoints that the vessel has already passed
	If vessel has a DomainIn inside of the TSS zone	Eliminate TSS Waypoints that the vessel has already passed
	Vessel coming from Cape Cod	Keep all Waypoints north of Cape Cod Entrance
Buzzards Bay North entrance	Headed to Providence	Keep all Waypoints in Additional Routing Area
Newark-New York Entrance	Headed into New York using 'New York Eastern Approach: Nantucket To Ambrose, Inbound', 'New York Southeastern Approach: Hudson Canyon To Ambrose, Inbound', or 'New York Southern Approach: Barnegat To Ambrose, Inbound'	Eliminate Waypoints that are South or East of current location
New Bedford entrance	Is the vessel south of 41.5° latitude?	remove the last TSS waypoint
Salem entrance	Is the vessel north of the first waypoint?	eliminate by latitude, but only below 42° latitude eliminate by longitude for vessels above 42° latitude
Portsmouth entrance	Is the vessel north of the waypoint?	Eliminate waypoints north of the vessel
Portland entrance	Is vessel using "Portland Maine Eastern Approach, Inbound" TSS Zone?	Eliminate waypoints east of the current vessel location
	Is vessel using "Portland Southern Approach, Inbound" TSS Zone?	Eliminate waypoints south of the current vessel location

The rules for selection of outbound TSSs were developed from examination of AIS vessel tracks. A portion of the validation effort was to ensure that TSS selection was appropriate.

In certain cases that largely depend on the starting location of a vessel, it is necessary to eliminate waypoints from the computed TSS waypoint set (Table D - 3 and Table D - 4). If the vessel's starting point is within a TSS, it is necessary to eliminate waypoints it would have passed if the simulation had started earlier. (This leads to an initial condition problems that cannot be readily overcome without starting the simulation prior to the European discovery of the New World.)

Special handling is required for traffic originating north of Cape Cod and entering ports at Rhode Island or north of Long Island because of the utilization of TSSs associated with Boston and New York (Table D - 5 and Table D - 6).

Table D - 5: Inbound TSS Waypoint Exceptions to Account for entry into the New York Fairways.

Port Name	Decision	TSS Route
Boston Harbor entrance	Vessel is coming from Long Island or Providence	<ul style="list-style-type: none"> Shipping Safety Fairway + Nantucket Ambrose Safety Fairway Traffic Lane + New York Eastern Approach: Ambrose To Nantucket, Outbound - East Precautionary Area-ecfr + New York: Precautionary Areas – Eastern Traffic Lane + Boston Harbor Traffic Lane, Inbound Precautionary Area-ecfr + Boston Harbor

Table D - 6: In-Transit TSS Waypoint Generation.

Outbound Port Name	Inbound Port Name	TSS Route
Portland Entrance	Providence Entrance	<ul style="list-style-type: none"> Traffic Lane + Boston Harbor Traffic Lane, Outbound (south of bend in traffic lane) Precautionary Area-ecfr + New York: Precautionary Areas – Eastern Traffic Lane + New York Eastern Approach: Nantucket To Ambrose, Inbound – East Shipping Safety Fairway + New York Shipping Safety Fairway

Table D - 7: TSS Waypoint Generation for Tugs and Towing Vessels. Except for these Rules, No Other TSS Routes are Utilized.

Port Name	Vessel Type	TSS Route
Delaware Bay entrance	Pusher Tug	Follows TSS Zones with the same rules as Cargo and Tanker vessels.
	All Towing	If towing vessel is traveling between Newark-New York entrance and Delaware Bay entrance, uses the Traffic Lane + Delaware Bay Northeastern Approach, Two-Way Zone

According to the AIS data (Appendix A) tugs and towing traffic typically do not utilize TSSs. However, at the Delaware Bay entrance, tugs and towing do utilize the TSSs in the case of pusher tugs (Table D - 7). Also, at the Delaware Bay entrance, all tugs and towing traffic utilize the northeastern two-way traffic lane (Table D - 7).

D.9 Wind and Current

Wind and current data are included in the MVT model as two factors of the environment that vessels must handle during voyages. (Visibility is another environmental factor that may be addressed in future scenarios.)

Wind data were obtained from NOAA (2013a) with coverage of much of the Northern Hemisphere from latitudes 0° to 85° and longitudes -2° to -211° . Locations are spaced approximately 32 kilometers apart and at 12-hour time intervals. The wind data are for the two simulation periods in the first two weeks of March and July 2011 (Figure D-6). These data are trimmed so that only the data locations within the Atlantic Coastal domain are included in an analysis. Trimming is necessary to reduce the number of locations through which a vessel has to search. Wind is utilized in setting encounter distances during a simulation. (Inclusion of the effect on vessel motion may be addressed in future scenarios especially in the case of a vessel's loss of steerage or propulsion. Scenarios that include wind fields stronger than seen during the July and March 2011 simulation periods can be based on storms from other periods.)

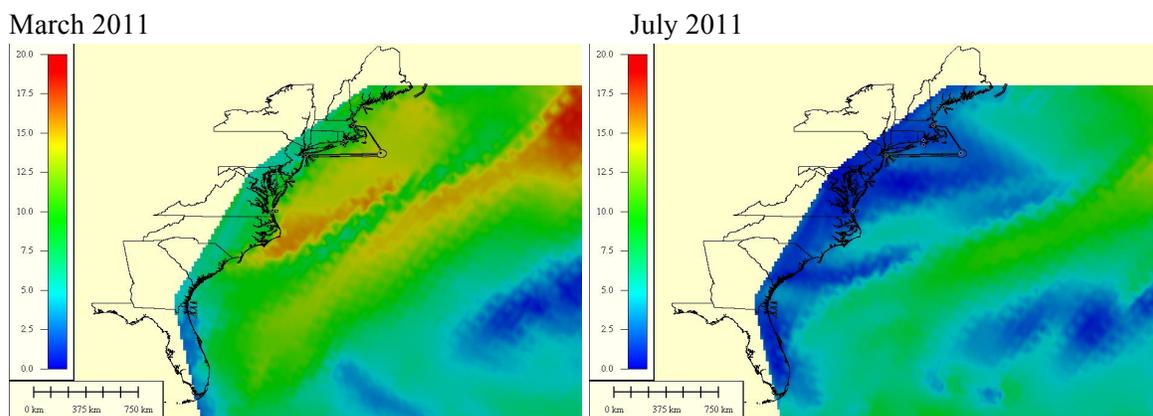


Figure D - 6: Maximum Wind Speed (m/s) for the Atlantic Coast. used during the March 2011 and July 2011 Simulation Periods

D.10 Vessel Interactions

The primary purpose of the MVT model is to evaluate vessel interactions, which are used in the analysis of risk to navigation from the presence of combined wind area. Within the MVT model, vessel interactions are implemented with the following processes:

1. Target identification and vessel detection
2. Potential Points of Collision (PPCs) are computed and logged

3. If PPC logged, then “rules of the road” cases are logged
4. Logging of encounters

D.10.1 Target Identification and Vessel Detection

Within the MVT code, distances and azimuth between all vessels are computed at regular, but relatively infrequent, intervals and the results stored in a global vessel interaction matrix (gVIM). The gVIM only stores vessel data if the distance between a vessel and its potential target vessels are within a radius larger than the largest radar range of all vessels. During the simulation, a vessel queries and requests updates for subsets of the gVIM. The requests are made at relatively frequent intervals and vessel information is updated only for vessels that have been identified as potential targets in the gVIM. If the distance is within own vessel’s radar range, further computations (discussed in the following subsections) are made to handle the consequences of vessel interactions.

Simulation of the vessel detection is based on the radar and visual horizons of own vessel. The distance to the radar horizon is given by the following equation:

$$d_r = 1852 * 2.21\sqrt{H_r}$$

with d_r being the radar distance range in meters and H_r being the height of the radar unit above the surface of the Earth in meters (Bole et al 2005). This formulation does not include the height of target vessels, making the distance detection limit conservative. The distance equation assumes standard atmospheric conditions, sufficiently powerful radar pulses, the target configuration is such that it will return a signal, and there is no undue attenuation of pulses by the atmosphere from precipitation (Bole et al 2005).

The distance to the visual horizon is given by the following equation:

$$d_v = 1000 * 3.57\sqrt{H_v}$$

with d_v being the radar distance range in meters and H_v being the height of the observer above the surface of the Earth in meters (NASA 2004). This formulation does not include the height of target vessels, making the distance detection limit conservative.

If wind farms are present, additional computation is required, which is discussed in the Wind Farms section.

D.10.2 Estimating of Potential Points of Collision

The computation of potential points of collision (PPCs) involved estimating the positions of target and an operator’s own vessel into the near future and determining the proximity of the vessels to each other. If they are in close proximity (less than the encounter distance of 0.5 nautical miles), an encounter is logged by MVT and output at the end of the simulation (Figure D - 7).

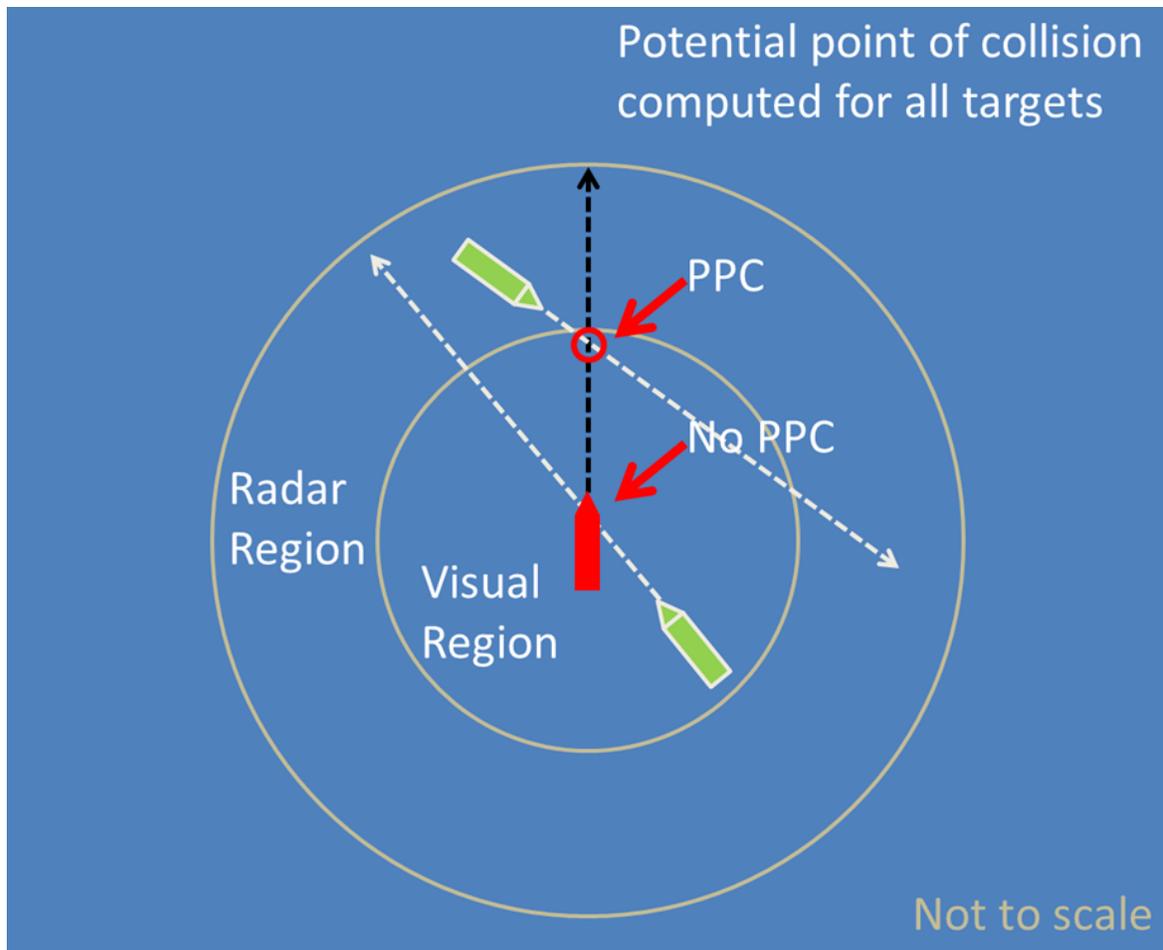


Figure D - 7: Schematic of the Method used to compute Potential Points of Collision (PPC).

For the purpose of computing the PPC, the speeds and courses of each vessel are required. For the target vessel, own vessel computes the speed and course from 2 successive tracked positions. Own vessel uses its current speed and course. To compute the positions into the near future, the speeds and courses are assumed to be constant at each time interval over the calculation period. Geodetic methods are used to compute the distances between the target and own vessels. If the computed distance is less than own vessel's encounter zone size (at present, specified as a constant distance of 0.5 nm), a PPC is logged.

D.10.3 Usage of the Rules of the Road

The United States Coast Guard (USCG) publishes navigational rules (USCG 2013), which include overtaking, head on, and crossing situations. As implemented in the MVT, these situations are considered only if a PPC has been found and logged for two vessels.

To determine if the PPC is for an overtaking situation, the following conditions must be satisfied:

1. The azimuth to the target vessel and heading to PPC are within own vessel's forward angle threshold (± 45 deg)
2. The course of the target is similar (± 5 deg) to the course of own
3. Net speed (target speed minus own speed) is less than own vessel's speed
4. Speed ratio of target: own is less than 1

If the PPC is not for an overtaking situation, then a determination is made if a head-on situation applies. For an overtaking situation, the following conditions must be satisfied:

1. The azimuth to the target vessel and heading to PPC are within own vessel's forward angle threshold (± 45 deg)
2. The course of the target is nearly (± 5 deg) the reciprocal to the course of own
3. Net speed (target speed minus own speed) is greater than own vessel's speed
4. Speed ratio of target: own is greater than 1

If the PPC is not for an overtaking or a head on situation, then a determination is made if a crossing situation applies. For a crossing situation, the following conditions must be satisfied:

1. The azimuth to the target vessel and heading to PPC are within own vessel's forward angle threshold (± 45 deg)
2. The target vessel is ahead and starboard of own vessel

The MVT model does not explicitly simulate responses to hazardous situations through application of the rules of the road. Once one of the situations is found to apply, it is logged for output at the end of the simulation.

D.10.4 Identification of Vessel Encounters

Vessel encounters are logged when the distance between two vessels is less than the encounter zone size (Figure D - 8). Generally, the encounter zone is specified as being less than 0.5 nautical miles (DNV 2010, Akhtar and Jean-Hansen 2009). However, in the case where high wind is encountered by a vessel, the encounter zones are scaled as follows:

- Greater than 22 knots (strong breeze), increase by a factor of 1.25
- Greater than 28 knots (near gale), increase by a factor of 1.50
- Greater than 34 knots (gale), increase by a factor of 2.00

These wind speed demarcations come from NOAA (2013b), while the scale factors are based on engineering judgment.

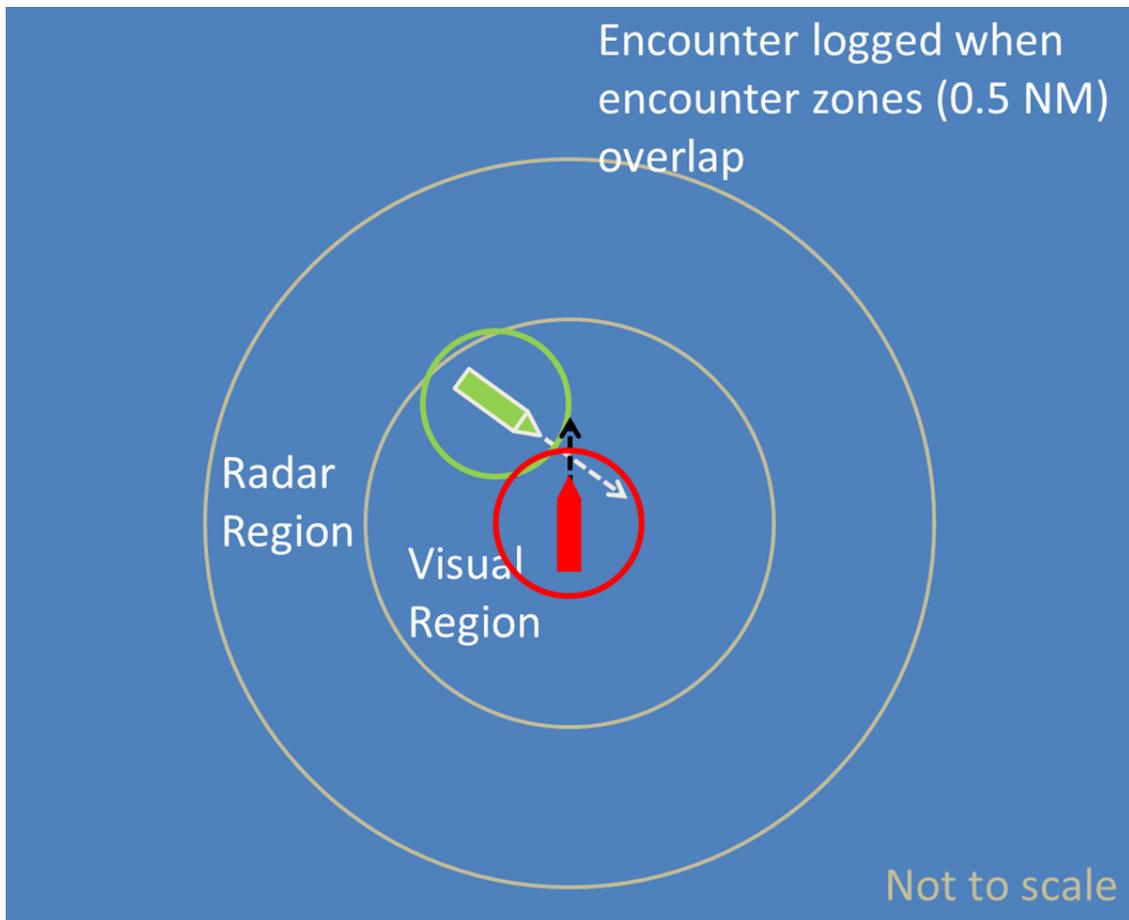


Figure D - 8: Schematic of the Method used to log when two vessels have an encounter.

D.11 Wind Farms

D.11.1 Combined Wind Areas Input

Each combined wind area (CWA) is inputted into the model via a list of latitude and longitude points describing the vertices of the wind area. A box is devised around the wind farm using a projection from key points specified in the wind farm input file (Figure D - 9). This box is projected at different distances away from the wind farm. The wind farm box is used to simplify a complex shape for more straightforward computation and navigation.

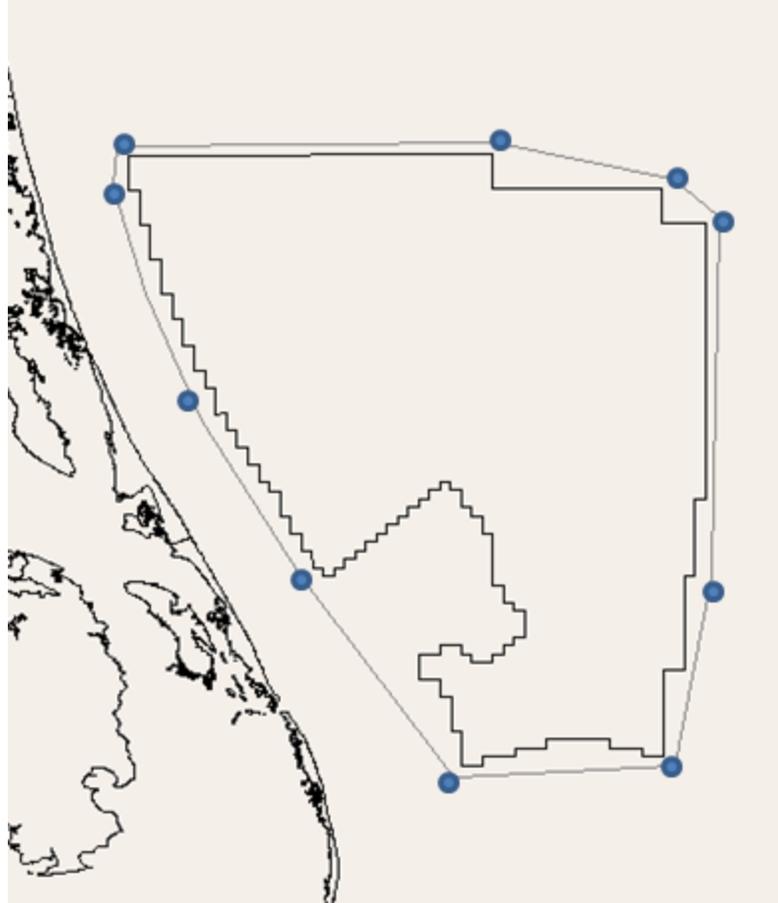


Figure D - 9: Demonstration of box points drawn around North Carolina wind area.

D.11.2 Waypoint elimination

If a voyage file waypoint is inside of the 2 nautical mile simplified wind farm box, it is eliminated (Figure D - 10). This ensures that waypoints that previously would have guided through the wind area instead can be guided around the wind farm. Occasionally, vessels have a starting or ending point in a windfarm. In this case, the point is not eliminated and the vessel is allowed to transit through a windfarm. This case will be ameliorated in the coming year.

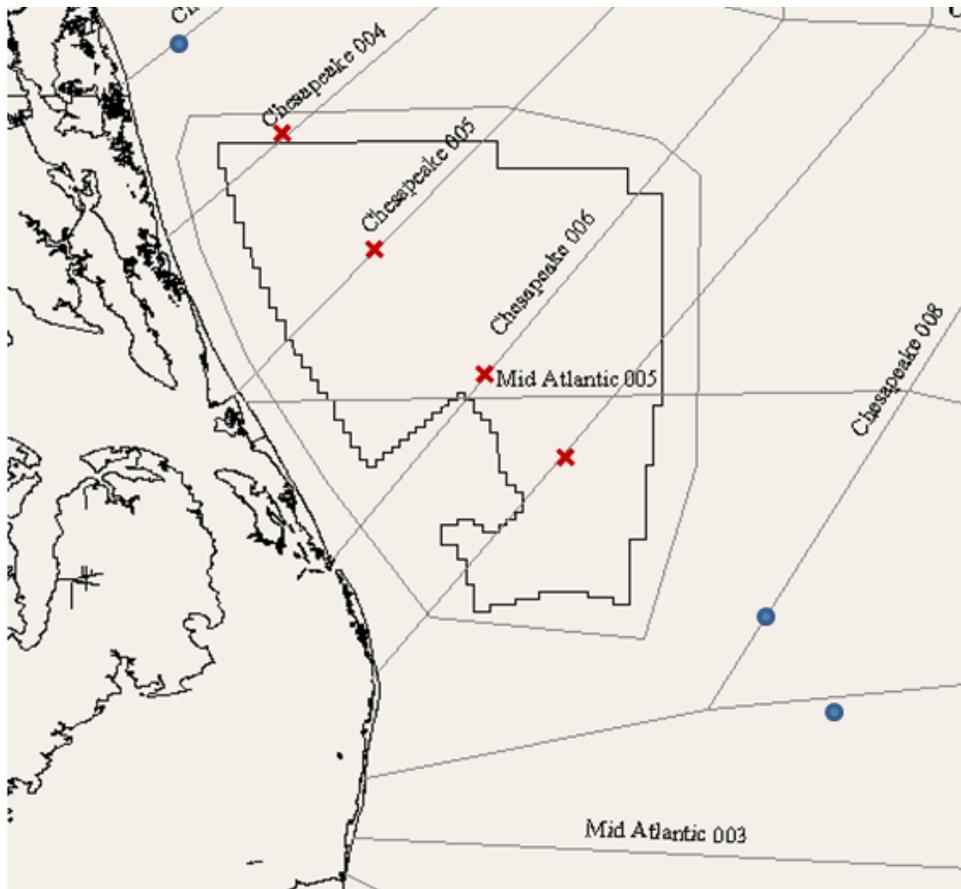


Figure D - 10: Demonstration of eliminated points inside of a wind area.

D.11.3 New Waypoint Generation

As the vessel approaches a wind farm, the model must decide which way to transit around the wind farm and generate a new set of waypoints to guide the vessel around the wind farm. The model has two methods for deciding how to transit the windfarm:

1. Choosing the shortest distance around the area
2. Pushing the vessel seaward or landward based on type, where cargo and tanker vessels are pushed seaward and towing vessels choose the landward route.

'Special Instructions' can also be used to specify individual windfarm rules. For example, the three wind areas in Buzzard Bay are combined to function as one, so vessel cannot transit it the small cut out between the farms. Additionally, all vessels around the large North Carolina wind area are pushed seaward, as the area between the farm and coast is shallow.

The model uses the previously generated simplified box points to pick waypoints. The model continues to choose box points until the projected heading from the current generated windfarm waypoint to the next primary waypoint no longer intersects a wind farm (

Figure D - 11). An example of the *Hoegh Tropicana* from July 2011 is shown both with and without wind farm waypoints (Figure D - 12).

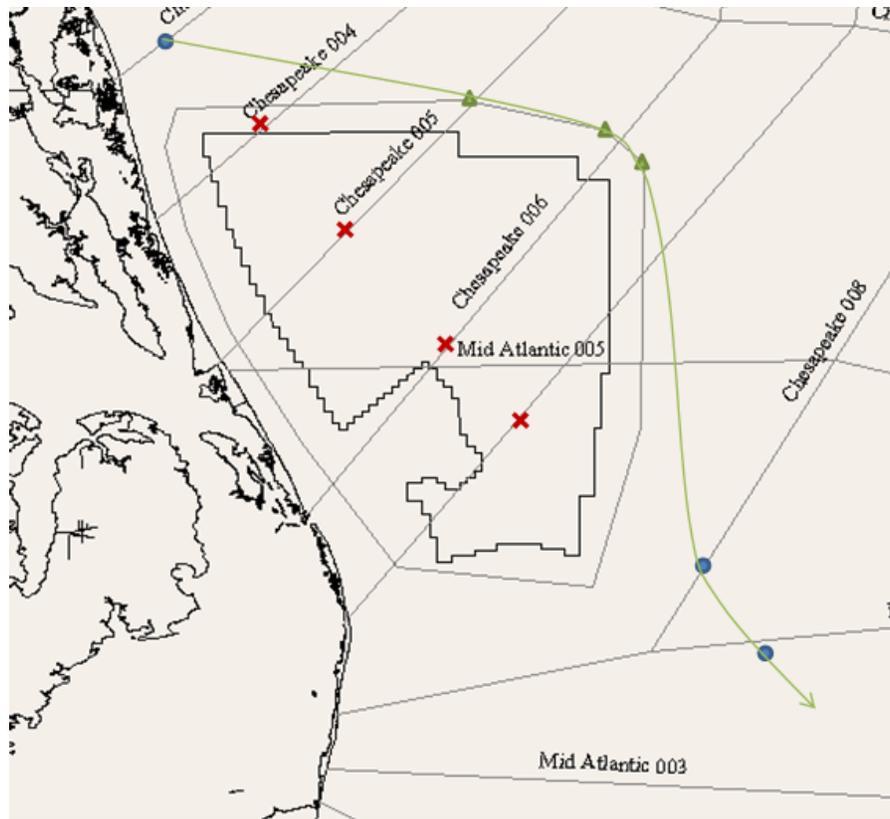


Figure D - 11: Generated Waypoints (green triangles) and estimated path (green line) to guide vessel around a windfarm. The input file waypoints are also shown, with eliminated waypoints in red and kept waypoints in blue.



Figure D - 12: Example of the Hoegh Tropicana July 2011 route both with wind area waypoints (right) and without (left).

D.11.4 Combined Wind Area Radar Interference

When combined wind areas (CWAs) are present, there is a potential that the CWA will interfere or block radar pulses and prevent the detection of potential target vessels. In the MVT model the presence of a CWA is assumed to completely block radar pulses. Within the MVT, a computation is made to check if there is a CWA between own and potential target vessels. If so, no vessel is detected.

D.12 References

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Appendix E - Model Validation

E.1 Introduction

A variety of methods were used to validate the model. A small set of representative vessels were used for validating model updates, as well as validating model speeds. The full two-week sets of data were used to further validate the model speeds, as well as compare total distances traveled.

E.2 Model Validation Vessels

The model was validated by choosing a subset of 41 cargo, tanker, and towing vessels. Model runs of these vessels were compared against the corresponding vessels actual AIS tracks and speeds. For each added functionality to the model, the same set of validation vessels were used to ensure correct performance. The vessels were chosen so that each type of vessel hit all the ports and had a full range of use of TSS zones and precautionary areas for the type. The validation also was used to confirm vessel speeds in the model.

For each vessel type, individual vessels were chosen by hand. The range of vessels transited every port on the Atlantic coast. Track data was pulled from any of three years. When developing a voyage file, all vessels were set to start at the same time, though they may have originated from different months or years. The model validation was run for 20 days. One goal was to represent the original tracks accurately, while also minimizing the number of input waypoints into the model.

E.2.1 Cargo Vessel

A subset of 18 cargo vessels was chosen to represent a range of potential routes for cargo vessels. Cargo vessels use all TSS zones and other routing areas. The model was run and then overlaid over the original track lines to verify that the model handled cargo movement appropriately (Figure E - 1). When model tracks do not match original tracks, it is a result of including fewer specific waypoints in the model input file. Additionally, the model cuts off data at port entrances, where track files continue into port.

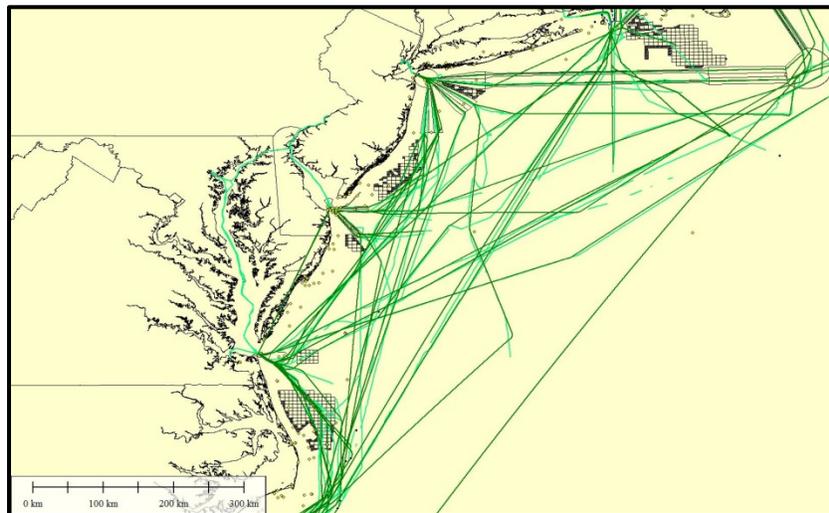


Figure E - 1: Cargo model validation tracks overlaid onto original AIS tracks. The darker green lines represent the model run, and the lighter color lines are the AIS tracks.

E.2.2 Tanker Vessels

A subset of 10 tanker vessels was chosen to represent a range of potential routes for tanker vessels. All tanker vessels use TSS zones and other routing areas. The model run output tracks were overlaid with the original track files (Figure E - 2). When the two sets of tracks do not line up, it is a result of a simplified set of points input into the model.

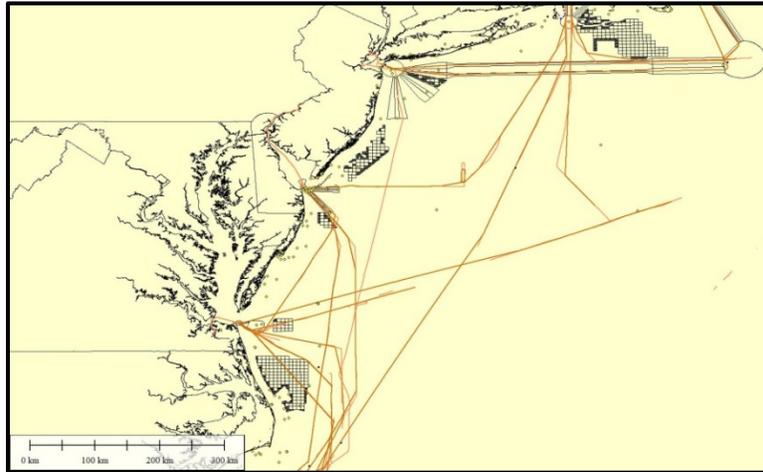


Figure E - 2: Tanker model validation tracks overlaid onto original AIS tracks. The darker orange represent lines the model run, and the lighter color are the AIS tracks.

E.2.3 Towing Vessels

A subset of 13 towing vessels was chosen to represent a range of potential routes for tanker vessels. Observation of the validation run led the PNNL team to determine that towing vessels typically do not use TSS zones and other routing areas, but do occasionally use the TSS zones in Delaware Bay. The model run output tracks were overlaid with the original track files (Figure E - 3). When the two sets of tracks do not line up, it is a result of a simplified set of points input into the model.

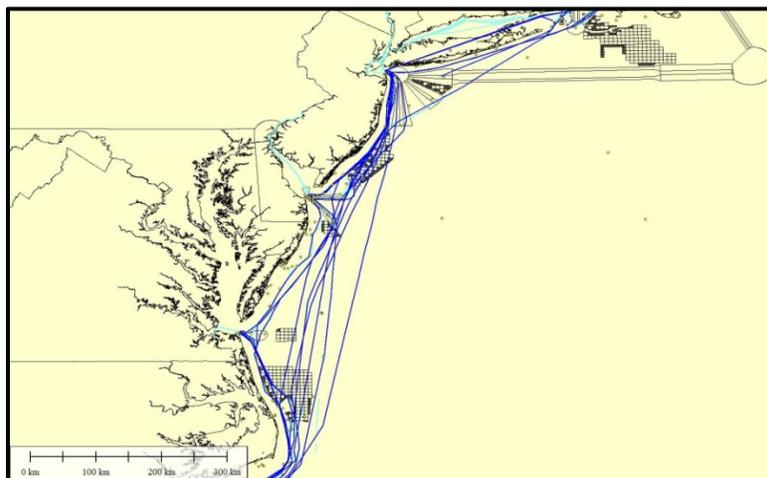


Figure E - 3: Towing model validation tracks overlaid onto original AIS tracks. The darker orange represent lines the model run, and the lighter color are the AIS tracks.

E.3 Model Validation Speed Checks

Model speeds are set by scaling the average speed determined for each vessel by the input files, so these scaling factors were being validated. Average speeds at the intersection points were compared against non-zero average model speeds. Iterative testing was used as speed factors were changed for different locations, such as precautionary areas, TSS zones, and open water. The goal was to fit a line with a slope and R² as close as possible to 1 (

Table E - 1). Speeds were also compared against time to view correlation between the model and reality. The alignment showed varied results with some vessels lining up better than others (Figure E - 4 & Figure E - 5).

Table E - 1: Examples of iterative checking of speed scaling factors for 41 vessel model validation runs.

Sample Set Vessels							
Model Scaling Factors (Avg. Speed) - Excluding Zeros							
Precautionary Inbound	TSS Inbound	Precautionary Outbound	TSS Outbound	Open Water		Slope	R ²
0.7	0.9	0.8	1.0	1.3		0.8700	0.9896
0.7	0.9	0.8	1.0	1.1		0.9664	0.9936
0.6	0.8	0.7	0.9	1.1		0.9869	0.9921
0.7	0.8	0.8	0.9	1.1		0.9746	0.9930
0.8	0.9	0.9	1.0	1.05		0.9939	0.9951
0.9	0.8	0.9	1.0	1.05		0.9998	0.9942
0.9	0.7	0.9	1.0	1.05		1.0099	0.9923
0.9	0.7	0.9	1.05	1.05		0.9987	0.9942

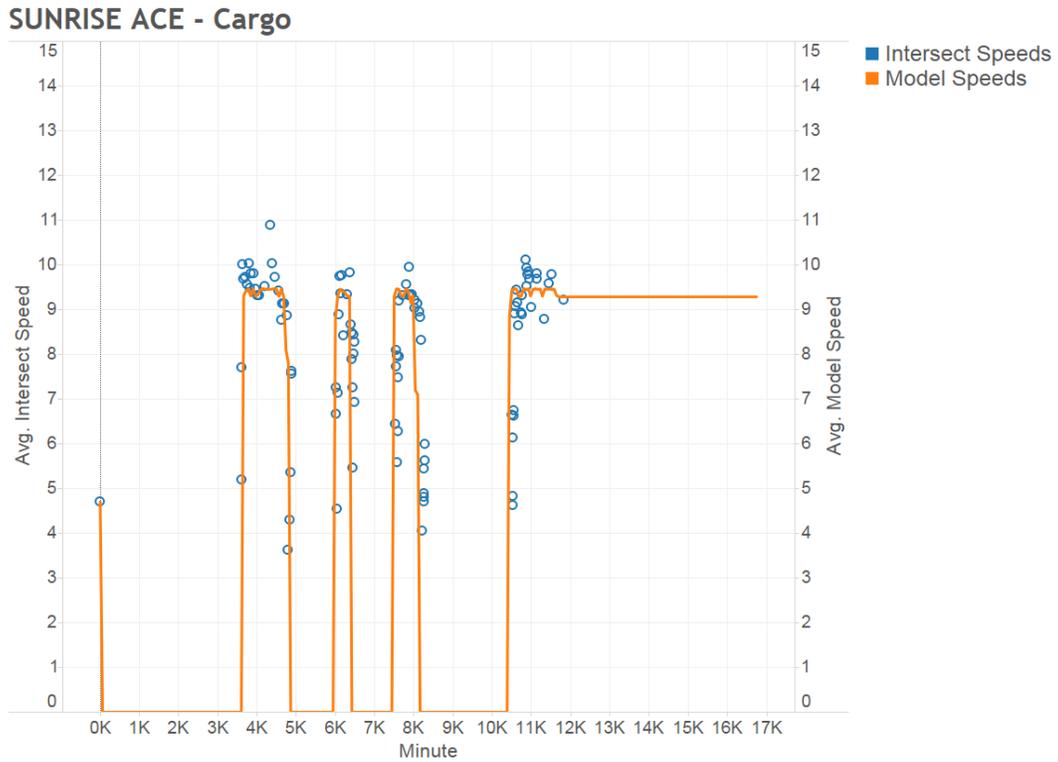


Figure E - 4: Example of speed checks against time to view correlation of model and original intersection files. The Sunrise Ace, a cargo vessel, had a very good correlation with the above scaling factors.

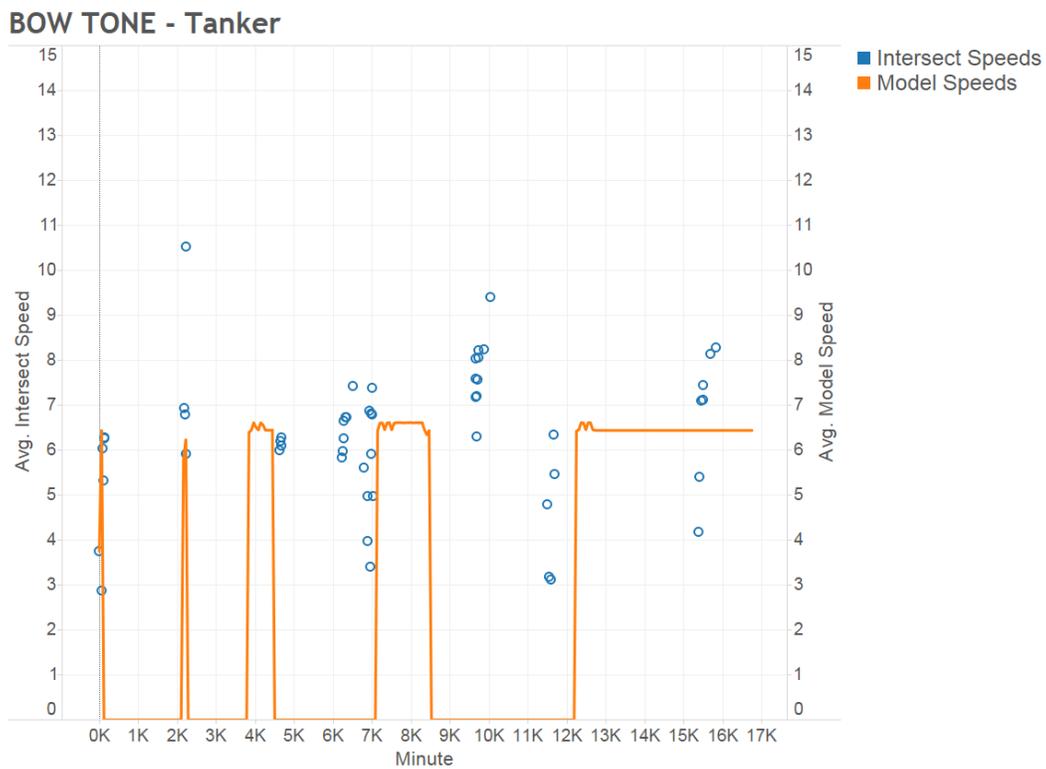


Figure E - 5: Example of speed checks against time to view correlation of model and original intersection files. The Bow Tone, a tanker vessel did not have a perfect correlation with the model scaling factors.

E.3.1 Full July Case Validation

The base case with all vessels for the 2 week July run were examined to discover the speed factors to be applied to various travel methods (open water, TSS, and precautionary area) (Table E - 2). The average intersect speeds were compared against the average model speeds that corresponded with the same time. These values were averaged per ship and plotted with a line of best fit forced to intersect at Y=0 (Figure E - 6). If the model speed was zero at any corresponding time, the point was dropped from the averaging.

Table E - 2: Examples of iterative checking of speed scaling factors for 2 Week July model runs.

2 Week Vessels - July							
Model Scaling Factors (Avg. Speed) - Excluding Zeros							
Precautionary Inbound	TSS Inbound	Precautionary Outbound	TSS Outbound	Open Water		Slope	R ²
0.9	0.8	0.9	1.0	1.05		1.0009	0.9795
0.9	0.8	0.9	1.0	1.1		0.9717	0.9793
0.9	0.8	0.9	0.9	1.0		1.0390	0.9811
0.7	0.8	0.8	0.9	1.05		1.0130	0.9809
0.7	0.8	0.9	1.0	1.05		1.0094	0.9811
0.7	0.8	1.0	1.0	1.05		1.0062	0.9811
0.8	0.8	0.9	1.0	1.05		1.0043	0.9817
0.9	0.8	0.9	1.0	1.05		0.9993	0.9819
0.9	0.7	0.9	1.0	1.05		1.0059	0.9811
0.9	0.8	0.9	0.9	1.05		1.0028	0.9818
0.9	0.8	0.9	1.05	1.05		0.9977	0.9820

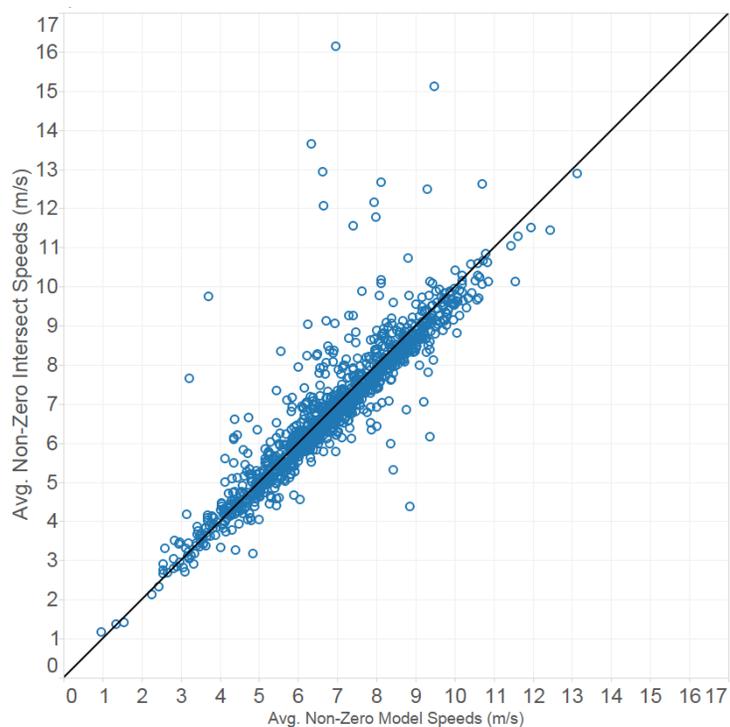


Figure E - 6: Plot of model average speed versus intersection file average speed. A perfect model would have a 1:1 ratio and the scaling factors come near to achieving this, with an R^2 value of 0.9819 and slope of 0.9993.

Iterative testing as shown in Table E - 2 eventually resulted in a line of best fit that very closely represents a 1:1 ratio (Figure E - 6).

E.4 Distance Traveled Validation

Checking the distance traveled is an additional indication of proper model functionality. Comparing total distance traveled for the two week data sets showed that the model traveled 96-98% of the distance of the original data (Table E - 3). The model results are shorter smaller than the AIS data since the simulated vessels travel directly between waypoints while the AIS vessel tracks may have greater variation between waypoints. This can be seen in the comparisons of cargo, tanker, and towing tracks shown in Figure E - 1, Figure E - 2, and Figure E - 3.

Table E - 3. Distance traveled in the model output data versus the original AIS intersection data.

	Distance Traveled (km)					
	AIS				Model	Model/AIS
	Cargo	Tanker	Tow	Total	Total	
July 2011 AIS	597,645	169,850	138,445	905,940	870,276.6	0.9606
March 2011 AIS	513,405	113,526	108,962	735,893	720,812.4	0.9795

Appendix F - Base Case and Scenario Development

F.1 Introduction

To evaluate the effect of the development of wind energy areas on marine vessel traffic a comparison is made between base case conditions and various scenarios. The scenarios include deviations from the base case with the inclusion of combined wind area footprints and potentially more extreme environmental conditions (higher wind, etc.). PNNL developed two base cases in which no wind farms were present. These two base cases were used as a baseline for analyzing risk in each corresponding scenario. All scenarios used the Atlantic coast as the domain. In addition to the base cases, four scenarios were developed (Table F - 1). All base cases and scenarios incorporated two weeks (length of the simulation period) of processed AIS data (Appendix A), which included the creation of a list of vessels and their characteristics for the simulation period and voyage definitions from the period of simulation. The remainder of this appendix will describe each scenario in depth.

Table F - 1: Describes the domain, time period, inputs, and adjustments made for each scenario analyzed with the model.

Scenario	Base Case	Domain	Sub Domain	Additional Inputs	Adjustments
Base Case	July	All Atlantic	none	Wind for July 2011	
Base Case	March	All Atlantic	none	Wind for March 2011	
1	July	All Atlantic, all wind areas	none	Wind for July 2011	
2	March	All Atlantic, all wind areas	none	Wind for March 2011	
3	July	All Atlantic, all wind areas	Divide north and south	Add additional high wind speeds to simulate foul weather	Scale encounter distance for high seas (at a Strong Breeze 22 knots, Near Gale at 28 knots, and Gale at 34 knots).
4	March	All Atlantic, all wind areas	Divide north and south	Add additional high wind speeds to simulate foul weather	Scale encounter distance for high seas (at a Strong Breeze 22 knots, Near Gale at 28 knots, and Gale at 34 knots).

F.2 July Base Case

The July Base case includes all cargo, tanker, and towing vessels recorded in the processed AIS data set from July 1-July 14, 2011 (Table F - 2). For example, vessels lacking data around Cape Hatteras might transit overland, so a waypoint was added to the route. The July base case was chosen as an example of a typical two week period. The July base case contains NOAA wind data specific to the time

period. Examination of the wind data showed that the wind was calmer in the July base case than in March.

Table F - 2: Counts from July Base Case input to the model.

	July 2011 – 2 Weeks		
	Cargo	Tanker	Towing
Total Vessels	657	278	225
Combined Vessels	1160		

F.3 March Base Case

The March base case includes all cargo, tanker, and towing vessels recorded in the AIS data set from March 1-March 14, 2011 (Table F - 3). Vessels with obvious errors were corrected by adding waypoints to the voyage. For example, a vessel lacking data around Cape Cod would be forced to transit overland, so a waypoint was added to the route. March was chosen as a second base case because it was observed to have a high casualty rate, presumably from inclement weather. The March base case contains NOAA wind data specific to the time period analyzed. The NOAA data used for March 2011 had higher winds than the July base case. Though the March base case had a larger total number of vessels and voyages, the March track data revealed that vessels tended to stay closer inshore during this two week period.

Table F - 3: Counts from March Base Case inputted into the model.

	March 2011 - 2 Weeks		
	Cargo	Tanker	Towing
Total Vessels	729	274	190
Combined Vessels	1193		

F.4 Scenario 1: July Case, All Wind Areas

Scenario 1 used the same input vessels as the July base case, as well as the baseline wind data. All wind areas provided by BOEM were included in this model.

F.5 Scenario 2: March Case, All Wind Areas

Scenario 2 used the same input vessels as the March base case, as well as the baseline wind data. All wind areas provided by BOEM were included in this model.

F.6 Scenario 3: July Case, All Wind Areas, High Wind

Scenario 3 used the same input vessels as the July base case, and also included the baseline wind data multiplied by 3. The encounter distance in this scenario was scaled with the wind speed at the following levels: a Strong Breeze 22 knots, Near Gale at 28 knots, and Gale at 34 knots. The encounter distance scaled by 1.25, 1.5, and 2 respectively. All wind areas provided by BOEM were included in this scenario.

F.7 Scenario 4: March Case, All Wind Areas, High Wind

Scenario 4 used the same input vessels as the March base case, and also included the baseline wind data multiplied by 3. The encounter distance in this scenario was scaled with the wind speed at the following levels: a Strong Breeze 22 knots, Near Gale at 28 knots, and Gale at 34 knots. The encounter distance scaled by 1.25, 1.5, and 2 respectively. All wind areas provided by BOEM were included in this scenario.

Appendix G - Experts' Panel

G.1 Purpose of the Experts' Panel

The Expert Panel (Panel) was organized to provide applied, real-world input during the development of the model, as well as to gain constructive feedback and fine-tune the beta version as it became operative. The inclusion of the members of the Panel also served to inform concerned parties, both ashore and at sea, of efforts being made to assess and mitigate risks to mariners early in the development process, and to give them an opportunity to meaningfully contribute to the project. An additional benefit came in the opportunity to address questions and concerns from the various stakeholders.

Overall, the Panel provided benefit to all parties involved- the model was provided with information beyond AIS tracks, marine practitioners learned more about scenarios they might expect when encountering windfarms.

G.2 Recruiting and Communicating with the Experts' Panel

The members of the Panel were gathered through a number of means. Initial email and telephone contacts were made with stakeholders such as East Coast port agencies, professional mariner associations, relevant US government agencies, shipping lines, and wind industry representatives. Contact information was collected through internet search, and by networking. Many of the participants were found via secondary references, such as members of professional organizations contacted by the organizations' officials.

Participation and input was provided through email, telephone calls, teleconferences, and webinars. Ad hoc information was solicited directly from regional experts on matters of navigation, communication and radars. Conference calls with pilots, in coordination with the American Pilots' Association provided excellent localized navigational information. American Waterways Operators helped bring together towboat operators, who provided very valuable information regarding configuration and navigational preferences specific to the towing industry.

G.3 Experts' Panel Membership

The members of the Experts' Panel are listed in Table G - 1.

Table G - 1: Members of the Experts' Panel by sector with their affiliations.

Organization	Name	Position	Location
Passenger Vessels			
Passenger Vessel Association (PVA)	Edmund Welch	Legislative Director	Alexandria, VA
Cruise Lines			
Cruise Lines International Association (CLIA)	Stan Deno	Director of Operations	Fort Lauderdale, FL
Towing Vessels			
American Waterways Operators (AWO)	John Harms	Manager Atlantic Region	Arlington, VA,
American Waterways Operators (AWO)	Kevin J. Dowling	Government Affairs Associate	Arlington, VA,

Vane Brothers Company	Mason Keeter	General Manager	Norfolk, VA
Dann Marine Towing	Stephen Furlough	President	Chesapeake City, MD
Norfolk Tug Company	Hugh McCrory	Safety Manager	Norfolk, VA
Express Marine	Wayne Huebschman	Captain	Camden, NJ
Kirby Offshore Marine	Jeff Parker	Port Captain	Chesapeake, VA
Deep Draft Shipping			
Texas Cargo Transport	Marc Marling	Executive Vice President	Norfolk, VA
World Shipping Council	Doug Schneider	Vice President	Washington, DC
Chamber of Shipping of America	Kathy J. Metcalf	Director, Maritime Affairs	Washington, DC
Pilots			
American Pilots' Association	Captain Michael Watson	President	Washington, DC
Pilots' Association for the Bay and River Delaware	Steve Roberts	Chairman, Mariners Advisory Committee	Lewes, DE
Maryland Pilots	Joe Smith	2nd Vice President	Baltimore, MD
Boston Pilots	Bob McCabe	Harbor Pilot	Boston, MA
American Pilots' Association	Gary Maddox	Vice President	Tampa, FL
Portland Pilots	Mark Klopp	Harbor Pilot	Portland, ME
Association of Maryland Pilots	Captain John P. Hamill	1st Vice President	Baltimore, MD
Pilots' Association for the Bay and River Delaware	Capt. James R. Roche	President	Lewes, DE
Portsmouth Pilots	PJ Johnson	Harbor Pilot	Portsmouth, NH
Ports			
American Association of Port Authorities (AAPA)	Meredith Martino	Director of Environmental Policy	Alexandria, VA
American Association of Port Authorities (AAPA)	Susan Monteverde	Vice President for Government Relations	Alexandria, VA
Virginia Port Authority	Kevin P. Abt, P.E.	Chief Engineer	Norfolk, VA
Port of Davisville, Quonset Development Corporation	Evan Matthews,	Port Director	North Kingstown, RI
Georgia Ports Authority	Christopher B. Novack, P.E.	Director of Engineering & Facilities Maintenance	Savannah, Georgia
MASSPORT	Captain F. Bradley Wellock	Manager, Maritime Regulatory Affairs	East Boston, MA
Port of New York/New Jersey	Edward J. Kelly,	Ex-Director, Maritime Authority,	NY, NY
Wind Industry			
Offshore Wind Development Coalition (OffshoreWindDC)	Doug Pfeister	Senior Vice President	Washington, DC
American Wind Energy Association (AWEA)	Christopher Long	Manager of Offshore Wind and Siting Policy	Washington, DC
Governmental			
USCG Research & Development Center	Lee Luft	NAIS Technical Support	New London, CT

USCG Headquarters	Emile Benard	Contractor	Washington, DC
Bureau of Offshore Energy Management	Will Waskes	Oceanographer	Herndon VA
Department of Energy, Wind and Water Power	Gary Norton	Contractor	Washington, DC

G.4 Experts' Panel Meetings

Four webinars and two additional meetings were held with the experts' panel between January and November 2013, as shown in Table G - 2. Additional one-on-one meetings were also held with specific panel members when the need arose.

Table G - 2: List of expert panel meetings and dates.

Meeting Date	Meeting Format
January 16, 2013	Webinar
May 2, 2013	Telecon meeting
July 9, 2013	Webinar
October 28, 2013	Telecon meeting
November 15, 2013	Webinar (towing industry only)
November 25, 2013	Webinar

Appendix H - Technical Committee

H.1 Introduction

The Technical Committee met regularly to determine progress on the project, help refine topics of importance to the processing of AIS data, model development and validation, scenario development, and risk calculation. Table H - 1 shows the membership of the Technical Committee. Table H - 2 indicates the meetings of the group.

Table H - 1: Members of the Technical Committee and their affiliations.

Name	Organization
Casey Reeves	BOEM
Will Waske	BOEM
Stephen Creed	BOEM
Josh Wadlington	BOEM
George Detweiler	USCG
Emile Benard	USCG (Contractor)
Brittney Baker	USCG (Contractor)

Table H - 2: Meeting dates and locations for the Technical Committee.

Meeting Date	Meeting Location
August 10, 2012	Online
August 24, 2012	Online
September 7, 2012	Online
September 18, 2012	Online
October 4, 2012	Online
November 7, 2012	Herndon VA. Presentations in Herndon and Washington DC in conjunction.
November 20, 2012	Online
January 31, 2013	Online
February 13, 2013	Online
February 22, 2013	Online
February 27, 2013	Online
March 13, 2013	Online
March 20, 2013	Online
May 20, 2013	Online
May 29, 2013	Online
July 2, 2013	Online
June 19, 2013	Online
July 2, 2013	Online
July 16, 2013	Herndon VA. Presentations in Herndon and Washington DC in conjunction.
August 1, 2013	Online
August 15, 2013	Online
September 18, 2013	Online
October 30, 2013	Online
November 19-21, 2013	Seattle WA, in conjunction with model training

Appendix I - Risk Analysis Methodology

I.1 USCG Casualty Data and AIS Data

The United States Coast Guard (USCG) tracks vessel casualties (collisions, allisions, and groundings) within US territorial waters. These casualty data are stored with the Marine Information for Safety and Law Enforcement (MISLE). Data records of importance for the analysis of risk include Event Type, Event Class, Waterway Name, Waterway Detail, Latitude, and Longitude. For this project, the Waterway Name and Waterway Detail were selected to include the term “Atlantic Ocean” only to eliminate events with harbors, bays, and inland waterways.

USCG provided MISLE data for the years 2001 through 2011 and within that period there were a total of 63 events. Within that period there were 32 collisions, 10 allisions, and 21 groundings (Table I - 1), giving an annual average of 2.9 collisions, 0.9 allisions, and 1.9 groundings. The average for 2010 and 2011 (when AIS data are available) are 2.5 collisions, 0.5 allisions, and 4.0 groundings.

Table I - 1: Casualty data from MISLE within Atlantic Ocean waters of the US.

Calendar Year	Collisions	Allisions	Grounding	Total
2011	1	0	1	2
2010	4	1	7	12
2009	1	1	0	2
2008	4	1	0	5
2007	4	0	4	8
2006	6	0	1	7
2005	1	1	1	3
2004	4	5	2	11
2003	5	1	1	7
2002	1	0	4	5
2001	1	0	0	1
Total	32	10	21	63
Annual Average	2.9	0.9	1.9	5.7
2010 and 2011 Average	2.5	0.5	4.0	7.0
Annual Maximum	6	5	7	12
Annual Minimum	1	0	0	1

Filtered AIS data are available for 2010 through 2012 have been made available to BOEM and USCG; processing procedures are detailed in - AIS Data Processing Appendix A. With the analyses of the AIS data, statistics of total number of voyages (Table I - 2), total time of travel (Table I - 3), and total

distance traveled were computed (Table I - 4). For 2010 and 2011, the annual average statistics were as follows:

- Total number of voyages per year was 72,165
- Total vessel travel time was 39,215 days
- Total vessel travel distance was 18,395,990 km

Table I - 2: Total Number of Voyages for All Vessels computed from AIS data.

	Cargo	Tanker	Towing	Total
2010	39,325	13,345	16,864	69,534
2011	41,153	13,617	20,026	74,796
2012	39,653	11,777	23,774	75,204
Annual Average	40,044	12,913	20,221	73,178
2010 and 2011 Average	40,239	13,481	18,445	72,165

Table I - 3: Total Travel Time (days) by All Vessels computed from AIS data.

	Cargo	Tanker	Towing	Total
2010	22,543	6,940	8,508	37,991
2011	23,769	7,296	9,374	40,439
2012	22,218	6,234	9,044	37,496
Annual Average	22,843	6,823	8,975	38,642
2010 and 2011 Average	23,156	7,118	8,941	39,215

Table I - 4: Total Distances (km) Traveled by All Vessels computed from AIS data.

	Cargo	Tanker	Towing	Total
2010	13,407,718	3,45,810	2,816,417	16,224,135
2011	14,000,235	3,552,080	3,015,530	20,567,845
2012	12,858,635	3,005,243	2,881,440	18,745,318
Annual Average	13,422,196	3,278,662	2,904,462	18,512,433
2010 and 2011 Average	13,703,977	3,552,080	2,915,974	18,395,990

Pairing the casualty data with the AIS statistics provides the rate of occurrence for each type of event per metric (Table I - 5). For example, using a metric of events per 1,000 km traveled, the rate of collision is 1.24×10^{-4} (collisions per 1,000 km traveled) (Table I - 1). These casualty rate values are used in the computation of risk from MVT model results.

Table I - 5: Casualty rates per voyage, per day traveled, and per 1,000 km traveled. The rates are derived from MISLE casualty data and AIS data for 2010 and 2011.

2010 and 2011	Casualty Events			
	Collisions	Allisions	Grounding	Total
Total Number of Vessel Voyages (events per voyage)	3.5E-05	6.9E-06	5.5E-05	9.7E-05
Total Vessel Travel Time (events per days)	6.4E-05	1.3E-05	1.0E-04	1.8E-04
Total Vessel Travel Distance (events per 1,000 km)	1.24E-04	2.48E-05	1.98E-04	3.47E-04

I.2 MVT Model Output

During the MVT model simulation (two week periods), vessel encounters, fixed-object encounters, and potential groundings are logged. Encounters are logged if two vessels approach within a specified distance of each other. Currently that default distance is 0.5 nautical miles; this distance can be increased if the vessel happens upon wind that exceeds speed thresholds. Encounters are used in the computation of risk for collision. Grounding potential is logged if computation shows a vessel is headed for a bathymetry contour that is shallower than the draft of the vessel. Grounding potential is currently computed 10 minutes into the future.

I.3 Computation of Risk

The USCG provided MISLE and the AIS data, which form the real-world basis for the computation of risk. The computation uses a rate calculated from a reported casualty event in the MISLE database (collision, allision, or grounding) and either the number of voyages, the number of days traveled, or the number of km traveled (expressed as logged events per 1,000 km traveled) from the AIS data. For example, using the USCG data, a collision rate of 1.24×10^{-4} collisions per 1,000 km traveled was computed (Table I - 5). The same types of rates are also computed for allisions and groundings (Table I - 5).

From the MVT model results, the computation of risk uses a rate calculated from events logged during the simulation (vessel encounters or potential groundings) and either the number of voyages, the number of days traveled, or the number of km traveled (logged events per 1,000 km traveled). For example, using the MVT model results based on distance traveled, computation for the combined base case results in a logged rate of vessel encounters is 3.03 encounters per 1,000 km traveled (row labeled (12) in Table I - 6). Logged rates are also computed for potential groundings (row labeled (12) in Table I - 7). Results based on the number of voyages can also be used (rows labeled (4) in **Error! Reference source not found.** and Table I - 7).

The next step in the computation of risk involves combining the casualty rate computed from the USCG with the logged rates from the MVT model. Continuing with the example, the number of casualties per logged event is computed as follows:

$$1.24 \times 10^{-4} \text{ collisions per 1,000 km traveled} / 3.03 \text{ encounters per 1,000 km traveled} = 0.409 \times 10^{-4} \text{ collisions per encounter (row labeled (13) in Table I - 6).}$$

The same types of rates are also computed for potential groundings (row labeled (13) in Table I - 7). Results based on the number of voyages can also be computed (rows labeled (5) in Table I - 6 and Table I - 7).

The final risk analysis result is to be reported as casualty events per year. However, each MVT model simulation is only two weeks long. There are currently two simulations made in different months (March and July 2011), which provides a total simulation period of four weeks. To obtain an annual rate, the results from the MVT model need to be scaled as follows:

$$52 \text{ weeks per year} / 4 \text{ weeks simulated} = \text{duration scale factor of 13 per year}$$

The duration scale factor is multiplied times the MVT model metric (number of voyages or km traveled) to provide an annual extrapolated value. For the example, the extrapolated value is 2.07×10^7 km traveled per year (or 2.07×10^4 1,000 km travel per year) (row labeled (14) in Table I - 6). (For voyages this is in the row labeled (6) in Table I - 6 and Table I - 7. For distance traveled this is also in the row labeled (14) in Table I - 7).

Next, an annual extrapolated logged event count is computed from the extrapolated MVT metric (number of voyages per year or distance traveled per year) and the number of logged events per metric. Continuing with the example, the number of encounters per year is computed as follows:

$$3.03 \text{ encounters per 1,000 km traveled} \times 2.07 \times 10^4 \text{ 1,000 km traveled per year} = 6.27 \times 10^4 \text{ encounters per year (row labeled (15) in Table I - 6).}$$

The same types of rates are also computed for potential groundings (row labeled (15) in Table I - 7). Results based on the number of voyages can also be computed (rows labeled (7) in Table I - 6 and Table I - 7).

Finally, the annual rates are computed as the product of the casualty event per MVT logged event times the annual extrapolated logged event. Continuing with the example, the annual number of collisions per year is computed as follows:

$$0.409 \times 10^{-4} \text{ collisions per encounter} \times 6.27 \times 10^4 \text{ encounters per year} =$$

2.6 collisions per year (row labeled (16) in Table I - 6ate than that based on voyages.

).

The same types of rates are also computed for potential groundings (row labeled (16) in Table I - 7). Results based on the number of voyages can also be computed (rows labeled (8) in ate than that based on voyages.

and Table I - 7).

For the scenario cases, the calculations are the same, with the values of casualty events per logged event taken from the base case. For the example, the number of collisions per encounter (row labeled (13) in Table I - 6) is greater than that based on voyages.

) are also used to compute the risks for the scenarios. This is necessary because these values are computed for the conditions as they existed at the time (or were simulated for that time period). No casualty data exist for the scenario with wind farms; that is the purpose of the modeling computations.

I.3.1 Collisions

Overall, the risk analysis results are as follows for collisions using the voyages based calculations:

- The combined base cases have a current collision rate of 1.8 per year, with a range from 1.7 to 1.8 per year computed for each base case run. This is smaller than the rate of 2.5 collisions per year from the casualty data for 2010 and 2011 (Table I - 1).
- Under the scenarios with the combined wind areas included, the expected collision rate is 2.0 per year, with range essentially the having the same value of 2.0 collision per year.
- The inclusion of the combined wind area increased the risk of collision by 12%.

For a risk analysis based on distance traveled the results for collisions are as follows:

- The combined base cases have a current collision rate of 2.6 per year, with a range from 2.3 to 2.8 per year computed for each base case. This is similar to the rate of 2.5 collisions per year from the casualty data for 2010 and 2011 (Table I - 1).
- Under the scenarios with the combined wind areas included, the expected collision rate is 2.9 per year, with a range from 2.5 to 3.2 per year computed for scenarios 1 and 2.
- The inclusion of the combined wind area increased the risk of collision by 12%, which is the same as computed using voyage based calculations.

Comparison of the basis for the risk calculation indicates that risk values based on distance traveled provides a more accurate estimate than that based on voyages.

I.3.2 Groundings

Overall, the risk analysis results are as follows for grounding using the voyages based calculations:

- The combined base cases have a current grounding rate of 2.9 per year, with a range from 2.8 to 2.9 per year computed for each base case. This is smaller than the rate of 4 groundings per year from the casualty data for 2010 and 2011 (Table I - 1).
- Under the scenarios with the combined wind areas included, the expected grounding rate is 2.9 per year, with the range essentially having the same value of 2.9 groundings per year.
- The inclusion of the combined wind area increased the risk of grounding by <1%.

For a risk analysis based on distance traveled the results for collisions are as follows:

- The combined base cases have a current grounding rate of 4.1 per year, with a range from 3.7 to 4.5 per year computed for each base case. This is similar to the rate of 4 groundings per year from the casualty data for 2010 and 2011 (Table I - 1).
- Under the scenarios with the combined wind areas included, the expected grounding rate is 4.1 per year, with a range from 3.7 to 4.5 per year computed for scenarios 1 and 2.
- The inclusion of the combined wind area increased the risk of grounding by <1%, which is the same as computed using voyage based calculations.

Comparison of the basis for the risk calculation indicates that risk values based on distance traveled provides a more accurate estimate than that based on voyages.

Table I - 6: Computations of Risk of Collision utilizing the MISLE and AIS data from Table I - 5 and MVT model computed estimates of Vessel Encounters. Change in risk is computed for the combined results since it uses a longer simulation period. The N/R entries indicate that the calculation is not required.

	Base Case July	Base Case March	Combined Base Cases	Wind Farm July	Wind Farm March	Combined Wind Farm
(1) Simulation Duration (weeks)	2	2	4	2	2	4
(2) Model Total Encounters	2,707	2,113	4,820	3,078	2,299	5,377
RISK BY VOYAGE						
(3) Model Count of All Voyages	1932	2032	3,964	1932	2032	3,964
(4) Model Total Encounters per voyage	1.4011	1.0399	1.2159	1.5932	1.1314	1.3565
(5) Collisions per encounter	2.47E-05	3.33E-05	2.85E-05	N/R	N/R	N/R
Annual Extrapolation						
(6) Extrapolation of Model All Voyages	50232	52832	51532	50232	52832	51532
(7) Extrapolation of Model Encounters	70382	54938	62660	80028	59774	69901
(8) Expected number of Collisions	1.7	1.8	1.8	2.0	2.0	2.0
(9) Change in risk						0.116
RISK BY DISTANCE						
(10) Model Distance Traveled By All Vessels (m)	870276625.3	720812433.2	1,591,089,059	879483503.2	732573899.1	1,612,057,402
(11) Model Distance Traveled By All Vessels (km)	870276.6253	720812.4332	1,591,089	879483.5032	732573.8991	1,612,057

(12) Model Total Encounters per km	3.11E-03	2.93E-03	3.03E-03	3.50E-03	3.14E-03	3.34E-03
(13) Collisions per encounter	3.98E-05	4.23E-05	4.09E-05	N/R	N/R	N/R
Annual Extrapolation						
(14) Extrapolation of Model All Distances (km)	2.26E+07	1.87E+07	2.07E+07	2.29E+07	1.90E+07	2.10E+07
(15) Extrapolation of Model Encounters	7.04E+04	5.49E+04	6.27E+04	8.00E+04	5.98E+04	6.99E+04
(16) Expected number of Collisions per Year	2.8	2.3	2.6	3.2	2.5	2.9
(17) Change in risk						0.116

Table I - 7: Computations of Risk of Grounding utilizing the MISLE and AIS data from Table I - 5 and MVT model computed estimates of Potential Groundings. Change in risk is computed for the combined results since it uses a longer simulation period. The N/R entries indicate that the calculation is not required.

	Base Case July	Base Case March	Combined Base Cases	Wind Farm July	Wind Farm March	Combined Wind Farm
(1) Simulation Duration (weeks)	2	2	4	2	2	4
(2) Model Total Potential Groundings	24,701	27,980	52,681	25,035	27,873	52,908
RISK BY VOYAGE						
(3) Model Count of All Voyages	1932	2032	3,964	1932	2032	3,964
(4) Model Potential Groundings per voyage	12.7852	13.7697	13.2899	12.9581	13.7170	13.3471
(5) Groundings per Potential Grounding	4.34E-06	4.03E-06	4.17E-06	N/R	N/R	N/R
Annual Extrapolation						
(6) Extrapolation of Model All Voyages	50232	52832	51532	50232	52832	51532
(7) Extrapolation of Model Potential Groundings	642226	727480	684853	650910	724698	687804
(8) Expected number of Collisions	2.8	2.9	2.9	2.8	2.9	2.9
(9) Change in risk						0.004
RISK BY DISTANCE						
(10) Model Distance Traveled By All Vessels (m)	870276625.3	720812433.2	1,591,089,059	879483503.2	732573899.1	1,612,057,402
(10) Model Distance Traveled By All Vessels (km)	870276.6253	720812.4332	1,591,089	879483.5032	732573.8991	1,612,057

(12) Model Potential Groundings per km	2.84E-02	3.88E-02	3.31E-02	2.85E-02	3.80E-02	3.28E-02
(13) Groundings per Potential Grounding	6.99E-06	5.11E-06	5.99E-06	N/R	N/R	N/R
Annual Extrapolation						
(14) Extrapolation of Model All Distances (km)	2.26E+07	1.87E+07	2.07E+07	2.29E+07	1.90E+07	2.10E+07
(15) Extrapolation of Model Encounters	6.42E+05	7.27E+05	6.85E+05	6.51E+05	7.25E+05	6.88E+05
(16) Expected number of Groundings	4.5	3.7	4.1	4.5	3.7	4.1
(17) Change in risk						0.004

Appendix J - User Manual

J.1 Introduction

This User Manual contains basic instructions to use the executable model ‘VisualModel.exe’. It contains a brief overview of the structure of the input files and graphic user interface. Pre-processing of vessel and voyage input files are covered in Appendix A.

J.2 Structure and Format of Input Files

The input files are a series of text files that provide the necessary data to run the model (Table J - 1). Shoreline data, delineated or regulated areas, buoy locations, environmental data, and bathymetry data remain unchanged through all model runs, though the data inputs could be changed if better data were to arise. Wind data are specific to the time period of interest. Wind farm data are included when adding wind areas into the model, but not in the base cases. In general, the input files are case sensitive.

Table J - 1: List of input files names and the data each file contains.

Input File Data Description	Input File Name
Marine Vessel Transit (MVT)	InputFiles.mvt
Shoreline data	CoastalAtlanticStates.xy
Bathymetry Data	AtlanticCoast contours - 5 m interval + 18mChes.xyz
Buoy locations	ENC layer data-buoy-beacon-light-landmark.xyz
Delineated or regulated areas	TSS Lanes and Areas and Fairways and Zones rev4.xyz
Wind Farm data	WindFarms_10_2013.xyz
Wind data	NARR_2011_March U timeupdated.dat NARR_2011_March V timeupdated.dat
Vessel data	Vessel.dat
Voyage data	Voyage.dat
Runtime information	Runinfo.dat

J.2.1 Marine Vessel Transit

The basic file input for every model run is the Marine Vessel Transit (MVT) file. The MVT file points to all other input files (Figure J - 1).

```

//Input files to be read

//Shoreline ←
CoastalAtlanticStates.xyz

//Bathymetry
AtlanticCoast contours - 5 m interval + 18mChes.xyz

//BuoyLocations
ENC layer data-buoy-beacon-light-landmark-rev1.xyz

//Delineated-RegulatedAreas
TSS Lanes and Areas and Fairways and Zones-rev4.xyz

//WindFarms
WindFarms_10_2013.xyz

//WindData
NARR_2011_March U timeupdated.dat
NARR_2011_March V timeupdated.dat

//VesselData
Mar2011_2WK_ALL-Vessel102513.dat ←

//VoyageData
Mar2011_2WK_ALL-Voyage111213.dat

//Runtime
Mar2011_2WK_ALL-Runinfo.dat

```

Each new file has a header that begins with '//'. The headings must be exact

For the vessel and voyage file, the file MUST be of file type '.dat'. However, the name can be any name.

Figure J - 1: Example and description of Marine Vessel Transit (.MVT) file, for the 2 week March 2011 wind farm scenario (Scenario 4).

J.2.2 Shoreline Data

Shoreline data are input into the model using a list of latitude and longitude for each coastal state (Figure J - 2).

```

DESCRIPTION=Unknown Area Type
CLOSED=YES
STPO=CT
FIPS_C=09
FIPS_I=9.00000
STATENAME=Connecticut
FIPSCTRY=US
STCATEGORY=State
STSTARTDAT=
NOTE=
BOTTOM=40.97990
TOP_=42.05059
LEFT_=-73.72777
RIGHT_=-71.78699
NAD83UTM=26918.00000
-72.3368529230,41.2947382140
-72.3366999960,41.2947152140
-72.3365170470,41.2947533140
-72.3363498990,41.2948063370
-72.3361658960,41.2948523380
-72.3359529230,41.2949053620
-72.3358308980,41.2948753390
-72.3356630480,41.2947912380
-72.3354799230,41.2946611370
-72.3348539970,41.2943182380
-72.3339078210,41.2937153120
-72.3327937950,41.2928913370
-72.3314509940,41.2922053630
-72.3305269410,41.2916983020
-72.3303680450,41.2916322850
-72.3292849210,41.2911443610
-72.3270408910,41.2902903630
-72.3265519140,41.2900461370
-72.3261709150,41.2898171870
-72.3259108880,41.2895652360
-72.3257130150,41.2892832620
-72.3255298890,41.2889552870
-72.3253769630,41.2886871840
-72.3253620390,41.2884513860
-72.3253769630,41.2883592090

```

Figure J - 2: Example of data from shoreline data file for Connecticut.

J.2.3 Bathymetry Data

Bathymetry data are input into the model through a series of latitude and longitude points that make up contour lines (Figure J - 3).

```

DESCRIPTION=Contour Line, Minor
NAME=20
ELEVATION=20
-74.975878,37.876941,20.000000
-75.052070,37.841831,20.000000
-75.104790,37.797032,20.000000
-75.162489,37.766537,20.000000
-75.170646,37.755993,20.000000
-75.158595,37.741884,20.000000
-75.158826,37.731804,20.000000
-75.188408,37.716918,20.000000
-75.197656,37.701412,20.000000
-75.223577,37.677222,20.000000
-75.241244,37.671074,20.000000
-75.276672,37.666678,20.000000
-75.267217,37.608995,20.000000
-75.269160,37.587907,20.000000
-75.276131,37.572401,20.000000
-75.293074,37.560616,20.000000
-75.299914,37.546351,20.000000
-75.308230,37.539611,20.000000

```

Figure J - 3: Example of bathymetry data contour lines used to predict groundings in the model.

J.2.4 Buoy Locations

Buoy locations are specified using a single latitude and longitude point (Figure J - 4).

```

GM_TYPE=Buoy
DESCRIPTION=Buoy, special purpose/general
NAME=ACOE Block Island Lighted Research Buoy 154
RCID=485
PRIM=1
GRUP=2
OBJL=19
RVER=1
AGEN=550
FIDN=114415376
FIDS=4500
BOYSHP - Buoy shape=pillar
CATSPM - Category of special purpose mark=recording mark
COLOUR - Colour=yellow
OBJNAM - Object name=ACOE Block Island Lighted Research Buoy 154
STATUS - Status=private
SCAMIN - Scale minimum=700000
SORDAT - Source date=20120313
SORIND - Source indication=US, US, reprt, 1st CGD, LNM 11/12
-71.1216667000,40.9810500000,-999999

```

Figure J - 4: Example of single latitude/longitude point of buoy data.

J.2.5 Delineated and Regulated areas

The delineated and regulated areas file contains the vertices of each regulated zone (Figure J - 5). Since many of the specific names in this file are hard-coded into the model and other input files, the names of each individual zone should be retained.

```
//TSS DATA
DESCRIPTION=Unknown Area Type
NAME=Lanes
CLOSED=YES
OBJECTID=201
officialDe=Traffic Lane
instanceCo=<Null>
effectiveD=07/14/2010
authority=Coast Guard, Department of Homeland Security
localHoriz=1.200000000000e+002
boundaryId=
RMSEmeters=22
boundaryCl=Portland Southern Approach, Outbound
Shape_Leng=7.62105355865e-001
Shape_Area=1.14734003149e-002
-69.9262518620,43.1278764131,1
-69.9591183180,43.1202934531,1
-70.0993541080,43.4359812781,2
-70.0685597250,43.4476504451,2
-69.9262518620,43.1278764131,-999999
```

Figure J - 5: Delineated and regulated areas input file contains the vertices for each zone, as well as a specific unique name for each zone.

J.2.6 Wind Farm data

The primary data in the wind farm file are the latitude and longitude coordinates of each vertices of the wind area (Figure J - 6). From those data, a simplified box is created. The box is designated in the input file by assigning the third value after latitude and longitude as an angle from North (0°). If latitude and longitude point is not used, the third value is assigned -999999 (Figure J - 7).

```
//WINDFARM DATA
DESCRIPTION=Unknown Area Type
CLOSED=YES
Id=0
INFO=North Carolina 3
Source=Wind Planning Areas 9/18/13
-75.2679086457,36.4761868731,10
-75.2677598600,36.4329141097,-999999
-75.0535522260,36.4332023505,40
-75.0535225312,36.3899288200,-999999
-75.0000000002,36.3899408115,60
-75.0000000002,36.0437411143,-999999
-75.0133218133,36.0437381537,-999999
-75.0133054501,35.9463680989,90
-75.0266108991,35.9463658866,-999999
-75.0265711113,35.8273531881,-999999
-75.0531422151,35.8273443765,-999999
-75.0530702784,35.7191489997,160
-75.0796053977,35.7191343732,-999999
-75.0796161626,35.7299539926,-999999
-75.1194241799,35.7299210684,-999999
-75.1194403317,35.7407384602,-999999
-75.1990668749,35.7406330633,-999999
-75.1990399546,35.7298157128,-999999
```

Figure J - 6: Example of wind farm input file, showing North Carolina Kitty Hawk Wind Energy Area latitude and longitude points.

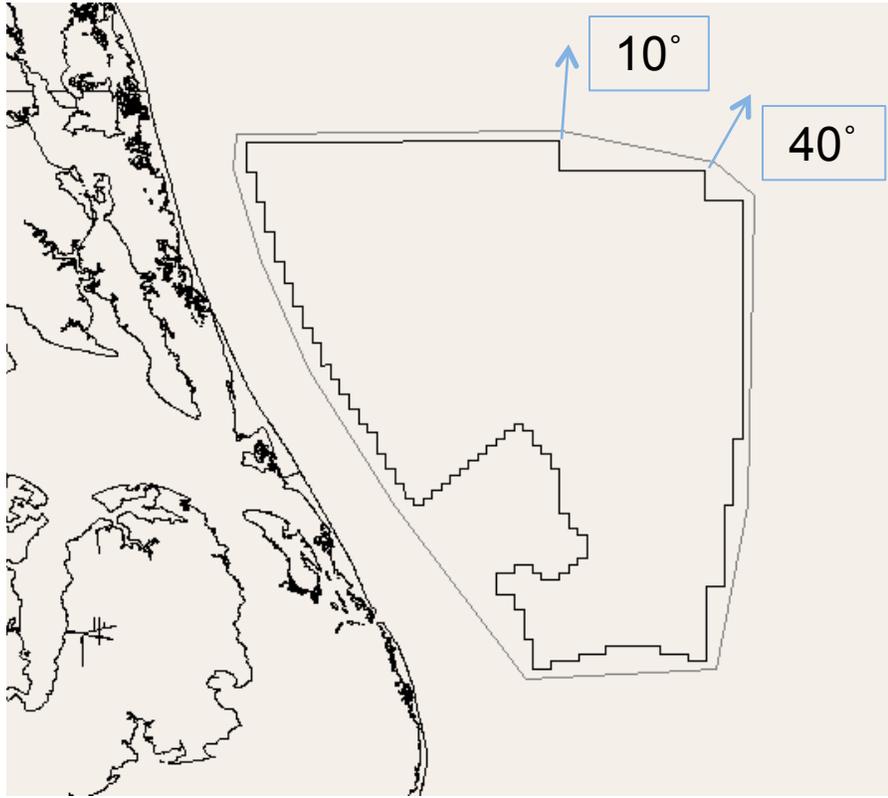


Figure J - 7: The directions to which box points are projected are delineated by the arrows; this allows for a simplified geometry for each wind area.

J.2.7 Wind data

Wind data takes a different format than the other input files, as the data are part of a time series. The two files contain wind speeds in both the x and y directions for every 12 hours of the model run's two week duration. A separate data file is needed for each time period of interest (Figure J - 8).


```

//Vessel and Pilot data
//THE DATA SECTION NAMES MUST HAVE ONLY THE TEXT BEING COMPARED, NOTHING EXTRANEOUS. THAT IS ONLY "/>

```

Speed scaling factors must be present in the vessel file

Response matrix describes vessel response and movement

Figure J - 9: Example of vessel file header input files, showing both the speed scaling factors and response matrices.

```
//Vessel ←
Type = Towing-Articulated Pusher Tug
Name = MORTON S BOUCHARD IV
MMSI = 366941510
Pilot = Steve
Width = 18.288
Length = 121.92
Draft = 6.096
BlockCoefficient = 0.91
Displacement = 12678018.56
Horsepower = 12278
MaxSpeed = 5.732439
AverageSpeed = 5.107656
MaxRudderAngle = 35.0
Navigation = TBD
Detection = v
DetectionZone = TBD
SafetyZone = TBD
VesselDriftDragCoefScaleFactor = 1.0
VesselDriftLiftCoefScaleFactor = 0.6
RudderAreaScaleFactor = 1.0
DragCoefDuringRotation = 1.3
MaxRudderApplicationRate = 3.0
EffectiveRudderWakeFraction = 0.4
WakeEffectExponent = 1.7
```

Each set of vessel characteristics must be preceded by '//Vessel'.

Figure J - 10: Example of vessel characteristics from the vessel file. This example is a single vessel entry from the vessel file.

J.2.9 Voyage data

The voyage data file contains a header with information about how vessels navigate TSSs and other regulated zones (Figure J - 11). The voyage file also contains data about each ship's voyage in the form of a list of waypoints (Figure J - 12). Every ship listed in the voyage tables must also have vessel characteristics in the vessel file for the model to run correctly.

```
//Voyage data
//THE DATA SECTION NAMES MUST HAVE ONLY THE TEXT BEING COMPARED, NOTHING EXTRANEIOUS. THAT IS
//THE VOYAGE DATA ARE AN ORDER LIST WITH NO SPACES BETWEEN LINES

//PortTSS
TSSNumber=10 //number of TSS records is listed first
TSSRouteNumber=6 //number of TSS Route records is listed second
Port=Boston Harbor entrance //port record is listed third
TSS=(1) Precautionary Area-eCFR + Boston Harbor //parentheses are required around the TSS
TSS=(2) Precautionary Area + Massachusetts Bay
TSS=(3) Precautionary Area + Cape Cod Canal
TSS=(4) Precautionary Area-eCFR + New York: Precautionary Areas - Eastern
TSS=(5) Separation Zone + Boston Harbor Traffic Lane
TSS=(6) Traffic Lane + Boston Harbor Traffic Lane, Inbound
TSS=(7) Traffic Lane + Boston Harbor Traffic Lane, Outbound
TSS=(8) Traffic Lane + Massachusetts Bay to Cape Cod Bay, Two-Way
TSS=(9) Traffic Lane + Massachusetts Bay to Cape Cod Canal, Two-Way
TSS=(10) Traffic Lane + Massachusetts Bay to Provencetown Harbor, Two-Way
TSSRouteIn=4, 6, 1
TSSRouteOut=1, 7, 4
TSSRouteIn=3, 9, 2, 8, 1
TSSRouteOut=1, 8, 2
TSSRouteIn=10, 2, 8, 1
TSSRouteOut=1, 8, 2

//PortTSS
TSSNumber=3
TSSRouteNumber=4
Port=Brunswick entrance
TSS=(1) Traffic Lane + Brunswick Georgia North Approach, Two-Way
TSS=(2) Traffic Lane + Brunswick Georgia South Approach, Two-Way
TSS=(3) Precautionary Area + Brunswick Georgia
TSSRouteIn=1, 3
TSSRouteOut=3, 1
TSSRouteIn=2, 3
TSSRouteOut=3, 2
Specified=4
Inbound=5
WayPoint= -80.858875, 31.026371, TRAFFIC LANE + BRUNSWICK GEORGIA NORTH APPROACH, TWO-WAY
WayPoint= -81.201771, 31.051078, TRAFFIC LANE + BRUNSWICK GEORGIA NORTH APPROACH, TWO-WAY
WayPoint= -81.240438, 31.046920, PRECAUTIONARY AREA + BRUNSWICK GEORGIA
WayPoint= -81.260661, 31.058618, ADDITIONAL WayPoint
WayPoint= -81.374928, 31.123639, ADDITIONAL WayPoint
```

Names of TSS zones match names in the 'TSS Lanes and Areas and Fairways and Zones rev4.xyz' file.

h take vessels south of the CAPE COD
ke vessels south of the CAPE COD BAY

Figure J - 11: Example of beginning of header for voyage file.

```
//Voyage
VesselName=C&PRICORN
VesselMMSI=311011800
NumberOfNavigationPoints=25

DomainIn=Chesapeake 010,-75.066497,37.261833,2011-03-06 05:43:56.676666,1.885602,8.267591
WayPoint=Chesapeake 005,-75.044276,37.353058
WayPoint=Chesapeake 006,-74.947424,37.588853
WayPoint=Chesapeake 007,-74.859277,37.806279
WayPoint=Chesapeake 008,-74.754360,38.041003
WayPoint=Delaware Bay 006b,-74.709759,38.149701
WayPoint=Delaware Bay 005,-74.686238,38.207183
WayPoint=Delaware Bay 004,-74.631207,38.419374
WayPoint=Delaware Bay 003,-74.770996,38.568235
WayPoint=Delaware Bay 002,-74.856999,38.650918
WayPoint=Delaware Bay 001,-74.970871,38.750084
PortIn=Delaware Bay entrance,-75.053374,38.813785,2.765980,2011-03-06 14:07:56.263333
PortOut=Delaware Bay entrance,-75.064223,38.802862,153.864521,3.777815
WayPoint=Delaware Bay 001,-75.001650,38.737268
WayPoint=Delaware Bay 002,-74.902659,38.633478
WayPoint=Delaware Bay 003,-74.828151,38.545793
WayPoint=Delaware Bay 004,-74.681654,38.380950
WayPoint=Delaware Bay 005,-74.689289,38.208086
WayPoint=Delaware Bay 006b,-74.712580,38.148965
WayPoint=Chesapeake 008,-74.754527,38.041151
WayPoint=Chesapeake 007,-74.857717,37.804810
WayPoint=Chesapeake 006,-74.948003,37.589440
WayPoint=Chesapeake 005,-75.044937,37.353742
WayPoint=Chesapeake 006,-75.161208,36.246136
DomainOut=Mid Atlantic 005,-75.109689,36.062339
```

Figure J - 12: Illustrates a complete voyage from March 2011 base case.

J.2.10 Runtime Information

The runtime file contains several switches for choosing how the model will function (Figure J - 13), as well as the voyage start and end time in Julian Days. By entering a date into Microsoft Excel in 'Date' format, then converting into Excel's 'General' format, one can convert any date and time to Julian Days.

```

//Runtime Info

SeaTrialAnalyses = false //true // override all voyage inputs and conduct standard se
LogOutput = false//true//output high volume, intermediate data to a log file during t
VesselInteractions = false //true //switches on/off computation of vessel interaction

StochasticPilot= false //true //switches on/off computation during the run of varying

ProbablisticWaypoint= false //true //switches on/off inclusion of randomized variatio

TimeStep = 1.0 //time step in seconds
PositionUpdateFreq=1 //check update of waypoint heading//time step intervals to updat
OutputFreq=60 //2 //1 //15 //number of position update intervals to write output

StartTime= 40603.0 //time in JD =2011-03-01 00:00
EndTime = 40617.0 //time in JD

```

Switches on/off various model functionalities

Choose time step and number of output intervals

Changes start and end date for model run

Figure J - 13: Example of Runtime input file.

J.3 Graphic User Interface

To begin running the model, open the executable file (Figure J - 14).

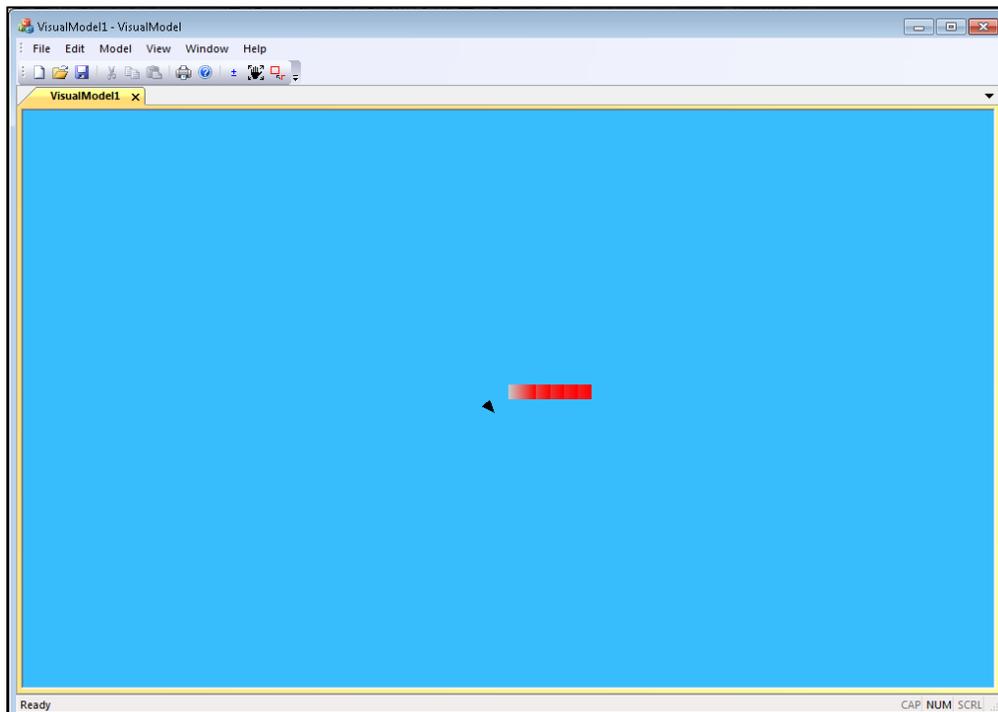


Figure J - 14: Start screen of executable file.

J.3.1 Choosing the MVT File

To open the .MVT file, click on the yellow folder, then navigate to the appropriate file path where all the input files and .MVT file are located (Figure J - 15). Click on the .MVT file, then select open. Once opened, it will take a few seconds (a few vessels) up to a few minutes (a full two weeks of vessel) to load the Atlantic Coast image (Figure J - 16).

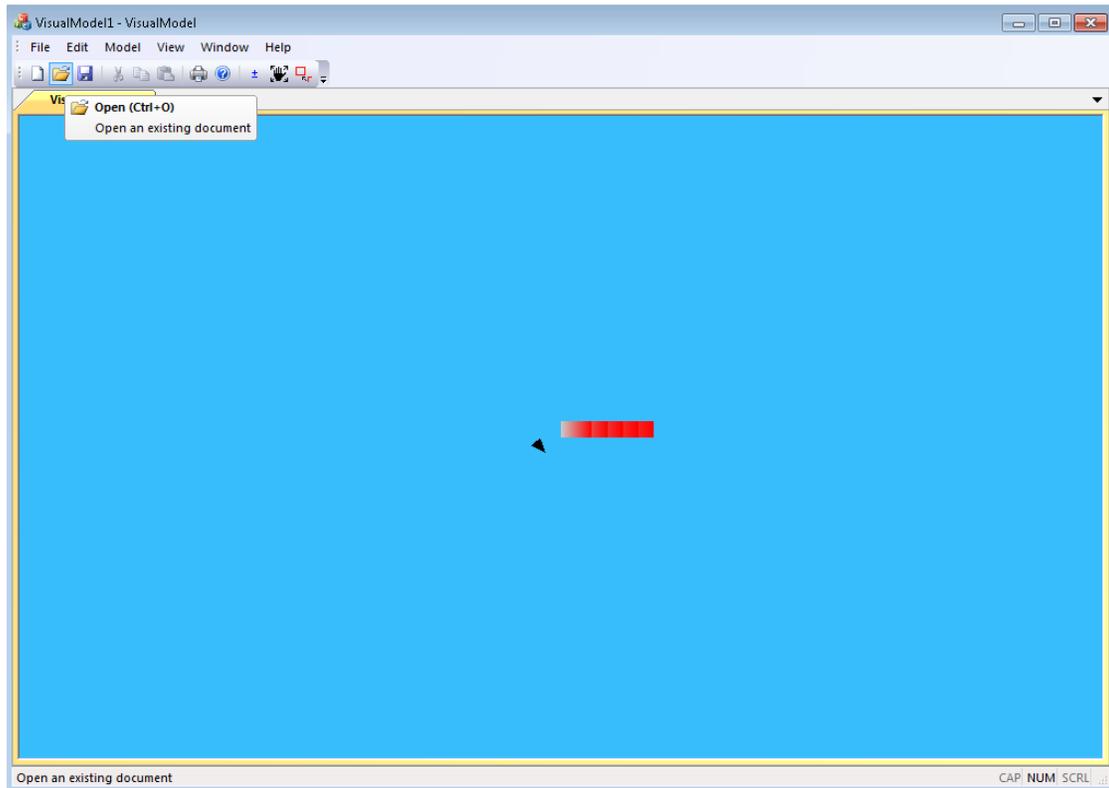


Figure J - 15: Instructions for opening the .MVT file: navigate to the appropriate folder where the input files and .MVT are located, and click.

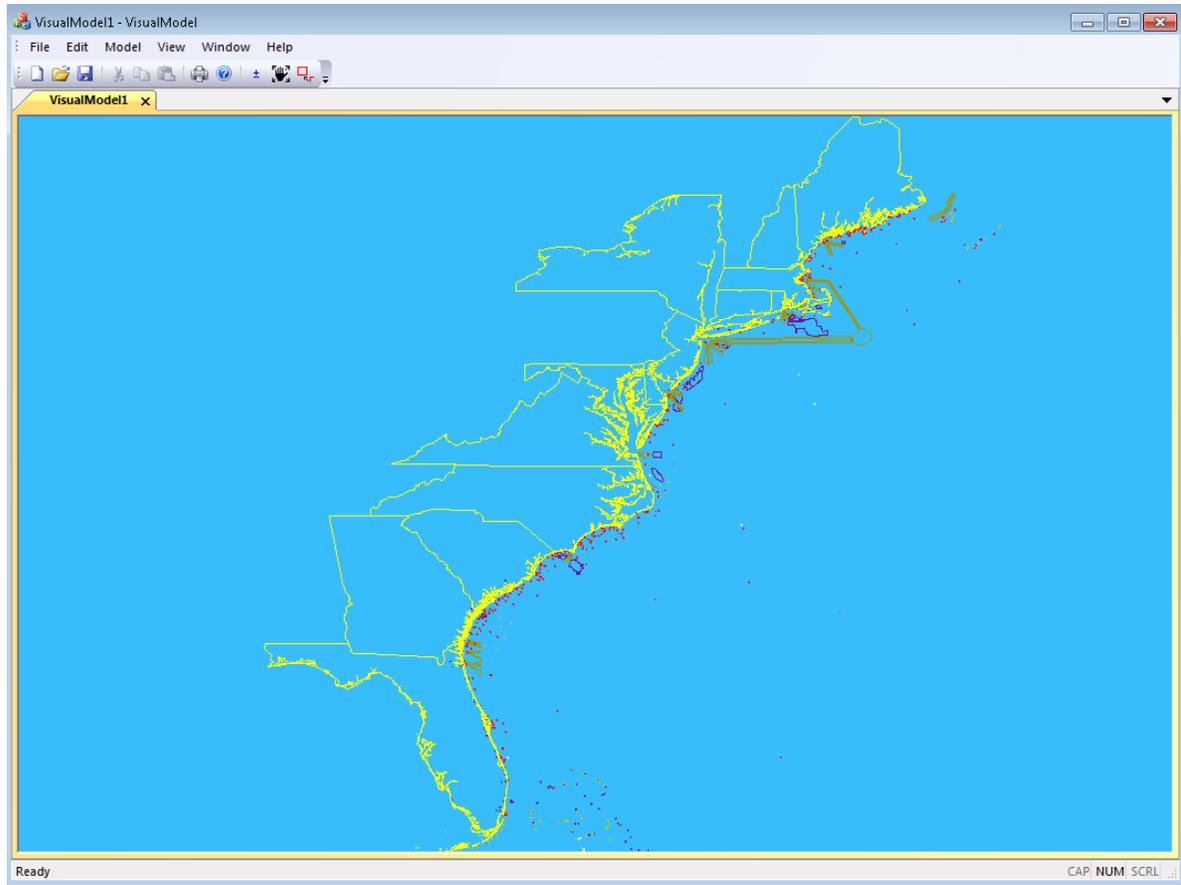


Figure J - 16: .MVT loaded into model executable.

J.3.2 Running the Model

The model is run by choosing “model” from the top navigation bar, then ‘Run Model’ (Figure J - 17). Once running, the model may take a few minutes (a few vessels) up to a few hours (~two weeks of vessel) to complete the analysis.

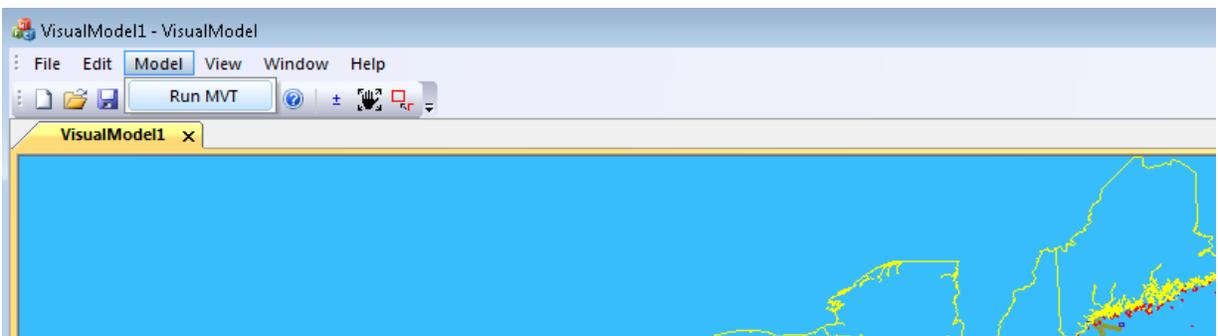


Figure J - 17: Choose Model, then Run Model to begin running the model.

J.3.3 Viewing Results

Once that model has been run, the results should be loaded into the graphic interface by selecting the yellow folder from the navigation bar (as was done to open the MVT file). From the list of file extensions, the ‘MVT binary output (*.bou)’ should be selected. From there, a .bou file with the same name as the original .MVT file will appear (Figure J - 18). Click to load this file into the model.

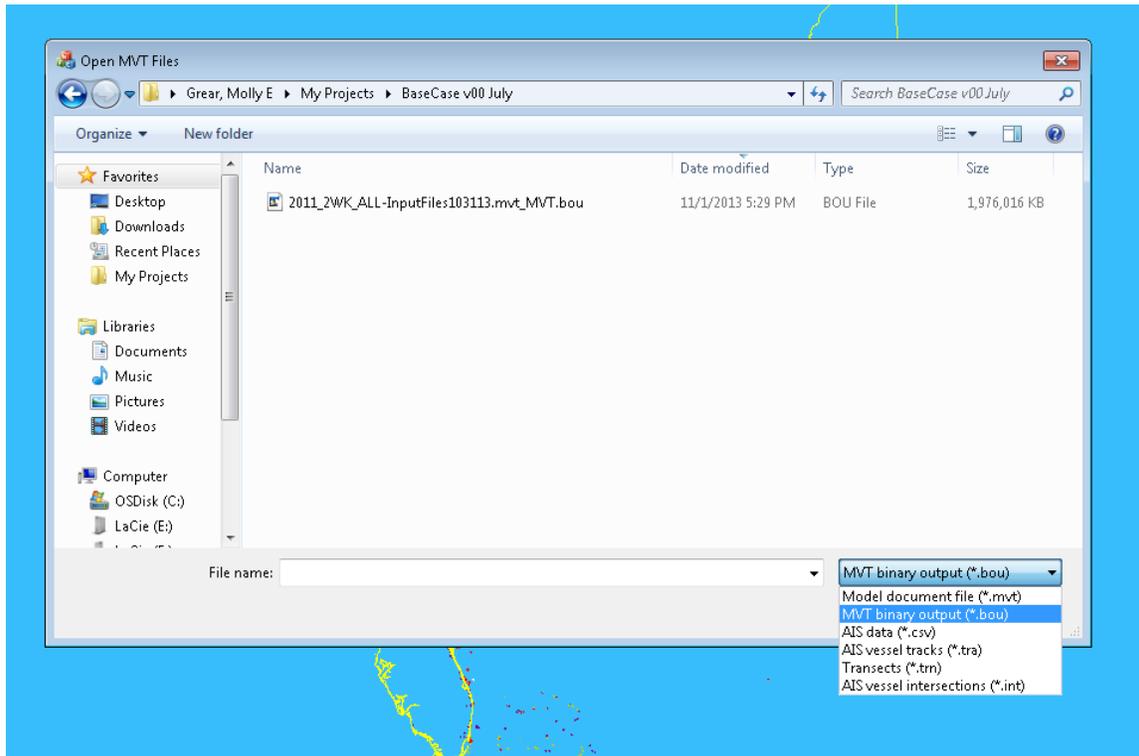


Figure J - 18: Open the binary output (.bou) file by selecting the correct file extension, then selecting the .bou file of interest.

Once open, the results can be viewed as tracks or as an animation by choosing View→Model Output as Tracks or View→Animate Model Output (Figure J - 19). To save the results in comma-delimited format, choose from the navigation File→Save As. Choosing save instead of save as **will not** save the file correctly.

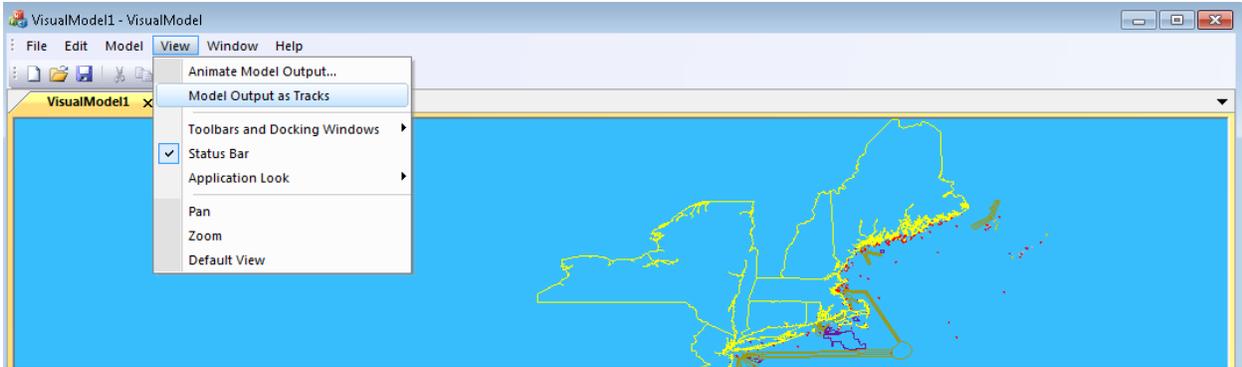


Figure J - 19: To view model results, choose an option to either 'Animate Model Output' or 'Model Output as Tracks'.