

## Spatial Analysis of Hurricane Sandy's Effect on Ship Traffic

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### Author Note:

Acknowledgments go to Joseph Sienkiewicz and LT Joseph Phillips of NOAA/National Weather Service/Ocean Prediction Center and LT Anthony Klemm of NOAA/Office of Coast Survey/Marine Chart Division

## **Abstract**

Ship locations are tracked using Automatic Identification Systems (AIS), which is an automatic tracking system used for maritime collision avoidance. AIS transceivers transmit GPS position and movement information over very high frequencies between ships and to shore stations and satellite receivers. Recently the Ocean Prediction Center and Office of Coast Survey combined forces to find a way to see how ship traffic was affected by weather events forecasted in the open ocean using that AIS data. For this project, the data from Hurricane Sandy was used since she was such a destructive hurricane at a historic level. The best way to do this was to analyze the ship location data by utilizing a GIS (Geospatial Information System) to discover where ship traffic typically is and how it changed in response to the specified weather event. By building ship tracks before and during Hurricane Sandy, as well as performing Getis Ord Gi\* Hot Spot Analysis and Density Analysis this information could be gathered which showed almost a complete absence of traffic off of the New York and New Jersey coast near landfall. Based on the methods and results, this analysis could be used for many other events throughout the world providing very useful information about where traffic would normally be and where they might go to avoid potential severe weather in the seas and remain safe.

## Spatial Analysis of Hurricane Sandy's Effect on Ship Traffic

### **Introduction**

The National Weather Service/Ocean Prediction Center (OPC) in conjunction with the National Ocean Service/Office of Coast Survey (OCS), both a part of the National Oceanic and Atmospheric Administration (NOAA), have an interest in ship traffic patterns in response to inclement weather and forecasts released by the National Weather Service. Ship locations are tracked through the Automatic Identification System which is an automatic tracking system using a GPS receiver to collect position and movement information. AIS transceivers automatically broadcast information, such as their position, speed, and navigational status, at regular intervals via a VHF (Very High Frequency) transmitter. This information is currently used so that other vessels and base stations can receive the data to display these locations for vessel traffic services as well as collision avoidance. The International Maritime Organization (IMO) requires all vessels over 299 gross tonnage to carry an AIS transponder on board, which transmits their position, speed and course, as well as other information, such as the vessel's name, dimensions and voyage details.

The response to inclement weather is of great concern and interest to not only OPC and OCS, but many other government and private sector businesses as well as the public. Over time, as weather events unfold, ships have to change their course and by studying these courses in a specific weather event, patterns can be discovered between the typical ship traffic and the change in the ship traffic due to weather. A good example of a weather event to study for this project is Hurricane Sandy which was the most destructive hurricane of the 2012 hurricane season and the largest hurricane in size of the Atlantic basin ever (National Weather Service, 2012). Hurricane Sandy developed in the western Caribbean through Jamaica and Cuba, curving West-Northwest travelling all the way to New Jersey and New York before moving onshore. Since Hurricane Sandy moved through almost all of the Atlantic Ocean along the East Coast of the United States, the coverage is perfect for studying. The fact that she also made landfall near the busiest port in the East Coast means that ship traffic was severely affected giving even more reason to use this as a study case.

### **Literature Review**

Many organizations are interested in using AIS data and GIS to study marine traffic to prevent collisions and find the most common traffic patterns but for this project knowing how the marine traffic reacts to weather events in its path is the main focus. For this project, specifically, AIS data during Hurricane Sandy will be examined. Since AIS data has been introduced there have been many applications developed to ingest and display the data that are extremely useful to many organizations, mariners, and more but more recently the need of a Geographic Information System (GIS) to help to analyze and visualize this information has been realized. As noted most importantly by Saladas et al., GIS is ideal for the spatial analysis of AIS data and using the two

together is very useful for spatial planning to facilitate the interactive and objective analysis of all objects, environmental features, and traffic at sea. GIS software is extensively used “to provide insight into trends, logistics, and environmental impact and for various other complex features of the world” (Saladas et. al., 2009) and through many studies the necessity of using GIS to help determine the spatial and temporal characteristics of shipping incidents and behavior has been understood. As technology increases and more ships are required to use AIS, the growth of the available data is exponential, and the task of extracting and mapping the data becomes much more time consuming and arduous. This is why the data being used for this project were cut down to a smaller study area of the Western Atlantic Ocean where Hurricane Sandy was present as well as the actual frequency of data. Data every 5-10 minutes are being used to perform all the calculations for spatial analysis.

While many articles discuss the importance of analyzing AIS data in general, a few articles actually addressed strategies for analysis as well as any types of limitations when it comes to AIS in a GIS. At the time, strategies to analyze AIS data within a GIS are being developed but more research is necessary. As Popovich et al., 2009 noted, one of the current limitations of using GIS to integrate and analyze the data is that the data are too large and complex still to be fully understood and “the current systems are not adapted to the management of dynamic phenomena due to the lack of modelling and processing interoperability with real-time navigation systems.” (Popovich et al., 2009) Although these conclusions were made in 2009, they are still applicable in today’s realm of research. The sheer size of these datasets is a big issue when it comes to management of the databases and being able to even perform any kind of operations upon the datasets is very time intensive as mentioned before.

Many studies stated the same forms of analysis for pattern recognition within the AIS data. Both Ray, et al., Pallotta et al., and Popovich et al. discuss largely the use of the combination of AIS data points to make tracks and trajectories of the ship traffic. Popovich et al. noted in their article that the “aggregation of these trajectories provides typical routes that are useful for the analysis of navigation traffic as patterns and trends.” (Popovich et al., 2009) This has been done by all three studies to see the density of ships in different regions and “these features enable the discovery of maritime traffic knowledge that can be used to implement higher level anomaly detection tools” (Pallotta et al., 2013) as well. To start, for this project, the actual point data are being used to perform kernel density calculations to see the concentration of ships at different times throughout the study period. The idea for the hot spot analysis and possible method for it came about from the article by Pallotta et al. discussing the ever increasing degree of automation in transforming data into meaningful information to support operational decision makers. “One possible approach is to subdivide the area of interest into a spatial grid whose cells are characterized by the motion properties of the crossing vessels. Although effective for small area surveillance, the main limitations of the grid-based approach reside in the required computational burden when increasing the scale.” (Pallotta et al., 2013) The grid will be applied to the study area in the Atlantic Ocean in order to get counts of ships within each grid square but this

approach does indeed cause quite the load on computations. Looking into more complex modeling with AIS, there were not many articles showing any information about this except for Ray, Ciril, et al. It was seen that in their article further processing had been done with a “traffic analysis module that integrates intelligent inference mechanisms that can use data mining to derive traffic patterns” integrating “simulation capabilities in order to control and predict the evolution of ship behavior and trajectories” (Ray, Ciril, et al., 2007) but these modules were not accessible for use in this project.

Based on past research and information from other studies using GIS to study ship traffic patterns it was decided that analyzing with a GIS is the best approach. This is the main push for the use of GIS to analyze this AIS data during Hurricane Sandy to truly see what kind of information can be gathered about the response of maritime traffic to adverse weather conditions. For this project, the vessel’s location at any given date and time as mentioned above will primarily be used from AIS data. Finding the density of ships overall as well as hot spots of ships throughout time will show a lot of information that can be used for pattern recognition. The OPC and OCS as well as other agencies will be able to use this information in future inclement weather planning for ship traffic too.

## **Objectives**

The main objective of this project is to analyze AIS point ship location data to identify patterns and calculate the changes in ship traffic during inclement weather in the Atlantic Ocean, namely Hurricane Sandy. The results will then be presented within a web GIS application in an ArcGIS Online Story Map for users to better visualize the results.

The following questions will be answered:

- What are the most common traffic tracks and patterns for ships in the western Atlantic Ocean?
- How did the traffic patterns deviate with respect to Hurricane Sandy?
- Where are the hot spots of ship traffic during usual and fair weather conditions vs. Hurricane Sandy?

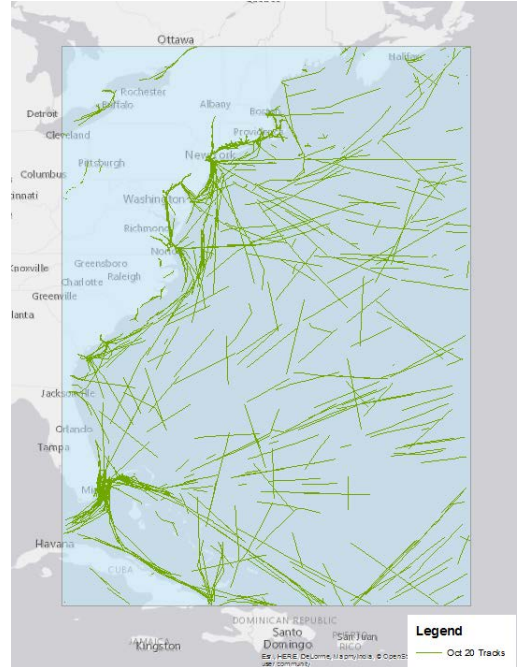
## Study Area and Data

### *Study Area*

The study area for this project is the Western Atlantic Ocean with the spatial extent of 60W to 82W and 20N to 45N to show the region impacted by Hurricane Sandy. Hurricane Sandy formed in the tropics and made its way through the Caribbean making landfall on the New Jersey Coast. The image to the right with the blue rectangle shows the spatial extent of the study area.

### *Data Sources*

The idea for this project was created for an internship through the Ocean Prediction Center (OPC) in conjunction with the Office of Coast Survey (OCS). The OCS has access to Automatic Identification System (AIS) data for the whole world which was made available for this project. The specific table of their database used for this project contains AIS worldwide satellite data from July 2012 to June 2013 of ships that are underway. The data for the month of September 2012, and October 21-31 and November 1-4, 2012 were used. Hurricane track data were also used and accessed from the program Hurricane Mapping which is accessible through certain National Oceanic and Atmospheric Administration (NOAA) accounts. The Hurricane Sandy data were downloaded from the National Hurricane Center for Advisory 13, 17, 21, 25, 31, and 35 with data to 3Z October 31, 2012 which was the last hurricane track advisory given for the storm. The shapefiles used in the download were for the Past Track points and lines, as well as the Forecast Track points and lines, and the Error Swath of the storm forecast. These were used for visual reference within the map images to see the change in traffic as the hurricane moved through.



Name	Time Period	Year Created	Reference
AIS Ship Location Point Data	September, October 21-31, and November 2012	2016	Office of Coast Survey
Past and Forecast Track Point Data	October 21-31, 2012	2012	National Hurricane Center
Past and Forecast	October 21-31, 2012	2012	National Hurricane Center

Track Line Data			
Error Swath Polygons	October 30, 2012	2012	National Hurricane Center
Wind Range Polygons	October 30, 2012	2012	National Hurricane Center

**Table 1.** Data used for this project: Name, Time Period, Year Created, and Reference

### *Data Processing*

Within ArcMap, a database connection was made to the OCSAIS database. There are many types of AIS data available from the OCS but the data used for this project as mentioned above is AIS worldwide satellite data from July 2012 to June 2013. Once the query layer window is populated, the specified data will show up in ArcMap and can be exported to a file and personal database feature class. This was done for the data during September 2012 as well as October 21-31 and November 1-4, 2012. First, the study area polygon was created using a KML file that was edited to have the corresponding coordinates of the necessary spatial extent. Then, in ArcMap, the KML to Layer tool was used to make the shapefile. All of the AIS point data (September and October) were first clipped to the study area. Then using selections based off of the time periods, new shapefiles were created for 6 hour increments from October 21-31 from 0-6Z, 6-12Z, 12-18Z, and 18Z-0Z in accordance with the National Hurricane Center (NHC) advisories.

### *Data Quality*

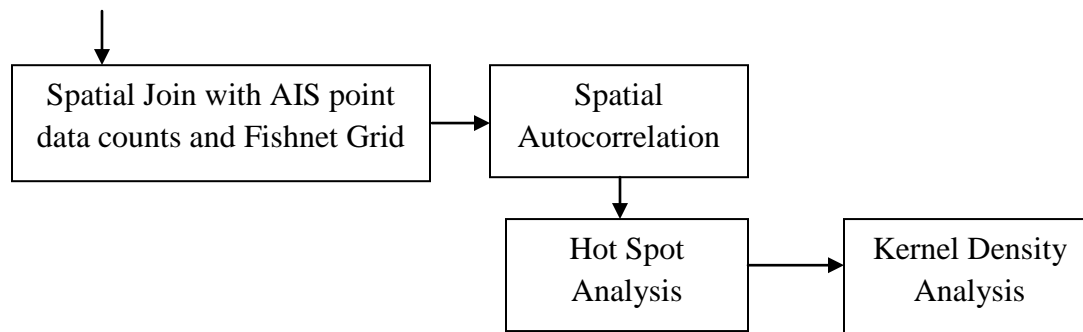
The quality of the data is very high since the data came directly from the source, the Office of Coast Survey. These data are sent to and out via satellite directly to the OCS so they are stored immediately from receipt after being sent out from the ships. All of the data was received the same times for which they were collected.

## **Methods**

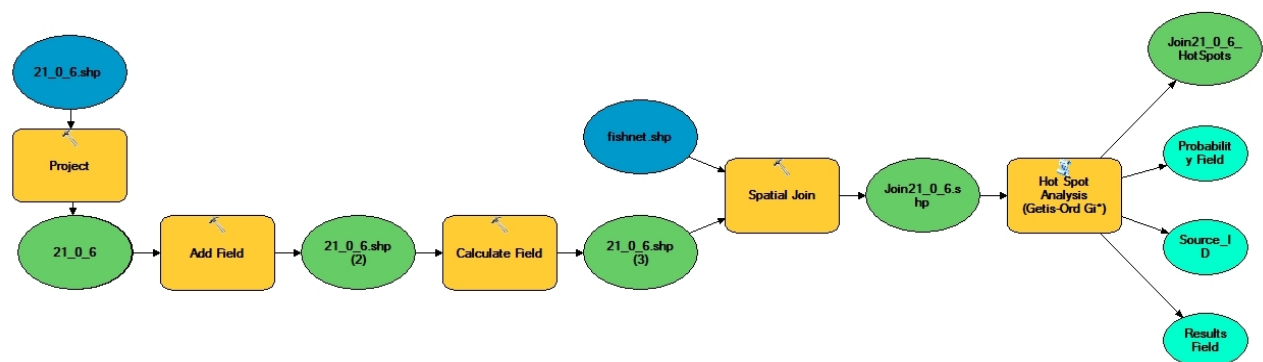
### *ArcMap*

The main objectives of the analysis of the AIS data within ArcMap were to perform hot spot analysis, kernel density analysis, and build ship track lines. To get the AIS data ready to be used for the different calculations, a lot of pre-processing had to be done as noted in the Data section. The following flowchart shows the overall necessary steps for the final results. There are smaller steps in between that will be further addressed throughout this section.

<p>Create Fishnet</p>
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In order to perform the hot spot analysis, an analysis field had to be created within each of the 6 hour incremented shapefiles of point data. Since they were just point locations originally, this field had to be created for each shapefile and filled with a value of 1. Create Fishnet was used to create a feature class containing a net of rectangular cells using the study area as the template extent with 10,000 m X 10,000 m cell width and height. This was necessary to create gridded polygons over the study area to get the total count of ship locations. A spatial join was done to count the number of events falling within each grid. Model builder was used to create a model to cut down on the individual file processing time. Within the model below in Image 1, data were first projected to North America Albers Equal Area Conic since the data covered such a large expanse. The *add field* tool was added for each AIS data point in the shapefile and the entire column was filled with 1 with *calculate field* tool. A *spatial join* was used next to get the sum of the point ship locations within each grid of the fishnet feature class. The resulting shapefile was a polygon shapefile with the count of points in each of the grids.

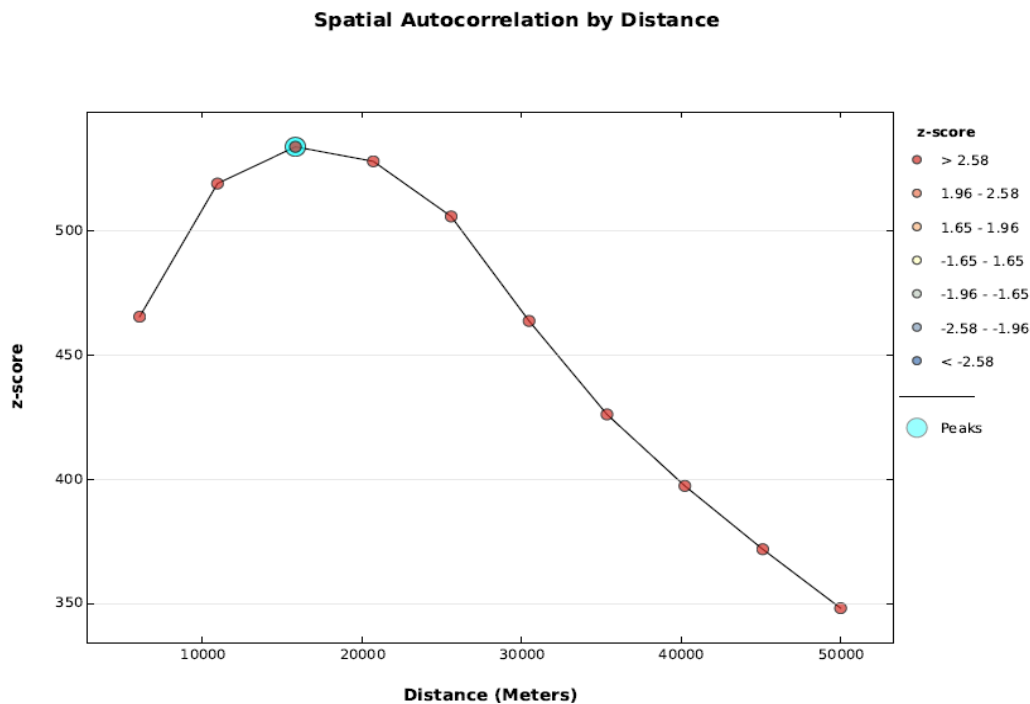


**Image 1.** The set up of the model created through model builder to project data and take it through all the steps to complete Hot Spot Analysis.

Incremental Spatial Autocorrelation was performed on the spatial join layers to measure the spatial autocorrelation for a series of distances and created a line graph of those distances and their corresponding z-scores. By doing this on the September data first (Image 2), and a random



selection of the 6 hour data layers, the fixed distance was selected. The September data were found to have the highest spatial autocorrelation a bit below 20,000 meters and others were a little higher so an average was taken to use 20,000 meters as the fixed distance for the Hot Spot Analysis. Originally the model did not have Hot Spot Analysis added in since only a random selection of time periods had been run through the model. Once the fixed distance was chosen, Hot Spot Analysis was added in for the resulting data files.



**Image 2.** Spatial Autocorrelation results for the month of September 2012.

Once data were all processed and ready to be analyzed a few operations were performed. As noted, the Hot Spot Analysis was done to find statistically significant hot spots and cold spots of ship traffic using the Getis-Ord  $G_i^*$  statistic. Kernel Density analysis was done to calculate a magnitude-per-unit area from the point ship traffic data using a kernel function to fit a smoothly tapered surface to each point. A cell size of 10,000 meters was used with a search radius of 40,000 m. Both of these analyses were performed on the resulting layers from the Spatial Join layers for each of the 6 hour incremental shapefiles of data.

Another tool was used which was downloaded from the Marine Cadastre website called the Track Builder Tool. This tool converts a collection of point features into a track line. The input data includes the date and time values for each point and the ship identifier value was used to group points in a line. This was done for 6 hour increments and then the full 24 hours of data to make track lines that showed more information. It was also done for October 29-31 which will be referred to as Sandy for the remainder of this paper (the last Monday - Wednesday of October which covers the day Sandy made landfall and 2 days after) and September 24-26 which will be

referred to as Baseline for the remainder of this paper (the last Monday -Wednesday of September). Kernel Density analysis was run on the last two analyses mentioned and then those layers used within the *Raster Calculator* to subtract the September density from the October density showing the overall change in ship density during these time periods.

Upon completion of all of the map images, the specific data to be shared through the University of Maryland map server were chosen. Maps showing the Hot Spot Analysis for October 21, 2012 18-0Z and October 30 0-6Z were shared as cached map images only to be displayed at the country to county scale. These were used for the map application Story Map on ArcGIS Online through ESRI. Other maps with 24 hour tracks from October 20 and October 29 (just before landfall) were also shared as a map service through ArcMap. The third set of maps showed the density analysis from Baseline and Sandy. The last map was of the difference in those density analyses. Once these had been shared to the map server, data were accessible to be used in a web application.

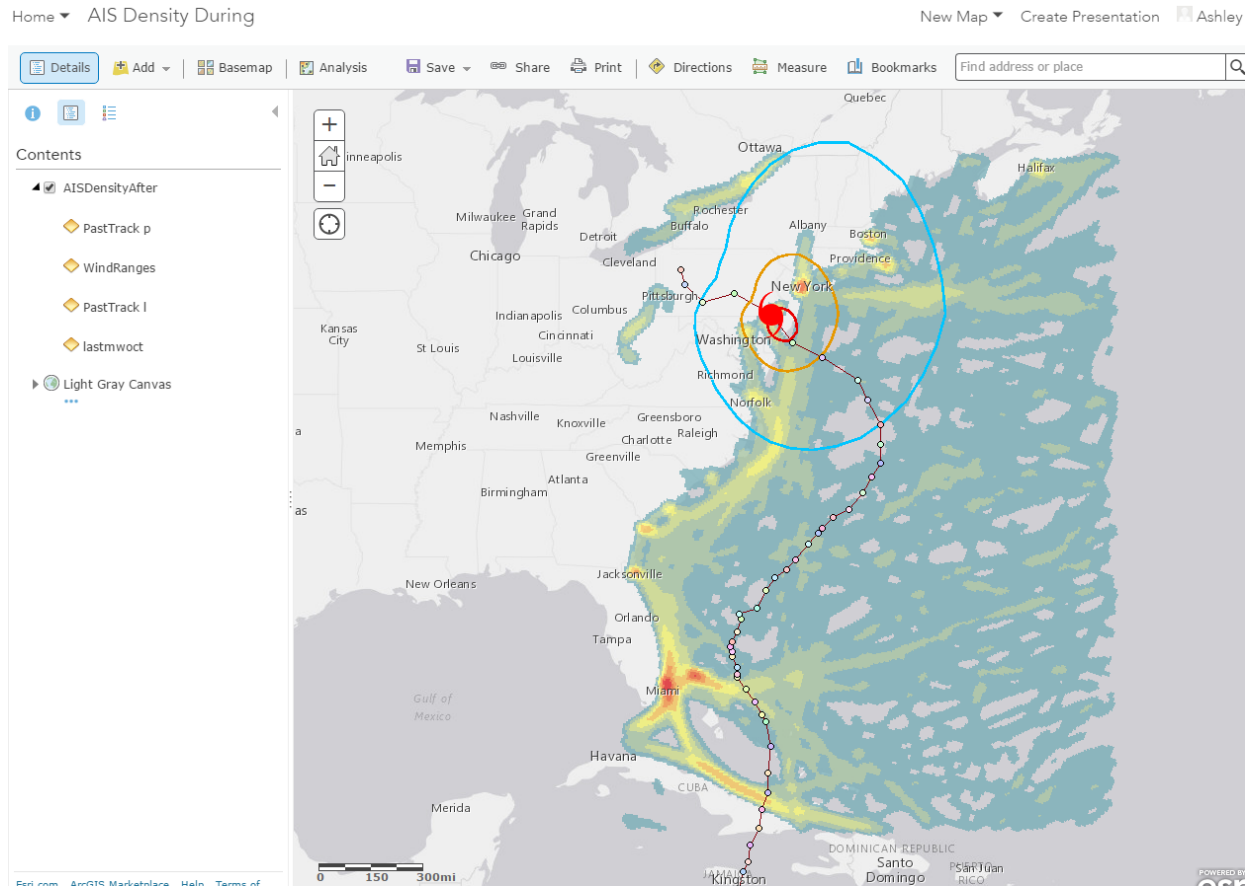
### *ArcGIS Online*

These map services were accessed through the University of Maryland ArcGIS REST Services Directory and opened in ArcGIS Online. Each service was saved as a corresponding map under My Content in the ArcGIS Online account. These maps were symbolized and any other data were uploaded to the maps through zipped file uploads, such as the line and point data used for the hurricane track, then they were ready to be used in a web map application.

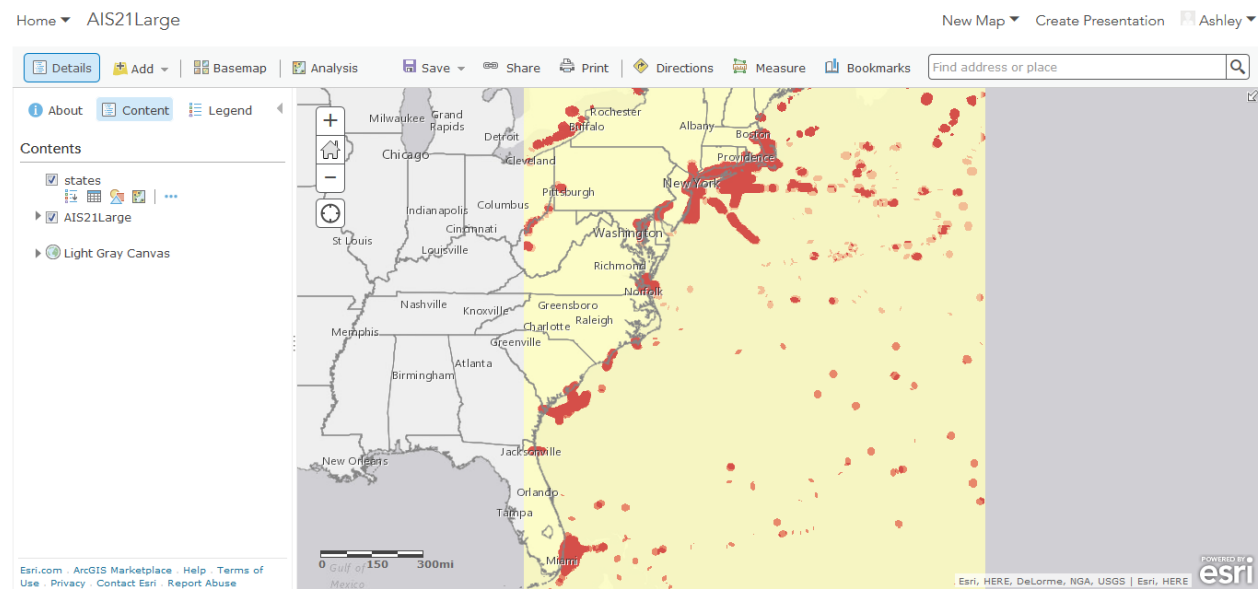
ESRI Story Maps let the user combine geospatial information from maps with descriptive text, images, and multimedia content. They make it easy to connect the power of maps and geography to tell a story. There are different types of Story Map applications, but the Map Journal was chosen to best represent the analysis results and tell a story in multiple map frames of how ship traffic was affected by Hurricane Sandy. The Story Map interface is user friendly as long as all of the data are ready to be presented. Each frame was created to tell a story about Hurricane Sandy using the many web maps already made, as well as different photos, videos, and gifs available on the internet. The story map was made to give an overview of what Hurricane Sandy was and the damage she caused along the coast. It then leads into the hurricane's effects in the ocean which is where the results of this project were presented.

### **Implementation**

As mentioned in the Methods section, the required data were shared to the University of Maryland map server. Web Maps were created in ArcGIS Online for hot spots on October 21 and October 30, density for the whole month of September, Baseline, and Sandy, as well as ship tracks on October 20 and 29, 2012 and the raster difference of density from Baseline and Sandy. Appropriate hurricane point and line track layers were added within ArcGIS Online along with wind swaths and wind ranges. Two examples of one of the web maps can be seen in Image 3 and Image 4.

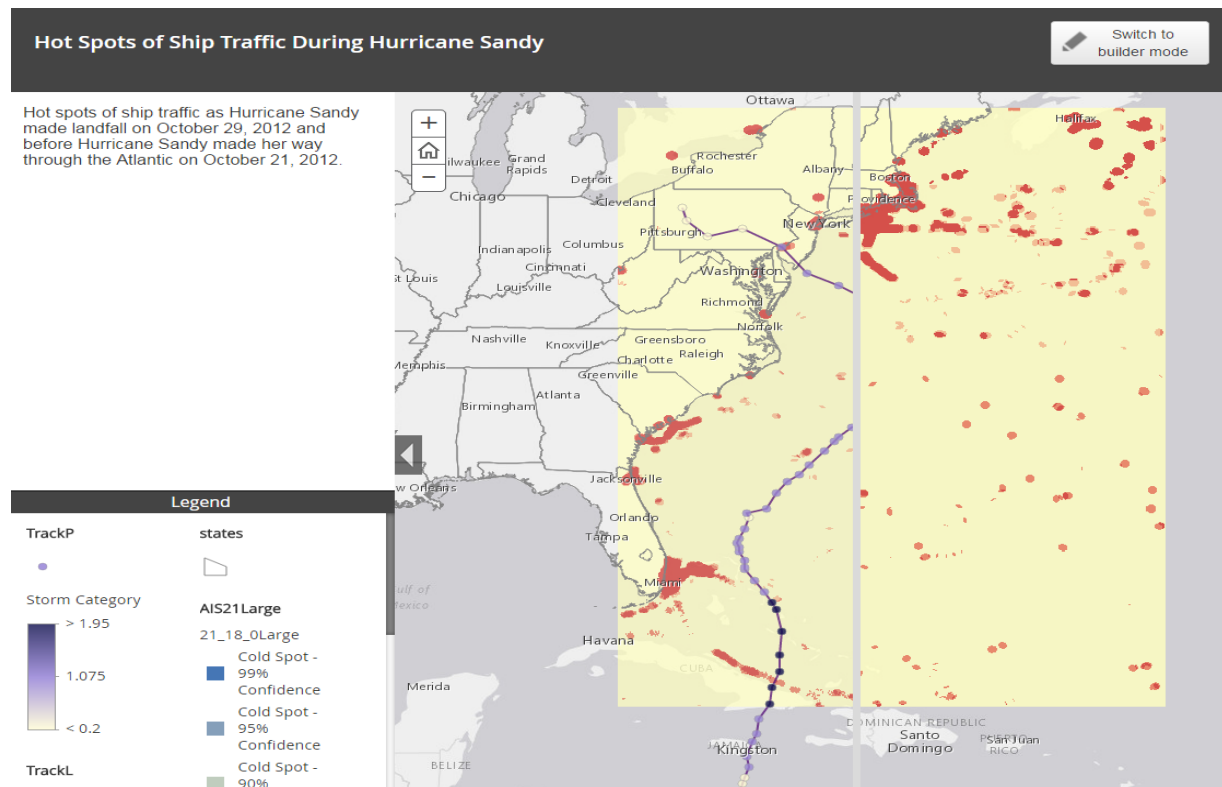


**Image 3.** Web Map representing the density of ship traffic from October 29-31, 2012 with Hurricane Sandy's track, current location and wind ranges at the time of landfall.

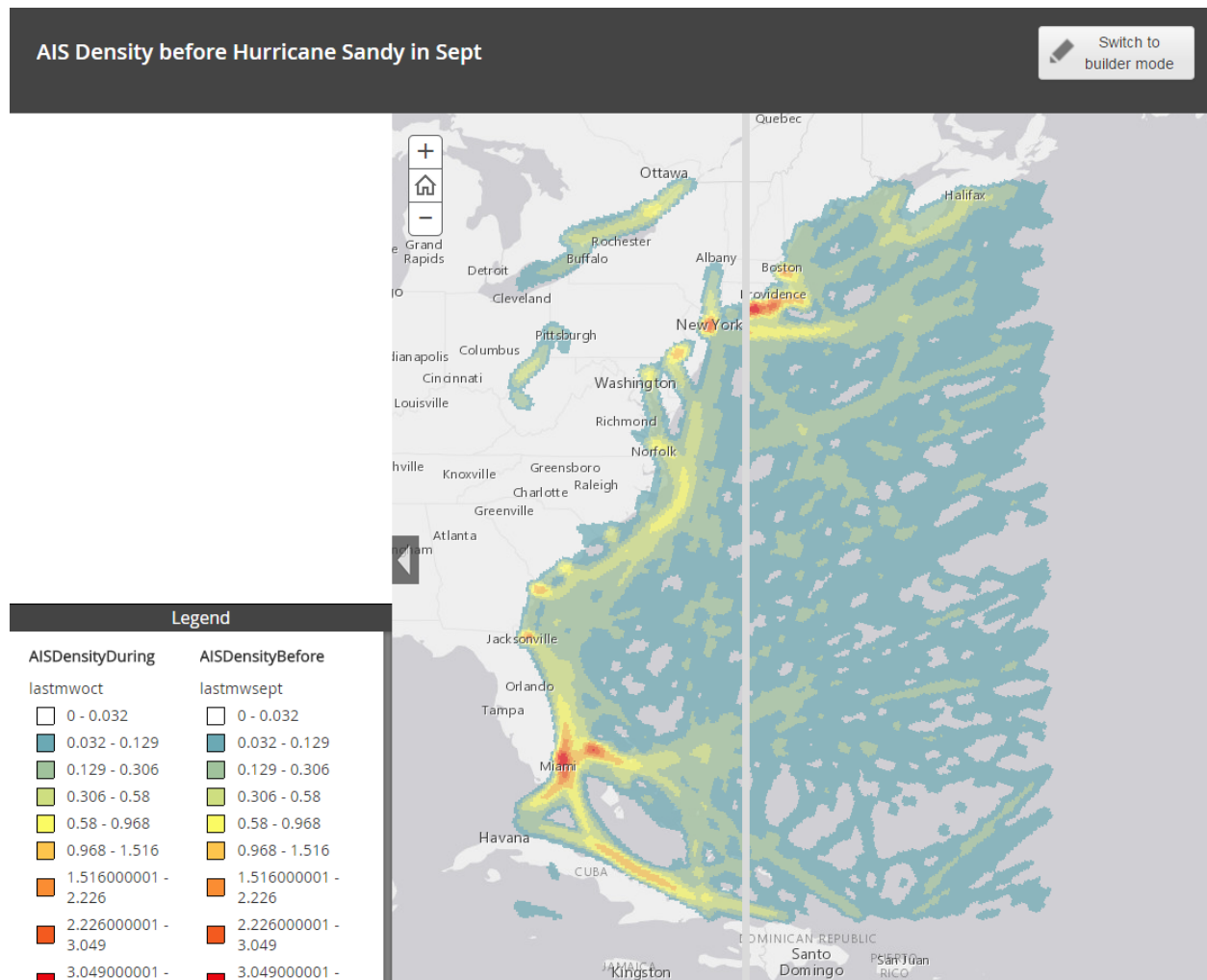


**Image 4.** Web Map representing the hot spots of traffic on October 21, 2012.

Swipe Story Maps were utilized so the user can swipe back and forth to see the difference between two different sets of data. The web maps created with the hot spot analysis results and the kernel density analysis results are shown in Image 5 and 6 below.



**Image 5.** Swipe Story Map Application to show the difference between Hot Spots on October 29 and October 21, 2012.



**Image 6.** Swipe Story Map Application to show the difference between densities from Baseline, September 24-26, 2012, and Sandy, October 29-31, 2012, during and post landfall of Hurricane Sandy.

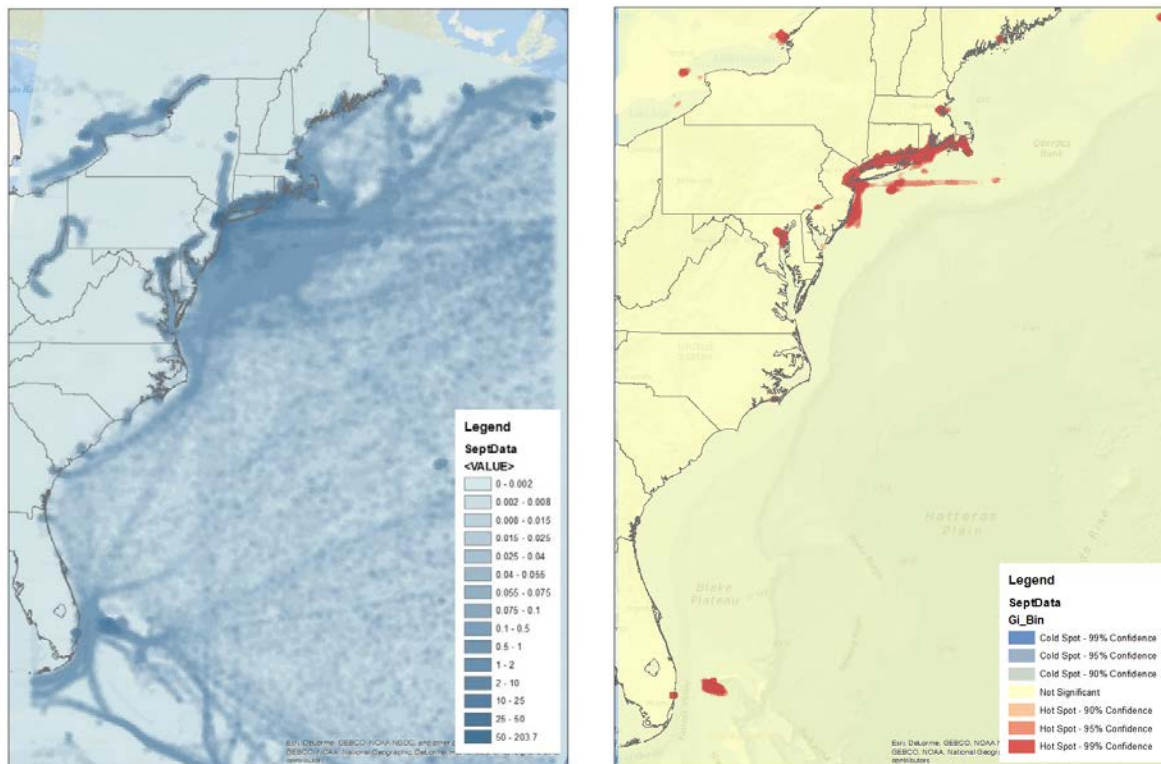
## Results and Discussion

### *ArcMap*

The analyses were run on all of the data from September as well as the October time periods. Once the model was run initially for the first data set, it was run for each 6 hour time period. Each run took about 30-50 minutes depending how close it was to the hurricane landfall time. As time got closer to landfall, the time required for the model to run was less since there was less ship traffic.

To get a monthly baseline of information about where ship traffic normally would be the kernel density analysis and hot spot analysis were done on the whole month of September 2012 as seen in Image 7. The kernel density analysis for September showed more visually than the hot spot

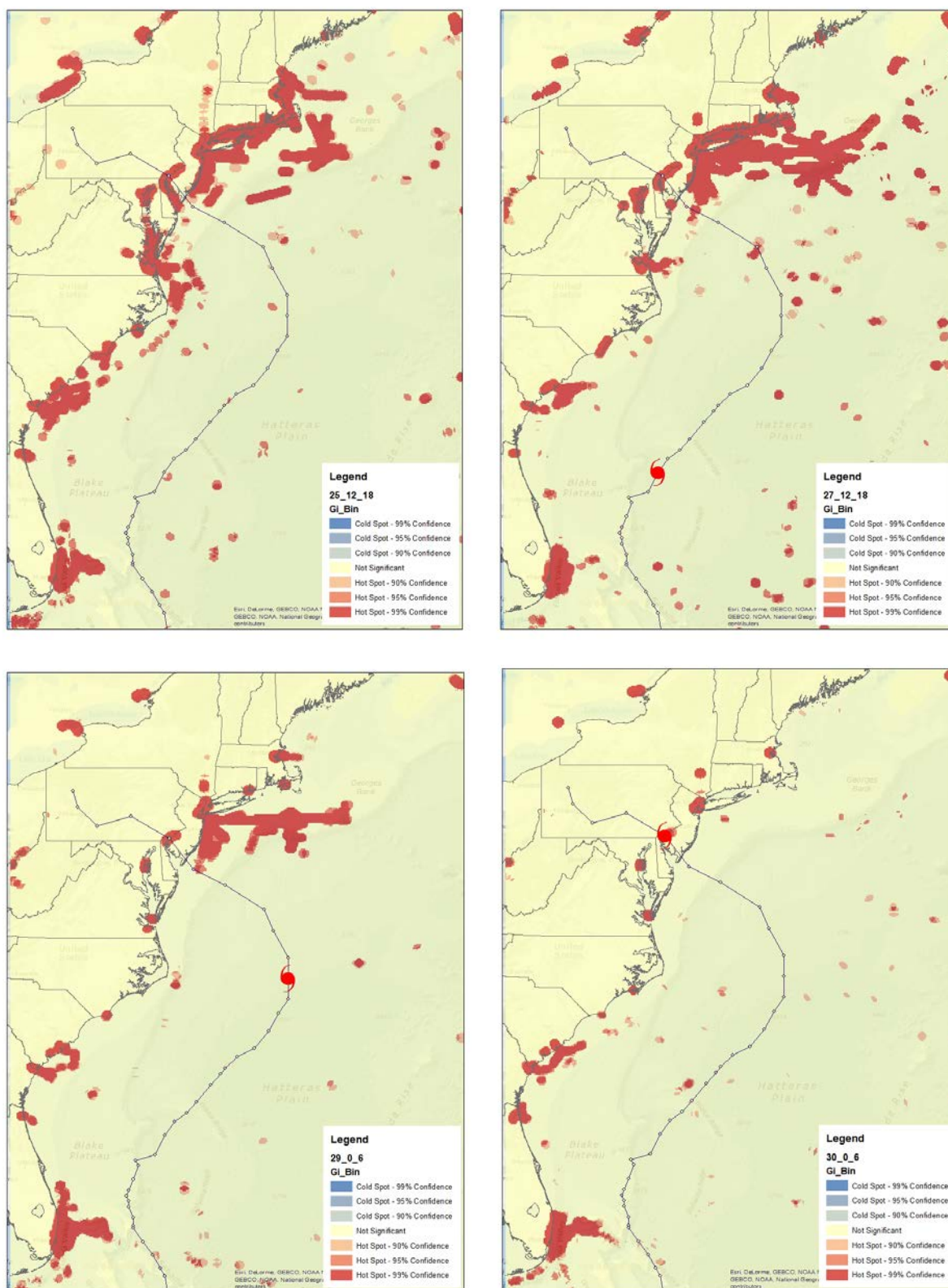
analysis, but as the time periods were cut into shorter 24 and 6 hour periods, more information could be seen.



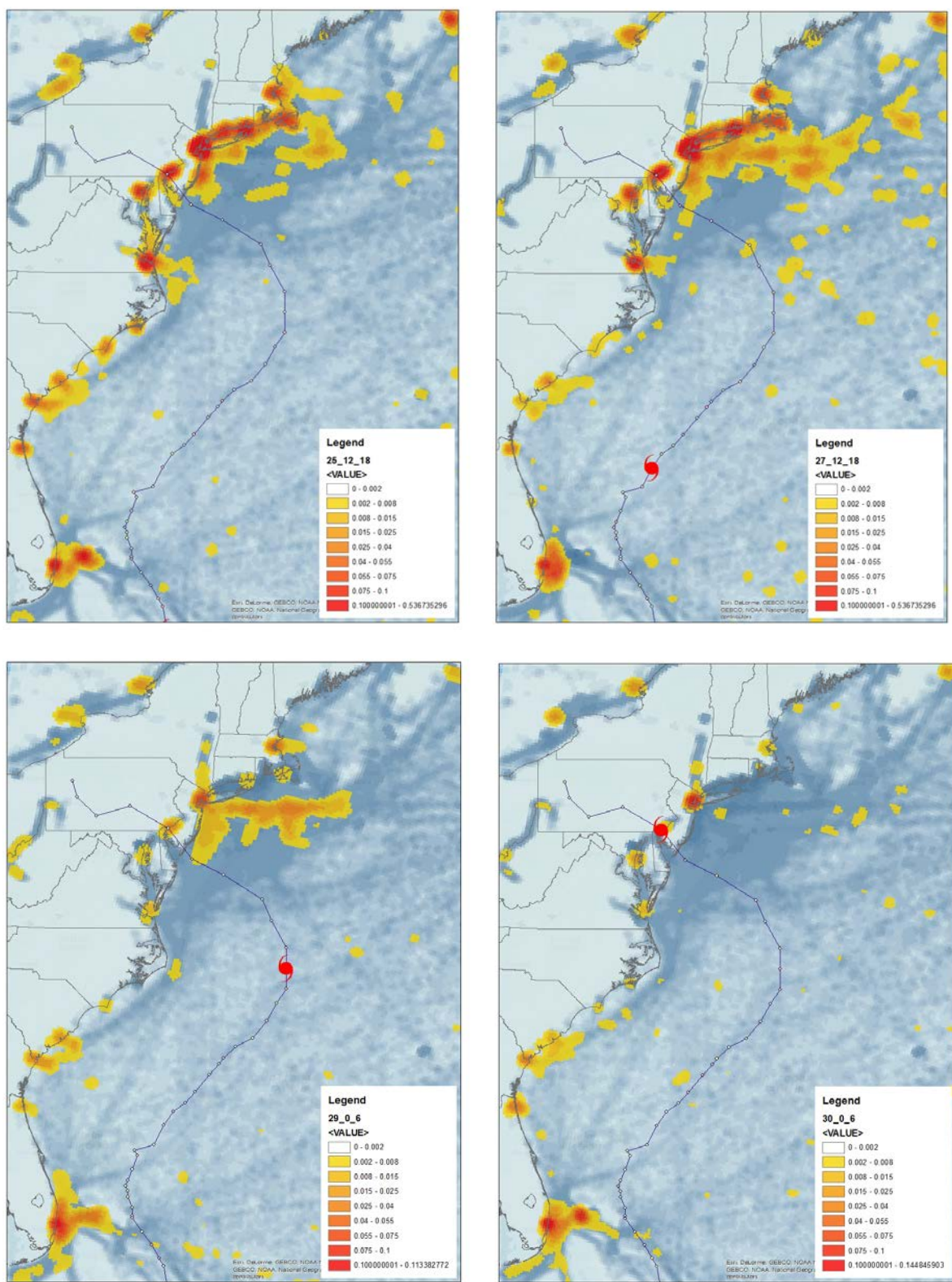
**Image 7.** Kernel Density and Hot Spot Analysis of all data for September 2012. The hot spot analysis does not show much information because there are so many points for that time period.

Upon completion of the Hot Spot Analysis and Kernel Density Analysis for the shorter time periods, it was clear that traffic drastically dropped off the map the closer Hurricane Sandy approached. GIFs were created showing each of the 6 hour time increment map images for hot spots and kernel density moving through time with the location of Hurricane Sandy in each image. These were then uploaded to TerpConnect (URL in References). Image 8 shows the hot spots and Image 9 shows the density that diminished significantly off the coast of the Northeast United States as Hurricane Sandy approached closer and made landfall.





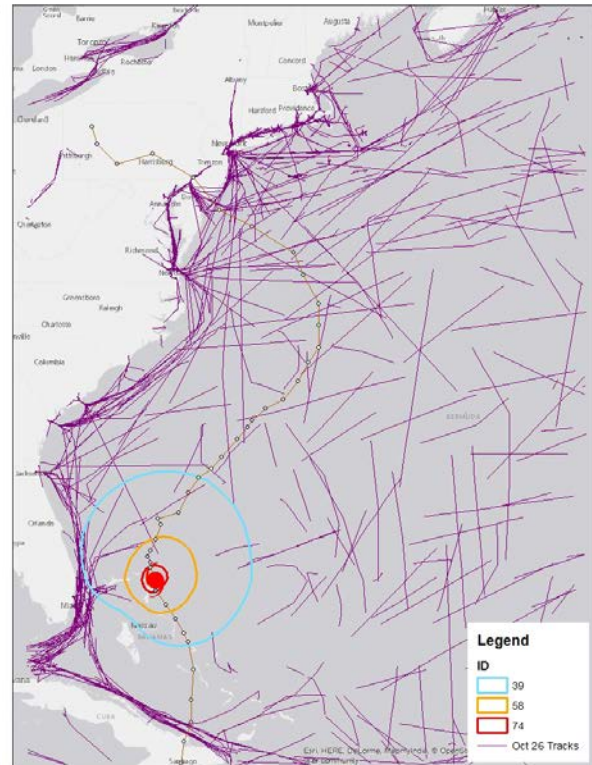
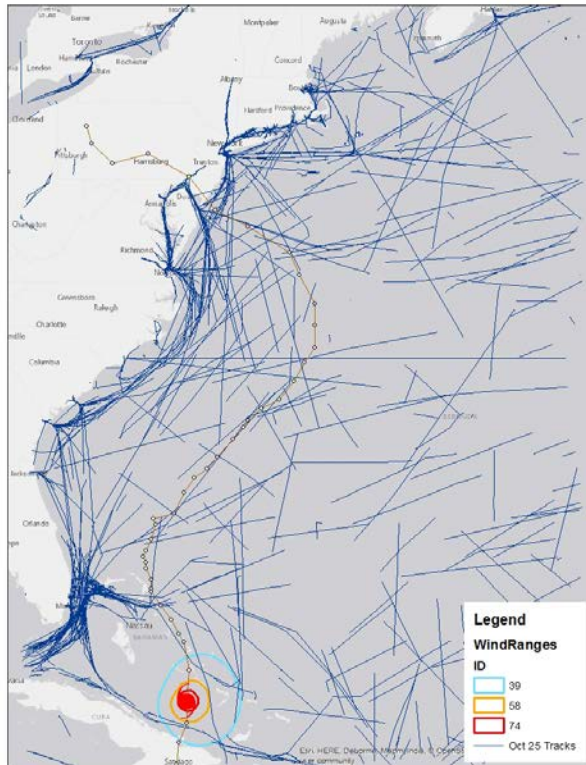
**Image 8.** Hot Spot Analysis from October 25, 12-18Z on the top left, October 27, 12-18Z on the top right, October 29, 0-6Z on the bottom left, and October 30, 0-6Z on the bottom right as Hurricane Sandy made landfall

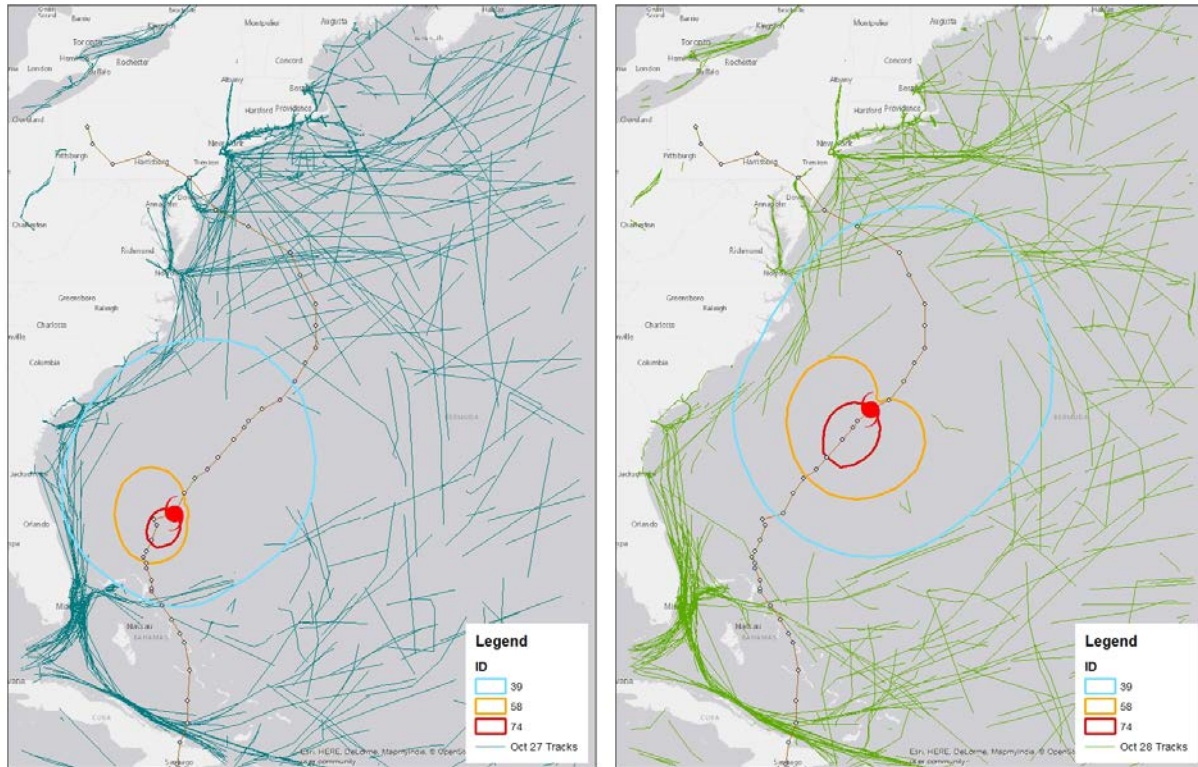


**Image 9.** Kernel Density Analysis from October 25, 12-18Z on the top left, October 27, 12-18Z on the top right, October 29, 0-6Z on the bottom left, and October 30, 0-6Z on the bottom right as Hurricane Sandy made landfall



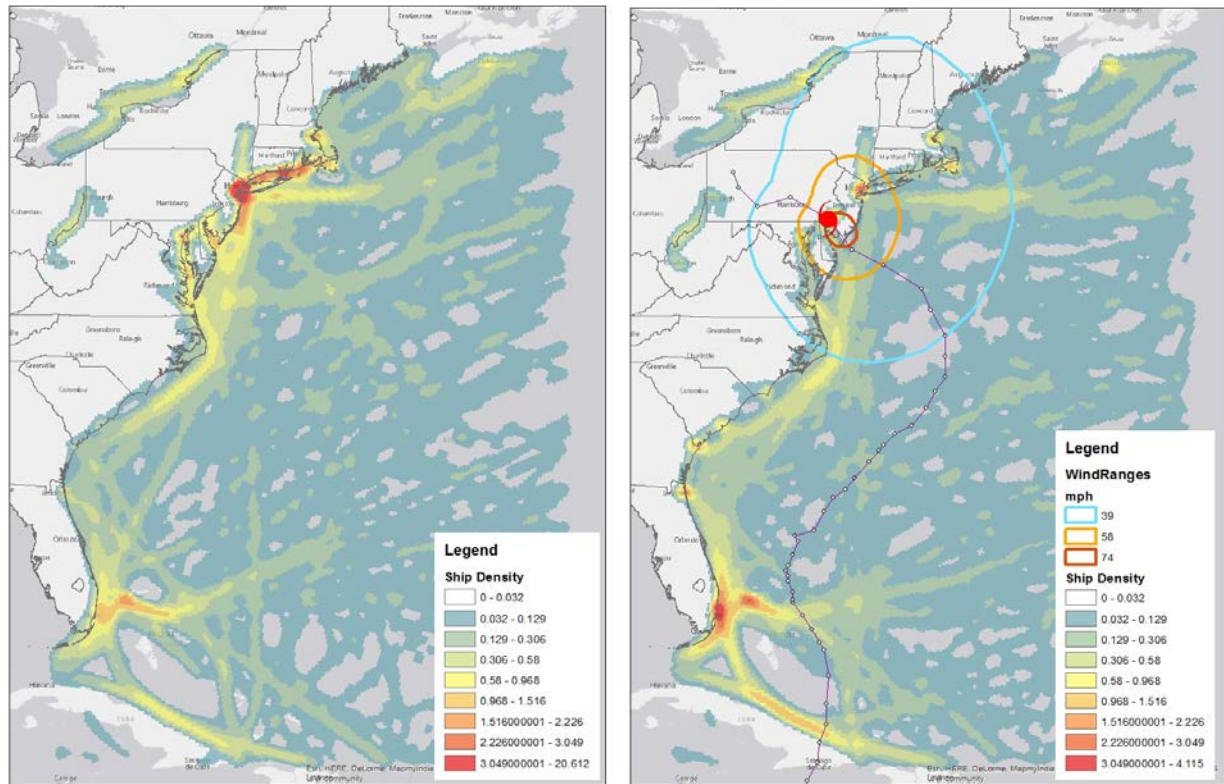
The Marine Cadastre Track Builder Tool created 24 hour tracks for October 25-28 as seen below in Image 10. When plotted with Hurricane Sandy's location and corresponding wind ranges for that same time, it can be seen that ships may be using at least 50 knots (58 mph) as a criteria for avoidance. As the storm gets larger through time, the area with no ship tracks grows larger with ships avoiding even lower wind speeds due to the size of Hurricane Sandy.





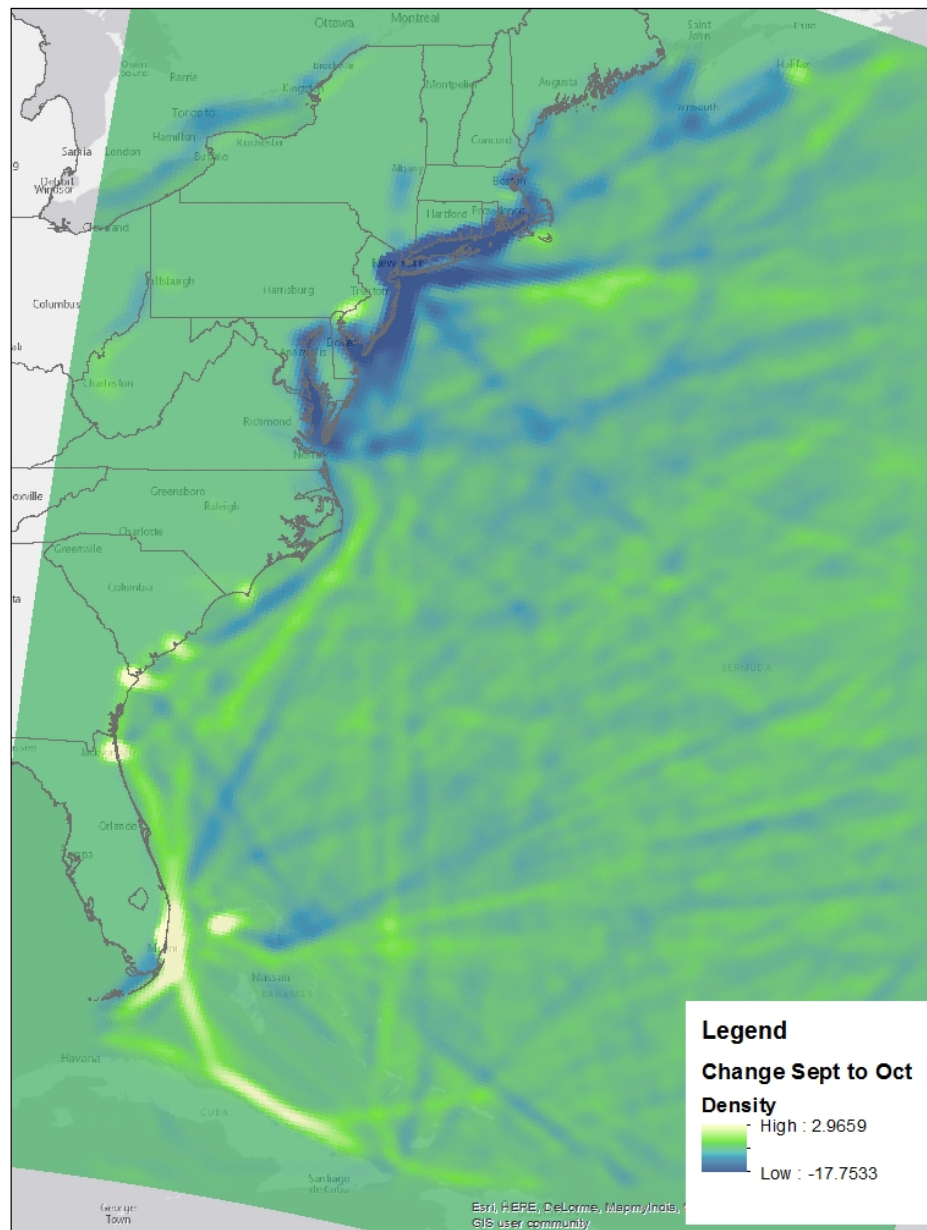
**Image 10.** Tracks for 24 hour periods from October 25 (top left), October 26 (top right), October 27 (bottom left), and October 27 (bottom right) with Hurricane Sandy's corresponding location and wind ranges from 15Z each day

The point location data for Baseline and Sandy had to be merged using the *merge tool* for the following analysis. Kernel density analyses were performed using the point location data from Baseline and Sandy. The *merge tool* and Marine Cadastre Track Builder were used to produce the results shown in Image 11. The raster calculator displayed the difference from the 3 day data from September to October in Image 12. There are large negative values throughout New England and the Mid-Atlantic and slightly positive values near the ports of Charleston, Savannah, and Jacksonville. The highest concentration of positive values were along Southeast Florida and the Caribbean.



**Image 11.** Density of ship tracks Sept 24-26, 2012 (left) Density of ship tracks Oct 29-31, 2012 pre/post Hurricane Sandy landfall with the Wind Ranges of Hurricane Sandy at landfall





**Image 12.** October 29-31,2012 – September 24-26, 2012 kernel density analysis raster calculator result

The calculate geometry option for length was run on the ship tracks for the two time periods to see how the ship routes, in regards to distance, by Hurricane Sandy. In table 2 below, the number of ship tracks only differed by about 100. The maximum ship track is actually longer for the October time period which could have been due to ships taking longer routes to avoid Hurricane Sandy. Because ships appear to be stationary off the coast of the Northeast United States, average ship tracks were approximately 67 kilometers less than the Baseline time period. The standard deviation is about 10 kilometers larger as well in October. This could be hinting to the

fact that the range was wider since many tracks were shorter as they waited out the storm or possibly longer taking a longer route to get away from the storm.

	<b>September 24-26, 2012</b>	<b>October 29-31, 2012</b>
<b>Ship Track Count</b>	1629	1730
<b>Minimum</b>	0	0
<b>Maximum</b>	3983305	5698965
<b>Mean</b>	404556	337248
<b>Standard Deviation</b>	460606	470441

**Table 2.** Ship Track Count and Statistics from Ship Track lengths in meters for Sept 24-26 and Oct 29-31, 2012

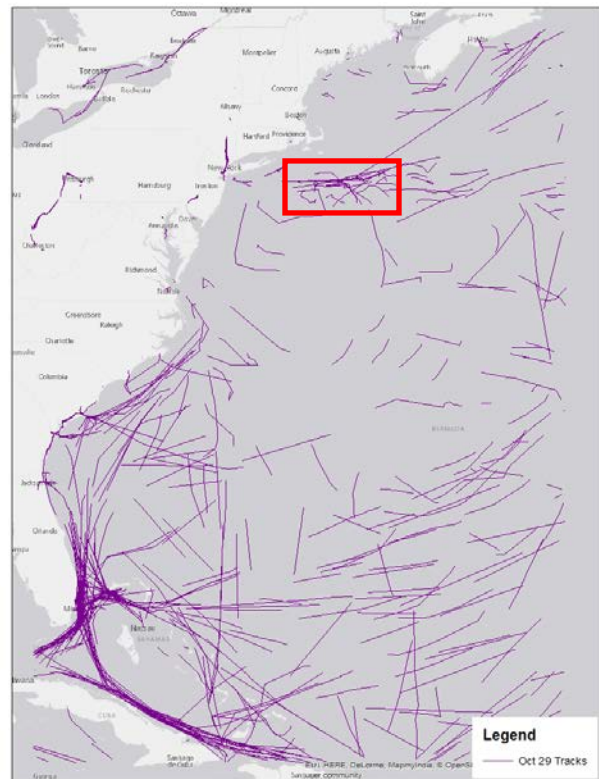
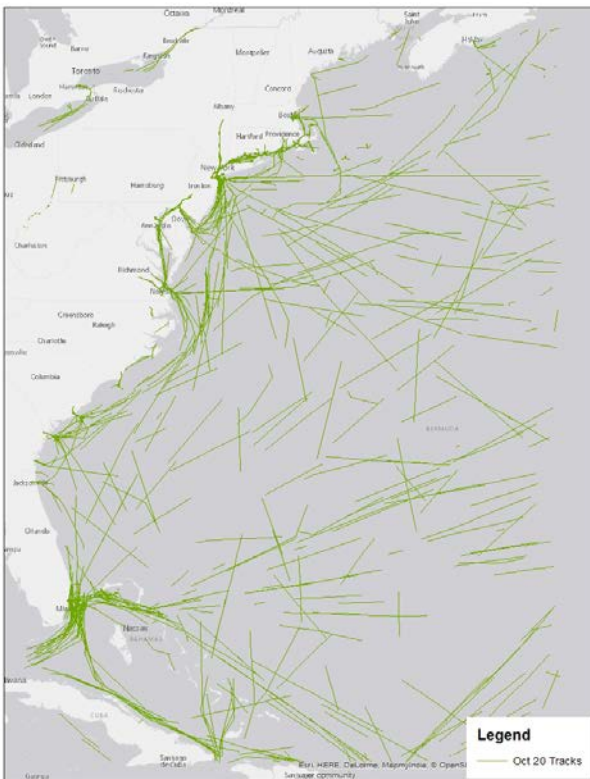
The number of ship tracks leading up to Hurricane Sandy's landfall, which were created using the *merge tool*, are shown in Table 3. On October 29 and October 30 as landfall occurred, traffic off the northeast United States coast was halted. Overall, the mean track lengths don't vary by more than 18 kilometers. The standard deviation shows the most information though because it was so much higher on October 29 when Hurricane Sandy was just off the coast and about to make landfall. As seen previously in Image 12, traffic in ports other than New York increased dramatically while traffic in New York essentially disappeared.

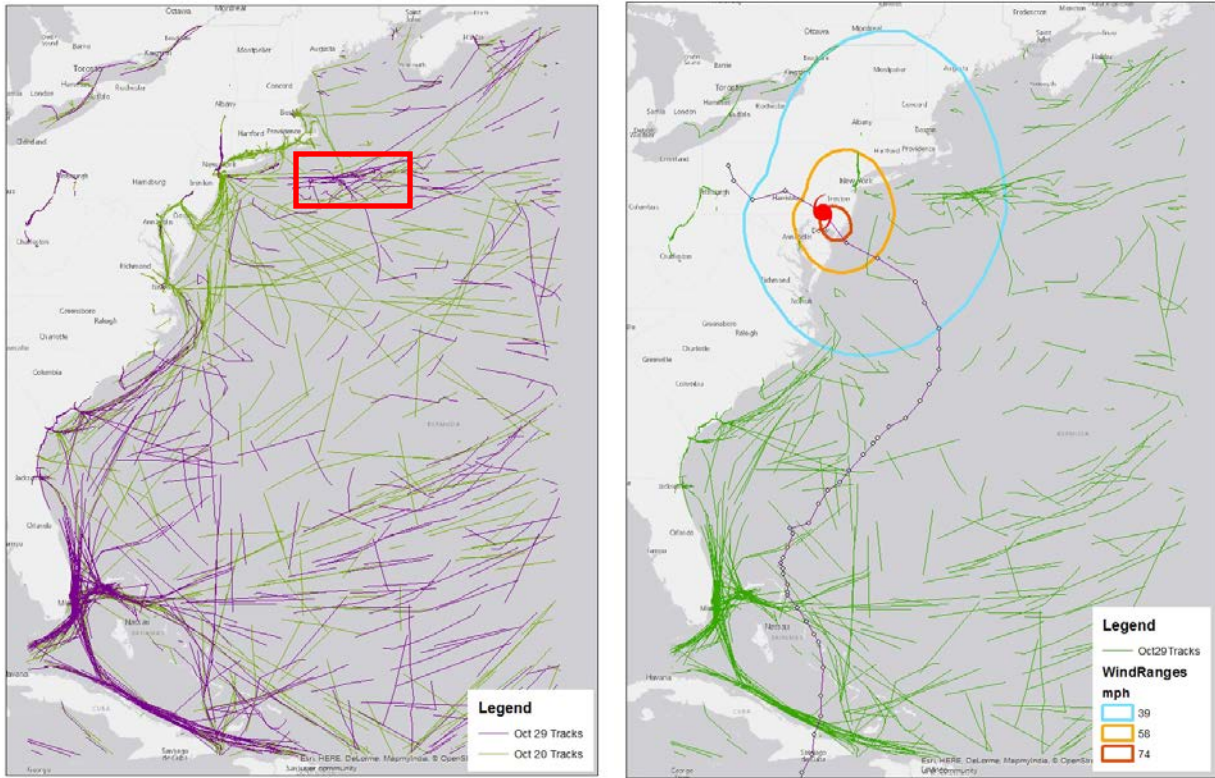
	<b>10/25</b>	<b>10/26</b>	<b>10/27</b>	<b>10/28</b>	<b>10/29</b>	<b>10/30</b>
<b>Ship Track Count</b>	1328	1309	1294	1139	950	1101
<b>Minimum</b>	0	0	0	0	0	0
<b>Maximum</b>	2385042	881493	1000924	934172	4133120	828233
<b>Mean</b>	151167	146415	153395	157206	164113	140802
<b>Standard Deviation</b>	185995	176284	184682	187290	228988	186785

**Table 3.** Ship Track Count and Statistics from Ship Track lengths in meters for October 25-30, 2012

The red boxes in Image 13 highlight an abnormally large concentration of ship tracks near the Hudson Canyon. This is right as Hurricane Sandy was off shore of New Jersey and New York. Ships could not enter any ports without being in danger due to hazardous weather conditions. It

is even more apparent that there was little to no traffic near the coast of New England or the Mid-Atlantic on October 29, when Hurricane Sandy was 24 hours from making landfall. The tracks off the east coast of Florida are more plentiful and longer on October 29 than October 20. There are also many more tracks right along the coast in South Carolina and Georgia which are not normally there. This further shows ships stayed farther South to avoid the storm and also shows, as seen in image 13 bottom right, this may give even more evidence that ships use a 50 knot (58 mph) wind threshold for avoidance.





**Image 13.** On top left, ship tracks on October 20 in green and on the top right, ship tracks on October 29 in purple. In the bottom left, ship tracks on October 20 and 29, 2012 to show the comparison of them overlaid together. In the bottom right, ship tracks from October 29 with the track and wind ranges of Hurricane Sandy overlaid.

#### *ArcGIS Online- The Story Map Journal*

Once all of the web maps were created and all data to be used for the story map were collected, the story map journal was developed. Web maps, images, a video, GIFs, and text were used to present information on Hurricane Sandy and its impact to the coast, specifically ship traffic through analysis of AIS data. Table 3 shows the order of the story map and indicates which data are used when.

Page	Title	Data Shown
1	Hurricane Sandy's Effect on Ship Traffic	Hurricane Track and Error Swath in a Web Map
2	Hurricane Sandy's Impact Along the Coast	FEMA Assessment of Hurricane Sandy's Impact by County in a Web Map

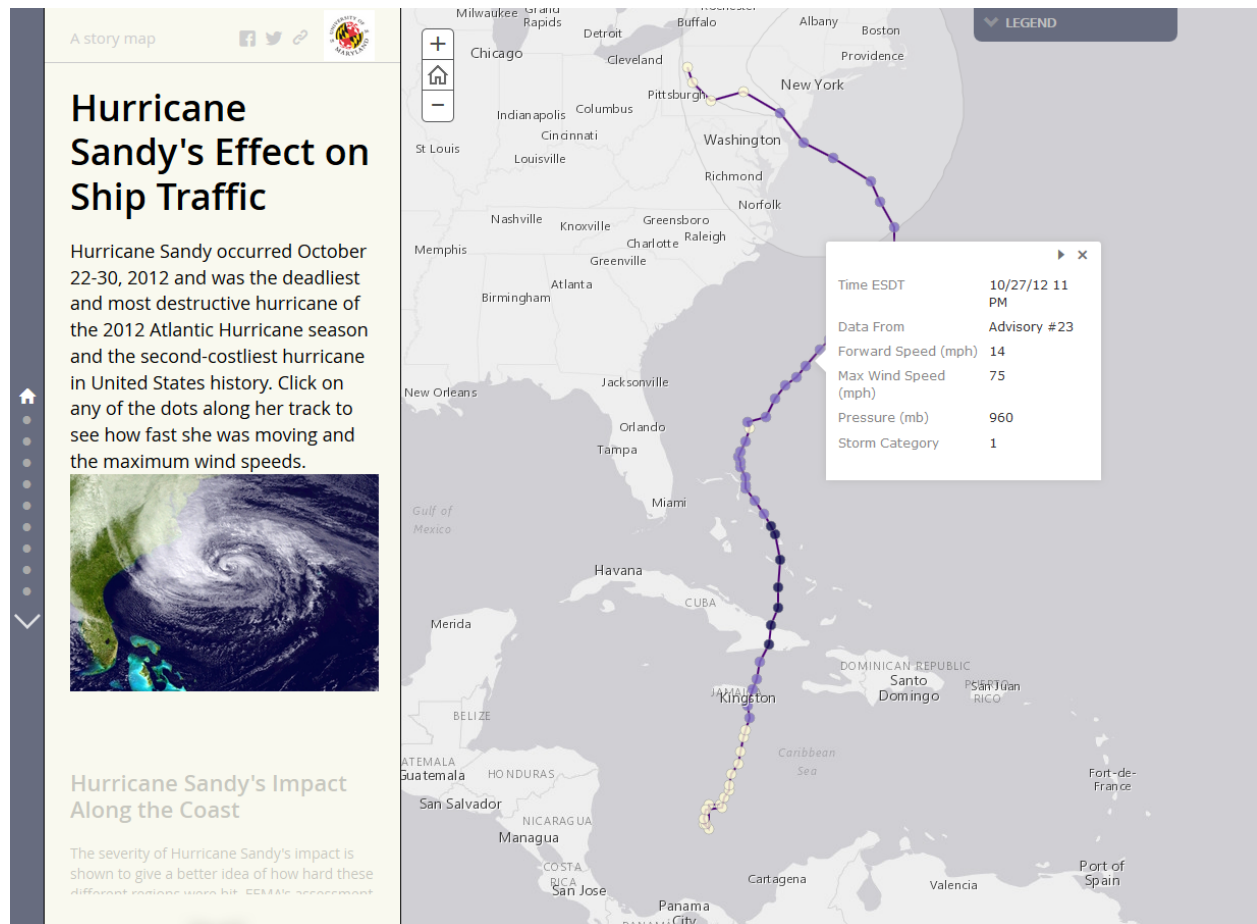
3	Surface Analysis of Hurricane Sandy	Ocean Prediction Center Surface Analysis
4	Wave Heights of Hurricane Sandy	Image showing Significant Wave Heights Valid at 18Z October 29, 2012
5	Typical Ship Traffic	Kernel Density Analysis of September Ship Traffic in a Web Map
6	Hurricane Sandy Storm Track with Ship Density	Kernel Density from October 29-31, 2012 and Storm Track with Wind Ranges in a Web Map
7	Ship Traffic During and Before Hurricane Sandy	Swipe Story Map of ship density in September and October
8	Difference in Ship Density	Difference from October to September density values in a Web Map
9	Ship Density Through Time	GIF of Kernel Density Analysis from TerpConnect October 25-31, 2012
10	Hot Spots of Ship Traffic	Swipe Story Map of hot spots on October 21 and October 29, 2012.
11	Hot Spots of Ship Traffic Through Time	GIF of Hot Spot Analysis from TerpConnect October 25-31, 2012
12	Effects Along the Coast of the United States	YouTube Video showing damage from Hurricane Sandy

**Table 3.** Order of Story Map by page number, Title, and Data used

The application is located at the following address: <http://arcg.is/1RKT45F>. To view the application, all security measures must be disabled because the University of Maryland servers are hosted on http instead of https. Mozilla Firefox works best to view this.

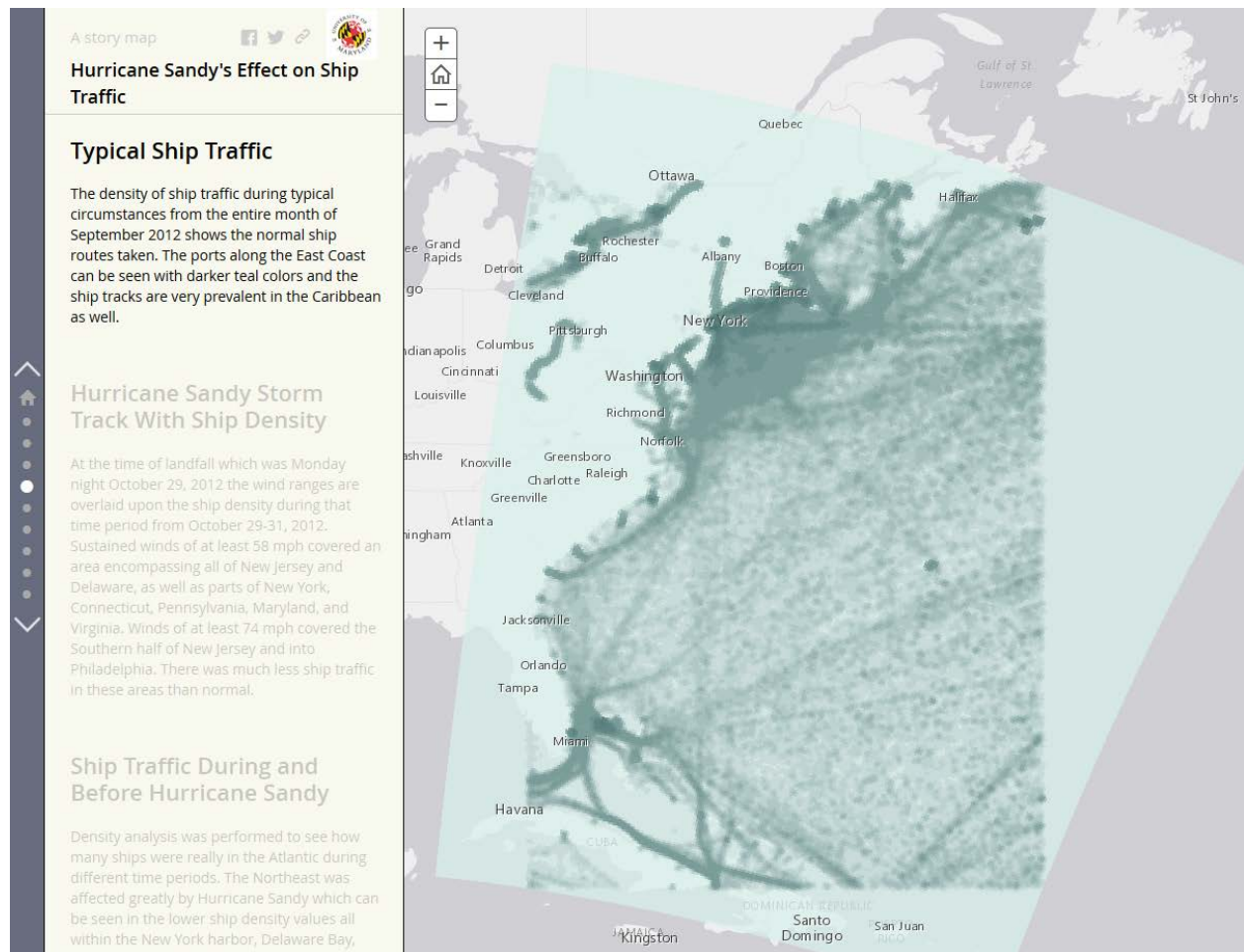
The front page of the application (as seen in Image 14) gives a short introduction to Hurricane Sandy and allows the user to interact with its track. The user can click on any of the point locations and the following information will be given: time, the advisory the data are from, forward speed, maximum wind speed, barometric pressure, and the storm category. These options were edited through the configure pop-up box within ArcGIS Online.



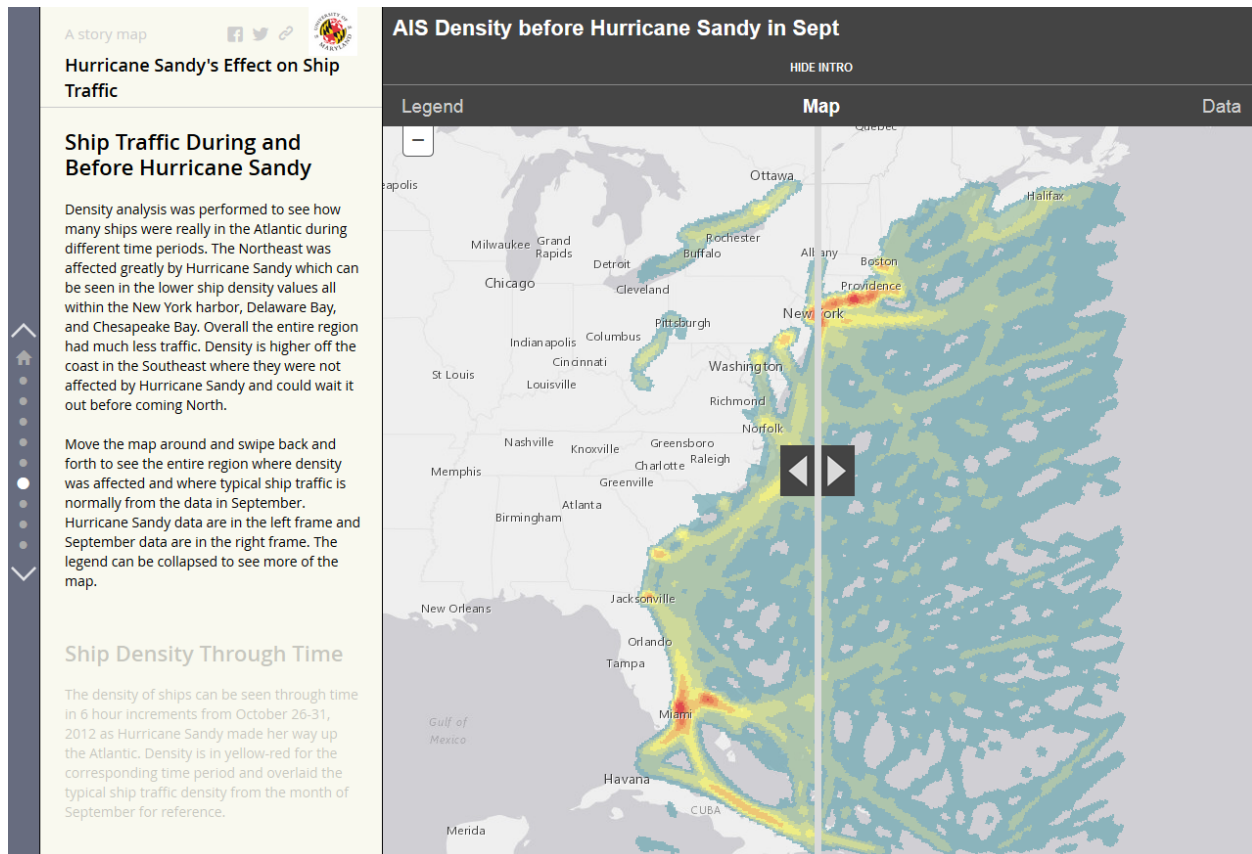


**Image 14 .** The front page of the Story Map Journal giving an introduction into Hurricane Sandy hosted through ArcGIS Online.

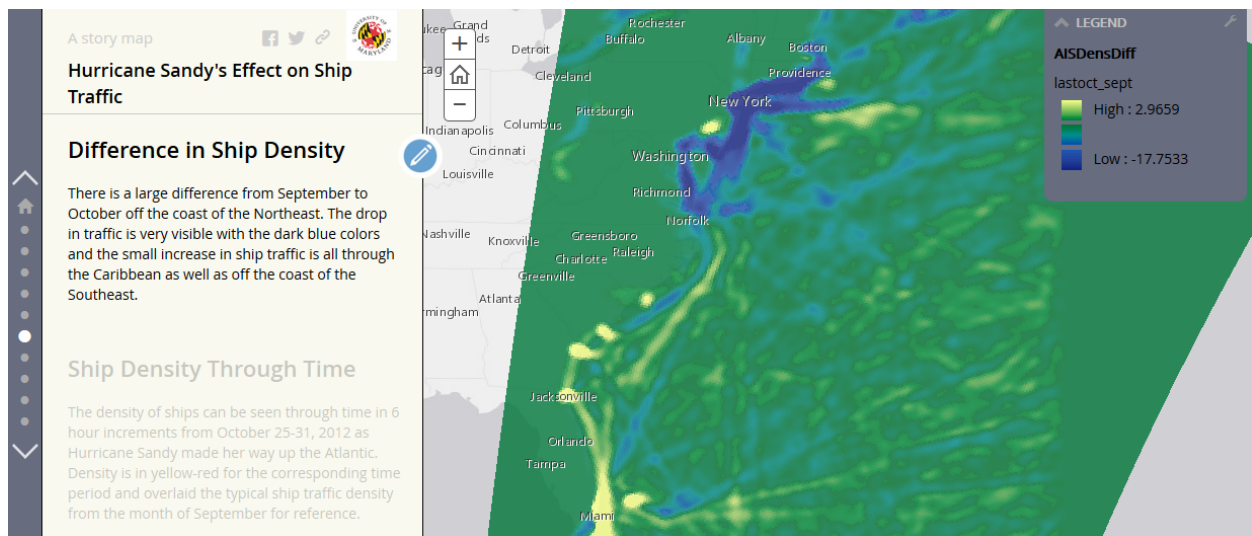
Additional screen shots of the Story Map Application, highlighting pages devoted to traffic densities and Hot Spot Analysis, are shown in Image 15, 16, 17, and 18.



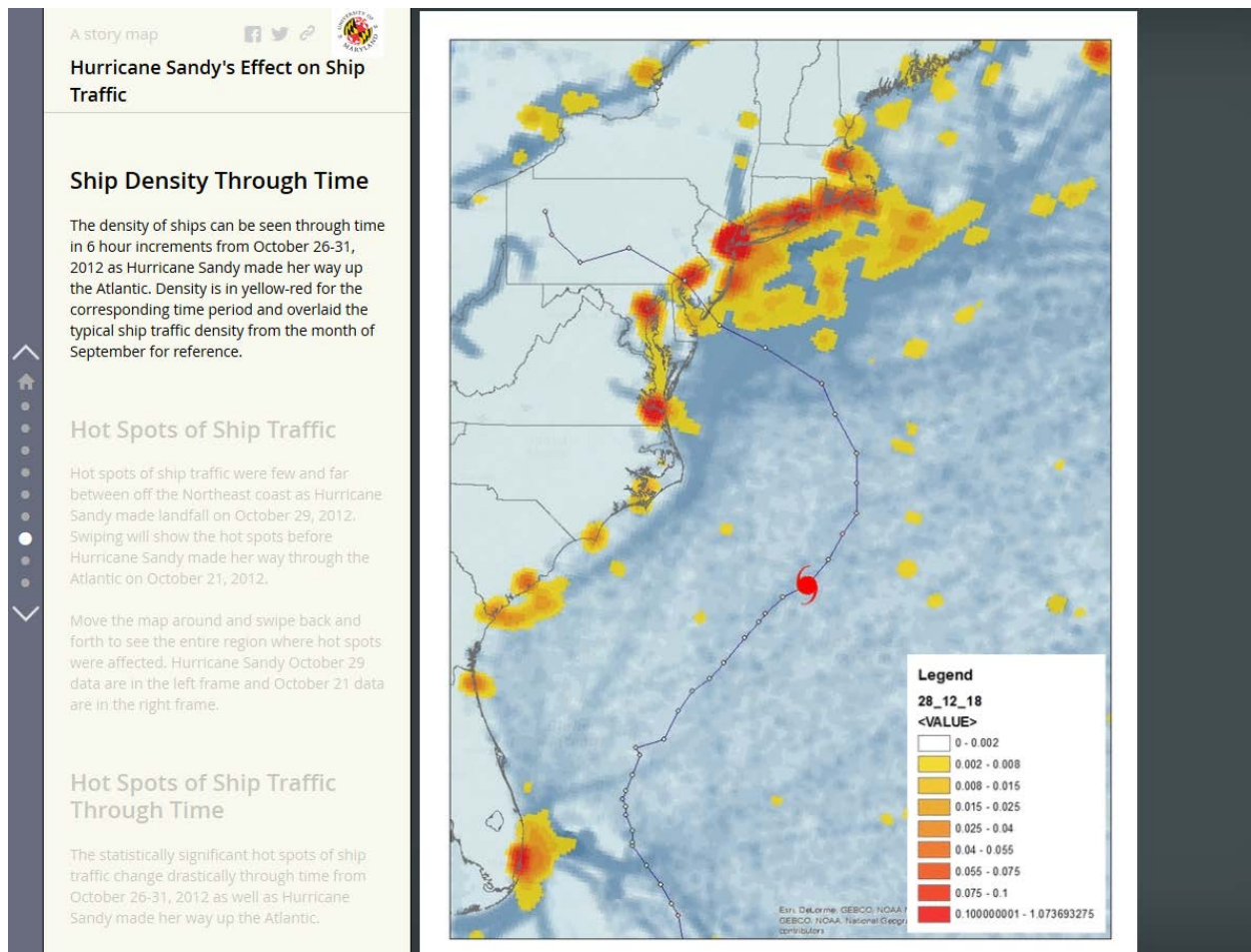
**Image 15.** Typical ship traffic density for month of September 2012.



**Image 16.** The Swipe Story Map used within the Story Map Journal to show the difference in densities.



**Image 17.** The difference in ship density from September to October as seen in the Story Map



**Image 18.** An example of the GIF hosted on TerpConnect used within the Story Map Journal

## Conclusions and Future Work

Using a GIS for this project enabled many different types of analysis, providing useful and insightful results. There are many possibilities when it comes to GIS and because of that, the patterns of ship traffic during normal conditions and during Hurricane Sandy could be observed. The results showed that there was a significant impact to ship traffic due to Hurricane Sandy. Analysis of the evolution of ship traffic density, in response to the forecasts of Hurricane Sandy, illustrated that commercial vessel traffic in the New York Bight area ceased within 24 hours of Sandy's approach and landfall. Many ships avoided high winds and seas by heading southeast of Cape Cod. Increased traffic density was evident at alternative ports to New York such as Halifax, Boston, and all major ports south of North Carolina especially offshore south of Hurricane Sandy off the coast Florida and the Bahamas. The most important part of these results comes from not only seeing the comparison of before and during the hurricane. Seeing the movement through time of the ship density and hot spots further shows how much of a drastic drop in traffic there is. Additionally, ship track locations around forecasted wind speed radii suggest that 50 knot winds are the avoidance threshold for many vessels.

Only the data from ships that were underway were used in this study. Future work using anchored ship AIS data could prove useful for identifying where ships seek shelter. Additionally, these analysis techniques could produce valuable results if applied to AIS data around other tropical cyclones or to extra-tropical cyclones anywhere in the world, especially in areas in close proximity to significant ports or vessel traffic lanes.

The global economy's dependence on vessel traffic, especially in United States ports, means that recognizing vessel traffic patterns and their weather avoidance behavior could prove beneficial to many groups and agencies outside of meteorological forecasting. For example, these analysis techniques have potential applicability to NOAA charting survey priorities. Using these same methods could give a better idea of how ships respond.

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Saladas et al. "GIS ideal for spatial analysis of AIS data." *MARIN Report* December (2009): 98.

URL for TerpConnect Hot Spot Analysis GIF:  
<https://terpconnect.umd.edu/~awelty/FINAL/hotspots.gif>

URL for TerpConnect Density Analysis GIF:  
<https://terpconnect.umd.edu/~awelty/FINAL/dens.gif>