AN ANALYSIS OF AUTOMATIC IDENTIFICATION SYSTEM DATA IN DETECTING FISHERY MOVEMENTS IN THE GULF OF MEXICO FROM THE INTERNATIONAL SPACE STATION

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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ABSTRACT

I am analyzing Automatic Identification System (AIS) data from exactEarth over a period of 3 months (January to March of 2016) and AIS data from NASA over a period of 6 months (December 2016 to April 2017) to document whether it is possible to detect and how fishing vessels operating in the GoM are changing their areas of operations, hypothesizing that this is a proxy for changing fisheries locations. The AIS data will be compared with historical records compiled by Love et al., 2013 as part of the Deepwater Horizon oil spill to assess changes over periods as long as decades.

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1.0 INTRODUCTION

Fishing in the Gulf of Mexico (GoM) is a multibillion-dollar industry conducted by many of the surrounding countries. The United States (US), particularly the states of Texas, Alabama, Louisiana, Mississippi, and Florida, rely on the GoM fishing industry as a part of their job market and economy (Kildow, 2014). To the south, Mexico's small fishing industry (1.3 million metric tons per year) has led the country to become one of the top 20 fish exporters, one quarter of which is centered about its GoM coastal cities (Hernandez, 2003). In contrast, Cuba has a long tradition of subsistence fishing in the GoM and boasts some of the Caribbean's most intact ecosystems, but recent data indicate that more than 40% of important fish species are overfished (Adams, 2004). Adding to the human impact of overfishing is climate change, which is causing ocean temperatures in the GoM to rise to above normal (~27˚C - 30˚C) conditions (Love, 2013). Many species of fish are sensitive to their environmental conditions and a rise in temperature can make waters uninhabitable for them. In studies conducted by the National Oceanic and Atmospheric Administration (NOAA), fish have been documented to move northward in U.S. coastal areas, away from their original habitats towards cooler waters (Nye, 2009). This means that fisheries can change and impact the economies of the countries dependent upon them. Of course, tracking the migration of fish is difficult, but tracking fishing vessels, which must successfully find fish in order to stay in business, is straightforward using automatic tracking system data such as the Automatic Identification System (AIS).

AIS was developed in 1998 with an aim to improve navigation and aid in maritime safety and traffic control. Estimates are that 80% - 85% of maritime incidents are caused by human oversights (Harati-Mokhtari, 2007), so AIS systems were developed to reduce human error incidents by introducing computerized navigation. Current US Coast Guard (USCG) regulations require only certain commercial and passenger ships built after July 2002 to transmit AIS data. Under Title 33 Section 164 in the Code of Federal Regulations, ships required to have AIS installed onboard are defined as commercial vessels larger than 65 feet, towing vessels larger than 26 feet, passenger vessels that can carry 150 passengers or more, or fishing vessel engaged in commercial activity. Until recently, AIS receivers were also primarily used for coastal transit management, meaning receivers recording AIS data are mainly land based (Figure 1). Due to the curvature of the Earth, land based receivers can only detect small vessels, like fishing vessels and small commercial crafts, 5 to 6 miles off shore and large vessels, like oil tankers and cruise liners, 20 to 30 miles off shore (Milltech Marine, 2017).

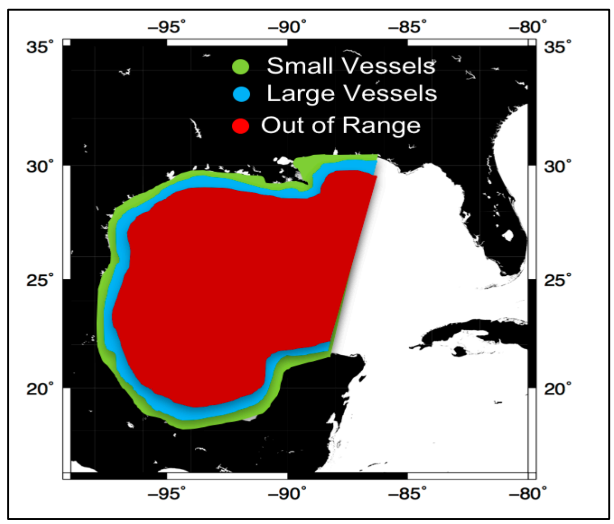


Figure 1: Estimated Land Based AIS Receiver Ranges Based on Ship Size

Unfortunately, AIS data can also be "spoofed" to broadcast incorrect vessel positions or the AIS system can be shut off, so AIS data do not provide a 100% accurate depiction of ship traffic (Harati-Mokhtari, 2007). The USCG and other enforcement agencies thus also monitor vessel tracking systems that are more accurate and are less vulnerable to tampering.

This project aimed at answering two questions. Is it possible to detect fishery movements by using fishing vessels as a proxy for fish, and by using this method, is it possible to detect climate or seasonal changes in the location of these GoM fisheries? Since satellite data is uploaded and can be viewed in real time, I hypothesized that using satellites to view vessel fishing patterns would be much more accurate than the records fishing vessels are required to turn in upon docking. Because of this, these more accurate fishing locations could then be compared to changing climate data and it could be determined if there was a correlation between fishery movement and changing climate. Muhling et al. (2011) predicts that current temperature levels in the GoM will continue to rise as climate change occurs with as much as a 2.0º C increase in water temperatures by the mid 21st century. These changes can all be attributed to climate change and pose risks to fish health and to fisheries.

2.0 BACKGROUND

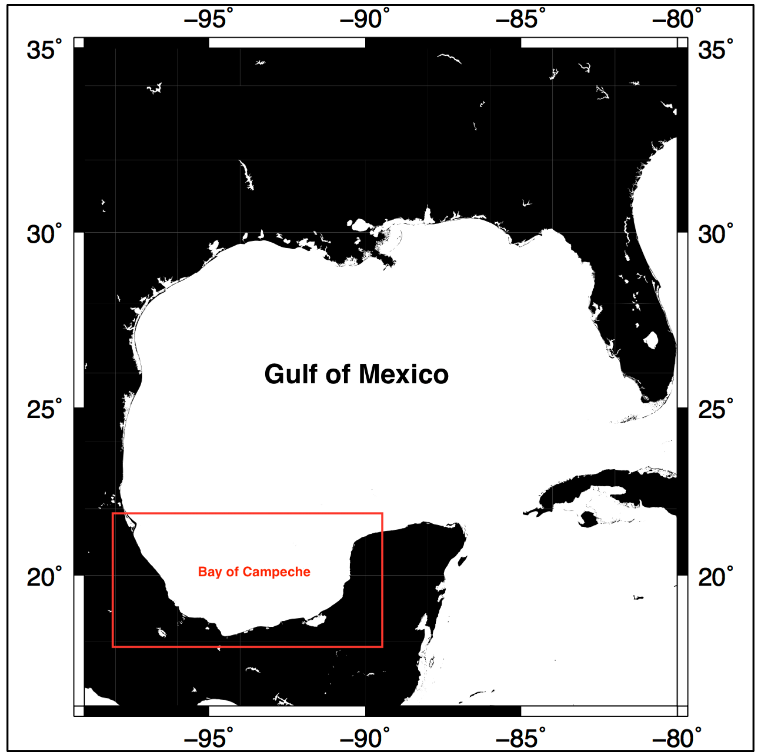


Figure 2: The Gulf of Mexico (GoM) and the Bay of Campeche (outlined)

The Gulf of Mexico was selected for this project because of its geographic location, high vessel traffic, and international waterways and because the United States, Mexico, Central American and Caribbean countries rely on the GoM's resources. Natural resources in the GoM include oil, gas, and fish, all of which have been actively harvested by the surrounding nations. The GoM covers a 1.6 million km^2 area ranging from ~18-30° N and 80-98° W (Figure 2) and serves as a major habitat to a wide range of species that depend on salt marshes, mangrove forests, barrier islands, and coral reefs. Important fisheries include oysters, shrimp, crab, and a variety of fish. Important fishery species for the GoM include: Brown Shrimp, Eastern Oysters, White Shrimp, Royale Red Shrimp, Blue Crab, and Red Snapper (Love, 2013).

Fish that live in the mid-latitudes, like the GoM, tend to be the least affected by sea temperature change because they are more adapted to seasonal fluctuations compared to fish species living in colder latitudes (Pörtner, 2010). This does not mean that fish in mid-latitudes are completely immune to a rise in water temperature. Different stages of a fish's life cycle can be affected by temperature changes. For example, Pörtner (2010) has hypothesized that a change in sea surface temperatures of about 5˚C could devastate the overall shrimp and fish population in the GoM in the future. The current range of water temperature is about 21ºC in the northern parts of the GoM to about 26º C in the southern areas (Bianchi, 1999), but climate change has been linked to an increase of water temperatures in the GoM (Pörtner, 2010). Currently in the GoM, the western section's sea surface temperature is increasing faster than the eastern. The northern section of the gulf has been observed to be increasing at approximately 0.31 degrees every 10 years (NOAA, 2017).

In addition to changes resulting from warming of surface waters, climate change may impact rainfall levels around the GoM or the number and intensity of hurricanes in the region. The GoM's coastal area, about 300,000 km long, makes it vulnerable to intense weather systems.

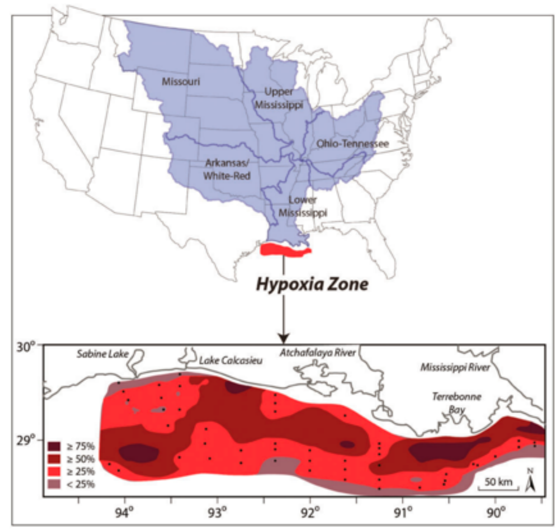


Figure 3: Hypoxic Zone Forming in Northern part of the GoM

Currently in the GoM, the second largest hypoxic zone in the world is forming along the U.S. coast (Figure 3). This hypoxic zone forms as a result of nutrient-filled waters flowing out of the Mississippi and Atchafalaya River Basin. Primary produces, like algae, eat the nutrients and then begin to decompose, depleting the surrounding area of oxygen and making it uninhabitable for living organisms. The depletion of oxygen and increased levels of CO_2 from decomposing organic matter and from the atmosphere increases the acidity levels of the GoM (Rabalais, 2002). The loss of habitat causes organisms that are capable of moving to find new areas for habitation.

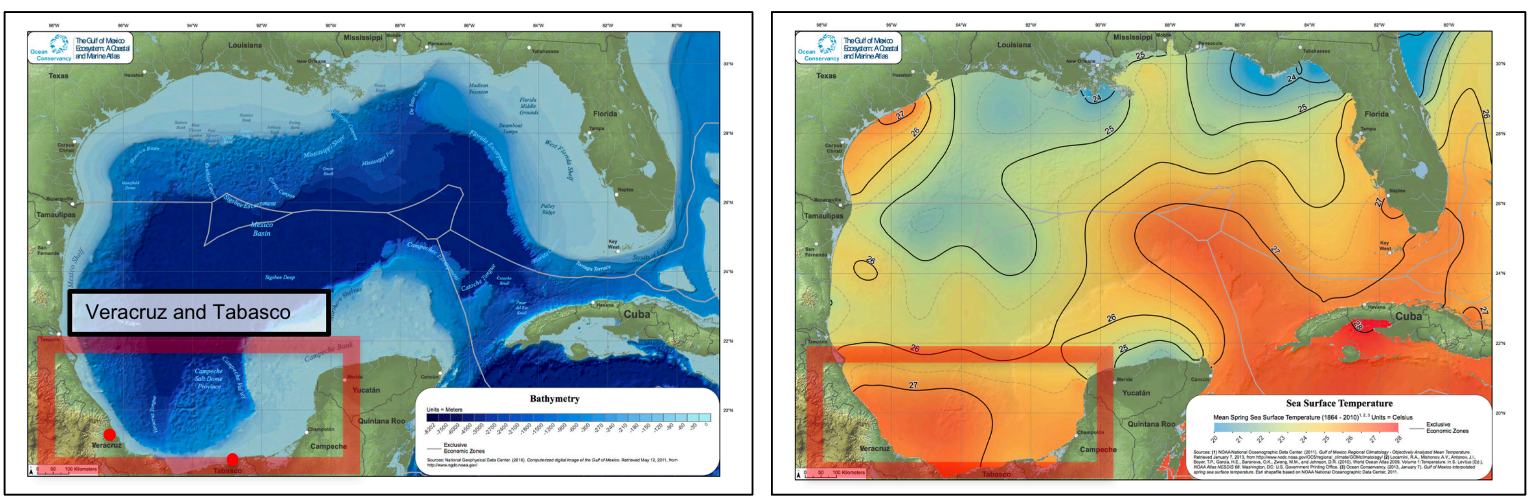
3.0 METHODS

For this project, three data sources were used. The first dataset was provided through a private company called exactEarth. exactEarth is a for profit-company that provides real-time ship positioning through a network of AIS tracking systems. Currently, there are nine satellites in the exactEarth constellation. By having nine satellites simultaneously collecting data globally, exactEarth can track and record multiple ships at multiple times a day. The second data source was provided by the International Space Station (ISS) which orbits the Earth roughly every 90 minutes. The dataset recorded by the ISS was provided by a project sponsored by NASA known as the Global AIS on Space Station (GLASS). The third set of data was used to establish preexisting physical characteristics of the GoM. This dataset came in the form of maps created by Love et al. as part of a study conducted on the GoM after the Deepwater Horizon oil spill in 2013.

AIS data from ships were transmitted to responders onboard the satellites. From there, the AIS data were then filtered and formatted into comma separated value (.csv) files. The .csv files contained ship identifiers that allowed me to target certain types of vessels at a certain location. For this project, I focused on using the ships longitude and latitude location (18˚ N – 30˚ N and 80˚ W – 98˚ W), the Maritime Mobile Service Identities (MMSI), and the numerical ship types of 30 (fishing vessel) and 38/39 (unspecific/private).

The first step in this project was to filter out any vessel from the AIS data files that were not fishing vessels. However, due to a delayed launch and installation of the GLASS AIS receiver on the ISS, I had to begin with the incomplete AIS data from exactEarth. Once I received the GLASS data, it became clear that the data would be unusable due to the amount of ships, only a few hundred, it was able to record in the GoM. Using the Generic Mapping Tool (GMT) I plotted out all ships recorded in the GoM by the exactEarth data set onto a map. I used this map to identify potential fishing hot spots around the Gulf of Mexico and to also identify anomalies in ship movements. Using the MMSI and numerical ship type, I then attempted to filtered out all non-fishing vessels, such as oil tankers and cruise liners, in the GoM.

These maps created with the exactEarth data were then compared to known fisheries location maps created by the NOAA as part of a national study on the Gulf of Mexico after the BP oil spill that affected the region in 2010 (Figures 4, 5, and 6).



Figures 4 and 5: Bathymetry and Average Spring Sea Surface Temperature of the GoM (Love et al., 20013)

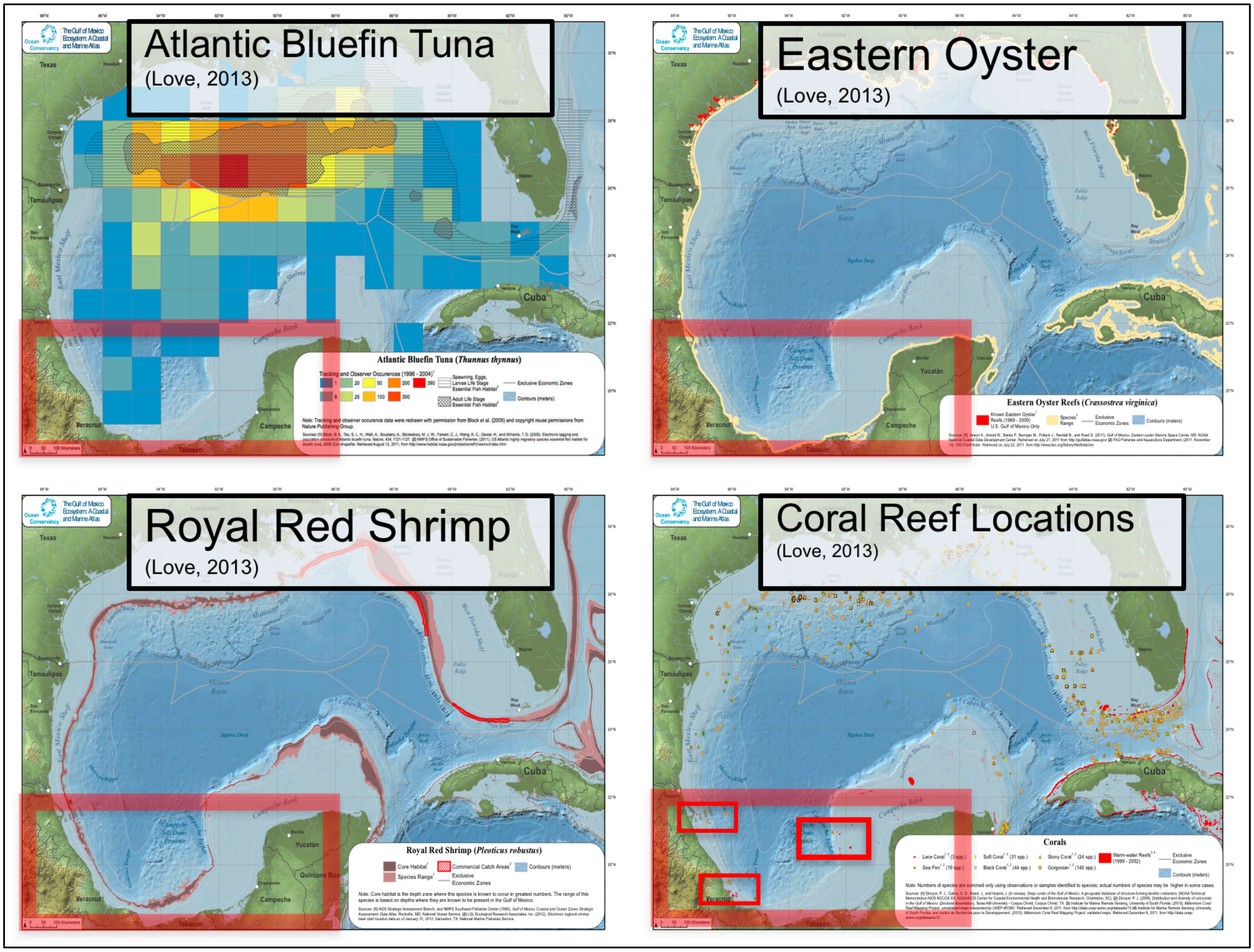


Figure 6: Known Important Fisheries in the GoM (Atlantic Bluefin Tuna, Eastern Oyster, and Royal Red Shrimp) as well as Important Coral Reef Habitats (Lover et al., 2013)

4.0 RESULTS

4.1 exactEarth Data

The exactEarth data time range was from January 1st to April 30th, 2015. The data from the exactEarth data set exclusively focused on the GoM, recording tracks for a variety of vessels including shipping and fishing vessels when they were stationary or moving. The exactEarth data set showed very clear patterns, with some consistent with typical vessels operations (i.e., transit from port to port, long-line fishing operations), and others, more unusual and potentially artifacts caused by hardware or software errors.

Discerning between non-fishing vessels and fishing vessels with the exactEarth dataset is difficult because of the fields representing AIS information such as ship type and MMSI numbers were not consistently reported. However, cargo vessels, like large freighters or oil tankers, were easily to identify and remove from this analysis due to the approximately straight tracks that they create. By removing the long sections of straight tracks associated with transit vessel movements, I was able to detect regions where other types of vessels congregated, often within 100 km of the nearest shore line of the GoM. The majority of these large congregations happened in the southern sector of the GoM, inside the Bay of Campeche (Figure 7).

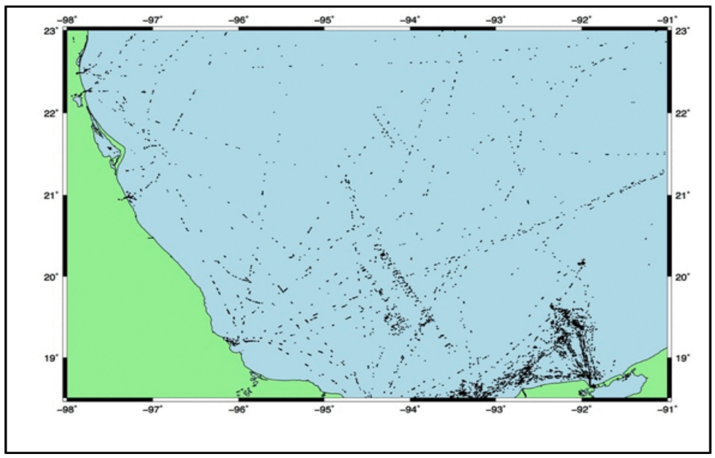


Figure 7: High Ship Densities in the Southern GoM

Areas of high vessel concentrations appear to stay constant throughout the January-April time frame. These regions of high vessel traffic, after the transit vessel tracks were removed, are mostly confined within the shallow shelf that encompasses the GoM. A few high concentrations of ships were observed in deeper waters beyond the continental shelf, however due to missing ship type information, the types and activities of the vessels can't be determined.

The most common high density areas of non-transit ships were typically located in areas near pre-existing coral reefs or small islands. Many of the ship concentrations also appear to be within the range of various commercially farmed species such as shrimp and certain types of fish according to a study done on the GoM following the BP oil spill disaster. (Love et al., 2013) I made several speculations about the objective of vessels due to lacking descriptors in exactEarth data, however, I was able to use what I knew about fishing vessels to constrain my results. For example, fishing vessels usually do not travel in long, straight lines and they only show transiting patterns traveling to and from regions known to be fishing grounds. These fishing grounds were easily located because of the study done by Love et al. (2013) on the GoM that outlined their approximate ranges**.**

As mentioned previously several artifacts were also detected in the exactEarth dataset. These artifacts had unique shapes that seemed unlikely to be produced by a ship operating within water currents and winds, and they only occur in certain portion so of the gulf. The shapes remained noticeably constant in size and shape and included four or more individual ships heading in the same direction. These artifacts appeared either as approximately square shapes or as large, almost perfect circles in the southern part of the GoM (Figures 8 and 9). Other noteworthy vessel tracks occurred off the coast of Tabasco, Mexico where ships would leave port and only travel a short distance to shallow coral reef (Figure 10). Once at the reef for the day the ships would turn back and return to their original port, creating a triangle between the two major ports in the Bay of Campeche and the coral reef.

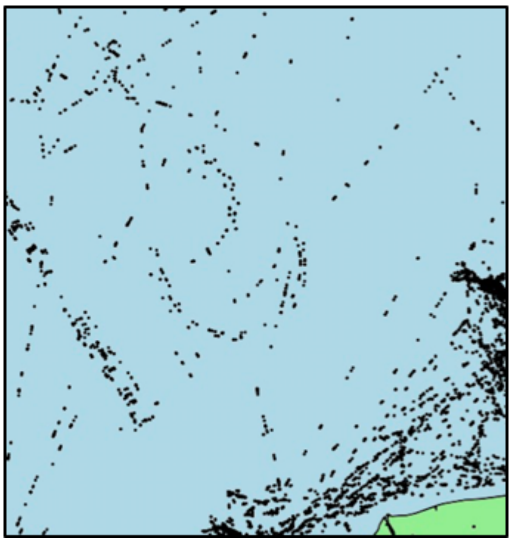


Figure 8: Circles Appearing in April, 2015 data file

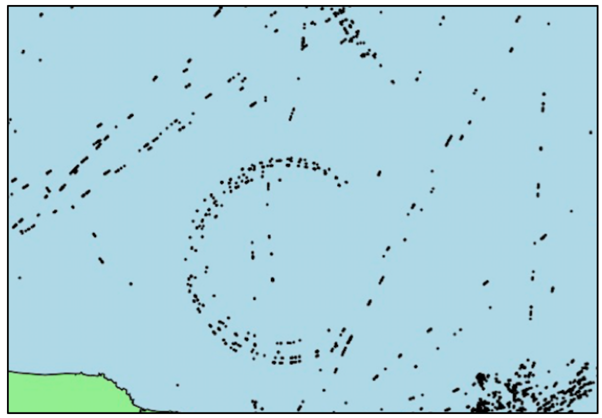


Figure 9: Circles Appearing in March, 2015 data file

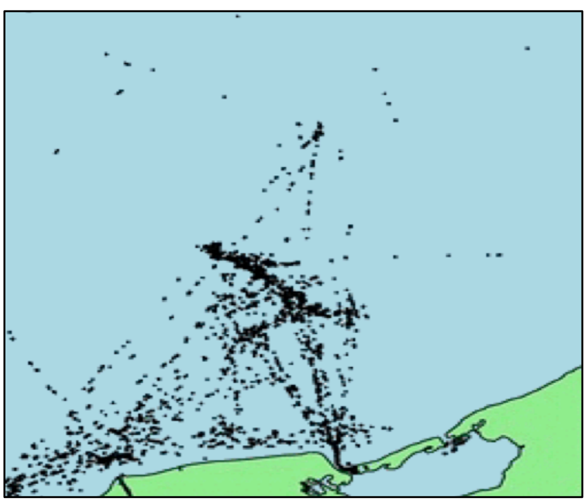


Figure 10: High Vessel Concentration around Coral Reef off the Coast of Tabasco

4.2 *Global AIS on Space Station Data (GLASS)*

The GLASS dataset showed a much larger view of vessel tracks and movements because the data from the ISS covered the entire world, not just the GoM. However, due to the shifting orbit of the ISS described previously, the coverage and number of ships recorded in the GoM was much smaller than the exactEarth dataset. Globally, the GLASS dataset was more voluminous than the exactEarth dataset and the information contained within the dataset was specific enough to easily identify fishing vessels - only a few ships throughout the three-month period didn't show the ship type designator. However, due to the lack of ship points recorded in GLASS dataset for the GoM, I could not interpret the finer details of ship movements. The heat maps constructed for three months show a gradual improvement in ship detections in the later months, however no significant movement or patterns can be detected from day to day in one specific area because of the low number of ships recorded (Figure 11).

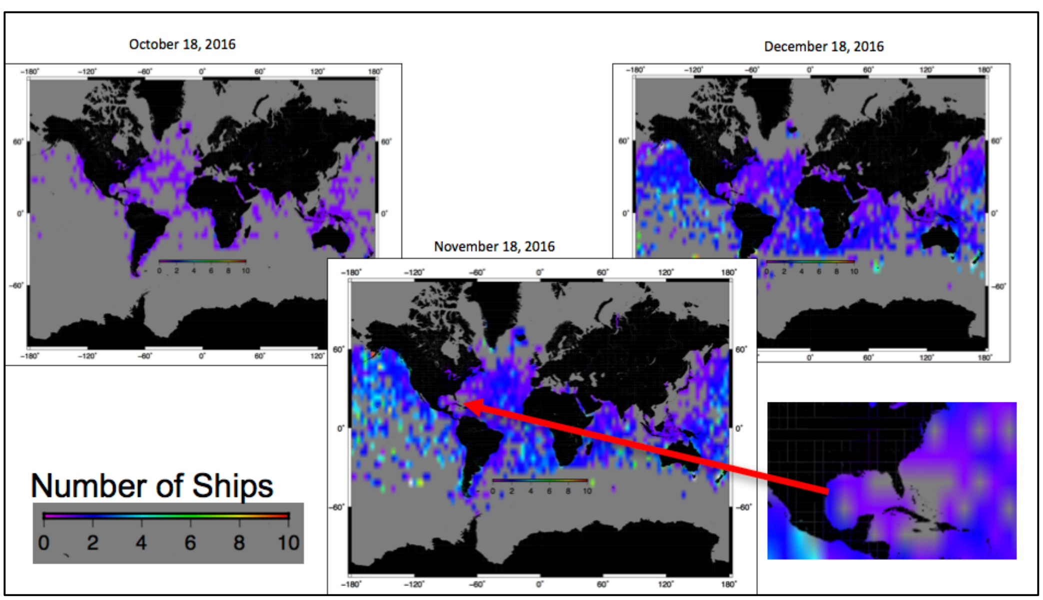


Figure 11: GLASS Data Set only Recording ~20,000 Ships Worldwide and only a Few Hundred in the GoM.

5.0 DISCUSSION

Using the exactEarth data with some support from the GLASS data shows locations in the GoM of high vessel concentrations. By removing the transit and all vessels designated as not fishing vessels, I was able to detect locations with high concentration of vessels that remained relatively constant in size and location throughout the three-month period of the data. These high-density areas were mainly located in the southern portion of the GoM and along the shallow continental shelf. The high-density locations of these commercial fishing and recreation vessels were generally also located alongside pre-existing reefs or small islands in the GoM.

Comparing the high vessel concentration to maps of known active fisheries in the GoM shows that there is a possible relationship with the high concentrations of vessels and the type of fisheries located in the GoM. Shrimp fisheries tend to be the most well documented fisheries in the GoM and the majority of these high concentrated areas lay within the estimated shrimp habitats along the shelf of the GoM.

The unique shapes found, almost entirely in the Bay of Campeche are likely due to several ships moving on the exact same course. By looking at the data strings, that when plotted make the large rectangles and circle, each individual ship track within appear to be made from a unique vessel (i.e. the same vessel wasn't going around in a continuous circle). The ship types and MMSI numbers associated with the ships revealed that each track was also created by ships of different classes (i.e. cargo, fishing, and a cruise liner). Because no other ship tracks around these artifacts were distorted, the ships that created these shapes must be making them, however, no answer as to why these shapes, particularly the circle, was found.

The GLASS data, while providing ship designators, had the problem of not being able to detect as many ships as the exactEarth satellites could in the GoM. Each day of the GLASS data was only able to detect roughly 20,000 vessels worldwide, but only a small fraction of those ships was located in the GoM and an even smaller fraction of those vessels were designated as fishing vessels.

In comparison to the exactEarth's nine-satellite constellation, the ISS used by the GLASS project is the only satellite receiver used by NASA to track and record AIS singles. The ISS orbits Earth every 90 minuets making it orbit the same longitudinal location on Earth roughly 18 times in a day. The ISS's orbit is a non-circular orbit, meaning that each rotation the ISS makes, has a latitudinal displacement. This displacement can have varying effects on reporting the location of ships due to the curvature of the Earth's surface and the current position of the ISS. Data collected from exactEarth gave a more accurate view of a specific location because the satellites orbited in a way that there was always coverage of the area. Because of how the ISS orbits and its, being only limited to one AIS receiver, data collected by the ISS cannot compete, in terms of quantity of ship points, with other satellite constellations like the one exactEarth uses.

6.0 CONCLUSION

The goal of the GLASS project was to see if maritime safety could be improved by adding an AIS receiver on board the ISS. Before the recent advances in technology in the past few years, being able to track vessels remotely from space wasn't even a possibility. Even with projects and companies dedicated to making these advances in technology, the process of obtaining a satellite and mounting an antenna to receive AIS transmissions is still a new and costly field.

The largest source of uncertainty in this project was the lack of ship designation information. Without it, identifying vessel movements and activities is impossible. The exactEarth data could provide more than 40,000 vessels each day in the GoM, but because of the lack of ship identifiers, it's hard to tell whether the ships recorded were fishing. On the other hand, the GLASS data provided 20,000 vessels each day worldwide, with complete ship identifiers.

In terms of this project, the datasets from the exactEarth's satellites worked much better because they could show clear vessel densities in the GoM and were able to record vessel activities at all hours of the day. These vessels densities were not able to be seen on the GLASS dataset purely because the ISS was not set up to only focus on one spot, but the entire world. With the amount of high vessel traffic happening continuously around the world, it would be impossible for a single satellite receiver, like the ISS, to record all vessel activity.

Though I was not able to answer the question of whether fishing vessel locations could be used as a proxy to observe climate change, I was able to see that it is possible to observe different patterns and ship movements in the GoM. Leading me to believe that with a complete data source, and a long enough time series, seeing if fisheries are changing due to climate change is possible.

LITERATURE CITED

Adams, Charles M., Emilio Hernandez, and James C. Cato. "The economic significance of the Gulf of Mexico related to population, income, employment, minerals, fisheries and shipping." *Ocean & Coastal Management* 47.11 (2004): 565-580.

Bianchi, Thomas S., Jonathan R. Pennock, and Robert R. Twilley, eds. *Biogeochemistry of Gulf of Mexico estuaries*. John Wiley & Sons, 1999.

Harati-Mokhtari, A., Wall, A., Brooks, P., & Wang, J. (2007). Automatic Identification System (AIS): data reliability and human error implications. *Journal of navigation*, *60*(03), 373-389.

Hernandez, Alvaro, and Willett Kempton. "Changes in fisheries management in Mexico: effects of increasing scientific input and public participation." *Ocean & Coastal Management* 46.6 (2003): 507-526.

Kildow, Judith T., et al. "State of the US ocean and coastal economies 2014." (2014).

Love, Mattew S., et al. "The Gulf of Mexico Ecosystem: A Coastal and Marine Atlas." *Ocean Conservancy*. 2013.

Milltech Marine. "AIS Frequently Asked Questions" 2017, www.milltechmarine.com/faq.htm.

Muhling, Barbara A., et al. "Predicting the effects of climate change on bluefin tuna (Thunnus thynnus) spawning habitat in the Gulf of Mexico." *ICES Journal of Marine Science* 68.6 (2011): 1051-1062.

Nye, Janet A., et al. "Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf." *Marine Ecology Progress Series* 393 (2009): 111-129.

NOAA National Centers for Environmental Information, State of the Climate: Global Climate Report for Annual 2016, published online January 2017, retrieved on August 20, 2017 from https://www.ncdc.noaa.gov/sotc/global/201613.

Pörtner, Hans-Otto, and M. A. Peck. "Climate change effects on fishes and fisheries: towards a cause-and-effect understanding." *Journal of fish biology*77.8 (2010): 1745-1779.

Rabalais, Nancy N., R. Eugene Turner, and William J. Wiseman Jr. "Gulf of Mexico hypoxia, aka "The dead zone"." *Annual Review of ecology and Systematics* 33.1 (2002): 235-263.