ADVANCED PREDICTION OF THE INTRA-AMERICAS *SARGASSUM* SEASON THROUGH ANALYSIS OF THE *SARGASSUM* LOOP SYSTEM USING REMOTE SENSING TECHNOLOGY

A Thesis

by

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ABSTRACT

Sargassum is a common type of seaweed observed in the Sargasso Sea, located in a portion of the western mid-Atlantic. Seasonally Sargassum inundates the beaches of Texas and the cost for its removal results in great strain on the coastal economies. Although this is an annual occurrence its cyclic migration patterns are relatively unknown. The research reported herein investigates the following null hypothesis, that Sargassum does not enter the Gulf of Mexico via the northern passages of the Caribbean and Yucatan Strait, where it amasses on the shores of the Gulf Coast or gets carried out the Florida Strait, in what is known as the Sargassum loop System. Once a seasonal migration patter is discerned, it is then hypothesized that certain aspects of the upcoming *Sargassum* season can be predicted in advance, using satellite imagery to monitor the corridors between the Sargasso Sea and the Gulf of Mexico.

The *Sargassum* season was previously thought to be erratic and unpredictable, however the theory of the *Sargassum* loop system sheds light on the seasonal migration patterns of the macro-algae. Through use of NASA's Landsat satellite imagery the presence and abundance of *Sargassum* has been analyzed. Based on several factors, such as ocean currents, wind patterns, time of the year, and size of seaweed mats, the arrival and intensity of the upcoming *Sargassum* season can be approximated prior to its arrival in the *Sargassum* loop system. The *Sargassum* season starts months in advance in the Sargasso Sea when high pressure anomalies form. Their formation creates circulating northern wind currents that direct *Sargassum* southbound into the Caribbean latitudes.

Once *Sargassum* has entered the Caribbean Passages, the Gulf Stream carries it westward, where depending on the direction and magnitude of ocean and wind currents, the Seaweed can take from two to five months to reach the Texas Coast. The *Sargassum* that does not reach land is flushed out through the Florida Straits and returns to the Sargasso Sea. This creates the *Sargassum* loop system. This, if monitored correctly, assists in forecasting the upcoming *Sargassum* season. Remote sensing, along with data from other ocean monitoring devices provides the necessary data for use in a Sargassum Early Advisory predictive model that allows for a more advanced warning of its arrival.

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TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGEMENTS iv

TABLE OF CONTENTS v

LIST OF FIGURES vi

LIST OF TABLES ix

INTRODUCTION 1

HISTORICAL BACKGROUND 6

SCIENTIFIC BREAKDOWN OF *SARGASSUM* 8

SARGASSUM EARLY ADVISORY SYSTEM 15

THE CARIBBEAN'S ROLE IN THE *SARGASSUM* LOOP SYSTEM 17

REFINING OF THE *SARGASSUM* SYSTEM 33

LONG RANGE FORECASTING 44

AZORES HIGH PRESSURE SYSTEM – DRIVING MECHANISM 49

CONCLUSION 52

REFERENCES 54

LIST OF FIGURES

Page

Figure 1. *Sargassum* loop system. This graphic represents the *Sargassum* loop system that initiates in the Sargasso Sea, as developed by the SEAS program. Atmospheric conditions create wind patterns that push *Sargassum* south, into the Caribbean where it is pushed west, by the oceanic and atmospheric currents carrying it into the Gulf of Mexico. There it either washes ashore on the Gulf Coast or gets swept out the Florida Strait via the Gulf Stream.. 5

Figure 2. Gyre formation. This graphic depicts the influence that wind patterns have on gyre formations. Southwesterly and northeasterly winds acts together to push water into a bulge, forming the Mid-Atlantic gyre. Arrows indicate how wind currents assist in the locomotion of the gyre 13

Figure 3a. El Niño Southern Oscillation. This graphic depicts the oscillation between El Niño southern oscillation events and La Niña events. An examination shows a major ENSO event occurring just before the 2011 Southern Caribbean *Sargassum* event... 20

Figure 3b. El Niño Southern Oscillation magnified. This graphic depicts the oscillation between El Niño southern oscillation events and La Niña events. An examination shows a major ENSO event occurring just before the 2011 Southern Caribbean *Sargassum* event 21

Figure 4. Salinity gradient 1. This graphics depicts a large, low saline plume coming from the Orinoco and Amazon Rivers. This plume is carried west but does disperse due to pycnoclines. Blue, purple, and white indicate a low salinity pocket of fresh surface water... 24

Figure 5a. Salinity gradient 2. This graphic depicts the pocket of low saline river discharge as it spreads out heading toward the west pushed by equatorial currents. Blue, purple, and white indicate a low salinity pocket 25

Figure 5b. Temperature gradient 1. This graphic shows a satellite image of the temperature of the water runoff plume is relatively high compared to the surrounding waters. Red and yellow indicate a warm water pocket 26

Figure 6a. Salinity gradient 3. This graphic shows a satellite image of the low-saline plume as it reaches the East coast of the Caribbean Islands. This is the same time that the initial wave of *Sargassum* hit the beaches of those islands. Blue, purple, and white indicate a low salinity pocket...................... 27

Figure 6b. Temperature gradient 2. This graphic shows a satellite image of the temperature of the warm water pocket reaching the Caribbean islands. The eddy formations indicate circulating water which is optimal for *Sargassum* Growth. The orange and red areas indicate a pocket of warmer surface water 28

Figure 7a. Salinity gradient 4. This graphic shows a satellite image of the low-saline plume extending past the Eastern Caribbean. Blue, purple, and white indicate a low salinity pocket 29

Figure 7b. Temperature gradient 3. This graphic shows the center of the relatively high temperature of the runoff water has reached the Eastern islands of the Caribbean. This corresponds with the second wave of *Sargassum* seaweed that covered the islands' beaches. The orange and red areas indicate a pocket of warmer surface water............ 30

Figure 8. Caribbean Passages. This figure shows a map of the Caribbean. The Northern Caribbean Passages, referred to as the Windward, Mona, and Anegada Passages, are where *Sargassum* is most frequently observed 31

Figure 9a. Mona Passage satellite image. This graphic illustrates a satellite image of *Sargassum* migrating through the Mona Passage into the Caribbean Sea. *Sargassum* and its slicks are denoted by the yellow ovals 36

Figure 9b. Mona Passage satellite image magnified. A magnified view of the satellite image reveal a linear green glow or if the mat is too small to be seen in the image, a darker outline in linear patterns. This is because the size of the mat is too small to be seen in the image, only the disturbance of the wave attenuation around it can be seen 37

Figure 10. Yucatan Strait satellite image. A satellite image of the Yucatan Strait on March 22, 2014 illustrating *Sargassum* moving westward via the Gulf Stream. *Sargassum* manifests itself in the form of a slick. Since the size of the mat is too small to be seen in the image, only the disturbance of the wave attenuation around it can be seen 40

Figure 11.Gulf Stream current graphic. This graphic represents the Gulf Stream that generates a western current in the Caribbean. The current is then pushed north into the Gulf of Mexico where it 'loops' and exits out of the Gulf via the Florida Strait 41

Figure 12. Florida Strait satellite image. A satellite image of the Florida Strait on April 24, 2014 illustrates *Sargassum* exiting the Gulf of Mexico via the Florida Strait and rejoining the Sargasso Sea 43

Figure 13. Azores High Pressure System graphic. The Azores High Pressure system creates anticyclonic winds over the Sargasso Sea and becomes the driving mechanism behind the migration of *Sargassum* 50

LIST OF TABLES

Page

Table 1. *Sargassum* sightings in the Caribbean Passages. This graphic illustrates the number of times *Sargassum* has been spotted in the passages in a single month. Historic satellite imagery was obtained and analyzed to review when *Sargassum* initiates its journey through the *Sargassum* loop system ... 32

Table 2. Intensity of *Sargassum* sightings per year. This graphic depicts the annual difference between *Sargassum* sightings in the Caribbean Passages. Note that during the 2008 and 2011 seasons, more *Sargassum* was seen the Caribbean Passages, which correlates to the relatively higher rates of *Sargassum* events on the Texas Coast. The 2007 and 2010 years yielded less *Sargassum* in the passages, which correlates to the lower volumes of *Sargassum* seen in the Gulf of Mexico. This denotes that the intensity of the upcoming *Sargassum* season is reflective in the Caribbean Passages during preluding months 46

INTRODUCTION

Sargassum is a brown algae that has for thousands of years washed ashore on the coast of Texas during the summer months. Still, little is known about the path it takes to reach the coasts of the Western Gulf of Mexico. For centuries, *Sargassum* has been looked on as a plague because of its unsightliness and pungent odor produced by its decay. However, recent discoveries suggest that *Sargassum* mats deliver several benefits that are essential to the health of the oceans' and coastal ecosystems. These recent findings are revealing more positive aspects of *Sargassum* and are turning the tide on its historically negative image.

Texas beaches are a major source of income for the coastal communities. Tourism is an integral part of the economy of the Texas Coast. It accounts for an income of $ 2.1 billion annually. In order to attract the maximum number of tourists to the region, there is a major effort made to keep the landscape 'pristine' (Environmental Defense Fund, 2013). *Sargassum* has historically been viewed as a nuisance to the coastal communities in Texas when it inundates the beaches. Massive *Sargassum* episodes cause odorous and hazardous conditions that prevent tourists from enjoying the sandy beach and marginal conditions for wildlife observation. The presence of the surface-dwelling algae obstructs and entangles fishing lines, deterring fishermen. Because of the relatively negative impacts of *Sargassum*, it drives away tourism and negatively affects the local economies (Webster, 2014).

Coastal beach managers are charged with mitigating the impact *Sargassum* events have on the local economy, which often results in removal efforts using heavy machinery. Since these *Sargassum* events also provide nutrients to dune vegetation and assist in replenishing sand on the beach by capturing windblown sediment, its removal is opposed by various groups. In order to utilize these benefits, the Texas General Land Office implemented a policy that regulates what one can do with *Sargassum* wrack. Once it has made landfall, *Sargassum* cannot be removed from the aerial beach (defined as the land from the low tide line to the vegetation line). Because of this, beach managers are forced to take creative measures in order to mitigate the impact of *Sargassum* episodes.

There are a few techniques used in mitigating major *Sargassum* episodes. The first is to let the *Sargassum* naturally degrade and disintegrate on the sandy beach. This is not an effective method for major episodes because it does nothing to mitigate the impacts of *Sargassum* on tourism. The second technique involves using front-end-loading tractors to push *Sargassum* into a pile toward the toe of the sand dune. This technique cleans the beaches and assists the dunes by adding nutrients and trapping windblown sediment, both of which help build and support the dune system. However, when tractors are used, sand along with *Sargassum* is also removed. This can scar the sand which can then accelerate erosion processes. The third method involves using 'beach raking machines' that combs the top layer of sand for *Sargassum* and debris. It then delivers the wrack to a holding compartment via a conveyer belt that vibrates the majority of sediment out of the *Sargassum*, which is then disposed of at the toe of the dune. The beach rake process appears to be the least impactful method of relocating *Sargassum*, however both the front-end-loader and the beach rakes are used to mitigate the impacts of *Sargassum* inundations. These methods also require the use and storage of expensive machinery in corrosive conditions. The maintenance and reduced lifespan of this equipment require constant expenditure, leading to a perpetual shortage of mitigation equipment. This is especially exacerbated when the remaining functional equipment is spread across all 397 miles of Texas coastline.

Until recently, there has never been a way to predict where *Sargassum* is going to land and in what quantities. This creates a bigger issue because there are not enough resources to sufficiently provide the entire coast with adequate *Sargassum* mitigation equipment during the peak of the *Sargassum* season.

In 2010, principle investigator Dr. Thomas Linton and Doctoral candidate Robert Webster initiated the *Sargassum* Early Advisory System (SEAS) program. It was a program, in which, through use of remote sensing technology, it would be possible to locate *Sargassum* mats (wrack) off the Texas Coast and predict, well in advance, when it would make landfall using remote sensing technology. By examining current satellite imagery from NASA's Landsat database, the SEAS program monitored for and analyzed *Sargassum* patterns in the Gulf of Mexico. Using oceanic and wind vector data, the program was able to create an approximate set and drift for the mats. These techniques allowed the SEAS program to effectively forecast the 2011 *Sargassum* season and send out advisories predicting the landfall of *Sargassum* mats with a success rate of 84%. A successful advisory is defined as predicting a significant *Sargassum* wrack (enough to form a windrow) on the beach arriving within an eight day period. Before the *Sargassum* Advisory program began, coastal communities had no means of determining where *Sargassum* would make landfall, nor in what volume. This caused the *Sargassum* relocation equipment to be spread thinly across the coast. This caused delays in response time. The advisories alerted coastal managers of the size and approximate location of an upcoming *Sargassum* episode, so that they could allocate and concentrate their *Sargassum* mitigation efforts more efficiently.

Satellite imagery limitations restricted the SEAS program's advisories to a maximum forecast period of sixteen days. Further, the satellite imagery did not detail the initiation and the intensity of the upcoming *Sargassum* season until it had arrived. In order to provide a more robust advisory, several months in advance of the season, the SEAS program looked to expand its area of observation.

An atypical and unusually massive *Sargassum* event in the Southern Caribbean in 2011 initiated the expansion of the SEAS program, expanding its monitoring efforts to the Caribbean and Sargasso Sea. This paper theorizes that the observations in historical imagery of the newly incorporated region reveal a seasonal pattern of *Sargassum* migration. Annually, *Sargassum* is witnessed migrating south out of the Sargasso Sea and into the Caribbean, where it is swept northwest into the Gulf of Mexico by the Gulf Stream. Here it is theorized that *Sargassum* either washes ashore on the western coasts of the Gulf or is swept back out into the Atlantic, carried by the Gulf Stream current. This yearly voyage has been deemed the *Sargassum* loop current (Figure 1). The research reported in this paper attempts to document this *Sargassum* loop system so that it can be monitored and analyzed using remote sensing technology. This in turn, allows for an advanced forecast of the upcoming Intra-American *Sargassum* season.

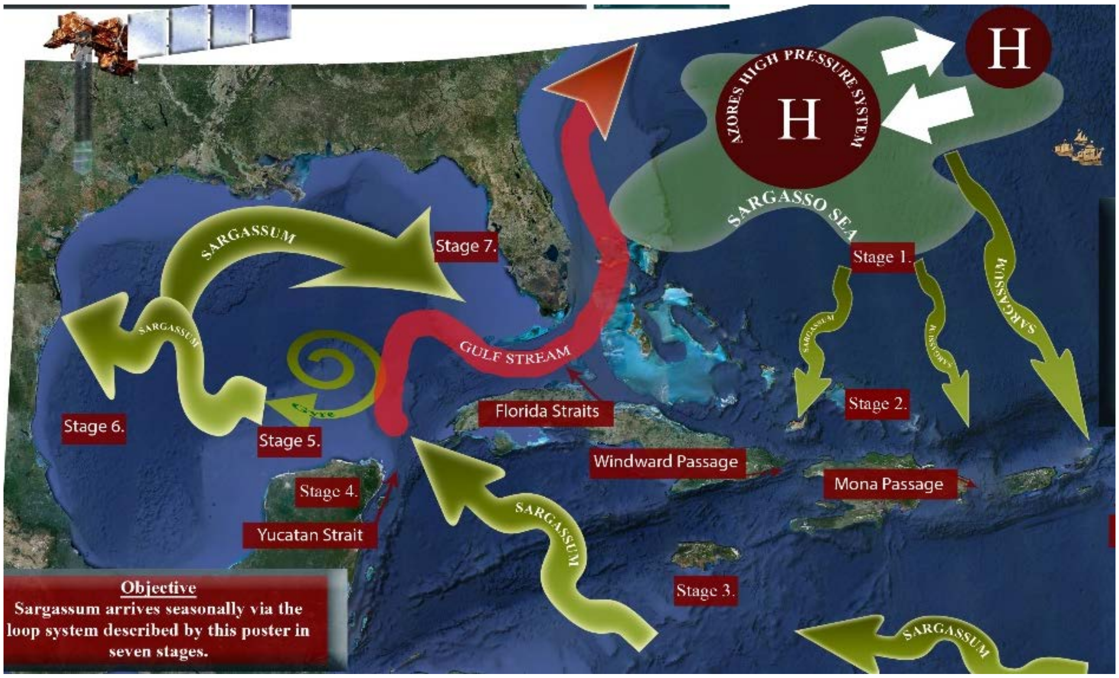

Figure 1. *Sargassum* loop system. This graphic represents the *Sargassum* loop system that initiates in the Sargasso Sea, as developed by the SEAS program. Atmospheric conditions create wind patterns that push *Sargassum* south, into the Caribbean where it is pushed west, by the oceanic and atmospheric currents carrying it into the Gulf of Mexico. There it either washes ashore on the Gulf Coast or gets swept out the Florida Strait via the Gulf Stream (Webster, 2014)

HISTORICAL BACKGROUND

Sargassum has accumulated on the southern and eastern borders of the United States since before recorded history. In fact, its name originates from Christopher Columbus' lieutenants during his journey to the new world. Gonzalo Fernandez de Oviedo served as deckhand on Columbus' journey and also as the official chronicler of the voyage for the Queen of Spain. Oviedo is known for being one of the first to create a truly systematic description and depiction of the flora and fauna that was discovered in the Americas, particularly in the Caribbean (Carillo, 2000).

On Oveido's path to the new Americas, he was in charge of chronicling all undiscovered vegetation that he observed. The recovered travel logs were organized into a publication in 1850, entitled *La Historia general y natural de las Indias.* In the description of his journey, he details his navigation through a 'sea of vegetation' which is later termed the 'Sargasso Sea' (Carillo, 2000). He describes the free-floating vegetation as similar to 'rockweed,' a reference to a type of kelp (*Ascophyllum nodosum*) that is abundant on the rocky shores of the European Coasts. He names this new, pelagic seaweed 'Sargaço' which, from Portuguese to English, is transliterated to 'Sargasso.' (Carillo, 2000). This is the earliest historic record that exists of *Sargassum* in the Western Atlantic and Caribbean Seas.

Sargassum has relatively less nutrients when compared to similar marine algae (Matanjun, 2009), suggesting that is relatively less beneficial to the ocean than its relatives. This, coupled with its planktonic lifestyle creates façade an impression that

Sargassum has a negligible role in the environment, and because of this, it has not been the focal point of many scientific studies of marine flora. However, when scrutinizing the accounts in newspapers of the period (Galveston Daily News, 1845) of major historic events on the southern and eastern coasts of the United States, one finds many references to the presence of *Sargassum*. Local newspapers contain accounts of the use of *Sargassum* wrack as camouflage for Confederate spies as a battalion of Union soldiers proceeded up the Texas Coast to attack southern ports (Galveston Daily News, 1845). Although *Sargassum* is not the focal point of the article, it nonetheless documents that *Sargassum* has been present on the coasts of the Gulf for centuries.

SCIENTIFIC BREAKDOWN OF *SARGASSUM*

Sargassum Seaweed is classified as a type of macro-algae, belonging to the kingdom Protista. It therefore lacks some of the key characteristics of plant species, such as a root and vascular system. This means *Sargassum* does not use photosynthesized nutrients as is done by the members of the plant kingdom. In the members of the Protista kingdom, each individual cell is responsible for obtaining nutrients from its surroundings through osmosis rather than actively dispersing the nutrients by means of a common system throughout the organism.

Sargassum is taxonomically placed in Class Phaeopyceae, commonly referred to as brown algae (Wallentinus, 1999). This Class contains a group of mostly macro marine species of algae that generally occur in colder climates in coastal and neritic regions. This class also includes other large macro-algae, such as kelp, a robust brown algae that has formed its own specialized ecosystem, known as “kelp forests”. These are similar in size and nature to the Sargasso Sea ecosystem.

‘*Sargassum*’ is a scientific genus name for the species found in the Sargasso Sea and Caribbean, however there are multiple species of the organism. The two species that occur in the Sargasso Sea, the Caribbean Sea and Gulf of Mexico are *Sagassum fluitans* and *Sargassum natans*. The characteristic that separates these species from the other species within the *Sargassum* genus is their pelagic and free-floating existence (Wallentinus, 1999). Other members of the Class Phaeopyceae are commonly seen attached to a hard substrate or the sea floor. Since there are relatively limited areas of suitable benthic regions in or near the photic zone, this serves as a limiting factor on the size to which these “kelp forests” can grow. *Sargassum fluitans and natans* have no such limitations because at no point in their lifecycle do they require benthic attachment to hard substrate. This characteristic allows the species to travel and prosper with relatively little competition throughout its geographic range.

Sargassum consists of several small fronds and air vesicules held together by a series of stipes, which function as the stem. These leaf-like fronds are small and plentiful and thus increase surface volume, a feature which promotes nutrient uptake (Enos, 1997). Since *Sargassum* is a pelagic species with no holdfast, it must be buoyant enough to float at the surface in order to carry on photosynthesis. *Sargassum* has pneumatocysts. These are grape-like structures filled with carbon dioxide that assist in providing positive buoyancy (Wallentinus, 1999). If these structures puncture or deflate the organism is destined to lose buoyancy and sink out of the photic zone and perish.

Sargassum has no means to maneuver. However being pelagic and residing at the surface, it migrates under the power of the prevailing wind and oceanic surface currents. It has the ability to rapidly spread and invade new areas because of a few key traits that allows it to travel and thrive simultaneously. It is kept afloat by CO_2 filled peumatocysts that are buoyant and hold the seaweed at the surface thus receiving optimal exposure to sunlight. It has a rapid growth rate of two- to four cm per day and a long lifespan (Enos, 1997). *Sargassum* is a macro-algae, and by definition is self-fertile which means that it can both release Spermatozoids and produce eggs. Therefore small amounts of

Sargassum can propagate into massive amounts. Collectively these traits equip macro-algae with an exceptional ability to thrive as a pelagic species.

Sargassum episodes occur in the spring to late summer depending on temperatures and currents. It tends to propagate in temperate water and can tolerate lower salinity levels than most other marine plant life (Wallentinus, 1999). It has a high fecundity (large production of propagules) and an accelerated growth rate, allowing it to bloom and colonize rapidly.

Sargassum is a relatively adaptable type of algae because it can survive in a wide range of temperatures, nutrient levels, and light intensities. The Class Phaeopyceae is commonly abundant in temperate to polar regions, however *Sargassum* has been tracked well into the lower latitudes of the tropics (Enos, 1997). Brown algae start to show signs of reduced capacity when exposed to temperatures as high as twenty degrees Celsius. A recent study reported that optimal *Sargassum* growth occurs in temperature ranging from fifteen to twenty five degrees Celsius (Jiang, 2009). On the contrary, *Sargassum* has been located and studied in surface waters as high as twenty-eight degrees Celsius. This relatively high tolerance for tropical temperatures allows the seaweed to migrate to a wider range of environments (Jiang, 2009).

Sargassum's nutrient uptake also varies widely. This is best demonstrated by its ability to thrive in both nutrient rich and nutrient poor environments. *Sargassum* collects and amasses in the Sargasso Sea between latitudes 66 and 25 degrees North (Kalsson, 1988), the limiting factors being light and temperature. The Sargasso Sea is characterized as having virtually no upwelling and thus very low available levels of essential nutrients, i.e. carbon and nitrogen. To compensate for these environmental deficiencies Sargassum survives by reducing growth rates while maximizing surface volume through the addition of fronds, in order to optimize nutrient uptake (Jiang, 2009). *Sargassum* also commonly thrives in nutrient rich neritic waters and coastal "greenwater" of the Caribbean and Gulf of Mexico, where it encounters high concentrations of nutrients from coastal upwelling, equatorial upwelling, and freshwater runoff. Once in this environment its rate of growth increases dramatically and it significantly increases in volume.

Class Phaeophyceae is characteristically able to survive changes in salinity. The vast majority of brown algae have shown the ability to survive in tide pools and estuaries, where salinity fluctuates widely. Studies have shown that *Sargassum* can survive in salinities ranging from five practical salinity units (PSU) up to thirty-five PSU before growth rates begin to be effected (Jiang, 2009). This characteristic of *Sargassum*, when coupled with its abilities to survive in higher temperature and a wide range of nutrient levels, allows it to migrate into a variety of environments that other species of vegetation cannot.

Since *Sargassum* rests atop of the water column, the two main forces that affect it are ocean currents and wind currents. The effects of the ocean currents appear more apparent because they are well mapped and tend to be static in location, direction, and intensity. The Sargasso Sea is formed by the circulation of the North Atlantic Gyre, which is driven by the Coriolis Effect. This phenomenon is a function of earth's rotation around its north to south axis. Since earth is a spheroid, the relative speed of earth's surface is faster at the equator, than at the poles, thus intensifying the Coriolis Effect on lower latitudes (University of Illinois, 2010). Earth's landmasses rotate east to west, however ocean bodies are unfixed to earth's rotation and therefore are effectively held in place by inertia. As the ocean basins spin eastward, the water bodies are 'pushed' westward. The Atlantic Gyre is held in the Mid Atlantic Bight of the Eastern coast of the Southern United States due to westward intensification of ocean currents, caused by the earth's rotation and convection of the oceans. Massive bodies of water are rotated at relatively increasing speeds as they approach lower latitudes, causing water circulation to veer to the right in the northern hemisphere. The gyre currents are also assisted by the convection of wind cells (Figure 2). Warm, tropical air rises at the equator and travels north, where it then cools and descends at around thirty degrees latitude, generating winds from the northeast. The same concept occurs in a reciprocal manner from thirty degrees latitude to sixty degrees latitude. Convection creates winds from the southwest. The Sargasso Sea gyre's circulation is, in part, assisted by these wind formations pushing surface currents in a rotating pattern.

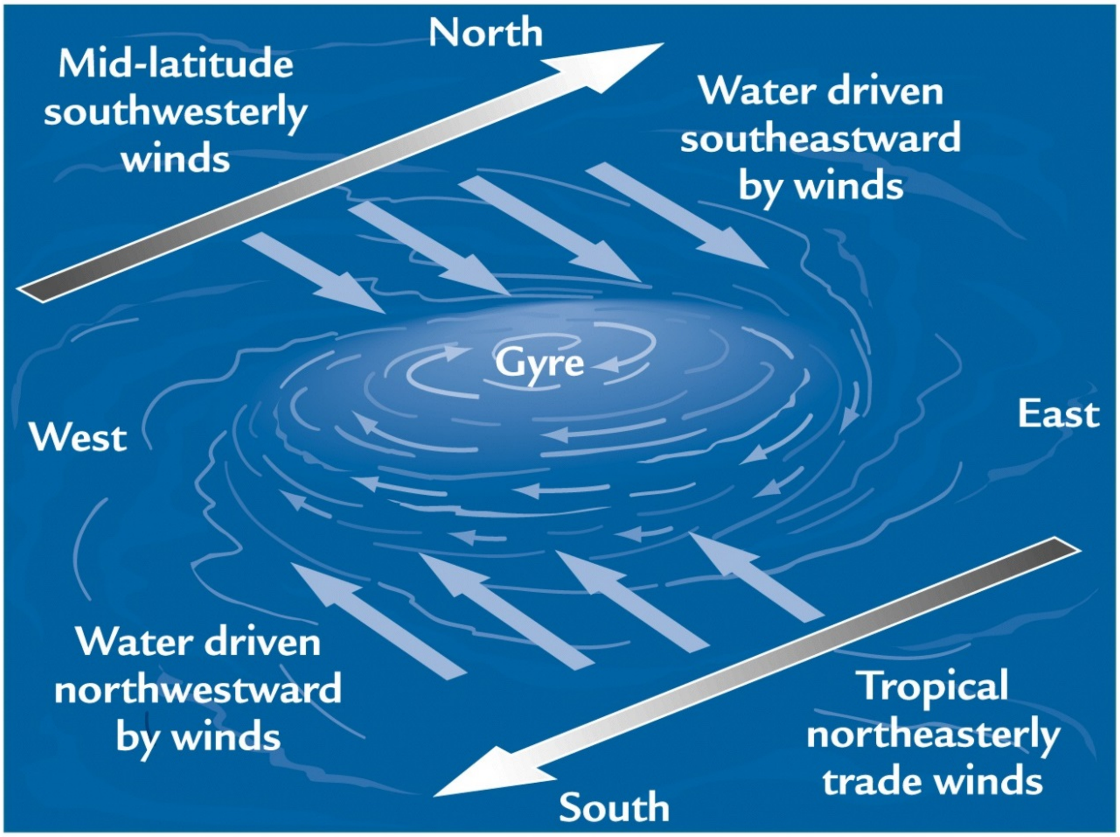

Figure 2. Gyre Formation. This graphic depicts the influence that wind patterns have on gyre formations. Southwesterly and northeasterly winds acts together to push water into a bulge, forming the Mid-Atlantic gyre. Arrows indicate how wind currents assist in the locomotion of the gyre (Ruddiman, 2001).

Sargassum accumulates in the center of the Gyre as a result of this phenomenon, until other, more prevailing forces affect its location. Wind currents have a surprisingly significant impact on *Sargassum*. With no freeboard, one would expect *Sargassum* to have little response to atmospheric conditions, however, this study suggests that the initiation of *Sargassum* migration is most closely correlated with the Azores High Pressure System. This high pressure weather phenomenon generates southbound winds over the Sargasso Sea, causing the *Sargassum* to migrate into lower latitudes. The mechanism leading to this magnitude of effect by wind intensity and direction on *Sargassum,* is still being studied, however the distinct correlation of wind patterns and seaweed migration can be inferred.

During the summer season, a *Sargassum* accumulation off the western coast of the Gulf of Mexico, creates a second *Sargassum* reservoir, from which the seaweed washes ashore in massive quantities. Such occurrences have been documented, in newspapers, on the coast of Texas dating back to the late eighteen hundreds. While the intensity of the summer *Sargassum* episodes have varied greatly from year to year, it has continued to occur, without explanation. Until now, little was known about the driving mechanism and origin of this seasonal *Sargassum* cycle. The research findings set forth in this paper describe the studies undertaken to explain the underlying mechanism by which the annual season of *Sargassum* occurs, as well as the area of origin of the wracks seen on the Texas Gulf Coast.

SARGASSUM EARLY ADVISORY SYSTEM

In 2009, Dr. Thomas Linton and Doctoral candidate Robert Webster formed the *Sargassum* Early Advisory System (or SEAS). The SEAS program set out to predict upcoming *Sargassum* events on the Texas Coast, utilizing remote sensing technology. Using satellite imagery, the coastal waters of Texas were monitored and analyzed for presence of *Sargassum* (Webster, 2011).

The Landsat program initiated by National Aeronautics and Space Administration (NASA) in the 1960's was designed to assist in monitoring the terrestrial aspects of the earth from space (Irons, 2014). As the technology and program evolved, the imagery resolution and frequency increased. NASA, in conjunction with United States Geological Survey (USGS), began releasing this imagery to the public to assist in large scale monitoring and analysis of earth's terrain. These images are taken from the satellite as it orbits the earth every sixteen days and are published online for public access (USGS, 2014). The imagery predominantly serves as a method to monitor crop health and terrain. A vegetative filter is applied to the 'natural color' imagery to emphasize the chlorophyll b concentration, and create a green glowing haze effect over healthier crops, (Irons, 2014). Because this tool was intended for terrestrial use, only the imagery involving land cover was continuously updated on the publicly accessible USGS satellite imagery server. But in addition to satellite images of land-based crops, there were images from over the waters of the Gulf of Mexico. The SEAS program requested and received access to this oceanic imagery to further assist in the monitoring for *Sargassum* (Webster, 2014).

From its initiation, the SEAS program utilized the satellite imagery near the Texas Coast, taken by NASA's Landsat 7 satellite, to monitor for *Sargassum*. By analyzing the coastal satellite imagery as it is published in sixteen day cycles, the SEAS program could effectively monitor for *Sargassum*. Wind and ocean current data gathered from Texas Automated Buoy System (or TABS) and National Oceanic and Atmospheric Administration (NOAA) were then applied to estimate the set and drift of the *Sargassum* (Texas Automated Buoy System, 2014). This method allows the SEAS program to forecast the *Sargassum* arrival and deliver advisories to the Texas Coast. In 2013, NASA launched the Landsat 8 satellite, which updates imagery on an eight day cycle, allowing for a more comprehensive examination of the coastal waters of Texas.

By 2012, the SEAS program had refined its process of forecasting seaweed episodes to provide up to 97% accuracy. However, the most advanced warning of an impending episode an advisory could give at the time was sixteen days (Webster, 2014). The mechanism that initiates the *Sargassum* season on the Texas Coast had yet to be discovered. Once this was determined, it was theorized that entire *Sargassum* seasons could be forecasted, giving unprecedented forewarning to the coastal communities in Texas.

THE CARIBBEAN’S ROLE IN THE *SARGASSUM* LOOP SYSTEM

So where does *Sargassum* originate from and where does it congregate during winter months? One source suggests that a reservoir of *Sargassum* forms in the Bay of Campeche annually during the winter months, then drifts north and amasses in spring and summer months, depositing on the shores of the Gulf of Mexico (Gower and King, 2012). A review of historic satellite imagery showed no observable amounts of *Sargassum* in that area during the winter months. The concept of *Sargassum* originating in the Sargasso Sea, along the Mid Atlantic Bight, seemed evident; however the path from the East coast of the United States to the Western Gulf of Mexico appeared much less certain. The path from the Atlantic through the Florida Straits to the Gulf was the most direct. However a close examination of the currents between Florida and Cuba shows that the swift Gulf Stream is heading easterly and directly opposing the route which *Sargassum* must take to get to the Western Gulf of Mexico.

In 2011, an atypical event occurred in the Southern Caribbean islands that initiated the idea that *Sargassum* may drift as far south as the Caribbean from the Sargasso Sea. It was theorized that if *Sargassum* could seasonally drift to tropical latitudes, then it could utilize westerly Caribbean currents to enter the Gulf through the Yucatan Passage. But if this event in 2011 was so uncommon, how could a seasonal occurrence of *Sargassum* in the Caribbean go unnoticed for so long? An in-depth examination of the 2011 *Sargassum* episodes in the Southern Caribbean revealed the connection between the Sargasso Sea and the seasonal *Sargassum* in the Gulf of Mexico.

In the late summer of 2011 there was an atypical accumulation of *Sargassum* on the Southeastern islands in the Caribbean. By nature, *Sargassum* is a resilient algae, however, it typically does not reach latitudes lower than 20 degrees N in large quantities, and thus not the Southern islands of the Caribbean. There are several theories proposed to explain the driving mechanism of this unusual bloom, e.g. the Deepwater Horizon Oil spill, global climate change, and the degradation of surface currents. These ideas are suggestive but do not show a direct correlation with this uncommon *Sargassum* event.

A close examination of the water runoff from South America a plausible cause for this event was found. *Sargassum* typically does not grow as far South as Brazil, however a large-scale flooding event could change the conditions off the coast of Northern Brazil to allow it to thrive in these lower latitudes. In 2011, there were unusually large amounts of rainfall in Northern South America causing massive upstream flooding that eventually discharged out the Orinoco and Amazon Rivers. This massive influx of warm, freshwater occurred prior to the time leading up to the massive Caribbean *Sargassum* landing. This could have prompted the *Sargassum* bloom at these lower latitudes and thus have been the source of the atypical accumulations that struck the Southern Caribbean island shores. *Sargassum.* typically does not grow as far South as Brazil, however a large-scale flooding events in those major rivers could change the conditions off the coast of Northern Brazil enough to where the seaweed could allow it to thrive in these lower latitudes.

In 2011, there were unusually large amounts of rainfall in Northern South America causing massive floods that eventually discharged out the Orinoco and Amazon

Rivers. Typically this region is not subjected to annual flooding however it is prone to feel the effects of La Niña, which is the reciprocating event of El Niño Southern Oscillation (ENSO). During a typical ENSO event, Northeastern Brazil would receive minimal rainfall while during a La Niña event there are torrential increases in precipitation. The direct correlation can be seen when comparing the climatic events with government-initiated states of emergency. Although direct precipitation rates for South America have been historically unavailable, newspaper articles In October 2009, inform us that Hugo Chavez, president of Venezuela ordered water rationing to be put into effect due to low precipitation rates, decrease in the Orinoco river, and increase in water demand. During this time, one of the most prominent ENSO events was building up in the Pacific (See Figure 3). Likewise, in May 2011, ENSO had slipped into one of the most prominent La Niña events ever recorded (Samenow, 2012). This event brought heavy rains, initiating a State of Emergency for eight States in the country of Venezuela (Boothroyd, 2011).

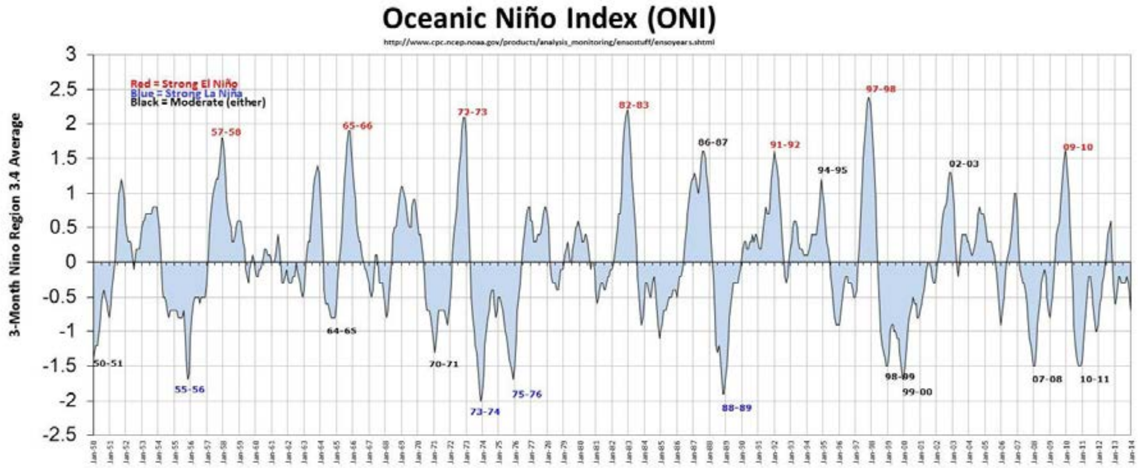

Figure 3a. El Niño Southern Oscillation. This graphic depicts the oscillation between El Niño southern oscillation events and La Niña events. An examination shows a major ENSO event occurring just before the 2011 Southern Caribbean *Sargassum* event (LePage, 2013)

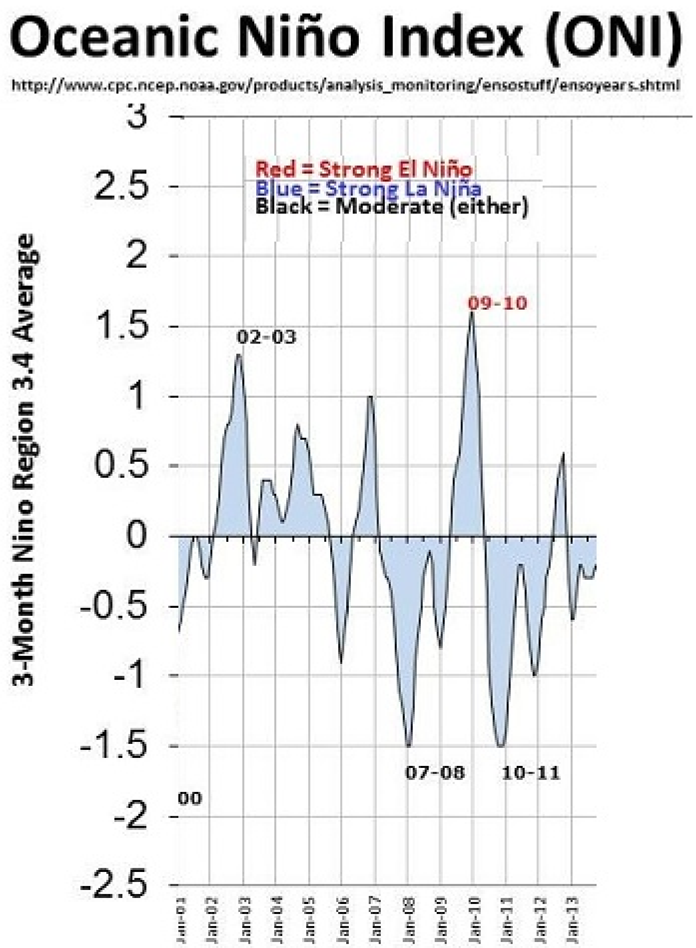

Figure 3b. El Niño Southern Oscillation magnified. This graphic depicts the oscillation between El Niño southern oscillation events and La Niña events. An examination shows a major ENSO event occurring just before the 2011 Southern Caribbean *Sargassum* event (LePage, 2013).

In 2011, Venezuela received four to five inches of rainfall from mid-May to mid-June. Although the country receives similar rainfall proportions in November, Venezuela was not prepared for this constant, heavy precipitation because of high river levels from last year's rainfall, and unpredictability of the climate. The Orinoco River rose an additional fourteen feet in some areas. This precipitation eventually ran down the Orinoco and Amazon River and was released into the equatorial Atlantic.

River runoff water has a different chemistry than that of seawater, some differences being obvious, such as salinity, but others being less apparent. The three main differences that will affect marine life are salinity, temperature, and nutrient concentrations. The relatively low salinity is not well tolerated by all ocean-dwelling organisms. Since some organisms, such as *Sargassum* can survive in low salinity, the salinity gradient can act as a barrier to predation or competition for nutrients from other plant species. Since river water runoff originates from land, it tends to have a higher temperature footprint in the ocean. This is because of the relatively low heat capacity of rocks and sediment when compared to the high heat capacity of water, allow for the river water to absorb heat from the surrounding land and be discharged into the ocean at a higher temperature than surrounding ocean waters. The final difference is the concentration of nutrients in river water versus seawater. Although the coast of Brazil and Venezuela benefit from coastal upwelling and equatorial upwelling (both of which bring nutrients to surface waters) the seawater still has a low concentration of nitrogen and carbon, nutrients that are essential to plant life. River water has a much higher concentration due to input from ecosystems along the river, such as organic carbon and detritus.

This paper theorizes that the conditions formed by this massive amount of runoff create an optimal habitat for *Sargassum* seaweed. The relatively warmer temperatures of the river water runoff create eddies at the surface of the sea, staying stratified from saltwater due to the thermocline and halocline. These pycnoclines also act as a barrier to other competing plants and algae. Once *Sargassum* has entered these eddies its growth rate rapidly accelerates due to the abundance of nutrients. Since it has pneumatocysts, it can maintain buoyancy without needing a hard substrate to attach to. Its relatively high reproduction rate allows them to expand in population count, producing massive amounts of *Sargassum* off the coast of the Southeastern Caribbean islands.

This paper theorizes that there is a direct correlation from the 2011 summer floods in Northern South America and the *Sargassum* seaweed mass that landed on the Eastern coasts of the Southeastern Caribbean islands. Regional news outlets and photographs show the *Sargassum* mats once they had already reached the shores of the islands but to determine the origin, one must look to the stars. Satellite imagery, from the Landsat data system, shows atypical *Sargassum* propagations forming off the Northeastern coast of South America. These images show masses of seaweed during the summer of 2011, that until then were not commonly seen below 20 degrees north, occurring as far South as 10 degrees north. Using the recurring satellite photographs of the region, one can track these masses as they are swept westward by the North Atlantic Gyre and Equatorial currents.

This plume of river water runoff, characterized by its high temperature, low saline, and high nutrients, allowed the *Sargassum* to spawn and expand as it was carried westward to the beaches of the Virgin Islands, Barbados and other Caribbean Islands. These unusual conditions created optimal conditions for the seaweed to flourish. The *Sargassum* reached the beaches in two waves, the first reaching land in mid-August, and the second in late September.

A low saline plume can be seen via satellite, forming off the coast of South America around 7 degrees North and 50 degrees West around the end of May, 2011 (Figure 4). This water mass has a higher temperature, which can also be tracked by satellite. The Low saline mass is then carried westward by the equatorial current and the Coriolis Effect. As the summer progresses the plume slowly travels west (See Figures 5a & 5b), where it contacts *Sargassum*. The pocket of low-saline, high-nutrient, and warm water eventually hits the Southeastern Caribbean islands in mid-August (see Figures 6a & 6b). This is the same time that the massive amounts of *Sargassum* began washing up on the same beaches (Butler, 2012). Towards the end of September, the center of the plume of runoff water has reached the islands (See Figures 7a & 7b). This is when the second surge of seaweed reached the beaches.

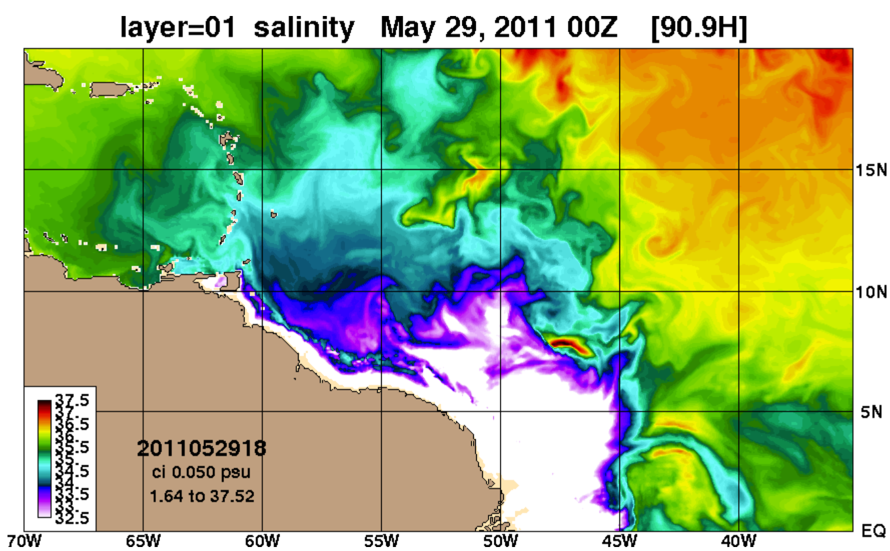

Figure 4. Salinity gradient 1. This graphics depicts a large, low saline plume coming from the Orinoco and Amazon Rivers. This plume is carried west but does disperse due to pycnoclines. Blue, purple, and white indicate a low salinity pocket of fresh surface water (HYCOM, 2014).

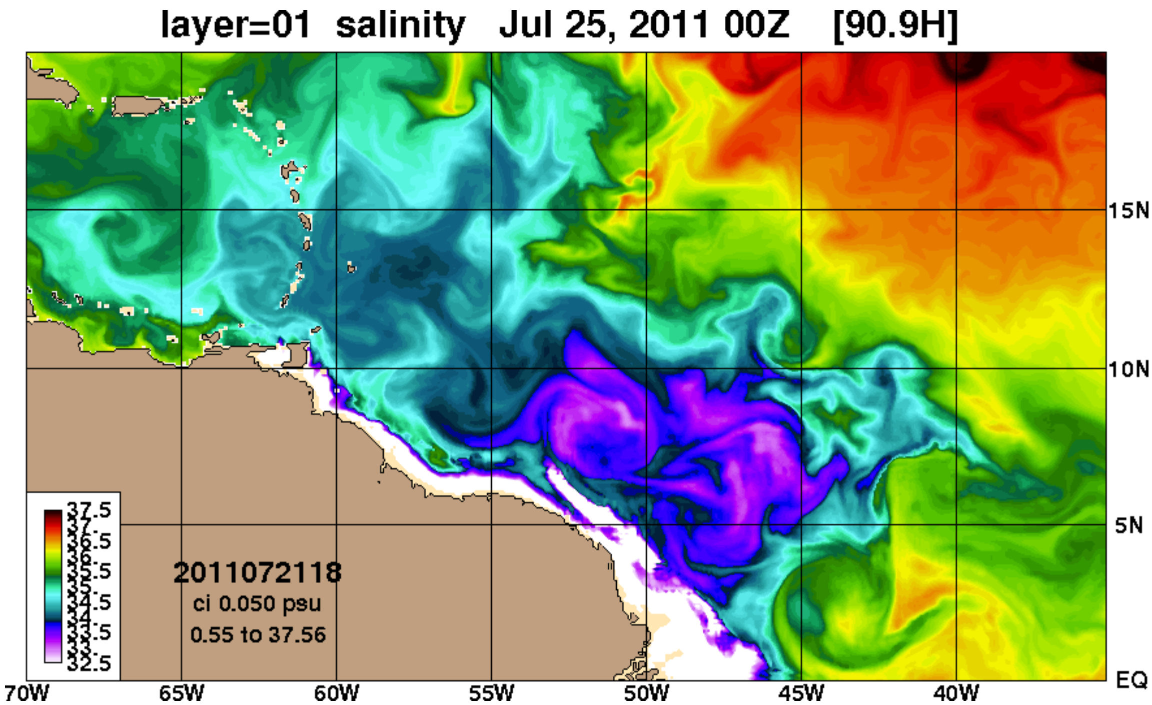

Figure 5a. Salinity gradient 2. This graphic depicts the pocket of low saline river discharge as it spreads out heading toward the west pushed by equatorial currents. Blue, purple, and white indicate a low salinity pocket (HYCOM, 2014).

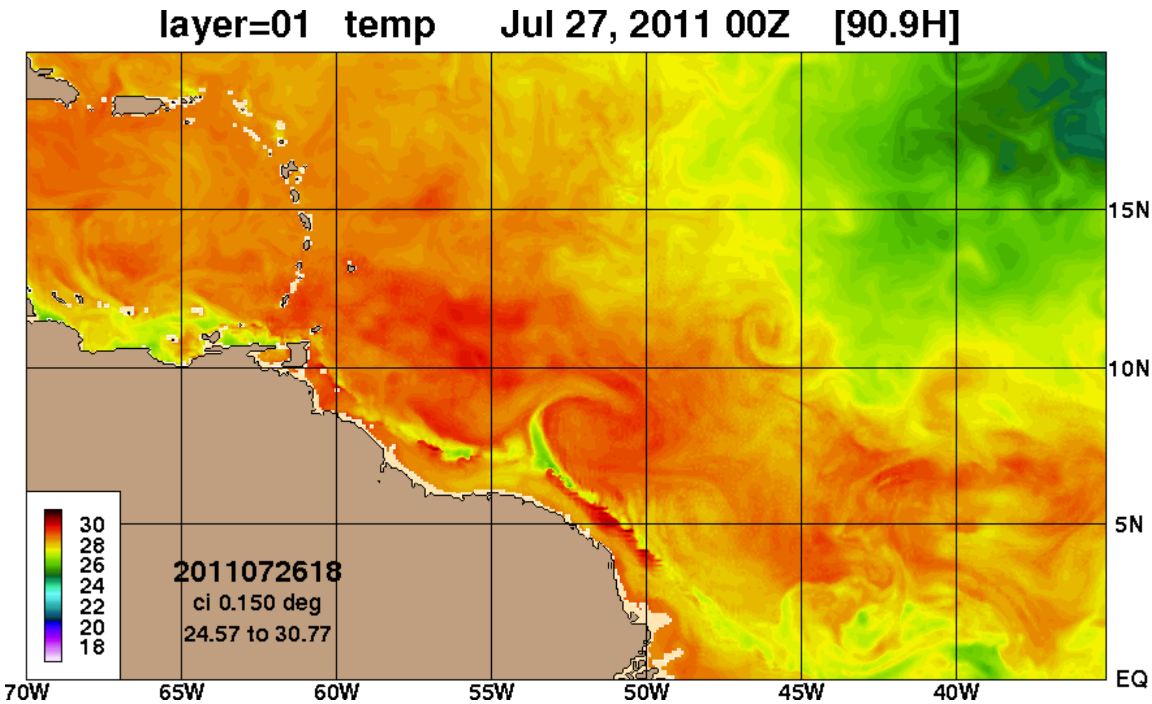

Figure 5b. Temperature gradient 1. This graphic shows a satellite image of the temperature of the water runoff plume is relatively high compared to the surrounding waters. Red and yellow indicate a warm water pocket (HYCOM, 2014).

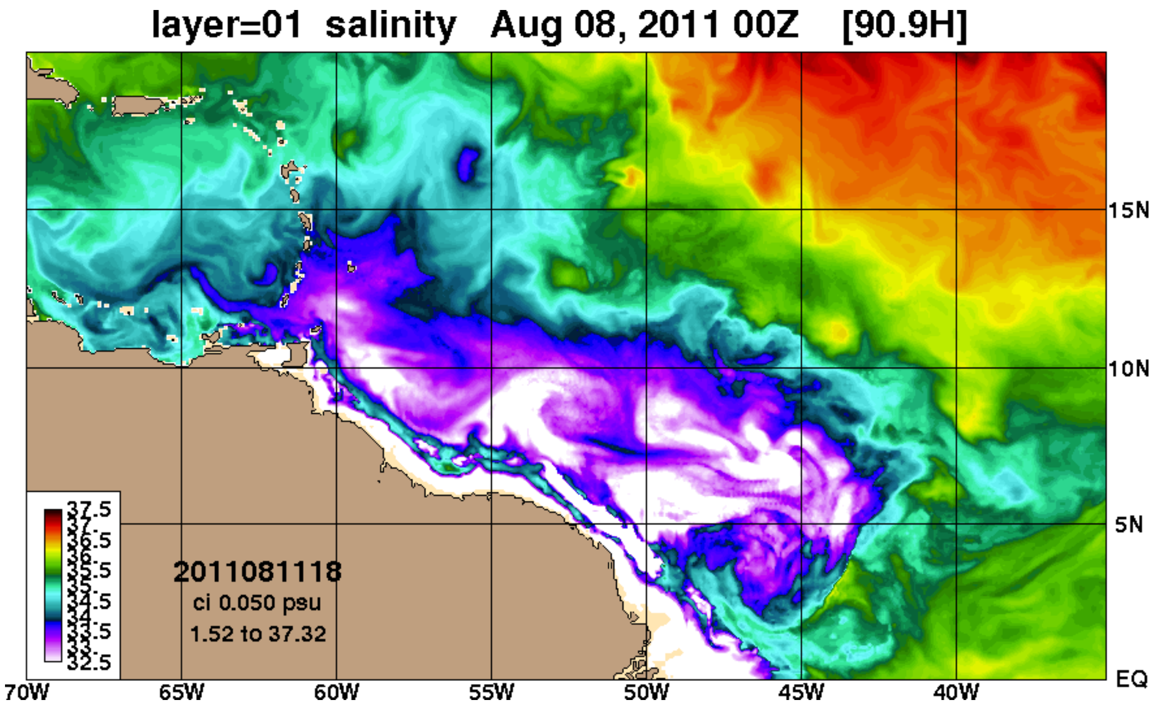

Figure 6a. Salinity gradient 3. This graphic shows a satellite image of the low-saline plume as it reaches the East coast of the Caribbean Islands. This is the same time that the initial wave of *Sargassum* hit the beaches of those islands. Blue, purple, and white indicate a low salinity pocket (HYCOM, 2014).

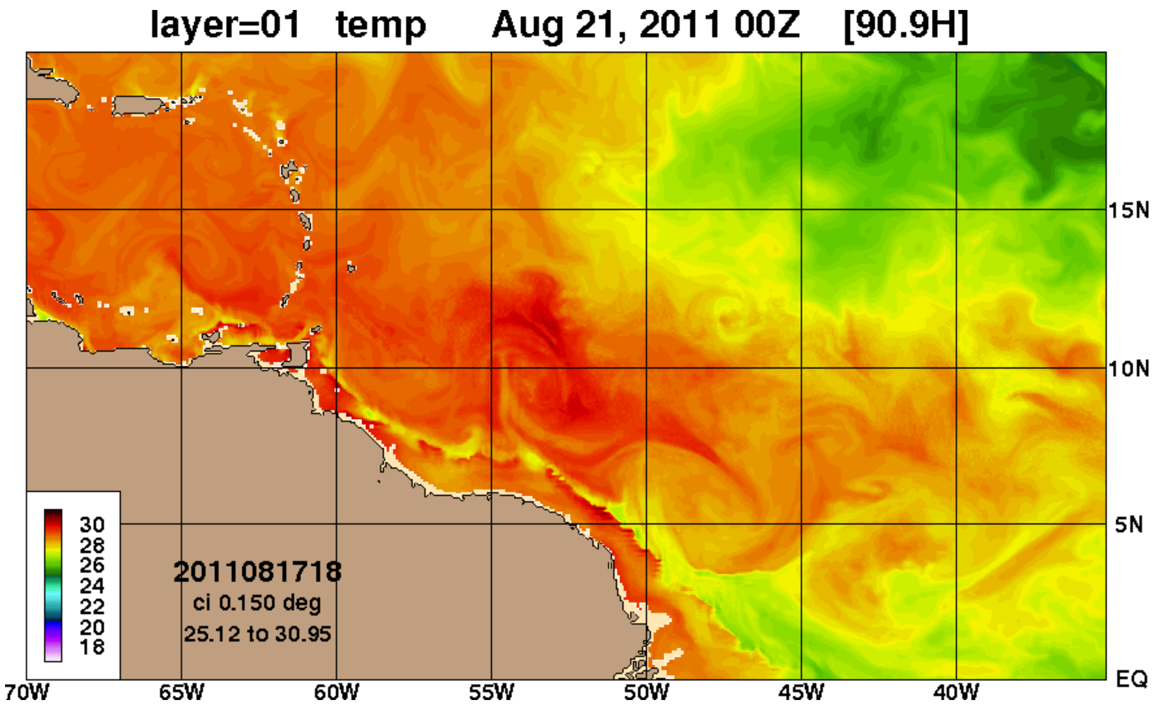

Figure 6b. Temperature gradient 2. This graphic shows a satellite image of the temperature of the warm water pocket reaching the Caribbean islands. The eddy formations indicate circulating water which is optimal for *Sargassum* Growth. The orange and red areas indicate a pocket of warmer surface water (HYCOM, 2014).

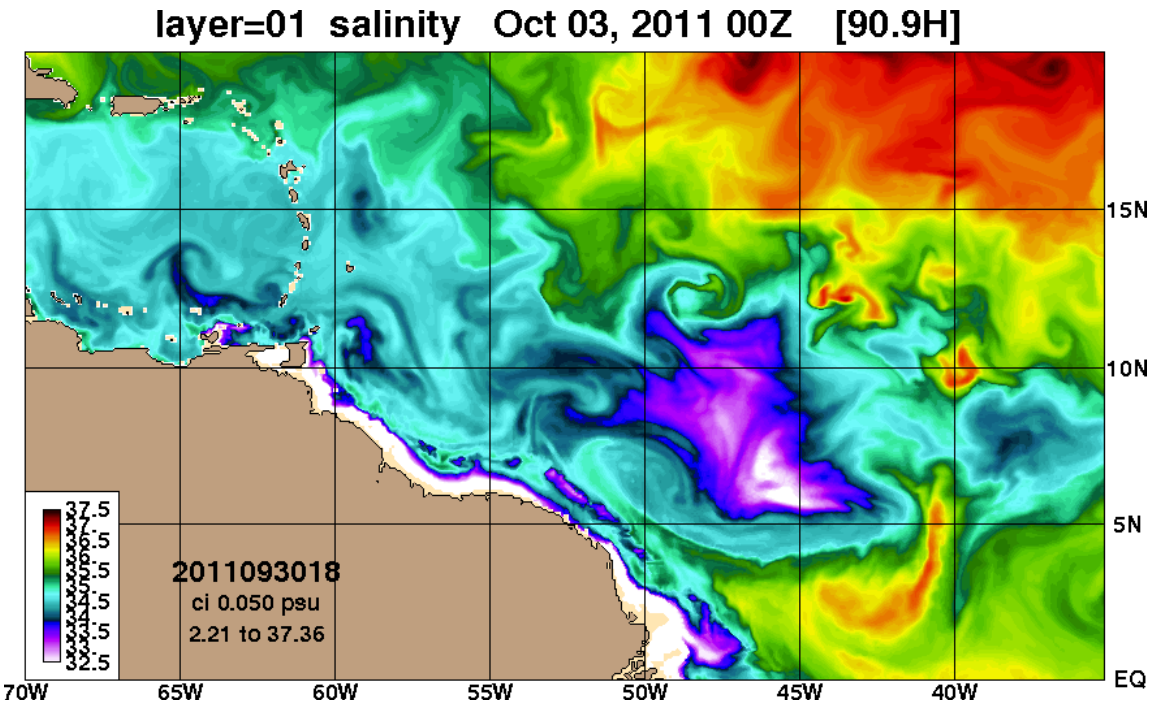

Figure 7a. Salinity gradient 4. This graphic shows a satellite image of the low-saline plume extending past the Eastern Caribbean. Blue, purple, and white indicate a low salinity pocket (HYCOM, 2014).

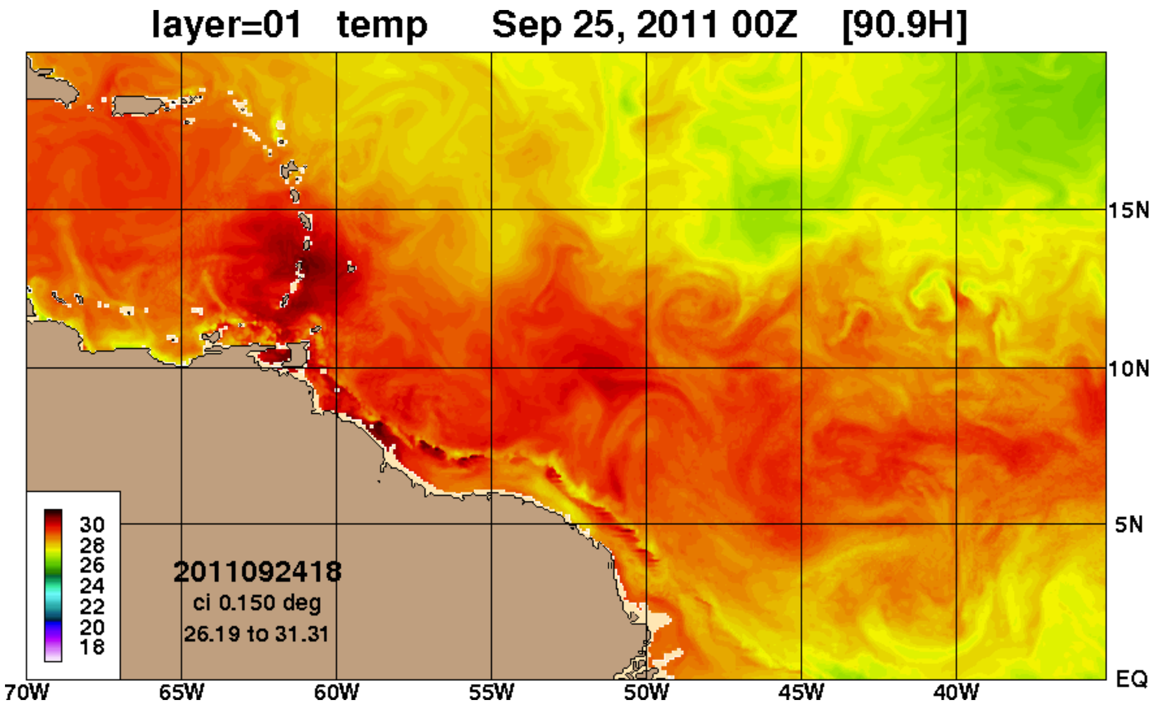

Figure 7b. Temperature gradient 3. This graphic shows the center of the relatively high temperature of the runoff water has reached the Eastern islands of the Caribbean. This corresponds with the second wave of *Sargassum* seaweed that covered the islands' beaches. The orange and red areas indicate a pocket of warmer surface water (HYCOM, 2014).

The river water runoff from the 2011 South American floods offers a plausible explanation to the driving mechanism of the 2011 massive *Sargassum* seaweed landing in the Caribbean. Other popular theories include the recent oil spill and global warming. There is no proven direct correlation between the release of crude oil and the increase of *Sargassum* in the southeastern Caribbean. Global climate change is commonly faulted for a variety of environmental changes but does not offer a reason as to why it was a single occurrence rather than perpetually increasing like the trend of global warming. The water runoff theory offers a direct source of nutrients, optimal growth conditions, and a transport method. Evidence concludes that the massive seaweed propagations reaching the islands at the same time are not coincidental.

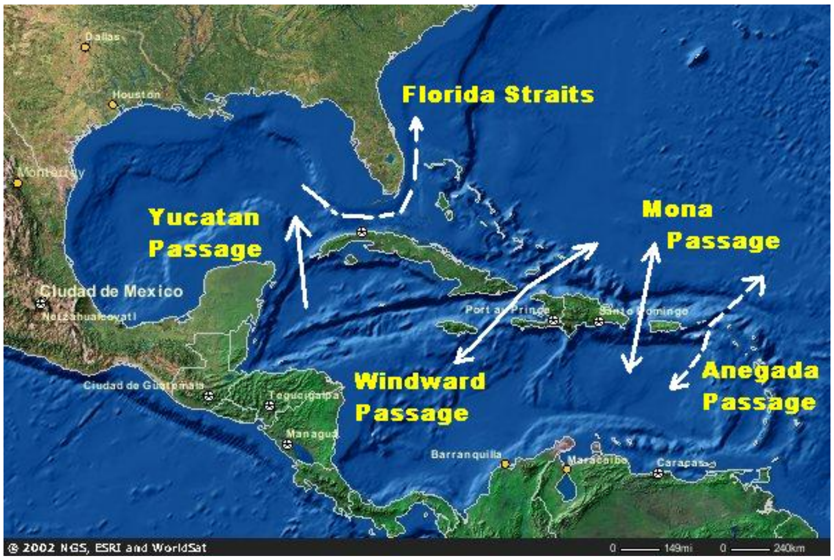

Figure 8. Caribbean Passages. This figure shows a map of the Caribbean. The Northern Caribbean Passages, referred to as the Windward, Mona, and Anegada Passages, are where *Sargassum* is most frequently observed (Webster, 2014).

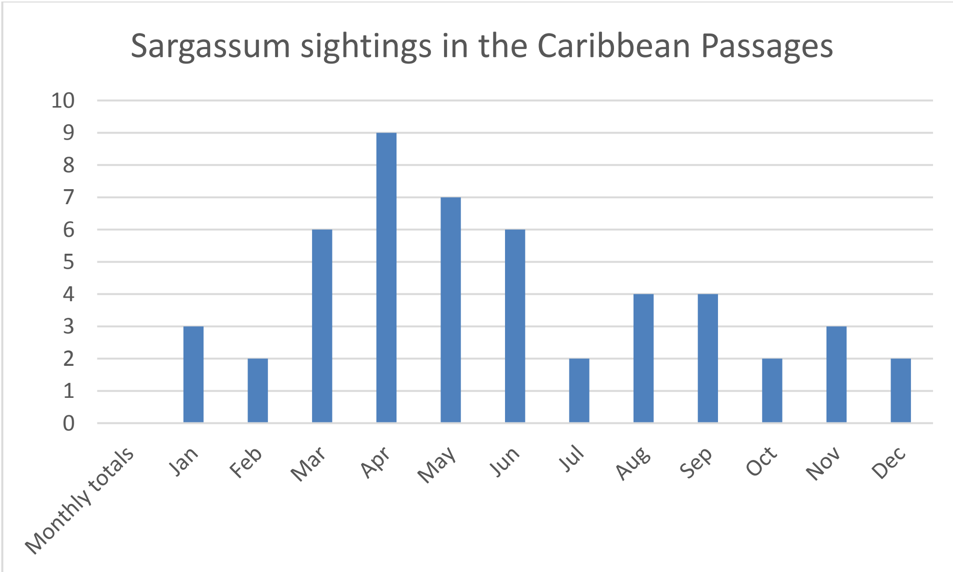

Table 1. *Sargassum* sightings in the Caribbean Passages. This graphic illustrates the number of times *Sargassum* has been spotted in the passages in a single month. Historic satellite imagery was obtained and analyzed to review when *Sargassum* begins its journey through the *Sargassum* loop system.

One can monitor the Caribbean passes, specifically, the Anagada, Mona, Windward, and Yucatan passes, and the Eastern Caribbean Islands for the seaweed to drift into the higher nutrient waters of lower latitudes. Every time *Sargassum* is spotted in the areas under study, it is documented and posted to the SEAS website as an early advisory for when the *Sargassum* will hit landfall.

REFINING OF THE *SARGASSUM* SYSTEM

The 2011 Southern Caribbean *Sargassum* event generated the theory that *Sargassum* has the ability and resiliency to migrate from the Sargasso Sea into tropical waters. However, since *Sargassum* sightings have been sparsely recorded in the historical archives of the Southern Caribbean, one can deduce that an irregular occurrence sparked this 2011 phenomenon. This paper proposes that *Sargassum* was capable of reaching such low latitudes because the algae received the necessary nutrients from runoff waters caused by floodwaters from the Orinoco and Amazon Rivers. Since the typical climate is not conducive to spring flooding in the Orinoco and Amazon River Basins, the conditions for lower latitude *Sargassum* growth usually are not present. This means that *Sargassum* could potentially migrate south annually, however, under normal conditions, it could not extend as far south as it did during the 2011 Caribbean *Sargassum* event. So what happens to the *Sargassum* once it enters the Caribbean Sea?

Hypothesis 1) *Annually, atmospheric wind currents drive Sargassum south out of the Sargasso Sea into the Northern Caribbean, where the Gulf Stream carries it into the neritic Gulf of Mexico. Once in the Gulf, it amasses and is either carried west by prevailing wind currents or carried out the Florida Strait back to the Sargasso Sea via the Gulf Stream, in what is known as the Sargassum loop system.*

Atmospheric conditions in the Atlantic create anti-cyclonic high pressure systems that produce concentrated northern winds across the Sargasso Sea, which pushes a portion of the sea of macro-algae out of the North Atlantic Gyre and into the Caribbean. Once in the Caribbean, the anti-cyclonic wind currents assist the Gulf Stream in carrying the *Sargassum* through the Yucatan Strait and into the Gulf of Mexico. *Sargassum* is then carried through the loop current, where wind or fluctuations in the loop current can cause the algae to break off and drift westward, where it will land on the Texas Coast. The remaining *Sargassum* that does not deviate from the loop current is carried back out into the Mid Atlantic bight, where it returns from its Intra-Americas journey.

The *Sargassum* loop system is believed to be a critical journey that *Sargassum* must take annually in order to sustain life in the nutrient-deprived Atlantic Ocean. The nutrient rich coastal waters of the Caribbean and the nutrient heavy Gulf of Mexico, fed by the Mississippi River, act as a nursery to the *Sargassum* and allow it to propagate rapidly.

In order to investigate the theory of the *Sargassum* loop system, The SEAS program expanded their area of observation to the northern Caribbean and southern Sargasso Sea regions. Using historic satellite imagery, the *Sargassum* loop system can be observed as it occurs annually throughout the Intra-Americas. An examination of this archived imagery reveals several patterns that occur seasonally and could be an earlier indication of the *Sargassum* migration, allowing for a more advanced prediction of the impending *Sargassum* season.

Hypothesis 2) *The Impending Sargassum season for the Intra-Americas can be predicted in advance by comparing migration patterns of Sargassum in current satellite imagery to the migration patterns of Sargassum in historic satellite imagery.*

Satellite imagery with sufficient resolution to see *Sargassum* is archived as far back as 2000. During the period of January of 2000 to May of 2013, the Landsat satellites took images every sixteen days, or twenty-two images a year. NASA doubled their image rate by introducing Landsat 8 in May of 2013. From May of 2013 to the present, the Landsat program produced imagery every eight days. This created an archive of 347 images for each passage, not accounting for any imagery that is unusable, such as complete cloud cover, or data missing from the satellite imagery database. In order to obtain an appropriate sample of images of the passages, seventy images (or twenty percent of the archived database) of each passage were analyzed for the presence of *Sargassum* (See figure 9 for example). Sargassum manifests in two forms. If the pelagic mat is large enough, it will produce a green glow in the satellite image, this is due to the vegetative growth filter added to the landsat images. The second manifestation of *Sargassum* is what is referred to as a ‘slick’ meaning that *Sargassum* itself cannot be seen in the image, however its presence at the ocean surface disrupts the surface tension and wave attenuation, thus creating a darker slick around the otherwise invisible mat. An examination of archived satellite imagery of the newly expanded area of observation revealed that not only has *Sargassum* been historically present, but also that it was seen in patterns that appeared to repeat annually.

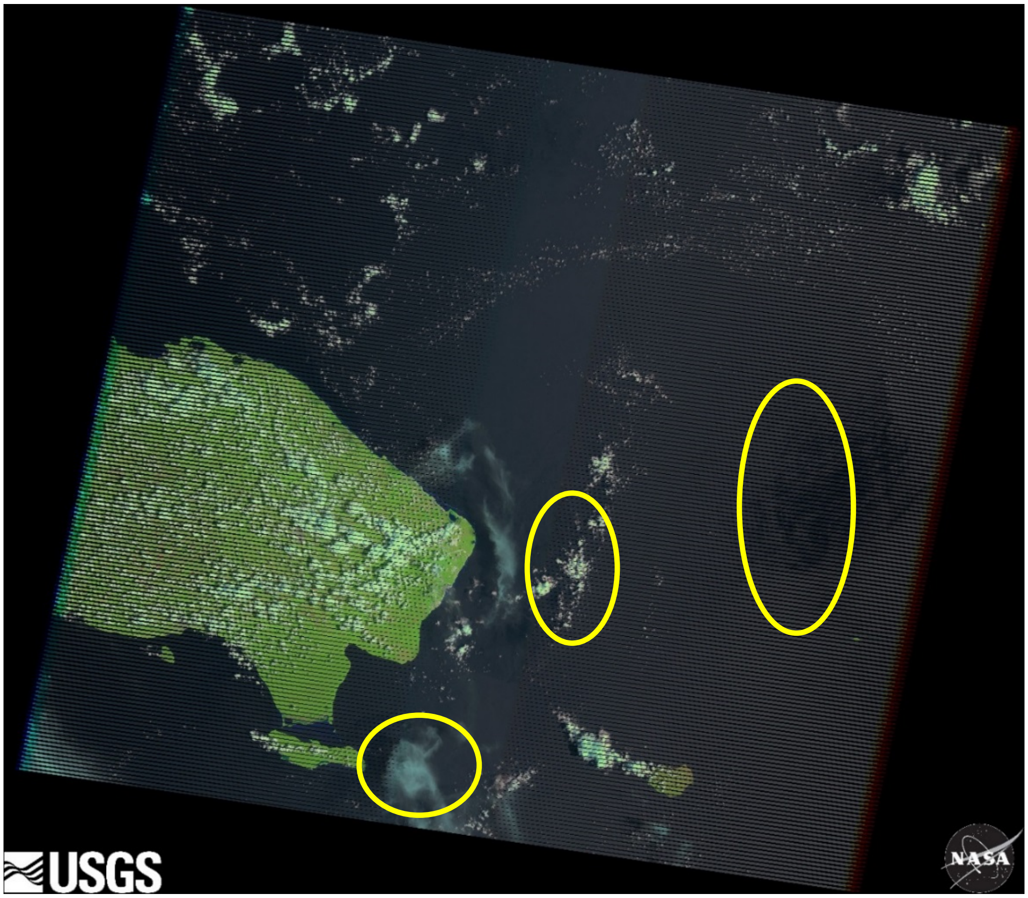

Figure 9a. Mona Passage satellite image. This graphic illustrates a satellite image of *Sargassum* migrating through the Mona Passage into the Caribbean Sea. *Sargassum* and its slicks are denoted by the yellow oval (United States Geological Survey, 2014).

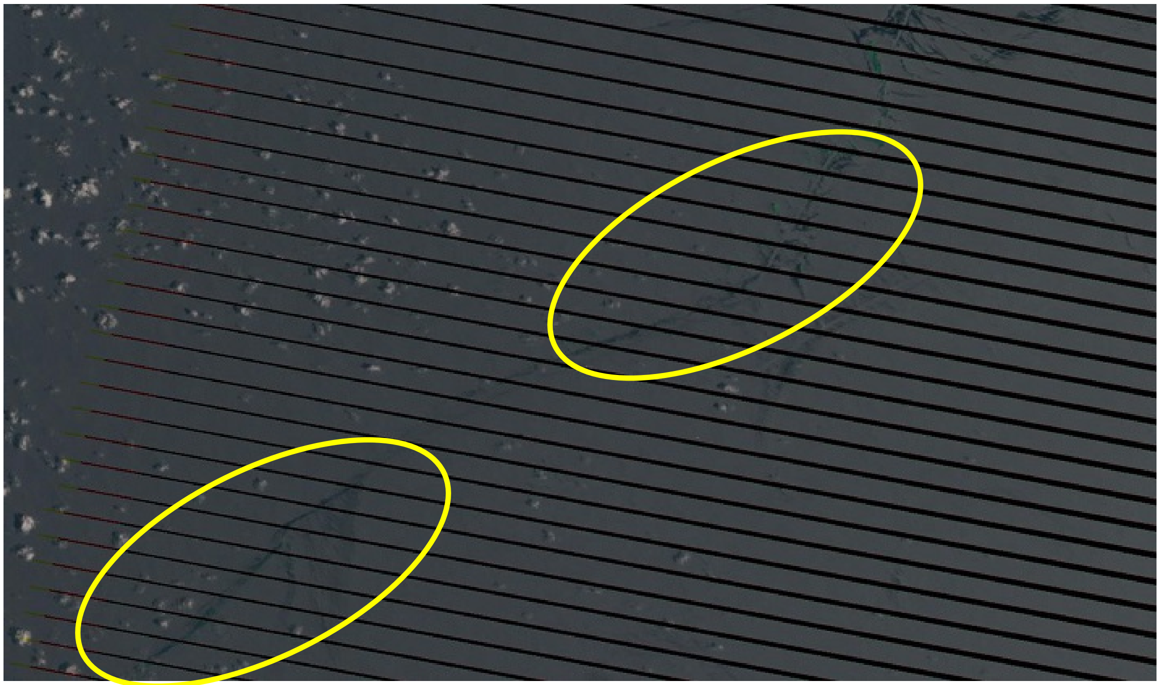

Figure 9b. Mona Passage satellite image magnified. A magnified view of these images reveal a linear green glow or if the mat is too small to be seen in the image, a darker outline in linear patterns. This is because the size of the mat is too small to be seen in the image, only the disturbance of the wave attenuation around it can be seen (United States Geological Survey, 2014).

Several patterns involving the southern migration of *Sargassum* emerged from the historical analysis of Caribbean Satellite imagery. The first pattern involves the initiation of Southern migration of *Sargassum* which starts as early as December, but typically occurs between February and April (See Table 1). *Sargassum* can be seen breaking away from the typical boundaries of the Sargasso Sea set by the motion of the North Atlantic Gyre. It is theorized that seasonal northerly winds produce adequate locomotion for the *Sargassum* to break away from its origin, pushing it south, toward the Caribbean. Although gyrating currents formed from the Coriolis Effect are strong enough to concentrate the *Sargassum* into the center of the gyre, these forces are relatively weak compared to locomotive forces produced by the wind and the Gulf Stream. Even though *Sargassum* has little to no freeboard, wind currents still affect *Sargassum* drift significantly. The estimated time it takes to get from the Sargasso Sea to the Gulf Coast is roughly two to five months, so the long range prediction indicates the initiation, intensity, and climax of the upcoming *Sargassum* season. This is shown in Table 1, which lists the number of sightings of *Sargassum* seen in each month. A spike in observations occurs during the winter to spring months (March through May). This precedes the *Sargassum* episodes seen on the Texas Coast by two to five months. For accurate and precise forecasting, the prediction of landfall is not made until after the *Sargassum* has entered the Gulf of Mexico.

Once it has broken free from the North Atlantic gyre, a second pattern begins to manifest. As the free-floating algae reaches the Northern Caribbean Islands, it either washes ashore on the islands of Cuba, Haiti, Dominican Republic, and/or Puerto Rico, or it gets funneled through the passes between the islands and into the Caribbean Sea (See Figures 8 and 9). Because of the passage are narrow, monitoring the Windward, Mona, and Anegada Passages are emphasized.

Once *Sargassum* has reached the neritic waters of the Caribbean Sea, the chemistry of the water is more favorable for *Sargassum* growth. The shallow, coastal waters have relatively high concentrations of nutrients such as carbon and phosphorous, compared to the nutrient poor waters of the Atlantic. Once in the Caribbean, the *Sargassum* mats start to increase in size.

The third and final pattern that emerged from the examination of the historical Caribbean satellite imagery is observed once the *Sargassum* has reached the Caribbean. *Sargassum* is seen migrating westerly once in the Caribbean Sea (See Figure 10). An analysis of the Gulf Stream shows a relatively concentrated current from east to west in the Caribbean Sea, which is theorized to assist *Sargassum* in its annual migration (See Figure 11). It is observed exiting the Caribbean through the Yucatan Passage where it arrives in the Gulf of Mexico. This seasonal *Sargassum* migration theory connects the Sargasso Sea, or the origin, to the Gulf, where it can be seen deposited along the coastline of Texas.

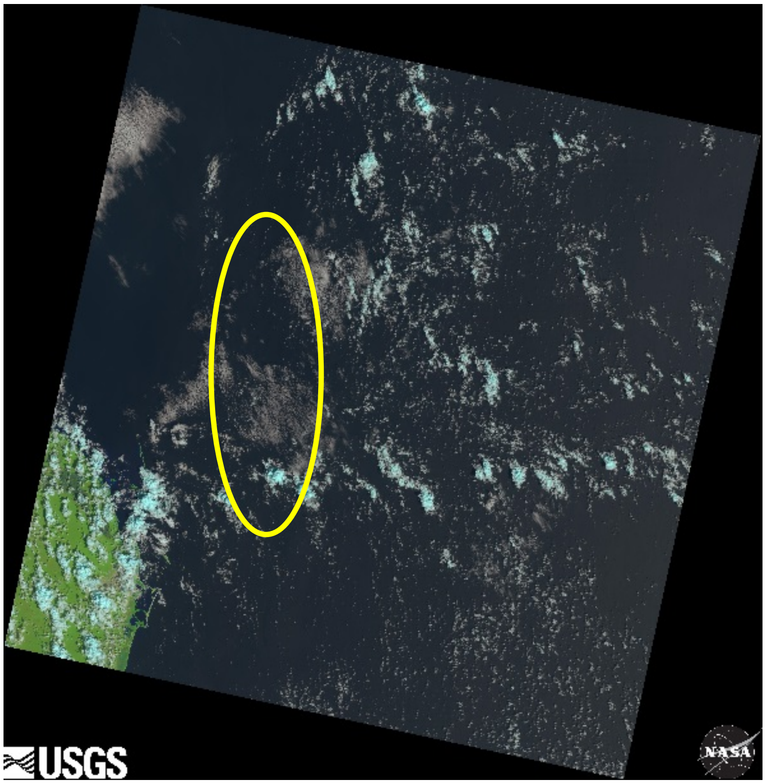

Figure 10. Yucatan Strait satellite image. A satellite image of the Yucatan Strait on March 22, 2014 illustrating *Sargassum* moving westward via the Gulf Stream. Sargassum manifests itself in the form of a slick. Since the size of the mat is too small to be seen in the image, only the disturbance of the wave attenuation around it can be seen (United States Geological Survey, 2014).

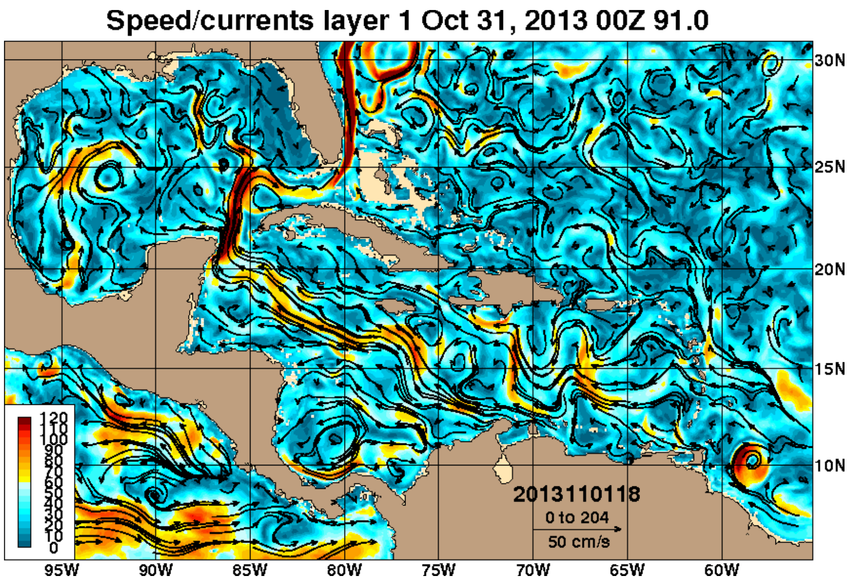

Figure 11. Gulf Stream current graphic. This graphic represents the Gulf Stream that generates a western current in the Caribbean. The current is then pushed north into the Gulf of Mexico where it 'loops' and exits out of the Gulf via the Florida Strait (HYCOM, 2014).

This annual voyage that *Sargassum* makes has been called the *Sargassum* loop system. During the winter months, atmospheric conditions create northerly winds that initiate *Sargassum*'s yearly migration south, through the Northern Caribbean passage (Table 1). Once it reaches the Caribbean, it is caught in the Gulf Stream, where it is taken by concentrated surface currents into the Gulf of Mexico. Upon further investigation, it was found that a portion of the *Sargassum* that lands on the Texas Coast, while some *Sargassum* continues entrained in the Gulf Stream, until discharged out of the Gulf of Mexico through the Florida Straits (See Figure 11). This can be seen in the abundant presence of *Sargassum* in the Florida Straits during the late summer and fall seasons (see Figure 12). Once it has reached the Atlantic again, it is theorized that it returns to its origin, in the Sargasso Sea. This returning *Sargassum* has had the benefit of drifting through the neritic waters of the Caribbean and Gulf of Mexico, and can act as replenishment to assist in the sustainability of the nutrient poor waters of the Sargasso Sea. *Sargassum* also provides a floating ecosystem to the community of organisms that surround it (Casazza, 2010). *Sargassum* mats act as a buoyant sanctuary where juveniles of many species can feed on and be protected by the seaweed. During seaweed's migration, it can provide a form of transportation allowing organisms a voyage into, and across the Caribbean (Ryther, 1956).

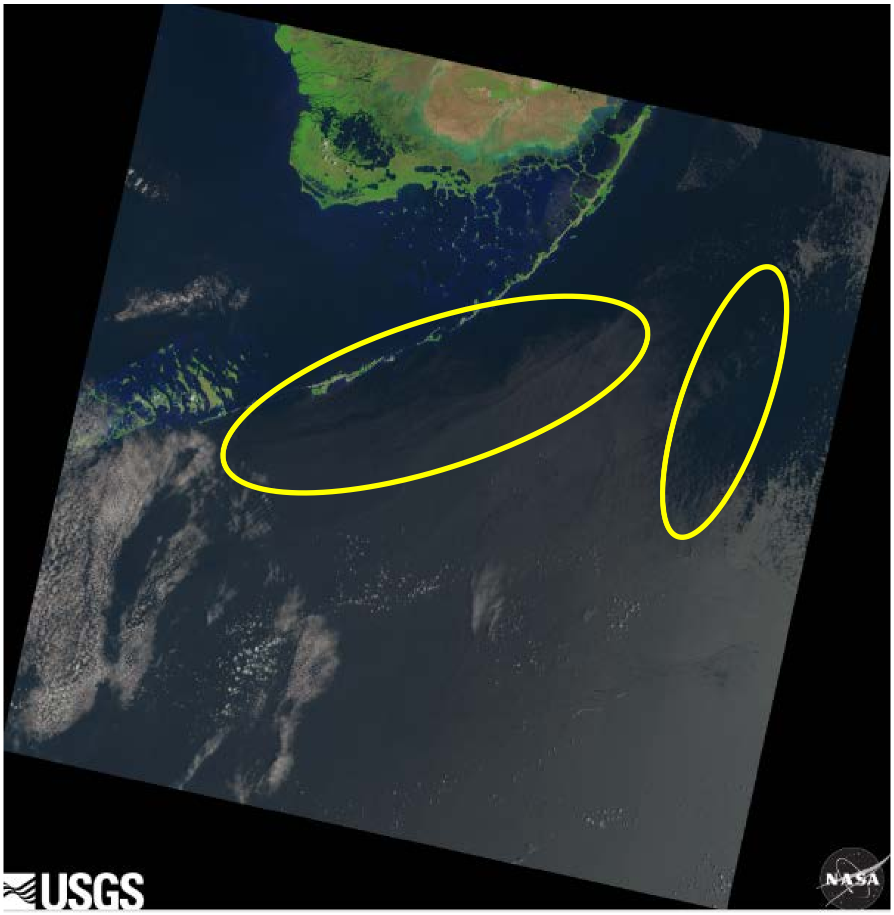

Figure 12. Florida Strait satellite image. A satellite image of the Florida Strait on April 24, 2014 illustrates *Sargassum* exiting the Gulf of Mexico via the Florida Strait and rejoining the Sargasso Sea (United States Geological Survey, 2014).

LONG RANGE FORECASTING

The discovery of this *Sargassum* loop system now allows for the monitoring, analysis, and long range forecasting of the Texas' annual *Sargassum* season via remote sensing. Since seaweed that eventually lands on the Texas coast has drifted south through the Caribbean passages several months prior, one can use this foresight to advise the coastal communities of the forecast for the initiation of the upcoming *Sargassum* season, as well as the intensity of the *Sargassum* episodes expected to occur that season, and the commencement of landfall events.

The start of the *Sargassum* season occurs several months after atmospheric conditions allow *Sargassum* to migrate south out of the Sargasso Sea and into the Caribbean. Once this occurs, wind current magnitude and direction are gathered from weatherbuoy.com and ocean current vector data is obtained from HYCOM. A set and drift (Texas Automated Buoy System, 2014) is extrapolated from the oceanic and atmospheric conditions, which can then forecast the approximate time it takes to reach the Texas Coast. Since there is still a distance of over three thousand miles to be traveled, several factors can affect the *Sargassum* before it makes landfall on the Texas coast. Variables, such as oceanic and atmospheric conditions are dynamic, growth rates are affected by nutrient and temperature conditions during the migration, which can affect the quantity of *Sargassum* in the *Sargassum* loop system, as it amasses. Not all *Sargassum* that journeys into the Gulf will make landfall on the coast, but instead be discharged through the Florida Straits. Because of these reasons, at this point in the loop system, exact landfall dates cannot be predicted.

Relative correlations between the amount of *Sargassum* that can be seen in the passages and the amount that makes landfall can be made. It is observed that *Sargassum* is more commonly sighted in the passages during seasons of heavier *Sargassum* inundations, such as the 2008 and 2011 *Sargassum* seasons, of the coastal communities of the Gulf (Table 2). In contrast, during lighter years of *Sargassum* episodes, such as the 2006 and 2010 *Sargassum* seasons, *Sargassum* sightings in the Caribbean passages occur less commonly (Table 2). The frequency of *Sargassum* sightings in the passages can be directly correlated with the abundance of *Sargassum* in the Gulf and therefore, can forecast the intensity of the upcoming season, however one cannot extrapolate an absolute volume.

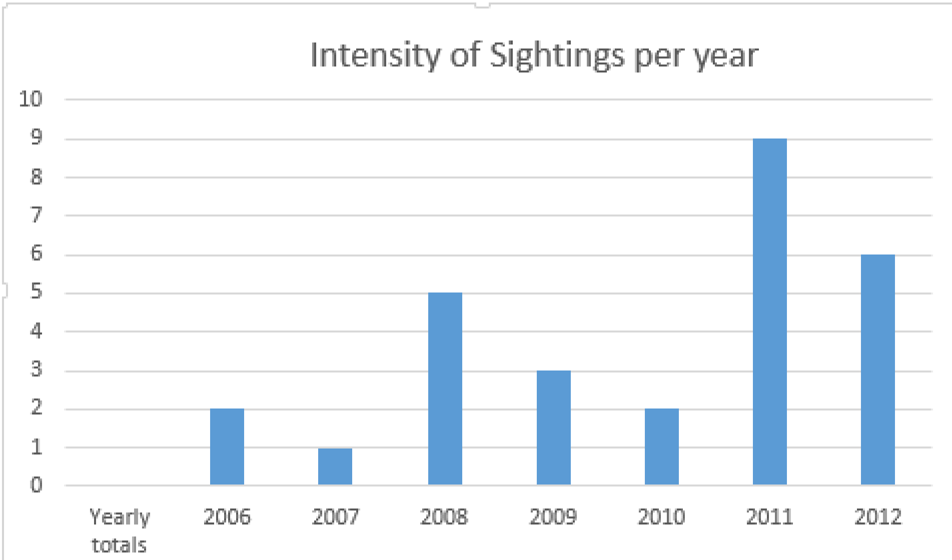

Table 2. Intensity of *Sargassum* sightings per year. This graphic depicts the annual difference between *Sargassum* sightings in the Caribbean Passages. Note that during the 2008 and 2011 seasons, more *Sargassum* was seen the Caribbean Passages, which correlates to the relatively higher rates of *Sargassum* events on the Texas Coast. The 2007 and 2010 years yielded less *Sargassum* in the passages, which correlates to the lower volumes of *Sargassum* seen in the Gulf of Mexico. This denotes that the intensity of the upcoming *Sargassum* season is reflective in the Caribbean Passages during preluding months.

The end of the *Sargassum* season occurs when atmospheric conditions that encourage *Sargassum* become reduced in frequency and intensity, reducing the locomotive energy in the wind, the driving force of the *Sargassum* migration. This termination of the seaweed season is observed in both the degradation of the northerly winds over the Sargasso Sea and in the absence of *Sargassum* in the Caribbean passages.

There are a few caveats in the advanced prediction of the upcoming *Sargassum* season. First, the model used to predict the set and drift of flotsam and jetsam (floating debris) in the Gulf of Mexico is still in the experimental phase. Several entities have attempted to create drift models, such as NASA's debris prediction model, Coast

Guard's Oil prediction model, and NOAA's trash and flotsam predictive model, however none have proven accurate or effective for *Sargassum* prediction or for their orignal intended purposes. This forces us to use a more simplistic and experimental model of vector addition. Once *Sargassum* is located, the regional ocean and wind currents are obtained and overlaid over the mat of *Sargassum*. It is known that wind has a stronger effect on *Sargassum* than ocean currents, despite *Sargassum* having a negligible amount of freeboard, allowing it to be more affected by air. Because of this, the wind current is given more weight when modeling the drift of the seaweed mats. The exact effect that wind and water currents have on *Sargassum* is still unknown, however, it is currently believed that wind and ocean currents have a seven to three ratio effect on *Sargassum*. i.e. If wind is blowing 10 knots pushing *Sargassum* due north and reciprocal ocean currents moving at 10 knots pushing *Sargassum* due south, the *Sargassum* will be 2.3 times more effected by the wind, and thus travel north. *Sargassum* does not actually travel the same speed as the prevailing currents. Flotsam and jetsam travel at a rate of three percent of the currents acting upon it (Gyory, 2013). i.e. If ocean and atmospheric currents are acting on *Sargassum* at a rate of 15 knots, the *Sargassum* mat is only drifting at a rate of 0.45 knots. This prediction model is simplistic and is still in the early experimental stages of development.

Another constraint on long range forecasting is provided by the dynamic variables. Since *Sargassum* is being forecasted months in advance, there are several factors such as ocean and atmospheric conditions that change daily, and cannot be accurately incorporated into the model. Because of this, a more simplistic average is being taken of the wind and ocean currents. Another variable that affects the drift of *Sargassum* is the bathymetry, which affects wave patterns and tidal cycles. Since *Sargassum* must travel a minimum of 1,800 miles, accounting for the bathymetry and the added variables that it entails, it is impractical to incorporate them into the model. These discrepancies in the modeling for *Sargassum* set limitations on the accuracy of *Sargassum* predictions.

Expanding the SEAS program's area of observation into the Caribbean has increased the forewarning time from sixteen days to up to two to five months in advance. Knowledge of the initiation and intensity of the upcoming summer seaweed episodes allows coastal communities to allocate the necessary resources and better prepare for the impending *Sargassum* season.

AZORES HIGH PRESSURE SYSTEM – DRIVING MECHANISM

An atmospheric phenomenon called the North Atlantic Oscillation occurs over the Northern Atlantic Ocean. In this phenomenon, a series of pressure systems, alternating between high pressure and low pressure, move across the northern hemisphere of the Atlantic Ocean (See Figure 13). When a low pressure system has set in, it is commonly referred to as negative state. Low pressure systems have a mean sea level pressure of 1009 millibars or less, and rotate counter clockwise. These low pressure systems are also the predecessors to more ominous weather related catastrophes, such as tropical storms and hurricanes. These pressure systems are specifically analyzed and forecasted because they is constantly monitored for tropical depressions in the Atlantic, which can accumulate energy and evolve into a potentially destructive hurricane.

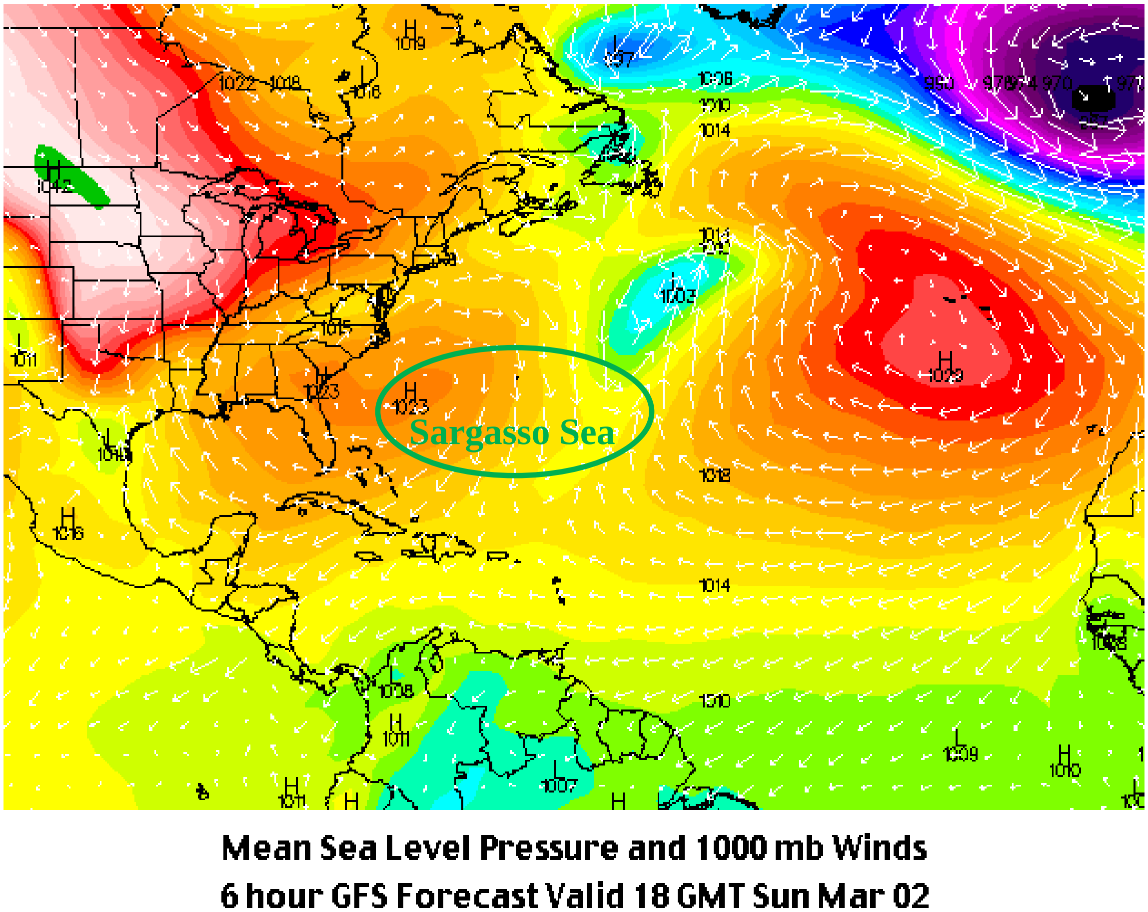

Figure 13. Azores High Pressure System graphic. The Azores High Pressure system creates anticyclonic winds over the Sargasso Sea and becomes the driving mechanism behind the migration of *Sargassum* (Masters, 2014)

In contrast, when a high pressure system has moved into the region of interest, it is said to be in a positive mode. The high pressure systems are characterized as having a mean sea level pressure of at least 1010 millibars, but commonly range between 1020 to 1030 millibars, and is anticyclonic, meaning it rotates clockwise. One particular high pressure system situated in this region is commonly referred to as Azores High Pressure

System, and oscillates from the Eastern to the Western Atlantic, frequently around latitudes of thirty degrees.

The Azores High Pressure System is theorized to be the initiating force behind *Sargassum* migration from the Sargasso Sea to the Gulf of Mexico. During the winter and spring months, the Azores Pressure System shifts over to the Eastern Atlantic where it resides over the Sargasso Sea (See Figure 13). Anti-cyclonic conditions create swift northwesterly winds over the Sargasso Sea. These winds are believed to be a strong enough driving mechanism to push the floating algae out of the North Atlantic Gyre and down south toward the Caribbean, initiating the *Sargassum* Loop System.

CONCLUSION

The increased foresight brought on the by expanding the SEAS's area of observation into the Caribbean, allows for the forecasting of *Sargassum* in the Gulf of Mexico months in advance. It also helps explain the secret to the sustainability of the Sargasso Sea, an oasis of vegetation located in a nutrient-barren region. The 2011 massive *Sargassum* event in the Southern Caribbean was then thought to be generated by unusually massive flooding. Although it may have seemed like a dead end, this investigation of the unusually massive *Sargassum* episode led to the theory of *Sargassum*'s annual migration from the Sargasso Sea to the Gulf and the creation of the Long range forecasting of *Sargassum* in the Caribbean Sea. Previously, *Sargassum* could not be forecasted until it had reached the coastal waters of the Gulf of Mexico. This expansion of the SEAS program allows for the upcoming *Sargassum* season on the Texas Coast to be forecasted months in advance. The frequency of appearance and volume of *Sargassum* in the Caribbean passages during the winter and spring months are indications of the initiation, intensity and eventually the commencement of *Sargassum* season in the Caribbean and Gulf of Mexico.

The *Sargassum* loop system has the potential to explain the mystery of the Sargasso Sea's sustainability. Conditions of the North Atlantic Bight do not support a healthy, vegetation-rich ecosystem. The abundance and magnitude of *Sargassum* mats in the Atlantic have never been well explained. The concept of the *Sargassum* loop system provides a theory to explain the sustained existence of *Sargassum* which is first noted by

Aveido, on his voyage with Christopher Columbus to the new world in 1492. The sustainability of the Sargasso Sea could be aided by a portion of its contents migrating through the neritic waters of the Caribbean and Gulf of Mexico. *Sargassum* that exists the Gulf through the Florida Straits rejoins the *Sargassum* Sea, potentially providing a jolt of nutrient-rich, healthy *Sargassum* that amassed during its journey though the *Sargassum* loop system, however a further investigation on the Sargasso Sea nutrient cycles and the health of its *Sargassum* is needed before any conclusions can be drawn.

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