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Recently Observed Seasonal Hypoxia in Eastern Louisiana within Chandeleur Sound and near Coastal Mississippi within the Gulf of Mexico

Theryn Henkel, MS, John Lopez, Ph.D., Ezra Boyd Ph.D., Andy Baker, MS. Dallon Weathers, MS, Chuck Cropp and Nicholas A. Robins, Ph.D.

Introduction

Chandeleur Sound is the shallow-water (up to 20 feet deep) area between Chandeleur Islands, the Biloxi Marsh and the barrier islands along the Mississippi coast. The sound extends southward behind remnants of the Curlew and Gosier Barrier Islands and then connects to Breton Sound to the south. The two sounds are separated by the MRGO conveyance. At the north end of Chandeleur Sound, the sound's water bottom forms a broad trough which slopes seaward toward the Gulf of Mexico. This trough narrows westward to the Cat Island Channel south of Cat Island, Mississippi. The Lake Pontchartrain Basin Foundation (LPBF) has monitored water quality in the sound in 2008, 2010 and 2011, working in partnership with the Marine Research and Assistance Council (MRAC). MRAC is a volunteer organization of mariners based in New Orleans which conducts scientific and environmental research and education. LPBF and MRAC will continue seasonal monitoring in 2012. The cumulative observations to date have revealed that an area of hypoxia (see next section for discussion of hypoxia) develops in this area seasonally. A report outlining the results of the 2008 and 2010 monitoring can be found at http://saveour lake.org /PDF-documents/our-coast/ChandeleurSound_WaterQuality_10-2010.pdf. This report summarizes the 2011 water quality observations including additional data collected by the Louisiana Universities Marine Consortium (LUMCON) which monitored water quality off the coast of Mississippi in 2011.

Hypoxia

Hypoxia can develop in a water column for many different reasons but usually the root of the development of hypoxia is stratification in the water or a lack of mixing. In this general case, waters that are near the coastline tend to receive freshwater inputs from nearby rivers and streams and tend to be warmer because water depths near the coast are shallower. In contrast, deeper waters just off the coast tend to be more saline and colder. Fresh water and warm water are less dense than saline water and cold water. Therefore, as the warmer, fresher waters from the coastal environments encounters the colder, more saline waters off coast, the less dense coastal waters float on top of the denser off coast water. This causes a pycnocline (layer where the density gradient is greatest) to develop which prevnets mixing, especially in the absence of strong winds or currents. Hypoxia then develops in the lower layer as oxygen becomes depleted by decomposition and is not replenished from oxygenated surface waters because there is no mixing (**Figure 1**). Water is considered to be hypoxic when it has less than 2 mg/l of oxygen. As discussed later, this mechanism or others may apply to the hypoxia documented along this portion of the coast.

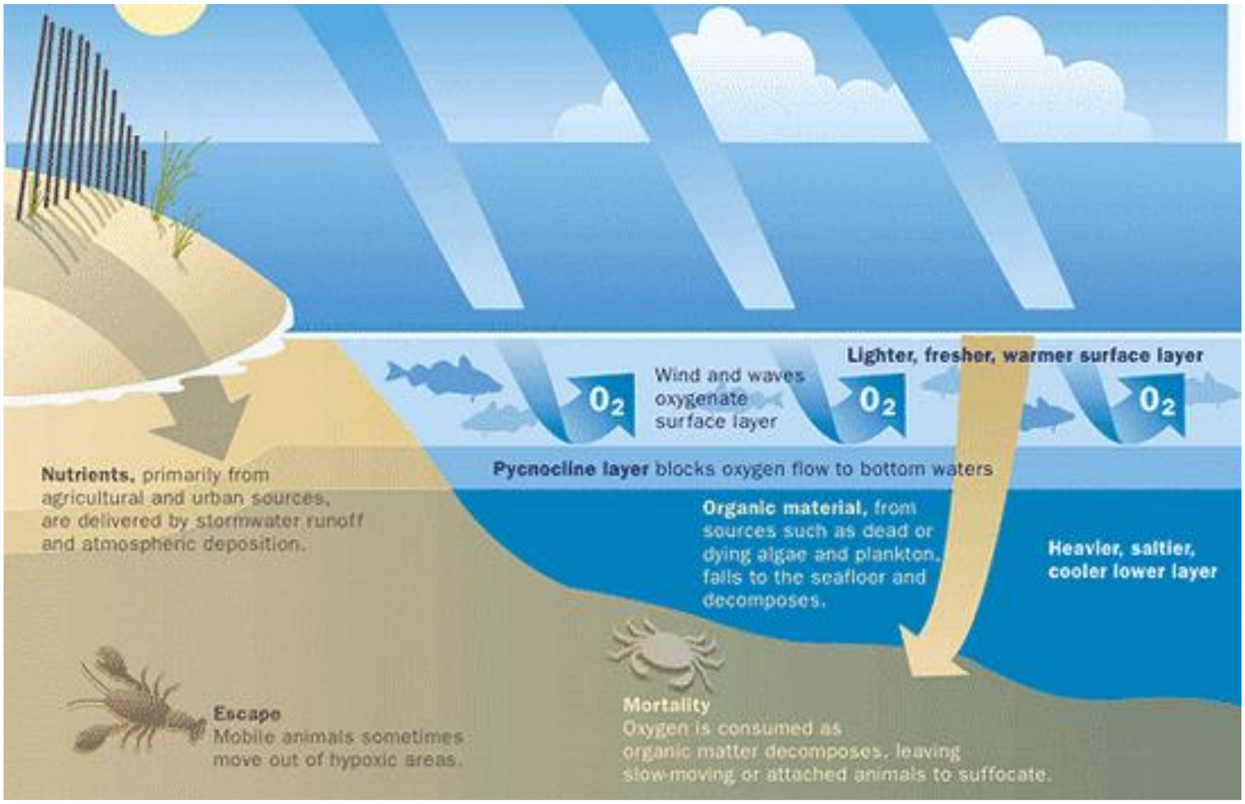

Figure 1: Schematic showing how hypoxia can develop at depth in the water column (Figure from http://hypoxiadeadzone.weebly.com/causes.html).

Summary of 2008 and 2010 Results

In 2008, two marine surveys fortuitously documented the occurrence of a low oxygen layer in Chandeleur Sound. In June 2008, the University of Southern Mississippi was conducting shark research and collected environmental data in Chandeleur Sound. Later that month, the Nekton Research Laboratory at the University of New Orleans was en route to do research around the Chandeleur Islands and collected water quality data while crossing Chandeleur Sound. These two data sets were provided to LPBF and are shown on **Figure 2**.

In 2010, Chandeleur Sound was resurveyed to ascertain if the low dissolved oxygen detected in 2008 was an anomaly for that year or if it was a phenomenon that developed more often. Hypoxia was detected again in the Chandeleur Sound area (**Figure 3**).

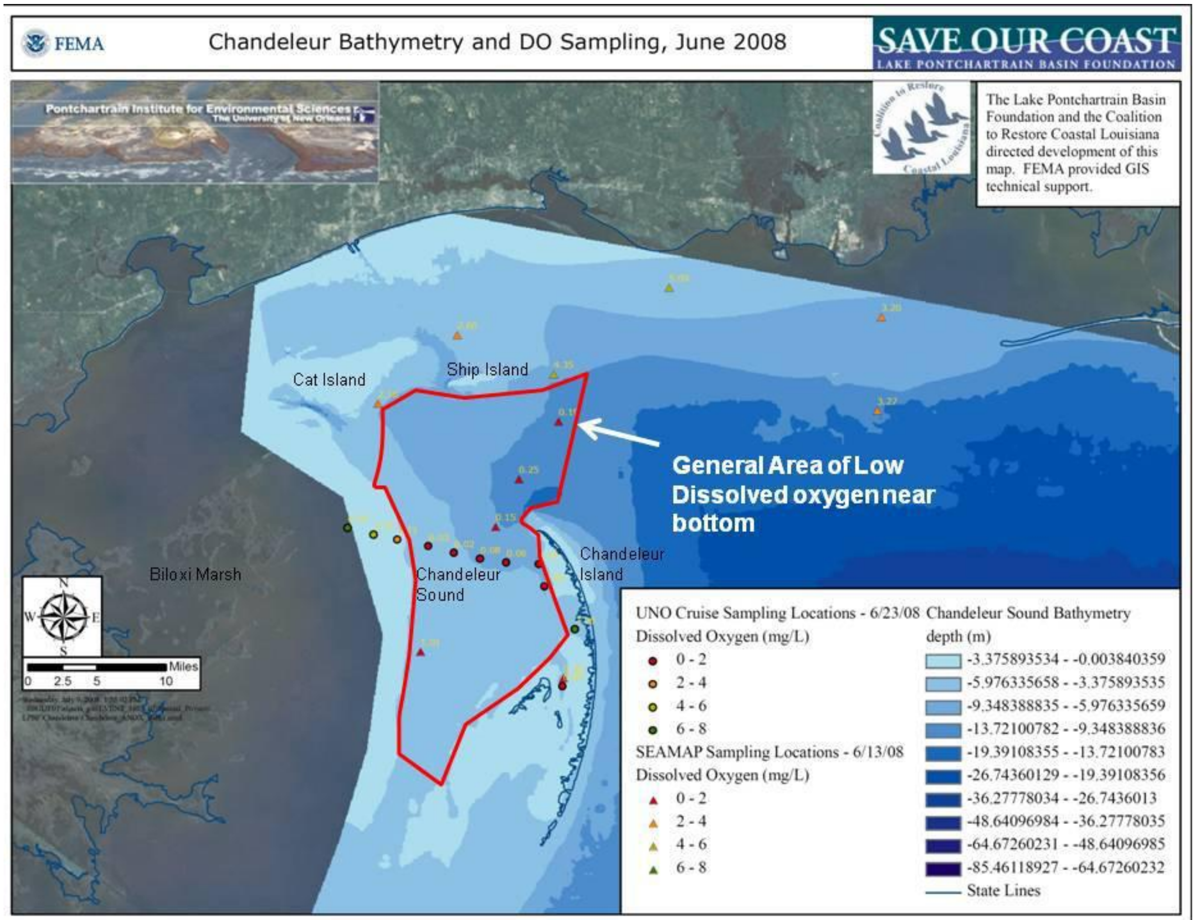

Figure 2: Map of the Chandeleur Sound area and the approximate location of low dissolved oxygen observed in 2008 by University of New Orleans and the University of Southern Mississippi.

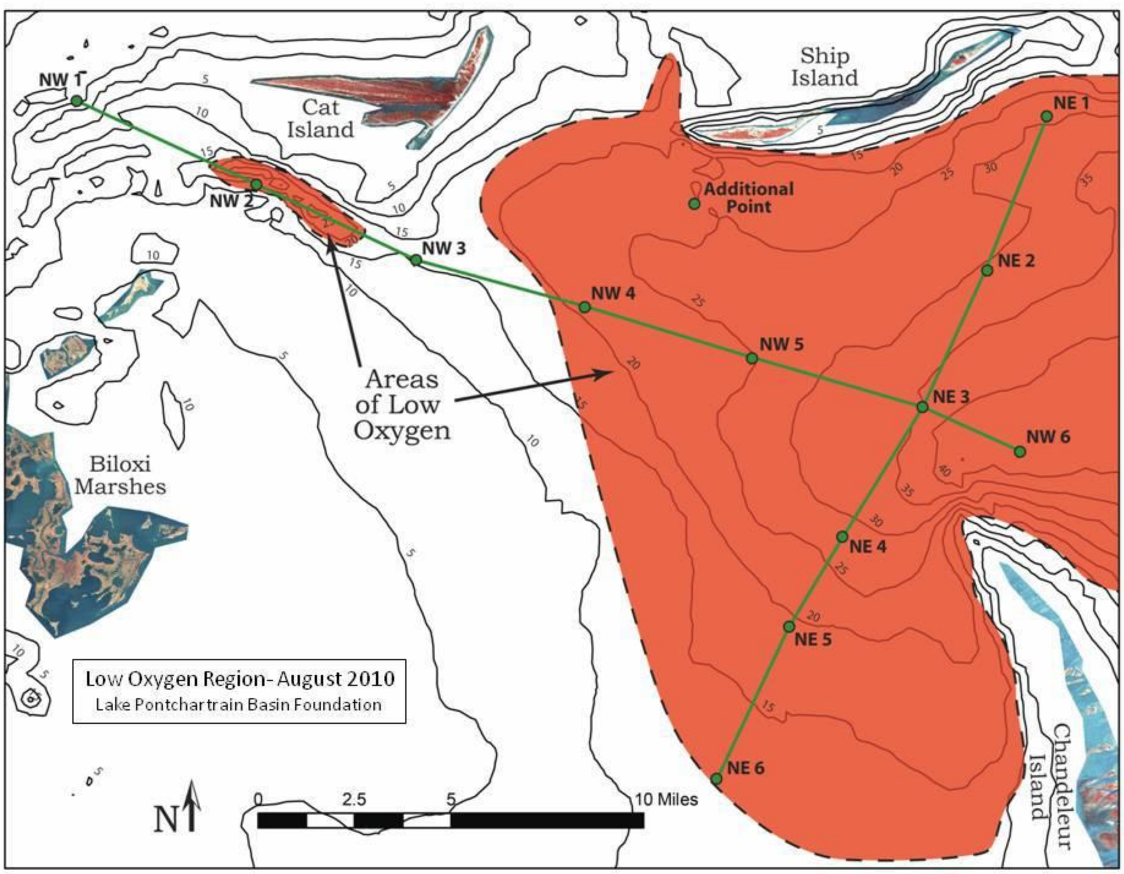

Figure 3: Map of Chandeleur Sound with the area of hypoxia observed in August 2010.

Methods

In July of 2010, LPBF partnering with MRAC developed a water quality monitoring protocol for Chandeleur Sound. LPBF used the same transects **(Figure 4, circles)**, sampling protocol, and a sampling frequency plan developed in 2010 for the 2011 survey. Briefly, a YSI meter with a 60 foot cable for the sensor was used to detect DO levels, salinity and temperature. The sensor cable was marked at 2-foot increments. First, total depth was estimated using two on board acoustic depth finders. Then, the cable was lowered to take measurements at approximately 2 feet above bottom, the midpoint, and 2 feet below the surface. At each location we acquired measurements of salinity, DO and temperature. Two transects were selected which crossed the deepest axial through portions of the Chandeleur Sound. One transect ran through Cat Island Channel to the deep hole near the northern end of Chandeleur Sound. The other transect ran from eastern Ship Island southward to the central area of Chandeleur Sound. A total of 15 stations were acquired in July, 2011.

Also in July of 2011, LUMCON surveyed an area of the Gulf of Mexico, starting about 8 miles from the coast of Mississippi to 24 miles from the coast into the Gulf (**Figure 4, triangles**). The survey also extended eastward of the Chandeleur Islands south to the Mississippi River. The LUMCON survey was conducted in deeper waters, on the continental shelf. The specific data collected by LUMCON is not included in this report but the extent of hypoxia that was detected by LUMCON has been combined with the hypoxia detected by MRAC-LPBF to gain a total picture of the area of hypoxia off of the coast of Southeast Louisiana and Mississippi.

For the remainder of this report, figures depicting the area of hypoxia are using combined MRAC-LPBF and LUMCON data whereas the graphs depict only data collected by the MRAC-LPBF transect sampling effort.

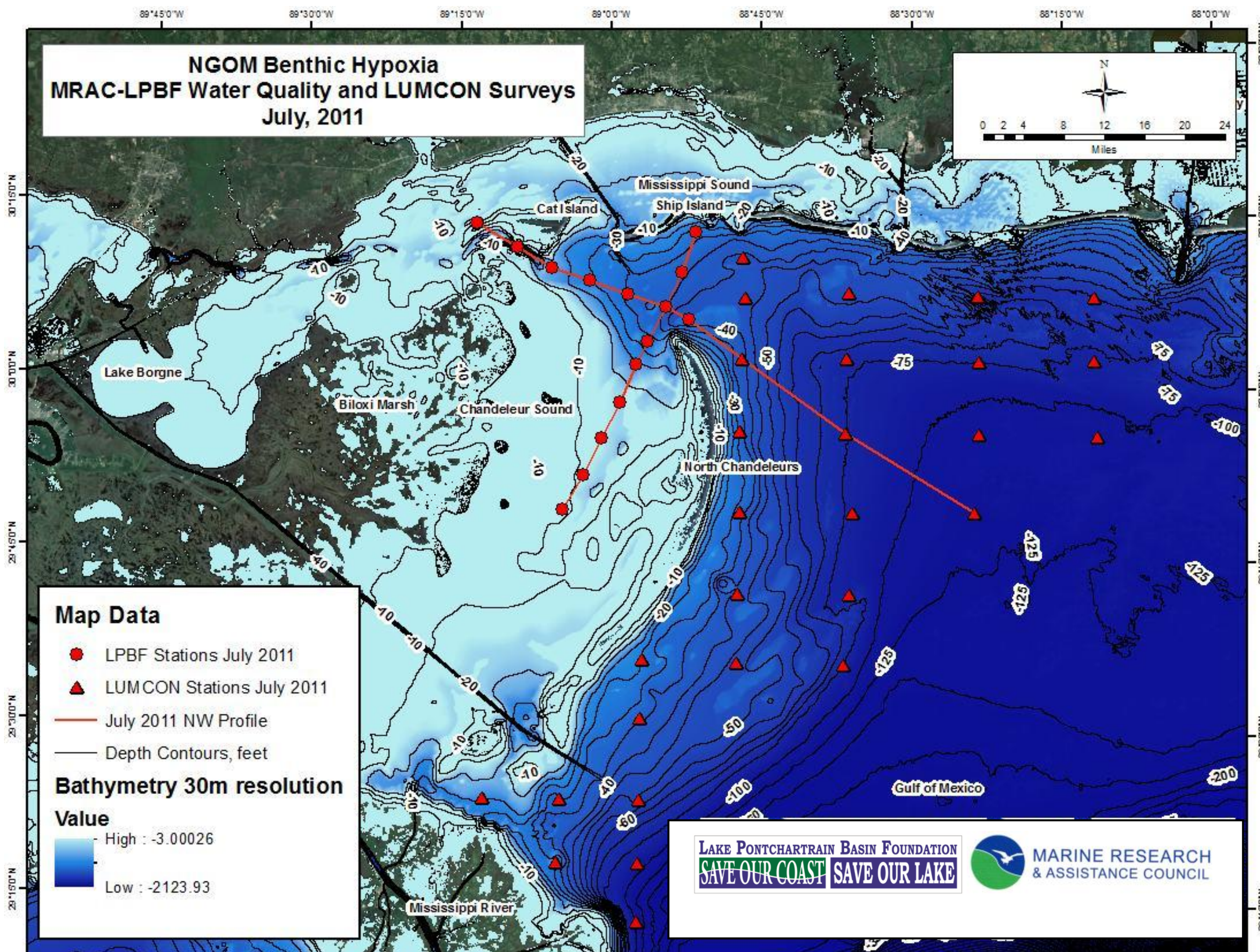

Figure 4: Locations of MRAC-LPBF and LUMCON sample points in Chandeleur Sound and the Gulf of Mexico in 2011.

.Results

A large area of hypoxia was detected in July of 2011 in the vicinity on the Chandeleur Islands extending into the Gulf of Mexico (**Figure 5**). The area of the detected hypoxia was approximately 1,050 square miles. However the hypoxic zone was most likely larger as data collection did not extend past the Mississippi/Alabama boarder. A total of 43 points were surveyed between the MRAC-LPBF and LUNCOM sampling efforts (**Figure 4**). Of these 43 points hypoxia was detected at 25 sites, over half of the points surveyed.

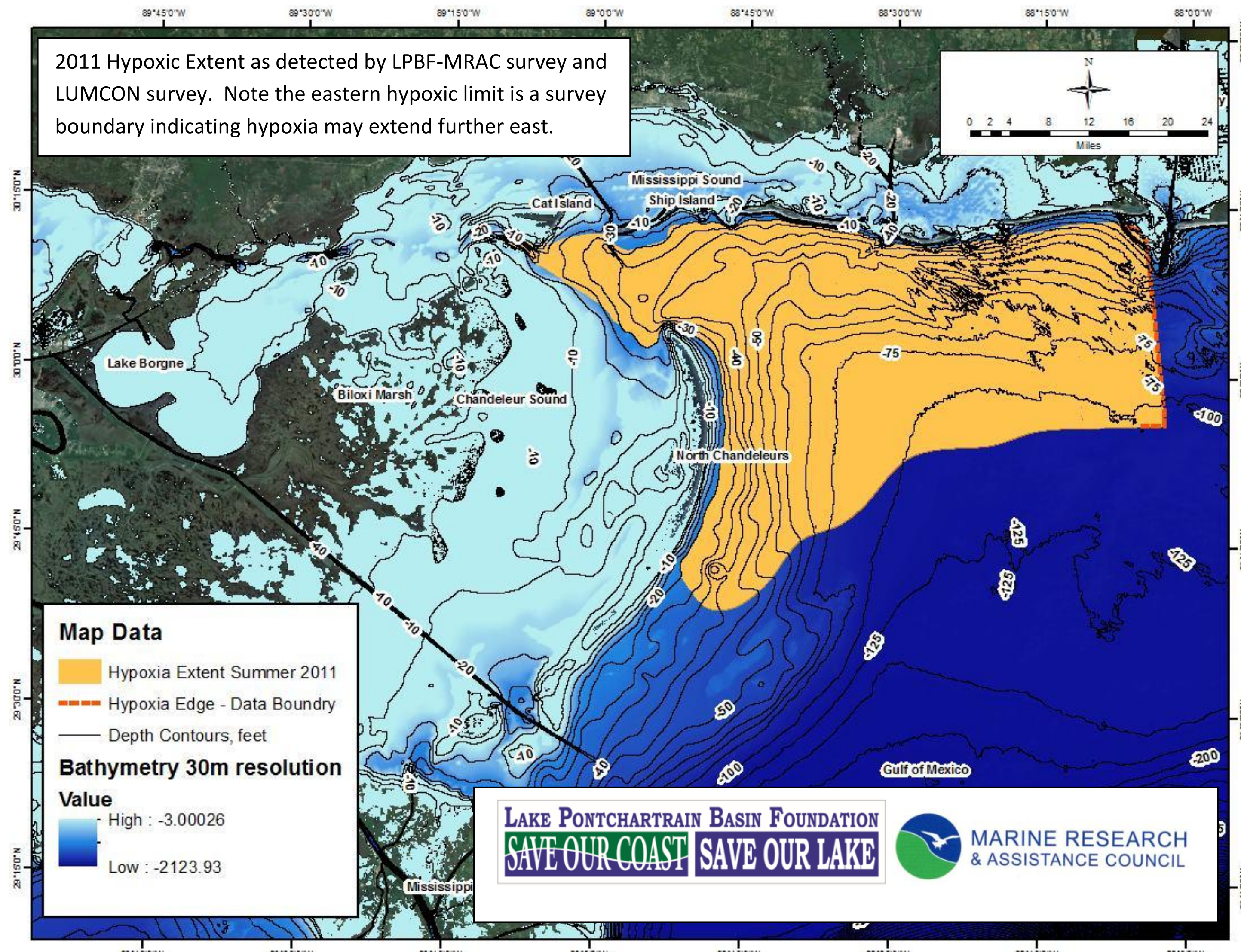

Figure 5: Map showing the area of hypoxia detected in MRAC-LPBF and LUNCOM surveys in July of 2011. The area of hypoxia most likely extends further east but the survey was terminated at the Mississippi /Alabama boarder.

A hypoxic zone at depth was detected in 2011. The depth of the boundary (pycnocline) ranged from 10 to 25 feet. **Figures 6, 7 and 8** illustrate the depth-dependent segregation of salinity, dissolved oxygen and temperature data, which demonstrate the development of a pronounced boundary between lower salinity, oxygenated waters above and higher salinity, hypoxic waters below. In the hypoxic zone the lower layer had 5 ppt thousand higher salinity, 5 mg/l lower oxygen and was 3.7 C° cooler, on average (**Table 1**). In the area where hypoxia was not present the differences between the upper layer and lower layer in salinity, dissolved oxygen and temperature were negligible (**Table 1**).

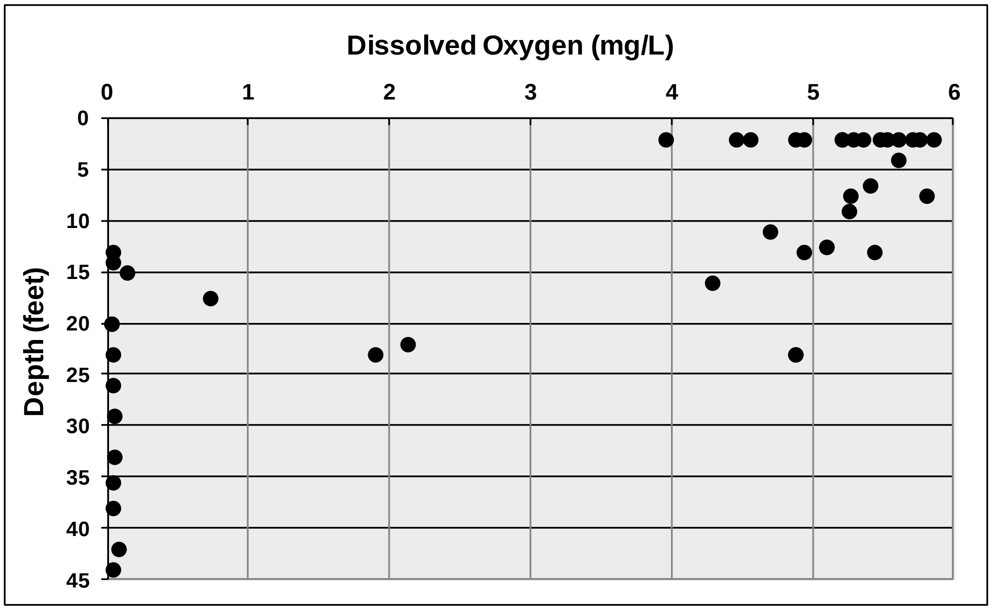

Figure 6: Graph showing dissolved oxygen with depth in 2011, using the MRAC-LPBF data. Notice a decline of dissolved oxygen with depth and the rapid decline in oxygen around 10-20 feet deep.

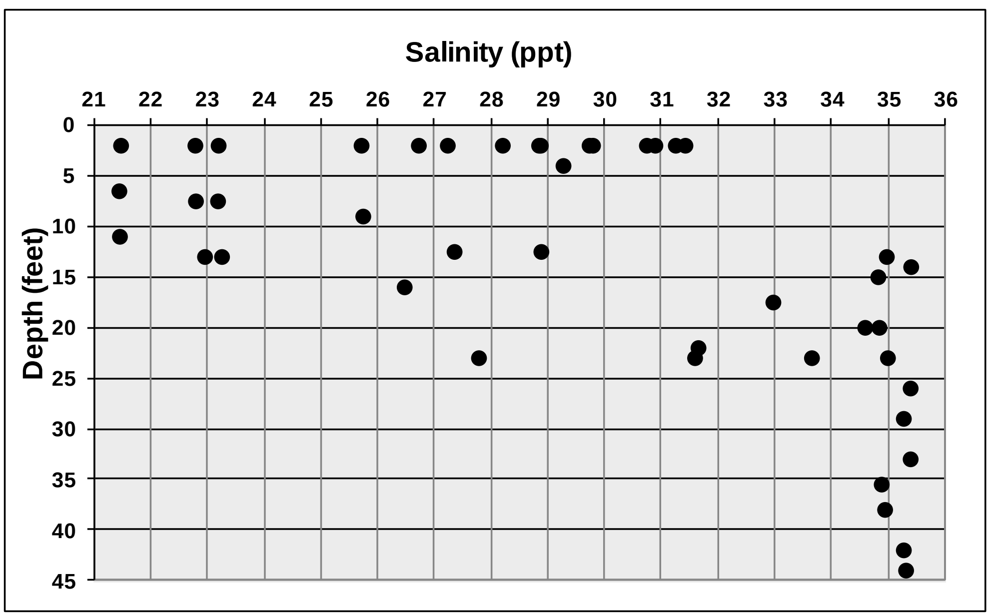

Figure 7: Graph showing changes in salinity with depth in 2011, using the MRAC-LPBF data. Notice the increase in salinity with depth with the increase occurring around 10 to 20 feet deep.

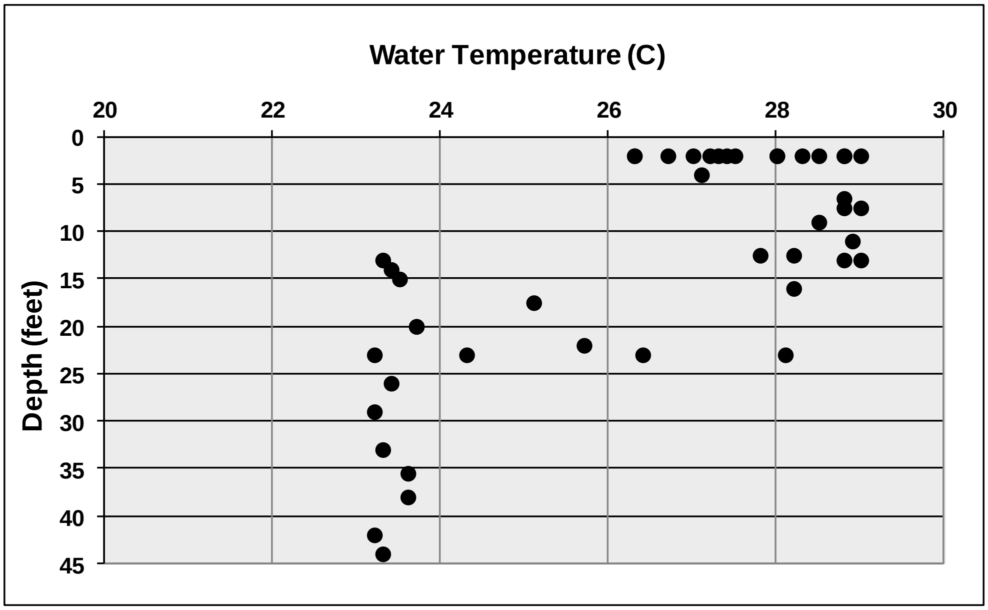

Figure 8: Graph showing change in water temperature with depth in 2011, using the MRAC-LPBF data. Notice the cooler temperatures with depth with the decline in temperature occurring around 10-25 feet deep.

Table 1: Average difference in salinity, dissolved oxygen and temperature between the upper and lower layers of the water column in 2011 in the hypoxic zone (upper table) and the area with no hypoxia (lower table).

Hypoxic Area

	Average Salinity (ppt)	Average DO (mg/l)	Average Temperature (C°)
Upper Layer	**29.71**	**5.03**	**27.16**
Lower Layer	**34.99**	**0.08**	**23.46**
Difference	**5.28**	**-4.94**	**-3.70**

Area of No Hypoxia

	Average Salinity (ppt)	Average DO (mg/l)	Average Temperature (C°)
Upper Layer	**25.33**	**5.40**	**28.39**
Lower Layer	**26.38**	**4.95**	**27.77**
Difference	**1.06**	**-0.44**	**-0.61**

The hypoxic zone in 2011 had lower dissolved oxygen and higher salinities than the hypoxia in 2010 indicating that the hypoxia detected in 2011 was more severe than in 2010. However, overall salinities were higher and dissolved oxygen and temperatures were lower, even at the surface, than in 2010. In 2011, the deep layer reached salinities above 35 ppt. In 2010 the maximum salinity was around 33 ppt. In 2011, the dissolved oxygen was close to zero with nine out of the fifteen stations having dissolved oxygen lower than 1 mg/l while in 2010 only two stations had oxygen depletion to that extent. The differences between the surface layer and the layer at depth in 2011 are equal to or less than the differences observed in 2010.

The hypoxia did not develop in shallow waters less than 10 feet deep (on the continental shelf). The hypoxia usually developed in waters deeper than 30 feet (**Figures 9 and 10**). The hypoxia continued into deep water but always developed near the bottom with the hypoxia boundary (pycnocline) growing deeper with increasing water depth. Below **figures 9 and 10** show the depth profile and the depth of the pycnocline for data collected by MRAC-LPBF along the two transects shown in **Figure 4**.

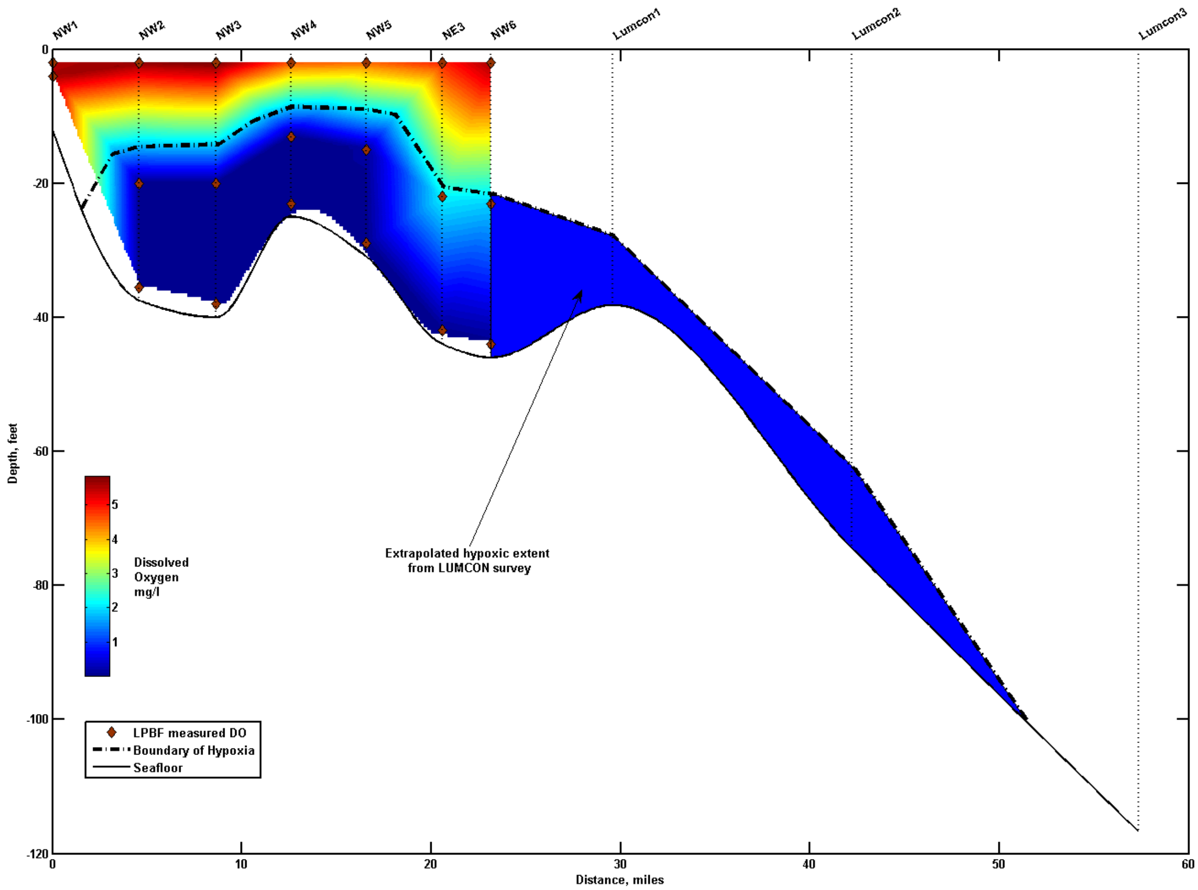

Figure 9: Depth profile and depth of pycnocline created from data taken along the transect running from the northwest near Cat Island to the southeast crossing just north of the Chandeleur Islands by MRAC-LPBF. This figure also includes an extrapolated extent of the hypoxia from the LUMCON data. Notice that the depth of the hypoxia increases with increasing depth of the water column. Blue colors indicated hypoxic waters and red, yellow and green colors represent oxygenated

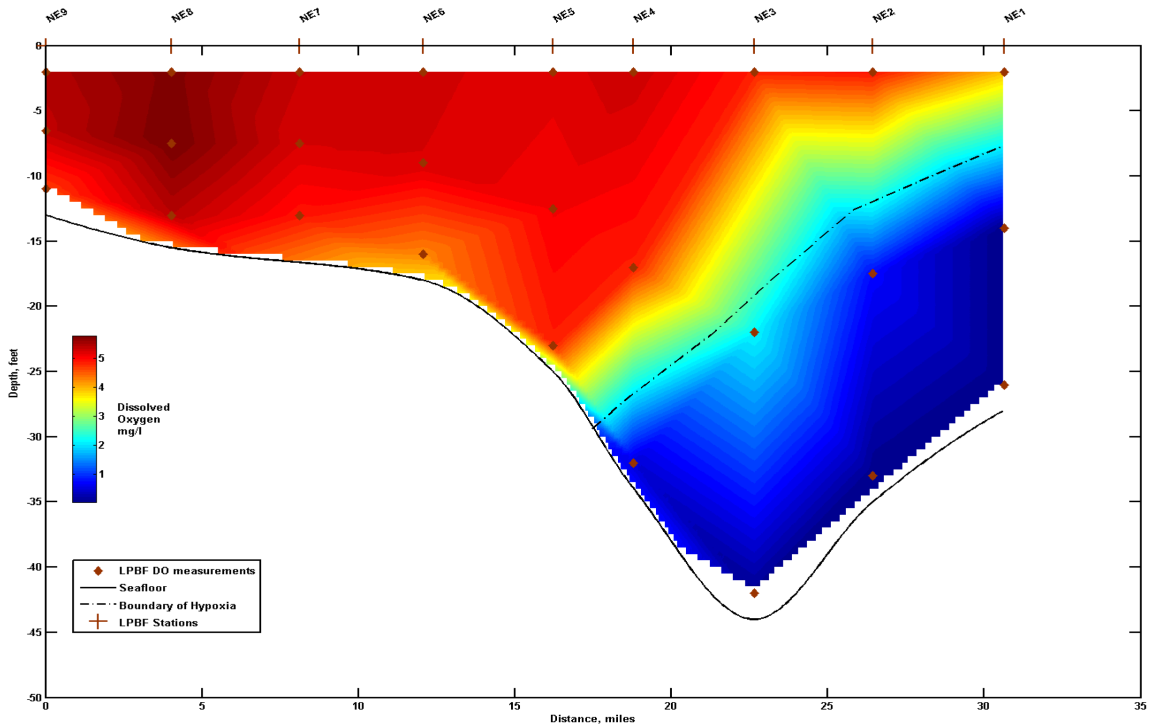

Figure 10: Depth profile and depth of pycnocline created from data taken along the transect running from the southwest in the Chandeleur Sound to the northeast near Ship Island by MRAC-LPBF. Blue colors indicated hypoxic waters and red, yellow and green colors represent oxygenated waters.

In 2008 the hypoxia was detected in June, in 2010 the beginnings of hypoxia was detected in May, was more prevalent in July and was well developed by August and was gone by October and in 2011 it was detected in July. The development of the hypoxia is most likely seasonal and occurs in the summer months when coastal waters become heated. The stratification and therefore the hypoxia are most likely disrupted by fronts, strong storms or hurricanes that come through the area in late summer/early fall. The extent of the effect of these hypoxia events on the organisms and ecology of the region is unknown. Fish are most likely less affected as they can move into more oxygen rich waters. Other less mobile organisms that live near the bottom may suffocate under these hypoxic conditions, depending on the length of time that hypoxic conditions persist (some organisms can tolerate low oxygen for brief periods of time).

Discussion

The well documented dead zone along the Louisiana coast in the Gulf of Mexico (at the mouth of the Mississippi River is thought to be triggered by excess nutrients and stratification which occurs seasonally in the summer months (Rabalais et al. 2002). Prior to the closure of the Mississippi River Gulf Outlet (MRGO), the well-documented dead zone in Lake Pontchartrain was triggered by high salinity water which had been allowed to enter Lake Pontchartrain via the MRGO and the Industrial Canal (LPBF 2006; Poirrier 1978; 1984). In both the Gulf and Lake dead zones, a lack of circulation and cumulative demand on oxygen within the water column conspired to create very low oxygen deeper in the water column. Many sessile organisms that inhabit the water bottom can be suffocated and die, even with brief periods of low oxygen. Hence, these are referred to as “dead zones”. In Lake Pontchartrain, the dead zone was evident by the absence of large lake Clams (*Rangia cuneata*), simply because clams were killed before they could mature (Poirrier et al. 1984).

The cause of the development of hypoxia in Chandeleur Sound and coastal Mississippi is not definitively known. The cause may be anthropogenic, natural or a combination of both. In the three years that have been surveyed (2008, 2010 and 2011), there has been potential sources of excess nutrients entering the system. The excess nutrients and stratification may contribute to the development of hypoxia in a manner similar to the development of the "Dead Zone" at the mouth of the Mississippi River (Rabalais et al. 2002).

In 2008, the Bonnet Carré Spillway was opened which discharged nutrient rich river water into Lake Pontchartrain which eventually flows into Lake Borgne and then into the Chandeleur Sound. Algal blooms did occur in Lake Pontchartrain in 2008 (Moffatt & Nichol 2010). In 2010, the BP oil spill occurred during which local river diversions, such as Caernarvon, were operated at full capacity in hopes of preventing oil from landing. In 2011, the Bonnet Carré Spillway was again opened at a high capacity for 42 days in May and June. No significant algal bloom occurred in Lake Pontchartrain in 2011, possibly due to a lower ratio of phosphorous and nitrogen in the river water (Nguyen et al. 2011; Roy et al. 2011). However, there are some rivers that flow into the Gulf off of the Mississippi coast, such as the Pearl River, Mobile River and the Pascagoula River, which also could have introduced elevated nutrients to coastal waters. Excess nutrients could have entered the Chandeleur Sound and contributed to the formation of deepwater hypoxia in the area in 2011. However, it is unrealistic that high nutrient concentrations remained high enough to cause hypoxia extending all the way to the Mississippi/Alabama boarder. In addition, the high salinity of the upper layer suggests that the freshwater influence is minimal. Therefore, it is questionable whether high nutrient concentrations are the primary cause of the hypoxia, and other hypotheses should be considered.

We propose that the cause of the formation of hypoxia may be a naturally induced phenomenon simply due to a lack of energy available to mix the coastal and deep Gulf waters, thus causing density driven stratification to develop on a seasonal basis (**Table 2**). The hypoxic area is a reentrant that appears to be isolated from ocean currents prevalent in the open Gulf of Mexico. (**Figures 11 and 12**). The region where hypoxia develops seems to be bypassed by the prevailing currents in the Gulf of Mexico. The hypoxia also sets up at a time in of the year when winds are low in the summer. The low wind and lack of current energy allows the stratification to develop due to density contrasts (**Figure 13**). Because there are low winds in the Gulf of Mexico in the summer time there is less vertical mixing which again leads to stratification (**Figure 14**).

Table 2: Water quality sample collection dates with whether or not hypoxia (DO less than 2 mg/l) was detected.

Date	Hypoxia Detected?
June 13, 2008	Yes
June 23, 2008	Yes
May 9, 2010	Beginning
July 14, 2010	Yes
August 25, 2010	Yes
October 11, 2010	No
July 15, 2011	Yes

Due to the conditions present in the hypoxic zone in the summer time (low winds, outside of the prevailing current path, warm shallow waters) it is probable that the observed stratification develops on a consistent basis due to natural existing conditions, regardless of anthropogenic nutrient additions. The question remaining seems to be whether excess nutrients are necessary to increase BOD and deplete oxygen in the stratified water over the short seasonal time period that it develops. It is intriguing that the exact opposite energy condition prevails with a tropical system. Tropical systems (hurricanes, tropical depressions) have strong east or southeast winds, which tend to focus water through the reentrant (hypoxic) area. These events undoubtedly cause significant mixing and likely terminate the seasonal hypoxia. If so, Tropical Strom Lee, in early September, 2011, most likely ended the 2011 hypoxia (**Figure 13**).

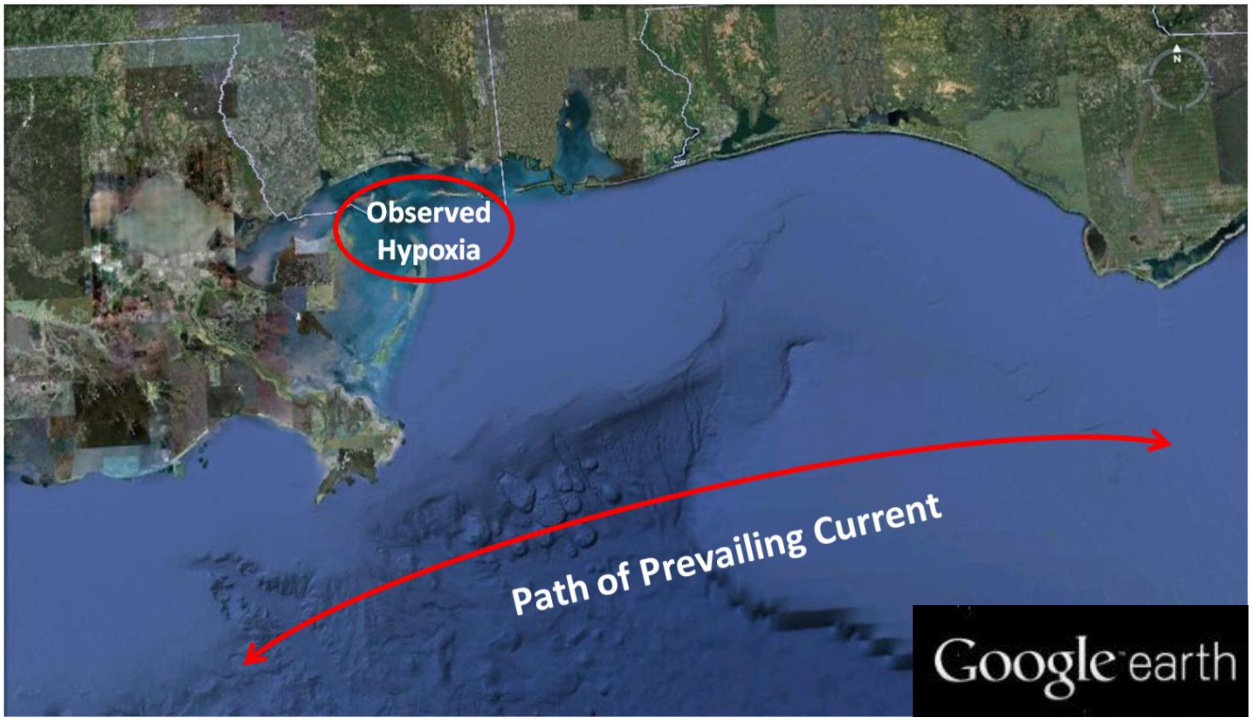

Figure 11: Location of the hypoxia east of the river in a regional context showing how the hypoxic area is out of the path of the prevailing Gulf of Mexico currents.

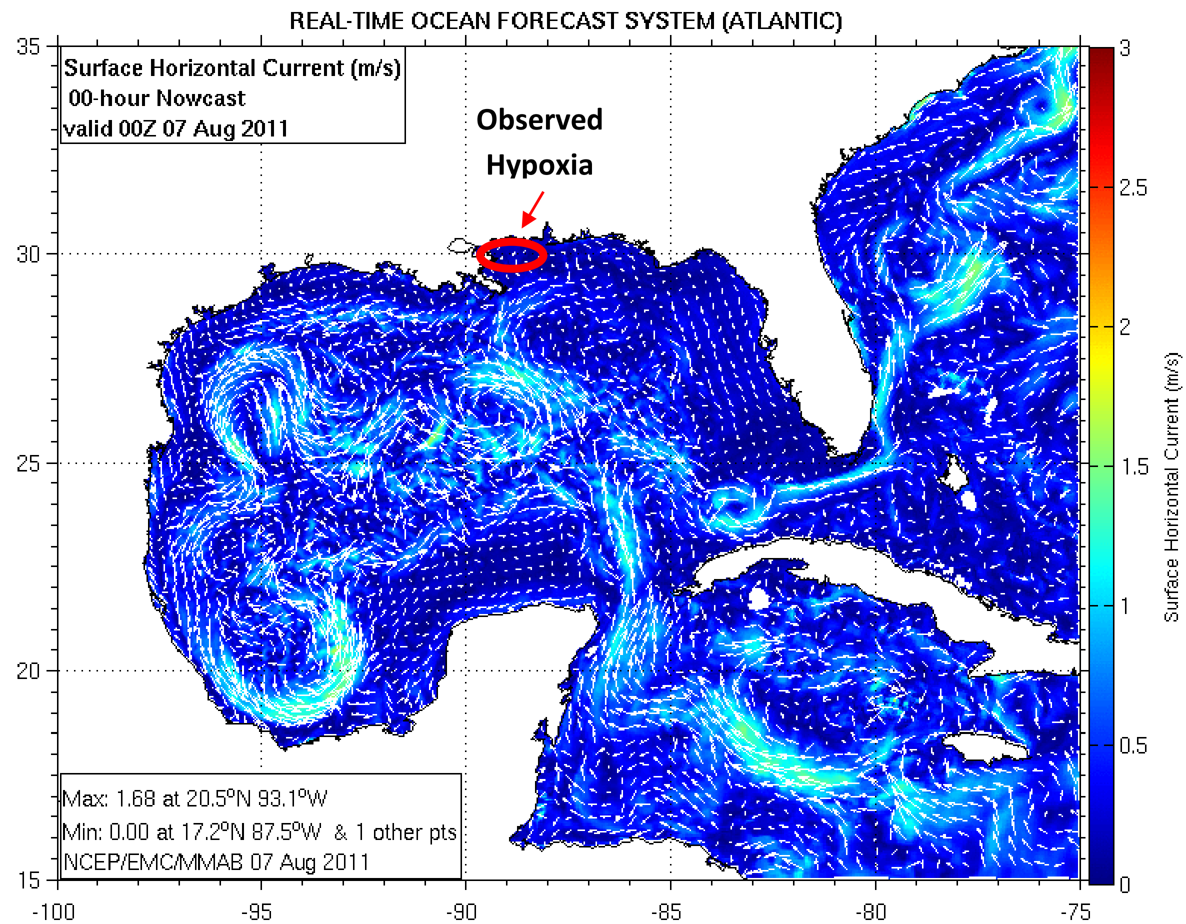

Figure 12: Surface water currents in the Gulf of Mexico on August 7, 2011 showing the low speed currents that are present in the summer and how the hypoxic area east of the river is out of the main current (from NOAA: EMC Modeling and Analysis Branch, http://polar.ncep.noaa.gov/ofs/viewer. shtml?-gulfmex-cur-0-large-rundate=latest).

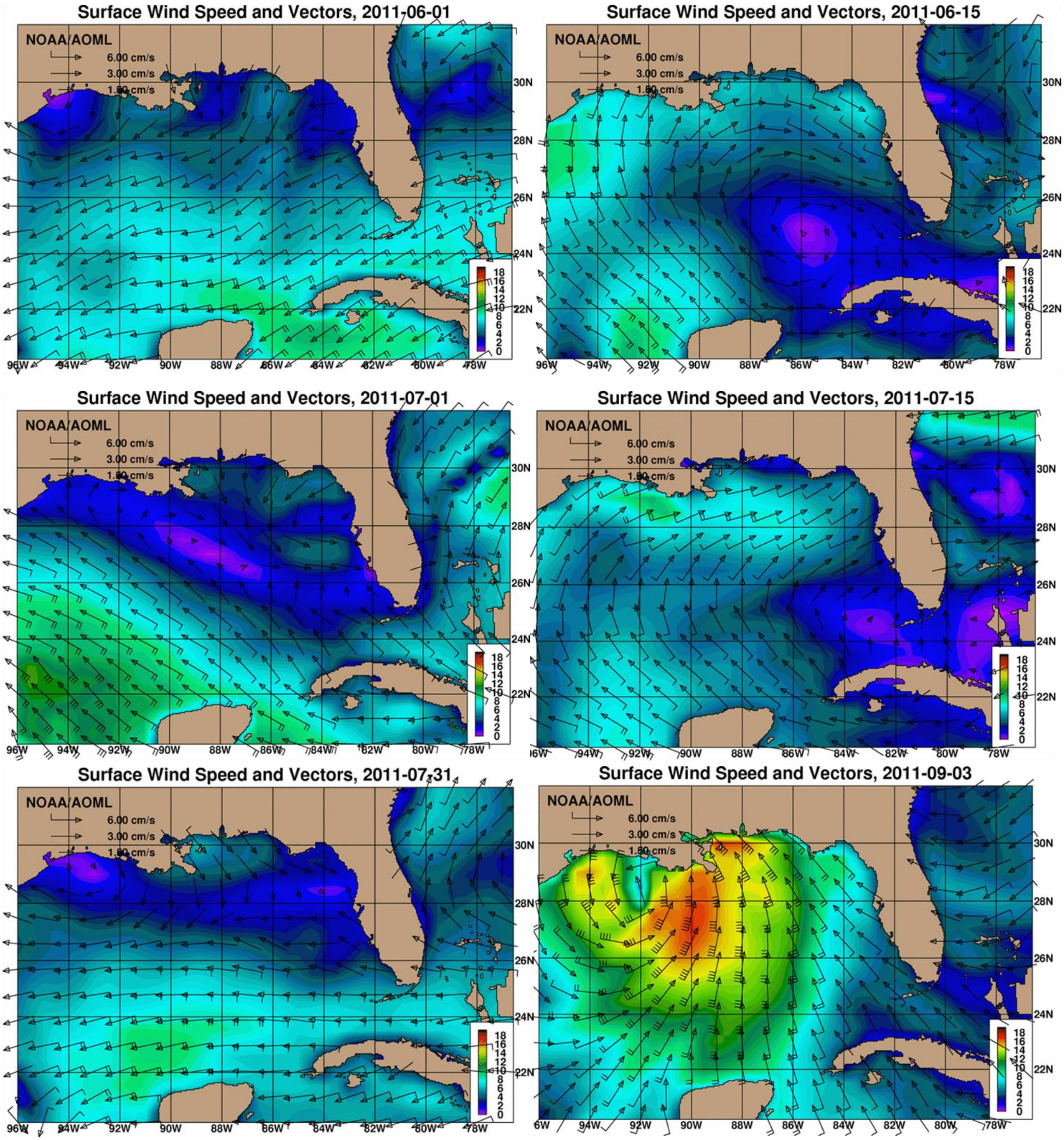

Figure 13: Surface wind speed and direction in the Gulf of Mexico from June 1st (top right) to July 31st, 2011 (bottom left) and on September 3rd, 2011 during Tropical Storm Lee (bottom right). Notice very low winds speeds in the Gulf of Mexico in general and in the hypoxic zone during the summer when hypoxia develops (from NOAA: Monitoring the Gulf of Mexico Conditions, Numerical Model Outputs, http://www.aoml.noaa.gov/phod/dhos/models.php).

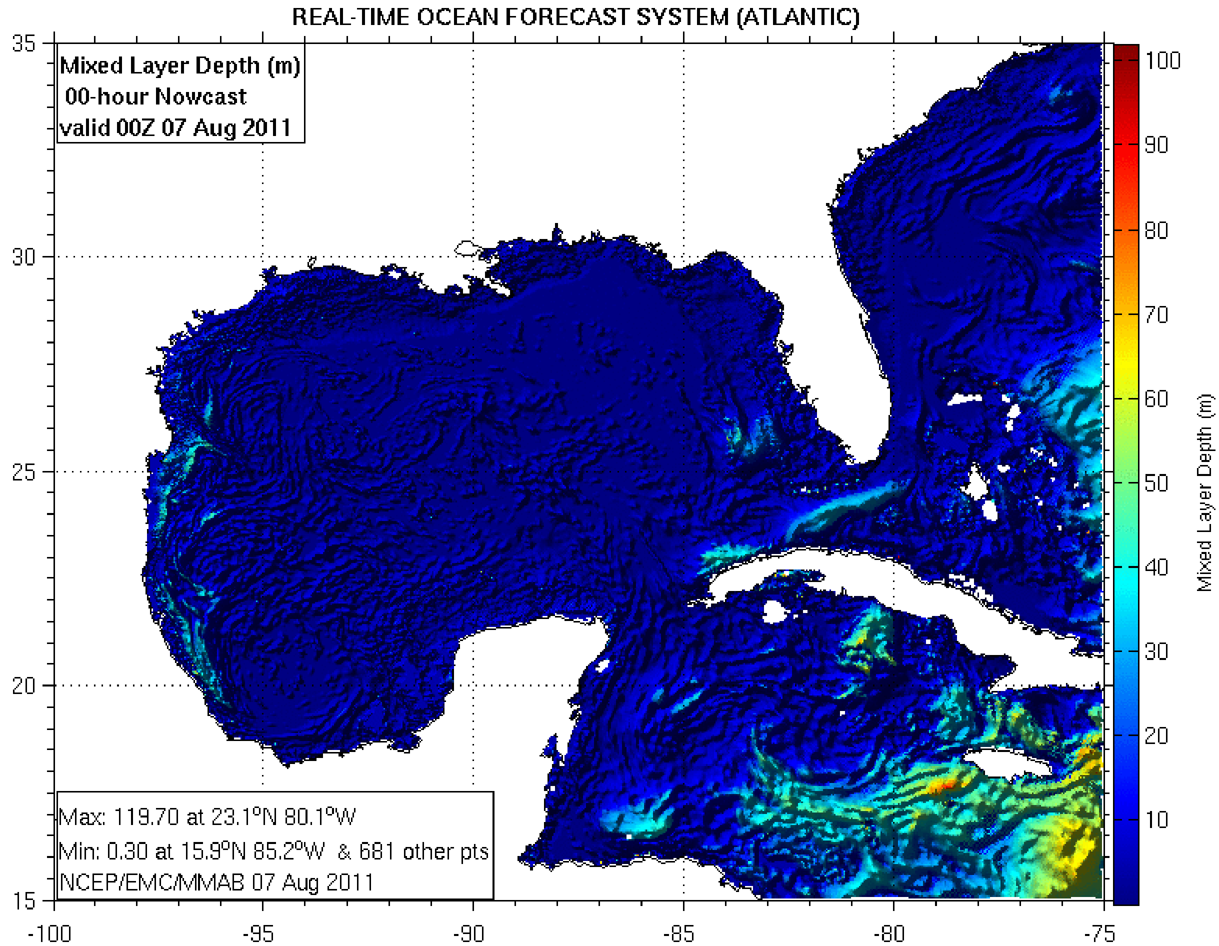

Figure 14: Mixed layer depth, defined as a nearly isothermal surface layer caused by wind stirring and convection, in the Gulf of Mexico on August 7th, 2011. This shows that there is very little vertical mixing in the summer (from NOAA: EMC Modeling and Analysis Branch, http://polar.ncep.noaa.gov/ofs/ viewer.shtml?-gulfmex-cur-0-large-rundate=latest).

It is important to move forward from speculation of the cause of hypoxia and find the actual cause or causes. To ascertain the cause of the hypoxia in the Chandeleur Sound and Coastal Mississippi, monitoring of the area will continue in the future. LPBF will continue to partner with MRAC to monitor the Chandeleur Sound area. The goal is to expand the research program to include multiple samplings during the hypoxic event to determine when hypoxia develops and when it disappears. LPBF will investigate the predicted local and regional currents to determine if the hypoxic area is indeed outside of the prevailing current path and therefore stratification develops readily. LPBF will collaborate with other agencies to ascertain the full extent of the hypoxic zone (it most likely extends past the Mississippi/Alabama boarder but how far past is undetermined).

LPBF will encourage LUMCON to continue the monitoring it conducted in 2011, and LPBF will contact agencies in Mississippi and Alabama to monitor the coastal regions for hypoxia. This would be a larger joint sampling effort as samples will need to be collected around the same time following similar protocols so the data can be combined and compared. Additionally, studies into the effects of this hypoxia on the ecology of the area are also needed. Finally, the Chandeleur hypoxic area will be compared to other hypoxic events, such as the one west of the mouth of the Mississippi River.

Summary

In the three years surveyed (2008, 2010, and 2011), hypoxia was detected in the Chandeleur Sound area. It is strongly expected that the hypoxia is an annual, seasonal event. In 2011, it was determined that the hypoxic zone extended farther east into the open Gulf of Mexico making the known area of hypoxia approximately 1,050 square miles. The pycnocline developed at similar depths in 2010 and 2011, ranging from 15 to 25 feet deep. Shallow oxygenated water has distinctly higher temperatures and lower salinities than the deeper layer. The ecological effects and organism death due to the hypoxia has not yet been determined and is an area of future research.

Currently, the exact cause of the development of the hypoxia is unknown but we speculate that it may develop primarily due to the seasonal low-energy conditions that are conducive to the development of stratification, which prevents mixing and ultimately leads to hypoxia. This low energy condition is a result of the combined effects of the typical seasonal meteorologic and oceanographic patterns for the region. If this is the cause, hypoxia most likely develops, in this region, under normal conditions (low wind, high temperature surface waters, and no tropical systems) during early to mid summer. Contrary to the dead zone elsewhere in the Gulf, excess nutrients may not be the primary driver of the hypoxia in Chandeleur Sound.

Monitoring of the hypoxia in Chandeleur Sound will continue and there are plans to expand the sampling program if adequate funding is available. LPBF anticipates partnering with other agencies to expand the areal extent of the sampling effort to determine the actual, complete size of the hypoxic zone. Determining the effect of the hypoxia on the ecology of the region may also be a focus in the future.

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