Innovative Environmental Sampling During the Summer of 2010 in the Western Gulf of Mexico

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Abstract- The recent Gulf of Mexico (GOM) oil tragedy is emphasizing the importance of collecting sound, real-time ocean observations through collaborations of academia, government, and industry. Ocean observing systems (OOS) provide continuous data for various environmental, oceanographic, and atmospheric parameters. Many systems, such as moorings and buoys, are in fixed locations providing excellent time series, but are limited in spatial coverage. To improve spatial and temporal resolution, a Sea Sciences Inc. Acrobat system was deployed in summer 2010 to aide in the cross-shelf sampling of the western GOM coastal waters as part of a multi-year National Oceanographic and Atmospheric Administration (NOAA) to understand mechanisms controlling GOM hypoxia. Two weeklong surveys were conducted in the northern GOM, in which the Acrobat was deployed to determine the spatial and temporal extents of the Louisiana dead zone and the areal extent of the Texas hypoxic region. The data from this state-of-the-art cabled instrument combined with a real-time mooring, Galveston Instrument Garden for Environmental Monitoring (GIGEM OOS), deployed since 2009 provides valuable insight into the spatial and temporal scales of hypoxia on the Texas shelf, as well as emphasizes the need to developing management policies and future plans for surveying the northern GOM to accurately monitor processes responsible for hypoxia and to provide immediate data in the event of an unexpected environmental hazard.

I. INTRODUCTION

Real-time ocean observations are powerful tools for coastal managers responding to environmental coastal hazards. The British Petroleum (BP) oil spill on April 20, 2010 has reiterated that OOS are vital to providing the necessary data to managers in order to make informed and effective mitigation decisions as outlined by the Integrated Ocean Observing System (IOOS). Described by IOOS initiative, coastal OOS should fulfill seven societal goals, including an environmental design, service to variety of coastal users, and useful in natural hazard mitigation [1]. Recently, OOS efforts have shifted focus to the development of regional coastal systems for climate monitoring and hazard mitigation [2]. Additionally, trends in OOS are shifting from stationary platforms and devices and autonomous vehicles to a system combining both stationary and autonomous elements to build more complete and comprehensive solutions to monitoring coastal environments and hazards. Texas A&M University (TAMU) Department of Oceanography is leading initiatives in the Gulf of Mexico to revitalize currently existing systems by adding new instrumentation and survey techniques to assist hazard-monitoring efforts, such as unexpected oil spill disasters to seasonal impacts of yearly and persistent Louisiana dead zone. The Gulf of Mexico Coastal Ocean Observing System (GCOOS) Regional Office is supported within TAMU Department of Oceanography and serves as a data repository and management branch for collaborating among academic, private, and government OOS networks and disseminating data to aid with IOOS goals in the Gulf of Mexico. In addition to GCOOS as an OOS resource, TAMU also includes the Geochemical and Environmental Research Group (GERG) who operates the Texas Automated Buoy System (TABS) built in 1995 to predict oil spill trajectories off the coast of Texas based on ocean currents in the northern Gulf of Mexico. TABS now assists with environmental water quality monitoring and climatology along the Louisiana-Texas (LATEX) coast and is the primary OOS in a major TAMU research initiative to study northern GOM hypoxia. Furthermore, TAMU and GERG researchers are continuing to enhance and increase OOS instrumentation to better improve temporal and spatial monitoring of western GOM hypoxia and to provide support for hazard monitoring.

A. Hypoxia along the Texas Coast

Hypoxia occurs globally and is a condition increasing in severity throughout the world’s ocean [3]. The frequency of hypoxic regions continues to increase and is often attributed to the input of anthropogenic nutrients in coastal waters and an influx of freshwater onto coastal shelves causing stratification preventing atmospheric-water column oxygen exchange [4]. Hypoxia refers
to low dissolved oxygen concentrations in bottom waters of 2.0 mg/l (equivalently 1.4 ml/l) and often is attributed to detrimental effects on marine organisms in coastal ecosystems [5]. The famous hypoxic region in the northern GOM, referred to as the LA dead zone, occurs near the outflow of the Mississippi and Atchafalaya Rivers. The LA dead zone has a traditional seasonal occurrence in the summer months and severity and size of the region is controlled by the anthropogenic sources entering the GOM from the Mississippi River drainage basin and non-Mississippi basin sources, such as coastal upwelling providing organic material to the coastal microbial ecosystem [6].

Studies in past two decades have shown another separate hypoxic system in the northern Gulf of Mexico occurring along the northern Texas coastline. The Texas Parks and Wildlife Department (TPWD) has surveyed heads of the Texas five major freshwater passes from 1998 to 2008 providing initial data of hypoxia occurring from Sabine to Rio Grande coastal waters [7]. Unlike the seasonal LA dead zone, hypoxic areas in Texas waters appeared more frequent and episodic. Studies in 2009 and 2010 conducted at TAMU, have reiterated the same trend in hypoxia along the Texas coast and this trend will be discussed further in this publication. Spatial distinctions in the LATEX areas have redirected hypoxia research in the GOM to determine the sources and processes responsible for hypoxia formation in Texas. Based on TPWD water data and other historical evidence, Texas hypoxia has occurred for 22 of the last 24 years, but events were not entirely in the summer months. Current surveying measures completed by TPWD and the National Oceanographic and Atmospheric Administration (NOAA) National Marine Fisheries Service Southeast Area Monitoring and Assessment Program (NOAA-NMFS SEAMAP) provide coverage of the low oxygen waters on the shelf, but do not investigate the potential processes leading to and sustaining hypoxia formation. A mooring off the coast of Galveston in 2009, the Galveston Instrumental Garden for Environmental Monitoring (GIGEM OOS), provided real-time observations profiling multiple episodic, short-lived hypoxic events starting in late August and continuing early in October [8]. Other moorings in the region, Texas Automated Buoy System (TABS), provide real-time (hourly) observations of surface currents, salinity, and temperature. Data analysis has shown these events to be statistically distinct in formation and unique from traditional Louisiana dead zone, further emphasizing the belief that GOM large-scale hypoxia is not limited or bound to the Louisiana shelf. More so, the recent oil spill has also shown how little is understood on the impact of oil hypoxia formation in the GOM or the effects of oil on the western GOM ecological community.

Comparing the TX shelf to LA dead zone formation, there is no major outflow of anthropogenic nutrients and freshwater into the Texas coast similar as evident with the Mississippi River. However, the Brazos River watershed does discharge freshwater directly onto the Texas shelf, witnessed in the summer of 2007 when Texas experienced an unusually heavy rainfall leading to flooding across the state. Discharge from the Brazos basin exceeded historical values for June and July, resulting in stratification of the waters from Galveston to Freeport, TX. Non-riverine sources, such as benthic biodegradation of organic materials, depleted oxygen concentrations in the bottom waters to severely low levels. The flooding lasted two months until Hurricane Humberto passed over the area, mixing the water column, and re-ventilating oxygen in the bottom layers. According to water gauge data collected by the United States Geological Service (USGS), the Trinity and Brazos watershed have experienced numerous precipitation events leading to significantly higher...
flow rates and volume transports than expected for this time of year in the historical records (Fig. 1).

Current surveying methods led by NOAA (NMFS-SEAMAP) and TWPD continue to provide a general spatial survey of Texas hypoxia from early summer to early fall months, but these cruises do not extend into determining the processes leading up to and sustaining hypoxia in the coastal waters. Recently, as part of the multi-year Mechanisms Controlling Hypoxia (MCH) project, at TAMU are documenting the spatial and temporal scales of GOM hypoxia and are determining the riverine and non-riverine processes responsible for a separate hypoxic region in the northern Gulf of Mexico (hypoxia.tamu.edu). Two major components in this NOAA-funded (NOAA Center for Sponsored Coastal Ocean Research NA09N0S4780208 & NA06N0S4780198) project include two moorings, including the Galveston Instrument Garden for Environmental Monitoring (GIGEM OOS), and a series of northern Gulf of Mexico shelf-wide surveys using a state-of-the-art towed cable system, the Sea Sciences Inc. Inc. Acrobat (Fig. 2). GIGEM OOS monitors coastal waters and provides real-time data to investigate the processes controlling Texas hypoxia. Analysis from the summer of 2009 showed Texas hypoxia to be episodic on order of 18 to 36 hours, frequent, and not present at this location until late August. Short-lived hypoxic events continued until early October and correlated to atmospheric disturbances over central and south Texas contributing fluxes of freshwater to Texas shelf allowing strong stratification and ultimately hypoxia. Preliminary data from deployment in 2010 has shown statistically unique differences from the summer of 2009, mainly with immediate formation of hypoxia occurring at this location in early June and continuing in conjunction with freshwater pulses potentially related to La Nina wet season in central Texas. GIGEM OOS remains to be the only coastal OOS collecting real-time environmental water quality measurements on the Texas shelf however, but is limited in the spatial extent to really understand the processes influencing formation of hypoxic regions in Texas.

To improve spatial resolution along the Texas shelf, a Sea Sciences Inc. Acrobat system was deployed June and August 2010 as a new component in MCH project (Fig. 2). Work presented details the results from the first Acrobat deployment in the western GOM and the integration of this data with historical data to understand the impact of environmental hazards on the Texas shelf. Analysis will include results from data integration into developing managerial approaches to studying GOM coastal waters and the future of hypoxia science, included advances in data visualization, policy management, and coastal community outreach. Future extensions include compiling Acrobat data to a geographic information system (ESRI ArcGIS 9.3) for fast response to coastal hazards, 3D visualizations, and methods for incorporating the coastal communities in understanding the coastal ocean environment and the need for future GOM OOS to protect against ocean hazards.

II. METHODS

A. The Sea Sciences Inc. Acrobat Design and Deployment

The Acrobat is a lightweight, computer-controlled vehicle towed by a cable behind small boats in coastal shallow waters (http://www.seasciences.com/lv.htm) (Fig. 3). The system is designed to hold a wide variety of oceanographic sensors that provide real-time data from the water column to the scientists onboard. The Acrobat operates with 5 standard underwater profiles: constant depth, constant altitude above the bottom, constant undulation between two depths, adapting undulation between a set depth and varying bottom, and maximum number of undulations between two survey positions. Essentially, the system oscillates up and down in the water column in a short period of time from as quickly as 25 seconds to 90+ seconds to reach the bottom and back to the surface. For MCH MS deployments, the Acrobat was flown from depths of 2 – 3 meters below the sea surface, dependent on surface wave height, and 1 meter above bottom in approximately 10 – 40 meters of water for cross-shelf track lines across the Louisiana-Texas continental shelf. Additionally, the oscillation rate was maintained between 50 and 75 seconds depending on the oxygen levels in a particular area. If the waters were hypoxia, the Acrobat was manually programmed to spend longer period of time at the bottom depths, which was controlled by the drivers.
The Acrobat includes a customizable instrument rack capable of integrating with a range of major oceanographic companies’ sensors (Fig. 3). The Acrobat instrument cage is equipped with 5 additional sensors. The instruments on the body are: a Seabird CTD, two types of dissolved oxygen sensors (Seabird Electronics SBE-43 19plus V2 and RINKO III Galvanic O2 ARO CAV Micro-sensor, and two fluorometers (WETLabs ECO CDOM). Two types of oxygen sensors were used to understand how sampling rates could impact the validity of the measurements. The RINKO III is a fast response optical sensor capable of providing oxygen saturation in less than 1 second with a resolution of 0.4% and accuracy of ±2%. The model is operated with a DC 12V and compatible with CTD-RMS. Due to the fast response time, the instrument experiences no difference in dissolved oxygen profiles on an upward or downward cast of any platform it is attached. The design specifications made it a suitable model to compare with the Seabird SBE-43, which showed a time lag during sampling when attached to the Acrobat during test flights in 2008 and 2009.

The Acrobat was deployed from the NOAA R/V Manta at any time during night or day depending on the ship’s location and the desired track line. Due to an engine malfunction, three days were cut from the weeklong cruise and the Texas coast tracks shown in Fig. 2. Before each flight, the sensors were clean and calibrated if necessary. The system was deployed and cable was paid out to a ratio of 1:2.5 meters of cable to water depth, allowing for Acrobat to safely maneuver with the preprogrammed flight plan detailed above. Data were recorded internally to a computer hard drive based on the track line label for preliminary QA/QC while on the R/V Manta. Flights were conducted for 4 to 8 hours at a time depending on the conditions of the sensors or adjustments to ship’s demands. There were no major malfunctions with the system or any instrument however; one incidental issue did cause an unexpected recovery. When surveys were conducted closer to coastline, the Acrobat flew through large patches of Sargassum, a macroalgae common to the GOM. The clumps attached to the cage would alter the buoyancy of the cage by not keeping an equal weight on all four corners and cause the Acrobat to either surface or struggle to maintain a programmed flight plan, i.e. not be able to consistently dive or rise to the surface. If this happened, the Acrobat would be recovered, cleaned, and immediately redeployed in the same location. Overall, the system and sensors encountered no major setbacks and flew approximately 28 total hours of the three-day cruise.

B. 2010 GIGEM OOS Mooring Design

In 2009, two main components of the GIGEM OOS mooring were deployed off an experimental wind farm platform maintained by Wind Energy System Technologies Inc. [9]. The components, a mooring and acoustic Doppler current profiler (ADCP) mounted in a trawl-resistance bottom mount (TRBM), was deployed 70 meters and 140 meters respectively from the northeast side of the platform. The electronics and computer system is housed in a protective shed on the platform and data is sent back in real-time through a Globalstar satellite connection. The data transmitted soundly from June 23, 2009 until early October 2009 from the SBE-44 IMP-IDO Microcats. The NAS 3E Chemical Nutrient Analyzer was not recovered and ISUS V3 Optical Nutrient Analyzer did not transmit data in real-time during the entire deployment. The data from the mooring stopped transmitting on October 18 and a dive team sent to recover the mooring discovered that the mooring sensors and cable were stripped from the ADCP bottom package. Only the ADCP was recovered for maintenance and preparation for the summer 2010 deployment.

For the 2010 GIGEM OOS deployment, the sensor array was built similar to the 2009 design [10] (Fig. 4). The SBE units were placed at 13, 12, 6 and 1 meter above the bottom and the NAS at 6 meters above the bottom. The major change for the system deployment in 2010 was cabling the mooring inside the platform’s center instead of 70 meters.
away to prevent repeat vandalism and losing the package. The ADCP was cleaned and redeployed back into the TRBM at its original location 140 meters from the platform. The electronics and communication system remained intact through the year and was rebooted once the instrumentation was in place. The mooring went online on June 6th and has been recording real-time temperature, salinity, oxygen, nitrogen, and current data. A maintenance cruise was conducted on July 11th to repair a cable connection between the mooring and the computer as a result of corrosion from intense amount of summer rain in the platform vicinity and to clean biofouling off the sensors.

C. Quality Assurance/Quality Control (QA/QC)

Oceanographic data collected during TAMU or GERG projects undergo two orders of QA/QC. The first order involves outlier removal and statistical and calibration comparison for sensors. Outlier removal includes both statistically significant removal and gross outlier removal, which is determined by comparing the collected time series for the entire cruise. The sensors also undergo post-cruise calibrations according to specific manual specifications and the calibration standards are compared to the data collected during the cruise. Additionally, sensor data are compared with similar spatial observations from previous cruises, historical limits, and with calibration coefficients determined before and after deployment in a laboratory setting. The second order involves the recovery post calibration and advanced statistical analysis, including post-calibrations of datasets after instrument recovery and the partitioning of variance. The QA/QC procedures are necessary before publishing data products and to determine the maintenance cycle for the instrumentation implemented in future 2010 cruises and to help identify offsets between different types of sensors used in the mooring and the Acrobat cage. All data collected are formatted and published into function American Standard Code for Information Interchange (ASCII), with header data describing the time, depth, flight path, and parameters relayed by the Acrobat cable and mooring computer. Data will be compiled and distribute to GCOOS and served via the web through the GCOOS Data Portal, the National Data Buoy Center (NDBC), and archived to the National Ocean Data Center (NODC).

While the Acrobat is flying, data is transmitted instantaneously through the cable and stored on a hard drive inside the boat. The data are downloaded and are in the process of undergoing two orders of QA/QC, which is standard procedure for ocean observations at Texas A&M University and GERG laboratories. Currently, the data are in preliminary stages of the first order of QA/QC, where data are examined for outlier removal and undergo statistical and calibration comparisons for each sensor. The Acrobat system data are also plotted and matched to the ship’s GPS track to ensure the locations align and to include any post calibrations for ship speed if necessary. The CTD data on the Acrobat are currently being compared to the values collected on the stationary CTD deployments during the cruise and compared against previous cruise data from past Mechanisms Controlling Hypoxia surveys with the Acrobat. The WetLabs ECO CDOM data collected from the two sensors has not been analyzed, but analysis will start at the end of the summer after the second survey cruise is completed. The oxygen sensors data are being compared to each other and against past sampling stations to validate the voltages and to determine if there is a lag effect from the sensor based on the sampling rate. The sampling rate of the SBE is longer and during Acrobat test flights last summer, the lag was determined to be approximately 1.25 seconds to the Acrobat flight path. This lag was applied to the oxygen data archived from the SBE-43 and the corrected data is being compared to the RINKO III results.

Following similar procedures to 2009 GIGEM OOS deployment, the data transmit to GERG every half hour and are transformed immediately into graph products displayed for public access on a website monitored by TAMU Department of Oceanography and GERG (http://tabs.gerg.tamu.edu/hypox/) [11]. The QA/QC first order procedures are conducted before publication to data products and include profiles of currents every 3 meters from surface to bottom, wave characteristics (period,
energy, height), and water quality (temperature, salinity, dissolved oxygen, nutrients). Data values are formatted into ASCII, then adjoined with header information about time, date, location, etc., and placed in a zipped folder online accessible for free. Zipped files are updated every 24 hours and the graphs update and are available to download on the quarter-hour every 24 hours. After the mooring is retrieved, the entire data series will be processed for submission to GCOOS, NDBC, and NODC after undergoing second order QA/QC. After analyzing issues with deployment last summer, this summer’s deployment was minimized to a one-day multi-stage effort. Instrumentation was provided by TAMU Department of Oceanography and GERG, with GERG technicians conducting mooring assembly two months prior to the deployment in June. The weather cooperated and deployment was finished in 14 hours with a series of divers and GERG technicians. GIGEM OOS will be recovered in late September or early October 2010, in which the system will undergo servicing, calibration, and storage for remainder of the year. The system has proved beneficial in providing water quality data during the 2010 hypoxic season and BP oil spill and deployment in summer 2011 is currently in discussions.

III. RESULTS

A. Sea Sciences Inc. Acrobat Results

As part of the MCH Survey cruises, the Acrobat will be flown throughout the western GOM as seen by the track lines crossing from Texas into Louisiana (Fig. 2). In June, the first survey cruise was severely limited in spatial coverage due to a ship engine malfunction accounting for the parallel tracks lines as opposed to a cross- and along-shelf track providing ample coverage for interpolating a hypoxic area coverage on the LATEX shelf. Despite this setback, the Acrobat proved successful in acquiring an extensive data for investigating hypoxic formation on the northern Texas shelf.

Figure 6 is a series of panels for MS track A13, the closest track to GIGEM OOS and only TX cross-shelf tracks conducted on the June survey cruise. Each panel isolates a depth range from 12 meters to ~17.5 meters, which is the deepest depth programmed into the Acrobat flight plan. From the entire track, hypoxic oxygen levels were extracted and plotted at points along the track. The Acrobat collected 49,246 instantaneous points on this track, oscillating from approximately 1 meter to ~17.5 meters over the course. The sample points are collected from the GPS unit on the Acrobat’s computer and projected in WGS84. The red segments represent hypoxic points at depth bins. For example, 12 meters includes depth bins from 12.0000 to 12.999 meters continuing to 17.999 meters. Orange segments on the track are sample points within the depth bin that are oxygenated, or above 2.0 mg/l. Any area of the track with no samples in the bin range are shown in dark gray and may be areas where the system was either being deployed, recovered, or adaptations were made to the flight plan to mitigate a potential problem. Due to the sampling density, it is difficult to see breaks in the track for the following reasons, including maintenance recoveries to remove Sargassum or to clean the sensor pumps.

Preliminary analysis shows the track line to be approximately 17 nautical miles with over 8 nautical miles of hypoxic bottom depths, equating to half of the track experiencing hypoxic values at near bottom depths. When examining histograms of the oxygen data for both hypoxic segments, oxygen levels are concentrated between 1 and 1.5 mg/l (Fig. 7). Values at or below zero are most likely correlated to deployment and recovery when the Acrobat was not in the water. Extremely low oxygen to anoxic levels are seen in the MS 1 GA track heading back into Galveston Bay and sea floor values may be as deep since the Acrobat flies 1 to 2 meters above bottom. When examining panels of oxygen values for the entire track, the majority of values are oxygenated,
recording between 6 and 7 mg/l (Fig. 7). Higher values were recorded on tracks completed near the LATEX border, but values have not been correlated at surface depths with sea state or wind conditions. Another interesting feature on the histogram is the cyclic pattern of oxygen levels around 1, 3, and 5 mg/l, which is being further investigated after the QA/QC completion. The final panel shows the SBE-43 IMP-IDO oxygen values for all sample points collected on track A13. The colorbar shows oxygen levels in mg/l against water depth in meters. The purple line marks the hypoxic (< 2.0 mg/l) boundary, which total 3,720 data points. The majorities of upcast and downcast oscillations of the Acrobat are mostly coherent in the upper water column and start to deviate as Acrobat flies below 12 meters. Additionally, the hypoxic layer on A13 is not limited to the bottom waters, but extends up to slightly above 12 meters, which is about 7-9 meters above the sea floor (Fig. 8).

The last oxygen representation of Acrobat data from MS1 A13 is Fig. 8. The plot maps oxygen values by latitude in decimal degrees (projected in WGS84) against depth in meters. The 2D profile plots approx. 40,000 sample points collected by the Acrobat in June 2010. The oxygen values for all depths are colored with reds representing oxygenated waters and dark blues representing hypoxic waters. The most noticeable feature on the plot is the volume of the hypoxic zone varies with latitude as indicated by the differentiating depths of the blue points in the bottom corner moving towards the bottom right corner of the plot. Though latitude is not plotted, the distributions do show a change in latitude with blue values behind orange values up to 6 to 8 meters above the bottom. The hypoxic zone is thick (4-5 meters) until the Acrobat flies over a shoal starting at -94.7 degrees, in which the waters become oxygenated. After passing the shoal, the bottom waters briefly become hypoxic again as track continues further from Texas coast. Another unique feature on the plot are the zonal changes in oxygen from the surface to the bottom, indicating changes in oxygen zones consistent with fluctuations in the pycnocline. Additional oceanographic data is undergoing QA/QC and will be compared with the oxygen values to determine the shift of the pycnocline and upwelling boundaries on the Texas coast contributing to the hypoxia formation. The oxygen data will be analyzed in 3-D visualization platforms in ESRI ArcGIS 9.3 and Fledermaus to statistically analyze how the vertical density and volume of the Texas hypoxic zone changes and differs from the LA dead zone. The ability of the Acrobat to collect large oxygen datasets over a short time will be invaluable to determining the processes responsible for the spatial and temporal formation of Texas hypoxia and to truly understand how hypoxia varies across the northwestern Gulf of Mexico.

Figure 9 plots the distribution of temperature and salinity collected from MCH MS1 A13. The top panel shows the distribution of temperature for the entire track with an oscillation evident between warm, surface temperatures and rapid decrease in temperature in the pycnocline at 25°C. The high density of colder waters is the points taken from 16m and below. The vertical water column range for A13 ranged from 28.2°C to 23.8°C. When compared to GIGEM OOS temperature collected in 2009, the average surface temperatures were about 1.0 – 1.5°C cooler in 2010. This slight change is most likely attributed cooler temperatures in early 2010 summer from the excessive storms and precipitation events. The second panel in Fig. 9 plots the salinity histograms and most evident spike is range of values between 33 and 33.5 PSU. When compared to GIGEM OOS 2009 data, the overall distribution was less saltier, implying more fresh water flowing out on the coastal shelf in 2010 than in dryer 2009 summer. The largest spike in the distribution is currently being analyzed spatially to determine the lateral and vertical extent of fresher water on coast.
A month after deployment, GIGEM OOS sensors went offline. When performing a maintenance cruise, technicians found the mooring cable pulled into one of the platform legs and most likely be shifted after being caught on fishing lines. Efforts were made to restore the cable position and connections from the instrumentation to computer were repaired. The top and middle depth sensors continued to record however, the bottom sensor stopped recording in mid-July. Additional maintenance cruises are in planning stages to repair the mooring and secure the mooring with sturdier, heavier anchor weights within the platform legs. The nutrient data are internally recording in the NAS 3E Chemical Nutrient Analyzer and will be recovered in late September 2010. Despite setbacks, the data collected in June and early July, currently undergoing QA/QC, are showing unique differences from the profiles collected in June 2009.

In Figure 1, monthly water gauge levels for the Trinity and Brazos watersheds are significantly higher than the historical median levels. As atmospheric conditions shift into a La Nina cycle, Texas experiences unusually wet summers and even flooding in the south-central areas. In addition, Gulf of Mexico hurricanes and tropical storms have added to the coastal freshwater inputs and the impact has extended as far south as the Rio Grande Valley, which severely flooded due to Hurricane Alex in July 2010. The wind patterns along Texas coast were unusual, in that winds did not blow in the traditional upcoast and offshore pattern, but rather were weak or reversed in response to unusual atmospheric conditions [12]. The combinations of these unusual factors allowed for Mexican salty surface water to travel onto the Texas shelf as the coastal currents reversed and potentially weakened the stratification potential along the shelf, which is evident in the histogram (Fig. 9) [13]. Due to flooding events from central Texas storms, the freshwater inflow reached the coast about three weeks after allowing episodic and severe stratification resulting in hypoxic areas of up to 6 meters off the bottom. Comparisons with TABS Buoy B show lower salinities three weeks after major Texas precipitation event, indicating fresher water moving downshelf and allowing strong stratification and resulting in longer, more persistent hypoxic region than witnessed in 2009. This pattern is also seen in the GIGEM OOS data (Fig. 11). In June 2009, there was one short hypoxic event at the platform whereas the same location is hypoxic immediately when GIGEM OOS is deployed on June 6th, 2010. More so, the hypoxic volume is greater than previous events in 2009, reaching up to the middle sensors at 12 meters above bottom. Based on evidence from both the Acrobat and GIGEM, the data provide significant detail for how little is still understood about the spatial and temporal extent of Texas hypoxia and the processes responsible for Texas hypoxia, including how the Texas system varies from LA dead zone.

IV. DISCUSSION AND FUTURE DIRECTIONS

As with any oceanographic field project, setbacks happened with both Sea Sciences Inc. Acrobat and GIGEM OOS in the early summer. Despite issues out of researchers’ control, large quantity and high quality data series was still collected from the first MCH survey cruise (MS 1) in June. The data collected revealed an opposite occurrence of Texas hypoxia from observations last summer. Both sampling methods each contributed unique and significant observations valuable to truly understanding the processes and formation of Texas hypoxia. Both OOS were successful in providing real-time environmental temporal and spatial water quality data pertinent to this investigation. The second MCH survey cruise will be conducted from August 1st to 7th, 2010 and if no complication arises, a 16-track along- and cross-shelf sampling plan will be conducted. Completing this survey will provide another large dataset to understand the areal and volume extent of hypoxic areas over the entire northern GOM. Additionally, repeating track lines will allow researchers to also investigate temporal coverage of varying hypoxic areas in the northern GOM to more effectively accomplish the management goals of IOOS coastal monitoring efforts and aid in better coastal hazard management programs for future decades.
From initial analysis of A13, data show that Texas hypoxia does not follow a similar seasonal pattern to the traditional summer formation of the LA dead zone and does not exhibit as same spatial and temporal profiles. Based on the track surveys and comparisons to SEAMAP data products, Texas coastal hypoxia is not a large continuous spatial area, is more frequent and episodic, and sensitively responds to freshwater pulses from small-scale river discharges than compared to consistent outflow of the Mississippi River. The Acrobat is an extremely valuable tool for truly mapping the oxygen values on the shelf in a relatively short amount of time and effort, allowing better estimates of spatial area and volume vital to significantly calculating separations between GOM hypoxic zones. In Ref. 14 and 15, Mullins et al. and DiMarco et al. described GIGEM OOS contribution a valuable system for examining the temporal extent of Texas coastal hypoxia and the role of stratification based on oxygen ($\delta^{18}$O) isotopes from Brazos and Trinity freshwater outflow as major process responsible for potentially persistent hypoxia at times of high flow and episodic events at times of low flow [14][15]. The yearly atmospheric variability also proved important in emphasizing the variability of Texas coastal hypoxia compared to the LA deadzone and stresses the need for continual monitoring and more efficient and effective survey methods possible with a towed system. The MCH survey cruises will continue through summer 2012 and we hope to continue operation of GIGEM OOS in the future for long-term environmental monitoring off Galveston Bay as an additional data collection resource in the event of a major coastal hazard.

To respond effectively to environmental hazards, it is necessary to sample in situ to cover spatial and temporal needs for understanding impacts on the coastal ocean. Data acquisition is important to know the current state of the environment, but is also crucial to building predictive models in order for response to large-scale hazardous events in the GOM. Testing the reliability of model output can only be accomplished by the continued addition of real-time observations for model validation. In conjunction with GIGEM OOS, the results from summer 2010 reveal the areal and temporal structure of hypoxia on the Texas and Louisiana shelves differs significantly between yearly summer seasons and monthly with a summer season. On the Texas shelf, results continue to show that hypoxic formation deals largely in part to physical processes, such as freshwater pulses entering from the Trinity and Brazos watersheds allowing the Texas shelf to stratify long enough for severe hypoxia to occur. Based on GIGEM OOS data from last summer combined with GIGEM OOS data and the Acrobat data from this summer, the hypoxic conditions on the Texas shelf may change more rapidly than conditions on the Louisiana shelf. Continuing to investigate these hypoxia dynamics will allow researchers to continue to how sensitive the variability can be in the northern Gulf of Mexico from season to season and more so, the need to reevaluate the Gulf of Mexico dead zone as one large-scale system.

Though tragic, the BP oil spill event of 20 April 2010 has shown researchers and coastal communities the necessity to meet the IOOS societal goals of protecting and restoring coastal ecosystems and improving coastal weather and ocean predictions. As seen this past summer, GOM is susceptible to severe environmental hazards that can persist for months and severely impact the coastal environment. One of the major difficulties with investigating such events is the ability to respond efficiently and effectively due to increasing costs for ship time and acquiring appropriate instrumentation. The Sea Sciences Inc.
Acrobat offers a viable solution for obtaining real-time and large-scale spatial data to understand environmental hazards affecting the coastal waters. In addition to investigating processes controlling hypoxia in the Gulf, the Acrobat is vital cost-effective in providing shelf-wide data to integrate into modeling efforts, monitoring environmental response to the BP oil spill, and for orchestrating environmental management policies for the Texas coast.

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