Real Time Monitoring of Water Quality Parameters in Corpus Christi Bay to Understand Hypoxia

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Abstract- **Corpus Christi Bay (Texas, USA) is home to the nation's seventh largest port with numerous petrochemical facilities. This shallow wind-driven bay (average depth 3m) is very dynamic, and is typically a well-mixed system. However, the water column becomes stratified during the summer months in the south-east portion of the bay, and so dissolved oxygen (DO) in the upper-layer water column is not able to mix with the lower-layer water column. Therefore, an hypoxic condition can develop at the lower portion of the water column in the bay, and as this bay is very stochastic in nature, this condition lasts on the order of hours. It is difficult to 'capture' this kind of episodic events through discrete sampling at limited locations in the bay. Our research group has developed an integrated data acquisition system which can measure horizontal and vertical variation of various water quality parameters 'synchronically' over a highly-resolved spatial regime. Also, software has been developed in our laboratory which can display the horizontal and vertical variation of these parameters in real time and thereby, guides in determining the spatial extent of the water quality parameters of interest. As part of our routine monitoring of Corpus Christi (CC) Bay, we conducted an east-west transect of the bay's ship channel on November 29, 2006 and March 22, 2007. The data collected by our system suggests that the inverse estuary situation exists in the ship channel, i.e., the water becomes more saline and dense as we moved away from the mouth of the Gulf of Mexico towards the bay interior. The prevailing south-east wind on those days 'pushed' the high saline water from the mouth of the Laguna Madre and Oso Bay toward the ship channel. The preliminary results of the hydrodynamic model developed by our research collaborators showed the similar circulation pattern. Integrating the model with the observed data will help us in characterizing the stratification pattern of the bay and therefore, greater understanding of the hypoxic phenomena. Also, particle concentrations measured by a particle sizer (one of the instruments in our suite of instruments) are well correlated with the acoustic backscatter intensity measured by our acoustic Doppler current profiler. This kind of relationship is very important because it provides a greater capability to characterize the particle dynamics of the bay. Particles can transport 'particulate BOD' (biochemical oxygen demand), thus affecting hypoxia. Quantification of the particle influx/outflux to the Gulf of Mexico through the ship channel may help us to understand the contribution of the ship channel effects on hypoxia in the bay.**

Keywords- hypoxia, inverse estuary, water quality and real time monitoring

I. INTRODUCTION

Hypoxia develops when the concentration of dissolved oxygen (DO) in a water body dips below 2 mg/l; most aquatic organisms cannot survive under this condition. In the summer months, portions of Corpus Christi (CC) Bay (Texas, USA) routinely experience hypoxic events. Various factors such as eutrophication, water column stratification, geomorphology of the bay, meteorology etc. may contribute to the development of hypoxia [1]. Texas researchers have concluded that eutrophication is not the likely cause for hypoxia in this particular bay since, over the past 14 years, freshwater inflow rates into the bay have decreased and nutrient levels have not changed significantly [2]. Although water column stratification is a possible cause for hypoxia, CC Bay would not be considered a likely candidate for stratification because it is a shallow wind-driven bay (average depth 3m) with an expected high-level of mixing. However, hypoxic events occur in the southeast portion of the bay, near the Laguna Madre and at the mouth of nearby Oso Bay [3]. On closer inspection, quiescent periods, when combined with tidal cycling and inflows of hypersaline water (up to 60 psu) from these two adjoining water bodies can lead to conditions favorable to stratification in Corpus Christi Bay.

A stratified water column can become mixed through several mechanisms, including double-diffusive instabilities driven by unstable salinity or unstable temperature, shear or Kelvin-Helmholz instabilities, and advective instabilities. The relative importance and distribution of these instability mechanisms in controlling stratification of CC Bay could help in predicting the spatial and temporal extent of an hypoxic event. Analyzing parameters such as temperature, salinity, particle concentration and vertical shear structure of the water column can aid in understanding these mechanisms. However, monitoring of water quality parameters and environmental indicators poses a challenge due to the spatial extent and dynamics involved, and since CC Bay is a dynamic system, it is not possible to fully capture the conditions that lead to episodic events (such as hypoxia) through discrete sampling. As such, it is necessary to measure these parameters at higher spatial and temporal resolution.

Over the past several years, our research group has been expanding our monitoring system in CC Bay. This system consists of observational remote, fixed and mobile platforms equipped with real-time sensors. A vertical profiling robot is installed on each of the fixed platforms and can measure the vertical variation of various water quality parameters (e.g., dissolved oxygen, particle size/concentration, chlorophyll-a, salinity, temperature, etc). One of the fixed platforms is located where hypoxia has been observed every summer since 1988 [4]. Our mobile platform (i.e., research boat) is equipped with an integrated data acquisition system that can measure a similar spectrum of environmental parameters 'synchronically' over a highly-resolved spatial regime in an undulating (vertical sinusoidal) pattern.

In this paper, we discuss the use of our mobile system to capture the water quality parameter variation in CC Bay's ship channel. Included is an acoustic Doppler current profiler (ADCP), which can determine vertical shear structure of the water column. Particle influx and outflux between the bay and the Gulf of Mexico (through the ship channel) can transport significant amounts of particulate BOD (biochemical oxygen demand), thus potentially affecting hypoxia. Therefore, it is necessary to characterize the particle dynamics of the bay to better understand hypoxia and other environmental phenomena. Past researchers have observed the positive correlation between acoustic backscatter intensity measured by an ADCP and particulate concentrations in the water column [5, 6, 7]. One of the objectives of this research is to correlate the acoustic backscatter intensity with the particle concentration measured and thereby aid in understanding of the particle dynamics in CC Bay.

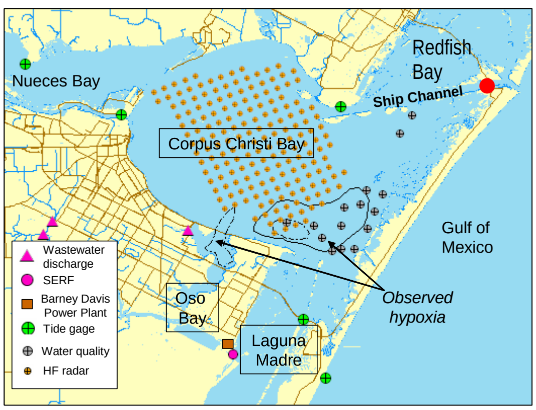

Figure 1. Characteristic Features of Corpus Christi Bay

II. SITE DESCRIPTION

Corpus Christi Bay is located on the Gulf of Mexico (approximately 200 miles southwest of Houston, TX) and has an area of 434 sq. km [8]. It is surrounded by four water bodies, namely Oso Bay in the southwest, Nueces Bay in the northwest, Upper Laguna Madre in the south and Redfish Bay in the northeast. This bay has almost uniform depth (~3m) except in the 15-meter ship channel, which runs east-west in the northern portion of the bay. CC Bay is connected to the Gulf of Mexico through the ship channel. Figure 1 shows the characteristic features of CC Bay. Hypoxia has been reported to occur at the mouth of the Oso Bay and near the Laguna Madre. As the Upper Laguna Madre is very shallow (~2m), it brings highly saline water into CC Bay during the summer time. The red circle in Figure 1 shows one of the locations of the Texas Coastal Ocean Observation Network (TCOON) platform in Port Aransas, TX. The wind data measured at this platform is used in our data analysis.

III. MATERIALS AND METHODS

A. Research Cruise Objective

On November 29, 2006 and March 22, 2007, we conducted east-to-west transect cruises along the Corpus Christi Bay Ship Channel. The objective was to measure various water quality parameters and begin to address their effects on naturally-occurring phenomena such as hypoxia. We also attempted to identify the relationship between particle concentrations measured by the particle size analyzer and the intensity of acoustic backscatter measured by the ADCP. This kind of relationship will help us in better understanding the particle dynamics of the bay because the ADCP can measure acoustical backscatter (ABS) intensity at highly resolved spatial and temporal regime. Also, since particle flux can carry significant amounts of particulate BOD, this relationship will help to better characterize the DO variation in the bay.

B. Integrated Data Acquisition, Communication and Control (IDACC) System

For these cruises, our research group has previously developed an Integrated Data Acquisition, Communication and Control (IDACC) system which can measure vertical variation of various water quality parameters 'synchronically' over a highly-resolved spatial regime. This unit is capable of adaptive sampling to facilitate and guide data acquisition exercises and has been used successfully in several deployments in simulated emergency spill response, routine bay profiling as well as dye-tracer experiments [9]. Instruments currently included in this system are a particle size analyzer (LISST-100 by Sequoia Scientific), a dissolved oxygen sensor (Optode by Aanderaa), a fluorosensor (Eco-FL3 by WETLabs), a GPS (Global Positioning System) and a CTD (Conductivity, Temperature and Depth) sensor. This integrated instrument suite is towed by our research vessel in a vertically-undulating fashion within the water column. Along with this system, an ADCP has been installed on the research vessel to determine water currents, acoustic backscatter intensity and the vertical shear structure within the water column.

We have performed quality assurance and quality control tests (within 5% error limit) for each instrument of the IDACC system. All instruments are pre- and post-calibrated for each research cruise. Cycle time of each set of synchronized measurements is determined by considering the fastest stable response time for all sensors in the instrument suite.

C. Multi-Parameter Instrument Array and Control System (MPIACS) software

In addition to the IDACC system, Multi-Parameter Instrument Array and Control System (MPIACS) software was also developed in our laboratory for the real-time data acquisition and display of the horizontal variation of intensities of the parameter (measured value relative to a pre-set peak value). It aids in locating "cold" and "hot" spots for the constituent of interest along the transect route. Since CC Bay is very dynamic in nature, significant vertical gradients can also exist. Therefore, we have recently modified our MPIACS software to also display the vertical variation of water quality parameters along the transect route. Figure 2 presents a snapshot of the graphical user interface (GUI) from one of our routine monitoring activities of CC Bay. The lower left portion of the GUI gives the user the option to select the type/number of instruments to be used in each monitoring activities. At present, a maximum of six instruments can be included for synchronized measurements, and more instruments can easily be added in future. The user also has the option to select the area to be monitored. Currently, Corpus Christi Bay, Matagorda Bay, Galveston Bay, Galveston Offshore area have been loaded in the software so that user can use them directly as reference boundary of their monitoring activities. The lower middle panel of the GUI displays the color-coded trace line of the travel route whereas the upper middle panel shows the vertical variation of a water quality parameter along that route. In this snapshot, it shows the DO variation along the travel route but the user can select other monitored parameters to be displayed (e.g., temperature, salinity, total particle concentration (totvol), etc.). This software also displays the numerical values of the other synchronized measurements of various water quality parameters, and latitude and longitude of the measurement location in the edit boxes at the lower right side of the GUI. The real time display of each parameter helps the user to identify the transect route for the determination of the spatial extent of water quality parameter of interest.

IV. RESULTS

In both of our cruises, we started our transect from the mouth of the ship channel where it is connected with the Gulf of Mexico (to the east) and moved towards the bay in a westerly fashion along the ship channel. Wind was blowing from south-east during both of our cruises (Fig. 3). Figure 4 presents the color-coded (magenta-to-cyan) east-to-west trace line of the November cruise in the Corpus Christi Bay Ship Channel. This color-coded trace line is also presented in the subsequent data plots to help visually link the data with the location of measurement. On each figure, the solid black line represents the seabed profile. Figures 5 and 6 present the vertical variation of salinity along the IDACC route on the November and March cruises, respectively. The color coded (magenta-to-cyan) trace line in the CC Bay map of Figure 6 shows the track line of travel on the March cruise. As we moved from east to the west over time, we expected a lower-salinity condition; however, our observed data from both cruises indicated the opposite profile (Fig. 5 and Fig.6). The persistent south-east wind prior to our cruises may bring highly saline water from the mouth of the Oso Bay and upper Laguna Madre into the ship channel. Low freshwater flow and the dominance of evaporation over rainfall tends to increase the salinity levels in the

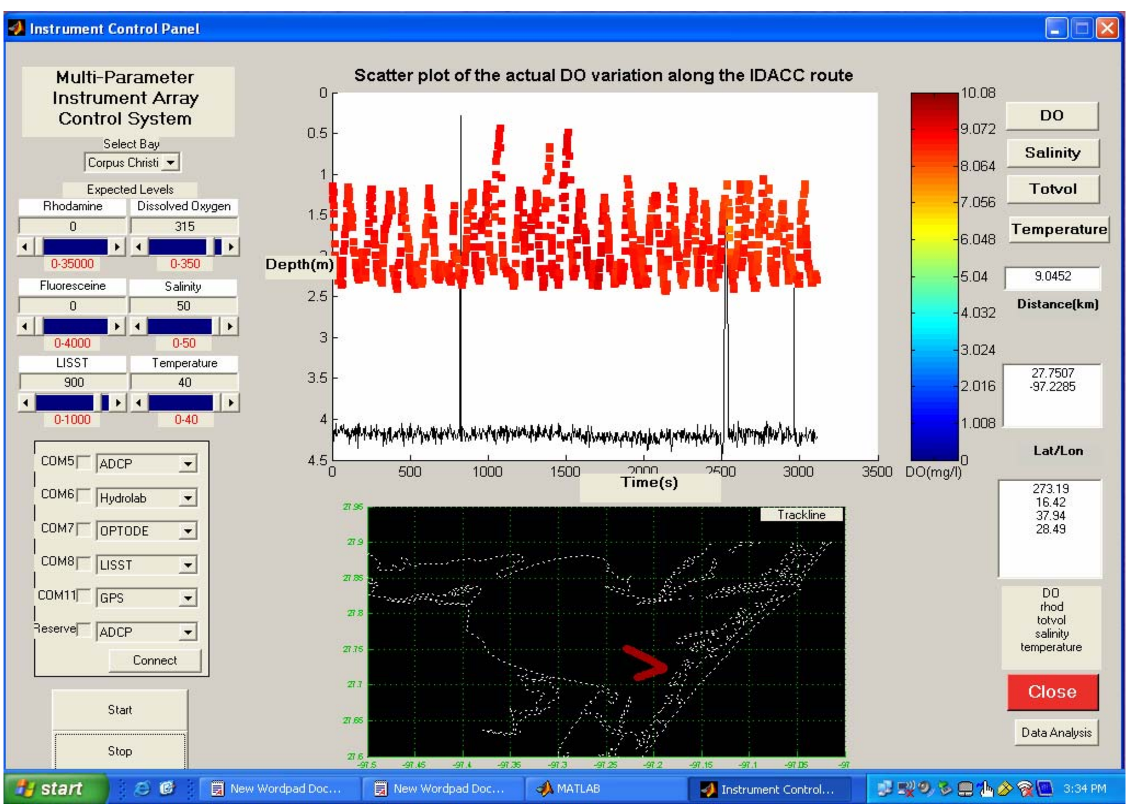

Figure 2. Snapshot of Graphical User Interface (GUI) generated by our real time data acquisition and visualization software (MPIACS-II) in one of our routine monitoring activities of the CC Bay.

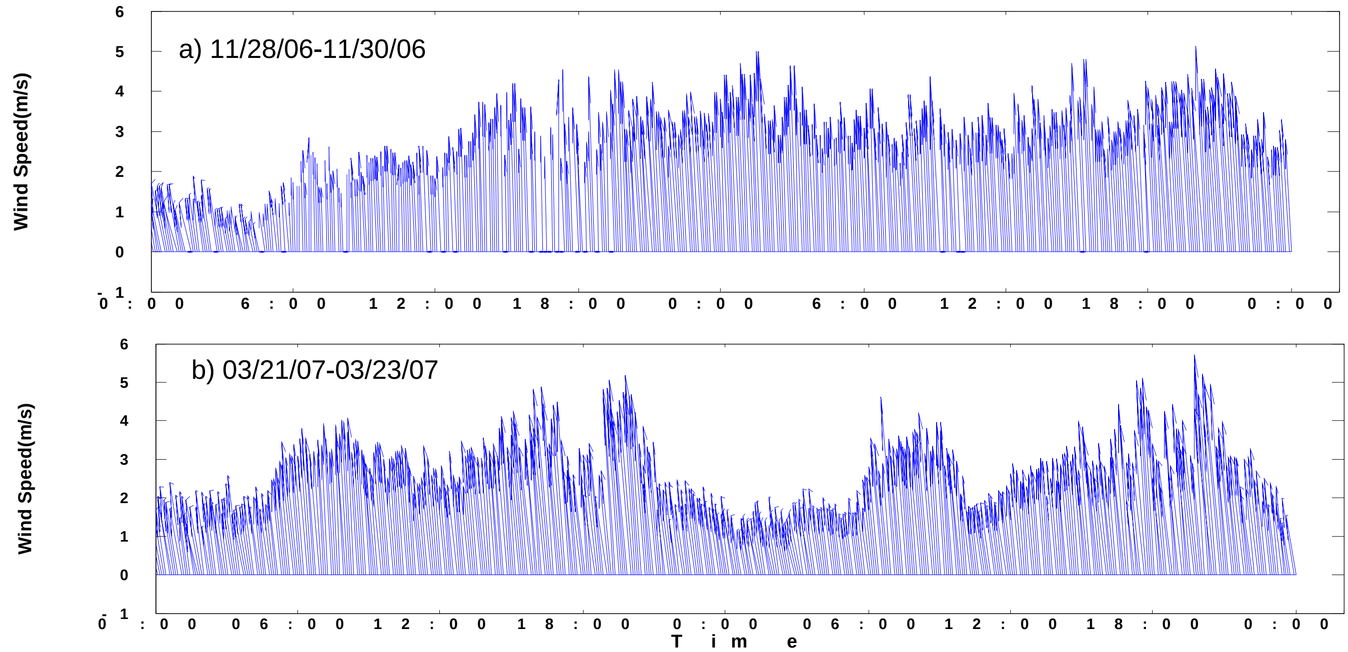

Figure 3. Six-minute averaged wind vectors at Port Aransas in the Corpus Christi Bay for the (a) November cruise and (b) March cruise. Positive vectors represent the wind is blowing from south.

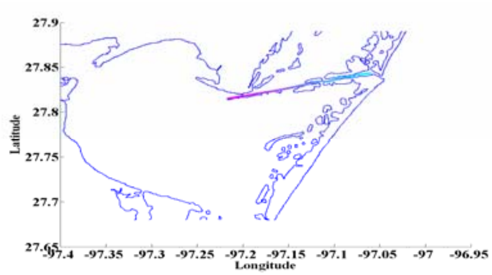

Figure 4. IDACC transect route (in ship channel in CC Bay) on Nov 29, 2006 (Note: direction of transect was east-to-west).

shallow upper Laguna Madre and the mouth of the Oso Bay as compared to the rest of the bay. The preliminary results of the hydrodynamic model developed by our research collaborator (Dr. Ben Hodges, University of Texas Austin, personal communications) finds the similar circulation pattern., i.e., higher salinity water from the Laguna Madre (shallow water body~2m depth) moves along the south-east coastline towards the ship channel. Integration of the model with observed data will provide more insight into the circulation pattern of the bay and thereby, help in

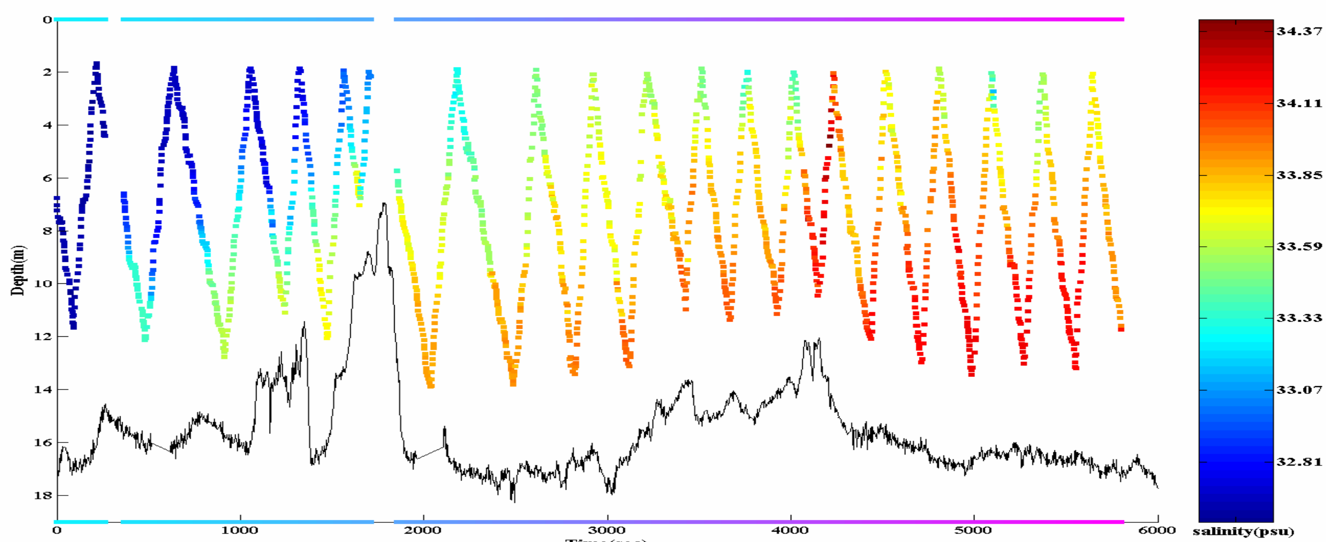

Figure 5. Salinity variation along the IDACC route on Nov. 29, 2006. (Note: the colored horizontal lines at the top/bottom of the figure correlate to the transect route as presented in Figure 4).

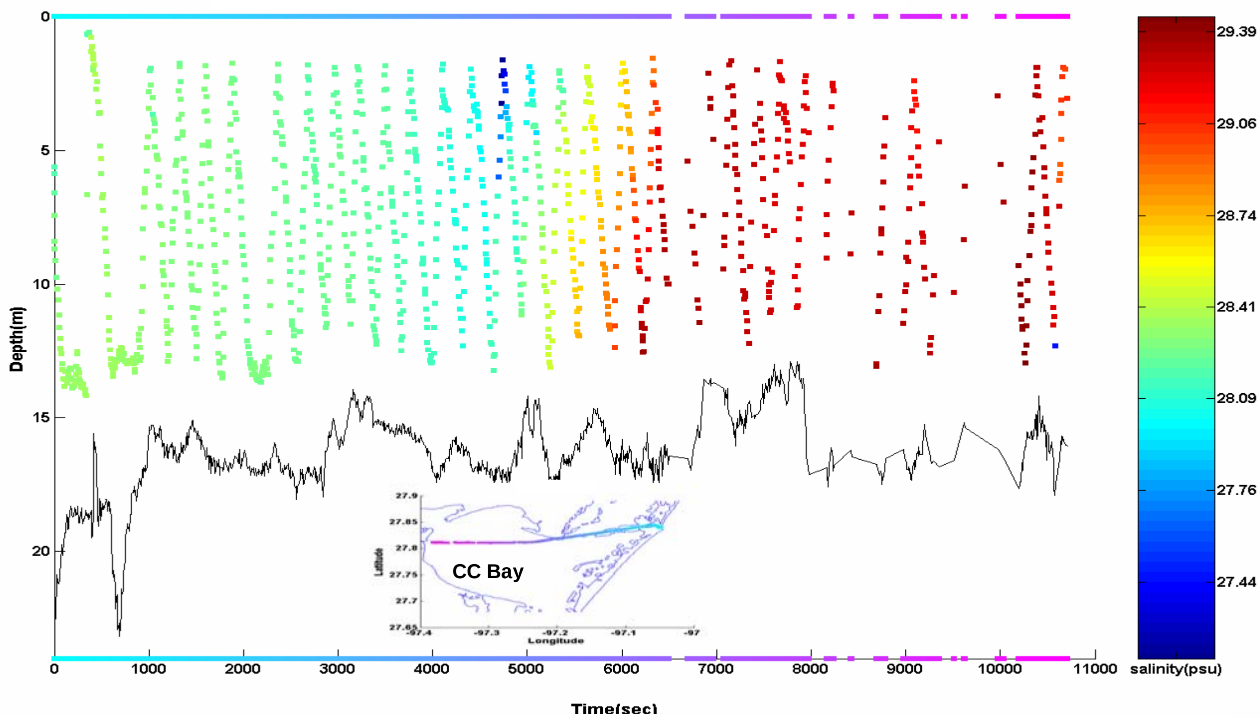

Figure 6. Salinity variations along the IDACC route on March 22, 2006. Note map insertion showing east-to-west trace line of the cruise.

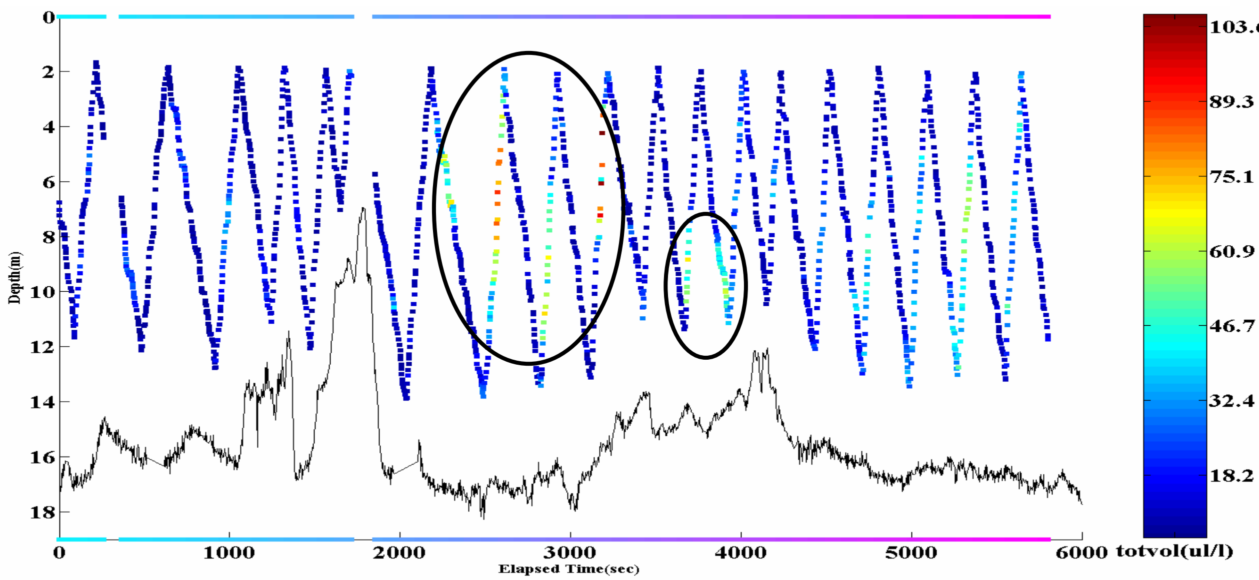

Figure 7. Particle concentration variation along the Nov. 29, 2006 cruise transect. (Note: the colored horizontal lines at the top/bottom of the figure correlate to the transect route as presented in Figure 4).

understanding the frequency and extent of hypoxic events in CC Bay.

Figure 7 presents the particle concentration while Figure 8 presents the acoustic backscatter intensity variation along the transect route on Nov. 29, 2006. Note that Figure 8 presents only a portion of the transect data for the ADCP (from T=2100 sec through T=4800 sec). Comparing Figures 7 & 8, it is clearly visible that higher particle concentrations (encircled in black, Figure 7) correspond to the higher acoustic backscatter intensity data (encircled in black, Figure 8). In order to interpret and understand a quantitative relationship between acoustic backscatter intensity with the actual particle concentration, it is necessary to analyze other water quality parameter measurements such as salinity, temperature, particle type and size distribution in the water column. Future research will provide more insight in clarifying the relationship between acoustic backscatter intensity and particle concentration with all the water quality parameter measurements by our IDACC system and therefore, will help in better understanding the particle dynamics of the CC Bay. Particles can transport 'particulate BOD' (biochemical oxygen demand), thus affecting hypoxia. Quantification of the particle influx/outflux to the Gulf of Mexico through ship channel may help us to understand the contribution of ship channel in controlling hypoxia of the bay.

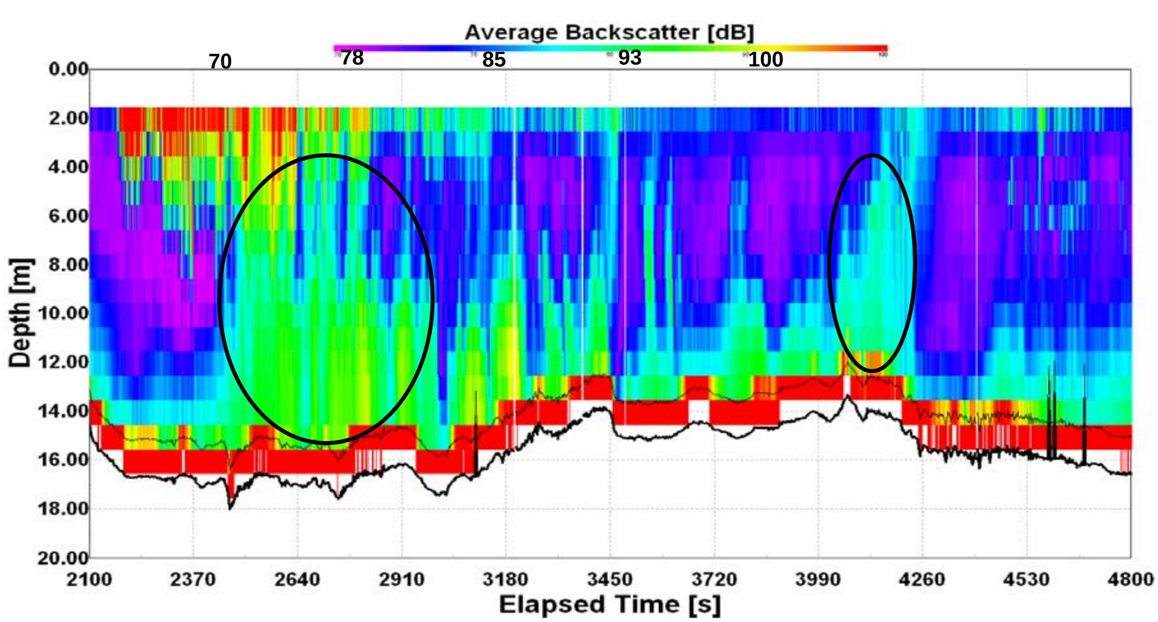

Figure 8. Average acoustic backscatter intensity variation along the IDACC transect route on Nov 29, 2006.

V. CONCLUSIONS

As presented in this paper, the observed data from two of our field monitoring activities proved the capability of our IDACC system as an aid in capturing the dynamics of the bay. Inflows of the hypersaline water from the Laguna Madre and Oso Bay may be responsible for the observed inverse estuary situation captured by our IDACC system. Understanding the circulation pattern of the bay with the observed data will help us to better predict the stratification event that causes the hypoxia in bay through preventing vertical mixing of water column. As oxygen-consuming organisms and particulates in the stratified water column can not move to upper surface layer, they will consume all the available oxygen in the lower layer of the water column and make the water hypoxic. The positive correlation between acoustic backscatter intensity measured by the ADCP and particle concentration measured by the LISST-100 will allow us to develop a quantitative relationship between these two parameters and potentially with the other observed data as measured by our IDACC system. The development of these kinds of quantitative relationships is the subject of our future research, which will then facilitate better understanding the particle dynamics of the bay that significantly affect the hypoxia through the transport of the particulate BOD in/out of the bay. Also the development of water quality and three-dimensional hydrodynamic models with observed-data integration will assist in greater understanding of the processes that control hypoxia in this shallow wind-driven bay.

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