

Using Numerical Modeling and Direct Observation to Investigate Hypoxia in a Shallow Wind-Driven Bay

Mohammad Shahidul Islam, James S. Bonner, Temitope Ojo, and Cheryl Page
(Texas A & M University, College Station, Texas, USA)

Abstract- Corpus Christi (CC) Bay, Texas, USA is a shallow (average depth around 3m) wind-driven bay that is subjected to diurnal wind variation. However, our observations suggests that this bay becomes stratified during the summer time and hypoxic (<2mg/l dissolved oxygen [DO]) condition develops in the south-east part of it, near the Laguna Madre and at the mouth of Oso Bay. As this system is very energetic, it is not possible to capture or fully understand the dynamic patterns of DO concentrations through spatially- or temporally-limited sampling schemes typical of discrete sampling or continuous monitoring at limited locations. Therefore, in this study, a system is being developed to measure various water quality parameters at higher spatial and temporal resolution. To get the vertical variation of different water quality parameters, a vertical profiling robot has been installed at one of our fixed monitoring platforms in the bay. Four more platforms/profilers are targeted for installation in the near future. This profiler's instrumentation suite measures DO, temperature, salinity, chlorophyll concentration and particle size. The same spectrum of environmental parameters is measured 'synchronously' over a highly-resolved spatial regime through our mobile platform equipped with an IDACC (Integrated Data Acquisition, Communication and Control) system. Short time analysis of observed data indicates the potential of these observation systems in identifying the factors that may affect hypoxia. In addition, a 2-dimensional hydrodynamic model which produces water surface elevation and depth-averaged velocity variation with time has been developed for CC Bay using the ADCIRC (ADvanced CIRCulation) model. This model will be extended into a 3-dimensional model which is then coupled to a water quality model for dissolved oxygen. Integrating model output with observed data will contribute into the understanding of processes that lead to the development of hypoxia and other environmental phenomena.

I. INTRODUCTION

Dissolved oxygen is an important water quality parameter that indicates the status of the life of an aquatic ecosystem. Hypoxia develops when the concentration of dissolved oxygen (DO) in the water column dips below 2 mg/l and most aerobic aquatic organisms cannot survive under this condition. Various factors like eutrophication, water column stratification, geomorphology of the bay, meteorology etc. may contribute to the development of hypoxia [1]. According to Ritter, Montagna and Applebaum, 2005, eutrophication does not cause hypoxia in CC Bay because over the last fourteen years, freshwater inflows rates have decreased and nutrient levels also have not changed significantly [2]. Ritter and Montagna also observed the hypoxia at relatively stagnant portion of the CC Bay where the vertical salinity gradient is very high [3]. But since Corpus Christi (CC) Bay is very shallow and predominantly wind driven, it ordinarily would not be expected to become stratified. However, this

phenomenon does occur during the summer time in the south-east portion of the bay, near the Laguna Madre and at the mouth of nearby Oso Bay [3]. Therefore, it is necessary to identify the circulation pattern of CC Bay to contribute to the understanding of how/why hypoxic events occur in this bay. In this study, a 2-dimensional (2D) hydrodynamic model which produces water surface elevation and depth-averaged velocities variation with time has been developed for CC Bay using the ADCIRC (ADvanced CIRCulation) model [4]. This model will be extended into a 3-dimensional model which will give detailed hydrodynamic information including the circulation pattern and stratification structure.

Spatial extent, frequency and duration of hypoxia determine the level of disturbance it causes to the ecosystem. As CC Bay is very dynamic system, it is not possible to fully capture the extent of a hypoxia event through discrete sampling or continuous monitoring at one or very few locations. Therefore, in this study, an observational system has been developed that will supply surface current maps, vertical profiles of currents, DO, temperature, salinity and other chemical and biological water quality parameters at higher spatial and temporal resolution. This system consists of observational fixed and mobile platforms equipped with water quality measuring instruments which will be guided by the output of the water quality and 3D hydrodynamic model. A vertical profiling robot installed on a fixed platform can measure vertical variation of various water quality parameters whereas our mobile platform (i.e., research boat) equipped with an IDACC (Integrated Data Acquisition, Communication and Control) system can measure the same spectrum of environmental parameters 'synchronously' over a highly-resolved spatial regime in an undulating (vertical sinusoidal) pattern.

II. MATERIALS AND METHODS

A. Vertical Profiler (with Instrumentation Suite) on Fixed Platform

An automated vertical profiler system, which lowers an instrument package periodically through the water column and houses it above the water between profiles, is well suited to measure the vertical water quality parameters continuously over long time period. This profiler consists of three main parts: the payload, which houses the instruments, the profiler, which raises and lowers the payload, and the control software, which operates the previous two components. The payload is suspended from the profiler by two cables, with a single power/data cable connecting the instruments to the control

software. The profiler is deployed off a tall pylon with an arm reaching over the side of the platform overlooking the water. Two suspension cables connect the payload to this arm, and from there to an electric motor responsible for winching the payload up and down. This motor is operated by an electronic controller module, which in turn is operated by control software developed as part of this research effort. The control software operates the profiler and payload to provide a vertical profile of the water to raise and lower the payload and runs the instruments in the payload to gather data. The payload capacity of the profiler is such that we will be able to deploy a minimum of up to four instruments. The instruments deployed on this profiler are a particle sizer (LISST 100X, by Sequoia Sciences), a DO sensor (Optode, by Aanderra), a CTD (Conductivity, Temperature and Depth) sensor (SBE 37 SIP, by Sea-Bird Electronics, Inc.) and a flurometer (Eco-FL3, by WETLabs). The profiler lowers the instrument from mean low-water level to the bottom of the bay within 2.5 minutes and measures water quality parameters at five equi-distant depth levels. It then pulls the instrument suite out of the water and dries them through the exposure to the sunlight. This helps in reducing the bio-fouling of the instruments. The cycle time of profiler is 15 minutes. The optimal cycle time and data collection time will be determined through due consideration of the time scale of the variation of the actual water quality parameters and the response time of each instruments.

B. IDACC System on Mobile Platform

The IDACC system has been previously developed in our research group to measure various water quality parameters ‘synchronously’ over a highly-resolved spatial regime [5]. 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. Instruments included in this system are a particle size analyzer (LISST 100X), a flurosensor (Eco-FL3, GPS (Global Positioning System) and a CTD (Conductivity, Temperature and Depth) sensor (SBE 37 SIP). A DO sensor has been newly added with this instrumentation suite to measure DO variation. The output of the water quality model and in-situ water quality parameters measured by the vertical profiler will aid in determining the time and route of future mobile platform (IDACC) transects designed to capture a hypoxia event or phenomena of interest.

C. Hydrodynamic Model

The hydrodynamic model developed for Corpus Christi Bay is the ADvanced CIRCulation (ADCIRC) Model for Coasts, Shelves, and Estuaries [4]. It is a two-dimensional depth-integrated finite-element model. The original grid developed by Scheffner, Carson, Rhee and Mark [6] is modified in the area of interest with details added using Surface Modeling System (SMS) software. Coastline data and bathymetric data were obtained from Geophysical Data System (GeoDas), National Oceanic and Atmospheric Administration (NOAA) database and U.S. Army Corps of Engineers (USACE)

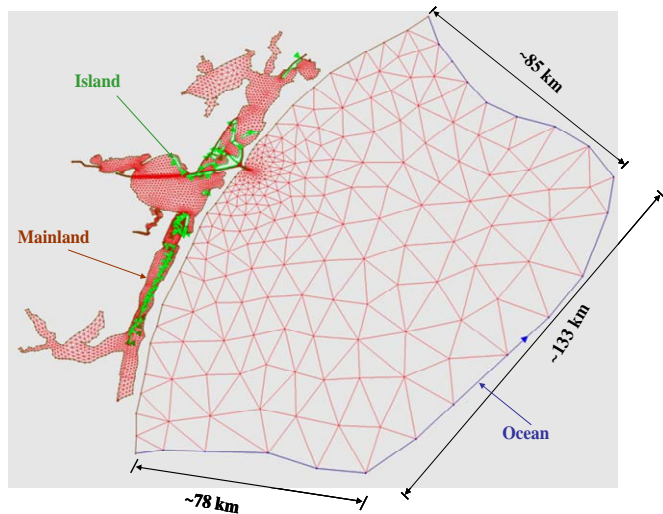


Figure 1 Computational Domain

surveys. The computational domain for this model is presented in Fig. 1. Three types of boundary are considered, namely mainland, island (no flux condition), and Open Ocean (tidal flux only). Atmospheric and wind forcing information, collected from Windbird instrumentation (by R.M. Young Company) at our nearby Oso Bay monitoring platform, were applied at the whole computational domain. The amplitude, frequency and other parameters of tidal potential constituents were determined for a specified time that the model ran using the Le Provost Database [7]. Eight constituents for the tidal forcing frequencies and five constituents for tidal potential were used in this model. The optimal time step (6 seconds) was calculated based on Courant number criteria. Our research group at Shoreline Environmental Research Facility (SERF) has deployed and operates two HF (High Frequency)-Radar unit to monitor real time hydrodynamic information of the Corpus Christi (CC) Bay [8]. This unit has coverage of 600 square km at 1 square km grid spacing. Radar measurements are hourly averages of 10 min time series data obtained using the Bragg scattering principle applied to incident radio waves. These hourly current vectors are coincident temporally with model output which was interpolated spatially into radar grid space.

III. RESULTS AND DISCUSSION

The dynamic pattern of dissolved oxygen variation depends on the complex interplay of physical, chemical and biological processes. The robotic profiler equipped with various instruments measure various water quality parameters at five equidistant levels from the surface to the bottom of the bay. An example of a series of vertical profiles on June 15, 2006 is presented in Figure 2. Fig. 2(a) presents the depth variation of the sea levels over this 24-hour time period, while Figures 2(b), 2(c) and 2(d) depict corresponding vertical dissolved oxygen, salinity and total particle concentration variations with time, respectively. All measurements are referenced with GMT time. These synchronized measurements may aid in understanding various phenomena. For example, from Figures

2(b), 2(c) and 2(d), it is clearly visible that a sediment resuspension event occurred between 10:00 and 15:00 (GMT). Both salinity and total particle concentration levels noticeably increased during that time frame. The decreased DO levels shortly thereafter suggest that the bottom hypoxic or anoxic sediments may have consumed a portion of the oxygen from the water column (Fig 2(b)). Long term analysis of these water quality parameters will facilitate in exploring various important environmental phenomena that contribute to the hypoxia.

In recent years, Ritter and Montagna [3] have observed hypoxia in the southeast portion of CC Bay during the months of July and August. Thus, we are in the process of deploying a fixed platform (for vertical profiling) in that region to collect data that will aid in the study of hypoxia. Moreover, we can use these water quality parameter data as the input of our

water quality model. The model output will help in determining the location and timing of subsequent field transect runs using our mobile platform equipped with IDACC system. The IDACC system measures various water quality parameters at higher spatial resolution but lesser temporal resolution. These runs may help in determining the spatial extent of a hypoxic event. On 7 April 2006, we conducted a south-to-north transect of the bay to investigate the spatial variation of salinity. We found slightly higher salinity levels at the south end of the bay (near the opening to the Laguna Madre) and the northern end of the bay (near the ship channel (Fig 3)). Salinity levels at the southern portion could be affected by the shallower depths, which can lead to the higher evaporation rates. This spatial profile of salinity concentration shows how these types of monitoring activities with the

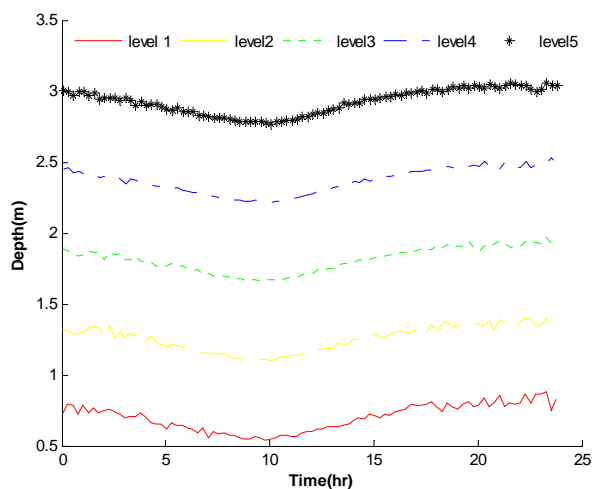


Figure 2(a) Depth variation of different level with time on June 15, 2006(GMT).

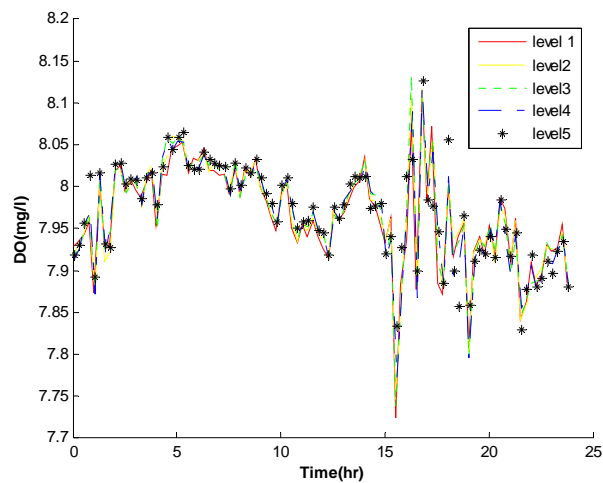


Figure 2(b) Vertical dissolved oxygen variation with time on June 15, 2006(GMT).

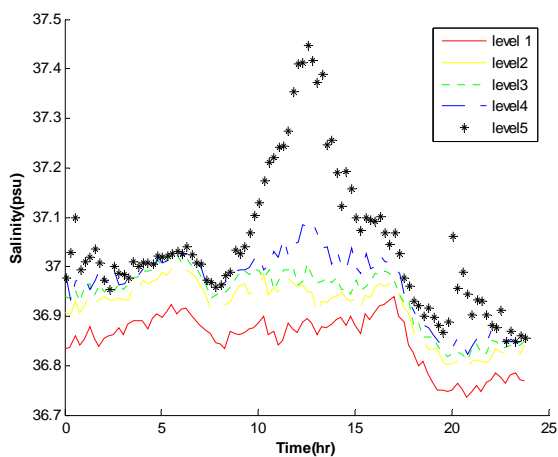


Figure 2(c) Vertical salinity variation with time on June 15, 2006(GMT).

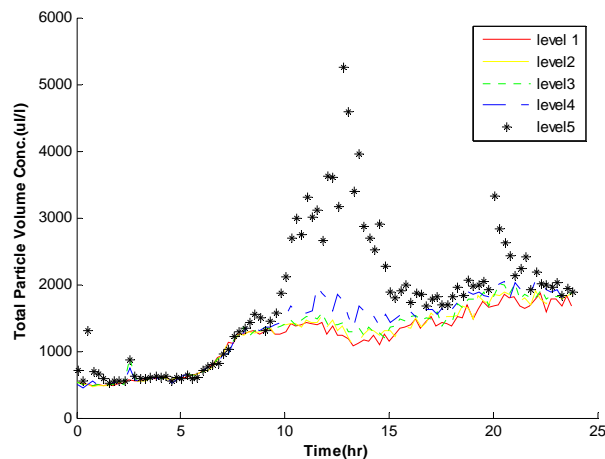


Figure 2(d) Vertical variation of total particle concentration with time on June 15, 2006(GMT).

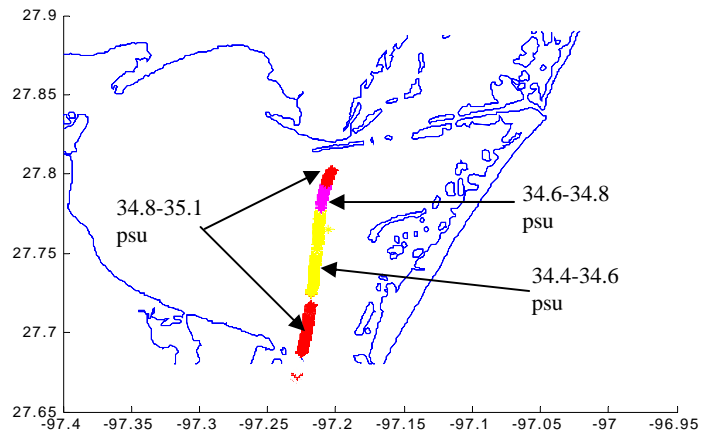


Figure 3 Salinity variation along the transect route of the IDACC run on April 7, 2006.

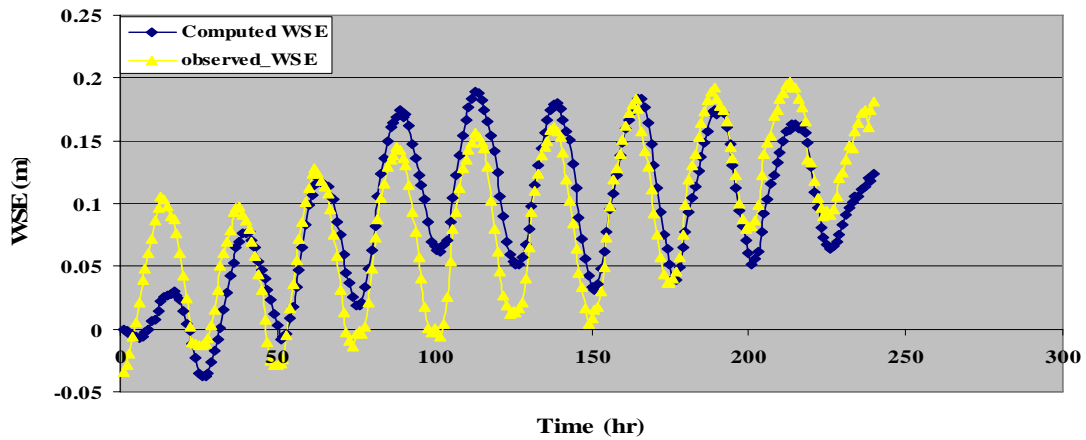


Figure 4 Observed vs computed Water Surface Elevation (WSE) at Packery Channel.

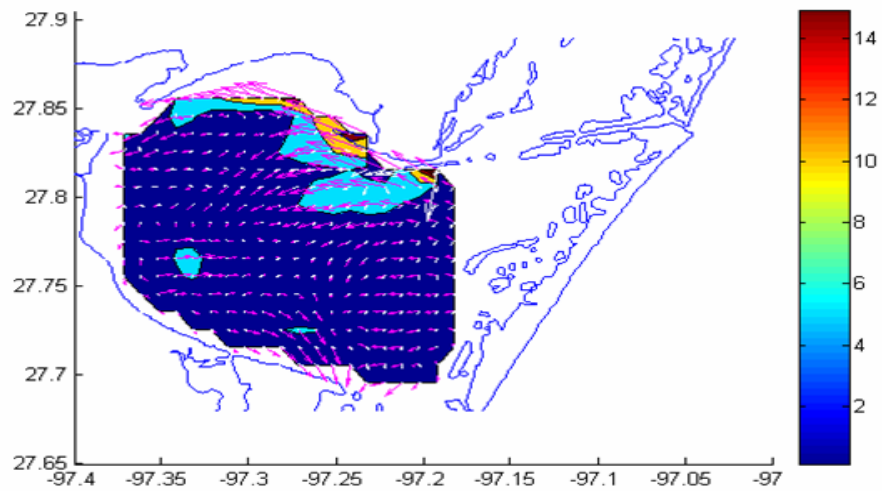


Figure 5 Velocity magnitude residual plots for observed and model-computed velocities; Note: Observed radar measured current (pink arrows), Model-computed current (white arrows); range is 0 cm/s to 14 cm/s.

IDACC system can aid in providing various water quality parameters at greater spatial resolution.

A 2-dimensional hydrodynamic model, which produces water surface elevation and depth-averaged velocities variation with time, was developed for Corpus Christi Bay using the ADCIRC (ADvanced CIRCulation model). The model was calibrated with observed water surface elevation and surface current data. Once calibrated, the model was verified by another set of observed data (Windbird instrumentation). The comparison between observed and model-computed water surface elevation (WSE) variation at Packery Channel (southern portion of CC Bay), as presented in Fig. 4, are in good agreement. Fig. 5 illustrates the residual plot between model-computed current velocities and observed surface currents by HF (High Frequency) radar. From the velocity magnitude residual plot (Fig. 5), it is inferred that differences between the observed- and model-computed velocity magnitudes are usually within the range of 8 cm/s. Chapman et al., 1997 showed the error in measuring current velocities by HF radar to be in the range of 7 to 8 cm/s [9]. So this model captures the dynamics of the bay within tolerable limits. This model will be extended into a 3-dimensional model, which is then coupled to a water quality model for dissolved oxygen. All the data collected by our observational systems will be fed into our water quality model, and model parameters will be adjusted through the comparison of model-predicted data with the observed data. The prediction of the modified model will then guide the sampling strategies and route of our observational systems. This mutual adjustment between the observational system and the model will help in better understanding of the dynamic system in Corpus Christi Bay and thereby, further clarify this critical hypoxia phenomenon.

IV CONCLUSION

Corpus Christi Bay, which can be described as a stochastic pulsed system, has very complex hydrodynamic and water quality conditions. The dynamic patterns of DO concentration variation in this dynamic system can be explored through the integration of real time observation systems that can measure various water quality parameters at a higher spatial and temporal resolution with water quality models. Our observational system consists of fixed and mobile platforms equipped with various water quality measuring instruments. A robotic profiler, installed at our fixed platform, can measure the vertical variation of various water quality parameters. The IDACC system, towed by our mobile platform, can determine the same spectrum of environmental parameters 'synchronously' over a highly-resolved spatial regime. Short-time analysis of observed data proved the potential of these observation systems in identifying the factors that may affect hypoxia. Long time analysis of the observed data will clarify many factors that contribute to hypoxia and help us understand this critical phenomenon. All the data collected by our observational systems will be fed into our water quality

model, and model parameters will be adjusted through the comparison of model-predicted data with the observed data. The prediction of the modified model will then guide the sampling strategies and route of our observational systems. At the first stage of this endeavor, we developed 2D hydrodynamic model for the CC Bay that can determine water surface elevation and depth-averaged velocity variation with reasonable accuracy. This model needs to be extended into a 3-dimensional model for getting the detail hydrodynamic information and will then be coupled to a water quality model for dissolved oxygen. The integration of this model with our observational system will aid in understanding hypoxia and other natural phenomena observed in the CC Bay, Texas.

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