Long-term Acoustic Monitoring of Environmental Parameters in Estuaries

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Abstract- Coastal environment is controlled by a complex interaction of physical, chemical, biological, and geological processes. Physical processes are responsible for controlling the transport and distribution of all dissolved and suspended matters in coastal waters. A comprehensive understanding of these processes is crucial to the design and implementation of management strategies that track ecosystem health and protect coastal and estuarine waters from environmental and ecological disasters. To characterize the temporal processes occurring in the ocean, new types of infrastructure equipped with novel techniques, such as acoustical tomography, to facilitate cutting-edge oceanographic research are needed. These methods are capable of providing long-term, high-resolution observations of critical environmental parameters.

I. INTRODUCTION

The concept of Global Ocean Observing System has attracted attention and call for support from the international community in recent years. A few high profile international conventions have called for the establishment of such a system. On the US national level, the recent report of the National Research Council calls for the development of integrated ocean observing systems; both the executive and legislative branches of the government have become increasingly cognizant of the need for offshore and nearshore environment monitoring.

Physical processes in coastal and estuarine waters often carry significant spatial and temporal variability. The large spatial variability is a direct result of the complex bathymetry and geometry often found in these waters. The temporal variability stems from the fact that coastal and estuarine waters respond to a variety of forcing mechanisms over a broad spectrum of time scales, ranging from short-period tidal motions to long-period motions induced by wind and river discharge events [1]. Historically, marine scientists have relied on in-situ measurements to examine the circulation pattern and the distributions of physical properties such as temperature and salinity. Unfortunately these conventional means of observation typically cover either intensive, but short-term observations or long-term observations with very limited spatial resolution. In recent years remote sensing methods have gained increasing recognition for their potential in measuring the distribution of water properties. Most of the currently available remote sensing techniques, however, are limited to detecting features that appear on the surface. There is a critical need for the development of innovative remote sensing technologies that measure physical properties within the water column. Acoustic methods represent an excellent example of such technologies that can be used in complex coastal systems.

This paper presents the preliminary results of a monitoring station established in the Delaware Bay estuary for the purpose of providing real-time data to the community. These data can be used for variety of different purposes such as managing the health of the ecosystem based on selected measurements, to aid for mariners and shipping traffic. In addition the feasibility of using broadband acoustic tomography to provide cost-effective acoustic-based monitoring of the physical processes in coastal and estuarine waters is provided as an example of the versatility of this observing system. While broadband acoustic signals can be used to measure a wide range of physical parameters in coastal regions, the focus of the present study lies in the determination of current fluctuations in the lower Delaware Bay using such techniques. A combination of data derived from conventional oceanographic sampling platforms and broadband acoustic wave propagation measurements is reported.

II. DELAWARE BAY OBSERVING SYSTEM (DBOS)

As a major step toward accomplishing predictive capabilities, a number of Coastal Ocean Observing Systems have been deployed in North East states such as the Chesapeake Bay Observing System (CBOS) operated by the University of Maryland, the Long-term Ecosystem Observatory (LEO-15) located offshore of Tuckerton, New Jersey, operated by Rutgers University, and the Physical Oceanographic Real-Time System (PORTS) operated by NOAA in the Port of New York and Delaware Bay.

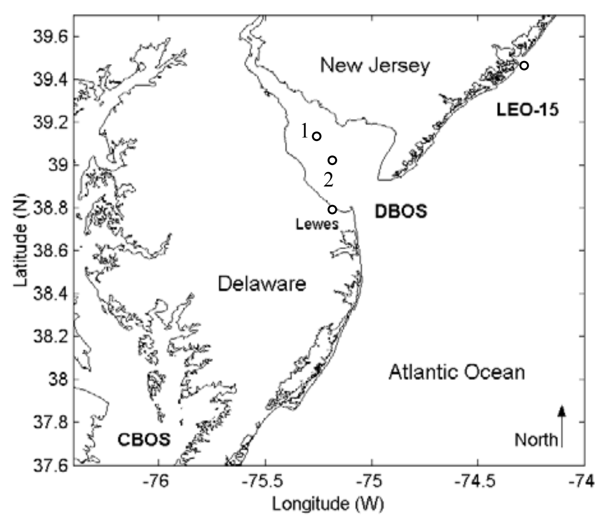

Figure 1: Map of the Delaware Bay and the two lighthouses in DBOS, (1) Elbow of Cross Ledge lighthouse, (2) Fourteen Foot Bank lighthouse. Also shown is the location of the Rutgers' LEO-15 coastal observatory in New Jersey and the CBOS network in Chesapeake Bay.

The Delaware Bay Observing System (DBOS), operated by the University of Delaware, consists of a series of lighthouse-based platforms located along the lower and middle reaches of Delaware Bay. At each lighthouse, the platform (node) is equipped with instrumentation to provide long-term, real-time observations of oceanographic and meteorological parameters. The node is modular in design so that innovative and highly specialized sensors can be integrated into the general node to provide additional measurements. With the basic instrumentation package, DBOS can provide information on the physical variability of Delaware Bay at tidal and subtidal time scales. This information is crucial for establishing the relationship between the physical processes in the bay and forcing mechanisms such as astronomical tides, remote and local winds, and freshwater discharge. This will help in the development of statistical nowcast and forecast models to predict the physical parameters of the bay (such as current and sea level) based on the forcing variables (such as wind) available from the integrated database of DBOS. The skill of the statistical models can be evaluated based on the real-time observations of the physical parameters from DBOS.

At the present time two lighthouses (see Fig. 1 for locations) are equipped with measurement systems. The general node includes both meteorological and water column measurement systems. A block diagram of a node is shown in Fig. 2. The lighthouse stations are either powered from shore (using electrical lines) or equipped with a power generation system consisting of solar panels and wind generators. The power generation system is designed to constantly charge a battery set necessary to power different components of the system. The central part of the node is a Data Acquisition (DAQ) server that acts as a control and can be used as data storage device. At the present time three separate sensor systems are configured on the server. These include digital camera and video streaming, weather station, and water borne sensors consisting of ADCP, CT, and other sensors. Depending on the bandwidth of the data of interest, these data ports can be modified to accept high data rates. The data stored on the server is transferred to shore using an R/F link. This link is also used to communicate with the other lighthouse stations. A shore based computer station is used to receive and archive the data. We plan to set up a web archival database to store and distribute the collected data. This network is designed to provide sufficient temporal and spatial coverage of the Delaware Bay to permit an analysis of the coupling between the environmental parameters in the bay and the external forcing variables. In concept, this network is modular in that it can accept any innovative measurement system as an integrated node.

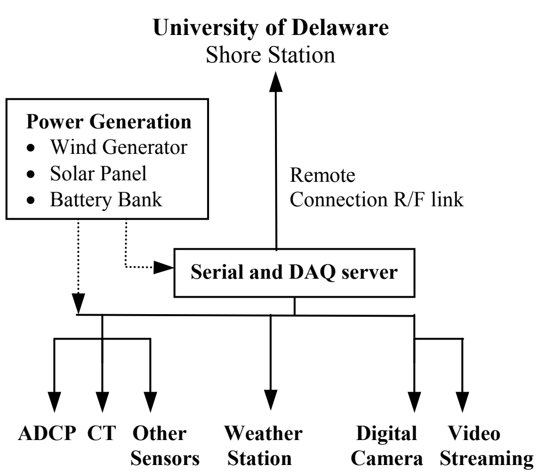

Figure 2: Block diagram of the DBOS at the Fourteen Ft. Light (point number 2 in Fig. 1).

The existence of large spatial variability in winds over Delaware Bay may have significant safety consequences for recreational and commercial shipping alike. To provide the wind distributions with enhanced spatial resolution, we seek to establish an integrated database that combines real-time measurements from the DBOS lighthouses, from the NOAA PORTS sites in the lower bay, from the University of Delaware's weather tower at Lewes, Delaware, and from Dover Air Force Base in Delaware.

Figure 3 shows a sample of the data (wind speed and direction, water temperature and conductivity at three depths, and vertical profile of the N-S component of current) collected by DBOS at the Fourteen Foot Bank Lighthouse during the first week of February 2003. This figure gives a clear example of the importance of astronomical tides on estuarine variability, as the temporal variations in temperature, conductivity, and current are dominated by the effect of the semidiurnal tide. It is important to note that the data also reveals the significance of wind in modifying the observed variability at longer (subtidal) time scales.

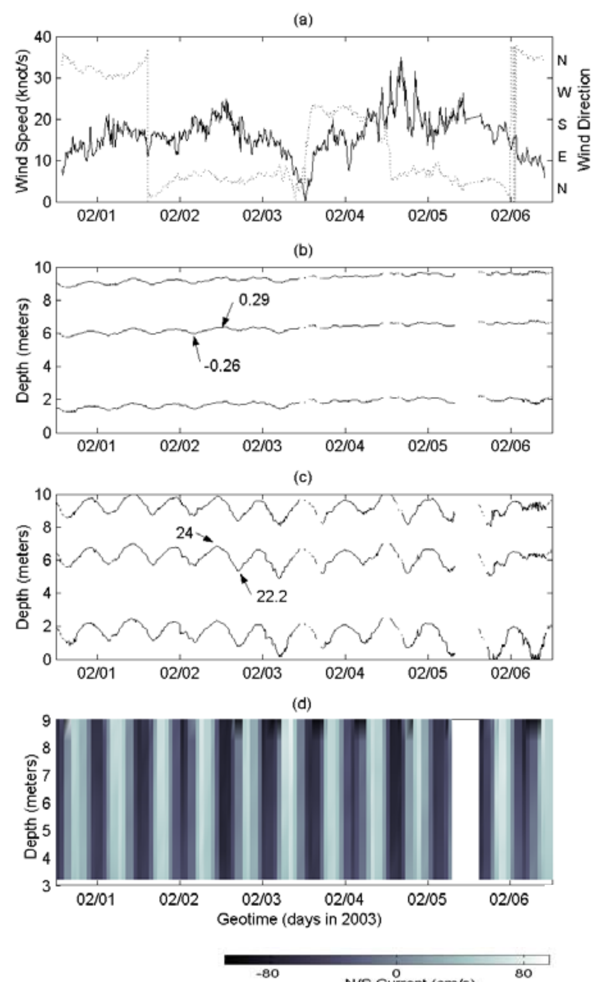

Figure 3: Example of oceanographic measurements in Delaware Bay using DBOS; (a) Wind speed (solid line) and direction (dotted line) measured above the surface, (b) Temperature (Celsius), (c) conductivity (milliohms), (d) N/S current (cm/s). The variations of the peak values of temperature and salinity are shown in figures (b) and (c).

As an example of the versatility of DBOS and its modular design criterion, sound wave propagation measurement were used to infer information from the physical parameters of this ecosystem. Reciprocal transmissions of acoustic signals were transmitted and received with three tripods attached to one of the nodes of DBOS (see Fig. 2). Figure 4 shows the schematic of these arrays connected to the lighthouse modular data acquisition server. The collected acoustic and environmental data were transmitted to shore using R/F link. The same R/F link was also used to modify the sampling rates of the sensors based on the experimental conditions. A brief description of the usage of this system to obtain current at a depth between a sound source and receiver is provided in the next section.

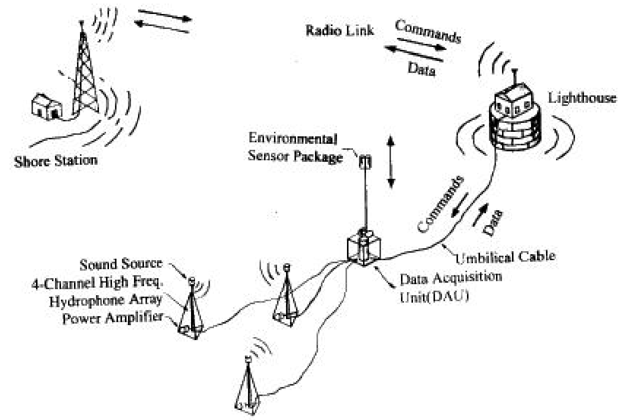

Figure 4: Schematic diagram of the DBOS with acoustical oceanography system attached.

III. ACOUSTICAL OCEANOGRAPHY USING DBOS

Development of novel techniques for measuring physical parameters in coastal oceans is of high priority in contemporary oceanographic research. One such technique that has recently become of particular interest is the use of sound waves to obtain parameters such as current, sea surface roughness, temperature, and salinity. The specific objective of the acoustic technique here was to provide spatial distributions of current speed and direction in the Delaware Bay based on the acoustic measurements at DBOS lighthouses. The frequency band of the acoustic chirp signals was from 1kHz to 18kHz [2]. All of the acoustic and environmental data were synchronized with a common time stamp to allow for absolute time of arrival of chirp signal propagation.

To test the feasibility of this acoustic technique, carefully measured environmental parameters were required for comparison with acoustic estimates. Environmental data at DBOS allowed acoustic tomography experiments to be conducted with the simultaneous collection of highly calibrated oceanographic data and the acoustic transmissions data. Figure 5 shows the orientation of the three tripods used and the trajectories along which reciprocal transmissions were sent. Estimation of current speed along a transmission trajectory was obtained by calculating the difference in travel times of signals sent in each direction along the trajectory. Current speed estimates along each of the three transmission trajectories were then used to obtain the north and east components of the current velocity. Figure 6 shows a comparison between the current velocity measured by an ADCP deployed at the center of the three tripod configuration and the current velocity obtained using tomography. A 24-hour period is shown for both North-South (N-S) and East-West (E-W) components of the current at the source-receiver depth.

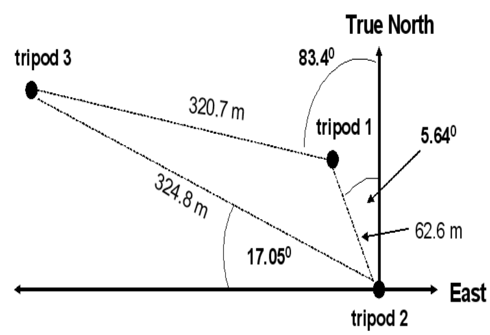

Figure 5: Orientation of acoustic tripods on the sea bottom during the acoustic tomography experiment. Black lines between the nodes represent reciprocal transmission trajectories.

The N-S component of the current obtained by tomography is lower than the values measured by ADCP while the E-W component is higher. This may be due to the variation of other environmental parameters such as salinity, temperature, and wind speed. Changes in these parameters can have significant effects on acoustic signal propagation and the arrival time of the signal. Analysis of the DBOS environmental measurements currently underway can provide an explanation for trends observed in acoustic current estimates.

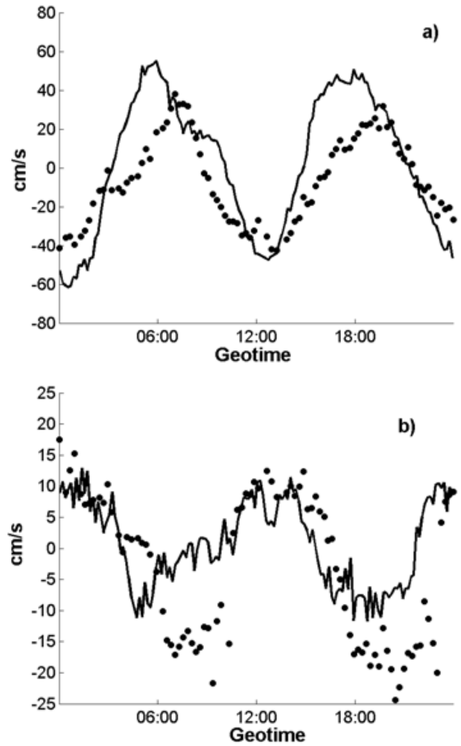

Figure 6: 24 hours of data from December,18th 2000. Acoustically estimated velocity (dots) and measured ADCP velocity (solid line) for a) north and b) east velocity components.

IV. SUMMARY

Establishment of long-term observing systems in coastal and estuarine environment can have immediate benefit to a variety of causes. An improved description of the wind field would be useful for both commercial and recreational mariners in minimizing the potential hazard of stormy weather. The accurate prediction of wind-forced subtidal variation in sea level and current has enormous consequences for the commercial shipping industry. In addition, the observing systems hold great promise for using relatively inexpensive active and passive sound wave measurements to infer environmental variability. This study represents an effort in developing products based on currently available technology in DBOS and exploring an emerging technology that would yield promising results in the future. The use of broadband acoustic waves could provide long-term, inexpensive tool to measure the physical parameters of the water column and the sea surface.

Information generated by coastal and estuarine observing systems can be used for safe marine operation, fishery, mitigation of natural and man-made hazard, and management of ecosystems and human living resources in the watershed of the Delaware estuary.

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