Using Acoustic Modeling to Develop a Hybrid H-ADCP Configuration

S. Jack Stamates
NOAA Atlantic Oceanographic and Meteorological Laboratory
Miami, FL USA

Abstract—The Port Everglades Shipping Channel (PESC) in Ft. Lauderdale, Florida is thought to be a pathway by which anthropogenic nutrients and pathogens reach the coastal ocean from inland waters. To quantify this, a flow measurement system was installed in the PESC. In planning this measurement system, conventional vertical and horizontal ADCP configurations were considered but found to be unsuitable for differing reasons. This motivated the development of a hybrid deployment configuration. A Teledyne-RDI 300 kHz H-ADCP was deployed near the surface with an 8.5 degree downward tilt so that measurement cells nearest to the instrument would record data from the upper water column while cells further from the instrument would record data from deeper depths. The PESC is often times vertically stratified and it was realized that this stratification could affect the data received from a system deployed in this manner. To estimate these effects, sound speed profiles taken in the PESC were used as input to an acoustic propagation model. This model simulated the acoustic paths from the instrument deployed at different angles. Analysis of these simulations enabled the selection of the optimal angle for deployment that allowed for the maximum profiling range while minimizing the effects of stratification on the acoustic path.

Keywords-Acoustic Doppler, Ray trace

I. INTRODUCTION

The Port Everglades Shipping Channel (PESC), located in Ft. Lauderdale, Florida, is one of the largest coastal inlets on the eastern coast of Florida (Figure 1). The PESC serves as the entrance to Port Everglades and is utilized by commercial shipping vessels, cruise ships, and recreational vessels. Inside the PESC, inland waters from the metropolitan Broward County area merge with oceanic waters and twice a day, on the ebb tide, some combinations of these two water masses are transported seaward. Along the south Florida coastline there are three tracts of reefs that run parallel to the shoreline [1]. Anthropogenic nutrients and microbes contained in the waters exiting the PESC have the potential to impact these reefs and other coastal amenities. The mixing of inland and ocean water inside the PESC will sometimes cause the PESC to become vertically stratified [2]. In an effort to quantify the flux of these materials into the coastal ocean, a system to measure the velocities of the water moving through the PESC

Figure 1. Location of Port Everglades Shipping Channel.

was required. Commercially available Doppler current profilers designed to make measurements inside a channel are typically deployed in one of two ways. (It will be assumed that the reader is familiar with the fundamentals of acoustic Doppler profilers. If this is not the case, please refer to [3].)

A vertical-looking system is typically placed on the bottom of a channel somewhere near the channel's center with the acoustical transmission paths arranged around the vertical axis. Advantages of this type of system are that the profiler measures the vertical velocity profile of the channel at the location where the instrument is deployed. In many cases, the velocities near the channel center are relatable to a theoretical mean channel velocity that can be used to estimate a total volume transport through the channel [4]. A disadvantage of this type of system is that the logistics of deploying equipment in the middle of a busy channel can be very difficult. If a connection to shore to supply power and retrieve data is desired, cables must be laid across the bottom of the channel.

A second type of system used to measure velocities in a channel is the horizontal or side-looking Doppler profiler. These systems are typically mounted somewhere near or on the side of the channel, at the mid water depth, with the transmission paths arranged in a horizontal plane. These instruments generate a profile of velocities that represent the velocities that lie in this horizontal plane of the channel. Advantages of this type of system are that by mounting the system on or near the side of a channel, power and data cables

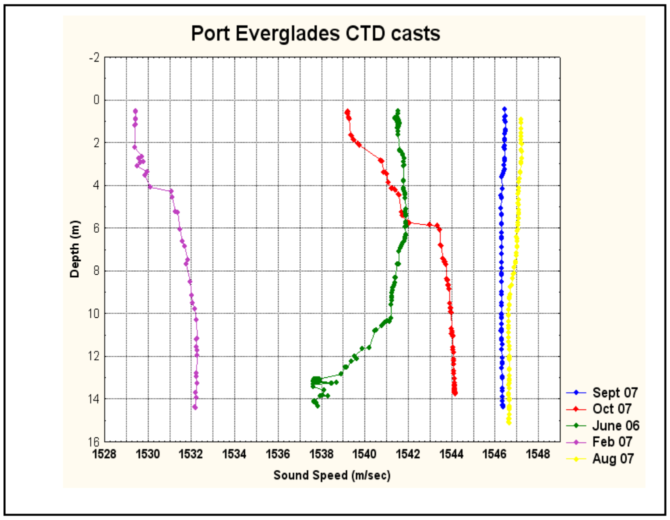

Figure 2. Sound speed profiles derived from CTD casts.

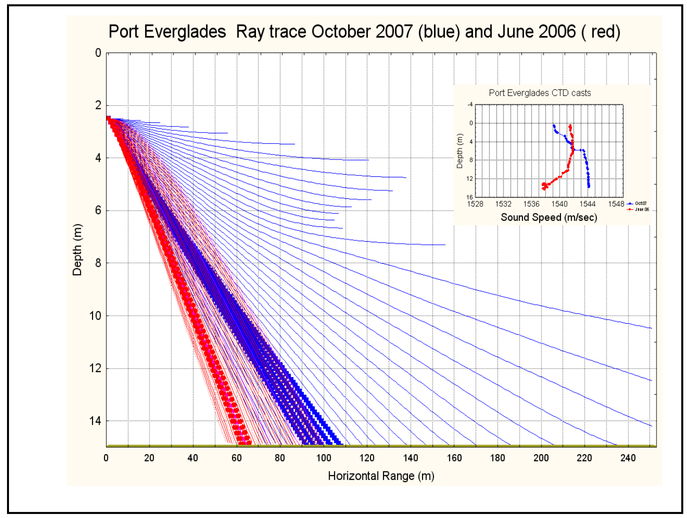

Figure 3. Ray trace diagram for October and June sound speed profiles.

can be kept short and the difficulties of performing deployment and service operations inside an active shipping channel are minimized. A disadvantage of this type of system is that velocity measurements lie completely in a horizontal plane and no information regarding the vertical structure of the velocities is available.

As previously stated, in a vertically stratified channel, information regarding the vertical velocity structure is desirable. The design discussed here is a hybrid design utilizing a commercial, horizontal-looking Doppler profiler. Instead of mounting this instrument so that its transmission paths would look out horizontally, the instrument was deployed near the surface of the channel and the transmission paths were pointed down at a small angle so that each successive measurement cell farther from the instrument would have a depth greater than the cell that preceded it.

II. METHODS

By deploying a Doppler profiler near the surface tilted down at a shallow angle, several advantages are realized. With the instrument located in the upper part of the channel, the depth of the first measurement cells are near to the depth of the instrument itself and, therefore, estimate the velocity in the upper parts of the water column. Measurement cells farther from the instrument are at successively deeper depths and extend farther horizontally out into the channel. An ideal deployment angle would place these measurement cells, which are horizontally located at the channel center, somewhere near the midpoint in the vertical water column [5]. Considering the aspect ratio of the PESC (250 m wide and 15 m deep), this equates to a small angle relative to the horizontal.

In considering this plan, it was realized that in a stratified environment there exists the potential for the path of an acoustical signal to be refracted as it passes through water masses of differing density, temperature, salinity, and, therefore, sound speed. If the refraction were severe enough, the acoustical signal returned to the instrument would not be from the depth that it would be expected to be from, and this data would be difficult to interpret.

Fortunately, it came to our attention that our colleagues at the Broward County Department of Planning and Environmental Protection [2] had been measuring vertical profiles of temperature and salinity near the location of the proposed instrument installation. These profiles were collected during summer and winter months and were collected during ebb tides when stratification was most likely to occur. From these data, it would be possible to calculate a vertical profile of sound speed for each of the casts and use this as input to an acoustical propagation model. These sound speed profiles are shown in Figure 2. Results from such a model would enable the estimation of the effects the vertical variations in sound speed would have on the data collected by the instrument.

To simulate the path of the acoustical energy propagating through this environment, a type of model known as a ray trace simulation was used. In this type of modeling, acoustical energy transmitted from a source is idealized as a line or "ray," which represents the path of the acoustic wavefront as it propagates through the given environment [6]. To calculate this ray path, the initial conditions of position, angle of the source transducer relative to the vertical, and sound speed at the source are given. With the initial angle of the source defined, the acoustic ray is propagated an incremental distance, and the new depth of the ray is then determined. The sound speed at this new depth is determined by interpolating the available sound speed data and then, by Snell's law, EQ 1, where θ is the angle relative to the vertical and c is the sound speed at that depth, a new angle for the ray is calculated. By successive applications of this process, the path of the ray may be calculated. If a ray reached a boundary or a turning point (a point where a ray changes its vertical direction of travel from downward to upward), the ray was truncated at that iteration.

$$\frac{\sin(\theta_1)}{c_1} = \frac{\sin(\theta_2)}{c_2} \tag{1}$$

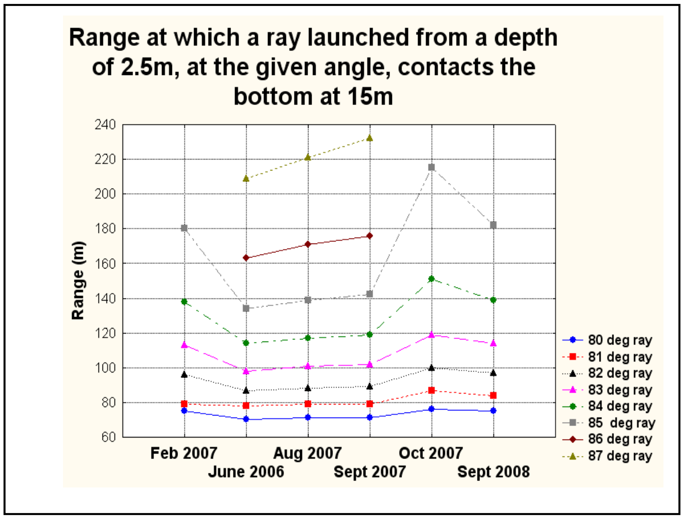

Figure 4. Summary of ray trace analysis.

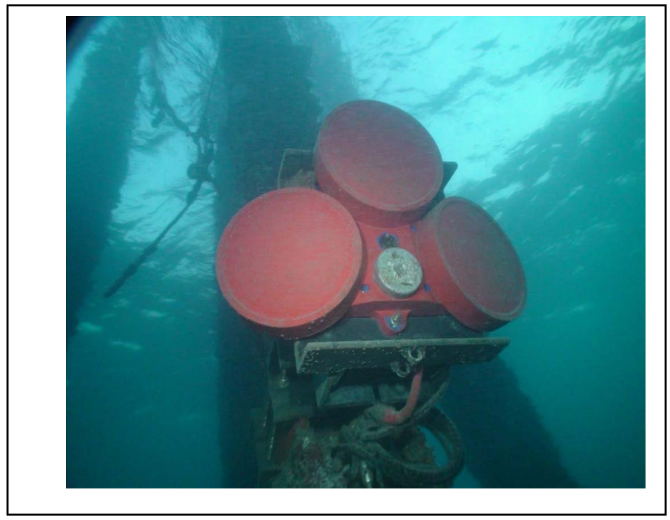

Figure 5. H-ADCP installed in the Port Everglades shipping channel

The model was initialized with the source deployed at a depth of 2.5 meters. For each of the available sound speed profiles, the model was evaluated for a range of initial source angles of 89.75 to 80.5 degrees with respect to the vertical, in 0.25 degree increments. Figure 3 shows the calculated rays for launch angles of 0.25 degrees to 10.25 degrees relative to the horizontal in 0.25 degree increments for two of the sound speed profiles (October 2007 and June 2006). These two examples were chosen to illustrate the extremes of acoustic propagation conditions that were realized by performing the ray traces on the available sound speed profiles. In the ray trace for the October profile, it can be seen that many of the rays launched at a shallow angle relative to the horizontal will turn upward. The ray trace for the June 2006 sound speed profile shows all the rays refracting downward. The rays ranging from 7.5 to 8.5 degrees are highlighted, as this is the range of angles that would ultimately be considered for the instrument deployment.

To summarize the data from the model runs for all the available sound speed profiles, the horizontal range at which a ray reached a depth of 15 m was identified. The data for rays with integer launch angles from 80 to 87 degree are presented in Figure 4. This graph illustrates what range of initial launch angles for the given set of sound speed profiles would yield a set of rays that would travel a similar path and reach the 15 m depth at roughly the same horizontal distance from the instrument. The data from the model output were used to identify that launch angle which would provide a balance between having an acoustic path that is minimally influenced by changing sound speed conditions and the desire to retrieve data from as near to the channel center as possible.

While the ray trace simulation represents the acoustic propagation path with a line, an acoustic signal (or beam) transmitted by an instrument has a width associated with it. The width of the beam is often defined as that angle from the beam axis at which the acoustic power level falls to half that level present at the beam's central axis. From the ray trace analysis, it becomes apparent that a profiling instrument with a narrow beam width is desirable so that the beam is not significantly deformed by the differences in the sound speed at its upper and lower extent in the water column.

Of the commercially available acoustic profilers suitable for this application, the Teledyne RD Instrument 300 kHz H-ADCP with 25 cm transducers was chosen. This instrument, shown as deployed in Figure 5, uses three acoustic transducers aligned in a plane. The central transducer defines the central axis of the instrument, while the other two transducers are angled 20 degrees to the right and left of the central transducer. This instrument is specified to have a beam width of ± 0.43 degrees off the central axis.

After identifying the instrument to be used and evaluating the data from the ray traces, a deployment angle of 8 degrees down from the horizontal (82 degrees from the vertical) was chosen. This selection of deployment angle is a compromise between the desire to profile across the channel as much as possible and the desire to have the beam minimally affected by the effects of the changing sound speed profile. The instrument was set to collect data in 1.5 m bins with the center of the first bin located 3.45 m from the transducers. In this configuration, the center of each bin is 1.48 m farther than the preceding bin in the horizontal plane and 0.208 m deeper than the preceding bin in the vertical plane. This small vertical change from bin to bin allows for good vertical resolution and redundancy in measurements of the vertical layer.

The effects of the sound speed environment on the acoustic propagation path must be kept in mind when attempting to assign an absolute position to any of the data, and caution must be used when interpreting data near the channel bottom. Figure 6 is a schematic of the deployment showing the trajectory of the beam as a straight line when the instrument is deployed at an 8 degree down angle relative to the horizontal. Red lines show the angle 2 degrees above and below the beam center. At the location where the instrument is to be deployed, the bottom depth is 14 m relative to the mean water level.

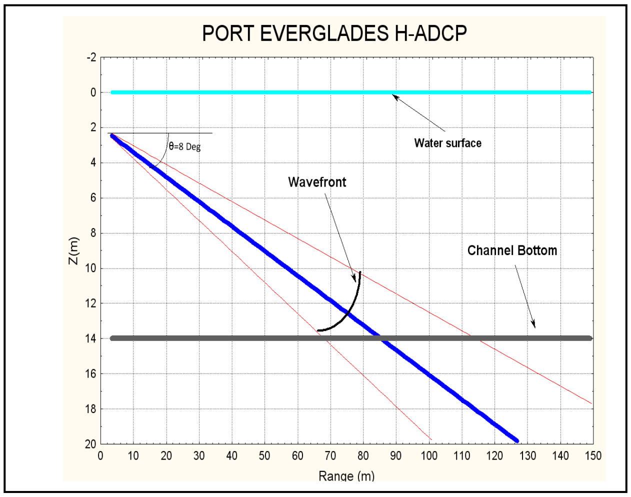

Figure 6. Diagram of H-ADCP installation.

If the beam were to travel along a straight path, the beam's central axis would reach the bottom at a horizontal range of 83 m from the instrument mounting location. The lower extent of this idealized beam reaches the bottom at a horizontal range of 65 m. Beyond the point where the lower extent of the beam begins to touch the bottom, data returned to the instrument are potentially biased by the bottom and must be interpreted with great caution. This diagram may not illustrate all the factors that can affect the maximum depth from which valid data can be expected to be returned and, as such, a conservative maximum depth should be used when interpreting data from such a system.

III. Installation

On March 16, 2009, the system was deployed by clamping the instrument to one of the support legs of the United States Coast Guard number 7 channel marker on the south side of the PESC. The instrument was deployed at a depth of 2 m relative to the mean water level. At the same depth as the Doppler profiler, a conductivity and temperature sensor was also deployed. Power and data cables were laid across the channel bottom and terminated on shore at the U.S. Navy Florida Ocean Measurement Facility. At the location of the terminus of the data and power cables, a suite of meteorological sensors was also installed. The instruments record data from all sensors at six-minute intervals. A battery power backup system was incorporated into the design so that the system could remain operational for 72 hours in the event of a power failure. The data from the meteorological sensors are transmitted in near real time via GOOS satellite and are part of the NOAA ICON/CREWS network. These meteorological data are also available from the National Data Buoy Center (station ID PVGF1).

IV. Summary

The use of existing environmental data and ray trace models gave insight into how an acoustical system would be expected to perform in this environment. Having these advanced predictions was clearly an asset in developing this system. As

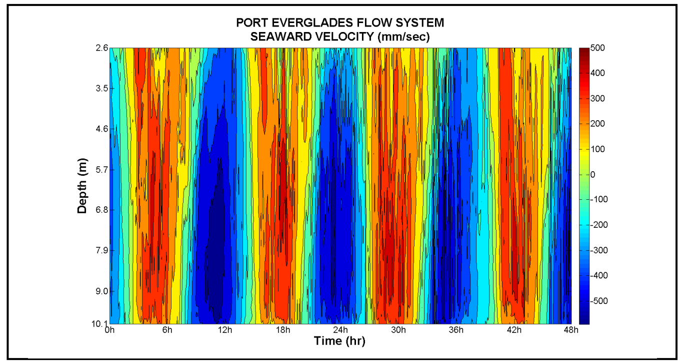

Figure 7. Example of data from the Port Everglades flow system.

of December 2010, the PESC system has been operational for 22 months and has been continually collecting data. Data from the system have been compared to data collected by a vessel-mounted, downward-looking acoustic Doppler system, and the data are in good agreement. Figure 7 shows an example of the data from the instrument showing the velocity structure of the inlet during flood and ebb tides. While it is acknowledged that the effects of the vertical stratification in sound speed are not completely eliminated by deploying the instrument in this manner, the data suggest that stable measurements are being gathered from the upper and lower extent of the channel.

Acknowledgments

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