Portable Autonomous Vertical Profiler for Estuarine Applications

Janelle V. Reynolds-Fleming[1*], Jason G. Fleming[2], and Richard A. Luettich, Jr[1]

[1]University of North Carolina at Chapel Hill
Institute of Marine Sciences
3431 Arendell Street
Morehead City, North Carolina 28557

[2]North Carolina State University
Mechanical and Aerospace Engineering
Box 7910
Raleigh, NC 27695

*Corresponding Author
tel: (252) 726-6841 ext. 162
fax: (252) 726-2426
email: janelle@email.unc.edu

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Abstract

The design and implementation of a portable autonomous vertical profiler are documented and example data sets from a mesotidal estuary and a microtidal, wind-driven estuary are presented. The profiler sampling range dynamically adjusts to changes in water column depth and a typical vertical sampling resolution of 4 cm is attained. Example data detail the onset and vertical and temporal extent of stratification in the water column. The profiler is ideal for water quality monitoring programs in shallow estuaries that require frequent profiles of hydrographic, chemical and biological parameters that can be measured in situ.

Introduction

The physical, chemical and biological characteristics of estuaries change in response to external forcing due to the tides, winds, and/or freshwater discharge (Sanford, et al., 1990; Simpson, et al., 1990; Yin, et al., 1995a, 1995b; Painchaud, et al., 1995; Savenkoff, et al., 1997; Geyer, et al., 2000). These temporal changes, which are sometimes rapid, can lead to sharp vertical gradients, i.e. stratification, in the water column. Stratification, usually due to temperature and/or salinity, serves to isolate portions of the water column and therefore affect concentrations of dissolved gases and contaminants. Water quality monitoring programs are often interested in these concentrations and how they are impacted by the development and breakdown of stratification.

Accurate measurements of the onset of stratification and its vertical and temporal extent facilitate the determination of biological and chemical reaction rates in a system. Technological innovations such as water quality multiprobes with increased battery life and memory capacity as well as small data loggers/controllers with advanced programming capabilities and increased data storage have allowed the design of a relatively inexpensive autonomous vertical profiler (AVP) to become a reality. This paper documents the design and implementation of a portable autonomous vertical profiler (P-AVP) for estuarine applications.

An AVP is less expensive and provides higher resolution than deploying a moored vertical array of replicate instruments while reducing the amount of manual labor associated with operation and maintenance. One of the first automated vertical samplers was designed for use in the Chesapeake Bay to monitor water quality conditions around a nuclear power plant (Carter, et al., 1978). Honji, et al. (1987) designed a self-governing profiling system that moved up and down a mooring line with a vertical resolution of greater than 2 m in deepwater applications. Another profiler, PSWIMS (Luettich, et al 1993), consisted of a sensor mounting bracket that traveled up and down on a threaded rod and four guide poles. The sensor bracket and rod system stopped at a select number of intervals in the water column and was supported by a 2.0 m PVC frame which limited its applications to shallower and more protected estuarine environments. Purcell, et al. (1997) developed a bottom mounted, winch-based vertical profiler that is permanently moored nine km off the coast of New Jersey in 15 m of water. It was designed to allow a deployment rate of 5 m min^{-1} with a 1 cm vertical resolution. A buoyancy-controlled profiler was designed by researchers from the University of Minnesota (Research Notes, 1997). This device is programmed to stop at certain locations within the water column and is accurate to ±0.2 m of the requested depth. It has been tested in deep lakes like Lake Michigan. Another deepwater profiling instrument was designed by Doherty, et al (1999) that records CTD and velocity measurements along a mooring wire. Modifications to that system for commercial development are currently underway (Morrison, et al, 2000). The oceanographic community is rapidly recognizing the need for and importance of autonomous profilers in both deepwater, coastal, and shallow estuarine waters.

The P-AVP design presented here is a good match for the conditions of a shallow estuary. Its floating design allows easy transport to a desired deployment site and it may be moored using common anchors such as concrete blocks or diver-deployed screw anchors. It has been deployed in relatively unprotected areas, is designed for autonomous operation, dynamically adjusts the profile range for changes in water depth, has a vertical resolution of 4 cm and uses a standard, commercially available, multi-parameter water quality probe to collect water quality data during each profile. During warm weather months, the system requires weekly servicing due to bio-fouling of the multi-parameter water quality probe.

Profiling System Design

The core component of the P-AVP is a computer-controlled winch, which unwinds and rewinds cable to the appropriate depth. The P-AVP consists of three parts: 1) a computer controlled winch assembly and acoustical altimeter (WAAA); 2) a water resistant housing and deployment platform; and 3) a sensor package comprised of a multi-parameter water quality probe and an external data logger.

Computer Controlled Winch Assembly and Acoustical Altimeter

The Winch Assembly and Acoustical Altimeter (WAAA) consists of a standard boat trailer winch (model T1200), a spring loaded tensioner which helped provide constant tension on the winch spool (fabricated locally by Bircher Machinist), a 102 RPM DC motor (Dayton, model

1L475), a 12V marine battery, an optical encoder, a digital acoustical altimeter (Datasonics, model PSA-916), and a microcontroller (ONSET Computer Corp., Tattletale model TFX-11).

The TFX-11 controls power to the acoustical altimeter, optical encoder, and DC motor. It also queries the acoustical altimeter to determine the water depth and monitors the optical encoder to determine the angular displacement of the winch (see figures 1 and 2).

The optical encoder was constructed in our lab and consists of a hand-fabricated encoder wheel and a slotted optical photoswitch (Optek, model OPB830W55). The encoder wheel is a thin plastic disk with two holes around the perimeter (figure 3). The wheel is attached to the motor shaft and positioned to allow the edge of the wheel to pass through the photoswitch. The photoswitch is a horseshoe-shaped electronic component with an LED (“emitter”) on one side and a phototransistor (“detector”) on the other side. If power is supplied to the photoswitch and the detector can “see” the emitter, the detector output is HIGH. If the detector cannot see the emitter, the detector output is LOW. As the wheel turns, periodic interruptions in the beam, or “state transitions”, are counted by the TFX-11. With a winch spool (drum plus cable) diameter of 5 cm and an encoder wheel configured with two holes, vertical position can be resolved to approximately 4 cm.

The TFX-11 has a real time clock, which allows it to perform each profile according to pre-programmed times and duration. When the clock indicates that it is time to start a profile, the TFX-11 switches on power to the motor and optical encoder and raises the sensor package from its parked position to the surface. Upon reaching the surface, the TFX-11 switches off power to the motor and optical encoder and applies power to the acoustical altimeter. The TFX-11 collects an ensemble of depth readings (typically 10) from the altimeter and determines the average water depth. This water depth can be logged by the TFX-11 if desired.

After the depth is determined, the TFX-11 calculates how many optical encoder state transitions are required to lower the sensor package to the bottom, based on the depth measurement and a calibration curve for the relationship between angular displacement of the motor shaft and the linear displacement of the winch cable. We estimate 5-10 cm of uncertainty in this calibration due to variability in the wrap of the cable on the winch drum. After calculating the number of state transitions, the motor is turned on and lowers the sensor package at a typical speed of 4 cm s^{-1}. When the bottom of the profile is reached, the sensor package is raised back to its parked position near mid-depth.

Water Resistant housing and deployment platform

The design of the deployment platform (figure 4) is similar to that of a small floating dock. It is constructed of marine treated lumber and is 1.8 m x 1.8 m with a 0.31 m x 0.31 m hole in the center. Two marine grade floats provide buoyancy for both the platform and instrumentation. The platform is sturdy enough to moor a boat and large enough to hold two average sized adults. Two platforms are easily loaded onto a boat trailer for transport and may be towed into place with a medium sized powerboat.

Two pedestals on top of the platform support a water-resistant housing. The WAAA package is raised above the platform to reduce corrosion from sea spray and to allow the sensor package to be brought to the surface for a complete sample of the water column.

The platform can be moored with any convenient means such as concrete anchors or diver-deployed screw anchors. We attached 7.5 m of heavy (2.2 cm) chain to each anchor and 2.54 cm nylon line to each chain. The nylon line is then secured to the corners of the platform so that approximately 1.5 m of chain is off the bottom.

Water Quality Probe and External Data Logger

A commercially available multi-parameter water quality probe (Hydrolab Datasonde, model 4a, HD4A) configured with conductivity, pressure, dissolved oxygen (with circulator) and temperature sensors has been used to measure water quality conditions through the water column. We found that the internal data logger that came with the HD4A is not flexible enough to accommodate our sampling schedule and therefore we used a separate, external data logger (ONSET Computer Corp., Tattletale Model 8). The Model 8 and 6 “C” cell batteries are mounted in a waterproof housing that is strapped to the HD4A, figure 5. The HD4A and external data logger housing are shackled to the winch cable and are easily removed for servicing.

The Model 8 has a real time clock that is synchronized with the clock on the TFX-11 and is used to turn the HD4A on and off according to the profiling schedule. When a profile begins, the Model 8 activates its serial port, which is connected to the HD4A. The HD4A is configured to power itself up and send data at a rate of 1 Hz whenever its serial port is activated. The Model 8 writes the incoming data to a flash memory card (Periperal Issues, model Persistor CF8). When the profile is scheduled to end, the Model 8 turns off its serial port, causing the HD4A to stop sending data and return to a low power mode. Recovering the stored data requires swapping the flash memory card with a fresh card. Based on a typical lowering speed of 4 cm s^{-1} and a 1 Hz sampling rate, profile data is collected at a vertical resolution of 4 cm.

Deployments

The P-AVP minimum sampling depth is limited by the size of the platform floats and the acoustical altimeter. The bottom of the platform floats sit approximately 0.8 m below the water level, while the acoustical altimeter needs a minimum of 1 m water depth in order to obtain good depth readings (Datasonics, 1997).

The P-AVP is trailered and towed into position for deployment and attached to its anchors. The Model 8 control program is initialized with the profiling schedule and the water quality probe and external data logger assembly are shackled to the winch cable. The TXF-11 control program is then initialized with the profiling schedule. Servicing frequency is determined primarily by bio-fouling of the sensors (primarily the dissolved oxygen sensor) on the water quality probe. Servicing is accomplished by lifting the water quality probe and external data logger assembly to the surface, detaching it from the winch cable, replacing the water quality probe with one that has been cleaned and calibrated in the lab, swapping the flash memory card with a fresh one, replacing batteries (if necessary) and re-initializing the profiling schedule in the Model 8 and TXF-11.

To date the P-AVP has been deployed in two different estuarine environments.

Bogue Sound

Bogue Sound is a mesotidal estuary located on the eastern shore of North Carolina. It has two connections with the Atlantic Ocean: Beaufort Inlet in the East and Bogue Inlet in the west. Water level in the Sound is characterized by a strong semi-diurnal variation due to tidal forcing from the coastal ocean (Peterson et al, 1996). The water velocity reaches approximately 1 m s^{-1} at maximum flood and ebb.

The P-AVP was deployed near the north shore of Bogue Sound (figure 6) for a period of 2 d. It was moored with a two point anchoring system with one side attached to a dock piling and the other side secured with a danforth anchor.

The P-AVP was programmed to collect a profile every 15 min. Figure 7 is a comparison between the depth recorded by the acoustical altimeter and the HD4A at its bottom-most position. The two agree well with a mean absolute error of less than 5 cm. The influence of the semi-diurnal tide is seen clearly in the water level data, which indicates a tidal excursion of 60 cm. The sediment at this location consists of medium to fine sand and produced a strong reflection for the acoustical altimeter.

Contours of dissolved oxygen, salinity and temperature (figure 8) show that the tidal currents are sufficiently strong to vertically mix the water column as there is no indication of stratification in either the salinity or temperature data. Dissolved oxygen data indicate a well oxygenated water column with values greater than or equal to 5 mg l^{-1}.

Neuse River Estuary

Also located on the eastern shore of North Carolina, the Neuse River Estuary (NRE) is a microtidal estuary. The NRE is a drowned river valley that averages 4 m deep, 5 km wide, and approximately 70 km long. It empties into the largest lagoonal estuary in the United States, Pamlico Sound. Circulation in the estuary is primarily driven by freshwater discharge, meteorological forcing, and basin wide seiching with maximum velocities in the range of 0.2 m s^{-1}, (Luettich et al, 2000).

The P-AVP was used in an across-channel hydrodynamic and water quality study. Two P-AVPs were deployed near opposite shores of the NRE and collected data from June 12 through September 28, 2000. The TFX-11 was programmed to take a profile every 15 min, which was completed in approximately 5 min. The system was serviced every 4 – 7 d. For brevity, only results from one site are presented. Figure 9 gives a representative slice of the data from a 3 d time period.

This set of data differs strongly from the Bogue Sound data. The NRE is a mesohaline estuary and rarely experiences salinity values as high as 33 ppt. Periods of strong stratification as well as well-mixed conditions are identified within this three-day record. Low dissolved oxygen conditions occur simultaneously with and to the same vertical extent as high salinity water. This suggests that low DO water is advected into the study site rather than generated locally.

Water level in the NRE is highly variable and weather dependent. A wind-driven water level variation as large as 1.5 m has been observed (Luettich et al, 2000). The P-AVP was able to adjust to the variable water depth throughout the course of the 3.5 mo deployment. The acoustical altimeter appeared to perform as well with the muddy substrate of the NRE as with the sandy substrate of Bogue Sound.

Conclusion

The careful design of the P-AVP included minimal custom components and represents a collection of predominately “off-the-shelf” parts. It has proven itself to be a reliable means of collecting quasi-continuous vertical profiles of standard hydrographic and water quality parameters in shallow estuaries. Its floating design allows easy transport to a desired deployment site and it may be moored using common anchors such as concrete blocks or diver-deployed screw anchors. It has been deployed in relatively unprotected areas, is designed for autonomous operation, dynamically adjusts the profile range for changes in water depth, has a vertical resolution of 4 cm and uses a standard, commercially available, multi-parameter water quality probe to measure water quality data during each profile. The ability to automatically adjust to different water depths is important in shallow estuaries that experience water level fluctuations that are a significant fraction of the depth. During warm weather months, the system typically requires weekly servicing due to bio-fouling of the multi-parameter water quality probe (primarily the dissolved oxygen sensor). If bio-fouling is not an issue, one 12V marine battery can run the P-AVP for approximately two weeks in deployments such as those described above.

Data storage is not a significant limitation since flash memory cards with capacities in excess of a hundred megabytes are now readily available.

The WAAA package is highly adaptable and can be programmed to suit any specific sampling strategy, brand of water quality probe and water quality probe configuration. Due to variability in the cable wrap on the winch, the winch can position the probe in the water column with an absolute accuracy of 5 – 10 cm. This error has minimal effect on the profile data since the profiles are re-constructed for plotting and analysis using the depth below the water surface determined from the pressure sensor on the water quality probe. However, it does suggest a safe distance from the bottom to terminate the profile to keep the water quality probe from coming into contact with the bottom. This safe distance should also take into account wave conditions at the deployment site since vertical platform motion will be translated to the water quality probe. We anticipate that the present P-AVP design can function in up to 20 m water depth with little or no modification.

Presently planned modifications to this P-AVP include the construction of a cage to hold and protect the water quality probe and the external data logger. Our previous experience has indicated that during rough weather these can bang against the platform when they are at the top of a profile. Also, the winch tensioner will be eliminated and replaced with a pulley system that can better control the cable winding on the winch drum. The retrieval of data in real-time can be highly desirable and we are working to incorporate this in the future.

Acknowledgements

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Figure Captions

Figure 1. The top view of the winch assembly package which shows the connections between motor, optical encoder and winch. A 12V marine battery supplies power to the 12 V DC motor, which turns both the optical encoder and trailer winch. The optical encoder measures the angular displacement of the winch and the tensioner provides constant tension for a smooth wrap on the drum.

Figure 2. A Tattletale model TFX-11, the computer controller for the WAAA, controls the distribution of power to the DC motor as shown in this motor control design schematic.

Figure 3. The schematic of the optical encoder shows a plastic disc with two holes (gray area), which serves as the encoder wheel. The photoswitch detects transitions in the light beam that are counted by the TFX-11 controller and used to determine how much cable has been paid out by the winch.

Figure 4. Two Ace marine floats support the Water Resistant housing and deployment platform. The WAAA package sits approximately 1 m above the surface to prevent corrosion from sea spray. The platform is sturdy enough to moor a powerboat and hold 2 adults.

Figure 5. The water quality sensor package consists of a multi-parameter water quality probe and an external data logger located in a separate waterproof housing. (a) The components associated with the external data logger are 6 “C” batteries, a Tattletale Model 8 microcomputer

and a compact flash memory card recorder. (b) The multi-parameter water quality probe is strapped to the external data logger housing; a serial data cable connects the two housings. The housings are shackled to a thimble on the end of the winch cable.

Figure 6. Deployment sites for the P-AVP are located in eastern North Carolina, USA. One mesotidal estuary location in Bogue Sound and a microtidal, wind-driven estuary location in the Neuse River Estuary are marked by the ⊗.

Figure 7. Time series depth comparison for the Bogue Sound deployment over the 2 d data collection period yielded a mean absolute error of less than 5 cm. The solid line denotes the acoustical altimeter depth and the dashed line denotes the depth recorded by the HD4A.

Figure 8. A well-mixed water column is evident in the contours of dissolved oxygen (a), salinity (b) and temperature (c) for the Bogue Sound deployment in April, 2000.

Figure 9. Strong diurnal stratification is evident in the contours of dissolved oxygen (a), salinity (b) and temperature (c) for a site in the Neuse River Estuary, June, 2000.

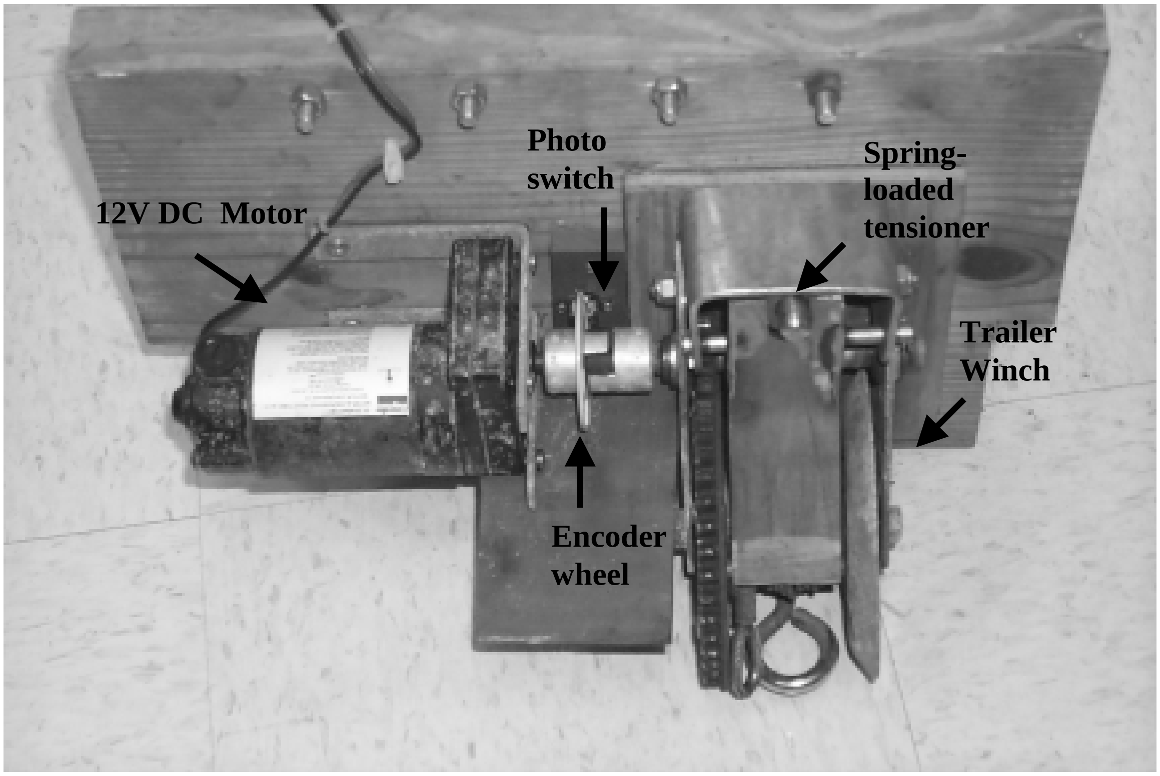
Photo
switch
Spring-
loaded
tensioner
12V DC Motor
Trailer
Winch
Encoder
wheel

Figure 1

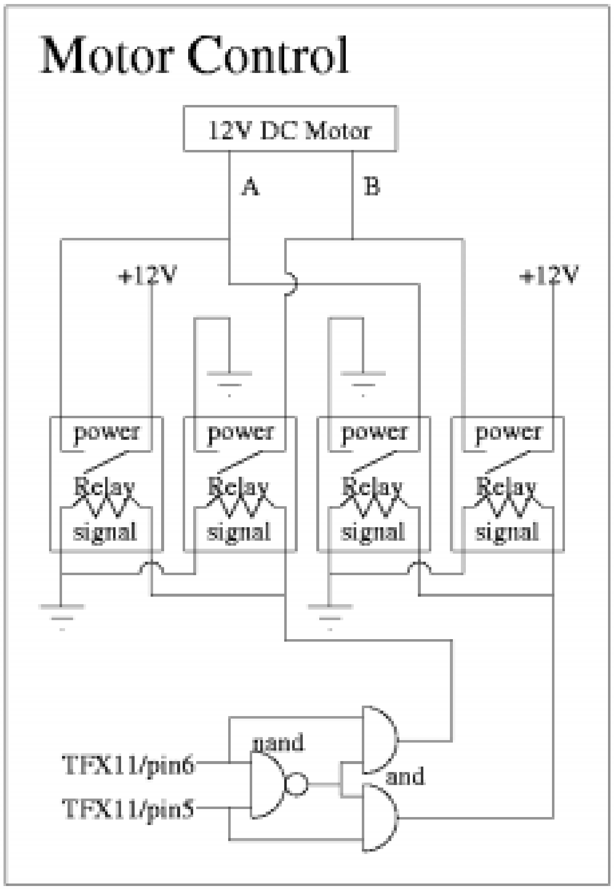
Motor Control
12V DC Motor
A
B
+12V
+12V
power
Relay
signal
power
Relay
signal
power
Relay
signal
power
Relay
signal
nand
and
TFX11/pin6
TFX11/pin5

Figure 2

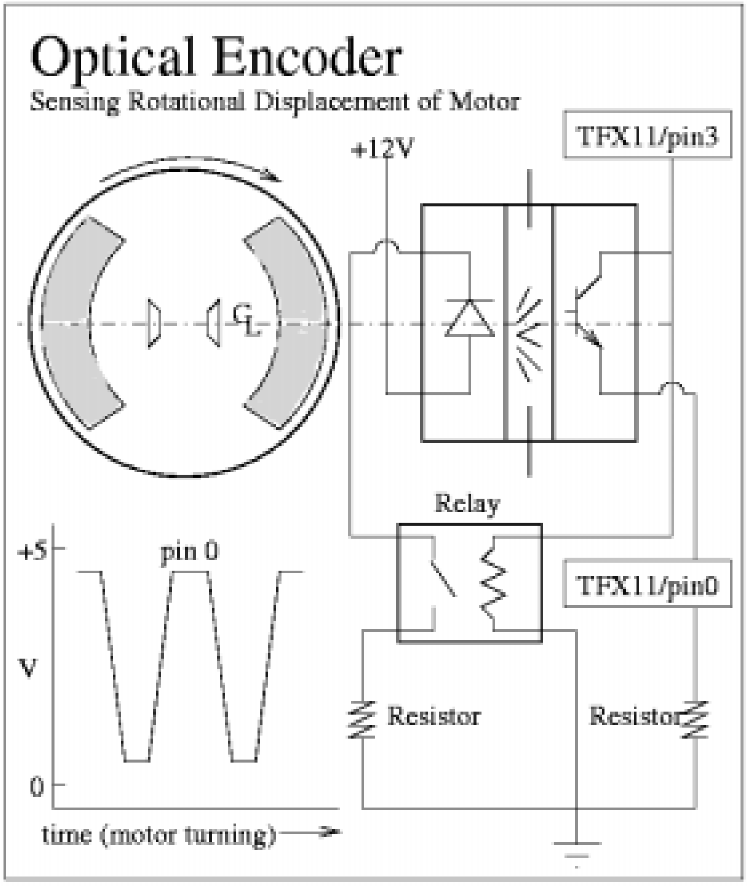
Optical Encoder
Sensing Rotational Displacement of Motor
+12V
TFX11/pin3
Relay
TFX11/pin0
+5
pin 0
V
0
time (motor turning)
Resistor
Resistor

Figure 3

Figure 4

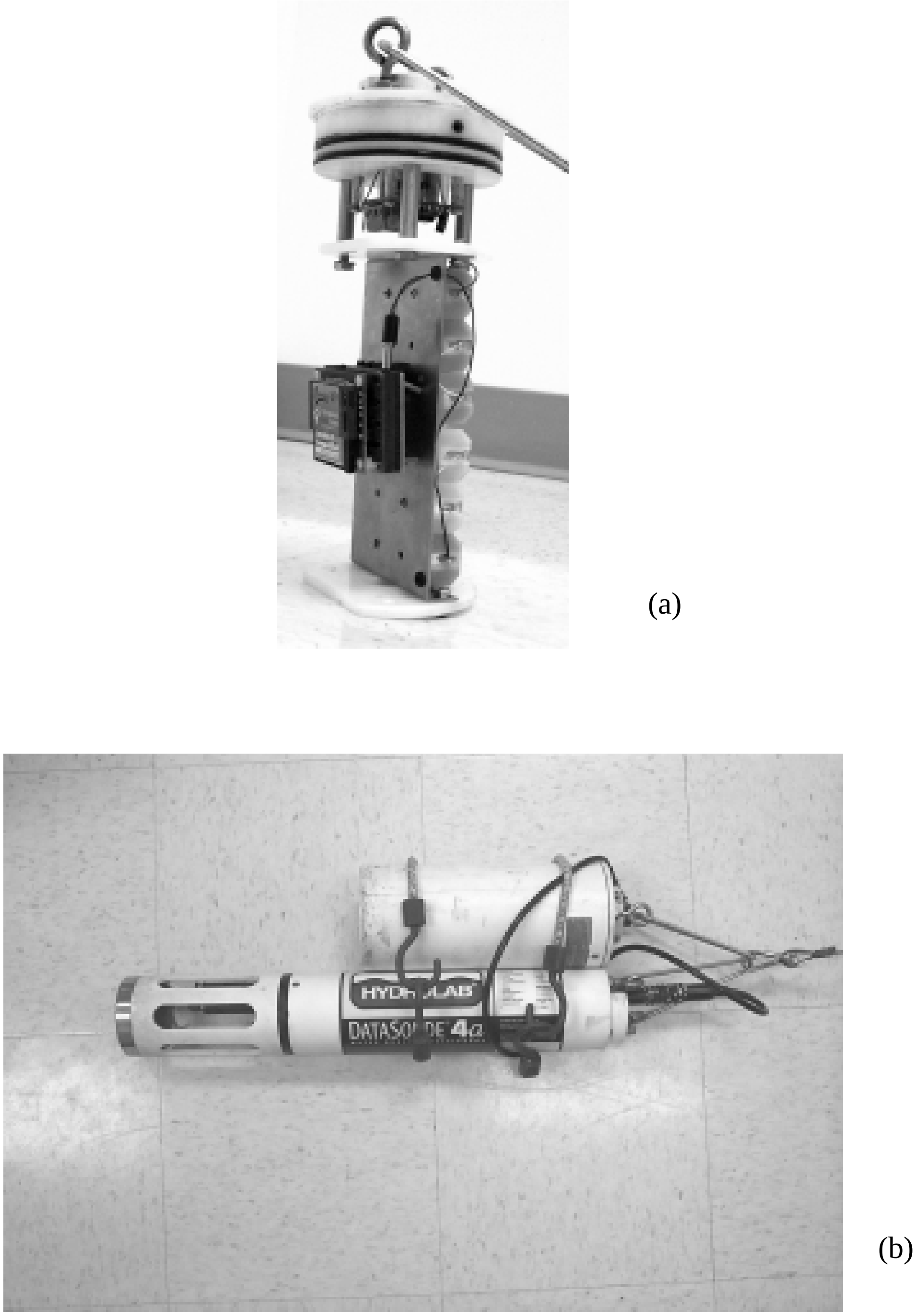

Figure 5

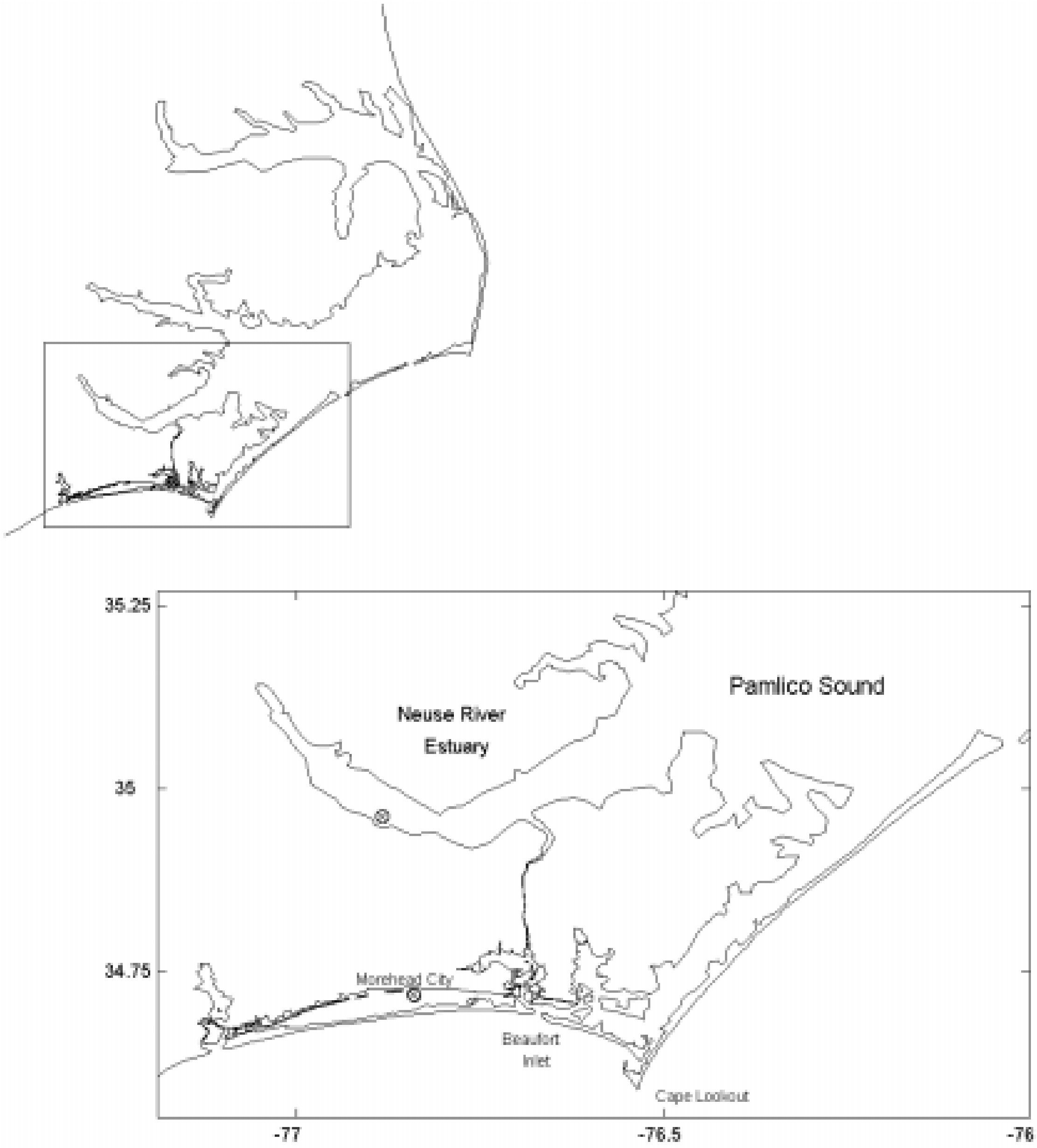
35.25
35
34.75
-77
-76.5
-76
Pamlico Sound
Neuse River
Estuary
Morehead City
Beaufort
Inlet
Cape Lookout

Figure 6

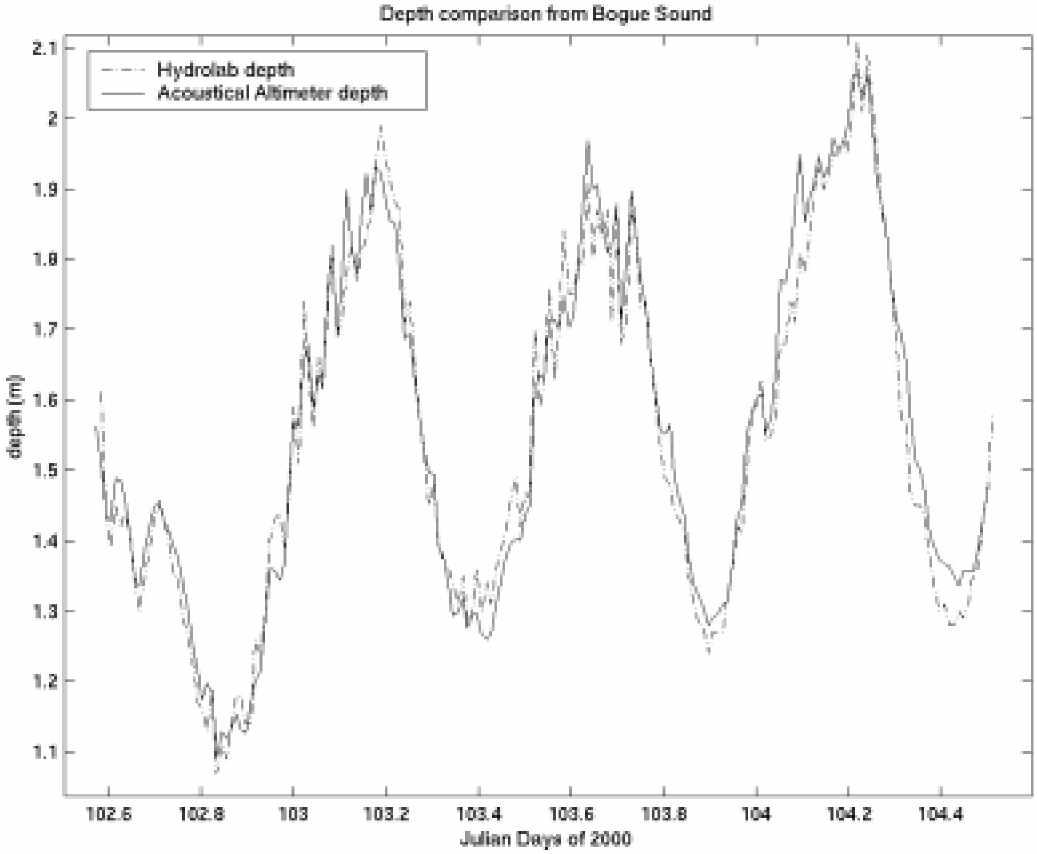
Depth comparison from Bogue Sound
Hydrolab depth
Acoustical Altimeter depth
depth (m)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
102.6
102.8
103
103.2
103.4
103.6
103.8
104
104.2
104.4
Julian Days of 2000

Figure 7

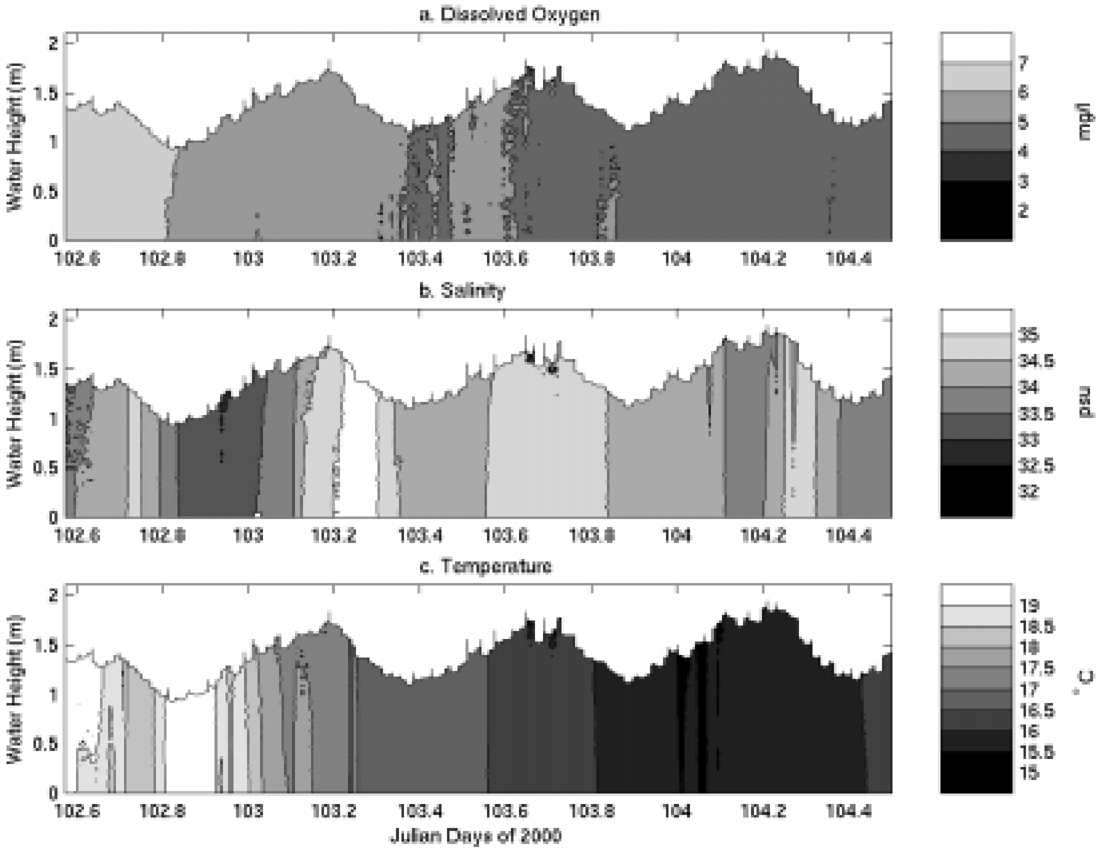
a. Dissolved Oxygen
Water Height (m)
2
1.5
1
0.5
0
102.6
102.8
103
103.2
103.4
103.6
103.8
104
104.2
104.4
7
6
5
4
3
2
mg/l
b. Salinity
Water Height (m)
35
34.5
34
33.5
33
32.5
32
psu
c. Temperature
Water Height (m)
19
18.5
18
17.5
17
16.5
16
15.5
15
°C
Julian Days of 2000

Figure 8

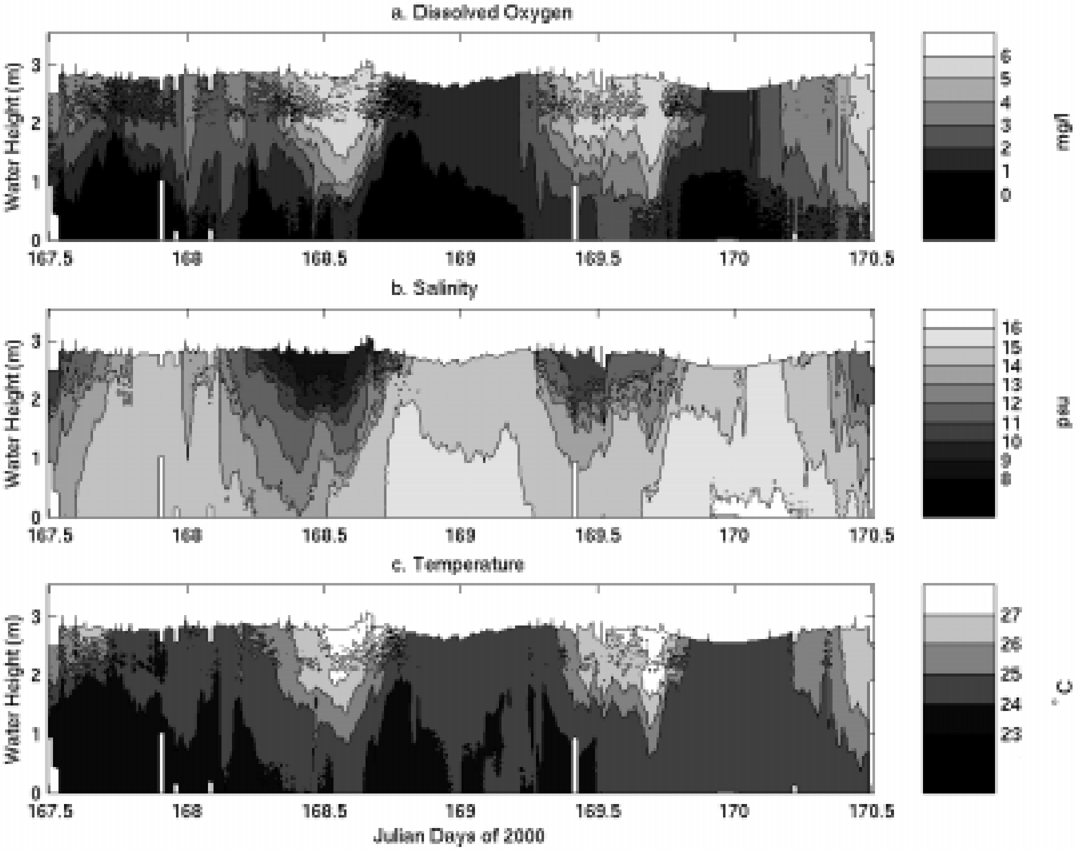
a. Dissolved Oxygen
Water Height (m)
0
1
2
3
167.5
168
168.5
169
169.5
170
170.5
6
5
4
3
2
1
0
mg/l
b. Salinity
16
15
14
13
12
11
10
9
8
psu
c. Temperature
27
26
25
24
23
°C
Julian Days of 2000

Figure 9