NOAA Technical Report NOS CO-OPS
**Ocean Systems Test and Evaluation Program**

# Engineering Study

## ADCP Platform and Mooring Designs for CO-OPS Current Surveys

### An Engineering Review of Existing Platforms and Moorings for the 2006 Field Season

**Silver Spring, Maryland**
**May 2010**

noaa **National Oceanic and Atmospheric Administration**

**U.S. DEPARTMENT OF COMMERCE**
**National Ocean Service**
**Center for Operational Oceanographic Products and Services**

**Department of Commerce**
**National Oceanic and Atmospheric Administration**
**National Ocean Service**
**Center for Operational Oceanographic Products and Services**

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The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient, and environmentally sound maritime commerce. The Center provides the set of water level and tidal current products required to support NOS' Strategic Plan mission requirements, and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. For example, CO-OPS provides data and products required by the National Weather Service to meet its flood and tsunami warning responsibilities. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U. S. harbors, and the National Current Observation Program consisting of current surveys in near shore and coastal areas utilizing bottom mounted platforms, subsurface buoys, horizontal sensors and quick response real-time buoys. The Center: establishes standards for the collection and processing of water level and current data; collects and documents user requirements which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products.

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# Table of Contents

## List of Figures

## List of Tables

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# Executive Summary

CO-OPS obtains critical data by deploying acoustic Doppler current profilers (ADCPs) in multiple U.S. locations. There are several ways to deploy ADCP platforms, including bottom-mounted, subsurface taut-moored, shore-mounted horizontal, ship-mounted or towed, and buoy-mounted. The deployment method depends upon the prevailing environmental conditions, as well as user requirements and other variables.

This engineering review focuses on bottom-mounted and subsurface taut-moored platforms. During 2001-2005 there were 48 bottom-mounted deployments in Maine, New York (Hudson River), Southeast Alaska, and California. These deployments used the Flotation Technology AL-200, Mooring Systems, Incorporated (MSI) Tripod, and ES I, ES II, ES III, and ES IV. The ES platforms were designed in-house by Dr. Eddie Shih. Between 2001 and 2005, there were 57 subsurface mooring deployments in Alaska, California, and Delaware Bay, with a recovery rate of 98%. These deployments used the Open Seas Instrumentation Streamlined Underwater Buoy System (SUBS) Model A2.

The overall success rate for deployments of both platforms was 94%. Of the 105 total deployments, 99 were successfully deployed and recovered. Of the 48 bottom-mounts, 43 were successfully deployed and recovered (90% success) and of the 57 SUBS, 56 were successfully deployed and recovered (98% success). The most recent results have been even better, with successful deployments/recoveries for all in Southeast Alaska and all but one in the Hudson River.

Bottom-mounted platforms generally performed well in shallow water (less than 50 meters). The Flotation Technology AL-200 trawl-resistant bottom mount (TRBM) platform was more successful in conditions with low sedimentation, while the ES II proved to be more suitable in high sedimentation. The most common problem for these systems was sedimentation that accumulated inside the platform, covering the release mechanism and the acoustic transducer. Generally, bottom mounts are used when diver assistance for ADCP recovery is available and where trawling is not likely. Since there are several choices of bottom-mounted platforms, the selection of the most appropriate system is based upon the environmental conditions, marine activities, deployment risks, and specific location of the deployment.

The Open Seas SUBS, the sub-surface taut-moored platform that was tested, provided satisfactory results for current surveys. The most common concern with this system is the effect of tilting on data quality. Twisted mooring lines and strong currents also caused failure of some deployments. Subsurface taut-moored platforms are particularly well-suited for deep water (greater than 50 meters) deployments and may work better than bottom-mounted systems where strong currents are present.

There are several important criteria to consider during deployment site selection. These criteria include the water depth, estimated maximum and minimum current speed, type of sea bottom, volume of suspended materials, chance of bio-fouling, types of marine activities within the targeted area, and the risk of deployment failure. These criteria are all examined during site reconnaissance, which is performed prior to determining the exact deployment location.

During this review period, modeling tests contributed to a greater understanding of why certain failures occurred. Modeling should be expanded to provide guidance for future design

improvements. The modeling tool used most often by CO-OPS personnel was Mooring Design and Dynamics (MD&D). It was used to determine the optimal setup and design of the Benthos Model 875-A popup buoy and SUBS. The MD &D and the Woods Hole Oceanographic Institution (WHOI) Cable v2 modeling tool are particularly suitable to assist in evaluating mooring designs. An intercomparison between the two models should be considered for the future.

The selection of the best existing platform for use in a specific deployment is dependent upon careful site reconnaissance and evaluation of selection criteria. Based on the framework outlined in this report, CO-OPS should ultimately choose the platform that will deliver the required data with the least risk of failure.

# 1.0 Introduction

## 1.1 Background

CO-OPS conducts current surveys using acoustic Doppler current profilers (ADCPs), which provide real-time measurements of ocean and estuarine currents. These data are critical to CO-OPS and our partners who use current information to ensure safe navigation and successful search and rescue operations, as well as to those scientists who observe and analyze complex coastal and ocean processes.

There are several platform options for ADCP deployment, including bottom-mounted, subsurface taut moored, shore-mounted horizontal, ship-mounted or towed, and buoy-mounted. The type of system deployed depends upon the environment, user requirements, equipment available, and other variables. Deploying ADCPs using the best option for the prevailing environmental conditions can help to ensure that instruments are properly protected during deployments and may increase the probability that the ADCPs will return high quality data. This report focuses on a review of bottom- and subsurface moored options.

The case studies referenced in this review were conducted on the west and east coasts of the U.S. from 2001-2005 (table 1). Bottom-mounted system deployments took place in Maine, New York (Hudson Bay), Southeast Alaska, and California. Subsurface deployments took place during the same timeframe in Alaska, California, and Delaware Bay. Of the 105 deployments performed during this time, 99 of them were successfully deployed and recovered (an overall success rate of 94%). Forty-eight of these were bottom-mounted systems, with four lost or not recovered in 2002 and one not recovered in 2005 (a success rate of 90%). The remaining 57 were SUBS, with only one lost (a success rate of 98%). Most recent recovery results include 100% success in Southeast Alaska and all but one in the Hudson River.

**Table 1. Summary of 2001-2005 Deployments**

| | **Bottom-Mounted Platforms** | | **SUBS** | |
|---|---|---|---|---|
| **2001** | Southeast Alaska<br>New Jersey Oil Spill | 4<br>1 | Delaware Bay | 1 |
| **2002** | Southeast Alaska<br>COI<br>Las Mareas | 5<br>5<br>2 | | |
| **2002/03** | Humboldt Bay | 4 | Humboldt Bay | 1 |
| **2003** | Southeast Alaska<br>CSI Florida<br>New Jersey Oil Spill | 3<br>4<br>1 | Southeast Alaska<br>COI | 4<br>8 |
| **2004** | Southeast Alaska<br>Humboldt Bay<br>Hudson River | 2<br>1<br>1 | Southeast Alaska<br>COI<br>Humboldt Bay | 7<br>5<br>1 |
| **2005** | Southeast Alaska<br>Penobscot Bay<br>Hudson River<br>Money Point Intercomparison | 1<br>4<br>9<br>1 | Southeast Alaska<br>COI | 6<br>24 |
| | **48 Total Deployments** | | **57 Total Deployments** | |

## 1.2 Purpose

The purpose of this document is to evaluate the successes and failures of bottom-mounted and subsurface ADCP deployments used over the past years, serving as a basis for recommendations to improve retrieval rates.

## 1.3 Options Reviewed For This Report

There are six bottom-mounted options and one subsurface option for ADCP deployment discussed in this report. They are:

| Bottom-Mounts | Subsurface |
|---|---|
| ▪ Flotation Technology TRBM AL-200<br>▪ MSI Tripod | ▪ Open Seas Instrumentation SUBS with and without Argos Beacon Model A2 |
| ▪ ES I | |
| ▪ ES II | |
| ▪ ES III | |
| ▪ ES IV | |

# 2.0 Mount or Mooring Options

**Bottom-Mounted Platform Systems.** Bottom-mounted platform systems provide a safe way to mount an upward-looking ADCP. CO-OPS reviewed two commercially-designed systems and four in-house designs by Dr. Eddie Shih. These systems used either a Benthos 867A transponding release (Flotation Technology Trawl Resistant Bottom-Mount AL-200) or Benthos Model 875-A release (Mooring Systems Incorporated tripod and ES I-IV) and had varying degrees of protection against trawling operations. Systems were deployed under a variety of current and seabed conditions. Some were exposed to strong currents (> 4 knots), while others had entire systems buried in extremely muddy sea bottoms. Test locations include Maine, New York (Hudson River), California, and Virginia (Chesapeake Bay). Appendix A provides additional information on TRBM case studies.

**Subsurface Taut-Moored Systems.** Subsurface taut-moored systems operate with the ADCP attached to 5/16-inch (in) mooring cables, typically configured to sample 2-6 meter (m) bins. These systems, known as Streamlined Underwater Buoyancy Systems or SUBS, are designed for a subsurface depth of 100 m-200 m. Deployments reviewed for this report used ORE Offshore (formerly Edgetech) releases, and some systems were tested with ancillary equipment, such as Argos beacons and pingers.

One subsurface mooring system, Open Seas Instrumentation's Model A2, was deployed in Southeast Alaska, Cook Inlet, Alaska, and Humboldt Bay, California. Subsurface floats from Flotation Technology (StableMoor™) and OceanScience (Tuna) may be tested in the future. Versions of these models that CO-OPS may test are presently in the design phase, prototype, or limited production status by the vendors.

The following paragraphs describe the design characteristics, strengths, and weaknesses of each system.

## 2.1 Flotation Technology Trawl-Resistant Bottom Mount (TRBM)

The TRBM Model AL-200 (fig. 1) works with the Teledyne RD Instruments (TRDI) Sentinel ADCP and is deployed by lowering it to the bottom, using either a slip-line or an acoustic release to place it. Once deployed, the double axis gimbal keeps the ADCP in a vertical position. Prior to retrieval, the buoyant recovery pod is attached to a high-strength mooring line that assists in the recovery of the detachable anchoring base. The AL-200 is rated for 200 m-500 m and is constructed of Flotec™ high impact syntactic foam and 5000 series aluminum.

The AL-200 is very stable, even in current flow > 4 knots. It is free-fall deployable, and the aluminum construction protects instruments without affecting the compass. The buoyant recovery pod allows instrument retrieval and can be used with a variety of acoustic releases.

Earlier models from Flotation Technology matched the pod to the base; however, these have been redesigned because many of the bases have been lost, rendering the TRBM unusable. The low platform height and the use of an aluminum frame introduce weakness to the TRBM AL-200 platform, including attenuated transponder acoustic communication, malfunction of release mechanism due to severe sediment cover, and corrosion from contact of dissimilar metals with the aluminum frame. The ADCP gimbal on top of the platform helps to reduce the silt accumulation;

however, the protruded ADCP transducer head is vulnerable to trawl damage. Table 2 provides specifications for the TRBM AL-200.

**Figure 1.** Flotation Technology Trawl-Resistant Bottom Mount (TRBM)

**Table 2.** Specifications for Flotation Technologies AL-200

| | |
|---|---|
| **Shape/Size** | Four-Sided Truncated Pyramid – 1.8 m (72 in) × 1.8 m (72 in) × 0.46 m (18 in) high |
| **Buoyancy** | Flotec™ high impact syntactic foam; 300 lbs. positive |
| **Base** | Corrosion resistant, high strength 5000 series aluminum |
| **Weight in Air** | 700-900 lbs. (depends on amount of lead ballast installed) |
| **Weight in Water** | 130-330 lbs.(depends on options and bottom conditions) |
| **Standard Use Depth** | 200 m |

## 2.2 Mooring Systems, Incorporated (MSI) Tripod

The MSI tripod is a low-cost bottom-mounted platform that uses gimbals to house ADCPs. Made of light-weight 6061-T6 aluminum, it is gimbaled up to 20°, with three legs and spreader bars that accommodate several pieces of equipment (fig. 2). The tripod will accommodate a variety of instrumentation and has adjustable ballast for different bottom types. Options available on the tripod include a popup buoy recovery system, an outer cover to enclose the tripod, a lowering bridle to assist in deployment, extra instrument clamps and tie downs to accommodate additional instruments, and lead ballast. The platform is less stable than other types that were studied and is vulnerable to negative impacts (tilting, damage, or dislodging) from mobile debris anchors and anchor lines, etc. Table 3 provides specifications for the MSI tripod.

**Figure 2.** MSI Tripod

**Table 3.** . Specifications for MSI Tripod

| | |
|---|---|
| **Angle of sides** | 45° |
| **Overall height** | 50.8 cm (20 in) |
| **Overall Diameter** | 1.5 m (60 in) |
| **Weight in Air** | 75 lbs. - includes 36 lbs of lead; no instruments |
| **Weight in Water** | 56 lbs. - includes 36 lbs of lead; no instruments |

## 2.3 ES I, II, III, and IV

ES I through ES IV ADCP platform systems were designed by Dr. Eddie Shih to meet varying bottom ambient challenges, such as heavy suspended sediments and strong current flow. ES I and ES II are constructed from molded reinforced fiberglass plastic (RFP) and use a two-axis Delrin gimbal to maintain the ADCP in an upright–looking position (appendix B). These features were the first of their kind in the user community. The merits of these platforms include their simplicity, corrosion resistance, structural strength, stability (from deep skirted bottom), and good ADCP orientation. Both were originally designed for real-time data transmission using underwater electro-mechanical (EM) cable.

ES III and ES IV are open-frame platforms designed for sites where sand bar movement is frequent and suspended sediment load is heavy (such as Benicia and Humboldt Bay, California). They are constructed of marine grade aluminum pipe and U-channel members. The U-channels at the base are inverted with a skirted bottom and a flat top to which weight elements are attached to increase sliding resistance.

### 2.3.1 ES I

The ES I (fig. 3) is designed for portability and diver-assisted deployment and retrieval. It contains no acoustic release but can be retrofitted if needed. Retrieval can be accomplished using diver attached lines or a lift bag, or by pulling up the real-time EM cable. The deep (6-in) bottom skirt provides strong holding power against platform sliding in a strong current. The platform was tested for deployment and sliding at the U.S. Navy David Taylor Model Basin's (DTMB) Circulating Water Channel. The ADCP is gimbaled below the top of the platform and is well protected by the platform. The ½-in thick RFP platform is strong and can withstand the impact of trawlers. The ES I accommodates the RDI Workhorse Sentinel and Sontek ADCPs, as well as similar instruments by other manufacturers. The pivoting release mechanism consists of a simple lever that reduces the risk of release line entanglement. Table 4 provides specifications for the ES I.

**Figure 3.** ES I

**Table 4.** Specifications for ES I

| | |
|---|---|
| **Shape/Size** | Lamp shade-like, 1.3 cm (½ in) thick RFP, 46.5° sloping side |
| **Overall height** | 64.8 cm (25.5 in) |
| **Overall Diameter** | 43.2 cm (17 in) (top) 1.6 m (62.4 in) (base) |
| **Weight in Air** | Approximately 400 lbs. (with 200 lbs lead) |
| **Weight in Water** | Approximately 320 lbs. |

### 2.3.2 ES II

The ES II (fig. 4) contains two large openings on the top: one for the ADCP and the other for the release float. The ADCP and gimbal work similarly to those in ES I, except that the ADCP is supported by an RFP flange of an RFP cylinder versus an inverted flange in ES I. A Benthos Model 875-A popup acoustic release/float/rope bucket module is used for platform recovery.

The larger size and heavy weight provide more strength and stability than the ES I. The height of the platform reduces the danger of sediment burying the ADCP and release mechanism. The large inside space is easy to work with and allows installation of additional instruments (such as underwater acoustic modems and battery packs). The ADCP is gimbaled below the top of the platform; therefore, it is well protected against trawl damage. The popup float protrudes slightly above the platform to ensure successful float exit. However, these two large (16-in diameter) top openings are sources of sediment accumulation inside the platform when operated in sediment-ladened waters. Proper drain holes (on the bottom and side), an acoustic transparent plastic cover plate, and a properly designed float (see section 6.3) could reduce this problem. The platform system was successfully deployed during 2003-2004 at four sites in the Chesapeake Bay for an NOS partnership project.

The system is heavy and provides good stability in high currents. However, the deck space (though more spacious than the ES I) severely limits the space available for the required instruments, especially flotation instruments. Table 5 contains specifications for the ES II.

One major disadvantage of both the ES I and ES II is the excessive amount of sediment that the system captures. A cover could be designed for the ADCP; however, it must be tested to determine the effect of refraction on data quality.

**Figure 4.** ES II

**Table 5.** Specifications for ES II

| | |
|---|---|
| **Shape/Size** | Trapezoidal-shaped with bottom plate 2 m (79 in) × 1.6 m (64 in) × 0.7 m (28 in) high |
| **Construction Material** | 1.3 cm (0.5 in) fiberglass |
| **Weight in Air** | 450 lbs. |
| **Weight in Water** | 100 lbs.(Platform) and 200-400 lbs. (Lead) (depends on bottom sediment) |
| **Popup Float** | 38 cm (15 in) overall dimension ; net buoyancy ~ 57 lbs. |
| **Retrieval Line** | Spectra .64 cm (.25 in) × 76 m (250 ft) rope |
| **Standard Use Depth** | 50 m (164 ft) |
| **Workload** | 1200 lbs. with 1 knot current |

### 2.3.3 ES III and IV

ES III and ES IV are similar in design. The difference is in the number of top openings—ES III (fig. 5) has two and the ES IV (fig. 6) has four. The extra windows allow the user to install a redundant release float and other instruments (such as an underwater acoustic modem or CTD sensors). The open frame allows water and sediment to pass through. The reduced flow drag adds less weight, and the reduction of flow-induced scouring on the lee side of the platform helps to maintain stable platform position. The U-channel structural members at the base also prevent sliding. The open frame, however, is vulnerable to mobile debris and anchor line entanglement. The ES IV houses the same instrumentation as the ES III and contains an additional acoustic release popup float. Tables 6 and 7 provide specifications for each design.

The ES III was deployed near the entrance channel of Humboldt Bay from 21 July through 15 October 2004 at a depth of 12.7 m (41.7 ft). The site is known for its active sand bar movement. The platform was reported to be buried in the sand after collecting data for 86 days. The Benthos popup float did not surface when expected. Probably covered with sediment, it made its way to the surface within a couple of days. Once there, a boater inadvertently separated it from the platform's lift line. Divers eventually retrieved the ADCP and float but left the platform onsite.

In a 2003-2004 deployment in the Chesapeake Bay, the ES IV platform was strapped with PVC plates to prevent fishing line entanglement (fig. 7).

**Figure 5.** ES III

**Table 6.** Specifications for ES III

| | |
|---|---|
| **Shape/Size** | Trapezoidal shaped, two top openings |
| **Overall height** | 66 cm (26 in) |
| **Overall Diameter** | 1.5 ft × 2.75 ft (top) 5 ft × 5 ft (base) |
| **Weight in Air** | 120 lbs. (without lead) |
| **Weight in Water** | 210 lbs. (with 150 lb. lead bricks) |

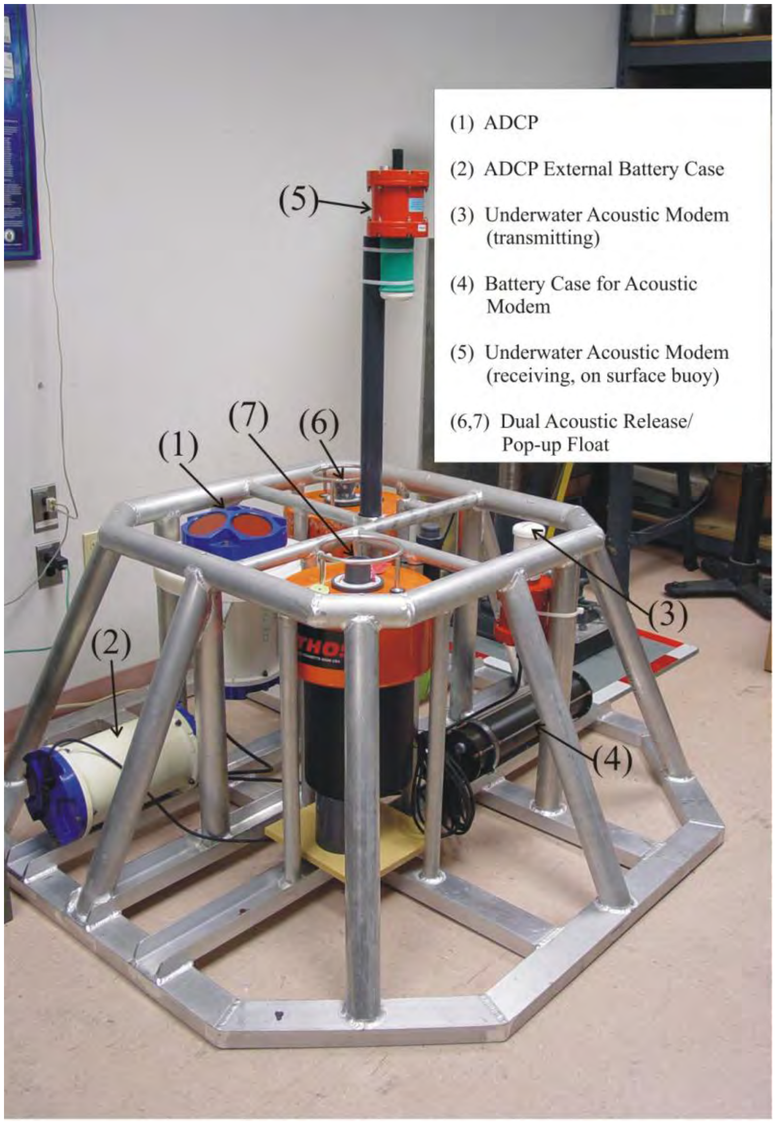



**Figure 6.** ES IV with dual Benthos popup releases, ADCP/external battery case and underwater acoustic modem/external battery case. (Item 5 is for illustration only. It is to be mounted on a surface buoy.)

**Table 7.** Specifications for ES IV

| | |
|---|---|
| **Shape/Size** | Trapezoidal, aluminum open frame |
| **Overall height** | 66 cm (26 in) |
| **Overall Diameter** | 1.5 m (60 in) × 1.5 m (60 in) (base) 0.89 m (35 in) × 0.89 m (35 in) (top) |
| **Weight in Air** | 150 lbs. |
| **Weight in Water** | 230 lbs. (with 150 lb. lead bricks) |

**Figure 7.** ES IV with PVC plates (used in the Chesapeake Bay during 2003-2004)

## 2.4 Open Seas Instrumentation SUBS

The Open Seas Instrumentation SUBS Model A2 is a stable instrument buoy made of a strong ultra-violet (UV) protected high-density polyethylene (HDPE). The buoy is attached to a mooring cable made of 5/16-in steel, which is attached to an anchor at the bottom of the seabed (appendix C). CO-OPS uses railroad wheels as anchors and often achieves additional buoyancy by adding floats to the mooring lines. Figure 8 shows the Model A2 with an Argos antenna/transmitter module attached to the tail fin. Table 8 provides specifications for the A2 design.

**Figure 8.** Open Seas SUBS Model A2

There are two operational concerns related to the SUBS A2. First, the installation and removal of the ADCP require that the shells be taken apart (including the tail fin section). There are about 40 fasteners, and the shell is often deformed from weathering, therefore installing (or removing) the ADCP could take several hours. The second concern is that there is significant void between the ADCP and the two 32-cm (13-in) hollow plastic floats at the front and back sections. These voids tend to trap sediment, especially in the Alaskan waters, which results in the loss of buoyancy. Design changes have been made to address these concerns (section 6.3).

**Table 8.** Specifications for Open Seas SUBS A2

| | |
|---|---|
| **Dimensions (L × W × H)** | 1.3 m (57.5 in) × 0.44 m (17.3 in) × 0.58 m (22.8 in) |
| **Weight in seawater w/out flotation or instruments** | 5 lbs. |
| **Weight in air w/out floatation or instruments** | 53 lbs. |
| **Weight in air w/ ADCP, w/o floatation** | 79 lbs |
| **Buoyancy in seawater with ADCP** | 72 lbs. |
| **Working Depth Rating** | 200 m |
| **Drag Coefficient, actual (vs. theoretical)** | 0.6 |
| **Material** | High strength UV protected HDPE |
| **Flotation** | 2 hollow plastic floats 13 in |

### 2.4.1 Tilt Study

Subsurface buoys are subject to tilt in the presence of strong currents (> 4 knots), vertical excursion, or other influences including sedimentation, if not properly trimmed. CO-OPS performed a tilt study of 13 SUBS deployments at locations in Cook Inlet, Southeast Alaska, and Humboldt Bay, California. For comparison, two tank tests were performed to evaluate SUBS tilts in a non-current environment (one using an Argos beacon and one without). This study was conducted using ADCPs from TRDI. Individual instruments have their own specifications, and will often vary in the exact degree of tilt tolerated before the data quality degrades. The TRDI tilt sensor has a range of ±35°, but only meets the ±2° specification over the range of ±15°. More detail can be found in appendix D.

Recent tests that show the effect of the Argos module on ADCP tilt (at speeds of 0-5 knots) were also performed at the Naval Circulating Water Channel. These results can be found in appendix E.

## 2.5 Supporting Equipment

Some tests and deployments were conducted using supporting equipment, such as Argos beacons, pingers, and transponder releases, to enable CO-OPS to track the accuracy and position of the buoys. For example, the Argos beacon signals an alert if the mooring inadvertently surfaces at a time other than a scheduled recovery. This device, the SoTP Subsurface Argos Beacon manufactured by Technocean, uses a large T-shaped antenna that is difficult to mount. Pingers were also used in some of the tests.

Several types of transponder releases manufactured by Benthos were used in ES I-ES IV and TRBM deployments. Coastal Acoustic Release Transponders (CART) releases, manufactured by ORE Offshore, were used in 2003 field season deployments in Southeast Alaska and Cook Inlet, Alaska. There were two releases attached in tandem to a mooring line on each of 12 SUBS moorings with ADCPs. Ten of the 12 releases, which were the key to retrieving the SUBS with ADCPs, failed to surface when the acoustic release signal was sent to the units. This is discussed further in section 3.2. Table 9 provides specifications for acoustic releases used during deployments.

**Table 9. Specifications for Acoustic Release Equipment**

| Equipment | Beam Width (degrees, cone) | Acoustic Range (m) | Communication Equipment | Receive/ Transmit Frequency (KHz) | Depth Rating (m) | Battery Life | Note |
|---|---|---|---|---|---|---|---|
| **Benthos 875-A-PUB Pop Up buoy (used in ES II)** | ± 45° (Omni-directional) | 10 km (6.2 miles) slant range | Benthos DS-7000 Deck, DS-8000 or DS-8750 unit | Factory set | 305 | 6 months (standard alkaline pack) 12 months (lithium pack) | Cannot provide release confirmation |
| **Benthos UAT-376EL transponder (Used in ES I-IV) (5 cm [2-in] diameter × 30.17 cm [11.88 in] L)** | ± 90° (Omni-directional) Note: Diver ranger interrogator has received beamwidth of ± 15°. Cone | 1000 | Benthos diver ranger interrogator DRI-267A & ACU-266 surface conversion kit | 26.0/25, 27, 28, 29, 30, 31, or 32 | 750 | 12 months (with 6 9V alkaline batteries), or 24 months (with 6 9V lithium batteries) | Anodized aluminum housing. Transducer is inside PVC end cap with Delrin closure cap. The two metal screw terminals activate the unit when in contact with water. |
| **Benthos UAT-376 (Used in ES I-IV) (2-in diameter × 7.25 in L)** | ± 90° (Omni-directional) Note: Diver ranger interrogator receive beam width: ± 15°. Cone | 1000 | Benthos diver ranger interrogator DRI-267A & ACU-266 surface conversion kit | 26.0/25, 27, 28, 29, 30, 31, or 32 | 750 (180 m for DRI-267A) | 4 months (with 2 9V alkaline batteries), or 8 months (with 2 9V lithium batteries) | Anodized aluminum housing, Transducer is inside PVC end cap with Delrin closure cap. The two metal screw terminals activate the unit when in contact with water. |
| **Benthos 867-A transponder release (used in TRBM)** | ± 90° (Omni-directional) | 10 km (6.2 miles) slant range | Benthos DS-7000 Deck, DS-8000 or DS-8750 unit | Factory set/user selectable | 305 | 1 – 2 years or 25,000 pings, with 18 alkaline C cells) | In addition to providing release confirmation, use tilt switch to report orientation (may be configured to any installation orientation). |
| **ORE Coastal Acoustic Release Transponder** | ±90° (Omni-directional) | 10 km slant range | Edgetech & Benthos DS-7000, DS-8000, DS-8750 | Factory set, Interrogate 11 kHz, Reply 12 kHz | 1000 meters | 18 months | Release confirmation and tilt orientation |

## 2.6 Systems Proposed for Trial

The Evans Hamilton platform (fig. 9) was deployed successfully in the Hudson River in 2006 and will be retrieved and considered for future deployments. This platform is a low- profile trapezoidal shape made of aluminum.

The Flotation Technology StableMoor™ and the OceanScience Tuna (fig. 10) are also potential candidates for testing. The StableMoor™ can house both upward- and downward-looking ADCPs, and has a lower drag and greater buoyancy than the SUBS. The Tuna will have a much lower drag than what is currently available; however, it is still in the design phase. There is currently no prototype available.

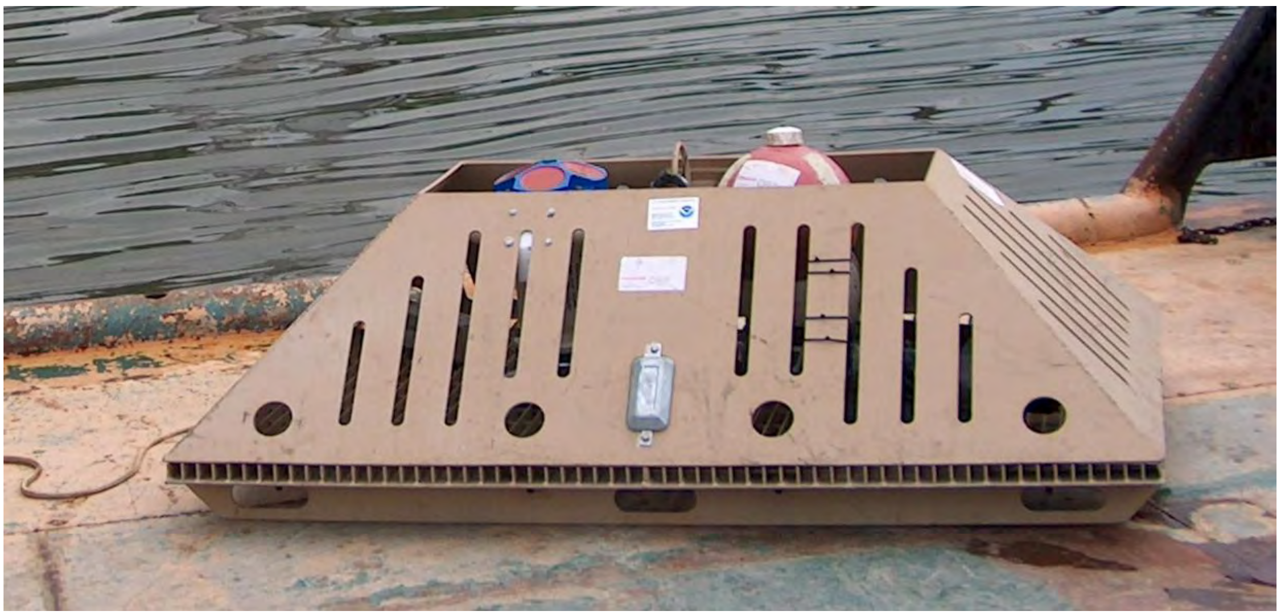


**Figure 9.** Evans Hamilton Platform

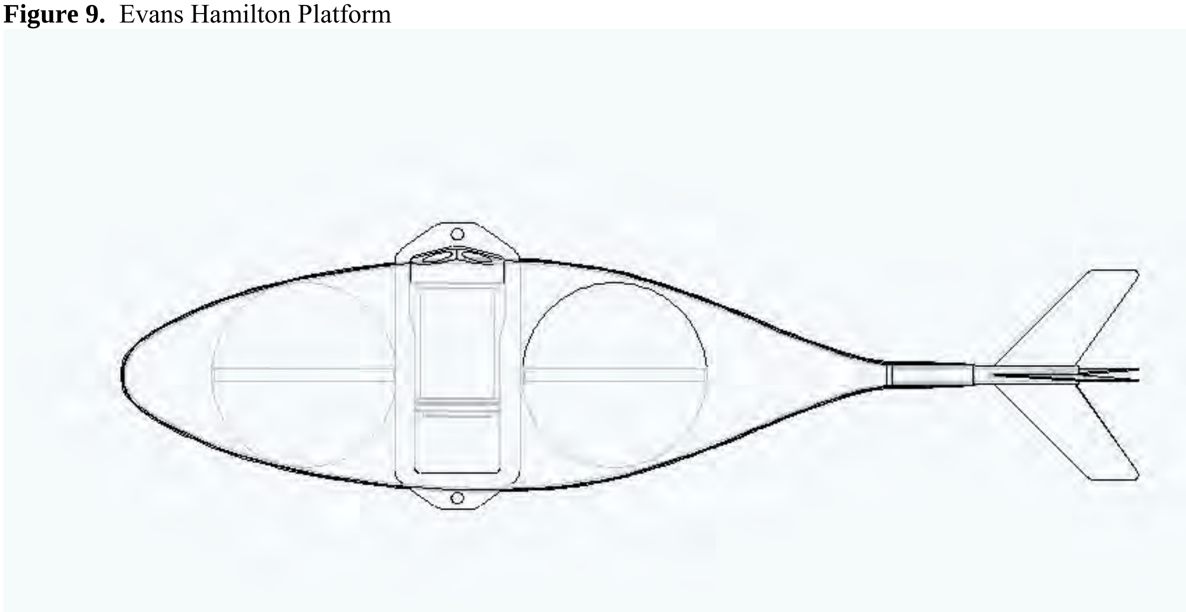


**Figure 10.** OceanScience Tuna subsurface float

# 3.0 Summary of Case Study Failures

**Bottom-Mounted Platforms.** Bottom-mounted platforms have been used successfully in the past to house ADCPs. They are extremely stable, with enough weight to withstand strong currents, and they work best in shallow water (less than 50 m).

The Flotation Technologies TRBM AL-200 consistently performed well in environments with low sedimentation and hard bottoms, such as Southeast Alaska and the Hudson River. The ES-II results were better in the Chesapeake Bay, which has higher sedimentation and more mud. Table 10 contains a summary of bottom-mount deployments included in this report.

**Table 10.** Summary of Bottom-Mount Deployments

| Location | Option Tested | Deployment Results/Reason For Failure | Data Quality |
|---|---|---|---|
| Bangor, ME | TRBM FT-AL-200 | Silt, sticks, and twigs throughout station | ADCP failed |
| Snub Point, ME | TRBM FT-AL-200 | Silt, sticks, and twigs throughout station | Worked until batteries died |
| Winterport, ME | TRBM FT-AL-200 | Station buried deep in mud; only the top of ADCP was visible | Worked until batteries died |
| Humboldt, CA | TRBM FT-AL-200 | Heavy sediment buried entire pod | Ceased after a few days |
| Haverstraw, NY | ES-II | Normal recovery failed likely due to corrosion and/or early release | Worked as expected, no quality issues |
| Bucksport, ME | ES-II | Periodically covered with wood chips from a paper plant. Normal recovery failed. | Data was collected even when partially covered. The only time no data were collected was when totally covered. |
| George Washington Bridge, NY 2nd Deployment | ES-II | Station recovered by divers<br>Pop-up float recovered at Sandy Hook, NJ<br>See Section 4.4.3 | Data quality good |
| Delaware Bay, DE | TRBM FT-AL-200 | Served as intercomparison test with SUBS A2 | Worked as expected; no quality issues |

**Subsurface Moorings.** The Open Seas Instrumentation SUBS A2 performance was generally sufficient for current surveys. Although there are concerns about the vertical excursion and its effect on bin mapping quality, the SUBS A2 performed well within tolerances at both high and low speed currents.

Data show that longer mooring systems have a large influence on the vertical excursions. SUBS are susceptible to greater vertical excursions in currents greater than 1.1 meters per second (m/s) due to increased drag. Generally, moorings less than 10 m long were very stable in currents 0.5 m/s or less. Current speeds less than 0.5 m/s caused only a small amount of vertical movement. As the mooring length increased (especially when stronger currents were present), the vertical excursion was greater. Assessing the vertical excursion of the SUBS is critical to evaluating data quality.

The initial SUBS A2 field tests were performed in Delaware Bay during 2000-2001. The Delaware Bay was selected because of its strong currents, deep water, and available vessel support. In the first field test (July 2000), the ADCP flooded soon after deployment. The second deployment, made at the same site in December 2001, was more successful and returned more than 33 days of good data.

During 2001-2005, there were 57 SUBS A2 deployments in Cook Inlet, Alaska, Southeast Alaska, and Humboldt Bay, California. The deployments lasted 30-60 days and were exposed to a variety of environmental conditions, including heavy sediment, strong currents, deep water, and large tidal ranges. Mooring lengths ranged from 3 m to 100 m with current speeds greater than 3 m/s. Appendix F contains more detailed information concerning the initial field tests and SUBS A2 deployments.

### 3.1 Sedimentation

Most of the failures noted in the case studies of both systems were due to environmental issues. The most common problem for the bottom-mounted platform systems was sedimentation that accumulated inside the platform (fig. 11), covering the release mechanism and the acoustic transducer (or transponder). For shallow bottom-mounted platforms, the sedimentation resulted in platforms buried deeply enough that the release failed to respond. Heavy silting and debris accumulation caused by strong currents also resulted in several TRBMs sinking into mud (fig. 12 and appendix A).

**Figure 11.** Sedimentation inside the ES II

**Figure 12.** Sedimentation inside the base of the TRBM**.** Note that some silt has been washed away when the base is lifted up through the water column.

For SUBS, sedimentation did not appear to be a factor in the Southeast Alaska deployments. However, it could have caused some release mechanisms to fail, or inhibited some release pins from disengaging the release shaft. Aside from inhibiting release mechanisms, sedimentation may not cause a problem until recovery. The ES II typically weighs approximately 600 lbs; however, when it is recovered, its weight can double (sometimes even more) if there is heavy sedimentation. This can cause a problem for recovery vessels that are not equipped to handle this much weight.

## 3.2 Acoustic Release Malfunction

Acoustic release malfunction was responsible for several failures of both bottom-mounted systems and SUBS. Possible causes of the malfunctions include sedimentation, mechanical failure, and/or twisted/entangled mooring lines.

The SUBS used two CART releases, which are manufactured by ORE Offshore. The high failure rate prompted a field test to determine the most likely causes of failure (appendix G). The dry tests, conducted at the CO-OPS Chesapeake, Virginia facility, were performed by Jennifer Ewald, Charles Payton, Carl Kammerer, Mike Newton, and Warren Krug. The first set of tests used the original release pins, which had failed in the previous deployments. The second set of tests used a redesigned ORE Offshore release pin, which is recommended for use with lower buoyancy units. Both tests were performed for the duel 1 and duel 2 systems. On every test, the original release pin failed to fully release from the shaft and drop the chain. The redesigned release pin worked successfully on all tests except for one. The one failure had a 25° tilt on the unit. Figure 13 shows the modified release hook. The beveled release hook allows the release link to pull out easily at the small line tension.


**Figure 13. Modified CART release hook**

## 3.3 Bio-fouling

Bio-fouling does not appear to contribute to failures with either mounting option. Most deployments are less than 80 days and anti-fouling coatings are used on many of the surfaces. Trinidad 1675 (red) anti-fouling paint, which is copper-based and has been quite effective in minimizing bio-fouling growth, was used. CO-OPS has also found that Desitin, a zinc-based baby cream used to prevent diaper rash, is effective and can be easily applied to small surface areas, such as ADCP and other acoustic transducer faces. Bio-fouling is also more likely to occur in the warmer waters, such as the Chesapeake Bay, Virginia, and Florida.

## 3.4 Corrosion

CO-OPS has encountered several recovery failures of ES II bottom-mounted ADCPs caused by hardware corrosion on the Benthos popup float. An eye nut, flat washer, and locking washer are attached to the bottom of the bail, which protect the release transducer and serve as a lifting point. All components are stainless steel; however, the exact type (304, 316, etc.) is unknown. The line connecting the ES II to the popup float is tied to this eye nut. Figure 14 shows the stainless steel eye nut on the popup float before deployment.

Some stainless steels are more sensitive than others. For example, the 316 stainless steel lifting rings and the 304 stainless steel U-bolts holding them show very little sign of corrosion after many years of deployments (fig.15).


**Figure 14.** Stainless steel eye nut on popup float

**Figure 15.** Intact stainless steel lift ring on the GW Bridge platform where the eye nut corroded. Most of the dark spots are paint or bio-debris

Figure 16 shows the remains of the eye nut after a deployment of just a few months in the Hudson River. Corrosion caused the entire eye to fall away and extensively wasted the eye nut body. The popup float performed as designed, but failed to lift the connecting line to the surface during recovery. Although all components were stainless steel, they were sufficiently dissimilar to cause the eye nut to corrode. Because the corrosion occurred so quickly, it is presumed that other factors are at play. Anoxic conditions deplete the protective oxidation barrier on the surface of stainless steel and greatly accelerate the rate of corrosion; therefore, it is likely that the bottom-mounted ES II experienced anoxic conditions. All stainless steel components should be regularly inspected for corrosion after recovery.

Figure 17 shows the replacement titanium eye nut offered by Benthos. It is substantially larger and more corrosion resistant. However, dissimilar metals and anoxic conditions remain, and only future deployments will provide sufficient experience to determine whether the titanium eye nut is a satisfactory solution.

**Figure 16.** Remains of eye nut after deployment

**Figure 17.** Benthos titanium eye nut

A more reliable and less costly solution is to remove all critical metal components. The connecting line is attached to the float by simply drilling another hole all the way through the float and knotting the connecting line on each side. Flotation Technology, manufacturer of the syntactic foam float, agrees that this will not cause degradation of the float. Although the line could abrade on potentially sharp edges of the hole, there is little load or time for such abrasion to occur during recovery, so this should not be a concern. Non-metal eye nuts are not a commonly available item; however, a substitute can be easily made from a Delrin rod. The Delrin eye nut can be used alone or as a redundancy with the line through the float (fig. 18).

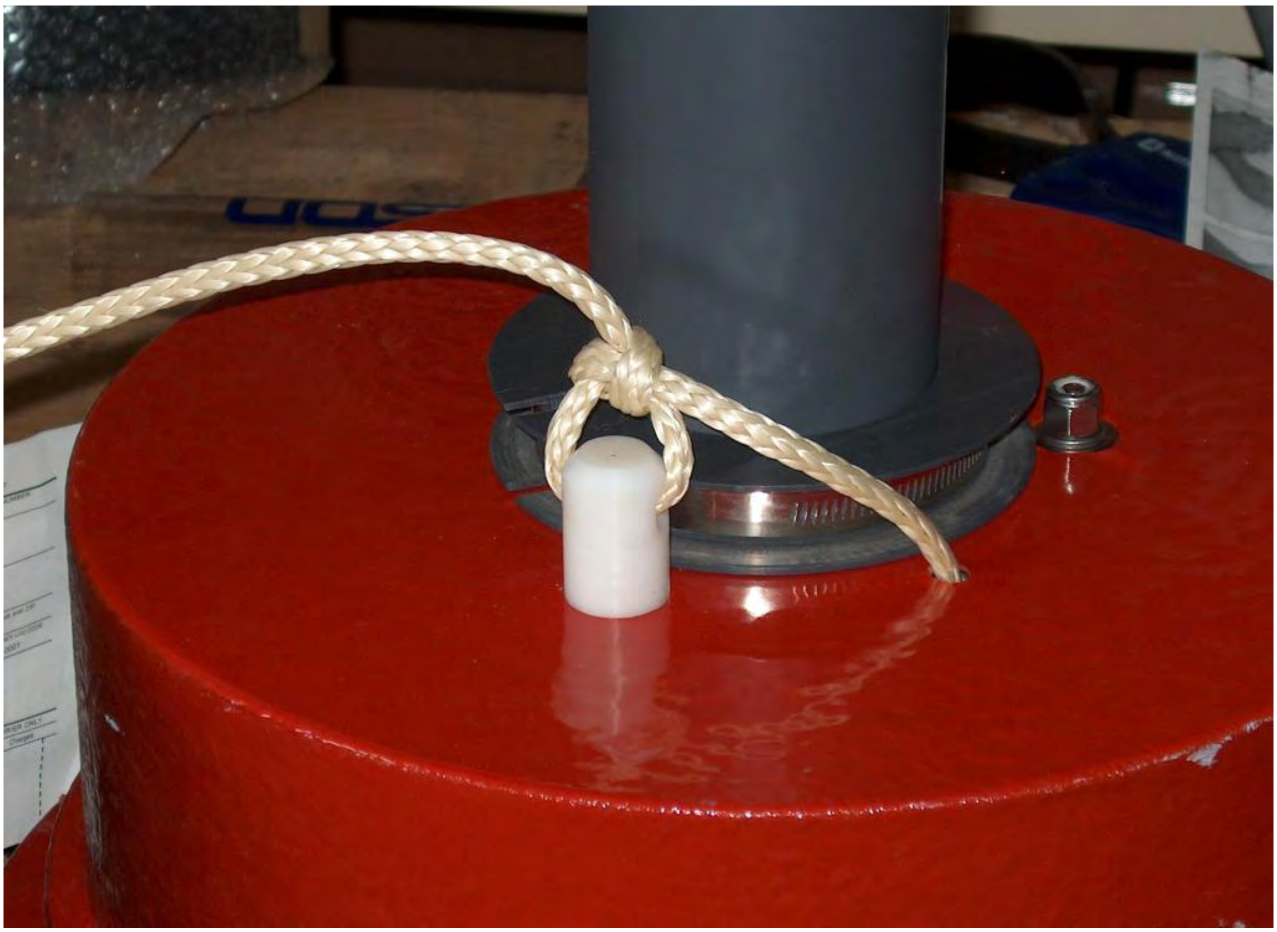


**Figure 18.** Delrin eye nut

# 4.0 Site Reconnaissance

Since each type of ADCP platform has its own operational characteristics, site reconnaissance is needed to obtain environmental data to assist in platform selection. Basic environmental data needed in order to select the most appropriate platform include water depth, expected maximum and minimum current speeds, type of bottom sediment and conditions, suspended sediment and drifting debris, and marine activities. The criteria for platform selection are discussed in detail in section 5.0.

Once the platform is selected, there are several key issues that must be addressed during the site reconnaissance. The following paragraphs cover most of these issues.

## 4.1 Vessels

After platform selection, a vessel from which to deploy the ADCP must be chosen. The vessel must have adequate space, range, and lifting capacity to accommodate the platform. Typically NOAA, the USCG or the U.S. Army Corps of Engineers (USACE) vessels of opportunity are used. If there are no vessels available from these sources, private vessels are chartered. Section 8.0 includes a discussion of vessel safety issues. Personnel to operate the vessel and to deploy the platform must be identified and recruited, and points of contact (POC) must be identified to ensure that the selected individuals possess the necessary skills and credentials to perform the required tasks, as well as to coordinate schedules for vessel personnel availability.

Arrangements for alternate vessels must also be made for the deployment. Since the logistics for ADCP deployment are extensive, it is prudent to allow for contingencies that might arise with the vessel. Possible contingencies include engine problems, failure to pass a safety inspection, inclement weather and scheduling conflicts, or the failure of other type of equipment that renders a vessel inoperable or unable to operate safely.

## 4.2 Bathymetry

Once the general physical location of the deployment is determined, the exact latitude, longitude, and depth of the desired location is obtained and discussed with the local POC. Also, side scan or multibeam imagery might be obtained from the Office of Coast Survey to identify any bathymetry issues of concern. Areas near significant features, such as holes, steep gradients, or wrecks, should be avoided unless there are compelling reasons to deploy in those locations, or unless specifically requested to characterize such locations.

## 4.3 Logistics

Several other important logistical issues must be addressed. Shipping, staging, loading, retrieval, and cleaning facilities must be arranged for the ADCP deployment. Planning for these and other issues must include local POCs so that all potential concerns are identified and addressed during the site reconnaissance to help minimize unforeseen issues that may arise during the deployment. It is also important to develop and implement an outreach program that will explain CO-OPS' mission and the project purpose to the local population.

Other maritime issues are also considered prior to the deployment. For example, dredging within the deployment area would bring the deployment to a halt, so site reconnaissance includes contacting the proper USACE District to ensure that no dredging is taking place during the deployment. It is also important to ensure that the proposed location has sufficient depth to accommodate the draft required by the vessel to be used for the deployment.

The weather forecast for the day of deployment is also an important consideration. This is often a last-minute task, albeit a very important one. Strong winds, rough seas, and swift currents can create problems for the deployment, posing a potential risk to life and property.

Site reconnaissance also includes the location of appropriate lodging and restaurants for deployment personnel. Comfortable accommodations help to boost morale and build camaraderie.

## 4.4 Tools

Certain tools are useful in identifying specific problems that certain bottom characteristics might present for a deployment. Two of the most widely used tools are discussed in the following paragraphs.

### 4.4.1 Clam Grabs

A clam grab (fig. 19) is occasionally used to obtain samples of the seafloor in order to assist with any bathymetry issues that might arise. Seafloor samples are often used in conjunction with side scans or multibeam images to help further analyze the bathymetry in a specific area being considered for deployment.

**Figure 19.** Clam Grab

### 4.4.2 Side Scans

Another tool that may be useful in performing site reconnaissance is the side scan. Figure 20 shows a Marine Sonics 600 kHz side scan image of an ES II, collected by the SEA SEARCH, a private vessel operating out of Little Creek Naval Amphibious Base. The side scan is useful for deployment siting, which in this case shows evidence of strong bottom currents and shifting bathymetry. Side scans are also useful for recovery when bottom-mounted platforms fail to respond to acoustic commands. It is wise to confirm that the platform is still there before dispatching divers to perform a recovery.

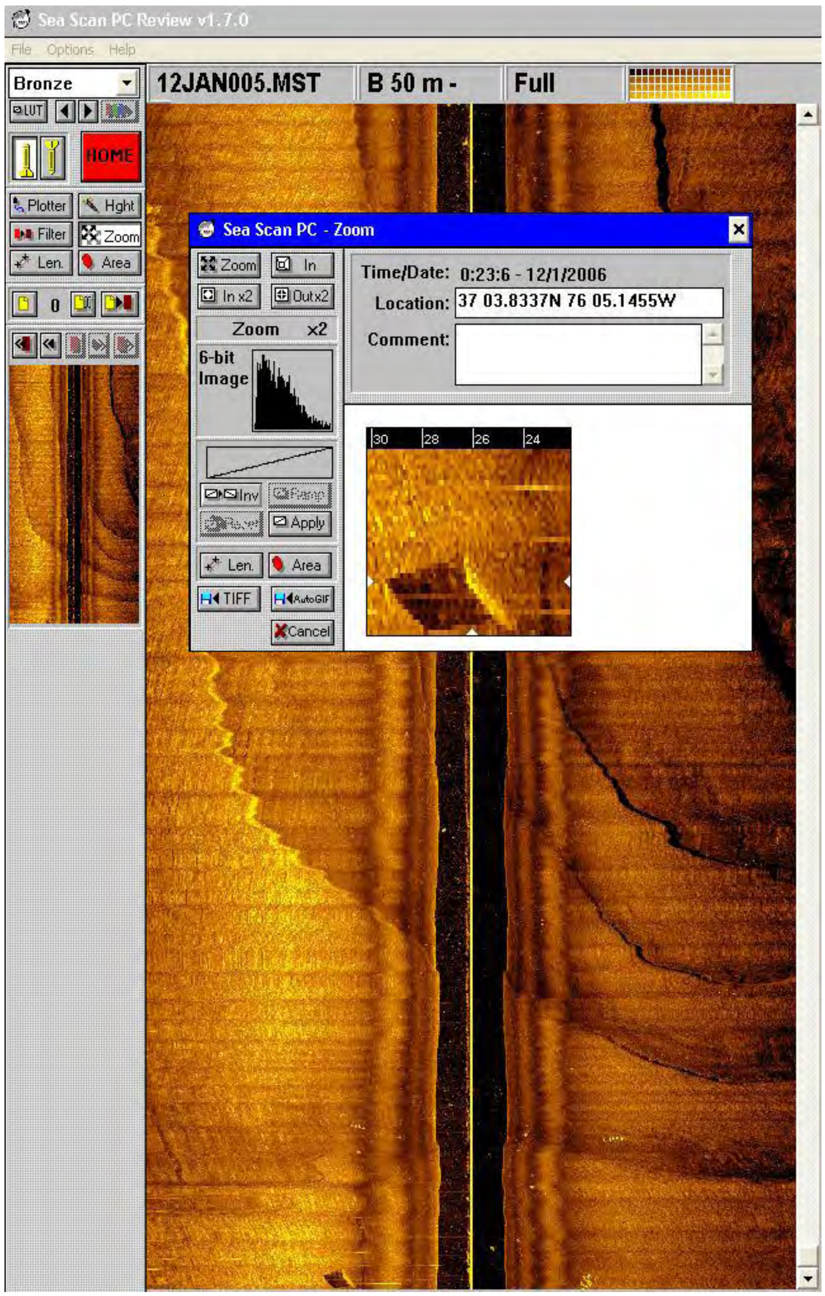



**Figure 20.** Side Scan

### 4.4.3 Multibeams

The multibeam is also a useful tool for deployment siting. Figure 21 shows the Kongsberg Simard EM300, which was used for locating a bottom-mounted ADCP at the George Washington Bridge in November 2005. The unit is pole-mounted with a 200 KHz frequency, and runs with HyPack's Hysweep program. It features 127 beams, backscatter, and is corrected at the transducer with an Odom Digibar CTD. The boat was equipped with an Applanix POS MV4, which corrects for the boat's movements during survey. Figure 22 shows the multibeam image obtained from the George Washington Bridge ES II survey.

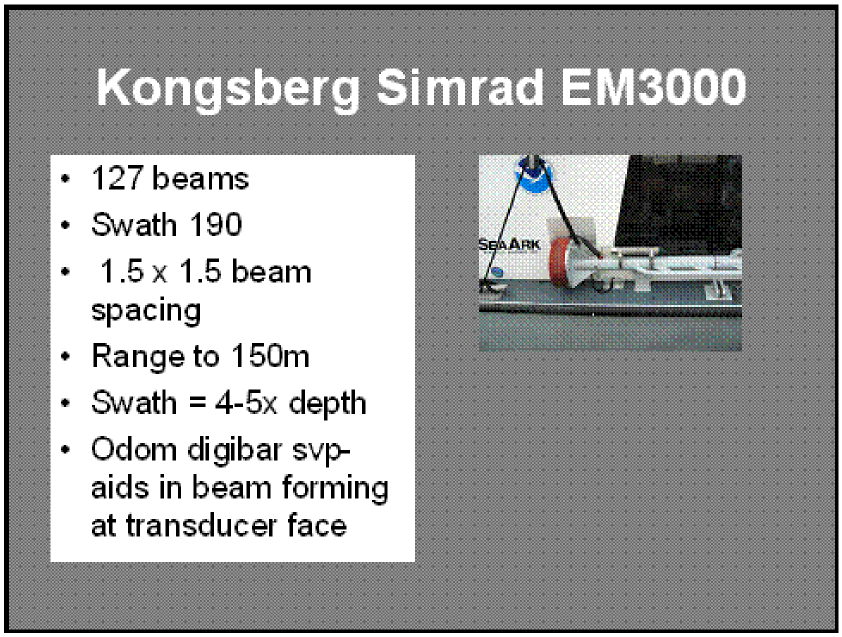



**Figure 21.** Multibeam used to locate ADCP at George Washington Bridge

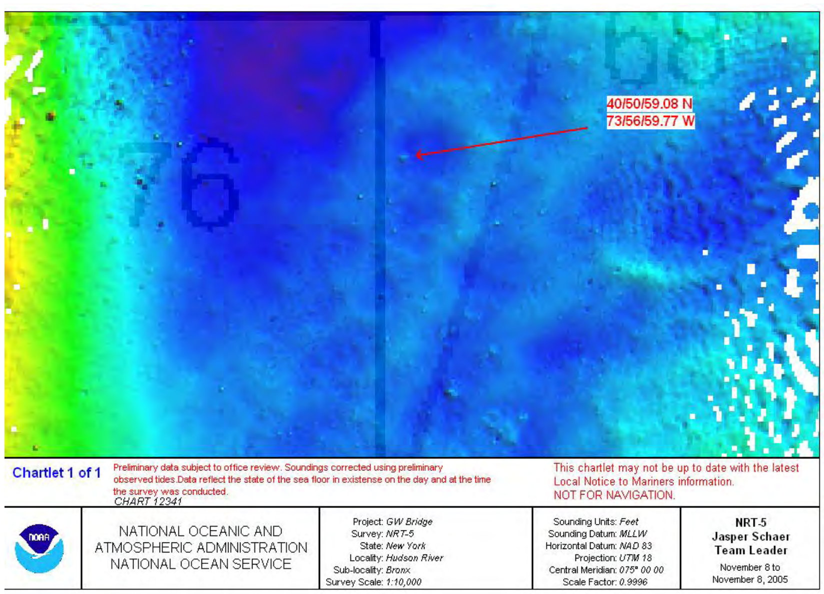



**Figure 22.** Multibeam image from the George Washington Bridge ES II survey

## 4.5 Deployment Risks

All oceanographic instrumentation deployments place equipment at risk. The scaled factors in table 11 provide a somewhat quantitative measure of the deployment risk and are useful for establishing the relative risk among deployments. With experience, risk thresholds may be established to better control loss rates. Initially, deployments with cumulative risk assessments above eight or individual factor risk rates of three or more should be considered high risk, and special consideration should be assigned before proceeding. Risk assessments of five to eight are tolerable, and assessments of four or less are readily achievable.

**Table 11.** Deployment Risk Analysis

| | |
|---|---|
| **Water Depth** | 0 deployment is in water depth that exceeds all vessel draft<br>1 deployment is outside of commercial traffic and depth exceeds draft of most vessels<br>2 deployment is in an area of commercial traffic where vessels are depth constrained<br>3 deployment is inside a heavily traveled marked channel |
| **Current Speed** | 0 Anticipated maximum deployment current is less than 1 knot.<br>1 Anticipated maximum deployment current is 1- 2 knots.<br>2 Anticipated maximum deployment current is 2 – 3 knots.<br>3 Anticipated maximum deployment current is 3 – 4 knots.<br>Etc. |
| **Bottom Type** | 0 Bottom is rock, hard pack, or other solid and stable material<br>1 Bottom is uniform depth composed of particles 0.5 cm or greater<br>2 Bottom is non-uniform depth, evidence of a shifting bathymetry, particles <0.5 cm<br>3 Bottom is loose, unstable, or flocculent in nature, with a risk of platform submergence |
| **Deployment Duration** | 0 Deployment is less than 45 days<br>1 Deployment is 45 - 90 days<br>2 Deployment is 90 – 135 days<br>3 Deployment is 135 – 180 days<br>Etc. |
| **Maritime Activity** | 0 Remote location with little or no commercial or recreational traffic<br>1 Area infrequently subject to commercial or recreational traffic<br>2 Area subject to frequent recreational traffic or regulated commercial activity<br>3 Area subject to extensive recreational traffic or commercial activity<br>4 Area is a commercial fishery with extensive dredging operations. |

# 5.0 Mount or Mooring Selection Criteria

CO-OPS deployment locations offered a variety of conditions, providing an effective means to develop criteria for selecting the best system for each environment. Generally, the TRBM worked well in areas with hard seabed bottoms and low sedimentation. The ES II was more effective than the TRBM in high sedimentation areas, such as the Chesapeake Bay. The SUBS worked well in high silt areas, but encountered more difficulty in higher currents. The following paragraphs provide further details of the four criteria for system selection.

## 5.1 Depth

Both bottom-mounted and moored systems are appropriate for depths up to 100 m-200 m. Generally, bottom-mounted ADCP systems should be deployed in shallow (<50 m) waters, where diver operation is feasible. Subsurface moored ADCP systems are intended for deeper water depths, where diver-assisted recovery is not practical.

In waters where bottom trawling exists, deployments are discouraged, moored systems should not be used, and bottom-mounted systems should be modified to keep instruments/float inside the platform.

In deeper water, it may be desirable to measure current velocities close to the surface. In this case, the ADCP should be closer to the water surface, and the mooring line should be stiffer (with significant buoyancy elements). The Open Seas SUBS may be the system of choice for the deeper locations, although the quality of the data delivered by the ADCP was consistently better for shorter bins (2 m-3 m) and depths less than 100 m.

## 5.2 Expected Maximum and Minimum Current Speeds

Generally, currents greater than 4 knots posed a problem for SUBS. Swifter currents result in more buoy tilt and can interfere with the data quality. The unbalanced trim caused by the Argos module can contribute to this problem (appendix E). CO-OPS should develop an Argos beacon housed inside a subsurface float (to eliminate the T-shaped antenna that causes drag).

## 5.3 Type of Bottom

Tests were performed in locations with bottoms ranging from hard to muddy. Open frame platforms (such as ES III and ES IV) are suitable in areas where moving sand bars occur frequently. Stable and high platforms (such as ES II) can be used where there are moving bed loads (rocks and gravel).

## 5.4 Suspended Materials

As expected, the bottom mounts were more subject to high sedimentation, accumulating sand, twigs, and other debris. Although less subject to silting than the bottom-mounts, the SUBS were also subject to sedimentation resulting from sand waves and strong currents. TRBMs are vulnerable to entanglement with twigs, as are the Benthos popup release rings and gaps surrounding the popup floats. Filling the voids with foam materials will be helpful in this case (section 6.0).

## 5.5 Bio-fouling Rates

Bio-fouling occurred mostly in warmer test sites, such as the Chesapeake Bay and Florida. The application of anti-fouling coatings helped to reduce bio-fouling. This, coupled with the short deployments (< 80 days) reduced the severity of bio-fouling.

## 5.6 Marine Activities

Areas with bottom trawling should be avoided for both bottom-mounted and subsurface moored platforms. If necessary, both ES I and ES II should have adequate structural strength to withstand trawl impact; however, the popup float for ES II should be modified to reduce protrusion (section 6.0).

Table 12 provides list of advantages, disadvantages, and recommended uses of bottom-mounted platforms.

**Table 12.** Capabilities and Limitations of Bottom-Mounted Platforms

| Platform | Merits | Concerns | Recommendations |
|---|---|---|---|
| **For Bottom Mounted ADCP (for water depth less than 50 m to allow diver operation, if needed)** | | | |
| **TRBM** | Portable.<br>ADCP is embedded in the release float.<br>Benthos model 867 release module has release confirmation capability | Little space for additional instrument/battery packs; vulnerable to sediment cover, which may affect transponder performance and release mechanism. Floating debris may stick in the slotted aluminum side walls. Need care to prevent galvanic corrosion on aluminum frame. Difficult to find proper anti-fouling paint (paints for metals are less effective – cannot be copper based). The ADCP transducer head protrudes above the platform and is vulnerable to trawl damage. | Use in areas free from bottom trawling and heavy mud accumulation. |
| **MSI Tripod** | Portable | Weak in stability | Use in protected area and for short duration testing project. |
| **ES I** | Corrosion resistant, portable, excellent impact resistance, good trawl impact resistance. | Retrieve via divers or electro-mechanical cable. | Suitable for real-time ADCP system with electro-mechanical cable attached. Otherwise, modification to attach acoustic release (Benthos 875 popup model), or divers are required for retrieval. |
| **ES II** | Corrosion resistant, excellent impact resistance, excellent trawl impact resistance (release float needs to be kept below top of platform), large space for additional equipment, adequate height to reduce effect of sediment cover. | Silt entry from two top openings (modifications such as proper drain holes, could be made to reduce this problem).<br>Benthos 875 popup release module does not have release confirmation (transponder) capability. | Suitable for long-term deployment when stability and strength of platform are important. |
| **ES III** | Portable.<br>Open frame allows water and sediment to pass through (thus reducing risk of sand cover and scouring). | Risk of fishing line or floating debris entanglement.<br>Requires care to prevent galvanic corrosion. Is difficult to find proper antifouling paint. | Suitable for areas where bottom sand dunes moves frequently |
| **ES IV** | Portable.<br>Open frame allows water and sediment to pass through (thus reducing risk of sand cover and scouring), has additional top windows for 2nd popup float release module and other instrument. | Risk of fishing line or floating debris entanglement.<br>Requires care to prevent galvanic corrosion, difficult to find proper anti-fouling paint. | Suitable for areas where bottom sand dunes moves frequently. |
| **Evans Hamilton TRBM** | Low profile trapezoidal. A spherical popup buoy is used (ADCP stays with the platform). | The float protrudes above the top of the platform and is vulnerable to bottom trawling damage. Cannot use copper paint on aluminum. | CO-OPS does not yet have any experience with these.<br>Do not see major improvement over existing TRBM. |
| **For Sub-surface moored ADCP (in water depth < 200 m and diver operation is not planned)** | | | |
| **SUBS taut-moored system** | Relatively easy to deploy and retrieve.<br>Non-diver assisted operation, uses dual releases with transponders. | Use in trawling free area.<br>Quality of ADCP data may be degraded by mooring line motions and deflection. | Suitable for deep water operation. |

# 6.0 Mount or Mooring Modifications

CO-OPS has made several recent modifications to systems in response to deployment problems deployment problems. The following paragraphs describe these modifications.

## 6.1 Flotation Technologies TRBM Spring Assisted Release

The low profile TRBM with slotted side walls is generally covered by bottom sediment. Potential effects of sedimentation include attenuation of transponder signal and interference of release mechanism operation. Flotation Technologies has proposed the use of a spring assisted release to minimize interference from sediment. In experimental modification, the manufacturer made leaf springs out of fiberglass, which, unfortunately, delaminated.

## 6.2 ES Popup Float Corrosion Prevention

Corroded metal eyebolts caused previous failures of several popup floats. To prevent corrosion in the new float, metal eyebolts were eliminated. Instead, a hole was drilled in the foam float and a Delrin eye nut replaced the metal eye nut. The rope was tied to the eye nut and then fed through the hole and tied to the bail.

## 6.3 ES II Popup Float Based on Benthos Model 875A Acoustic Release

The Benthos popup float has a diameter of 12 in, which is smaller than the 16-in platform window. As shown in fig. 23, copper tubes were used to guide the float as it rises. This is important, especially when the platform is resting on the ocean bottom in a tilt situation. In addition, there are two other concerns related to this float: The float has insufficient buoyancy (10 lb) to operate in rivers where significant river flow may keep the float from surfacing during platform recovery. The large gap around the float is also a source of debris entanglement and sediment accumulation inside the platform. A new float has been designed (fig. 24) to correct these problems. The new float's large flange (17-in diameter) will block the gap and its greater buoyancy (40 lb) will allow the float to surface in currents of 2-3 knots.

**Figure 23.** Benthos popup float with acoustic release core at the center

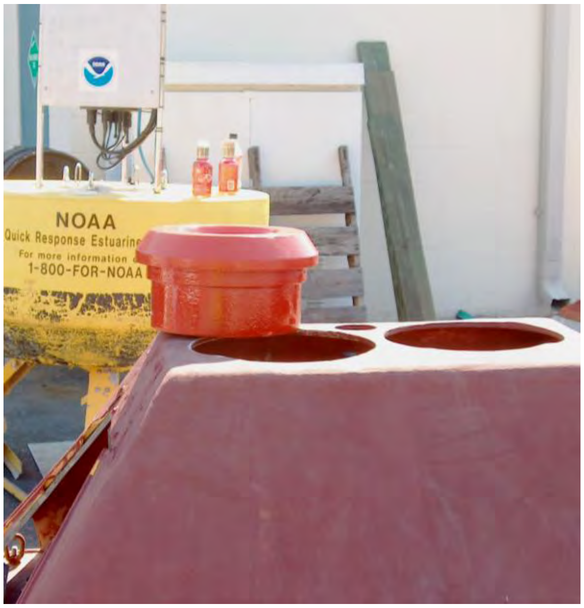



**Figure 24.** New popup float (flange will sit on top of the platform). Acoustic release core and protecting ring not installed at this time.

## 6.4 Modifications to SUBS

Figures 25 and 26 indicate changes in the ADCP installation fixture and added flotation module. The new fixture allows users to install/remove the ADCP in minutes, and the flotation module increases the buoyancy by 78%.


**Figure 25.** Changes in ADCP installation fixture: ADCP container (left), installing ADCP (right)


**Figure 26.** Changes in ADCP installation fixture: New bracket (left), added flotation module (right)

CO-OPS has also filled voids with foam materials to help reduce sedimentation and to improve buoyancy in SUBS. The flotation material, IL220, is a rigid, closed cell PVC foam with a density of 227 kg/$m^3$. The material, manufactured in the United Kingdom by the CRP Corporation, has a rated depth of 300 m.

# 7.0 Mooring Modeling

Models provide valuable information for predicting which moorings will operate the most effectively within specific environmental conditions. The following paragraphs describe models that are appropriate and available to CO-OPS.

## 7.1 Available Models

A variety of numerical computer mooring models have been developed. The two models that CO-OPS staff has used are Mooring Design and Dynamics (MD&D) and Woods Hole Oceanographic Institution (WHOI) Cable v2.0.

**MD&D.** The MD&D program, developed at the University of Victoria, British Columbia by Richard Dewey, allows the user to design and evaluate single point surface and subsurface moorings. The program utilizes graphical user interfaces (GUI), MATLAB routines, and a preliminary database of mooring components. The model is capable of simulating the static and dynamic response of each mooring component. CO-OPS personnel consider the program user-friendly and predict that it holds great potential for future modeling.

**WHOI Cable v2.0**. .The ―WHOI Cable v2.0: time domain Numerical Simulation of Moored and Towed Oceanographic Systems" computer model was developed by Jason Gobat and Mark A. Grosengaugh of WHOI. It evolved from Gobat's Ph.D. thesis at the Massachusetts Institute of Technology. The model is capable of simulating either two- or three-dimensionally for both static (steady-state) and dynamic (under forcing by waves, time-varying current, wind, ship speed and cable pay-out rates) mooring conditions (subsurface taut mooring, towing, deployment, etc.). The code is written in C and runs with a 32-bit Microsoft Windows operating system (95/98/2000/NT). A Windows XP operating system environment is needed for animation. CO-OPS staff has limited experience with this tool.

## 7.2 Model Selection

Most computer models were derived from well-developed mooring line equations. Both the MD&D and WHOI models have been widely used and are continuously improved via user feedbacks. The current CO-OPS approach—to excel in one model and validate it carefully—is adequate at present. Model comparisons could be planned as a future task.

## 7.3 Inputs

The performance of a good model also depends on the quality of data inputs. Major inputs to the model are mooring component physical properties (buoyancy, dimension, and drag coefficient); component configuration; environmental forcing (currents, waves, and winds); water depth; water density; and bottom sediment type (anchor frictional coefficient). The drag coefficients derived from CO-OPS' recent tests in the Naval Circulating Water Channel provide basic data for our current application.

## 7.4 Model Results

**Acoustic Release.** Model simulations were performed using the MD&D program in order to determine the optimal design and setup of the Benthos popup buoy (PUB). To evaluate the response of the buoy, two different scenarios were examined. The first used non-uniform time varying currents with a small vertical component, while the second was a steady state uniform environment with one horizontal component. The required input parameters for the model included mooring elements, water depth, current profiles, and density. Because the model cannot simulate the release path of the PUB, it is configured as a moored surface buoy with a positive buoyancy floatation device, a neutral buoyancy retrieval line, and an anchor.

We concluded from these model simulations that to maximize the chances for recovery of the PUB, we should: 1) increase the line length; 2) attempt retrieval during low speed currents; and 3) increase the positive buoyancy of the flotation device. The standard retrieval line used in the Benthos PUB is approximately 50 m. This should be increased to approximately 60 m, at which length scenario one (fig. 27) predicts a leveling off of the percent buoyancy gained from further increasing line length. More investigation is required to find the optimal line length as a function of water depth (a depth of 40 m was used in the model). Numerous variables (not evaluated here) such as surface roughness, rope diameter, elasticity, buoyancy, severe loads, and line relaxation must be considered when calculating the total drag of the retrieval line.

The results of the steady state system show an increased recovery speed for the 4.55-kg buoyancy PUB when the retrieval line is increased from 25 m at 0.75 knot, to the standard 50-m line at 1.75 knots, and 2.5 knots for a 100 m line, an increase of 1.75 knots (fig. 28). The response of the PUB to increasing float buoyancy demonstrates that retrieval rate is more dependent on a longer line than higher float buoyancy. Figure 29 shows the results of increasing buoyancy for a 75-m line—at 4.55 kg the maximum recovery speed is 2.25 knots, but when the buoyancy is doubled the recovery speed increases to 3.25 knots, a 1.0 knot increase.

As the length of the mooring line increases, so does the maximum current at which the PUB remains afloat; therefore, the percent surface buoyancy required to keep the PUB afloat decreases. Table 13 shows that, when the float is submerged, the longer the mooring line, the greater the response of the float to increasing buoyancy.

To increase the chance of a successful retrieval, a safety buffer, or margin of error, should be added to the maximum current speed. This margin of error is left to the discretion of the project lead, and depends on such factors as current shear and the overall dynamic nature of the environment. Generally, to maintain 60% reserve surface buoyancy, this value should be lowered by 10% from the results of scenario one, or to 1.35 knots.

The full model study report can be found in appendix H.

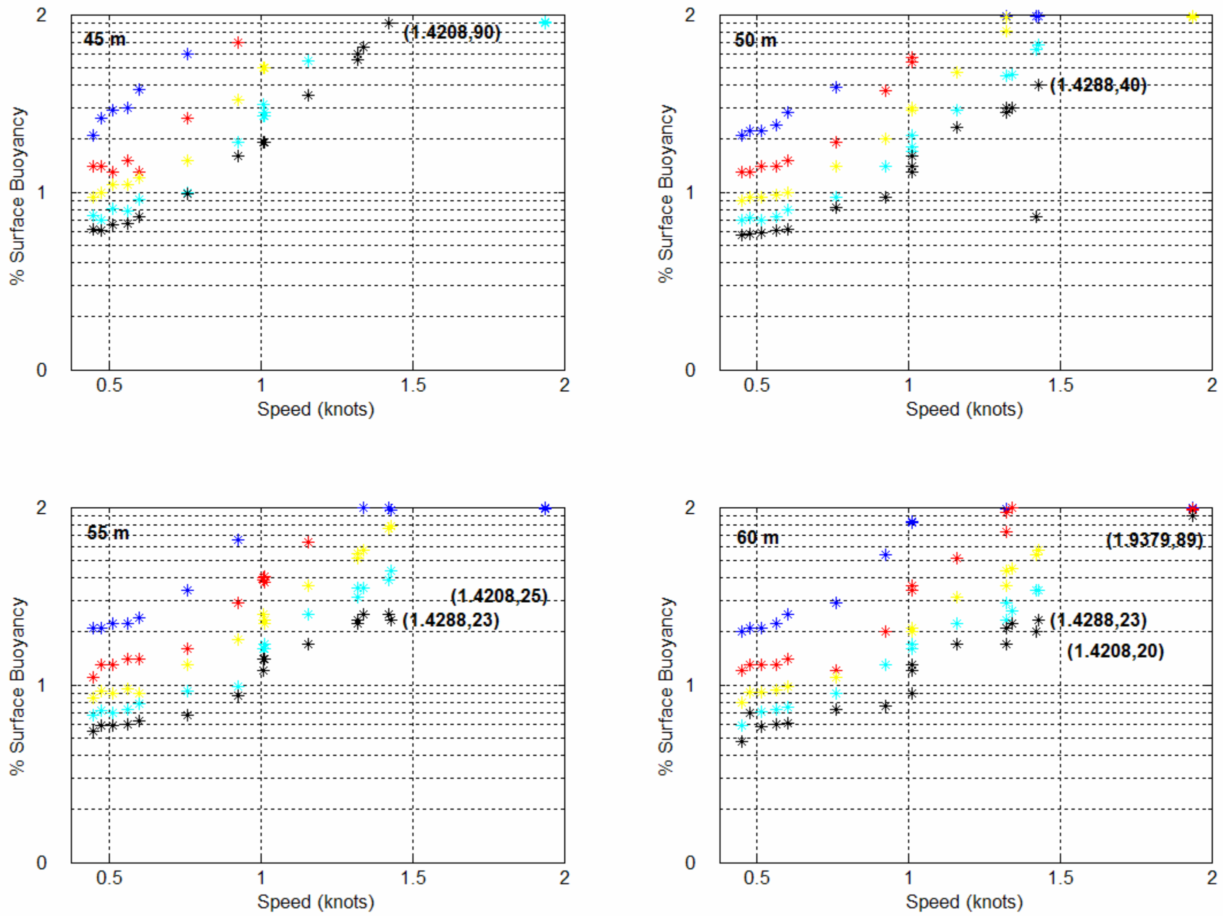



**Figure 27.** Percent available buoyancy needed to keep PUB afloat during weak current. The Y-axis represents the amount of surface buoyancy (0-100%). Figures in the upper left corners (45 m, 50 m 55 m, 60 m) represent the recovery line lengths. Marker colors represent positive buoyancy weight: blue is 3.3 kg; red is 5.3 kg; yellow is 7.3 kg; cyan is 9.3 kg, and black is 11.3 kg.

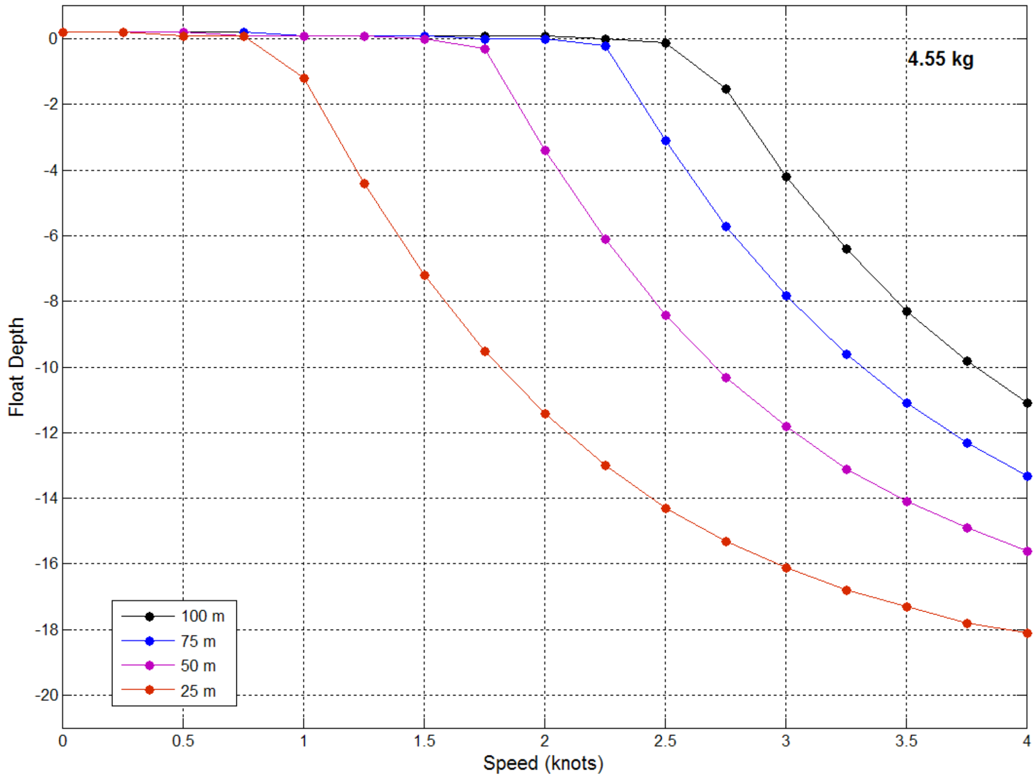



**Figure 28.** Float depth of PUB as a function of increased retrieval line length and current speed

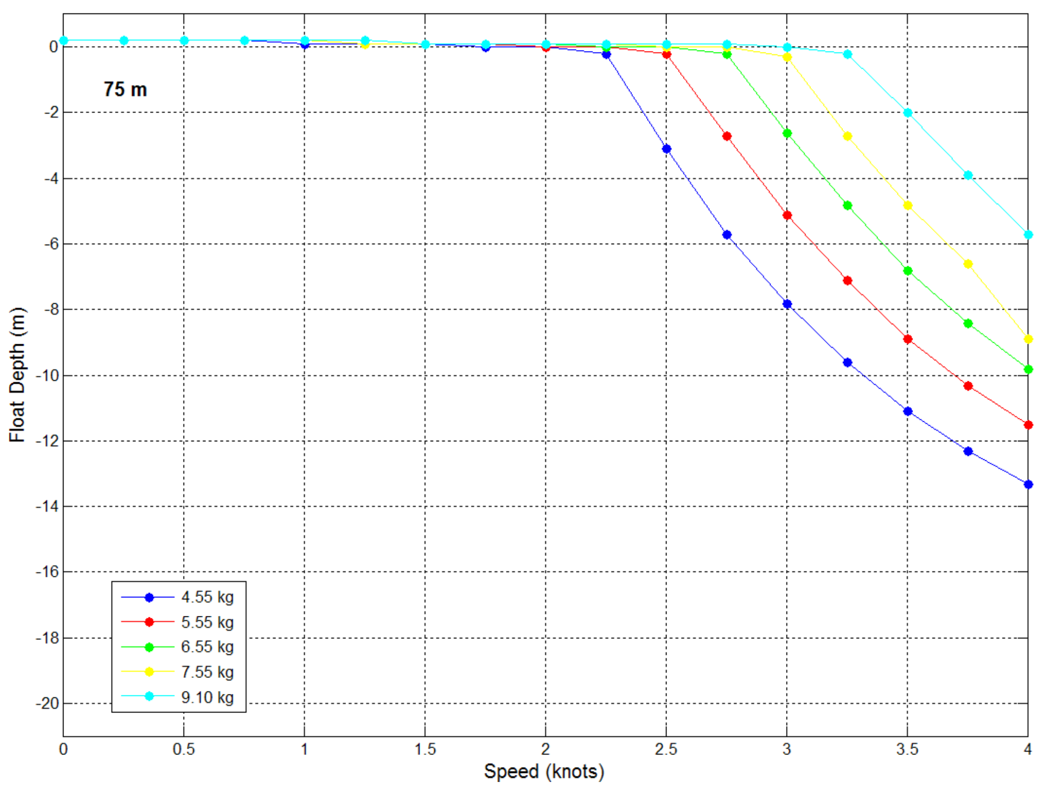



**Figure 29.** Vertical depression of the A2 SUBS as a function of current speed and float buoyancy

**Table 13.** Response of PUB to retrieval line and buoyancy changes

| Buoyancy Change (kg) | Line Length (m) | Slope |
|---|---|---|
| 1.00 | 25 | 1.30 |
| 3.55 | 25 | 1.03 |
| 4.55 | 25 | 1.02 |
| 1.00 | 50 | 2.30 |
| 3.55 | 50 | 1.66 |
| 4.55 | 50 | 1.80 |
| 1.00 | 75 | 2.90 |
| 3.55 | 75 | 0.08 * |
| 4.55 | 75 | 0.70 * |
| ***PUB does not submerge** | | |

**A2 SUBS.** To evaluate the performance of the A2 SUBS, model simulations were again performed for two different scenarios using the MD&D program. The first used non-uniform time varying currents, and the second was a steady state uniform environment. Both scenarios examined the response of mooring configuration on vertical excursion. The required input parameters for the model are the same as those presented earlier.

Table 14 provides an overview of the results for the steady state environment. From these simulations, it is evident the orientation of the in-line acoustic release significantly impacts the performance of the mooring line. An A2 SUBS of 52.62 kg positive buoyancy with a single release in a 4.0-knot current has a tilt angle of 21.8° and a float depression of 0.29 m, but with a dual release oriented broadside the vertical depression increases to 0.41 m. In addition to acoustic release orientation, available buoyancy and current speed impact mooring performance. Figure 28 demonstrates this effect; twice the original buoyancy and the current can increase 0.5 knot before the float begins to move.

To test the impact of increased buoyancy on mooring performance, the model used actual current data collected in Cook Inlet, Alaska during the summer of 2004. Figure 30 shows the results for two configurations, 33 kg and 63 kg buoyancy. During times of relatively low current speed, the difference in float depth is minor, but during peak speed it can reach as much as 10 m (fig. 31). These results agree with empirical data.

A successful survey includes a mooring configuration that has vertical excursions smaller than the ADCP bin size. Based on these results, the A2 buoyancy should be increased by a factor of two, or the maximum limit; and, if possible, a single acoustic release should be used, or a dual release oriented parallel to current direction.

**Table 14.** A2 SUBS response to changes in mooring components and configuration

| Mooring Configuration | Water Depth (m) | Mooring Length (m) | Total Buoyancy (kg) | Float Depth (m) | Vertical Excursion (m) | Tension on Anchor (kg) | Vertical Tension (kg) | Horizontal Tension (kg) | Speed (knots) | Tilt Angle |
|---|---|---|---|---|---|---|---|---|---|---|
| release broadside | 7.5 | 3.09 | 33 | 5.1 | 0.69 | 24.4 | 16.8 | 17.7 | 4.00 | 46.5 |
| release broadside, 0.5 m buoy chain | 7.5 | 3.71 | 33 | 4.6 | 0.81 | 23.4 | 14.9 | 18.0 | 4.00 | 50.4 |
| release correct | 7.5 | 3.09 | 33 | 5.0 | 0.59 | 23.3 | 18.2 | 14.6 | 4.00 | 38.7 |
| release correct, 0.5 m buoy chain | 7.5 | 3.71 | 33 | 4.4 | 0.61 | 22.3 | 16.4 | 15.1 | 4.00 | 42.6 |
| release broadside | 7.5 | 3.09 | 52.62 | 4.8 | 0.39 | 42.5 | 37.0 | 20.8 | 4.00 | 29.3 |
| release broadside, 0.5 m buoy chain | 7.5 | 3.71 | 52.62 | 4.2 | 0.41 | 41.2 | 35.2 | 21.4 | 4.00 | 31.3 |
| release correct | 7.5 | 3.09 | 52.62 | 4.8 | 0.39 | 42.0 | 38.3 | 17.3 | 4.00 | 24.3 |
| release correct, 0.5 m buoy chain | 7.5 | 3.71 | 52.62 | 4.2 | 0.41 | 40.8 | 36.6 | 18.0 | 4.00 | 26.2 |
| single release | 7.5 | 3.09 | 52.62 | 4.7 | 0.29 | 45.7 | 42.4 | 17.0 | 4.00 | 21.8 |
| 2 original SUBS | 156 | 20.08 | 97.84 | 136.2 | 0.28 | 77.5 | 76.8 | 11.0 | 1.00 | 8.2 |
| 2 original SUBS | 156 | 20.08 | 97.84 | 137.1 | 1.18 | 75.3 | 65.4 | 37.4 | 2.00 | 29.8 |
| 2 original SUBS | 156 | 20.08 | 97.84 | 139.3 | 4.10 | 74.8 | 46.9 | 58.3 | 3.00 | 51.2 |
| 2 original SUBS | 156 | 20.08 | 97.84 | 141.3 | 6.10 | 87.6 | 42.1 | 76.9 | 4.00 | 61.3 |
| 3 original SUBS | 156 | 20.08 | 149.84 | 136.2 | 0.28 | 128.0 | 127.3 | 13.5 | 1.00 | 6.1 |
| 3 original SUBS | 156 | 20.08 | 149.84 | 136.9 | 0.98 | 121.4 | 112.0 | 47.0 | 2.00 | 22.8 |
| 3 original SUBS | 156 | 20.08 | 149.84 | 138.8 | 2.88 | 111.1 | 82.1 | 74.9 | 3.00 | 42.4 |
| 3 original SUBS | 156 | 20.08 | 149.84 | 140.9 | 5.70 | 117.1 | 66.6 | 96.3 | 4.00 | 55.3 |

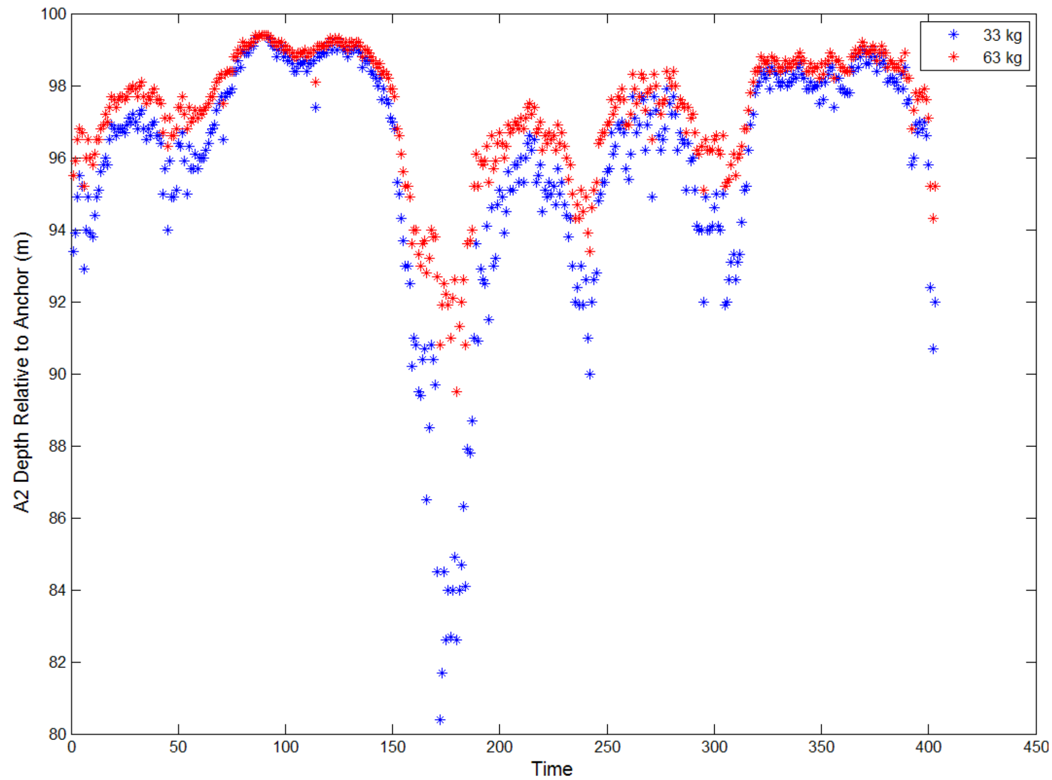



**Figure 30.** Time series of A2 depression

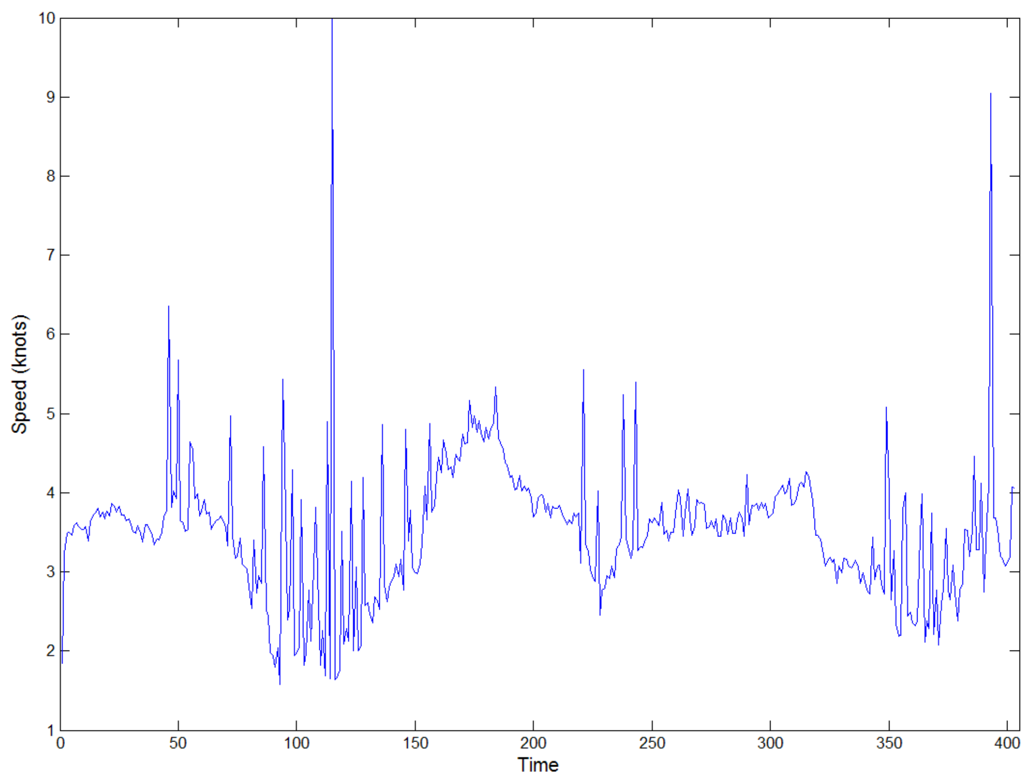



**Figure 31.** Time series of A2 peak current speed

# 8.0 Safety

The deployment of ADCPs, regardless of platform, requires that personnel work with various kinds of equipment that, if handled carelessly, could result in personal injury or death. To help avoid injuries, personnel must observe agency-wide safety regulations. The occupational health and safety of all personnel depend on adherence to regulations outlined in Department of Commerce, NOAA, NOS, and CO-OPS regulations as well as guidelines established by the NOAA Environmental Compliance Office (SECO). Generally, considerations must be given to the following areas:

**Training**

- Attend NOAA Employee Safety Awareness Course
- Review the U.S. Department of Commerce Safety and Health Manual
- Review NOAA NAO-209-1
- Review NOS Environmental Health and Safety Action Plan for FY 2006
- Attend equipment-specific training that covers topics that include, but are not limited to:
  - Equipment safety rating
  - Proper operational use of equipment

**Maintenance**

- Perform quarterly inspections on all equipment
- Correct any deficiencies found in routine inspections, including the replacement of parts that are broken, corroded, loose, or worn

**Regulatory Compliance**

- Ensure compliance with all Federal, state, and agency requirements

Personnel shall report any violations or concerns to their supervisor.

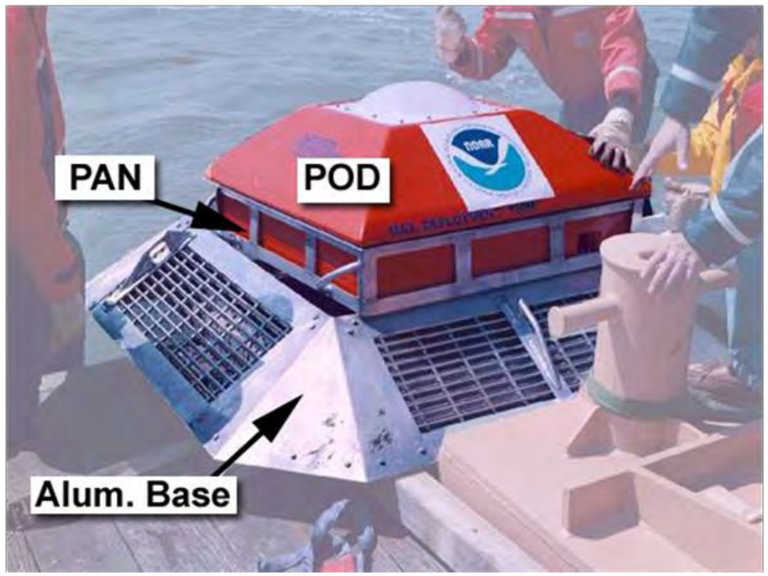
# 9.0 Conclusions and Recommendations

1. Selection of platform should consider the ADCP range limitation. If the water depth is more than 46 m (150 ft) deep, the ADCP profile may not reach the surface.
2. Selection of bottom mounted versus subsurface taut-moored platforms is based mainly on the requirement for diver assistance. Generally, bottom mounted platforms are used for water depths less than 50 m where diver-assisted operation (typically during recovery when the release module fails) is practicable. Generally bottom mounted platforms are used for ADCP range less than 50 m.
3. Selection of bottom mounted platforms is based on system capabilities and limitations. Table 12 provides a general guide. Note that some of the concerns may be correctable. Examples are those related to ES II Benthos 875 popup release modules that have been recently completed. A more reliable design release using a single CART transponder release inside the ES II platform (which may be more cost effective and reliable) is also being studied.
4. The subsurface taut-moored platform has demonstrated its capability, especially in the high current coastal waters of Alaska. Some modifications have been made to ease system assembly and increase the buoyancy of the SUBS A2 buoy and are ready for implementation. Other modifications, such as to trim imbalance caused by the Argos antenna/transmitter module, are easily corrected. Other ways to report the latitude/longitude (besides using the present Argos module) are available and should be explored.
5. Mooring models provide guidance in subsurface mooring design and should be used as a planning tool for all mooring designs. The MD&D model should be validated continuously with any new mooring data acquired. CO-OPS has limited experience with the WHOI mooring program at present; however, an intercomparison between the two models should be considered as a future task. The WHOI model has some unique capabilities.
6. The Naval Circulating Water Channel is a suitable facility for mooring component tests and could be used to obtain hydrodynamic data for any new mooring components (instrument, equipment, and buoy).
7. When the SUBS platform is in a more dynamic environment, explore recording single ping beam data instead of Earth coordinate averages. With large amounts of ADCP memory now available, this may allow better bin mapping. Special software is required in order to accomplish this task.

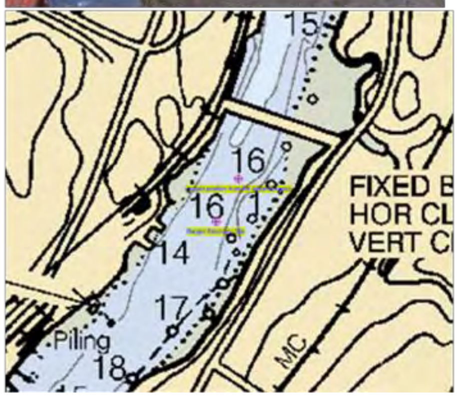
# List of Appendices

# **Appendix A** Case Studies: Trawl-Resistant Bottom Mounts

# CASE STUDIES
# TRAWL-RESISTANT BOTTOM MOUNTS (TRBM)



# TRBM Case 1 – Bangor, ME




- Configuration
  - TRBM with Benthos 867-A transponding release and a Datasonics (now Benthos) UAT-376 EL

- Timeframe
  - Deployed April 5, 2005 under extreme conditions (flow>4 knots according to USCG readings)
  - 1st Attempted Recovery in late May
  - Recovered 04 August by divers (using a combination of transponder readings/ locator readings and a search sweep. Recovery was 130 meters downstream.

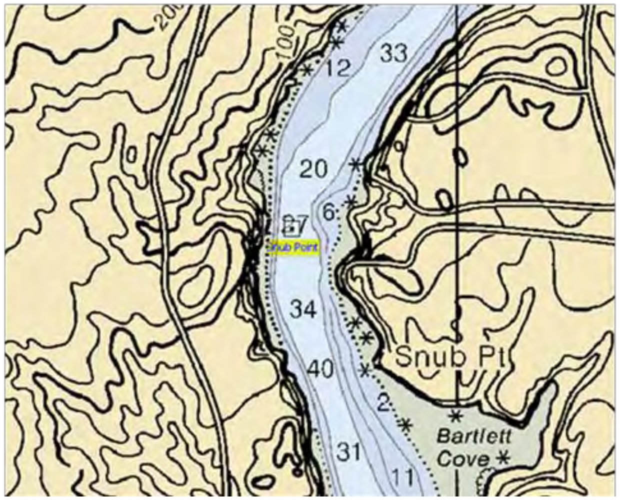
# TRBM Case 1 – Bangor, ME

- Operational Environment
  - Assumed bottom type was pebbles to cobbles, which appears to have been correct. Divers found the instrument sitting upright on bottom with no obvious external issues.
  - This turned out to be a sediment laden river flow environment with river currents of >4 knots.
- Assessment
  - The station was found to have silted on the inside with a large amount of sticks and twigs throughout, most probable cause of failure.
  - Release seems to have responded correctly.
  - Station recovered with crowbar.
- Data Quality
  - N/A. ADCP failed to record anything, (this was a problem that we thought we had solved).

# TRBM Case 2 – Snub Point, ME

- Configuration
  - TRBM with Benthos 867-A transponding release.
- Timeframe
  - Deployed April 5, 2005
  - 1st Attempted Recovery in late May
  - Recovered July by divers at deployment location.
- Operational Environment
  - Assumed bottom type was hard mud to cobbles (not charted, not visited prior to deployment, no bottom sample).
  - Divers found the instrument sitting slightly buried (~2-4″) by sedimentation.
  - This was during an exceptional flow period bringing in higher than expected sediment.

# TRBM Case 2 – Snub Point, ME

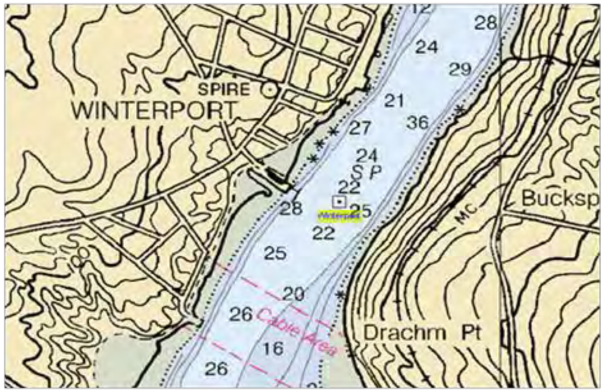



- Assessment
  - The station was found to have silted on the inside with a large amount of mud, sticks and twigs throughout, most probable cause of failure.
  - Release seems to have responded correctly; the pod released from the base as the base was being moved.
- Data
  - Instrument worked until batteries wore out.
  - Bottom Mounted (TRBM and ES-2) ADCP data is the benchmark for other platform types due to its stability (<4 knots in aluminum).

# TRBM Case 3 – Winterport, ME

- Configuration
  - TRBM with Benthos 867-A transponding release.
- Timeframe
  - Deployed April 5, 2005
  - 1st Attempted Recovery in late May
  - Recovered by divers at deployment location in August.

# TRBM Case 3 – Winterport, ME

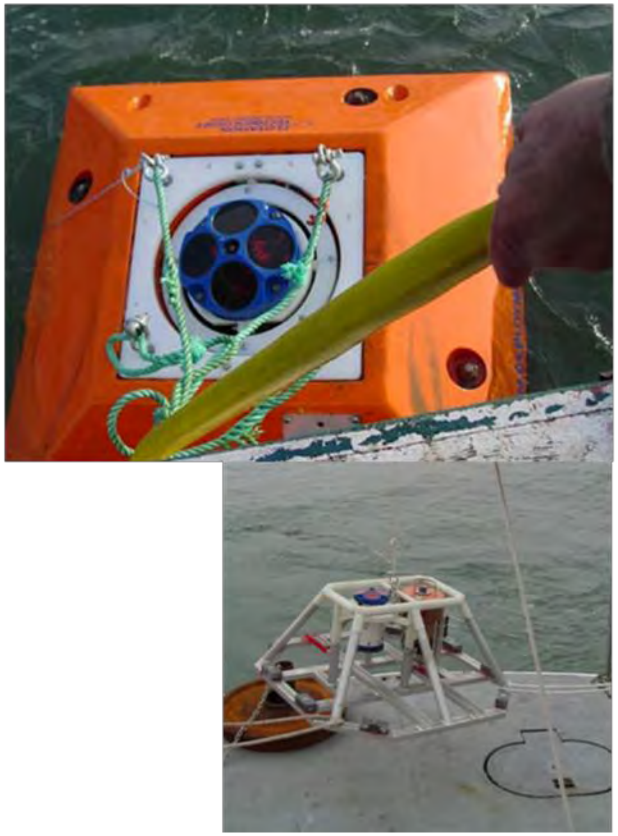



- Operational Environment
  - Assumed bottom type was sand and pebbles (charted - no site visit, no bottom sample). which appears to have been incorrect.
  - Divers found the instrument buried to the gimbals. The divers only could see the blue ADCP head. Our attempt to recover the base parted the spectra and additional lifting lines.
  - This was during an exceptional flow period bringing in higher than expected sediment.

# TRBM Case 3 – Winterport, ME

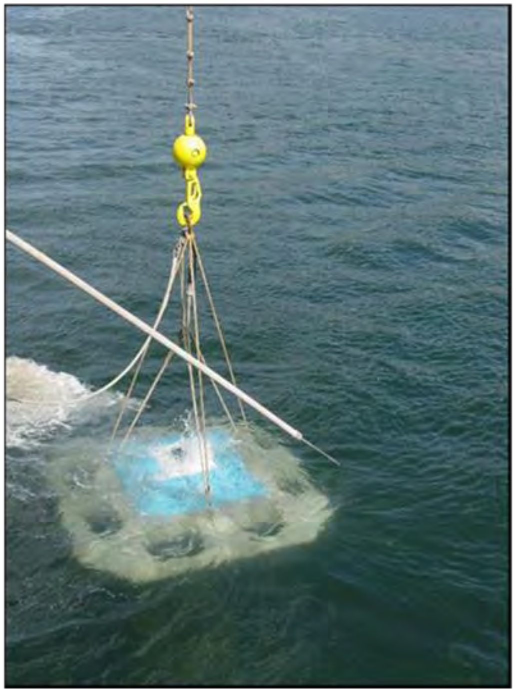

- Assessment
  - The station was found to have buried deep into mud. Most probable cause of failure.
  - Release seems to have responded correctly. Diver used a crow bar to release pod.
- Data
  - Instrument worked until batteries wore out.
  - TRBM ADCP data is the benchmark for other platform types due to its stability (<4 knots in aluminum).

# TRBM Case 4 – Humboldt, CA



- Assessment
  - Heavy sediment buried entire pod. Found by divers with staff, bridal was made to attach to gimbals so fire hose could be used to pump out pod.
- Data
  - Buried after a few days.
- Other TRBMs
  - Two other stations partially buried. Divers located instruments using diver locator. One side of pod was jammed into sand. Divers had to push down to level out system.

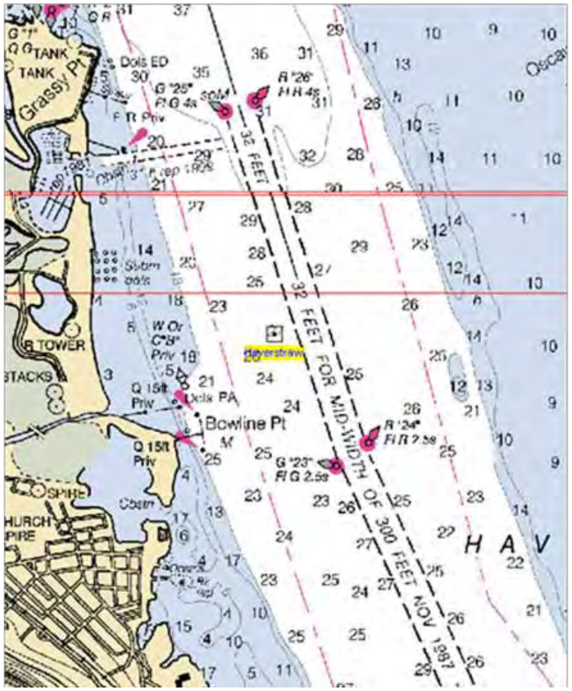
# Where TRBMs Work



- Low sedimentation & hard bottom
  - Southeast Alaska
    - of all the TRBMs deployed in SEAK from 2001-2005 only 1 (very deep) station didn't get recovered.
  - Hudson River
    - 4 (so far) All seem to have had low sed. rates during deployments

# CASE STUDIES
# EDDIE SHIH 2 (ES2) Failure

# ES2 Case 1 – Haverstraw Hudson River, NY

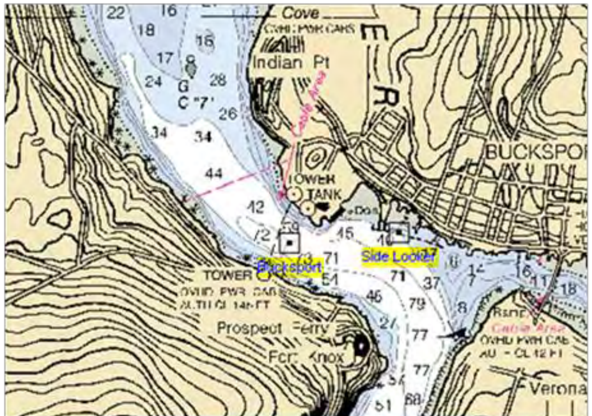


- Configuration
  - ES2 with Benthos 875 PUB release.
- Timeframe
  - Deployed, June 2004
  - Recovery first attempted July 27 2004.
  - Recovered by divers at deployment location in July 28 2004.

# ES2 Case 1 – Haverstraw
# Hudson River, NY

- Operational Environment
  - Bottom type was hard mud (bottom sample).
  - Divers found the instrument sitting slightly buried (~2-4") by sedimentation.
  - Divers found the instrument on location with no pop-up buoy. Recovery line still had a bowline tied into it!
- Assessment
  - The station was found to have very little mud and moderate growth.
  - Release seems to have disengaged prematurely.
  - The Bowline still being in the line with no release??? See ES2 Case 2- Bucksport
- Data
  - Instrument worked as expected with no quality issues.

# ES2 Case 2 – Bucksport, ME




- Configuration
  - TRBM with Benthos 867-A transponding release.
- Timeframe
  - Deployed April 5, 2005
  - 1st Attempted Recovery in late May
  - Recovered by divers at deployment location in August.

# ES2 Case 2 – Buckport, ME

- Operational Environment
  - Bottom type was assumed to be hard.
  - First Dive attempt found the site covered by wood chips (sit is just off a paper mill)
  - Second divers found the instrument sitting upright with no chips on location with no pop-up buoy in the canister and the line paid out.
- Assessment
  - Release seems to have disengaged at some point, but didn't rise to the surface until we were onsite moving the base with the dive boat. The ring holding the line to the popup had become brittle/corroded and parted while during the movement. Thus, the line became free and still had a bowline tied on it…
  - DO WE NEED THE RING??? (AKA Its always the 25c part that fouls you!)
- Data
  - Instrument worked as expected with apparent covering at times (data times being collected, but no current data).

# ES-2 Case #3
# George Washington Bridge Deployment #2

- ES2 Deployed July 2005
- Attempted recovery in August 2005
- Station recovered by divers in November 2005
- Station was deployed longer than the First GW Bridge deployment, which was recovered successfully

# Where ES2s Work

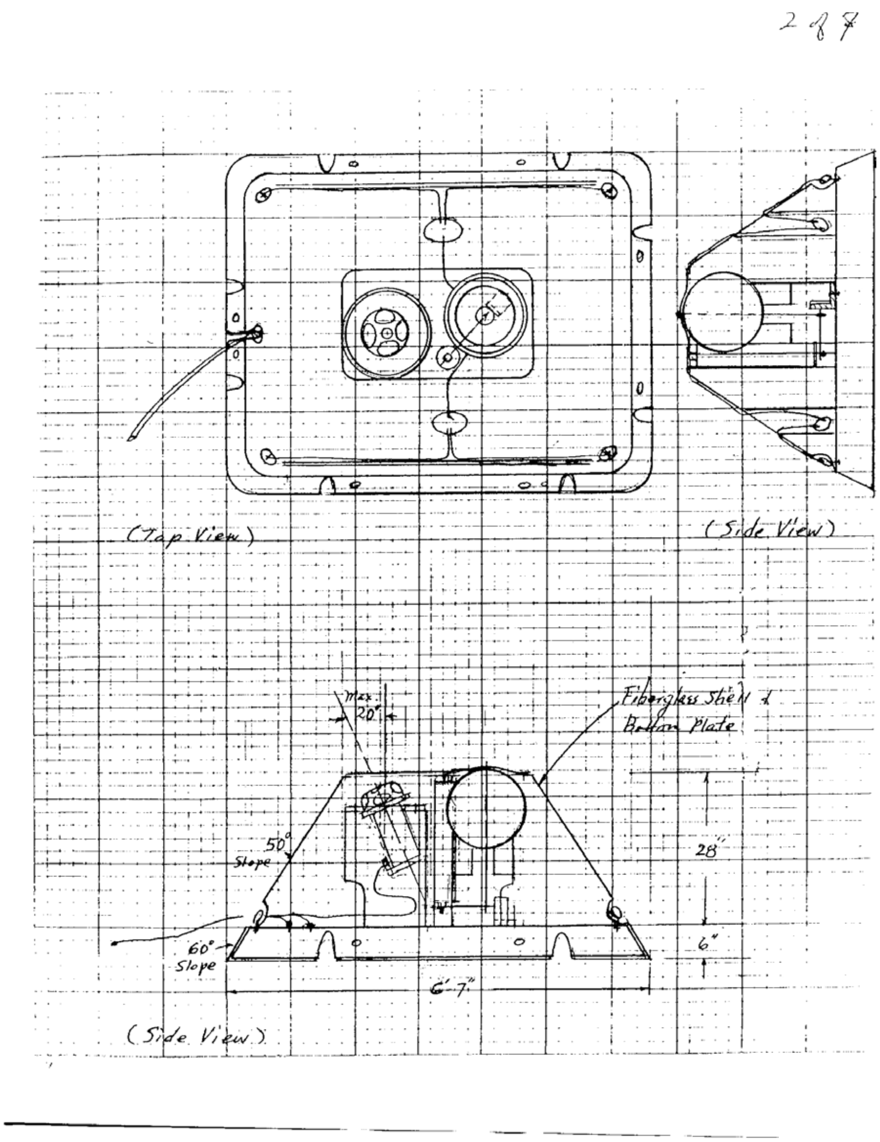
Hudson River Deployment

1…but a ton (literally!) of mud collected in the base. ES4 might have been a better option!

# Where ES2s Work

- Chesapeake Bay
- Florida

# **Appendix B** ES II Drawings



287
(Top View)
(Side View)
Max.
20°
Fiberglass Shell &
Bottom Plate
50°
Slope
28"
60°
Slope
6"
6'-7"
(Side View)


**Figure 1**

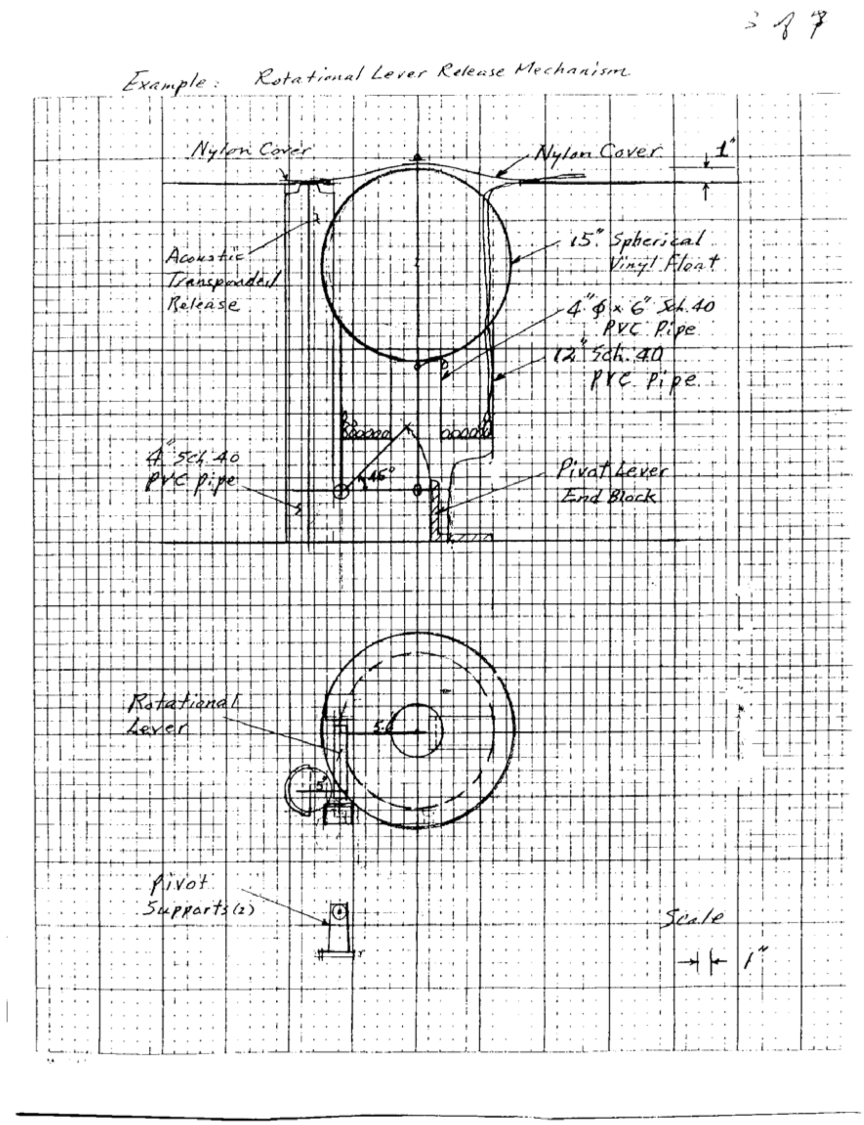
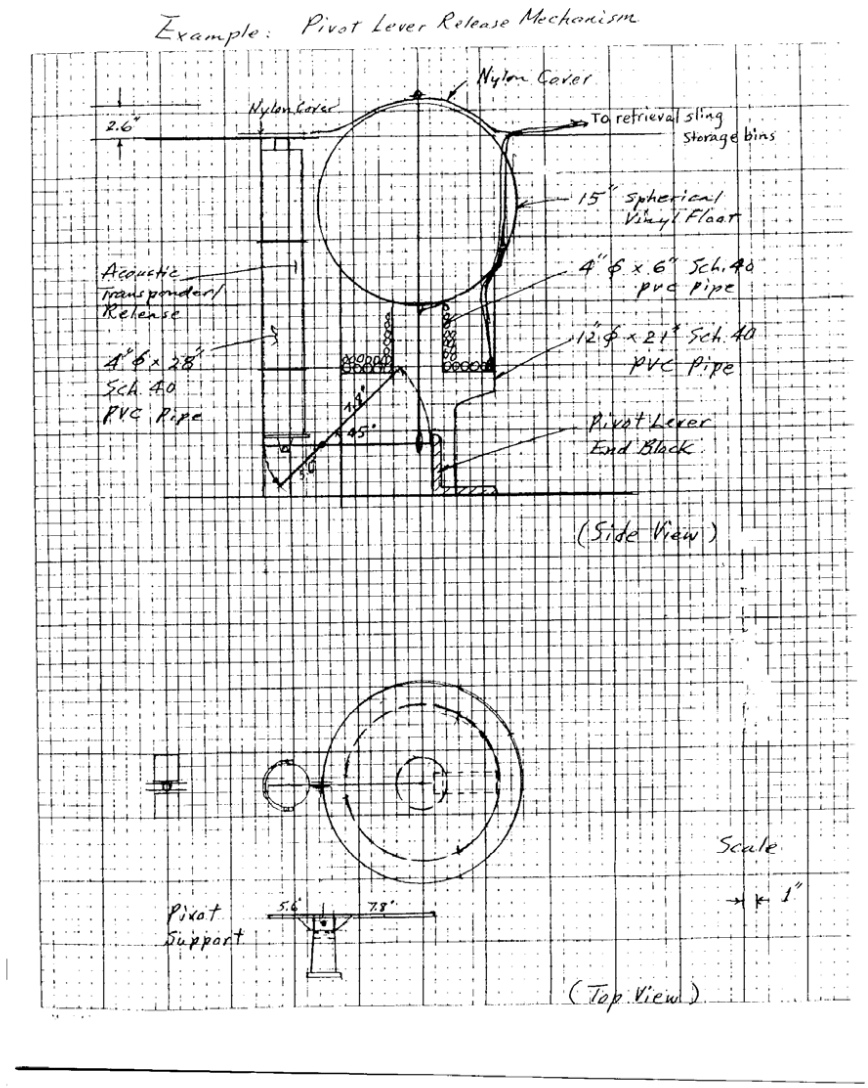

Example: Rotational Lever Release Mechanism
Nylon Cover
Nylon Cover
1"
Acoustic Transponder Release
15" Spherical Vinyl Float
4" ϕ x 6" Sch. 40 PVC Pipe
12" Sch. 40 PVC Pipe
4" Sch. 40 PVC pipe
45°
Pivot Lever End Block
Rotational Lever
Pivot Supports (2)
Scale
1"

**Figure 2**

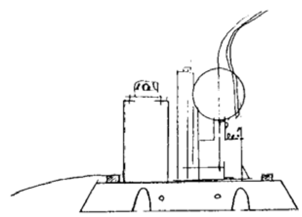


Example: Pivot Lever Release Mechanism
Nylon Cover
Nylon Cover
2.6"
To retrieval sling Storage bins
15" Spherical Vinyl Float
Acoustic Transponder/ Release
4"φ x 6" Sch. 40 pvc pipe
12"φ x 21" Sch. 40 PVC Pipe
4"φ x 28" Sch. 40 PVC Pipe
45°
Pivot Lever End Block
(Side View)
Scale
1"
Pivot Support
5.6"
7.8"
(Top View)

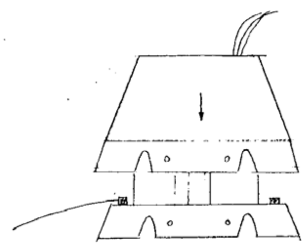

Figure 3

## Cartoons

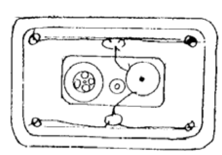
### Installation



(1) Mount hardware on the bottom plate
- . acoustic release/transponder
- . pop-up float/release mechanism/release lead line
- . ADCP/gimbal
- . E-M cable and cable break-out connections
- . lead bricks



(2) Lower top cover into position
- . fishing out two retrieval sling lead lines & a pop-up float release line
- . install titanium fasteners.



(3) prepare retrieval lead lines
- . tighten up pop-up float release lead line & secure to top of float
- . attach four synthetic retrieval lifting slings to platform lifting eyes, hide slings in protective channel and storage bins

**Figure 4**

2. **Deployment**

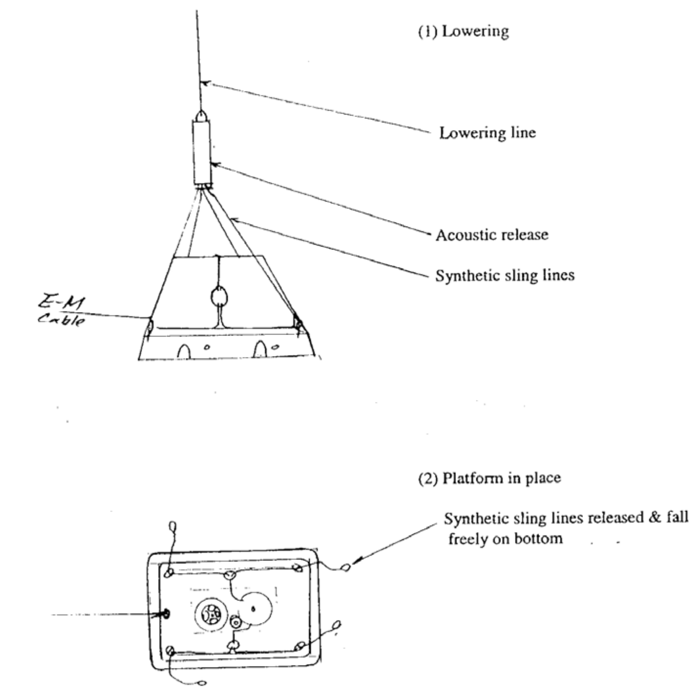



**Figure 5**

7 8 7

## 3. Retrieval

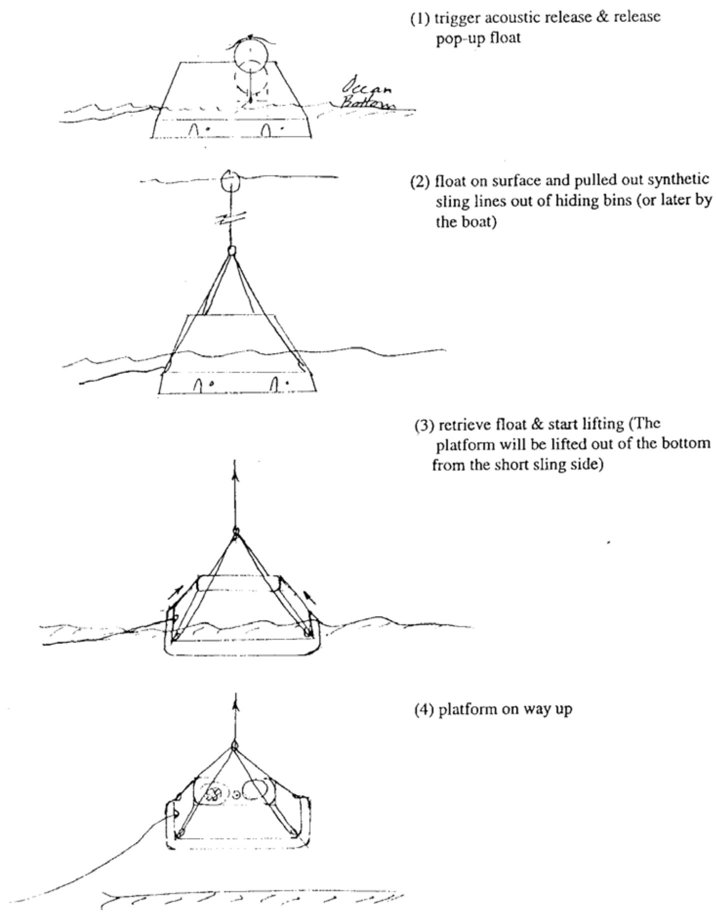



**Figure 6**

# **Appendix C** Assessment of Sub-Surface Mooring Dynamics with Acoustic Doppler Current Meters in High Speed Environments

# Assessment of Sub-Surface Mooring Dynamics with Acoustic Doppler Current Meters in High Speed Environments

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***Abstract*— Acoustic Doppler Current Profilers (ADCP) twenty-six Streamlined Underwater Buoyancy Systems (SUBS) were analyzed during the 2002-2005 field season in Southeast Alaska; Cook Inlet, Alaska and Humboldt Bay, California. SUBS have been deployed at various depths, current speeds, tidal ranges and other conditions. The performance of each SUBS deployment is evaluated by the pressure and tilts data recorded by the ADCP. Assessing the vertical movement of the SUBS is critical to evaluating the data quality. The tide signal as observed by local National Ocean Service tides stations is subtracted from the pressure sensor record to approximate the vertical movement of the buoy. The mooring lengths range from 3 meters to 100 meters with speeds up to 3 meters per second.**

## I. Introduction

The Center for Operational Oceanographic Products and Services (CO-OPS) of NOAA's National Ocean Service (NOS) manages the National Current Observation Program (NCOP) with the primary purpose of collecting water current data in support of safe navigation. Its main products are tidal current predictions derived from data collected in ports, harbors and navigable waterways. Current meters have been deployed in various mounting systems depending on the local vessel traffic and environmental conditions. In shallow waters where commercial fishing occurs the trawl resistant bottom mount has proven successful. In deeper channels or where sedimentation is a problem Streamlined Underwater Buoyancy Systems (SUBS) moorings with Acoustic Doppler Current Profilers (ADCP) have been utilized.

One of the greatest challenges in collecting quality data with subsurface moorings is reducing the strumming, vibrations and vertical movement or excursions of the mooring. The Pacific Marine Environment Lab (PMEL) of the National Oceanic and Atmospheric Administration (NOAA) has been monitoring upper-ocean and atmospheric variability using an array of moored instruments in the tropical Pacific for more than two decades and has found that the mooring excursions are attributed to drag on the mooring line [1]. Utilizing line with reduced drag characteristics has shown decreased depth excursion. The traditionally ADCP sub-surface mooring mount, a spherical in-line buoy, is also a significant source of drag. Cross-flow acceleration is typically reduced by two orders of magnitude by replacing the spherical buoy with streamlined flotation [2]. Use of the streamlined buoyancy was also shown to reduce the overall drag on the mooring thereby significantly reducing instrument excursions and inclinations.

Twenty-six SUBS stations deployed by NCOP during the 2002-2005 field seasons were evaluated. The stations were deployed in Southeast Alaska; Cook Inlet, Alaska and Humboldt Bay, California. The SUBS were deployed at various depths, current speeds, tidal ranges and other conditions. The performance of each SUBS deployment was evaluated by data recorded from the internal pressure and tilt sensors of the ADCP. Assessing the excursion of the SUBS is critical to evaluating the data quality. The tidal signal as observed by local NOS/CO-OPS tides stations is subtracted from the pressure sensor record to approximate the excursion of the buoy. The mooring lengths range from 3 meters to 100 meters with speeds over 3 meters per second (m/s).

## II. Background

### A. *Field Test in Delaware Bay*

NCOP field tested the SUBS with a bottom mounted platform at the entrance to the Delaware Bay in 2000 and 2001 [3]. The primary objective of the field test was to assess the quality of the SUBS-ADCP measurements, specifically the tidal current predictions derived from the measurements. A comparison of several analysis products, including tidal constituents, tidal current predictions, and Greenwich intervals suggested no significant data degradation due to the sub-surface mooring dynamics. The secondary objective was to describe the motion of the sub-surface buoy from analysis of pressure, tilts and heading to determine how well the mooring buoy performs in higher flows. Observations from the [3] field test follow:

1) The roll of the SUBS decreased with increased current speeds; the pitch of the SUBS became larger at higher speeds.

2) Accumulation of sediments in the SUBS or settling of the anchor into sediments caused an increased excursion over the time of the deployment.
3) Comparing floods and ebbs of the same magnitude, it is evident the flood currents consistently caused a slightly larger vertical displacement than the ebb currents at some stations.
4) Vertical displacement was greatest (1.9 meters) with the flood current at 1.2 m/s. Slightly weaker ebbs produced a maximum vertical displacement of 0.6 meters.

*B. Field Deployments 2002-2005*

All deployments were short term, on the order of 30 to 60 days in order to obtain tidal constituents for predictions. Internal batteries and memory allow the system to be self-contained; all data were retrieved once the ADCP is recovered. Data were collected in binned intervals from the upward looking ADCP ranging from one to eight meters. Sampling intervals range from two to six seconds and were averaged over six minute intervals.

*1) Cook Inlet, Alaska :* This body of water connects the Gulf of Alaska with the Port of Anchorage, the major marine transportation corridor of goods to the people of Alaska. This water body is characterized by a heavy load of glacial and volcanic sediments throughout the entire water column in the upper regions of the Inlet. Cook Inlet also exhibits some of the largest tides in the country. At Anchorage the mean tide range is eight meters with a maximum range of 14 meters during spring tides. These large tidal ranges coupled with relatively shallow bathymetry and constricted passages couse very high tidal currents, up te 3.5 m/s in some areas. CO-OPS deployed a SUBS in Cook Inlet in 2002 using the shallow system configuration shown in Fig. 1, the length of this mooring was under 10 meters and proved to be successful in the high sediment environment of Cook Inlet. After this success, SUBS were used exclusively in the Inlet for the 2003 - 2005 deployments.

*2) Southeast Alaska :* Southeast Alaska is comprised primarily of more than one thousand islands of the Alexander Archipelago. The Inside Passage, a major marine highway for Alaska, has many critical navigation hazards due to the geography of island systems which cause high current speeds. SUBS mooring were deployed at eleven deep channel stations during the 2003 - 2005 field seasons.

*3) Humboldt Bay, California:* The SUBS deployments were located outside the harbor near the south jetty of Humboldt Bay. The first deployment in the winter of 2002 lasted for less than six days before large ocean swells broke the mooring. During this time, currents greater than 2.5 m/s were measured and the ADCP's pressure and tilt sensors indicated high eneryg wave action. The second deployment on July 21, 2004 recorded 49 days during the milder summer season at the same location. Maximum currents were observed at 0.75 meters per second. The pressure record did not indicate any excursion at these speeds or wave action.

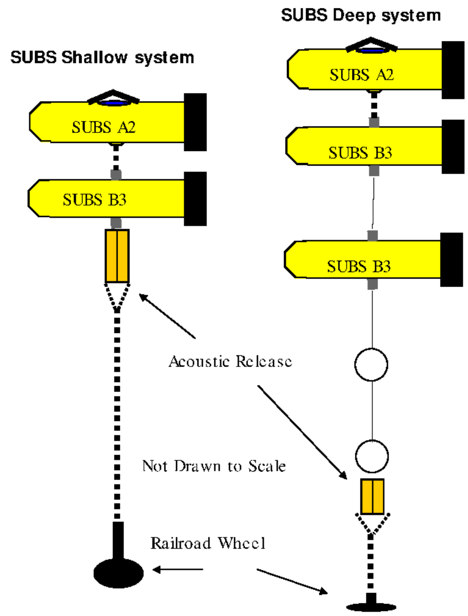


Fig. 1. Two SUBS configurations.

## III. Equipment

Currents were measured with Workhorse Sentinel 300, 600 and 1200 kHz ADCPs manufactured by RD Instruments. The SUBS floats were manufactured by Open Seas Instrumentation. The A2 model houses the ADCP containing 72 pounds of bouyancy while the B3 model contains 115 pounds of additional bouyancy. The test in Delaware Bay and the first deployment in Cook Inlet used the Edgetech 8242 acoustic release, all other deployments utilized the ORE Coastal Acoustic Release Transponder in tandem. Argos tracking beacons were developed and manufactured by Technocean including a special antennae configuration to accommodate the SUBS. The Argos tracking beacon was added to stations in 2004 in order to track the unit if it surfaced at some time other than the scheduled recovery. A tank test was done on April 1, 2004 to evaluate the SUBS tilts in a non-current environment with the Argos beacon attached. Findings showed the influence of the additional beacon was within the limits of each SUBS and correctable by the internal bin mapping algorithms of the ADCP [4]. Mooring configurations vary with the depth of each station. Galvanized 5/16 inch cable was used on the longer mooring and stainless steel 5/16 inch chain was used between the SUBS A2 and B3. Galvanized 3/8 inch chain was used with a rail road wheel anchor of approximately 800 pounds.

## IV. Performance Criteria

### *A. Tilts and headings*

Of the four transducer beams, beam three is used by the ADCP as a reference point for the internal measurement of the tilts and heading. In the SUBS, beam three (typically the forward facing beam) is 45 degrees from the center of each SUBS causing the pitch and roll to be measured in this plane, not along the center of the SUBS. Each SUBS has a two to three degree list in the neutral position and the ARGOS beacon increases the pitch by up to two degrees. All tilts within 20 degrees are correctable by the ADCP. A few cases did not meet this criteria due to influences caused by being too close to the surface or becoming entangled during the deployment. All headings are internally recorded and measurements compensated by the internal rapid response toroidal compass of the ADCP.

### *B. Pressure sensor*

Each ADCP has a pressure sensor which is internally processed by the ADCP to calculate depth. This measurement was compared to the closest NOS water level gauge and, if needed, corrected for phase and depth using NOS secondary station offsets to align with the ADCP pressure data. In the cases where the vertical excursions were not observed the pressure sensor was in strong agreement with the NOS water level measurements.

## V. Observations

Table I gives a brief overview of the 26 stations in Humboldt Bay, Cook Inlet and Southeastern Alaska. These stations can be better assessed by dividing them into three categories based on the mean current speed and the length of the mooring. High speed currents are defined as mean current speed equal or greater than 0.5 meters per second (about one knot) due to the rapid vertical excursion effect these speeds have upon the SUBS. There are four stations that have both high speed currents and moorings longer than 10 meters. These SUBS will be investigated in more detail below because of their interesting dynamics. Eleven stations showed vertical excursions greater than their bin length. Fifteen stations experience high speeds however vertical excursions on eleven of these stations are low because the mooring lengths are less than 10 meters. Eleven stations experienced low speed currents. Such low speed of the current does not exert enough force upon the SUBS to overcome the upward buoyancy to any great extent.

The speed of the current plays a major roll in the stability of the SUBS due to the vertical and horizontal fins. In high speed waters, the SUBS heading changes quickly as the system points into the direction of the current with more stability than in low speeds (see middle graph in Fig. 2). At lower speeds the heading tends to shift or make gradual direction changes (see middle graph in Fig. 3). Pitch and tilt, on the other hand, exhibit the opposite effect with water speeds. The lower graphs of Fig. 2 and Fig. 3 show the typical behavior, that pitch is more stable at low water speeds and tend to increase with greater speed. In general the tilts remain within acceptable

TABLE I
OVERVIEW OF STATIONS.

| Station ID | Station Depth (m) | Mooring Length (m) | Mean Speed (cm/s) | Max Speed (cm/s) | Vertical Movement (m) | Bin Size (m) |
|---|---|---|---|---|---|---|
| CI0418 | 200 | 100 | 50 | 164 | 22.52 | 4 |
| AK0405 | 90 | 60 | 72 | 196 | 22.39 | 3 |
| AK0402 | 80 | 50 | 83 | 290 | 22.95 | 3 |
| SEA0502 | 228 | 65 | 16 | 56 | 1.81 | 8 |
| SEA0501 | 107 | 35 | 22 | 84 | 1.96 | 4 |
| AK0304 | 101 | 20 | 21 | 87 | 2.16 | 4 |
| AK0404 | 35 | 20 | 60 | 168 | 1.13 | 2 |
| AK0301 | 79 | 10 | 7 | 31 | 0.70 | 4 |
| AK0307 | 90 | 10 | 29 | 129 | 1.01 | 2 |
| CI0213 | 25 | 9 | 99 | 206 | 2.22 | 1 |
| CI0420 | 46 | 8 | 63 | 167 | 1.49 | 2 |
| CI0302 | 21 | 8 | 103 | 261 | 2.80 | 1 |
| CI0303 | 31 | 8 | 101 | 307 | 2.90 | 1 |
| CI0419 | 52 | 8 | 57 | 166 | 3.16 | 2 |
| CI0301 | 19 | 8 | 166 | 320 | 2.34 | 1 |
| CI0306 | 24 | 7 | 98 | 202 | 4.27 | 1 |
| CI0307 | 22 | 7 | 87 | 174 | 4.60 | 1 |
| CI0421 | 55 | 8 | 15 | 166 | 1.94 | 2 |
| CI0422 | 55 | 8 | 15 | 54 | 2.02 | 2 |
| HB0401 | 15 | 4 | 13 | 70 | 1.43 | 1 |
| AK0407 | 130 | 82 | 3 | 15 | 0 | 2 |
| AK0408 | 90 | 21 | 2 | 8 | 0 | 2 |
| AK0305 | 98 | 12 | 5 | 18 | 0 | 4 |
| HB0201 | 12 | 3 | 79 | 258 | – | 1 |
| CI0304 | 37 | 8 | 107 | 278 | – | 2 |
| CI0305 | 15 | 7 | 105 | 280 | – | 1 |

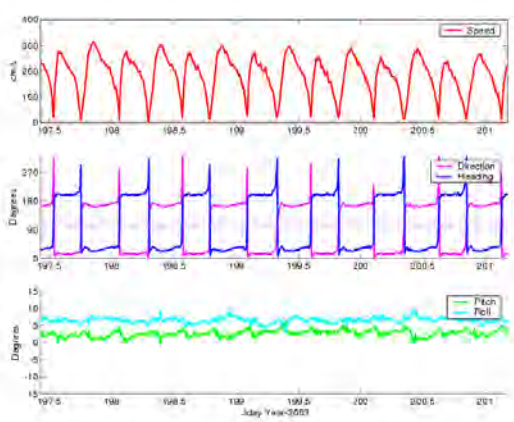


Fig. 2. Time series plot of high speed (top), heading and direction (middle), and pitch and roll (bottom) for July 16-20, 2003 at Station CI0301, Northwest of Knik Arm, Cook Inlet, Alaska.

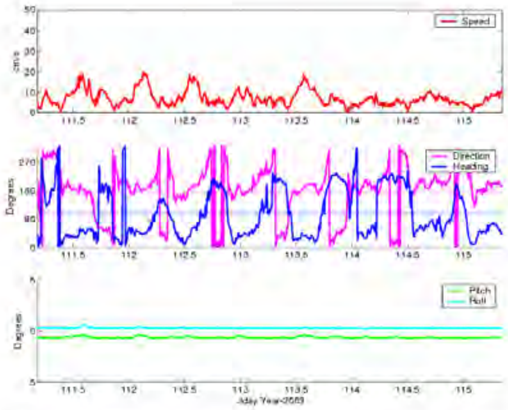


Fig. 3. Time series plot of low speed (top), heading and direction (middle), and pitch and roll (bottom) for April 21-25, 2003 at Station AK0301, Deadman Reach, Southeast, Alaska.

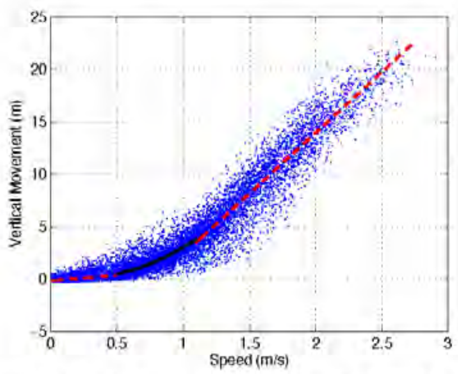


Fig. 4. Plot of vertical movement verse speed for station AK0402, the South approach to Snow Passage, Southeast Alaska on April 23 - June 26, 2003. High current speeds and a long (50 meter) mooring give this typical curve.

limits (±20°) except for a few cases where other factors are limiting the performance.

Comparisons between the ADCP's pressure data to nearby water level stations, shows that moorings greater than 10 meters in length experienced a significant vertical excursion in currents when current speeds were over 0.5 meters per second. In the following analysis, best fit water level data was subtracted from the ADCP pressure sensor data to remove the vertical effects of the tides. In general, there exists three different flow regimes in which the SUBS exhibit different responses to water speeds. Fig. 4 shows a typical SUBS vertical excursion response to increasing current speed when mooring lengths exceeded 10 meters. The three regimes have curves fitted to the data to help quantify the rate of vertical excursion. Up to about 0.5 m/s of current, the SUBS exhibit very little vertical movement with a slope of 1.0 m per m/s water speed to as little as 0.02 m per m/s, which is very stable. At current speeds from about 0.5 m/s to 1.1 m/s the SUBS experience an exponential decrease in depth per increase in speed. After this threshold, the SUBS experience another linear regime however one in which the vertical excursion is much greater per increase in speed, with a slope (for the example in Fig. 4) of 11.6 m per m/s.

TABLE II

MOORING LENGTH AND SLOPE OF THE HIGH CURRENT SPEED REGIME (SPEEDS GREATER THAN 1.1 M/S) OF THE TYPICAL SUBS VERTICAL EXCURSION CURVE.

| Station ID | Mooring Length | High Speed Slope |
|---|---|---|
| CI0418 | 100 m | 22.7 m per m/s |
| AK0405 | 60 m | 16.9 $m_V$ / m/s |
| AK0402 | 50 m | 11.7 $m_V$ / m/s |
| AK0404 | 20 m | 3.5 $m_V$ / m/s |
| CI0213 | 9 m | 0.89 $m_V$ / m/s |

The slope of the high speed linear regime becomes steeper as the length of the mooring increases. Table II is a comparison between mooring length and the slope of the high speed current regime of the curve. The amount of vertical movement is dependent on the length of the mooring, shown by Fig. 5 (the graph of Table II). Longer moorings suffer from greater rates of vertical movement in high speed currents. Longer moorings have the disadvantage of having both more distance to be depressed and a greater amount of area in the line of the mooring for frictional forces. Moorings under 10 meters in length can sustain high speed currents with less than a meter of vertical movement per meter per second of current speed.

## VI. SUMMARY

SUBS moorings are proving to be a benefit for the NCOP program at NOAA. In both high and low speed currents, the tilts and headings of the SUBS are preforming well within tolerances. Data shows that longer mooring systems have a large influence on the vertical excursions. These SUBS suffer from greater amounts of vertical excursions in currents with speeds greater than 1.1 meters per second because of the increased drag. Further investigations need to be made in order to quantify the drag and buoyancy effects of the longer SUBS systems.

To ensure safe navigation, NOAA will undoubtedly continue to place current meters in locations where current measurements are difficult due to both great ocean depths and high speed currents. To proved reliable data at these locations, keep the length of the mooring as short as possible by maximizing the range of the ADCP and adjusting the measurement bin

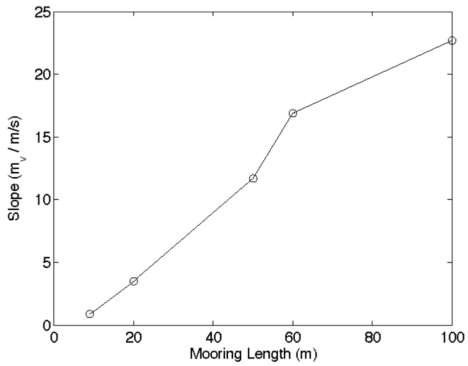


Fig. 5. Slope of the high current speed regime (speeds greater than 1.1 m/s) verse mooring length.

size so the vertical excursion is within the measured bin. The drawback of increasing bin size is that side lobe contamination increases decreasing data coverage of the surface. When dramatic vertical excursions are unavoidable, averaging of the bins may provide greater precision, otherwise post process the data to step up or down bins as necessary to stay close to the true water level.

## ACKNOWLEDGMENTS

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[1] Plimpton, Freitag, and McPhaden, "Processing of Subsurface ADCP Data in the Equatorial Pacific," Technical Memorandum OAR PMEL-125, NOAA, 2004.

[2] J.M. Hamilton, G.A. Fowler, and D.J. Belliveau, "Mooring Vibration as a Source of Current Meter Error and Its Correction," *Journal of Atmospheric And Oceanic Technology*, vol. 14, pp. 644–655, June 1997.

[3] S. Bourgerie, Garner, "Coastal Current Measurements Using an ADCP In a Streamlined Sub-surface Mooring Buoy," tech report conference proceedings, NOAA, 2001.

[4] Jennifer Ewald, "Comparison of Subsurface Underwater Buoyancy Systems Tilts and Argos Beacon Test." Internal test document., 2004.

# **Appendix D** Comparison of Subsurface Underwater Systems, Tilts, and Argos Beacon Test Draft

# Comparison of Subsurface Underwater Buoyancy Systems Tilts & ARGOS Beacon Test - DRAFT

**Jennifer Ewald**

**April 6, 2004**

Subsurface underwater buoyancy systems (SUBS) floatation units have been used during the 2002-2003 projects listed in Table 1. An ARGOS tracking beacon was added to station CI0307 in order to track the unit if it surfaced at some time other than the scheduled recovery and are planned to be added to all SUBS deployments. A tank test was done on April 1, 2004 to evaluate the SUBS tilts in a non-current environment (Figure 1).

| Station ID | Project | Year | ARGOS Beacon |
|---|---|---|---|
| CI0213 | Cook Inlet | 2002 | No |
| CI0301 | Cook Inlet | 2003 | No |
| CI0302 | Cook Inlet | 2003 | No |
| CI0303 | Cook Inlet | 2003 | No |
| CI0304 | Cook Inlet | 2003 | No |
| CI0305 | Cook Inlet | 2003 | No |
| CI0306 | Cook Inlet | 2003 | No |
| CI0307 | Cook Inlet | 2003 | Yes |
| SE0301 | Southeast Alaska | 2003 | No |
| SE0304 | Southeast Alaska | 2003 | No |
| SE0305 | Southeast Alaska | 2003 | No |
| SE03TA | Southeast Alaska | 2003 | No |
| HB0201 | Humboldt Bay | 2002 | No |
| TEST-A | Dive Tank | 2004 | Yes |
| TEST-B | Dive Tank | 2004 | No |

Table 1. Stations deployed with SUBS units.

Figures 3 to 15 show sub-sets of the ADCP tilts, current speed and heading of the ADCP for the stations listed in Table 1. Figure 2 shows a graph summary for the entire data set. The ADCP can measure a maximum tilt of 20°, once that tilt is reached the data is compromised.

Additionally, Station CI0302 tilts to its side during low water slack. Station CI0304 became entangled causing the unit to sit on its side. Station CI0305 was dropped too shallow and looses data during low water, it is not shown in the graph summary (Figure 2). Station HB0201 broke away during day 5.

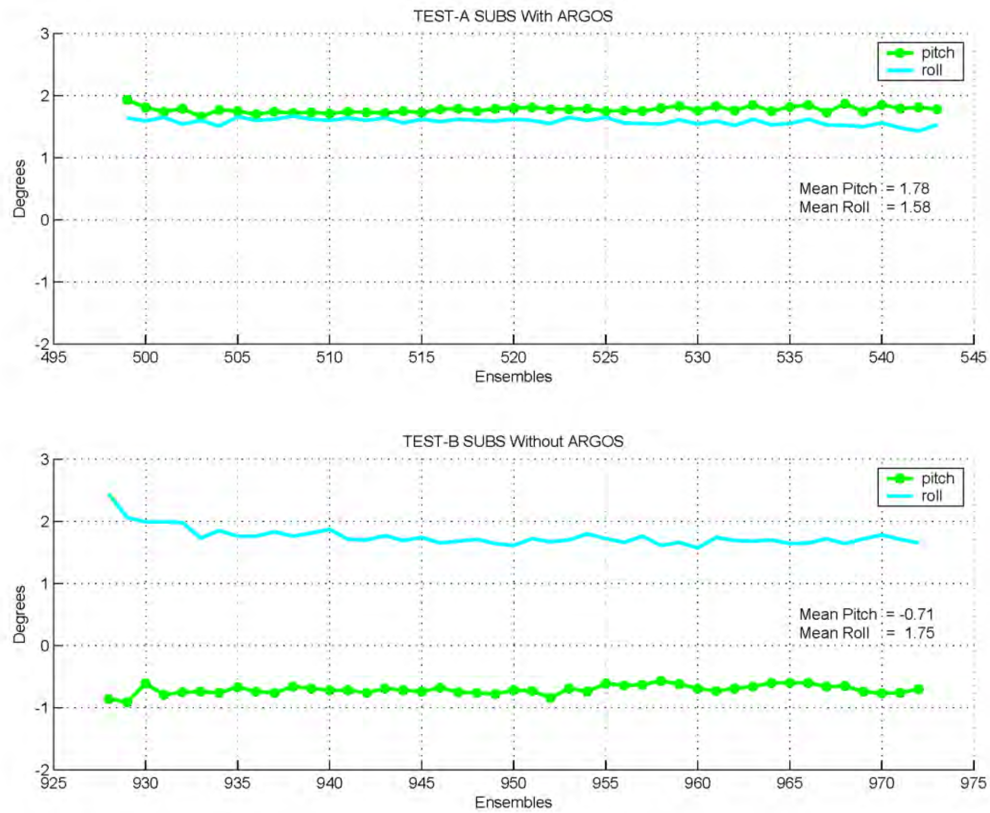
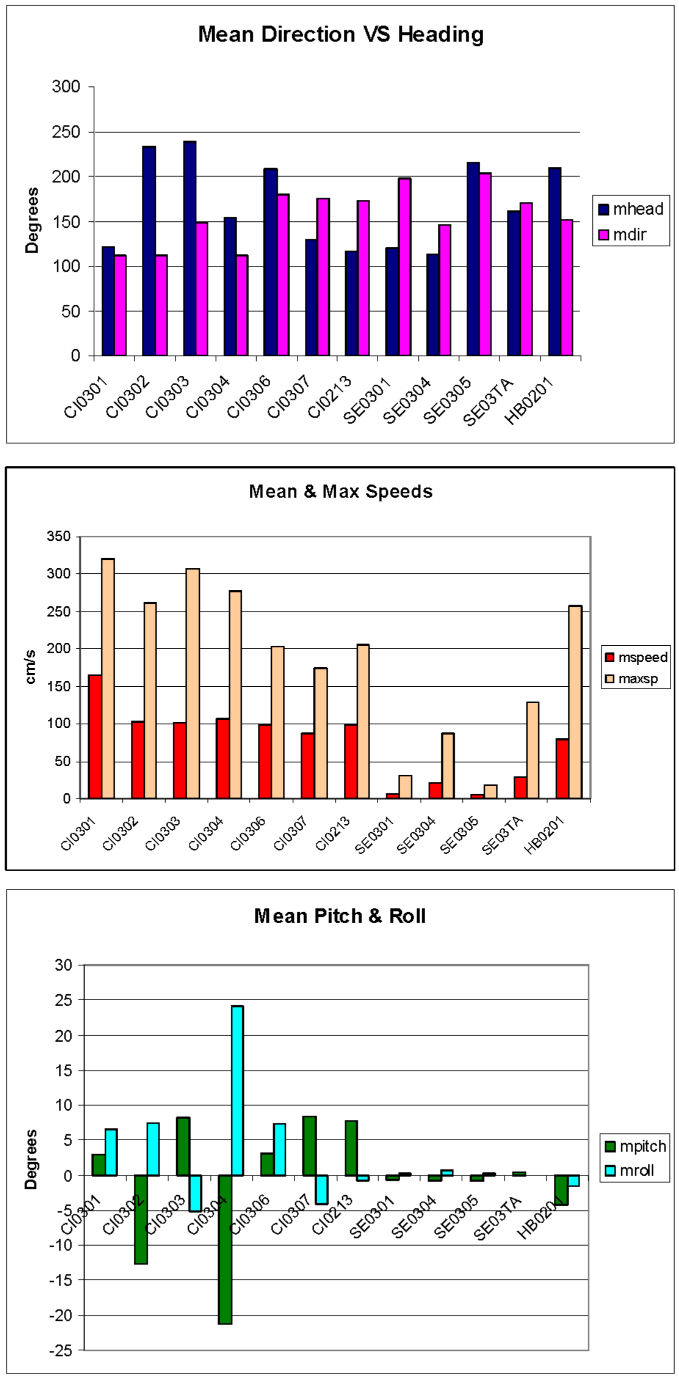

TEST-A SUBS With ARGOS
pitch
roll
Mean Pitch = 1.78
Mean Roll = 1.58
Degrees
Ensembles
TEST-B SUBS Without ARGOS
pitch
roll
Mean Pitch = -0.71
Mean Roll = 1.75
Degrees
Ensembles

Figure 1



Mean Direction VS Heading
Degrees
300
250
200
150
100
50
0
CI0301
CI0302
CI0303
CI0304
CI0306
CI0307
CI0213
SE0301
SE0304
SE0305
SE03TA
HB0201
mhead
mdir
Mean & Max Speeds
cm/s
350
300
250
200
150
100
50
0
CI0301
CI0302
CI0303
CI0304
CI0306
CI0307
CI0213
SE0301
SE0304
SE0305
SE03TA
HB0201
mspeed
maxsp
Mean Pitch & Roll
Degrees
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
CI0301
CI0302
CI0303
CI0304
CI0306
CI0307
CI0213
SE0301
SE0304
SE0305
SE03TA
HB0201
mpitch
mroll


Figure 2

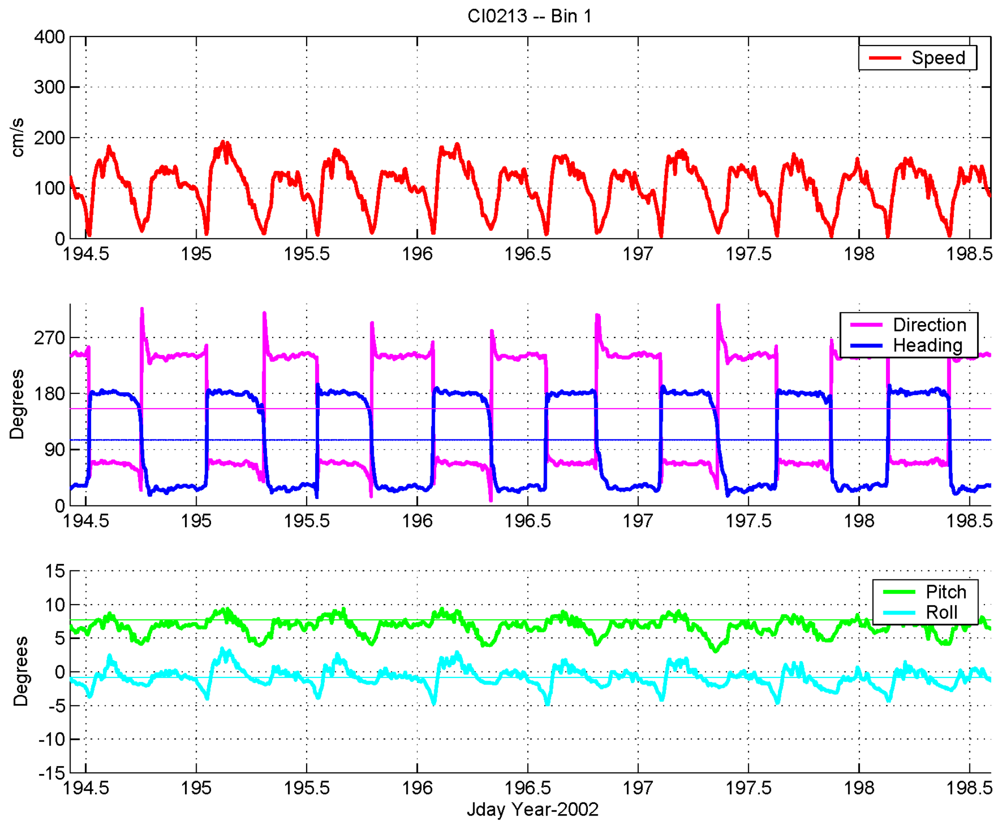
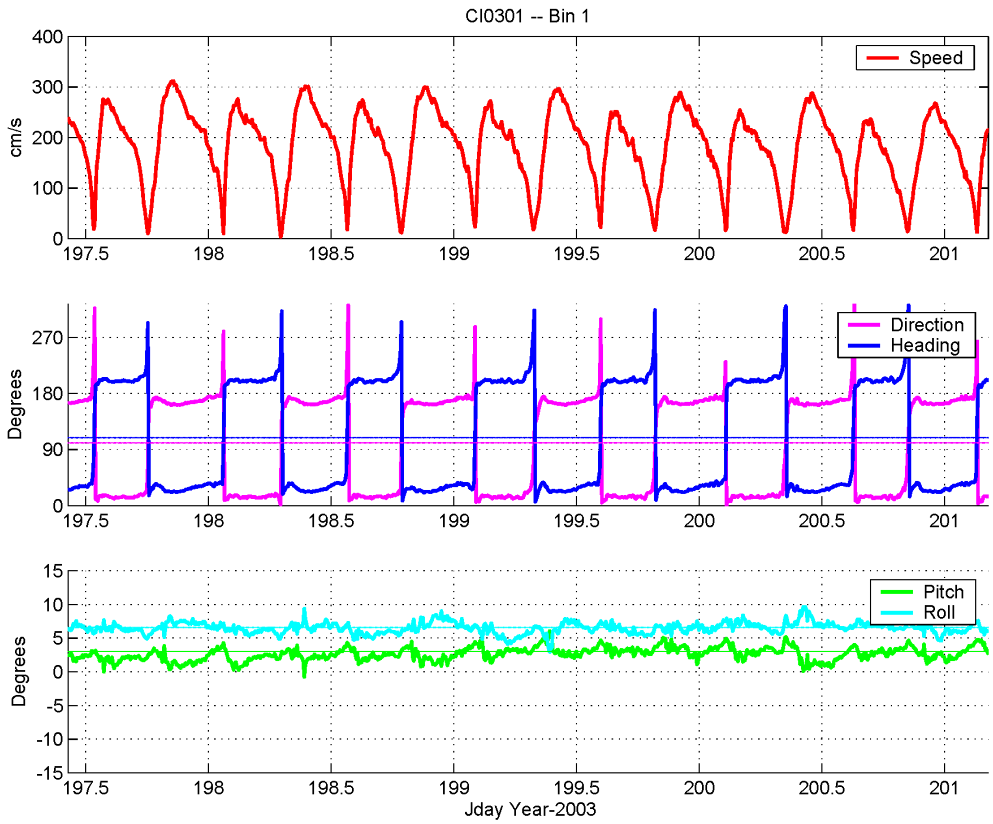
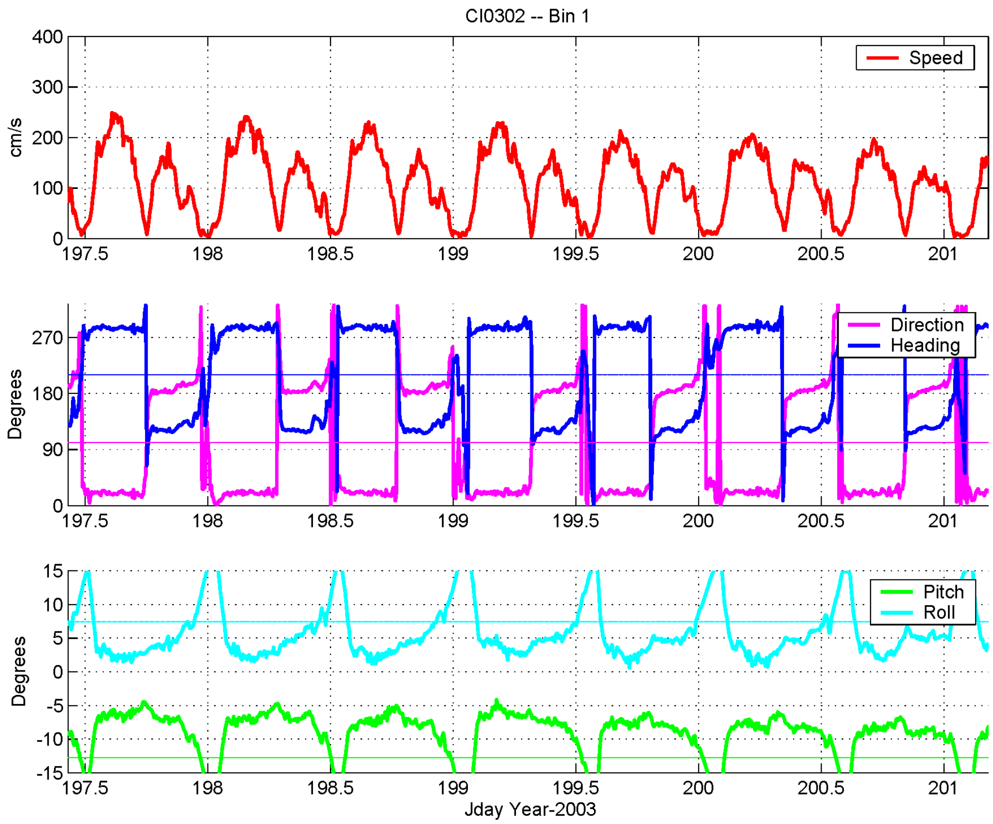

CI0213 -- Bin 1
Speed
cm/s
400
300
200
100
0
Direction
Heading
Degrees
270
180
90
0
Pitch
Roll
Degrees
15
10
5
0
-5
-10
-15
194.5
195
195.5
196
196.5
197
197.5
198
198.5
Jday Year-2002

Figure 3



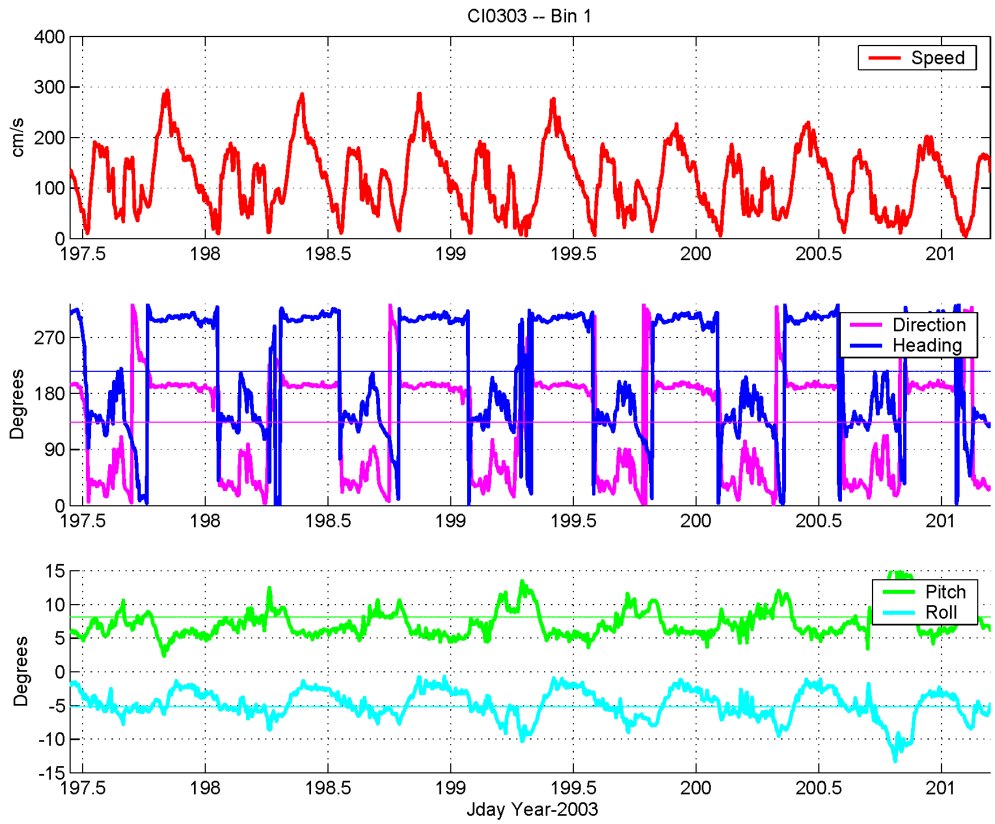
CI0301 -- Bin 1
Speed
cm/s
Direction
Heading
Degrees
Pitch
Roll
Jday Year-2003


Figure 4



CI0302 -- Bin 1
Speed
cm/s
400
300
200
100
0
197.5
198
198.5
199
199.5
200
200.5
201
Direction
Heading
Degrees
270
180
90
0
Pitch
Roll
15
10
5
0
-5
-10
-15
Jday Year-2003


Figure 5



CI0303 -- Bin 1
Speed
cm/s
Direction
Heading
Degrees
Pitch
Roll
Degrees
Jday Year-2003


Figure 6

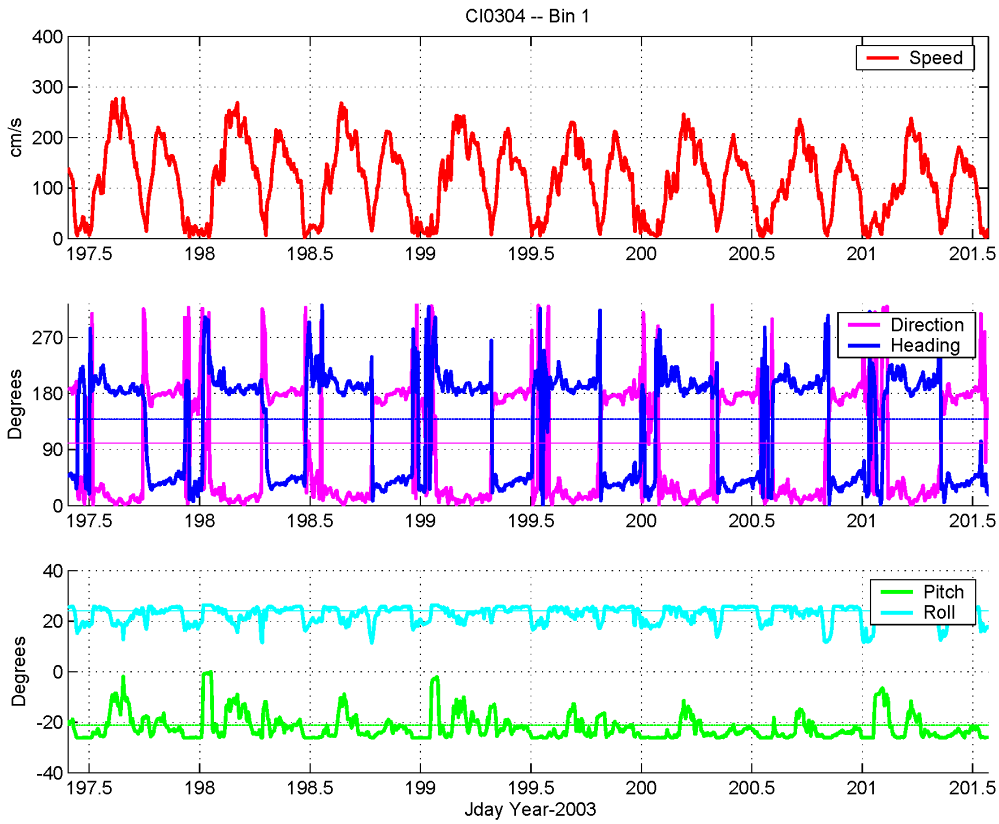
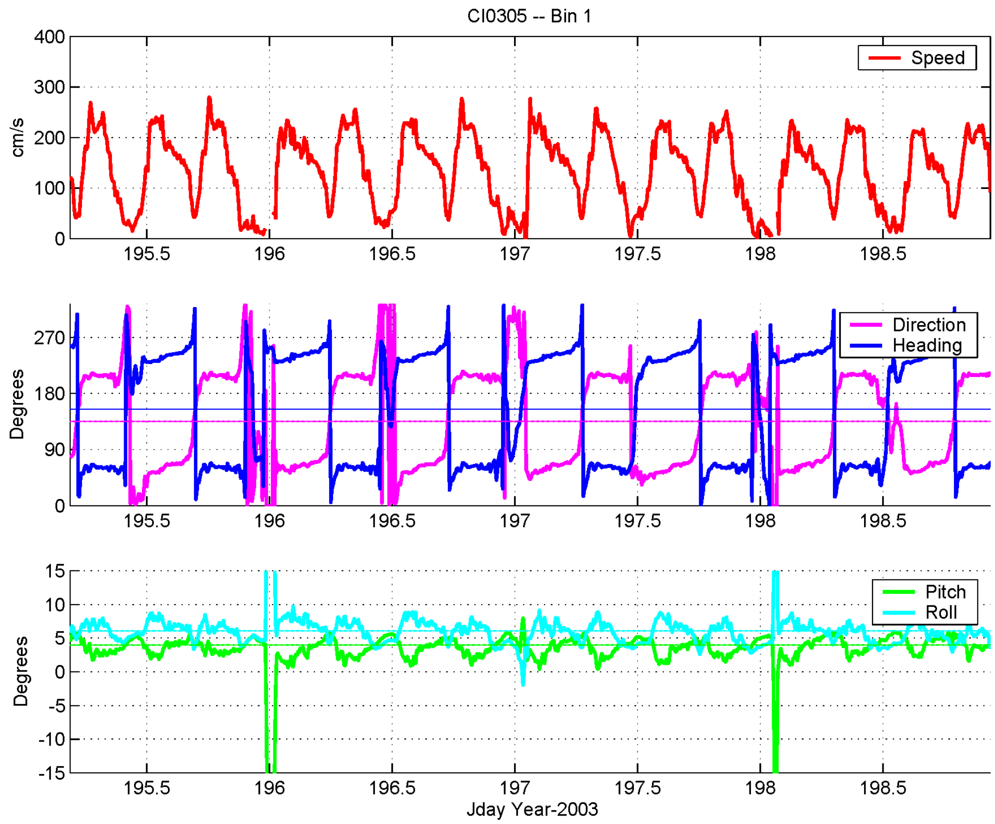
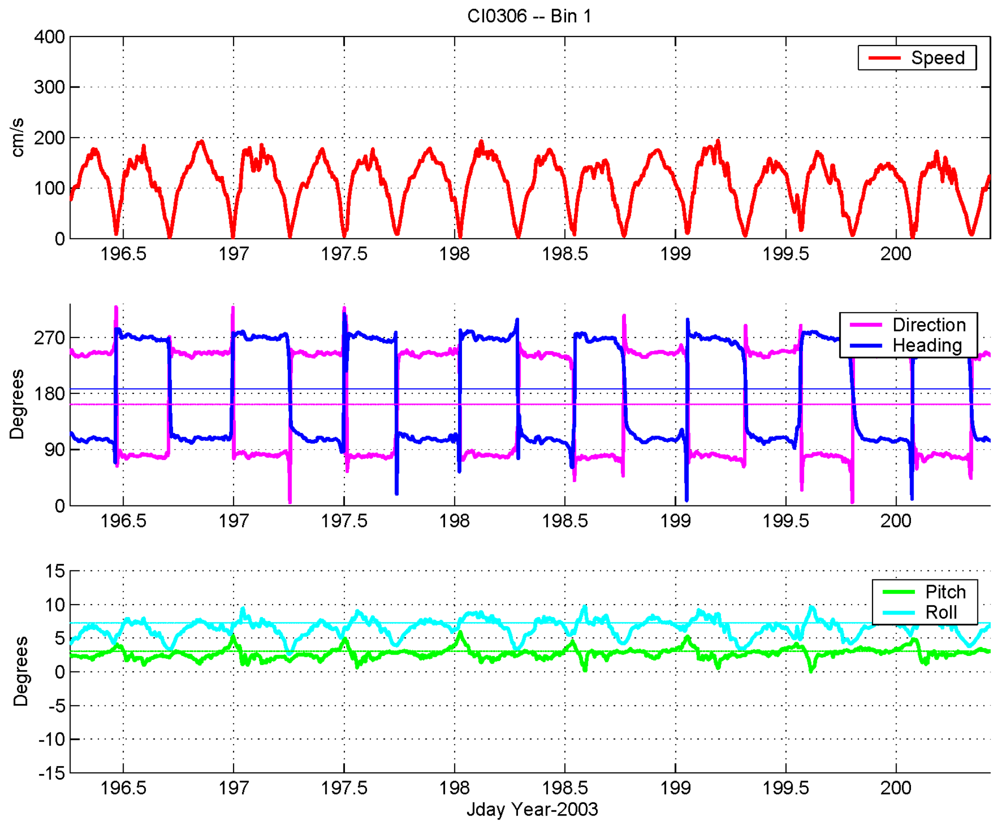

CI0304 -- Bin 1
Speed
cm/s
Direction
Heading
Degrees
Pitch
Roll
Jday Year-2003

Figure 7



CI0305 -- Bin 1
Speed
cm/s
400
300
200
100
0
195.5
196
196.5
197
197.5
198
198.5
Direction
Heading
Degrees
270
180
90
0
Pitch
Roll
15
10
5
0
-5
-10
-15
Jday Year-2003


Figure 8



CI0306 -- Bin 1
400
300
200
100
0
cm/s
Speed
196.5
197
197.5
198
198.5
199
199.5
200
270
180
90
0
Degrees
Direction
Heading
196.5
197
197.5
198
198.5
199
199.5
200
15
10
5
0
-5
-10
-15
Degrees
Pitch
Roll
196.5
197
197.5
198
198.5
199
199.5
200
Jday Year-2003


Figure 9

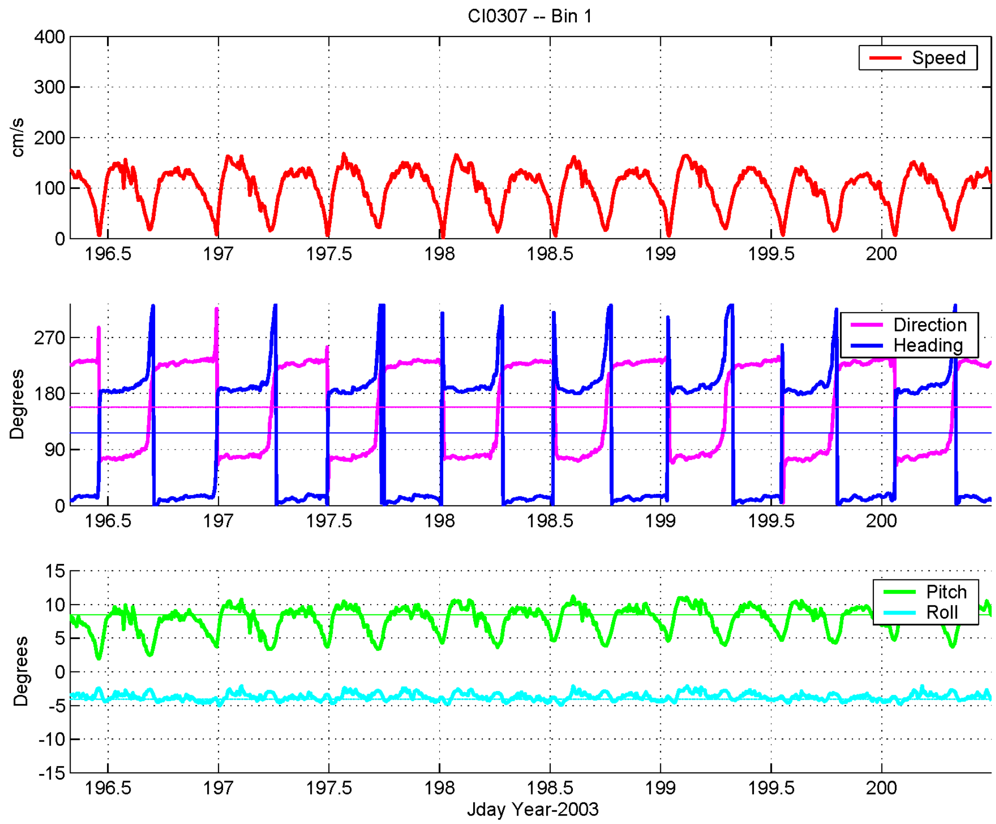
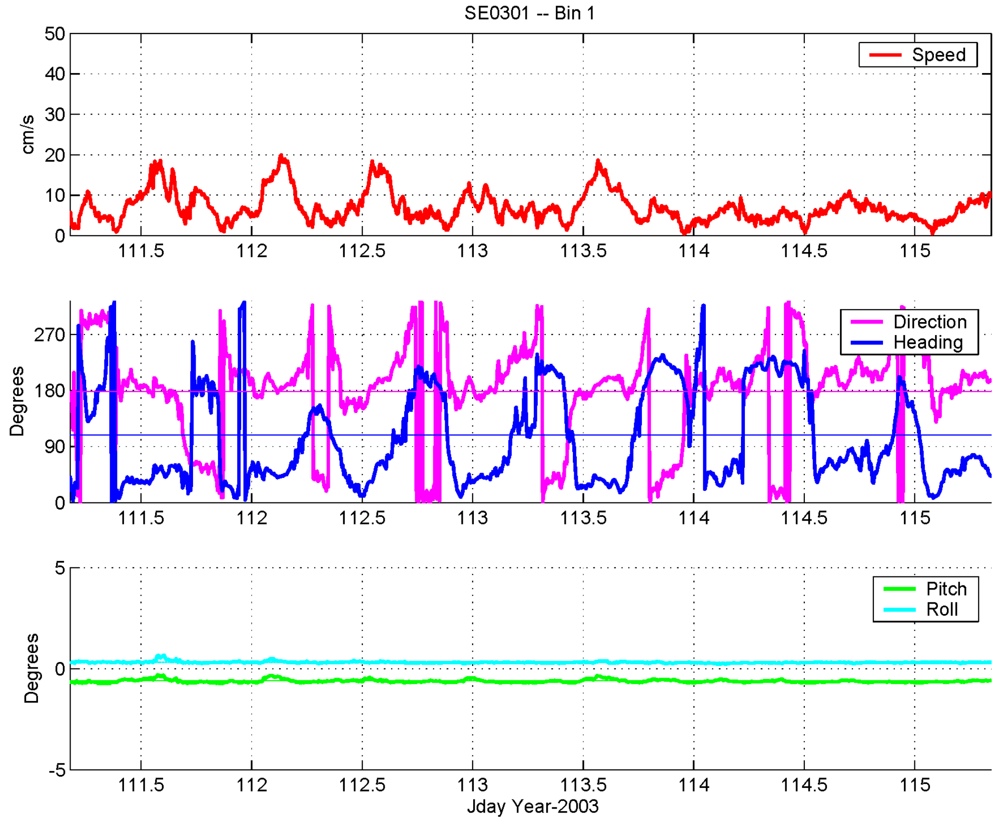

CI0307 -- Bin 1
cm/s
Speed
Degrees
Direction
Heading
Pitch
Roll
Jday Year-2003

Figure 10



SE0301 -- Bin 1
Speed
cm/s
Direction
Heading
Degrees
Pitch
Roll
Degrees
Jday Year-2003


Figure 11

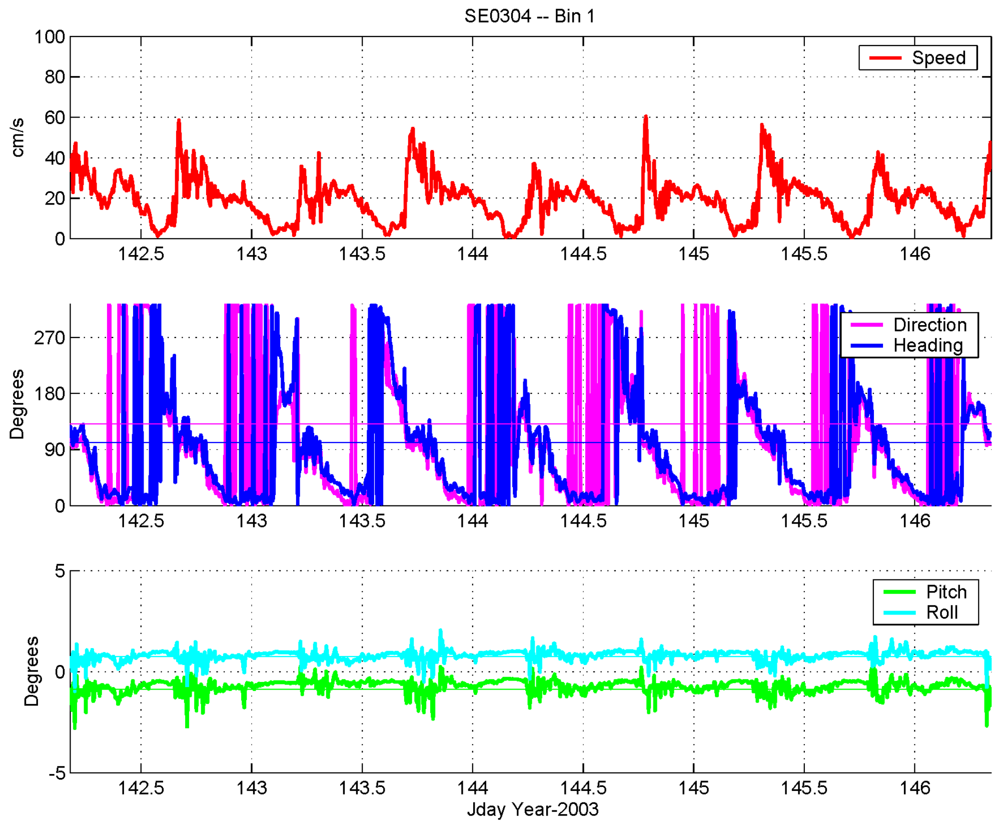
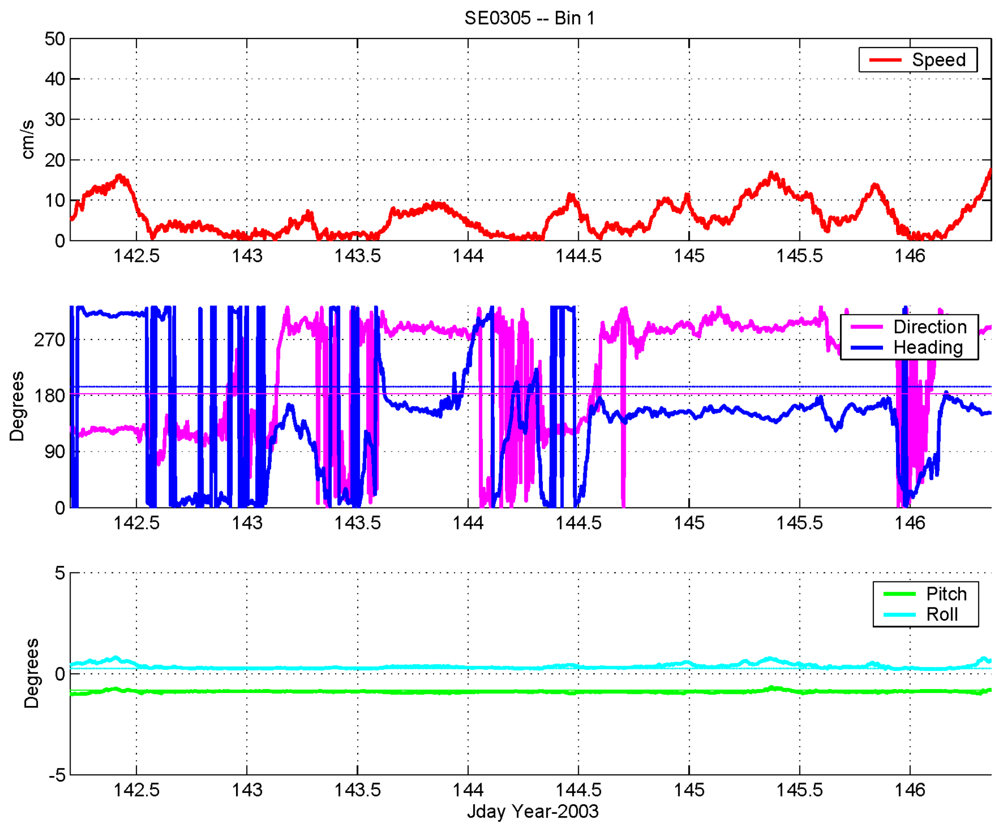

SE0304 -- Bin 1
Speed
cm/s
Direction
Heading
Degrees
Pitch
Roll
Degrees
Jday Year-2003

Figure 12


SE0305 -- Bin 1
Speed
cm/s
50
40
30
20
10
0
142.5
143
143.5
144
144.5
145
145.5
146
Direction
Heading
Degrees
270
180
90
0
Pitch
Roll
5
-5
Jday Year-2003

# Figure 13

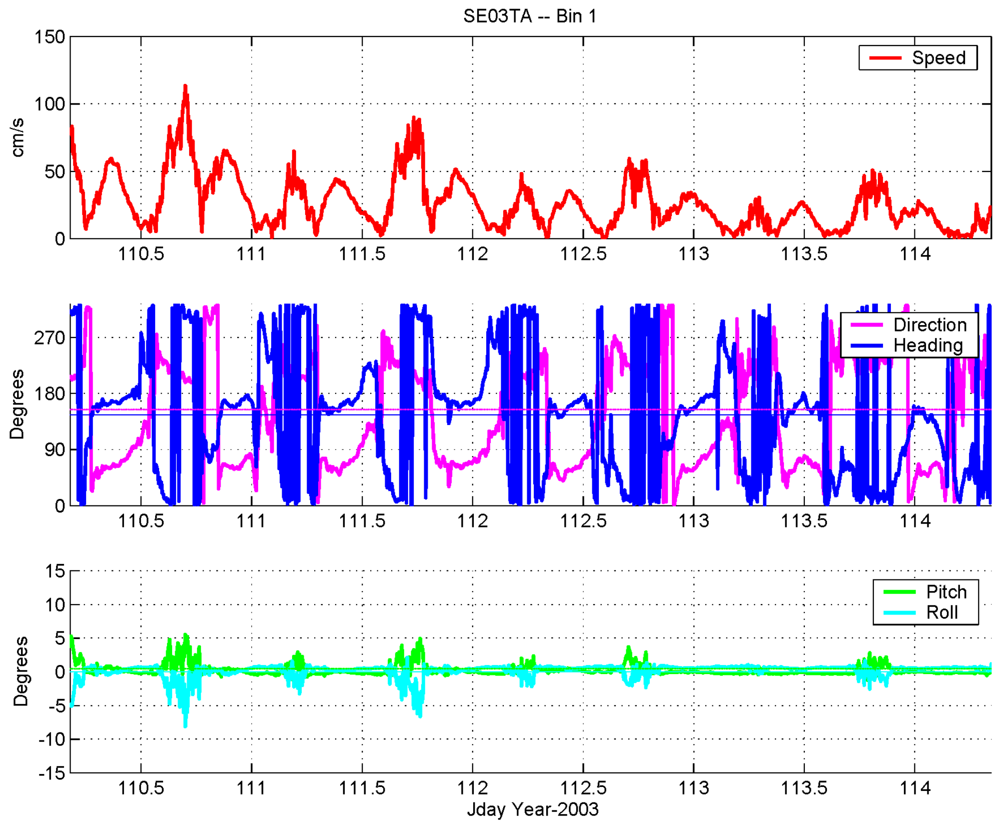

SE03TA -- Bin 1
Speed
cm/s
150
100
50
0
110.5
111
111.5
112
112.5
113
113.5
114
Direction
Heading
Degrees
270
180
90
0
Pitch
Roll
15
10
5
0
-5
-10
-15
Jday Year-2003

Figure 14

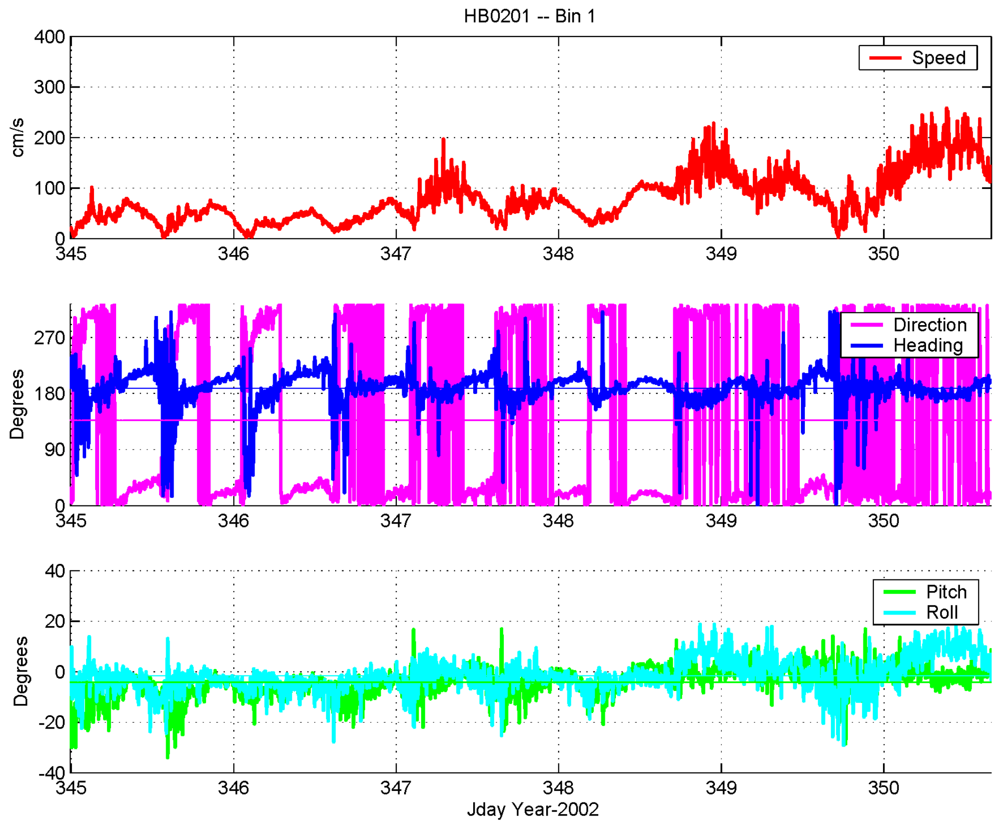

HB0201 -- Bin 1
Speed
cm/s
400
300
200
100
0
345
346
347
348
349
350
Direction
Heading
Degrees
270
180
90
0
Pitch
Roll
40
20
0
-20
-40
Jday Year-2002

Figure 15

# **Appendix E** Naval Circulating Water Channel Tilt Tests with ARGOS Module

## Summary of Test Result

1. **Purpose of the Test**
The primary purpose of the test is to determine the drag coefficients of various mooring components used in the CO-OPS subsurface ADCP mooring platforms. These data are needed for accurate computer modeling of the mooring system. In addition, the dynamic mooring conditions of these components were observed, which provide us with a better understanding of the dynamic behavior of these components.

2. **Test Facility**
Test was conducted in the Circulating Water Channel (CWC) at the Naval Surface Warfare Center, also known as the David Taylor Model Basin (DTMB), in Carderock, MD. The dimensions of the working section are 60 ft. in length, 22 ft. in width and 9 ft. in depth with a 3.3 ft. freeboard above the free water surface. The maximum velocity at the working section is 10 kts. Two 12.5 ft diameter adjustable pitch, two bladed axial flow impellers operating in parallel propel the flow. The impeller blade angle is controlled by a hydraulic servo system capable of maintaining test section water velocity within ± 0.01 kt. There are observation windows on both sides and the bottom of the working section.

3. **Instrumentation and Data Collection**
Sensors used in the test consist of a Sensotec load cell for cable tension measurements and a rotary potentiometer for cable angle measurements. The load cell has a range of 0-250 lbs. and accuracy of ± 1% FS. Accuracy of cable measurement is about ± 0.75 degree. The sensors were calibrated prior to the test and curve fitted for interpretation. The sensors and cable attachment fixture are assembled to a plate, which is designed to slide into a fixed holder at the bottom of the flow channel. **Fig. 1** shows the assembly. Velocities were measured by 3 Pitot tubes across the channel at about 1 ft above the channel bottom and the speed accuracy is about ± 0.1 knot. Video camera and still digital cameras were used for photographic recording. Computer data recording and display systems (**Fig. 2**) are available for data collection. The data set for each test run consists of cable tension, cable angle and kite angle. Both mean and time series of these data over a 1-minute steady state period were recorded.

In order to facilitate the time for configuration changes, a buoy depressor fixture was constructed (**Fig. 3**), which allows the sensor plate to slide easily into position. Average time required for configuration change was about 20 minutes.

Each configuration was tested at velocities of 0, 1, 2, 3, 4 and 5 (not for all) kt. Velocity changes were typically made within 1-4 minutes. Data were collected when speed reached steady state. Each speed run took about 3 minutes to complete.

4. **Test Configurations**
Eleven (11) mooring configurations were tested (**Table 1**). These were needed to obtain the following data:
- drag coefficient and mooring dynamics of standard A2, with and without Argos module,
- drag coefficient and mooring dynamics of modified A2, with and without Argos and additional flotation module,
- drag coefficient and mooring dynamics of B3,
- drag coefficient and mooring dynamics of dual-CART acoustic release module,
- drag coefficient and mooring dynamics of 13" vinyl float, stand alone and under tension with A2,
- drag coefficient and mooring dynamics of D2 (a larger SUBS buoy designed for deep water application).

5. **Drag Force and Drag Coefficients**
With the mooring cable in nearly straight configuration, the drag forces of each mooring component were computed from the cable tension (T) and tilt and kite angles as follows:

Drag = T x cos(tilt angle) x cos(kite angle)

Drag coefficients (Cd) were computed by:

$Cd = Drag/(0.5 \rho A_F V^2)$

Where ρ is the water density, $A_F$ is the frontal area (see Table 2 for the value used), and V is the current speed.

Drag force of dual-CART/chain release module was computed from differences of test no. 8 and test no. 6. The vinyl float oscillated sideways significantly when moored alone. To simulate real conditions, the modified A2 (without additional flotation and Argos) was attached above the float (test no. 11). The line tension nearly suppressed the oscillation. The drag and drag coefficient for both cases are shown in **Figs. 4 and 5**. Also shown in **Fig. 5** are benchmark drag coefficients for the free standing sphere. The differences between the measured and the reference are likely due to interference from mooring line/shackle, surface roughness, and level of free stream turbulence (very noticeable in the circulating channel). Variations in drag coefficients obtained by various investigators are common due to differences in measurement techniques and flow conditions. For engineering design purposes, it is believed that the values obtained from these tests are adequate.

The drag (and drag coefficient) is affected by factors such as boundary layer characteristics, location of flow separation, fluid density (lots of air bubbles appeared at high current speeds) , vortex shedding and interference from connecting hardware. These are typically characterized by the Reynolds number. **Fig. 6** shows this dependency with velocities (or Reynolds numbers).

6. **Net Buoyancy of Mooring Components**
Buoyancy (or weight) of each mooring components was computed from the vertical cable tension at zero velocity. Cable weight and drag were properly considered in both drag and buoyancy computations. Since fresh water was used in the circulating channel, the buoyancy values were adjusted to that corresponding to sea water density at 60 degrees Fahrenheit (by a ratio of 64/62.4). These values are included in **Table 2**.

5. **Observation of Mooring Dynamics**
Some noticeable mooring dynamics of the moored components were observed. These include:
- The Argos module installed at the tail fin was not aligned with the center of the buoy (**Fig. 7**) and caused kiting. Mean kite angle varied from 0 to 4 degrees (at 5 kt) and 0 to 9 degrees (at 5 kt) depending which side of the fin the clamps were installed.
- The Argos module also caused A2 (or ADCP) to pitch nose up. The pitch angle increased from 6.5 degrees at zero current speed to approximately 15-20 degrees (visual observation) at 5 kts (**Fig. 8**). This is caused by the weight of the Argos module (see next section on static trim test).
- The dual-CART/chain release module remained stable with its broad side facing the flow (**Fig. 9**). The large drag force caused the mooring cable to tilt significantly as current increased.
- The vinyl float oscillation was suppressed when A2 buoy was attached above it (**Fig. 10)**. Drag was reduced when oscillation was absent.
- The modified A2 behaved similar to the unmodified A2 in all tests (**Fig. 11**) (with and without Argos, with and without additional flotation module).

6. **Static Trim Test**
A static trim test was conducted on the unmodified A2 (with Argos) at the end of low speed tow tank. The buoy pitched nose up 6.5 degrees. A weight of 5.475 lbs. attached at 14.25" forward of the mooring point corrected this problem. Argos module weighs 2.1 lbs. in sea water and can be balanced out by inserting foams in the four (4) slots at the rear section of the buoy shell.

7. **Performance of A2 Modifications**
As described in item #5, there were no noticeable differences in dynamic mooring conditions between the modified A2 and unmodified A2 (with and without Argos). As shown in **Fig. 5**, the drag coefficients between the two are also practically the same. The additional flotation module increased the net buoyancy of A2 by 78%.

8. **Recommendations**

(a) On computer simulation – The drag coefficients (Cd) were derived based on the front area values shown in Table 2. Variation of Cd with current speed should be considered. For the dual-CART/chain module, Cd varies with both current speed (**Fig. 5**) and tilt angle (**Fig. 6**). An iteration procedure may be needed to converge the tilt angles.

(b) On A2 modifications – Both the quick ADCP installation fixture and the added buoyancy module showed no adverse effects in the mooring dynamics.

(c) Other future modifications – The static trim unbalance caused by the Argos weight can be easily corrected by inserting forms into the existing empty slots of the shell near the tail section. The correction will reduce the ADCP tilt, especially at high current speeds. Miniature Argos antenna/transmitter with auto switch (by pressure or light) could also be considered in the future. The large drag associated with the dual-CART broadside orientation with respect to the flow can be corrected by installing a plastic airfoil shield similar to those used to reduce cable strumming.

Table 1 Test configurations

| Test No. | Mooring Components | Mooring Line | Notes |
|---|---|---|---|
| 1 | 13" vinyl float | mooring line: 1/8" dia. x 45" L, 7x19 strand cable, swivel near load cell | |
| 2 | modified A2 (ADCP installation fixture and additional flotation module) | ditto | |
| 3 | un-modified A2 | ditto | *flooded ADCP |
| 4 | modified A2 (with Argos module) | ditto | |
| 5 | B3 | ditto | |
| 6 | unmodified A2 | ditto | good ADCP |
| 7 | unmodified A2 (with Argos module) | ditto | good ADCP |
| 8 | unmodified A2 and dual-CART/chain link release module | 12" L cable between A2 and CART, addition swivel above CART | good ADCP |
| 9 | D2 | same as Test No. 1 | *flooded ADCP |
| 10 | modified A2 (additional flotation module removed, with Argos module) | ditto | good ADCP |
| 11 | modified A2 (without additional flotation and Argos) and 13" float | 24" cables above and below the float | |

* A damaged ADCP and a good ADCP were used to facilitate the test.

Table 2 Physical data of mooring components

| Component | Dimension (inch) | Diameter (or equivalent, inch) | Front Area (sq. ft) | Buoyancy or weight (-) in sea water (lbs.) | Drag coefficient |
|---|---|---|---|---|---|
| unmodified A2 (with ADCP and Argos) | 66.5"L x 21.5" W x 26.4" H (overall) | 16.552 | 1.494 | 65.2 | see Fig. x |
| modified A2 (with ADCP, additional flotation module and Argos) | ditto | 16.552 | 1.494 | 116.1 | ditto |
| Argos module | 26"L x 1.5" dia. (antenna housing) x 23.75"L x 3.5" dia. (transmitter housing) | NA | NA | -2.1 | ditto |
| dual-CART & chain link module | 43"L x 9.25" W x 5.5" D (overall) | NA | 1.5 (9" x 24" equivalent broad side area) | -25 | ditto |
| Float | 13" sphere | 13.56 | 1.0 | 36.9 | ditto |

Fig. 1 Load cell assembly

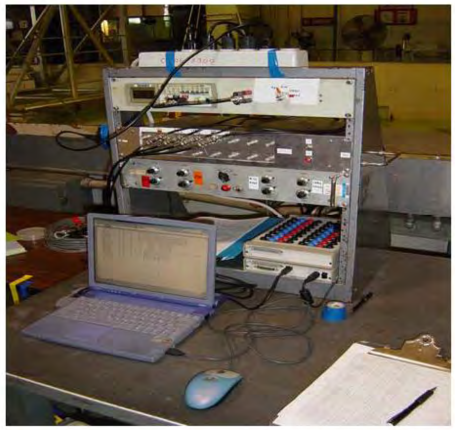


Fig. 2 Data collection system

Fig. 3 Buoy depressor

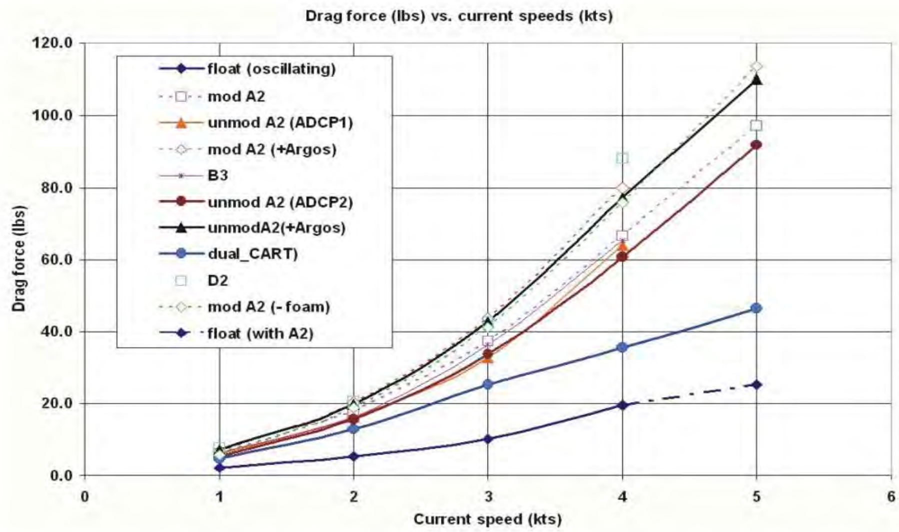



Fig. 4 Drag forces of various mooring components (thick lines with solid symbols are for those currently being used in the surface mooring)

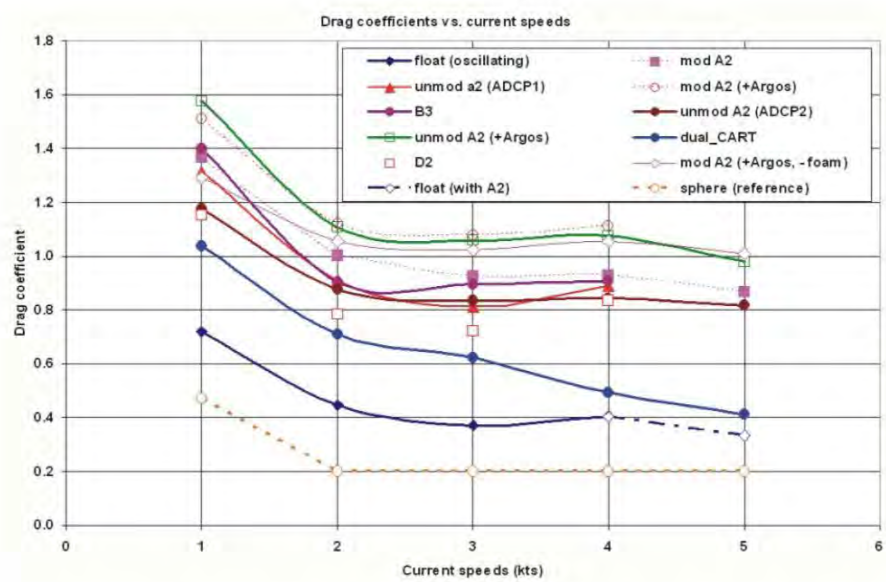



Fig. 5 Drag coefficients of various mooring components (thick lines with solid symbols are for those currently being used in the subsurface mooring

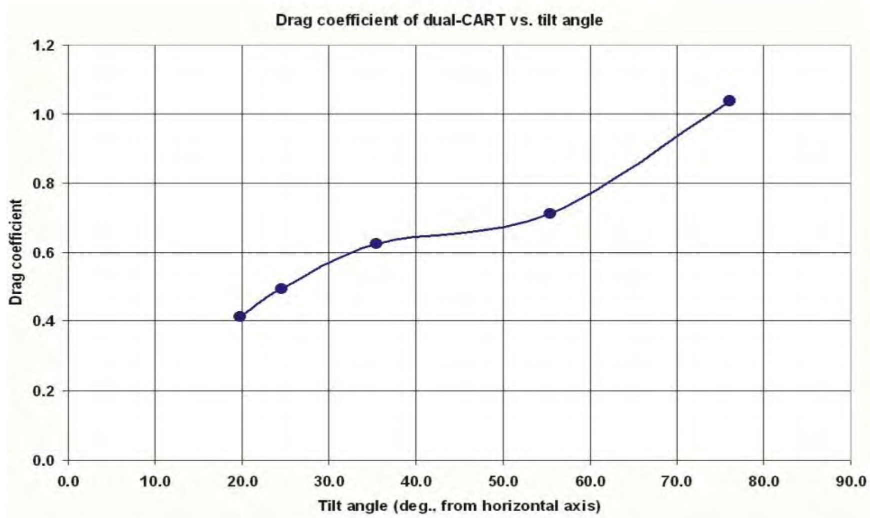



Fig. 6 Drag coefficient of dual-CART/chain module as function of tilt angle

Fig. 7 Argos module attachment (notice its slightly off centered position)

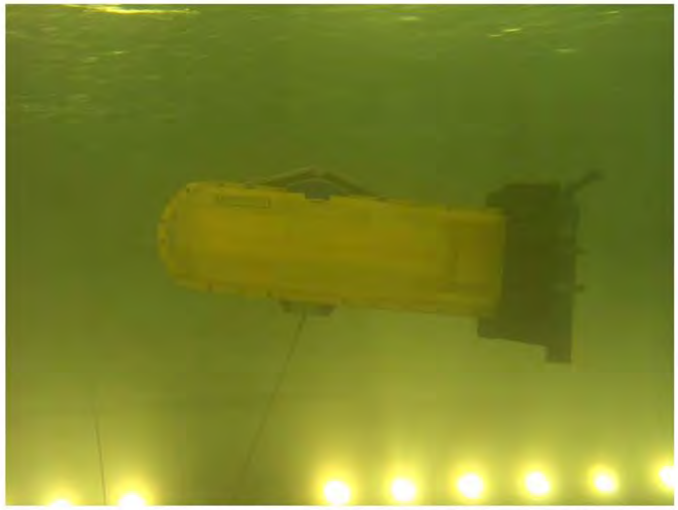


Fig. 8 Unmodified A2 with Argos (notice its pitching up condition)

Fig. 9 A2 and dual-CART/chain module (notice its broadside facing the flow)

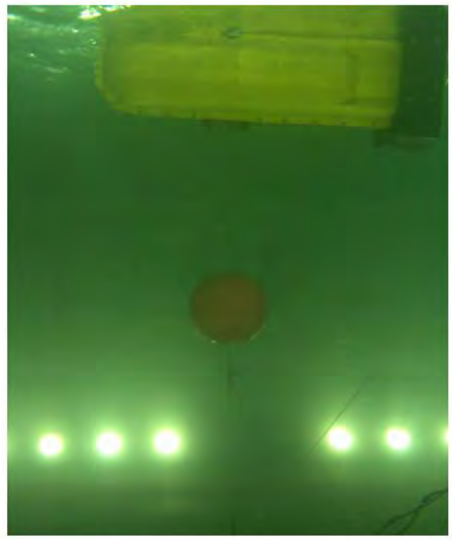


Fig. 10  A2 and Float (The float did not oscillate in this case)

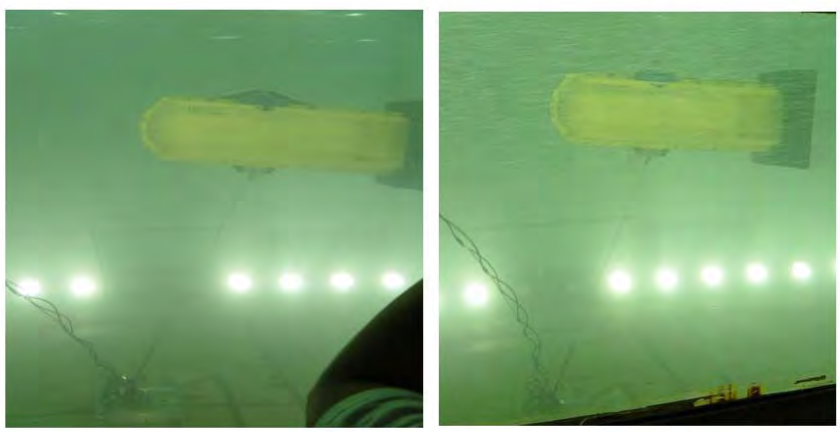


Fig. 11 Flight conditions of unmodified A2 (left) and modified A2 (right)

# **Appendix F** Coastal Current Measurement Using an ADCP in a Streamlined Subsurface Mooring Buoy

# Coastal Current Measurements Using an ADCP In a Streamlined Sub-surface Mooring Buoy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***Abstract* - A field test of a streamlined sub-surface mooring buoy, containing an acoustic Doppler current profiler, was performed in the winter of 2001/2002 at the entrance to Delaware Bay. Time series of pressure, tilts, and heading were analyzed to track the behavior of the mooring in the tidal current. Current measurements collected in a standard bottom-mounted platform served as a reference in assessing the quality of data collected in the mooring buoy. Tidal analyses were performed on both data sets. A comparison of several analysis products, including tidal constituents, tidal current predictions, and Greenwich intervals suggests no significant data degradation due to the sub-surface mooring dynamics. In light of the positive results from this test, NOAA's Ocean Service will begin to routinely use streamlined sub-surface moorings, when appropriate, for tidal current surveys.**


## I. INTRODUCTION

The Center for Operational Oceanographic Products and Services (CO-OPS) of NOAA's Ocean Service (NOS) manages a Current Observation Program (Earwaker, 1999) with a main objective of improving the quality and accuracy of the annually published Tidal Current Tables (NOS, 2001). The dissemination of tide and tidal current predictions is a critical part of NOS' efforts toward promoting safe navigation in our Nation's waterways.

To assure that the tidal current predictions are reliable, new observational data must be collected periodically, requiring a variety of current meter platforms suitable for different environments. CO-OPS strives to use off-the-shelf technologies, when possible, to help reduce costs and improve efficiency of field operations. During the past decade, CO-OPS has primarily used low-profile bottom-mounted platforms for housing acoustic Doppler current profilers (ADCP). Bottom-mounted platforms have proven to work well on condensed bottom sediments, in relatively shallow water depths. One alternative platform, allowing deployment in deeper water, is a sub-surface mooring buoy. This type of system can simplify field operations and be deployed on a variety of bottom types.

The primary goal of this project was to assess the quality of sub-surface buoy current measurements, and specifically the predictions derived from them, by comparing them to current data collected from a stable, bottom-mounted platform. A secondary objective was to describe the motion of the sub-surface buoy from analysis of pressure, tilts, and heading to determine how well the mooring buoy performs in higher flows.

## II. MEASUREMENTS AND INSTRUMENTATION

Field tests of a streamlined, sub-surface buoy system were performed by NOS in 2000 and 2001. A mooring site in the mouth of the Delaware Bay was selected (Fig. 1) for various reasons: fairly strong currents (> 100 cm/s), relatively deep water (45 m), and readily available vessel support. Currents at the entrance to the Delaware Bay are tidally dominated; they are rectilinear in that the water flows alternately in approximately opposite directions, with a minimum current (slack water) at each reversal of direction. The currents are semidiurnal, consisting of two flood and two ebb periods each day.

In July 2000, two current profilers were deployed within 100 m of each other, one in a streamlined sub-surface buoy and another in a standard bottom-mounted platform. One month later, both systems were recovered. Unfortunately the current meter in the sub-surface mooring buoy flooded almost immediately upon deployment, and yielded no usable data. However, the bottom-mounted current meter successfully collected 34 days of data, and these data are used as the reference measurement throughout the paper.

A second attempt to collect data with the mooring was made at the same site in December 2001. This time, a bottom-mounted platform was not co-deployed because of logistical constraints. The sub-surface mooring was recovered, the current meter having collected more than 33 days of good data.


Fig. 1. Location of the sub-surface mooring at the entrance to the Delaware Bay, in 45 m water depth.

*A. Current Meter*

An RD Instruments, Inc. (RDI) Workhorse Sentinel, WH-300, was used in both platforms. The instrument transmits a sound pulse along 4 narrow beams; the acoustic signal reflects off of scatterers in the water (i.e., plankton and particulates) and back to the ADCP. It then computes current velocities throughout the water column by measuring the Doppler shift of the sound transmissions. The most important feature of the ADCP is its ability to measure current profiles, which are divided into uniform segments called depth cells or "bins" (RDI, 1996).

*B. Sub-surface Mooring Buoy*

An "A2-SUBS" sub-surface streamlined buoy, manufactured by Open Seas Instrumentation, Inc. contained an RDI WH-300. This torpedo-shaped buoy (SUBS) was developed and field-tested at the Bedford Institute of Oceanography (Hamilton, 1997). It is relatively lightweight (just under 40 kg with ADCP), and is considerably easier to handle than the 350 kg bottom-mounted platforms typically used for CO-OPS' Current Observation Program. Using the streamlined SUBS buoy in place of a spherical buoy effectively reduces drag and greatly reduces mooring vibration induced by vortex shedding (Hamilton, 1989).

A simple mooring design was used for this test. The SUBS was attached to a 12.7 m length of ¼" wire rope; three Viny floats (0.35 m diameter), each having a buoyancy of 21 kg, were clamped onto the mooring near the bottom of this wire. Situated immediately below the floats was an Edgetech model 8242 acoustic release (28 kg weight in water), attached below to a 4.5 m length of ⅝" chain, which in turn was shackled to a 900 kg concrete anchor. The overall mooring length was approximately 19.8 m (Fig. 2).

The upward-looking ADCP in the SUBS buoy was programmed to continuously sample at 1.5 s intervals, and average every 90 s, with 2.0 m cells. Prior to deployment, it was estimated that the internal battery pack would allow collection of more than 30 days of profile data.

*C. Bottom-Mounted Platform*

A trawl-resistant platform (model "AL-200") manufactured by Flotation Technologies, Inc. was used in the test. NOS has primarily used this type of bottom-mounted (BTM) platform since 1997 for its Current Observation Program. The 300 kHz RDI ADCP in this platform was programmed to continuously sample at 1.2 s intervals and average every 180 s, with 2.0 m cells.

## III. ANALYSIS AND RESULTS

*A. SUBS Buoy Dynamics*

The dynamics of the SUBS were determined from the ADCP's pressure sensor, tilt sensors, and compass. The buoy tilts fluctuated regularly with the reversing tidal current; the pitch ranged from 0 to -6 degrees, and the roll ranged from –3 to –6 degrees. While the roll of the SUBS improved with increased current speeds, the pitch of the SUBS became larger at higher speeds. However, these tilts are internally corrected by the ADCP, and are well within acceptable limits.

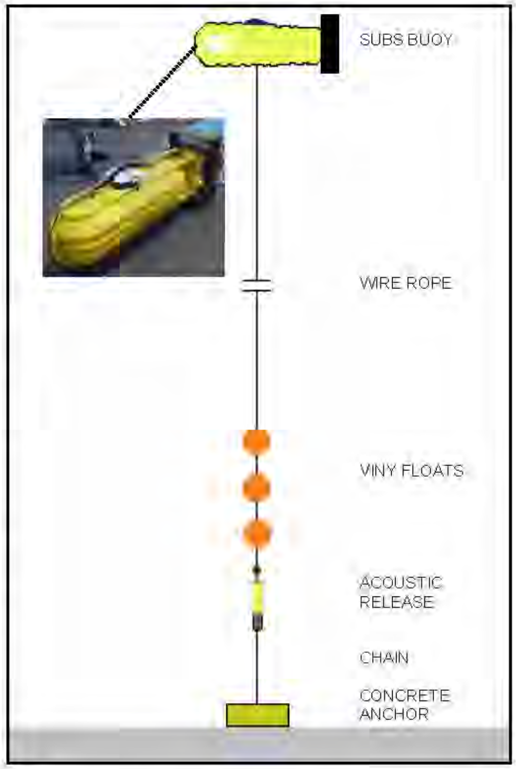


Fig. 2. Schematic of the subsurface buoy system as deployed for this project. Note that the image is not to scale.

The current applies a force along the entire mooring length, causing the mooring to incline, and lowering the SUBS down in the water column. This vertical displacement is an important factor when analyzing and interpreting the profile data. If the SUBS is regularly displaced beyond the cell size, the mapping of the cell depths becomes overly complicated.

The vertical displacement was isolated from the ADCP's pressure sensor measurements by removing the tidal signal observed at a nearby NOS tide gauge in Lewes, DE. Assuming a small time-lag between the two locations, and referencing both measurements to the same datum (MLLW), the water levels at Lewes were subtracted from the pressure sensor measurements, to arrive at a value referred to as ΔH, which is illustrated in Fig. 3.

The ΔH values represent the distance from the pressure sensor to the water surface (minus the tide), and approximate the vertical movement of the buoy. Fig. 3 shows ΔH over the entire deployment period; there is a regular pattern of spikes as well as a distinct shift that occurred about 9 days into the deployment period. One possible explanation of this vertical shift could be an accumulation of sediment within the cavities of the SUBS; a significant volume of mud was found oozing out

Table 1 lists six main tidal current constituents along the principal current axis. The six listed tidal constituents comprised more than 93% of the total current. The differences seen in the amplitudes and phases of the two data sets are likely due to a changing density (i.e., salinity and temperature) structure of the Bay, or other seasonal changes in water conditions and flow, over the course of the year. The reference BTM observations were collected in the summer, while the SUBS observations were collected in the winter. Also, the slight difference in the geographical positions of the two measurements could explain some of the tidal constituent differences.

Tidal current predictions for the 33 days of the SUBS measurement period were generated from each set of 24 constituents (SUBS and BTM). The two predicted time series were compared to the SUBS observations. Fig. 6 illustrates good agreement between all three series over a representative period of time.

Tidal current predictions for the 34 days during the BTM deployment in July/August 2000 were also generated from SUBS tidal constants. SUBS-derived tidal current predictions seem to slightly underestimate the current near maximum flood (Fig. 7). However, the overall RMS of the residual current (BTM observed – SUBS predicted) is 15.3 cm/s, which is within the typical range of values seen for flows of this magnitude.

Another means of verifying the quality of the SUBS predictions was to compare them with the standard BTM predictions. A time series comparison (Fig. 6) provides a look at these two sets of predictions over a short time period, but a more meaningful comparison over several depths, and a broader time scale requires a different approach. Six-minute SUBS and BTM predictions were computed for an entire year (2001) at several depths; Figs. 8 and 9 show the results of analyses on these new sets of predictions for 2001. The nearly exact match between Greenwich intervals (usually within 10 minutes) for both sets of predictions at all four stages lends confidence to the timing of the predictions (Fig. 8). However, large discrepancies appear in the comparison of mean current speeds (Fig. 9).

TABLE 1.
PRINCIPAL TIDAL CURRENT CONSTITUENTS: AMPLITUDES (ALONG-CHANNEL) AND PHASES OF SIX OF THE LARGEST COMPONENTS.

| Tidal Constituent | Amplitude (cm/s) | | Phase (Local Epoch) | |
|---|---|---|---|---|
| | SUBS | BTM | SUBS | BTM |
| $M_2$ | 67.3 | 75.8 | 205.6 | 205.6 |
| $N_2$ | 13.6 | 15.3 | 186.3 | 181.4 |
| $S_2$ | 13.1 | 10.1 | 213.5 | 225.5 |
| $K_1$ | 6.0 | 9.2 | 70.8 | 51.5 |
| $O_1$ | 5.2 | 5.4 | 49.6 | 68.1 |
| $M_4$ | 1.3 | 3.9 | 334.7 | 357.5 |

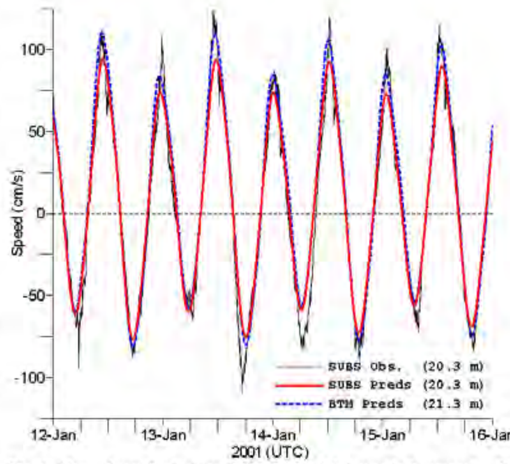


Fig. 6. Along-channel velocities during a typical 4-day period, comparing the SUBS & BTM predictions with the SUBS observations.

## IV. DISCUSSION

The SUBS buoy has demonstrated its ability to provide satisfactory data for tidal current prediction applications. A spectral analysis of mooring motion parameters (pitch, roll and pressure) confirms that there were no significant high frequency mooring vibrations. The fairly large vertical displacement of the SUBS in higher current flows, although not appearing to degrade the data quality, requires further investigation.

A possible design improvement for upcoming sub-surface mooring deployments of this type is the replacement of the three vertically-aligned Viny floats with one or two SUBS flotation units, which have a buoyancy of 52 kg. This should minimize

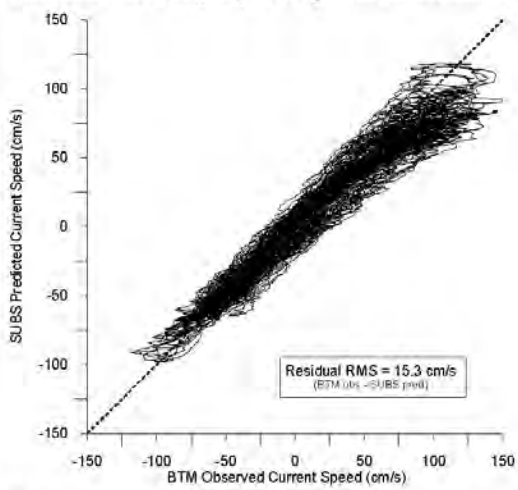


Fig. 7. Scatter plot of the SUBS-derived tidal current at 20.3 m vs. the BTM observed current at 21.3 m.

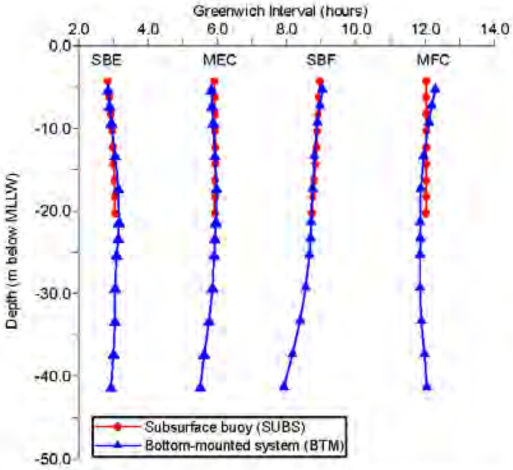


Fig. 8 Vertical profiles of Greewich intervals from the SUBS-predicted and BTM-predicted tidal currents, using the entire year, 2001. *SBE* = slack before ebb; *MEC* = maximum ebb current *SBF* = slack before flood; *MFC* = maximum flood current.

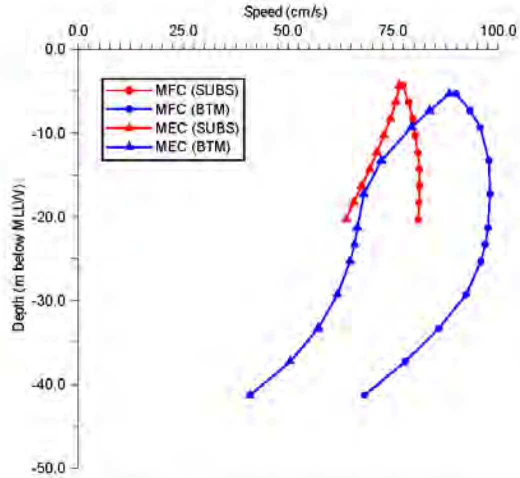


Fig. 9. Vertical profiles of the mean maximum current speeds from 2001 SUBS-predicted and BTM-predicted tidal currents. *MFC* =maximum flood current; *MEC* = maximum ebb current.

the drag on the mooring, as well as reduce the vertical displacement of the buoy. Another approach to reducing SUBS vertical displacement is to shorten the mooring line to take advantage of lower boundary layer currents near the bottom (Fig. 9).

The SUBS mooring was exposed to maximum current speeds of approximately 120 cm/s. At speeds of this magnitude, the mooring angle was steep and vertical displacement approached 2.0 m. Many areas have significantly stronger currents than those observed at the mouth of the Delaware Bay, and hence the sub-surface buoy may not be a suitable platform for these locations.

## V. CONCLUSIONS

A field test of a sub-surface streamlined buoy system was successfully completed in coastal waters that are typical of NOS operational locations. The comparison of tidal current analyses including tidal constituents, tidal current predictions, and Greenwich intervals show no significant data degradation due to sub-surface mooring dynamics. In these conditions, the SUBS mooring buoy system proved to be a good alternative to the standard bottom-mounted platform. Test results indicate that the SUBS mooring is potentially a very useful tool for CO-OPS' Current Observation Program.

## ACKNOWLEDGMENTS

The authors and NOS would like to express their gratitude to the US Coast Guard Aids to Navigation Team, Cape May, New Jersey for providing excellent support in the deployment and recovery of our equipment in the winter 2000/2001. The crews on their buoy tender and SAR vessel were extremely helpful and showed a high level of professionalism and patience. Also, the NOAA SHIP WHITING diligently provided vessel support for the deployment and recovery of equipment in the summer 2000.

Warren Krug of NOS was a key participant in all of the field work. His consistent dedication and high quality of work was one of the most important factors contributing to the success of the project.

The authors would also like to thank Scott Duncan of NOS for assisting in some of the data interpretation. Chris Zervas, Stephen Gill, and William Stoney of NOS reviewed the paper, and provided important input for the final version.

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# **Appendix G** Coastal Acoustic Release Dry Transponder Test Results

## Coastal Acoustic Release Transponder Dry Test Results

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**Contributors: Eddie Shih, Jim Sprenke, Warren Krug, Charles Payton, Carl Kammerer, Mike Newton**
November 17, 2003

I. Statement of Problem

The National Current Observation Program deployed at total of twelve stations using Streamlined Underwater Buoyancy Systems (SUBS) moorings with Acoustic Doppler Current Profilers (ADCP) during the 2003 field season in Southeast Alaska (SEAK) and Cook Inlet Alaska (CIAK). Ten of the twelve systems failed to surface when the acoustic release signal was sent to the units. Each system had two Coastal Acoustic Release Transponder (CART) releases manufactured by ORE Offshore (formerly Edgetech) attached in tandem to a mooring line that were the key to retrieving the SUBS with ADCP. The following list shows the stations and times for the systems to reach the surface:

In SEAK - AK0301 (OK), AK0304 (**77.5 hours**), AK0305 (OK), AK03TA (**3 hours**)
In CIAK - CI0301 (**5 hour**), CI0302 (dragged recovery), CI0303 (**36 hours**), CI0304 (**7 hours**), CI0305 (dragged recovery), CI0306 (dragged recovery), CI0307 (dragged recovery), CI0308 (released on own, not recovered)

The purpose of this testing will be to determine the most likely failure mode and develop a solution to be used with future deployments.

II. Possible Cause of Problem and Solution

Environmental conditions that may cause failure of the releases could include bio-fouling, sediments or other debris accumulating in the release mechanism or inhibiting the release pin to disengage from the release shaft. Mechanical problems could include a failure of the release shaft to turn to the released position and lack of sufficient buoyancy force to release the pin from the shaft (Figure 1). Other problems could include the release chain or mooring line getting twisted or entangled.

In SEAK there was no obvious sediment or bio-fouling problems, possible entanglement of the chain may have occurred and the release shaft appears to have turned properly.

In CIAK sediments within the water column were substantial, total accumulation of sediments inside the SUBS are unknown, but significant thus reducing buoyancy. Woody debris was found on chain, but did not appear to inhibit the release mechanism. No bio-fouling was apparent and the release shaft appears to have turned properly.

A total of eight dual CART systems were recovered with no apparent mechanical failure of the release shaft or accumulation of sediments or bio-fouling in the release mechanism. The failure appears to be the release pin getting hung up in the shaft without enough force to move the pin and release the unit.

The amount of buoyancy necessary to immediately release the unit is still undetermined. ORE has a re-designed release pin to be used with lower buoyancy units. Increasing the buoyancy and using the redesigned pin may be one solution.

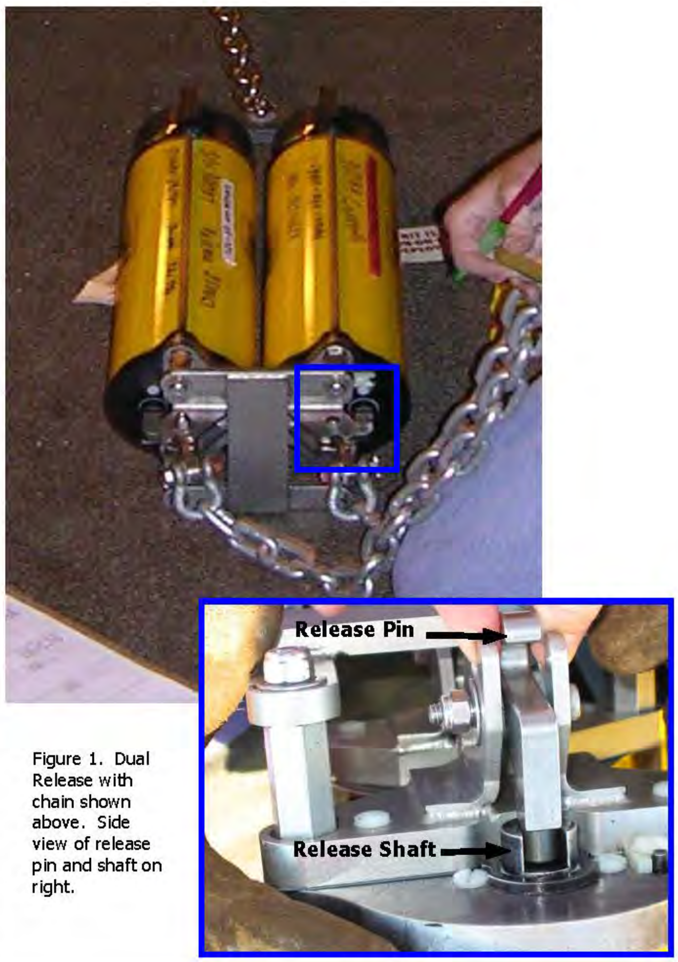



Figure 1. Dual Release with chain shown above. Side view of release pin and shaft on right.

## III. Testing Method

On November 7, 2003 the following tests were conducted at the Field Operations Division in Chesapeake Virginia. The tests were performed by Jennifer Ewald, Charles Payton, Carl Kammerer, Mike Newton and Warren Krug. Table 1 describes the releases used. The duel 1 system had been previously deployed in CIAK (CI0306) and S/N 29062 was part of another duel system deployed in SEAK (AK0305), one of the stations that did not fail. The first set of tests with duel 1 were done with the original release pins to duplicate failure mode. A second set was then done with the redesigned pins. The duel 2 system was deployed in CIAK (CI0307) and tested with the redesigned pins. A single release was then tested with the original and redesigned pins, it was not deployed due to a release shaft failure which had been replaced before the test.

| CART S/N | System | Previously Deployed | Replaced shaft |
|---|---|---|---|
| 30083 | Duel 1 | Yes | No |
| 29062 | Duel 1 | Yes | No |
| 30084 | Duel 2 | Yes | No |
| 30087 | Duel 2 | Yes | No |
| 30089 | Single | No | Yes |

Table 1. List of CART releases used in the testing.

All tests were done in air. Due to the nature of the acoustic signal in air, all valid trails were defined by an acoustic response from each release. 15 pings in one second intervals were heard when the release responded in the 'released' position, 15 two second pings were heard when in the 'not release' position.

Figure 2 shows the testing system. A fork lift was used to hold up the test unit with a railroad wheel anchor below. A come along was used to produce the force which was measured with a scale. The release signal was sent with a Benthos DS-8000 deck unit. The first test was done with the release chain as the only weight, 50 pounds of force was then added until the release responded correctly. When a unit released properly either a 'twist' in the chain or tilt to the unit were applied to investigate the influence of each (Figure 2).

## IV. Test Results

The duel 1 system failed to properly release for all trials (1-18) with the 'old' or original release pins (Table 2). The release shaft did not rotate properly for any of the trails over rotating between 1˚- 5˚ (Figure 3). On some occasions the release shaft would rotate 360˚ returning to the previous position. The 15 ping response did agree with the position in which it stopped rotating. Figure 4 shows the test system with the railroad wheel lifted applying the maximum test force approximately equal to 800 lbs.

For trials 33-42 the 'new' release pins replaced the 'old' in each release. The results were positive for each trial with the 'new' pins dropping for each scenario including an added twist in the chain and 25˚ tilt on the unit (Table 2).

| Trial # | CART S/N | Force (Lbs) | Pin Mode | Pin Released | Rotation Good | Chain Twist 90˚ | Tilt |
|---|---|---|---|---|---|---|---|
| 1 | 30084 | chain only | Old | No | No | No | No |
| 2 | 30087 | chain only | Old | No | No | No | No |
| 3 | 30084 | 50 | Old | No | No | No | No |
| 4 | 30087 | 50 | Old | No | No | No | No |
| 5 | 30084 | 100 | Old | No | No | No | No |
| 6 | 30087 | 100 | Old | No | No | No | No |
| 7 | 30084 | 150 | Old | No | No | No | No |
| 8 | 30087 | 150 | Old | No | No | No | No |
| 9 | 30084 | 200 | Old | No | No | No | No |
| 10 | 30087 | 200 | Old | No | No | No | No |
| 11 | 30084 | 250 | Old | No | No | No | No |
| 12 | 30087 | 250 | Old | No | No | No | No |
| 13 | 30084 | 300 | Old | No | No | No | No |
| 14 | 30087 | 300 | Old | No | No | No | No |
| 15 | 30084 | 400 | Old | No | No | No | No |
| 16 | 30087 | 400 | Old | No | No | No | No |
| 17 | 30084 | 800 | Old | No | No | No | No |
| 18 | 30087 | 800 | Old | No | No | No | No |
| Same releases new pins | | | | | | | |
| 33 | 30084 | chain only | New | Yes | No | No | No |
| 34 | 30087 | chain only | New | Yes | No | No | No |
| 35 | 30087 | 50 | New | Yes | No | No | No |
| 36 | 30084 | 50 | New | Yes | No | No | No |
| 37 | 30087 | 200 | New | Yes | No | No | No |
| 38 | 30084 | 200 | New | Yes | No | No | No |
| 39 | 30087 | 200 | New | Yes | No | Yes | No |
| 40 | 30084 | 200 | New | Yes | No | Yes | No |
| 41 | 30087 | 200 | New | Yes | No | No | 25˚ |
| 42 | 30084 | 200 | New | Yes | No | No | 25˚ |

Table 2. Results for the duel 1 system.

The duel 2 system was tested with the 'new' redesigned pins. Both of these release shafts over rotated as did the duel 1 system (Table 3). The amount of rotation was again between 1˚- 5˚. The 'new' pins did release from the shafts for each of the trials except for one (Table 3). The failure occurred on a 250 lb force load with a 25˚ tilt for only one of the releases (S/N 29062). The shaft did over rotate to approximately 3 - 5˚.

| Trial # | CART S/N | Force (Lbs) | Pin Mode | Pin Released | Rotation Good | Chain Twist 90° | Tilt |
|---|---|---|---|---|---|---|---|
| 19 | 30083 | chain only | New | Yes | No | No | No |
| 20 | 29062 | chain only | New | Yes | No | No | No |
| 21 | 30083 | 100 | New | Yes | No | No | No |
| 22 | 29062 | 100 | New | Yes | No | No | No |
| 23 | 30083 | 200 | New | Yes | No | Yes | No |
| 24 | 29062 | 200 | New | Yes | No | Yes | No |
| 25 | 29062 | 150 | New | Yes | No | No | 5° |
| 26 | 29062 | 150 | New | Yes | No | No | 20° |
| 27 | 29062 | 250 | New | No | No | No | 25° |
| 28 | 30083 | 150 | New | Yes | No | No | 5° |
| 29 | 30083 | 150 | New | Yes | No | No | 20° |
| 30 | 30083 | 250 | New | Yes | No | No | 25° |
| 31 | 29062 | 150 | New | Yes | No | No | 25° |
| 32 | 30083 | 150 | New | Yes | No | No | 25° |

Table 3. Results for the duel 2 system.

Testing results on the single release S/N 30089 are given in Table 4. The rotation of the release shaft was good for each trial (43-52). The 'old' style pin again failed for all trials (43-49), while the 'new' style pin released properly for all trials (48-50). A chain twist and tilt were not introduced since the unit was not in the duel system.

| Trial # | CART S/N | Force (Lbs) | Pin Mode | Pin Released | Rotation Good | Chain Twist 90° | Tilt |
|---|---|---|---|---|---|---|---|
| 43 | 30089 | chain only | Old | No | Yes | No | No |
| 44 | 30089 | 50 | Old | No | Yes | No | No |
| 45 | 30089 | 200 | Old | No | Yes | No | No |
| 46 | 30089 | 300 | Old | No | Yes | No | No |
| 47 | 30089 | 345 | Old | No | Yes | No | No |
| 48 | 30089 | 400 | Old | No | Yes | No | No |
| 49 | 30089 | 800 | Old | No | Yes | No | No |
| 50 | 30089 | chain only | New | Yes | Yes | No | No |
| 51 | 30089 | 50 | New | Yes | Yes | No | No |
| 52 | 30089 | 200 | New | Yes | Yes | No | No |

Table 4. Results for the single release 30089.

## V. Summary

The 'old' style release pins failed to fully release from the shaft and drop the chain for each trial up to 800 lbs of force. The results were greatly improved by replacing the 'old' style pin with a 'new' pin. Though only slightly different the 'new' pin released properly dropping the chain for all trials but one. A 25° tilt was on the unit when the failure occurred.

There was a problem in the release shaft for each release tested in the duel systems. This was an over rotation which may cause the release pin to be held up in the shaft. The rotation problem was discovered in four of the sixteen releases purchased for the CIAK work. One of those four (S/N30089) was tested with a replaced release shaft mechanism. The rotation was accurate for this release, but it had not been deployed. The releases used in the duel 1 & 2 system had previously tested ok before their deployments.

VI. Cost Related to Release Failures

Search and recovery of the eight units in CIAK included five NOAA personnel for a ten day period. Assistance was provided by the US Coast Guard and Civil Air Patrol during this time and for weeks after NOAA left. Due to the failures a second deployment was terminated. Another survey year will need to be added to cover the eight stations that were to be deployed in August of 2003.

| | |
|---|---|
| Seven days on Cook Inlet Tug and Barge vessels: | $22,000.00 |
| Three days of flight time: | $ 795.00 |
| Fabrication of drag: | $ 195.00 |
| NOAA testing | $ 2,000.00 |

A. Testing system.

B. Angle on release chain.

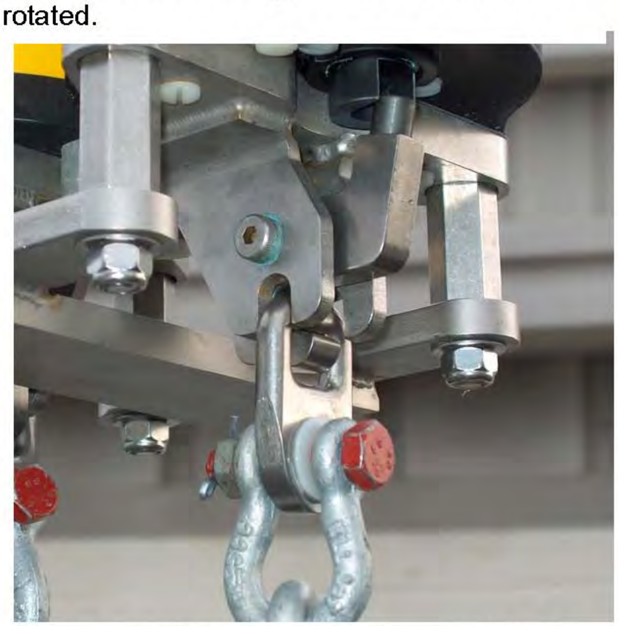
C. Shackle on chain to simulate a twist in the chain.

Figure 2. Photos of testing system.

7

A. CART S/N 30084 @ 200 lbs. Shaft is over rotated.

B. CART S/N 30084 @ 400 lbs.



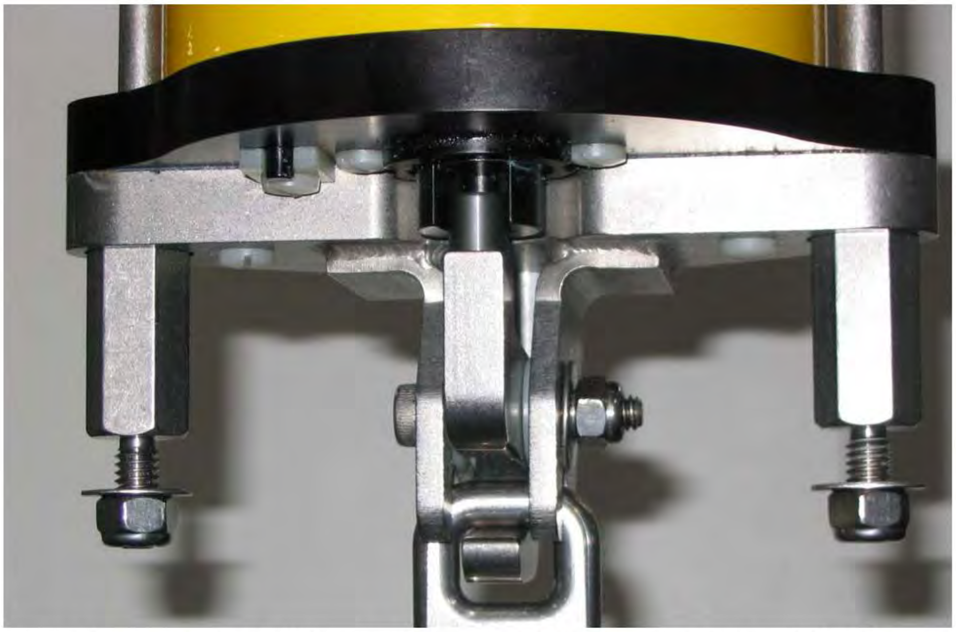
C. CART S/N 30084 @ 400 lbs. Pin is half out of shaft and unreleased.

D. CART S/N 30084 @ 800 lbs. Pin is out of shaft but unreleased.

Figure 3. Photos of release pin and shaft failures.

Figure 4. Duel 1 system with 800 lb railroad wheel lifted. Both release shafts are in ‘released’ position, but the ‘old’ style pins are hung up.

9



Replaced release shaft which turned properly without any rotation. Old style pin on a single release system. It did not release with railroad wheel off the ground.

Figure 5. Single release test.

10

# **Appendix H** Pop-up Buoy Analysis Benthos Model 875-A PUB

Pop Up Buoy Analysis Benthos Model 875-A-PUB
Karen Grissom, January 2006
Ocean Systems Test and Evaluation Program
NOAA/NOS, Center for Operational Oceanographic Products and Services

In order to determine the optimal design and setup of the Benthos Pop Up Buoy (PUB), model simulations were run using the Matlab program Mooring Design and Dynamics. To evaluate the response of the buoy, two different scenarios were examined. The first scenario uses non-uniform time varying currents with a small vertical component, while the second is a steady state uniform environment with one horizontal component. The required input parameters for the model include mooring elements, water depth, current profiles, and density. Since the model is unable to simulate the release path of the PUB, it's configured as a moored surface buoy with a positive buoyancy floatation device, a neutral buoyancy retrieval line, and a railway wheel anchor.

The first scenario used a water depth of 40 meters and includes time varying currents with a maximum speed of 5.5 knots, a vertical shear ranging from 0 to almost 4 knots, float buoyancy ranges from 3.3 - 11.3 kg, and the length of the mooring line varies from 45 - 60 meters, for a total of 2460 different model simulations. The steady state environment (scenario 2) had a water depth of 21 meters with uniform currents ranging from 0 - 4 knots at ¼ knot intervals for a total of 17 current profiles. The mooring line for scenario two ranges from 25 - 100 meters at 25 meter intervals, and float buoyancy ranges from 4.55 – 9.10 kg. In all 204 different simulations were run for scenario two. Both scenarios used a uniform water density of 1025 $kg/m^3$.

The model uses an iterative approach to solve for the positions of each mooring element until the positions converge to within 1 cm in the vertical. The solution does not consider inertial affects, and assumes: 1) steady-state conditions, 2) static force balance, 3) constant tension over the length of the line, and 4) that the cable does stretch under tension. The specific solution is obtained by calculating the tangential and normal drag on each element in three directions using the total current speed for each component. Next, the model estimates the tension and vertical angles necessary to hold the mooring element in place in the given current. The standard outputs include percent surface buoyancy, total tension on anchor, vertical and horizontal load. In addition, the code was modified midway through the analysis to output float depth.

The results of scenario one are given in Figure 1. Each plot shows the results for one mooring length with the five different buoyancies. Note the PUB stays afloat until the current approaches 2 knots. Beyond the 2 knot threshold more than 80% of the surface buoyancy is required for floats with ≤ 9.3 kg buoyancy and 67% for the 11.3 kg float. Figure 1 demonstrates that using a high percent of the available buoyancy, which occurs during a strong currents make the floats less predictable and more susceptible to submersion. Figure 2 shows the apparent logarithmic response of the PUB during weak currents. For a 45 meter line 90% of the surface buoyancy is required to keep the PUB afloat during a 1.42 knot current, whereas only 25% is needed for a 55 meter line, and 20% for 60 meter line. At speeds greater than 1.43 knots the PUB is submerged on a 45 m line, uses 40% surface buoyancy for a 50 m line and 23% buoyancy for a 55 and 60 m line.

The trend of improved response to increased line length is further confirmed by the results of scenario two, the steady state system (Figure 3). During a 2.5 knot current with 4.55 kg positive buoyancy float, the float depth decreases as line length increases, this nearly linear behavior is shown in Figure 4. The response of the PUB to increasing float buoyancy is shown in Figure 5. In general, Figure 5 demonstrates that retrieval rate is more dependant on a longer line than higher float buoyancy. As the length of the mooring increases so does the maximum current at which the PUB remains afloat, or put another way, the percent surface buoyancy required to keep the PUB afloat decreases. Figure 6 illustrates the response of the float during a 2.5 knot current to increasing buoyancy. The results of this figure are summed up in Table 1, the ratio of the change in the float depth over the change in buoyancy, the slope of each segment of line. In general, Table 1 shows that when the float is submerged (as in Figure 6) the longer the mooring line the greater the response of the float to increasing buoyancy.

From these model simulations we can conclude that to maximize the chances for recovery of the PUB we should; 1) increase the line length, 2) attempt retrieval during low speed currents, and 3) increase float buoyancy. At present, the standard retrieval line used in the Benthos PUB is approximately 50 m, this should be increased to approximately 60 m, at which length scenario one (Figure 2) predicts a leveling off of the percent buoyancy gained from further increasing line length. Further investigation is required to find the optimal line length as a function of water depth. Numerous variables, not evaluated here, such as surface roughness, rope diameter, elasticity, buoyancy, severe loads, and line relaxation will need to be considered when calculating the total drag of the retrieval line. The results of the steady state system using the present configuration, a 50 m line and 4.55 kg buoyancy (Figure 3 and 5), show a maximum current speed for recovery of 1.75 knots, but when a non-uniform current is considered (Figure 2), this value is lowered to approximately 1.5 knots. To further increase the chance of a successful retrieval, a safety buffer, or margin of error, should be added to the maximum current speed. This margin of error of should be left to the discretion of the project lead, and will depend on such factors as current shear, and the overall dynamic nature of the environment, but in general to maintain 60% reserve surface buoyancy (Figure 2) this value should be lowered by 10%, or to 1.35 knots. Lastly, the buoyancy of the floatation device can be increased. Table 1 shows the advantages to be gained are related to the line length, yet Figure 2 demonstrates 3x the original buoyancy increases the maximum current speed for recovery by approximately 1 knot.

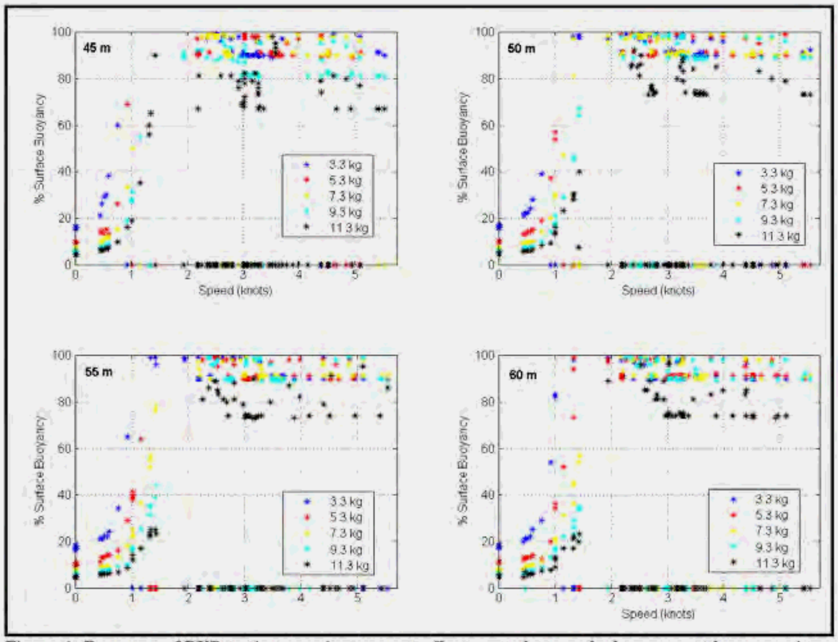


**Figure 1: Response of PUB to time varying currents, float are submerged when percent buoyancy is zero.**

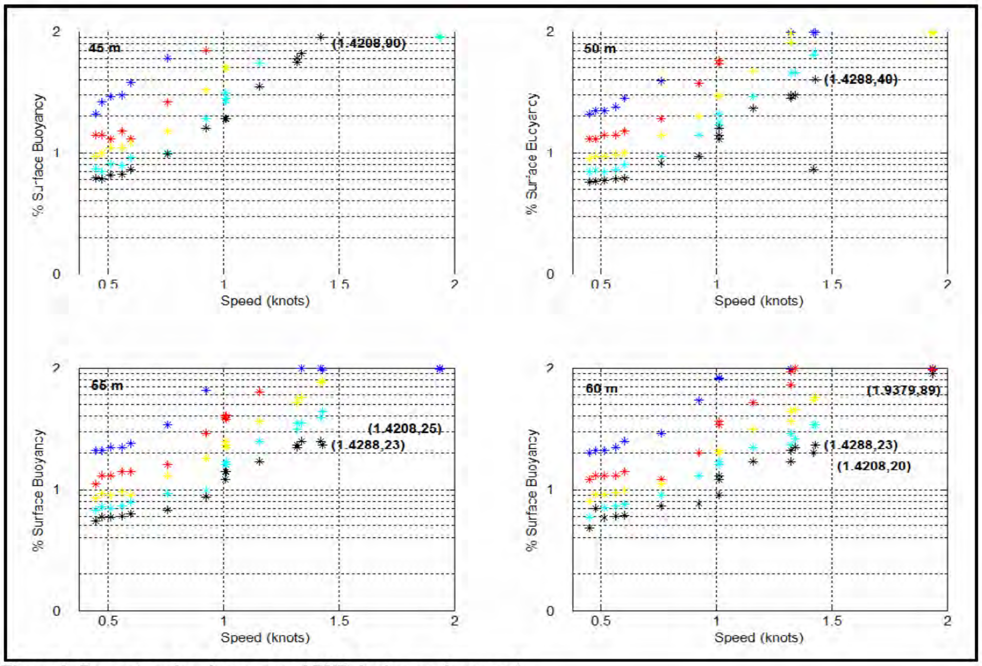



**Figure 2: Percent surface buoyancy of PUB during weak current.**

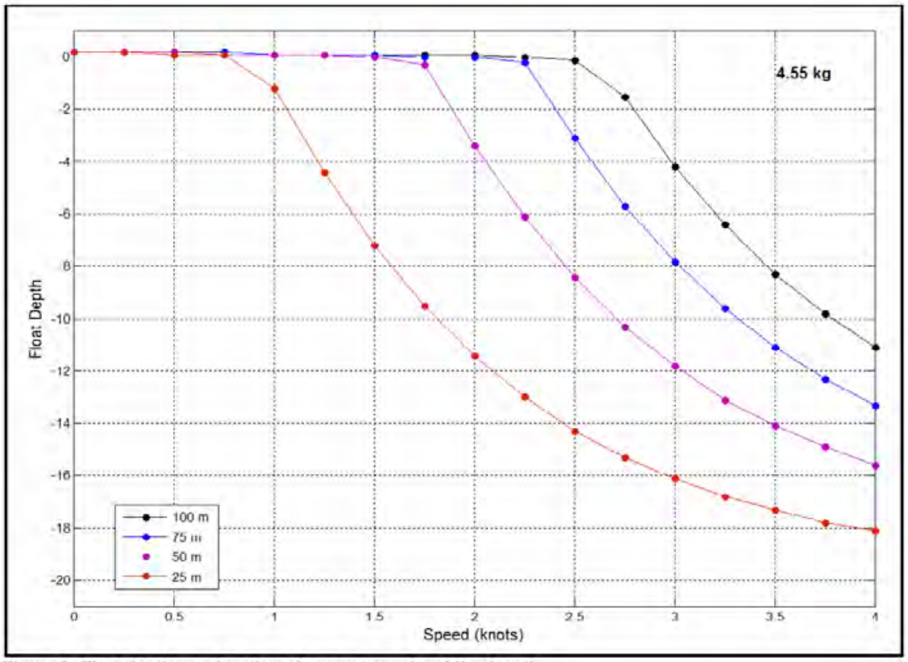



**Figure 3: Float depth as a function of current speed and line length.**

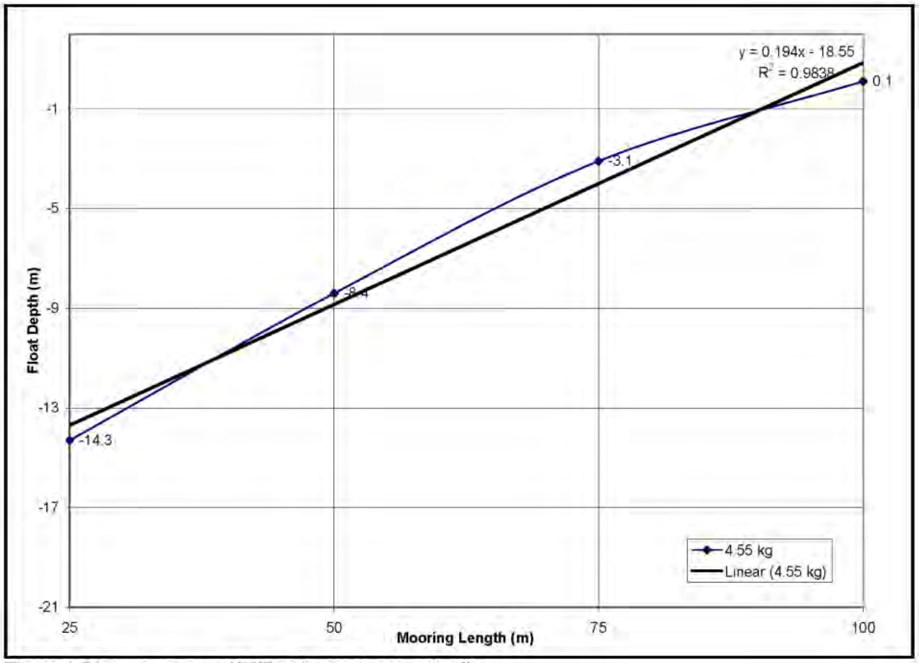


**Figure 4: Linear response of PUB to increasing mooring line.**

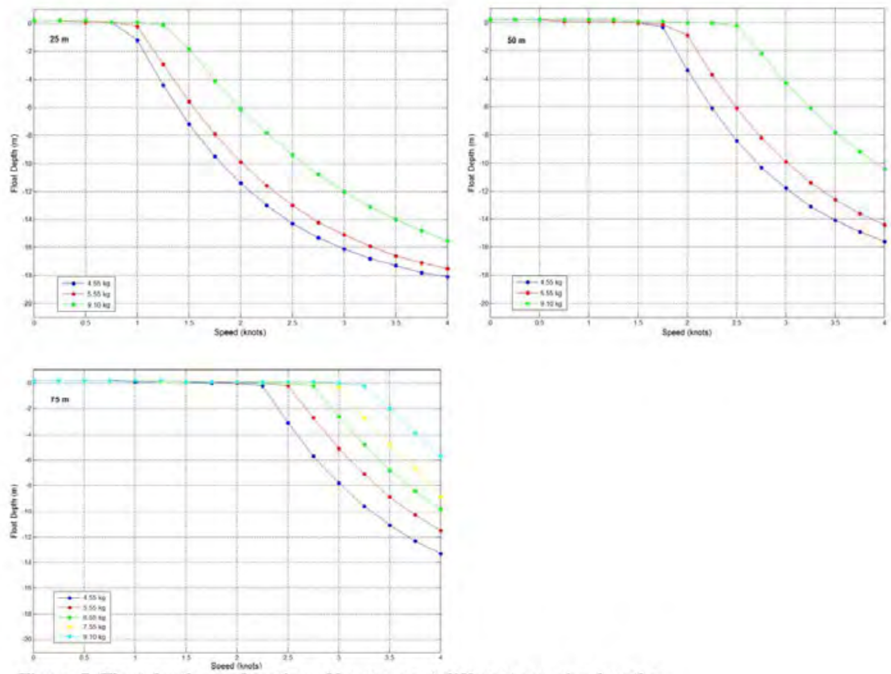



**Figure 5: Float depth as a function of buoyancy at different mooring lengths.**

**Table 1: Ratio of the change in float depth to increased buoyancy**

| Buoyancy Change (kg) | Line Length (m) | Slope |
|---|---|---|
| 1.00 | 25 | 1.30 |
| 3.55 | 25 | 1.03 |
| 4.55 | 25 | 1.02 |
| 1.00 | 50 | 2.30 |
| 3.55 | 50 | 1.66 |
| 4.55 | 50 | 1.80 |
| 1.00 | 75 | 2.90 |
| 3.55 | 75 | 0.08 |
| 4.55 | 75 | 0.70 |

## Acronyms

| | |
|---|---|
| **ADCP** | Acoustic Doppler Current Profiler |
| **ASCII** | American Standard Code for Information Interchange |
| **ATON** | Aid to Navigation |
| **CART** | Coastal Acoustic Release Transponders |
| **CECAT** | Coastal and Estuarine Current Analysis Team |
| **CO-OPS** | Center for Operational Oceanographic Products and Services |
| **CTD** | Conductivity, Temperature, Depth |
| **DAS** | Data Acquisition System |
| **DCP** | Data Collection Platform |
| **EM** | Electro-Mechanical |
| **ES** | Eddie Shih |
| **FOD** | Field Operations Division |
| **GPS** | Global Positioning System |
| **GUI** | Graphical User Interface |
| **IP** | Internet Protocol |
| **KHz** | Kilohertz |
| **MD&D** | Mooring Design and Dynamics |
| **MSI** | Mooring Systems, Incorporated |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NOS** | National Ocean Service |
| **OSTEP** | Ocean Systems Test and Evaluation Program |
| **POC** | Point of Contact |
| **PORTS®** | Physical Oceanographic Real-Time System |
| **PSD** | Products and Services Division |
| **PUB** | Popup Buoy |
| **PVC** | Polyvinyl Chloride |
| **RFP** | Reinforced Fiberglass Plastic |
| **SUBS** | Streamlined Underwater Buoyancy Systems |
| **TRDI** | Teledyne RD Instruments |
| **TRBM** | Trawl Resistant Bottom Mounted |
| **USACE** | United States Army Corps of Engineers |
| **USCG** | United States Coast Guard |
| **UV** | Ultra-Violet |
| **WHOI** | Woods Hole Oceanographic Institution |