

Subsurface ADCP Buoy for Near Surface Current Observations in 200-300m Coastal Waters

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Abstract—Several recent field applications at the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) have required measurements of current profiles in the top 30m of a 200-300 m water column, for a 60-90 day duration. Maximum near surface current speeds at sites of interest range from 2-2.5 m/s. To address this emerging requirement, CO-OPS developed and field tested a subsurface, moored buoy system consisting of commercial-off-the shelf (COTS) components. The moorings topmost component is an ellipsoid, syntactic foam buoy, which houses an upward looking 300 kHz acoustic Doppler current profiler (ADCP). The ellipsoid buoy has lower drag than a spherical shaped buoy and significantly higher buoyancy than many COTS available streamlined buoys, allowing the ADCP to be positioned within the top 50 m of the water column when moored with adequate line length. CO-OPS very recently completed a long-term field demonstration of the system off the coast of North Carolina near the Gulf Stream in approximately 275 m of water, from May 2017 - June 2018. Details of the mooring design along with initial field test results will be presented.

Keywords—ADCP, near surface currents, subsurface buoy,

I. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) manages the National Current Observation Program (NCOP) to collect, analyze, and distribute observations and predictions of tidal currents in major ports and harbors across the United States. Data analysis products are developed and disseminated to ensure safe, efficient and environmentally sound maritime commerce and to support physical oceanographic research and coastal engineering applications. Several recent NCOP current survey applications have required short term collection (60-90 days) of current profile measurements in the top 30m of the water column at sites with water depths ranging from 200-300m and maximum near surface current speeds of 2-2.5 m/s. Specific 2018 sites of interest include North Inian Pass, Alaska and several locations across the Puget Sound and Straits of Juan de Fuca, Washington. Available historical current observations for some

sites of interest only cover depths 50 m below the sea surface and deeper. Derived navigational support products are not representative of conditions in the top most portion of the water column, where currents will most significantly impact vessel operation.

To address these emerging NCOP needs, CO-OPS developed and tested a subsurface, moored buoy system consisting of commercial-off-the-shelf available (COTS) components from Mooring Systems, Inc (MSI). The mooring's topmost component is an ellipsoid shaped, syntactic foam buoy, which houses an upward looking 300 kHz acoustic Doppler current profiler (ADCP). The ellipsoid buoy combines low drag and high buoyancy to position the upward looking ADCP as close as possible to the near surface area of interest and to keep the ADCP within desired tilt thresholds.

Members from CO-OPS Engineering Division's facility in Chesapeake, Virginia, with support from the University of North Carolina Coastal Studies Institute (CSI), Wanchese, NC, conducted an initial test deployment of the moored ADCP system at field site approximately 22 nmi (40.75 km) East of Cape Hatteras, North Carolina, starting in May 2017. The site is at the edge of the Gulf Stream and offers a 250-275 m depths with strong currents in the range of 2-3 m/s. The deployment of the system was completed on May 17, 2017 and initial plans were for a 12 month field test. The recovery was delayed several weeks however, due to ship availability, scheduling, and weather. The system was successfully recovered on June 22, 2018, resulting in a 401 day field test.

Details of the mooring design, field deployment and recovery operations are presented along with an initial look at field test results. Only a limited discussion of initial data results are included here as the system recovery was delayed to take place close to the submission due date of this proceedings paper. More details of data results will be provided in the associated October 2018 conference presentation. Plans for continuing data analysis are outlined along with thoughts for future operational use of the system.

II. MOORING SYSTEM DESIGN

The following top-level requirements guided the system design:

- water depth at the measurement site: 200–300 m
- primary measurement region of interest: within 5–30 m below the sea surface
- max expected current speed at the surface: 2–2.5 m/s (4–5 knots)
- max expected current speeds within 50–100 m below the surface: 1.5 m/s (3 knots)
- minimum deployment duration: 60–90 days
- vertical spatial resolution: 1 m
- data sampling: 6-min average, with sensor internal recording

Considering the top-level system requirements listed above, along with other characteristics of NCOP field sites of interest, a subsurface, taut line mooring with an upward-looking ADCP was selected as the optimal basis for the system design. The option of a surface buoy with a downward-looking ADCP was ruled out in part for the following reasons:

- The size and buoyancy required for a surface buoy and mooring for 300 m water depth with 2 m/s surface currents would result in a system that is very impractical for the short-term deployment/recovery cycle typical of an NCOP tidal current survey (60–90 days).
- All NCOP sites of interest experience high shipping traffic; a system with no surface presence offers a significant advantage.
- Real-time data telemetry is not a requirement, eliminating a potential advantage of a surface buoy platform.

The ADCP is expected to lose profile measurements over approximately 10% of its vertical field of view at the sea surface due to acoustic side lobe interference. As such, one main challenge of resolving near-surface currents in 300 m water depth is positioning the upward-looking ADCP as close as possible to the top section of the water column to reduce the total size of the 10% region of loss. Also, the ADCP tilt must remain less than the $\pm 15^\circ$ tolerance required for quality current profile measurements.

The new mooring was designed with support from Mooring Systems, Inc (MSI). A 58 in diameter (1.47 m) ellipsoid-shaped, syntactic foam buoy, which houses the upward-looking ADCP (Fig. 1) along with a GPS locator beacon, is the topmost component. The ellipsoid buoy offers significantly lower drag than a spherical shaped buoy (drag coefficient of 0.07 as opposed a sphere's 0.5) and significantly higher buoyancy (1,155 lb) than streamlined buoys that are currently available in CO-OPS' NCOP existing inventory [1].

A relatively long line is required to position the buoy with ADCP in the topmost section of a 250–300 m water column. Wire rope was selected for this purpose, which combines strength, low weight, and low drag. The topmost section of the wire rope includes a fairing to eliminate potential strumming of the taut line. The particular fairing used was from Zippertubbing and consists of 0.01 in thick PVC coated polyester and 3.5 inch long fingers.

The bottom of the mooring includes an acoustic release mechanism with a smaller, 33 in diameter (0.84 m) ellipsoid buoy, with 200 lb buoyancy, to keep the release upright and off the seafloor. The recommended anchor weight for the system is 2000 lb (wet).

In support of CO-OPS' design effort MSI produced results with mooring performance model and prediction software, SMOOR, designed by Henri Berteaux [2,3], to predict mooring trajectory and loading of the subsurface ADCP buoy for a variety of different mooring configurations. Site conditions listed in requirements were used as model input. Results were used to optimize mooring parameters, focused on positioning a 300 kHz ADCP close enough to the sea surface to resolve the topmost 5–30 m of the water column. CO-OPS also independently produced model results using James Dewey's Mooring Design and Dynamics tools (MD&D) [4]. Select model results are shown in the following section.

Fig. 2 shows a diagram of the mooring and Table 1 provides a top down listing of the mooring's components.

The make and model of mooring instrumentation components:

- ADCP - Teledyne RDI, 300 kHz Workhorse, with external battery canister
- Acoustic Release - Edgetech, 8242XS.
- Locator Beacon - XEOS Technologies, XMi

The ADCP was configured with typical CO-OPS NCOP sampling scheme of 6 minute ensembles and 1 meter vertical bins. Considering the mooring line length, planned water column depth, and the ADCP power and memory requirements for a 12 month deployment, the ADCP was configured to measure over 70 bins. Three battery packs (18VDC, 36 D-Cell) were used with the ADCP; one installed in the ADCP unit and the two other in an external battery case. Fig. 3 shows the ADCP and external battery case installed inside the MSI mounting cage for the 58 in ellipsoid buoy.



Fig. 1. Ellipsoid shaped buoy with ADCP (Mooring Systems, Inc).

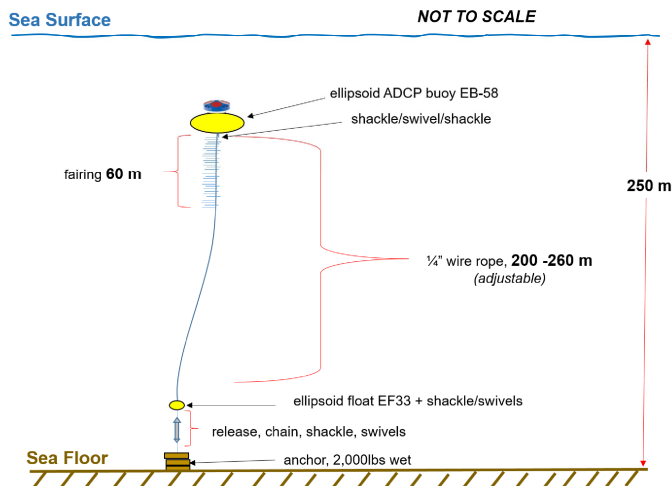


Fig. 2. Design diagram for ellipsoid buoy based ADCP mooring.



Fig. 3. ADCP, extra battery canister, and locator beacon installed in mounting cage of the 58 inch diameter ellipsoid buoy.

III. FIELD TEST

A. Test Site

The field site selected for the initial test of the mooring system was 35.1374 N, 75.0940 W, approximately 22 nmi (40.75 km) East of Cape Hatteras, at the continental shelf break (Fig. 4). This region was selected for initial testing for the following reasons:

- A mid-Atlantic field test location is close to the CO-OPS engineering facilities in Chesapeake, Va.
- The coast of NC offers the shortest east coast transit to 200–300 m deep water (at the continental shelf break)
- The edge of the Gulf Stream offers near surface currents 2 m/s and higher
- Opportunity for collaboration and technical exchange with University of North Carolina’s Coastal Studies Institute (UNC\CSI)
- Nearby reference measurements are available for data evaluation including, the IOOS supported HF radar and CSI’s bottom mounted 75 kHz ADCP

The water depth at the deployment site is 250 m. The selected test duration was 12 months.

B. Deployment and Recovery

The vessel selected for the field test deployment and recovery was the UNC\CSI 42-foot Duffy offshore research vessel. The vessel has an A-frame, winch and davit suitable for the lift and deployment of the mooring components. UNC\CSI has a team of highly trained and qualified vessel operators and marine technicians with much expertise deploying oceanographic equipment across the NC continental shelf and Gulf Stream region. The vessel is berthed at the UNC\CSI waterfront facility in Wanchese, N.C. (location shown in Fig. 5). Fig. 5 show the vessel before and after the test mooring components were loaded.

The vessel departed the dock on the morning of 05/17/2017. Transit time from UNC\CSI to the test site took approximately 4 hours, with arrival on site near 1130 EST. Once on site, the deployment procedure followed a top-down approach (relative to mooring components). First, the topmost buoy with ADCP was lifted and deployed using the vessel’s A-frame and winch. Next, the buoy was allowed to drift out while the moorings wire rope was paid out. Once the rope’s end was near, it was tied off, while the lower buoy and acoustic release were attached and prepared for deployment. Following the deployment of the lower buoy and release, the anchor was carefully dropped off the aft deck using the winch lift and A-frame. Photographs of deployment procedure are shown in Fig. 6.

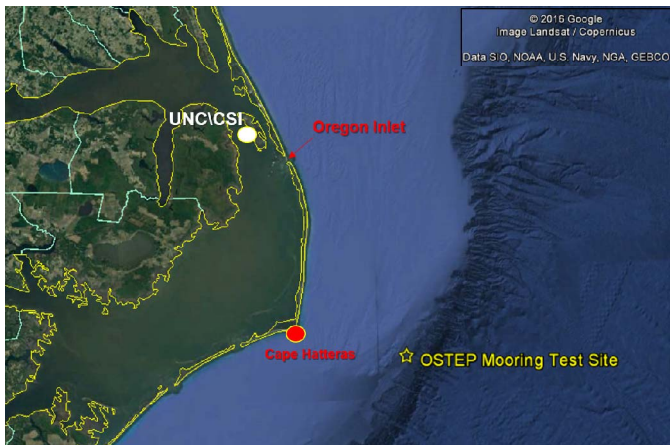


Fig. 4. Field test site, off the coast of North Carolina.

The recovery took place on June 22, 2018, 401 days following the deployment. Upon arrival to the site, communications were successfully established with the Edgetech acoustic release using a Benthos universal deck box. Once within range, a release command was issued and received, and the release successfully detached the mooring from the anchor. Once the top buoy reached the surface (Fig. 7) the XEOS XMi beacon successfully transmitted latitude-longitude positions (via Iridium satellite system).

After the surfaced buoy was located, the recovery of all components was successfully completed in less than 30 minutes. First, the large topmost buoy was recovered and brought on deck using the vessel's A-frame and winch. The wire rope was brought in by hand, and then the smaller buoy and acoustic release were lifted with the A-frame and winch.



Fig. 5. UNC\CSI vessel before and after mooring system on load.

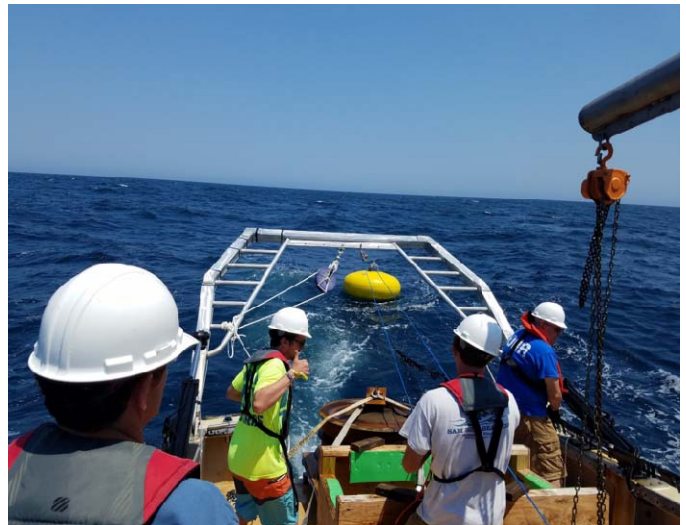
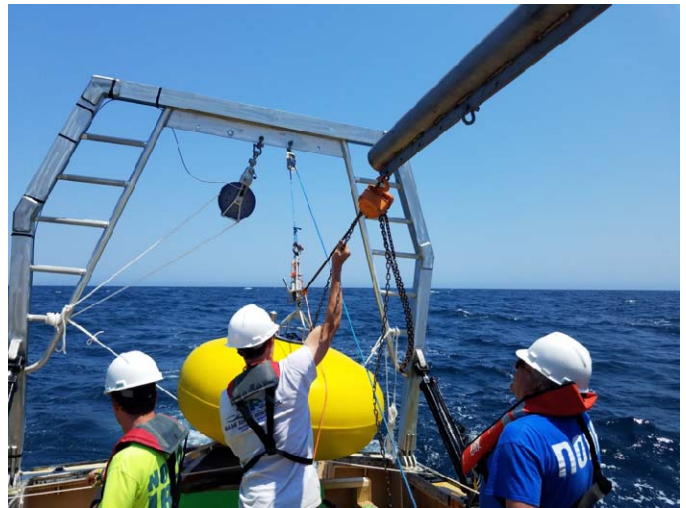


Fig. 6. Deployment of the topmost ellipsoid buoy.



Fig. 7. Both of the mooring systems ellipsoid buoys surfaced following acoustic release from sea floor upon recovery.

IV. INITIAL RESULTS

A. Condition of the System

The system's two buoys, wire rope, acoustic release, beacon, shackles, swivels and rings were all in good condition. All swivels maintained rotary mobility. Pictures of the moorings key components following recovery are shown in Fig. 8 and 9.

The system's 60 m section of PVC coated polyester fairing along the top most section of wire rope did not hold up well. As shown in Fig. 9(b)-(c), several sections had torn fingers, some were twisted and deformed sections, and others were torn off and detached from the wire rope. CO-OPS is working closely with MSI to assess what may have occurred and how to improve use of fairing in future deployments.

The power pin on the ADCP bulkhead connector was discovered corroded following recovery. Additional assessment of the cable and connector are taking place. The ADCP used was from CO-OPS existing inventory, had more than 10 years in service and passed a series of pre-deployment checks and tests prior to deployment. The recovered ADCP data indicate the sensor operated and recorded successfully for approximately six months of the 13 month deployment. Data missing for the last seven months of the test are most likely a result of the ADCP failing after the power pin corroded. The resulting available data are adequate for assessment of the mooring systems performance.

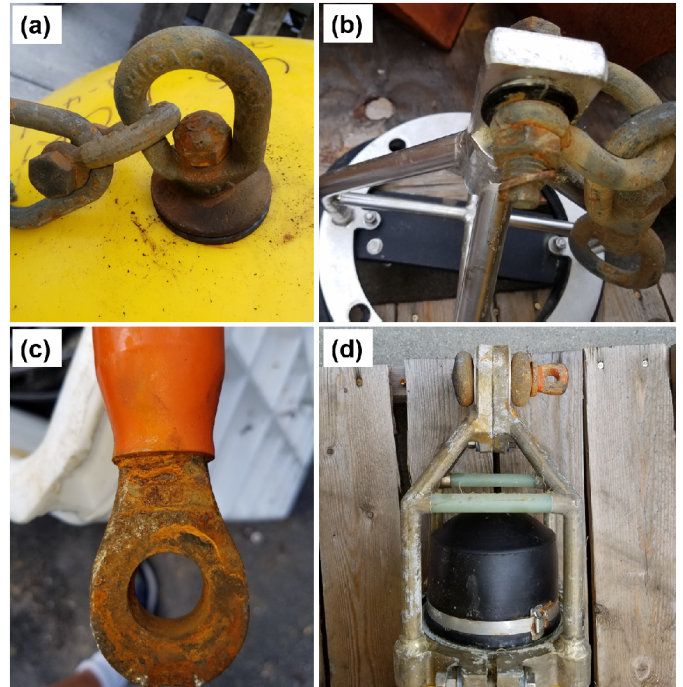


Fig. 8. System components, all in good condition for 401 days deployed, (a) swivel, shackle, and ring on lower buoy, (b) shackle and swivel on ADCP cage, (c) termination on wire rope, (d) top of acoustic release.

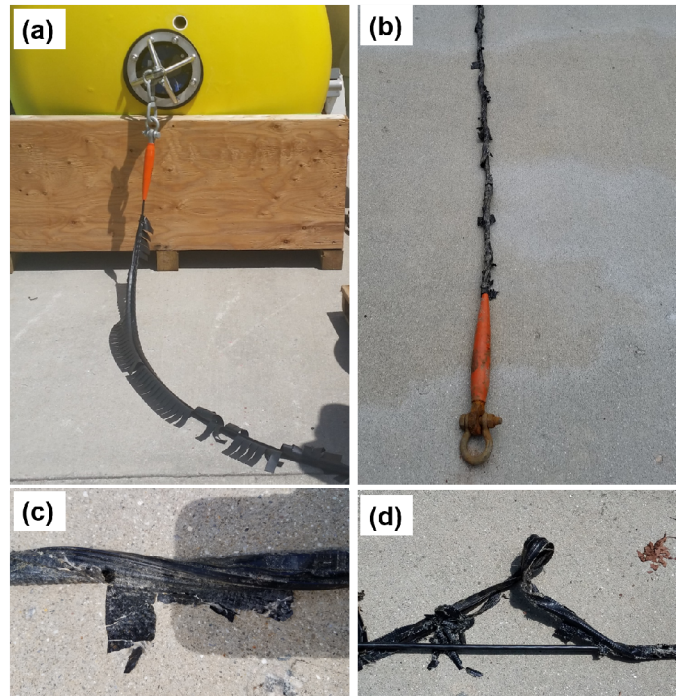


Fig. 9. Wire rope fairing before the field deployment (a) and after recovery (b)-(d).

B. Initial Data Results

Fig. 10 shows profiles of the horizontal current magnitude from May - October 2017. Data shows a broad range of currents occurred at the site throughout the field test, resulting in an excellent data set to evaluate system performance. During the six months of data collection, currents were in the range from 1.5-2 m/s. On a few occasions, currents in the entire vertical measurement range remained below 0.5 m/s for several days; and currents reached as high as 3 m/s in the upper portion of the ADCPs vertical aperture.

Fig. 11 (a) shows a time series of currents at the ADCP's first range bin, representative of currents closest to the buoy, and corresponding motion data available from the ADCP sensor: (a) tilt from the liquid tilt sensor (b) depth from the pressure sensor, and (c) degree heading from the compass. Fig. 12 shows average surface currents derived from IOOS HF radar observations near the test site (red dot) for the two time periods marked in red dashes on the ADCP measured time series in Fig. 11 (a). HF radar shows location of large scale Gulf Stream features corresponds to the ADCPs measured currents.

An initial look at a scatter plot of sensor tilt versus current speed (Fig. 13) shows that the ADCP remained within the recommended tilt threshold of ± 15 degrees for the majority of the test. The 15n degree threshold was only slightly exceeded on a small number of occasions when current speeds near the ADCP buoy exceeded 2 m/s.

Preliminary analyses of depth excursions estimated from the ADCP pressure sensor readings show excursions remained within a reasonable range when considering system configuration options and measurement requirements. Fig. 14 shows observed depth excursions versus bin 1 current speeds (blue dots). Modeled excursions produced with MD&D (black circles) compare reasonably well with observations.

Continuing data analysis will include a closer investigation of ADCP motion over the range of different current conditions observed along with additional mooring excursion modelling for comparison. Comparison of ADCP measurements to surface currents from HF radar and lower depth profiles from a nearby bottom mounted 75 kHz ADCP, maintained by UNC/CSI, will be also be conducted.

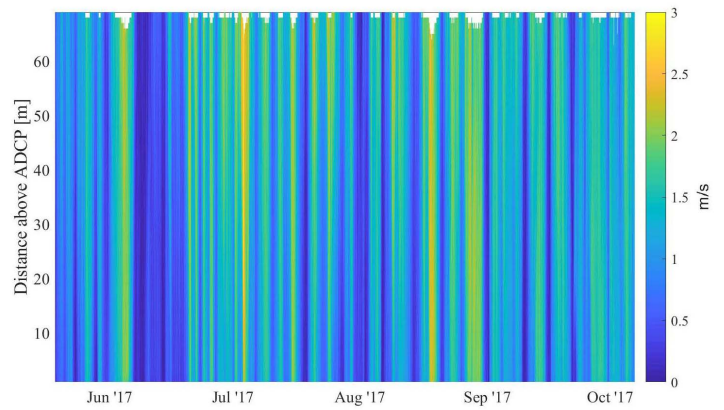


Fig. 10. ADCP profile of current magnitude.

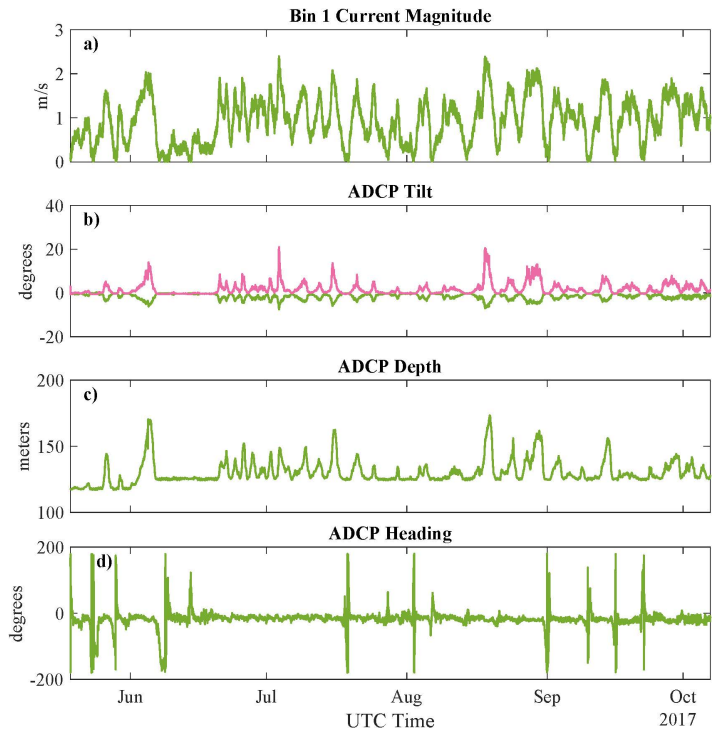


Fig. 11. ADCP measurements: (a) bin 1 current speed, (b) tilt, (c) depth, (d) heading.

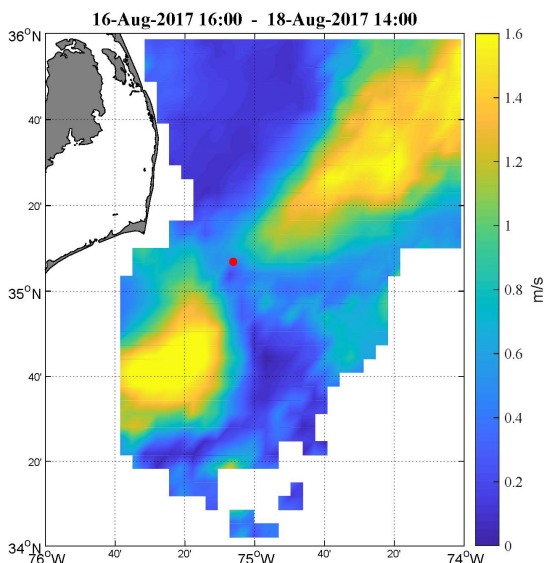
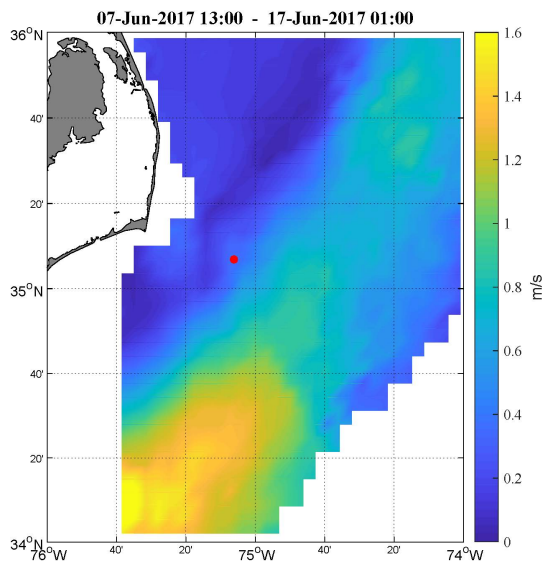


Fig. 12. Average surface currents from HR radar near test site (red dot) for time period corresponding to first set (top) and second set (bottom) of red dashed lines on Fig. 11(a).

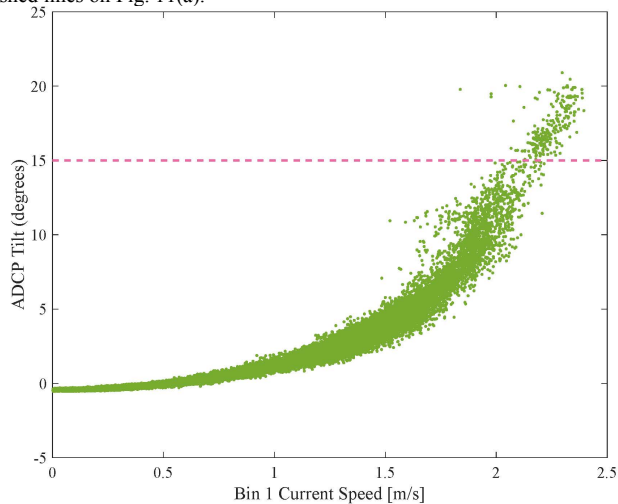


Fig. 13. ADCP tilt versus bin 1 current speed.

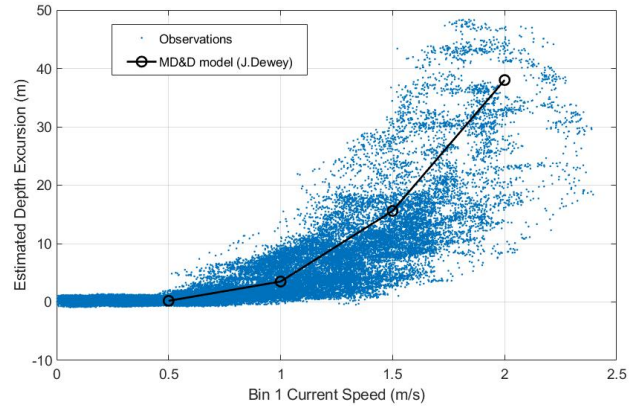


Fig. 14. Measured ADCP depth versus Bin 1 current speed (blue dots) and modeled depth excursion results using J. Dewey MD&D Matlab tool (black circles) [4].

V. SUMMARY

Emerging CO-OPS NCOP applications at U.S. west coast sites require current profile measurements in the topmost portion of a water column with 200-300m depth. To address this need, CO-OPS worked with MSI to design a subsurface moored system using an ellipsoid buoy with an upward looking ADCP. With much assistance from UNC\CSI, CO-OPS recently completed the first field test deployment off the coast of North Carolina, on the edge of the Gulf Stream. Observing system deployment and recovery were successfully completed and the mooring system performed outstanding. With the exception of the 60 m section of fairing, all mooring components were recovered in excellent condition following the 401 day deployment. ADCP measurements cover 6 months capturing a broad range of current conditions, resulting in an excellent data set to further evaluate system performance. Initial analyses of the data show that the ADCP remained within the desired sensor tilt threshold (± 15 degrees) for more than 99% of the time and observed depth excursions compared well with expectations based on modeled results.

As the observing system was recovered very close to the submission date of this proceedings paper, data analysis will continue and more detail will be presented at the associated October 2018 MTS/IEEE Oceans conference and in subsequent articles. CO-OPS next field deployment of the system is tentatively planned to take place at North Inian Pass, Alaska during the summer of 2019.

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and many things related to the planning and execution of a successful field deployment and recovery.

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