PAPER

Recent Development and Field Test of CO-OPS' Real-Time, Shallow Water CURrents BuoY (CURBY)

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ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service Center for Operational Oceanographic Products and Services (CO-OPS) manages the National Current Observation Program (NCOP) and Physical Oceanographic Real-Time Systems (PORTS®). These programs provide tide and current predictions, as well as real-time current and meteorological information. Outdated current predictions, navigational support requirements, and incident response scenarios (e.g., oil spills, vessel accidents) have highlighted CO-OPS' need for a rapidly deployable system that provides near-surface current and meteorological observations. To address this, CO-OPS designed, developed, and tested a real-time system based on a surface buoy platform, hereinafter referred as CURrents BuoY (CURBY). This paper provides an overview of the system design, field test results, operational applications, and future plans.

In 2018, CO-OPS completed the build, integration, and testing of the first prototype CURBY. A successful field test was completed during 2018 in the Chesapeake Bay, and the first operational deployment followed shortly on the Delaware River in 2019. Resulting measurements were used to improve tidal current predictions and to plan for a 2021 regional survey. Initial success with tidal current survey operations led to design enhancement and wider use. During 2020–2021, CO-OPS partnered with the NOAA Office of Response and Restoration to build two new CURBYs to support emergency response applications in the Gulf of Mexico region. During 2022, two CURBY systems were deployed in the Columbia River, Oregon, to support additional NCOP operations. Future plans include establishing a long-term CURBY system for Kings Bay, Georgia, PORTS®.

Keywords: buoys, currents, real-time

Introduction

The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) manages three major coastal observatory systems: the National Water Level Observation Network (NWLON), the Physical Oceanographic Real-Time Systems (PORTS®), and the National Current Observing Program (NCOP). Current measurements are a critical component of both NCOP and PORTS® programs.

The primary objective of NCOP is to collect, analyze, and distribute observations and predictions of tidal currents in major ports and harbors across the United States. NCOP current surveys involve deploying a series of temporary measurement systems, typically for durations ranging from approximately 45 days to 1 year. Following field collection, data analysis products are developed and disseminated to ensure safe and environmentally sound maritime commerce and to support oceanographic research and coastal engineering applications.

PORTS's® primary objectives are closely aligned with those of NCOP: decision support for maritime commerce and coastal resource management. PORTS® consists of regional integrated suites of long-term, real-time coastal observing stations at 38 major harbors throughout the United States. PORTS's® primary products include real-time data and a variety of derived real-time analysis products, forecasts, and other geospatial information. PORTS's® long-term coastal stations measure and disseminate observations of water levels, currents, salinity, and meteorological parameters that mariners need to navigate safely (Edwing, 2019; Wolfe & MacFarland, 2013).

Prior to 2018, CO-OPS' operational current measurement system inventory could be classified into three categories, with all systems employing acoustic Doppler current profiling (ADCP) sensors: (1) subsurface, vertical profiling, including a variety of standalone bottom mounts and subsurface moored buoys with upward looking ADCPs; (2) shore based, horizontal profiling, including shore side systems with submerged, 2-D horizontal ADCP installed on various structures that extends into the water; and (3) ATON (Aids to Navigation) buoy-mounted, vertical profiling, consisting of downward looking ADCP affixed to existing ATON buoys (Hensley & Heitsenrether, 2017).

Over the years, NOAA has successfully met all nearshore currents and meteorological measurement needs by relying on land-based and subsurface measurement platforms, as well as systems installed in existing U.S. Coast Guard ATON platforms, including offshore structures and surface buoys that mark shipping channels. Up until 2018, CO-OPS did not have a standalone, surface buoy-based measurement system in its operationally ready inventory. Over the years, limited efforts to design, develop, and test a standalone surface buoy-based measurement system were pursued; however, previous efforts primarily focused on incident response applications, such as oil spills, vessel groundings, and other maritime emergencies that require a rapid establishment of real-time current/met observations (Burke & Graff, 2007; Symons & Holman, 2006). Although previous efforts included successful development and field demonstrations of a surface buoy platform, related systems never transitioned to broader support of NCOP and PORTS operational applications. As a result, previous buoy system development efforts suffered atrophy due to irregular timing and occasional infrequent field use based on the nature of emergency response applications. One lesson learned and applied to CO-OPS latest buoy system development efforts was to adapt the system to support a variety of programs, including PORTS®, NCOP and other NOAA program office needs, to ensure robust support and routine operational use.

In recent years, there have been several NCOP and PORTS® applications with a critical need for quick establishment of near-surface, real-time current and meteorological observations in an effort to support safe navigation and hazardous event responses. In many cases, a small surface buoy platform would be extremely valuable in meeting program goals and could have provided increased spatial resolution of oceanographic and meteorological measurements. Applications of interest involve deployment durations ranging from 1–12 months in a range of nearshore coastal environments.

To address these needs, CO-OPS designed, developed, and tested a real-time current measurement system based on a surface buoy platform, henceforth known as CURBY (CURrents BuoY). The system was designed, developed, and tested throughout 2018, initially transitioned to NCOP operations during 2019, and is currently being used in NCOP operations in 2022. The first long-term PORTS® application is planned for late 2022. This paper provides an overview of the system design, a summary of field results to date, initial operational deployment experiences and resulting design evolutions, resulting tidal current products, and mooring model results. Finally, near future plans and design enhancement recommendations are discussed.

System Overview

The following is a summary of top-level system requirements that have driven the design of the CURBY:

Measurement Parameters

- Vertical ocean current profile over the upper 1–40 m of the water column
- Conductivity/temperature 1 m below sea surface
- Wind speed and direction
- Air temperature
- Barometric pressure
- Six-minute average sampling period

Data Communications

- Six-minute transmission rate
- Two-way communications connection for occasional remote troubleshooting
- WiFi connection for onsite system check

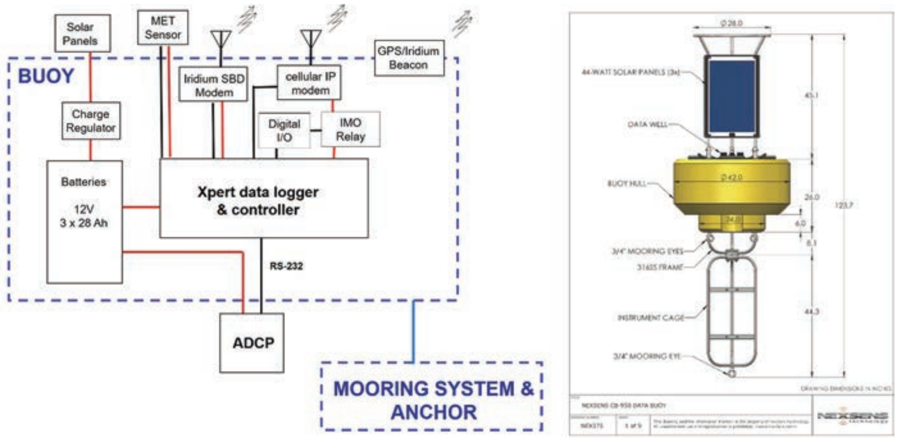
Operating Features

- For use in nearshore regions with water depths in the 5- to 50-m range.
- Assembled buoy (without mooring) not to exceed 300 lb.
- Easily deployed from a relatively small boat with 500-lb dynamic lift capability.
- Easily towable from smaller vessels without overhead lift capability.
- Requires no more than three people to deploy.

The make and model of the surface buoy platform selected for the system is the NexSens CB950 (Figure 1), which includes a foam hull, tower, subsurface instrument cage, and

FIGURE 1

Left: High level system design diagram. Right: NexSens buoy dimensions.



power system. The power system includes three 46-W solar panels (on tower), three 28 Ah, 12-V batteries (in well), and charge regulator (in well). Key specifications are shown in Table 1. The total weight of the buoy's structural components and power system is less than 250 lb (113.4 kg) and remains under 325 lb (147.4 kg) after the addition of the payload components listed in Table 2.

The system's real-time payload is based on the same Sutron Xpert data logger that is currently employed throughout NWLON and PORTS® long-term stations. Primary real-time communications are via Iridium Short Burst Data (SBD) modem, and the system also includes a cellular modem for two-way communications. A high-level overview of primary system components is depicted in Figure 1, and brief description of the primary system components follows.

The system's data collection platform (DCP) is housed in a 12 × 10 × 6 in (30.48 × 25.4 × 15.24 cm) polycarbonate box, which is mounted inside the tower behind the solar panels. The primary components of the system's DCP include an Xpert Dark data logger/controller, an Iridium SBD modem, a Sierra Wireless RV50 Cellular/IP modem, and a U.S. Converters, serial to WiFi converter (Table 2).

The CURBY system includes the following three sensors: an AirMar, WX200 "all-in-one" meteorological sensor with ultrasonic wind, air temperature, barometric sensor, a Nortek 600-kHz Z-Cell (or 1 MHz) Aquadopp current profiler, and a SeaBird SBE37 SMP conductivity-temperature-depth (CTD) sensor. The buoy platform can easily accommodate a variety of acoustic current profiler types. Ongoing development involves integration of the Nortek Signature current profiler with real-time motion compensation capability.

Figure 2 shows each sensor mounted to the CURBY system's CB950 surface buoy platform: (a) AirMar sensor in 4-ft mast extension atop the tower; (b–c) Aquadopp profiler in buoy hull well insert mount; and (d) SBE37 in the subsurface instrument cage, Aquadopp profiler transducer head location after well insertion.

The CURBY also includes a XEOS Technologies ROVER locator beacon that is independent from all power and electronics of the buoy system to retain an emergency location system in any possible event that would result in a DCP failure. The beacon transmits latitude and longitude positions every 2 hr by default, via its own internal Iridium SBD modem. The ROVER beacon is mounted along with all other communication system antennas on the ring at the top of the buoy tower (Figure 2a).

TABLE 1

NexSens buoy dimensions and specifications.

Component	Size
Hull dimensions	42" (106.7 cm) outside diameter, 20" (50.80 cm) tall
Tower dimensions	44" (111.76 cm) tall, ⅞" tubular
Main inner well dimensions	9.9" (25.15 cm) inside diameter, 26" (60.04 cm) tall
Weight in air	250 lb
Buoyancy	950 lb
Hull material	Cross-linked polyethylene foam with polyurea coating and stainless
Tower/hardware material	304 stainless steel
Mooring attachments	1 or 2 points, ¾" eye nuts
Solar power	(3) 46-watt 12 VDC solar panels
Batteries	(3) 28 Ah

TABLE 2

Primary payload components.

System Component	Make/Model
Data logger/controller	Sutron, Xpert2 Dark
Digital I/O module	Sutron, 8080-0002-3
IMO relay and socket	B&B Smart Worx, ETS-1C-N-SL12VDC-10 (relay), SRISI24AC/DC-10 (socket)
Iridium SBD modem	Sutron 9602N SBD
Cellular IP modem	Sierra Wireless, RV50
Acoustic current profiling sensor	Nortek, Z-cell Aquadopp Profiler, 600 kHz

The basis for the buoy mooring used in all CURBY field deployments to date is an all-chain, slackline mooring that provides a 2:1 scope. Design details are based on buoy specifications and have been adapted for each field trial, depending on specific site conditions. As an example, for the 2018 deployment in the south Chesapeake Bay, the following site conditions were used for mooring design:

- Depth, average: 9.1 m (30 ft,) max: 10.7 m (35 ft)
- Sand/mud bottom
- Surface not to exceed currents: 3 m/s (1.5 kts)
- Significant wave height not to exceed: 3 m
- Deployment duration: 90 days
- Desired radius of buoy's watch circle: 18.2 m (60 ft) or less

Mooring components selected for this example are presented in Table 3.

The pyramid anchor, provided by DorMor, Inc., is designed to penetrate the seafloor upon deployment and to submerge quickly. When completely submerged under a sand/mud bottom, the anchor has a specified holding strength of 10 times its weight.

FIGURE 2

CURBY system's three sensors: (a) AirMAR WX200 met, (b–c) AquaPro in well insert, and (d) SBE37 CTD and AquaPro transducer head.

Field Deployments

Field Test, Chesapeake Bay

The initial field test of the prototype system was conducted between July 31 and September 11, 2018, in the south Chesapeake Bay, approximately 4 km (2.2 nmi) westward off the coast of Cherrystone, VA, 37° 19.158' N, 76° 3.893' W. The average water depth at the site is approximately 14.8 m (49 ft). The Aquadopp profiler was configured following the PORTS® standard sampling and telemetry regime for currents applications: 300-s sampling duration, 6-min telemetry frequency, and 1-m vertical profile bin size. The prototype system did not include meteorological or CTD sensors. In addition to the buoy system, a bottom-mounted ADCP system was deployed nearby to serve as a source of stable reference measurements. This reference system consisted of a Nortek 600-kHz Acoustic Wave and Current (AWAC) Sensor installed in a Mooring Systems, Inc. Trawl Resistant Bottom Mount (TRBM). It was deployed approximately 190 m north of the buoy, far enough away to avoid inter-sensor acoustic interference, but

TABLE 3

Mooring components for 2018 Chesapeake Bay field test.

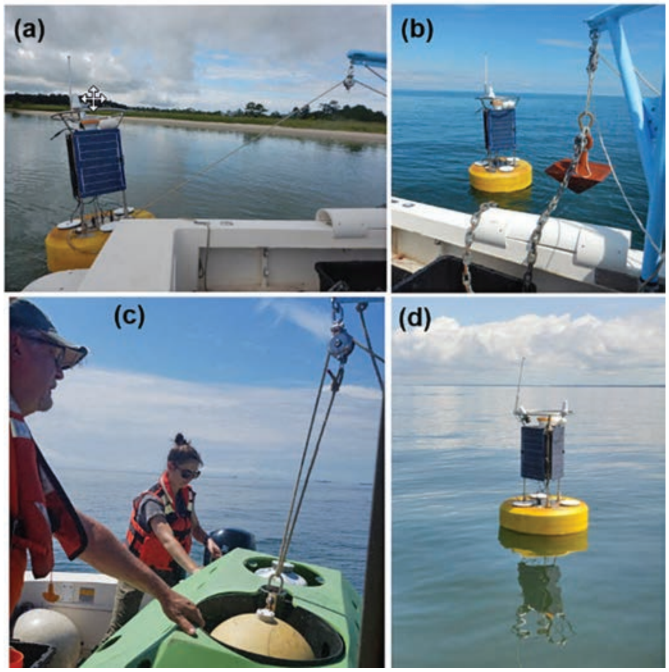
Mooring Components for 2018 Chesapeake Bay Field Test (Top Down)	
Component	**Length**
Shackle-swivel-shackle	
¾” Heavy chain	10 ft (3.048 m)
Shackle-swivel	
Shackle-swivel-shackle	
½” Light chain	25 ft (7.62 m)
Shackle-swivel-shackle	
⅝” Medium chain	35 ft (10.668 m)
Shackle-pear link-shackle	
300 lb (136 kg) Pyramid anchor	

close enough to experience close to the same average current conditions as the buoy system. The AWAC was configured to measure currents for 300 s every 360 s (6 min) and also sampled waves once an hour, with a burst consisting of 1,024, 1-Hz samples.

The field test deployment of the two systems took place on July 31, 2018, from CO-OPS' small boat, the R/V Tornado (25 ft). The buoy was towed out to the test site, then the mooring was payed out, and the anchor dropped off at the desired location (Figure 3). The reference bottom mount system was lifted over the side of the gunwale using the davit and then, once in the water, lowered to the seafloor with a slip line. Both systems were recovered on September 11, 2018, using a slightly larger vessel (40 ft), with greater lift capacity, the Cape Henry Launch's M/V Diamond.

FIGURE 3

Deployment from CO-OPS' R/V Tornado, (a) buoy tow out, (b) buoy anchor rigged to quick release, (c) deploying reference system in TRBM, and (d) buoy post deployment.



Both the test buoy system and reference system in the TRBM successfully collected continuous data over the entire field test, as planned. Throughout the test, the site experienced several high wind events, when winds exceed 10 m/s. Also, maximum wave heights exceeded 1.5 m on four occasions.

Field Test, Performance

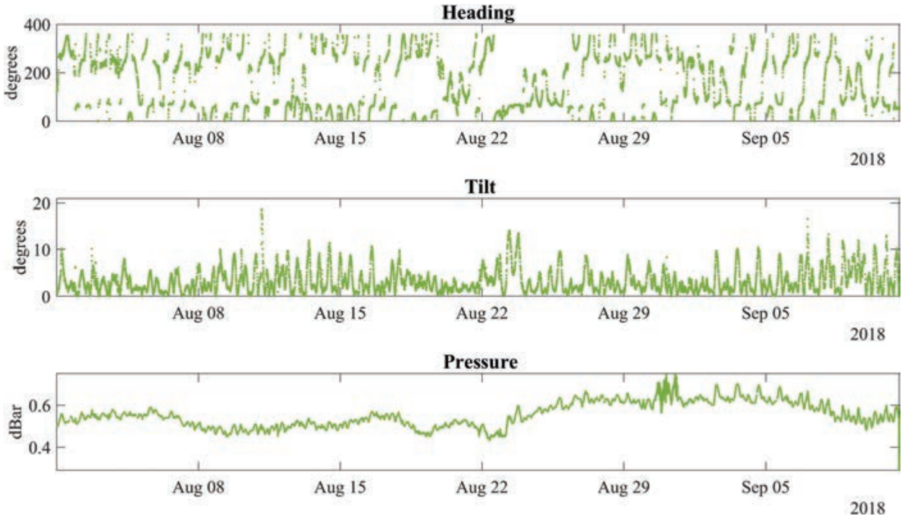
To best represent the end-to-end system performance, all results featuring the buoy system's real-time current observations presented below are based on data downloaded from CO-OPS Current Measurement Interface for the Study of Tides (CMIST) online tool, the very end of the CO-OPS' real-time currents data pipeline. Daily average data throughput rates exceeded system requirements (no less than 95%) every day of the test. Average throughput was all near 100% or at 100%, and the average throughput over the entire test was 99.71%.

Figure 4 shows 6-min average data from the Aquadopp current profiler's compass, tilt, and pressure sensors. Results indicate the buoy-mounted sensor remained relatively stable on average, within a reasonable range of motion; most importantly, the sensor remained within the vendor's recommended 15° pitch/roll threshold, which is to ensure accurate vertical current profile measurements.

Raw echo amplitude from the Aquadopp profiler's three beams

FIGURE 4

Data from Aquadopp current profiler's motion and pressure sensors during Chesapeake Bay field test.



indicated that that return signal strength was well above the sensor's noise floor (25 counts) over the entire water column. There are no features that indicate acoustic signal interference with the buoy mooring components. The expected jump in echo amplitude associated with the sea floor interface is apparent across bins 14 and 15. For analysis presented in following sections, bin 13 was selected as the last good data bin of the Aquadopp profiler.

Figure 5 provides a look at the current profile observations collected by the test systems Aquadopp profiler. The plot shows that the vertical profile series of U and V current components (top two panels) and near surface current magnitude (Bin 1) and direction (bottom panel) look reasonable. As expected for the test site, currents are predominantly tidal with magnitudes varying at the M2 period, within approximately ±1 m/s (2 knots most times). A quick look at wind observations from the Kiptopeke, VA, NWLON station show that instances when currents deviate from the typical tidal cycle are correlated to meteorological events. Detailed comparison of the buoy-mounted Aquadopp profiler's measurements and the bottom-mounted reference AWAC are to follow.

The system voltage remained well over the nominal 12 V and greater than 12.5 V over the entire test with the exception of just one brief time period shortly after initial deployment. The latitude/longitude position time series provided by the buoy's GPS tracking beacon indicate the buoy held its position for the entire test, confirming the mooring design employed was suitable for the range of conditions experienced over the test period. As expected based on the slack, single-point mooring design (2:1 scope, max water depth 52 ft), the maximum watch circle radius remained less than 100 ft the majority of the test.

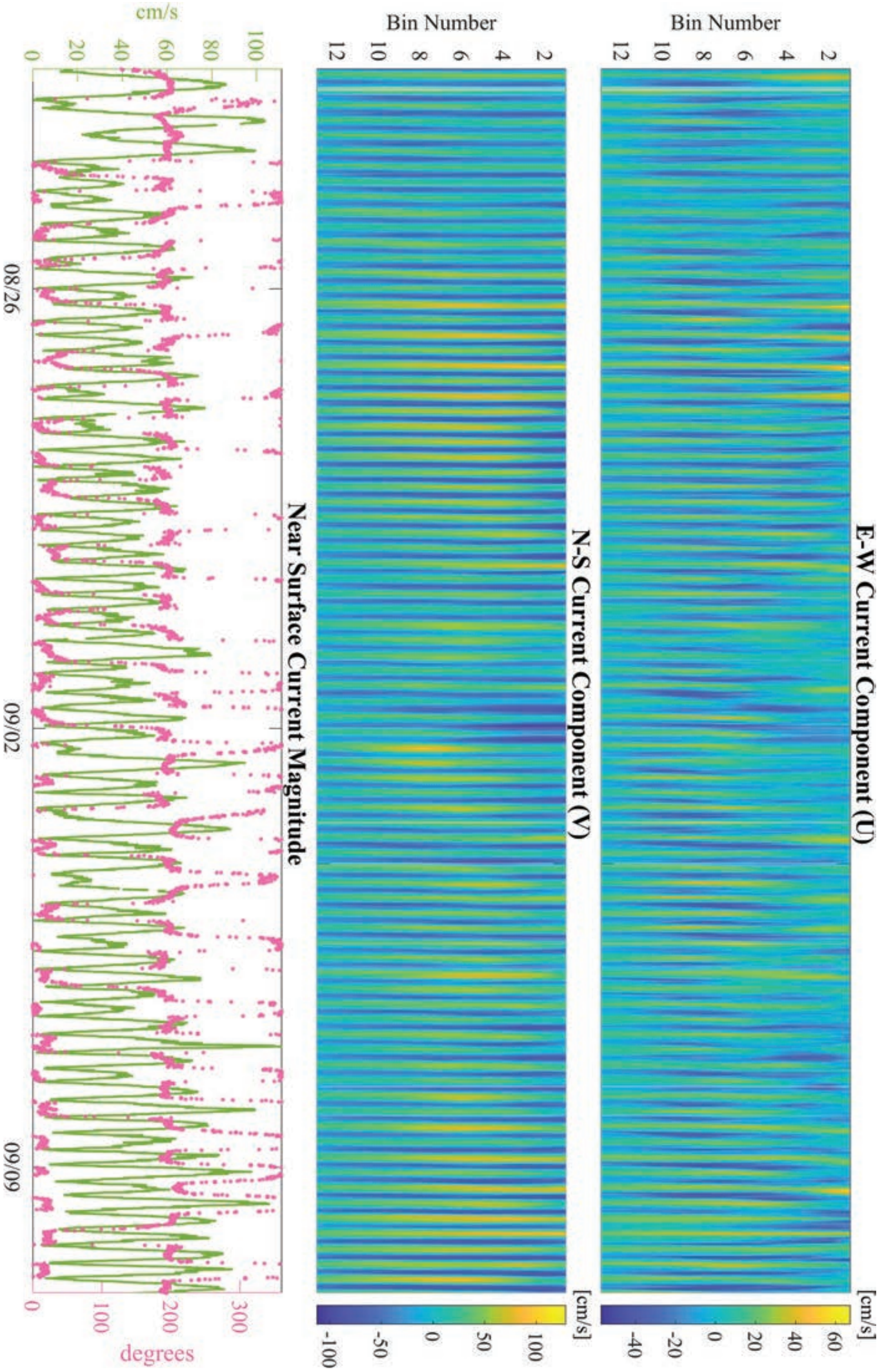
Field Test, Bottom Mount Comparison

Based on CO-OPS' past experience with the Nortek AWAC Sensors (Heitsenrether et al., 2015), and the expected stability of the GP-TRBM platform deployed on the seafloor, there is high confidence that data collected from the bottom AWAC in this field test will provide an accurate source of reference measurements.

Prior to comparing measurements from the test buoy system and the bottom-mounted reference, several preconditioning steps were applied to test data. First, extra vertical bins were removed for both the test and reference system, based on jumps in echo amplitude associated with seafloor interaction. Next, we applied a magnetic declination correction to the sensor heading for the reference AWAC. This same correction was automatically applied to the Aquadopp profiler upon ingestion. Since the buoy was following the sea surface, profile measurements from the buoy-mounted Aquadopp profiler were depth interpolated to the vertical bins of the AWAC sensor, which remained fixed relative to the sea floor. Each Aquadopp profiler 6-min vertical current profile was interpolated individually. For each, the known Aquadopp profiler transducer depth below the sea surface and the most recent AWAC water depth reading were used to estimate the vertical separation between the two sensors' range bins. Next, the Aquadopp profiler profile measurements were interpolated to the AWAC bin depths using a basic linear interpolation function in MATLAB (interp1). Although, both the test system Aquadopp profiler and reference AWAC were programmed with identical current sampling configuration, the AWAC current data still were not completely correlated to that of the Aquadopp profiler as a result of hourly wave bursts fit in at the top of each hour. In order to ensure time-aligned,

FIGURE 5

U and V component vertical profile times series and near surface current magnitude and direction from Chesapeake Bay field test.



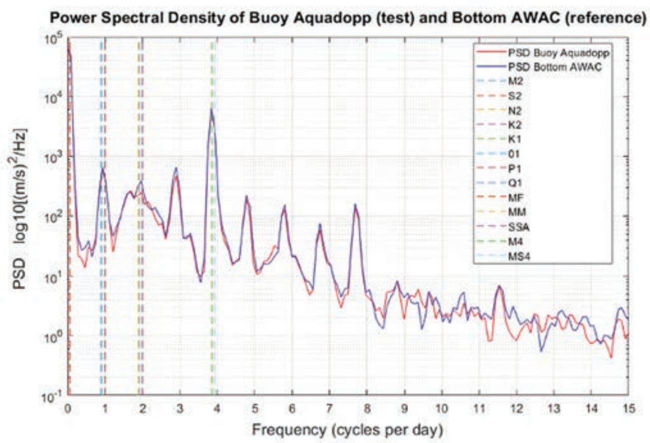
equally spaced current samples, which is particularly important for the tidal harmonic results shown below, the AWAC sensor's current measurements were interpolated to align with the Aquadopp sensor's sample times using a basic linear interpolation function in MATLAB (interp1).

Power spectral density (PSD) for both sensors' depth averaged current magnitude was computed across the entire time series (approximately 42 days) (Figure 6). The MATLAB pwelch function was used to calculate PSD with an NFFT width equivalent to approximately 10.6 days and a Hamming window with 50% overlap. The selection of 10.667 days (or approximately 256 hr) resulted in a window that was 512 points wide (power of 2) for ease of use with the MATLAB pwelch function and Hamming window; 10.667 days provided the optimal result for (1) resolving the range of tidal constituents plotted, M2 (12.42 hr period) to MS4, (6.10 hr period), and (2) applying a level of smoothing (from ensemble averaging of each windows individual PSD) that results in clear representation of constituents in the plot. It is our opinion that the most important step was ensuring that the PSD for both the buoy/Aquadopp and bottom/AWAC were computed using the identical method and parameters. The AWAC's wave sampling regime resulted in four missing 6-min current measurements at the top of each hour. As a result, to generate a continuous, evenly spaced time series from which a PSD is calculated, both sensors' current profile records were decimated to 30 min.

Results show that PSD of test buoy system measurements (red line) compare very well to that of the bottom reference system (blue line). A qualitative look shows that peaks associated with periods at the primary tidal constituents compare very well between the two PSDs. There are no clear signs of platform motion–induced noise at higher frequencies in the buoy system's PSD. Higher frequency buoy motion could potentially result in aliased energy at lower frequencies and elevated spectral

FIGURE 6

Power spectral density of Buoy AquaPro and Bottom AWAC for field test.

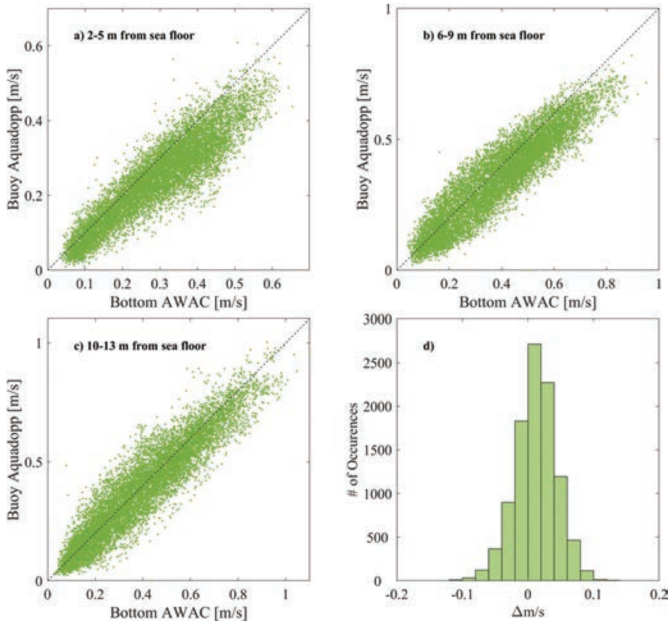


levels at the higher frequency end of the spectra. Agreement of distinct peaks between the AWAC and Aquadopp and no signs of aliased energy between peaks of the Aquadopp profiler spectra suggest that buoy motion was not likely impacting measured current time series.

Scatter plots of the current speeds from both the AWAC and Aquadopp profiler are shown in Figure 7 for three different regions of the water column. Overall, the average difference between the two sensors of the depth average current speed over the entire measured water column was 1.23 cm/s, with a root mean square error (RMSE) of 3.37 cm/s. More comparison results are shown in Table 4, and a distribution of the differences in current speed (AWAC-AquaPro) is shown in Figure 7d. One notable result is a bias in higher speeds in bins near the sea floor (Figure 7a). This has been noted in other studies (Velasco & Nylund, 2019; Heitsenrether et al., 2018) and primarily attributed to large tilt in the ADCP and large vertical shear. These can both affect the bin size and depth.

FIGURE 7

Depth averaged current magnitude by depth: (a) 2–5 m from sea floor, b) 6–9 m from sea floor, (c) 10–13 m from sea floor, and (d) the distribution of AWAC–AquaPro magnitude differences.



First Operational Deployment, Delaware River

The CURBY was deployed operationally for the first time in July 2019 in the Delaware River near Philadelphia in response to the regional pilot captains' requests to better resolve complex tidal currents near Petty Island. This deployment was conducted between 9 July 2019 and 18 October 2019 in the Delaware River, between Philadelphia and Petty Island, at approximately 39.967N and 75.117W. The average water depth at the site is 11.9 m. The Aquadopp profiler was configured following the PORTS® standard sampling and telemetry regime for currents applications: 300-s sampling duration, 6-min telemetry frequency, and 1-m vertical profile bin size. An SBE37 CTD was deployed near the surface in the cage just below the buoy hull and sampled every 6 min.

First Operational Deployment, Performance Results

The buoy system successfully collected continuous data over the entire deployment. Throughout the test, the site experienced several high wind events, when winds exceeded 10 m/s. To best represent the end-to-end system performance, all results featuring the buoy system's real-time current observations presented below are again based on data downloaded from

TABLE 4

AWAC and AquaPro comparison results.

	Mean Difference (AWAC – AquaPro) [cm/s]	RMSE [cm/s]
Entire water column	1.23	3.37
Bottom (2–5 m from seafloor)	4.59	6.98
Middle (6–9 m from seafloor)	3.66	7.89
Surface (10–13 m from seafloor)	0.58	3.37

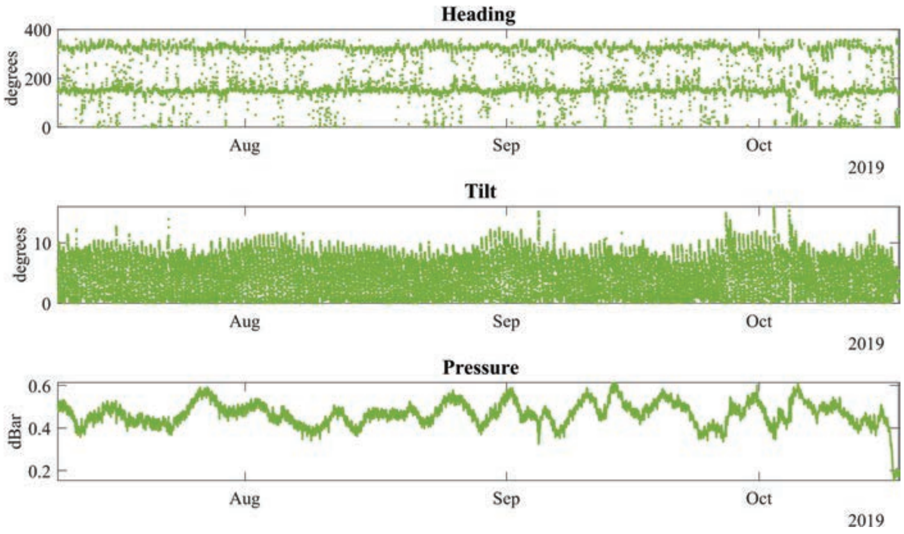
CO-OPS CMIST. Daily average data throughput rates exceeded system requirements (no less than 95%) on all but 1 day of the test. Average throughput was all near 100%, and the average throughput over the entire test was 99.33%.

Figure 8 shows 6-min average data from the Aquadopp current profiler's compass, tilt, and pressure sensors. Results indicate the buoy-mounted sensor remained relatively stable on average, within a reasonable range of motion; most importantly, the sensor remained within the vendor's recommended 15° pitch/roll threshold, which is to ensure accurate vertical current profile measurements. The Aquadopp profiler and CTD performed well for the entire deployment.

The CURBY observations and least squares harmonic analysis (LSQHA) fit to the observations were compared with nearby historical currents predictions at Petty Island and nowcast output from a nearby grid point in NOAA's Delaware Bay hydrodynamic model (Delaware Bay Operational Forecast System [DBOFS]) to determine differences in timing and magnitude, and possible discrepancies with historical predictions. The historic predictions are based on data collected over 15 days in 1984 at 7.3 m (24 ft) below Mean Lower Low Water, and the station was located 74.08 m southwest of the CURBY location. The closest CURBY bin depth for comparison is Bin 7 located at 7 m and DBOFS Vertical Layer 4 (6.4 m) and is used for this analysis.

FIGURE 8

Data from Aquadopp current profilers motion sensors during Delaware River deployment.



The CURBY observations showed the flow at this station is very tidally driven with the LSQHA resolving 25 tidal constituents over the 98-day analysis period and solving up to 97% of the total current energy. The semidiurnal currents are very rectilinear with the major axis variance reaching up to 99.8%. The floods are stronger than the ebbs throughout the water column with the mean observed maximum flood speed of 1.04 m/s at 4 m depth and mean observed maximum ebb speed of 0.92 m/s at 3 m depth. There is a mean ebb current of approximately 0.04 m/s.

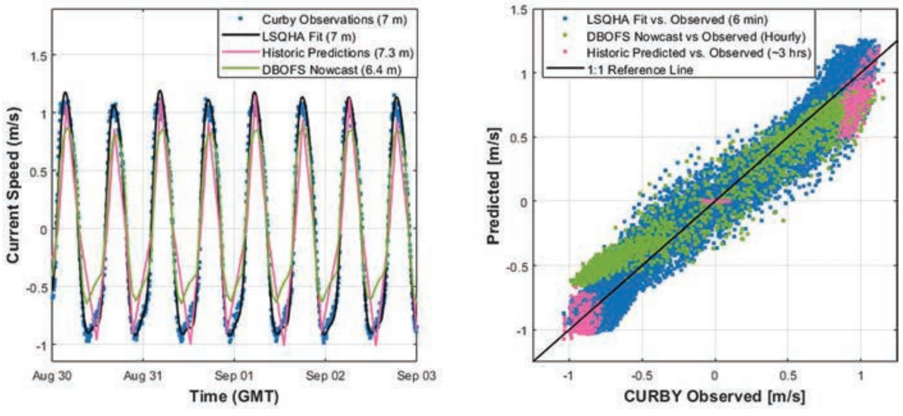
Compared to the historic predictions, the CURBY observed slightly faster flood (+0.04 m/s) and slower ebb (−0.04 m/s) speeds and the flood and ebb directions were backed to the north by 7°T and backed to the south by 12°T, respectively. The timing of the maximum flood and ebb derived from CURBY measurements occurs 3.4 min earlier and 18.24 min later, respectively, than the historic predictions, and the slack before flood and ebb occurs 17.8 min earlier and 5.2 min later, respectively, than the historic predictions.

An error analysis was performed between the CURBY observations and each of the following: LSQHA fit, DBOFS nowcast, and the historic predictions over the deployment period. The CURBY observations were subsampled to align in time with the hourly DBOFS nowcast output and roughly every 3 hr to align with the semidiurnal historic predictions that include the timing and speed of the max flood, max ebb, and slack currents. The RMSE was largest between the CURBY and DBOFS (0.22 m/s) and smallest with the LSQHA fit (0.11 m/s) and slightly higher with the historic predictions (0.12 m/s). The average residual magnitude of speed was lowest between the CURBY and historic predictions (|0.08| m/s), slightly higher between the CURBY and LSQHA fit (|0.09| m/s), and highest between the CURBY and DBOFS (|0.19| m/s). The bias was positive between all three comparisons (0.11 m/s, 0.17 m/s, and 0.06 m/s) in speed indicating the CURBY typically observed faster speeds than predicted by the LSQHA fit, DBOFS, and historic predictions, respectively. This can be seen in Figure 9, which shows a small portion of the 98-day time series of the 6-min CURBY observations, the 6-min LSQHA fit, hourly DBOFS nowcast output, and historic predictions. Figure 9 also shows a scatter plot of the CURBY observations aligned in time via subsampling compared to the LSQHA fit (6 min), DBOFS nowcast output (hourly), and historic predictions (approx. 3 hr). It can be seen the CURBY typically observed faster floods than the DBOFS and historic predictions. On the ebbs, the DBOFS underpredicts the max speeds relative to the CURBY observations while the historic predictions fell roughly around the 1:1 line with a slight skew toward over predicting speeds.

Differences between the recent observations compared to the historic predictions could possibly be attributed to a longer time series (98 vs. 15 days), updated sensors and technology, and channel dredging and deepening that was recently completed by the U.S. Army Corp of Engineers leading to bathymetric impacts on the flow. It is also important to keep in mind that although the time series is long for this comparison (98 days), the error analysis is done using a single point in space (depth and location), which may cause higher errors due to limited model resolution, and this error analysis is not representative of the entirety of the DBOFS domain.

FIGURE 9

(Left) A snapshot of data toward the middle of the deployment on a spring tide and includes the 6-min CURBY observations, the 6-min LSQHA fit, hourly DBOFS nowcast output, and historic predictions. (Right) A scatter plot of the CURBY observations (x-axis) aligned in time via subsampling compared to the LSQHA fit (6 min), DBOFS nowcast output (hourly), and historic predictions (approx. 3 hr). The black line shows the 1:1 comparison line.



These results were disseminated in January 2020 in an effort to improve existing CO-OPS tidal current predictions and associated navigational support products at this location. In addition to supporting the navigation community, the data collected will help validate numerical models and inform circulation studies supported by the academic community and other interested stakeholders.

First Operational Deployment, Mooring Model

A post deployment assessment of the 2019 CURBY deployment in the Delaware River was conducted using the marine dynamic analysis software Proteus DS (DSA Ocean). DSA Ocean's Proteus DS is a time-domain, finite element, dynamics analysis software packaged that can be used to test offshore and subsea marine systems, including buoy moorings. The software was used here to validate its results with those from the field deployment with the intention to use the software in the future to better prepare for future deployments. The model allows for the adjustment of current profiles and speeds, the addition of winds and waves, as well as the ability to add or remove different mooring components.

The mooring was set up in model software with each component of the mooring, including buoy components, instruments, and mooring chain parts. We used the built-in model QuasiStaticCable, which is a finite-element cable model that solves for the static equilibrium cable profile for each integration time step. The current speeds measured by the Aquadopp profiler ranged from 0–1.1 m/s (in both directions) and were primarily uniform throughout the water column. The model was run a total of seven times, with uniform current profiles ranging from 0 m/s to 1.5 m/s (0.25-m/s intervals) in the x-direction.

The most useful model result for this particular system is the buoy inclination and its increase with current speed. The vendor recommended maximum tilt for the Aquadopp profiler is 15°, beyond which accurate current measurements are not guaranteed. These model results compared well to the field measurements (Figure 10). The current speeds did not exceed 1.3 m/s, and the buoy tilt rarely passed 15°. However, the model tracks well with the measured tilt and predicts the tilt will generally go over the threshold around 1.38 m/s. This number is an estimate and will change with depth, as well as wind and waves, which are not included in the model at this time. Future plans include testing the model with current CURBY deployments, as well as adding wind. Other useful parameters calculated by the mooring software include knockdown, line and anchor tension, grounded line length, horizontal excursions, and more. We plan to further pursue use of this mooring software and will use it to choose the best mooring designs and components for different environments and uses.

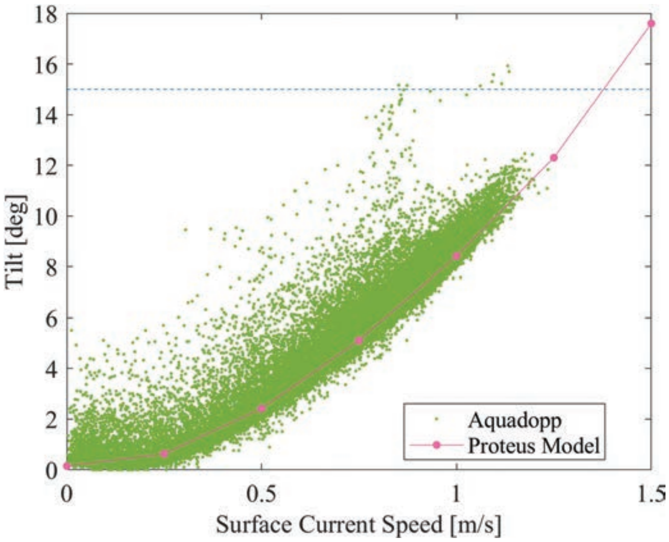
Operations and Beyond

Current Surveys

Following the successful use of the CURBY in the Delaware River, NCOP made plans to use the system in its next current survey in the Columbia River in Oregon. As of the writing of this manuscript, there are two CURBY systems in use in the Columbia River, where they will remain for the duration of the summer 2022 current survey (approximately 5 months). They will be used again the following summer for the second part of the survey. A CURBY will also be used as part of a NCOP current survey reconnaissance mission in Savannah Georgia in July 2022.

FIGURE 10

Buoy/AquaPro tilt with surface current speed (green) and results from the ProteusDS mooring software (pink). The dotted blue line indicates the 15° tilt threshold recommended by Nortek.



PORTS®

While the CURBY system was originally developed to support NCOP, CO-OPS has realized the potential for other uses. Currents stations are currently available in many PORTS® and primarily utilize shore-mounted current meters and current meters mounted on Coast Guard ATON structures and buoys.

Response and Restoration's

In addition to internal CO-OPS uses, additional CURBY systems have been funded by the NOAA Office of Response and Restoration's (OR&R) Disaster Response Center (DRC). The first operational deployment of the CURBY in the Delaware River led to the OR&R interest in utilizing the system as a prospective tool for incident response applications. An agreement was formalized for CO-OPS to build and support the buoys, and a joint use, operations and maintenance, and deployment protocol for the systems was created to support both CO-OPS and OR&R mission requirements. Two complete CURBY systems were built for the Gulf of Mexico DRC, and CO-OPS delivered and provided an initial training on the systems in September 2021. CO-OPS also developed field guides and standard operating procedures to ensure successful deployments. The units are staged in the Gulf Coast region—one at the DRC in Mobile, AL, and the second at the CO-OPS Field Office in Gulf Breeze, FL.

Conclusion

To ensure that its observing system network provides the most up-to-date oceanographic and meteorological products and services available, CO-OPS keeps abreast of evolving technology and continues to invest in development, test, and evaluation of new and improved instrumentation and measurement systems. Although current and meteorological measurement applications spanning NCOP and PORTS® programs have led to a range of different coastal measurement system design types, prior to 2018 CO-OPS did not have a standalone, surface buoy-based oceanographic and meteorological measurement system in its operational inventory. The only buoy-based current observations in PORTS® came from CO-OPS real-time system installed on existing U.S. Coast Guard AToN buoys.

Several emerging measurement needs for NCOP motivated the initial development of the CURBY, a portable, real-time oceanographic and meteorological buoy. Initial success led to broader use across NCOP, support from OR&R to develop two new systems to support emergency response in the Gulf of Mexico region, and plans to use CURBY to establish long-term, real-time systems in Kings Bay PORTS® to support safe and efficient navigation. The new CURBY system fills a measurement system gap, broadens CO-OPS capabilities, and improves the ocean observing network.

Continuing work includes:

- Integrating additional physical and chemical oceanographic sensors and using PORTS navigational support CURBY's as platforms of opportunity to support other oceanographic and water monitoring research efforts.
- Integrating the next generation Nortek acoustic profiling sensor, the Signature AD2CP with high-resolution Attitude and Heading Reference Sensor and real-time bin motion compensation. This will allow deployment in more dynamic environments with less concern about Aquadopp profiler motion impacting current profile accuracy (Heitsenrether et al., 2018).

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References

Burke, P.B., & Graff, T. 2007. A Fast Response Capability within NOAA/NOS/CO-OPS. In: OCEANS 2007. pp. 1–5. IEEE. https://doi.org/10.1109/OCEANS.2007.4449259.

DSA Ocean. http://dsa-ltd.ca/software/proteusds/description/.

Edwing, R.F. 2019. NOAA's physical oceanographic real-time system (PORTS®). J Oper Oceanogr. 12(Suppl. 2):S176–86. https://doi.org/10.1080/1755876X.2018.1545558.

Heitsenrether, R., Holcomb, N., Gray, G., Teng, C.C., & Wilson, D. 2015. NOAA's recent field testing of current and wave measurement systems–Part I. In: 2015 IEEE/OES Eleventh Current, Waves and Turbulence Measurement (CWTM). pp. 1–9. IEEE. https://doi.org/10.1109/CWTM.2015.7098138.

Heitsenrether, R., Fiorentino, L., Velasco, D., & Wilson, W. 2018. Evaluating performance of acoustic current profiler sensor on small, dynamic surface buoy. In: Oceans 2018 MTS/IEEE. pp. 1–8. IEEE. https://doi.org/10.1109/OCEANS.2018.8604697.

Hensley, W., & Heitsenrether, R. 2017. Iridium telemetry of real-time ocean current data from U.S. Coast Guard ATON buoy platforms. In: OCEANS 2017-Anchorage. pp. 1–7. IEEE.

ProteusDS 2015 Manual. 2016. Dynamic Systems Analysis Ltd., – Solver v2.25.

Symons, L., & Holman, A. 2006. Safe Seas: 2006 Emergency Response Exercise. NOAA National Marine Sanctuaries online report. https://sanctuaries.noaa.gov/safeseas/.

Velasco, D.W., & Nylund, S. 2019. Performance improvement for ADCPs on surface buoys. 2019 IEEE/OES Twelfth Current, Waves and Turbulence Measurement (CWTM). pp. 1–6. IEEE. https://doi.org/10.1109/CWTM43797.2019.8955135.

Wolfe, K.E., & MacFarland, D. 2013. An Assessment of the Value of the Physical Oceanographic Real-Time System (PORTS®) to the US economy. https://www.co-ops.nos.noaa.gov/publications/ASSESSMENT_OF_THE_VALUE_OF_PORTS_TO_THE_US_ECONOMY.pdf.