NOAA’s Recent Development of a Real-Time Ocean Observing System to Support Safe Navigation along U.S. Arctic Coasts

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***Abstract*— Recent studies on global climate change have identified the Arctic as the fastest warming region on Earth. Resulting trends of receding sea ice have led to more accessible Arctic waterways during summer months and an anticipated increase in maritime transport throughout the region. Prolonged access between North America and Europe via the Northeast Passage is of significant interest to the international maritime community. NOAA National Ocean Service’s Center for Operational Oceanographic Products and Services (CO-OPS) understands these changing conditions and recognizes the critical need for real-time oceanographic and meteorological observations along the U.S. Arctic coasts to support safe navigation. CO-OPS has been developing and testing a new, real-time oceanographic and meteorological observing system to address measurement needs at remote coastal sites where lack of infrastructure limits the use of land-based designs. The prototype system has two main components: 1) a bottom mounted ocean measurement platform and 2) a surface buoy with meteorological sensors and a satellite telemetry system. These two components are connected wirelessly, via an underwater acoustic link. Design details of the new system under development are presented here, along with results from three mid-Atlantic field trials successfully completed with an evolving prototype system, during 2014-2016. Plans for continuing work include completing a yearlong field trial in a relevant environment, along Alaska’s northern slope, a critical step required to move the prototype system to the next technology readiness level.**

Keywords—Arctic water levels, navigational safety, real-time ocean observatory, hydrographic survey, bottom mounted pressure gauge

I. INTRODUCTION

The critical need for real-time oceanographic and meteorological observations along Unites States’ coasts continues to grow. Primary data users including maritime forecasters, emergency managers, vessel and marine operators, port authorities, coastal planners, coastal engineers, and many other decision makers. In addition to real-time data applications, resulting long-term data records are extremely valuable for a variety of oceanographic research applications. To support those who rely on coastal oceanographic and meteorological information, the National Oceanic and Atmospheric Administration’s Center for Operational Oceanographic Products and Services (CO-OPS) continues to maintain and expand the National Water Level Observation Network (NWLON) and Physical Oceanographic Real-Time Systems (PORTS®). Together, these networks consist of over 300 long-term, real-time stations distributed across the United States’ coasts. Near real-time data, measured and disseminated from CO-OPS coastal network, include water levels, ocean currents, waves, water temperatures and conductivity, bridge clearance, visibility and several meteorological parameters.

As the Arctic warms faster than any other region on Earth [1-4], the corresponding decrease in sea ice loss has made Arctic waterways more accessible during summer months [5]. One result of this regional trend is the potential for a significant increase in maritime transport throughout the region. Prolonged access to North Europe via the northern sea route and to the eastern United States via the Northwest Passage is of significant interest to the international commercial shipping industry. In addition, longer and warmer Arctic summers could significantly increase tourism, especially by cruise ships in the far north, where marine based tourism has been limited by current conditions. Presently Artic waters within the U.S. Exclusive Economic Zone (EEZ) have very few navigational support products and services [5].

Recognizing the changing environmental conditions within the U.S. Arctic EEZ, CO-OPS anticipates a critical need for real-time oceanographic and meteorological observations to support safe navigation across the region. To date, CO-OPS operates 26 long-term NWLON observatory stations along Alaska’s coasts; however, significant spatial gaps in observations remain in the western and northern Alaska regions, including the Aleutian Islands, Bristol Bay, Nushagak Bay, Pribilof Islands and vicinity, Kuskokwim Bay, Kvichak Bay, Attu, Amchitka Island, Yukon River Delta, Kotzebue Sound, Bering Strait, Chukchi Sea, and Beaufort Sea areas.

In support of long-term plans to modernize of the United State’s coastal observatory network, CO-OPS has been developing and testing a new real-time oceanographic and meteorological (ocean/met) observing system. This ocean/met system will address measurement needs along the United States' remote Arctic coasts, where lack of infrastructure may limit the use of CO-OPS traditional, land-based station designs.

To date, numerous bottom mounted ocean sensor platforms have been deployed throughout the Arctic to support studies of oceanographic variability in the rapidly changing Arctic environment [6-9]. Most of these platforms have been offshore, in deep-water locations with limited real-time data telemetry. Also, bottom mounted pressure sensors have been deployed to measure water levels in shallow water along Alaska's remote coasts to support NOAA hydrographic surveys, but typically for shorter periods (45-90 days) and without real-time data telemetry [10,11]. The CO-OPS effort described in this paper is focused on the design and development of an infrastructure free, ocean/met system with real-time data telemetry for use in nearshore, coastal waters. The design allows the system to be adapted for both short- and long- term deployments. CO-OPS primary applications of interest include supporting navigational safety, hydrographic surveys, and establishing tidal datums in coastal regions where they remain unknown. Additionally, resulting measurements will benefit a variety of oceanographic research.

CO-OPS' prototype measurement system currently under development includes two main components: 1) a bottom mounted ocean measurement platform with conductivity, temperature, pressure (CTP) and acoustic wave and current (AWAC) sensors, and 2) a surface buoy with meteorological sensors and a satellite telemetry system. The two components communicate wirelessly, via an underwater acoustic modem system. The bottom platform measures and transmits real-time oceanographic information to the surface buoy, which stores and transmits both oceanographic and meterological measurements via the Iridium satellite system.

The system is designed for deployment in nearshore waters, within water depths up to 35 m. For Artic sites of interest, the surface buoy is intended to be deployed to provide near real-time data telemetry during ice free conditions only, while the bottom mount can remain deployed year round, measuring and internally recording, under sea surface ice cover.

Starting in 2014, CO-OPS has been working on the design and development of the real-time system described above. Initial field trials completed in the Chesapeake Bay region during 2014 were reported at the MTS/IEEE Oceans'15 Conference and the MTS/ONR 2016 Buoy Workshop [12]. The focus of this paper is on following design improvements to the prototype system, along with results from the two most recent field trials, conducted during 2015-2016.

First, top-level system requirements are provided followed by a system design description and recent field test results. Details on the analysis and evaluation of water level measurements from the system's bottom mounted pressure gauge, along with a discussion addressing sources of measurement error are presented in a separate paper that is included in this conference's proceedings and technical program [13].

II. SYSTEM REQUIREMENTS

The following is a summary of top-level system requirements that have driven the design of the latest prototype ocean/met system:

A. Data Sampling and Telemetry

- The system's bottom-mount component will collect 6-minute average measurements of water conductivity, temperature, and pressure (CTP); and 30-minute measurements of vertical current profile and surface waves.

- Data will be transmitted from the bottom platform to the buoy near real-time via an acoustic modem system, at the same rate as parameter sampling – C,T, and P every 6 minutes and currents and waves every 30 minutes.

- The surface buoy will collect 6-minute average measurements of near surface water conductivity and temperature, true wind speed/direction, air temperature, and barometric pressure.

- The surface buoy will be equipped with a real-time satellite telemetry system; real-time, satellite data telemetry from the buoy will be at the same rate as parameter sampling: C, T, P, and meteorological data every 6 minutes; currents and waves every 30 minutes.

- The system must operate with real-time data telemetry for a minimum 90 day duration; the bottom mounted component of the system must be capable of measuring C, T, P, currents and waves with internal recording for a minimum 18 month duration.

B. System Communications

- The buoy will be equipped with a low power, wireless connection to its data collection platform with at least a 60 m (200 ft) range.

- The buoy will be equipped with a primary communication system to be used for all real-time data telemetry and an additional, secondary 2-way communication system for remote system troubleshooting.

- The buoy's data logger/controller will include the capability to issue a full suite of commands to the acoustic modem system; commands can be issued from the logger to the modems when connected to the remote 2-way communication system.

C. Other System Features

- The bottom mount component will have no surface presence and be retrievable with an acoustic release and popup float system.
- Bottom mount and buoy will each remain under 160 kg (350 lbs), to be deployable and recoverable from a small vessel with minimal overhead lifting capability.
- The buoy's power system will be solar chargeable and capable of continuously operating for at least a 10 day period with no sunlight.

III. SYSTEM DESIGN

Figure 1 shows a depiction prototype system's two components, bottom mounted ocean sensor platform and surface buoy, and Figure 2 shows a high-level system design diagram. One key feature of both components is modularity. Although prototype systems discussed here only measure CO-OPS' top priority parameters, additional sensors could be integrated for future applications with relatively little additional system design effort.

A. Surface Buoy

System requirements described above and several preliminary design discussions led to the decision to search for a commercial-off-the-shelf (COTS) buoy platform that includes a solar chargeable power system. The rest of the buoy payload was designed using individual COTS components with hardware and software integration completed by CO-OPS. The weight of payload components and the system's power requirements were primary drivers in the selection of a COTS buoy. Table I lists the make and model of the main components that were selected for the buoy payload, along with approximate weights of each.

A power budget was calculated for the buoy payload based on the components listed in Table I and the required sampling and telemetry frequencies. Estimated average current draw for the system is 214 mA and daily average usage is 5.15 Ah. Based on total weight and power requirements of the payload, the COTS buoy selected was a NexSens Technology model CB-950 buoy with three 30 W, 12 VDC solar panels and three 28 Ah batteries. Key dimensions of the NexSens CB-950 are shown in Figure 3 (drawing from the product brochure, reused with permission from NexSens) and key specifications are listed in Table II.

The payload's data logger and communication system components are installed in water-tight enclosure box that is mounted inside the buoy's solar panel tower. The three, 28-Ah batteries are installed in the buoy hull's inner well.

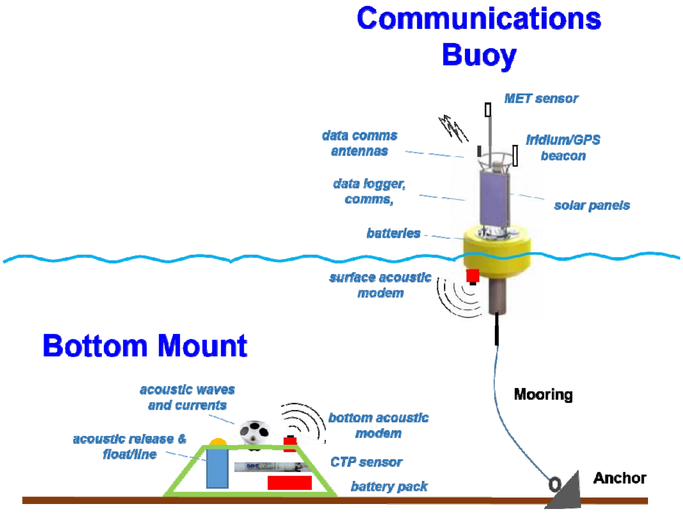

Fig. 1. Depiction of the bottom mount and surface buoy; the buoy is intended for use in ice free conditions only.

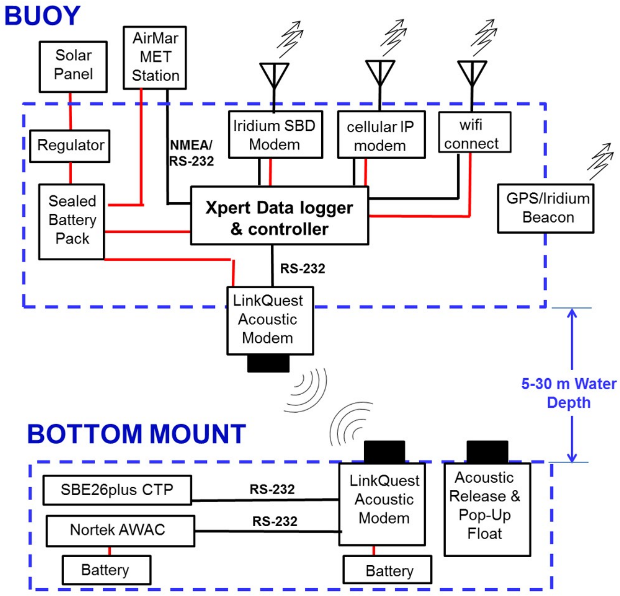

Fig. 2. System design schematic for the bottom mount and surface buoy.

The buoy's hull includes three 15.2 cm (6 in) diameter PVC wells for housing additional near surface ocean instrumentation. One of these wells is used to house the surface unit of the acoustic modem pair. A custom 15.2 cm PVC extension well with end cap is attached to the base of one of the wells.

TABLE I. COMPONENTS OF BUOY PAYLOAD WITH WEIGHTS

System Component	**Make/Model**	**Weight (lbs)**
Data logger/controller	Sutron, Xpert Dark	3
Communications	Sutron, Iridium 9610N SBD modem	0.17
	Sierra Wireless, Airlink LS300, Wireless IP Modem	0.2
	Roving Networks WyFly, GC-WIFLY-DTE, wireless module	0.1
	LinkQuest 2000H acoustic modem	8
Meteorological Sensor	AirMar WX-150 all-in-one met sensor	0.8
Misc mounts and hardware	DCP/comms	2
	Met sensor	5
	Antennas	5
	Acoustic modem	5
	Standalone nav light	10
	Iridium/GPS beacon	2.3
Misc Cabling		10
	Total Weight (lbs)	**51.57**

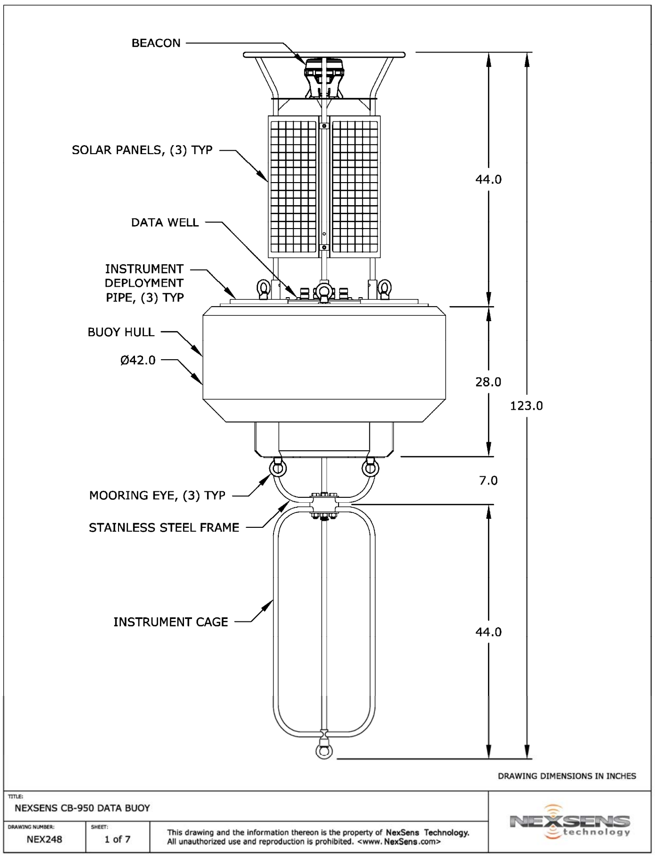

Fig. 3. NexSens CB-950 buoy (drawing from NexSens' online brochure).

TABLE II. KEY BUOY SPECIFICATIONS

Hull Dimensions	42" (106.7 cm) outside diameter; 20" (50.80 cm) tall
Tower Dimensions	44" (111.76 cm) tall, 7/8" tubular
Main Inner Well Dimensions	9.9" (25.15cm) inside diameter; 26" (66.04cm) tall
Weight in Air	250 lbs
Buoyancy	950 lbs
Hull Material	Cross-linked polyethylene foam with polyurea coating & stainless
Tower/Hardware Material	304 stainless steel
Mooring Attachments	1 or 2 point, ¾" eyenuts
Solar Power	(3) 30-watt 12 VDC solar panels
Batteries	(3) 28 Ah

The surface acoustic modem unit is attached to a 14.9 cm diameter (5 7/8 in) PVC pipe that can be inserted into the extended buoy well. This can be done before or after the buoy is deployed, depending upon logistics of the operation. The PVC pipe with surface acoustic modem is held into place by a compression cap that mounts to the top of the well. This setup will result in the modem's acoustic transducer being located approximately 46 cm (18 in) below the base of the buoy hull. Figure 4 shows a picture of the PVC extension well attached to the buoy, prior to the insertion of the surface acoustic modem unit.

After all payload components are added to the surface buoy, its total weight is less than 136 kg (300 lbs).

The buoy mooring used in the all field trials to date was designed with assistance from Dor-Mor, Inc. The basis is an all-chain, slackline mooring that provides a 2:1 scope. Design details are based on buoy specifications shown in Table II and adapted for each field trial, depending on specific site conditions. For the most recent field trial, 1.3 km (0.7 nmi) off the Atlantic coast of southeast Virginia (further discussed in section IV below), the following field site conditions were used for mooring design:

- Depth, average: 9.1 m (30 ft,) max: 10.7 m (35 ft)
- Sand/mud bottom
- Maximum expected surface currents: 3 m/s (1.5 kts)
- Maximum expected significant wave height: 4 m
- Deployment duration: 90 days
- Desired radius of buoy's watch circle: 18.2m (60 ft) or less

Mooring components selected for this example, top down:

- Shackel 5/8 in
- Swivel 3/4 in
- Shackel 3/4 in
- Heavy Chain 3/4 in, 10 ft length,

- Shackle/Swivel 3/4 in
- Jacketed Galvanized Wire (for mounting CT sensor) 3/16 in, 6 ft length
- Shackle/Swivel 1/2 in
- Light Chain 1/2 in, 18 ft
- Shackle/Swivel 5/8 in
- Medium Chain 5/8 in, 35 ft length
- Shackel 3/4 in
- Pyramid Anchor 136 kg (300 lb)

The pyramid anchor is designed to optimally penetrate the seafloor upon deployment, for quick submergence. When completely submerged under a sand/mud bottom, the anchor has a specified holding strength of 10 times its weight.

Figure 5 shows a picture of the system's surface buoy deployed for an initial wet test in a shallow water lake near NOAA's Chesapeake, VA office.

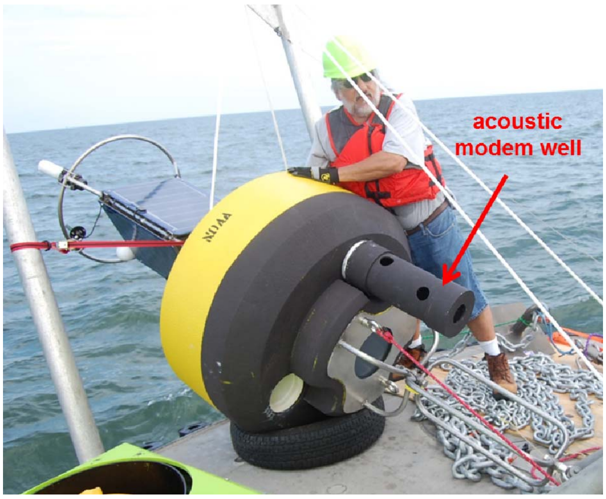

Fig. 4. Surface acoustic modem well attached to the base of the buoy hull, before acoustic modem is inserted.

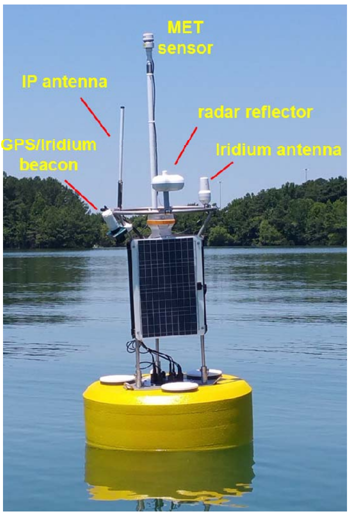

Fig. 5. Surface buoy deployed for initial wet test at local park lake.

B. Bottom Mount

The basis of the bottom mounted platform's frame is a Mooring Systems, Inc. General-Purpose Trawl Resistant Bottom Mount (GP-TRBM). There are two primary sensors on the system's bottom mount component: 1) a SeaBird SBE 26plus CTP sensor, which includes a high accuracy Quartz crystal pressure sensor, and 2) a NortekUSA Acoustic Current and Waves sensor (AWAC). In addition to these two sensors, the GB-TRBM houses the bottom component of the acoustic modem pair, battery canisters for the acoustic modem and AWAC, and an EdgeTech SPORT LF acoustic release rigged to the GP-TRBM's standard pop-up float/line recovery system (Figure 6). After all components are added the GB-TRBM, the bottom mount's total weight is approximately 340 lbs.

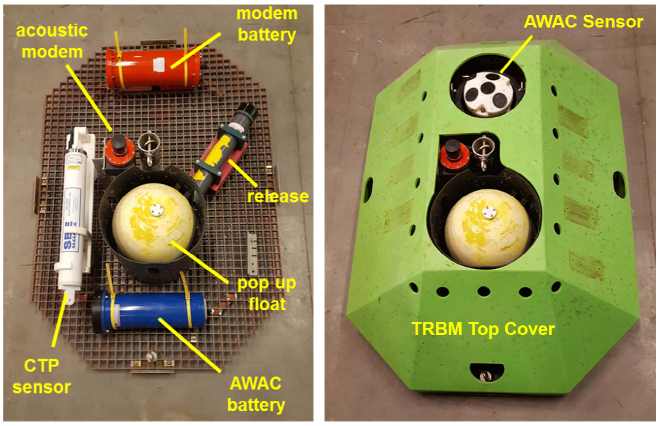

Fig. 6. The mottom mount platform, GP-TRBM without (left) and with cover (right).

IV. FIELD TEST RESULTS

Throughout 2014-2016, CO-OPS conducted three field trials with an evolving prototype system based on the design shown in Figures 1 and 2. Test sites covered three distinct Atlantic coastal environment types (locations shown in Figure 7's two maps):

- September-December 2014, South Chesapeake Bay, Virginia
- September-December 2015, St. Andrews Sound, Georgia
- September-December 2016, southeast Virginia, Atlantic Ocean coast

Average water depths at all three sites were approximately 9.1 m (30 ft)

Details of the 2014 field test conducted with the initial version prototype system, in the South Chesapeake Bay, were presented at previous MTS\IEEE and MTS conferences [12]. Only a short summary is given here. Results from the most recent two field tests, during 2015-2016, are reported in more detail.

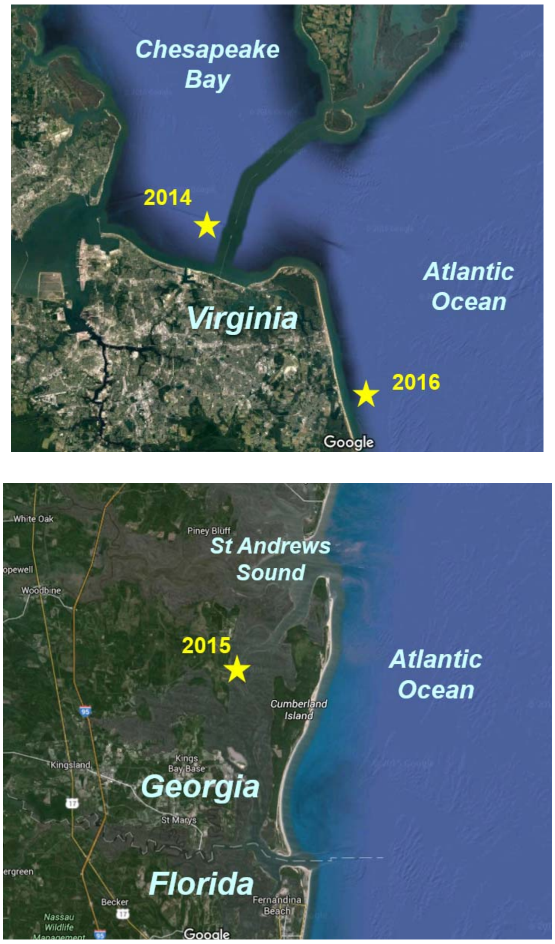

Fig 7. Locations of the system's three major field trials, marked by test year.

A. South Chesapeake Bay, Virginia 2014

The first field trial in 2014 involved deploying the initial version prototype system near the mouth of the Chesapeake Bay, approximately 5.56 km (3 nmi) north of the Virginia Beach, Virginia coastline and 609 m (2,000 ft) West of a CO-OPS maintained NWLON station on the southernmost island of the Chesapeake Bay Bridge and Tunnel. The initial prototype system's buoy component did not include the full communications system depicted in Figure 2 here, but only the primary data telemetry system, an Iridium Short Burst Data modem (SBD). Also, the bottom mount included only one of the two primary sensors, the SBE26plus CTP.

Over the first 5 days of deployment, the system operated as expected continuously, with approximately 98% successful data throughput rate. Late on day 5 however, an issue with a bulkhead connection leak on the buoy's inner well was encountered during the passage of a high wind, nor'easter storm event. After Iridium data transmissions from the buoy failed, a service visit followed to assess the damage and to recover the buoy. An on-site acoustic communications check indicated the system's bottom mount component was operating as expected so it was left on the sea floor. The buoy component was recovered, repaired, tested, and re-deployed at the same location next to the bottom mount by October 8, 2014. Following deployment of the repaired buoy, the system operated successfully through early December 2014 [12].

Results from the 2014 test motivated several system design enhancements, including moving the buoy payload from the inner well up to the tower, simplifying the cable/connector layout and implementing the full communications suite as depicted in Figure 2. Also, the acoustic modem system's command suite was implemented on the buoy system's data logger for ease of buoy-to-bottom platform acoustic communications checks and diagnostics, either on-site or via remote 2-way connection to the buoy payload.

B. St Andrews Sound, Georgia, 2015

The second major field trial, of the prototype system, was conducted within the St Andrews Sound, along the southeast coast of Georgia (Figure 7) from September 17 through December 7, 2015. Primary motivations for test site selection included:

- NOAA\NOS' Office of Coast Survey was conducting a hydrographic survey in the region, offering the opportunity to demonstrate prospective data applications.
- The site offered several challenging environmental conditions including: tidal water level ranges as high as 2.1 – 2.4 m (7-8 feet); tidal currents as high as 1.25 – 1 m/s (2.5 - 3 knots); long ranges of remote marsh coastlines with no infrastructure; dynamic bottom morphology.

The 2015 prototype system included the full buoy communications suite as depicted in Figure 2, however the bottom mount component again included only one of the two primary sensors, the SBE 26plus CTP sensor.

The vessel used for deployment and recovery of the system was the 72-foot R/V Georgia Bulldog (Figure 8), a former shrimp trawler based in Brunswick, Georgia, operated by the University of Georgia's Marine Extension.

The 81 day Georgia test was considered a success as the prototype field test system met all performance requirements. The system sampled the following parameters at a 6 minute rate: bottom pressure, water temperature and conductivity, wind speed and direction, barometric pressure, air temperature, and system battery voltage. All data were transmitted via Iridium SBD and the system demonstrated a real-time throughput success rate greater than 96%.

Figure 9 shows daily average real-time throughput rates for the 81 day field test (the percentage of the 240 expected daily 6 minute messages that arrived to CO-OPS data server on time). With the exception of 5 days, daily real-time data throughput rates were greater than 95%. Although the long-term, average real-time data throughput rate was very high, the Figure 9 plot indicates an issue noted during this test: on days where data throughput was less than 95%, dropout periods were always several hours; there was never an instance where only a small number of 6 minute transmissions were missing. Further evaluation of results indicated that dropouts were a result of an acoustic modem configuration setting, while there was no indication of significant issues with the Iridium SBD performance. Further discussions with LinkQuest technical support indicate this was a result of a ‘sleep mode’ feature, where after a failed transmission, the acoustic modem continually increases the time between subsequent unsuccessful transmission retries to conserve power. An attempt to optimize this particular acoustic modem configuration setting will be pursued in following work.

Figure 10 shows select data from the test system collected over the 81 day field test: wind speed (top), processed water levels (middle) and water temperature and salinity (bottom). The tidal (astronomical) and non-tidal (residual) components of water level overlaid in the middle plot were derived using Dr. John Boon’s “TC Tools” Matlab harmonic analysis tool [ref]. Results show a perigean spring tide captured on September 28 (Julian Day 271) with a tidal water level range greater than 3 m. Also captured are several high wind storm events that correspond to residual water levels exceeding 0.5 m. The salinity time series shows the expected summer-to-fall seasonal transition, while several sudden drops are likely due to near-bottom sediment fouling of the conductivity sensor. Impacts of conductivity sensor fouling experienced during this test are further discussed in reference 13.

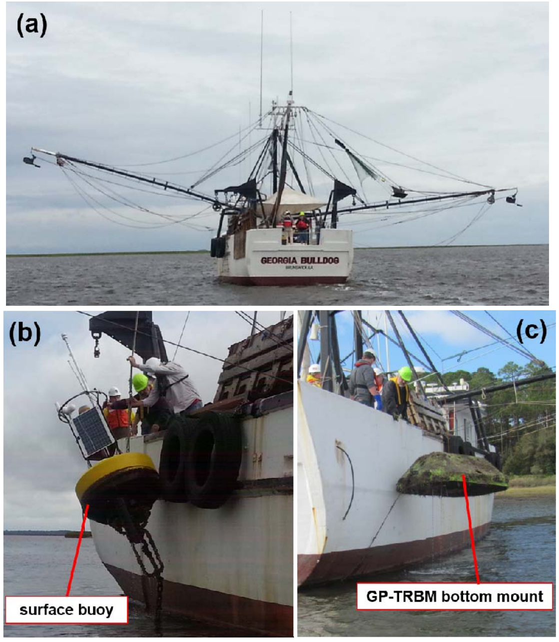

Fig 8. System recovery from University of Georgia’s R/V Georgia Bulldog.

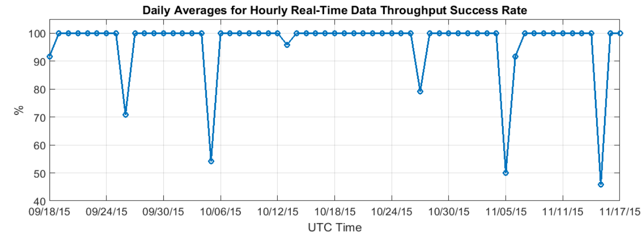

Fig 9. Daily average real-time data throughput success rate.

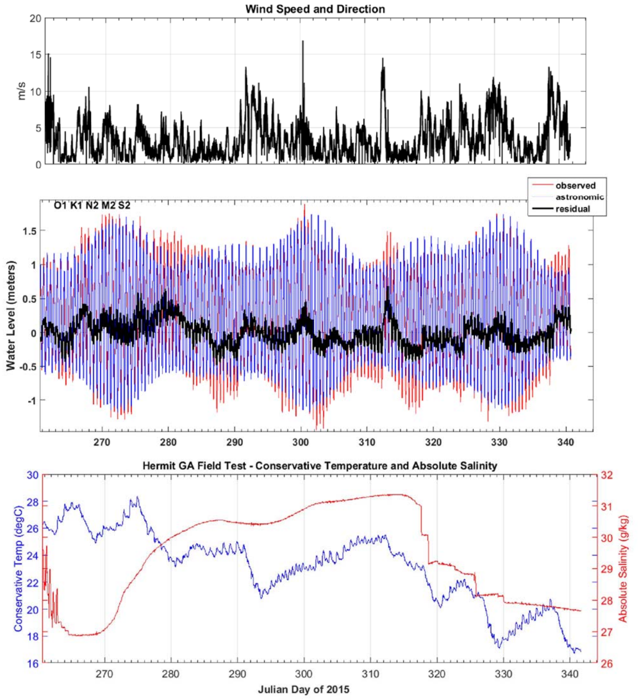

Fig 10. Select data collected during the 2015 Georgia field test (from top down): wind speed, processed water levels, water temperature and salinity

C. Atlantic Ocean Coast, Southeast Virginia, 2016

The most recent field test of the latest version prototype system was conducted in the Atlantic Ocean, approximately 1.3 km (0.7 nmi) off the coast of Virginia Beach, VA (fig 7) from September 14 through October 18, 2016. Details of the site are listed in section II above (along with buoy mooring design details). This was the prototype system’s first field trial in an open ocean environment.

The 2016 version prototype system included all system features depicted in Figure 2. The bottom mount component included both primary sensors, the CTP and the AWAC. The acoustic modem pair was upgraded to include LinkQuest’s “data fusion” capability, allowing the two bottom mounted sensors to be integrated to a single acoustic modem channel. Software modifications on the buoy’s Xpert data logger enabled logging and data transmission for the two primary sensors’ measurement records using one acoustic channel.

The prototype system was deployed from the Crusader - a 45 ft re-purposed Coast Guard lifeboat, owned and chartered by the Cape Henry Launch Service (CHL), Virginia Beach, VA [11]. Figure 11(a) shows the Crusader underway with the buoy and bottom mount loaded; (b) and (c) show the buoy and bottom mount being deployed from the aft deck.

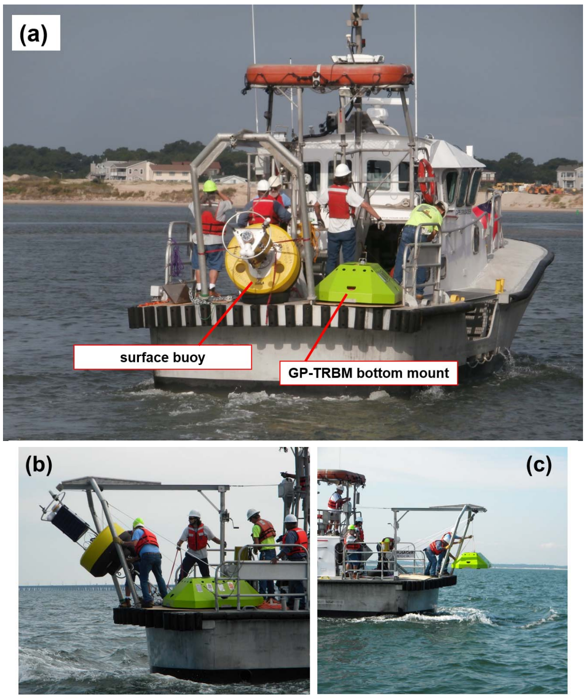

Fig 11. 2016 Atlantic Ocean test deployment; (a) the Crusader underway with the buoy and bottom mount loaded (b) buoy and (c) bottom mount deployments

The prototype system performed well over the first few weeks of the Atlantic Ocean field test, which included several high wave events. Unfortunately, the field test was concluded significantly earlier than planned due to the passage of Hurricane Matthew across through the test region, during October 8-9 (Figure 12). However, the extreme conditions associated with the major storm event resulted in the capture of a very unique ocean/met data set and the conduct of a valuable system survivability test.

The top panel of Figure 13 shows the system's real-time daily average real-time data throughput rates during the 2016 test. These percentages are representative of all parameters sampled and transmitted from the system: bottom pressure, water temperature and conductivity, wind speed and direction, barometric pressure, air temperature, and system battery voltage (6 minute rate), current profile and bulk wave parameters (30 min rate). The bottom two panels of Figure 13 show full record of system's internally logged data (downloaded post recovery) for two parameters to indicate the timing of the storm passage: wind speed (middle) and significant and maximum wave heights (bottom panel).

During the first 24 days of the field test the system performed very well, with greater than 95% real-time data throughput rate on 5 days when maximum wave heights exceeded 3 meters. One large data communication dropout occurred during September 27-28. This was a result of a software issue on the buoy system's Xpert data logger. The software issue was addressed remotely on September 29 and system throughput resumed with rates above 95% until the nearby passage of Hurricane Matthew brought wind gusts exceeding 30 m/s and maximum wave heights exceeding 7 m. During peak storm conditions (late October 8), the buoy's locator beacon indicated the buoy had moved outside of its watch circle and started to drift southward, at approximately 0.12 m/s. Shortly after, the buoy lost acoustic communications with the bottom mount, but continued to collect met sensor readings and transmit shortened Iridium SBD messages. After approximately 8 hours of transit, the buoy stopped at a new location, with close to the same water depth (9.1 m), and approximately 3.7 km (2 nmi) southward. The buoy remained at its new location for 9 days until weather conditions permitted a safe recovery.

On October 18, 2016, both prototype system components, the surface buoy and bottom mounted sensor platform, were successfully recovered. Both components were found to be fully operational and still measuring and logging data, although there was no bottom mount to buoy's real-time acoustic link due to the 3.7 km range between the two components. The bottom mount with CTP and AWAC sensors was recovered at the original deployment location and the buoy was recovered 3.7 km south at it's new locations. Upon recovery, the buoy's payload was fully operational with no signs of major system damage. A connection was successfully made to the buoy payload using the wireless communications link, prior to recovery. The mooring was found intact. It has been hypothesized that the Dor-Mor pyramid anchor became detached from the sea floor during episodic storm event and then it reset and re-submerged itself on the sea floor at the new location. Although the buoy's mooring proved not to be suitable for the unexpected 7 m maximum wave height (in 10 m water depth), the buoy payload survived the extreme event. Additionally, the bottom mount remained operational and upright with its CTP and AWAC sensors capturing the event.

Additional observations captured by the system's bottom mounted sensors are presented in Figure 14, including water depth, near surface currents, and non-directional wave spectra. Additional analysis of the unique storm event that was captured will be pursued in subsequent work and further discussed during the conference presentation. Of particular interest are the wave data captured by the bottom mounted AWAC during the passage of Hurricane Matthew.

The authors acknowledge that following analysis of the storm wave event captured in the test system's AWAC record must include detailed evaluation of the sensor's ancillary measurements and QA parameters, similar to previous works involving analysis of large wave events captured by nearshore, bottom mounted AWAC sensor [14]. Preliminary observations shown here (Figure 15) include a set of example hourly power spectral density (PSD) measurements from the AWAC, before the storm passage, Oct. 4, at the initial arrival of Hurricane generated swell (from the South), Oct. 6, and nearby the peak of storm conditions, Oct. 9. For initial comparison, also included in these plots are corresponding PSD measurements from a nearby wave rider buoy, operated by the Scripps Institute of Oceanography Coastal Data Information Program (CDIP) [15]. The CDIP Buoy (Cape Henry, VA Station 186, shown in Figure 12) is approximately 15.5 km (8.4 nmi) offshore of the Virginia coast, in 11.9 m (39 ft) water.

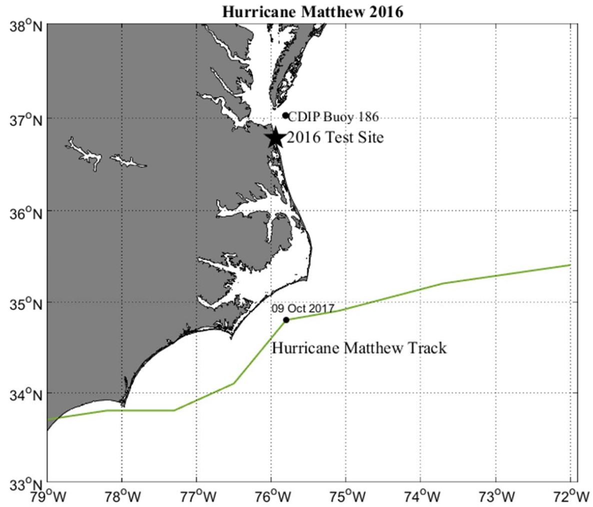

Fig 12. Storm track of the center of Hurricane Matthew relative to the field test location (marked "Hermit")

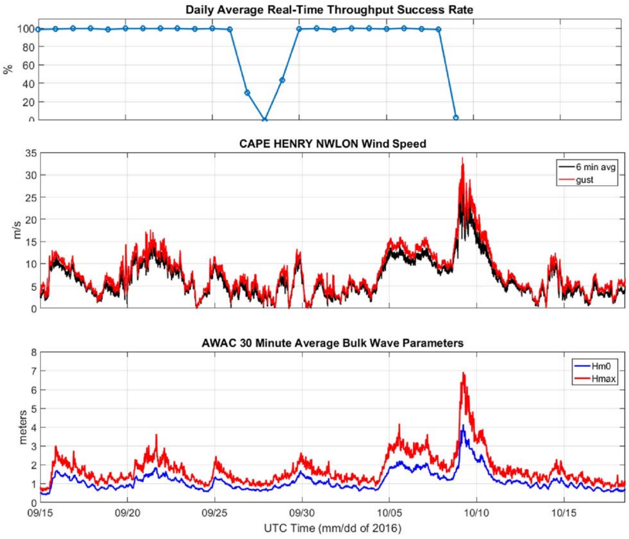

Fig 13. Data from 2016 ocean test., raily average real-time data throughput success rate, wind speed and gusts, signficant and maximum wave height.

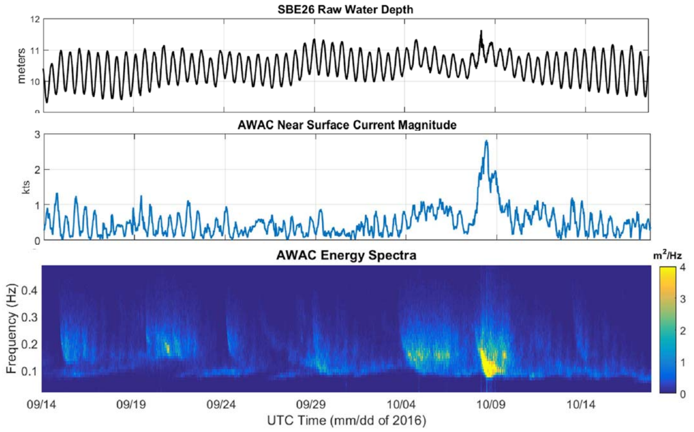

Fig 14. Select data measured by the field test system in 2016 (from top downward) raw water depth, near surface currents, and non direction surface wave spectra.

V. SUMMARY

NOAA\NOS\CO-OPS recognizes the rapidly changing environmental conditions within the U.S. Artic EEZ along with the potential for increased maritime traffic throughout the region. There are many gaps in the current NWLON network along the western and northern coasts of Alaska and there will likely be a growing need for real-time oceanographic and meteorological observations along these coasts to support safe and efficient navigation.

As an initial step to meet these anticipated growing maritime needs, CO-OPS has been working on the design, development and testing of a real-time ocean\met measurement system for use in remote Arctic coastal regions with very limited infrastructure. One key feature of measurement system under development is modularity. Integration of additional sensors to support a variety of potential future missions could be completed with relatively little additional design effort.

Based on system developments and successful prototype field trials, CO-OPS considers the system to be at the technology readiness level 6 [16]. Critical next steps toward transition through technology readiness levels 7-9 include completing a field demonstration in a relevant environment, along the North coast of Alaska, and commencing a technology transfer process with a regional partner who can support CO-OPS' future needs. CO-OPS is currently planning such a field trial for 2018.

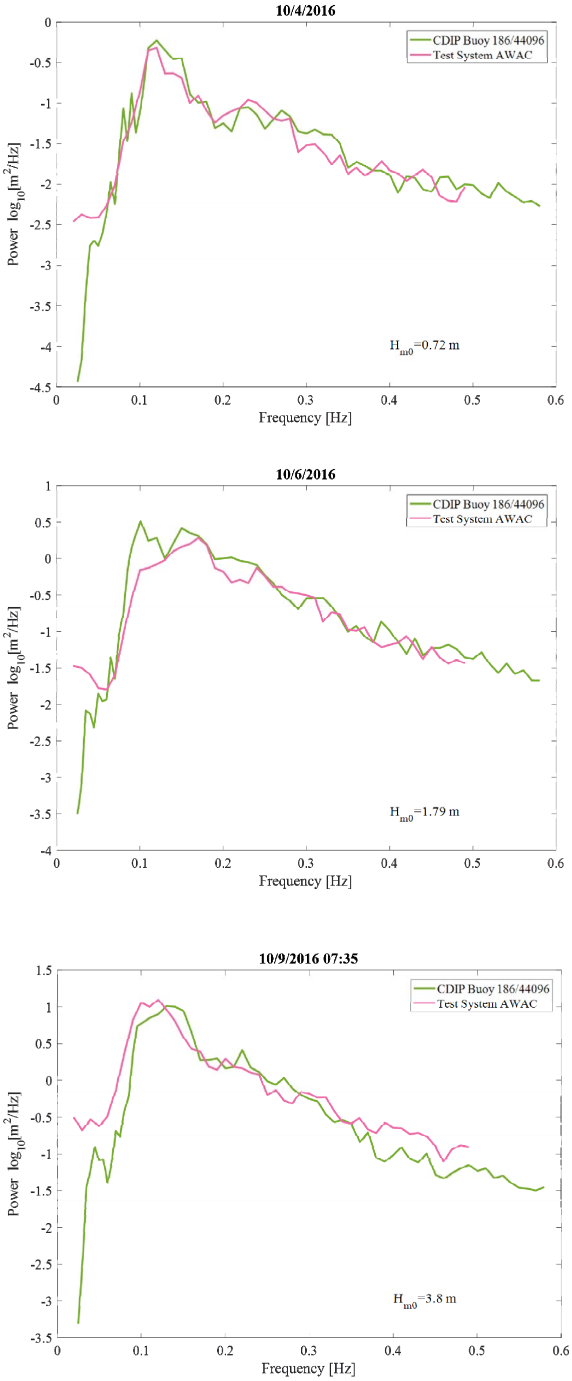

Fig 15. Example hourly PSD measured by the test system's AWAC and the nearby CDIP Wave Rider (187) befor the storm and during it's passage

REFERENCES

[1] M. C. Serreze, Crawford, A., Stroeve, J. C., Barrett, A.P. and Woodgate, R.A. Variability, trends and predictability of seasonal sea ice retreat and advance in the Chukchi Sea. Journal of Geophysical Research, 121, October 2016.

[2] M. Jeffries, J. Richter-Menge, J. Overland, Arctic Report Card: Update for 2014, NOAA online report, January 2015:

http://www.arctic.noaa.gov/reportcard/

[3] D. Perovich, J.. Richter-Menge, Regional variability in sea ice melt in a changing Arctic, Philosophical Transactions of the Royal Society A, vol. 373 (2045), June 2014.

[4] IPPC, Climate Change 2013: The Physical Science Basis, Contributions of Working Group I to the Fifth Assessment Report of the Intergovernmental panel on Climate Change, Cambridge, United Kingdom and New York, NY, USA, Cambridge Univseity Press, 2013.

[5] U.S. Committee on the Marine Transportation System (CMTS), 2013. U.S. Arctic marine transportation system: overview and priorities for action: http://www.cmts.gov/downloads/CMTS%20U%20S%20%20Arctic%20MTS%20Report%20%2007-30-13.pdf

[6] C. Peralta-Ferriz, J.H. Morison, S.E. Stalin, C. Meinig, Measureing the Ocean Bottom Pressure at the North Pole, Mariten Technology Society Journal, v 48 (5), September/October 2014.

[7] R. Woodgate, Aagaard, K., Weingartner, T. Whitledge, I. Lavrenov, University of Washington, Applied Physics Laboratory, Bering Strait Pacific Gateway to the Arctic:

http://psc.apl.washington.edu/HLD/Bstrait/bstrait.html

[8] Cynthia S. Trav, Quantifying Sea-Ice Volume Flux using Moored Instrumentation in the Bering Strait. Masters Thesis, Uniteristy of WA, 2012 http://psc.apl.washington.edu/HLD/Bstrait/TraversC2012_MScThesis_BeringStraitIceFlux.pdf

[9] Woods Hole Oceanographic Institution's Beaufort Gyre Exploration Project: http://www.whoi.edu/beaufortgyre/

[10] NOS Hydrographic Surveys Specifications and Deliverables, Department of Commerce, National Oceanic and Atmospheric Administration, April 2015:

http://www.nauticalcharts.noaa.gov/hsd/specs/Specs_2015.pdf

[11] J. Sprenke., S. Gill, J. Kent, and M. Zieseri. 201,. Tides under the ice: measuring water levels at Barrow, Alaska 2008-2010. NOAA Technical Report NOS CO-OPS 062,. Silver Spring, Maryland, 201:

http://tidesandcurrents.noaa.gov/publications/Tides_under_the_Ice_Measuring_Water_Levels_at_Barrow_Alaska_2008-2010.pdf

[12] R. Heitsenrether, Hensley, W., Krug, W., Breuer, E., Development of a standalone real-time water level measurement system to support safe navigation along Alaska's arctic coasts. MTS/IEEE Oceans'15 Washington D.C. Conference Proceedings, October 2015.

[13] E. Breuer, Heitsenrether, R., Fiorention, L., Hensley, W., Krug, W., Error analysis of sea level measured from a bottom mounted ocean platform. MTS/IEEE Oceans'17 Anchoage, AK Conference Proceedings, September 2017.

[14] Magnell Current and wave measurements off the coast of New Jersey during the second most severe storm of the past 28 years. IEEE\OES 11th Current Waves and Turbulence Measurement Technology Conference St Patersburg, FL, Conference Proceedings, March 2015.

[15] Sripps Institue of Oceanography Coastal Data Information Program website: https://cdip.ucsd.edu/

[16] NASA Technology Readiness Level definitions: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html