Development of a Standalone Real-Time Water Level Measurement System to Support Safe Navigation Along Alaska's Arctic Coasts

Robert Heitsenrether, Winston Hensley, Warren Krug, and Eric Breuer
Center for Operational Oceanographic Products and Services
U.S. National Oceanic and Atmospheric Administration
Chesapeake, VA

Abstract*— The United States National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) is responsible for developing and maintaining the National Water Level Observation Network (NWLON) which consists of over 200 long term observatories throughout all U.S. coasts. CO-OPS continually pursues efforts to identify potential improvements to its observatory network. Many recent studies on global climate change have identified a significant increase in Arctic warming rates. Resulting trends of increased sea ice loss have led to Arctic waterways becoming more accessible during summer seasons. As a result, an increase in maritime transport throughout the region is anticipated for the near future. Presently, Artic waters within the U.S. Exclusive Economic Zone (EEZ) have very few navigational support products and services. NOAA, recognizing the changing conditions, anticipates a growing, critical need for real-time oceanographic and meteorological observations across the region. In support of long term modernization plans, CO-OPS has been working on the design, development, and testing of a standalone, real-time water level measurement system for use in remote Arctic coastal regions with very limited infrastructure. Two types of system designs have been identified, for short and long term applications. Both design types include a bottom mounted pressure gauge for the primary source of water level measurements. The long-term system design involves a cable run from an offshore bottom mounted pressure gauge to a small, shore station. The short term system design includes a surface buoy with satellite telemetry and acoustic modem; and a bottom unit consisting of a conductivity, temperature, pressure sensor and acoustic modem. The buoy based system is intended for real-time communications during ice-free periods. Details of the short-term version system design will be presented along with results from a recent field trial conducted in the lower Chesapeake Bay region near Virginia Beach, Virginia during 2014-2015. Plans for continuing system development and test will be discussed.

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

I. Introduction

The United States National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) is responsible for developing and maintaining the National Water Level Observation Network (NWLON). NWLON consists of over 200 long term observatories that provide near real-time, 6 minute average, water level observations from locations throughout all U.S. coasts, including the Great Lakes and U. S. island territories. Like most operational oceanographic observation programs, CO-OPS continually analyzes state-of-the-art and emerging technologies to identify potential improvements in data quality and operating efficiency and to maintain core expertise for authorized missions.

Many recent studies on global climate change have identified the Arctic as warming faster than any other region on Earth [1-3]. Resulting trends of increased sea ice loss have led to Arctic waterways becoming more accessible during summer seasons along with an anticipated 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 [4].

NOAA, recognizing these changing environmental conditions within the U.S. EEZ, anticipates a critical need for real-time oceanographic and meteorological observations along with a suite of new navigation charts to support safe navigation across the region. To date, CO-OPS operates 26 long-term NWLON tide stations in Alaska, 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 modernization plans for the NWLON observatory network, CO-OPS has been working on the design, development and testing of a real-time water level measurement system for use in remote Arctic coastal regions with very limited infrastructure. Two types of real-time system designs have been identified, for short and long term applications. Both design types include a bottom-mounted pressure gauge as the primary source of water level observations.

To date numerous bottom mounted pressure gauges have been deployed throughout the Arctic Ocean to support studies investigating variability of both water levels and ice coverage in order to better understand the rapidly changing Arctic environment [5-8], although most have been offshore, in deep water locations with limited real-time data telemetry. Also, bottom mounted pressure gauges have been deployed to measure water levels in shallow coastal regions to support NOAA hydrographic surveys where there is little shore based infrastructure, but typically with no real-time data telemetry at all [9]. The CO-OPS effort described here is focused on a design and development of an infrastructure free water level system with continuous real-time data telemetry for use in nearshore, coastal waters. An initial design is proposed with the intent of adapting to both long and short and long term deployment applications. CO-OPS primary applications of interest include supporting navigational safety, supporting hydrographic surveys, and establishing tidal datums in coastal regions where they remain unknown; data collected would also likely be very useful for various oceanographic research and coastal engineering applications, in particular for regions were no such long term, nearshore water level time series are currently available.

CO-OPS' proposed long-term system design involves a cable run from an offshore, bottom-mounted pressure gauge to a small, infrastructure-free shore station. The short-term system design includes a similar bottom-mounted pressure gauge along with a real-time communications buoy, to be deployed some distance away from the coastline. An acoustic link provides real-time communications between the buoy and bottom mount components. The buoy component is intended for real-time communications only during ice-free season; although the bottom-mount component could remain deployed while internally recording measurements without the real-time telemetry for extended periods under the ice. The buoy includes an Iridium satellite based real-time data telemetry system along with a meteorological station.

During 2008-2009, CO-OPS completed the test deployment of a bottom-mounted conductivity/temperature/pressure (CTP) sensor with acoustic communications offshore of Barrow, Alaska. The system was internally recording without real-time, surface communications. The acoustic link was used for intermittent data downloads from a user at the surface [10].

During 2013-2014, design and development of the two real-time systems described above was conducted leading up to an October 2014 field test deployment of the short term version system, the bottom-mounted CTP sensor with a surface communications buoy. Results from the 2014 field trial have been used to implement several design improvements to the system's buoy component during 2015. A following field trial of the system is planned to take place in the St. Andrews Sound region of Georgia during September 2015, in coordination with a NOAA Office of Coast Survey (OCS) hydrographic survey.

Details of the recently developed short term version system and results from the field trial are discussed in detail here. A summary of key, top level requirements are provided followed by a system design description, and then results from initial field trials. Finally, plans for continuing work are presented, including system design modifications to the buoy and plans for additional field trials.

II. System Requirements

The following top level system requirements were defined to drive the design of a first version, short term system during 2014:

- The system must operate with real-time data telemetry for a 6o day duration; the bottom mounted sensor must be capable of remaining deployed with internal recording for an 18 month duration.

- The bottom-mounted system will collect 6-minute average values of conductivity, temperature, and pressure (CTP); data will be transmitted to the buoy real-time via acoustic modem and also recorded internally on the bottom platform.

- The bottomed-mounted frame will have no surface presence and be retrievable with an acoustic release with popup float.

- The surface buoy will be equipped with underwater acoustic communications, a real-time satellite telemetry system with global coverage and a meteorological system that measures 6-minute average true wind speed/direction, air temperature, and barometric pressure.

- Real-time, satellite data telemetry from the buoy will be at an hourly rate.

- Each primary system component, bottom mount, buoy, and mooring will remain under 300 lbs each to be reasonably deployable and recoverable from a small vessel with minimal overhead lifting capability.

- The buoy's power system must be solar rechargeable and capable of continuously operating for at least 7 days with limited sunlight.

The following additional system requirements associated with buoy system enhancements were defined following results from the initial field trial in 2014 (more details are provided in sections IV and V) :

- Low power, wireless connection to the buoy's data collection platform with at least ~ 200 foot range
- Remote 2 -way communication connection to the buoy's data collection platform which can be turned on/off using Iridium mobile terminated messaging
- Implementation of the acoustic modem command functions onto the buoy's data logger/controller .

III. System Design

Figure 1 shows a depiction of the short term version system's two components, bottom mounted CTP sensor and surface communications buoy, and fig. 2 shows a high-level design diagram.

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 budget were primary drivers in 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 estimated based on the components listed in table I and the planned sampling and telemetry frequencies. Estimated average current draw for the system is 164 mA and daily average usage is 3.93 Ah. Based on total weight and power requirements for the buoy payload, the COTS buoy selected was a NexSens Technology model CB-950 buoy with three 12 VDC solar panels and two 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.

Figure 4 shows the buoy's 9.9″ diameter well where additional payload components are installed, including the data logger and communications system. The two 28-Ah batteries are installed at the bottom of the well. Available space above the batteries is approximately 13″ high. As shown in fig. 4, the buoy well includes two sections of all-thread that hold batteries in place. These two rods of all-thread were extended to run the entire height of the well. Figure 4 also shows how the extended all-thread is used to hold a custom fabricated mounting plate for internal payload components.

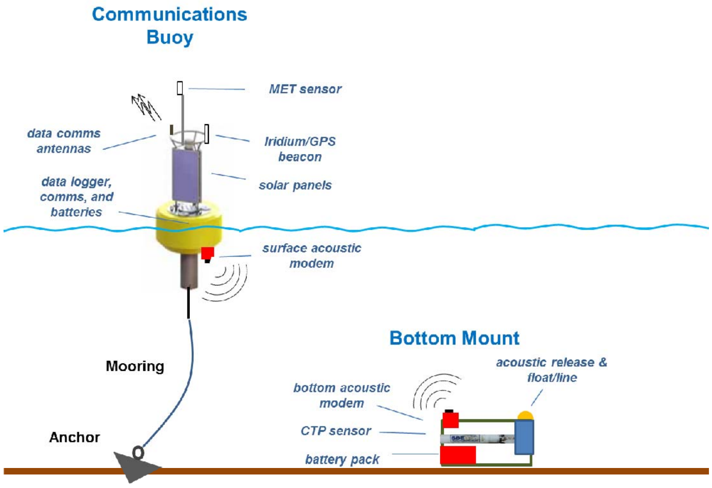

Fig. 1. Depiction of the short term version system, bottom mount and surface communicaitons buoy; the buoy is intended for use in ice free conditions only.

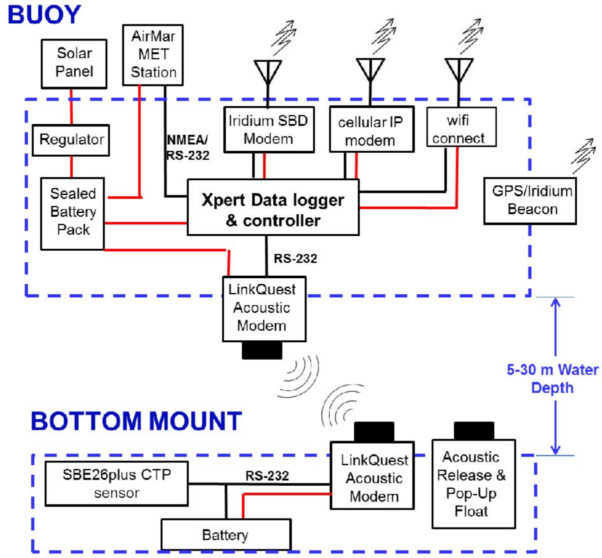

Fig. 2. System desin schematic for the bottom mount and surface buoy.

TABLE I. COMPONENTS OF BUOY PAYLOAD WITH WEIGHTS

System Component	Make/Model	Weight (lbs)
Data logger/controller	Sutron, Xpert Dark	3
Communications	Sutron, Iridium 9601N 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+ 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 Weigt (lbs)	**51.57**

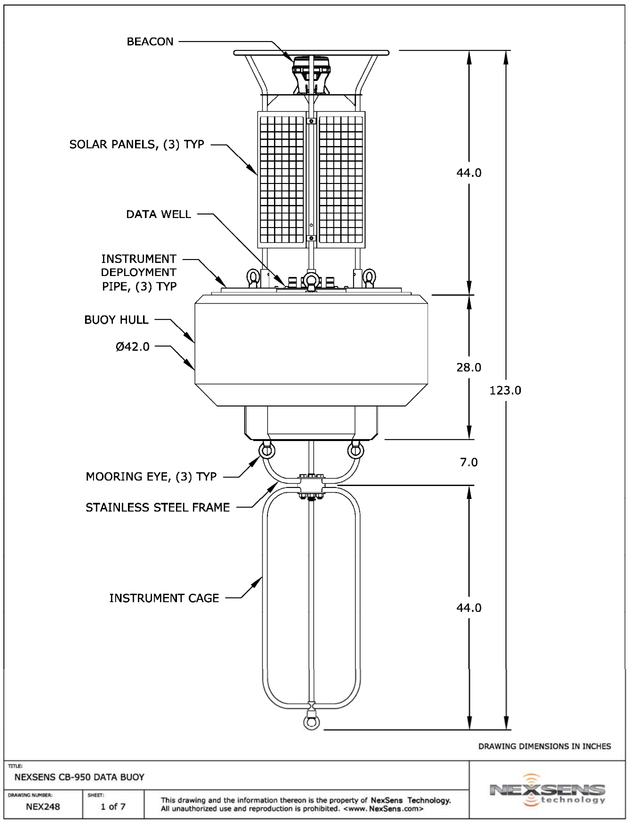

Fig. 3. NexSens CB-950 buoy (drawing from NexSens' online brochure, resused with permission from NexSens).

TABLE II. KEY BUOY SPECIFICATIONS

Hull Dimensions	42" (106.7cm) outside diameter; 20" (50.80cm) tall
Tower Dimensions	44" (111.76cm) tall, 7/8 tubular
Data Well Dimensions	9.9" (25.15cm) inside diameter; 26" (66.04cm) tall
Weight	250 lbs (including full vendor provided payload)
Buoyancy	950 lbs.
Hull Material	Cross-linked polyethylene foam with polyurea coating & stainless steel deck
Tower /Hardware Material	304 stainless steel
Other Material	Galvanized ballast chain
Mooring Attachments	1 or 2 point, ¾" eyenuts
Batteries	Two 28-Ah lead dry cell batteries
Solar Power	(3) 30-watt 12 VDC solar panels

The buoy's hull includes three 6″ PVC wells for housing additional ocean instrumentation to be submerged near the water surface. One of these wells is used for mounting the surface unit of the LinkQuest acoustic modem set.. A custom 6″ PVC extension well with end cap was added to one of the buoy instrumentation wells for mounting the surface acoustic modem. Figure 5 shows a drawing and a picture of the surface acoustic modem mounting well. To avoid damage to the modem's transducer the mount was designed to allow the option to insert the surface acoustic modem after the buoy is deployed. The surface acoustic modem can just as easily be installed prior to buoy deployment as well, if preferred.

The modem's base is attached to the bottom of a 2″ PVC pipe with a base flange. The cabled modem and pipe can be inserted down the extended 6″ well by pulling alongside the deployed buoy in a vessel. The modem and pipe are held into place using a compression cap that fits atop to the well opening. This setup provides the surface modem's acoustic transducer being located approximately 18″ below the buoy hull.

After all payload components were added, the buoy weighed slightly over 280 lbs.

The buoy mooring used in the first field trial was designed with assistance from Dor-Mor, Inc. The design was based on buoy specifications shown in table II and expected conditions at the planned test site in the lower Chesapeake Bay. The components from top down included:

- buoy mooring eye
- 5/8'' shackle
- 3/4'' swivel
- 5/8'' shackle
- 10' length of ¾'' chain (for additional ballast)

- 5/8" shackle
- 25' length of ½'' chain
- 5/8'' shackle
- 3/4'' swivel
- 35' length of 5/8" chain
- 5/8" shackle
- 200 lb pyramid anchor

Figure 6 shows a picture of the buoy deployed for an initial wet test in a shallow water lake near NOAA's Chesapeake, VA office.

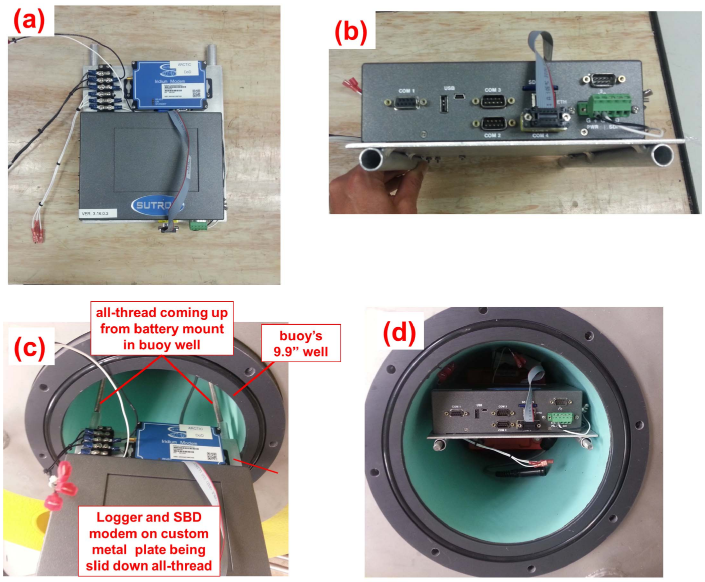

Fig. 4. Xpert logger and Iridium SBD momdem on custom mounting plate being inserted into buoy well using allthread sections as guide.

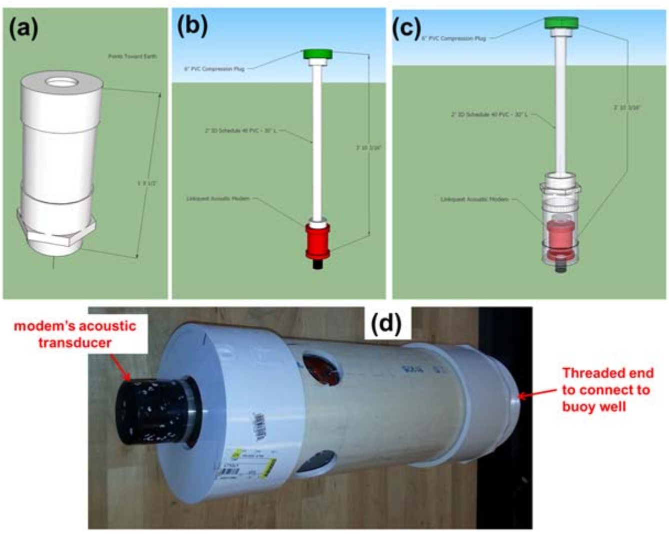

Fig. 5. Surface acoustic modem mount (a) threaded 6″ PVC well extension (b) acoustic modem mounted to PVC pipe with flange, (c) modem and mount inserted into well extension, (d) photo of acoustic modem inserted into well extension (prior to attaching to the buoy).

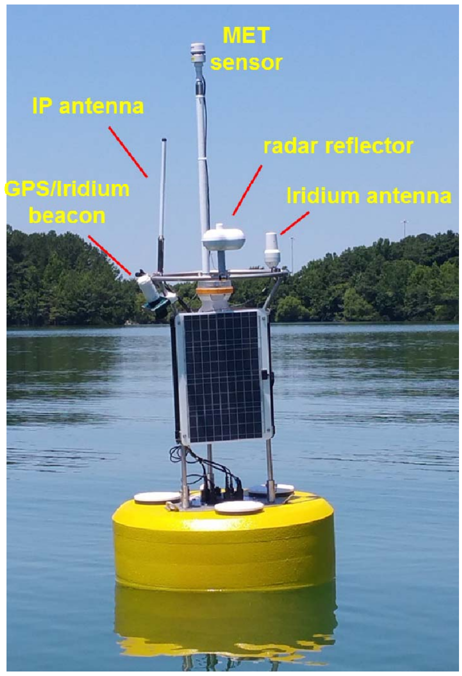

Fig. 6. Communications buoy deployed for initial wet test at local park lake.

B. Bottom Mount

The primary sensor package selected for this system is the SeaBird SBE 26plus conductivity, temperature, and pressure sensor, which includes a high accuracy Quartz crystal pressure sensor. The bottom mounted platform consists of a Mooring Systems, Inc. General-Purpose Trawl Resistant Bottom Mount (GP-TRBM), the SBE 26plus, the bottom component of the LinkQuest modem pair, and a battery canister that provides power to the modem. The three components are connected with a simple, custom fabricated 'Y' cable. Additionally, the GP-TRBM is equipped with an EdgeTech SPORT LF acoustic release rigged to the GP-TRBM's standard pop-up float/line canister. The total weight of the bottom mount in air is approximately 270 lbs.

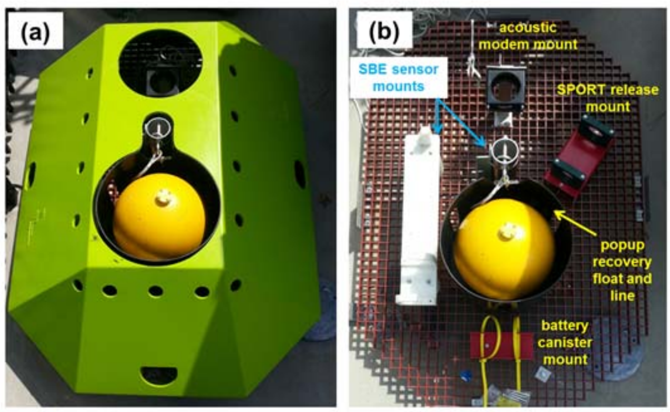

Fig. 7. The mottom mount platform, GP-TRBM with and without cover

IV. Initial Field Testing

An initial field test of the standalone real-time water level measurement system was conducted in the lower Chesapeake Bay during September – December 2014. This test involved the first version of the buoy system which did not include the wireless connection and cellular IP modem shown in the diagram in Figure 2 (b). These features have been added to the latest version buoy design, motivated by initial field experiences discussed below.

The initial field test site was near the mouth of the Chesapeake Bay, approximately 3 nautical miles North of the Virginia Beach, VA coastline and 2,000 ft (609 m) directly West of a CO-OPS maintained NWLON station on the southernmost island of the Chesapeake Bay Bridge Tunnel (36.967552° N, 76.121315 °W). The site is just South of a main shipping channel (Thimble Shoal Channel). Average water depth at the site is approximately 28 ft (8.5 m) relative to mean lower low water (MLLW). Figure 8 shows a regional satellite view surrounding the test site (top) and a zoomed in view of the area on NOAA nautical chart # 12222 (bottom), with the deployment site area marked by a red dashed box.

The system was deployed from the Crusader - a 45' re-purposed Coast Guard life boat, owned and chartered by the Cape Henry Launch Service (CHL), Virginia Beach, VA [11]. The boat has the required lifting capability offered by a winch, capstan, and A-frame. Figure 9(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.

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 the buoy was encountered during the passage of s high wind, nor'easter storm event. Data transmissions from the buoy became intermittent during the peak of the storm and then communications with the buoy were completely lost several hours later. A service visit that followed a few days after the storm passage revealed that a bulkhead connection leak on the buoy had significantly damaged the Xpert data logger and several other internal electronics components. The buoy was recovered shortly after while the bottom mount was left deployed. The buoy was repaired, re-tested, and redeployed at the same location next to the bottom mount by October 8. Following redeployment of the repaired buoy, the system operated successfully through early December when the bottom mounted acoustic modem's power supply began to reach its expected end of life. Figure 10 shows a sample time series of pressure, water temperature and conductivity measured by the bottom mount along with winds and atmospheric pressure measured by the buoy's meteorological sensors during an extended period of successful operation.

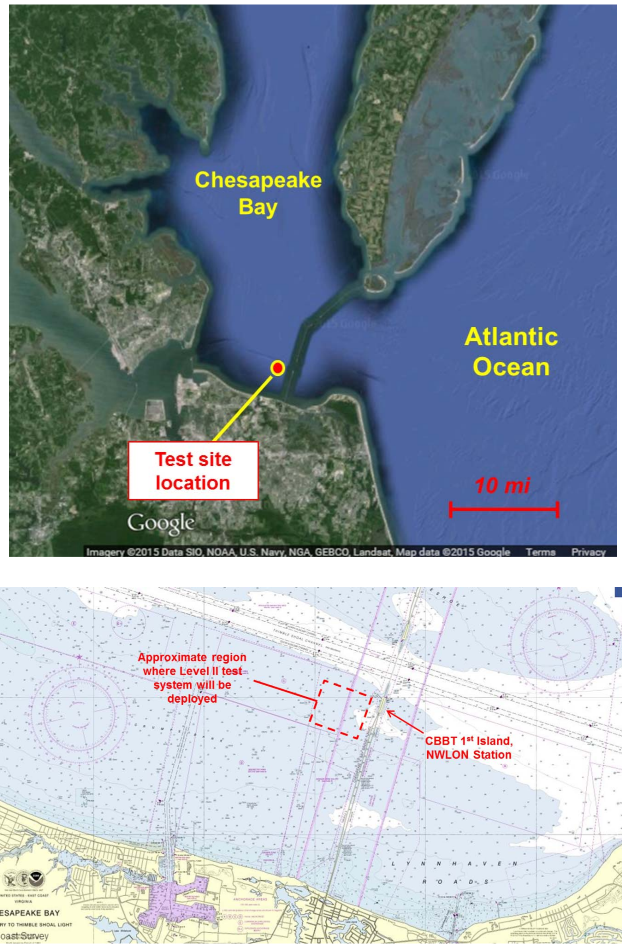

Fig. 8. Field test location of the first version system.

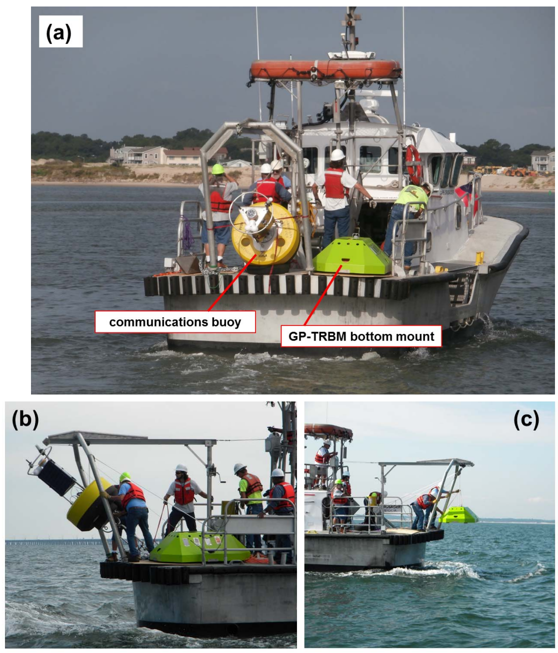

Fig. 9. Initial test deployment in the South Chesapeake Bay; (a) the Crusader underway with the buoy and bottom mount loaded (b) buoy and (c) bottom mount deployments

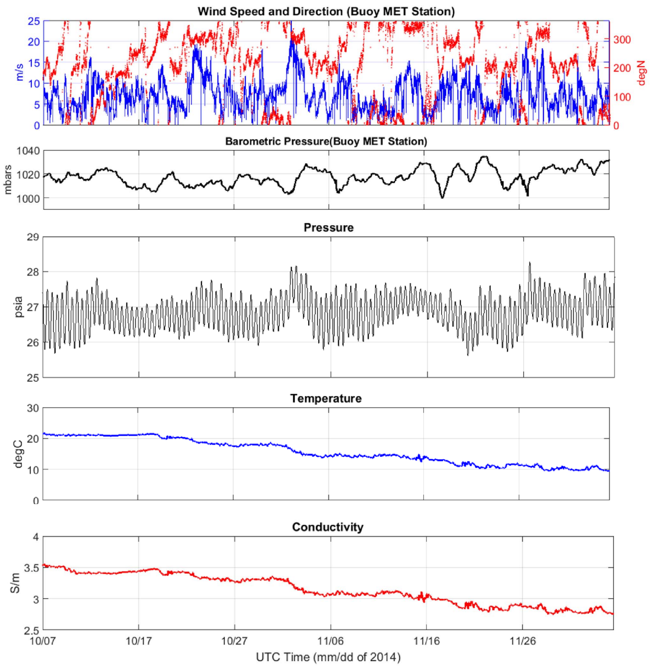

Fig. 10. Sample time series of winds and atmposhperic pressure from the buy's met station and pressure, water temperature and conductivity from the bottom moutned SBE26+ sensor durign an extended period sucessful operation.

After the first, unplanned recovery of the buoy in September following the bulkhead connector leak, inspection of the system indicated that the leak occurred at a connection that provides interface to the Xpert data logger/controller via RS232 cable and operator computer. This connection was originally intended for initial diagnostic checks of the buoy's system after initial power up, on land or on the deck of the boat. During the initial field test deployment of the system in September 2014 however, this bulkhead connection was used to communicate to the buoy's Xpert logger multiple times post-deployment while tying up to the buoy with a small vessel. Although the system initially worked as expected, several unplanned diagnostic checks were conducted to confirm multiple data logger operations. At the time, a period of calm weather and seas provided what seemed to be safe conditions to make a vessel side hard connection to the buoy to operator laptop. However, it is very likely that multiple boat side connections that each required the removal of the bulk head connectors dummy plug, screw on/off of the cable connector, and then replacement of the dummy plug likely increased leakage potential prior to the passage of the storm.

V. Future Work

Results from the Chesapeake Bay 2014 field test of the initial version system highlighted several buoy design details that need improvement. Very little modification has recommended for the bottom mount component.

Following system recovery in December 2014 through the time this paper was written, a slightly modified, new and improved buoy system has been under development and test. This involves implementation of minor modifications to the 2014 version buoy system design, which remains based on the NexSens CB-950 system. These buoy system enhancements are reflected in the system diagram shown in figure 2(b) and additional requirement's shared at the end of section II. They include:

- low power wireless connection that allows an operator to interface to the buoy's Xpert logger/controller from a vessel following deployment while within approximately 200-300' of the buoy.
- IP modem to provide remote, two-way communications to the Xpert; in order to conserve power, the IP modem will remain off and can be turned on when needed via Iridium mobile terminated message (MTM).
- implementation of several LinkQuest acoustic modem commands on the Xpert logger so in the event an issue is encountered with the acoustic link, several commands can be issued over the modems while remotely connected to the buoy's Xpert logger.

A second field trial for the latest version system is planned to take place in the St. Andrews Sound region of Georgia during September of 2015. This will be in coordination with a planned NOAA\NOS Office of Coast Survey hydrographic survey being conducted in the region, to simulate the exercise of a typical operational deployment application. Additionally, the region where the buoy is to be deployed, South of the St. Andrews Sound entrance and West of Cumberland Sound, is very remote, with limited coastal infrastructure. Physical conditions will likely present an additional challenge, including a predicted 7-8 foot tidal water level range and tidal currents exceeding 1.5 knots. This environment may bring the system testing one small step closer toward the challenging conditions that are likely to be encountered in remote Alaskan coastal regions of interest.

VI. 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 theses 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 water level measurement system for use in remote Arctic coastal regions with very limited infrastructure. Two types of real-time system designs have been identified, for short and long term applications. Both design types include a bottom-mounted pressure gauge as the primary source of water level observations. A short term system has been under development and testing from mid-2013 through the time this paper was written. A field test of the latest version system is planned to take place in coordination with an OCS survey during September 2015. Following efforts during 2016 will include planning a test deployment in a region of interest, along Alaska's remote Artic coasts.

REFERENCES

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

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

[2] 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.

[3] 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.

[4] 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

[5] 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), Aeptember/October 2014.

[6] R. Woodgate, K. Aagaard, Tom 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

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

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

[9] 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

[10] 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

[11] Cape Henry Launch Service, Virgnia Beach, VA:

http://www.capehenrylaunch.com/