Chesapeake Bay Dissolved Oxygen profiling using a lightweight, low-powered real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels

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Final Report
Submitted to the Chesapeake Bay Trust regarding Grant 16793

Scope 8: Pilot a cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia

January 2021

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1. RFP and expected deliverables

On 20 December, 2018, the Chesapeake Bay Trust published a Request for Proposals, including a Scope of Work for supporting the Chesapeake Bay Program Scientific, Technical Assessment and Reporting Team and Sustainable Fisheries Goal Implementation Team. The SOW was to "*Pilot a cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia*."

The requested deliverables were:

1. Identification of existing platforms of opportunity that can be used at the selected locations (e.g., Chesapeake Bay Interpretive Buoy System). Platforms of opportunity could include existing platforms such as the Chesapeake Bay Interpretive Buoy System that can be leveraged as appropriate with a partner to support a long-term vertical profiler monitoring program into the future.
2. Identification of appropriate sensors considering the balance of operations and maintenance (O&M) time and costs with producing data of sound quality and integrity (e.g., sensor calibrations, their frequency, any swap out of instrumentation that might be necessary on a schedule shorter than the seasonal deployment, etc.).
3. Sensor deployment design, monitoring protocol (e.g., identify depth intervals of data collection, data collection frequency per profile (e.g., a good target is 15 minute to hourly data target for water quality standards attainment assessment)), O&M plan, and life cycle cost projections.
4. Documentation of the pilot deployment targeting a test period during spring that may provide insight on adjustments needed, then targeting a full summer season (June-September) deployment with data collection, management and delivery.
5. Presentations for CBP teams/workgroups (as agreed to in Task 1).
6. Mid-point report presented to project leads and identified stakeholders.
7. Final report including lessons learned and recommendations delivered to project leads and identified stakeholders.

2. Proposed Solution

Caribbean Wind LLC proposed the following approach:

Introduction

Water Quality impairment in the Chesapeake Bay, caused primarily by excessive long-term nutrient input from runoff and groundwater, is characterized by extreme seasonal hypoxia, particularly in the bottom layers of the deeper mainstem (although it is often present elsewhere). In addition to obvious negative impacts on ecosystems where it occurs, hypoxia represents the integrated effect of watershed-wide nutrient pollution, and monitoring the size and location of the hypoxic regions is important to assessing Chesapeake Bay health and restoration progress.

Present Chesapeake Bay Program direct Water Quality monitoring has been by necessity widely spaced in time and location, with monthly or bi-monthly single fixed stations separated by several kilometers. The need for continuous, real time, vertically sampled profiles of dissolved oxygen has been long recognized, and improvements in hypoxia modeling and sensor technology make it achievable.

Requirements

The RFP SOW 8 requests 4 outputs (paraphrased):

*1) lessons learned regarding a **reliable** infrastructure that sustains the deployment;*

*2**) reliable**/dependable infrastructure assessment of the gear deployed;*

*3) successes and challenges of the piloted equipment in collecting, storing, and providing **reliable** data in the summer season in the mainstem Chesapeake Bay;*

4) details of protocols to be adopted and invested in for deployment of vertical profiling infrastructure.

The highest priority requirement based on these (noted in 3 of 4) is ***reliability***. Additional considerations, based on extensive experience designing and supporting real-time environmental monitoring systems in Chesapeake Bay, as well as familiarity with CBP and partners' interests, are:

- Meet CBP and partners' data needs
    - Provision of desired parameters (in this case Dissolved Oxygen concentration – which requires coincident Temperature and Salinity for accurate calculation)
    - Adequate quality – initially and over the whole of a seasonal deployment
    - Vertical resolution – ability to capture the important features of vertical structure
    - Timely, easy, and dependable real-time data delivery
- Sustainability – includes long term capital and resource requirements, personnel expense
    - Minimum initial cost to acquire and deploy
    - Minimal level of field support required during deployment
    - Long lifetime of equipment and ease/cost of off-season repairs and refurbishment
- Flexibility – Can the system be successfully utilized in all required locations, recognizing diverse, often extreme physical environments and conditions that may be faced.

These requirements define the approach. There are two basic ways to acquire a vertical water column profile – either by a) moving a sensor package repeatedly through the water column, or by b) locating sensor packages at multiple fixed depths, with vertical sensor spacing adequate to meet observational requirements. Either way, data must be regularly collected and transmitted from the *in situ* system location to an accessible data structure. Our proposed solution is b), described below, with rationale for how the solution best fits requirements.

Approach
A Lightweight, Low-powered Real Time Inductive CTDO2 Mooring with sensors at multiple vertical measurement levels

Sensors will be independent, integrated Temperature / Conductivity / Dissolved Oxygen (optional Pressure) units developed with collaborator Darius Miller, President and Principal Engineer at SoundNine. Units collect data and transmit inductively, clamped to a semi-taut mooring line with a surface data collection and cellular transmission buoy (SoundNine UltiBuoy). T/C/P sensors with inductive modems are manufactured by SoundNine Inc., and will integrate OEM fluorescence-based microDOT Dissolved Oxygen modules supplied by Precision Mechanical Engineering (PME). *(RFP Deliverable 2)*

Why fixed sensors instead of a profiler?
Reliable
- No moving parts, robust (but adjustable) attachment to mooring cable.
- Extremely low power, alkaline batteries will power sensors for a season at 15 minute sampling.
- Redundant data storage within each sensor and controller within the platform.
- Proven hardware with accurate individual sensor components
- Controller / Communications buoy designed to be fully submersible to 5 meters to remain semi-taut and withstand surface wave conditions in any Chesapeake Bay water depths

Sustainable
- Sensor modules are low cost (estimated $4-5K) so spares are affordable
- Should not require cleaning during season
- Full Mooring with sinker is hand-deployable/recoverable by two persons in small boat

Flexible
- Modular components
- Works in any depth – deep or shallow - found in Chesapeake Bay
- Designed to withstand extreme Chesapeake Bay wave conditions

Meets Data Needs
Analysis below shows that a reasonable number of sensors can achieve accurate measurement of vertical hypoxia structure while still maintaining the reliability and sustainability advantages of a simple 'no moving parts' platform.
Data are stored 2 locations internally and transmitted in real-time to SoundNine cloud-based storage system, where data QC will be performed per US IOOS QARTOD methodology, available to CBP and partners with low time latency and including QC flags. Low power consumption of inductive technology allows 15-minute sampling for a full season deployment *(RFP Deliverable 3)*.

While a single profiling instrument is another approach, our experience with these devices is that they have more structural and logistical complexities and failure points (both in the profiling mechanism and in the mooring/structure supporting the profiler) that increase the risk of service visits in-season (cost) and associated periods of missing data. Reliability can be maximized by having the simplest solution that meets the requirements. Additionally, initial cost is greater; moorings are larger with associated higher acquisition, deployment, and recovery costs; and a single instrument failure leads to loss of entire profile.

Analysis

In evaluating the fixed vertical sensor approach, we considered a Pilot deployment at CBP fixed monitoring Station CB4.3E (38.55624 N , 76.39121 W) – about 2.5 km E of CBIBS Gooses Reef buoy, where there is real time surface environmental data nearby from GR, as well as bottom DO and pH data *(Deliverable 1)*. Additionally, this station is in a reasonably deep location (21-22m) and out of shipping channels (a problem when surface buoys are required for real-time communications, addressed later).

Figure 1A shows CB4.3E DO profiles from 2002-2018 June/July/August/September. Assuming that we want to be able to at least match the ability of the existing sampling to resolve structure and measure vertical extent of hypoxia (DO < 2.0 mg/l) for use in DO volume estimations and forecast model comparisons, simulations were run with various fixed sensor depths. Table 1 shows how well different vertical sensor arrays capture full water column Vertical Hypoxia Extent - the amount of the vertical water column with Dissolved Oxygen concentration below 2.0 mg/l. For station CB4.3E, reasonable results can be achieved with six sensors – graphical comparison of the six-sensor model is shown in Figure 1B. This is a preliminary model, it is likely that more rigorous placement modeling would reduce uncertainty even further.

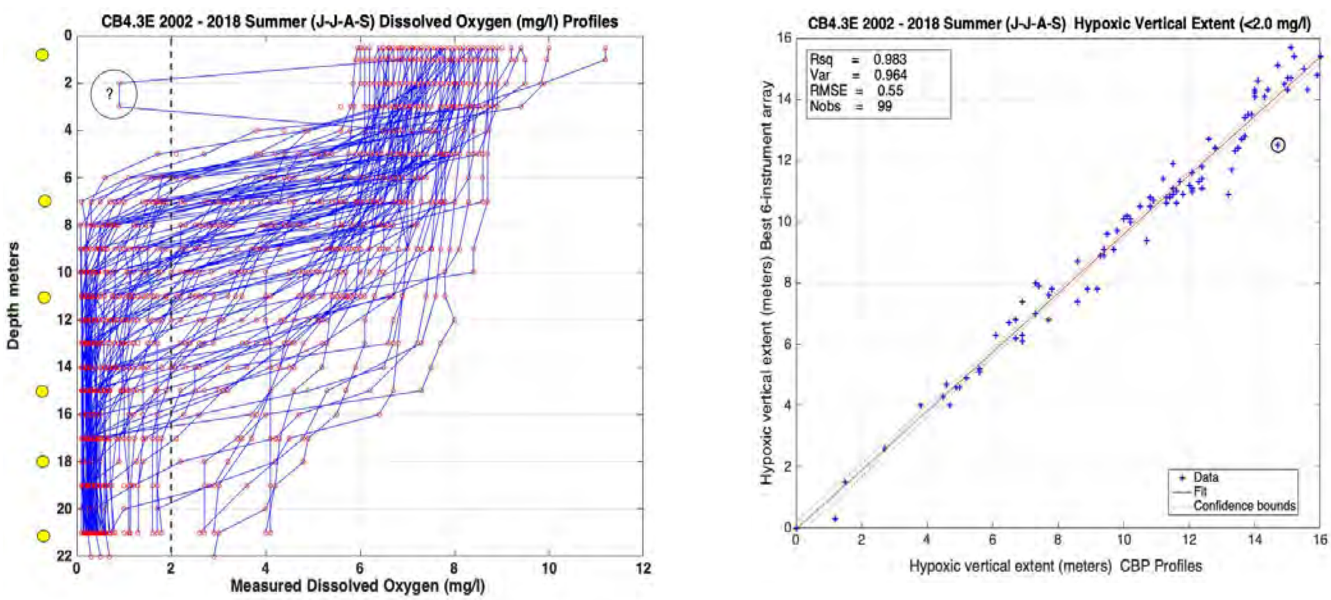


Figure 1. Measuring Dissolved Oxygen profiles with fixed depth sensors.

(A) Profiles of Dissolved Oxygen from all 2002-2018 Jun-September measured CBP stations at CB3.4E. Red dots are original sample depth locations, connected by blue profile lines. Yellow circles represent a six-instrument array used in (B).

(B) Comparison of 'Vertical Hypoxia Extent (Meters)' calculate using measured profiles (X axis) and the same quantity calculated using a hypothetical array of six sensors shown in (A). Different arrays were tested and results shown in Table 1.

Number of Sensors	Depths (meters)	R^2	% Variance	RMS Error
21	[1,2,3,...,19,20,21]	0.999	0.994	0.22
11	[1,3,5,7,...,17,19,21]	0.994	0.985	0.33
10	[1,5,7,9,...,17,19,21]	0.993	0.984	0.33
9	[1,6,9,11,13,15,17,19,21]	0.990	0.977	0.42
7	[1,6,9,12,15,18,21]	0.988	0.977	0.46
6	[1,7,11,15,18,21]	0.982	0.964	0.55

Table 1. Evaluation of capability of a multi-sensor vertical array to reconstruct the 1-meter spaced dissolved oxygen profile.

Expected Outcomes and Deliverables

We can meet the suggested Task Implementation timeline; comments on Tasks below (includes *Deliverables 4-7).*

System schematic (Figure 2, right) is based on the example of CB4.3E, but adaptable to other desired monitoring locations.

We have chosen a small buoy to maintain a nearly taut mooring (and fixed sensor depths relative to the bottom) in all depths and conditions. The UltiBuoy electronics components are waterproof to >5 meters and will simply submerge in extreme wave conditions, storing data and retransmitting if transmissions are missed. Sensors are tightly affixed to inductive cable but can be adjusted to meet sampling requirements. Optional intermediate floats can be used to maintain wire tautness.

SoundNine Inductive TCOP sensors provide accurate, low-power, measurements. System is light enough to be deployed and recovered by 2 persons in a small boat, and should require no maintenance during a season.

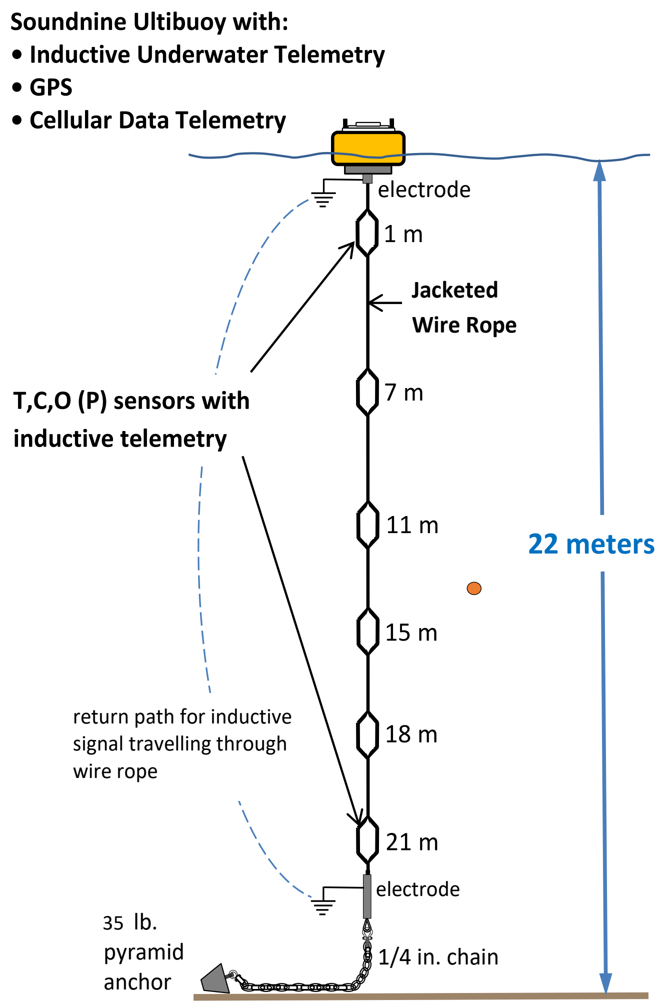


Figure 2. Mooring schematic

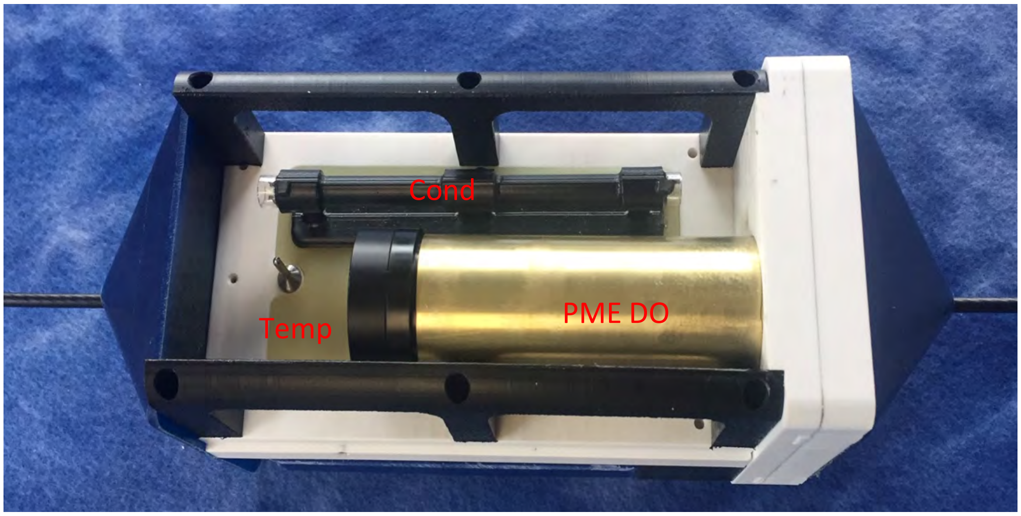


Figure 3. Soundnine inductive CTO_2 Instrument, sensor side, protective cover removed. Reverse side has batteries and inductive wire clamps.

Experience / Qualifications of Offeror
Doug Wilson of CWLLC has extensive experience with ocean instrumentation; ocea
collection and quality control; and design, installation, and maintenance of coastal
estuarine moorings. This includes all aspects of designing and maintaining oceanographic observing systems, moored platforms, and sensors in Chesapeake Bay, Florida Bay and Florida Keys, Coastal Atlantic, Caribbean Sea, rivers and large inland lakes. He was an Oceanographer at the NOAA Chesapeake Bay Office (2001 – 2012), and during that time designed, deployed, and managed 10-buoy CBIBS system for environmental monitoring in Chesapeake Bay and tributaries. Work also included reports, publications, and presentations on results. Developed real-time data system including data acquisition and storage, web display and access, and quality control using US IOOS Quality Assurance for Real Time Ocean Data (QARTOD) standard procedures. Doug Wilson has been active in Chesapeake Bay water quality and Dissolved Oxygen measurement, including CBIBS and other buoys, autonomous vertical profilers, and AUV deployments. He was co-PI in several proposal submissions to NOAA with Dr. Marjy Freidrichs of VIMS (and others) to provide dissolved oxygen profiles supporting VIMS Hypoxia forecast model, and as a result he is quite familiar with ongoing work by VIMS and that of Bever, et al. (2018), and has an excellent working relationship with the community. Doug Wilson served on the U.S. IOOS QARTOD (Quality Assurance of Real-Time Oceanographic Data) Dissolved Oxygen Manual Team (Ref 2015).

Accepted Proposal
The proposal submitted by Caribbean Wind LLC on 13 February 2019 was accepted by Chesapeake Bay Trust on 31 May 2019.

Per the contract: The objective of this project is to demonstrate a reliable, cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia. In collaboration with the Chesapeake Bay Goal Implementation Team and regional hypoxia modelers, Caribbean Wind LLC will complete the following: Select an appropriate demonstration location; design and build a vertical array of inductive CTO2 sensors and a data controller and real-time transmission buoy; deploy, maintain, and monitor the array throughout the summer hypoxia season; and collect, quality control, and make data available in real-time. Follow-up reports will evaluate system performance, reliability, cost and sustainability, and data quality, handling, and availability. Caribbean Wind LLC will also share results with hypoxia modelers to determine the best vertical sensor and array locations to support their nowcast-forecast systems. The project team has extensive experience in coastal and estuarine (including the Chesapeake Bay) data collection platforms, as well as CTO2 sensors, data analysis, and quality assurance and control.

b) Drafting final report and deliver by August 1, 2020, with lessons learned about the equipment used in the study, the effort, the costs for infrastructure, its maintenance and data collection, management, and delivery. Including recommendations that address these areas of lessons learned applied to establishing a system of at least two vertical profiles for measuring vertical habitat conditions impacting living resources and involves the annual hypoxia cycle expressed in the deep waters of Chesapeake Bay; and

c) Briefing report to project leads and other stakeholders identified by the project leads, including a final presentation to the CBP STAR.

3. Proposal Timelines and Deliverables and Approved Modifications

The initial proposed deliverables, by Task, were as follows:

Task 1: Kickoff meeting with Project Leads; current efforts; Pilot locations. We are suggesting CB 4.3E for proximity to GR CBIBS; for moderate depth; for not in conflict with shipping lanes. At this point in the timeline, application to USCG for Private Aids to Navigation should occur. This latter issue can be problematic; many of the deep stations in the Chesapeake Bay where hypoxia is significant (including those considered in Bever, et al.) are located in designated ship channels where ship strikes are likely to damage a surface transmitting buoy (and where it is unlikely US Coast Guard will approve Private Aids to Navigation permits). At some point we can discuss long-term solutions to this problem, including working with modelers to develop a sampling array that optimizes non-conflicting locations, possibly utilizing interim non-real-time profiles with subsurface upper floats. This inductive technology also lends itself to subsurface vertical arrays with a horizontally offset surface transmission buoy.

Task 2: We are promoting the *Lightweight, Low-powered Real Time Inductive CTDO2 Mooring with sensors at multiple vertical measurement levels* approach based on our experience and our understanding of the project requirements. Establishment of details during Task 2 provides an opportunity to work with Project leads to refine the approach to explain, modify, and finalize designs and protocols to make sure all requirements are met. A preliminary QAPP outline will be developed, to be completed utilizing experience gained from Tasks 3 and 4.

Task 3: SoundNine and PME are in the process of integrating PME DO sensor into an S9 inductive Cond-Temp-Presssure module, resulting in a standalone CTDO inductive module. We will stage mooring building and testing activities out of Maritime Applied Physics waterfront location in Baltimore, where CWLLC has a working agreement, or other location provided by Project partners. Testing will include in-water testing and full sensor-to-client pipeline, including QC. QC procedures will be overseen by collaborator Mark Bushnell, Coastal Obs Tech Services, presently serving as National Coordinator for US IOOS QARTOD.

Task 4: Proposing a June 2019 deployment using CWLLC boat or provided partner assets. Performance will be continuously monitored (data will also be available continuously to Project participants) and maintenance will be conducted if necessary. Two interim platform visits will be conducted to evaluate fouling; if fouling is not affecting performance, sensors will not be cleaned, in order to evaluate full-season capability. If available, we would like to integrate two SeaBird SBE37 inductive CTDO sensors owned by NCBO into the pilot deployment for independent sensor validation. These sensors are compatible with the SoundNine modem and data can be included in real-time transmission. Platform will be recovered in September 2019 using CWLLC or provided small boat.

Task 5: Reports and Presentations as requested, including final QAPP. CWLLC is Baltimore-based and available for in-person meetings.

Task 6: Consultation, Reports, Briefings, and Presentations as requested.

In collaboration with CB Trust Program Management and the CBP Steering Committee, a series of modifications were made in the Tasks (and Timeline, Section 4). Factors leading to changes were: Delayed awarding of contract; delays in provision of instrument components by contractors; seasonal considerations for deployment; and finally, in 2020, COVID-19 restrictions.

Task 1-2 were completed as proposed with a July 15 2019 presentation to SC and subsequent discussions and updates concerning project and sensor details. Due to delays in acquiring completed sensors and approaching end of working season Chesapeake Bay, future Scope of Work and Timeline adjustments were made, pushing Tasks 4-6 into 2020.

Task 3 was completed during Spring 2019, with additional delays due to COVID-19 restrictions. It was agreed with SC that field testing would consist of two 2020 deployments during hypoxia season – one test deployment (Task 3) and a second longer deployment addressing any testing issues (Task 4). Details and results of the test deployment were reported to the SC in 'CBTrust Hypoxia Report 24 June', in Appendix A 4.

Task 4 was completed in September-October 2020 as reported in *CBTrust Hypoxia 2nd Deployment Update* and *CBP CAP WG CBTrust Hypoxia Wilson.*

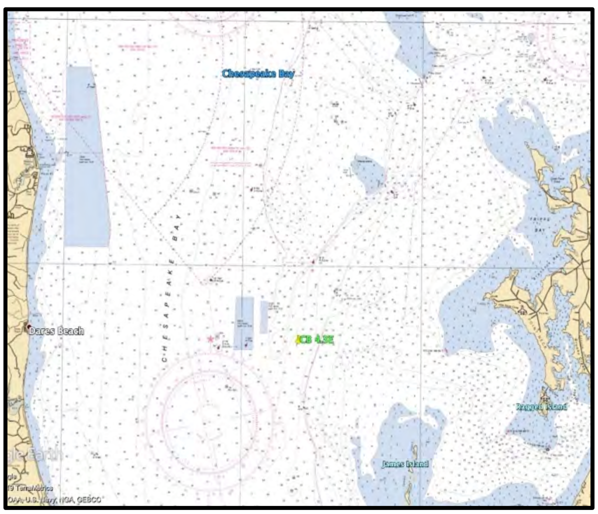
Task 5 consists of the submission and presentation at the CBP Criteria Assessment Protocol WG of the *CBP CAP WG CBTrust Hypoxia Wilson* report, and creation and submission of this final report document.

Task 6 is ongoing, as discussed with SC there will be discussions, reports, and presentations in 2021 to various CBP and other meetings.

4. **Summary of Hardware, Fieldwork, and Related Activities**

Based on multiple critical criteria – among them simplicity, reliability, cost - and in-depth analysis of historical CBP monitoring data, components and procedures were carefully specified or, if need be, developed.

Mooring
A test location (CBP Station CB4.3E) was chosen with significant seasonal hypoxia, representative depth (~21.5 m), current, and wave conditions, and away from commercial boat traffic. The location was also within 1 km of NOAA CBIBS Gooses Reef Buoy.



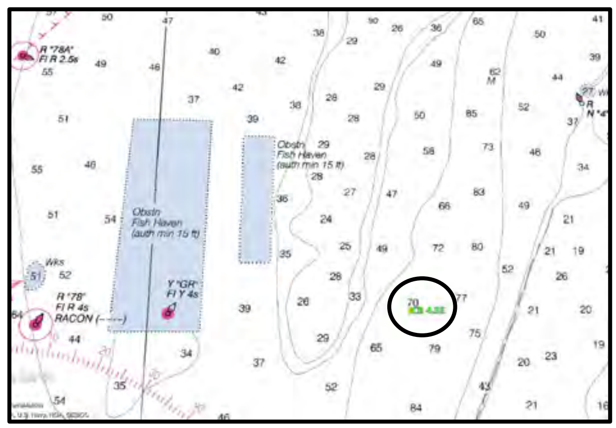


Figure 4. NOAA Charts showing test deployment location at CBP station CB 4.3E.

A site inspection in October 2019 confirmed adequacy of location – flat bottom at 71 ft (mean tide), minimal commercial fishing and maritime traffic, and good cellular service. A bottom DO measurement was hypoxic.

The Soundnine Ultibuoy (UB) was chosen as the mooring framework. The UB has characteristics important to meeting the specifications for this application. Because -

- We want the entire mooring to be deployed and recovered by hand from a small boat – the UB is small and lightweight, and requires a small (in this case 35 pound) anchor.
- We want to use inductive telemetry to allow freedom of instrument vertical placement and low power – the UB has a built-in inductive mode.

- We will use a taut mooring line to maintain instrument depth – the UB is waterproof to >5 m depth
- We want ease of maintenance – the UB has integrated battery, solar charging, cellular modem, and GPS

The buoy uses jacketed steel wire as both the anchor line and the inductive transmitter. Bottom depth is measured carefully, with the cable terminated at the proper length on a steel electrode near the bottom so that the lowest instrument can remain within 1 m of the seabed, an important consideration for hypoxia monitoring. The weight/buoyancy relationship is carefully calculated; some wave action is absorbed by chain near the bottom, but there is net negative buoyancy so the buoy can be drawn underwater in exceptionally high seas.

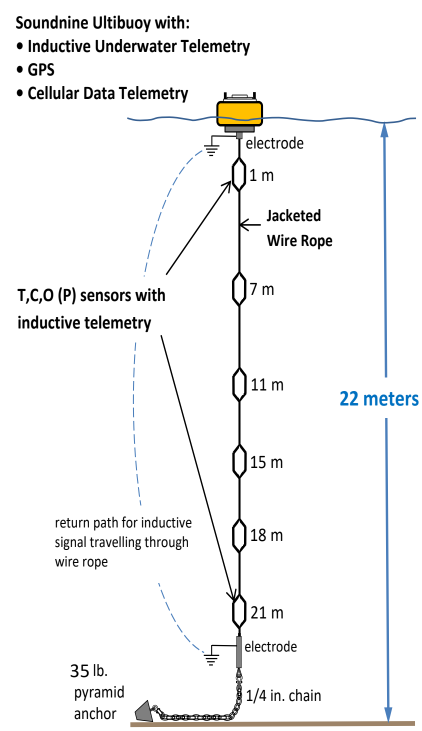


Figure 5. Mooring Schematic

Inductive telemetry allows for the placement of any number of instruments at any depth in order to best resolve the dissolved oxygen profile.

Recoveries are facilitated with The use of padded gloves, with cable grips and heavier line to haul up the thin wire rope. Nevertheless, it can be done manually by a single individual in a small boat, keeping costs low.

Figure 6. Essential Recovery Tool - Tyler Cable Grip

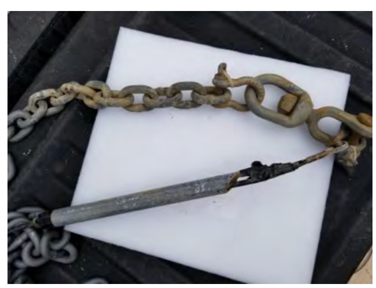


Figure 7. Cable termination showing cable, electrode, termination, swivel, and chain to sinker.

UltiBuoy is 55 cm diameter x 30 cm high foam with ground plate / cable fairlead and concrete ballast below, buoy controller/comms/solar panel module on top. Weight is 25 kg, with 55 kg of buoyancy. Ballast and hull below waterline were painted with anti-fouling paint prior to launch.

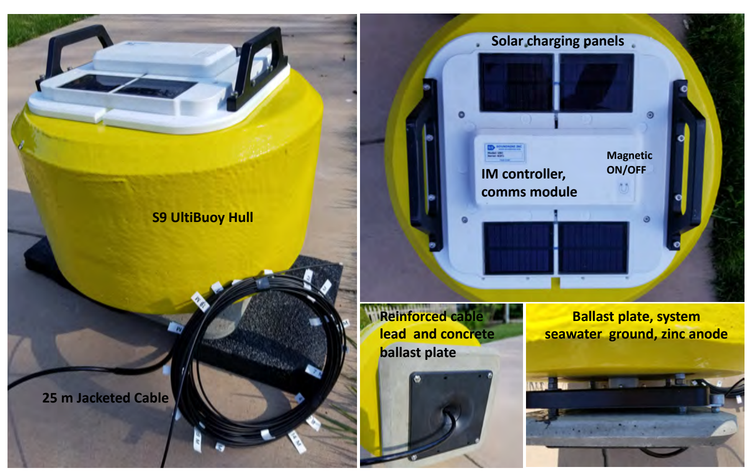


Figure 8. Images of UltiBuoy used in deployments.

Instruments

While there are inductive CTO_2 instruments presently on the market, their cost is high – typically in the $15K+ range - making the cost for a full mooring (5-10 instruments) excessive. Our goal was to create a much lower cost inductive CT O_2 instrument meeting the necessary specifications. Soundnine Inc. of Kirkland, WA have developed an inductive CT(P) module based on their Enduro Temperature sensor, and Precision Measurement Engineering of Vista, CA had a new, smaller MicroDOT prototype of their successful MiniDOT Dissolved Oxygen recorder. We were able to bring these together into a single CT(P)O instrument manufactured by Soundnine at a lower price (target $4-5K) with additional features of extremely long battery life, integral acceleration sensors, and anti-fouling protection.

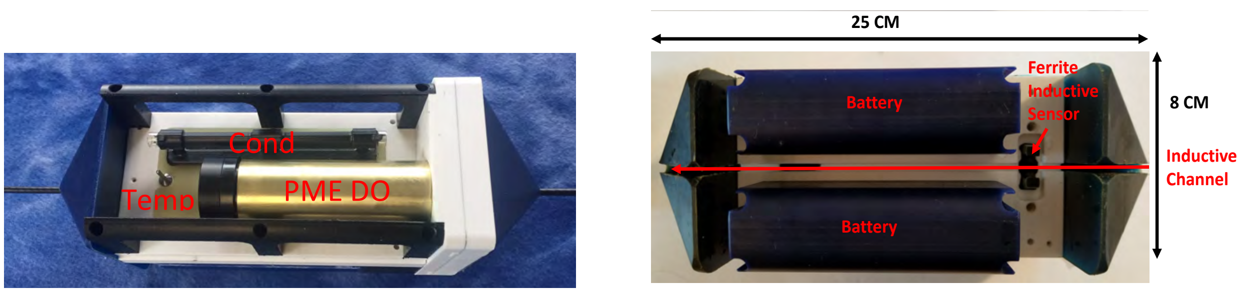


Figure 9. Front and back views of Soundnine/PME CTO_2 sensor. Clamps on reverse hold sensor to inductive cable in inductive channel, including a ferrite loop to close inductive connection. PME OEM MicroDOT is housed in a brass casing with an internal connection to Soundnine electronics.

Instruments have unique addresses , and the UltiBuoy controller is programmed to query instruments at regular intervals (in our case 10 minutes). The controller is designed to also work with instruments using standard SeaBird Electronics inductive modem protocols. In both deployments we incorporated SeaBird SBE 37-IMP-ODO instruments belonging to NOAA Chesapeake Bay Office into the mooring.

Three $CTPO_2$ instruments were built and delivered by Soundnine for the pilot deployments. Each was calibrated prior to the first deployment and have been returned to Soundnine for post-calibration. Additionally, design modifications based on test experiences have been implemented into three Version 2 instruments purchased for the program, and the three Version 1 have been updated.

In addition to the real-time instruments, each deployment was instrumented with several internally recording PME MiiniDOTs and a YSI 600 CTO_2 placed between the real-time sensors. These were used for comparisons and post-deployment data-denial evaluations.

Deployments and Recoveries

Test Deployment 1

Deployment 1 was deployed on 30 May 2020 1545 UTC and recovered on 19 June 2020 1645 UTC. The configuration was real-time sensors at 1 (S9), 7 (S9), 11 (S9), 16 (SBE), and 20 (SBE) meters.
A full description of the deployment is contained in Appendix A.4, *CB Trust Hypoxia Report 24 June.* There was a failure of the dissolved oxygen sensor on the 1 meter instrument; post-recovery diagnostics showed a wiring failure leading to water intrusion. The SBE at 16m had a battery failure.

There was one data transmission problem (with the Soundnine data server) that lasted for more than 24 hours. The system behaved as expected and designed, with the data stored onboard and fully transmitted when the server became available. Data collected are shown below.

Test Deployment 2
Deployment 2 was deployed on 13 September 2020 1700 UTC and recovered on 08 October 2020 1600 UTC. The configuration was real-time sensors at 1 (S9), 7 (S9), 13 (SBE), and 20 (SBE), and internally recording sensors at 4 (PME), 7(PME), and16 (YSI 600) meters.
A full description of the deployment is contained in Appendix A.6, *Hypoxia 10_13_Report_C.* During this deployment, all real-time instruments performed well, as did the recorders at 4m and 16 m. During the 25 day deployment, the 4-instrument mooring showed a 99.6% (14100/14164 instrument records) data return, with all sensors reporting all variables for the entire time. Data collected are shown below.

The intent was to leave the mooring out through October, but on 06 October around 0900Z, data transmission was interrupted, resuming about 3 hours later, 3.75 nm NNE of the deployment site. We were notified on 7 October that the buoy had been run over by the Atlantic Surveyor, a vessel on hydrographic survey contract to NOAA, entangled in a side scan sonar cable, and released and left near the entrance to the Choptank River channel. This dragged the mooring from 22 m depth to approximately 14 m depth, at a speed of over 1 knot. While the buoy did not transmit or receive GPS data during this time – it was likely underwater – it did still continue to collect data from the sensors. The buoy was recovered, fully intact and operational except for damage to the urethane foam float covering, on 8 October.

Between the two deployments, all dissolved oxygen sensors were tested at 100 per cent oxygen saturation. It is not unusual for a fluorescent dissolved oxygen sensor to lose sensitivity at 100% level after a field deployment. Based on this result, we were able to add a calibration-corrected value to the data base, while saving the original transmitted value.

Data Collection
The system uses inductive signals – low powered transmissions sent through the mooring cable and encoded/decoded by inductive modems coupled to the wire by ferrite loops. A sample data acquisition query and response are seen in Appendix E. These data responses are combined with information from the integral GPS and other UltiBuoy-based sensors and transmitted via cellular data network to a server at Soundnine. The details of the server,

database, and data access are given below. All data from sensors are also stored permanently in the UltiBuoy.

Raw data are entered immediately upon arrival into the data base; in some cases these are already in engineering units; in other cases calibration coefficients are applied. PME dissolved oxygen values are corrected for Salinity using Soundnine Temperature and Conductivity. In all cases, both raw data and calibrated/converted data are stored. Basic QA tests are applied to the data. Full cellular two-way communication is available with the UltiBuoy, allowing data collection program changes, firmware updates, or data queries and downloads.

Data Base and Web access

Soundnine collects data from the UltiBuoy through direct IP cellular connection from a cloud server, stores and parses the resulting data, and stores it using MariaDB, an open source fork of the MySQL relational data base system. Permission can be granted to access the password-protected database for direct SQL access. Soundnine also provides a java-based data access and visualization tool called S9vis, which allows data viewing, plotting, and downloading as a CSV file.

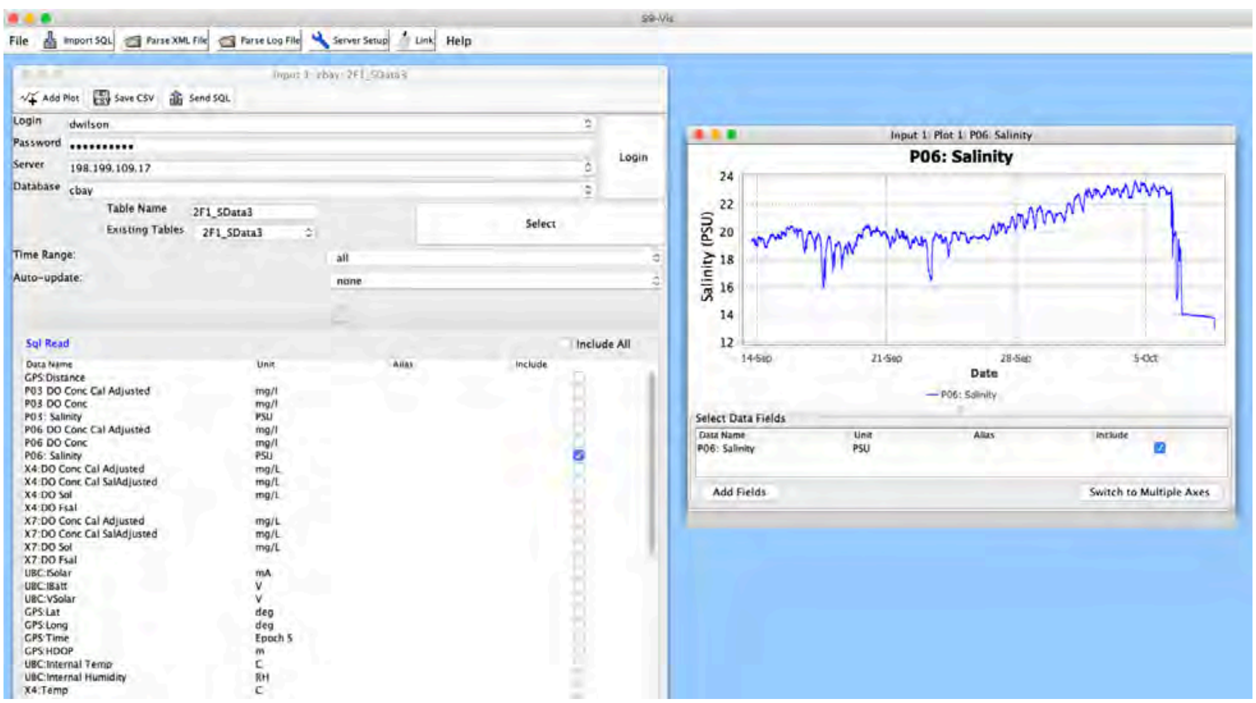


Figure 10. Soundnine S9vis screen shot, accessing a variable in the database and plotting. Database can also be directly accessed with SQL commands, or variables selectively downloaded

For better real-time viewing, we went to AXIOM Data Services, a company used by many of the US Integrated Ocean Observing System Regional Associations to provide real-time data visualization and access, as well as having former CBP and NCBO data guru Kyle Wilcox as a principal. By putting the profiling data into their standard US IOOS web template, we were able to seamlessly access many features leading to visual and data compatibility with US IOOS standards. Figure 11 is a screen shot of the second deployment. In addition to the shown ‘curtain’ or ‘heat’ time/depth plots for all sensors, line plots are an option.   Some less obvious capabilities are marked and numbered:

1   Other nearby data sites can be accessed via the live map, and this site is available to others.
2   Link to sponsoring organization
3   Link to IOOS-compliant metadata
4   Modify/set plot / access time range
5   Data downloads: links to full data and metadata downloads with options for ERRDAP, NetCDF, or CSV formats
6   Display IOOS QARTOD QC summary, parameters, and activity for this data plot

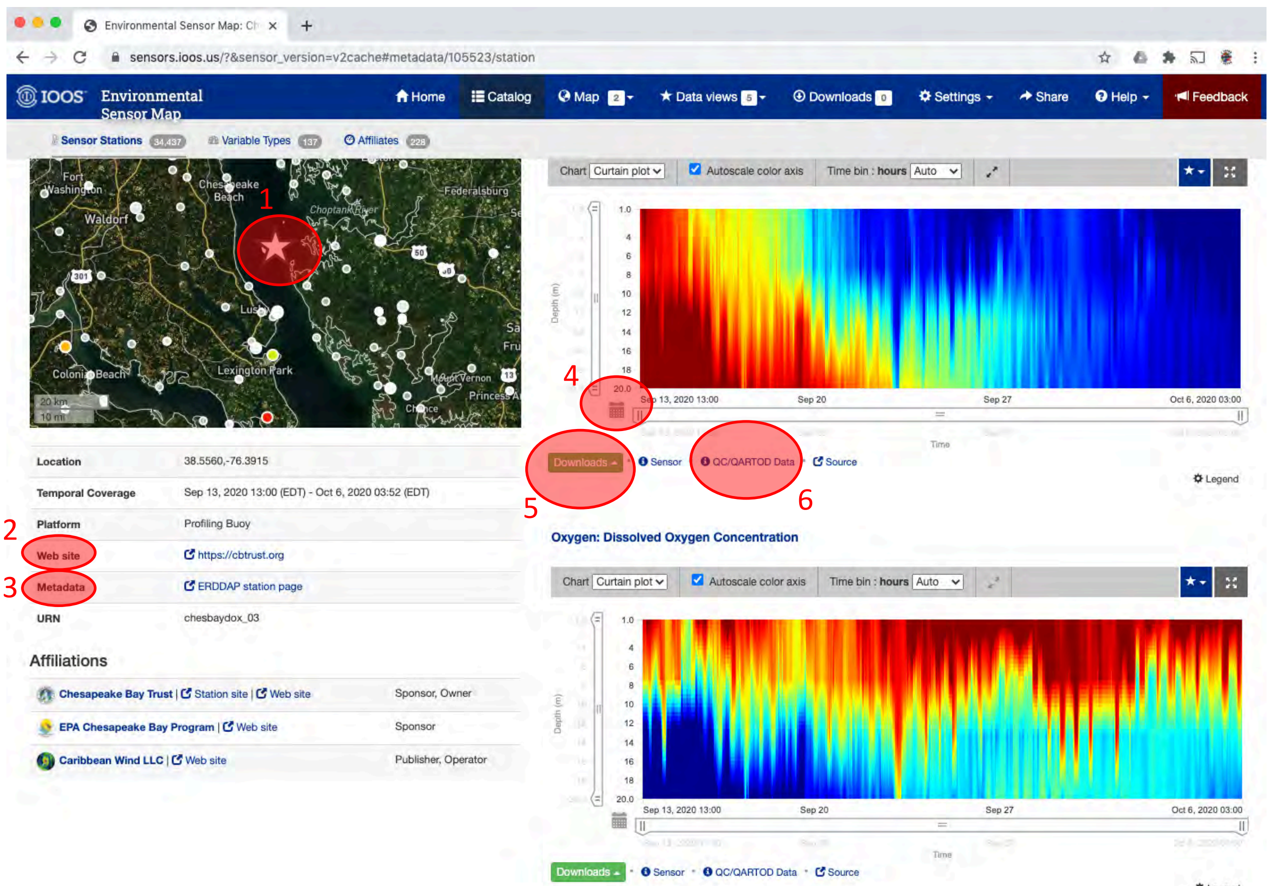


Figure 11. Screen shot from US IOOS compliant web interface for mooring platform.

5. Summary of Results

Below are Dissolved Oxygen Time-Depth plots from the first and second test deployments, based on data downloaded into CSV format using S9vis and Matlab.

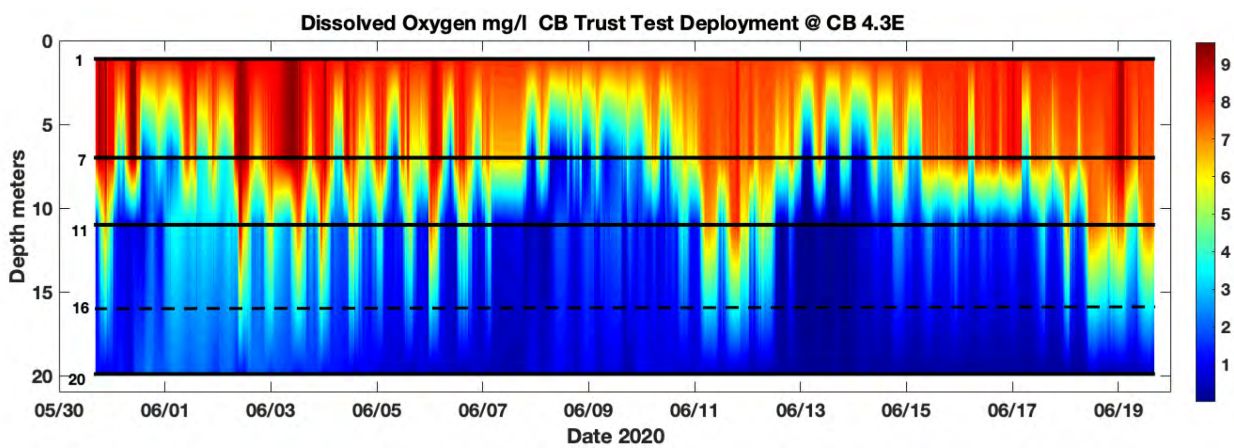
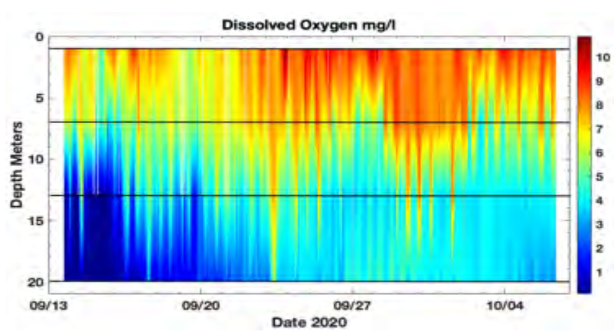


Figure 12. Dissolved Oxygen from first test deployment, 30 May – 19 June 2020.

Notes: Due to failure of DO on 1 m sensor, missing DO data at 1m filled in with greater value of <100 % saturation OR measured value at 7 m>; 16 m data missing.
Strong semidiurnal tidal signal often mixes high surface DO to at least below 11m sensor.



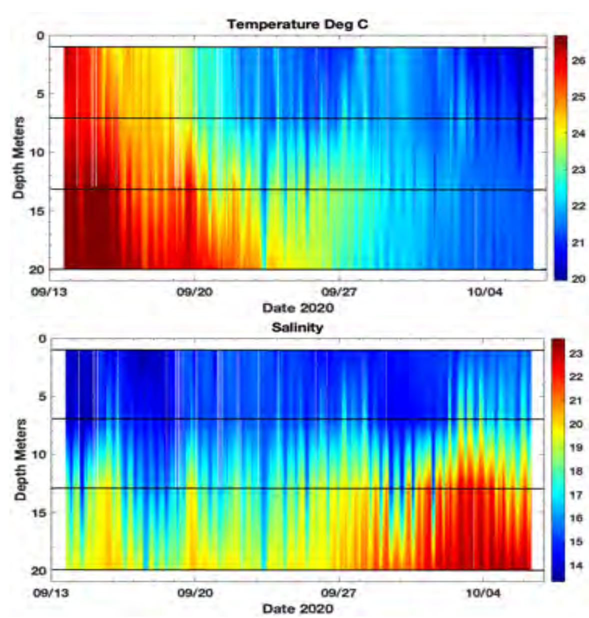


Figure 13. Dissolved Oxygen, Temperature, and Salinity from second test deployment, 13 September - 06 October 2020.

Notes: All sensors performed well. Oxygen sensors were corrected using a pre-deployment single-point 100% saturation calibration. Deployment was terminated early due to mooring being snagged and displaced by a survey vessel.
This deployment caught the breakdown of the bottom hypoxic layer – going from half the water column to none in less than a week. This was associated with a cold front passage and lower temperatures reaching the bottom – but – also a replacement of deep waters by an intrusion of high salinity water from elsewhere.

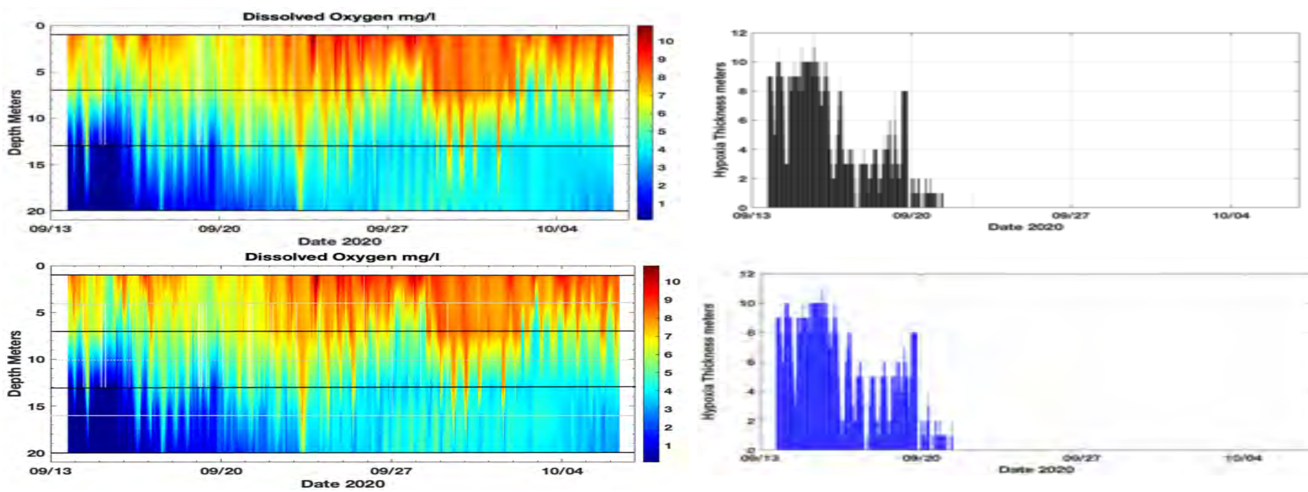


Figure 14. Second deployment Dissolved Oxygen data contoured using 4(upper left) and 6 (lower left) sensors. On right, thickness of hypoxic layer calculated from profiles using 4 (upper) and 6 (lower) sensors.

Presence of additional internally recording sensors supported a 'data denial' experiment with sensors at 4 and 16 m, to see difference between four- and six- sensor arrays. The optimally efficient design was six sensors. Over the 25 day record, mean differences were 0.09 mg/l at 4 m and 0.06 mg/l at 16 m, suggesting that even fewer sensors are necessary under many circumstances.
Calculated thickness of Hypoxic Layer using 4- and 6- sensor profiles show hypoxic conditions ending on the same date, with the time-integrated totals differing by less than 5%.

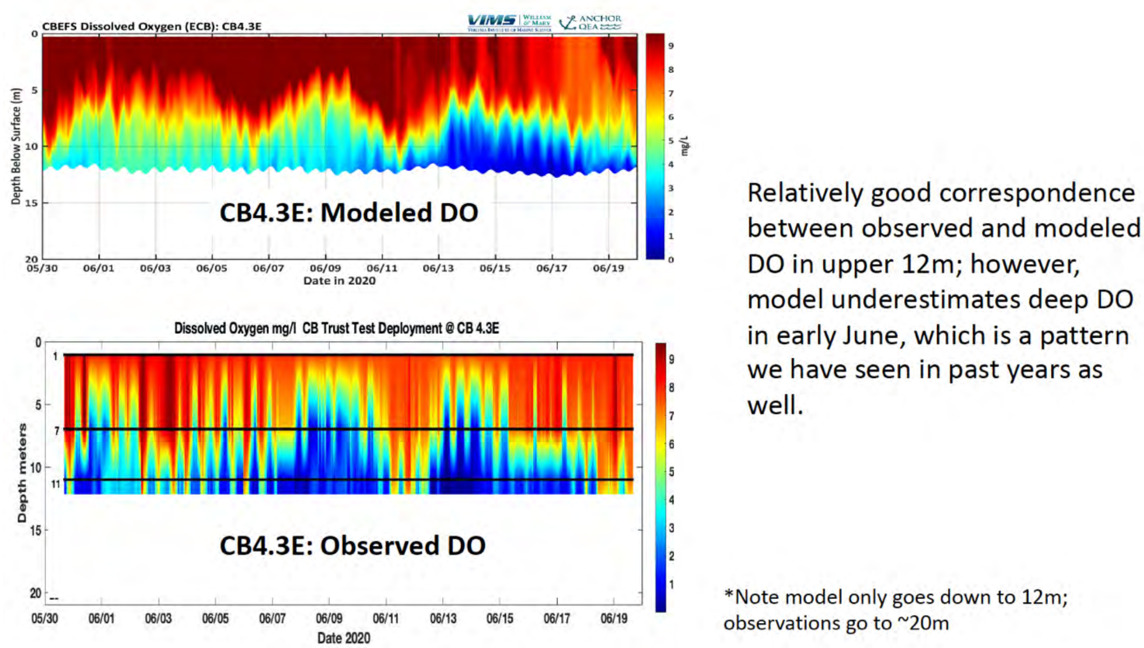


Figure 15. Comparison between VIMS Chesapeake Bay Dissolved Oxygen model and Deployment 1 Oxygen data. (from Aaron Bever, Anchor QEA and Marjy Friedrichs, VIMS.

One request in SoW was to communicate with VIMS regarding comparison with their Chesapeake Bay dissolved oxygen model. Comparison with Deployment 1 is in Figure xxx above. This version of the model does not properly resolve bathymetry, so depths are not right; a higher resolution version is in development.

6. Future applications

As a result of this funded proposal, Caribbean Wind LLC will have six upgraded, calibrated Soundnine CTO_2 instruments. Additionally, the two NCBO SeaBird SBE 37 IMP-DO could be used, although they need factory maintenance and recalibration. The UltiBuoy will have the flotation section replaced and delivered with a new cable and termination; chain and anchor are on hand. The SQL data bases and platform web pages already exist. A 6 to 8 (including SBEs) instrument deployment could be arranged for Spring 2021 at relatively low expense (see estimated costs).

Additional deployments could be accommodated with sufficient advance notice, as the components are not at present available off-the-shelf and are provided by small businesses. Estimate for delivery of instruments and UltiBuoys and preparation for deployment is likely 60-90 days after receiving order.

Estimated budget for future deployments:

Instruments	\$5000 each, delivered and calibrated

UltiBuoy	$7000 with controller and cable	
Mooring anchor/chain	$600	
Mooring Prep by CWLLC, including testing and build		$4000
Deployment / Recovery / Maintenance per trip, incl. vessel cost, CWLLC		$2000 each
Data management	$1000	

For a 6-instrument deployment and recovery, approximate cost would be around $47K. From a power standpoint, batteries will last an entire hypoxia season (estimated 8 months). One may want to budget one cleaning trip, totaling under $50K. One might also consider a spare instrument

Ideally, locations for new deployments would be developed in conjunction with researchers operating the VIMS model so that they could be optimized for ability to contribute to accurate estimates of Chesapeake Bay Hypoxic Volume.

7. Best practices and basic manuals

In lieu of a full system manual, included here are manuals for Soundnine components (PME MicroDOT is fully integrated and should require no user interaction or maintenance) and notes on best practices.

Discussion and Best Practices

Soundnine CTO_2 instruments are assigned a semi-permanent address in their firmware. The instruments used in these deployments were 09M, 09K, and 09J. Addresses are used to identify instruments when requesting data and on logging data. When using the SBE instruments, they must be assigned integer numbers; we had P06 assigned to SBE37 SN 9817 and P03 assigned to SBE SN 9820.

The Ultibuoy has the capability (see manual) to include a serial communication cable into the inductive modem loop (see manual) and query the instruments directly. This is used to test each instrument by querying it directly, and logging the resulting data. These tests should be undertaken before deployment to verify proper operation. This also allows direct communications to the Ultibuoy controller for firmware updates, program storage, time setting, and data inspection and downloading.

Soundnine CTO_2 instruments can only be addressed and triggered to take a measurement inductively through the UltiBuoy, Ultimodem, Soundnine SIMC, or another inductive modem. One of these must be attached for calibration or testing, with an inductive wire loop grounded to itself. Until a CTO_2 instrument manual is available, it should be noted that these instruments respond to the same commands as the Soundnine Enduro Temperature sensor.

During preparation, we placed 1-meter tags along the cable to facilitate instrument placement and monitor during deployment and recovery. Tags should be placed relative to estimated buoy waterline. It is important to have lowest instrument as close to the bottom as possible, so necessary to have an accurate bottom depth measurement at the proposed site. Go to site and make multiple electronic depth sounder measurements of known validity, understanding tidal variation and stage of tide during measurements. Do an additional depth measurement with a vertical lead line, and test strength of GSM service at site.

Evaluate marine traffic (commercial and recreational) at the site – that will be required for permitting. We have asked Soundnine to integrate a flashing navigation light into the UltiBuoy. Evaluate current velocity estimates, using models if necessary. The mooring is fairly stiff and low drag, and one can track mooring tilt in real time using pressure measurements. The termination (wire thimble to upper chain shackle) should be situated to be about 0.5 m less than measured water depth at MLW, we used 3 m of 3/8" chain (more required for a larger tidal range) and a 35 lb. Dor-Mor pyramid anchor.

Deployment and recovery can be accomplished by hand from a small vessel; the primary difficulties come not from total submerged weight but rather in handling the 1/8" wire used as inductive/anchor line. Deployment is best carried out by having a ring in the anchor chain and lowering the anchor slowly with a 3/8" or larger line loop, controlling deployment of sensors and finally Ultibuoy.

Recovery is more difficult. We facilitated recovery using heavily padded gloves and the Tyler wire clamps mentioned above. Wire clamps with tag lines can be used to lift the wire vertically and stopped off on cleats, raising the mooring 1-2 meters per pull. We also found that the mooring may have to be initially dragged before recovery to break loose from bottom suction.

The snagging and subsequent 4 mile drag into shallower water of the mooring by the hydrographic survey vessel in October was an excellent test of the strength of the system.

Manuals located in Appendix C:
C 1 Soundnine Enduro Sensor Manual
C 2 Soundnine UltiBuoy Testing Notes
C 3 UltiBuoy Controller Manual
C 4 Ultimodem Manual R010Q

Proposed maintenance

We found it useful to paint the below-waterline parts of the UltiBuoy with antifouling paint, in this case Pettit Hydrocoat Black.

Original instruments as delivered did not have a cover; we provided covers made from several layers of heavy copper mesh. Additionally, exterior surfaces of the instruments were covered with copper tape and voids around the sensors were filled with light copper mesh. These did not impede flow and seemed to stop marine growth for the 3 to 4 week periods (June and September) that were tested. We expect that at most a single cleaning and inspection would be needed during a full seasonal deployment.

Calibrations

Calibrations are performed on all sensors at Soundnine prior to shipment, and they can be returned for recalibration. Temperature sensors are calibrated at multiple points in the 4^{o} C to 35 ^{o} C range. Conductivity is calibrated over a range of temperatures at each conductivity point; PME sensors are calibrated at the factory, and are tested again at Soundnine at a range of temperatures at 100% saturation. Standard salinity corrections are applied to Dissolved Oxygen measurements, as initial calibrations and calculations assume zero conductivity.

Since instruments report raw values, calibrations can be stored and changed in the data base for conversion to engineering units.

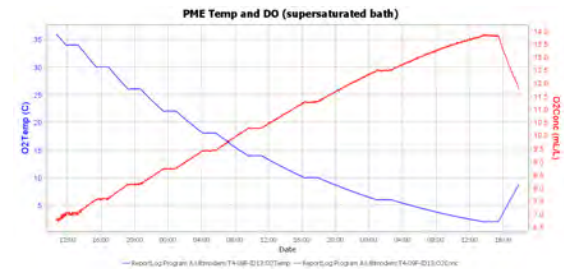


Figure 16. Example of Soundnine DO sensor calibration validation prior to shipping.

The data collection system allows for additional calibration adjustments to be made. Between the 2020 deployments, each Dissolved Oxygen sensor (Soundnine, SBE37, PME MiniDOT, and YSI 600) was tested in a 100% saturated fresh water bath. Sensor values ranged from 93 % to 97%. Factors were included in the data management system and these corrected DO values were included in the data base as additional output parameters.

8. QAPP

Quality Assurance Project Plan

Chesapeake Bay Dissolved Oxygen profiling using a lightweight, low-powered real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels

Based on CBP QAPP for MAINSTEM & TRIBUTARY FIELD PROCEDURES

This document is originally embedded the Project FINAL REPORT, which contains all information and references required to carry out the QAPP, and should be considered part of the QAPP.

Section A. Background and Description

1. Management Objectives
2. Project Objectives
3. System Design
4. Water Quality Measurements

Section B. Field Measurement Procedures

1. Sampling Sites
2. Mooring Deployment
3. Mooring Recovery
4. Calibration and Quality Assurance
5. Documentation and Records
6. In-water maintenance

Section C. References

1. Management Objectives

Water Quality impairment in the Chesapeake Bay, caused primarily by excessive long-term nutrient input from runoff and groundwater, is characterized by extreme seasonal hypoxia, particularly in the bottom layers of the deeper mainstem (although it is often present elsewhere). In addition to obvious negative impacts on ecosystems where it occurs, hypoxia represents the integrated effect of watershed-wide nutrient pollution, and monitoring the size and location of the hypoxic regions is important to assessing Chesapeake Bay health and restoration progress.

Chesapeake Bay Program direct Water Quality monitoring has been by necessity widely spaced in time and location, with monthly or bi-monthly single fixed stations separated by several kilometers. The need for continuous, real time, vertically sampled profiles of dissolved oxygen has been long recognized, and improvements in hypoxia modeling and sensor technology make it achievable. Recent results of Bever, et al. (2018) show that total Chesapeake Bay hypoxic volume can be estimated using a few analytically selected fixed continuous Dissolved Oxygen profiles. Towards that end, moorings supporting real-time transmission of dissolved oxygen and other parameters will be deployed for testing to evaluate their ability to efficiently and sustainably provide dissolved oxygen data to monitor Chesapeake Bay hypoxia.

2. Project Objectives:

2.1 Primary Objectives for the Project (*Chesapeake Bay Dissolved Oxygen profiling using a lightweight, low-powered real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels*) are:

2.2 Ensure the system and resulting data meet CBP and partners' data needs

2.2.1 Provision of desired parameters (in this case Dissolved Oxygen concentration – which requires coincident Temperature and Salinity for accurate calculation)

2.2.2 Adequate data quality – initially and over the whole of a seasonal deployment

2.2.3 Vertical resolution – ability to capture the important features of vertical structure

2.2.4 Timely, easy, and dependable real-time data delivery

2.3 Ensure the system is sustainable - including long term capital and resource requirements, personnel expense'

2.3.1 Minimum initial cost to acquire and deploy

2.3.2 Minimal level of field support required during deployment

2.3.3 Long lifetime of equipment and ease/cost of off-season repairs, refurbishment, and calibration

2.4 Ensure the system is flexible – Can the system be successfully utilized in all required locations, recognizing diverse, often extreme physical environments and conditions that may be faced.

3. System Design

3.1. The system will consist of: A moored Soundnine Ultibuoy with an inductive modem, cellular communications, GPS, and Ultibuoy controller; Mooring system supporting Ultibuoy and sensors; inductive $CTDO_2$ sensors, clamped to the mooring cable at vertical depths appropriate for resolution of local hypoxia profile; and shore-based data acquisition, management, and distribution systems.

3.2. The Soundnine UltiBuoy is 55 cm diameter x 30 cm high, foam with ground plate / cable fairlead, and concrete ballast below, buoy controller/comms/solar panel module on top. Weight is 25 kg, with 55 kg of buoyancy. Ballast and hull below waterline are painted with anti-fouling paint prior to launch.

3.3. The inductive communication and strength cable is jacketed stainless steel wire, terminated with a grounding electrode and swaged stainless steel thimble loop. Termination should be placed so that lower thimble is 0.5 m above the bottom at MLLW. An appropriate length (at least 3 m) of galvanized mooring chain is connected to the thimble with a swivel. An appropriately sized Dor-Mor pyramid anchor (35 lb. for this 21.5 m depth mooring) is shackled below the chain.

3.4. Sensors will be independent, integrated Temperature / Conductivity / Dissolved Oxygen (optional Pressure) units produced by Soundnine. Units collect data and transmit inductively, clamped to a semi-taut mooring line with a surface data collection and cellular transmission Ultibuoy. Prior to deployment, optimum sensor depths should be determined based on available historical data using analysis methods described in the proposal. Note that sensors using SeaBird IM protocol are compatible with the Ultibuoy communications system.

3.5. The Final Project Report provides a good example of the data collection commands, as well as the Ultibuoy command set and manuals. Data collected and transmitted by the Ultibuoy goes directly to the Soundnine server; test sensor function and setup using closed inductive loop and arrange data tests well prior to deployment to make sure inductive and cellular communications and database are properly configured. Access to the Soundnine system is through S9vis, a Java application. Each deployment location should have a sperate database AND a separate web page (arranged with AXIOM, Kyle Wilcox, kyle@axiomdatascience.com).

4. Water Quality Measurements

Each Soundnine sensor collects the following measurements:

DO Concentration	mg/l
Temperature	Deg C
Temperature Period	(Diagnostic)
Temperature Stability	(Diagnostic)
Conductivity	(S/m)
DO Temp	(Deg C Diagnostic)
DO 'Q' Factor	(Diagnostic)
Pressure Voltage	(to calc.pressure)
Pressure Temperature	deg C
Instrument Battery Voltage	V
Instrument Pitch	degrees
Instrument Acceleration	g
Instrument Signal Strength	units

These measurements are used to calculate the following water quality properties:

Temperature	deg C
Salinity	PSU
Dissolved Oxygen Concentration	mg/l
Pressure	decibar

Typically, measurements are collected and transmitted at 10-minute intervals.

Section B. Field Measurement Procedures

1. Sampling Sites

1.1. Once a sampling location is determined (input from CBP, VIMS O_2 Modeling group, other interested parties), the following should be evaluated: Estimated water depth, nearby CBP or other historical profiles for sensor locations, commercial and recreational marine traffic in the region, jurisdiction and process for buoy permitting, any other factors.

1.2. Visit the site and make accurate measurements of water depth (electronic acoustic sounding; and manual via sonde or CTD to bottom), noting charted depth and tidal stage. Location must have cell GSM (ATT, T-Mobile) cellular service.

1.3. Check bottom type and holding power with vessel anchor.

2. Mooring Deployment

2.1 Pre-Deployment

Cut mooring cable to proper length and attach grounding electrode; securely swage (2) loop with thimble just below electrode. Mark 1 me depths on cable and attach sensors at predetermined locations, O2 sensors downward. Mark depths on sensors; record locations; photograph each. Attach chain and swivel. Bend split pins or tie-wrap safety shackles.

Closing inductive loop with direct connection (including 1kΩ resistor for noise reduction), place buoy outdoors with clear view of sky and sensors in an oxygen-saturated, stirred bath. Start buoy with magnet. Let buoy collect data, transmit, and populate data base to check system end-to-end. Check all data, instrument and buoy voltages, GPS positions, and compare sensor values to each other. Compare Dissolved oxygen values to calculated 100% saturation values. Stop buoy with magnet. Take photos from multiple angles of each sensor on cable, buoy, and electrode/chain/sinker system. Complete full mooring diagram.

Set up a diagnostic email account for this buoy, and make sure Soundnine server is transmitting data records to the account.

2.2 Deployment

With all sensors, buoy, and data checked on land, coil wire and sensors for transport. When on station, check depth (against mooring cable length). Take a CTD cast. Lower sinker to bottom with an easily handled line looped through ring on chain, slowly deploying instruments over the side while keeping light tension on mooring cable. Mooring cable should not go slack, and buoy should be deployed last with waterline at approximately half buoy height. Note time. Stay on site until email confirmation of data receipt by Soundnine server and check of data validity. Contact AXIOS with database name and deployment metadata.

3. Mooring Recovery

3.1 Arrive on station. Note time, do CTD cast. Tie line to buoy handle and pull buoy with vessel (gently) until it is displaced and bottom suction is broken. If vessel has a davit or A-frame, use in a similar fashion to flowing instruction for recovery by hand.

3.2 Lift buoy into vessel with line and secure line. This should be accomplished only pulling chain off bottom (not anchor). Using Tyler wire clamp with larger diameter line tail, clamp cable as low as possible, pull cable over gunwale into boat, and cleat tail, keeping pressure on clamp. Repeat, alternating clamps and lifting instruments over rail and into boat. Reaching chain, loop line through lift ring and secure. Keep secured while lifting anchor into vessel.

3.3 Photograph buoy, instruments, mooring, and note any anomalies.

4. Calibration and Quality Assurance

4.1 Calibration

Instruments arrive with factory calibration. Pre-deployment validation compares all instruments against each other and Dissolved Oxygen at 100% saturation. If significant (<3% differences arise in comparison to 100% saturation, correction factors can be added to the database; these should be communicated to Soundnine. Following seasonal deployment, instruments should be returned to Soundnine for post- and re-calibration.

4.2 Quality Assurance

Data should be monitored using the IOOS QARTOD tools available on the AXIOS IOOS web site.

5. Documentation and Records

Field Data Sheets, Calibration results, Maintenance Logs, and photographic images should be maintained online (Google Drive, etc.) in a directory for each deployment.

6. In-water Maintenance

6.1 Platform and instrument preparation

Ultibuoy should be painted below waterline pre-deployment using non-toxic antifouling paint (Pettit Hydrolux or similar). Instruments should be covered in copper tape, have a copper mesh instrument guard, and have voids below the guard filled with fine copper wool in a way that does not interfere with conductivity sensor flow or dissolved oxygen optical paths.

6.2 Maintenance

Test deployments (3 weeks) did not reveal significant fouling. Until better data is collected on fouling, Maintenance visits should be conducted at 2 to 3 month intervals, or if data quality checks indicate data problems. A full recovery should be carried out, any fouling organisms removed from instruments and cable, instruments washed with fresh water, and any depleted copper antifouling treatment renewed. System should be redeployed with sensors in original locations unless replaced with new sensors.

Section C. References

This document is originally embedded the Project FINAL REPORT, which contains all information and references required to carry out the QAPP, and should be considered part of the QPP.

Appendices - Additional attachments

Chesapeake Bay dissolved oxygen profiling using a lightweight, low-powered, real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels

Doug Wilson Caribbean Wind LLC Baltimore, MD
Darius Miller SoundNine Inc. Kirkland, WA

Chesapeake Bay Trust EPA Chesapeake Bay Program Goal Implementation Team Support

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement CB96341401 to the Chesapeake Bay Trust. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

SCOPE 8: ***"…demonstrate a reliable, cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia."***

Water quality impairment in the Chesapeake Bay, caused primarily by excessive long-term nutrient input from runoff and groundwater, is characterized by extreme seasonal hypoxia, particularly in the bottom layers of the deeper mainstem (although it is often present elsewhere). In addition to obvious negative impacts on ecosystems where it occurs, hypoxia represents the integrated effect of watershed-wide nutrient pollution, and monitoring the size and location of the hypoxic regions is important to assessing Chesapeake Bay health and restoration progress.

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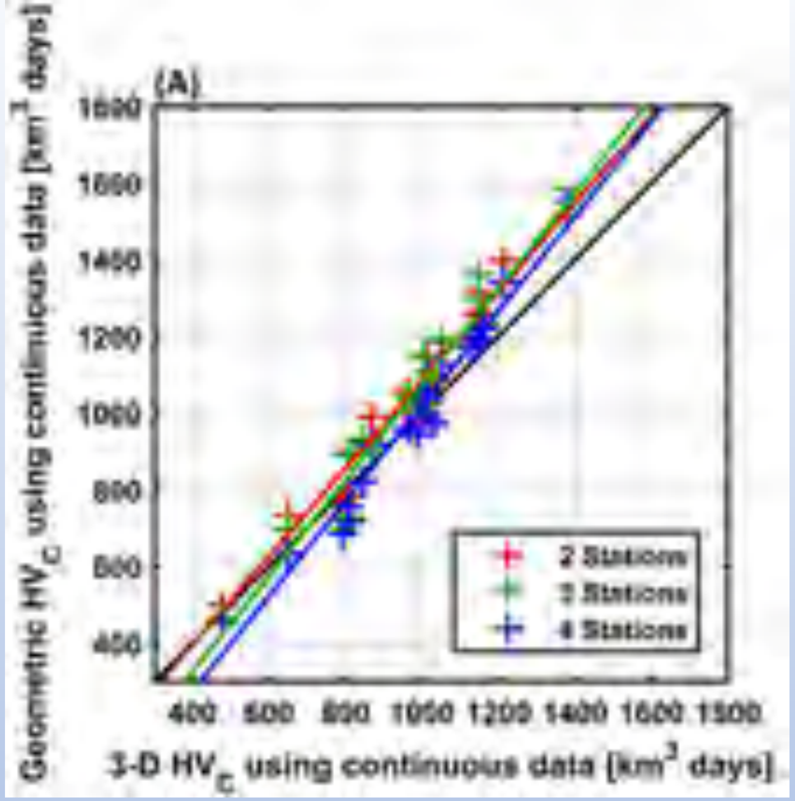
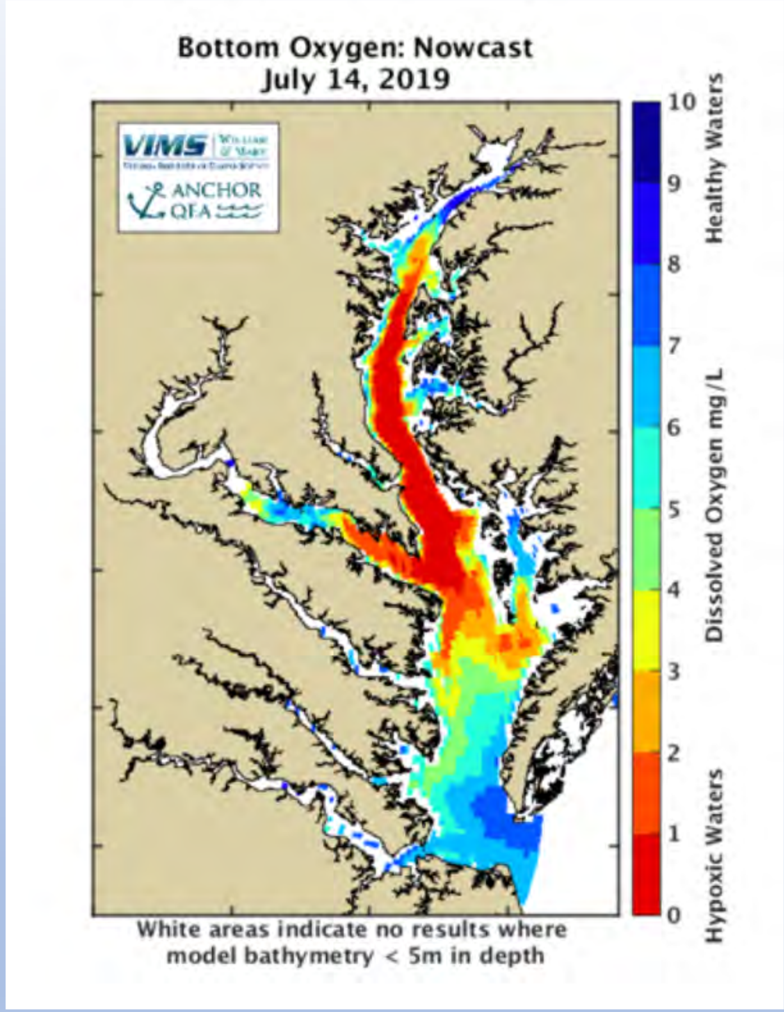


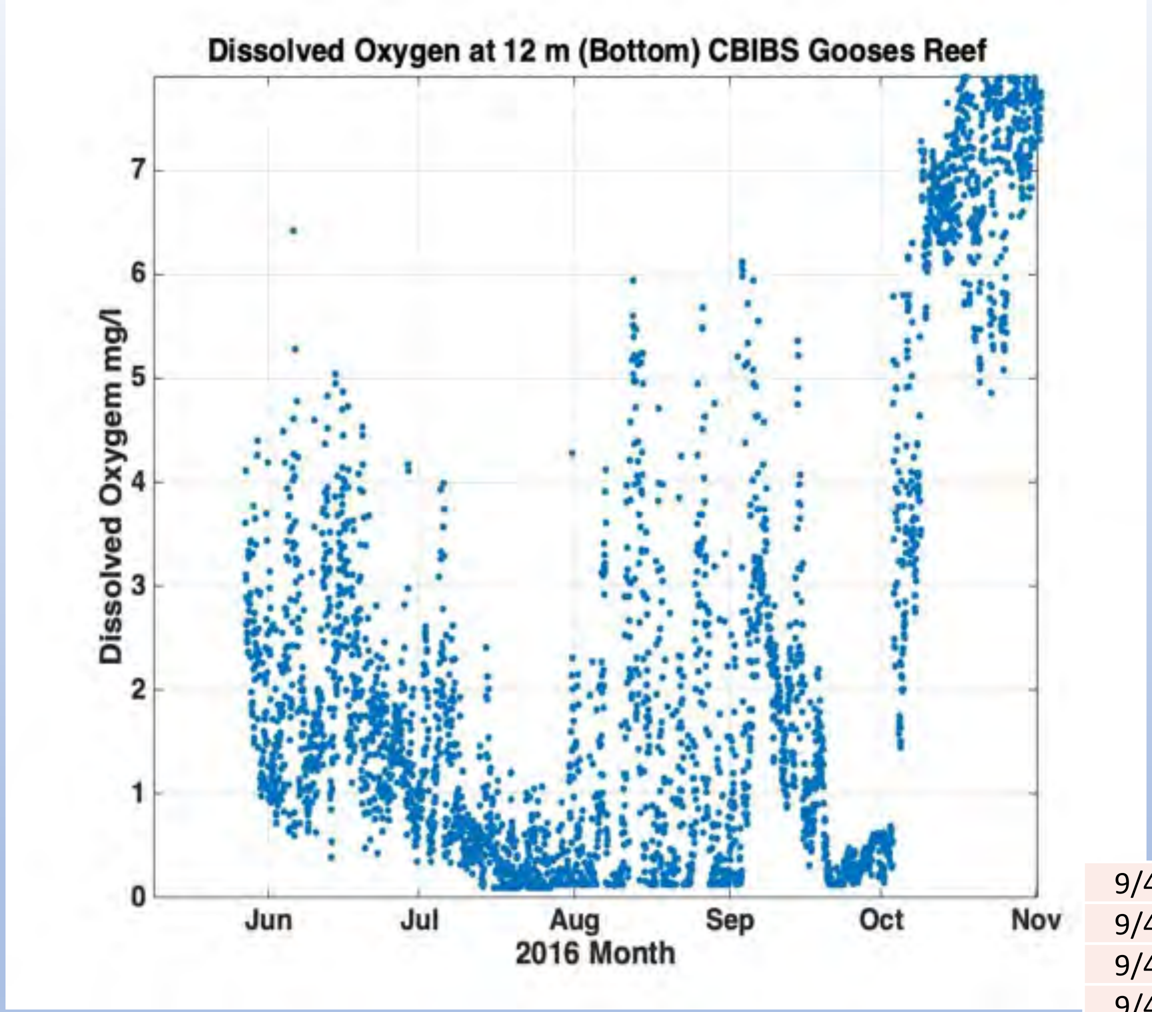
Bever, A. J., Friedrichs, M. A. M., Friedrichs, C. T., & Scully, M. E. (2018). Estimating hypoxic volume in the Chesapeake Bay using two continuously sampled oxygen profiles. *Journal of Geophysical Research: Oceans*, 123, 6392 - 6407. https://doi.org/10.1029/2018JC014129

Real-Time



VIMS Chesapeake Bay Hypoxia Forecast
https://www.vims.edu/research/topics/dead_zones/forecasts/cbay/index.php

Continuous



Chesapeake Bay Interpretive Buoy System
Gooses Reef Bottom Dissolved Oxygen]
buoybay.noaa.gov

9/4/16 09:00	0.97
9/4/16 10:00	0.81
9/4/16 11:00	0.71
9/4/16 12:00	5.15
9/4/16 13:00	5.34
9/4/16 14:00	5.72
9/4/16 15:00	2.54
9/4/16 16:00	1.31
9/4/16 17:00	1.07

Requirements

The RFP SOW requests 4 outputs (paraphrased, my emphasis):

1) lessons learned regarding a **reliable** infrastructure that sustains the deployment;

2**) reliable**/dependable infrastructure assessment of the gear deployed;

3) successes and challenges of the piloted equipment in collecting, storing, and providing **reliable** data in the summer season in the mainstem Chesapeake Bay;

4) details of protocols that can be adopted and invested in for deployment of vertical profiling infrastructure.

Additional requirements, based on extensive experience designing and supporting real-time environmental monitoring systems in Chesapeake Bay, as well as familiarity with CBP and partners, are:

- Meet CBP and partners' data needs
  - Provision of desired parameters (in this case Dissolved Oxygen concentration – which requires coincident Temperature and Salinity for accurate calculation)
  - Adequate quality – initial and over the whole of a seasonal deployment
  - Vertical resolution – ability to capture the important features of vertical structure
  - Timely, easy, and dependable real-time data delivery
- Sustainability – includes long term capital and resource requirements, and personnel expense
  - Minimum initial cost to acquire and deploy
  - Minimal level of field support required during deployment
  - Long lifetime of equipment and ease/cost of off-season repairs and refurbishment
- Flexibility – Can the system be successfully utilized in all required locations, recognizing diverse, often extreme physical environments and conditions that may be faced.

There are two basic ways to acquire a vertical water column profile – by either

a) moving a single sensor package repeatedly through the water column, or

b) locating sensor packages at multiple fixed depths, with vertical sensor spacing adequate to meet observational requirements.

Either way, data must be regularly collected from the sensor(s) and transmitted from the *in situ* system location to an accessible data structure. Our proposed solution is (b), the simpler and more reliable of the two options. This is described below, with rationale for how the approach best fits these requirements.

A lightweight, low-powered real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels

Sensors will be independent, integrated temperature / conductivity / dissolved oxygen (pressure optional) modules developed by collaborator Darius Miller, President and Principal Engineer at Soundnine.

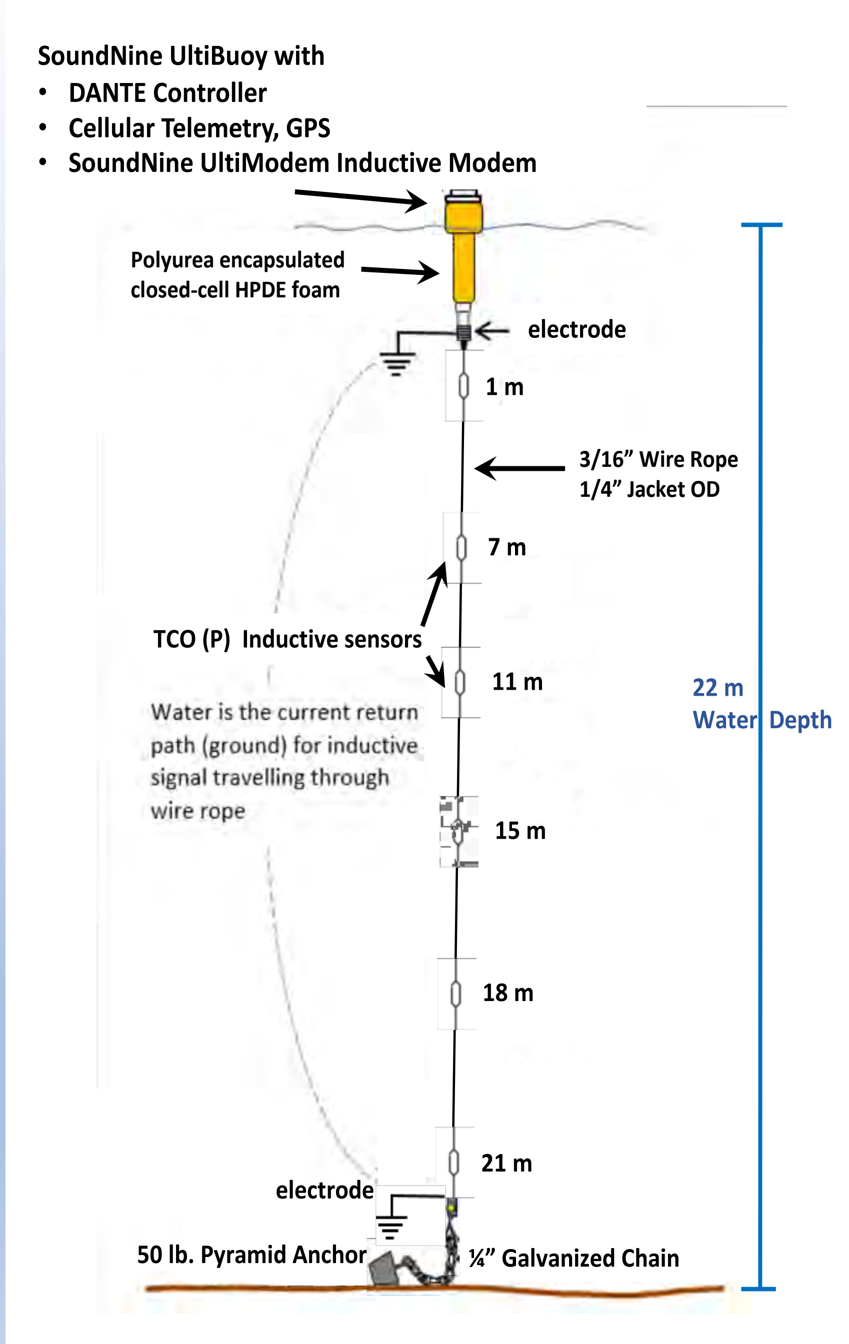
Units collect data and transmit inductively, clamped to a semi-taut mooring line with a surface data collection and cellular transmission buoy (Soundnine UltiBuoy).

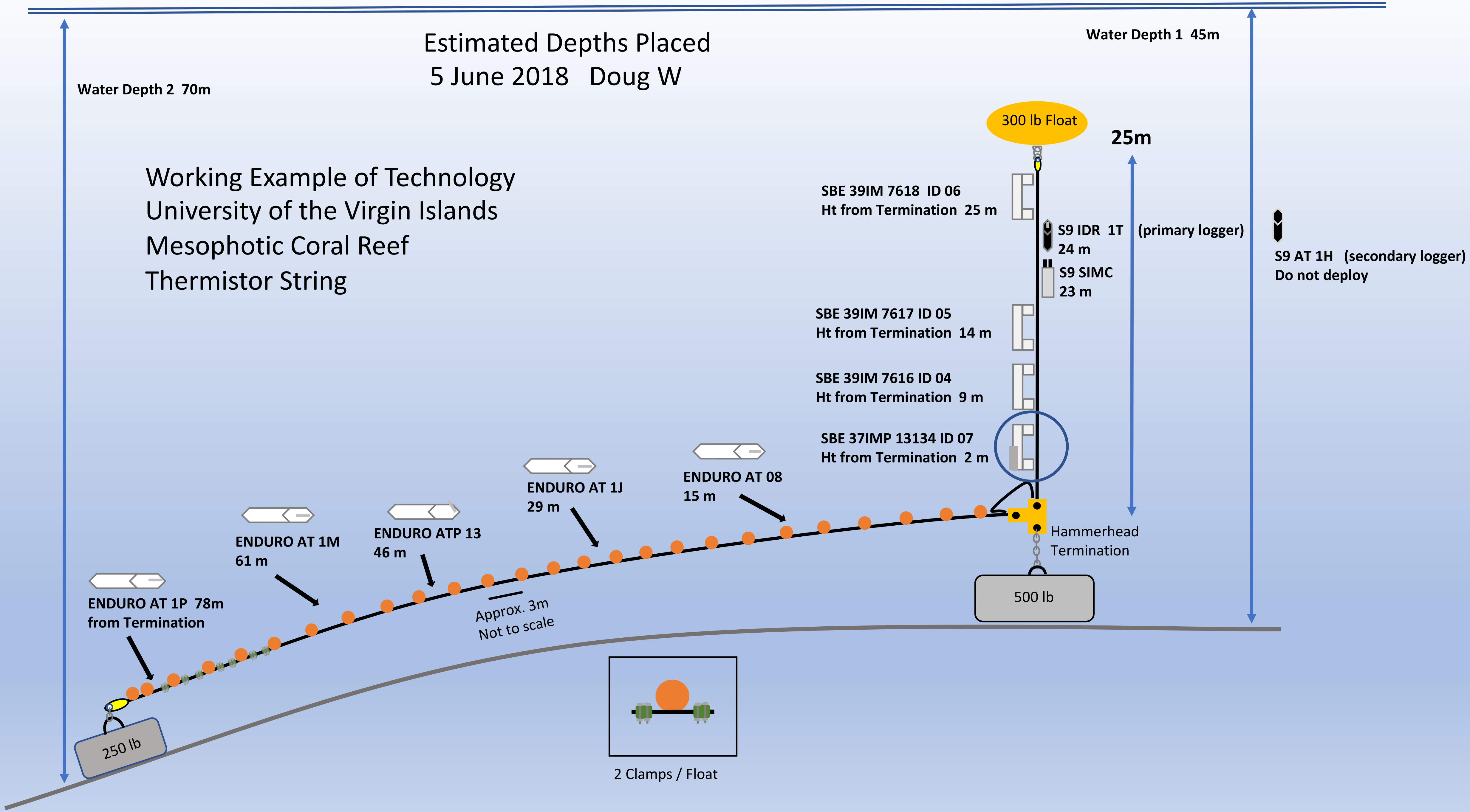
T/C/P sensors with inductive modems are manufactured by Soundnine Inc., and will integrate OEM fluorescence-based microDOT Dissolved Oxygen modules supplied by Precision Mechanical Engineering.

Why fixed sensors instead of a profiler?

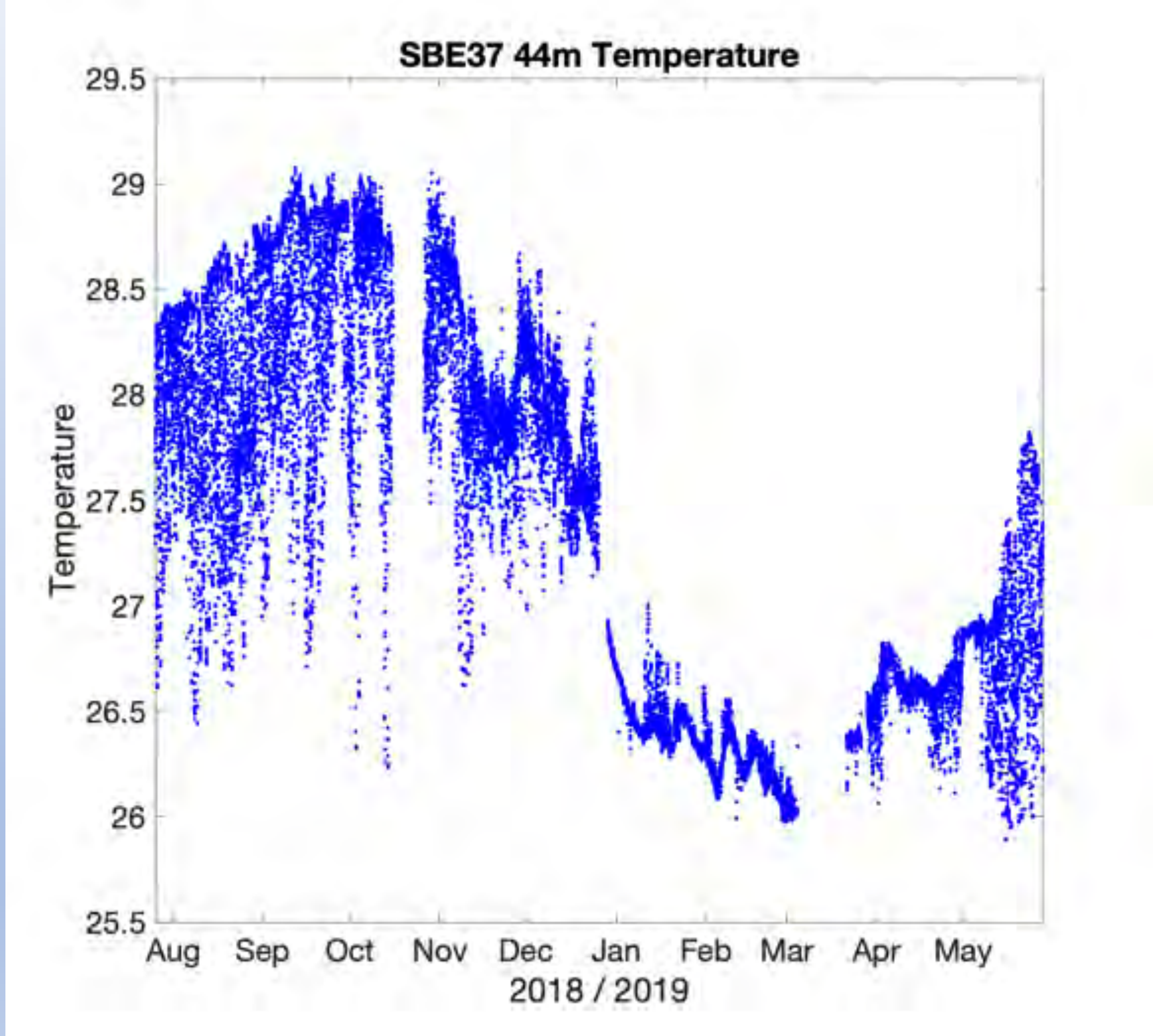
Reliable

- No moving parts, robust (but adjustable) attachment to mooring cable.
- Extremely low power, 2 AA $LiSOCL_2$ batteries will power sensors for a season at 15 minute sampling.
- Redundant data storage within each sensor and controller within the platform.
- Proven hardware with accurate individual sensor components
- Controller / communications buoy designed to be fully submersible to 10 meters to remain semi-taut and withstand surface wave conditions in any Chesapeake Bay water depths




Estimated Depths Placed
5 June 2018 Doug W
Water Depth 2 70m
Water Depth 1 45m
Working Example of Technology
University of the Virgin Islands
Mesophotic Coral Reef
Thermistor String
300 lb Float
25m
SBE 39IM 7618 ID 06
Ht from Termination 25 m
S9 IDR 1T (primary logger)
24 m
S9 SIMC
23 m
S9 AT 1H (secondary logger)
Do not deploy
SBE 39IM 7617 ID 05
Ht from Termination 14 m
SBE 39IM 7616 ID 04
Ht from Termination 9 m
SBE 37IMP 13134 ID 07
Ht from Termination 2 m
ENDURO AT 08
15 m
ENDURO AT 1J
29 m
ENDURO ATP 13
46 m
ENDURO AT 1M
61 m
ENDURO AT 1P 78m
from Termination
Approx. 3m
Not to scale
Hammerhead
Termination
500 lb
250 lb
2 Clamps / Float

University of the Virgin Islands
Mesophotic Coral Reef
Thermistor String



Sustainable

- Sensor modules are low cost (estimated $4-5K) so spares are affordable
- Protected from fouling, modules and sensors should not require cleaning during season
- Full mooring with sinker is hand-deployable/recoverable by two people using a small boat

Flexible

- Modular components
- Works in any depth – deep or shallow - found in Chesapeake Bay
- Designed to withstand extreme Chesapeake Bay wave conditions



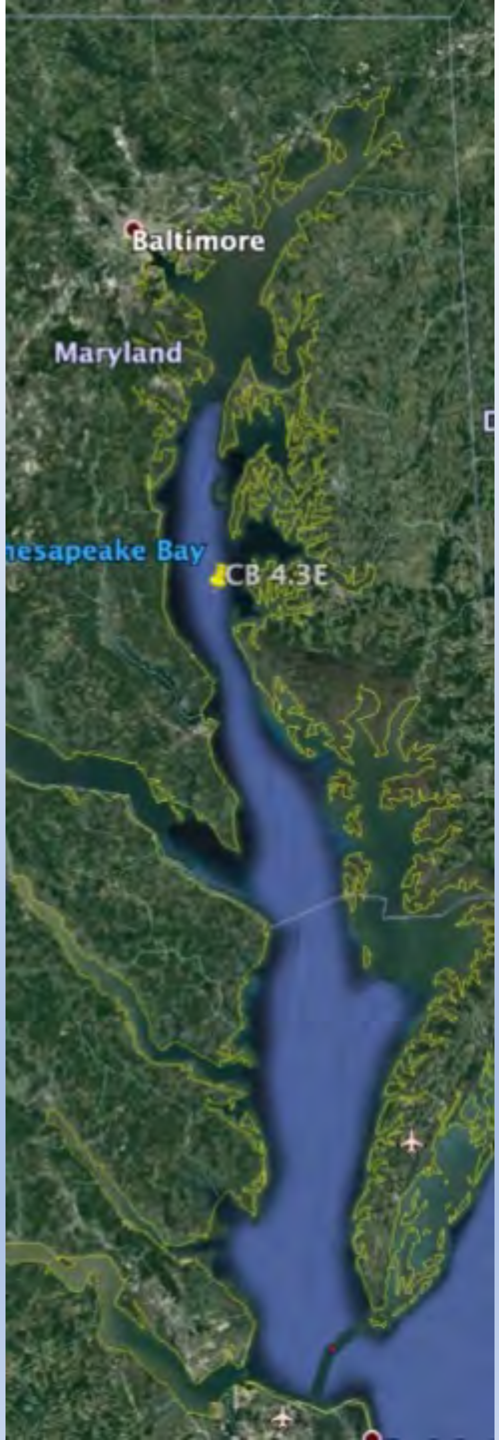
Meets Data Needs

- Samples are collected simultaneously at a prescribed fixed time interval
- Analysis shows that a reasonable number of sensors can achieve accurate measurement of vertical hypoxia structure while still maintaining the reliability and sustainability advantages of a simple ‘no moving parts’ platform.
- Data are stored in two locations internally and transmitted in real-time to Soundnine’s cloud-based storage system, where data QC will be performed per US IOOS QARTOD methodology (https://repository.library.noaa.gov/view/noaa/18659)
- The data will be made available to CBP and partners with low time latency and will include QC flags. Low power consumption of inductive technology allows 15-minute sampling for a full season deployment

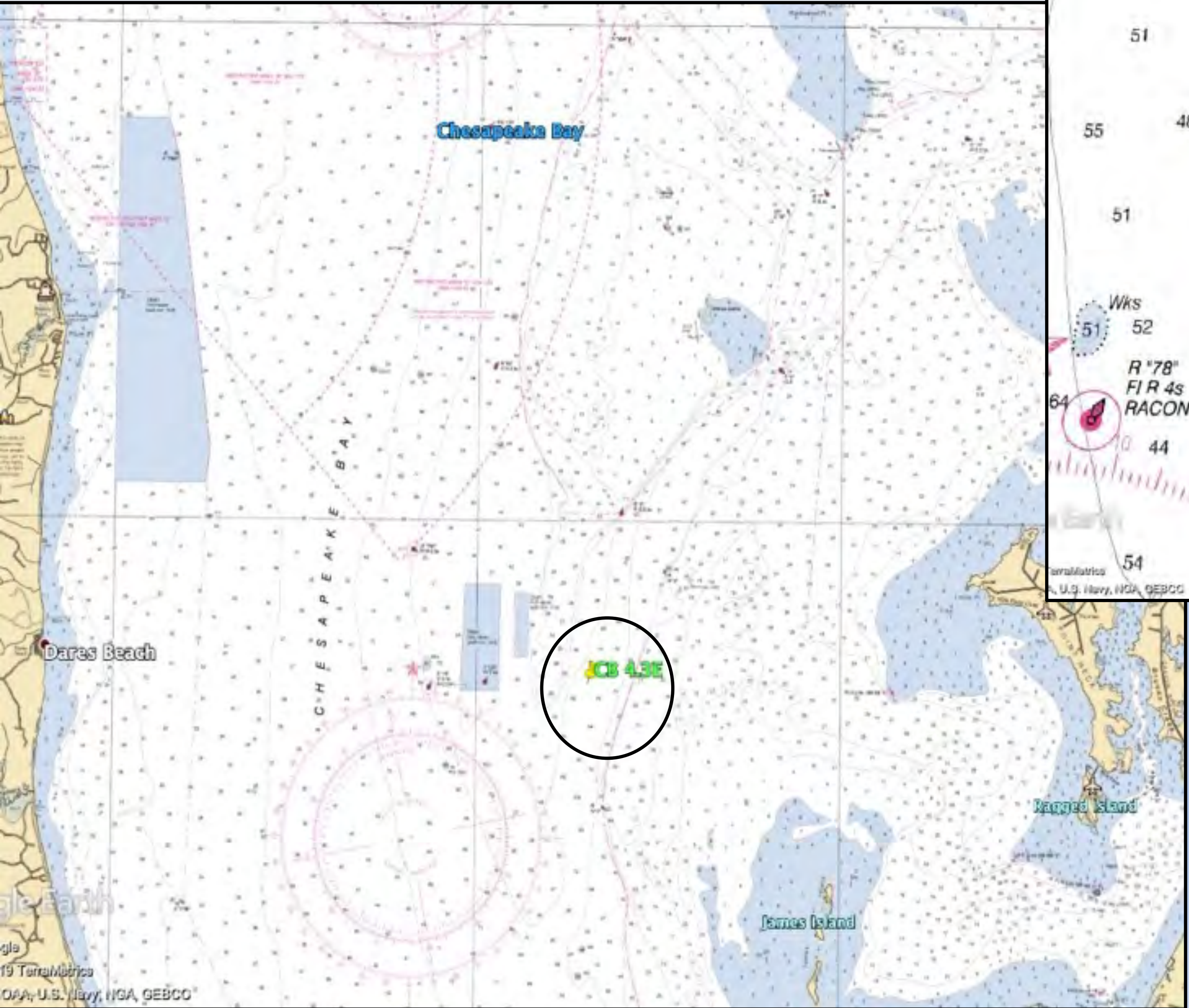
While a single profiling instrument is an alternative approach, our experience with these devices is that they have more structural and logistical complexities and failure points (both in the profiling mechanism and in the mooring/structure supporting the profiler). These increase the risk of service visits in-season (cost) and associated periods of missing data.

Reliability is maximized by using the simplest solution that meets the requirements.

Consider, as a Pilot example, deployment at CBP fixed monitoring station CB4.3E (38.55624 N, 76.39121 W) – about 2.5 km east of CBIBS Gooses Reef buoy, where there is real time surface environmental data nearby from GR, as well as bottom DO and pH data. Additionally, this station is in a reasonably deep location (21-22m) and out of main shipping channel.



NOAA Chart 12266_1



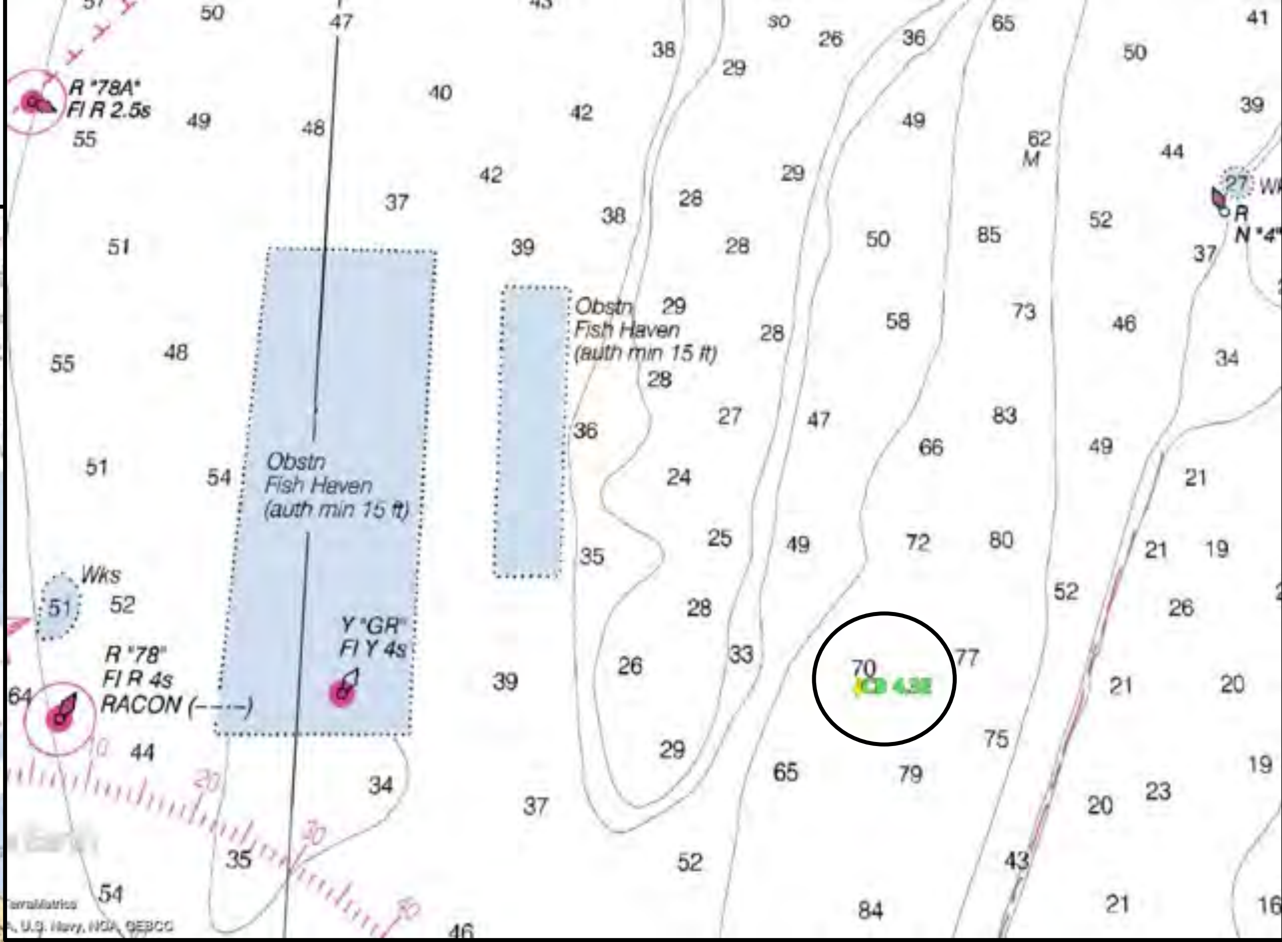
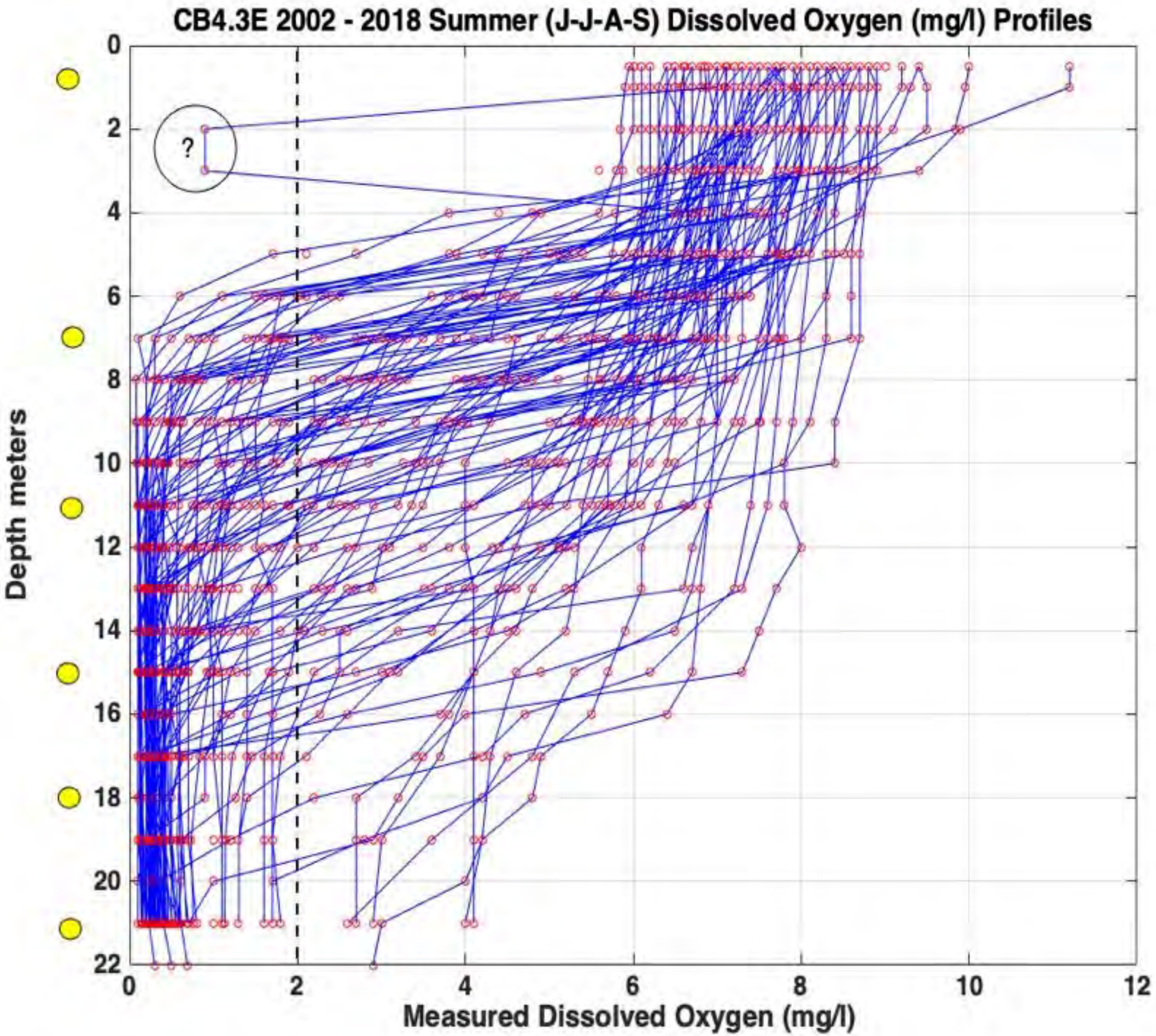
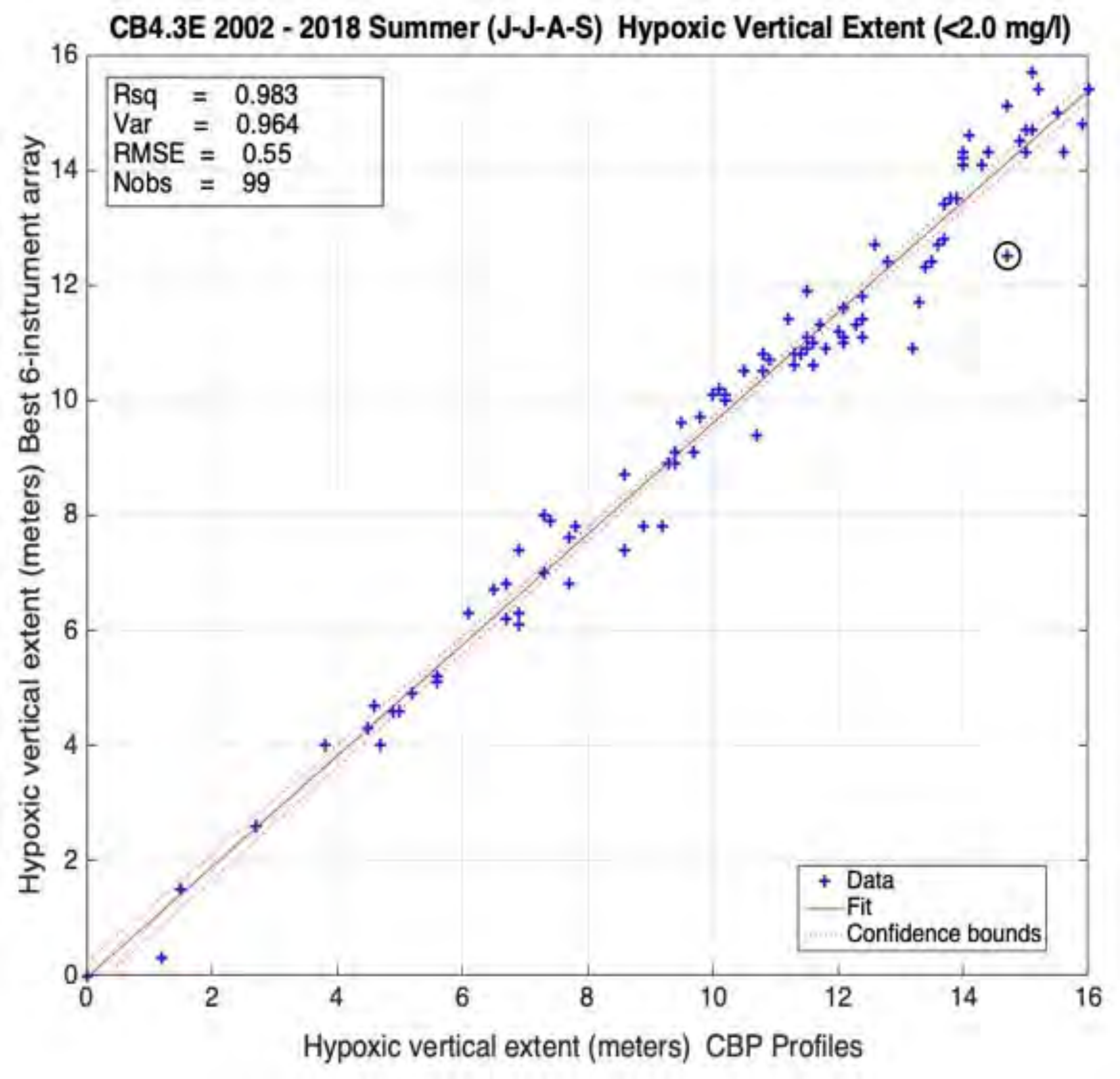


Figure shows CB4.3E DO profiles from 2002-2018 June/July/August/September. With the assumption that we want to be able to at least match the ability of the existing fixed station sampling to resolve structure and measure vertical extent of hypoxia
(DO < 2.0 mg/l) for use in DO volume estimates and forecast model comparisons, simulations were run with various fixed sensor depths.



For station CB4.3E, reasonable results can be achieved with as few as five or six sensors – graphical comparison of the six-sensor model is shown in Figure 1B. This is a preliminary analysis of sensor depths; it is likely that more rigorous placement analysis would reduce uncertainty even further.



Comparison of 'Vertical Hypoxia Extent (Meters)' calculated using measured profiles (X axis) and the same quantity calculated using a hypothetical array of six sensors shown in previous figure. Different arrays were tested; the results are shown in Table.

Table shows how well different vertical sensor arrays capture full water column Vertical Hypoxia Extent - the amount of the vertical water column with dissolved oxygen concentration below 2.0 mg/l.

Number of Sensors	Depths (meters)	R^2	% Variance	RMS Error (meters)
21	[1,2,3,…,19,20,21]	0.999	0.994	0.22
11	[1,3,5,7,…,17,19,21]	0.994	0.985	0.33
10	[1,5,7,9,…,17,19,21]	0.993	0.984	0.33
9	[1,6,9,11,13,15,17,19,21]	0.990	0.977	0.42
7	[1,6,9,12,15,18,21]	0.988	0.977	0.46
6	[1,7,11,15,18,21]	0.982	0.964	0.55
5	[1,7,12,17,21]	0.978	0.980	0.63

Analysis of performance of various configurations of number and placement of vertical sensors

In collaboration with the Chesapeake Bay Goal Implementation Team and regional hypoxia modelers, Caribbean Wind LLC will complete the following:

- Select an appropriate demonstration location;
- design and build a vertical array of inductive CTO2 sensors and a data controller and real-time transmission buoy;
- deploy, maintain, and monitor the array throughout the summer hypoxia season;
- and collect, quality control, and make data available in real time.

Follow-up reports will evaluate system performance, reliability, cost and sustainability, and data quality, handling, and availability. Caribbean Wind LLC will also share results with hypoxia modelers to determine the best vertical sensor and array locations to support their nowcast-forecast systems.

Task 1: (Timeline: 1st month, ~~March - April 2019~~**)** **JUNE 2019**

An initial meeting between contractor and project leads to:

a) go over the winning proposal to align timelines and ensure mutual understanding regarding deliverable expectations;

b) review current hypoxia monitoring efforts; and

c) agree on one or more potential locations for the pilot study. A minimum of two locations for long-term monitoring of bay hypoxia are recommended by Beaver et al. (2018) “Estimating Hypoxic Volume in the Chesapeake Bay Using Two Continuously Sampled Oxygen Profiles.” However, one test site location with at least two vertical data points will be sufficient if the contractor can produce a proof of concept for the system design.

Task 2: (**July / August 2019**)

- Establish the details of the scope of work.
- Develop the written monitoring design, and operation protocol.
- Include data collection/management/delivery with a Quality Assurance Project Plan (QAPP) for the vertical profile station(s) (selected in task 1). In addition, task 2 will include:

  a) Identifying sensor type;

  b) Identifying existing or new monitoring platform required;

  c) Finalizing sampling protocol;

  d) Final review of comments on operation and maintenance protocol (protocols will also bereported on in QAPP); and

  e) Convening project leads and contractor to review overall project design.

  f) begin process of obtaining buoy permits from US Coast Guard, Army Corps of Engineers and MDE.

Task 3: **(August / September 2019)**

Acquire sensors and prepare for test deployment. This task includes:

a) Purchasing sensors;

b) Building and/outfit pilot platform and profiler;

c) Testing sensors, pilot platform, and profiler

Task 4: **Test Deployment by 15 October**

Short term test to Implement, maintain and operate; pilot monitoring design and protocol. This task includes:

a) Deploying sensors, pilot platform, and profiler at one or more stations.

b) Regular monitoring and maintenance of pilot sensors and platform(s) per protocol;

c) Regular communication of performance by contractor with project leads;

d) Establish sensor and platform removal date with project leads (less than 1 month); and

e) Initial Test deployment performance report discuss project performance and adapt programming as necessary to address any significant issues in achieving success of the effort.

f) Meeting with project leads to discuss Initial Performance Report and plan 2020 Spring Deployment

Task 5**: (December 2019 to March 2020)**

a) Corrective measures as required to prepare for longer term Deployment; prepare instrumentation for longer Deployment.

b) Deploying sensors, pilot platform, and profiler at one or more stations. (March 2020)

c) Regular monitoring and maintenance of pilot sensors and platform(s) per protocol;

c) Regular communication of performance by contractor with project leads;

d) Establish sensor and platform removal date with project leads

e) Biweekly or Monthly check-in calls for 30 to 60 minutes to discuss project performance and adapt programming as necessary to address any significant issues in achieving success of the effort.

Task 6 **(March -June 2020)**

Recovery of platform following 60 to 90 day test period, maintaining procedures in Task 5;

Assemble dataset, analyze results, provide project leads with a draft midpoint report by June 15, 2020 for review/comment to brief project leads and stakeholders on pilot deployment
performance. This task includes:

a) Holding at least one meeting with project leads and stakeholders to review pilot deployment
results and performance

b) Providing a presentation to the Chesapeake Bay Program's (CBP) STAR, Water Quality and Sustainable Fisheries GITs on draft performance, experience, and findings

Task 7: **(August 2020)**

Complete and deliver final project report. This task includes:

a) Meeting with project leads regarding review/comments to identify and agree on final report content;

b) Drafting final report and deliver by August 1, 2020, with lessons learned about the equipment used in the study, the effort, the costs for infrastructure, its maintenance and data collection, management, and delivery. Including recommendations that address these areas of lessons learned applied to establishing a system of at least two vertical profiles for measuring vertical habitat conditions impacting living resources and involves the annual hypoxia cycle expressed in the deep waters of Chesapeake Bay; and

c) Briefing report to project leads and other stakeholders identified by the project leads, including a final presentation to the CBP STAR.

1 October Progress Report

Some delays in instrument production due to provision of PME MicroDOT sensor modules (one delivered 23 September for initial integration, awaiting calibration and delivery on six more).

Full instruments expected completion week of 21 October – will require final calibration and delivery.

Completing build on Ulti-Buoy week of 7 October.

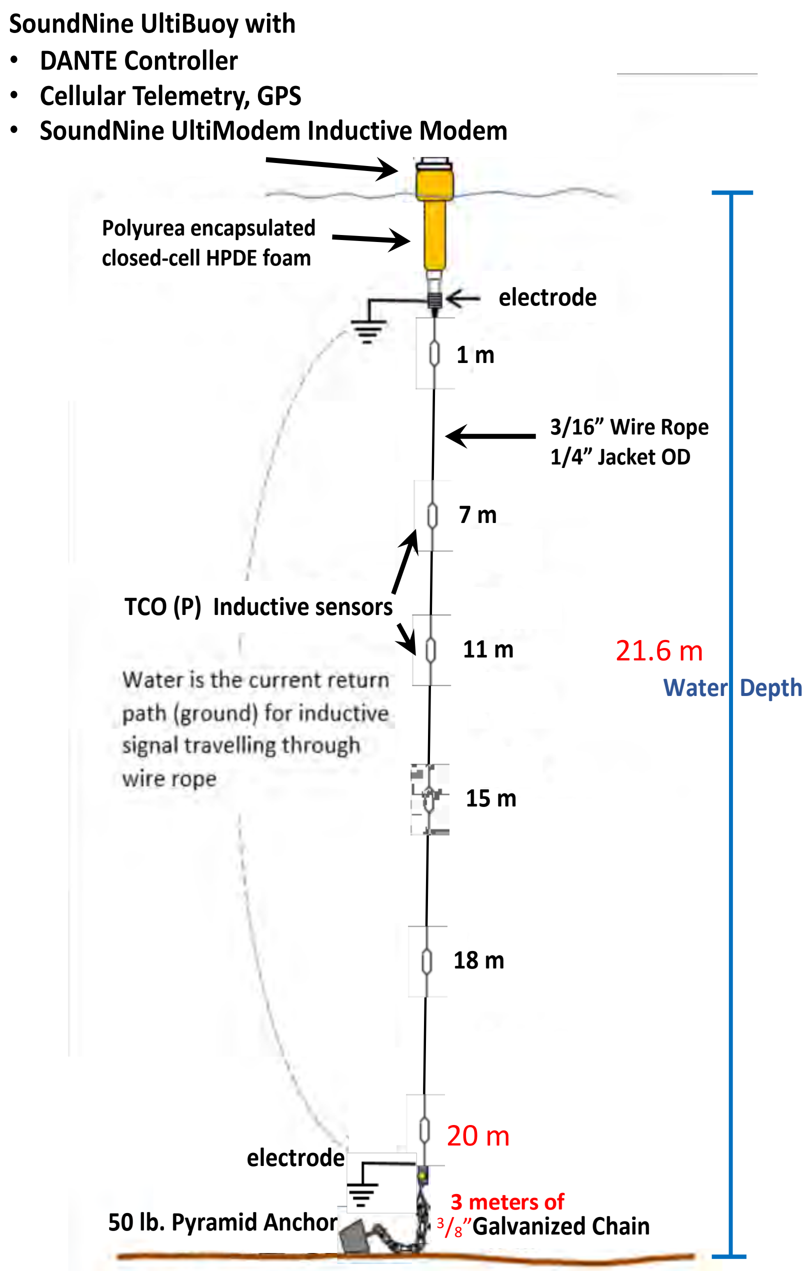
Completing construction of cable week of 14 October.

Based on delays and work schedules, expecting full mooring build early November (Completion of Task 3) and test deployment in mid-November (Begin Task 4).

Visited CB4.3E site for bottom survey and rough DO profile – found hypoxia below salinity mixed layer in upper 6m.   Measured depth (projected to MLLW based on tide table) is 71 feet (21.6 meters), consistent with CBP station depths.

Below, three views of SoundNine CTPO inductive instrument. This is taking a little longer than expected, but the result really will be a breakthrough instrument for simple, low-cost measurement hypoxia vertical structure.

Mooring Design adjusted for measured depth.
Additions for this test mooring will include 2 x SBE37 CTDO2 units from NCBO and an additional recording PME unit on the anchor.



Chesapeake Bay Hypoxia Profiling
Chesapeake Bay Trust
Caribbean Wind LLC
15 April Progress Report

Component availability and production delays (dealing with very small businesses on all counts) pushed back schedule significantly. Since early March we have begun to catch up and start testing equipment, although confined to land testing at present due to COVID-19 mobility restrictions.

October – February – Staying on top of instrument delays, visit to CB4.3E site (21.6 m)

2 March	Conference Call with EPA to discuss schedule
4 – 10 March	Pick up 2 x SBE37 CTDO2 instruments from NCBO, testing and prep
18 March	UltiBuoy arrival from S9
20-30 March	UltiBuoy setup and dry testing with SBE37s
3 April	Arrival of first calibrated Sound9 CTOD2 sensor
5 April -	Dry / tank testing with SBE and S9 instruments
5 April -	Tuning of data collection, visualization, and access system
5 April -	Begin writing operational instructions and manual.
5 April -	Begin preparing test and operational mooring components to be ready for deployment when allowed.
15 May -	Complete above tasks, acquire and test all instruments, ready to test deploy Long-term deployment following successful test deployment.

Summary
All components have been tested and hardware acquired. Buoy needs:
Anti-fouling paint
Cable Termination
Sealite SL-15 and GeoForce GT0 tracker and mounting hardware

SBE 37s (S/N 9820 and 9819) and S9 CTDO sensor (09F) have been successfully tested. Awaiting more S9 CTDO sensors.

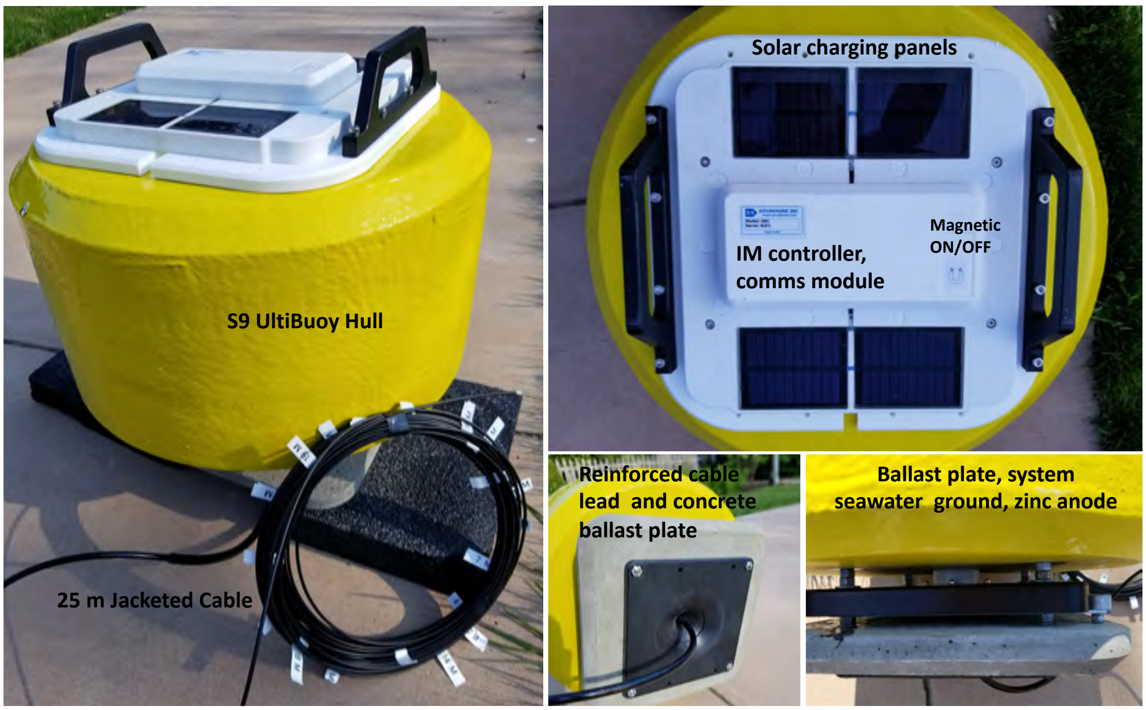
Cellular communications tested and working.

SoundNine UltiBuoy

The UltiBuoy platform supports inductive communications for sampling control and data collection; external communications (cellular in this case) to shoreside database; and power and solar charging. It is anchored using a jacketed wire rope that serves as the conduit for signals that are transmitted and received through inductive modems in instruments clamped to the cable (see figure ___). Product information https://www.soundnine.com/ulti-buoy/ .
UltiBuoy Manual:
https://www.soundnine.com/wp-content/uploads/2018/06/Ultibuoy-Manual-R0111.pdf .

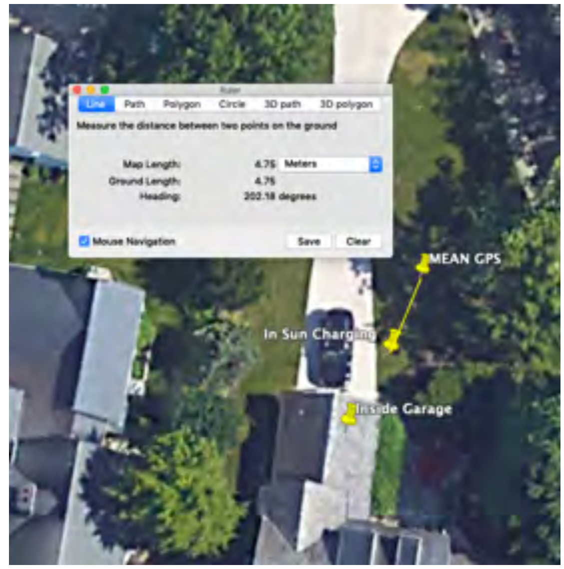
UltiBuoy Controller Manual
https://www.soundnine.com/wp-content/uploads/2018/06/Ultibuoy-Controller-Manual-R0110-002.pdf

This UltiBuoy is 55 cm diameter x 30 cm high foam with ground plate / cable fairlead and concrete ballast below, buoy controller/comms/solar panel module on top. Weight is 25 kg, with 55 kg of buoyancy. Ballast and hull below waterline will be painted with anti=fouling paint prior to launch.



UltiBuoy arrived 18 March 2020 and multiple aspects of performance were tested sequentially. Connection was made between bare cable end and buoy ground plate with a 100Ω resistor to simulate water ground return path. Sensor IDs were assigned (#03 to -09820 and #6 to -09819) and UltiBuoy was successfully programmed to take 10-minute samples from the SBE37s in air.

GPS Test



Buoy Position is recorded from internal GPS every sampling interval and reported on transmission. Mean buoy position recorded outdoors agreed to actual position within 5 meters. This method of tracking, while accurate, does depend on communications being operable – we will put a satellite tracker on the buoy for deployments.

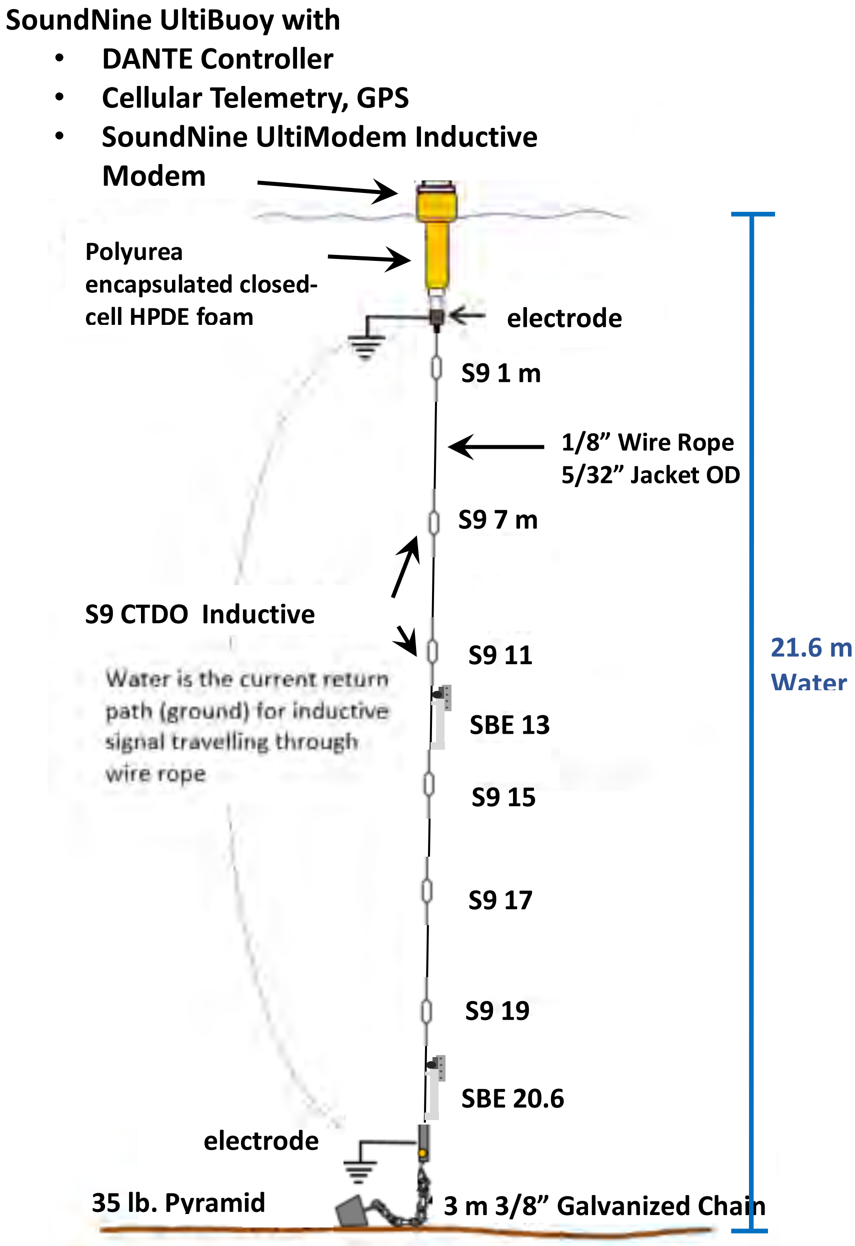
Battery and Charging Test

Nominal 7.4 V (rechargeable Li-Ion), maximum 8.2 V, transmission stops at 6.5 V.

Batteries discharged about 0.04 V / day transmitting at 10-minute intervals without solar recharging. A day of solar charging while transmitting returned about 0.3 V to the system. Plan is to run 10 minute sampling with hourly transmission, so no power shortages are expected.

Deployment considerations:

Site visit to CB4.3E confirmed water depth of 21.6m and adequate cellular service. Updated mooring diagram below. Attachments will be added to buoy handles to mount 1 SeaLite SL-15 anvigation light and 1 GeoForce GT0 Satellite Tracker.


SoundNine UltiBuoy with
• DANTE Controller
• Cellular Telemetry, GPS
• SoundNine UltiModem Inductive Modem
Polyurea encapsulated closed-cell HPDE foam
electrode
S9 1 m
1/8" Wire Rope
5/32" Jacket OD
S9 7 m
S9 CTDO Inductive
S9 11
Water is the current return path (ground) for inductive signal travelling through wire rope
SBE 13
S9 15
S9 17
S9 19
SBE 20.6
electrode
35 lb. Pyramid
3 m 3/8" Galvanized Chain
21.6 m
Water

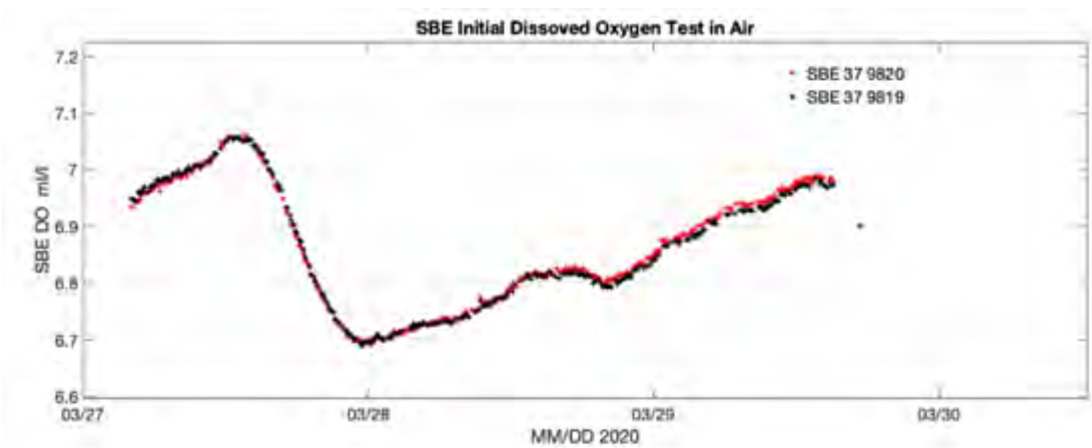
SBE 37 IMP-ODO Testing

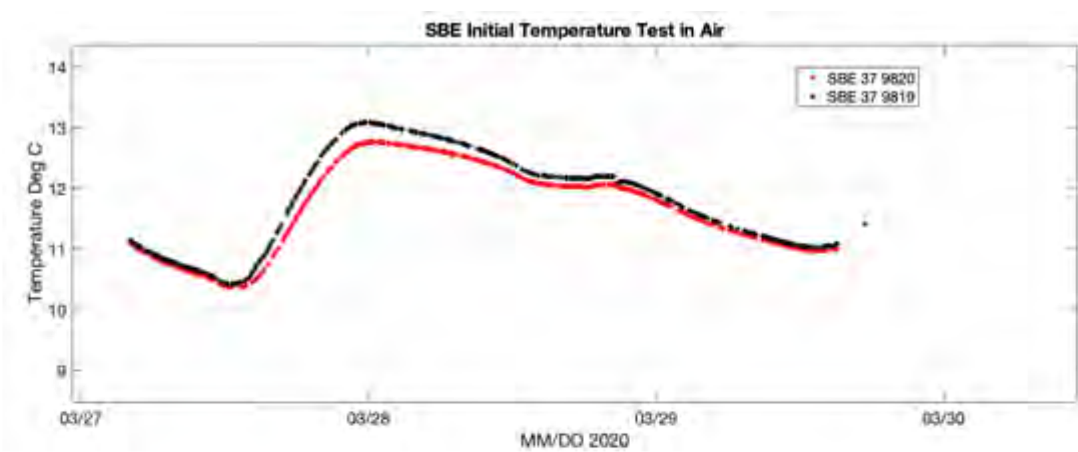
Two SeaBird Electronics SBE37 Inductive Modem Conductivity-Pressure-Depth instruments with Optical Dissolved Oxygen sensors were made available by NOAA Chesapeake Bay Office. These were manufactured in 2012 (with last sensor calibrations in July 2012) but have never been deployed, serial numbers 037-09819 and 037-09820. The Sound9 inductive modem (*UltiModem*) hardware used by the UltiBuoy is designed to be compatible with the SeaBird inductive modem system, and these can be used in the Hypoxia mooring.

Product Link
https://www.seabird.com/moored/sbe-37-im-imp-imp-odo-microcat/family?productCategoryId=54627473772
Manual
https://www.seabird.com/asset-get.download-en.jsa?id=54627862337

Details on Sensor Hardware are in Appendix .

In-Air test of SBE instruments



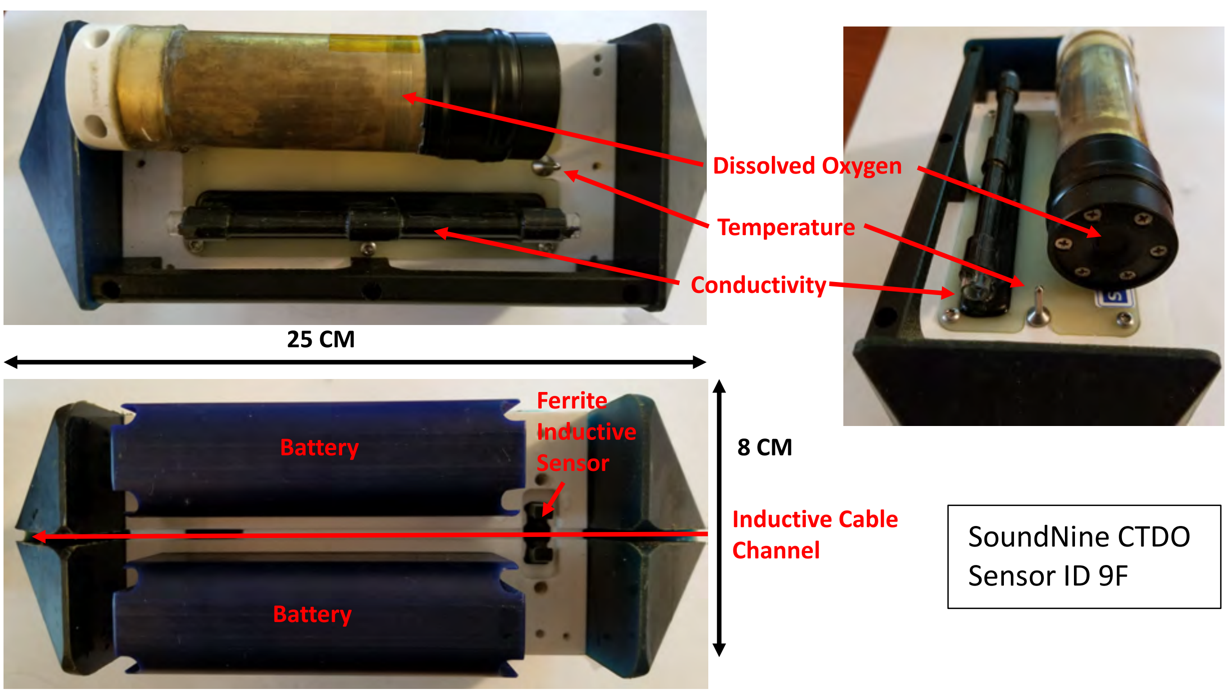


Initial Seabird SBE tests in air. Sensors were connected to UltiBuoy by looping inductive mooring cable through the SBE inductive coils, querying via UltiBuoy programming of Inductive modem interrogation commands (10 min intervals), and transmitting resulting data via cellular connection. As this was prior to build of online accessible SQL database for this buoy, data were collected via automatic emails which were automatically parsed and plotted using Matlab.

Results show excellent agreement in Oxygen and Temperature, with exhibited differences in Temperature likely due to real differential exposure of the instruments.

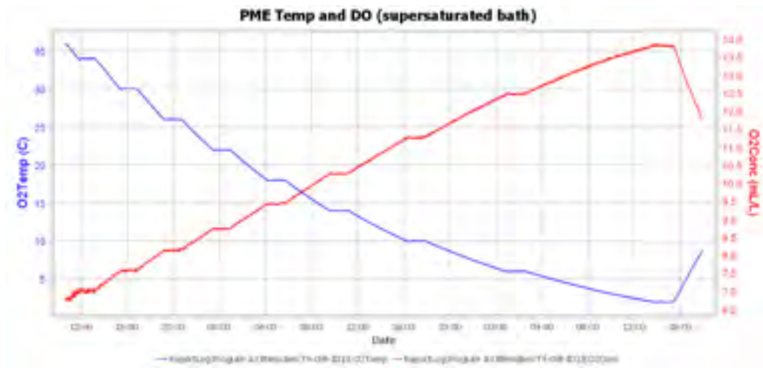
SoundNine CTDO sensor

The first S9 CTDO sensor arrived (after several production delays) in late March. At the time of original proposal, S9 had just completed modifying their original inductive Temperature-Pressure module https://www.soundnine.com/wp-content/uploads/2017/01/S9-X-TP-Sensor-Spec-2.pdf to include a conductivity sensor. The proposal was to take that CTD module and incorporate a Precision Measurement Engineering MicroDOT dissolved oxygen sensor (a smaller version of the PME MiniDOT https://www.pme.com/products/minidot) that was under development by PME. The final SoundNine product delivery was delayed by both availability of OEM microDOT sensors from PME and subsequent integration with Soundnine CTD. The first integrated product delivered is shown below.



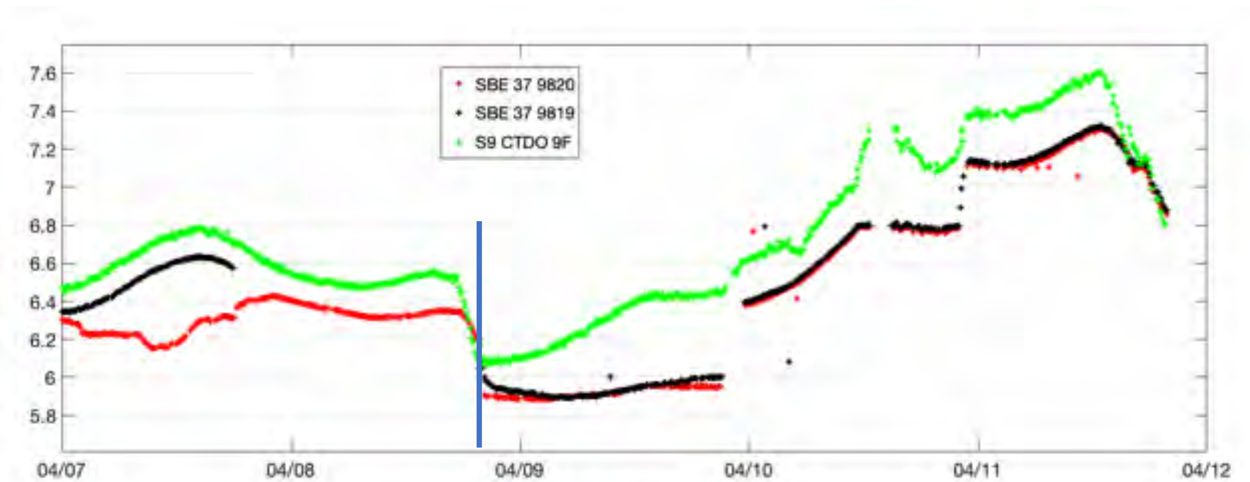
SoundNine CTDO Sensor ID 9F

In water Tests of SoundNine CTDO and SBE 37 Sensor



SoundNine CTDO sensor 9F initial Dissolved oxygen concentration calibration is shown at right, in a fresh water oxygen-supersaturated bath. Sensor typically reads close to 100% saturation.

S9 and SBE sensors were placed in a 5-gallon bucket of fresh water for testing. All data shown were collected using the program in the UltiBuoy at 10-minute intervals, transmitted to SoundNine server, and downloaded in real time for observation and analysis. Buoy and bucket were at times indoors or out, and at times water was aerated by an aquarium pump and air diffuser stone.



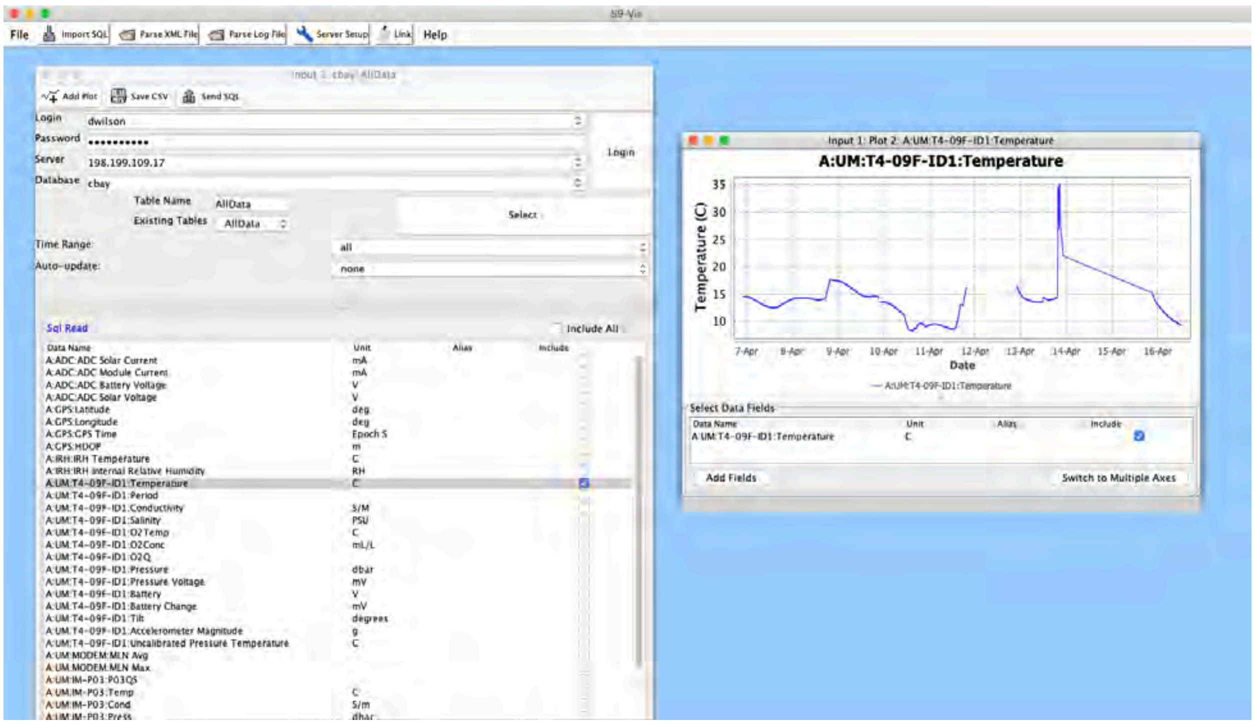
Dissolved Oxygen concentration (ml/l) SBE and S9 sensors. Line shows switch from unpumped to pumped sampling in SBEs. Air bubbler was on and off at different times.

Transition on 4/8 to pumped measurements in SBEs, where the DO sensor is located in a tube away from free water. Pumped samples will be used for deployment. When air bubbler was used, S9 achieved around 96% saturation, SBE around 90%, and recording PME MiniDOTS also were around 96%. SBE calibrations will be corrected to match S9 and PME ratios. All will be compared to additional S9s as they arrive.

Temperature values among SBEs and S9 (not shown) agreed to within 0.02 degrees at all times and will not need calibration corrections.

Communications and Data Transfer

Cellular communications were tested and worked with 100% throughput.
Data are pushed to the SoundNine server on the AWS cloud and stored in an SQL database where they can be accessed directly via SQL commands or plotted and downloaded into .csv files using the S9vis application software. Caribbean Wind is working with Kyle Wilcox at AXIOM Data Science to develop data collection and distribution routines as well as visually effective web-based images of vertical dissolved oxygen structure



Screen shot showing access to database and plotting tools via SoundNine S9VIS application.

Appendix: Ultibuoy sampling Program (as of 4/15/2020 1900Z)
For reference: Commands controlling sampling and communications

<FILE>

eclog	log event counter
adclog	log adc (analog channels)
irhlog	log irh (internal temp / rel humidity)
open im	open inductive modem connection
delay 1000	delay 1 sec
send im "\r"	wake up modem with carriage return
waitfor IM "S9>" 1000	wait up to 1 for modem response
delay 100	delay 0.1 sec
send IM "MLN\r"	monitor (output) modem line noise
delay 2000	delay 2 sec
send IM "MOD 4\r"	set modem MODULATION (comm speed) 4
delay 2000	delay 2 sec
send IM "\r"	wake up modem with carriage return
waitfor IM "S9>" 1000	wait up to 1 sec for modem response
delay 100	delay 0.1 sec
send IM "TELMODE 3\r"	set modem Mode 3 (for S9)
delay 200	delay 0.2 sec
send IM "XT2\r"	take sample
delay 200	delay 0.2 sec
waitfor IM "S9>" 3000	wait up to 3 sec for modem response
send IM "\e"	user abort
delay 200	delay 0.2 sec
send IM "MOD 1\r"	set modem MODULATION (comm speed) 1
delay 2000	delay 0.2 sec
send IM "\r"	wake up modem with carriage return
waitfor IM "S9>" 1000	wait up to 1 sec for modem response
delay 100	delay 0.1 sec
send IM "TELMODE 2\r"	set modem Mode 2 (for SBE)
send IM "FCL\r"	Capture Modem Line
delay 2000	delay 2 sec
send IM "#G0:TPS\r"	Send take pumped sample command to all SB devices on line
delay 1000	delay 1 sec
send IM "\e"	user abort
delay 45000	Delay 45 sec to allow for pumped samples to be taken
delay 200	delay 0.2 sec
send IM "#03SL\r"	Collect latest sample from SBE Dev ID 3
delay 5000	delay 5 sec
send IM "\e"	user abort
delay 200	delay 0.2 sec

send IM "#06SL\r"	Collect latest sample from SBE Dev ID 6
delay 5000	delay 5 sec
delay 200	delay 0.2 sec
send IM "#03SL\r"	Collect latest sample from SBE Dev ID 3
delay 5000	delay 5 sec
send IM "\e"	user abort
delay 200	delay 0.2 sec
send IM "#06SL\r"	Collect latest sample from SBE Dev ID 6
delay 5000	delay 5 sec
send IM "\e"	user abort
delay 200	delay 0.2 sec
save im	save data from inductive modem port
close im	close inductive modem port
gps on	open GPS
gps wff 60	wait for GPS fix; log GPS data
gps qos	log GPS Quality of Service data
gps set time	Set controller tome to GPS time
eclog	show event log?

</FILE>

Appendix
NCBO SeaBird 37 IMP-ODO Information

S/N 37-09820

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S/N 37-09819

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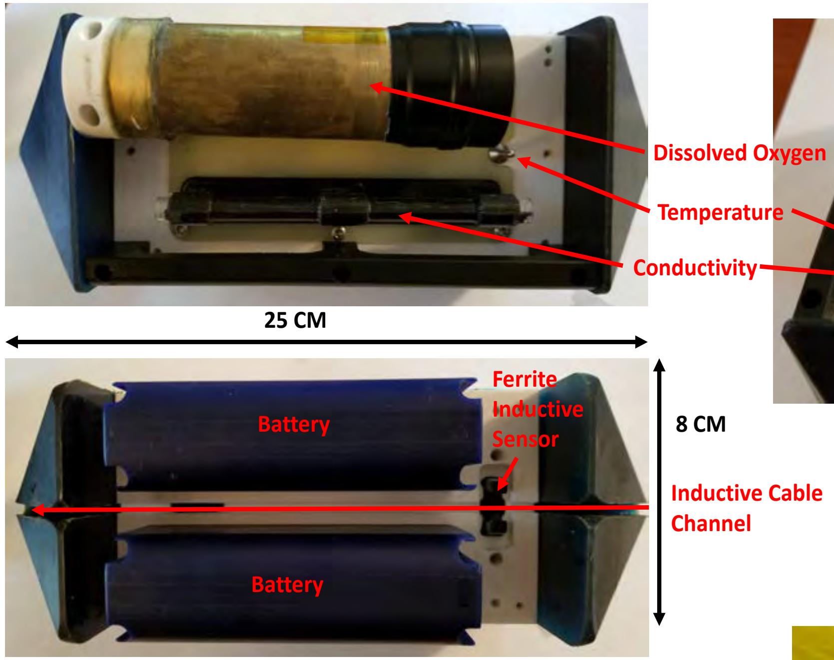
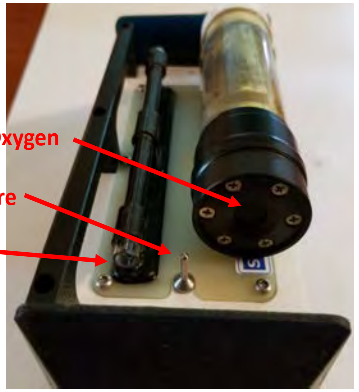
Chesapeake Bay Hypoxia Profiling Buoy
Test Deployment
Deployed 30 May 2020 1545 UTC
Recovered 19 June 2020 1645 UTC
38 33.3600 N 76 23.4870 W 22 m
SCIENTIFIC DATA BUOY



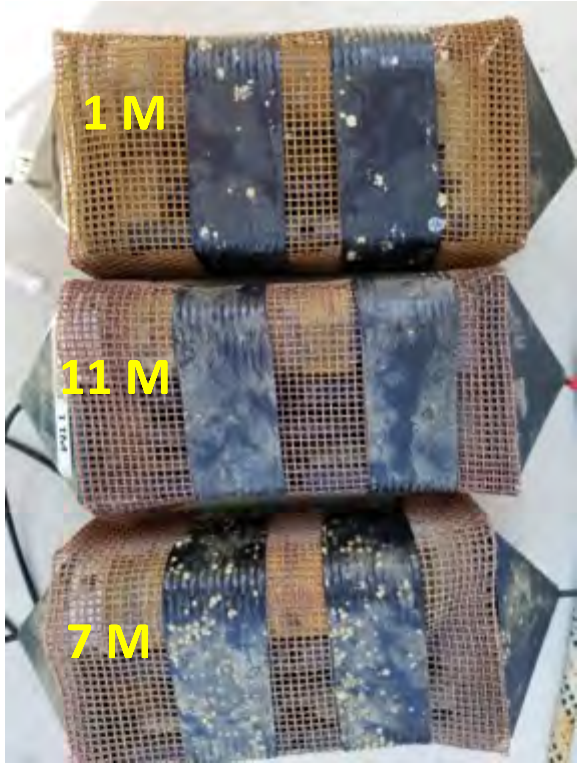


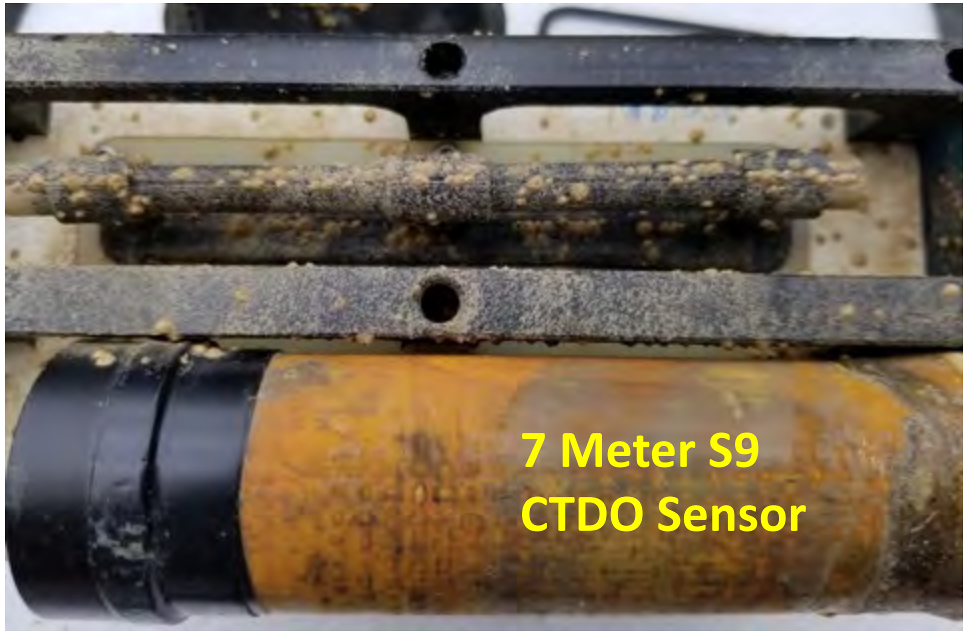
SoundNine CTDO
Sensor ID 9F

Sound Nine CTDO instruments and UltiBuoy

For now there is no cover, just wrap of heavy copper mesh for protection and antifouling

Post Recovery





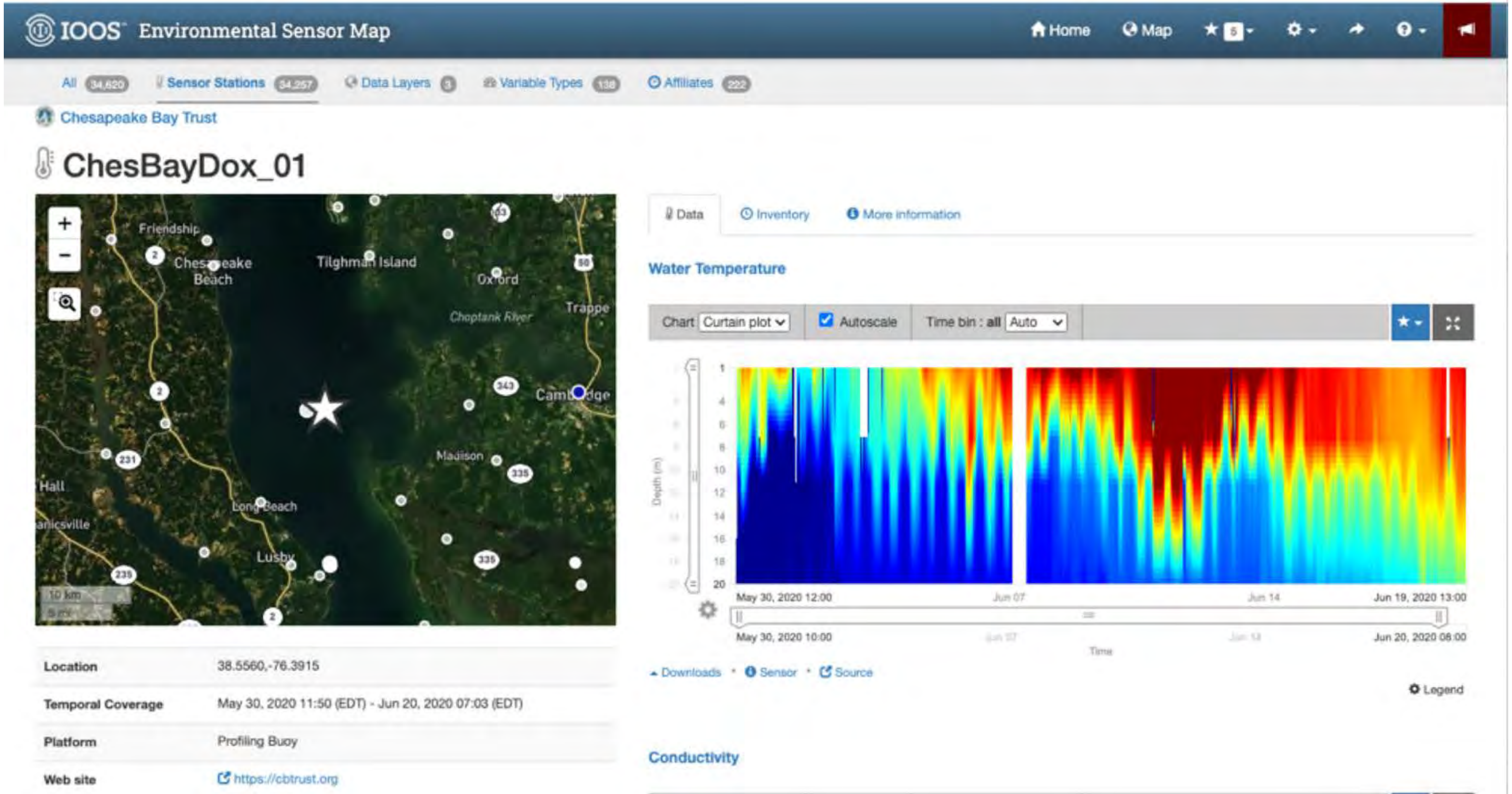
Data are downloaded every 10 minutes by cellular communications to SoundNine Cloud Server database

Web Site https://sensors.ioos.us/?#metadata/103543/station/data

Part of IOOS Environmental Sensor Map

Provided by AXIOM Data Science

Allows multiple visualization and access options as well as IOOS QARTOD data QC



Things we learned:

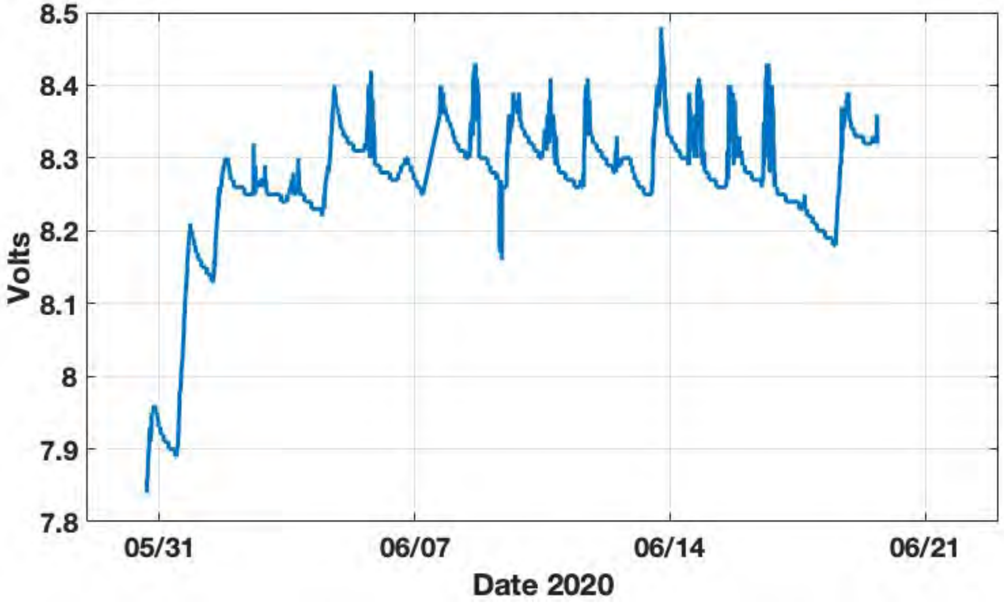
Mooring

Fully deployable and recoverable from 19 ft center console vessel with 2 persons
Secure with 35 lb Dor-Mor Pyramid anchor and 10’ 3/8 “ (14 lb) chain
Dor-Mor required tug with vessel motor to break loose from mud
Mooring properly configured for location; CTD and Depth Sounder agreed at 22m / 72 ft ; instrument near termination had mean depth of 20 m
Controller maintained full battery voltage with solar charging over 3 weeks
Buoy provided adequate flotation for configuration
One cellular data disruption of 6 hr – otherwise 100%
Background inductive noise level was low -> high data returns
Pettit non-copper antifouling Bottom paint worked well
No wear on buoy-cable joint
Would deploy again with exact configuration

Consider navigation flashing light for longer term deployment
have light, need to fabricate mount

Essential Recovery Tool – Tyler Cable Grip

UltiBuoy Controller Voltage



Things we learned:

Sensors

Performance:

- S9 CTDO sensors performed to specifications except: the PME Microdot Oxygen sensor on S9F at 1 m failed after 1 hour. Transmitted data (including valid temperature) but invalid Oxygen concentration. Returning to PME for diagnosis.
- SBE37 9820 failed after several hours. Post – recovery examination revealed loose internal battery pack (screw not properly tightened). Works now and can be re-deployed.
- Sensor internal alkaline battery pack voltage drop over 3 weeks of 10-minute sampling was minimal (approximately 0.016 V); estimated deployment duration at this rate is >10 years.
- Sensors provide tilt and acceleration data not presently used

Fouling:

- Copper mesh reduced fouling and kept organisms out but does not protect from larval barnacle ingress and subsequent attachment to instrument surfaces. Will need to cover surfaces with copper tape.
- Returned 9F to Soundnine to examine interior of conductivity sensor and perform post-calibration.
- Barnacle fouling at 1m and 7m only, not deeper (due to more prevalent hypoxia, less light)
- Screw holes will be added in instrument body to secure copper mesh.
- Some growth on Oxygen sensor face; will add copper covers as on PME MiniDOTs.

Things we learned:

Data return / management / access

SoundNine Inductive modem
- Low inductive noise on wire and message checksum provided minimal logged data errors
- SBE37 Measure once / broadcast twice improved returns (no checksum)
- Collecting data on system noise

SoundNine UltiBuoy controller
- Provides programmable modem controller, bidirectional cellular data service, and GPS position
- Logs data as backup to real-time transmission

SoundNine S9VIS data access Software
- Parses incoming data strings and stores in SQL (MariaDB open source SQL)
- S9VIS is Java module (runs on Mac!) to access database, make plots, and download database.

AXIOM Web Viewer
- Axiom Data Services is used by US IOOS and Regional Alliances to collect and present data
- Pulls regularly from S9 SQL server, provides multiple visualization and access capabilities
- Adds metadata, places in IOOS catalog, and provides QARTOD Quality Control checks

Next Steps:

Minor upgrades to buoy and instruments

- New batteries in SBE 37s
- Diagnosis on failed 9F MicroDOT Oxygen sensor
- Receive TWO more S9 CTDO sensors
- Add antifouling to sensors (copper tape on surfaces, better copper mesh attachment)

Make sure all data manipulations programmed in S9 database to covert raw sensor data to engineering values (particularly Pressure, Conductivity, and Salinity)

Minor fixes to database variable names and units

Check all metadata and links on IOOS Sensor Page

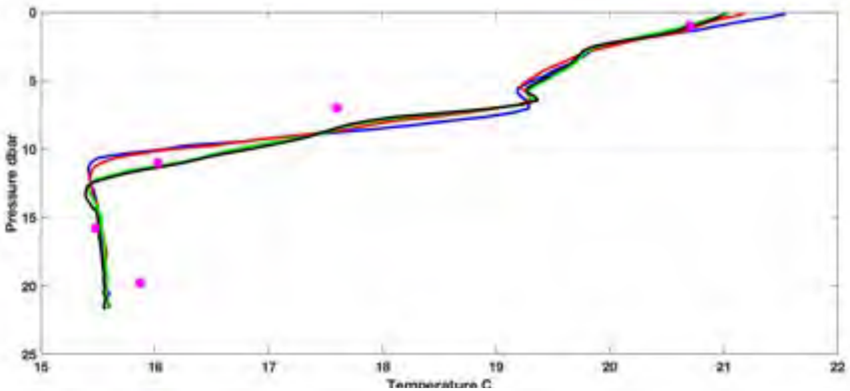
Next deployment to run through September

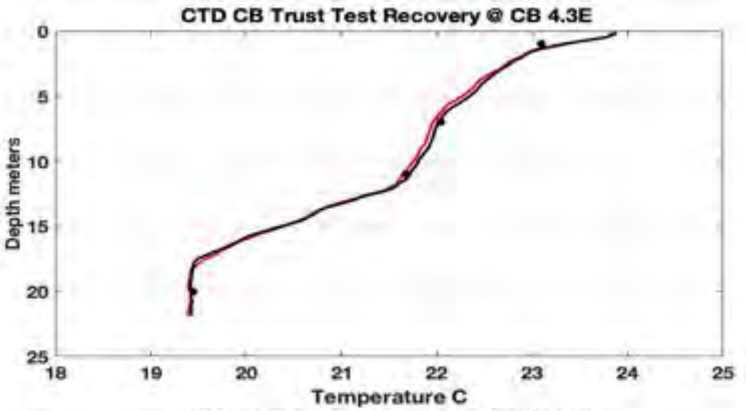
Proposed Sensor Depths [1 7 11 14 17 20] m

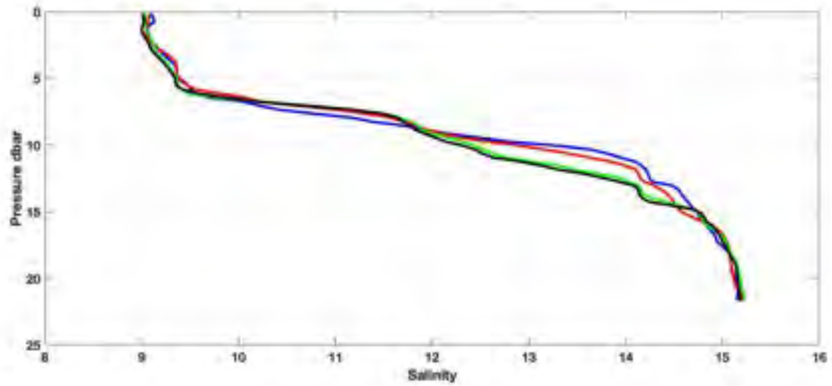
Contact VIMS for comparison model values

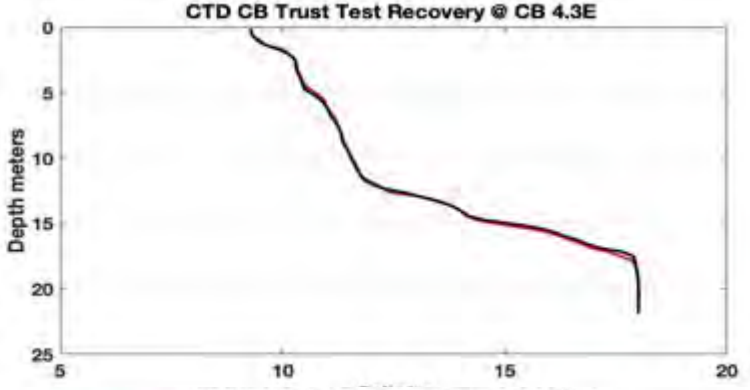
Some CTD plots from deployment / Recovery

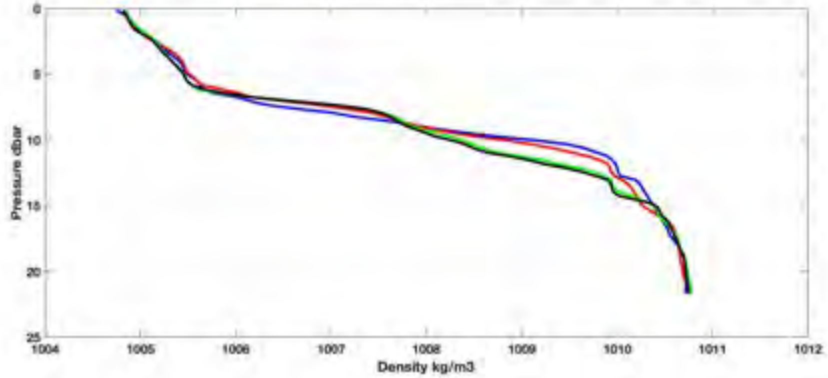
Beginning 30 May 2020 | End 19 June 2020

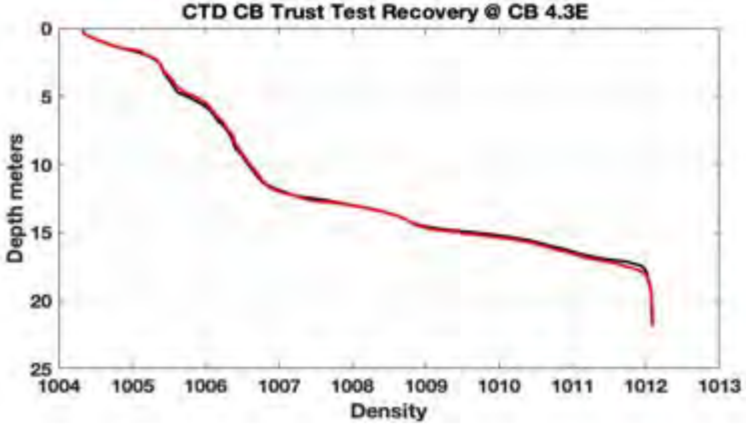






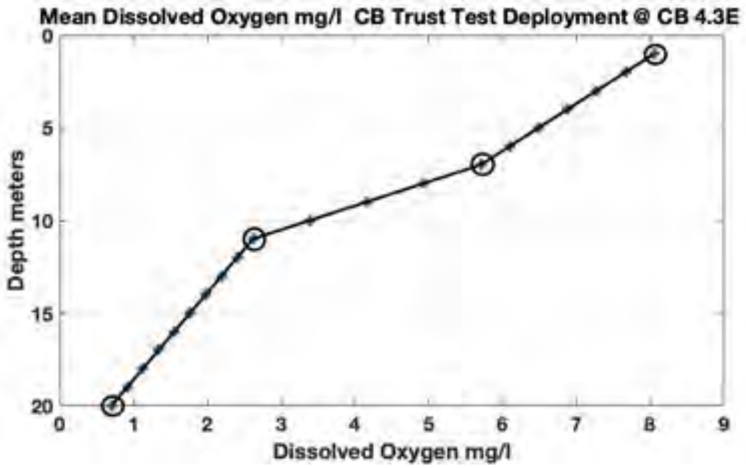


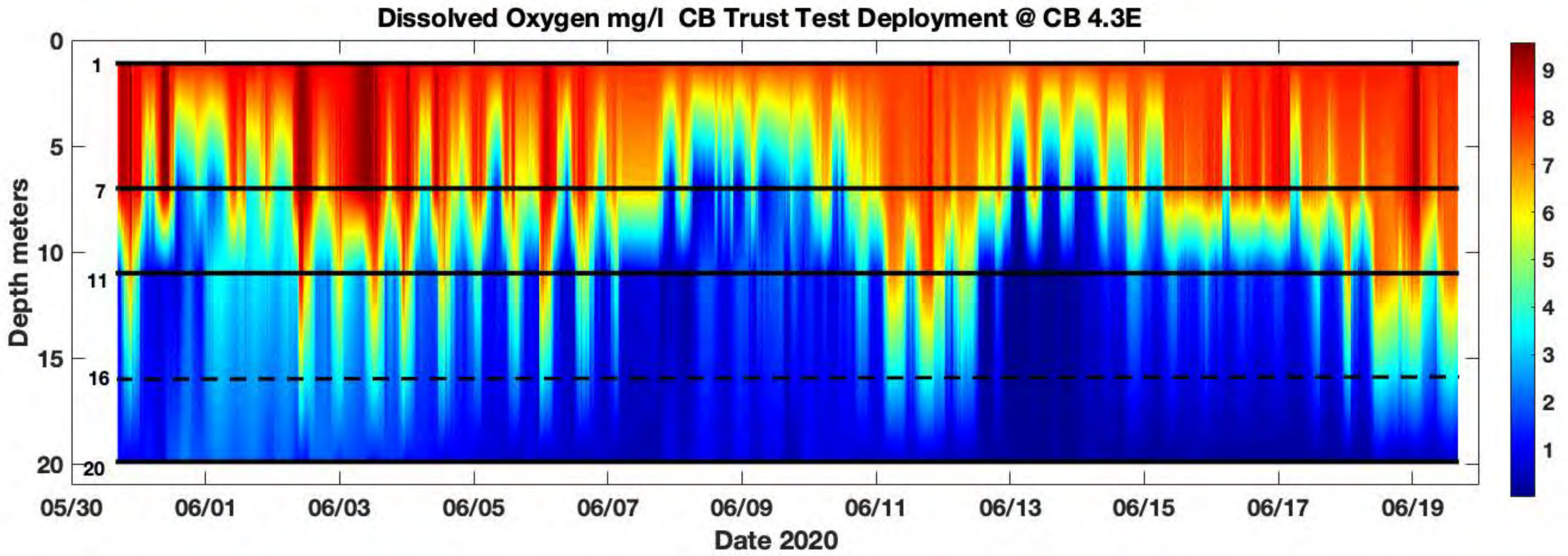




Some plots from deployment; see website for others
Missing data at 1m filled in with greater value of
<100 % saturation OR measured value at 7 m>
16 m data missing

Strong semidiurnal tidal signal often mixes surface DO to at least below 11m sensor. Need to correlate with wind from CBIBS Gooses Reef to explain variability in mixing depth.





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Chesapeake Bay Hypoxia Profiling Buoy

Test Deployment 2

Deployed 13 September 2020 1630 UTC

Recovered TBD

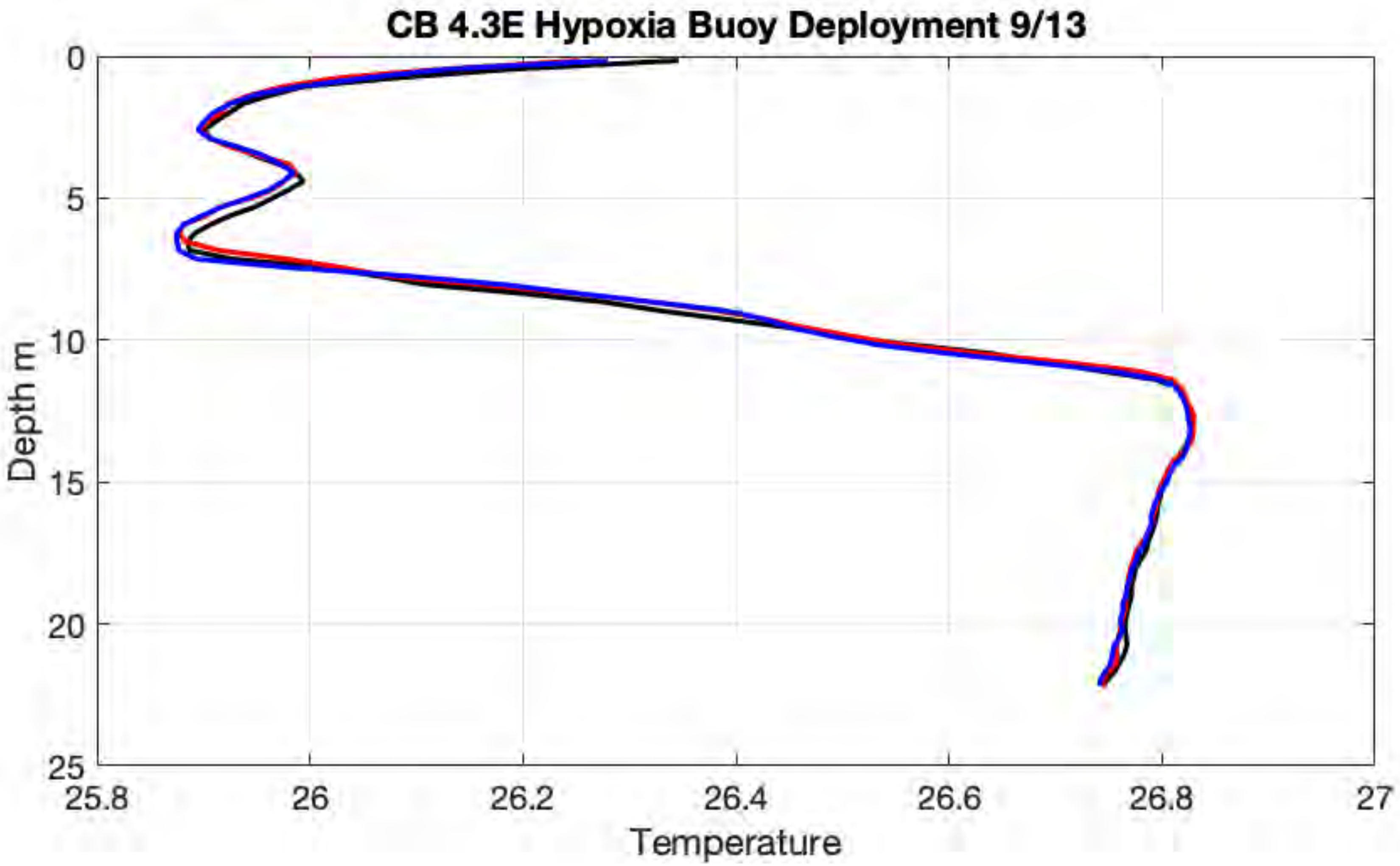
38 33.3600 N 76 23.4870 W 22 m

Update / Initial Data

Temperature Profile:

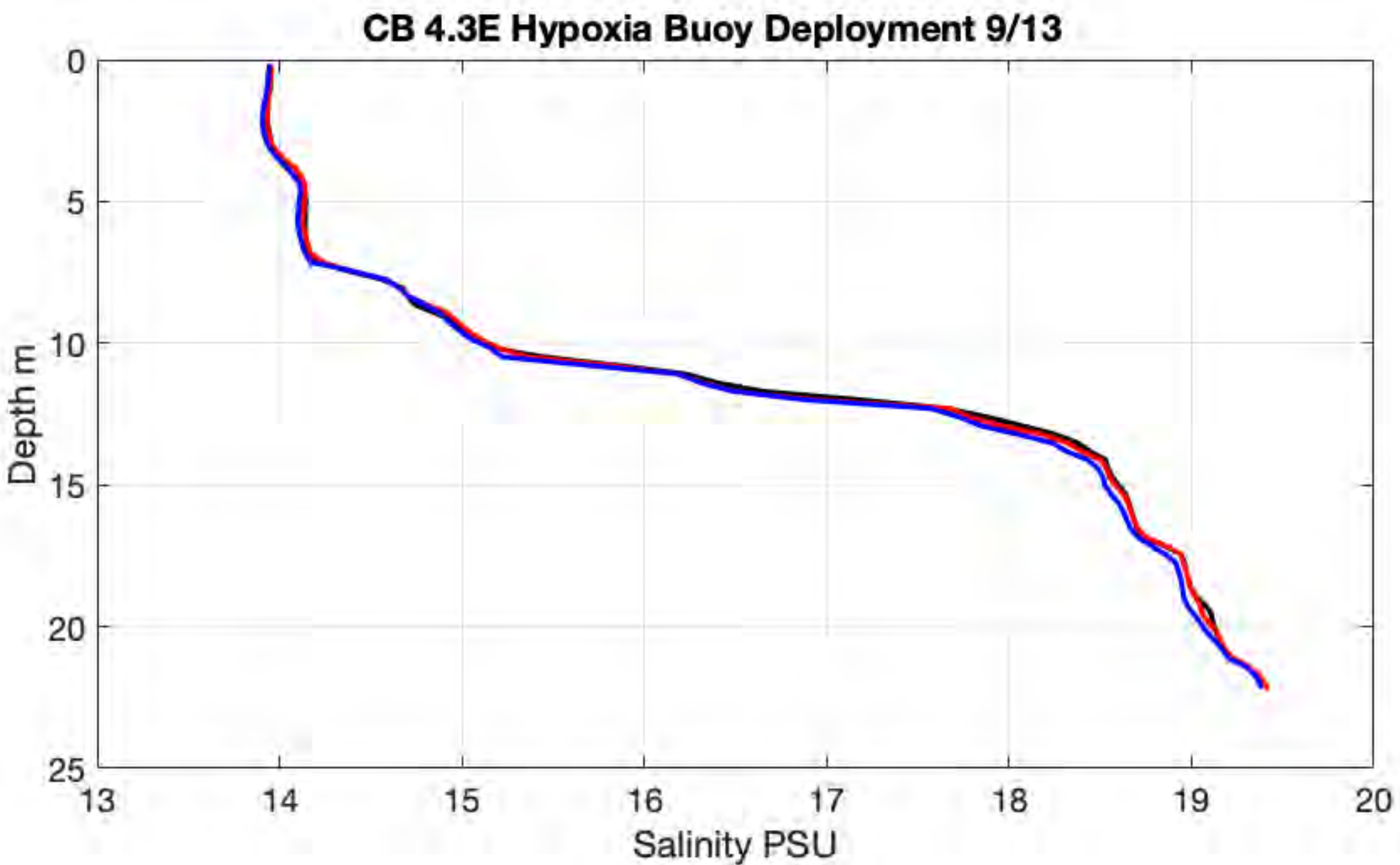
At end of summer season, water column is now almost fully isothermal – actually bottom water is slightly warmer.

These CTDs were collected at 1700Z on 13 September



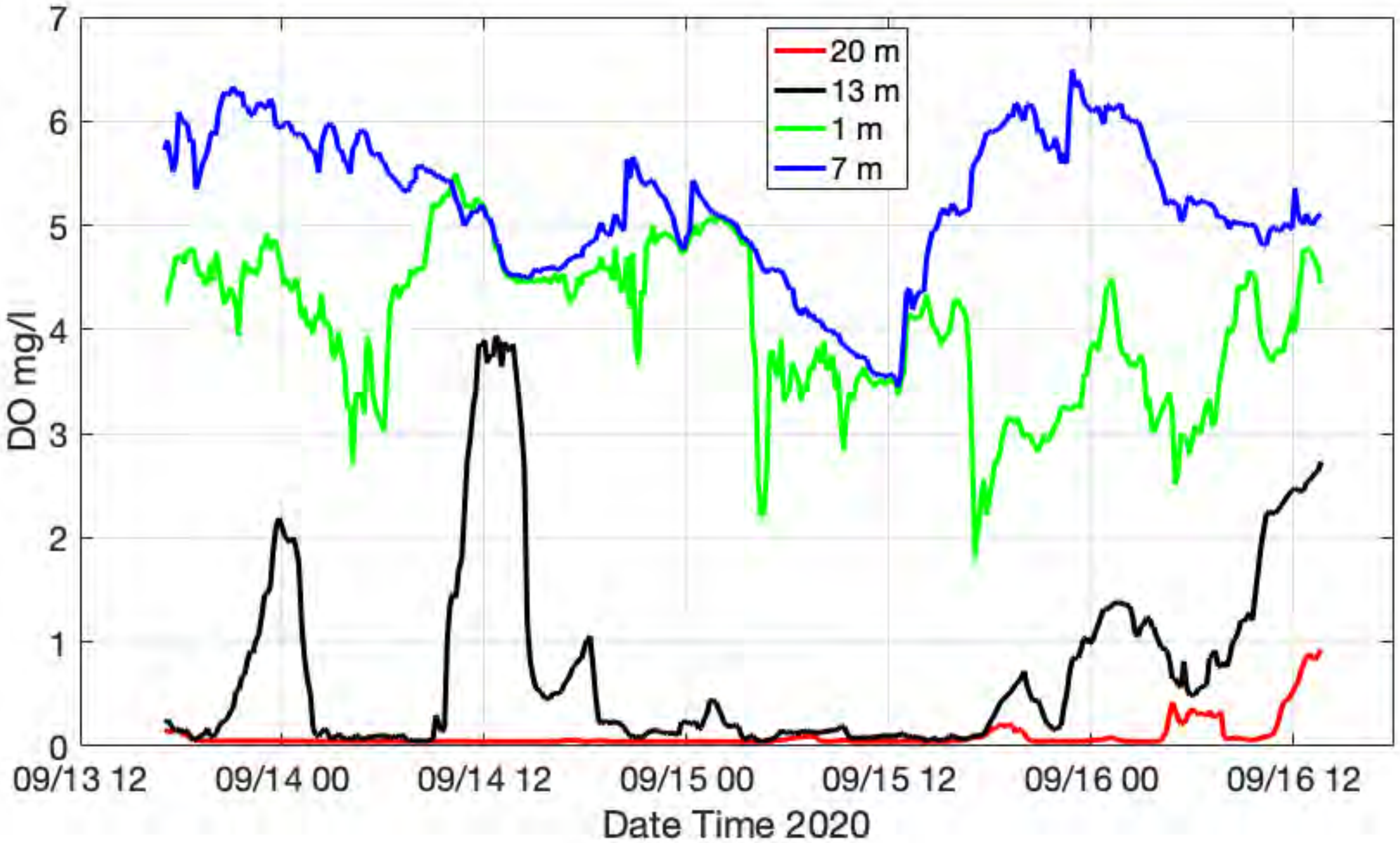
Salinity Profile:

So density structure is now almost completely due to Salinity – this is not very stable.

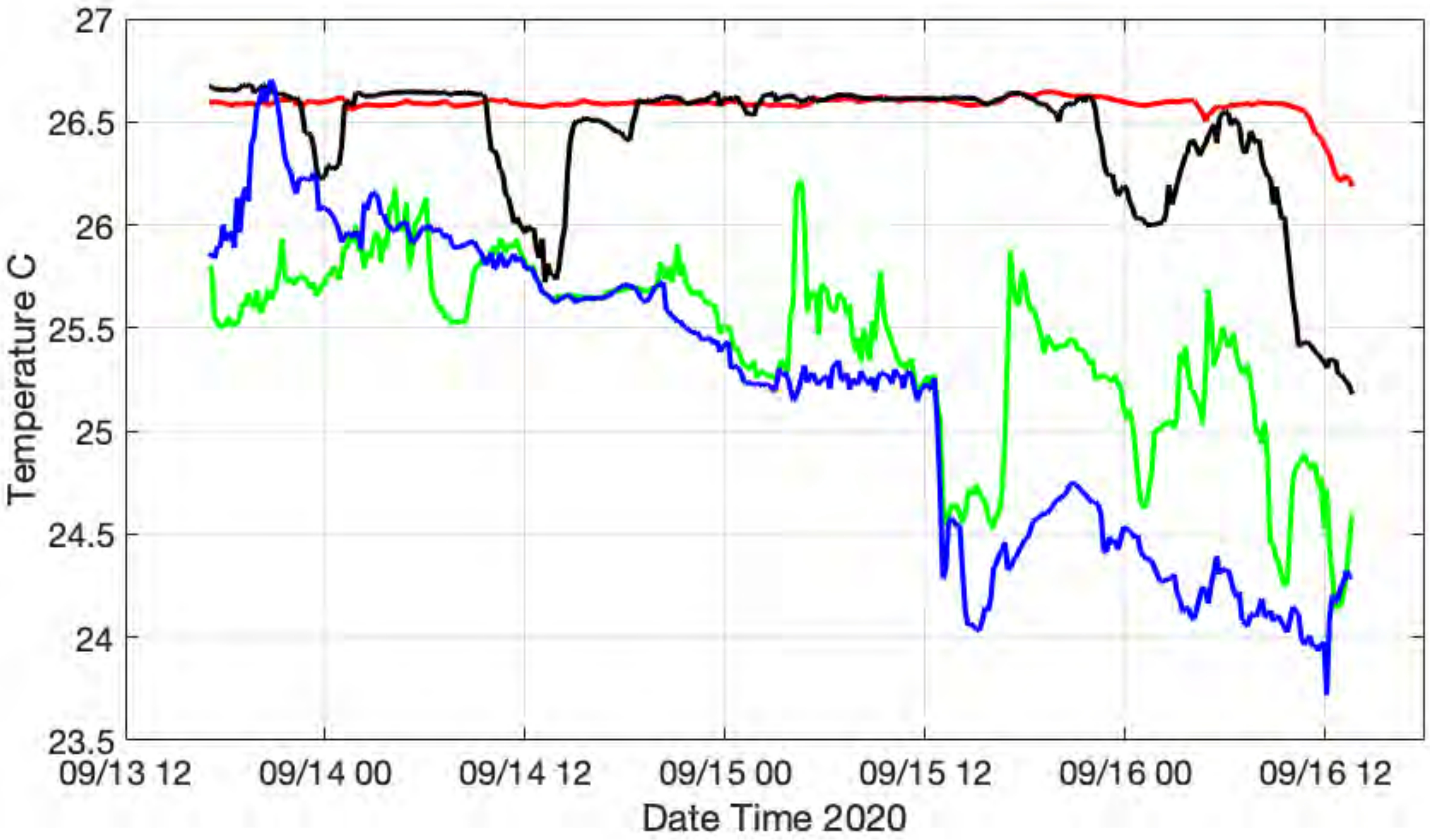


The present deployment has real-time instruments at 1m, 7m, 13 m, 20 m. We also have internally recording instruments at 4m, 10m, and 16m that will be used in post-recovery analysis.

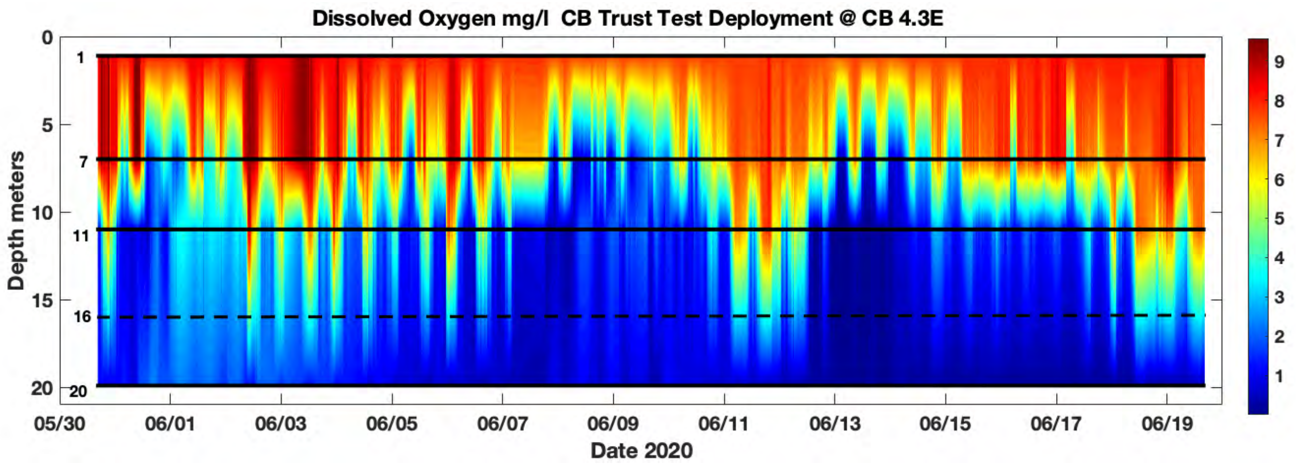
The station is fully anoxic at the bottom (20 m). You can see occasional higher surface O2 events extending downward, but not as regularly as seen in June.



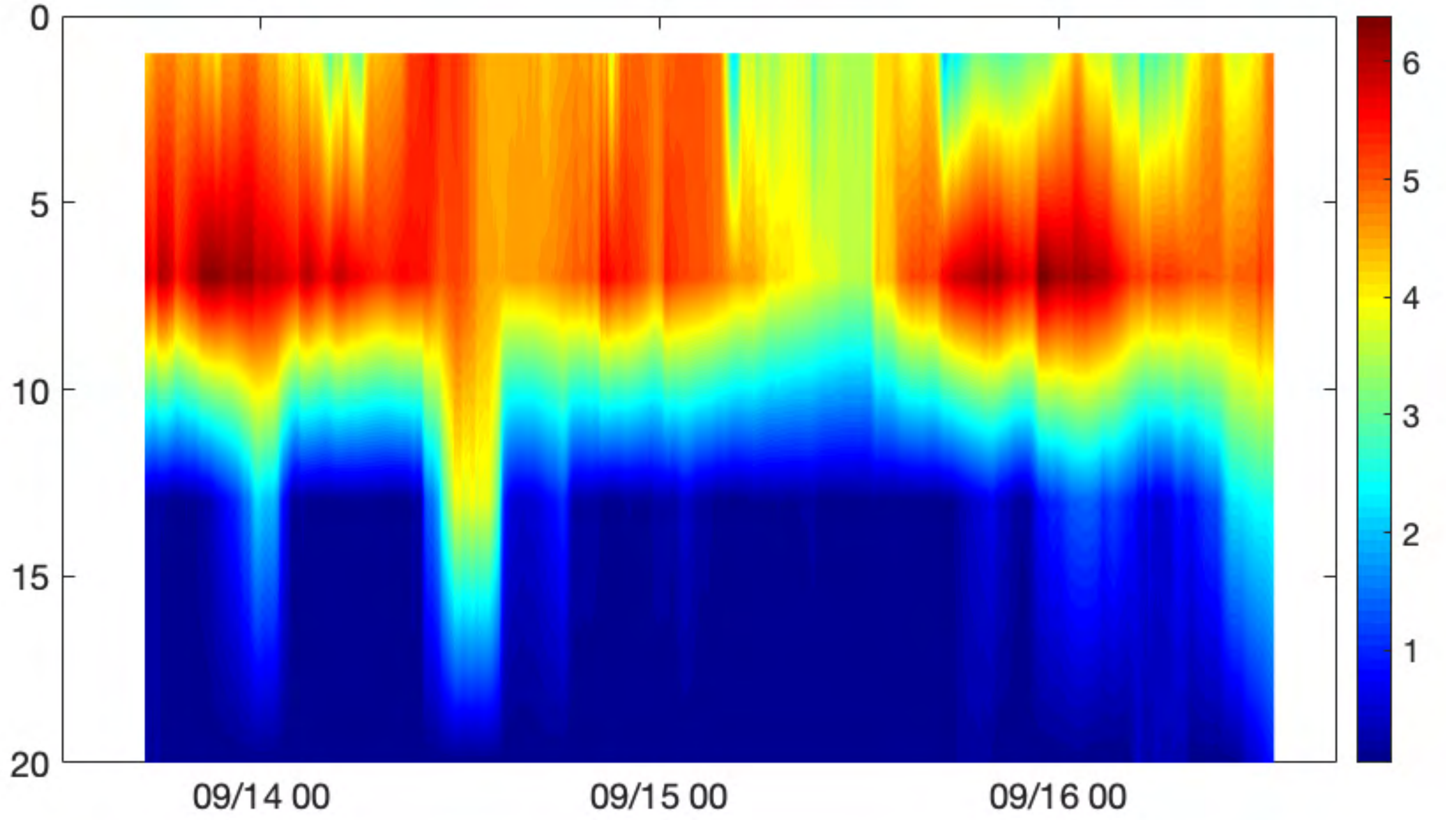
I think during this deployment, if we stay out into October, we will see deep mixing and the breakdown of the hypoxic structure – with cooler air temperatures following deployment, you already see the temperature drop at the surface beginning to affect bottom temperatures and DO levels.



DO – Time plot from June, strongly stratified



Current DO-Time plot – strongly anoxic at the bottom, but stratification beginning to break down




Chesapeake Bay Hypoxia Profiling Buoy
Test Deployment 2
Deployed 13 September 2020 1700 UTC
38 33.3600 N 76 23.4870 W 22 m
KEEP CLEAR
Doug Wilson
Caribbean Wind LLC
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DEPLOYMENT

The Chesapeake Bay Trust – CBP GIT Hypoxia mooring was re-deployed on 13 September at station location CB 4.3 E in 22 m of water.

For this deployment there were inductively real-time reporting SoundNine CTD_O2 sensors at 1 and 7 meters and SBE37 IM CTDO2 sensors at 13 and 20 meters.

In addition there were internally recording sensors placed at 4 (PME MiniDOT), 10 (PME MiniDOT), and 16 (YSI 600) meters.

Conditions were calm (see opening photo), first in-water data point was recorded at 1640 a record start time of 1700 Z was used.

Three CTD casts to full water depth (22 m) were recorded (next page).

Intention was to leave in for a month but system had to be recovered on October 8.

We did not activate the web site for this deployment but may do a future test on the archived data to finalize it prior to future deployments.

Data were

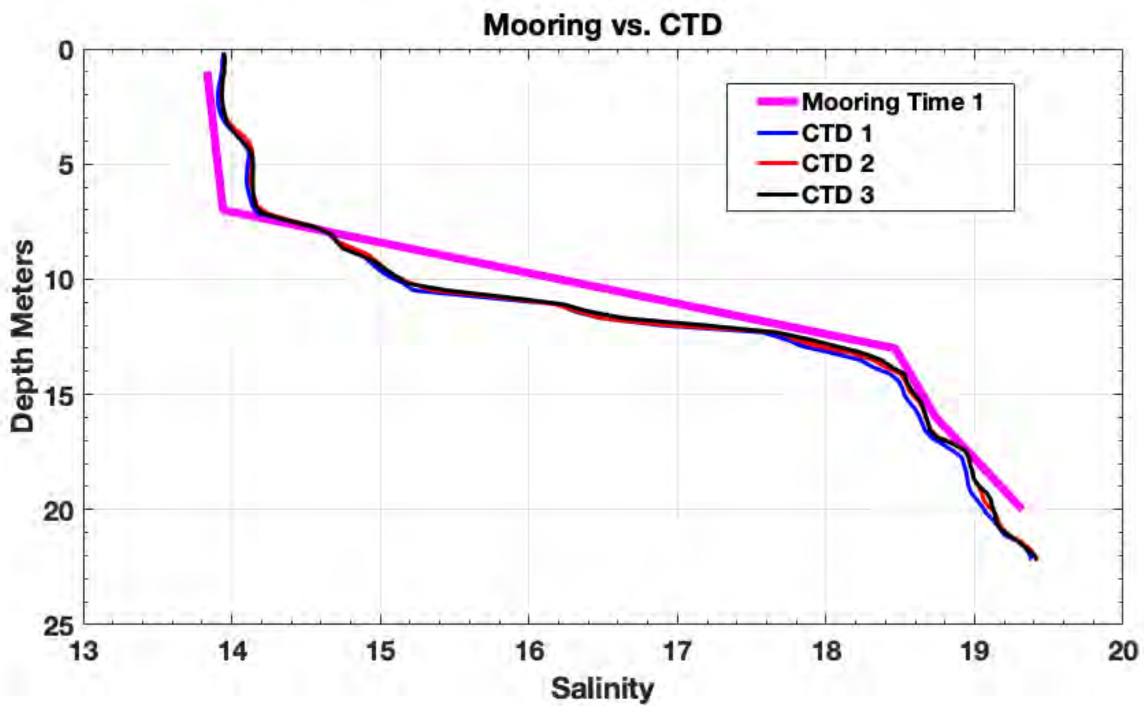
- Requested (UltBuoy controller sends transmit command)
- Received (by the UltiBuoy controller)
- Transmitted (via cellular service to SoundNine server)
- Logged (internally in controller and in SoundNine data base)

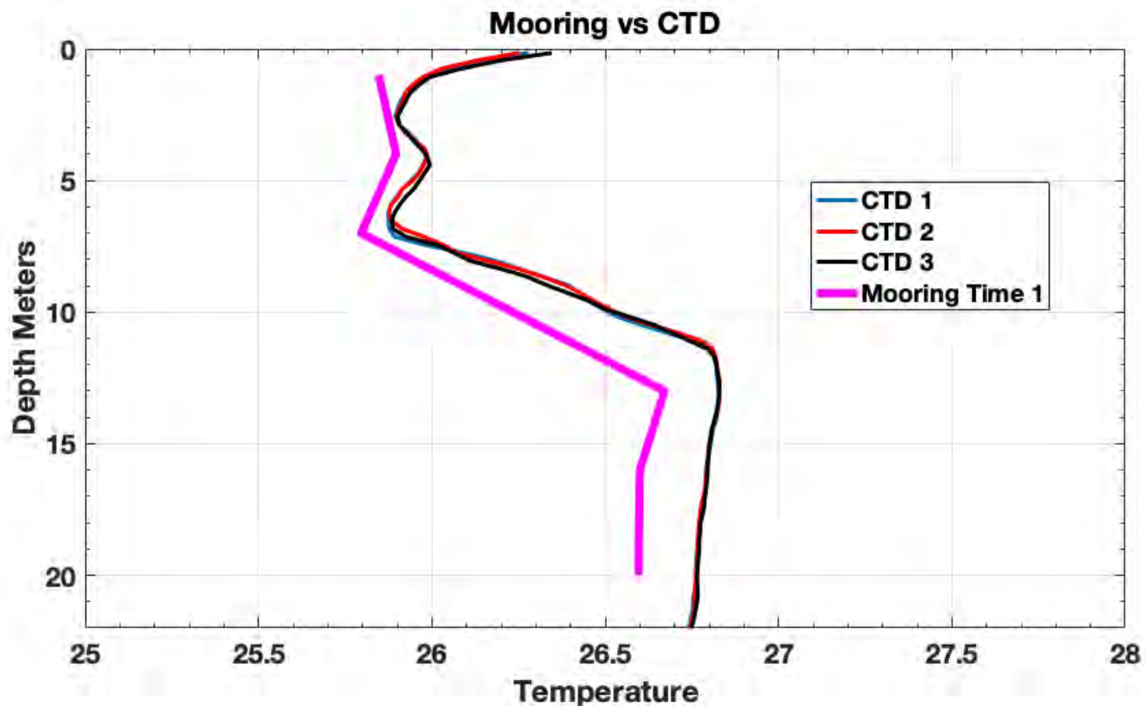
at 10 minute intervals, along with UltiBuoy status and GPS data.

Conditions at Deployment

Figures below show Temperature and Salinity profiles from CTD casts (three, taken at 1647 Z -1653 Z) compared to the linearly interpolated 1700 Z vertical profile created by averaging all available (real-time AND internally recording) T (6 points) and S (5 points) moored instrument values. Values agree to within 0.2 degrees C and 0.2 PSU, with T slightly biased (CTD warmer - need to check calibrations on both CTD and instruments).

At this point in the summer , the water column is very nearly isothermal (actually,slightly increasing with depth), with density stratification all due tosSalinity structure. Bottom waters are still hypoxic, but this is a fairly unstable vertical profile, and we expected that the bottom hypoxia would soon be disappearing.



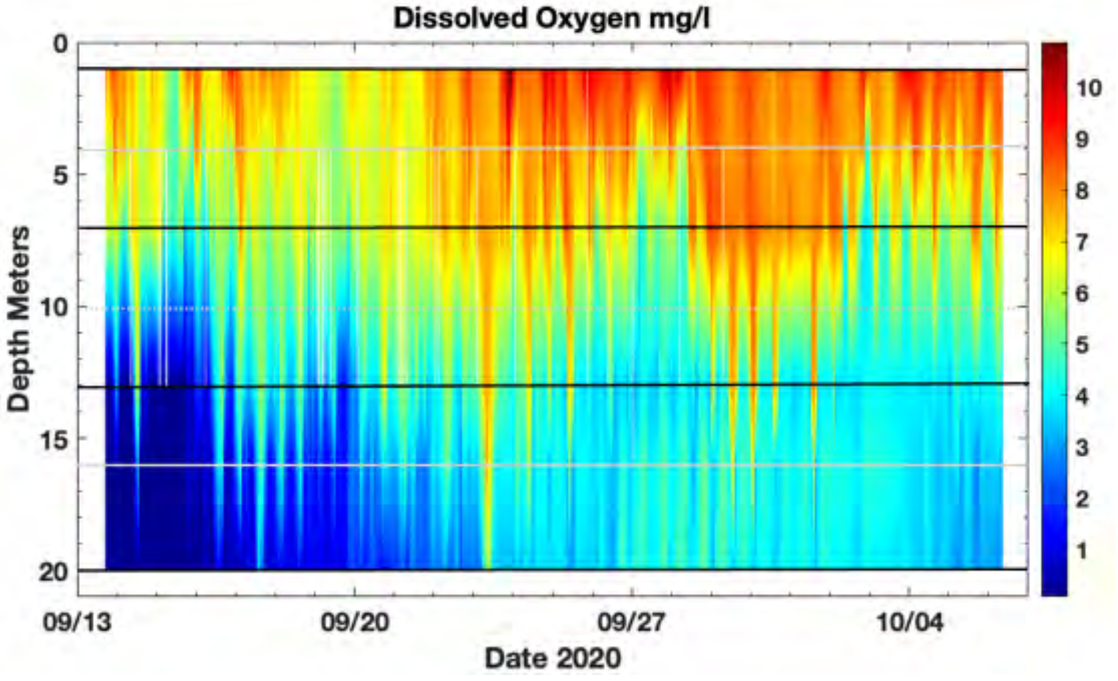


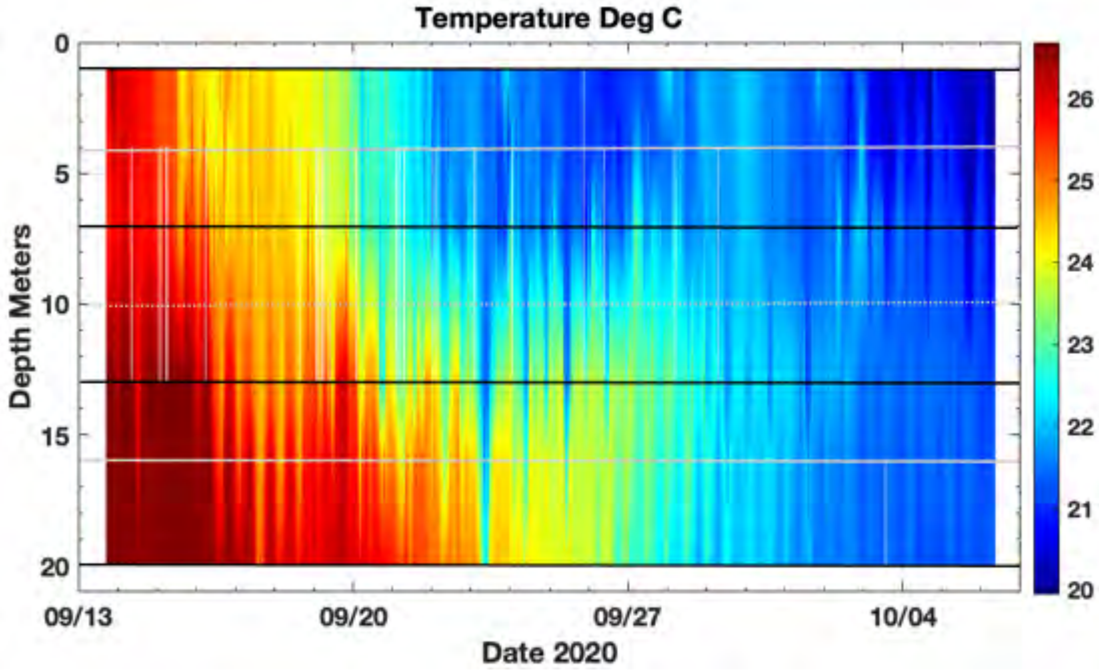
Data Time Series (1)

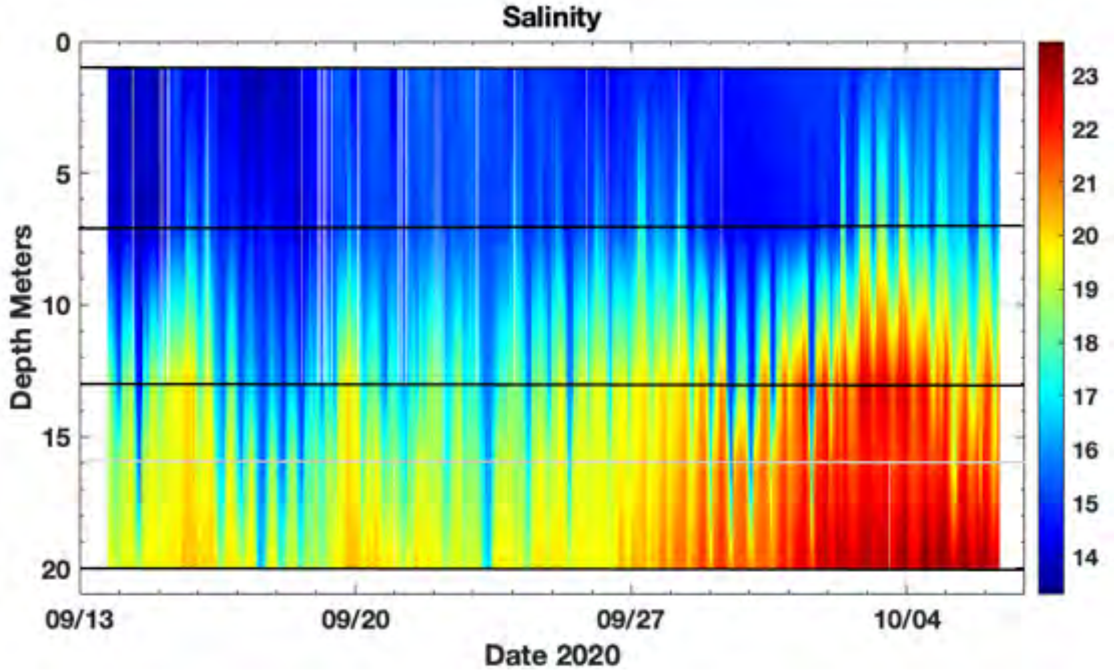
Figures show data as recorded at 10 minute intervals, with 1 meter linear vertical interpolation between surface (1 m) and bottom (20 m) sensors. Black lines are locations of intermediate real-time sensors, and grey lines are locations of internally recording sensors. PME O_2 sensor at 10 m did not record (user error).

Hypoxia, uniformly present in the lower half of the water column at the outset, was impacted by semidiurnal (tidal?) vertical mixing events as surface waters cooled (BWI T_{min} = 5 deg C on 22 September). Higher surface DO later in the record likely reflects higher saturation concentrations in colder water.

Notable that after about 27 September – after deep water stabilized at non-hypoxic levels – it showed intrusion of higher salinity water not previously seen at this location during the deployment.





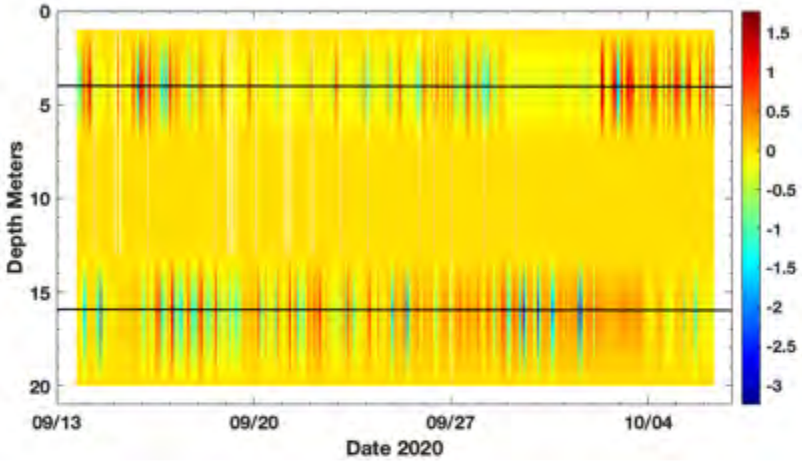


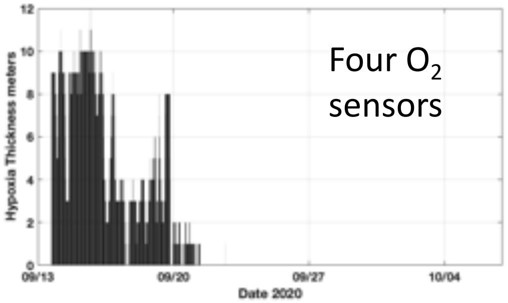
Data Time Series (2)

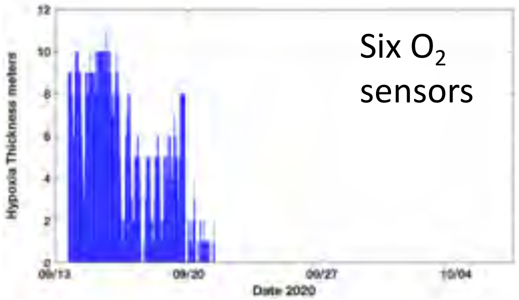
Figures at right show data as recorded at 10 minute intervals, with 1 meter linear vertical interpolation between surface (1 m) and bottom (20 m) sensors. Black lines are locations of intermediate real-time sensors. These plots are based on only the four real-time sensors.

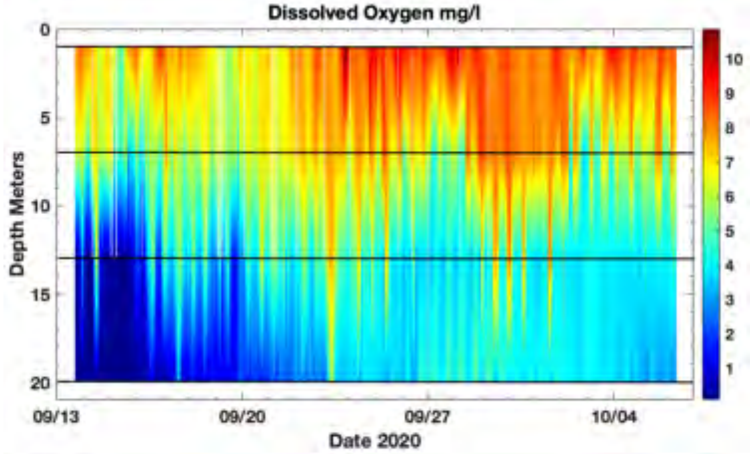
How does a four-sensor mooring compare to a six-sensor one? Qualitatively, it captures the major features. Quantitatively, the figure below right shows the difference between the series, localized around the additional sensors. The differences average out rather quickly in time, with the long-term mean differences 0.09 mg/l at 4 m and 0.06 mg/l at 16 m.

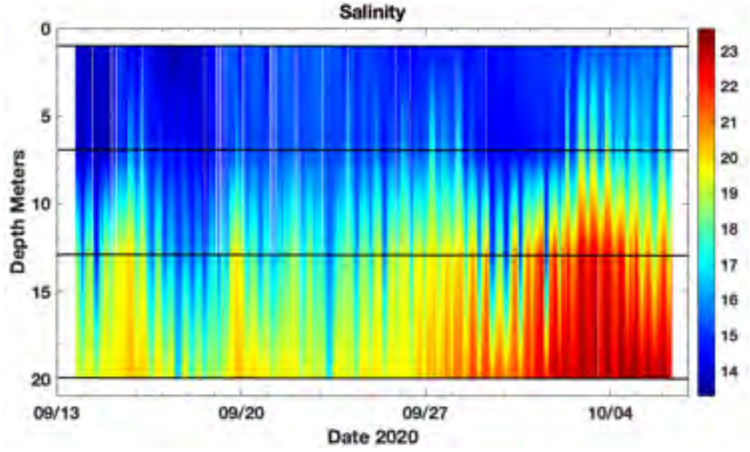
The figures below compare the estimates of hypoxic volume derived from the six- and four-sensor arrays, using the vertical space (in meters) with dissolved oxygen concentration less than 2.0 mg/l. Both show hypoxic condition ending on the same date, with the time-integrated totals differing by about 6%. These small levels of difference show positive proof of concept and point out some areas of research prior to operational deployments. Arguably, a considerable amount of the difference might be attributable to something as basic as the need for better pre- and post-deployment sensor calibrations.

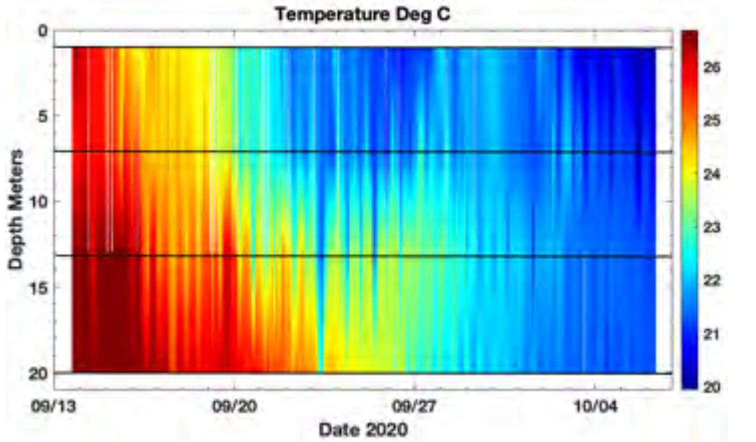












Recovery

During the 25 day deployment, the 4-instrument mooring showed a 99.6% (14100/14164 instrument records) data return, with all sensors reporting all variables for the entire time.

The intent was to leave the mooring out through October, but on 06 October around 0900Z, data transmission was interrupted, resuming about 3 hours later, 3.75 nm NNE of the deployment site. We were notified on 7 October that the buoy had been run over by the Atlantic Surveyor, a vessel on hydrographic survey contract to NOAA, entangled in a side scan sonar cable, and released and left near the entrance to the Choptank River channel. This dragged the mooring from 22 m depth to approximately 14 m depth, at a speed of over 1 knot. While the buoy did not transmit or receive GPS data during this time – it was likely underwater – it did still continue to collect data from the sensors. The buoy was recovered, fully intact and operational except for damage to the urethane foam float covering, on 8 October.

Pre Deployment

Buoy journey

Post Recovery

Urethane Damage

Lessons Learned and Next Steps

The two 2020 summer test deployments proved conclusively that hypoxia can be successfully monitored ‘*using a lightweight, low-powered, real-time inductive* $CTDO_2$ *mooring with sensors at multiple vertical measurement levels*’, as proposed.

During the project, we developed a new, low low cost instrument by integrated optical dissolved oxygen measurement technology into an inductive conductivity-temperature sensor, and successfully tested it in expected (and extreme) environmental conditions. Three of the proposed six sensors were used, with the remaining to be delivered with improvements based on experience. Details on performance will be in the final report.

Data were collected using inductive communications from a SoundNine UltiBuoy. The communications pipeline was robust (note the 99.5 % + return rate on second deployment), and we developed a [bonus!] web site for real-time data display.

We are developing a small, integrated LED navigation light for the UltiBuoy for future deployments.

Profiling using sensors at multiple levels did a good job of capturing the vertical structure and variability of dissolved oxygen (and other parameters) at the test location, supporting the preliminary analysis in the proposal. Further analysis , recommendations for best practices, and suggestions for deployments at other locations will be in the final report.

Doug Wilson 15 October 2020

Chesapeake Bay Trust
Chesapeake Bay Program Goal Implementation Team Project Support

Challenge: Pilot a cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia

Doug Wilson
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Requirements **(apologies for some text slides here… I won't read all the words)**

The RFP requested 4 outputs (paraphrased):

1) lessons learned regarding a *reliable* infrastructure that sustains the deployment;
2) *reliable*/dependable infrastructure assessment of the gear deployed;
3) successes and challenges of the piloted equipment in collecting, storing, and providing *reliable data* in the summer season in the mainstem Chesapeake Bay;
4) details of protocols to be adopted and invested in for deployment of vertical profiling infrastructure.

The highest priority requirement based on these (noted in 3 of 4) is ***reliability.*** **Additional considerations**, based on extensive experience designing and supporting real-time environmental monitoring systems in Chesapeake Bay, as well as familiarity with CBP and partners' interests, are:

- Meet CBP and partners' data needs
    - Provision of desired parameters (in this case Dissolved Oxygen concentration – which requires coincident Temperature and Salinity for accurate calculation)
    - Adequate quality – initially and over the whole of a seasonal deployment
    - Vertical resolution – ability to capture the important features of vertical structure
    - Timely, easy, and dependable real-time data delivery

- Sustainability – includes long term capital and resource requirements, personnel expense
    - Minimum initial cost to acquire and deploy
    - Minimal level of field support required during deployment
    - Long lifetime of equipment and ease/cost of off-season repairs and refurbishment

- Flexibility – Can the system be successfully utilized in all required locations, recognizing diverse, often extreme physical environments and conditions that may be faced.

These requirements define our approach.

There are two basic ways to acquire a vertical water column profile – either by

a) moving a sensor package repeatedly through the water column, or by

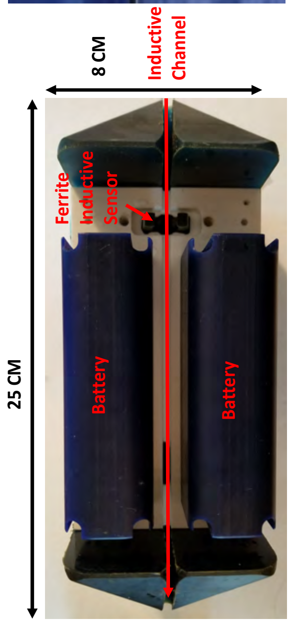
b) locating sensor packages at multiple fixed depths, with vertical sensor spacing adequate to meet observational requirements.

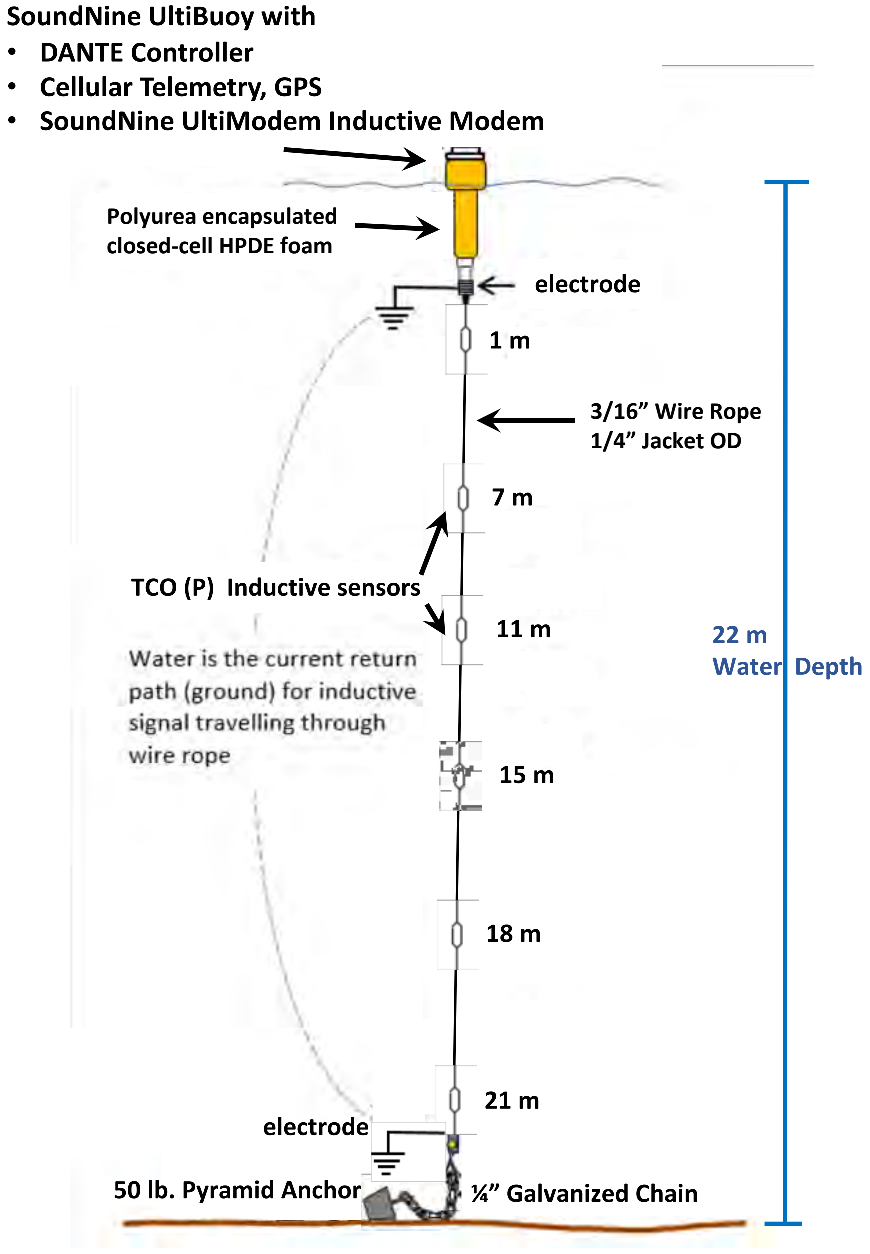
Either way, data must be regularly collected and transmitted from the *in situ* system location to an accessible data structure.

Our proposed solution is b), described below, with rationale for how the solution best fits requirements.

Approach *A Lightweight, Low-powered Real Time Inductive CTDO2 Mooring with sensors at multiple vertical measurement levels*

Sensors will be independent, integrated Temperature / Conductivity / Dissolved Oxygen (optional Pressure) units developed by collaborator Darius Miller, President and Principal Engineer at SoundNine. Units collect data and transmit **inductively**, clamped to a semi-taut mooring line with a surface data collection and cellular transmission buoy (SoundNine UltiBuoy). T/C/P sensors with inductive modems are manufactured by SoundNine Inc., and will integrate OEM fluorescence-based microDOT Dissolved Oxygen modules supplied by Precision Mechanical Engineering (PME).





Why fixed sensors instead of a profiler?

Reliable

- No moving parts, robust (but adjustable) attachment to mooring cable.
- Extremely low power, alkaline batteries will power sensors for >> a season at 15 minute sampling.
- Proven hardware with accurate individual sensor components
- Controller / Communications buoy designed to be fully submersible to 5 meters to remain semi-taut and withstand surface wave conditions in any Chesapeake Bay water depths

Sustainable

- Sensor modules are low cost (estimated $4-5K) so spares are affordable
- Should not require cleaning during season
- Full Mooring with sinker is hand-deployable/recoverable by two persons in small boat

Flexible

- Modular components
- Works in any depth – deep or shallow - found in Chesapeake Bay
- Designed to withstand extreme Chesapeake Bay wave conditions

Meets Data Needs

Analysis shows that a reasonable number of sensors can achieve accurate measurement of vertical hypoxia structure while still maintaining the reliability and sustainability advantages of a simple ‘no moving parts’ platform.

Data are stored internally and transmitted in real-time to SoundNine cloud-based storage system, where data will be available to CBP and partners with low time latency. Low power consumption of inductive technology allows 15-minute sampling for a full season deployment.

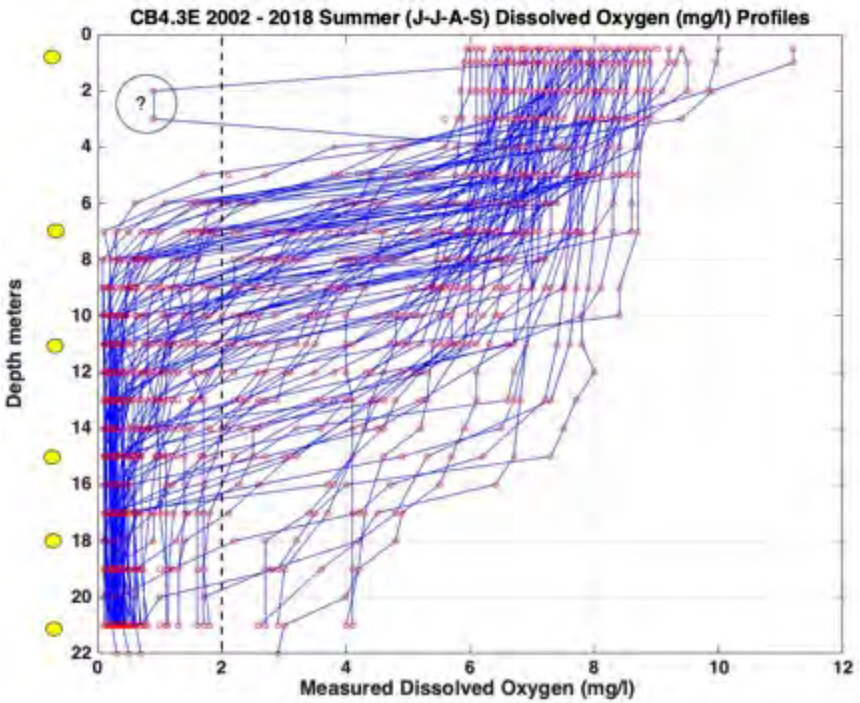
While a single profiling instrument is another approach, our experience with these devices is that they have more structural and logistical complexities and failure points (both in the profiling mechanism and in the mooring/structure supporting the profiler) that increase the risk of service visits in-season (cost) and associated periods of missing data. Reliability can be maximized by having the simplest solution that meets the requirements.

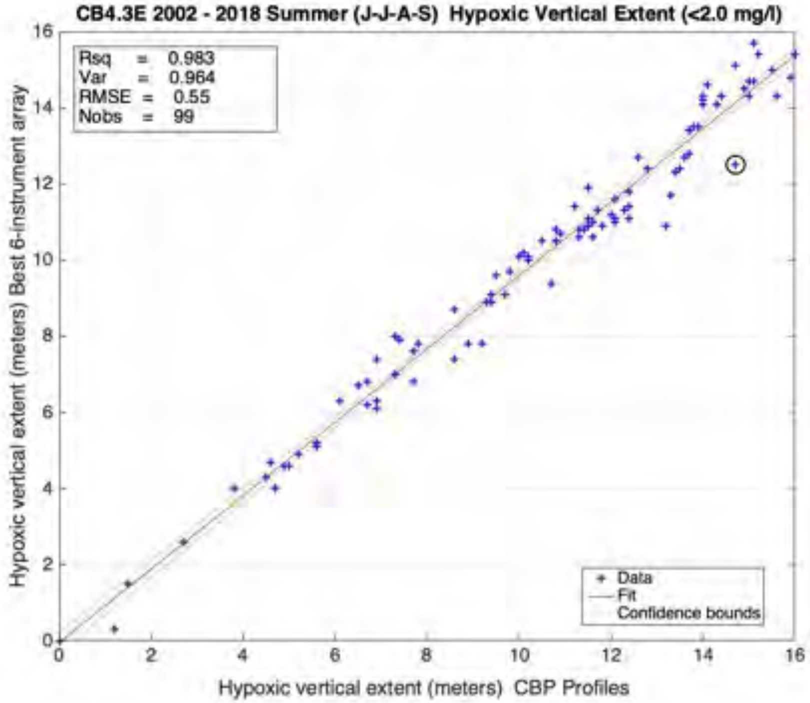
Analysis

In evaluating the fixed vertical sensor approach, we considered a pilot proof of concept deployment at CBP fixed monitoring Station CB4.3E (38.55624 N 76.39121 W) – about 2.5 km E of CBIBS Gooses Reef buoy, where there is real time surface environmental data nearby from GR, as well as bottom DO and pH data.

Additionally, this station is in a reasonably deep location (21-22m) and out of shipping channels (a problem when surface buoys are required for real-time communications).

Figure shows CB4.3E DO profiles from 2002-2018 June/July/August/September. Assuming that we want to be able to at least match the ability of the existing sampling to resolve structure and measure vertical extent of hypoxia (DO < 2.0 mg/l) for use in DO volume estimations and forecast model comparisons, simulations were run with various fixed sensor depths. Table 1 shows how well different vertical sensor arrays capture full water column Vertical Hypoxia Extent - the amount of the vertical water column with Dissolved Oxygen concentration below 2.0 mg/l. For station CB4.3E, reasonable results can be achieved with six sensors – graphical comparison of the six-sensor model is shown in Figure 1B. This is a preliminary model, it is likely that more rigorous placement modeling would reduce uncertainty even further.





Measuring Dissolved Oxygen profiles with fixed depth sensors.

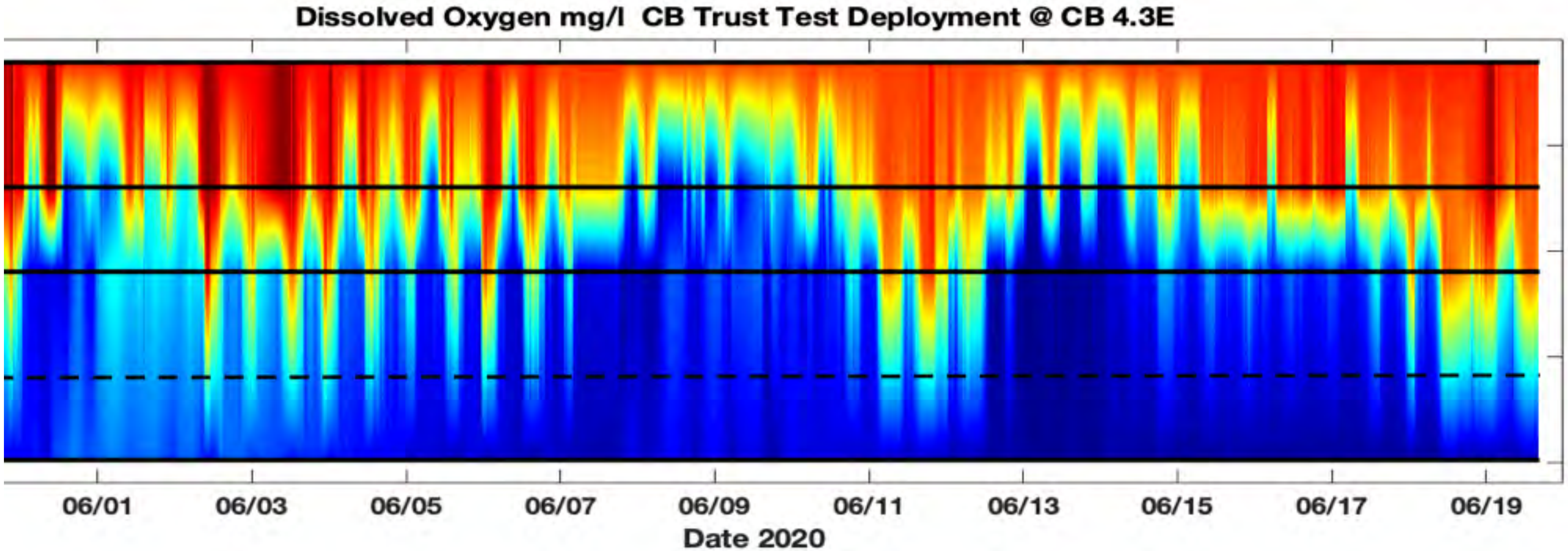
- Profiles of Dissolved Oxygen from all 2002-2018 Jun-September measured CBP stations at CB3.4E. Red dots are original sample depth locations, connected by blue profile lines. Yellow circles represent a six-instrument array used in (B).
- Comparison of 'Vertical Hypoxia Extent (Meters)' calculate using measured profiles (X axis) and the same quantity calculated using a hypothetical array of six sensors shown in (A). Different arrays were tested and results shown in Table 1.

Number of Sensors	Depths (meters)	R^2	% Variance	RMS Error
21	[1,2,3,...,19,20,21]	0.999	0.994	0.22
11	[1,3,5,7,...,17,19,21]	0.994	0.985	0.33
10	[1,5,7,9,...,17,19,21]	0.993	0.984	0.33
9	[1,6,9,11,13,15,17,19,21]	0.990	0.977	0.42
7	[1,6,9,12,15,18,21]	0.988	0.977	0.46
6	[1,7,11,15,18,21]	0.982	0.964	0.55

So how did we do?

Deployment 1

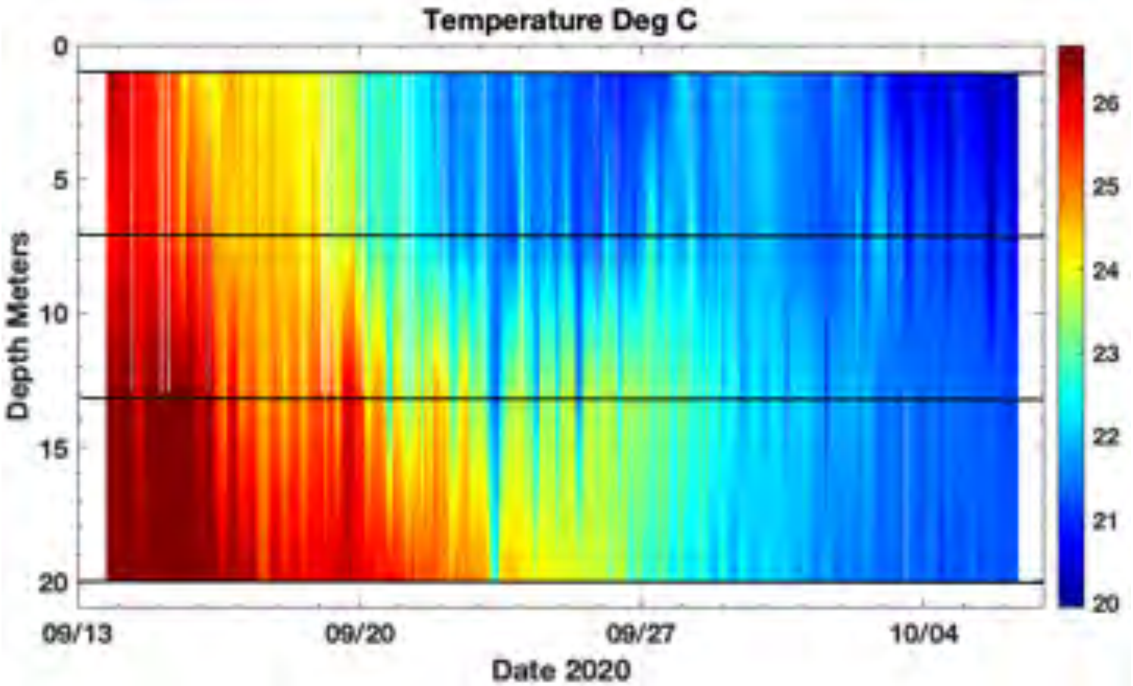
30 May 2020
19 June 2020

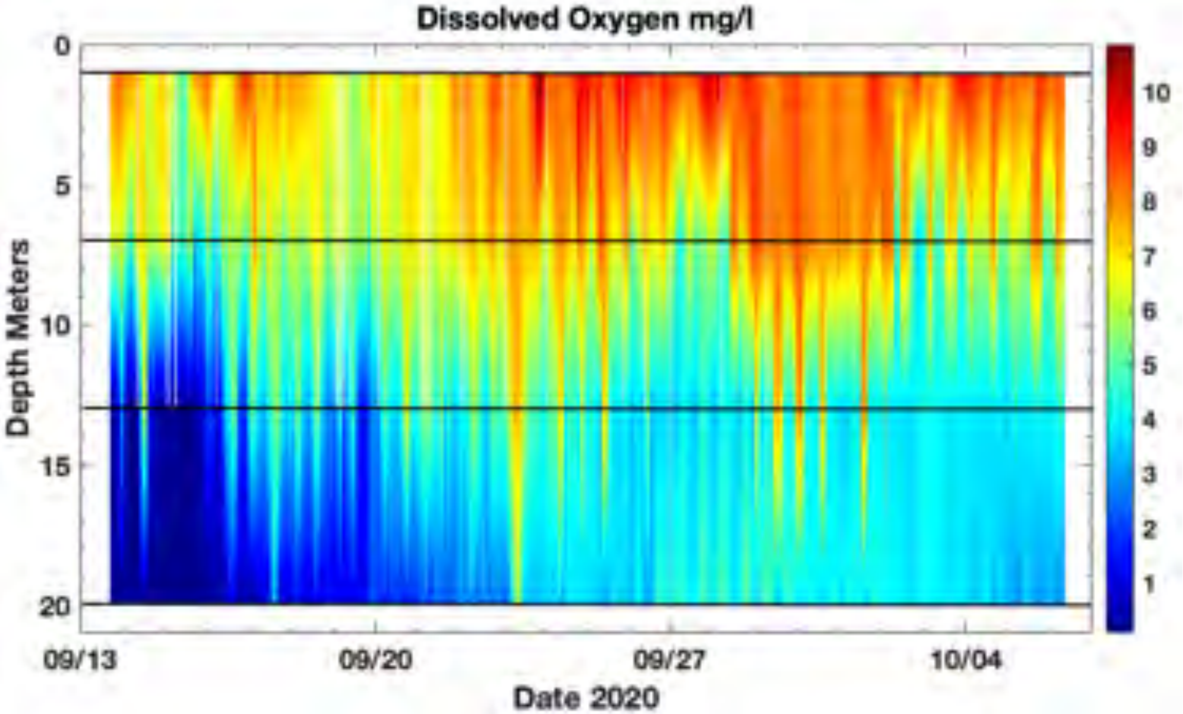


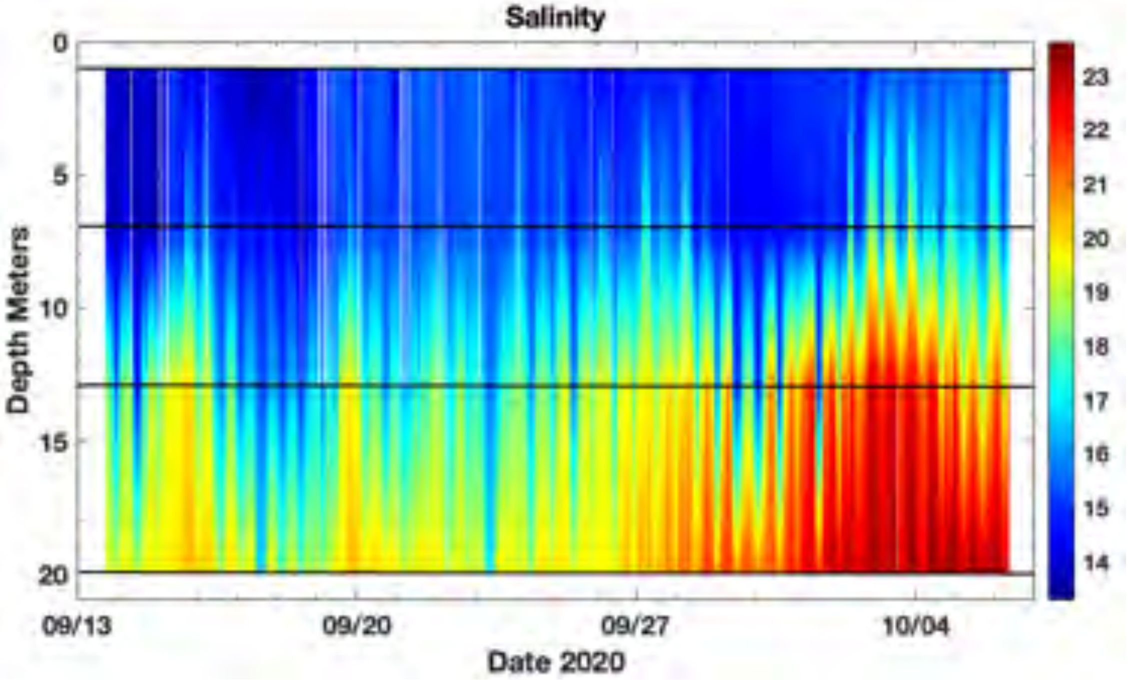
Deployment 2

13 September 2020
06 October 2020

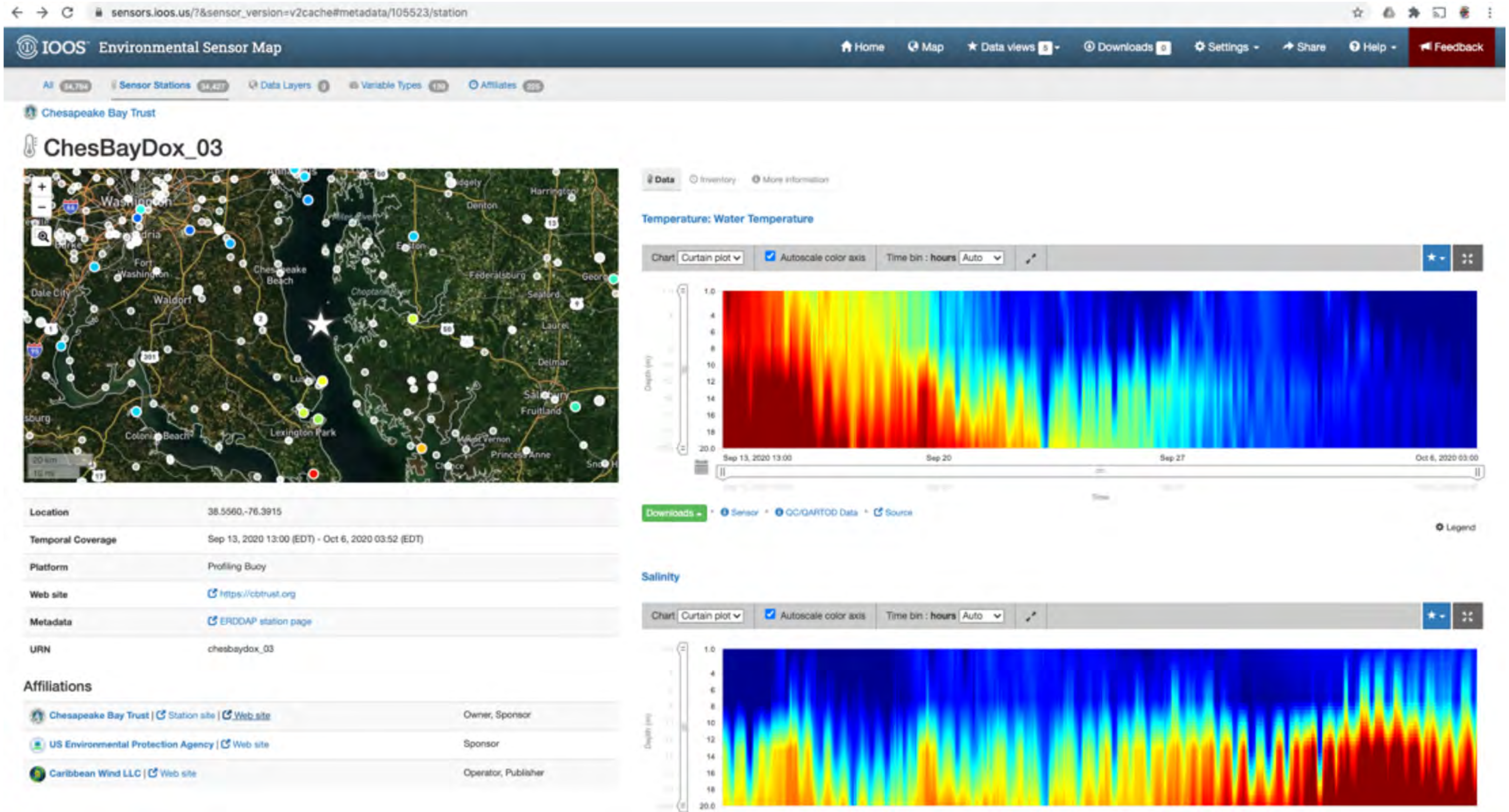
Ended prematurely when a NOAA hydrographic survey contract vessel snagged the mooring and dragged several miles. Good stress test – all still working afterwards!





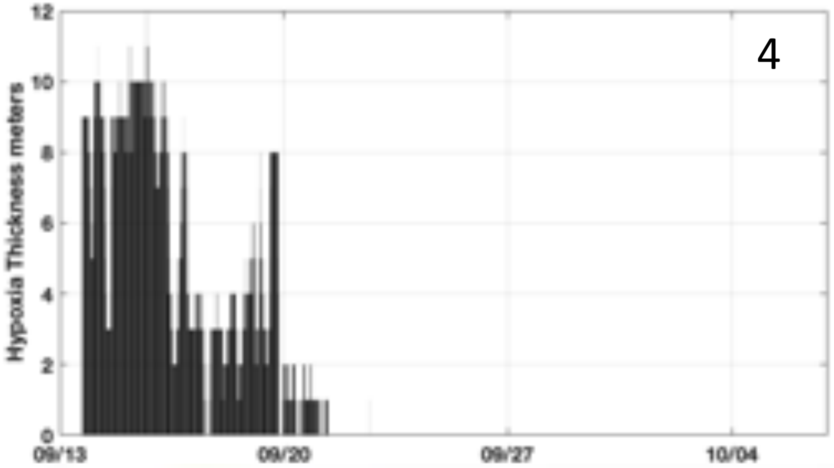


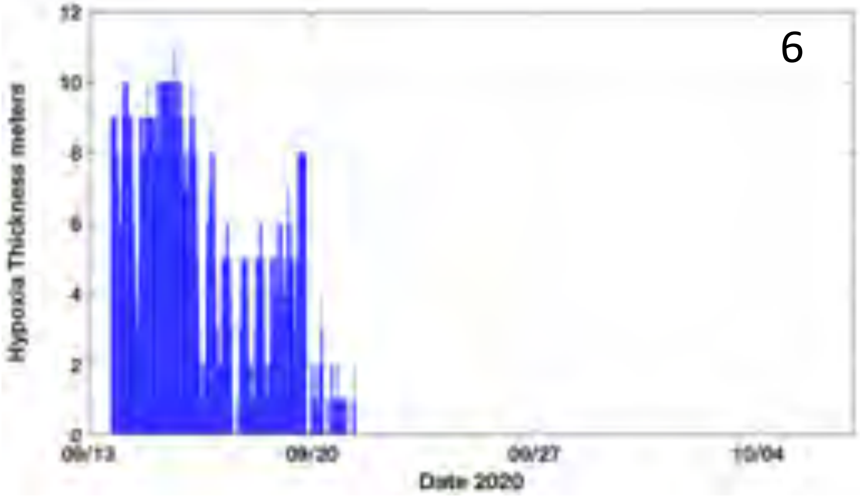
In addition to cloud-based data base at SoundNine (which allows direct access to data, AXIOM Data Science has created a real-time US IOOS format web site (includes access to nearby platforms and ERDDAP data access page)
at https://sensors.ioos.us/?&sensor_version=v2cache#metadata/105523/station



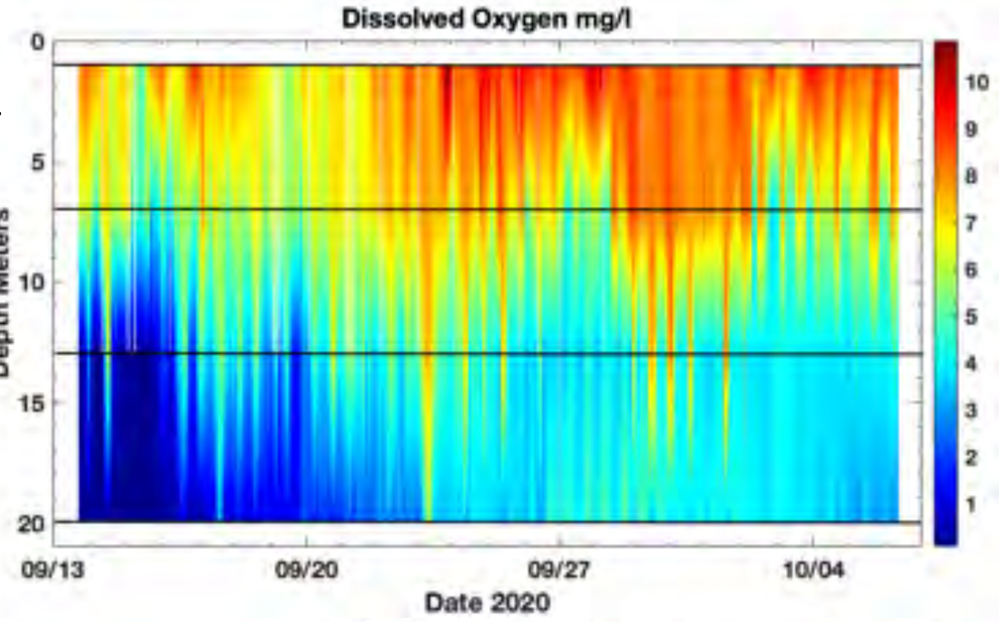
Also did a ‘data denial’ experiment with 2 recording non-reporting DO sensors at 4 and 16 m to see difference between Four and Six sensor arrays. Over the 25 day record, mean differences were 0.09 mg/l at 4 m and 0.06 mg/l at 16 m.

Calculated thickness of Hypoxic Layer (below) show hypoxic conditions ending on the same date, with the time-integrated totals differing by about 5%.

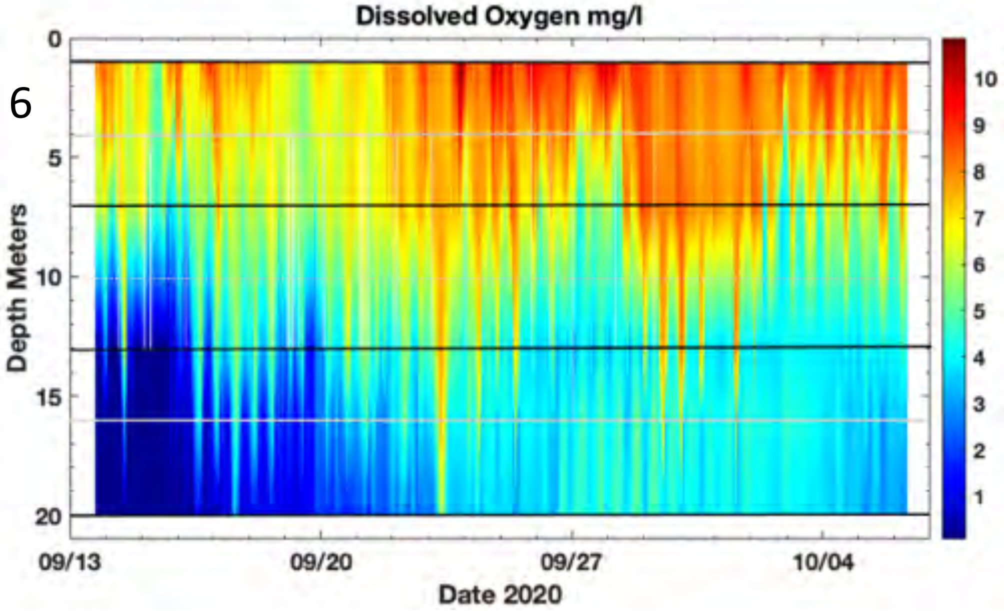




4



6



Lessons Learned

The two 2020 summer test deployments proved conclusively that hypoxia can be successfully monitored ‘*using a lightweight, low-powered, real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels*’.

During the project, we developed a new, low low cost instrument by integrating optical dissolved oxygen measurement technology into an inductive conductivity-temperature sensor, and successfully tested it in expected (and extreme) environmental conditions. Three of the proposed six sensors were used, with the remaining to be delivered with improvements based on experience.

Data were collected using inductive communications from a SoundNine UltiBuoy. The communications pipeline was robust - deployment 2 had 14100/14164 instrument records real-time data return (99.6%) - with all sensors reporting all variables for the entire time. We developed a [bonus!] web site for real-time data display.

Profiling using sensors at multiple levels did a good job of capturing the vertical structure and variability of dissolved oxygen (and other parameters) at the test location, supporting the preliminary analysis in the proposal. Further analysis , recommendations for best practices, and suggestions for deployments at other locations will be in the final report.

The mooring was deployed and recovered by hand by two persons from a 19 ft Boston Whaler.

Estimated 5 years of seasonal deployments with existing batteries.

Fouling was not an issue over 25 days in summer.

Equipment < $35,000 for a 6-sensor mooring (should come down with higher production)

Taking a deeper dive on oxygen in the Chesapeake Bay

New monitoring technology is helping scientists better estimate dead zones

A new monitoring system that would help scientists better estimate when and where hypoxia, or "dead zones," may occur, is being tested in the Chesapeake Bay watershed. (Photo By Doug Wilson)

by Kim Couranz

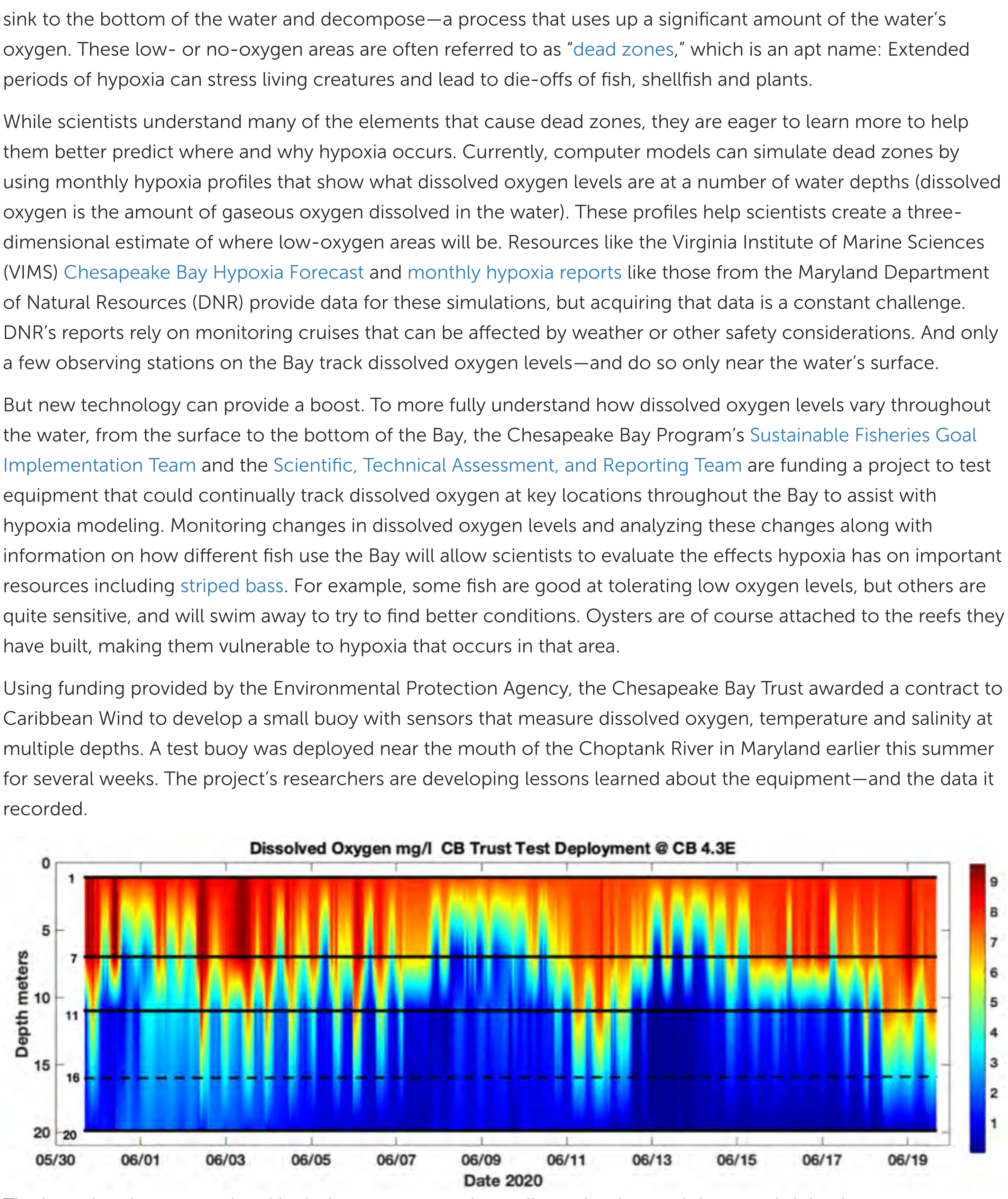
September 29, 2020

Living creatures—both on land and in the water—need oxygen to survive. But parts of the Chesapeake Bay often experience hypoxia, a situation where oxygen levels in the water get dangerously low. Hypoxia can result when excess nutrients run off the land into the water and fuel the growth of algal blooms. When these algae die, they sink to the bottom of the water and decompose—a process that uses up a significant amount of the water's oxygen. These low- or no-oxygen areas are often referred to as "dead zones," which is an apt name: Extended periods of hypoxia can stress living creatures and lead to die-offs of fish, shellfish and plants.

While scientists understand many of the elements that cause dead zones, they are eager to learn more to help them better predict where and why hypoxia occurs. Currently, computer models can simulate dead zones by using monthly hypoxia profiles that show what dissolved oxygen levels are at a number of water depths (dissolved oxygen is the amount of gaseous oxygen dissolved in the water). These profiles help scientists create a three-dimensional estimate of where low-oxygen areas will be. Resources like the Virginia Institute of Marine Sciences (VIMS) Chesapeake Bay Hypoxia Forecast and monthly hypoxia reports like those from the Maryland Department of Natural Resources (DNR) provide data for these simulations, but acquiring that data is a constant challenge. DNR's reports rely on monitoring cruises that can be affected by weather or other safety considerations. And only a few observing stations on the Bay track dissolved oxygen levels—and do so only near the water's surface.

But new technology can provide a boost. To more fully understand how dissolved oxygen levels vary throughout the water, from the surface to the bottom of the Bay, the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team and the Scientific, Technical Assessment, and Reporting Team are funding a project to test equipment that could continually track dissolved oxygen at key locations throughout the Bay to assist with hypoxia modeling. Monitoring changes in dissolved oxygen levels and analyzing these changes along with information on how different fish use the Bay will allow scientists to evaluate the effects hypoxia has on important resources including striped bass. For example, some fish are good at tolerating low oxygen levels, but others are quite sensitive, and will swim away to try to find better conditions. Oysters are of course attached to the reefs they have built, making them vulnerable to hypoxia that occurs in that area.

Using funding provided by the Environmental Protection Agency, the Chesapeake Bay Trust awarded a contract to Caribbean Wind to develop a small buoy with sensors that measure dissolved oxygen, temperature and salinity at multiple depths. A test buoy was deployed near the mouth of the Choptank River in Maryland earlier this summer for several weeks. The project's researchers are developing lessons learned about the equipment—and the data it recorded.



The buoy is solar powered and includes a computer that collects the data and then sends it back to a server on shore every 10 minutes—much more frequently than humans are able to collect during monthly scientific cruises. Data were collected at one, seven, 11, 16 and 20 meters below the surface, giving scientists a more comprehensive view of conditions throughout the Bay's water column—all the way from the surface to the bottom, the water that fish need for habitat.

During the initial test deployment, a few of the sensors didn't fully operate. Researchers also noticed some issues with fouling at a few of the sensor depths. Fouling is when biological growth, like algae, covers sensors and hampers their operations. With a few changes and improvements made to tackle these issues, a second test deployment is currently under way, slated to run through much of October. If this version of the buoy is successful, others could be developed as a critical tool in helping scientists better predict and understand hypoxia in the Chesapeake Bay, leading to more accurate dead zone forecasting. All of this could help resource managers develop more accurate and targeted regulations, helping to protect species when and where their oxygen levels are most threatened.

About Kim Couranz - Kim Couranz is Communications Specialist at the NOAA Chesapeake Bay Office, where she writes about fisheries science, data and observations, Bay education efforts, oyster restoration and much more. While she graduated from Brown University with a double concentration in international relations and Russian language, now she enjoys communicating about the Bay. Away from the office, she is an internationally ranked sailboat racer and recreational runner.

National Oceanic and Atmospheric Administration (NOAA) | dead zone | monitoring | water quality | Chesapeake Bay Trust | Choptank River | Scientific and Technical Advisory Committee (STAC)

Comments (2)

Chesapeake Bay Program
October 22, 2020

Hey Deborah, thank you for the question. If not properly disposed of, medicine that enters the water can certainly have a negative impact on local streams, rivers and the Bay. The Environmental Protection Agency has guidelines related to disposing medicine: https://www.epa.gov/hwgenerators/collecting-and-disposing-unwanted-medicines. Penn State Extensions also has information related to the topic: https://extension.psu.edu/pharmaceutical-disposal-and-water-quality. Hope this helps!

Deborah Slaybaugh
October 15, 2020

A hospital where I worked in south central Pa disposes of its unused narcotics down the drain. Will that have an effect on the Bay ?

Leave a comment:

Name (Required)

Email (Required)

Comment:

I'm not a robot
reCAPTCHA
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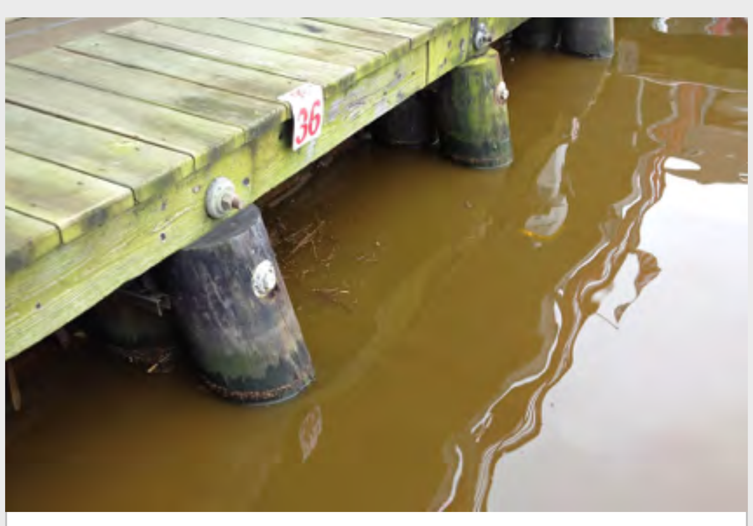
Submit

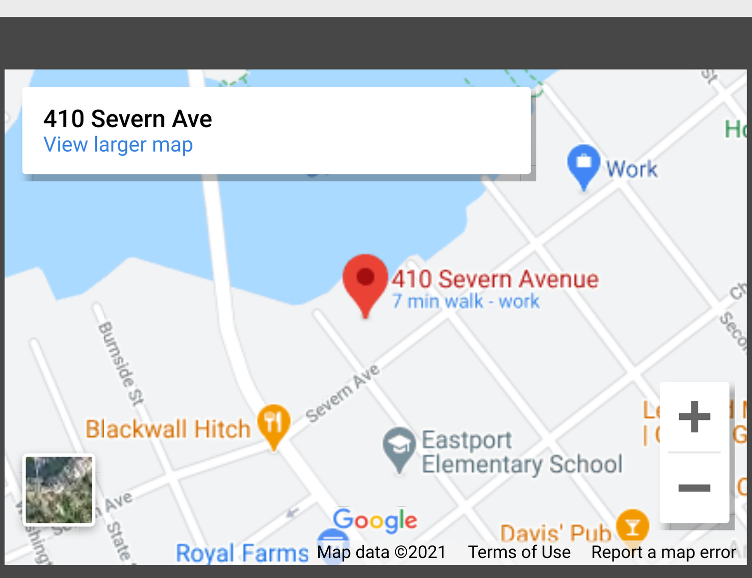
Related Articles

Above-average dead zone predicted for Chesapeake Bay

About a buoy



Chesapeake Bay dead zone measures slightly below average in 2015



Innovative Hypoxia Measurement

Collaboration with CTDO Sensors, Ultibuoy in Chesapeake Bay

By Doug Wilson • Darius Miller

When leaders make policy decisions, it is important that they make those decisions with good data in hand. This is especially true of choices that impact the environment and our natural resources. Chesapeake Bay is a prime example of an area where better policy decisions are aided by better data.

Chesapeake Bay covers 4,480 sq. mi. and stretches from Havre de Grace, Maryland, to Virginia Beach, Virginia. According to the U.S. Environmental Protection Agency (EPA), 500 million pounds of seafood, including oysters, blue crabs and striped bass, are harvested from the bay each year. In a 2009 report, NOAA estimated the annual haul in Virginia and Maryland alone contributed to 34,000 jobs, with an economic impact of $3.39 billion.

While commercial fishing in Chesapeake Bay is a thriving industry, it is under threat from extreme seasonal hypoxia caused by excessive nutrient input. Increased levels of nitrogen and phosphorous introduced to the bay through agricultural runoff, wastewater treatment effluent and air pollution promote spring blooms of algae growth. As the excess nutrients are consumed, the algae die off and sink to the bottom, where they are decomposed by bacteria. These bacteria consume oxygen from the water and cause dissolved oxygen (DO) levels to decrease. When the algae load is too high, the oxygen level can fall dramatically and create hypoxic dead zones with DO concentration less than 2 mg/l. These dead zones can be lethal to fish, oysters and crabs. Hypoxia in Chesapeake Bay generally occurs during the summer as rising temperatures cause increased phytoplankton productivity, subsequent decomposition and vertical stratification, all of which contribute to the formation of dead zones.

The Chesapeake Bay Program (CBP) is a multi-agency regional partnership managed by the Environmental Protection Agency. The CBP monitors dissolved oxygen levels to assess the bay's health and restoration progress. Researchers go out on the bay once or twice per month to measure vertical profiles of water properties, including dissolved oxygen, at a set of standard locations. These measurements require multiple small-boat cruises with lowered instruments and water samples. CBP uses these data to estimate the total volume of hypoxic water in the bay. The resources required make higher frequency sampling impractical.

Estimated hypoxic volume (the size of the dead zone) is an important indicator of bay health, as it is closely tied to total nutrient input and increases have broad negative impacts. University of Maryland Center for Environmental Science researchers Ming Li and Wenfei Ni suggest that rising temperatures associated with global climate change will lead to an increase in hypoxia in the bay. A joint study Li and Ni published with Andrew Ross from Princeton University and Raymond Najarr from Pennsylvania State University, titled "Large Projected Decline in Dissolved Oxygen in a Eutrophic Estuary Due to Climate Change," suggests that Chesapeake Bay could see a 10 to 30 percent increase in hypoxic and anoxic volume as we move into the 21st century. Studies like these highlight the importance of reliable, real-time data on hypoxic levels throughout Chesapeake Bay.

Real-Time Monitoring Solution

The Chesapeake Bay Trust (CBT) is a nonprofit dedicated to improving the watershed of Chesapeake Bay and other areas. In early 2019, the CBT issued a request for proposals to demonstrate a cost-effective, real-time, dissolved-oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia. The hope was to explore new methods of hypoxic volume estimation based on continuous measurement rather than on typically infrequent profiles.

Doug Wilson of Caribbean Wind LLC (co-author of this article) saw an opportunity to deliver a system that could provide continuous, real-time, vertical profiles of dissolved oxygen using just a few sensors at selected depths. The full vertical profiles could then be estimated by extrapolation between the fixed-depth sensors. Existing research supported approaches like this: Bever et al ("Estimating Hypoxic Volume in the Chesapeake Bay Using Two Continuously Sampled Oxygen Profiles," 2018) showed that hypoxic volume can be accurately estimated if continuous DO data are available from only a few strategically positioned vertical profiles.

There were two major problems. First, existing sensors with real-time capability were expensive, at more than $15,000 per sensor. Second, typical buoy systems with the ability to report subsurface measurements in real time were costly to acquire and maintain. They often required larger vessels with cranes or specialized research vessels to deploy and recover.

Over the previous year, Doug Wilson had collaborated with Darius Miller of Soundnine Inc. (co-author of this article) to support researchers at the University of the Virgin Islands (UVI) studying how fluctuations in temperature impact coral and fish populations. In the UVI project, Soundnine (www.soundnine.com) leveraged existing sensor and inductive communication technologies and created two new instruments that contributed to a unique and successful monitoring project. Wilson knew Soundnine had a new miniature buoy system designed for subsurface inductive communications and a new real-time conductivity, temperature and depth (CTD) sensor.

Wilson also had experience with the miniDOT Logger from Precision Measurement Engineering (PME, www.pme.com). The miniDOT is a small, accurate, submersible logging instrument that measures dissolved oxygen with an optical fluorescence method. He reached out and started a collaborative effort to combine these innovative technologies from different companies and meet the Chesapeake Bay Trust challenge.

Wilson proposed Soundnine integrate the PME sensor with its new CTD, but the miniDOT was too large. Fortunately PME was already working on a new, smaller sensor. A number of researchers familiar with the miniDOT Logger had previously requested PME offer a smaller oxygen sensor for various applications. PME determined they could develop a smaller sensor and maintain the same accuracy and long-term stability to help researchers meet their complex water measurement challenges. The final version of PME's research and development efforts became the microDOT sensor, which is a robust and low-power optical oxygen sensor. The microDOT provides stability, requires less calibration than other sensors currently available and is ideal for a wide range of monitoring needs.

Caribbean Wind and Soundnine proposed to meet the CBT proposal requirements with a new measurement instrument: a combination of the Soundnine CTD sensor with the PME microDOT DO sensor. These new instruments would mount below Soundnine's Ultibuoy, a miniature buoy with integrated controller, telemetry and inductive communications. The controller on the Ultibuoy includes batteries, cellular modem, GPS and inductive communications. All antennas are internal to maximize reliability. The buoy and controller are fully submersible, so the system can be pulled tens of meters underwater in storms and continue normal operation. The entire system would cost much less than any existing real-time system; its small size would minimize cost of deployment and maintenance.

The proposed CTDO sensor with the Ultibuoy would make a compact and efficient real-time monitoring system, but Wilson still had to show that vertical profiles could be accurately estimated from a few fixed depth measurements. He conducted an analysis of existing dissolved-oxygen reports at a representative fixed station from 2002 to 2018, looking at data collected each year between June and September. He ran simulations with various sensor depths to identify variances between existing and proposed methods of measurement. Dependent upon the proposed number of sensors to be used, the original 1-m resolution profiles could be recreated with variances from 0.980 to 0.994.

The proposal was compelling and CBT awarded the contract to Caribbean Wind and Soundnine for a first deployment in May 2020. PME delivered calibrated microDOT sensors. Soundnine designed a new instrument incorporating the microDOT, temperature sensor, conductivity cell, inductive telemetry and batteries. The instrument clamps to the anchor mooring cable, which also serves as an electrical conductor for the inductive communications system. Sensors can be positioned at any depth. The pilot deployment site was in 21 m of water at CBP sampling station site 4.3E, which is where the initial analyses were done.

Deployment and Findings

The deployment of the CTDO mooring and sensors occurred in two phases in 2020, with the first taking place from May 30 to June 19, and the second from September 13 to October 6. In keeping with the sustainability requirement and low-cost solution, Caribbean Wind was able to deploy the system from a 19-ft. center-console boat with two people. For each deployment, measurements were collected every 10 min. and forwarded by cellular modem to a Soundnine cloud server.

The first deployment successfully demonstrated some critical features of the system. The controller maintained full battery voltage with solar charging over three weeks. The buoy provided adequate flotation. There was a cellular network disruption during the deployment, and the controller successfully buffered data and forwarded the data when the disruption ended. The inductive communication system was very reliable, yielding high data returns. Sensors provided reliable data with minimal change in battery voltage, suggesting they could operate for five years or more on the same batteries.

Following the first deployment, Caribbean Wind applied minor upgrades to the buoy and sensors, including application of anti-fouling to the sensors. Anti-fouling incorporated copper tape on surfaces and better copper mesh sensor covers. Further, the Soundnine database system was updated to convert raw sensor data into engineering values for pressure, conductivity and salinity, and to apply calibration adjustments to the DO sensors.

During the second deployment, there was a 99.6 percent data return rate with 14,100 instrument records, and all sensors reported all variables for the entire time. In addition to standard CTDO sampling, the second deployment also included a data-denial experiment with two internally recording DO sensors located between real-time sensors to evaluate the difference between four- and six-sensor arrays. Over the 25-day record, mean differences were minimal, with hypoxic conditions ending on the same date and revealing time-integrated hypoxia totals differing by less than 5 percent.

The second deployment ended early when the buoy was accidentally snagged before dawn by a survey team and dragged several kilometers. The entire system continued operating and survived the encounter with only cosmetic damage to the buoy hull. Future deployments will require a beacon light to prevent such encounters.

Overall, the test deployments proved conclusively that hypoxia can be successfully monitored using a lightweight, low-power, real-time inductive CTDO mooring with sensors at fixed depths. The system did a good job of capturing the vertical structure and variability of dissolved oxygen (and other parameters) at the test location, confirming the preliminary analysis in the proposal. Data collected using Soundnine inductive communications were robust. The survey team encounter, while unfortunate, increased confidence in the mechanical robustness of the entire system.

Through the collaborative efforts of Caribbean Wind, Soundnine and PME, the project led to the development of a new, low-cost instrument meeting CBT guidelines with optical dissolved oxygen measurement technology integrated into a CTD sensor. This sensor was successfully tested in difficult environmental conditions. The instrument is estimated to run for five years of seasonal deployments at a cost of less than $40,000 for a six-sensor mooring.

Impacts and Implications for the Future

This successful demonstration of a cost-effective, reliable, low-maintenance, real-time hypoxia measurement system in Chesapeake Bay provides policy makers and organizations like CBP with tools required to advance environmental protection and restoration efforts. The implications of this project extend beyond Chesapeake Bay and may positively impact other areas suffering hypoxic conditions, like the Gulf of Mexico, salmon farms and recreational fisheries. The team effort between Caribbean Wind, Soundnine and PME shows how collaboration leads to innovative solutions, advances our understanding of the world, and helps leaders better navigate troubled waters.

"It's always exciting when researchers come to us to help solve complex water measurement challenges. Our technology is providing valuable data and ongoing monitoring to positively impact environmental decisions and water quality management," said PME CEO Kristin Elliott. "Understanding how watersheds and surrounding areas contribute to the overall health of a critical ecosystem supports the local environment and economy."

Acknowledgments

Caribbean Wind LLC would like to acknowledge the support of the Chesapeake Bay Trust, Annapolis, Maryland. This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement CB96341401 to the Chesapeake Bay Trust. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document. **ST**

Doug Wilson is an oceanographer and president of Caribbean Wind LLC. Prior to forming the oceanography consulting firm, he was an oceanographer at NOAA, studying ocean, coastal and estuarine dynamics. He is active in the ocean observing community and has served leadership roles in MARACOOS, IOCARIBE-GOOS and the Marine Technology Society. You can contact him at: doug@coastaloceanobs.com.

Darius Miller is president and founder of Soundnine Inc. He earned his engineering degree at the Massachusetts Institute of Technology and was recruited by Sea-Bird Electronics, where he served as principal engineer until 2009. In 2011 he founded Soundnine to develop innovative technologies in service of the oceanographic and maritime communities.

Fig1

Wilson's results supporting estimation of vertical profiles from fixed-depth sensors.

Fig2

Second-deployment DO measurements show significant short-term fluctuation. (Credit: Doug Wilson, Caribbean Wind)

Fig3

The system was deployed from a 19-ft. center-console boat. (Credit: Doug Wilson, Caribbean Wind)

Fig4

New sensor designed by Soundnine with inductive communications, CTD and PME microDOT sensor (guard screen removed). (Credit: Darius Miller, Soundnine Inc.)

Fig5

Ultibuoy mooring diagram.

Fig6

No caption

SOUNDNINE INC
Helping build successful monitoring systems

Enduro Operating Manual

Soundnine Inc Document #R010R
rev 2017-06-16

Table of Contents

Quick Start

All Enduro sensors are shipped sealed with a new battery, desiccant and SDHC memory card. This is the factory configuration:

- 60 second sample period
- Record time, temperature, pressure (if equipped), tilt and raw accelerometer values
- Store both raw data and data in engineering units
- Logging not started
- Inductive modem device id set to the last two digits of the sensor serial number. For example, sensor serial number A01B is set to device ID=1B.

With Ultimodem

Most users can use an Ultimodem to change configuration and start logging:

1. Connect an Ultimodem to a computer serial port and start a terminal program (19200 baud, 8 bits, no parity, 1 stop bit, handshaking set to either software, Xon/Xoff or none.
2. Create an IM loop by passing one end of a wire through the IM coupler of the modem, through the coupler of one or more Enduro sensors, then connect the two ends of the wire together.
3. Press enter a few times in the terminal program to get a S9> prompt from the Ultimodem.
4. Send the commands in the table below, replacing device id '1B' with the last two digits of the serial number of the Enduro you wish to configure:

Command	Action	Notes
FCL	Starts modem transmitting to IM line	Wait 1 second to be sure Enduro detected the signal before sending the next command.
!1Bperiod=60	Sets the sampling period in seconds (1 to 3600)	
!1Btime=2016-06-20T133000	Sets the time	
!1Bgetsd	Displays status	verify the time was set properly and there are no warning messages
!1Bgetcd	Displays configuration	
!1Bstart	Starts logging	
!1Btsc	Take sample, include checksum	Refer to Temperature Resolution Control The TMODE command sets the temperature resolution. Higher resolution requires more time to take a measurement and consumes more power. TMODE=1 provides 0.001C resolution, which is appropriate for most applications and minimizes power consumption.

		TMODE=2 provides the maximum resolution (0.0001C), but consumes more power. Note the AMODE and PMODE commands are reserved for similar features with the accelerometer and pressure sensor. These may include burst sampling modes. Retrieving Data with Checksums for details on checksum calculation
!1Bglc	Gets last sample with checksum	
*SAMPLE	Sample all endure on the line	**Refer to Temperature Resolution Control** The TMODE command sets the temperature resolution. Higher resolution requires more time to take a measurement and consumes more power. TMODE=1 provides 0.001C resolution, which is appropriate for most applications and minimizes power consumption. TMODE=2 provides the maximum resolution (0.0001C), but consumes more power. Note the AMODE and PMODE commands are reserved for similar features with the accelerometer and pressure sensor. These may include burst sampling modes. **Retrieving Data with Checksums** Several commands return data with checksums. These commands should be used whenever possible instead of the similar commands without checksums. The checksums should be verified whenever possible to prevent single-bit communication errors

		from contaminating sensor data. The checksum is a CRC7. Example code is included below (CRC7 Checksum Code). The checksum includes all bytes from the start of the line up to but not including the *. Examples: S9>tsc A01A,ATPE,2000-01-01T00:58:10,26.7679,-0.4065,54.7356,0.5653392,-0.4064664,19607,-19607,-19607*79 OK; 0 Events S9>tssc A01A,ATPE,2000-01-01T00:58:16,26.7588,-0.4072,54.7356,0.5655401,-0.4071817,19607,-19607,-19607*5E OK; 0 Events S9>glc A01A,ATPE,2000-01-01T00:58:16,26.7588,-0.4072,54.7356,0.5655401,-0.4071817,19607,-19607,-19607*5E OK; 0 Events S9> Using *SAMPLE section below

With USB

1. Open the housing and connect the USB cable.
2. Wait for the green light to flash once per second – this means the Enduro is connected to USB.
3. Open a terminal program and select the correct COM port. Use the highest available baud rate, no parity, 1 stop bit.
4. Press enter a few times to get a S9 prompt from the Enduro.
5. Send the following commands:

Command	Action	Notes
period=60	Sets the sampling period in seconds (1 to 3600)	
time=2016-06-20T133000	Sets the time	
getsd	Displays status	verify the time was set properly and there are no warning messages
Getcd	Displays configuration	
start	Starts logging	
ts	Take sample	
gl	Gets last sample	

Data Recording

The Enduro records each sample as a line of plain text with values separated by commas. Data is first stored in a RAM buffer (the S file). This RAM buffer is periodically recorded to a 7 Megabyte circular FLASH memory buffer (the D file). This FLASH memory buffer is periodically recorded to the removable SDHC memory card.

Removing the SDHC Memory Card

Always press the button and wait for the green light to flash before removing the memory card. The yellow light will flash quickly while Enduro transfers data. Three long yellow flashes indicate a problem writing to the memory card. One green flash means all data transferred and you can remove the card.

Data Format

Data downloaded from the Enduro or stored on the SDHC memory card is in a simple comma-separated table format. The data order is always the same:

TIME, Temp (C), Pressure (dbar), Tilt (deg)), raw thermistor, raw pressure, accel x, accel y, accel z

Depending on the FORMAT setting, some data may not be recorded. These values are left blank, so the data table always has 9 columns.

Time can be either IS0-9601 style (2016-07-20T13:38:00) or an integer number of seconds since 2000-01-01T00:00:00, referred to as SY2K – seconds since year 2000.

See the FORMAT command section to change the data format.

Examples:

Format ATE:

```
2016-07-21T11:22:57,29.7038,,87.3609,0.5045745,,,-6660,76,307
```

Format ATES:

```
522419600,29.3002,,88.4524,0.5124578,,,-6662,72,180
```

Opening and Closing the Housing

Opening

NOTE: If there is any indication of water inside the pressure housing then handle it with caution! Rattling or sloshing inside the housing, hissing or other noises may indicate water intrusion in the housing. If there is any chance the housing might contain water then please wear safety glasses and chemical resistant gloves – there could be pressure inside the housing or hazardous chemicals if the battery leaked. Please do not ship or transport the housing if it may have water in it.

1. Upon recovery rinse the housing with fresh water and dry it off.
2. Wait for the housing to reach room temperature. If the housing is below room temperature when opened then water may condense on and damage the electronics.
3. Place the housing on a clean surface with the faceplate facing up.
4. Remove the six faceplate screws with 3/32" hex driver
5. Lift the faceplate off. A few drops of water may cling to the underside of the faceplate – take care not to let water drip into the electronics.
6. Gently wipe the o-ring groove and faceplate with a tissue to remove any water.
7. Remove the desiccant bag and set it aside. The desiccant cannot be reused unless properly recharged.

Sealing

NOTE: The faceplate screws are titanium for optimal corrosion resistance. Screws of any other material will rapidly fail due to galvanic corrosion.

1. Remove the o-ring and inspect for tears or any irregularity. Wipe it clean if necessary – make sure there are no hairs, sand, water or dirt on the o-ring or in the o-ring groove.
2. If the o-ring is new or feels dry then lubricate it with a small amount of Molykote M44.
3. Place the o-ring in the o-ring groove. Make sure it is installed uniformly and not twisted.
4. Place a new or recharged desiccant bag over the battery.
5. The outside surface of the faceplate is flat, the inside is milled to match the opening in the housing. Align the faceplate to match the opening in the housing and gently press it in place.
6. Install all six screws partially before tightening, then tighten each screw finger tight – just enough to fully close the gap between the faceplate and the housing. Do not overtighten.

Command Set

Commands

Commands are not case sensitive. All commands must end with a carriage return (CR, '\r') character (automatically generated by a terminal program when you press enter). If a line feed character follows (LF, '\n') it will be ignored.

Any arguments or parameters may be separated by either a space or an equals sign(=). Note that Enduro accepts '=' or a space, but not both.

Status Commands

GETCD

Displays sensor configuration.

```
S9>getcd
<Config type='Enduro-AT' sn='A00G' v='0'>
<Hardware>
  <Assembly>5010B</Assembly>
  <Firmware>ENDURO APT V0.74</Firmware>
</Hardware>
<Cal>
  acx=0
  acy=0
  acz=0
  asx=16384
  asy=16384
  asz=16384
  bcx=0
  bcy=0
  bcz=0
  bsx=16384
  bsy=16384
  bsz=16384
  c0=1.1934415e-03
  c1=2.8425242e-04
  c2=0.0000000e+00
  c3=0.0000000e+00
  r0=3.3000000e+03
  p0=0.0000000e+00
  p1=1.0000000e+00
</Cal>
<Settings>
  ID=0G
  GROUP=E
  stype=ATES
  period=1
  amode=2
  arate=4
```

```
  ascale=0
  mscale=0
  STARTED
</Settings></Config>

OK; 0 Events
S9>
```

GETSD

Displays sensor status. This includes the battery voltage, memory status and SD card status. It is common for the sensor to pause for a moment during the GETSD command while the SD card initializes (this pause does not interrupt sampling).

Warnings are displayed in the GETSD response if the memory card is not installed or cannot be written to. These warnings mean the sensor cannot save data to the memory card and data recording is limited to the 7 megabyte internal memory. These are the two warning messages:

No memory card installed:

```
S9>getsd
<Status type='Enduro-AT' sn='A00G' v='0'>
<DataBuffer>
  nextWrite=956323
  not saved=38819
  total=38819
</DataBuffer>
<SDHC_CARD>
  ***WARNING:  SDHC MEMORY CARD NOT INSTALLED!***
  lastSampleTime=2016-07-10T10:00:03
  Vbat=2.303
  Vtx=2.377
  TIME=2016-07-10T10:00:03
  STARTED
</Status>
```

Cannot write to memory card:

```
S9>getsd
<Status type='Enduro-AT' sn='A00G' v='0'>
<DataBuffer>
  nextWrite=988984
  not saved=71480
  total=71480
</DataBuffer>
<SDHC_CARD>
  SDHC card installed
  ***WARNING: 71480 DATA BYTES NOT SAVED TO CARD!***
  ***WARNING: 603 STATUS BYTES NOT SAVED TO CARD!***
  <File  Name='none'  Size='0' />
  <File  Name='none' Size='0' />
```

```
</SDHC_CARD>
  lastSampleTime=2016-07-10T10:09:37
  Vbat=3.607
  Vtx=3.057
  TIME=2016-07-10T10:09:37
  STARTED
</Status>
```

This is the GETSD response when the memory card is working properly:

```
S9>getsd
<Status type='Enduro-AT' sn='A00G' v='0'>
<DataBuffer>
  nextWrite=1002342
  not saved=2968
  total=84838
</DataBuffer>
<SDHC_CARD>
  SDHC card installed
  <File  Name='S9A00G.TXT'  Size='84.8KB' />
  <File  Name='S9A00GS.TXT' Size='903' />
</SDHC_CARD>
  lastSampleTime=2016-07-10T10:16:18
  Vbat=3.604
  Vtx=3.057
  TIME=2016-07-10T10:16:18
  STARTED
</Status>
```

GETEC

Displays event counters. Event counters are a useful debugging tool for S9. Most events to not indicate a problem. If you are concerned about events recorded on your modem please feel free to forward the GETEC response to S9.

```
S9>getec
<EventData>
numEvents = 0
</EventData>
```

In the example above the event was Usart2.c, line 66. This means a framing error on the RS232 serial port input.

VER

Displays sensor hardware and firmware version.

```
S9>ver
HTYPE 5010B
CD AB0B0AE0, 12000002
```

```
CODE TYPE ENDURO
FIRM ENDURO APT V0.74
CDATE Jul 12 2016 23:01:08
```

Configuration Commands

Refer to Configuration Settings for a full list of settings.

ERASE CONFIG

This command resets all configuration settings to default values, but does not change calibration coefficients. Note the default ID setting is the last two digits of the serial number. Default settings from the GETCD response are listed here:

```
S9>getcd
<Config type='Enduro-AT' sn='A00G' v='0'>
…
<Settings>
  ID=0G
  GROUP=E
  stype=ATE
  period=60
  amode=2
  arate=4
  ascale=0
  mscale=0
  STOPPED
</Settings></Config>
```

TIME

The TIME command both sets and displays Enduro's current time. To display the time just enter the time command by itself:

```
S>time
time=2013-11-05T01:24:47
OK - 0 Events
```

To set the time include the current time in IS0-9601 format with no time zone. Multiple time formats are allowed:

```
time=2015-11-05T14:24:47
time 2015-11-05T14:24:47  (the = is optional)
time=20151105T142447
```

Note that Enduro accepts '=' or a space, but not both.
When the time is accepted the reply looks like this:

```
S9>time 2016-07-21T112000
Time changed to 2016-07-21T11:20:00
```

```
OK; 0 Events
```

FORMAT

The FORMAT command both displays and sets the data recording format. To display the current format enter the command by itself:

To change the format, use the command followed by any combination of the letters A, T, P, E and S (with no spaces).

A – Accelerometer
T – Temperature
P – Pressure
E – Engineering unit conversion. Saves temperature in degrees C, pressure in decibars and tilt in degrees from vertical.
S – Seconds since year 2000 time format (SY2K). Default is ISO-9601 format if the S is not included.

If you omit A, T or P from the sample format then the omitted sensors will not be sampled. This may be desired to save power.

Examples

Acceleration, temperature, engineering units and time in seconds since year 2000:

```
OK; 0 Events
S9>format
stype=ATE
TIME (ISO),TEMP (C), ,TILT (deg), THERM RAW, ,AX, AY, AZ
OK; 0 Events

S9>format ates
```

STYPE means sample type. This is a sample in format 'ATE':

```
2016-07-21T11:22:57,29.7038,,87.3609,0.5045745,,,-6660,76,307
```

Utility Commands

PWROFF or SLEEP

Returns the sensor to low-power sleep mode. This command is not allowed when the USB interface is active.

RESET

Forces a full reset (like a reboot). This forces sensor to return to low-power sleep mode, abandoning all in-process activity. When sending this command over USB you must disconnect the USB cable and close the terminal program, then reconnect the cable and open the terminal program.

RESETEC

Resets the event counters.

File Commands

The sensor has several files in RAM, flash memory and the SDHC memory card. Files are identified by one or more letters (F, S, D, ST, STR, SD).

Available Files

F File

The F file is used for scripts – most importantly firmware update scripts. Firmware update files are streamed to the F file, then the file is run with the RUN F command. The F file can may also be used for custom scripts where each line of the file is a modem command. Note that some commands cannot be used in scripts – check the 'blocks' section of the command table.

D File

The D file is a 7 Mbyte circular buffer for ASCII data. This file is too large to read over inductive modem, but it can be read in the USB interface. Data in the D file is periodically copied to the SDHC memory card.

S File

The S file is a short RAM buffer of recent samples, typically less than 2KB. This is the only data buffer readable through the inductive modem. Note that the GETSD command clears the S buffer, and the S buffer is automatically cleared periodically when Enduro transfers data to the D file in flash memory.

STR File

The STR file is a short status log file stored in RAM. This log includes power cycling, time changes and notes of any hardware or firmware events. It is readable through the inductive modem. Note that the GETSD command clears the STR buffer, and the STR buffer is automatically cleared periodically when Enduro transfers data to the ST file in flash memory.

ST File

The ST file is a circular status log file in flash memory. It is too large to read through the inductive modem. Data in the ST file is periodically copied to the SDHC memory card.

SD File

This is the data file on the SDHC memory card. This file is too large to read through the inductive modem, and may take tens of minutes to read through USB.

WRITE

Writes data to a file. Not all files support this command.

READ

Retrieves data from a file

ERASE

Erases a file.

RUN

Runs a script file. Only allowed with the F file.

DUMPFLASH

A utility command to retrieve the entire contents of flash memory. This allows significant data recovery if the D file is accidentally erased. This command takes about ten minutes to run.

(Not including calibration setting commands)

Command	Blocks	Parameters	Description
GETCD			Displays configuration settings
GETSD			Displays status data
GETEC			Displays event counters
VER			Displays hardware and firmware version
ERASE CONFIG			Resets all configuration to default values, does not change calibration values
PERIOD		1-3600	Sets the sample period in seconds
FORMAT		A,P,T,E and / or S	Displays or sets the data recording format
TS			Take sample, do not record the sample **TSC command is preferred for new applications!**
TSS			Take sample and store **TSSC command is preferred for new applications!**
TSC			Take sample, do not record the sample, include checksum
TSSC			Take sample and store, include checksum
GL GETLAST			Gets the last sample (if there is one) **GLC command is preferred for new applications!**
GLC			Gets the last sample (if there is one), includes checksum
START			Starts logging
STOP			Stops logging
TIME			Sets or reads the time

TXTEST			Transmits a test pattern for IM communications testing
PWROFF			Same as SLEEP. Terminates active mode (IM Service or Host Service)
SLEEP			Same as PWROFF. Terminates active mode (IM Service or Host Service)
RESETEC			Resets (clears) the event counters
RESET			Resets the modem – ending all processes and forcing return to sleep mode.
WRITE	FILE	F, D	Writes to a file.
READ	FILE IM*	F, D, S, ST, STR, SD	Reads a file. *READ S and READ STR are allowed on IM interface. READ D, READ F, READ ST and READ SD are allowed only on USB interface.
ERASE	FILE	F, D, MEM	Erases a file (ERASE MEM clears all files except those on the SDHC memory card)
RUN	FILE	F	Runs a file as a script. RUN F runs F file as a simple command script. RUN A runs the A file as a data collection script.
DUMPFLASH	FILE IM		Outputs the entire contents of the flash memory. May take 10 minutes to complete.
MODEM OFF	IM		Disables the inductive modem completely. This is recommended for logging applications where the inductive modem will not be used. **Must be entered through USB, can only be reversed through USB**
MODEM ON			Enables the inductive modem
TMODE		1-2	Temperature resolution mode: 1 is 0.001 C resolution (saves power) 2 is 0.0001 C resolution (maximum)
PMODE			Pressure mode – reserved for future use
AMODE			Accelerometer mode - reserved for future use
ARATE		1-50	Accelerometer sample rate – reserved for future use
ASCALE		0-3	Sets full scale range of the accelerometer (in g- for gravity) 2g,4g,6g,8g
MSCALE		0-3	Sets full scale range of the magnetometer (in gauss) 2g, 4g, 8g, or 12g

Configuration Settings

Note the name of each configuration setting is also a command to modify that setting. Use a space or = between the command and parameter value:

```
ID 01
```

and

```
ID=01
```

Are both acceptable.

Command	Parameter default value in ()	Description
ID	00-ZZ (01) Always two alphanumeric digits.	Modem ID for IM network.
GROUP	0-9; A-Z (E)	Group address for IM network.
PERIOD	1-3600	Sets the sample period in seconds
FORMAT	A,P,T,E and / or S	Displays or sets the data recording format
AMODE		Accelerometer mode - reserved for future use
ARATE	1-50	Accelerometer sample rate – reserved for future use
ASCALE	0-3	Sets full scale range of the accelerometer (in g- for gravity) 0=+/- 2g 1=+/- 4g 2=+/- 6g 3=+/- 8g
MSCALE	0-3	Sets full scale range of the magnetometer (in gauss) 0=+/- 2g 1=+/- 4g 2=+/- 8g 3=+/- 12g

Calibration Settings

Note the name of each calibration setting is also a command to modify that setting. Use a space or = between the command and parameter value:

```
ASX 0
```

and

```
ASX=0
```

Are both acceptable.

Setting	Range	Description
C0	-1 to 1	Temperature coefficient 0
C1	-1 to 1	Temperature coefficient 1
C2	-1 to 1	Temperature coefficient 2
C3	-1 to 1	Temperature coefficient 3
P0	-30 to 30	Pressure coefficient 0 (offset)
P1	0 to 5	Pressure coefficient 1 (scale)
ACX	-500 to 500	Accelerometer X offset
ACY	-500 to 500	Accelerometer Y offset
ACZ	-500 to 500	Accelerometer Z offset
ASX	14000 to 18000	Accelerometer X offset
ASY	14000 to 18000	Accelerometer Y scale

ASZ	14000 to 18000	Accelerometer Z scale
BCX	-500 to 500	Magnetometer X offset
BCY	-500 to 500	Magnetometer Y offset
BCZ	-500 to 500	Magnetometer Z offset
BSX	14000 to 18000	Magnetometer X offset
BSY	14000 to 18000	Magnetometer Y scale
BSZ	14000 to 18000	Magnetometer Z scale

Temperature Resolution Control

The TMODE command sets the temperature resolution. Higher resolution requires more time to take a measurement and consumes more power. TMODE=1 provides 0.001C resolution, which is appropriate for most applications and minimizes power consumption. TMODE=2 provides the maximum resolution (0.0001C), but consumes more power.

Note the AMODE and PMODE commands are reserved for similar features with the accelerometer and pressure sensor. These may include burst sampling modes.

Retrieving Data with Checksums

Several commands return data with checksums. These commands should be used whenever possible instead of the similar commands without checksums. The checksums should be verified whenever possible to prevent single-bit communication errors from contaminating sensor data.

The checksum is a CRC7. Example code is included below (CRC7 Checksum Code). The checksum includes all bytes from the start of the line up to but not including the *.

Examples:

```
S9>tsc
A01A,ATPE,2000-01-01T00:58:10,26.7679,-0.4065,54.7356,0.5653392,-0.4064664,19607,-19607,-19607*79
OK; 0 Events
S9>tssc
A01A,ATPE,2000-01-01T00:58:16,26.7588,-0.4072,54.7356,0.5655401,-0.4071817,19607,-19607,-19607*5E
OK; 0 Events
S9>glc
A01A,ATPE,2000-01-01T00:58:16,26.7588,-0.4072,54.7356,0.5655401,-0.4071817,19607,-19607,-19607*5E
OK; 0 Events
S9>
```

Using *SAMPLE

The Enduro – Ultimodem combination allows sampling all Enduro sensors on a mooring with a single command (*SAMPLE). Note *SAMPLE is an Ultimodem command, not an Enduro command.

The Ultimodem *SAMPLE command tells all Enduro sensors on the line to immediately take a sample. These samples will be synchronized in time to within a few milliseconds. Each endure then waits for an opportunity to transmit the sample.

The *SAMPLE system relies on the Enduro's ability to detect when other devices transmitting. This may be interfered with by mechanical or electrical noise on the mooring. Such interference may result in one or more sensors not responding.

If a sensor did not respond, it is very likely it did take a synchronized sample but did not detect an opportunity to transmit. In this case it may be polled individually with the GLC command.

Example:

```
PWRUP
S9>fcl
OK; 2 Events
S9>*sample

AT:A008,ATES,297,28.5816,,90.0000,0.5268511,,-6826,118,0*46*39535,32*
AT:A01H,ATES,186,22.8815,,89.4202,0.6660873,,-988,-16,-10*4E*40216,32*
AT:A021,ATES,192,27.2567,,89.1177,0.5546510,,-6623,-34,102*73*40720,32*
AT:A022,ATES,310,22.3738,,89.0272,0.6730605,,-6478,7,110*14*40126,32*
AT:A01T,ATPES,188,22.7412,,88.4345,0.6631864,,-6842,31,187*49*40287,32*

OK; 2 Events
S9>
```

CRC7 Checksum Code

This code calculates a CRC7 checksum. This is provided as-is with no warrantee for the free use of S9 customers and integrators.

```
const uint8_t crc7Table[256] = {
0x00, 0x09, 0x12, 0x1b, 0x24, 0x2d, 0x36, 0x3f,
0x48, 0x41, 0x5a, 0x53, 0x6c, 0x65, 0x7e, 0x77,
0x19, 0x10, 0x0b, 0x02, 0x3d, 0x34, 0x2f, 0x26,
0x51, 0x58, 0x43, 0x4a, 0x75, 0x7c, 0x67, 0x6e,
0x32, 0x3b, 0x20, 0x29, 0x16, 0x1f, 0x04, 0x0d,
0x7a, 0x73, 0x68, 0x61, 0x5e, 0x57, 0x4c, 0x45,
0x2b, 0x22, 0x39, 0x30, 0x0f, 0x06, 0x1d, 0x14,
0x63, 0x6a, 0x71, 0x78, 0x47, 0x4e, 0x55, 0x5c,
0x64, 0x6d, 0x76, 0x7f, 0x40, 0x49, 0x52, 0x5b,
0x2c, 0x25, 0x3e, 0x37, 0x08, 0x01, 0x1a, 0x13,
0x7d, 0x74, 0x6f, 0x66, 0x59, 0x50, 0x4b, 0x42,
0x35, 0x3c, 0x27, 0x2e, 0x11, 0x18, 0x03, 0x0a,
0x56, 0x5f, 0x44, 0x4d, 0x72, 0x7b, 0x60, 0x69,
0x1e, 0x17, 0x0c, 0x05, 0x3a, 0x33, 0x28, 0x21,
0x4f, 0x46, 0x5d, 0x54, 0x6b, 0x62, 0x79, 0x70,
0x07, 0x0e, 0x15, 0x1c, 0x23, 0x2a, 0x31, 0x38,
0x41, 0x48, 0x53, 0x5a, 0x65, 0x6c, 0x77, 0x7e,
0x09, 0x00, 0x1b, 0x12, 0x2d, 0x24, 0x3f, 0x36,
0x58, 0x51, 0x4a, 0x43, 0x7c, 0x75, 0x6e, 0x67,
0x10, 0x19, 0x02, 0x0b, 0x34, 0x3d, 0x26, 0x2f,
0x73, 0x7a, 0x61, 0x68, 0x57, 0x5e, 0x45, 0x4c,
0x3b, 0x32, 0x29, 0x20, 0x1f, 0x16, 0x0d, 0x04,
0x6a, 0x63, 0x78, 0x71, 0x4e, 0x47, 0x5c, 0x55,
0x22, 0x2b, 0x30, 0x39, 0x06, 0x0f, 0x14, 0x1d,
0x25, 0x2c, 0x37, 0x3e, 0x01, 0x08, 0x13, 0x1a,
0x6d, 0x64, 0x7f, 0x76, 0x49, 0x40, 0x5b, 0x52,
```

```
0x3c, 0x35, 0x2e, 0x27, 0x18, 0x11, 0x0a, 0x03,
0x74, 0x7d, 0x66, 0x6f, 0x50, 0x59, 0x42, 0x4b,
0x17, 0x1e, 0x05, 0x0c, 0x33, 0x3a, 0x21, 0x28,
0x5f, 0x56, 0x4d, 0x44, 0x7b, 0x72, 0x69, 0x60,
0x0e, 0x07, 0x1c, 0x15, 0x2a, 0x23, 0x38, 0x31,
0x46, 0x4f, 0x54, 0x5d, 0x62, 0x6b, 0x70, 0x79
};

/**
 * calculate CRC7
 */
uint8_t crc7Calc(char *data, uint8_t len){
    uint32_t i;
    uint8_t crc = 0;

    for (i = 0; i<len; i++) {
        crc = crc7Table[(crc << 1) ^ data[i]];
    }

    return crc;
}
```

Hardware

Size: 200 mm x 35 mm x 40 mm

Materals: PET & Titanium

Depth Rating: 1,000 meters

Mass: 308 grams

The Enduro assembled on a mooring cable is nearly concentric and will fit through a 5 cm diameter opening.

Serviceable Parts

Battery

Enduro uses a single AA 3.6V lithium battery. Saft LS14500 or equivalent. The LS14500 is rated 2.6 amp-hours, we usually de-rate to 2.0 amp hours to account for self-discharge and temperature effects.

O-Ring

Enduro uses an x-profile double-sealing o-ring. They are available from Soundnine or McMaster-Carr. We recommend Molykote M44 lubricant on the o-ring. Excess lubricant is not desirable, use just enough to wet the surface of the o-ring on all sides.

Faceplate Screws

The faceplate and screws are titanium. Replacement screws must be titanium – use of other materials will cause significant galvanic corrosion. Replacement screws are available Soundnine or McMaster-Carr.

Faceplate

Replacement faceplates are available from Soundnine. The faceplate should be replaced if accidentally bent, scratched on the o-ring sealing surface or otherwise damaged.

Desiccant

The desiccant package should be replaced every time the housing is opened. Replacement desiccant is available from Soundnine or McMaster-Carr.

Coupler Clamp

The coupler clamp assembly both clamps the Enduro to the mooring line and clamps the ferrite toroid half of the IM coupler in position. This clamp must be fully closed to guarantee reliable communications. There should be no gap between the coupler clamp and the Enduro housing.

The coupler clamp size must match the outer diameter of the mooring cable. Coupler clamps are available in a variety of sizes, please specify your cable outer diameter and if that diameter is a measured value or a nominal value when ordering.

Replacement Parts List

Item	Description	Soundnine Part Number	McMaster-Carr Part Number
O-ring	Double-Seal X-Profile O-Ring, Buna-N, Number 032	202CA	90025K426
Desiccant	0.6”x1.1” silica gel	2039E	2189K12
Faceplate screws (standard)	4-40 x 1/4” titanium socket head cap screw	20584	95435A338
Faceplate screws (long)	4-40 x 3/8” titanium socket head cap screw	20586	95435A350
Coupler Clamp Screws	M4-18mm Socket head cap screw, 316 stainless steel	2040A	92290A161
Coupler Clamp Screw Retainer o-ring	O-Ring, Buna-N, 1MM wide, 3MM ID,	2041F	9262K441
Faceplate	Custom machined titanium	50035	
Coupler Clamp	Custom polyester and ferrite assembly	50031 **Specify cable diameter when ordering**	

Firmware Updates

Firmware update files are text files with firmware encoded in ASCII hex. They are sent to the modem through the RS232 serial connection. Follow these steps to perform a firmware update:

1) Connect the USB cable
2) Open a terminal program (we prefer TeraTerm) and select the appropriate COM port
3) Set the port flow control to Xon/Xoff or 'SOFTWARE HANDSHAKING' (under Setup->Serial Port in TeraTerm)[1].
4) Press enter to get a S9> prompt from the sensor.
5) Type the VER command to check the current firmware version of your sensor
6) Send the firmware update file to the sensor. (no encoding – in TeraTerm use File->Send File)
7) Wait for the file transmission to finish.
8) Enter the RUN F command to initiate parsing, integrity checking and device type verification. This may take 10 to 15 seconds. If the file is OK the sensor will respond with:
   `Confirmed - ready to program`
9) Enter the PROGRAM command to start the firmware update. The firmware update takes only a few seconds. Do not disconnect the battery or USB cable within 10 seconds of sending the PROGRAM command, doing so may corrupt the firmware and disable the controller.
10) After the firmware update completes the sensor will be in sleep mode and the USB connection needs a full reset. Close the terminal program and disconnect the USB cable.
11) Reconnect the USB cable.
12) Open the terminal program and select the appropriate COM port.
13) Press a key to wake the sensor and use the VER command to verify the new firmware version.

[1] Xon/Xoff handshaking is not required for Enduro, but is included in these instructions for consistency with other S9 products where it is required.

Ultibuoy Testing Notes

rev 2019-12-22

1 Table of Contents

2 Summary

Each of the steps below is described in detail in this document.

1. Remove controller from buoy (4 screws)
2. Open controller housing (10 screws)
3. Install 4 batteries
4. Verify controller power-up
5. Insert desiccant package
6. Seal housing
7. Close inductive loop
8. Connect test cable and verify inductive loop
9. Remove test cable and connect inductive coupler

2.1 Tools and Supplies Required

- 18650 size rechargeable lithium ion batteries, 4 per controller
- New desiccant packets, about 3 grams silica gel. No larger than 40mm x 40mm. These absorb atmospheric moisture in less than 30 minutes – they must be kept sealed.
- Small cordless drill with adjustable torque.
- 3mm hex driver for drill. This is for hardware connecting controllers to buoys and sealing controller presure housings.
- Small neodymium magnet; about 8mm x 8mm x 3mm is good, but size is not important.

2.2 Removing Controller from Buoy

The controller attaches to the buoy with four M4 screws (circled in the picture below). These screws have a 3mm hex head. Each screw has a serrated washer – these washers keep the screw from vibrating loose when deployed, they are required.

2.2.1 Please Protect the Controller Connector

There is a M12 connector on the back side of the controller. This connects to the test cable during testing and to the inductive coupler while deployed. The controllers were shipped with a protective cap covering this connector. Please take care to replace this cap – the plastic face of the connector can be damaged by rough surfaces. If the connector face is damaged the connector may leak while deployed and disconnect from the inductive coupler.

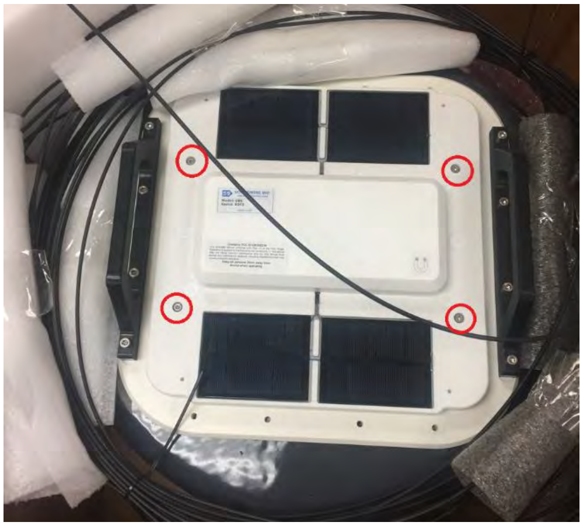


Figure 1: Controller Attachment to Buoy

2.3 Opening Controller Housing

The electronics inside the controller housing are sensitive to dirt and moisture. The housing should be opened in a clean and dry environment. If the controller is colder than the room where it will be opened please allow the controller to warmup before opening to prevent condensation from forming on the electronics.

2.3.1 Protect Connector Wires on Back Panel

Please take care when opening the housing – there are short wires connecting the removable back panel to the electronics inside. The wires are just long enough to flip the panel over and set it aside for battery installation.   If required these wires have connectors and may be removed, but they may be glued in place with a rubbery adhesive.

2.3.2 Protect Controller Back Panel O-Ring and Surfaces

The controller back panel seals to the controller body with a large o-ring. When removing the back panel the o-ring may move or fall out. This o-ring must be protected from scratches and contamination, especially dust, dirt, or hair.

The surfaces this o-ring seals against must not be contaminated or scratched – otherwise the o-ring will not seal properly and the controller housing will fill with water. The red line in the image below highlights the o-ring sealing area. Any mechanical damage to the recessed area around this red area may cause a failed seal.

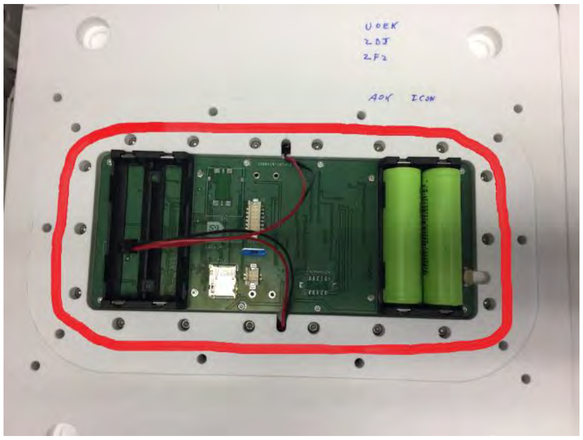


Figure 2 Controller O-Ring Sealing Surface

The controller housing seal uses ten M4x35mm screws on the back side of the controller, opposite the solar panels. These screws are circled in the image below. They have a 3mm hex head. After removing these screws the controller back panel will pull off easily. There may be a slight pressure seal if the controller is opened in a cold environment.

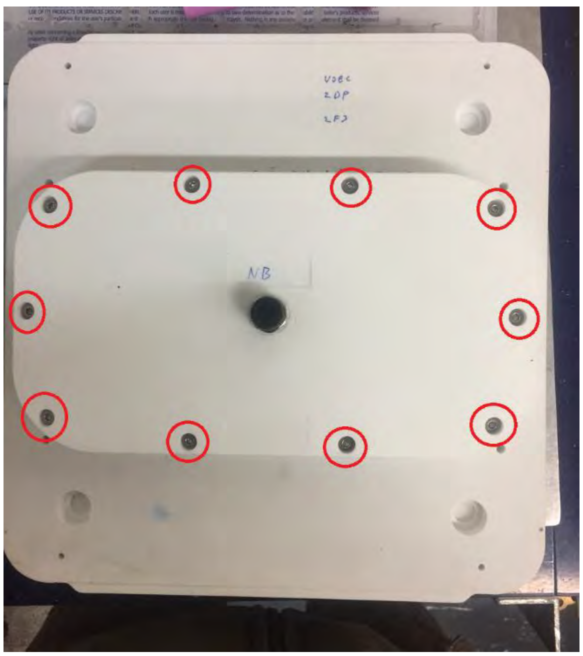


Figure 3 Controller Housing Screws

2.4 Installing Batteries

Please make sure the batteries are fully charged before installation, especially before deployment. This ensures the best possible performance of the system. Each controller requires four batteries. Samsung INR18650-35E batteries are a good choice. The controller maximum short-term current draw is less than 750mA per battery. Maximum current draw over several seconds is only 400mA.

Please remove the serial test cable when installing batteries. The RS232 serial connection may provide enough power to activate protection devices on the CPU and prevent a clean start up with battery power.

The battery holders are marked with + and – symbols. These markings are molded into the black battery holder and are slightly hard to see. Inserting the batteries backward may damage the solar charging system. Battery polarities alternate in the holders – the batteries will not all be aligned the same direction.

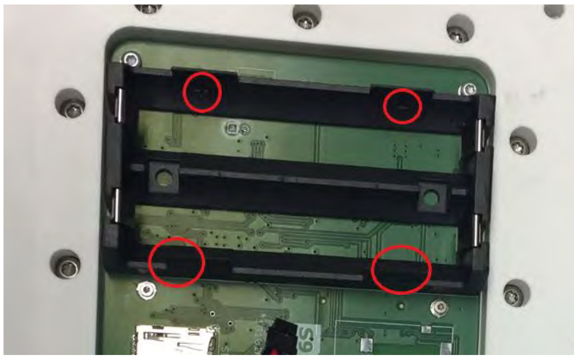


Figure 4 Controller Battery Polarity Marking

2.5 Verifying Controller Power-Up

It is important to verify proper power-up after inserting batteries. It is possible for the power and clock system of the CPU to fail on startup if the battery contacts bounce slightly when connected. Once the controller successfully powers up after battery replacement the CPU will be stable until after the batteries are too depleted to transmit.

There are two ways to test power-up:

a) With the serial test cable: press enter a few times. The S9> prompt should appear. Use the SLEEP command to put the controller in low power mode before disconnecting the cable.
b) With a magnet: place a magnet over the magnet image on the controller top cover. Hold the magnet still for about one second and the lights should flash. This starts the controller sampling – perform the same action with the magnet to stop the controller.

If the controller fails to respond to either test:

a) Remove the batteries
b) Disconnect the serial cable

It may also be necessary to disconnect the 4-pin solar power connector to fully power down the controller before reconnecting the batteries.

2.6 SIM Card Installation

The controller requires a standard SIM card (15 x 25mm). If your cellular service provider does not have this SIM card size available there are adapters available at most wireless stores.

Installing the SIM card requires opening the controller housing. Please refer to the other sections of this document to open and close the housing.

The SIM Card holder is a small metal piece above the S9 logo on the controller circuit board. The holder has a small door-like flap. There is a marking on the metal with arrows. Press a finger against the holder and slide up gently to unlock the door. Insert the SIM card, close the door, and slide down gently to lock the door. Refer to the images below.

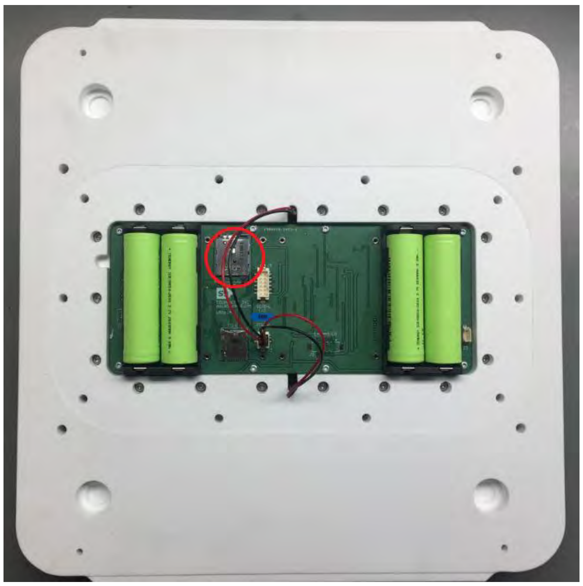


Figure 5: Sim Card Holder Location

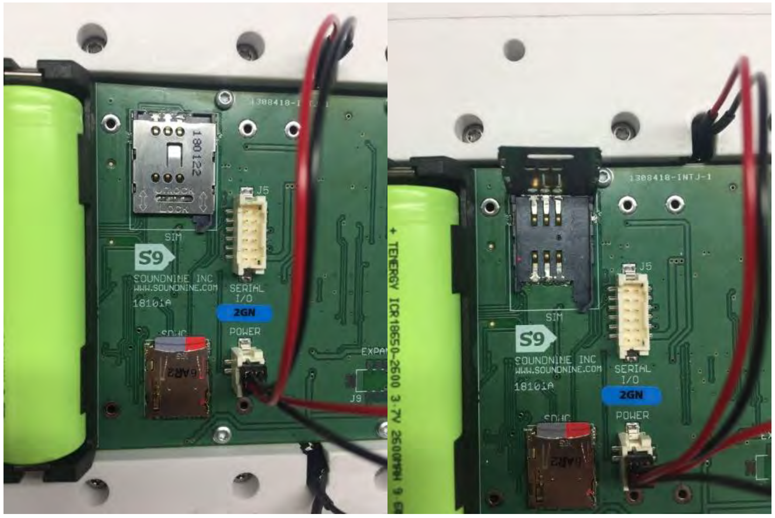


Figure 6: SIM Card Holder Door Closed and Open

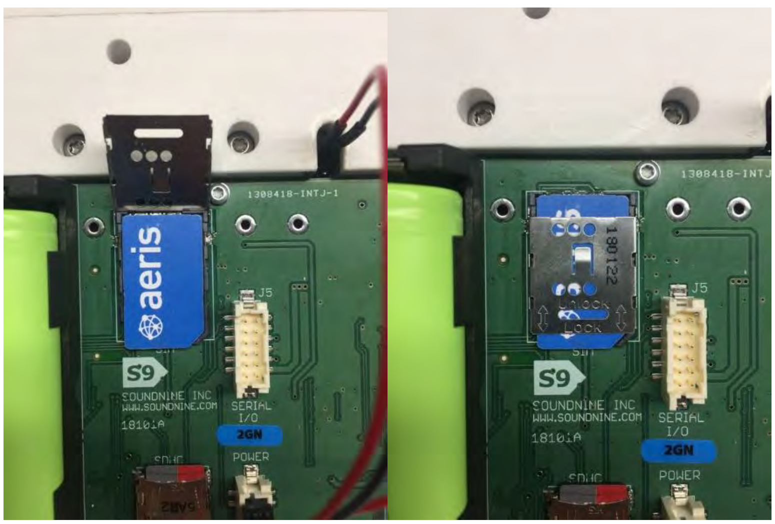


Figure 7: SIM Card Installed and Closed

2.7 Setting APN

The APN setting must match the requirements of your cellular service proivider. When possible S9 will pre-configure this setting. If it must be changed use the serial cable and terminal program to communicate with the controller. Serial communication is 115200 baud, 8 bits, no parity, 1 stop bit, XON/XOFF flow control. Refer to section 2.11 for more information about serial communications. Use the APN command as follows:

APN “your setting”

The GETCD command will show the current APN setting.

There may also be APN USER and APN PASSWORD settings. Most providers leave these blank. If your provider requires settings for these please contact S9; we do support these settings, but a minor firmware change may be required.

2.8 Desiccant Package Installation

A fresh desiccant package is important to prevent condensation in the pressure housing during test and deployment. If possible please install the desiccant in a warm and dry environment.

A 3 gram silica gel desiccant package is appropriate for the controller pressure housing. The desiccant bag can be taped to the PCB between the batteries or to the inside of the controller back cover between the batteries.

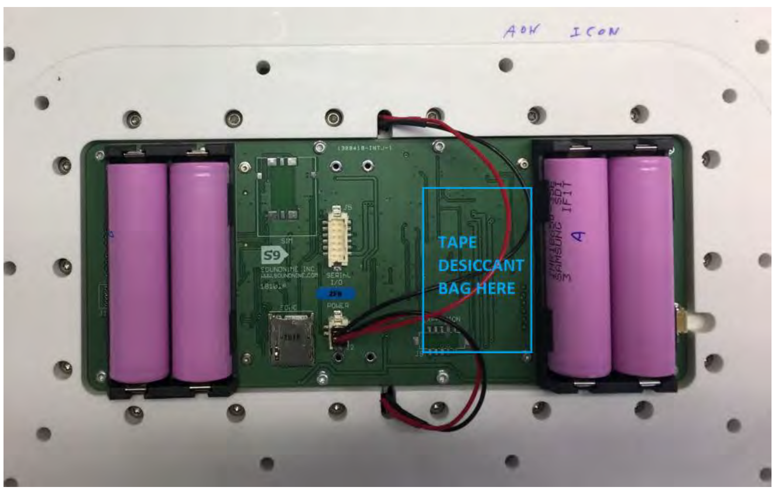


Figure 8 Controller Desiccant Bag Location

2.9 Sealing the Controller Housing

Seal the controller housing before testing or deploying in any damp environment. Before sealing plase inspect the o-ring and o-ring sealing surface for contamination – any dirt or hair may prevent a good seal. There are two important concerns when closing the housing:

1) Make sure the o-ring is clean and properly positioned in the o-ring groove. Molykote M44 lubricant may be used on this o-ring, sometimes the lubricant helps hold the o-ring in place when sealing.
2) Make sure the wires are properly connected to the PCB and are above the surface of the PCB and the batteries. It is possible to pinch the wires between the controller back cover and the controller body – this will damage the wires and prevent a proper seal. If necessary the wires can be taped to the PCB to avoid this issue.

- Close the controller back cover with the controller lying on soft foam with solar panels face down.

- Lower the back cover into place while watching the o-ring and wires from the side.
- After the back cover is in position check for any gaps between the back cover and the controller body – gaps may indicate pinched wires or badly aligned o-ring.
- If there are no gaps put all ten screws in place without tightening
- Tighten three or four screws about half-way, then tighten all screws with a small cordless drill set to the second lowest torque setting.

2.10 Closing the Inductive Loop

The inductive sensors do not respond unless the drifter cable forms a closed loop including both the sensors and the inductive coupler. The inductive coupler is in a tube in the middle of the buoy under the controller. It connects to the controller with a green plastic M12 connector.

When the buoy is in water the seawater closes the loop between the bottom of the cable and to top of the cable and buoy frame. On land this connection must be made manually. The easiest way to do this is to use a magnet to hold the bottom cable eye to any part of exposed metal on the buoy. In this case the purpose of the magnet is to make an electrical connection, using the fact that these components will stick to magnets. A silver colored neodymium magnet will work. A dark colored ceramic magnet or an epoxy coated magnet will not work here.

It is possible the connection of the cable to the frame may move slightly during shipping – this would prevent the inductive loop from closing on land, but not in the water. if the technique described above does not close the inductive loop the sensors will not respond. In this case connect the bottom of the cable to any exposed wire rope visible in the tube in the center of the buoy hull.

Figure 9 Closing Inductive Loop on Land

2.11 Connecting Test Cable and Testing Inductive Loop

For deployment connect the inductive coupler (4-pin M12 female) to the controller connector (5-pin M12 male). These connectors are compatible even though the coupler does not have the 5th pin in the center.

For testing the test cable connects between the controller and the inductive coupler.

The test cable connects a DB9 RS232 connector to a yellow cable section with five-pin female M12 connector and a black cable section with a green four-pin male M12 connector.

Table 1 Test Cable Connections

Female DB9 RS232 connector	Connect to PC serial port 115200 baud, 8,N,1
Stainless steel female 5-pin M12 connector	Connect to controller
Green male 4-pin M12 connector	Connect to inductive coupler on buoy

After connecting the test cable open a terminal program (115200 baud, 8-bits, no parity, 1 stop bit, xon/xoff flow control) to talk to the controller.

1) Use OPEN IM command to start a pass-through to the inductive modem built into the controller. Press enter a few times to get a S9> prompt from the modem. Use the escape key to exit this pass through at any time. Use the VER command to verify connection to the modem.
2) At the modem S9> prompt use the XT2 command to retrieve data from the sensors. This should take fewer than five seconds.

2.11.1 Example Sensor Data Retrieval

```
S9>OPEN IM
PASS THROUGH MODE
PRESS ESCAPE TO EXIT

PWRUP
S9>VER

HTYPE 5011M.1
CD AB0B0AE0, 12000002
CODE TYPE ULTI A
CV 6.3
FIRM ULTIMODEM V0.98K
CDATE Dec 11 2019 06:46:15

OK; 2 Events

S9>XT2
...
#X1:055:1:13.2374,2774.186,0.000,6.393,1.530,7,-56.964,1.004,-
12.7,1D5,77,0,4:987E*42174,32*175
#X1:042:2:13.5331,2581.107,0.000,8.041,1.539,7,87.062,1.006,-
16.3,1AE,67,0,2:5CE4*41571,32*168
#X1:037:3:13.7600,2707.823,0.000,9.289,1.530,7,-88.557,0.998,-
13.4,1B0,67,0,2:E8E3*41098,32*179
#X1:059:4:13.6427,2783.985,0.000,7.638,1.537,7,-88.280,0.992,-
13.3,1AD,67,0,2:8CE1*42405,32*179
#X1:03N:5:13.8382,2821.230,0.000,7.948,1.535,7,88.048,0.996,-
13.3,1B1,68,0,1:4DBA*42563,32*176
#X1:056:6:13.3946,2801.991,0.000,9.074,1.536,13,-85.020,0.991,-
14.1,1BD,63,0,1:7DCF*41080,32*177
#X1:054:7:13.6489,2961.799,0.000,10.172,1.543,8,85.609,1.008,-
17.7,197,4E,0,0: 326*40460,32*175
#X1:051:8:13.6160,2729.383,0.000,9.510,1.532,8,-89.043,0.998,-
13.6,1F2,5E,0,0:318F*41448,32*175
#T2:07D:9:12.9426,2818.536,287741.00,44.31,26,0.000,6.253,1.630,49,-
1.927,1.003,-14.3,7CB,77B,0,6:4BE3*40932,32*221
#T2:07U:11:10.6839,3098.313,288557.66,29.40,26,0.000,8.509,1.619,25,0.
627,1.002,-14.8,81A,791,0,F:A4BD*41664,32*218


OK; 2 Events

S9>
```

2.11.2 Failed Sensor Data Retrieval

If the inductive loop isn't closed the XT2 command will show no data, like this:

```
S9>XT2
...

OK; 2 Events

S9>
```

2.12 Starting and Stopping Controller with Magnetic Switch

The controller can be started or stopped without opening the pressure housing by holding a magnet against the magnet image on the top of the controller. The magnet must be still for about one second. The controller signals status with a red LED and a green LED, both visible through the top cover near the magnetic sensor.

When the controller detects the magnet it lights both red and green LED's at the same time for one second to signal magnet detection. Then the controller turns both LED's off for half a second and flashes twice with green to signal START or red to signal STOP. Finally the controller signals status OK with a one-second green flash or an error by one or more ¼ second red flashes followed by a one second red flash.

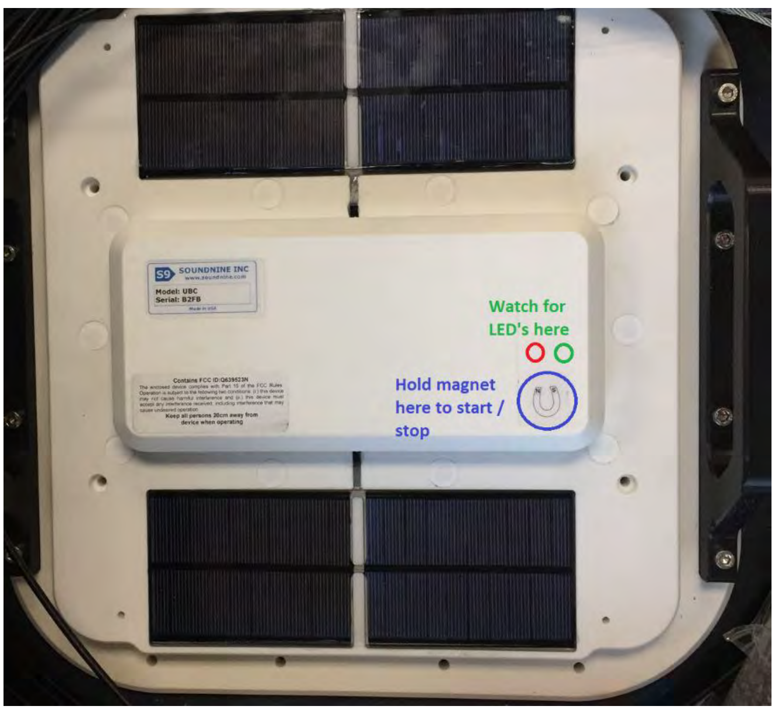
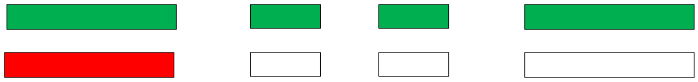
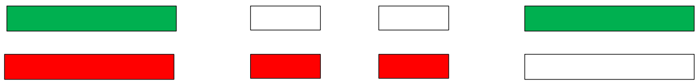


Figure 10 Magnetic Switch and LED locations

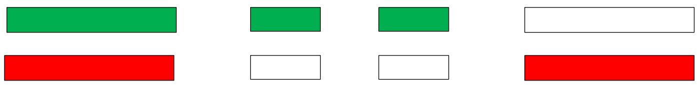
Controller Started, OK:



Controller Stopped, OK:



Controller Started, Error or Low Battery:



SOUNDNINE INC
Helping build successful monitoring systems

Ultibuoy Controller V1 Operating Manual

Soundnine Inc Document #R0116
rev 2019-05-28

1 Table of Contents

1.1 Quick Start

The controller usually ships sealed with new batteries, desiccant and SDHC memory card. In some cases it may be necessary to ship controllers without batteries. If your shipping documents specify 'no batteries' please follow the instructions below – otherwise skip to the next section.

Figure 1: RS232 Serial Connection

****

1.1.1 Battery Installation

The controller requires high quality lithium rechargeable 18650 size batteries with low self-discharge and internal protection PCB's. We recommend Tenergy brand ICR18650-2600 batteries. Samsung and Panasonic also offer suitable batteries. Many other companies offer batteries which fit mechanically but have unacceptably low capacity or high self-discharge rates. Many of these companies outrageously overstate the capacity and performance of their batteries. We recommend using a well known and trusted brand.

1.1.2 Cellular SIM Card

If your controller contains a cellular modem and was delivered outside of the United States then a SIM card must be installed. Refer to 3.2:Cellular SIM Card to obtain and install a SIM card. Controllers delivered within the United States have a SIM card pre-installed.

This is the factory configuration:

- 60 minute sample period
- Logging not started
- Program A measures battery and internal humidity

1.1.3 With RS232 Interface

1. Connect the serial cable. In single-port controllers the serial connection is in the center, the modem coupler is to one side.
2. Open a terminal program and select the correct COM port. Set the baud rate to 115200, no parity, 1 stop bit, software flow control (xon/xoff).
3. Press enter a few times to get a S9 prompt from the controller.
4. Send the following commands:

Command	Action	Notes
period=60	Sets the sampling period in minutes (1 to 10080)	
time=2016-06-20T133000	Sets the time	
getsd	Displays status	verify the time was set properly and there are no warning messages
Getcd	Displays configuration	
Read A	Displays sample program A	
Run A	Take sample (runs program A)	
Read sdd	Retrieves data from the SD card data file	This might take a long time – the SD card can hold a lot of data!
Read sds	Retrieves data from the SD card status file	This might take a long time – the SD card can hold a lot of data!
start	Starts logging	

1.2 Data Recording

The controller records data in a text-based XML format. Data is first stored in a RAM buffer (the S file). This RAM buffer is periodically recorded to a circular FLASH memory buffer (the D file). This FLASH memory buffer is periodically recorded to the removable SDHC memory card. These multiple buffers allow fast, reliable low power operation.

While running a sample program the controller may write directly to the D file, skipping the S file. This means the READ S command may not display all data.

The READ SDD command is the best way to retrieve data without opening the housing.

1.2.1 Removing the SDHC Memory Card

Always press the button and wait for the green light to flash before removing the memory card. The yellow light will flash quickly while the controller transfers data. Three long yellow flashes indicate a problem writing to the memory card. One green flash means all data transferred and it is safe to remove the card.

1.2.2 Data Format

Data downloaded from the controller or stored on the SDHC memory card is in a text-based XML format, similar to the format used for the DANTE controller. Each sample is enclosed in a Sample tag and data recorded from each serial port (including the internal Ultimodem) are wrapped in one or more SampleData tags. Dante Vis software can parse these files into CSV format.

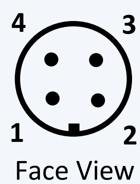
Depending on the sample program some data may not be recorded. The sample program can start and stop logging of data from any port at any time with the LOG command. Note that the DEBUGLEVEL setting overrides the sample program LOG command.

2 Connector Configurations

We offer controllers with several different connector configurations. Please identify the correct configuration for your controller before connecting any cables.

2.1 M12-4 Male RS232 Connectors

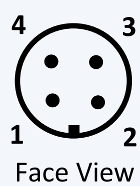
M12-4 Male RS-232
1 Common (Brown)
2 RS-232 Transmit Output (Blue)
3 RS-232 Receive Input (White)
4 Switched power + (Black)



Note the switched power output may be connected either to Vr or to V5, depending on the wiring of J5 of the controller. Vr is normally 12.0V and V5 is normally 5.0V, but both of these voltages can be customized in hardware for special applications.

2.2 M12-4 Male Solar Connectors

M12-4 Male Solar
1 NC (Brown)
2 NC (Blue)
3 Solar V+ (White)
4 Solar V- (Black)



Note the maximum allowable solar input voltage is 22.0V

2.3 Connector Configuration A

In Configuration A all connectors are accessible with the controller mounted on the buoy.
Left – RS232 Port A
Middle – Solar panel
Right RS232 Port B

3 Opening and Closing the Housing

3.1.1 Opening

NOTE: If there is any indication of water inside the pressure housing then handle it with caution! Rattling or sloshing inside the housing, hissing or other noises may indicate water intrusion in the housing. If there is any chance the housing might contain water then please wear safety glasses and chemical resistant gloves – there could be pressure inside the housing or hazardous chemicals if the batteries leaked. Please do not ship or transport the housing if it may have water in it.

1. Upon recovery rinse the housing with fresh water and dry it off.
2. Wait for the housing to reach room temperature. If the housing is below room temperature when opened then water may condense on and damage the electronics.
3. Place the housing on a soft clean surface with the connectors facing up and solar panels facing down
4. Remove the ten cover screws with 3mm hex driver
5. Lift the cover off. A few drops of water may cling to the underside of the cover – take care not to let water drip into the electronics.
6. Gently wipe the o-ring groove and cover with a tissue to remove any water.
7. Remove the desiccant bags and set them aside. The desiccant cannot be reused unless properly recharged (heat to 60C for three hours).

3.1.2 Sealing

1. Remove the o-ring and inspect for tears or any irregularity. Wipe it clean if necessary – make sure there are no hairs, sand, water or dirt on the o-ring or in the o-ring groove.
2. If the o-ring is new or feels dry then lubricate it with a small amount of Molykote M44.
3. Place the o-ring in the o-ring groove. Make sure it is installed uniformly and not twisted.

4. Place a new or recharged desiccant bag over the battery.
5. Align the cover to match the opening in the housing and gently press it in place so the mounting screw holes align.
6. Make sure the internal tooth star washer is in place on each screw.
7. Install all screws partially before tightening, then tighten each screw finger tight – just enough to fully close the gap between the cover and the housing. Do not overtighten.

3.2 Cellular SIM Card

If your controller contains a cellular mode and was delivered outside of the United States then a SIM card must be installed. SIM cards are available from local cellular service providers. Data-only SIM cards are appropriate for this controller. Some cellular providers offer multiple SIM card options for different cellular service classes (2G, 3G, LTE). Be sure the service class of your SIM card matches the capability of the modem in your controller.

The controller uses a 'Mini SIM', size code 2FF. The SIM interface supports both 1.8V and 3V SIM cards. The standard cellular modem (X3GA modem) uses 3G UMTS/HSPA with 2G GSM fallback. A 2G or 3G SIM card will work with this modem. If your cellular service provider requires an IMEI to register your SIM, you can try 357520073945178. If the specific IMEI of the modem is required refer to 3.2.3:Reading the Cellular Modem IMEI.

3.2.1 Cellular Service Provider Access Point Name (APN)

The controller needs the correct Access Point Name (APN) from your cellular service provider to connect to the cellular network. The controller APN configuration setting must exactly match the APN from your provider. The command to change this setting is

```
APN="CARRIER APN HERE"
```

Note the quotes are required. Use the GETCD command to verify the controller APN setting.

3.2.2 SIM PIN and Additional Settings

If your SIM requires a PIN number, APN Username or APN password please contact Soundnine technical support. We can support these features, but a firmware update may be required.

Your cellular service provider will provide an APN (Access Point Name) for your cellular service.

3.2.3 Reading the Cellular Modem IMEI

The Cellular Modem IMEI can be read with no SIM card installed. Use the following commands to read the IMEI:
MOD MON
REPORT

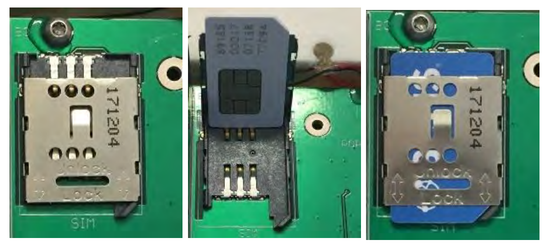
The IMEI number is highlighted in this example:

```
S9>mod mon
OK; 0 Events
```

```
S9>report
Starting report, use reset command to abort
þATATATATATATATATATATATATATATAT
OK
AT+CSQAT+CSQ
+CSQ: 99,99

OK
AT+CMEE=2AT+CMEE=2
OK
AT+CCIDAT+CCID
+CME ERROR: SIM not inserted
AT+CGSNAT+CGSN
357520073945178
```

3.2.4 Installing the SIM Card



Installing the SIM card requires opening the pressure housing. Refer to 3:Opening and Closing the Housing. After the housing is opened open the SIM card holder by pressing lightly on the silver piece and sliding towards the edge of the circuit board. Place the SIM card in the silver lid and close the lid while holding the card in position. Press gently and slide the lid towards the center of the circuit board to lock it in place.

Be careful to follow the instructions in 3.1.2:Sealing when closing the pressure housing.

Verifying SIM Installation

If the cellular modem can read the SIM card ICCID number then the SIM card is connected and operating. Use the following commands to read the SIM card ICCID number:
MOD MON
REPORT

The SIM ICCID number is highlighted in this example:

```
S9>mod mon
OK; 0 Events
S9>report
Starting report, use reset command to abort
þATATATATATATATATATATATATATATAT
OK
AT+CSQAT+CSQ
+CSQ: 99,99

OK
AT+CMEE=2AT+CMEE=2
OK
AT+CCIDAT+CCID
+CCID: 89185000170713877094
```

```
AT+CGSNAT+CGSN
357520073945178
```

Note the difference between this example and the example in 3.2.3:Reading the Cellular Modem IMEI where the SIM card is not installed.

3.3 Iridium SIM Card

If your controller is equipped with an Iridium 9523 modem for RUDICS telemetry it will have an Iridium SIM card pre-installed by the factory on the Iridium modem PCB. The Iridium SIM card should not be replaced – firmware configuration and Iridium activation must match the SIM card for the system to transmit properly.

In some configurations the Iridium modem uses the same SIM card holder as the cellular modem. This requires special instructions when ordering.

4 Internal Sensors

The controller has internal sensors for temperature, relative humidity, solar and battery voltages and currents. It also has a digital compass, accelerometer and gyroscope; each capable of sampling at tens of Hz.

At the S9> prompt use the ADC command to read internal temperature, humidity, voltages and currents. In sample programs use VBLOG or IRHLOG to log these data.

The compass, accelerometer and gyroscope firmware is still in development. Additional capabilities will be added with firmware updates.

5 Controller Serial Ports

The controller includes two RS232 serial ports, an internal logic level serial port shared between the Ultimodem inductive modem (IM) and the GPS receiver, and another internal logic level port shared by all telemetry modems.

The RS232 ports are labelled A and B, but they may also be referred to with their port numbers, 0 and 2.

The IM port and GPS port share a single hardware serial port, so simultaneous communication with these devices is not possible. Both devices may be powered and active at the same time. It is possible to enable the GPS and communicate with the IM while the GPS establishes location, then open the GPS port to read the location. The OPEN IM command automatically closes the GPS port and the OPEN GPS command automatically closes the IM port – but neither command changes to power state of the IM or GPS.

Port Description	Port Name	Port Number	Comments
RS232 Port A	A	0	
RS232 Port B	B	2	
Ultimodem	IM	1	Hardware port shared with GPS

GPS	GPS	3	Hardware port shared with IM
Modem	-	-	Not directly addressable

6 Data Files

The controller maintains two main files: the data file, containing all sensor data from sampling; and the status file, containing a log of all commands and events.

The controller uses a separate ram buffer, FLASH memory buffer and SD card file for each of these files. It stores data to RAM, then moves data from RAM to FLASH memory, then from FLASH memory to the SD card. This system allows a good balance between fast operation and low power consumption.

In addition to the Status and Data files, there is a sample script file (A) and a utility script file (F). The sample script file contains the instructions for data collection at each sample. The controller stores the sample script file in FRAM memory for high reliability. Firmware updates and factory testing use the utility script file.

File	Ram buffer Name	FRAM buffer name	Flash buffer Name	SD Card File Name
Data File	S	-	D	S9xxxx.TXT
Status File	STR	-	ST	S9xxxxS.TXT
Sample Script A	-	A	-	-
tility Script F	-	-	F	-

Note: use READ SDD to read the data file from the SD card, and READ SDS to read the status file from the SD card. It is not possible to erase data stored on the SD card.

7 Command Set

7.1.1 Commands

Commands are not case sensitive. All commands must end with a carriage return (CR, '\r') character (automatically generated by a terminal program when you press enter). If a line feed character follows (LF, '\n') it will be ignored.

Any arguments or parameters may be separated by either a space or an equals sign(=). Note the controller accepts '=' or a space, but not both.

7.1.2 Status Commands

7.1.2.1 GETCD

Displays configuration.

```
S9>getcd
<Config type='UBUOY' sn='17N' v='0'>
```

```
<Hardware>
  <Assembly></Assembly>
  <Firmware>UBUOY V1.0A</Firmware>
</Hardware>
<Cal>
  acx=0
  acy=0
  acz=0
  asx=16384
  asy=16384
  asz=16384
  bcx=0
  bcy=0
  bcz=0
  bsx=16384
  bsy=16384
  bsz=16384
</Cal>
<Settings>
  period=60
  debugLevel=5
  amode=2
  arate=4
  ascale=0
<X3GA>
  apn=neo.iot.net
  ip1=198.199.109.17
  ip2=198.199.109.17
</X3GA>
  STOPPED
</Settings></Config>
```

7.1.2.2 GETSD

Displays controller status. This includes the battery voltage, memory status, SD card status and status of the multiple command interfaces (serial A, serial B, inductive modem, cellular modem and Iridium modem (if installed). It is common for the controller to pause for a moment during the GETSD command while the SD card initializes. This pause does not interrupt sampling.

Warnings are displayed in the GETSD response if the memory card is not installed or cannot be written to. These warnings mean the controller cannot save data to the memory card and data recording is limited to the 7 megabyte internal memory. These are the two warning messages:

No memory card installed:

```
S9>getsd
<Status type='UBUOY' sn='17N' v='0'>
<DataBuffer>
  nextWrite=720896
  not saved=0
```

```
  last sample=0
  not transmitted=0
  total=0
</DataBuffer>
<SDHC_CARD>
  ***WARNING:  SDHC MEMORY CARD NOT INSTALLED!***
</SDHC_CARD>
  lastSampleTime=2000-01-01T00:00:00
  TIME=2000-01-01T05:05:24
  Vbat=4.015
<ACTIVEPORTS>
  SERIAL B
</ACTIVEPORTS>
  STOPPED
</Status>
```

Cannot write to memory card:

```
S9>getsd
<Status type='UBUOY' sn='17N' v='0'>
<DataBuffer>
  nextWrite=720896
  not saved=0
  last sample=0
  not transmitted=0
  total=0
</DataBuffer>
<SDHC_CARD>
  SDHC card installed
  ***WARNING: 71480 DATA BYTES NOT SAVED TO CARD!***
  ***WARNING: 603 STATUS BYTES NOT SAVED TO CARD!***
  <File  Name='none'  Size='0' />
  <File  Name='none' Size='0' />
</SDHC_CARD>
  lastSampleTime=2000-01-01T00:00:00
  TIME=2000-01-01T05:05:24
  Vbat=4.015
<ACTIVEPORTS>
  SERIAL B
</ACTIVEPORTS>
  STOPPED
</Status>
```

This is the GETSD response when the memory card is working properly:

```
S9>getsd
<Status type='UBUOY' sn='17K' v='0'>
<DataBuffer>
  nextWrite=720896
  not saved=0
  last sample=0
  not transmitted=0
```

```
  total=0
</DataBuffer>
<SDHC_CARD>
  SDHC card installed
  <File  Name='S917K.TXT'  Size='0' />
  <File  Name='S917KS.TXT' Size='0' />
</SDHC_CARD>
  lastSampleTime=2000-01-01T00:00:00
  TIME=2018-04-24T16:57:30
  Vbat=4.066
<ACTIVEPORTS>
  SERIAL B
</ACTIVEPORTS>
  STOPPED
</Status>>
```

7.1.2.3 ADC

Reads all analog measurement channels and displays the results.

```
S9>adc
Tint=22.86
RHint=46.15
Isol=-0.03
Ibatt=5.44
Vbat=4.002
Vsol=0.00
```

These channels are internal temperature (C), internal relative humidity (%), solar current (mA), battery current (mA), battery voltage (V) and solar voltage (V). The solar charging system uses a switching power supply, so solar voltage is not very useful as a light sensor.

7.1.2.4 GETEC

Displays event counters. Event counters are a useful debugging tool for S9. Most events to not indicate a problem. If you are concerned about events recorded on your device please feel free to forward the GETEC response to S9, along with the status log file from the SD card.

```
S9>getec
<EventData>
numEvents = 1
nextAddr = 7040
   0, 0F9F45, Usart1.c:71-0
</EventData>
```

In the example above there was an single event recorded – a framing error on USART 1.

7.1.2.5 VER

Displays controller hardware and firmware version.

```
S9>ver
HTYPE
CD AB0B0AE0, 13000002
CODE TYPE UBUOY V0
FIRM UBUOY V1.0A
CDATE May  1 2018 11:03:18
```

Configuration Commands

Refer to Configuration Settings for a full list of settings.

7.1.2.6 ERASE CONFIG

This command resets all configuration settings to default values, but does not change calibration coefficients or modem settings (in the X3GA section). Default settings from the GETCD response are listed here:

```
S9>getcd
<Config type='UBUOY' sn='17N' v='0'>
<Hardware>
  <Assembly></Assembly>
  <Firmware>UBUOY V1.0A</Firmware>
</Hardware>
<Cal>
  acx=0
  acy=0
  acz=0
  asx=16384
  asy=16384
  asz=16384
  bcx=0
  bcy=0
  bcz=0
  bsx=16384
  bsy=16384
  bsz=16384
</Cal>
<Settings>
  period=60
  debugLevel=5
  amode=2
  arate=4
  ascale=0
<X3GA>
  apn=
  ip1=
  ip2=
</X3GA>
  STOPPED
</Settings></Config>
```

7.1.2.7 TIME

The TIME command both sets and displays controller's current time. To display the time just enter the time command by itself:

```
S>time
time=2013-11-05T01:24:47
OK - 0 Events
```

To set the time include the current time in IS0-9601 format with no time zone. Multiple time formats are allowed:

```
time=2015-11-05T14:24:47
time 2015-11-05T14:24:47  (the = is optional)
time=20151105T142447
```

Note that controller accepts '=' or a space, but not both.
When the time is accepted the reply looks like this:

```
S9>time 2016-07-21T112000
Time changed to 2016-07-21T11:20:00
OK; 0 Events
```

7.1.3 Utility Commands

OPEN

Opens a serial pass through mode at specified port and baud rate. Press escape to exit the pass through mode.

`OPEN IM 19200` –Opens the IM port at 19200 baud (default for Ultimodem)
`OPEN A 115200` --Opens serial port A at 115200 baud
`OPEN GPS` --Opens the GPS receiver at the default baud rate

7.1.3.1 PWROFF or SLEEP

Returns the controller to low-power sleep mode.

7.1.3.2 RESET

Forces a full reset (like a reboot). This forces the controller to return to low-power sleep mode, abandoning all in-process activity

It is best to send an ERASE MEM command after a reset to guarantee integrity of the file system. If the controller was writing to flash memory (D File or ST file) during the reset then up to 64kB of data may be corrupted.

7.1.3.3 RESETEC

Resets the event counters.

7.1.4 File Commands

The controller has several files in RAM, flash memory and the SDHC memory card. Files are identified by one or more letters (F, S, D, ST, STR, SDD, SDS).

7.1.4.1 Available Files

7.1.4.1.1 F File

The F file is used for scripts – most importantly firmware update scripts. Firmware update files are streamed to the F file, then the file is run with the RUN F command. The F file can may also be used for custom scripts where each line of the file is a modem command. Note that some commands cannot be used in scripts – check the 'blocks' section of the command table.

7.1.4.1.2 D File

The D file is a 7 Mbyte circular buffer for ASCII data. Data in the D file is periodically copied to the SDHC memory card. Pressing the button inside the housing forces a copy to the SD card.

7.1.4.1.3 S File

The S file is a short RAM buffer of recent samples, typically less than 2KB. Note that the GETSD command clears the S buffer, and the S buffer is automatically cleared periodically while running sample programs and when controller transfers data to the D file in flash memory.

7.1.4.1.4 STR File

The STR file is a short status log file stored in RAM. This log includes power cycling, time changes and notes of any hardware or firmware events. Note that the GETSD command clears the STR buffer, and the STR buffer is automatically cleared periodically when controller transfers data to the ST file in flash memory.

7.1.4.1.5 ST File

The ST file is a circular status log file in flash memory. Data in the ST file is periodically copied to the SDHC memory card.

7.1.4.1.6 SDD File

This is the data file on the SDHC memory card. This file may take tens of minutes to read through RS232.

7.1.4.1.7 SDS file

This is the data file on the SDHC memory card. This file may take tens of minutes to read through RS232.

7.1.4.2 WRITE

Writes data to a file. Not all files support this command.

7.1.4.3 READ

Retrieves data from a file. Examples:
READ SDD – reads data file from SD card
READ SDS – reads status file from SD card
READ ST – reads status file buffer from FLASH memory
READ D – reads data file buffer from FLASH memory
READ S – reads data buffer from RAM.

7.1.4.4 ERASE

Erases a file.

7.1.4.5 RUN

Runs a script file. Only allowed with the F file or the A file.

7.1.4.6 DUMPFLASH

A utility command to retrieve the entire contents of flash memory. This allows significant data recovery if the D file is accidentally erased. This command takes about ten minutes to run.

7.1.5 Command Table

(Not including calibration setting commands)

Command	Blocks	Parameters	Description
GETCD			Displays configuration settings
GETSD			Displays status data
GETEC			Displays event counters
VER			Displays hardware and firmware version
ADC			Reads all analog measurement channels: Internal temperature, internal relative humidity, solar and battery currents and voltages.
ERASE CONFIG			Resets all configuration to default values, does not change calibration values
PERIOD		1-10080	Sets the sample period in minutes
START			Starts logging
STOP			Stops logging
TIME		20180401T235959	Sets or reads the time in common ISO8601 formats 20180401T235959 2018-04-01T235959 2018-04-01T23:59:59
PWROFF			Same as SLEEP. Terminates active mode (IM Service or Host Service)

SLEEP			Same as PWROFF. Terminates active mode (IM Service or Host Service)
RESETEC			Resets (clears) the event counters
RESET			Resets the modem – ending all processes and forcing return to sleep mode.
WRITE	FILE	F, D, A	Writes to a file.
READ	FILE	F, D, A, S, ST, STR, SDD, SDS	Reads a file: F – F file (script / utility file) S – S file (data ram buffer) D – D file (sample data buffer) DL – D file last sample only A – A file (program script) ST – Status buffer STR – Status ram buffer SDD – SD card sample data file SDS – SD card status data file
ERASE	FILE	D, MEM, ST, CAL, CONFIG	Erases a file (ERASE MEM clears all files except those on the SDHC memory card)
RUN	FILE	F, A	Runs a file as a script. RUN F runs F file as a simple command script. RUN A runs the A file as a data collection script.
OPEN		Port, baud	Opens a serial pass through mode Port: 0, A, 1, B, 2, IM Baud: any multiple of 1200 up to 115200 Press escape to exit the pass through mode.
DUMPFLASH	FILE		Outputs the entire contents of the flash memory. May take tens of minutes to complete.
AMODE			Accelerometer mode - reserved for future use
ARATE		1-50	Accelerometer sample rate – reserved for future use
ASCALE		0-3	Sets full scale range of the accelerometer (in g- for gravity) 2g,4g,6g,8g
MSCALE		0-3	Sets full scale range of the magnetometer (in gauss) 2g, 4g, 8g, or 12g

7.2 Configuration Settings

Note the name of each configuration setting is also a command to modify that setting. Use a space or = between the command and parameter value:

```
ID 01
```

and

```
ID=01
```

Are both acceptable.

Command	Parameter default value in ()	Description

PERIOD	1-10080	Sets the sample period in minutes (10080 = 1 week)
AMODE		Accelerometer mode - reserved for future use
ARATE	1-50	Accelerometer sample rate – reserved for future use
ASCALE	0-3	Sets full scale range of the accelerometer (in g- for gravity) 0=+/- 2g 1=+/- 4g 2=+/- 6g 3=+/- 8g
MSCALE	0-3	Sets full scale range of the magnetometer (in gauss) 0=+/- 2g 1=+/- 4g 2=+/- 8g 3=+/- 12g

7.3 Calibration Settings

Note the name of each calibration setting is also a command to modify that setting. Use a space or = between the command and parameter value:

```
ASX 0
```

and

```
ASX=0
```

Are both acceptable.

Setting	Range	Description
ACX	-500 to 500	Accelerometer X offset
ACY	-500 to 500	Accelerometer Y offset
ACZ	-500 to 500	Accelerometer Z offset
ASX	500 to 31000	Accelerometer X offset
ASY	500 to 31000	Accelerometer Y scale
ASZ	500 to 31000	Accelerometer Z scale
BCX	-500 to 500	Magnetometer X offset
BCY	-500 to 500	Magnetometer Y offset
BCZ	-500 to 500	Magnetometer Z offset
BSX	10000 to 22000	Magnetometer X offset
BSY	10000 to 22000	Magnetometer Y scale
BSZ	10000 to 22000	Magnetometer Z scale

8 Sample Programming

8.1 Basic Sample Program Structure

Sample programs are little more than a list of commands representing a non-branching and non-looping algorithm. Each line of a program represents a single command. When a command is completed the next command is processed. This repeats until the end of the file is reached. Lines starting with a '/' or ';' are treated as comments.

8.2 Sample Program Commands

Command	Parameter	Description
`Delay`	Delay length in milliseconds	Pauses the program (open ports are monitored during the pause)
Open	Port, baud	Opens a serial port at the specified baud rate. Port: 0,1,2,A,B or IM Baud: any multiple of 1200 up to 115200 Ex: `OPEN IM 19200`
SEND	Port, string	Sends a string to an open serial port Ex: `SEND IM "FCL\r"`
WAITFOR	Port, String, max wait	Waits for a specified data string from an open port with a maximum wait time in milliseconds. Ex: `WAITFOR IM "S9>" 10000`
SAVE	Port	Records data logged from the specified port to the D file. No data is saved if logging is disabled on the specified port!
PARSER	Port, Parser name	Specifies a data parser for a port. The parser name tells analysis software how to process the data from the specified port. Ex: `PARSER IM "IMTEST"`
CLEARBUFFER	Port	Erases the contents of the serial receive buffer for the specified port. Data previously saved with the SAVE command is not erased.
LOG	Port, ON/START/OFF/STOP	Enables or disables data logging on the specified port. Note the logging setting is overridden by the debuglevel setting: debuglevel >1 forces continuous logging.
GPS ON		Turns on the GPS receiver
GPS OFF		Turns off the GPS receiver
GPS QOS		Logs the GPS quality of service data
GPS FIX		
GPS WFF	[1-300]	Waits for valid GPS fix up to optional number of seconds and logs the GPS position
GPS TIME		Logs the current GPS time
GPS SET TIME		Sets the controller time to the current gps time (if fix valid)

8.2.1 Example Sample Program

This is a sample program for collecting GPS and XTP data through the Ultimodem:

```
vblog
irhlog
open im
delay 1000
send im "\r"
delay 500
send im "fcl\r"
delay 2000
```

```
send im "xtp 10\r"
waitfor im "S9>" 20000
send im "sleep"
delay 1000
close im
gps on
gps wff 60
gps set time
gps off
```

With this program the controller first logs battery voltages and currents and logs internal relative humidity. Then it enables the IM and samples two XTP sensors. After the XTP data is retrieved the controller waits for a valid GPS fix, logs the GPS data and sets the controller time to the current GPS time.

8.3 Serviceable Parts

8.3.1 Batteries

The controller uses up to six 18650 size rechargeable lithium ion batteries. Use Tenergy 2600mAh model 30005 or 30016 batteries with internal protection PCB or equivalent. Many commercially available batteries in this size have significantly overstated capacity claims, have high self-discharge and / or do not include internal protection PCBs. Please use only high quality replacement batteries from reputable sources. Be sure the polarity of the batteries match the orientation printed on the battery holders.

WARNING: Do not install primary (non-rechargeable) batteries in controllers equipped with solar cells! This may cause batteries to leak or explode causing risk of fire or chemical burns.

All internal batteries connect through diodes to a single power bus.

For controllers without solar panels it is possible to use 2/3A size primary lithium batteries, such as Saft LS17330. Two batteries fit in each 18650 size battery holder. Be sure the orientations of both batteries match the orientation printed on the battery holder.

8.3.2 O-Ring

The controller uses an x-profile double-sealing o-ring. We recommend Molykote M44 lubricant on the o-ring. Excess lubricant is not desirable, use just enough to wet the surface of the o-ring on all sides.

8.3.3 Desiccant

The desiccant package should be replaced every time the housing is opened. Replacement desiccant is available from Soundnine or McMaster-Carr.

8.4 Replacement Parts List

Item	Description	Soundnine Part Number	McMaster-Carr Part Number
O-ring	Double-Seal X-Profile O-Ring, Buna-N, Number 264	2071A	90025K399
Desiccant	silica gel desiccant	206B6	3492T12
Battery	Tenergy #30005 or 30016; 18650 size lithium rechargeable		
Housing cover screw	Socket head cap screw, M4x0.7x30mm	2070A	92855A425
Washer for housing cover screw	Internal tooth lock washer	2070C	93925A250
Connector cap	M12 connector sealing cap		
Connector pigtail	M12 connector pigtail		

8.5 Firmware Updates

Firmware update files are text files with firmware encoded in ASCII hex. They are sent to the modem through the RS232 serial connection. Follow these steps to perform a firmware update:

1) Connect the RS232 cable
2) Open a terminal program (we prefer TeraTerm) and select the appropriate COM port
3) Set the port flow control to Xon/Xoff or 'SOFTWARE HANDSHAKING' (under Setup->Serial Port in TeraTerm).
4) Press enter to get a S9> prompt from the controller.
5) Type the VER command to check the current firmware version of your controller
6) Send the firmware update file to the controller. (no encoding – in TeraTerm use File->Send File)
7) Wait for the file transmission to finish.
8) Enter the RUN F command to initiate parsing, integrity checking and device type verification. This may take 10 to 15 seconds. If the file is OK the controller will respond with: `Confirmed - ready to program`
9) Enter the PROGRAM command to start the firmware update. The firmware update takes only a few seconds. Do not disconnect the battery within 10 seconds of sending the PROGRAM command, doing so may corrupt the firmware and disable the controller.
10) After the firmware update completes the controller will be in sleep mode. Press a key to wake the controller and use the VER command to verify the new firmware version.

9 Specifications

9.1 Battery

Several battery configurations are available. There are hardware differences between these configurations, the battery configuration must be specified when ordering.

WARNING: Do not install primary batteries in a controller configured for rechargeable batteries! Doing so may cause fire or explosion.

9.1.1 Lithium Ion Rechargeable

Tenergy 18650 Model 30005 or 30016
4 cells, two batteries.
Dual 7.2V 2.6 Amp-hour (18.7 W-hour)
Charge Temperature: 0C to 45C
Discharge Temperature: -20C to 60C

Non-hazardous for shipping according to UN3481, P.I. 967, SECTION II, regarding " Lithium Ion Batteries contained in equipment ", specifically "Cells equal to or less than 20Wh; and Batteries equal to or less than 100Wh"
• No Shipper's Declaration
• Strong rigid outer packaging
• Completed Lithium Battery mark or Lithium Battery label if more than 4 cells and 2 batteries per package

NOTE: local lithium battery shipping restrictions may apply.

9.1.2 Lithium Primary

Saft LS17300
8 cells, 7.2V 8.4 Amp-hour (60.5 W-hour)
Discharge temperature -60C to +85C
Hazardous material – restricted shipping, cannot ship on passenger aircraft, warning label required:

UN3091, P.I. 970 Section II regarding "Lithium Metal Batteries contained in equipment" , specifically "Cells equal to or less than 1g; and Batteries equal to or less than 2g"
• No Shipper's Declaration
• Strong rigid outer packaging
• Completed Lithium Battery mark or Lithium Battery label if more than 4 cells and 2 batteries per package
• When the lithium battery label is used, the UN number must be on the package adjacent to the label.

NOTE: local lithium battery shipping restrictions may apply.

9.1.3 Alkaline

Duracell QU1400 (C)
Requires non-standard thicker back cover
6 cells
36 W-hours @ 25C
24.6 W-hours @ 0C
9.9 W-hours @ -10C

Per cell:
6 W-hours @ 25C
4.1 W-hours @ 0C
1.65 W-hours @ -10C

Duracell QU1500 (AA)
12 cells
38.2 W-hours @ 25C
23.7 W-hours @ 0C
18.5 W-hours @ -10C

Per cell:
3.19 W-hours @ 25C
1.98 W-hours @ 0C
1.54 W-hours @ -10C

9.2 Power Consumption

All measurements are at 7.2V unless noted. All current values are in milliamps.

Note the battery current measurement built into the controller has a +/- 5mA measurement offset which changes over temperature and battery voltage. Some controller configurations are optimized for lower power applications and have much lower measurement offsets.

Quiescent, Vr/v5 disabled: 7.2V 100uA
Quiescent, Vr/V5 enabled: 7.2V 150uA
PC Interface active: 3.18 with standard RS232 load, 1.63 with no RS232 load.
Sampling base current 1.35mA
Sampling with IM active (mod1): 1.65mA
Sampling with gps active: 13mA

9.3 GPS

Operating current: 12ma – 18ma @7.2V
Accuracy: 5 meter RMS typical
    Note the GPS WFF command waits for a HDOP of 2.0 or lower and four satellites with SNR > 15.
    WAAS and EGNOS enabled by default.
Time to first fix: about 90 seconds.
Time to repeat fix: 10-15 seconds typical--assuming controller power not interrupted and controller not moved significantly since last fix.

9.4 Iridium:

RUDICS Connection: 500mA maximum
Allow 20 seconds to establish connection and 900 bytes / second transmit speed.

SOUNDNINE INC

Helping build successful monitoring systems

Ultimodem Operating Manual

Soundnine Inc Document #R010Q

rev 2019-05-01

DOCUMENT IN PROCESS

Contents

1 Ultimodem Housing

Size: 230 mm x 35 mm x 46 mm

Materals: PET & Titanium

Depth Rating: 1,000 meters

Mass: 380 grams

The Ultimodem assembled on a mooring cable is nearly concentric and will fit through a 5 cm diameter opening. Allow at least 28 cm length for the modem and mating connector.

1.1 Serviceable Parts

1.1.1 Battery

The modem uses a single AA 3.6V lithium battery. Saft LS14500 or equivalent. The LS14500 is rated 2.6 amp-hours, we usually de-rate to 2.0 amp hours to account for self-discharge and temperature effects.

A typical IM system sampling six times per hour will last a bit longer than one year on this battery.

1.1.2 O-Ring

Modem uses an x-profile double-sealing o-ring. They are available from Soundnine or McMaster-Carr. We recommend Molykote M44 lubricant on the o-ring. Excess lubricant is not desirable, use just enough to wet the surface of the o-ring on all sides.

1.1.3 Faceplate Screws

The faceplate and screws are titanium. Replacement screws must be titanium – use of other materials will cause significant galvanic corrosion. Replacement screws are available Soundnine or McMaster-Carr.

1.1.4 Faceplate

Replacement faceplates are available from Soundnine. The faceplate should be replaced if accidentally bent, scratched on the o-ring sealing surface or otherwise damaged.

1.1.5 Desiccant

The desiccant package should be replaced every time the housing is opened. Replacement desiccant is available from Soundnine or McMaster-Carr.

1.1.6 Coupler Clamp

The coupler clamp assembly both clamps the modem to the mooring line and clamps the ferrite toroid half of the IM coupler in position. This clamp must be fully closed to guarantee reliable communications. There should be no gap between the coupler clamp and the modem housing.

The coupler clamp size must match the outer diameter of the mooring cable. Coupler clamps are available in a variety of sizes, please specify your cable outer diameter and if that diameter is a measured value or a nominal value when ordering.

1.1.7 Connector

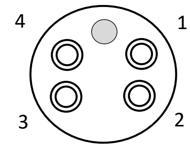
The MCBH connector should be replaced only by Soundnine. Some customers may be able to perform this service, but it requires using a soldering iron next to a plastic o-ring sealing surface – this is best done with the appropriate jigs and tools to protect the sealing surface.

1.2 Replacement Parts List

Item	Description	Soundnine Part Number	McMaster-Carr Part Number
O-ring	Double-Seal X-Profile O-Ring, Buna-N, Number 032	202CA	90025K426
Desiccant	0.6”x1.1” silica gel	2039E	2189K12
Faceplate screws	2-56 x 3/8” titanium socket head cap screw	2034B	95435A219
Coupler Clamp Screws	M4-18mm Socket head cap screw, 316 stainless steel	2040A	92290A161
Coupler Clamp Screw Retainer o-ring	O-Ring, Buna-N, 1MM wide, 3MM ID,	2041F	9262K441
Faceplate	Custom machined titanium	50035	
Connector	Subconn MCBH4-M		
Coupler Clamp	Custom polyester and ferrite assembly	50036 **Specify cable diameter when ordering**	

1.3 Power & Communication Connector

The UltiModem accepts input voltages from 3.5V to 28V. The input power is linearly regulated to 3.3V, so use the lowest available input voltage within the acceptable range to conserve power.



Male Face View
MCBH 4M

Signal	PCB Pin	Wire Color	MCBH4 Pin
GND	1	Black	1
+VDC	2	Green	4
Transmit Out	3	White	2
Receive In	4	Red	3

Power can be connected or removed at any time in normal operation[1]. There is no danger of corrupting the modem's configuration by removing power unexpectedly. If power is removed while the modem is writing to a file in flash memory then the data may not be recorded properly, but the data structure will not be corrupted.

Note the MCBH connector pinout RX and TX lines are reversed from the most common configuration – this allows 1-1 wiring of cables connecting the UltiModem to most instruments.

[1] Do not remove power when performing firmware updates.

2 OEM Modem

We offer OEM modems for manufacturers in both a S9 standard footprint and a larger footprint for replacing IMM's from Sea-Bird Electronics. OEM components are circuit boards with no housings.

2.1 Standard Footprint

The standard S9 footprint allows socket or solder mount on the application PCB. No screws or standoffs are required.

Figure 1 S9 Footprint PCB Layout

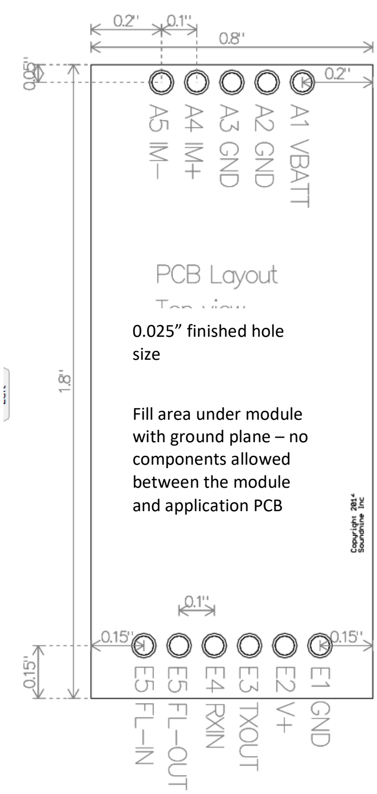


Table 1 S9 Footprint Pin Descriptions

Pin	Name	Description
A1	VBATT	Optional power supply input connection. 3.0V – 4.5V
A2	GND	
A3	GND	
A4	IM+	IM transmit + to coupler
A5	IM-	IM transmit – to coupler
E1	GND	
E2	V+	Positive power supply input 3.3V – 26V
E3	TXOUT	Serial transmit output (RS232 or logic level)
E4	RXIN	Serial receive input (RS232 or logic level)
E5	FLAGOUT	3.3V logic level flag output
E6	FLAGIN	3.3V logic level flag input

Module height over application PCB is 7mm

S9 Part numbers:

RS232 serial interface: 15011B-1

Logic-level serial interface (3.3V): 15011B-2

2.2 Sea-Bird Electronics IMM Compatible Footprint

S9 part number 15032B. Standoffs are not included – see mechanical drawing for standoff size and part numbers.

Table 2 SBE IMM Fooprint J1 10-pin Connector

Pin	Name	Description
1	IM+	IM transmit + to coupler
2	IM-	IM transmit – to coupler
3	FLAGIN	3.3V logic level flag input
4	FLAGOUT	3.3V logic level flag output
5	LLS TX OUT	Logic level serial transmit output (15032A-2 hardware only)

6	TXOUT	RS232 transmit output (15032A-1 hardware only)
7	LLS RX IN	Logic level serial receive input (15032A-2 hardware only)
8	RXIN	RS232 receive input (15032A-1 hardware only)
9	Vin +	Input voltage (3.3V – 26V)
10	GND	Power supply return

Table 3 SBE IMM Fooprint J2 4-pin Connector

Pin	Name	Description
1	IM+	IM transmit + to coupler
2	GND	Power supply return
3	IM-	IM transmit – to coupler
4	Vin +	Input voltage (3.3V – 26V)

Figure 2 SBE IMM Footprint PCB layout

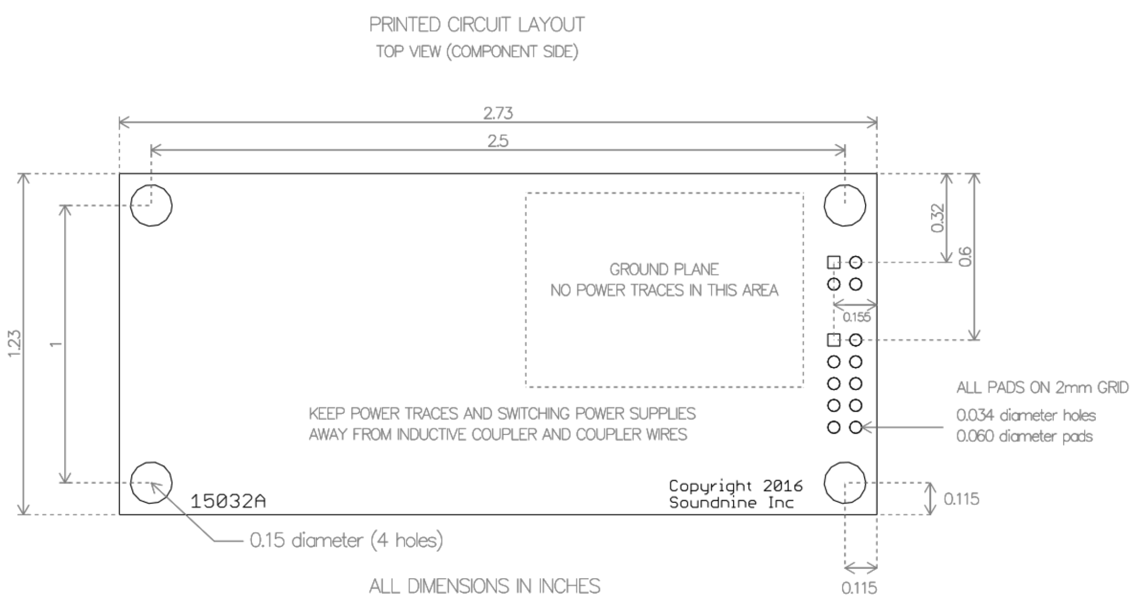
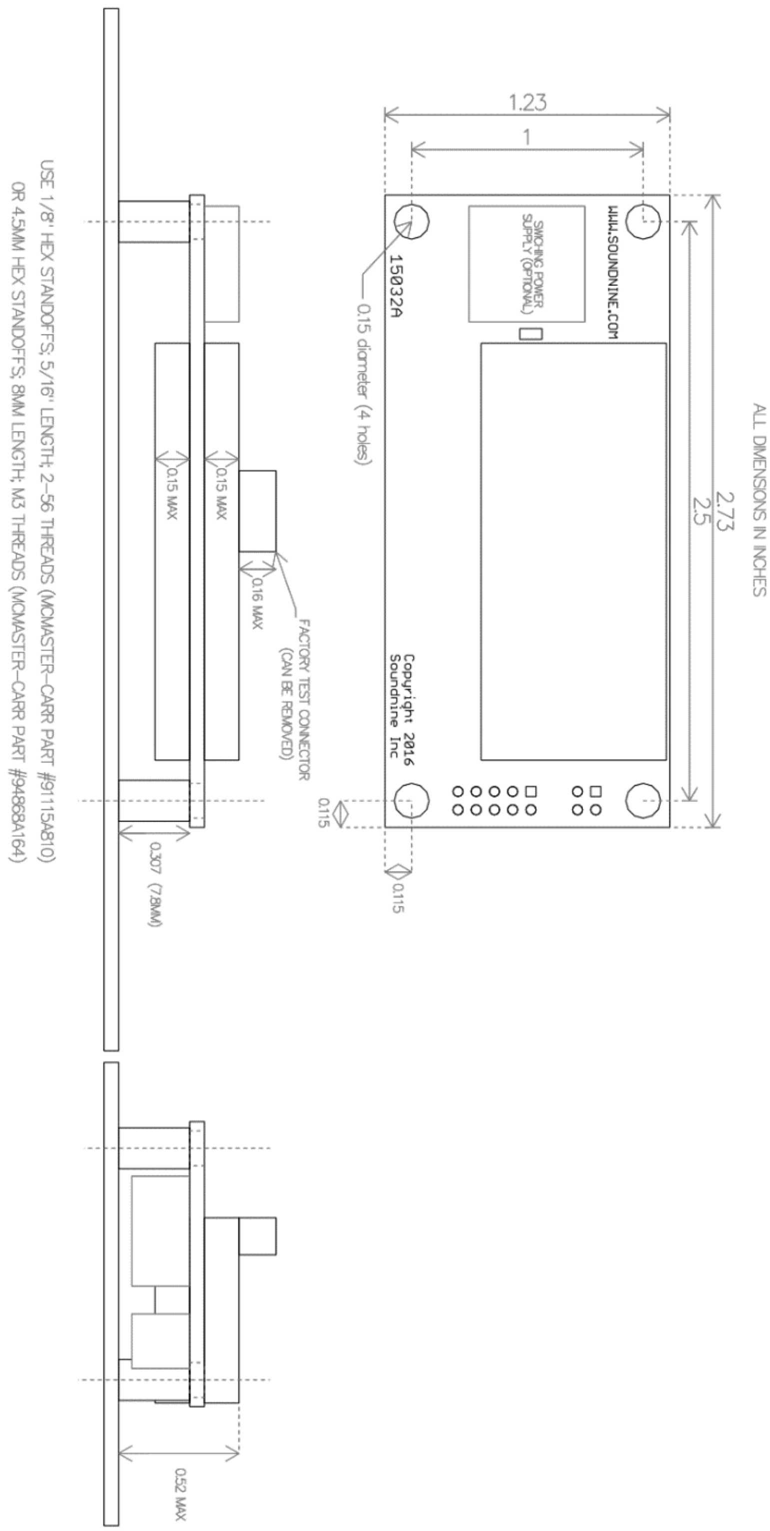


Figure 3 SBE IMM Footprint Mechanical Drawing



3 Operating Modes

3.1.1 Startup Mode

After connecting power to the modem the modem enters Startup mode. Startup mode initializes clocks and prepared the modem for normal operation. Startup mode lasts up to 1.5 seconds after the power input is stable.

Startup mode may be triggered at any time if the power supply to the modem is interrupted or drops below the minimum specified value even for a very short time. This may be a concern for OEM users. Switching power to other devices may cause supply voltage to the modem to drop for a few microseconds and trigger Startup mode.

If the power supply is not stable during startup mode it may be necessary to disconnect power and wait for the voltage at the modem supply input to drop to 0.3V or lower to fully reset the hardware.

3.1.2 Sleep Mode

After a Startup Mode, a PWROFF command, or a timeout the modem enters a low power Sleep mode. Power consumption in Sleep mode is typically 30 microamps. The modem wakes from Sleep according to the WAKEUPSRC setting.

3.1.3 Host Service Mode

Host Service mode is when the modem responds to commands from the RS232 serial port. This mode is used to initiate communication with other modems. Host service mode can be disabled with the WAKEUPSRC command. It is enabled by default.

When the modem wakes in response to activity on the RS232 serial port it immediately activates host service mode. Host Service mode is disabled if the WAKEUPSRC setting is 2 (IM only). Note that Host Service mode and IM Service mode may be active simultaneously (if the WAKEUPSRC setting is 0).

The RS232 serial interface default settings are 19200 baud, 8 bits, no parity, 1 stop bit.

When starting Host Service mode the modem:

1. activates the RS232 driver
2. waits 2 milliseconds
3. clears the receive buffer -- to clear the partially received character which caused the wakeup
4. waits 10 milliseconds for the RS232 driver fully power up
5. transmits:

```
PWRUP
S9>
```

The modem is ready to accept command as soon as this prompt is transmitted.

3.1.3.1 Returning to Sleep (Exiting Host Service Mode)

Use the SLEEP or PWROFF command to exit host service mode (these commands are identical). Modem behavior depends on the state of the modem when the command is received:

1. If IM line is captured:
   a. Send "SENDING PWROFF" to RS232 serial port
   b. Send PWROFF to the IM network.
   c. Wait for the PWROFF command to be transmitted
   d. Wait 10 milliseconds
   e. Disable the IM transmitter
   f. Wait another 10 milliseconds
2. Send "SLEEP" to the RS232 serial port
3. Disable serial output
4. Enter sleep mode if IM Service mode not active

3.1.3.2 Forcing Sleep Mode

The operator can force the modem to enter sleep mode (regardless of any other active modes) with the RESET command.

3.1.3.3 Timeout from Host Service Mode

The modem will automatically exit Host Service mode and return to sleep after a timeout period if no valid commands are entered. The cmdTO setting controls this timeout. Units are seconds, the default is 60 seconds. Each valid command resets this timeout. The timeout will not occur while a command is running. Note cmdTO also controls timeouts in IM Service mode.

3.1.4 IM Service Mode

The modem enters IM Service mode in response to activity on the IM network. When IM Service mode is active the modem can receive and reply to commands from the IM network. IM Service mode is disabled if the WAKEUPSRC setting is 1 (RS232 only). Note that Host Service mode and IM Service mode may be active simultaneously (if the WAKEUPSRC setting is 0).

3.1.4.1 Timeout from IM Service Mode

The modem will automatically exit IM Service mode and return to sleep after a timeout period if no valid commands are received. The cmdTO setting controls this timeout. Units are seconds, the default is 60 seconds. Each valid command resets this timeout. The timeout will not occur while a command is running. Note cmdTO also controls timeouts in Host Service mode.

Valid commands addressed to other modems do not reset this timeout counter. Valid group commands do reset this timer.

If the timeout occurs while a remote device is transmitting then the modem will quickly re-enter IM Service mode -- but there will be a brief window in which a command addressed to the modem may be missed.

3.1.5 Sample Mode

The only way to enter Sample mode is with the RUN A command. This tells the modem to run the A file as a sample script. Sample mode typically operates at the same time as IM Service mode, as when the modem receives a !iiRUN A or !G0:RUN A command. In this case IM Service mode remains active in parallel with Sample mode. IM Service mode may end (due to inactivity, for example) while the Sample mode continues, or the sample script may terminate while IM Service mode remains active. In either case the modem returns to Sleep after both Sample and IM Service become inactive.

It is possible to re-enter IM service mode any number of times while Sample is active without first returning to sleep.

If the RUN A command is received while Host Service mode is active, the sample script takes control of the serial port – essentially pausing Host Service mode. This may be useful in testing, but is not recommended in the field.

3.1.6 Power Off

Power to the modem may be disconnected at any time except during firmware operations. Removing power while writing to the D or F files may corrupt the file requiring an erase command to restore normal operations. This can be avoided by waiting for the S9> prompt before disconnecting power.

Any time power to the modem is interrupted the voltage at the supply input pin of the modem must be allowed to fall to 0.3V or less before reapplying power to guarantee proper startup.

4 Application Roles

The Ultimodem serves either as a 'master' modem attached to a controller / data logger controlling an IM network, as a 'slave' modem connecting a single instrument to an IM network, or as a 'peer' in a network with more symmetric operation. The same modem hardware serves all of these application roles.

4.1 Master Applications

When all communication on an IM network is initiated by a single modem, that modem may be referred to as a master. Often a modem connected to a buoy controller or data logger serves as a master.

When a modem serves as a master it usually should not wake from sleep into IM Service mode – because all communication is initiated from the master. Disable IM Service mode with the WAKEUPSRC command. WAKEUPSRC=1 prevents the modem from responding to unexpected signals on the IM network.

4.2 Slave Applications

When all communication with a particular modem is initiated remotely that modem may be referred to as a slave. Modems connected to instruments or sensors usually serve as slaves. In most applications modems serving as slaves should not enter Host Service mode in response to activity on the RS232 serial port. This could lead to situations where the serial instrument sends a prompt to the modem then the modem responds with a S9> prompt, resulting in an error message from the instrument, followed by an error message from the modem... creating an infinite loop wasting energy and preventing correct operation.

To prevent this, use the WAKEUPSRC command to disable Host Service mode. WAKEUPSRC=2 prevents the modem from responding to unexpected signals on the RS232 serial port.

4.3 Peer Applications

When an application requires a modem to both receive transmissions initiated from a remote modem and initiate communication with remote modems it acts as a 'peer'. Peer networks are more complex because:

1. multiple devices may attempt to communicate on the IM network at the same time.
2. commands arriving from either the IM network or RS232 port may attempt to access the same modem resources at the same time. For example, reading a data file through the IM network while writing to the file on the RS232 interface.
3. data for the RS232 port (a # command) may arrive from the IM network while the modem is accepting commands on the RS232 port.

The Ultimodem supports peer operation. Peer applications require significantly more planning and testing compared to master/slave networks.

5 Sending Commands from Master to Slave with Response from Slave

Most controllers use polling to collect data from remote instruments. The master sends a command to the slave and the slave responds to the command.

5.1 Maximum Command Length

The length of the command sent by the master is limited by the modems 256 character maximum command length[2]. Note this limit includes the address of the slave modem: #37test counts as 7 characters towards this command limit.

---

[2] Modems with firmware versions before 0.96C were limited to 127 characters. IMMs and other products from Sea-Bird Electronics have different limits – sometimes as few as 64 characters.

5.2 Maximum Response Length

There is no specific maximum response length. The response is limited by timing settings, specifically THOST3, which is the maximum reply time. The maximum THOST3 setting is 3 minutes, which means about 21Kbyte at 1200 baud (mod=1) and 86kByte at 4800 baud (mod=4).

5.3 Master Slave Polling Example

U004 (master – datalogger)	**U02N (connected to instrument)** **Receive**	**Transmit**
PWRUP S9>fcl OK; 0 Events S9>swt .... OK; 0 Events S9>id? <Remote> id = 37</Remote> <qs>28678</qs> OK; 0 Events S9>#37this is a test command	(CR) 10 millisecond delay this is a test command(CR)(LF) The first CR and 10 mS delay are because HOSTWAKEUP=2. Note THOST0=0 in this test. If THOST0 were not zero the modem would add additional delay before sending the data string. The CR LF at the end is because TERMTOHOST=254.	
<Remote> <Host>this is a test response</Host> TERM 5 </Remote> <qs>143143</qs> OK; 0 Events S9>sleep OK; 0 Events S9>SENDING PWROFF SLEEP		this is a test response(CR) This response can be long. The CR at the end of the response ends the response because TERMFROMHOST=13. Note the response may also be terminated by the THOST2, THOST3 or THOST4 settings.

5.3.1 <Remote> Tag

The master modem generates the <Remote> opening tag and </Remote> closing tag. All data between these tags is from the slave modem replying to the IM command.

5.3.2 <Host> Tag

The slave modem generates the <Host> opening tag and </Host> closing tag. All data between these tags is from the instrument connected to the RS232 port.

The TERM 5 after the </HOST> tag is the slave modem signaling the reply termination type. See 5.3.3:Reply TERM codes.

5.3.3 Reply TERM codes

Reply TERM codes explain why a modem ended the reply transmission after a #nn command. The replying modem transmits a TERM code after the </HOST> tag before ending the transmission.

Table 4: Reply TERM Code List

Number	Text Message (transmitted if debuglevel>0)	Description
1	THOST2 timeout (reply start)	No start of reply signal received (THOST2 setting)
2	THOST3 timeout (max reply time)--no first byte	Maximum reply time setting (THOST3) exceeded without receiving a single byte from the host instrument
3	THOST4 timeout (ICD)	Inter-character delay termination (THOST4)
4	THOST3 timeout (max reply time)	Maximum reply time setting (THOST3) exceeded.
5	term from host	Termination character received from host instrument

6 Commands

Commands are not case sensitive. They must be terminated by a carriage return character (CR, 0x0D). If a line feed (LF, 0x0A) follows the carriage return character it will be ignored. This may cause line feed characters to be dropped in file operations.

6.1.1 Status Commands

6.1.1.1 GETCD

Displays modem configuration.

```
S9>GETCD
<Config type='Ultimodem' sn='U00S' v='0'>
<Hardware>
  <Assembly>50109</Assembly>
  <Firmware>ULTIMODEM V0.96H</Firmware>
</Hardware>
<Settings>
  baud=19200
  mod=1200 baud@4.8k (1)
  id=0S
  group=0
  wakeupsrc=IM & RS232 (0)
  hostPrompt=S>
  cmdTO=60
  asyncRx=1
  telMode=1
  hostWakeup=2
  termFromHost=13
  termToHost=254
  thost0=0
  thost1=5
  thost2=3000
  thost3=12000
  thost4=500
  thost5=5
  tmodem2=500
  tmodem3=18000
  icd=1
  echo=1
  sflow=1
  debuglevel=1
</Settings></Config>
OK; 0 Events
S9>
```

6.1.1.2 GETSD

Displays modem status. This includes the battery voltage. Note the battery voltage may be low or zero when the modem is powered externally.

```
S9>GETSD
<Status type='Ultimodem' sn='U00S' v='0'>
<DataBuffer>
  nextWrite=2097152
  len=0
  CRC=FFFFFFFF
  lastEntryLen=0
  lastEntryCRC=FFFFFFFF
</DataBuffer>
  Vbat=3.498
   IM IDLE
   RS232 ACTIVE
</Status>
OK; 0 Events
S9>
```

6.1.1.3 GETEC

Displays event counters. Event counters are a useful debugging tool for S9. Most events to not indicate a problem. If you are concerned about events recorded on your modem please feel free to forward the GETEC response to S9.

```
S9>
<EventData>
numEvents = 1
nextAddr = 1040
   0, EA73, ../Usart2.c:66-1
</EventData>
```

In the example above the event was Usart2.c, line 66. This means a framing error on the RS232 serial port input.

6.1.1.4 VER

Displays modem hardware and firmware version. Note the HTYPE (hardware type) is different for OEM modems (14032-1) vs modems in housings (15011-1).

```
S9>VER
HTYPE 14032-1
CD AB0B0AE0, 12000002
CODE TYPE ULTI A
FIRM ULTIMODEM V0.6B
CDATE Feb  1 2016 14:37:24

OK; 0 Events
S9>
```

6.1.2 Configuration Commands

Modem configuration is extremely important. An improperly configured modem may seem unresponsive to either the RS232 port or the IM network. Use GETCD to retrieve the modem's configuration settings.

The name of each configuration setting is also a command to modify that setting. For example, the THOST1 setting can be changed with:

```
THOST1 100
```

or

```
THOST1=100
```

6.1.2.1 SETDEFAULTS

This command resets all modem configuration to default values.

6.1.3 Utility Commands

6.1.3.1 TXTEST

Supported in IM Service mode only. This transmits a series of characters as a communications test.

6.1.3.2 PWROFF or SLEEP

Terminates the current mode (IM Service or Host Service) allowing the modem to return to low-power sleep mode.

6.1.3.3 RESET

Forces a full reset (like a reboot). This forces the modem to return to low-power sleep mode, abandoning all in-process activity.

6.1.3.4 RESETEC

Resets the event counters.

6.1.4 File Commands

The modem has several files in flash memory (A, F, D) and one file in RAM (S). Files are identified by a single letter. Some files may be run as simple command scripts, others are reserved for data storage & transfer. Additional script files and file commands will be added soon.

6.1.4.1 Available Files

6.1.4.1.1 F File

The F file is used for scripts – most importantly firmware update scripts. Firmware update files are streamed to the F file, then the file is run with the RUN F command. The F file can may also be used for custom scripts where each line of the file is a modem command. Note that some commands cannot be used in scripts – check the 'blocks' section of the command summary for details.

6.1.4.1.2 D File

The D file is a 6 Mbyte circular buffer for ASCII data. It is intended for automatic data-transfer applications which are not yet fully developed.

6.1.4.1.3 A File

The A file is a script file used to retrieve data or perform other functions though the RS232 serial port. This file is described in more detail in Data Collection Scripts.

6.1.4.1.4 S File

The S file records data collected while the A file is running. The S file resides in RAM and can be read through the IM interface.

6.1.5 File Command Summaries

6.1.5.1 WRITE

Writes data to a file.

```
S9>write d
USE 'END S9D' OR ESCAPE TO END
this is being written to the file
USER ABORT (ESC)
OK; 0 Events
S9>
```

6.1.5.2 APPEND

Appends data to a file.

```
S9>erase a
OK; 0 Events
S9>append a this is a new line
OK; 0 Events
S9>append a this is another line
OK; 0 Events
S9>read a
<FILE>
this is a new line
this is another line

</FILE>

OK; 0 Events
S9>
```

6.1.5.3 READ

Retrieves data from a file. See example above under APPEND.

6.1.5.4 ERASE

Erases a file. See example above under APPEND.

6.1.5.5 RUN

Runs a script file.

6.1.5.6 DUMPFLASH

A utility command to retrieve the entire contents of flash memory. This allows significant data recovery if the D file is accidentally erased. This command takes about ten minutes to run.

6.1.6 IM Commands

6.1.6.1 CL or FCL (Capture Line)

This captures the IM network. Only one device can transmit at a time on an IM network. CL or FCL starts transmitting a carrier signal on the IM network. This is required prior to transmitting commands to the IM network.

6.1.6.2 SWT (Send wake-up Tone)

Sends a wake-up tone to the IM network. A wake-up tone is a 4800Hz tone which triggers many IM instruments (including older instruments from Sea-Bird Electronics) to wake from their sleep modes and start listening for commands on the IM network.

6.1.6.3 MLN (Measure Line Noise)

Measures the noise on the IM line.

6.1.6.4 IMMONITOR or IMMON

Starts a monitor mode where the modem attempts to decode signals from the IM network regardless of whether any devices are transmitting. If nothing is transmitting the modem will probably send a stream of random characters – including non-ASCII characters.

Press Escape (0x1B) to exit from this mode.

6.1.6.5 XTP

Performs a single sample and retrieves data from all XTP sensors on the IM network. Press escape (0x1B) to exit this mode early. If you exit this mode early any XTP's on the IM network may still be transmitting data. The IM line is released when the XTP command finishes.

For a known number of XTP sensors use XTP N – where N is the number of sensors. This saves time and therefore power by exiting the XTP command and releasing the line after all sensors have responded.

6.1.6.6 REL

Releases the IM line. This is the opposite of CL or FCL.

6.2 Communicating with Remote Devices

Communicating with other modems is currently a three-step process:

1) Capture the IM line with CL or FCL
2) Send IM commands to either remote modems (using ! commands) or through remote modems to the instruments connected to them (using # commands)
3) Release the IM line when finished

Most IM communication uses an addressing scheme where the first few characters of a transmission are the device ID (address) of the intended recipient. These address characters are followed by the data or commands to transmit. Only the modem with matching address replies.

6.2.1 Example Communication Session

```
PWRUP
S9>
S9>fcl
OK; 0 Events
S9>ID?
<Remote>
 id = 0A</Remote>
<qs>4049</qs>
OK; 0 Events
S9>!0Aver
<Remote>
HTYPE 14032-1
CD AB0B0AE0, 12000002
CODE TYPE ULTI A
FIRM ULTIMODEM V0.6B
CDATE Jan 21 2016 10:29:58

OK; 0 Events; qs 11780
</Remote>
<qs>4843</qs>
OK; 0 Events
S9>#0Atest
<Remote>
 <Host>
This is the reply from the remote serial port
</Host>
</Remote>
<qs>4843</qs>
OK; 0 Events
S9>rel
OK; 0 Events
S9>sleep
```

6.2.2 Communicating with Remote Modems

Communication with remote modems (as opposed to serial instruments connected to those modems) uses the ! command. In the Example Communication Session above, the line:

```
!0Aver
```

sent the VER command to the modem on the IM network with device ID=0A. The reply from modem 0A was surrounded with the <Remote> tag.

6.3 Communicating with Instruments Connected to Remote Modems

Communication through remote modems to their RS232 serial ports uses the # command. In the Example Communication Session above, the line:

```
#0Atest
```

Sends the string "test" to the RS232 port of the modem with device ID=0A. Any reply from the serial port is wrapped in the <host> tags. Both the reply and any errors or other communication from the remote modem are wrapped in the <Remote> tags.

The Ultimodem follows several steps when sending arriving data to the serial port and forwarding responses from the serial port. Most of these steps can be customized by changing configuration settings.

6.3.1 Stages of Processing Received #ii Commands

6.3.1.1 Serial Port Access

1) If the receiving modem is in Host Service mode when a #ii command is received:
    a. If configuration asyncRX setting is zero: the modem will not forward the received data – instead it will respond with a "SERIAL INTERFACE BUSY" Error.
    b. If configuration asyncRX setting is one: the modem will send "\r\n<IMRXA>\r\n" to the serial port to signal the asynchronous reception of a #ii command.

6.3.1.2 Host Wakeup

If the receiving modem is not in Host Service mode when a #ii command arrives it will

2) Initialize the serial port at the speed specified in the BAUD configuration setting
3) Disable software flow control
4) Wait 50mS for the RS232 driver to fully activate. This 50 mS delay occurs even in modems with logic level serial interfaces.
5) Wake the host according to the hostWakeup setting:
    a. If hostWakeup=1 the IMflag signal will go active. Note the active polarity of the IMFlag output is changed by the imfConfig setting.
    b. If hostWakeup=2 the modem will transmit '\r' to the serial port and wait 10mS after the transmission completes.
    c. If hostwakeup=3 the modem will activate the IMFlag output for 10mS, then deactivate the output
    d. If hostWakeup > 3 the modem will set a serial break condition for 10mS times the hostWakeup value. For example, hostWakeup=100 generates a 1000 mS break condition.

6.3.1.3 Confirming Host Wakeup

After the Host Wakeup stage the modem confirms the host is awake before sending the received data. There are several ways to confirm host wakeup.

6) Confirm host wakeup by:
    a. THOST0 timeout, measured from the end of the Host Wakeup stage
    b. Receipt of the hostPrompt from the serial port. HostPrompt is a configuration setting.
    c. Receipt of more than 15 characters from the serial port.

    Note that wakeup confirmation with the Hostflag input signal is not implemented. Please contact S9 if you need this feature.

6.3.1.4 Delay after Wakeup

7) THOST1 allows a configurable delay after confirming host wakeup. This delay is measured from the end of Host Wakeup Confirmation.

6.3.1.5 Sending Received Data to the Serial Port

8) The data received in the #ii command is forwarded to the serial port.

    If the ICD configuration setting is not zero then inter-character delay will be added. In this case the modem sends a single byte to the port, waits for the character to transmit, then waits the ICD time before sending the next character.

6.3.1.6 Terminating Data Transmission to Host

9) After sending the data received in the #ii command to the serial port, the modem sends additional characters as defined by the TERMTOHOST configuration setting.
    a. If TERMTOHOST=0 then no additional characters are transmitted.
    b. If TERMTOHOST=1 then the modem sends "\r\n". The ICD setting applies in this transmission.
    c. If TERMTOHOST is any other value the modem sends a byte of that value to the serial port.

6.3.1.7 Start of Host Reply

10) The modem waits according to the THOST2 configuration setting for the first byte of reply from the serial port.
    a. If THOST2=0 then the first byte timeout is disabled
    b. If THOST2 timeout expires with no bytes received from the serial port the modem disconnects from the serial port, responds with TERM 1, and if DEBUGLEVEL is greater than 0 the message "THOST2 timeout (reply start)"

Note the THOST3 setting applies at the same time as THOST2. THOST3 should never be set shorter than THOST2, but if it is and the THOST3 limit is reached before the THOST2 limit the modem will respond with TERM 2, and if DEBUGLEVEL is greater than 0 the message "THOST3 timeout (max reply time)--no first byte"

6.3.1.8 Host Data Relay

After the Start of Reply the modem forwards all data received from the serial port through the inductive modem. This continues until one of the Termination from Host conditions occurs.

The modem has an 8kB circular buffer for data received from the serial port. If the host will send more than 8kB it may be necessary to pause the data stream to avoid overflowing this buffer. If the buffer overflows a UERR 4 error will be logged in the event counters[3] and some of the data sent by the host will not be transmitted to the remote modem. A good rule when TELMODE=3 is to estimate 100 bytes per second leaving the buffer when MOD=1 and 400 bytes per second leaving the buffer when MOD=4.

Note the TELMODE setting in the receiving and transmitting modems must match for proper communication. TELMODE 3 is required for binary data when the remote modem is an Ultimodem from S9. TELMODE 1 or 2 is required when the remote modem is an IMM from SEA-Bird Electronics, depending on the IMM's BINARY setting. TELMODE 1 is required when the remote modem is a SIM from Sea-Bird Electronics.

6.3.1.9 Termination from Host

The Host Data Relay may be terminated by THOST3, THOST4 or receipt of one or more characters defined by the TERMFROMHOST configuration setting.

11) The Host Data Relay continues until:
    a. THOST4 inter-character delay timeout occurs with no additional bytes received. In this case the modem responds with TERM 3 and if DEBUGLEVEL is greater than 0 the message "THOST4 timeout (ICD)"
    b. THOST3 max reply timeout occurs. In this case the modem responds with TERM4 and if DEBUGLEVEL is greater than 0 the message "THOST3 timeout (max reply time)"
    c. Receipt of the TERMFROMHOST character(s):
        i. If TERMFROMHOST=0 there is no special character used to mark the end of data from the host
        ii. If TERMFROMHOST=254 then the string "\r\n" marks the end of data from the host
        iii. If TERMFROMHOST is any other value then receipt of a byte with that value from the serial port marks the end of data from the host.

If data from the host is terminated as in either ii or iii described above then the modem responds with TERM4 and if DEBUGLEVEL is greater than 0 the message "term from host"

6.3.1.10 Wait for IM Transmission

---

[3] Note the UERR event logs multiple types of UART errors, please refer to Table 5 Events with Text Codes for more details.

The baud rate from the serial port may be much faster than the rate of transmission to the remote modem. In theory there could be nearly 8kB of data remaining in the serial receive buffer waiting for transmission to the remote modem when the Termination from Host occurs. This data may take as much as 90 seconds to transmit in MOD 1, or 25 seconds in MOD 4.

12) The modem keeps the serial port open, RS232 driver enabled, and IMFlag signal active (if HOSTWAKEUP=1) until the last bytes received from the serial port are transmitted to the remote modem.

    During this time the THOST3 timeout can still occur. Be sure to allow enough time in THOST3 for IM transmission of the entire reply from the host with the selected MOD and TELMODE settings.

6.3.1.11 End of Transmission

After the last bytes from the serial port are transmitted to the remote modem the modem sends some additional data and performs a few more tasks before ending the IM transmission.

13) The modem sends "</Host>\r\n" to mark the end of data received from the serial port
14) The modem sends the TERM x message, including the numeric code signaling what terminated the host communication
15) The modem sends any additional messages enabled only when DEBUGLEVEL is greater than zero
16) If the modem was in Host Service mode with ASYNCRX=1 when the # command arrived then it sends </IMRX> to the serial port to signal the end of the #ii command interaction.
17) If HOSTWAKEUP=1 the modem deactivates the IMFlag output
18) The modem disables the serial port RS232 driver and waits 10mS for the driver to disable -- unless the modem was in Host Service mode with ASYNCRX=1 when the # command arrived, in which case it leaves the serial port active.
19) The modem ends the IM transmission

6.4 Data Collection Scripts

There are two types of script files. One is a command script (the F file) used for firmware updates or configuration scripts. The other is a data collection script (the A file) used to collect data from the RS232 serial port. Data collection scripts use a special limited command set. These commands are almost identical to commands used in the DANTE buoy controller to collect data from serial instruments.

When the A file script is running all data received from the serial port is recorded in the S file. Most applications run the A file then retrieve the data collected from the S file.

6.4.1 Data Collection Example

This is an example of running a data collection script on a remote modem and retrieving the result:

```
S9>fcl
OK; 0 Events
S>!0Arun a
<Remote>
 RUNNING PROGRAM A

OK; 0 Events; qs 11056
</Remote>
<qs>3471</qs>

OK; 0 Events
S>!0Aread s
<Remote>
<FILE id='S'>
This text was recorded from the serial port while file A script ran
</FILE>

OK; 0 Events; qs 11056
</Remote>
<qs>3636</qs>

OK; 0 Events
S9>
```

6.4.2 Script Commands

6.4.2.1 SERIAL ON

Enables the modem serial port at the specified baud rate. The baud rate may be any multiple of 1200 up to 115200.

```
SERIAL ON 9600
```

Enables the serial port at 9600 baud (8-bits, no parity, 1 stop bit, no flow control)

6.4.2.2 SERIAL OFF

Disables the modem serial port

6.4.2.3 BINARY

Sets the modem RS232 port to operate in binary data mode (default is ASCII). In binary mode all data received from the sensor is converted to ASCII hex. Note that data is stored as ASCII hex in the data buffer, meaning number of bytes stored in the sample data buffer is twice the length of the received binary data.

6.4.2.4 ASCII

Sets the modem RS232 port to ASCII mode (default is ASCII). In ASCII mode all data sent to and received from the serial port is expected to be plain text. Non-text characters (>0x7F) may be ignored, cause events in the event counters and / or be replaced with other characters ('X', '$' or '*').

6.4.2.5 CLEARBUFFER

Clears the contents of the S file (the receive data buffer). This is intended to remove characters that result from transients on the serial data lines when a sensor is powered. Any data received before a CLEARBUFFER command is lost and not recorded in any log file.

6.4.2.6 SAVE D

Saves the S file to the D file and clears the S file. Data from the S file is wrapped in <UMSample> tags with sample number, length and CRC parameters. Note the sample number increments each time the sample script runs (each RUN A command). It does not increment during a SAVE D command.

6.4.2.7 DELAY

Waits a specified time in milliseconds, up to a maximum of 15 minutes. (15 min * 60 seconds/min*1000 milliseconds per second = 900000 milliseconds).

```
DELAY 100
```

Waits 100 milliseconds

6.4.2.8 TIMESTAMP

The TIMESTAMP command is not yet implemented. The modem has a real time clock and can be updated to track time.

6.4.2.9 BREAK

Sends a serial break. Minimum is 10, maximum is 10000 (10 seconds).

BREAK 100

Sends a 100 millisecond serial break.

6.4.2.10 IMFLAG

Use IMFLAG 0 and IMFLAG 1 to set / clear the IMFlag output. Use IMFLAG 2 to output a 10mS pulse on the IMFlag output. Note the imfConfig setting affects polarity.

The IMFlag output is not automatically reset when the script terminates. Changes to IMFlag state persist until explicitly changed, a reset or a power cycle.

6.4.2.11 SEND

Transmits characters to the modem serial port. Behavior of this command depends on the ASCII/Binary setting (see ASCII and BINARY commands)

6.4.2.11.1 ASCII Mode (default)

```
SEND "a string\r"
```

Sends 'a string' followed by carriage return (hex 0D) to the serial port.

The maximum string length is 64 characters.

A few common character sequences are available to send special or non-printing characters to the modem serial port:

Sequence	Description	Hex Value
\r	Carriage Return	0D
\n	Line Feed	0A
\\	Front slash	2F
\"	Quote	22
\t	Tab	09

So `SEND "test\r\n"` will send 'test' followed by CR (hex 0D) and LF(hex 0A)

6.4.2.11.2 Binary Mode

```
SEND "6120737472696E670D"
```

Sends 'a string' followed by carriage return (hex 0D) to the serial port.

The maximum string length is 32 binary characters, which is 64 bytes of ASCII hex.

6.4.2.12 WAITFOR

Waits for a string to arrive on the modem serial port, with a maximum delay. If the maximum delay time is reached without receiving the target string then the modem adds 'UM-TIMEOUT' to the received data buffer and proceeds to the next line of the script. Behavior of this command depends on the ASCII/Binary setting (see ASCII and BINARY commands)

6.4.2.12.1 ASCII Mode

```
WAITFOR "S>",3000
```

Waits for the string 'S>' for up to 3 seconds. Note the ',' character is required before the delay

The maximum string length is 64 characters.

6.4.2.12.2 Binary Mode

```
WAITFOR "533E",3000
```

Waits for the string 'S>' for up to 3 seconds. (0x53 is hex for 'S', 0x3E is hex for '>')

The maximum string length is 32 binary characters, which is 64 bytes of ASCII hex.

6.5 Retrieving Data from XTP Sensors

XTP's are eXpendible Temperature and Pressure sensors with built-in inductive modems. XTP's use a simplified IM communication protocol with no device ID's. Use the XTP command to retrieve data from XTP sensors. The IM network must be idle for at least five seconds before sending the XTP command. The XTP command retrieves data from all XTP sensors on the IM network.

7 Event Counters

Event counters are an important tool for firmware testing, application testing, and debugging. The Event Counter is a system for recording potentially important events in the modem. It includes a dedicated space in nonvolatile memory to store these events. Most events are recorded in the order in which they occurred, but some events that occur in interrupt service routines are recorded later for maximum reliability.

Each event record includes a time code, a short text string, an integer number and a number of times the event occurred in a row. For most events the text string is the name of the source code file and the integer number is the line number of that file where the event is detected. Some events use a text / number identifier instead of a file and line number.

7.1 Event Resets

If the firmware detects a potentially serious error it will reset the modem. Every time the modem is reset it logs two events when it restarts. The first event is "EVENT RESET". The next event records the reason for the reset. The integer is always 555 for the second event event.

Most Event Resets indicate serious problems. One exception is the RESET command, which resets the modem and records both an EVENT RESET and a RESET Cmd event.

Table 5 Events with Text Codes

Error Text	Error Number	Description
OSC32FAIL	NA	The 32KHZ oscillator did not start up properly.
IMTXUR	NA	IM transmit interrupt latency error—transmission may have error
IMRXOF	NA	IM receive buffer overflow – a received character may be missing

UERR	0 not used 1 rx overwrite 2 framing error 3 rx buffer overflow 4 tx underflow 5 unknown error 6,7 not used	One or more serial port errors occurred. The error code uses bit flags to identify the error. The numbers on the left are bit numbers. For example, a UERR 5 means both a receive overwrite error and a receive buffer overflow error (2^1 + 2^5)
EVENT_RESET	NA	The firmware reset the modem. The next event records the reason for the reset.
RESET Cmd	NA	Indicates the Event Reset was cause by the RESET command.

7.1.1 MinWakeups

MinWakeups are when the modem detects a signal on the IM line and enters a low power state to determine if the signal is an actual IM signal. If it is not the modem logs the minwakeup and returns to sleep. If it is potentially an IM signal the modem enters IM Service mode.

7.1.2 SoftWakeups

Softwakeups are when the modem enters IM Service mode then detects 10 or more invalid characters in the IM data stream within the first 500 milliseconds. The modem assumes the wakeup was caused by noise, logs a SoftWakeup and returns to sleep.

8 Retrieving Data with a Script

In this example the master controller commands the slave to run a pre-configured script. The slave runs the program and records data from its host instrument. The master retrieves the data later when the program is completed.

8.1 Data Collection Scripts

There are two types of script files. One is a command script (the F file) used for firmware updates or configuration scripts. The other is a data collection script (the A file) used to collect data from the RS232 serial port. The A file data collection script uses a special limited command set. These commands are almost identical to commands used in the DANTE buoy controller to collect data from serial instruments.

When the A file script is running all data received from the serial port is recorded in the S file. Most applications run the A file then retrieve the data collected from the S file.

8.2 Script Related Modem Commands

Command	Notes
WRITE A	Writes to the A file
READ A	Reads the A file
READ S	Reads the S file
RUN A	Runs the A file. When run from the serial interface the command interface is disabled until the script ends.

8.3 The S File

The S file is a RAM buffer. It records data from the host instrument during the script. Scripts can use CLEARBUFFER to empty this file and SAVE D to save the current contents to the D buffer before clearing the file.

The maximum length of the S file is 6kB. If the host instrument sends more than 6kB then the script can use multiple SAVE D commands with an appropriate time delay in between.

8.4 A File Script Commands

These are the only commands available in the A file script.

Command	Examples	Notes
SERIAL ON	SERIAL ON 19200 SERIAL ON 9600	Enables the serial port at the specified baud rate
SERIAL OFF		Disables the serial port
CLEARBUFFER		Erases the contents of the S file
SAVE D		Saves S file to D file and clears S file
DELAY	DELAY 100 DELAY 10000	Pauses for a specified number of milliseconds (maximum 900000 – which is 15 minutes)
TIMESTAMP		Reserved – will add an ISO9001 time stamp in the S file.
BREAK	BREAK 100 BREAK 1000	Sends a break condition on the serial port for a specified number of milliseconds. (10 to 10000)
SEND	SEND “ts\r” SEND “SL\r”	Sends a string to the serial port. Common escape codes \r, \n, \t, \”and \\ are implemented. Use \e to send an escape character (0x1B);
WAITFOR		

8.4.1 SERIAL ON

Enables the modem serial port at the specified baud rate. The baud rate may be any multiple of 1200 up to 115200.

```
SERIAL ON 9600
```

Enables the serial port at 9600 baud (8-bits, no parity, 1 stop bit, no flow control)

8.4.2 SERIAL OFF

Disables the modem serial port

8.4.3 CLEARBUFFER

Clears the contents of the S file (the receive data buffer). This is intended to remove characters that result from transients on the serial data lines when a sensor is powered. Any data received before a CLEARBUFFER command is lost and not recorded in any log file.

8.4.4 SAVE D

Saves the S file to the D file and clears the S file. Data from the S file is wrapped in <UMSample> tags with sample number, length and CRC parameters. Note the sample number increments each time the sample script runs (each RUN A command). It does not increment during a SAVE D command.

8.4.5 DELAY

Waits a specified time in milliseconds, up to a maximum of 15 minutes. (15 min * 60 seconds/min*1000 milliseconds per second = 900000 milliseconds).

```
DELAY 100
```

Waits 100 milliseconds

8.5 TIMESTAMP

The TIMESTAMP command is not yet implemented. The modem has a real time clock and can be updated to track time.

8.5.1 BREAK

Sends a serial break. Minimum is 10, maximum is 10000 (10 seconds).

BREAK 100

Sends a 100 millisecond serial break.

8.5.2 BINARY

Sets the modem RS232 port to operate in binary data mode (default is ASCII). In binary mode all data received from the sensor is converted to ASCII hex. Note that data is stored as ASCII hex in the data buffer, meaning number of bytes stored in the sample data buffer is twice the length of the received binary data.

8.5.3 ASCII

Sets the modem RS232 port to ASCII mode (default is ASCII). In ASCII mode all data sent to and received from the serial port is expected to be plain text. Non-text characters (>0x7F) may be ignored, cause events in the event counters and / or be replaced with other characters ('X', '$' or '*').

8.5.4 SEND

Transmits characters to the modem serial port. Behavior of this command depends on the ASCII/Binary setting (see ASCII and BINARY commands)

8.5.4.1 SEND in ASCII Mode

```
SEND "a string\r"
```

Sends 'a string' followed by carriage return (hex 0D) to the serial port.

The maximum string length is 64 characters.

A few common character sequences are available to send special or non-printing characters to the modem serial port:

Sequence	Description	Hex Value
\r	Carriage Return	0D
\n	Line Feed	0A
\\	Front slash	2F
\"	Quote	22
\t	Tab	09
\e	Escape	1B

So `SEND "test\r\n"` will send 'test' followed by CR (hex 0D) and LF(hex 0A)

8.5.4.2 SEND in Binary Mode

```
SEND "6120737472696E670D"
```

Sends 'a string' followed by carriage return (hex 0D) to the serial port.

The maximum string length is 32 binary characters, which is 64 bytes of ASCII hex.

8.5.5 WAITFOR

Waits for a string to arrive on the modem serial port, with a maximum delay. If the maximum delay time is reached without receiving the target string then the modem adds 'UM-TIMEOUT' to the received data buffer and proceeds to the next line of the script. Behavior of this command depends on the ASCII/Binary setting (see ASCII and BINARY commands)

8.5.5.1 WAITFOR in ASCII Mode

```
WAITFOR "S>",3000
```

Waits for the string 'S>' for up to 3 seconds. Note the ',' character is required before the delay

The maximum string length is 64 characters.

8.5.5.2 WAITFOR in Binary Mode

```
WAITFOR “533E”,3000
```

Waits for the string ‘S>’ for up to 3 seconds. (0x53 is hex for ‘S’, 0x3E is hex for ‘>’)

The maximum string length is 32 binary characters, which is 64 bytes of ASCII hex.

8.6 Example Retrieving Data with a Script

In this example the slave modem is preconfigured with a script in the A file. The Slave WAKEUPSRC=1.

8.6.1 Sample Script Setup

This is the sample script pre-programmed in the slave modem:

```
S9>read a
<FILE>
serial on 19200
send "test command"
waitfor "end",10000
save d
</FILE>
OK; 0 Events
S9>
```

Master		Slave
	Receive	Transmit
PWRUP S9>fcl OK; 0 Events S9>!37run a <Remote> RUNNING PROGRAM A OK; 0 Events; qs 5421 </Remote> <qs>96216</qs> OK; 0 Events		
	test command	
		response: abcdefghijklmnopqrstuvwxyz0030 abcdefghijklmnopqrstuvwxyz0060 abcdefghijklmnopqrstuvwxyz0090 abcdefghijklmnopqrstuvwxyz0120 abcdefghijklmnopqrstuvwxyz0150 abcdefghijklmnopqrstuvwxyz0180

```
abcdefghijklmnopqrstuvwxyz0210
abcdefghijklmnopqrstuvwxyz0240
abcdefghijklmnopqrstuvwxyz0270
abcdefghijklmnopqrstuvwxyz0300
end
```

```
S9>!37read s
<Remote>
<FILE id='S' len='0'
crc='FFFFFFFF'></FILE>
OK; 0 Events; qs 5421
</Remote>
<qs>154654</qs>
OK; 0 Events
```

S file is empty because the sample script used SAVE D to move data to the D file.

```
S9>!37read dl
<Remote>
<FILE id='DL' len='381' crc='
48DD8BA'><UMSample v='0' n='9'
l='323'
crc='CFCD4D0C'>response:
abcdefghijklmnopqrstuvwxyz0030
abcdefghijklmnopqrstuvwxyz0060
abcdefghijklmnopqrstuvwxyz0090
abcdefghijklmnopqrstuvwxyz0120
abcdefghijklmnopqrstuvwxyz0150
abcdefghijklmnopqrstuvwxyz0180
abcdefghijklmnopqrstuvwxyz0210
abcdefghijklmnopqrstuvwxyz0240
abcdefghijklmnopqrstuvwxyz0270
abcdefghijklmnopqrstuvwxyz0300
end</UMSample>

</FILE>
OK; 0 Events; qs 5421
</Remote>
<qs>117921</qs>
OK; 0 Events
```

The READ DL command returns only the data from the most recent script. Read D could be used to read all data.

9

10 Using the D File

The D file is a general purpose text file stored in nonvolatile memory. The D file is intended for ASCII text, but it can store any characters except 0x00, 0x08, 0x1B, 0x7E and 0xFF. The D file is a circular buffer with maximum length 5Mbytes (5242880 bytes). Writing past this maximum length will delete the oldest data first in chunks of 65536 bytes.

10.1 Reading the D File

There are two commands to read the D file. The READ D command reads the entire D file. The READ DL command reads only the last entry in the D file. Both are accepted through the serial interface or IM interface.

Note some terminal programs may change lines ending in CR to CR LF and vice versa. Terminal programs may display lines differently depending on these characters. When using TeraTerm Version 2.82 we recommend configuring Setup->Terminal-> New-line receive CR+LF and transmit CR. This avoids confusion caused by new lines printing on top of previous lines. Another good technique is to log the data to a file and view the file in a text editor.

10.2 Writing to the D File

There are two ways to write data to the D file. On is the WRITE D command available through the serial interface. The other is the SAVE D command in a script (the A file). WRITE D allows immediate storage of data in the D file. SAVE D moves data from the S file to the D file (leaving the S file empty).

10.2.1 D File Last Entry

Each WRITE D command on the serial port or script run containing a SAVE D command resets the lastSampleLen and lastSampleCRC. This allows the READ DL command to respond with the data saved in the most recent entry and the CRC matching this data.

10.2.2 D File Status

Use the STATUS D command to read status of the D file. This data is also included in the GETSD command reply. The nextWrite value indicates the next write address within the modem's nonvolatile memory. It is included only for debugging purposes.

```
S9>status d
<DataBuffer>
  nextWrite=2097219
  len=67
  CRC=4D995C9D
  lastEntryLen=67
  lastEntryCRC=4D995C9D
</DataBuffer>
OK; 0 Events
S9>
```

10.2.3 Writing to D File Over Serial Interface

The example below uses CR (not CR+LF) at the end of each line. Data recording continues until the modem receives either 'END D' on a line by itself or the escape character (0x1B) or ~(0x7E).

```
S9>write d
USE 'END D' OR ESCAPE TO END
```

```
test1
end d

OK; 0 Events

S9>read d

<FILE id='D' len='6' crc='AC00FCE4'>test1
</FILE>

OK; 0 Events
```

Note the CR between ‘test1’ and ‘end d’ is included in the recorded data. To avoid this use the escape key (0x1B) or ~ (0x7E) to end the write.

```
S9>write d
USE 'END D' OR ESCAPE TO END
test2
end d

OK; 0 Events

S9>read d

<FILE id='D' len='12' crc='1963B1B7'>test1
test2
</FILE>
```

Note the second WRITE D command appended the data to the file.

```
OK; 0 Events

S9>read dl

<FILE id='DL' len='6' crc='872DAF27'>test2
</FILE>

OK; 0 Events

S9>
```

The READ DL command read only the data from the most recent write.

10.2.3.1 Unexpected LF characters

Some terminal programs send both CR and LF when the enter key is pressed, while others send only CR. The Ultimodem accepts the WRITE D command on the CR. If your terminal then sends LF then the data written to the D file will start with LF.

10.2.4 D File Command Table

Command	Notes
READ D	Read the entire D file
READ DL	Reads the last entry in the D file
WRITE D	Appends a new entry to the D file
ERASE D	Erases the entire D file
STATUS D	Returns the status of the D file including length and checksums of both the entire file and the last entry

10.2.5 Saving to D File in a Script

When used in a script (program A) the SAVE D command appends the contents of the S fileto the D file. The data is wrapped in <UMSample> tags with separate length, sample number and CRC data. In the example below the S filecontained "TEST DATA\r" when the WRITE D command was processed. The sample number was 2 (n='2'). The length is 10, which includes the CR at the end.

```
S9>read dl
<FILE id='DL' len='67' crc='4D995C9D'><UMSample v='0' n='2' l='10'
crc='957ADEB7'>test data
</UMSample>

</FILE>
```

It is appropriate to use the SAVE D command multiple times in a single script. This results in multiple <UMSample> tags with the same sample number. The READ DL command will return all data saved within the script even with multiple SAVE D commands in the program.

10.3 Example Retrieving Data Through D File

In this example a controller connected to the slave modem saves data to the D file and the controller on the master modem retrieves the data. Note for this example the slave WAKEUPSRC is set to 0 to allow the attached controller access to the serial command interface.

The master could also use the READ DL command to read only the last data written to the D file.

This example used MOD=4 for faster communication.

Note

Master	Slave
	PWRUP S9>write d USE 'END D' OR ESCAPE TO END test d file: abcdefghijklmnopqrstuvwxyz0030 abcdefghijklmnopqrstuvwxyz0060 abcdefghijklmnopqrstuvwxyz0090 abcdefghijklmnopqrstuvwxyz0120 abcdefghijklmnopqrstuvwxyz0150

```
abcdefghijklmnopqrstuvwxyz0180
abcdefghijklmnopqrstuvwxyz0210
abcdefghijklmnopqrstuvwxyz0240
abcdefghijklmnopqrstuvwxyz0270
abcdefghijklmnopqrstuvwxyz0300
end d
OK; 0 Events
S9>sleep
OK; 0 Events
S9>SLEEP
```

```
PWRUP
S9>fcl
OK; 0 Events
S9>!37read d
<Remote>
<FILE id='D' len='323'
crc='AE54A710'>test d file:
abcdefghijklmnopqrstuvwxyz0030
abcdefghijklmnopqrstuvwxyz0060
abcdefghijklmnopqrstuvwxyz0090
abcdefghijklmnopqrstuvwxyz0120
abcdefghijklmnopqrstuvwxyz0150
abcdefghijklmnopqrstuvwxyz0180
abcdefghijklmnopqrstuvwxyz0210
abcdefghijklmnopqrstuvwxyz0240
abcdefghijklmnopqrstuvwxyz0270
abcdefghijklmnopqrstuvwxyz0300
</FILE>
OK; 0 Events; qs 5569
</Remote>
<qs>155866</qs>
OK; 0 Events
S9>sleep
```

11 GDATA Commands

Sensors from Sea-Bird Electronics use commands like GDATA, DATA and SENDGDATA to synchronize sampling of all instruments on a mooring.

The Ultimodem now supports these commands.

11.1 SENDGDATA

Sends GDATA global command to all remote sensors. The IM line must be captured. This global command tells all sensors to take a sample.

11.2 GDATA

When an Ultimodem receives the GDATA global command it runs the A file data collection script. Refer to previous sections for details about the A file.

11.3 DATA

This returns the contents of the S file, which holds data collected by the A file script. Refer to previous sections for details about the S file.

Note there is no DATAii command. The master modem should use !nnDATA to retrieve data.

12 Possible Communication Failures

Several types of communication failures are possible. Proper handling of at least

12.1 No Reply

If noise occurs as the master transmits the command to the slave, the slave may not understand the command and may not reply.

```
S9>!37ver
Error:No reply

S9>
<qs>130</qs>

OK; 0 Events
```

12.1.1 No Response with Incorrect Reply Detection

If the slave modem did not reply there is a chance the master modem will read a start of reply marker in the background noise. In this case the master sends the <Remote> tag but the characters received are just noise.

12.2 Reply Detection Fail

If noise occurs at the start of a reply the master may not detect the slave modem reply. In this case the master must attempt to transmit until the slave reply terminates – otherwise two devices transmit at the same time and results are unpredictable.

```
S9>!37ver
Error:No reply

S9>
<qs>143143</qs>
```

Note the large number in the <qs> tags – this means something is transmitting. The controller should release the line (REL) and wait until the MLN command shows low noise.

Table 6: MLN Response With and Without IM Activity

Nothing Transmitting	Slave Modem Transmitting
S9>rel	S9>rel
OK; 0 Events	OK; 0 Event
S9>mln	S9>mln
00067	01166
00052	00993
00040	01190
00062	01220
00060	00920
00058	01002
00037	00978
00065	01128
00068	00900
00043	01195
OK; 0 Events	OK; 0 Events

12.3 Wrong Slave Responds

If noise corrupts the target slave address it is possible for the wrong slave to respond. This is most common with many slave devices on a mooring. The most reliable way to avoid this is to avoid using sequential slave addresses. Using slave addresses 01,02,03 is much more likely to have this issue than using 11,22,33.

12.4 Multiple Slave Response

Similar to Wrong Slave Responds, noise during the slave address portion of the signal can cause more than one slave to respond. This means more than one device transmits on the IM line at the same time. Usually the result looks like noise and garbage characters. This case may appear the same as No Response with Incorrect Reply Detection and it should be handled the same way.

13 XON XOFF Software Flow Control

By default the modem uses XON / XOFF software flow control. When the modem serial receive buffer reaches 380 characters the modem sends the XOFF character (0x13) requesting the host pause transmission, and when the buffer has emptied to 128 characters the modem sends the XON character (0x11) telling the host it is ok to continue transmission. This setting is particularly important for sending files, such as the F file used for firmware updates.

13.1 Disabling Software Flow Control

The XON and XOFF characters may cause confusion if they are not processed properly by the host instrument controller or terminal program. They can be disabled by setting SFLOW 0. Use SFLOW 1 to enable software flow control. This setting is included in the GETCD response.

13.2 Serial Buffer Length

The modem serial buffer size is 8kBytes. Writing more than 8kbytes with flow control disabled allows a risk the modem might not be able to handle the data fast enough and may drop some bytes.

14 Complete Command Set

Command	Blocks	Parameters	Description
GETCD			Displays configuration settings
GETSD			Displays status data
GETEC			Displays event counters
VER			Displays hardware and firmware version
SETDEFAULTS			Resets all configuration to default values
TXTEST	RS232		Transmits a IM test string
PWROFF			Same as SLEEP. Terminates active mode (IM Service or Host Service)
SLEEP			Same as PWROFF. Terminates active mode (IM Service or Host Service)
RESETEC			Resets (clears) the event counters
RESET			Resets the modem – ending all processes and forcing return to sleep mode.
WRITE	FILE	A, F, D	Writes to a file.
APPEND	FILE	A	Appends a file
READ	FILE IM*	A, S, F, D	Reads a file. *READ S and READ A are allowed on IM interface. READ D and READ F are allowed only on serial interface.
ERASE	FILE	A, S, F, D	Erases a file
STATUS		A, S, F, D	Displays status about a file (not implemented for all files)
RUN	FILE	A, F	Runs a file as a script. RUN F runs F file as a simple command script. RUN A runs the A file as a data collection script.
DUMPFLASH	FILE IM		Outputs the entire contents of the flash memory. May take 10 minutes to complete.
FCL	IM IM ACTIVE		Same as CL. Captures the IM line.
CL	IM IM ACTIVE		Same as FCL. Captures the IM line.
SWT	IM		Sends a wake-up tone
MLN	IM IM ACTIVE		Measures noise on the IM line.

IMMONITOR (same as IMMON)	IM IM ACTIVE	Same as IMMON. Starts a monitor mode displaying all characters received from the IM network.
IMMON (same as IMMONITOR)	IM IM ACTIVE	Same as IMMONITOR. Starts a monitor mode displaying all characters received from the IM network.
XTP	IM IM ACTIVE	Retrieves a sample from each XTP sensor on the IM network.
REL	IM	Releases the IM line
!	IM IM IDLE	Sends a command to a remote modem
!G	IM IM IDLE	Sends a group IM command to the network. There are no replies to group commands.
ID?	IM IM IDLE	Retrieves the device ID of the modem on the IM line. NOTE: this command does not work when more than one IM device is on the network!
#	IM IM IDLE	Sends a command through a remote modem to its serial port.
#G	IM IM IDLE	Sends a command through a group of remote modems to their serial ports.

15 Configuration

15.1 Modulation

Set both master and all slave modems to mod=4 to use 4800 baud IM communications. This mode is not compatible with modems from Sea-Bird Electronics. Use MOD=1 on all modems for 1200 baud IM communications.

15.2 Wakeup Source

The WAKEUPSRC setting is often an important difference between the master modem and slave modems.

Master: WAKEUPSRC=1 so the master modem will not waste time / power looking for IM signals initiated from other instruments.

Slaves: WAKEUPSRC=2 so the slave units will not respond to RS232 activity from the slave instruments except at request of the master. This prevents situations where the modem and instrument echo characters or invalid commands to each other in an infinite loop.

15.3 Configuration Summary

Below are the configurations of the master and slave modems used in this example.

U004 (master – datalogger)

```
S9>wakeupsrc=1
OK; 0 Events
S9>getcd
<Config type='Ultimodem' sn='U004'
v='0'>
<Hardware>
  <Assembly>50109</Assembly>
  <Firmware>ULTIMODEM
V0.96A</Firmware>
</Hardware>
<Settings>
  baud=19200
  mod=1200 baud@4.8k (1)
  id=04
  group=0
  wakeupsrc=RS232 Only (1)
  hostPrompt=S>
  cmdTO=60
  asyncRx=1
  telMode=1
  hostWakeup=2
  termFromHost=13
  termToHost=254
  thost0=0
  thost1=5
```

U02N (connected to instrument)

```
S9>wakeupsrc=2
OK; 0 Events
S9>getcd
<Config type='Ultimodem'
sn='U037' v='0'>
<Hardware>
  <Assembly>50109</Assembly>
  <Firmware>ULTIMODEM
V0.96A</Firmware>
</Hardware>
<Settings>
  baud=19200
  mod=1200 baud@4.8k (1)
  id=37
  group=0
  wakeupsrc=IM Only (2)
  hostPrompt=S>
  cmdTO=60
  asyncRx=1
  telMode=1
  hostWakeup=2
  termFromHost=13
  termToHost=254
  thost0=0
  thost1=5
```

```
   thost2=3000
   thost3=12000
   thost4=500
   thost5=5
   tmodem2=500
   tmodem3=18000
   icd=1
   echo=1
   sflow=1
</Settings></Config>

OK; 0 Events
S9>
```


```
   thost2=3000
   thost3=12000
   thost4=500
   thost5=5
   tmodem2=500
   tmodem3=18000
   icd=1
   echo=1
   sflow=1
</Settings></Config>

OK; 0 Events
S9>
```


16 Configuration Settings

Note the name of each configuration setting is also a command to modify that setting. Use a space or = between the command and parameter value:

`BAUD=19200`

and

`BAUD 19200`

Are both acceptable.

Command	Parameter default value in ()	Description
ID	00-ZZ (01) Always two alphanumeric digits.	Modem ID for IM network.
GROUP	0-9 (0)	Group address for IM network.
WAKEUPSRC	0 (RS232 and IM) (0) 1 (RS232 only) 2 (IM Only)	Selects interfaces which can wake the modem from sleep mode
MODULATION (same as MOD)	1-4 (1)	Selects the encoding used for IM communication – this determines the speed of communication on the IM network. Use MOD=4 for 4800 baud communication
MOD (same as MODULATION)		
BAUD	`1200, 2400, 4800, 9600, 14400, 19200, 38400, 57600, 115200`	Baud rate for serial port.
HOSTPROMPT	11 characters max, no spaces	Prompt expected from host serial device. This is one method of confirming host wake up.[4]
MODEMPROMPT	11 characters max, no spaces, S9>	Prompt displayed by Ultimodem in Host Service mode

[4]The Sea-Bird Electronics IMM has a modemprompt setting controlling the prompt sent in host service mode by the IMM. The Ultimodem has no such setting – its prompt is always S9>

CMDTO	10-300 (60) (seconds)	Time-out setting for Host Service mode. Host Service ends if no valid commands received for this length of time.
ASYNCRX	0 (off) 1 (on)	Enables/disables # commands on IM line when Host Service mode active. Only applies when WAKEUPSRC=0.
TELMODE	1 (old SBE compat) (1) 2 (IMM binary compat) 3 (max bandwidth)	Selects encoding of data on the IM network – allows full compatibility with IMMs, SIMs and instruments from SEA-Bird Electronics.
HOSTWAKEUP	0-255 (\r)	Selects action taken to wake host before forwarding data from incoming # commands. 0 - no action 1 – set IMFlag output to high state to wake host (note imfConfig may invert state) 2 – send CR (\r) followed by 10mS delay to wake host. 3 – pulse IMFlag output high for 10mS to wake host (note imfConfig may invert state) >3 – wake host with a serial break of length 10mS times HOSTWAKEUP setting. (HOSTWAKEUP=10 causes a 100mS break)
TERMFROMHOST	0-255 (0)	Selects a character from the host to trigger the end of a reply to an incoming # command. 0 – no termination character. 1-253 – termination character Note this reply may also be terminated by the THOST2, THOST3 or THOST4 settings.
TERMTOHOST	0-255 (254)	Selects a character to send to the host to terminate incoming # commands. 0 – no termination character 254 – CR (0x0D) followed by LF (0x0A)
THOST0	0 – 1000 (0)	Maximum wait for host wakeup confirmation
THOST1	0-300 (5)	Delay after confirming host wakeup (in tens of milliseconds)
THOST2	0-3000 (3000)	Maximum wait for start of host reply (in tens of milliseconds)
THOST3	100 – 18000 (12000)	Maximum host reply transmission time (in tens of milliseconds)
THOST4	5-18000 (500)	Inter-character delay timeout for host reply (in tens of milliseconds)
THOST5	5-3000 (5)	Not implemented
TMODEM2	0-3000 (500)	Max wait for start of IM reply (in Host Service mode, in tens of milliseconds)
TMODEM3	0-60000 (18000)	Max IM receive time (in Host Service mode, in tens of milliseconds)
ICD	0-50 (1)	Delay inserted between characters sent to host. Units are milliseconds.
DEBUGLEVEL	0-5(0)	debuglevel > 0 enables verbose messages when handling host commands (#ii commands)
imfConfg	0-1 (0)	IMFlag output configuration 0-IMFlag uses normal polarity (active signal is 3.3V) 1-IMFlag uses inverted polarity (active signal is 0V) NOTE: some hardware may have external inverting buffers or open-drain transistors on the IMFlag signal.

Note: THOST, TMODEM and a few other settings are implemented with function similar to the like-named settings in Sea-Bird Electronics IMM's. This is for the convenience of customers seeking the superior performance of the UltiModem in applications already using older IM modems.

16.1 Reading the D File

There are two commands to read the D file. The READ D command reads the entire D file. The READ DL command reads only the last entry in the D file. Both are accepted through the serial interface or IM interface.

Note some terminal programs may change lines ending in CR to CR LF and vice versa. Terminal programs may display lines differently depending on these characters. When using TeraTerm Version 2.82 we recommend configuring Setup->Terminal-> New-line receive CR+LF and transmit CR. This avoids confusion caused by new lines printing on top of previous lines. Another good technique is to log the data to a file and view the file in a text editor.

16.2 Writing to the D File

There are two ways to write data to the D file. On is the WRITE D command available through the serial interface. The other is the SAVE D command in a script (the A file). WRITE D allows immediate storage of data in the D file. SAVE D moves data from the S file to the D file (leaving the S file empty).

16.2.1 D File Last Entry

Each WRITE D command on the serial port or script run containing a SAVE D command resets the lastSampleLen and lastSampleCRC. This allows the READ DL command to respond with the data saved in the most recent entry and the CRC matching this data.

16.2.2 D File Status

Use the STATUS D command to read status of the D file. This data is also included in the GETSD command reply. The nextWrite value indicates the next write address within the modem's nonvolatile memory. It is included only for debugging purposes.

```
S9>status d
<DataBuffer>
  nextWrite=2097219
  len=67
  CRC=4D995C9D
  lastEntryLen=67
  lastEntryCRC=4D995C9D
</DataBuffer>
OK; 0 Events
S9>
```

16.2.3 Writing to D File Over Serial Interface

The example below uses CR (not CR+LF) at the end of each line. Data recording continues until the modem receives either 'END D' on a line by itself or the escape character (0x1B) or ~(0x7E).

```
S9>write d
USE 'END D' OR ESCAPE TO END
test1
end d

OK; 0 Events

S9>read d

<FILE id='D' len='6' crc='AC00FCE4'>test1
</FILE>

OK; 0 Events
```

Note the CR between 'test1' and 'end d' is included in the recorded data. To avoid this use the escape key (0x1B) or ~ (0x7E) to end the write.

```
S9>write d
USE 'END D' OR ESCAPE TO END
test2
end d

OK; 0 Events

S9>read d

<FILE id='D' len='12' crc='1963B1B7'>test1
test2
</FILE>
```

Note the second WRITE D command appended the data to the file.

```
OK; 0 Events

S9>read dl

<FILE id='DL' len='6' crc='872DAF27'>test2
</FILE>

OK; 0 Events

S9>
```

The READ DL command read only the data from the most recent write.

16.2.3.1 Unexpected LF characters

Some terminal programs send both CR and LF when the enter key is pressed, while others send only CR. The Ultimodem accepts the WRITE D command on the CR. If your terminal then sends LF then the data written to the D file will start with LF.

16.2.4 D File Command Table

Command	Notes
READ D	Read the entire D file
READ DL	Reads the last entry in the D file
WRITE D	Appends a new entry to the D file
ERASE D	Erases the entire D file
STATUS D	Returns the status of the D file including length and checksums of both the entire file and the last entry

16.2.5 Saving to D File in a Script

When used in a script (program A) the SAVE D command appends the contents of the S fileto the D file. The data is wrapped in <UMSample> tags with separate length, sample number and CRC data. In the example below the S filecontained “TEST DATA\r” when the WRITE D command was processed. The sample number was 2 (n=’2’). The length is 10, which includes the CR at the end.

```
S9>read dl
<FILE id='DL' len='67' crc='4D995C9D'><UMSample v='0' n='2' l='10'
crc='957ADEB7'>test data
</UMSample>

</FILE>
```

It is appropriate to use the SAVE D command multiple times in a single script. This results in multiple <UMSample> tags with the same sample number. The READ DL command will return all data saved within the script even with multiple SAVE D commands in the program.

16.3 Example Retrieving Data Through D File

In this example a controller connected to the slave modem saves data to the D file and the controller on the master modem retrieves the data. Note for this example the slave WAKEUPSRC is set to 0 to allow the attached controller access to the serial command interface.

The master could also use the READ DL command to read only the last data written to the D file.

This example used MOD=4 for faster communication.

Note

Master	Slave
	`PWRUP` `S9>write d`

```
USE 'END D' OR ESCAPE TO END
test d file:
abcdefghijklmnopqrstuvwxyz0030
abcdefghijklmnopqrstuvwxyz0060
abcdefghijklmnopqrstuvwxyz0090
abcdefghijklmnopqrstuvwxyz0120
abcdefghijklmnopqrstuvwxyz0150
abcdefghijklmnopqrstuvwxyz0180
abcdefghijklmnopqrstuvwxyz0210
abcdefghijklmnopqrstuvwxyz0240
abcdefghijklmnopqrstuvwxyz0270
abcdefghijklmnopqrstuvwxyz0300
end d
OK; 0 Events
S9>sleep
OK; 0 Events
S9>SLEEP
```

```
PWRUP
S9>fcl
OK; 0 Events
S9>!37read d
<Remote>
<FILE id='D' len='323'
crc='AE54A710'>test d file:
abcdefghijklmnopqrstuvwxyz0030
abcdefghijklmnopqrstuvwxyz0060
abcdefghijklmnopqrstuvwxyz0090
abcdefghijklmnopqrstuvwxyz0120
abcdefghijklmnopqrstuvwxyz0150
abcdefghijklmnopqrstuvwxyz0180
abcdefghijklmnopqrstuvwxyz0210
abcdefghijklmnopqrstuvwxyz0240
abcdefghijklmnopqrstuvwxyz0270
abcdefghijklmnopqrstuvwxyz0300
</FILE>
OK; 0 Events; qs 5569
</Remote>
<qs>155866</qs>
OK; 0 Events
S9>sleep
```

17 Telemetry Settings

The Ultimodem supports multiple inductive communication protocols. The two most important settings are the modulation and the encoding. The MOD setting controls modulation, the TELMODE setting controls the encoding. For two modems to communicate reliably they must be set to the same modulation and encoding.

17.1 Support for Sea-Bird Electronics SIM

MOD 1 / TELMODE 1 matches the modulation and encoding of the Surface Inductive Modem (SIM) from Sea-Bird Electronics.

17.2 Support for Sea-Bird Electronics IMM

MOD 1 / TELMODE 2 supports the IMM from Sea-Bird electronics.

17.3 High Speed Communication

The highest speed communication currently supported is MOD 4 / TELMODE 3. This allows 4800 baud inductive communication. The encoding allows single-character transmission for all but three characters.

18 Firmware Updates

Firmware update files are text files with firmware encoded in ASCII hex. They are sent to the modem through the RS232 serial connection. Follow these steps to perform a firmware update:

1) Make sure the serial interface and Host Service mode are enabled. If the WAKEUPSRC is set to 2 you need to change WAKEUPSRC to 0 through the IM interface using another modem.
2) Set mod=1. Firmware updates do not work when modulation setting is higher than 1.
3) Make sure the modem's battery has some life left in it – or connect an external power source. Firmware updates require a stable power supply.
4) Open a terminal program (we prefer TeraTerm)
5) Set sflow=1 to enable software flow control in the modem. This eliminates the possibility of dropped bytes when streaming the firmware update file.
6) Change the baud rate if desired – this allows the file to transmit faster. To do this, send BAUD 115200.
7) Reset the modem by sending the SLEEP command. This guarantees all changes to serial port settings take effect.
8) Set the terminal program port flow control to Xon/Xoff or 'SOFTWARE HANDSHAKING' (under Setup->Serial Port in TeraTerm).
9) Change the baud rate setting in the terminal program if required.
10) Press enter to get a S9> prompt from the modem.
11) Type the VER command to check the current firmware version of your modem
12) Send the firmware update file to the modem. (no encoding – in TeraTerm use File->Send File)
13) Wait for the file transmission to finish. This may take a minute or two at 19200 baud.
14) Enter the RUN F command to initiate parsing, integrity checking and device type verification. This may take 10 to 15 seconds. If the file is OK the modem will respond with:
    `Confirmed - ready to program`
15) Enter the PROGRAM command to start the firmware update. The firmware update takes only a few seconds. Do not disconnect power within 10 seconds of sending the PROGRAM command, doing so may corrupt the firmware and disable the controller.
16) After the firmware update completes the modem will be in sleep mode. Press a key to wake the modem and use the VER command to verify the new firmware version.

19 Power Consumption

Power consumption depends significantly on hardware, settings and operating mode. Modems with RS232 interface require significantly more power than modems with logic level serial interface. Modems with built-in switching power supplies are much more efficient at input voltages above 3.6V compared to modems optimized for use with 3.6V lithium batteries.

19.1 Units with Linear Voltage Regulators

The Ultimodem includes standard linear voltage regulators. These draw the same amount of current regardless of the voltage applied at the power input. For best efficiency use the lowest allowable voltage.

19.2 Units with High Efficiency Switching Voltage Regulators

The 15032B and 15122 circuit boards include switching voltage regulators. These draw a nearly fixed power, so reducing the input voltage increases the current draw and increasing the input voltage decreases the current draw.

We recommend OEM customers use units with built-in switching power supplies in systems with input voltages of 5V or greater.

Table 7 Power Consumption When MOD=1

Mode	15032B or 18122 Logic level 10 V Supply Current (uA)	15032B or 18122 RS232 10 V Supply Current (uA)	15011B logic level, 3.3V Supply Current (uA)	15011B RS232 3.3V Supply Current (uA)	Ultimodem In Housing R2232 3.6V battery Current (uA)
MOD 1 (1200 baud, SBE compatible)					
Sleep	27.5	30.2	28	30	30
19200 baud					
Host service					
Idle	260	1777	708	4846	4460
IM transmitting (FCL)	529	2120	1443	5782	6420
IM receiving (IMMON)	270	1810	736	4936	4450
IM Service					
IM receive	265	270	723	736	590
IM transmit (!xxTXTEST)	517	581	1410	1585	2600
57600 baud					
Host service					
Idle	370	1966	1009	5362	4610
IM transmitting (FCL)	641	2266	1748	6180	6720
IM receiving (IMMON)	380	1970	1036	5373	4690
IM Service					
IM receive	378	384	1031	1047	840
IM transmit (!xxTXTEST)	630	698	1718	1904	2600
115200 baud					
Host service					
Idle	370	1975	1009	5386	4620
IM transmitting (FCL)	641	2327	1748	6346	6730
IM receiving (IMMON)	380	1970	1036	5373	4730
Write D	835	2980	2277	8127	6010
Read D	3342	5630	9115	15355	12290
IM Service					
IM receive	378	385	1031	1050	840
IM transmit (!xxTXTEST)	631	696	1721	1898	2600

Table 8 Power Consumption When MOD=4

Mode	15032B or 18122 Logic level 10 V Supply Current (uA)	15032B or 18122 RS232 10 V Supply Current (uA)	15011B logic level, 3.3V Supply Current (uA)	15011B RS232 3.3V Supply Current (uA)	Ultimodem In Housing R2232 3.6V battery Current (uA)
MOD 4 (4800 baud)					
Sleep	28	30	28	30	30
19200 baud					
Host service					
Idle	583	2120	1590	5782	5100
IM transmitting (FCL)	785	2370	2141	6464	5720
IM receiving (IMMON)	629	2190	1715	5973	5260
Write D	740		2018		4550
Read D	1158		3158		6300
IM Service					
IM receive	651	667	1775	1819	1460
IM transmit (!xxTXTEST)	824	885	2247	2414	1890
57600 baud					
Host service					
Idle	584	2185	1593	5959	5250
IM transmitting (FCL)	790	2375	2155	6477	5650
IM receiving (IMMON)	630	2245	1718	6123	5280
Write D	950		2591		6600
Read D	2351		6412		9790
IM Service					
IM receive	651	667	1775	1819	1470
IM transmit (!xxTXTEST)	827	881	2255	2403	1900
115200 baud					
Host service					
Idle	584	2188	1593	5967	5260
IM transmitting (FCL)	790	2436	2155	6644	5630
IM receiving (IMMON)	630	2250	1718	6136	5330
Write D	1280	3730	3491	10173	7140
Read D	3900	6360	10636	17345	13650
IM Service					
IM receive	655	668	1786	1822	1470
IM transmit (!xxTXTEST)	828	885	2258	2414	1900

D Annotated UltiBuoy Program and data sample

This is an example of data queries and responses, annotated. See Enduro and Ultibuoy manuals for specific query commands.

```
PWRUP                         Response from Ultimodem START command

S9&gt;MLN                    MLN = Monitor Line Noise – listens passively to EM to see background noise level
00054
00065                         counts  - these are good low numbers
00066
00061
00053
00045
00061
00156
00064
00056

OK; 1 Events

S9&gt;MOD 4                  use 4800 baud comms
RESETTING TO APPLY NEW MODULATION SETTING
X
PWRUP

S9&gt;TELMODE 3              Soundnine encoding (Telmode 1 for Seabird)
OK; 3 Events

S9&gt;XT2                    Request data from 2 Soundnine instruments
...

#T4:09K:4:20.4384,2277.763,20124.32,1.53,124,15707.38,2.04,159,20.399,7.972,0.994,0.000,336.204,4.729,62,-12.876,0.953,-
7.6,84DF,37DB,0,18E:704F*41192,32*309
#T4:09M:7:20.1652,2714.102,20265.83,1.75,123,15941.59,2.82,157,20.140,8.736,0.984,0.000,336.233,4.708,65,-11.193,0.960,-
8.1,932,3713,0,3D:3397*41750,32*301
USER ABORT (ESC)
OK; 3 Events

S9&gt;MOD 1                        use 1200 baud comms (SeaBird)
RESETTING TO APPLY NEW MODULATION SETTING
X
PWRUP

S9&gt;TELMODE 2                     SeaBird encoding
OK; 3 Events

S9&gt;FCL                           Capture IM Line
OK; 3 Events

S9&gt;#G0:TPS
OK; 3 Events

S9&gt;
S9&gt;#03SL                         SEABIRD command to SBE 3 for data
&lt;Remote&gt;
 03709820,   21.4505,  2.96636,   12.761, 2.416, 05 Oct 2020, 14:26:17, 0
&lt;Executed/&gt;
&lt;/Remote&gt;
&lt;qs&gt;5737704&lt;/qs&gt;

OK; 3 Events

S9&gt;
S9&gt;#06SL                         SEABIRD command to SBE 6 for data
&lt;Remote&gt;
 03709819,   21.3263,  3.38594,   19.509, 1.943, 05 Oct 2020, 14:26:16, 2
&lt;Executed/&gt;
&lt;/Remote&gt;
```

<qs>5828779</qs>

OK; 3 Events

S9>#03SL SEABIRD command to SBE 3 for data (repeat for security)
<Remote>
03709820, 21.4505, 2.96636, 12.761, 2.416, 05 Oct 2020, 14:26:17, 0
<Executed/>
</Remote>
<qs>5956284</qs>

OK; 3 Events

S9>
S9>#06SL SEABIRD command to SBE 6 for data (repeat for security)
<Remote>
03709819, 21.3263, 3.38594, 19.509, 1.943, 05 Oct 2020, 14:26:16, 2
<Executed/>
</Remote>
<qs>6047358</qs>

OK; 3 Events

S9>
S9></SampleData> Get GS and UB data
<GPS_FIX>GPSF 38 33.358 N, 76 23.487 W, T=142704, D=051020</GPS_FIX>
<GPS_QOS>GPSQ NS=8, HD=0.96, SN1=36, SN2=32, SN3=35, SN4=34</GPS_QOS>
<TIME v='0'>2020-10-05T14:27:03</TIME>
<TIME v='0' n='1'>2020-10-05T14:27:04</TIME>
<Events v='1' n='0'></Events>
</Sample>
<Sample d='UBUOY' mid='2F1' p='A' T='2020-10-05T14:35:40' v='1'>
<Events v='1' n='0'></Events>
<ADC v='2'>101.58,1.619,8.29,9.55</ADC>
<IRH v='1'>19.02,28.86</IRH>
<SampleData mid='S001' lid='S001' pt='DEFAULT' b='0'>
X

Chesapeake Bay dissolved oxygen profiling using a lightweight, low-powered real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels

a) Partnership as in Sec 3.8 with Doug Wilson serving as Project Lead.

W. Douglas Wilson, Caribbean Wind LLC [MD SBE; CAGE Code: 6YLG2; DUNS: 071393999; EIN:45-5405221]
Baltimore, MD. Oceanographer and Principal Officer, 40 years
Darius Miller, Soundnine Inc. (S9) [CAGE Code 7AD41, DUNS: 078462398, EIN: 45-3980978]
Kirkland, WA. President and Principal Engineer, 16 years

b) **SOW 8 *Pilot a cost-effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia***

c) **Proposal - Introduction**

Water quality impairment in the Chesapeake Bay, caused primarily by excessive long-term nutrient input from runoff and groundwater, is characterized by extreme seasonal hypoxia, particularly in the bottom layers of the deeper mainstem (although it is often present elsewhere). In addition to obvious negative impacts on ecosystems where it occurs, hypoxia represents the integrated effect of watershed-wide nutrient pollution, and monitoring the size and location of the hypoxic regions is important to assessing Chesapeake Bay health and restoration progress.

Chesapeake Bay Program direct water quality monitoring has been by necessity widely spaced in time and location, with monthly or bi-monthly single fixed stations separated by several kilometers. The need for continuous, real time, vertically sampled profiles of dissolved oxygen has been long recognized, and improvements in hypoxia modeling and sensor technology make it achievable. Recent results of Bever, et al. (2018) show that total Chesapeake Bay hypoxic volume can be estimated using a few analytically selected fixed continuous dissolved oxygen profiles.

Requirements

The RFP SOW 8 requests 4 outputs (paraphrased):

*1) lessons learned regarding a **reliable** infrastructure that sustains the deployment;*
*2**) reliable**/dependable infrastructure assessment of the gear deployed;*
*3) successes and challenges of the piloted equipment in collecting, storing, and providing **reliable** data in the summer season in the mainstem Chesapeake Bay;*
4) details of protocols to be adopted and invested in for deployment of vertical profiling infrastructure.

The highest priority requirement based on these (noted in 3 of 4) is ***reliability***. Based on our extensive experience designing and supporting real-time environmental monitoring systems, particularly in Chesapeake Bay, as well as familiarity with CBP and partners' interests, additional critical considerations must be:

- Whether the system and resulting data meet CBP and partners' data needs
  - Provision of desired parameters (in this case dissolved oxygen concentration – which requires coincident temperature and salinity for accurate calculation)
  - Adequate data quality – initially and over the whole of a seasonal deployment
  - Vertical resolution – the ability to capture the important features of vertical structure
  - Real-time data delivery that is timely, easy, and dependable
- Financial sustainability
  - Minimum initial cost to acquire and deploy
  - Minimal level of field support required during deployment
  - Long lifetime of equipment and ease/cost of off-season repairs, refurbishment, and calibration
- Flexibility – the system must be successful in all required locations, recognizing that diverse, often extreme physical environments and conditions will be encountered.

These requirements define our approach. There are two basic ways to acquire a vertical water column profile – by either a) moving a sensor package repeatedly through the water column, or b) locating sensor packages at multiple fixed depths, with vertical sensor spacing adequate to meet observational requirements. Either way, data must be regularly collected and transmitted from the *in situ* system location to an accessible data structure. Our proposed solution is b, the simpler and more reliable of the two options. This is described below, with rationale for how the approach best fits these requirements.

Approach *A lightweight, low-powered real-time inductive $CTDO_2$ mooring with sensors at multiple vertical measurement levels*

Sensors will be independent, integrated temperature / conductivity / dissolved oxygen (pressure optional) modules developed by collaborator Darius Miller, President and Principal Engineer at Soundnine. Units collect data and transmit inductively, clamped to a semi-taut mooring line with a surface data collection and cellular transmission buoy (Soundine UltiBuoy). T/C/P sensors with inductive modems are manufactured by Soundnine Inc., and will integrate OEM fluorescence-based microDOT Dissolved Oxygen modules supplied by Precision Mechanical Engineering. *(Deliverable 2)*

Why fixed sensors instead of a profiler?

Reliable
- No moving parts, robust (but adjustable) attachment to mooring cable.
- Extremely low power, 2 AA $LiSOCL_2$ batteries will power sensors for a season at 15 minute sampling.
- Redundant data storage within each sensor and controller within the platform.
- Proven hardware with accurate individual sensor components
- Controller / communications buoy designed to be fully submersible to 10 meters to remain semi-taut and withstand surface wave conditions in any Chesapeake Bay water depths

Sustainable
- Sensor modules are low cost (estimated $4-5K) so spares are affordable
- Protected from fouling, modules and sensors should not require cleaning during season
- Full mooring with sinker is hand-deployable/recoverable by two people using a small boat

Flexible
- Modular components
- Works in any depth – deep or shallow - found in Chesapeake Bay
- Designed to withstand extreme Chesapeake Bay wave conditions

Meets Data Needs
- Samples are collected simultaneously at a prescribed fixed time interval
- Analysis below shows that a reasonable number of sensors can achieve accurate measurement of vertical hypoxia structure while still maintaining the reliability and sustainability advantages of a simple 'no moving parts' platform.
- Data are stored in two locations internally and transmitted in real-time to Soundnine's cloud-based storage system, where data QC will be performed per US IOOS QARTOD methodology (https://repository.library.noaa.gov/view/noaa/18659) The data will be made available to CBP and partners with low time latency and will include QC flags. Low power consumption of inductive technology allows 15-minute sampling for a full season deployment *(Deliverable 3)*.

While a single profiling instrument is an alternative approach, our experience with these devices is that they have more structural and logistical complexities and failure points (both in the profiling mechanism and in the mooring/structure supporting the profiler). These increase the risk of service visits in-season (cost) and associated periods of missing data***. Reliability is maximized by using the simplest solution that meets the requirements.***

Analysis

In evaluating the fixed vertical sensor approach, we considered, as Pilot example, deployment at CBP fixed monitoring station CB4.3E (38.55624 N, 76.39121 W) – about 2.5 km east of CBIBS Gooses Reef buoy, where there is real time surface environmental data nearby from GR, as well as bottom DO and pH data *(Deliverable 1)*. Additionally, this station is in a reasonably deep location (21-22m) and out of shipping channels (a problem when surface buoys are required for real-time communications, addressed below).

Figure 1A shows CB4.3E DO profiles from 2002-2018 June/July/August/September. With the assumption that we want to be able to at least match the ability of the existing sampling to resolve structure and measure vertical extent of hypoxia (DO < 2.0 mg/l) for use in DO volume estimates and forecast model comparisons, simulations were run with various fixed sensor depths. Table 1 shows how well different vertical sensor arrays capture full water column Vertical Hypoxia Extent - the amount of the vertical water column with dissolved oxygen concentration below 2.0 mg/l. For station CB4.3E, reasonable results can be achieved with as few as five or six sensors – graphical comparison of the six-sensor model is shown in Figure 1B. This is a preliminary analysis of sensor depths; it is likely that more rigorous placement analysis would reduce uncertainty even further.

Number of Sensors	Depths (meters)	R^2	% Variance	RMS Error (meters)
21	[1,2,3,…,19,20,21]	0.999	0.994	0.22
11	[1,3,5,7,…,17,19,21]	0.994	0.985	0.33
10	[1,5,7,9,…,17,19,21]	0.993	0.984	0.33
9	[1,6,9,11,13,15,17,19,21]	0.990	0.977	0.42
7	[1,6,9,12,15,18,21]	0.988	0.977	0.46
6	[1,7,11,15,18,21]	0.982	0.964	0.55
5	[1,7,12,17,21]	0.978	0.980	0.63

Table 1. Analysis of performance of various configurations of number and placement of vertical sensors

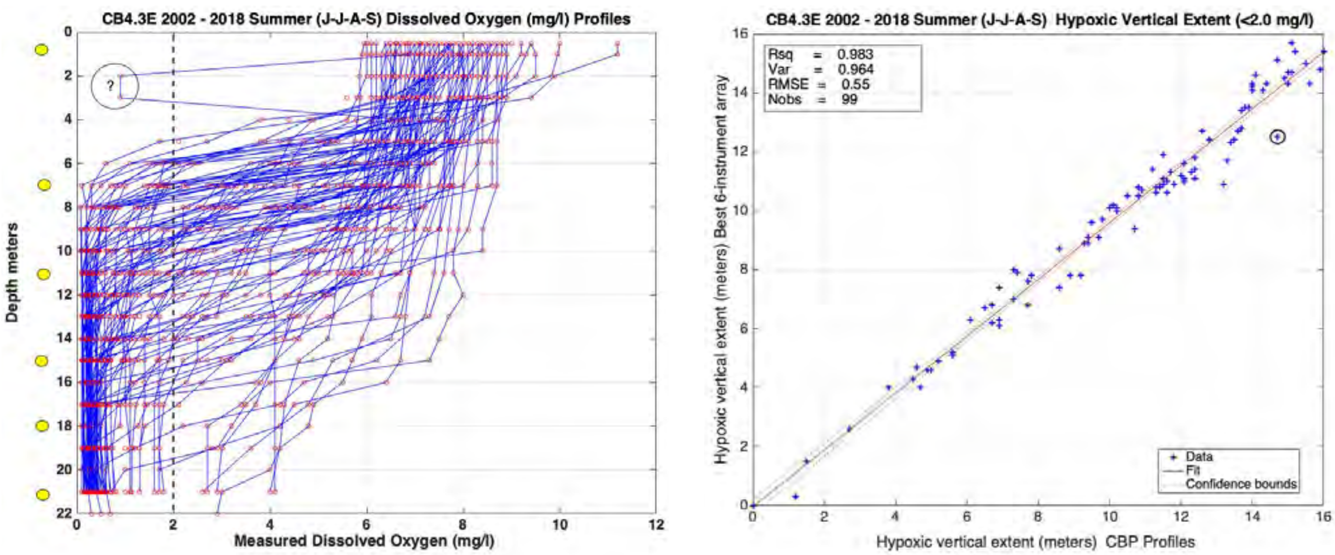


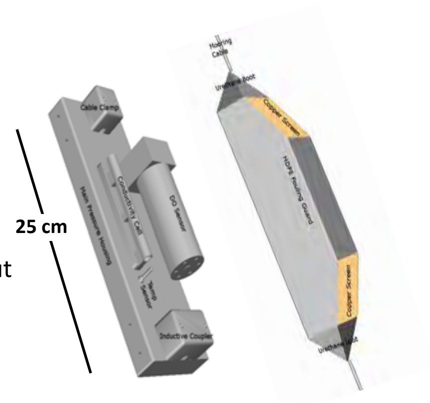
Figure 1. Measuring dissolved oxygen profiles with fixed depth sensors.
(A) Profiles of dissolved oxygen from all 2002-2018 June-September measured CBP stations at CB3.4E. Red dots are original sample depth locations, connected by blue profile lines. Yellow circles represent a six-instrument array used in (B).
(B) Comparison of 'Vertical Hypoxia Extent (Meters)' calculated using measured profiles (X axis) and the same quantity calculated using a hypothetical array of six sensors shown in (A). Different arrays were tested; the results are shown in Table 1.

Expected Outcomes and Deliverables

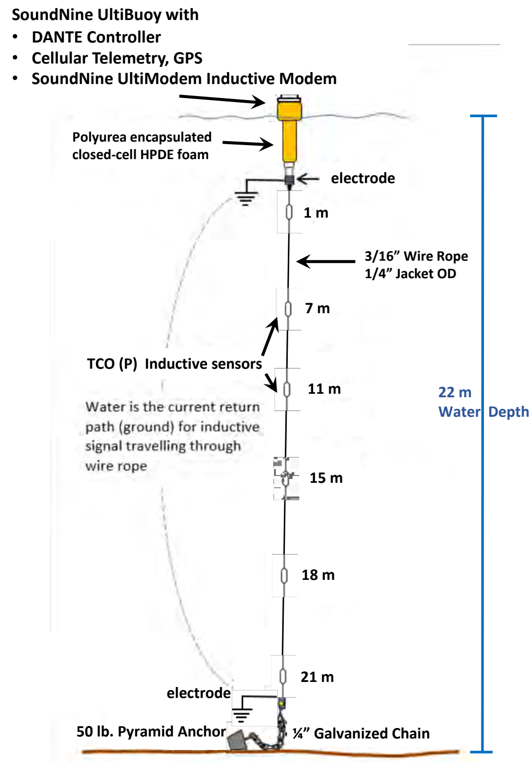
We can meet the suggested Task Implementation timeline; comments on Tasks below (includes *Deliverables 4-7).*

Task 1: Kickoff meeting with Project Leads; current efforts; pilot locations. We are suggesting CB 4.3E for proximity to GR CBIBS; for moderate depth; for not being in conflict with shipping lanes. At this point in the timeline, application to USCG for Private Aids to Navigation should occur. The shipping lane issue can be problematic; many of the deep stations in the Chesapeake Bay where hypoxia is significant (including those considered in Bever, et al.) are located in designated ship channels where ship strikes are likely to damage a surface transmitting buoy (and

System schematic (right) is based on the example of CB4.3E, but adaptable to other desired monitoring locations.
We have chosen a small, spar-like buoy to maintain a nearly taut mooring (and fixed sensor depths relative to the bottom) in all depths and conditions. The UltiBuoy electronics components are waterproof to >10 meters and will simply submerge in extreme wave conditions, storing data and retransmitting as necessary.
Sensors are tightly affixed to inductive cable but can be adjusted to meet sampling requirements.
Soundnine Inductive TCOP sensors provide accurate, low-power, measurements.
System is light enough to be deployed and recovered by 2 people from a small boat, and should require no maintenance during a season.



Rendering of Soundnine Inductive TCO(P) module, without cover showing sensors (left) and with protective antifouling cover (right).



where it is unlikely US Coast Guard will approve Private Aids to Navigation permits). We would work with VIMS researchers (see Letter of Support in (h)) to determine if there is a better (with respect to model validation) pilot location. Ultimately, we would work with them to find long-term solutions to this problem, including developing an optimal sampling array for non-conflicting locations, possibly utilizing interim non-real-time profiles with subsurface upper floats (for in-channel testing), as well as optimal vertical sensor placements. This inductive technology also lends itself to subsurface vertical arrays with a horizontally offset surface transmission buoy.

Task 2*:* We propose the *lightweight, low-powered real-time Inductive CTDO2 mooring with sensors at multiple vertical measurement levels* approach. This approach is based on our experience and our understanding of the project requirements. Establishment of details during Task 2 provides an opportunity to work with project leads to refine the approach to explain, modify, and finalize designs and protocols to make sure all requirements are met. A preliminary QAPP outline will be developed (ref. https://www.epa.gov/sites/production/files/2015-05/documents/assess4.pdf), to be fully completed utilizing experience gained during Tasks 3 and 4.

Task 3*:* Soundnine and PME are in the process of integrating the PME DO sensor into an S9 inductive Conductivity-Temperature-Pressure module, resulting in a low-cost, standalone $CTDO_2$ inductive module. We will stage mooring building and testing activities out of Maritime Applied Physics waterfront location in Baltimore, where CWLLC has a working agreement, or other location provided by Project partners. Testing will include in-water testing and full sensor-to-client pipeline, including QC. QC procedures will be developed with assistance from Mark Bushnell, presently serving as National Coordinator for US IOOS QARTOD (see Letter of Support). We will also pilot making quality-controlled data available in the longer term through MARACOOS (the US IOOS Mid-Atlantic Regional Association). This has the advantage of easier access to certified data for the VIMS hypoxia model, which is publicly available through MARACOOS.

Task 4*:* We propose an early June 2019 deployment using CWLLC boat or CBP partner-provided assets. Performance will be continuously monitored (data will also be available continuously to project participants) and maintenance will be conducted if necessary. Two interim platform visits will be conducted to evaluate fouling; if fouling is not affecting performance, sensors will not be cleaned. This will allow us to evaluate full-season capability. If available, we would like to integrate two Sea-Bird SBE37 inductive CTDO sensors owned by NCBO into the pilot deployment for independent sensor validation. These sensors are compatible with the Soundnine modem and data can be included in real-time transmission. The platform will be recovered in September 2019 using CWLLC or provided small boat.

Task 5*:* Reports and presentations as requested, including final QAPP. CWLLC is located in Baltimore and available for in-person meetings.

Task 6*:* Consultation, reports, briefings, and presentations as requested.

(d) **Experience / Qualifications of Offeror** (please see also (h), additional information)

Doug Wilson of CWLLC has extensive experience with ocean instrumentation; ocean data collection and quality control; and design, installation, and maintenance of coastal and estuarine moorings. This includes all aspects of designing and maintaining oceanographic observing systems, moored platforms, and sensors in Chesapeake Bay, Florida Bay and Florida Keys, Coastal Atlantic, Caribbean Sea, rivers and large inland lakes. He was an Oceanographer at the NOAA Chesapeake Bay Office (2001 – 2012), and during that time designed, deployed, and managed 10-buoy CBIBS system for environmental monitoring in Chesapeake Bay and tributaries. Work also included reports, publications, and presentations on results. He developed a real-time data system including data acquisition and storage, web display and access, and quality control using US IOOS Quality Assurance for Real Time Ocean Data (QARTOD) standard procedures. Doug Wilson has been active in Chesapeake Bay water quality and dissolved oxygen measurement, including CBIBS and other buoys, autonomous vertical profilers, and AUV deployments. He was co-PI in several proposal submissions to NOAA with Dr. Marjy Friedrichs of VIMS (and others) to provide dissolved oxygen profiles supporting the VIMS hypoxia forecast model, and as a result he is quite familiar with the ongoing work of VIMS and that of Bever, et al. (2018), and has an excellent working relationship with the community. Doug Wilson served on the U.S. IOOS QARTOD (Quality Assurance of Real-Time Oceanographic Data) Dissolved Oxygen Manual Team https://repository.library.noaa.gov/view/noaa/18659 (2015).

Darius Miller of Soundnine Inc. started his career in ocean instrumentation in 2003 when he was recruited to Sea-Bird Electronics by Ken Lawson with the support of mutual friends at the Edgerton Center at MIT. He became Principal Engineer of Sea-Bird in 2004. In his time at Sea-Bird he designed multiple new instruments, developed inductive communication systems, and participated in nearly every aspect of Sea-Bird's business.
After leaving Sea-Bird in 2009 he started a family and soon after started Soundnine Inc (S9) to continue developing innovative sensors and monitoring systems. Through Soundnine he has participated in countless monitoring projects with a wide variety of priorities including environmental compliance, education, and research. Please see the list of selected projects below

(e) **References**

Doug Wilson / Caribbean Wind LLC

Dr. Paul Jobsis, Director, CMES, UVI (Coastal Mooring and Mesophotic Coral Reef Inductive Mooring) 340 693-1381 pjobsis@uvi.edu

Tom Brauch, Advanced Monitoring Methods, Castle Rock, CO – Prime contractor for 5-buoy deployment for National Park Service in Lake Mead 720-897-7792 tom@advm2.com

Dr. Willam Boicourt , Professor, UMCES Long-time colleague and collaborator in Chesapeake Bay science and monitoring projects. 410-221-8426 / 443-521-1579 boicourt@umces.edu

Darius Miller / Soundnine Inc

David Durlach, president, TechnoFrolics, Somerville, MA. 617-441-8870, david@technofrolics.com

Brian Wilcox, Marine BioEnergy, inc, La Canada, CA, 818-952-6018, brian.wilcox@marinebiomass.com

Beth Curry, Oceanographer, University of Washington Applied Physics Laboratory, 206-851-3667, beth4cu@uw.edu

(f) Supplementary Budget Information

This proposal is being submitted as a Partnership between two established small businesses, Caribbean Wind LLC of Baltimore, MD, and Soundnine Inc. of Kirkland, WA. Doug Wilson of CWLLC will serve as Project Lead and manage construction, testing, deployment, recovery, and maintenance of the mooring(s), as well as responsibility for project updates, reports, and presentations. Darius Miller of Soundnine has designed and will provide S9 Enduro CTO_2 inductive modules and the S9 UltiBuoy with inductive modem and S9 DANTE controller/communications device.

Personnel

- Salary for Wilson – Construction, Testing, Deployment, Maintenance, Recovery of Mooring(s); Consultation with modelers, project leads, CBP STAR; Reports, Presentations, and Updates; QAPP plan.
- Salary for Miller – Manufacture of Sensors and Electronics; software and firmware development; data collection, management, access, and QC; consultation on mooring engineering.
- Fringe Benefits (25% Wilson and 24% Miller).

Indirect costs

- Less than 10%, only on salaries.

Supplies

- Mooring Supplies includes 70 lb. Dor-Mor Pyramid anchor, chain, jacketed steel cable with terminal swages, and hardware.
- Soundnine inductive CTO_2 sensors are unique products integrating a proven PME optical dissolved oxygen sensor with a proven Soundnine inductive Enduro CT sensor. These are manufactured by Soundnine and will be available for approximately $5000. The only other sensor meeting these specifications is the Sea-Bird 37-DO-IM, which costs over twice as much.
- Soundnine is also supplying an UltiBuoy, a small buoy incorporating an inductive modem/controller and a cellular communications module, both extremely low power. Size, low power, inductive capability, and water resistance make this the optimal buoy component for the system.

Travel

- Wilson local travel covers trips to the field for deploymewnts, maintenance, and recoveries, as well as trips to project lead locations for consultation, reports, and presentations.
- Miller travel is for two round trips Seattle – Baltimore.

Other

- Use of CWLLC 19' Boston Whaler for deployments, maintenance, and recoveries (subsidized by in-kind contribution)
- Materials and costs provided by Soundnine associated with data collection, archiving, and presentation (in-kind contribution)
- Services by Soundnine related to pre- and post-calibration of sensors (in-kind contribution)

(g) CVs / Resumes (Appended Below)

(h) Additional information on Experience and Capabilities

Caribbean Wind LLC selected projects

- Over 50 research cruises as NOAA Chief Scientist on global, coastal, and estuarine projects while a Research Oceanographer at NOAA Atlantic Oceanographic and Meteorological Laboratory, 1982-2001. Research projects in ocean and climate dynamics focused on data collection and analysis and shipboard and moored data collection applications. See CV.
- Principal Investigator for the South Florida Ecosystem Restoration Project, Florida Bay, 1995-2001. NOAA AOML. Design, deployment, maintenance, data analysis, publication, and presentation of bottom and mid-depth moorings for currents and environmental parameters in Florida Bay and Florida Keys.
- Chesapeake Bay Interpretive Buoy System, 2006-2012 (NOAA Chesapeake Bay Office) and 2012 – 2017 as CWLLC consultant through Chesapeake Research Consortium and Mid-Atlantic Coastal and Ocean Observing Regional Association. Designed, deployed, and managed 10-buoy CBIBS system for environmental monitoring in Chesapeake Bay locations. Created reports, publications, and presentations on results. Developed real-time data system including data acquisition and storage, web display and access, and quality control using US IOOS Quality Assurance for Real Time Ocean Data (QARTOD) standard procedures. CBIBS won a NOAA Administrator's Award in 2009; Doug Wilson was awarded the American Meteorological Association's Francis W. Reichelderfer Award, 2013, "…In recognition of distinguished contributions to the provision of operational environmental services to the public."
- Virginia Commonwealth University – Deployment of James River Environmental Buoy, 2012
- University of the Virgin Islands EPSCoR – Designed, deploedy, maintained EPSCoR Coastal Buoy, 2012 – 2017
- University of the Virgin Islands/CARICOOS – Mesophotic Coral Reef Monitoring Mooring. Used Soundnine inductive sensors, recorders, and controller to design and deploy a successful subsurface mooring in 50+ m with nine vertically spaced CTP sensors to monitor environmental conditions affecting deep coral reefs on St. Thomas, USVI shelf break. Deployed 2018.
- Sea-Bird Scientific – Consultant, Engineering and Sensor/System Design, 2012 – 2017. Instrument design consultation, field testing, and analysis for SeaBird Coastal, including contributions to the development of the Coastal SUNA Nitrate Sensor, the HydroCycle-P Phosphate Sensor, and the HydroCat-EP integrated CTDO2-Turb-ChlA-pH instrument (https://www.seabird.com/technical-papers/hydroCAT-EP-case-study). In 2013 Doug Wilson was a Research Team member of the National Ocean Partnership Program Excellence in Partnership Award 2013, "Long-term in situ chemical sensors for monitoring nutrients".
- US Dept. of Interior National Parks Service, Advanced Monitoring Methods -- Engineering and Installation of five Lake Mead Environmental Monitoring Buoys 2015-2016. Awarded subcontract to design and install environmental buoys in Lake Mead National Recreation Area, providing real-time waves/weather data to local National Weather Service and environmental data to the NPS. Deployed 2016-2017.
- NOAA Ocean Acidification Program – Design, deployment, and maintenance of First Landing (Chesapeake Bay, Virginia) Ocean Acidification Buoy, 2018. Grant from NOAA OA Program for CWLLC to design and deploy an Ocean Acidification buoy for the NOAA OA Coastal Mooring Program. Buoy designed using PMEL MAPCO2 and additional components, deployed in April 2017, presently managing maintenance and validation monitoring in collaboration with Dr. Wei-Jun Cai of University of Delaware.
- AXYS Technologies, US East Coast Projects Coordinator (2016-present) – Management of six offshore wind assessment floating LIDAR buoy platforms (http://axystechnologies.com/products/flidar-windsentinel/. Management of commissioning, deployment, and maintenance of Offshore buoys for wind assessment in MA, RI, NJ (presently deployed) and MD (Spring 2019) OSW Lease areas.
- Invited participant and contributor, National Coastal Ecosystem Moorings Workshop (NOAA), 2018. http://www.ioosassociation.org/IOOSsuccess . This workshop defined the national needs for an ecosystem mooring network including requirements and specifications for DO profiling.
- Development of a validated wave/current measurement buoy (2015-2019) – Doug Wilson and CWLLC led a collaborative project with AXYS Technologies, NORTEK-AS, and NOAA CO-OPS to develop and validate an integrated wave buoy with current profiling capabilities. Testing has taken place off Cape Charles, VA, in

Chesapeake Bay, with three sets of moored deployments including wave/current buoys, bottom mounted wave/current profilers, and other supporting buoys. Results have been extensively reported (see CV).

- Doug Wilson was Co-PI in several proposal submissions to NOAA with Dr. Marjy Friedrichs of VIMS (and others) to provide dissolved oxygen profiles supporting VIMS hypoxia forecast model. Proposals reviewed well (one proposal averaged 94/100) but were ultimately not funded due to funding availability cutbacks – however as a result we are quite familiar with ongoing work by VIMS and that of Bever, et al. (2018) and have an excellent working relationship.

Soundnine selected projects:

- October, 2014: Eight DANTE controllers from Soundnine Inc deployed off Darwin, Australia with water quality sensors. See article in Sea Technology Magazine; February, 2015 issue; "New Path to Affordable, High-Accuracy Real-Time Water Quality Monitoring"
- Soundnine Sensors included in UPTEMPO buoy (manufactured 2017, deployed 2018): http://psc.apl.washington.edu/UpTempO/BuoyInfo.php?cbuoy=7090&bname1=UpTempO%202018.
- February, 2016: Buoy with Soundnine DANTE controller and inductive telemetry deployed by University of Washington. Buoy still operating with original controller. Data feeds live to NANOOS: http://nvs.nanoos.org/Explorer?action=oiw:fixed_platform:NWIC_Bellinghambay
- DANTE Controller and Soundnine inductive modem deployed on Ross Ice Shelf December 2017 by Mike Brewer of National Institute of Water and Atmospheric Research (NIWA); still operating.

(i) Additional Information - Contributions

Contribution Letter from Mark Bushnell – US IOOS QARTOD

Contribution Letter from Marjy Friedrichs - VIMS

CV- William Douglas Wilson

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Email doug@coastaloceanobs.com; wdw623@gmail.com
Phone 410 507 8587
Skype wdwilson

Professional Interests

Integrated Ocean Observing Systems; coastal, estuarine, and ocean observations; moorings, autonomous platforms, and instrument development; Offshore Wind Data Collection Platforms and Operational Support; Ocean data management and visualization systems; Ocean circulation and heat transport; Oceanography of the Caribbean Sea, western tropical Atlantic, and Gulf of Mexico; western boundary currents; equatorial ocean dynamics; Chesapeake Bay and estuarine dynamics, water quality, and ecological monitoring and forecasting;

Professional Experience

June 11, 2012 – **Consultan**t: Ocean observing system design, implementation, and management; marine instrument and sensor development and integration; environmental data management and product and application development; Physical Oceanography.
Chief Science Officer, OCOVI (Ocean and Coastal Observing – Virgin Islands)
Project Coordinator, IOCARIBE-GOOS Regional GOOS Alliance
Senior Oceanographer, RPS (2012-2018)
Courtesy Professor, University of the Virgin Islands, Marine and Environmental Science

2001 – June 8, 2012 **Oceanographer** (Program Manager, Integrated Coastal Observations Program; Project Manager, Chesapeake Bay Interpretive Buoy System; Director, NCBO Coastal Prediction Center) NOAA Chesapeake Bay Office, Annapolis, MD

1982 - 2001 **Research Physical Oceanographer**, NOAA Atlantic Oceanographic and Meteorological Laboratory

Recent Awards

- American Meteorological Society Francis W. Reichelderfer Award, 2013
- '…In recognition of distinguished contributions to the provision of operational environmental services to the public.'
- National Ocean Partnership Program Excellence in Partnership Award 2013, "Long-term in situ chemical sensors for monitoring nutrients". Research Team Member]
- CSIRO (Government of Australia) Frohlich Fellowship, 2012
- NOAA Administrator's Award, 2007, 2009
- Co-Author, NOAA OAR Outstanding Scientific Paper Award, 2000: *The arrival of recently formed Labrador Sea Water in the Deep Western Boundary Current at 26.5E N*
- U.S Department of State, Meritorious Service Award, White Water to Blue Water Initiative, 2004

Recent Contracts and References, Caribbean Wind LLC

AXYS Technologies, Inc.
Project Support, US East Coast Projects Coordinator (2016-present), Project Integrator
Max Bottoni mbottoni@axys.com

Advanced Monitoring Methods
Installation of Lake Mead Weather Buoys
Tom Brauch Tom Brauch tom@advm2.com

Rutgers University
Principal Investigator, Mid-Atlantic Coastal Ocean Observing Regional Association
Chesapeake Bay Interpretive Buoy System (NOAA Chesapeake Bay Office)
Chesapeake Bay Ocean Acidification Buoy (NOAA Ocean Acidification Program)
Scott Glenn glenn@marine.rutgers.edu

University of the Virgin Islands
Deployment and Maintenance of EPSCOR Ocean Buoy
Deployment of a Real-time Current and Wind Measurement System
Integration and Deployment of a Real-Time Subsurface Thermistor Mooring
Paul Jobsis pjobsis@live.uvi.edu

Chesapeake Research Consortium
Chesapeake Bay Interpretive Buoy System Support
Kevin Sellner sellnerk@si.edu

Applied Science Associates
Associate: Senior Oceanographer
Project Manager: Mid-Atlantic Acoustic Telemetry Observing System
Eoin Howlett ehowlett@asascience.com

Sea-Bird Scientific
Consultant: Engineering, System Design, and Business Development
Lea Ann Zuellig LZuellig@hach.com

University of Puerto Rico
Development of a web-based ocean observing system visualization and data access system for CariCOOS and IOCARIBE-GOOS – P.I.
Ocean and Coastal Observing – Virgin Islands (OCOVI) co-PI
Julio Morell julio.morell@upr.edu

OEA Technologies
Development and Establishment of a Regional Marine Monitoring and Forecasting System for the OECS
Brian Whitehouse bwhitehouse@oeatech.com

IOC Subcommission for the Wider Caribbean Region
IOCARIBE-GOOS Project Coordinator
Cesar Toro c.toro@unesco.org

Virginia Commonwealth University
Deployment of James River CBIBS Buoy
Greg Garman ggarman@vcu.edu

Washington College, Chestertown Maryland
Projects Related to Development of the Chester River Watershed Observatory
Doug Levin dlevin2@washcol.edu

William Douglas Wilson Caribbean Wind LLC

Global Science and Technology
GEO Regional Water Quality Pilot Project for the Caribbean
Pail DiGiacomo Paul.DiGiacomo@noaa.gov

Science and Technology Corporation, Columbia, MD
Deputy Program Manager, NOAA PROTECH OCEANS
Krish Narasimhan narasimhan@stcnet.com

Current (Past) Professional Committees:

- Vice President, Sections, Marine Technology Society (2016-2018)
- Joint Technical Commission for Oceanography and Marine Meteorology Task Team for Integrated Marine Meteorological and Oceanographic Services within WIS (TT-MOWIS)
- Technical Program Chairman, MTS/IEEE OCEANS '15 Washington DC
- Panelist, Final Review, *Caribbean Research, A Multi-Disciplinary Approach*, Netherlands Organisation for Scientific Research
- Mid-Atlantic Coastal Ocean Observing Regional Association (MARACOOS) Board of Directors, 2010-present
- Co-Chair and Regional Project Coordinator, IOC IOCARIBE-GOOS Steering Committee.
- Steering Committee, Our Global Estuary Project
- (Chair, Working Group 2 (Sea Level), Intergovernmental Coordination Group, Caribbean Tsunami and Coastal Hazards Warning System)
- Interagency Ocean Observation Committee, Regional Integration Coordinating Entity Certification Workgroup
- United Nations World Ocean Assessment Pool of Experts
- Founding Steering Committee, U.S. Caribbean Observing System Regional Association (CaRA US- IOOS)
- IOCARIBE Tsunami Group of Experts
- IOC GLOSS Group of Experts
- Co-Chair, Steering Committee, Chesapeake Bay Observing System
- Steering Committee, Chesapeake Community Modeling Project
- (Steering Committee, US White Water to Blue Water Initiative)
- (Executive Committee, Intra-Americas Sea Initiative)
  NOS-COOP OSTEP Advisory Board Member
  (WOCE Data Products Committee (ADCP))
- Marine Technology Society, Buoy Technology Committee
- IEEE, Current Meter Technical Committee

Education

B.S. Florida Institute of Technology; Melbourne FL; Physical Oceanography; 1977; Bachelor, Honors; 3.3 GPA, 4 Point Scale; 637 Quarter Hours

M.S., University of Miami; Coral Gables FL; Meteorology and Physical Oceanography; 1981; Master; 3.5 GPA, 4 Point Scale; 45 Semester Hours

William Douglas Wilson **Caribbean Wind LLC**

Selected Publications

Heitsenrether, R, D. Velasco, W.D. Wilson, L. Fiorentineo. 2018. Evaluating performance of acoustic Doppler current profilers on small, dynamic surface buoys. OCEANS '18, Charleston, Proceedings, Institute of Electrical and Electronics Engineers, in press.

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Barbara A. Block, Christopher M. Holbrook, Samantha E. Simmons, Kim N. Holland, Jerald S. Ault, Daniel P. Costa, Bruce R. Mate, Andrew C. Seitz, Michael D. Arendt, John C. Payne, Behzad Mahmoudi, Peter Moore, James M. Price, J. Jacob Levenson, **Doug Wilson** and Randall E. Kochevar (2016). Toward a national animal telemetry network for aquatic observations in the United States. *Animal Biotelemetry,* (2016) 4:6.

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Wilson, D., 2011. Autonomous Water Quality Profiling With A Wetlabs Mini---Amp. *Oceans' 11 MTS/IEEE KONA, Proceedings,* Institute of Electrical and Electronics Engineers, pp. 1797---1805.

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Employment

Dec 2011 to present	**Soundnine Inc (3 years)** Owner / principal Responsible for business management, all technical development and limited marketing. Soundnine manufactures buoy controllers and oceanographic sensors with inductive communications for applications requiring real-time data.

Dec. 2004 to Aug. 2009	**Sea-Bird Electronics** (6 years) Principal Engineer Reported to John Backes (Vice President), worked closely with Nordeen Larson (President) Primary responsibilities: • Design of extremely precise oceanographic sensors, data loggers, inductive modem systems and software tools. • Relationships with key customers. • Project planning, supervision and mentorship of engineers. Secondary responsibilities: • Development of new sensors and measurement technologies • Design and supervision of automated electrical test system, including custom database and client / server software tracking production boards, test results, failure rates and repairs to monitor and raise overall quality.
Dec. 2003 to Dec. 2004	Senior Electrical Engineer Responsible for design of analog and digital electronic systems.

June 2001 to Dec. 2003	**DM Design** (2 years) Home-based engineering consultancy providing design, prototyping and software/firmware development services.

Oct. 1995 to June 2001	**TechnoFrolics** (5 years) Vice President Started as a part-time technician, continued as a full-time engineer during my time away from MIT. Responsible for electronic design, product development, business planning and limited marketing.

Summer 1995, Summer 1996	**Lockheed-Martin Infra-Red and Imaging Systems** Temporary Part-Time Co-op Technician MIT internship program.

Education

Jan. 2002 to May 2003, Aug. 1993 to Feb. 1996	**Massachusetts Institute Of Technology** Bachelor of Science in Electrical Engineering (voluntary withdrawal 1996, resumed 2002, completed 2003)

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Technical Strengths

- Broad mathematical and scientific background
- Analog and digital electronics
- Embedded systems
- Software / firmware design
- Printed circuit design
- Very low power electronic design
- Communications systems
- High-reliability systems
- Extensive programming experience in C, Java, basic, Matlab, Scilab, HTML
- Mechanical design / fabrication / manual and CNC machining
- Oceanographic sensing technology, especially extreme precision in temperature, conductivity and pressure measurements.

I am driven to expand my understanding as required to achieve goals, regardless of the disciplines involved. My motivation and broad experience allow me to achieve many goals efficiently. In my career I have consistently generated new and creative ideas and performed beyond expectations while thoroughly enjoying the process.

VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

February 10, 2019

Doug Wilson
Caribbean Wind LLC

Dear Doug,

I very much look forward to collaborating with you on your proposed project: "*Chesapeake Bay dissolved oxygen profiling using a lightweight, low-powered real-time inductive CTDO$_2$ mooring with sensors at multiple vertical measurement levels"* to be submitted to the Chesapeake Bay Trust RFP Proposal 8: "Pilot a cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia".

As you know, for several years I have been working together with Dr. Aaron Bever (Anchor QEA) developing a method for estimating hypoxic volume from a few continuous oxygen sensors in the Chesapeake Bay. We are very excited about your proposed effort to deploy a pilot real-time vertical monitoring system and are committed to working with you on the site selection, vertical sensor placement and strategy for longer-term deployments if funding for additional monitoring systems becomes available. In this effort we will quantitatively determine the optimal site selection based on logistical constraints as well as overarching management questions and science objectives. We are happy to provide this service to you free of charge, as we are excited to see these ideas come to fruition in the Chesapeake Bay.

Best regards,

Marjorie A M Friedrichs

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UNITED STATES DEPARTMENT OF COMMERCE
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Caribbean Wind LLC
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February 8, 2019

Dear Mr. Wilson

Thank you for inquiring about the potential for cooperation for real-time quality control of dissolved oxygen observations in the Chesapeake Bay, as an element of your proposal in response to the Chesapeake Bay Trust (https://cbtrust.org/wp-content/uploads/RFP-for-Outreach-Services-for-CBTs-DI-Initiative.pdf).

The U.S. Integrated Ocean Observing System (U.S. IOOS®) maintains the Quality Assurance / Quality Control of Real-Time Oceanographic Data (QARTOD) project (https://ioos.noaa.gov/project/qartod), to work with the oceanographic community to develop and implement real-time QC standards. The QARTOD mission includes limited support for all entities striving to develop QC processes in accordance with QARTOD standards. Examples of such support include specific test guidance, review of test thresholds selected, evaluation of test results, QC data flags, and documentation of successful implementation. It would not include actual development or operation of software, or any role in actual data management.

We would be happy to provide this limited assistance to you and others associated with this aspect of data management. The QARTOD Manual for Real-Time Quality Control of Dissolved Oxygen Observations (https://ioos.noaa.gov/ioos-in-action/manual-real-time-quality-control-dissolved-oxygen-observations) details eleven tests, either required, strongly recommended, or suggested. In particular, this project provides an opportunity to incorporate QARTOD elements into the EPA QAPP framework. We look forward to working with you determine which tests should be employed for your specific application, and wish you success with your proposal.

Best regards,

Mark Bushnell
US IOOS QARTOD National Coordinator