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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Chesapeake Bay Trust EPA Chesapeake Bay Program Goal Implementation Team Support

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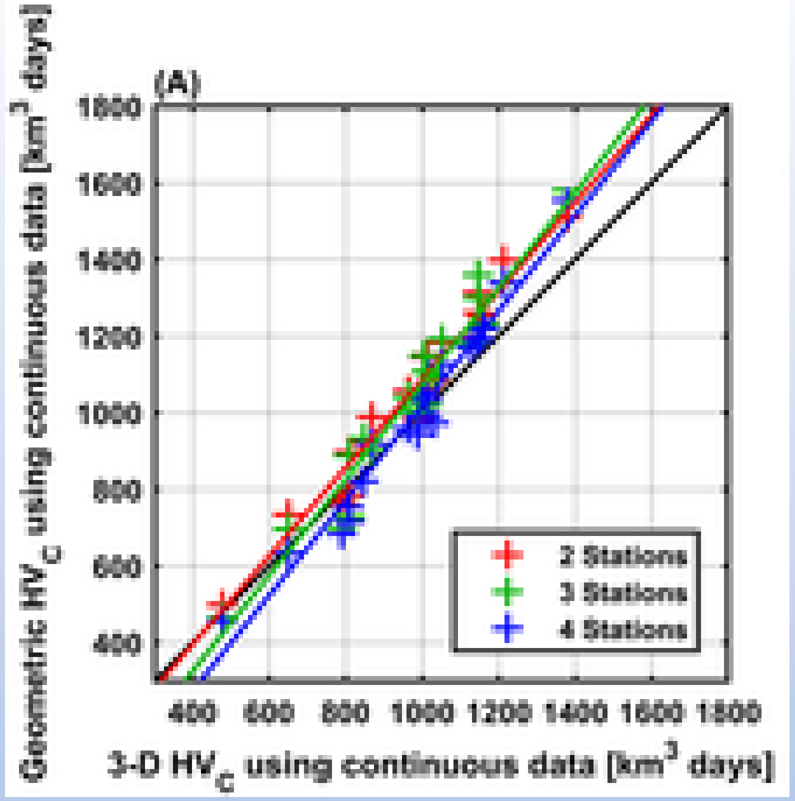
SCOPE 8: ***"…demonstrate a reliable, cost effective, real-time dissolved oxygen vertical monitoring system for characterizing mainstem Chesapeake Bay hypoxia."***

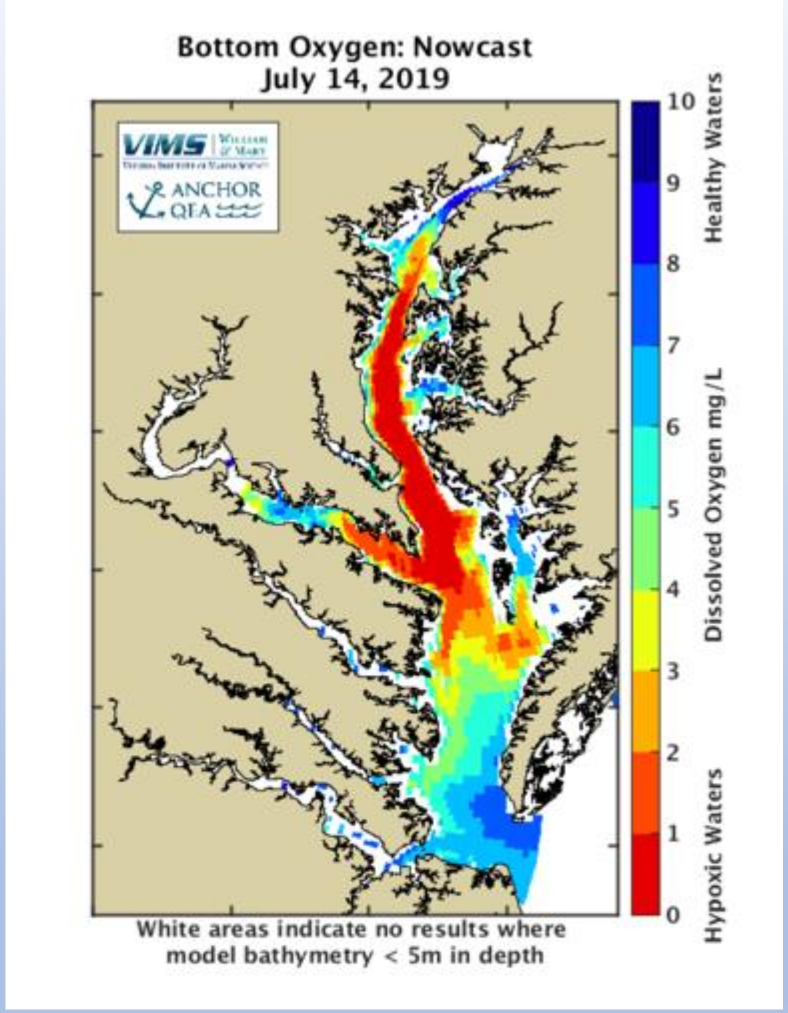
Water quality impairment in the Chesapeake Bay, caused primarily by excessive long-term nutrient input from runoff and groundwater, is characterized by extreme seasonal hypoxia, particularly in the bottom layers of the deeper mainstem (although it is often present elsewhere). In addition to obvious negative 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.

Chesapeake Bay Program direct mainstem 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.*



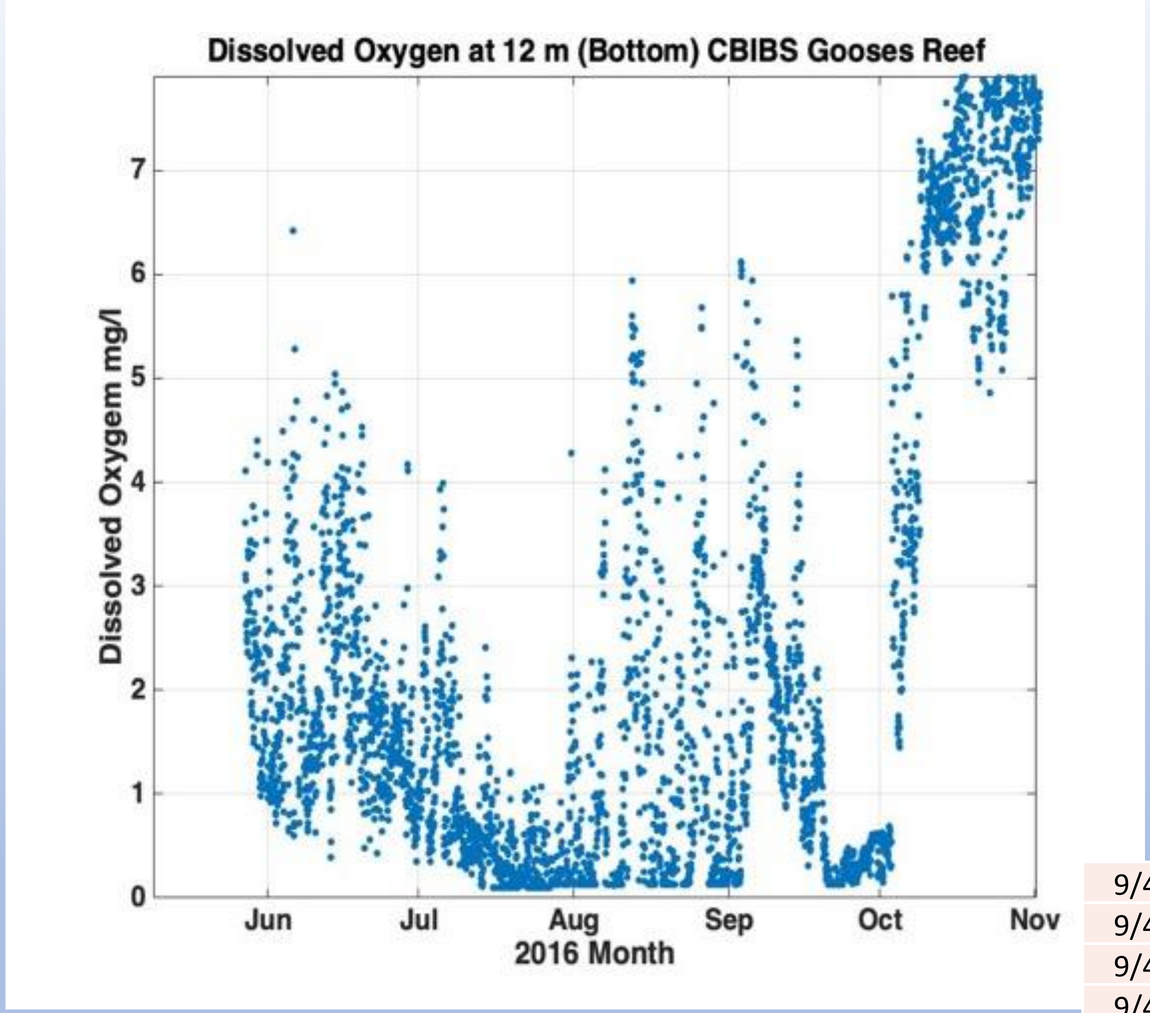
Bever, A. J., Friedrichs, M. A. M., Friedrichs, C. T., & Scully, M. E. (2018). Estimating hypoxic volume in the Chesapeake Bay using two continuously sampled oxygen profiles. *Journal of Geophysical Research: Oceans*, 123, 6392 - 6407.
https://doi.org/10.1029/2018JC014129

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.

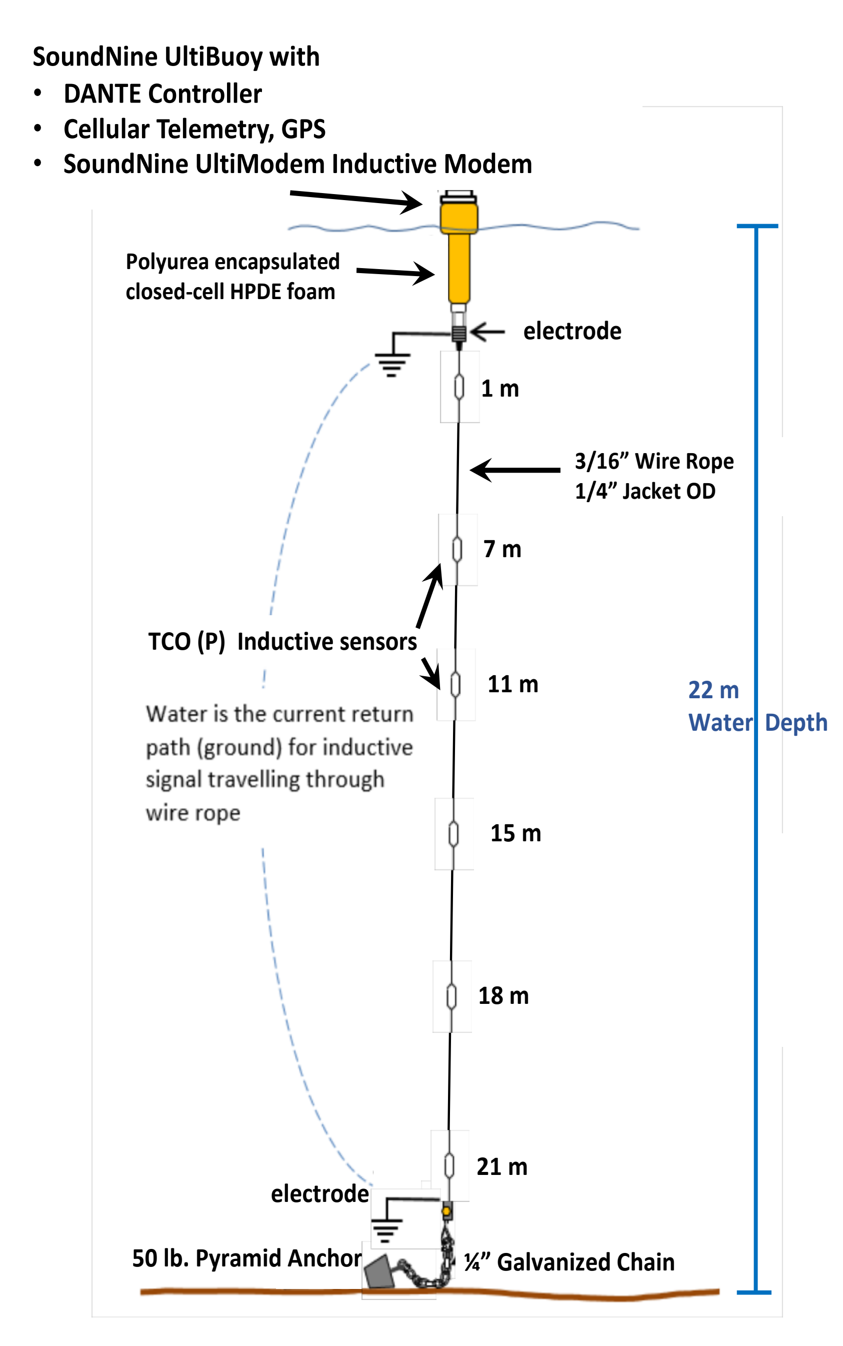
Units collect data and transmit inductively, clamped to a semi-taut mooring line with a surface data collection and cellular transmission buoy (Soundnine UltiBuoy).

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?

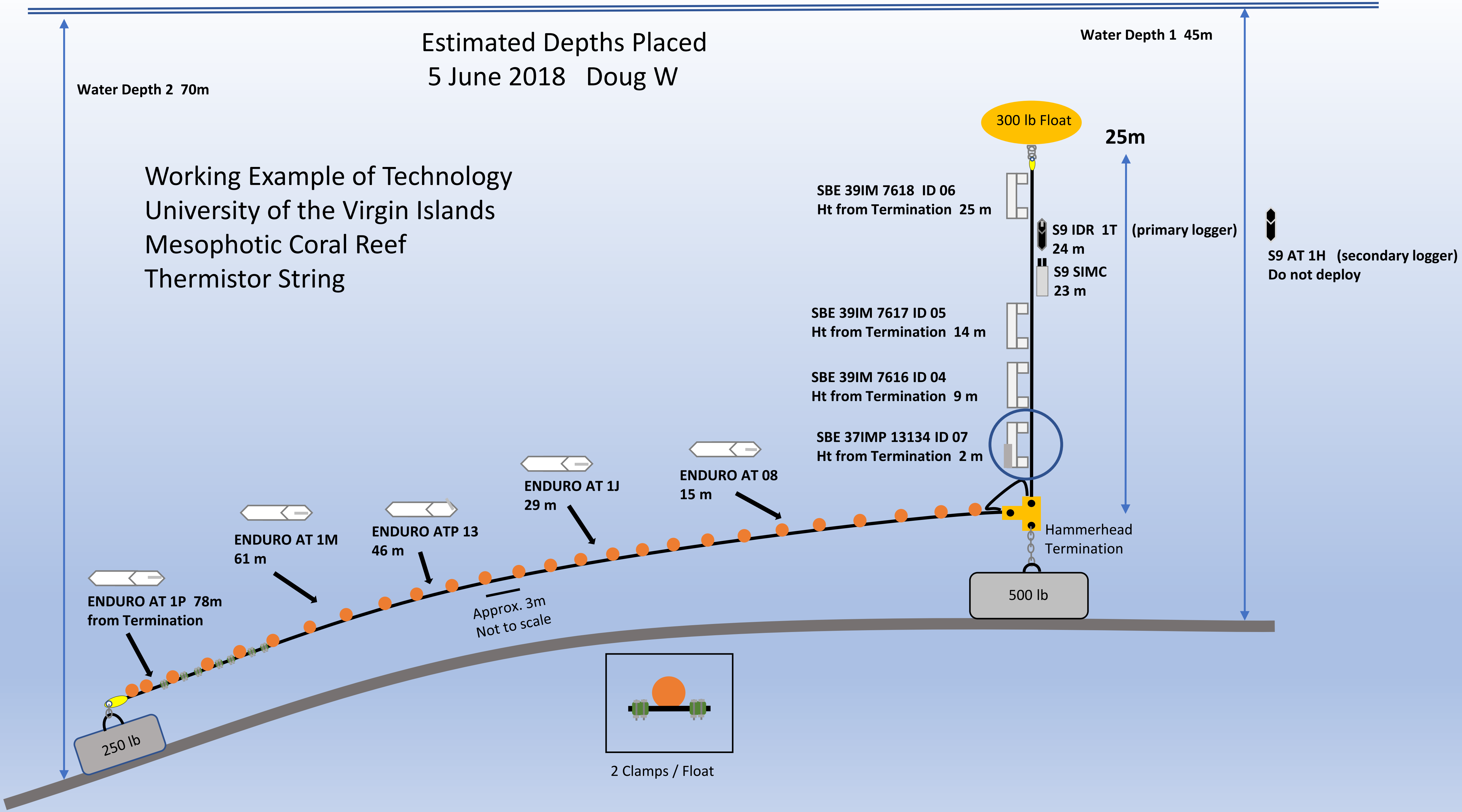
Reliable

- 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

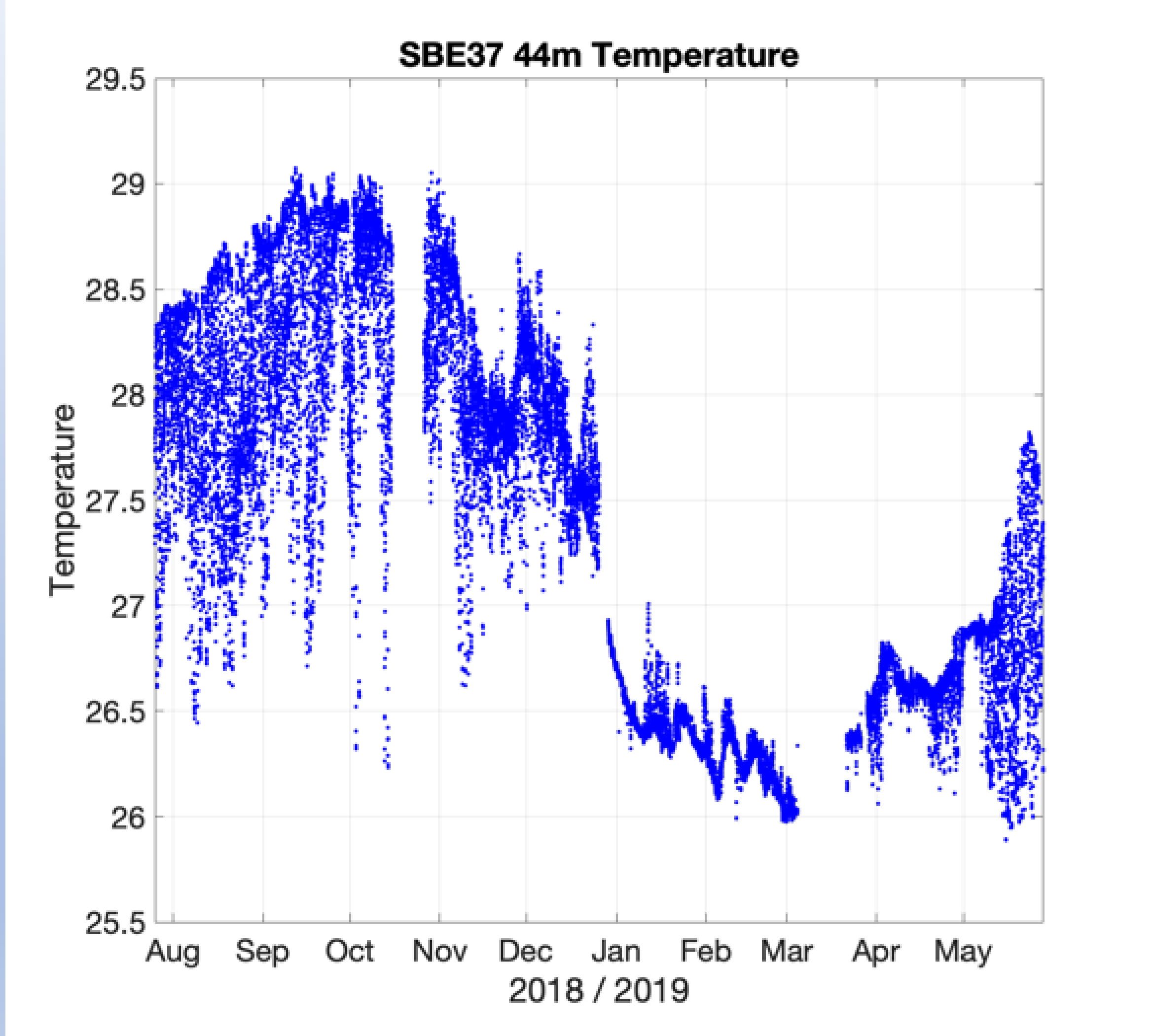


Estimated Depths Placed
5 June 2018 Doug W

Working Example of Technology
University of the Virgin Islands
Mesophotic Coral Reef
Thermistor String



University of the Virgin Islands
Mesophotic Coral Reef
Thermistor String



Sustainable

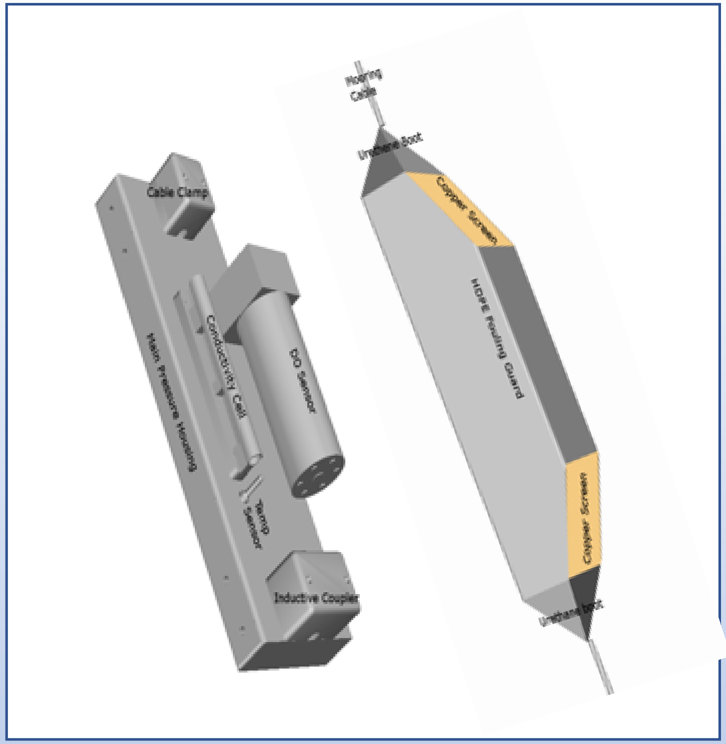
- Sensor modules are low cost (estimated $4-5K) so spares are affordable
- Protected from fouling, modules and sensors should not require cleaning during season
- Full mooring with sinker is hand-deployable/recoverable by two people using a small boat

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

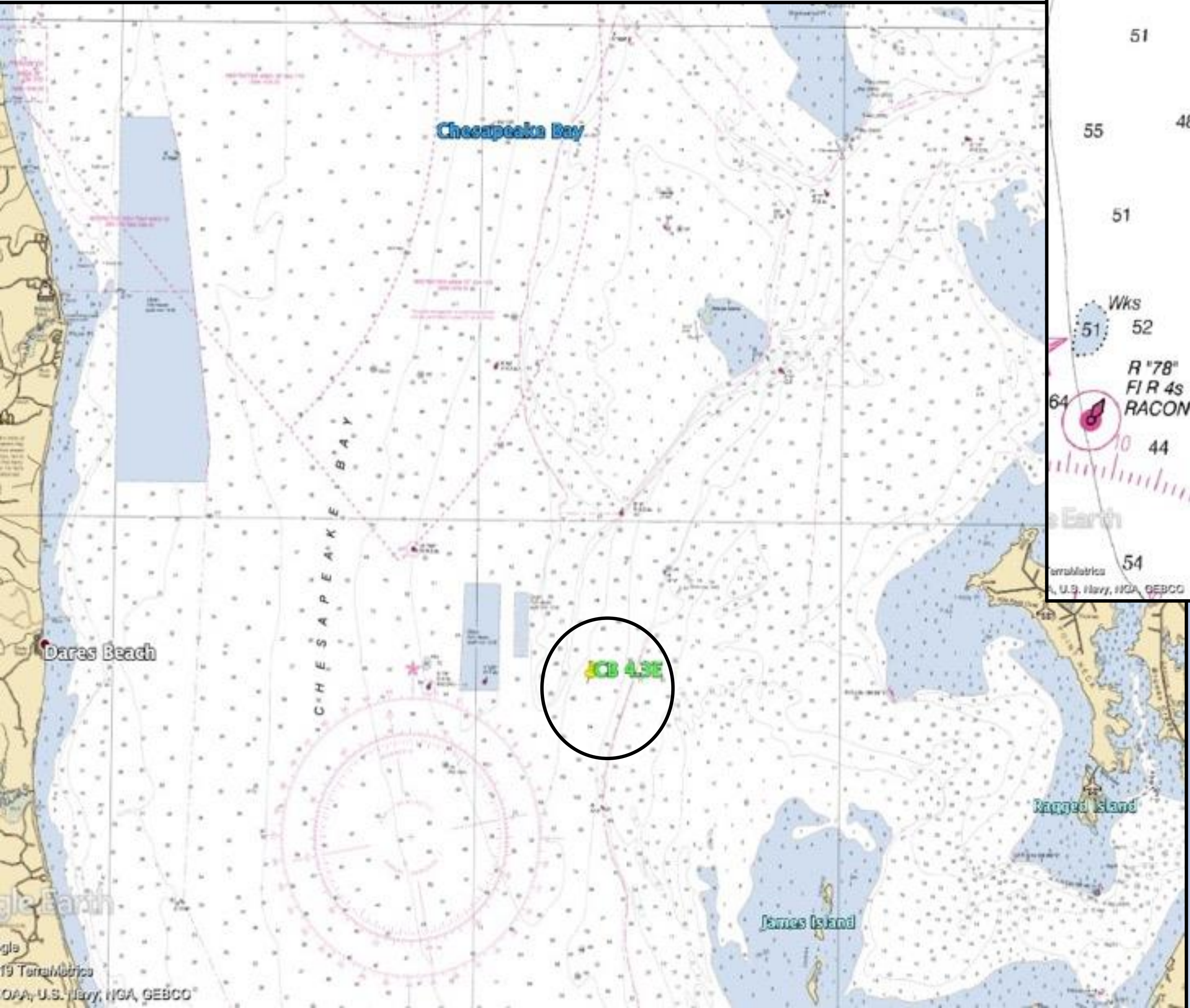


While a single profiling instrument is an alternative approach, our experience with these devices is that they have more structural and logistical complexities and failure points (both in the profiling mechanism and in the mooring/structure supporting the profiler). These increase the risk of service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



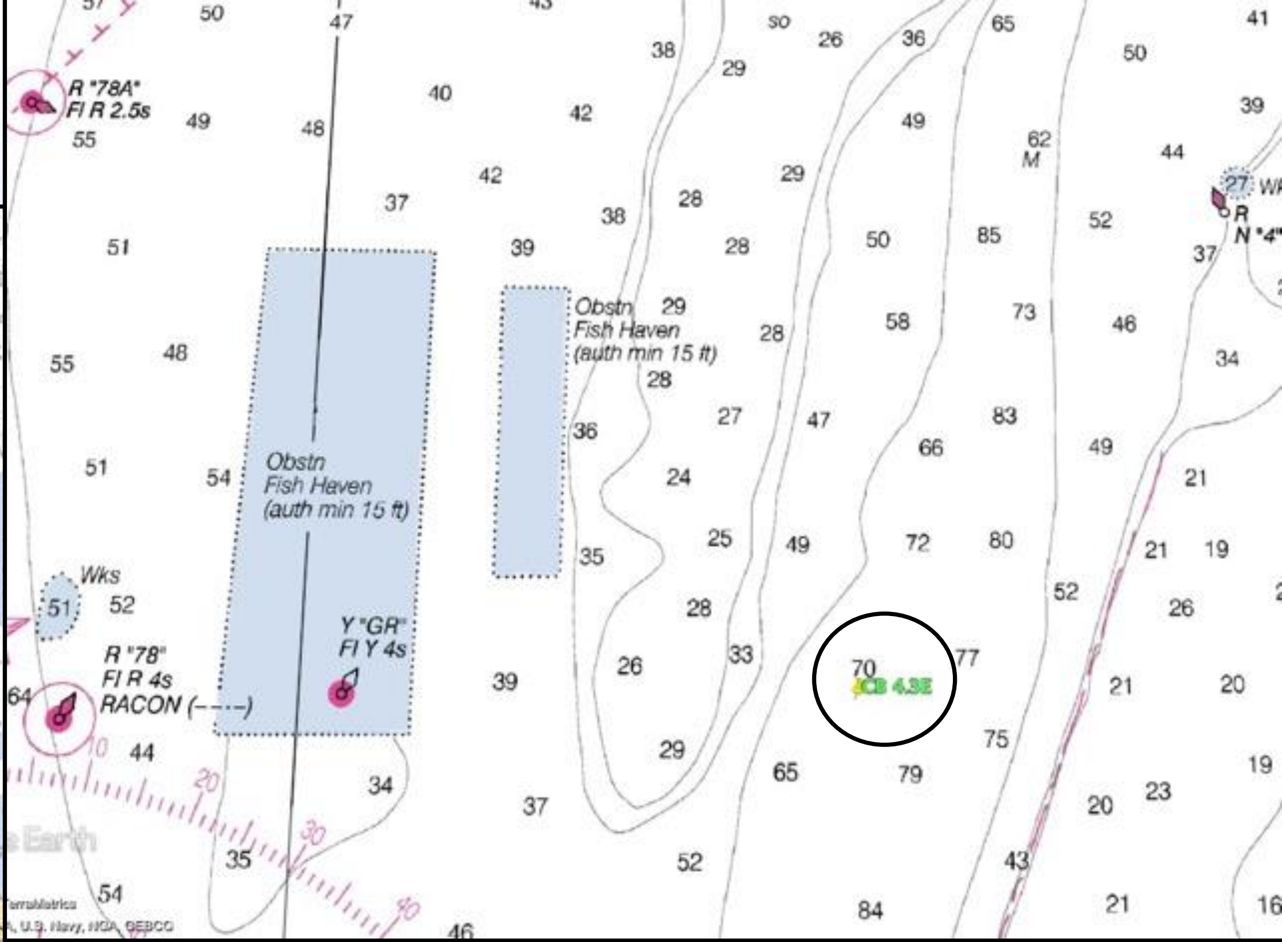
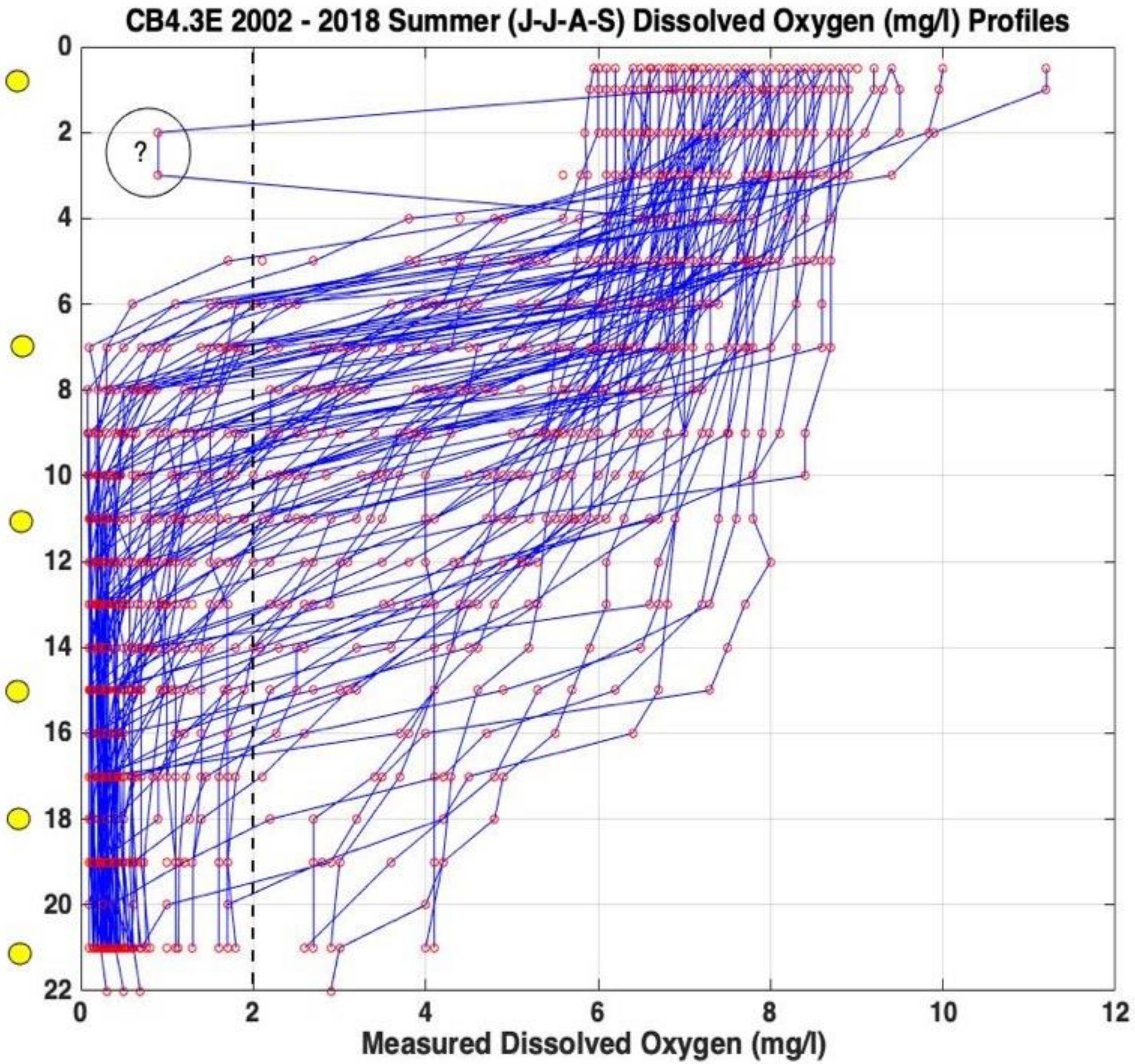
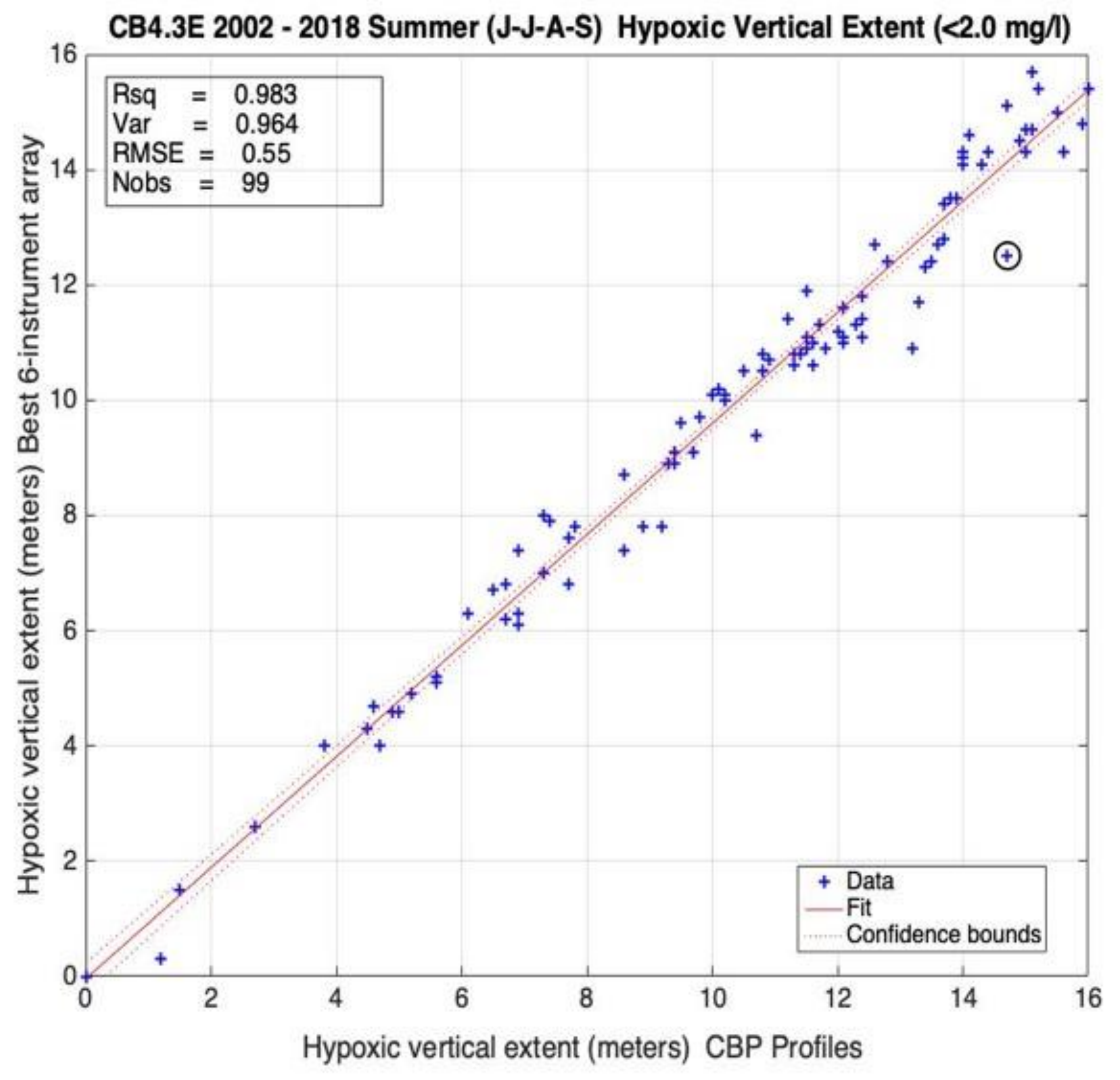


Figure shows CB4.3E DO profiles from 2002-2018 June/July/August/September. With the assumption that we want to be able to at least match the ability of the existing fixed station sampling to resolve structure and measure vertical extent of hypoxia (DO < 2.0 mg/l) for use in DO volume estimates and forecast 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 <u>at least two vertical data points</u> 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.