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

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Chesapeake Bay Trust

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

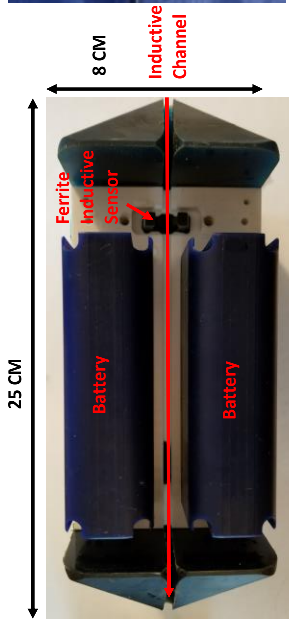
b) locating sensor packages at multiple fixed depths, with vertical sensor spacing adequate to meet observational requirements.

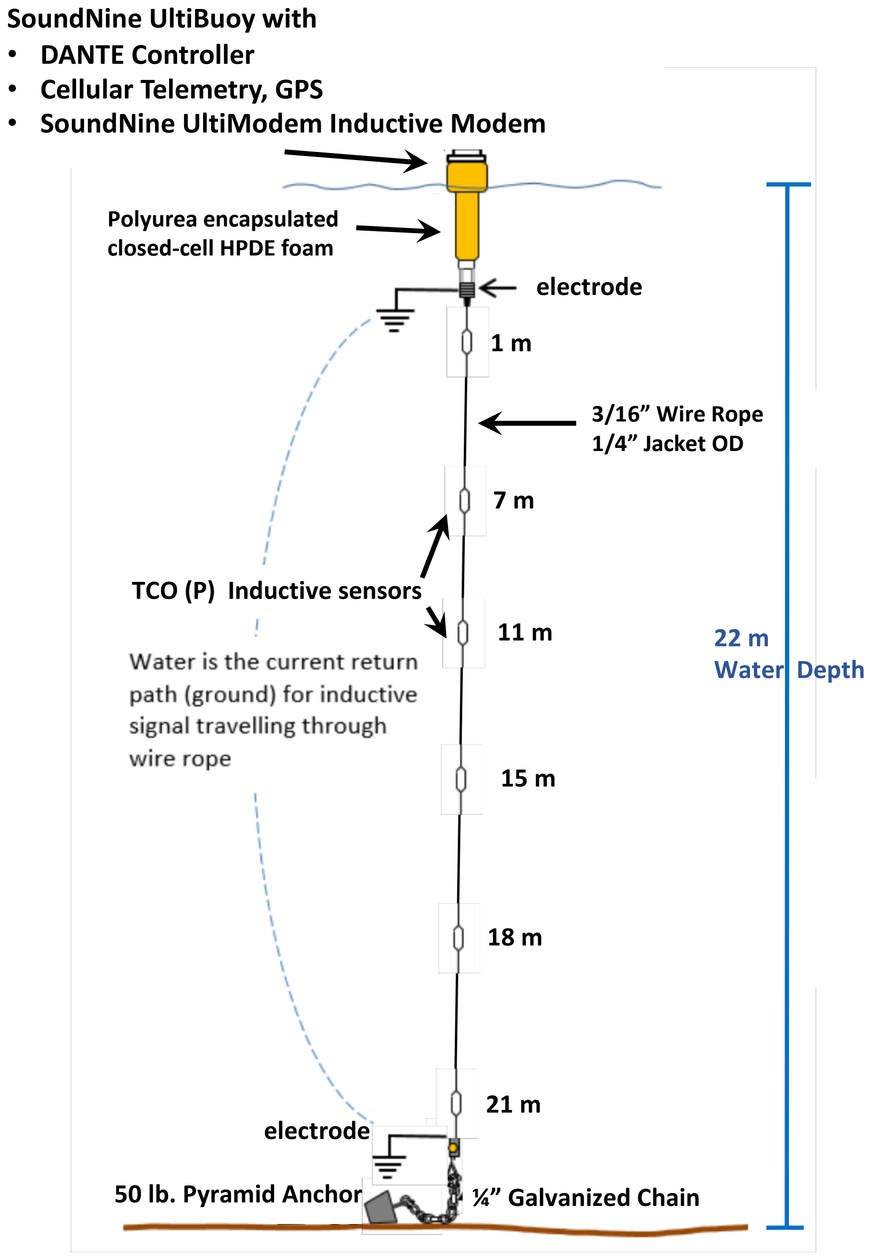
Either way, data must be regularly collected and transmitted from the *in situ* system location to an accessible data structure.

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.

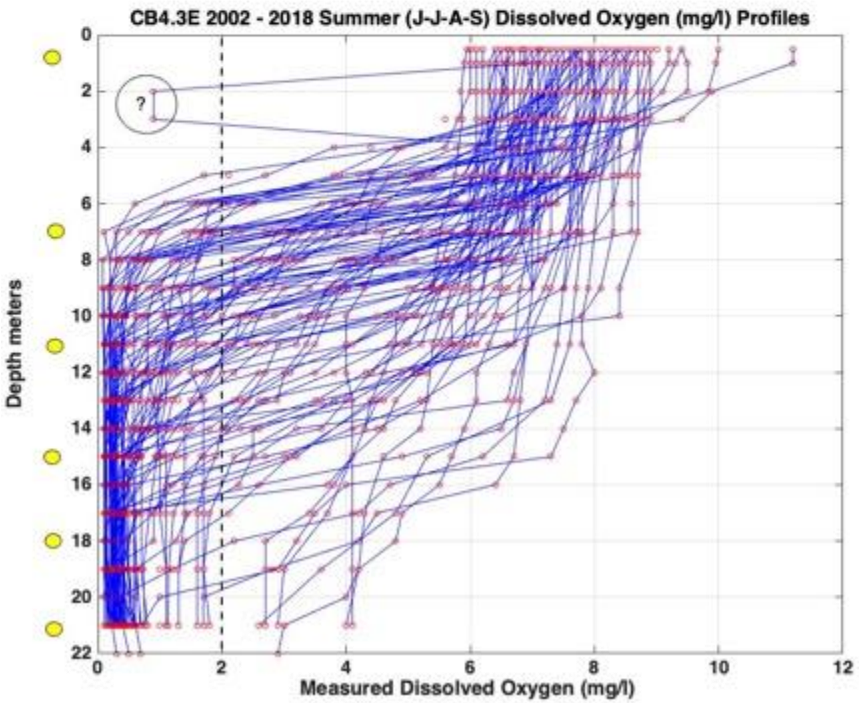
While a single profiling instrument is another approach, our experience with these devices is that they have more structural and logistical complexities and failure points (both in the profiling mechanism and in the mooring/structure supporting the profiler) that increase the risk of service visits in-season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

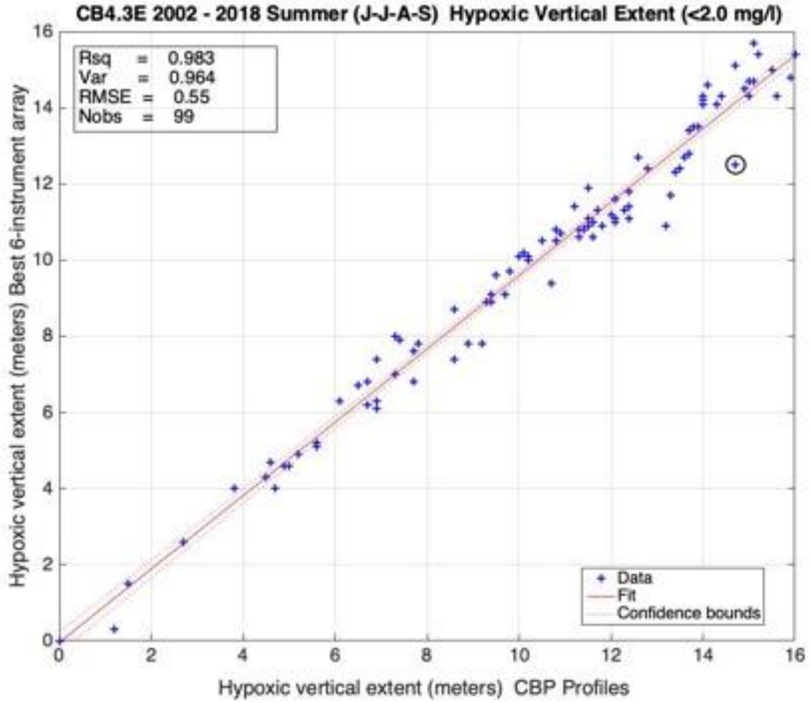
Analysis

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.

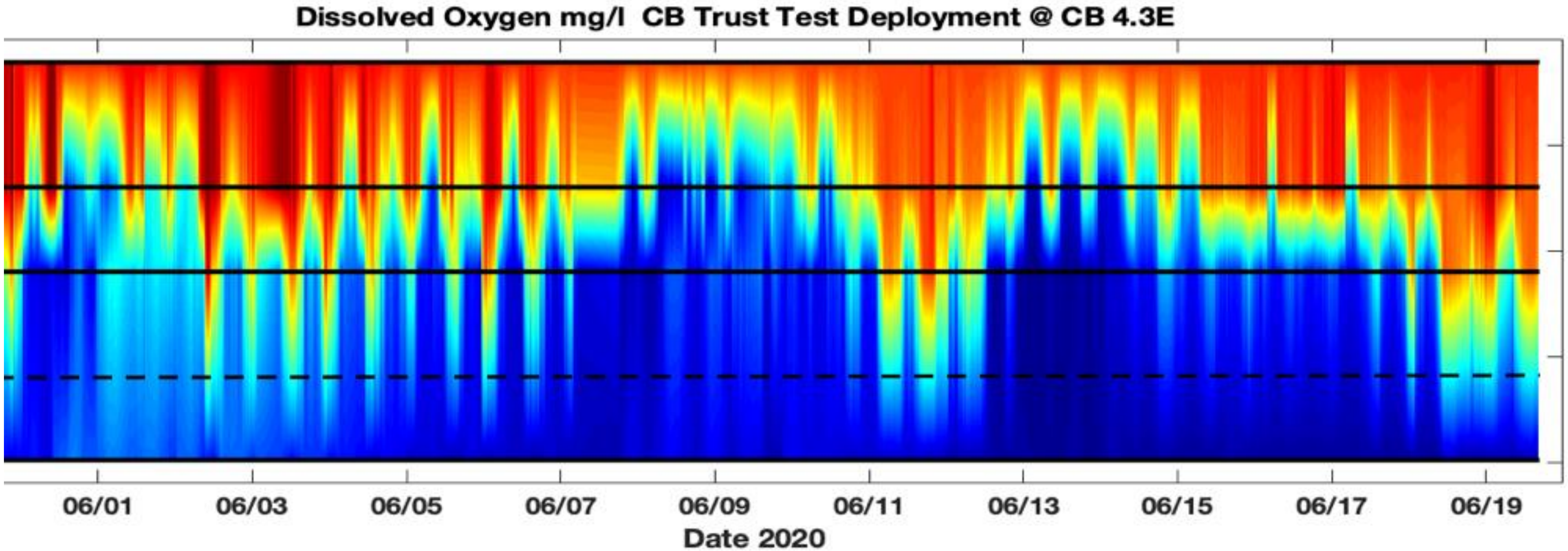
- Profiles of Dissolved Oxygen from all 2002-2018 Jun-September measured CBP stations at CB3.4E. Red dots are original sample depth locations, connected by blue profile lines. Yellow circles represent a six-instrument array used in (B).
- Comparison of ‘Vertical Hypoxia Extent (Meters)’ calculate using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

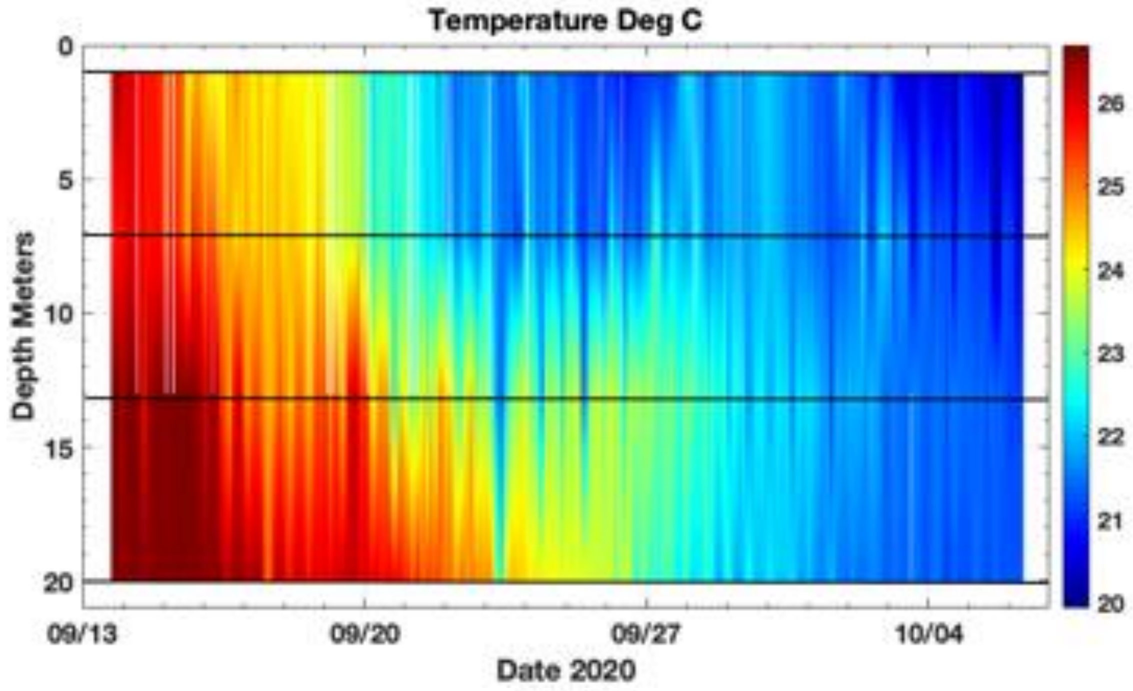
30 May 2020
19 June 2020

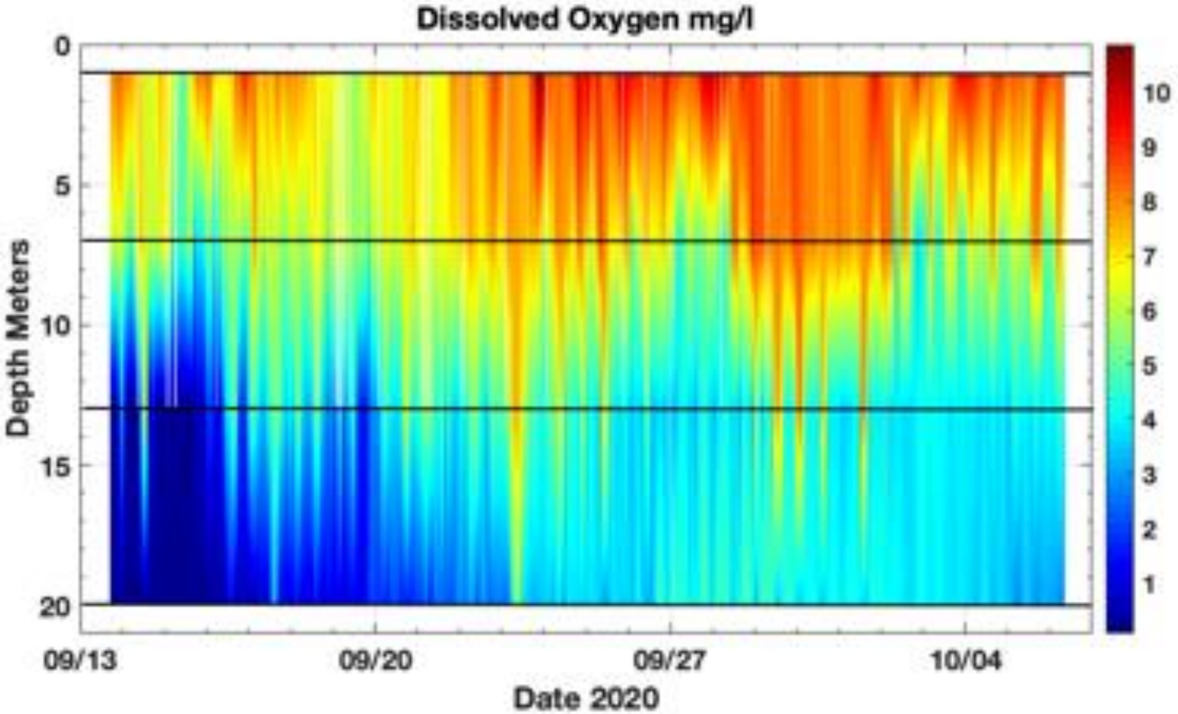


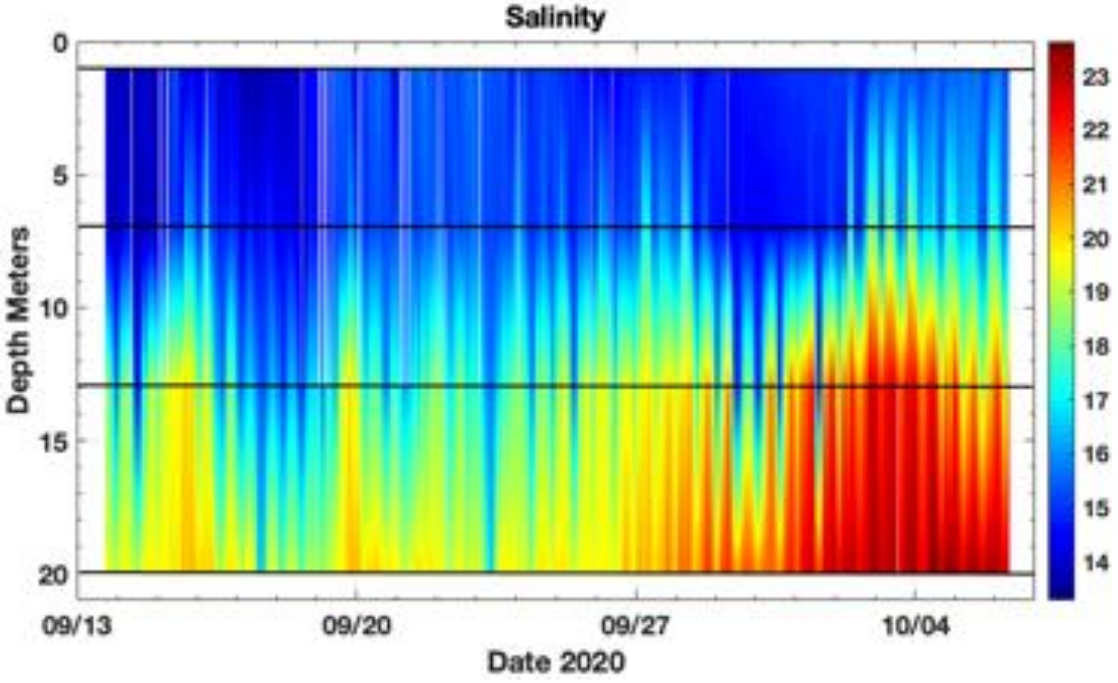
Deployment 2

13 September 2020
06 October 2020

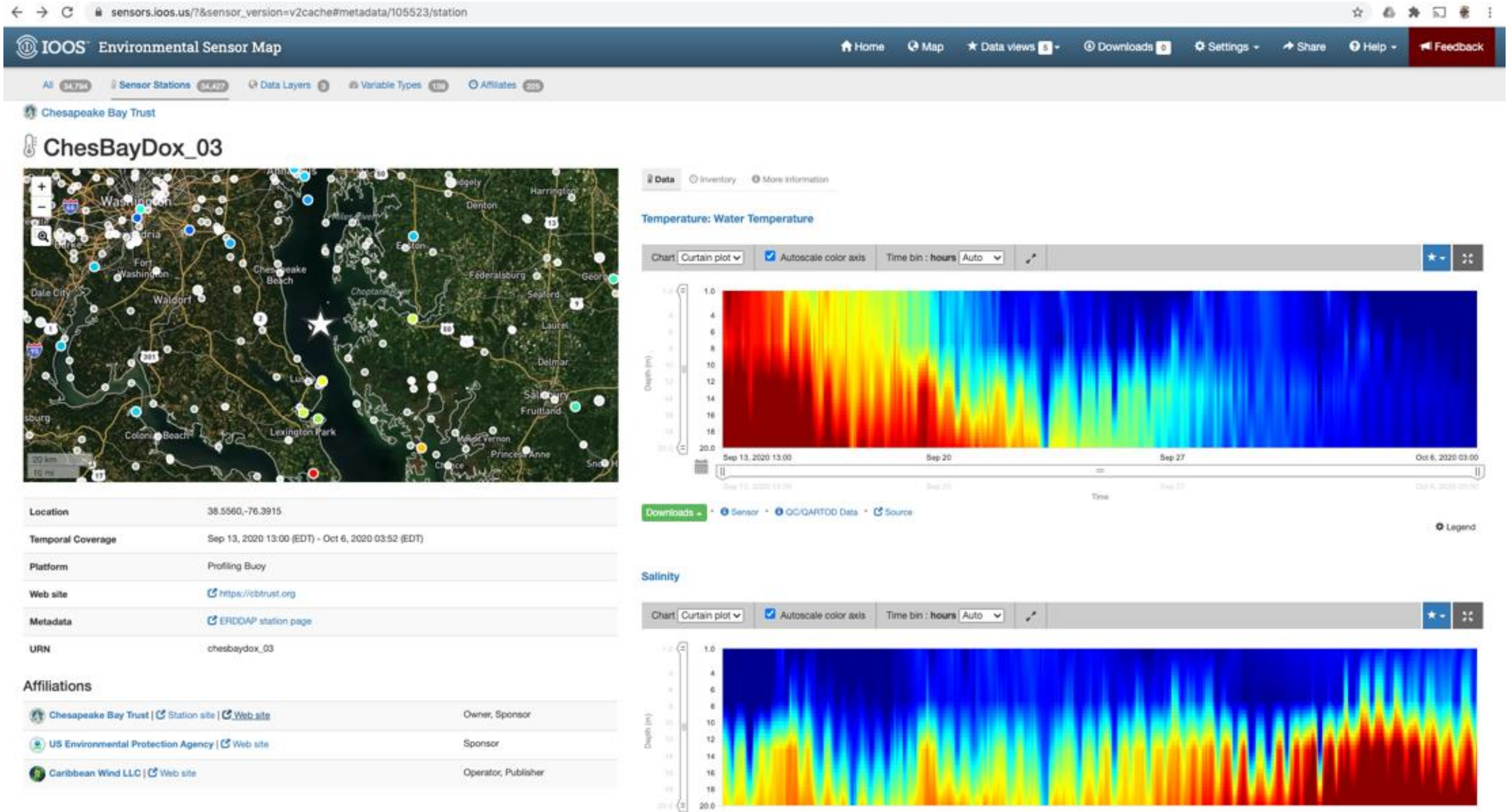
Ended prematurely when a NOAA hydrographic survey contract vessel snagged the mooring and dragged several miles. Good stress test – all still working afterwards!



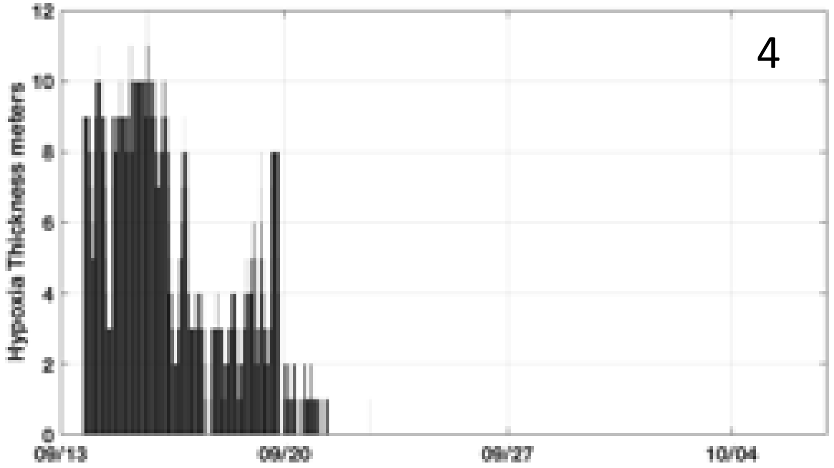


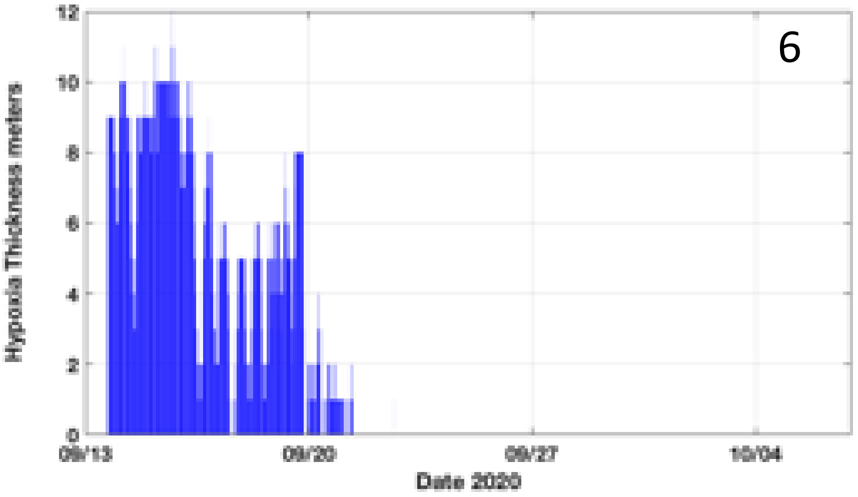


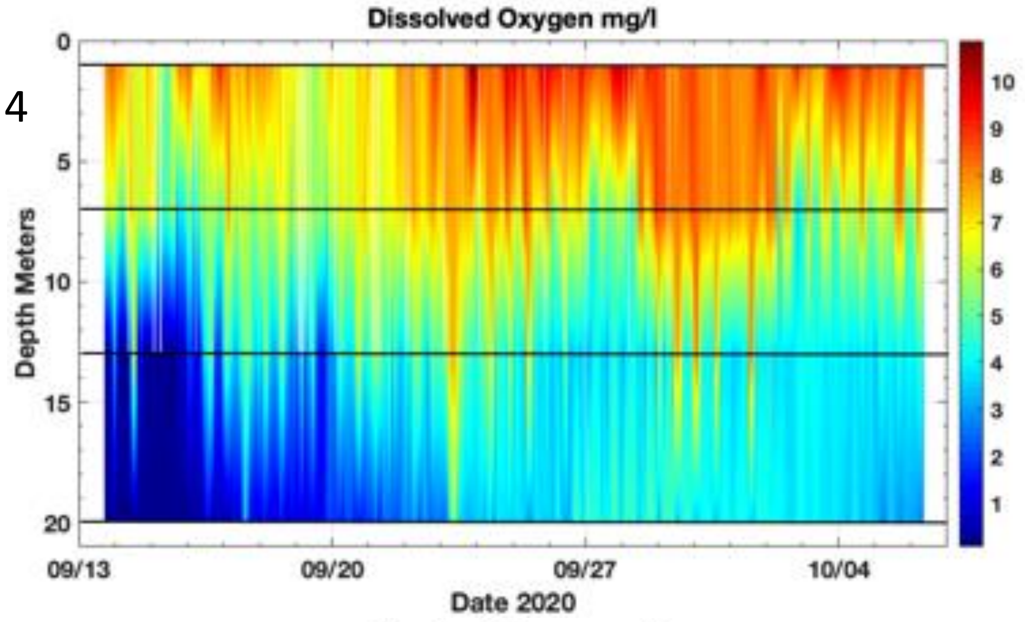
In addition to cloud-based data base at SoundNine (which allows direct access to data, AXIOM Data Science has created a real-time US IOOS format web site (includes access to nearby platforms and ERDDAP data access page)
at https://sensors.ioos.us/?&sensor_version=v2cache#metadata/105523/station

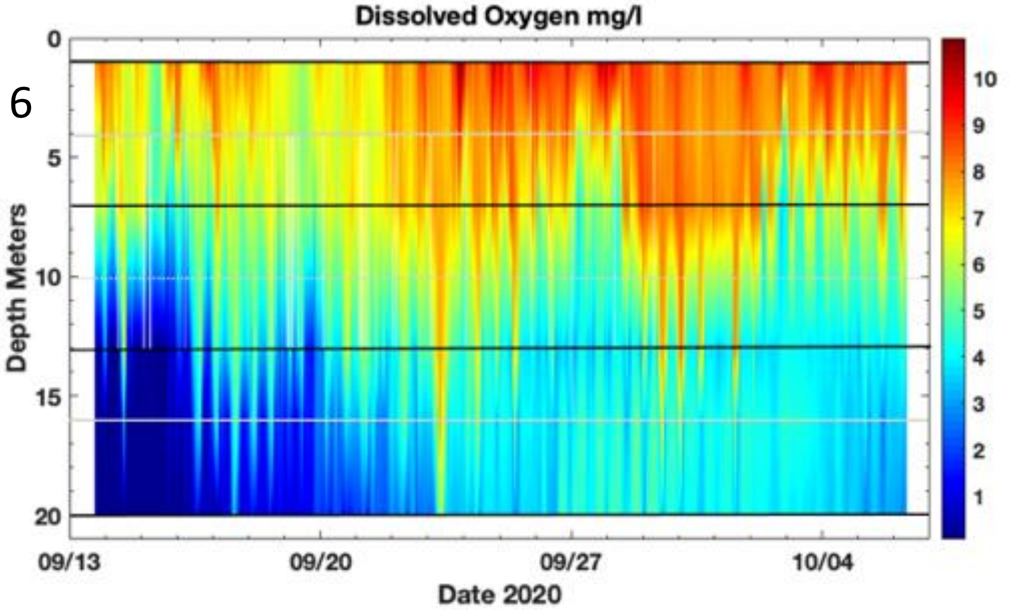


Also did a 'data denial' experiment with 2 recording non-reporting DO sensors at 4 and 16 m to see difference between Four and Six sensor arrays. Over the 25 day record, mean differences were
0.09 mg/l at 4 m and 0.06 mg/l at 16 m.
Calculated thickness of Hypoxic Layer (below) show hypoxic conditions ending on the same date, with the time-integrated totals differing by about 5%.









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)