Chesapeake Bay Water-Column Hypoxia Monitoring Quality Assurance Project Plan (QAPP)

February 2023

Version 1.0

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National Oceanic and Atmospheric Administration
Version 1.0

Publication Date Winter 2023
Publication tracking number XXXXXXXX

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Revision History

This table shows changes to this controlled document over time. The most recent version is presented in the top row of the table. Previous versions of the document are maintained by the Quality Assurance Manager.

Document Control Number	History/Changes	te

Preface

The NOAA Chesapeake Bay Office (NCBO) developed this quality-assurance project plan (QAPP) for use with a continuous vertical water column hypoxia monitoring project. This document has been prepared for the Chesapeake Bay Program (CBP) using existing documents prepared by the Environmental Protection Agency (EPA), U.S. Geological Survey, and Maryland Department of Natural Resources for other water-quality monitoring projects. The QAPP documents the standards, policies, and procedures used by NCBO for activities related to the collection, processing, storage, analysis, and release of continuous water-quality monitoring data. The policies and procedures that are documented in this QAPP for continuous vertical water column hypoxia monitoring activities are consistent with QAPPs developed by other CBP partners for water-quality measurements in the Chesapeake Bay.

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1. Project Management Elements

1.1 EPA R3 Signature Page

Project ID:

Effective Date:

EPA Document Control Number (DCN):

1.2 Approval Sheet

Concurrence

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Name: Max Ruehrmund IV Title: Electronics Technician Organization: NOAA NCBO	RUEHRMUND.MAX.ERNST.1598121962 Digitally signed by RUEHRMUND.MAX.ERNST.1598121962 Date: 2023.04.19 11:44:16 -04'00'

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EPA Region 3

Name: Title: R3 Designated Project Manager Organization:	

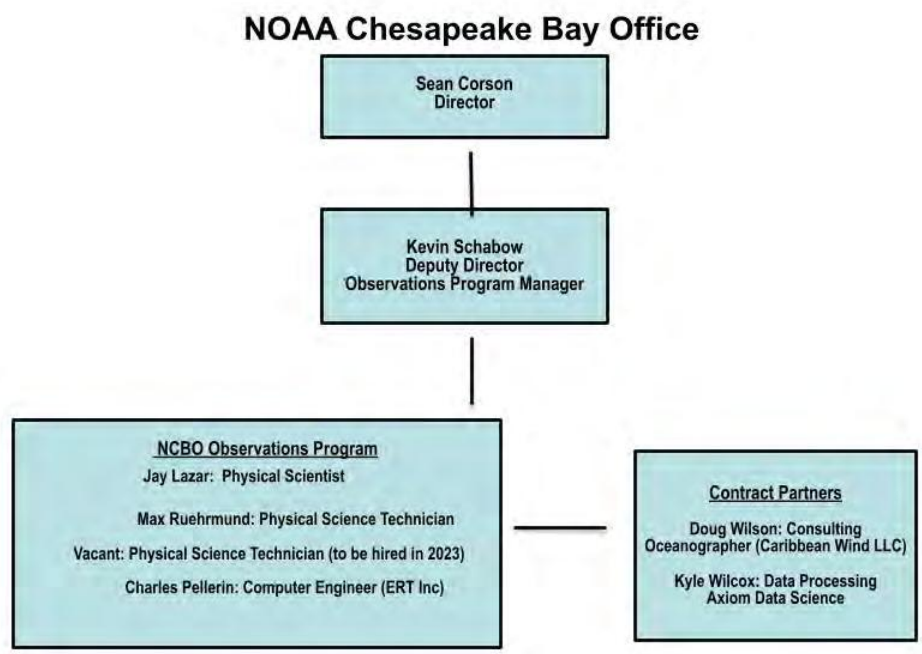
Approval

EPA Region 3

Name: Durga Ghosh Title: R3 Delegated Approving Official Organization: CBP USGS	

Note: This approval action represents EPA's determination that the document(s) under review comply with applicable requirements of the EPA Region 3 Quality Management Plan (https://www.epa.gov/sites/production/files/2020-06/documents/r3qmp-final-r3-signatures-2020.pdf) and other applicable requirements in EPA quality regulations and policies (https://www.epa.gov/quality). This approval action does not represent EPA's verification of the accuracy or completeness of document(s) under review, and is not intended to constitute EPA direction of work by contractors, grantees or subgrantees, or other non-EPA parties.

1.3 Hypoxia Program Organizational Chart



1.4 Project Organization and Responsibility

These individuals are responsible for the major aspects of NOAA's Hypoxia Water-Quality Monitoring Program.

Manager

Kevin Schabow, NOAA Chesapeake Bay Office, 200 Harry S. Truman Parkway, Suite 460, Annapolis, MD 21401, Kevin.Schabow@noaa.gov. Responsibilities: The manager is responsible for overseeing the administrative aspects of the program including fiscal management, coordination among other Chesapeake Bay Program partners, personnel management, and coordination with cooperating agencies and institutions.

Project Coordinator

Jay Lazar, NOAA Chesapeake Bay Office, 200 Harry S. Truman Parkway, Suite 460, Annapolis, MD 21401; Jay.Lazar@noaa.gov. Responsibilities: This individual is responsible for the overall coordination of the hypoxia program. This includes maintaining and coordinating the field resources and personnel to operate the system on a seasonal and daily basis. This person is also the liaison between NOAA and private businesses essential to the project, including the data management company, equipment supplier, and contractual project consultants.

Field Lead/Validation Lab Coordinator

Max Ruehrmund, NOAA Chesapeake Bay Office, 200 Harry S. Truman Parkway, Suite 460, Annapolis, MD 21401; Max.Ruehrmund@noaa.gov. Responsibilities: This individual is responsible for execution of field activities including deployment and recovery of equipment, on site data validation, scheduling sensor maintenance, and validation of sensors in the validation laboratory.

Instrument Management

New NOAA Hire, NOAA Chesapeake Bay Office, 200 Harry S. Truman Parkway, Suite 460, Annapolis, MD 21401. Responsibilities: This individual will be responsible for the management of all continuous monitoring equipment.

Quality Assurance Officer, Processing and Quality Assurance/Quality Control

Charles Pellerin, NOAA Chesapeake Bay Office, 200 Harry S. Truman Parkway, Suite 460, Annapolis, MD 21401; Charles.Pellerin@noaa.gov. Responsibilities: This individual is responsible for overseeing the management and processing of field and laboratory data collected under this program and maintaining existing data management software.

Consulting Oceanographer

Doug Wilson, Caribbean Wind LLC. Responsibilities: This individual is responsible for providing subject-matter expertise on Chesapeake Bay oceanographic conditions and processes, equipment and sensors used in the project, and ocean data processing, management, and quality assurance.

Data Scientist, Processing and Quality Assurance/Quality Control

Kyle Wilcox, Axiom Data Science (IOOS Consultant). Responsibilities: This individual is responsible for overseeing the management and processing of field and laboratory data collected under this program and maintaining existing data management software.

1.5 Distribution List

Position	**Name**	**Responsibilities**
Director, NOAA Chesapeake Bay Office	Sean Corson	Provides overarching direction and oversight for NOAA activities in support of this Project
Chief, Science, Analysis, and Implementation Branch Chesapeake Bay Program Office	Lee McDonnell	Provides overarching oversight for EPA in support of this Project
Monitoring Coordinator, Chesapeake Bay Program Office/USGS	Peter Tango	Coordinates the ad hoc CBP Hypoxia Collaborative providing technical guidance to the

		Project
Ecosystem Science and Synthesis Manager NOAA Chesapeake Bay Office	Bruce Vogt	Coordinates the ad hoc CBP Hypoxia Collaborative providing technical guidance to the Project
QA Coordinator/Chemist Chesapeake Bay Program/USGS	Durga Ghosh	Quality Assurance Project Plan lead reviewer

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3. Project Description

3.1 Background

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) (Bever et al., 2018). In addition to obvious negative impacts on ecosystems where it occurs, hypoxia represents the integrated effect of watershed-wide nutrient pollution. Therefore, monitoring to measure the vertical and horizontal extent and duration of the hypoxic regions is important to assessing Chesapeake Bay health and restoration progress.

Current Chesapeake Bay Program (CBP) water-quality monitoring is broadly distributed spatially and temporally, with monthly or bimonthly single fixed stations separated by several kilometers. The need for continuous, real-time, vertically sampled profiles of dissolved oxygen has been long recognized. Improvements in hypoxia modeling and sensor technology now make this monitoring achievable. A recent publication from Bever, et al. (2018) shows that total Chesapeake Bay hypoxic volume can be estimated using a few analytically selected fixed continuous dissolved oxygen profiles. Toward that end, vertical arrays supporting real-time transmission of dissolved oxygen and other parameters have been deployed for testing to evaluate their ability to efficiently and sustainably provide dissolved oxygen data to monitor Chesapeake Bay hypoxia.

Water-quality data produced by this project will be used to define water column habitat, including seasonal hypoxia, salinity, and temperature conditions necessary to support living resource management decision making. The information will also be used to develop and assess water-quality criteria standards with the goal of restoring regulatory segments of water in the Bay and its tidal rivers toward their attainment goals. Water-quality data is required to support refinement, calibration, and validation of the Chesapeake Bay Eutrophication and Watershed Models.

A pilot project addressing the above needs was funded through the Chesapeake Bay Trust (CBT) from May 30 to June 19, 2020. Caribbean Wind LLC competitively bid to develop and deploy a robust low-cost system for the NOAA Chesapeake Bay Office. Results of the feasibility project yielded the needed knowledge via a technical report required to scale the study to accurately quantify the hypoxic water volume in Chesapeake Bay.

3.2 Prior Deployments

Two test deployments followed the initial pilot project. These took place December 1–15, 2021, and May 19–September 30, 2022. Results were evaluated by NCBO with the intention to inform a full season deployment in 2023. The first one-station deployment, over two weeks in late fall 2021 provided an opportunity to test the new system. The second test deployment, from May-September 2022 consisted of two locations selected by the Chesapeake Bay Program’s Hypoxia Collaborative. This effort further evaluated the relative value of a shallow-water site (less than 8m) against a deeper site (20m) across a single latitude. Sites were visited roughly at three-week intervals to determine biofouling rates across the deployment seasons. During each visit, an independent Conductivity Temperature Depth-Dissolved Oxygen (CTD-DO) was recorded with a SeaBird SBE19 mounted SBE43 dissolved oxygen sensor. This second test deployment brought to scale various methods of deployment and recovery, data management, quality assurance, and quality control. Lessons learned from the CBT feasibility study as well as the 2021 and 2022 test deployments will be incorporated into the management of the hypoxia monitoring network in 2023.

3.3 Problem Definition and Objectives

Current CBP fixed station monitoring is only adequate to meet the “fair” level of water-quality monitoring toward the attainment of delisting a tributary or Bay segment (Bever, et al., 2018). Increasing the temporal resolution of those measurements in a select number of locations can move the level of water-quality monitoring from “fair” to “good.” These same stations can validate hypoxic volume models used to currently assess attainment levels and be used outside of the mainstem to more flexibly meet the demands of specific jurisdictions. This investment provides the data necessary to do a complete evaluation of habitat criteria for dissolved oxygen for the first time in any Bay segment since the criteria were published in 2003 and later adopted by the states, underpinning assessment of water-quality standards and related federal Clean Water Act reporting requirements.

The objectives of the hypoxia water column monitoring system are to:

- Profile dissolved oxygen using a lightweight, low-power, real-time inductive CTDO2 sensors. Mooring have sensors evenly dispersed at depth,
- Ensure the system and resulting data meet Chesapeake Bay Program and partners’ data-quality requirements,
- Provide adequate vertical resolution to demonstrate the ability to capture the important features of vertical structure, and
- Ensure the system is flexible and can be successfully used in all required locations, recognizing diverse, often extreme physical environments and conditions that may be faced.

3.4 Sample Parameters

Vertically deployed Soundnine, Inc., sensors report temperature, conductivity, dissolved oxygen, and pressure. Collected data is transmitted inductively through a semi-taut mooring line to a surface data controller and ultimately to a data server at Soundnine via cellular modem located in the Soundnine Ultibuoy (Table 1).

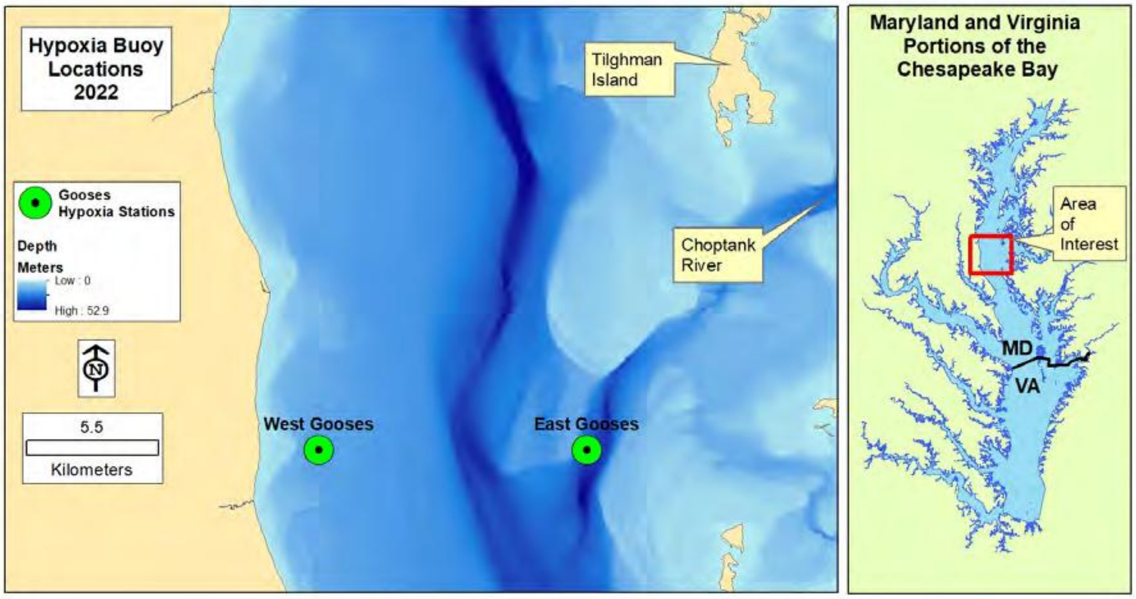
Parameters reported in situ include:

Dissolved Oxygen Concentration	mg/l
Temperature	Deg C
Temperature Period	Diagnostic
Temperature Stability	Diagnostic
Conductivity	S/m
Dissolved Oxygen Temperature	Deg C Diagnostic
Dissolved Oxygen ‘Q’ Factor	Diagnostic
Pressure Voltage	to calculate Pressure
Pressure Temperature	Deg C
Instrument Battery Voltage	Volts
Instrument Pitch	Degrees
Instrument Acceleration	g
Instrument Signal Strength	dB

Table 1: *Available parameters of the Soundnine, Inc., buoy system provided by system manual.*

3.5 Station Locations (2020-2022)

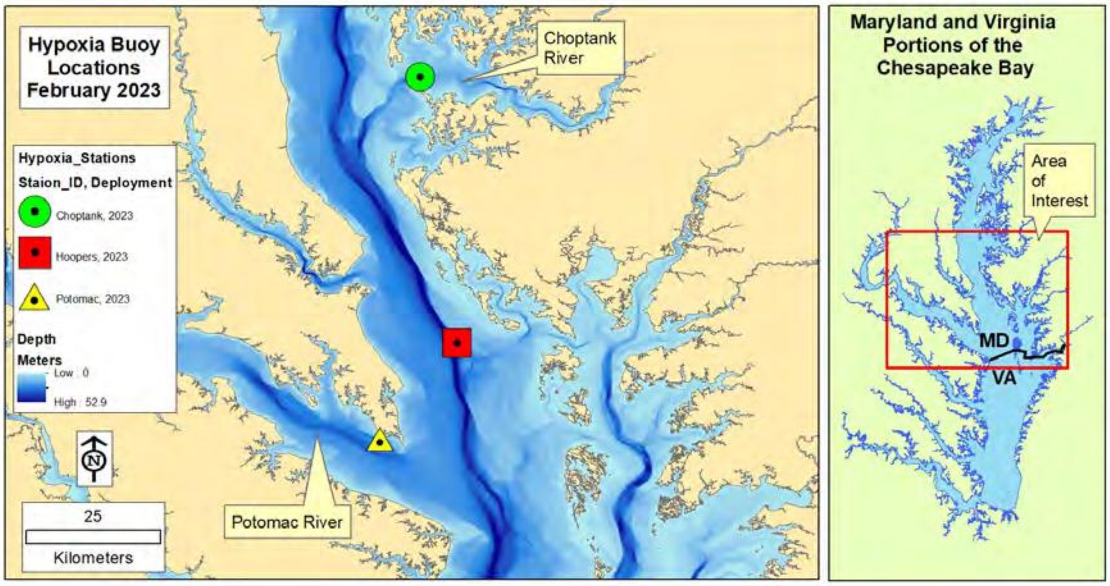
- NOAA Map Light Number 7676 GPS 38.55651; -76.49301 Depth 8.8m (West Gooses Hypoxia Station; CB4.3W) (Map 1)
- NOAA Map Light Number 7681.5 GPS 38.55650; -76.39218 Depth 18.8m (East Gooses Hypoxia Station; CB4.3E) (Map 1)



***Map 1**: Location of West Gooses and East Gooses stations as deployed in 2022. Both stations are within the Chesapeake Bay, southwest of Tilghman Island and the Choptank River, Maryland.*

3.6 Station Locations (2023)

Station locations for the 2023 field season have been proposed but not finalized as of late winter 2023. There is general consensus on the locations in Map 2. The Choptank, Potomac, and mid-Bay sites represent the initial phase of the hypoxia network. Permits need to be obtained prior to the listing of site names and coordinates.



***Map 2**: Planned locations for 2023 Choptank River (green), Hoopers Island (red), and Potomac River (yellow) hypoxia station deployments.*

4. System Configuration

4.1 Buoy Equipment

The system will consist of a moored Soundnine Ulti-Buoy with an inductive modem, cellular communications, GPS, flashing navigation light, and Ulti-Buoy controller. The mooring system includes a jacketed inductive communication cable, galvanized mooring chain (at least 3 m) connected to a thimble with a swivel and terminated with a 35-pound DOR-MOR anchor. Ulti-Buoy inductive XIM-CTD-DO sensors are clamped to the inductive mooring cable at vertical depths appropriate for resolution of local hypoxia profile (Figure 1) (Appendix G).

The Soundnine Ulti-Buoy is 45 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 the waterline are painted with antifouling paint prior to launch.

The inductive communication and strength cable is jacketed steel wire, terminated with a grounding electrode and swaged galvanized steel thimble loop. Termination is placed so that the lower thimble is 0.5 m above the bottom at Mean Lower Low Water. Prior to deployment, optimum sensor depths should be determined based on available historical data and available sensor inventory. Note that sensors using SeaBird IM protocol are compatible with the Ulti-Buoy communications system.

Soundnine UB45-IM	Ulti-Buoy hull, 45 cm dia., 56L, for inductive moorings
Soundnine UBC-ISC	Ulti-Buoy controller with inductive communication, GPS, integrated solar panel & batteries, cellular modem
Soundnine XIM-CTD-DO	XIM-CTD-DO Sensor - Conductivity, Temperature, Pressure & Dissolved Oxygen)sensor with inductive modem
Mooring Assembly	Jacketed wire rope assembly, 5/32 in. OD, 40-meter length with top & bottom terminations

Table 2*: List of buoy components.*

4.2 Site Selection Criteria

Once a sampling location is proposed with input from the CBP Hypoxia Collaborative Team and other interested parties, the following should be evaluated: estimated water depth, nearby CBP or other historical profiles, and commercial and recreational marine traffic in the region. Once a location is selected, in situ confirmation measurements of water depth (electronic acoustic sounding and manual via sonde or CTD to bottom), noting the charted depth and tidal stage shall be obtained. The location must have cellular data (ATT, T-Mobile, Verizon) 4G LTE service and be not endangered by marine traffic. Final approval must be obtained from the United States Coast Guard through the Private Aids to Navigation (District 5) permit process via submission of form CG-2554.

4.3 Buoy Build Out

Using the in situ confirmation measurements of water depth, cut the mooring cable to proper length and attach grounding electrode and securely swage looping with thimble for mooring chain attachment just below electrode on hypoxia buoy. On cable, mark 1 M interval depths (downward from approximate water line on the buoy) and attach sensors at predetermined locations. Wrap electrical tape as a protective layer around the cable in locations where the sensors will attach. Next, using excess mooring cable, cut 2-foot sections of cable and create a loop. Align the two ends of the line parallel to the mooring cable and secure with two or three wire cable clamps (Figures 1, 2, 5). Add a crimpable sleeve to the ends of the exposed loop.

On the physical sensors, mark depths with waterproof pens and serial numbers in an easily accessible location. To test the system once sensors are secured, close the inductive loop with a direct connection using alligator clips (including 1kW resistor for noise reduction). Lastly, place the buoy outdoors with a clear view of sky to test data transmission through cellular networks.

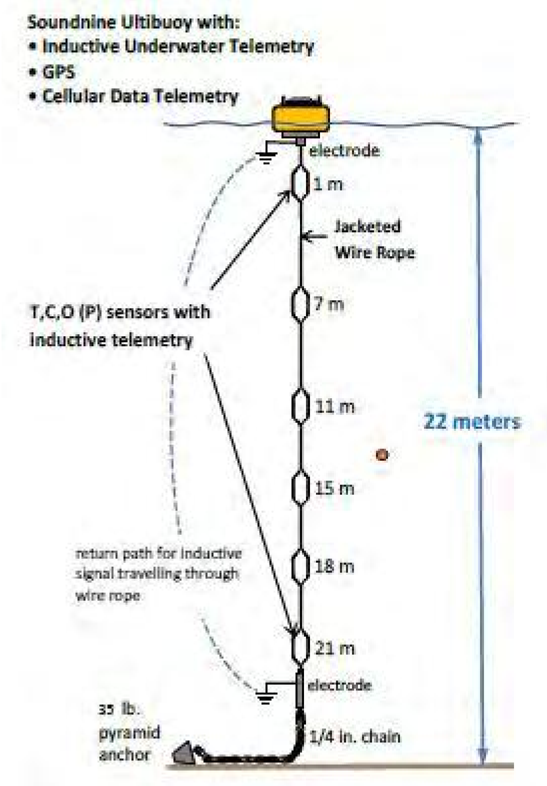


Figure 1: *Hypoxia buoy schematic diagram outlining how the deployed buoy sits in the water column. Parameters collected in this diagram are evenly distributed vertically in the water column. Parameters include (T) temperature, (C) conductivity, (O) oxygen, (P) pressure.*

A magnet is used to start the buoy computer and begin testing data collection and transmission. Data population in the Soundnine database occurs when Soundnine sets up a new database for the controller ID. Additional metadata including instrument and buoy voltages, GPS positions, and sensor values can be viewed. The same magnet is used to stop buoy transmission. Take photos from multiple angles of each sensor on the inductive cable, buoy, and electrode/chain/mooring system as a reference.

Figure 2*: Warehouse assembly of hypoxia buoy.*

4.4 Sensor Validation

Both new factory-calibrated sensors and sensors in the field reporting suspect or bad data are validated at the Oxford Cooperative Laboratory in Oxford, Maryland. After cleaning fouled instruments outlined in section 3.4, sensors are placed in 150-gallon tanks to begin the validation process (Figure 3). Each tank can be filled with filtered water from the Choptank River or with municipal water from the Town of Oxford. Tank water conditions are then manipulated to reflect relevant water-quality conditions similar to those observed in the Chesapeake Bay for sensor accuracy validation.

New hypoxia instruments arrive with factory-calibrated coefficients. At the factory, dissolved oxygen is calibrated at 100% saturation, while conductivity uses a multi-point calibration ranging from ocean to estuary conditions. Calibrations are finalized by comparing all instruments against each other. Upon delivery, NOAA's validation lab ensures their accuracy, functionality, and compatibility with our information technology systems.

Tank water conditions can be set up as in Table 3. These conditions are designed to test whether sensors are within accuracy specifications under typical Chesapeake Bay conditions. If specifications are not met, sensors may be returned for factory recalibration or have values adjusted by corrections to raw data (if corrections can be adequately accomplished by linear corrections). Tank values are targets to cover the typical range of values in the Chesapeake Bay; they need not be exact, but should be stable during the test period. Any of the tanks can be aerated to dissolved oxygen saturation (generally about 103%).

Table 3	TANK 1	TANK 2	TANK 3	TANK 4
TEMP C	10	15	20	25
SAL PSU	8	15	20	25
COND S/m	0.986	1.899	2.894	3.926
DO Saturation	Ambient	Ambient	Ambient	Air Saturated

Table 3: *Validation tank water conditions.*

Sensors in the field removed from hypoxia arrays for replacement or because of suspect performance are taken into NOAA's validation lab to diagnose the cause of questionable data output. They are soaked overnight in a bath of dilute acetic acid and nonionic surfactant soap (Triton-X) to break down any biofouling. Extensive biofouling such as barnacles inside the conductivity cell is subjugated to a circulating pump to flush any debris. Cleaned hypoxia sensors are then placed in validation tanks next to a factory-calibrated SeaBird SBE37 microCAT CTD-DO as a side-by-side comparison. Sensors will acclimate for 30 minutes in validation tanks that reflect dissolved oxygen, salinity, and temperature levels observed in the Chesapeake Bay. Hypoxia sensors are validated within a <3% tolerance against a factory-calibrated SeaBird microCAT CTD-DO. Sensors that do not meet these tolerances are returned to the manufacturer for calibration or repair and added to the Manual Data Flagging (MDF) datasheet as our justification for flagging data. SeaBird instruments are calibrated yearly by the manufacturer and recorded with appropriate documentation. Service and calibration methods performed by SeaBird Scientific can be found at https://www.seabird.com/service-calibration-information.

All calibration documentation is stored on a cloud-based server and can be accessed upon request.

Figure 3*: Oxford validation lab. Left photo shows filtration and temperature regulating system. Right photo shows 150-gallon tanks used to reflect various water-quality conditions such as high and low temperature/salinity/conductivity and dissolved oxygen.*

5. Field Operations

5.1 Pre-deployment Planning

The purposes of station visits once a station is deployed are to verify the quality of the measurements through independent sensor verification, maintain the cleanliness of the sensors, and inspect the assembly of the moorings. Station visits are planned for regular intervals, but the actual frequency of the visits is informed by the seasonality of biofouling organisms. Replacement sensors accompany each trip in case our field validations reveal a suspect instrument. Additional system components are included in our repair and replacement kit to cover any potential issue that arises.

The initial deployment, described in section 3.2, is accompanied by a station visit datasheet that documents all pertinent metadata associated with the initial deployment and subsequent station visits. The totality of the following protocols ensure that the data collected contain necessary metadata to flag good, suspect, and bad data along with NOAA’s justification for those flags. Prior to station visits, the station dashboards will be reviewed to identify obvious areas of concern for on-site inspections.

5.2 Mooring Deployment

Once all sensors, buoy, and data have been checked on land, the system is prepared for transport. Once the vessel is on station, the water depth is verified with tide-corrected vessel echosounder depths (against mooring cable length). The anchor is lowered to the bottom with a line looped through a ring on the anchor chain. Instruments are slowly deployed over the side while maintaining light tension on the mooring cable. The mooring cable should not go slack, and buoy should be deployed last with the waterline at approximately half the buoy height (Figure 4). After recording the time of deployment, remain on site until there is confirmation that data is being transferred to the Soundnine server. Begin following in situ data validation steps (section 5.6).

Prior to deployment, physical inspection by the lead field technician along with photo documentation of all mooring hardware connections should be conducted. Photos are stored within each site visit folder on a cloud accessible server.

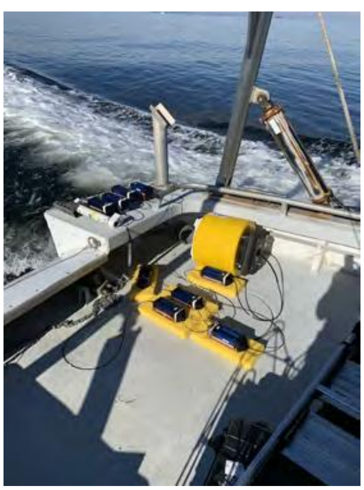
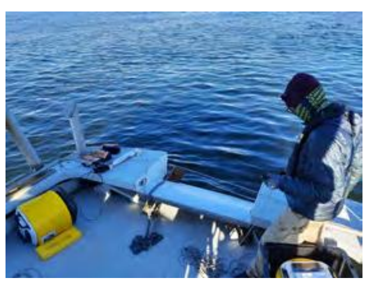
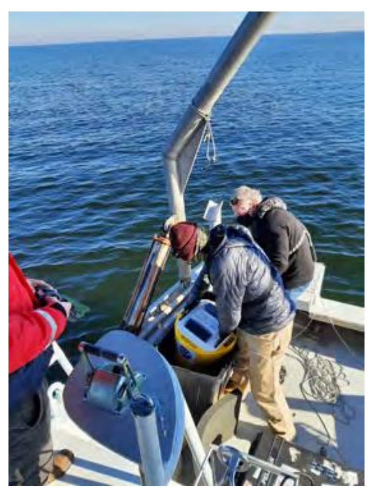
		

Figure 4:*Transportation and preparation of hypoxia buoys prior to deployment on NOAA vessels*

5.3 Mooring Recovery

The recovery methods are evolving to provide maximum protection of the inductive mooring wire and sensors. After arriving on station, the time is noted and a CTD-DO cast is performed following methods outlined in section 5.6. The hypoxia buoy is then secured to the vessel using the weight of the vessel to gently dislodge the anchor from the bottom. Recoveries involve lifting loops clamped to the inductive wire to improve safety (Figures 5, 6) and protect the inductive wire. The use of a davit or A-frame with hooks attached to a dynamic and static line is preferred to lift buoys out of the water. Attaching the hooks to loops on the hypoxia buoy cable, the weight of the buoy weight is transferred from a dynamic line to a static line, with the dynamic line lowered to the next available loop. The process is repeated until the mooring anchor is on board the vessel. A new recovery device placed just above the anchor chain connection, designed to catch a chain loop lowered over the cable, will be tested in 2023. Once the chain is reached, loop a spare line through the lift ring and secure it. Buoy is secured while lifting the anchor into the vessel. Photograph buoy, instruments, and mooring and note any anomalies.

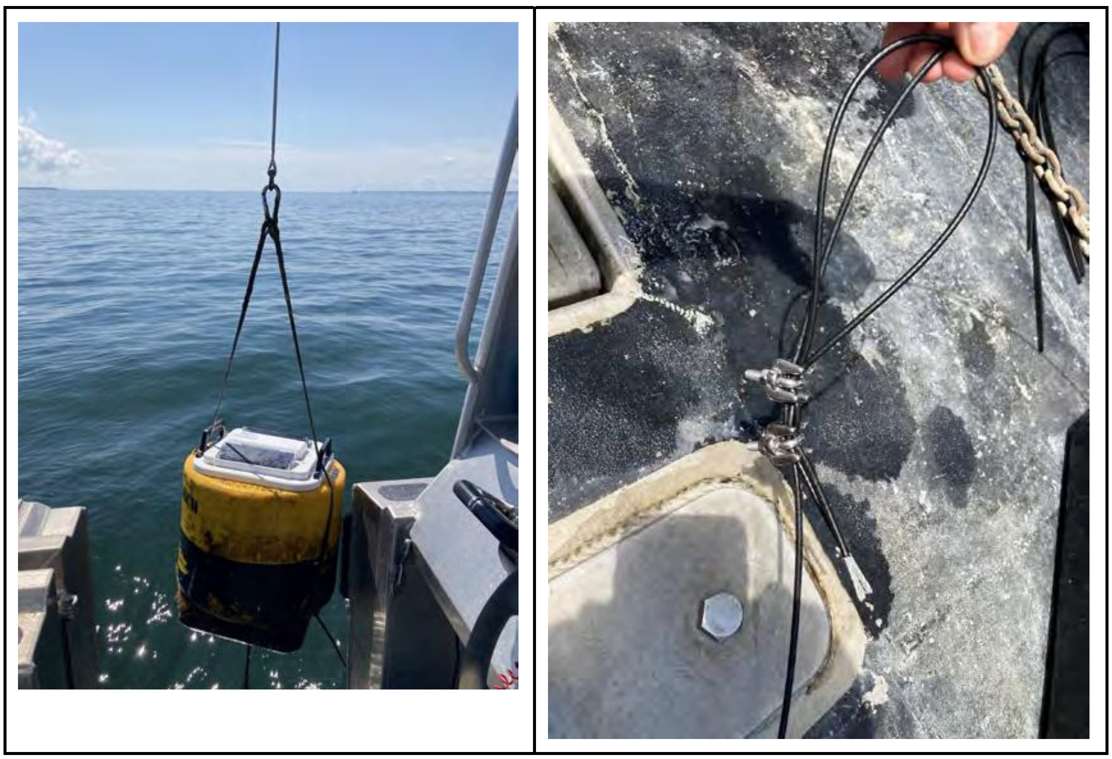


***Figure 5**: Buoy recovery operations. On the left, dislodging hypoxia buoy from the mud. On the right, loops installed on inductive cable are used as picking points for the vessel's A-frame to avoid cable damage and provide a more secure picking point.*

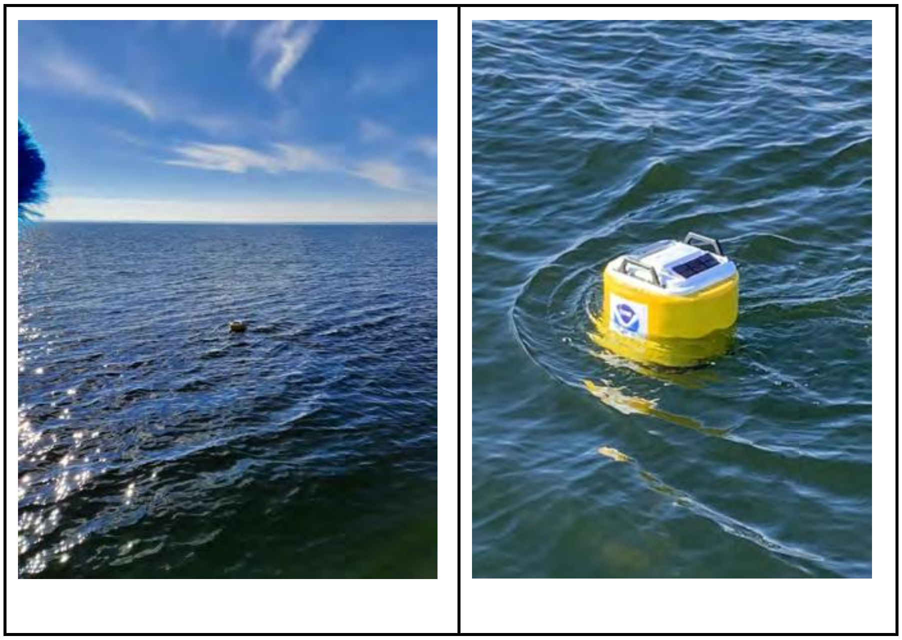


Figure 6*: Deployed hypoxia buoys.*

5.4 Antifouling Measures

The Ulti-Buoy is painted below the waterline prior to deployment using non-toxic antifouling paint (Pettit Hydrolux or similar). The back of the instruments are covered in copper tape, while internal instruments have copper wool mesh guard in a way that does not interfere with conductivity sensor flow or dissolved oxygen optical paths. Biofouling buildup will be gently removed with vessel washdown water and nonabrasive sponges or Kimwipes. Sensors will be inspected to ensure water can pass freely through copper mesh and sensor openings. Additional measures to create an environment not conducive to biological growth are being investigated.

Significant biofouling occurred during the third deployment in late May through early June from barnacles and in early August from sea squirts. Until better data is collected on fouling periods, maintenance visits should reflect known seasonal rates of biofouling, or if data quality checks indicate data problems. Systems will be redeployed with sensors in their original locations unless replaced with new sensors. Data sheets will document the extent of any sensor changes.

5.5 Field Maintenance

In the event of extensive biofouling or blockage of conductivity cells, sensors will be replaced and those removed will be cleaned back at the lab. Routine field maintenance recommendations provided by SeaBird Scientific will be applied to all instruments regardless of the manufacturer unless otherwise specified (Appendix C). To control the growth of bio-organisms in the conductivity cell, follow these rinsing and cleaning recommendations with Triton X-100 and white vinegar. Triton X-100 is a mild, non-ionic surfactant (detergent), valuable for the removal of surface and airborne oil ingested into the CTD plumbing as the CTD is removed from the water and brought on deck. SeaBird recommends then rinsing and cleaning the conductivity sensor in a Triton solution. White vinegar, which is 5–8% acetic acid, may be used to remove minor mineral deposits on the inside of the cell. Additionally, methods of dissolving barnacles are currently being explored by actively pumping acetic acid (75% acetic acid vinegar, typically used for agricultural applications) through the conductivity cell.

The conductivity cell is primarily glass and can break if mishandled. Best practice includes using Tygon Tubing with the appropriate internal and external diameter and a syringe to flush the cell and prevent damage to the cell. Do not brush the inside of the cell, as this can damage the electrodes and change the calibration. Extended Triton contact can cause sensitivity (slope) changes, usually temporary, to the sensors.

If extensive biofouling occurs, as observed in late May and early July 2022, replacement of the sensor with a backup sensor is recommended. The fouled sensor is taken to the validation laboratory for further evaluation (see section 4.4). Sensors undergoing extensive fouling and those that fall outside of the data specifications will be returned to Soundnine and evaluated for repair.

5.6 In Situ Data Validation

During station visits after buoy deployment, and prior to maintenance visits or recovery of hypoxia systems, CTD-DO casts will be performed to validate hypoxia system functionality and calibration. A recently calibrated SeaBird SB19 CTD-DO will profile the water column with the use of a winch to maintain a constant drop velocity. Our protocols require seastates to be <1 foot to ensure reliable CTD-DO casts of the full water column can be collected and unique depths are within the range of error we can account for. Casts need to be conducted as close as vessel safety allows to the hypoxia array. Timing is critical with the cast starting at the closest 10-minute interval (eg: 0930, 0940, 0950 etc) coinciding with the frequency the hypoxia array collects data.

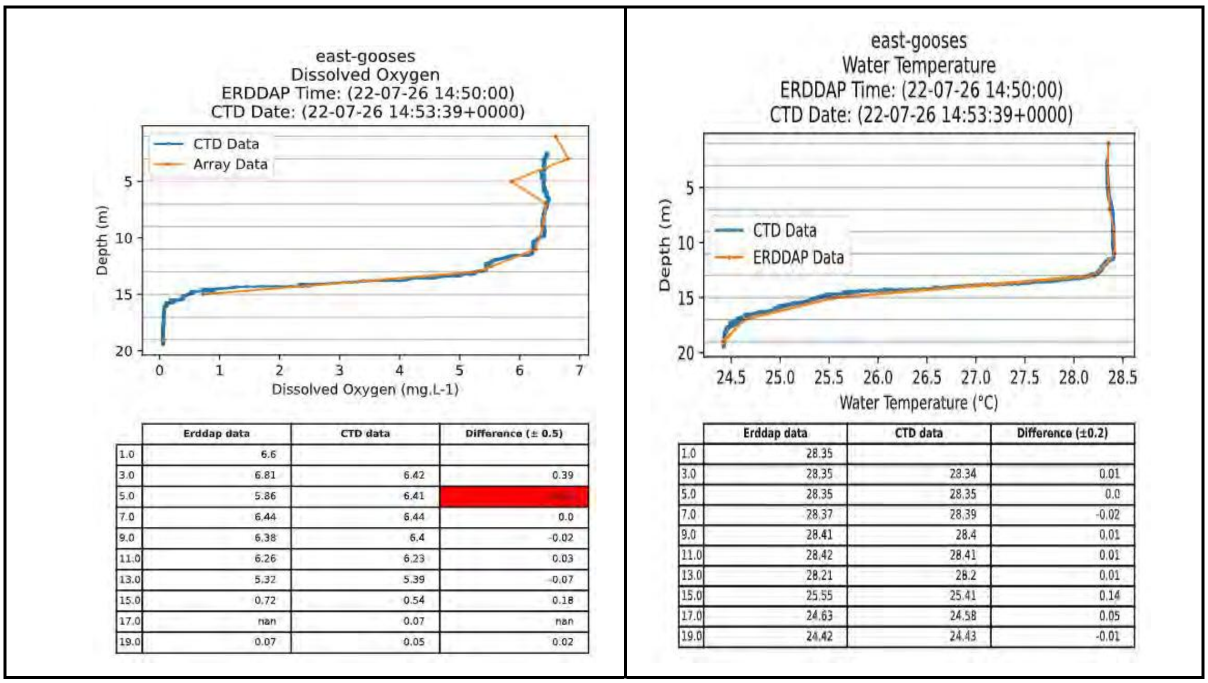
As the recovery of the hypoxia array begins, a manual flag is recorded in the MDF datasheet noting the system was taken out of the water. The flag will be updated noting when the array returns to its respected location and recording valid data.

At known depths of hypoxia sensors, time-stamped water-quality readings will be recorded for dissolved oxygen, temperature, and conductivity. To account for spatial variance in the water column, the post-processed CTD-DO cast will average water-quality data 0.5m above and below the known depths of hypoxia sensors. Data will be used as a preliminary assessment to test for variance in readings between the two systems at known depths. Acceptable tolerance of parameter variance will comply with regional partners' standards for in situ data validation (See Table 4).

Parameter	Value
Dissolved Oxygen	∓0.5 mg/L
Conductivity	∓5% of true value
Water Temperature	∓0.2 °C

Table 4. *Acceptable drift tolerances for hypoxia array post in situ check (Michael et al., 2021)*

Data from CTD-DO casts and NCBO server can be downloaded simultaneously and plotted using Python (Figure 7). If data exceeds parameter thresholds (Table 4), a decision can be made to swap out individual sensors on site. When an unreliable sensor is identified, a manual flag is recorded in the MDF datasheet for the sensors coinciding depth; accordingly, a human review of data is required to determine where the data became unreliable and record a manual flag following the flow chart for applying manual flags (Figure 10).



	Erddap data	CTD data	Difference (± 0.5)
1.0	6.6		
3.0	6.81	6.42	0.39
5.0	5.86	6.41	[illegible]
7.0	6.44	6.44	0.0
9.0	6.38	6.4	-0.02
11.0	6.26	6.23	0.03
13.0	5.32	5.39	-0.07
15.0	0.72	0.54	0.18
17.0	nan	0.07	nan
19.0	0.07	0.05	0.02

	Erddap data	CTD data	Difference (±0.2)
1.0	28.35		
3.0	28.35	28.34	0.01
5.0	28.35	28.35	0.0
7.0	28.37	28.39	-0.02
9.0	28.41	28.4	0.01
11.0	28.42	28.41	0.01
13.0	28.21	28.2	0.01
15.0	25.55	25.41	0.14
17.0	24.63	24.58	0.05
19.0	24.42	24.43	-0.01

Figure 7*: Plots of two validation CTD-DO casts. Dissolved Oxygen (left) and Water Temperature (right) with data downloaded from Axiom and CTD-DO cast. Blue lines show data from the CTD-DO, while yellow lines were collected from the Axiom server. Below each plot are automated QC checks to determine the variance between the CTD-DO and array. Data exceeding parameter variance thresholds are colored red.*

Sensors in otherwise working order will be carefully cleaned following methods outlined in section 4.4 with a bath of dilute acetic acid and nonionic surfactant soap (Triton-X) and redeployed. Fully deployed hypoxia array needs to acclimate for 30 minutes before a final validation CTD-DO cast is performed to ensure the hypoxia array is in working order timing with the closest 10-minute interval.

6. Sensor Management

6.1 Sensor location

Tracking the disposition of sensors from the manufacturer to the field and back requires an attention to detail and clear documentation that is recorded in a Hypoxia Sensor Deployment Database. This document will record all actions taken on a given sensor at all points in time.

6.2 Documents and Records

Documents and records connected to the hypoxia program include but are not limited to: Soundnine, Inc., manufacturer calibration data, SeaBird manufacturer calibration data, pre- and postdeployment data sheets, and CBIBS hardware mapping sheets. All paper documents will be scanned and archived in a digital format within compliance of the Integrated Ocean Observing System - Data Publishing for Data Access Services, Formats, and Metadata. Documentation and records will be maintained by the NOAA Chesapeake Bay Office's cloud-based servers.

- Manual Data Flag datasheet (MDF) - See Figure 9
  Human generated notes based on observations in system errors. Used as a high level QA/QC reference on NOAA servers before sending data to AXIOM
- CBIBS Hardware Mapping Field Deployment - See Appendix H
  Maintains a log of serial numbers and photos used in NOAA internal property database.
- Hypoxia Offset File - See Appendix I
  Used to keep track of file names and time differences between instruments and cloud based systems. Primary reference for CTD-DO casts and tracking file names of files generated during site visits
- Hypoxia Sensor Deployment Database - See Appendix D
  Continuous database documenting the location of hypoxia sensors at any given time.
- Field Data Sheets - See Appendix A and D
  A new file is generated every time a station is visited and is the initial location of notes collected during station visits. Information then transcribed to relevant documents.

7. Data Management, Verification, and Documentation

7.1 Data Movement and Storage

The movement of data is as follows (Figure 8):

1. Hypoxia arrays transmit in situ water-quality data every 10 minutes to Soundnine databases.
2. NCBO servers send data requests every several minutes for new data populating any new fields from the previous data pull.
3. NCBO servers read the Manual Data Flags datasheet (MDF) and apply manual flags before
4. Axiom Data Science pulls data from the NCBO server every several minutes.
5. Axiom servers can pull updates or corrective edits of the MDF from NCBO on a set schedule post field validation. Axiom/IOOS applies their own automatic Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) flags as data is received.
6. Long term data storage is sent to the National Centers for Environmental Information (NCEI).

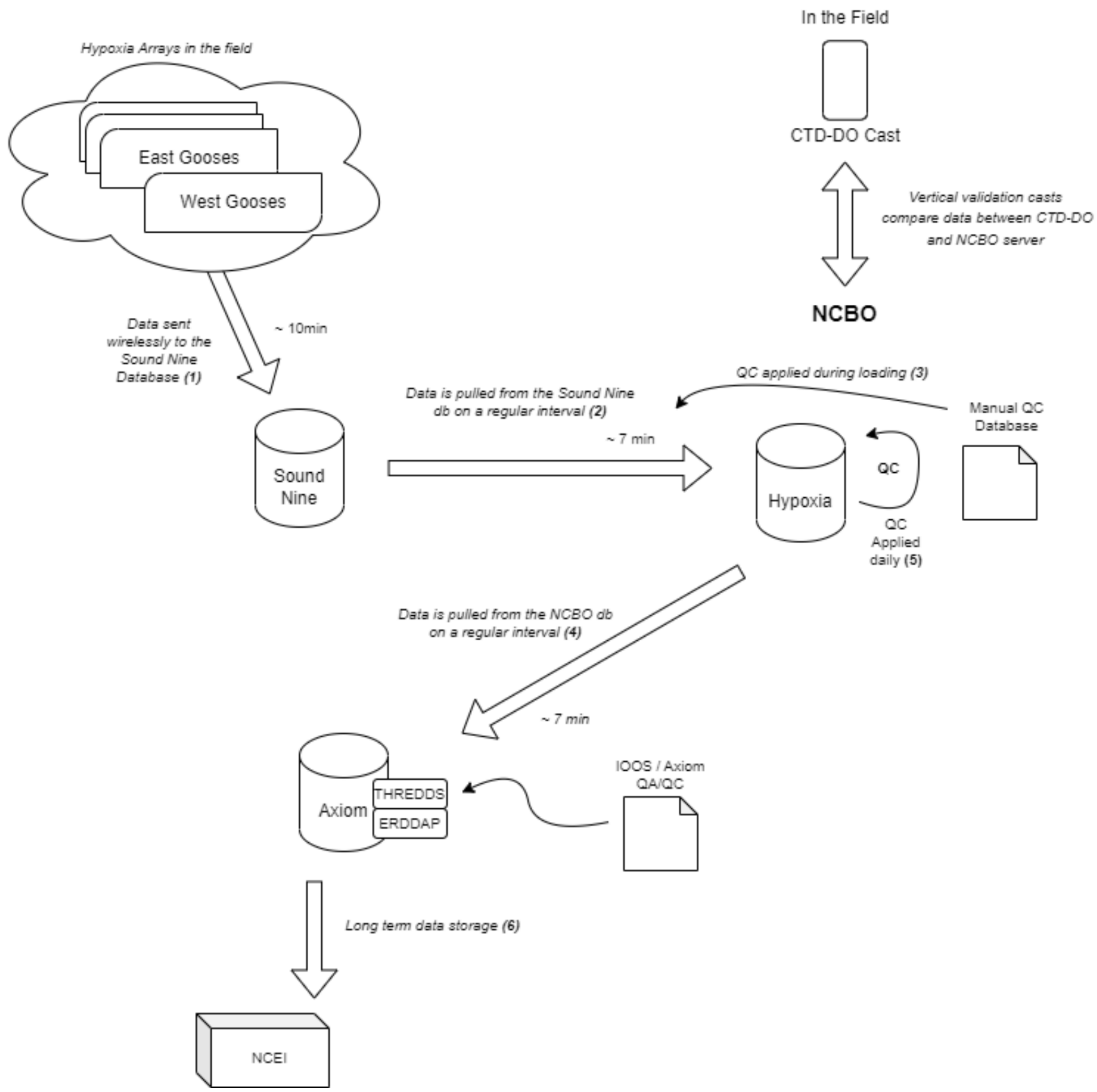
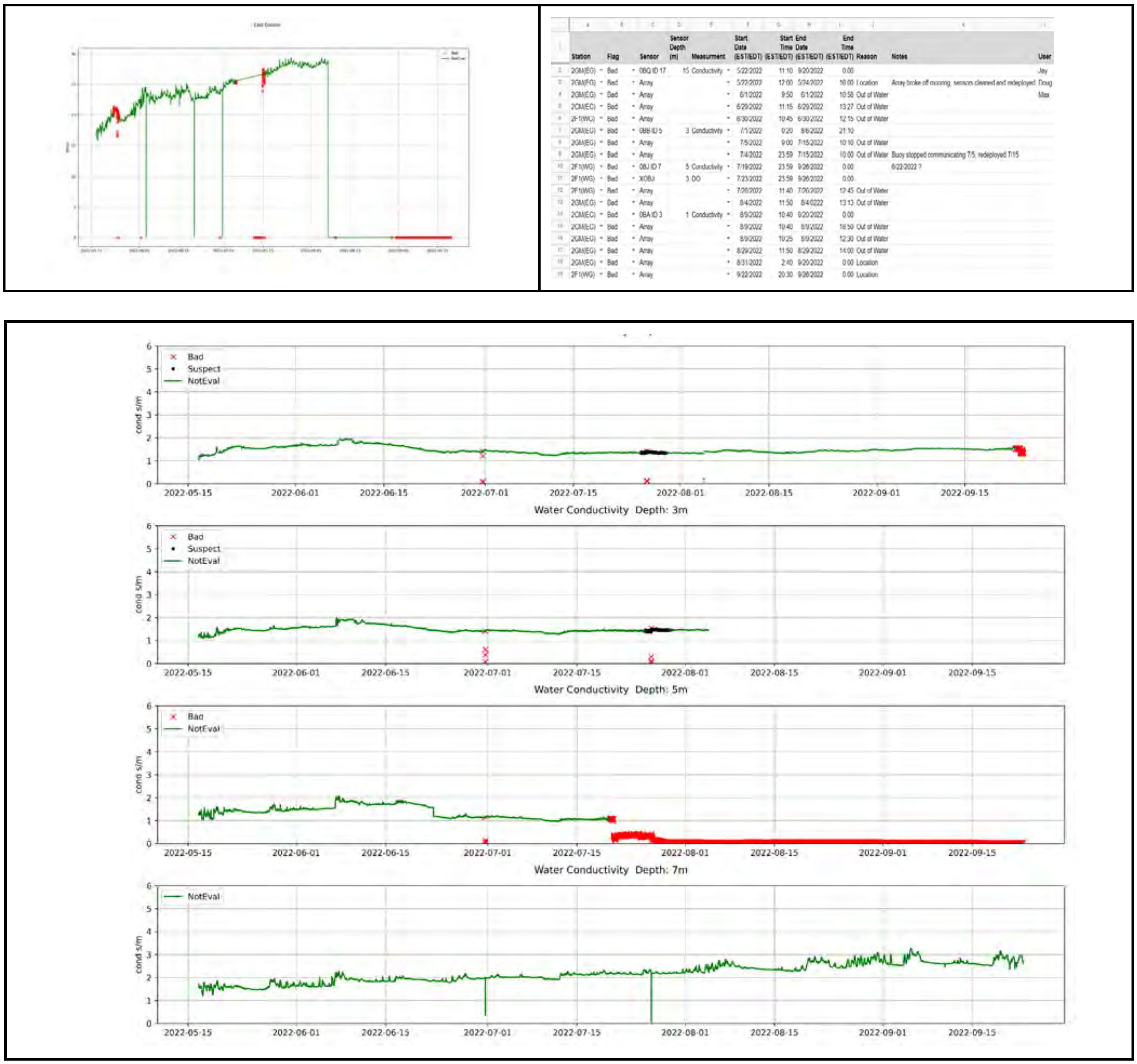


Figure 8*: Flow of data from the hypoxia buoys to Soundnine to NOAA Chesapeake Bay Office (NCBO) to Axiom and to National Centers for Environmental Information (NCEI).*

7.2 Manual Data Flagging Protocol

NCBO maintains a Manual Data Flag (MDF) datasheet as part of its data quality control protocol; edits as such will be referred to as Manual Flags. Flags indicate to external data analysts that they should further review portions of data before making conclusions about their impact on the larger dataset. Metadata includes station information, identifies individual sensor parameters or arrays, and includes start-stop time stamps for the suspect or bad data (Figure 9). The cloud-based document is manually updated by NCBO staff as needed to maintain a record of observations of sensors that are not necessarily detectable by IOOS Quality Assurance/Quality Control checks. Flags can indicate errors such as a hypoxia array being off station (recognizing that either geographically the station has moved or that the sensors are no longer in the water during routine maintenance) or that specific water-quality sensors are recognized as inoperable while still in the field.

Updates made to the MDF are uploaded to NCBO servers before being transmitted to Axiom, which further overrides any IOOS Quality Assurance for Real-Time Oceanographic Data (QARTOD) tests. Additionally, updates to historical data can be made at any time and will be reflected in stored data on NCBO, Axiom, and NCEI servers.



Station	Flag	Sensor	Sensor Depth (m)	Measurment	Start Date (EST/EDT)	Start Time (EST/EDT)	End Date (EST/EDT)	End Time (EST/EDT)	Reason	Notes	User
2GM(EG)	Bad	0BQ ID 17	15	Conductivity	5/22/2022	11:10	9/20/2022	0:00			Jay
2GM(EG)	Bad	Array			5/22/2022	17:00	5/24/2022	16:00	Location	Array broke off mooring, sensors cleaned and redeployed	Doug
2GM(EG)	Bad	Array			6/1/2022	9:50	6/1/2022	10:58	Out of Water		Max
2CM(EC)	Bad	Array			6/29/2022	11:15	6/29/2022	13:27	Out of Water		
2F1(WG)	Bad	Array			6/30/2022	10:45	6/30/2022	12:15	Out of Water		
2GM(EG)	Bad	0BB ID 5	3	Conductivity	7/1/2022	0:20	8/6/2022	21:10			
2GM(EG)	Bad	Array			7/5/2022	9:00	7/15/2022	10:10	Out of Water		
2GM(EG)	Bad	Array			7/4/2022	23:59	7/15/2022	10:00	Out of Water	Buoy stopped communicating 7/5, redeployed 7/15	
2F1(WG)	Bad	0BJ ID 7	5	Conductivity	7/19/2022	23:59	9/26/2022	0:00		6/22/2022 ?	
2F1(WG)	Bad	X0BJ	3	DO	7/23/2022	23:59	9/26/2022	0:00			
2F1(WG)	Bad	Array			7/26/2022	11:40	7/26/2022	12:45	Out of Water		
2GM(EG)	Bad	Array			8/4/2022	11:50	8/4/0222	13:13	Out of Water		
2CM(EC)	Bad	0BA ID 3	1	Conductivity	8/9/2022	10:40	9/20/2022	0:00			
2CM(EC)	Bad	Array			8/9/2022	10:40	8/9/2022	16:50	Out of Water		
2GM(EG)	Bad	Array			8/9/2022	10:25	8/9/2022	12:30	Out of Water		
2GM(EG)	Bad	Array			8/29/2022	11:50	8/29/2022	14:00	Out of Water		
2GM(EG)	Bad	Array			8/31/2022	2:40	9/20/2022	0:00	Location		
2F1(WG)	Bad	Array			9/22/2022	20:30	9/26/2022	0:00	Location		

Figure 9*: On the left, data-generated plots using flags from MDF for seasonal temperature (C) data from a single depth on hypoxia array. Green lines show data within acceptable range, while red shows data flagged as bad. On the right, MDF applied to hypoxia arrays identifying the station, type of flag, sensor or array, sensor depth, and duration of flag. Bottom shows additional data plots checked by the MDF.*

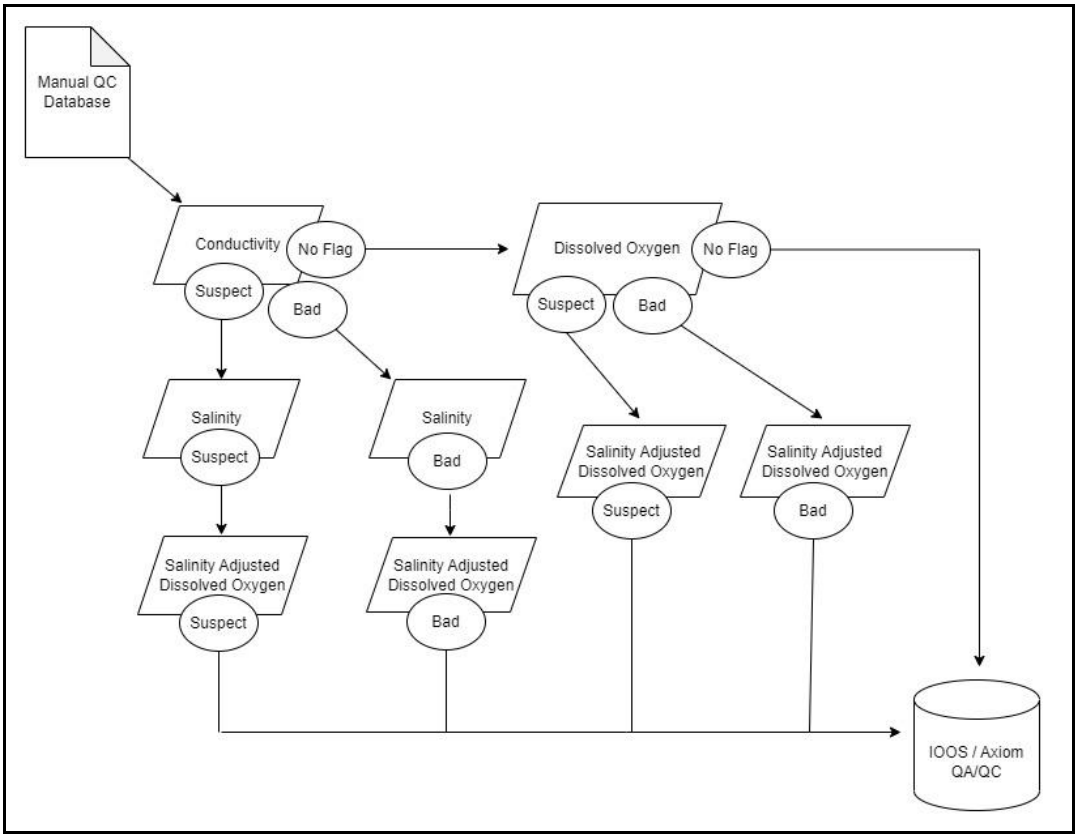


Figure 10: *Manual Data Flagging flow chart.*

7.3 Automated Data Flagging Protocol

Manually flagged data on the NCBO server is pulled by the Axiom server, where automated QARTOD tests are run and the additional flags may be applied. The current thresholds applied to the QARTOD tests are broad and will be refined as more data become available. Flags as such will be referred to as Automated Flags. See section 6 for further details.

7.4 Data Visualization

Nearly real-time QA/QCed data will be available for visual inspection and manipulation and download through pages on the Axiom Data Science's Integrated Ocean Observing System Environmental Sensor Map. Curtain plots on a time versus depth display for temperature, salinity, and dissolved oxygen are available to quickly visualize current in situ conditions (Figure 11, 12). Users can query specific parameters at depth or view the whole array as a time series. The colors displayed are correlated with an intuitive color spectrum from red to blue indicative of the range of values observed for each measurement.

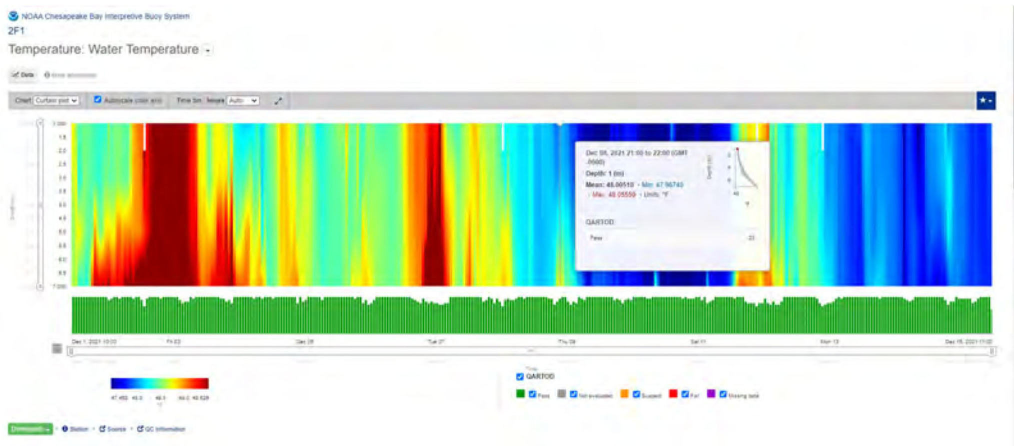


Figure 11: *Data and QA/QC graphic on Axiom servers.*

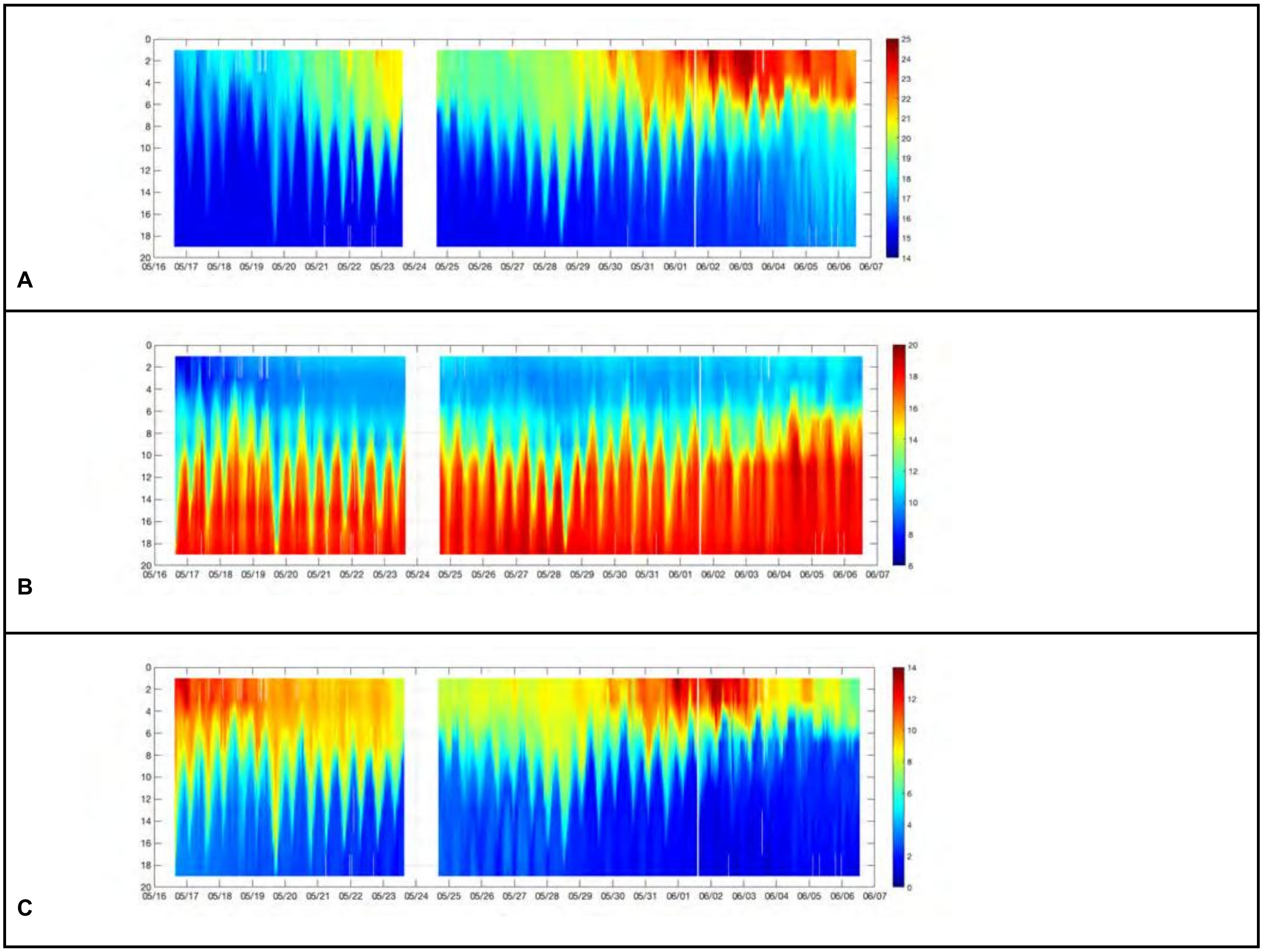


Figure 12: *Post-processed water column data from May 16, 2022, to June 6, 2022. A) Temperature (deg C); B) Salinity (PSU); C) Salinity-Adjusted Dissolved Oxygen concentration (mg/L).*

8. Quality Assurance/Quality Control of Real-Time Oceanographic Data

8.1 Integrated Ocean Observing System Program (IOOS) QA/QC Tests

Real-time data will be available to ensure data collection is occurring. These data are not QA/QCed until MDF occurs and Automatic Data Flagging (ADF) routines are complete. Archived data from prior years are "Quality Controlled" and also available for download. Public-facing data will be displayed through the Integrated Ocean Observing System (IOOS) Environmental Sensor Map (https://sensors.ioos.us/) with the following Quality Assurance/Quality Control parameters as found through IOOS QC: QARTOD and other quality control tests implemented in Python. Once a robust seasonal dataset is completed, each station will have a diverse set of statistical tests that reflect the Chesapeake Bay's regional marine environments (U.S. Integrated Ocean Observing System Program, 2022).

A. Gross Range Test (GRT): Check that values are within reasonable bounds. Given a 2-tuple of minimum/maximum values, flag data outside of the given range as FAIL data. Optionally, also flag data that falls outside of a user-defined range as SUSPECT. Missing and masked data are flagged as UNKNOWN.
B. Flat Line Test (FLT): Check for consecutively repeated values within a tolerance. Missing and masked data are flagged as UNKNOWN.
C. Rate of Change Test (RCT):Checks the first order difference of a series of values to see if there are any values exceeding a threshold defined by the inputs. These are then marked as SUSPECT. It is up to the test operator to determine an appropriate threshold value for the absolute difference to not exceed. Threshold is expressed as a rate in observations units per second. Missing and masked data are flagged as UNKNOWN.
D. Spike Test (ST): Check if the difference in values between a data point and its neighbors exceeds a threshold. Determine if there is a spike at data point n-1 by subtracting the midpoint of n and n-2 and taking the absolute value of this quantity, and checking if it exceeds a low or high threshold. Values that do not exceed either threshold are flagged GOOD, values that exceed the low threshold are flagged SUSPECT, and values that exceed the high threshold are flagged FAIL. Missing and masked data are flagged as UNKNOWN.

	Water Temperature (Celsius)	Salinity (Practical Salinity Scale)	Dissolved Oxygen (Milligram per Liter)	Conductivity (MilliSiemens Per Centimeter)	Sea Water Pressure (Decibar)
Gross Range Test					
suspect_span	(-2.0 °C, 35.0 °C)	(0.5 PSS, 30.0 PSS)	(0.5 mg/L, 15 mg/L)	(0.0 mS/cm, 46.0 mS/cm)	(0.5 dbar, 28.4.0 dbar)
fail_span	(-5.0 °C, 45.0 °C)	(0.002 PSS, 35.0 PSS)	(0 mg/L, 20 mg/L)	(0.0 mS/cm, 53.0 mS/cm)	(0.0 dbar, 30.0 dbar)
Flat Line Test					
tolerance	0.01 °C	0.001 PSS	0.005 mg/L	5.0E-4 mS/cm	0.001 dbar
suspect_threshold	2700 s	2700 s	2700 s	2700 s	2700 s
fail_threshold	3600 s	3600 s	3600 s	3600 s	3600 s
Rate Of Change Test					
threshold	0.003 °C/s	0.0005 PSS/s	0.003 mg/L/s	mS/cm/s	7.0E-4 dbar/s
Spike Test					
suspect_threshold	2.0 °C	3.0 PSS	5 mg/L	mS/cm	0.5 dbar
fail_threshold	10.0 °C	6.0 PSS	10 mg/L	mS/cm	1.0 dbar

***Table 5**: Minimum parameter thresholds for data to pass QA/QC in IOOS. Note that conductivity (mS/cm) measurements are inherently temperature-dependent and a prevailing standard of assuming a temperature of 25C/77F. Most salinity measurements in literature follow this convention.*

9. Data Deliverables

9.1 Storing Data and Federal Information Security Modernization Act Compliance

The NOAA Chesapeake Bay Office will adhere to the standards of the EPA Requirements for Quality Management Plans as outlined in EPA Region 3 Chesapeake Bay Program Office Requirements for Quality Management Plans and outlined in this document. Rigorous emphasis is placed on ensuring data reaching the public and regulatory agencies has been assessed by the most up-to-date statistical analysis based on the most relevant peer-reviewed methods available. This in turn will primarily align with the requirements set out by the Environmental Protection Agency, IOOS, and the Chesapeake Bay Program. These metrics will be publicly accessible through IOOS.

NCBO will further adhere to the Federal Information Security Modernization Act (FISMA). Signed into law in 2002 and updated in 2014, FISMA requires that federal systems meet a set level of security requirements. FISMA is U.S. government legislation that defines a comprehensive framework to protect government information, operations, and assets against threats. As part of NOAA’s Service Delivery Division (SDD), NOAA0201 Web Operations Center (WOC) is a diverse information system providing multiple cloud-based services to offices within NOAA. Services include Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Domain Name Service (DNS) tailored to meet customer needs. The WOC hosts and supports numerous (200+) websites that disseminate a wide variety of data and information to the scientific and meteorological communities and the public at large. This data and information is used for numerous purposes, including study of the ocean, atmosphere, and related ecosystems; natural disaster forecasting and monitoring; climatological analysis and climate change; biodiversity; weather prediction; and the preservation of life and property.

All WOC devices are provisioned in the Federal Risk and Authorization Management Program (FedRAMP)-Certified Amazon Web Services (AWS) Cloud, including US East-West (FedRAMP moderate impact) and GovCloud (FedRAMP high impact) computing environments. For the purposes of redundancy and availability, WOC customers have access to resources at multiple AWS facilities, and all AWS facilities used are within the continental United States (CONUS). Currently, this includes AWS GovCloud (based in northern Virginia (us-gov-east) and northern California (us-gov-west). WOC customers with moderate security categorization requirements have access to AWS US East-West based in northern Virginia (us-east-1), Ohio (us-east-2), Northern California (us-west-1), and Oregon (us-west-2)).

In addition, WOC has a recently updated SSP and PTA/PIA, encrypts data in transit, and is in the process (meaning POA&M) of encrypting sensitive data at rest.

9.2 Receivable Data Packages

Interagency agreements require NCBO to provide timely access to quality-controlled data consistent with the Quality Assurance Project Plan. Furthermore, a voluntary yearly end-of-season data summary with appropriate metadata with completed copies of documents outlined in section 4.2 will be included. Upon request, Python code for plotting data can be provided.

10. References

Axiom Data Science. Accessed November 30, 2021. https://www.axiomdatascience.com/.

Bever, A.J., Friedrichs, M.A., Friedrichs, C.T. and Scully, M.E., 2018. Estimating hypoxic volume in the Chesapeake Bay using two continuously sampled oxygen profiles. Journal of Geophysical Research: Oceans, 123(9), pp.6392-6407.

Environmental Protection Agency (2020). Quality Manual For The Chesapeake Bay Program Office. https://www.chesapeakebay.net/what/publications/chesapeake-bay-program-office-quality-manual

Environmental Protection Agency (2001). EPA Requirements for Quality Management Plans. [online] Available at: https://www.epa.gov/sites/default/files/2016-06/documents/r2-final.pdf.

Environmental Protection Agency, (2001a). EPA Requirements for Quality Assurance Project Plans. [online] Available at: https://www.epa.gov/sites/default/files/2016-06/documents/r5-final_0.pdf

Methods and Quality Assurance for Chesapeake Bay Water Quality Monitoring Programs. (2017). [online] Available at: https://www.chesapeakebay.net/documents/CBPMethodsManualMay2017.pdf.

Michael, B., Ebersole, E.L., Trice, M. and Heyer, C.J., 2021. Quality assurance project plan for the Maryland Department of Natural Resources Chesapeake Bay shallow water quality monitoring program. Maryland Department of Natural Resources.

Quality Assurance Considerations for Continuous Monitoring Presentation. Durga Ghosh, Chesapeake Bay Program, May 21, 2021.

"Quality Assurance/Quality Control of Real Time Oceanographic Data," The U.S. Integrated Ocean Observing System (IOOS), April 15, 2021, https://ioos.noaa.gov/project/qartod/.

U.S. Integrated Ocean Observing System Program., 2022. IOOS_QC package.IOOS QC Package. Retrieved January 15, 2023, from IOOS QC Package. Retrieved January 15, 2023, https://ioos.github.io/ioos_qc/api/ioos_qc.html#ioos_qc.qartod.rate_of_change_test

Appendices

Appendix A: Data Sheet 1

Field data sheet - Records relevant information of deployment, recovery and maintenance visits of hypoxia stations. Parameters include station location, weather/sea, state and CTD information.

FIll in space							
Date		7/26/22	**Weather**	Cloudy			
Crew	CJ Jake Max		**Sea State**	waves 0.5 feet			
Vessel	BC						
Cast 1							
CTD Cast	Vessel Depth	19.5					
Device:	SBE 19	SN:	6398	Buoy:	HYP E		Validation cast
Last Cal:		Start Time:	1045	End Time:	1049		
Cast 2							
CTD Cast	Vessel Depth	19.5					
Device:	SBE 19	SN:	6398	Buoy:	HYP E		Validation cast 2
Last Cal:		Start TIme:	1051	End Time:	1057		
Cast 3							
CTD Cast	Vessel Depth	9					
Device:	SBE 19	SN:	6398	Buoy:	HYP W		Pre Cleaning cast
Last Cal:		Start TIme:	1117	End Time:	1120		hypoxia west was out of the water
							microCAT at bottom was in good :
Cast 4							When pulling the sensors out of th
CTD Cast	Vessel Depth						Bad weather starting developing,
Device:	SBE 19	SN:		Buoy:			
Last Cal:		Start TIme:		End Time:			
Cast 5							
CTD Cast	Vessel Depth						
Device:	SBE 19	SN:		Buoy:			
Last Cal:		Start TIme:		End Time:			

Appendix B: SeaBird SBE 19 CTD-DO Spec Sheet

SEA·BIRD SCIENTIFIC

seabird.com
seabird@seabird.com

SBE 19plus V2

SeaCAT Profiler CTD

The SBE 19plus V2 SeaCAT measures conductivity, temperature, and pressure at 4 scans/sec (4 Hz) and provides high accuracy and resolution, reliability, and ease-of-use for a wide range of research, monitoring, and engineering applications. Pump-controlled, T-C ducted flow minimizes salinity spiking caused by ship heave and allows for slow descent rates without slowing sensor responses, improving dynamic accuracy and resolving small scale structure in the water column. The 19plus V2 supports numerous auxiliary sensors (dissolved oxygen, pH, turbidity, fluorescence, oil, PAR, nitrates, altimeter, etc.) with six A/D channels and one RS-232 data channel. Data is recorded in memory and can also be output in real-time in engineering units or raw HEX. Nine alkaline D-cells provide power for up to 60 hours of profiling.

The 19plus V2 is commonly used autonomously, recording data internally. It can also provide real-time acquisition and display over short cables via the RS-232 interface; a load-bearing cable for hand-hauled, real-time profiling is available. External power and communication over 10,000 m of single-core, armored cable can be provided with the SBE 36 Deck Unit and PDIM. The 19plus V2 is easily integrated with a Sea-Bird Water Sampler; both real-time and autonomous auto-fire operations are possible.

In moored mode, the 19plus V2 records data at user-programmable intervals. This is easily configured with setup commands and by removing the profiling T-C Duct and installing optional anti-foulant devices.

Shown with optional cage, SBE 5P pump, & SBE 43 DO sensor

Features

- Conductivity, Temperature, Pressure, and up to seven auxiliary sensors.
- User-programmable mode: profiling at 4 Hz, or moored sampling at user-programmable intervals.
- RS-232 interface, internal memory, and internal alkaline batteries (can be powered externally).
- Pump-controlled, T-C ducted flow to minimize salinity spiking.
- Depths to 600, 7000, or 10,500 m.
- Seasoft® V2 Windows software package (setup, data upload, real-time data acquisition, and data processing).
- Next generation of the SeaCAT family, field-proven since 1987.
- Five-year limited warranty.

Components

- Unique internal-field conductivity cell permits use of T-C Duct, minimizing salinity spiking.
- Aged and pressure-protected thermistor has a long history of exceptional accuracy and stability.
- Pressure sensor with temperature compensation is available in eight strain-gauge ranges (to 7000 m) and eleven Digiquartz® ranges (to 10,500 m). *Note: Sampling rate 2 Hz when Digiquartz installed.*
- Pump runs continuously (profiling mode), providing correlation of CTD and plumbed auxiliary sensor measurements.

19plus V2 SeaCAT

Options

- Plastic (600 m) or titanium (7000 or 10,500 m) housing; XSG/AG or wet-pluggable MCBH connectors.
- SBE 5M pump for pumped conductivity; or SBE 5P or 5T pump for pumped conductivity and auxiliary sensor(s).
- Sea-Bird Scientific auxiliary sensors — dissolved oxygen, pH, fluorescence, oil, radiance (PAR), light transmission, turbidity, nitrates (profiling only), etc.
- Auxiliary sensors from other manufacturers.
- Stainless steel protection cage.
- Rechargeable Nickel Metal Hydride (NiMH) batteries and charger.
- Moored mode conversion kit with anti-foulant device fittings.
- Load-bearing underwater cable for hand-hauled, real-time profiling.
- SBE 36 CTD Deck Unit & PDIM or SBE 33 Deck Unit & Sea-Bird water sampler (real-time operation on single-core armored cable to 10,000 m).
- Plastic shipping case.

Measurement Range

Conductivity	0 to 9 S/m
Temperature	-5 to +35 °C
Pressure	Strain-gauge 0 to 20/100/350/600/1000/2000/3500/7000 m; Quartz 20/60/130/200/270/680/1400/2000/4200/7000/10,500 m

Initial Accuracy

Conductivity	± 0.0005 S/m
Temperature	± 0.005 °C
Pressure	Strain-gauge ± 0.1% of full scale range; Quartz ± 0.02% of full scale range

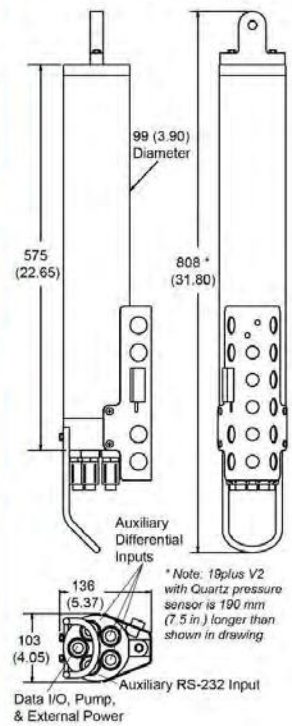
Typical Stability

Conductivity	0.0003 S/m per month
Temperature	0.0002 °C per month
Pressure	Strain-gauge ± 0.1% of full scale range per year, Quartz ± 0.02% of full scale range per year

Resolution

Conductivity	0.00005 S/m typical
Temperature	0.0001 °C
Pressure	Strain-gauge 0.002% of full scale range; Quartz 0.0025% of full scale range

Sampling Speed	Profiling: 4 Hz (strain-gauge pressure) or 2 Hz (Quartz pressure)
Memory & Data Storage	64 Mbyte non-volatile FLASH Bytes/sample: 6 T&C; 5 pressure; 2 each external voltage; 4 date & time (RS-232 sensor is sensor dependent)
Power Supply & Consumption	9 alkaline D-cell batteries, 60 hours CTD profiling (see manual)
Optional External Power	9 - 28 VDC; consult factory for required current
Auxiliary Sensors	Power out up to 500 mA at 10.5 - 11 VDC; Voltage sensor A/D resolution 14 bits & input range 0-5 VDC
Housing, Depth Rating, & Weight (add 0.3 to 0.7 kg [in air] for pump, depending on model)	Acetal Copolymer Plastic, 600 m, in air 7.3 kg, in water 2.3 kg 3AL-2.5V Titanium, 7000 m, in air 13.7 kg, in water 8.6 kg 6AL-4V Titanium, 10,500 m
Optional Cage (weight in air)	(strain-gauge pressure version) 1016 x 241 x 279 mm, 6.3 kg



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SBE 43
DISSOLVED OXYGEN SENSOR

SBE 43 voltage output sensor integrated with SBE 19plus V2 CTD

Overview

The SBE 43 is an individually calibrated, high-accuracy oxygen sensor to assist in critical hypoxia and ocean stoichiometric oxygen chemistry research on a variety of profiling and moored platforms. Careful choices of materials, geometry, and sensor chemistry are combined with superior electronics and calibration methodology to yield significant gains in performance.

The SBE 43 is designed for use in a CTD's pumped flow path, providing optimal correlation with CTD measurements. Elapsed time between the CTD and associated oxygen measurement is easily quantified, and corrected for, in post-processing. The black plenum and plumbing's black tubing blocks light, reducing in-situ algal growth. Plumbing isolates the SBE 43 from continuous exposure to the external environment, allowing trapped water to go anoxic and minimizing electrolyte consumption between samples for moored deployments.

Features

Voltage or frequency output.

Fully and individually calibrated; calibration drift rates of less than 0.5% over 1000 hours of operation (on time).

For use in CTD pumped flow path, optimizing correlation with CTD measurements.

Oxygen measurement dramatically improved because of improved temperature response.

Signal resolution increased by on-board temperature compensation.

Continuous polarization eliminates stabilization wait-time after power-up.

Hysteresis largely eliminated in upper ocean (1000 m) due to improved temperature response. Hysteresis at greater depths predicatable and correctable in post-processing.

No degradation of signal or calibration when used for profiling in hydrogen sulfide environments.

600 or 7000 m housing.

Five-year limited warranty (during warranty period, one sensor re-charge [electrolyte refill, membrane replacement, recalibration] performed free of charge).

Configuration Options

SBE 43 voltage output sensor can be integrated with any Sea-Bird CTD that accepts 0-5 volt auxiliary sensor input. It is available with 600 m plastic or 7000 m titanium housing; XSG or wet-pluggable MCBH connector; 0.5-mil membrane (fast response, typically for profiling applications) or 1-mil membrane (slower response but more rugged for enhanced long-term stability, typically for moored applications).

SBE 43F frequency output sensor can be integrated with SBE 52-MP or Glider Payload CTD, or used for OEM applications (requires OEM circuit board); it is available with 600 m plastic or 7000 m titanium housing. Another 43F version is used as an integral part in SBE 37-SIP-IDO MicroCATs.

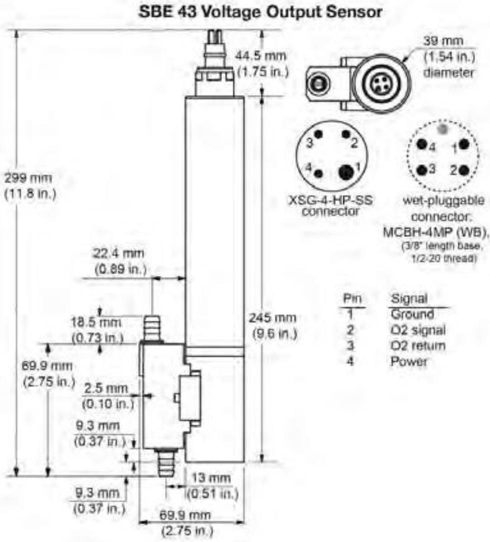
Performance	
Measurement Range	120% of surface saturation in all natural waters (fresh and salt)
Initial Accuracy	± 2% of saturation
Typical Stability	0.5% per 1000 hours of deployed time (clean membrane)
Response Time Tau*	2 to 5 sec for 0.5-mil membrane, 8 to 20 sec for 1.0-mil membrane
Electrical	
Input Power	6.5 - 24 VDC; 60 milliwatts (SBE 43) or 45 milliwatts (SBE 43F)
Output Signal	0 - 5 VDC (SBE 43), frequency (SBE 43F)
Mechanical	
SBE 43 (voltage output)	600 m Plastic housing - 0.5 kg in air, 0.1 kg in water 7000 m Titanium housing - 0.7 kg in air, 0.4 kg in water
SBE 43F (frequency output)	600 m Plastic housing - 0.3 kg in air, 0.1 kg in water 7000 m Titanium housing - 0.4 kg in air, 0.2 kg in water

*Time to reach 63% of final value for a step change in oxygen; dependent on ambient water temperature and flow rate (see Application Note 64 for discussion).

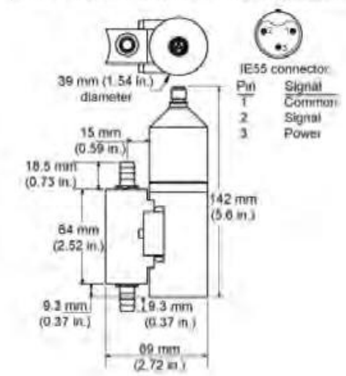
SBE 43

DISSOLVED OXYGEN SENSOR

SBE 43 Voltage Output Sensor



SBE 43F Frequency Output Sensor
(for 52-MP, Glider Payload CTD, & OEM applications)



SEA-BIRD SCIENTIFIC

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SBE 43.DS.53.Sep22

Appendix C: Manual 2—SeaBird Conductivity Cell Cleaning Instructions

SEA-BIRD SCIENTIFIC

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Application Note 2D

Instructions for Care and Cleaning of Conductivity Cells

(Revised August 2021)

This application note presents recommendations for cleaning and storing conductivity sensors. The application note is divided into four sections:

- General discussion
- Identifying damaged of severely fouled conductivity cells
- Rinsing, cleaning, and storage procedures
- Cleaning materials

General Discussion

Since any conductivity sensor's output reading is proportional to its cell dimensions, it is important to keep the cell clean of internal coatings. Cell electrodes contaminated with oil, biological growths, or other foreign material will eventually cause low conductivity readings. To control growth of bio-organisms in the conductivity cell, follow these rinsing and cleaning recommendations.

- Bleach is extremely effective in controlling growth of bio-organisms in the conductivity cell. Sea-Bird recommends cleaning the conductivity sensor in a dilute bleach solution.
- We provide a mild, non-ionic surfactant (detergent), valuable for removal of surface and airborne oil ingested into the CTD plumbing as the CTD is removed from the water and brought on deck. Sea-Bird recommends rinsing and cleaning the conductivity sensor in this solution.
- White vinegar, which is 5 – 8% acetic acid, **may** be used to remove minor mineral deposits on the inside of the cell.

No adverse effects have been observed as a result of dry storage, if the cell is rinsed or soaked with fresh, clean water before storage to remove any salt crystals. This leads to the following conductivity cell storage recommendations:

- Short-term storage (< 1 day, typically between casts): If there is no danger of freezing, store the cell with a dilute bleach solution in Tygon tubing looped around the cell. If there is danger of freezing, store the cell dry, with Tygon tubing looped around the cell.
- Long-term storage (> 1 day): Since conditions of transport and long-term storage are not always under the user's control, store the conductivity cell dry, with Tygon tubing looped around the cell ends. Dry storage eliminates the possibility of damage due to unforeseen freezing, as well as the possibility of bio-organism growth in water in the cell. Filling the cell with a surfactant solution for 1 hour before deployment will *rewet* the cell adequately.

The Tygon tubing looped around the ends of the conductivity cell, whether dry or filled with a bleach or surfactant solution, has the added benefit of keeping air-borne contaminants (abundant on most ships) from entering the cell.

Identifying Damaged or Severely Fouled Cells

Every conductivity calibration certificate has a frequency output for *zero* conductivity, obtained from a cell thoroughly rinsed in distilled or de-ionized water, with all the water shaken out (**dry cell**). A *zero conductivity frequency* that has changed by more than a few 10ths of a Hertz may indicate a cell that is damaged or considerably out of calibration. Noisy readings (± a few 10ths of a Hertz) indicate a dirty cell; follow the procedure for *Cleaning Severely Fouled Sensors* to clean a dirty cell.

Example Calibration Sheet

Frequency associated with *zero conductivity* (dry conductivity cell). Variation of ± few 10ths of a Hz indicates a dirty cell.

BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (Hz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
22.0000	0.0000	0.00000	[illegible]	0.0000	0.00000
1.0000	34.6962	2.96668	4921.91	2.9667	0.00000
4.5000	34.6766	3.27284	5108.92	3.2728	-0.00000
15.0000	34.6339	4.25160	5664.72	4.2516	-0.00000
18.5000	34.6244	4.59565	5847.26	4.5957	0.00000
24.0000	34.6134	5.15177	6130.50	5.1518	0.00000
29.0000	34.6065	5.67181	6383.64	5.6718	0.00000
32.5000	34.6019	6.04282	6558.06	6.0428	-0.00000

Rinsing, Cleaning, and Storage Procedures

Note: See *Cleaning Materials* below for discussion of appropriate sources / concentrations of water, surffactant, bleach, white vinegar, and tubing.

CAUTIONS:

- The conductivity cell is primarily glass, and can break if mishandled. Use the correct size Tygon tubing; using tubing with a smaller ID will make it difficult to remove the tubing, and the cell may break if excessive force is used. **The correct size tubing for cleaning / storing all cells produced since 1980 is 7/16" ID, 9/16" OD**. Instruments shipped prior to 1980 require 3/8" ID tubing.
- **Do not put a brush or object (e.g., Q-Tip) inside the conductivity cell to clean it or dry it.** Touching and bending the electrodes can change the calibration; large bends and movement of the electrodes can damage the cell.
- **If a dissolved oxygen (DO) sensor is plumbed to the CTD** - Before soaking the conductivity cell for more than 1 minute in the surfactant solution, **disconnect the tubing between the conductivity cell and DO sensor** to prevent extended contact with the DO sensor membrane (SBE 43) or optical window (SBE 63). Extended ssurfactant contact can cause sensitivity [slope] changes, usually temporary, to the sensors. For rinsing, cleaning, and storage, see *Application Note 64* for the SBE 43 or the SBE 63 manual for the SBE 63.
- **IDO** and **ODO MicroCATs** (37-SMP-IDO, SIP-IDO, IMP-IDO, 37-SMP-ODO, IMP-ODO) have an integrated dissolved oxygen sensor. **Do not follow the rinsing, cleaning, and storage recommendations in this application note;** extended surfactant contact with the DO sensor membrane (IDO MicroCATs) or DO sensor optical window (ODO MicroCATs) can cause sensitivity [slope] changes, usually temporary, to the sensors. For rinsing, cleaning, and storage, see the applicable MicroCAT manual.

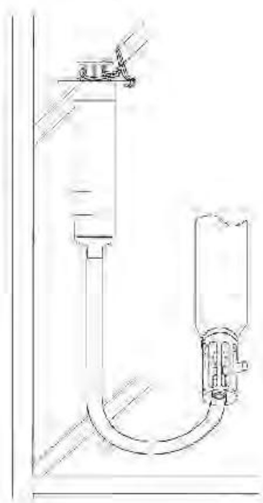
Active Use (after each cast)

1. Rinse: Remove the plumbing (Tygon tubing) from the exhaust end of the conductivity cell. **Flush** the cell with a **0.1%** surfactant solution. **Rinse** thoroughly with **fresh, clean water** and drain.
   - If not rinsed between uses, salt crystals may form on the conductivity cell platinized electrode surfaces. When the instrument is used next, sensor accuracy may be temporarily affected until these crystals dissolve.
2. Store: The intent of these storage recommendations is to keep contamination from aerosols and spray/wash on the ship deck from harming the sensor's calibration.
   - ***No danger of freezing***: **Fill** the cell with a **500 – 1000 ppm bleach** solution, using a loop of Tygon tubing attached to each end of the conductivity sensor to close the cell ends.
   - ***Danger of freezing***: Remove larger droplets of water by blowing through the cell. **Do not use compressed air**, which typically contains oil vapor. Attach a loop of Tygon tubing to each end of the conductivity cell to close the cell ends.

Routine Cleaning (no visible deposits or marine growths on sensor)

1. **Agitate** a **500 – 1000 ppm Bleach** solution warmed to 40 °C (wrist warm) through the cell in a washing action (this can be accomplished with Tygon tubing and a syringe kit – see *Application Note 34*) for **2 minutes**. **Drain and flush** with warm (not hot) fresh, clean water for **5 minutes* or until rinsed thoroughly**.
2. **Agitate** a **1%-2%** surfactant solution warmed to 40 °C (wrist warm) through the cell many times in a washing action (this can be accomplished with Tygon tubing and a syringe kit). Fill the cell with the solution and let it **soak** for **1 hour**. **Drain and flush** with warm (not hot) fresh, clean water for **5 minutes* or until rinsed thoroughly**.

*If you do not have a large supply of fresh water: As a minimum, flush the cell with enough warm, fresh, clean water to fill the cell five times, or until rinsed thoroughly.



2

Cleaning Severely Fouled Sensors (visible deposits or marine growths on sensor, and/or shift in zero conductivity frequency)

1. Repeat the *Routine Cleaning* procedure up to 5 times.
   A. Thoroughly rinse in distilled or de-ionized water, and shake out all the water. With the conductivity cell dry, take and record a raw conductivity reading (in Hz). Compare to the *zero conductivity frequency* on the calibration sheet. The output should be within a few tenths of a Hz of the *zero conductivity frequency*. If not, proceed to Step 2.
2. Clean with a white vinegar solution or diluted HCl solution; see the *Cleaning Materials* section of this application note for details.

If the zero conductivity is still outside the expected range, the conductivity cell may require factory cleaning.

Long-Term Storage (after field use)

1. Rinse: Remove the plumbing (Tygon tubing) from the exhaust end of the conductivity cell. **Flush** the cell with a **0.1% surfactant** solution. **Rinse** thoroughly with **fresh, clean water** and drain. Remove larger droplets of water by blowing through the cell. **Do not use compressed air**, which typically contains oil vapor.
2. Store: Attach a loop of Tygon tubing to each end of the conductivity cell to close the cell ends and prevent contaminants from entering the cell.
   - Storing the cell dry prevents the growth of any bio-organisms in water in the cell, thus preserving the calibration.
3. When ready to deploy again: **Fill** the cell with a **0.1%** surfactant solution for **1 hour** before deployment. Drain the surfactant solution; there is no need to rinse the cell.

Cleaning Materials

Water

De-ionized (DI) water, commercially distilled water, or fresh, clean, tap water is recommended for rinsing, cleaning, and storing sensors.

- On ships, **fresh water is typically made in large quantities by a distillation process, and stored in large tanks. This water may be contaminated with small amounts of oil, and should not be used for rinsing, cleaning, or storing sensors**.

Where fresh water is extremely limited (for example, a remote location in the Arctic), you can substitute **clean seawater** for rinsing and cleaning sensors. If not immediately redeploying the instrument, follow up with a **brief fresh water rinse** to eliminate the possibility of salt crystal formation (which could cause small shifts in calibration).

- **The seawater must be extremely clean, free of oils that can coat the conductivity cell. To eliminate bio-organisms in the water, boil the water or filter it with a 0.5 micron filter.**

Surfactant

Sea-Bird Scientific provides a surfactant that contains Octyl Phenol Ethoxylate, a mild, non-ionic detergent. This is included with every CTD shipment and can be ordered from Sea-Bird Scientific, but may be available locally from a chemical supply or lab products company. Other liquid detergents can probably be used, but scientific grades (with no colors, perfumes, glycerins, lotions, etc.) are required because of their known composition. It is better to use a non-ionic detergent, since conductivity readings taken immediately after use are less likely to be affected by any residual detergent left in the cell.

Bleach

Bleach is a common household product used to whiten and disinfect laundry. Commercially available bleach is typically 4 % - 7% (40,000 – 70,000 ppm) sodium hypochlorite (Na-O-Cl) solution that includes stabilizers. Some common commercial product names are Clorox (U.S.) and eau de Javel (French).

Dilute to 500 – 1000 ppm. For example, if starting with 5% (50,000 ppm) sodium hypochlorite, diluting 50 to 1 (50 parts water to 1 part bleach) yields a 1000 ppm (50,000 pm / 50 = 1000 ppm) solution.

Tygon Tubing

Sea-Bird recommends use of Tygon tubing, because it remains flexible over a wide temperature range and with age. Tygon is manufactured by Saint-Gobain (www.tygon.com). It is supplied by Sea-Bird, but may be available locally from a chemical supply or lab products company.

Keep the Tygon in a clean place (so that it does not pick up contaminants) while the instrument is in use.

White Vinegar

White vinegar is a common household product used to dissolve mineral deposits, and may be used to remove minor mineral contamination of the conductivity cell. Commercially available white vinegar is typically 5 – 8% acetic acid (CH_3COOH) in aqueous solution; verify that there are no oils or other ingredients.

1. Prepare for cleaning:
   A. Place a 0.6 m (2 ft) length of Tygon tubing over the end of the conductivity cell.
   B. Clamp the instrument so that the cell is vertical, with the Tygon tubing at the bottom end.
   C. Loop the Tygon tubing into a U shape, and tape the open end of the tubing in place at the same height as the top of the glass cell.
2. Clean the cell:
   A. Pour **weak white vinegar** solution (1 part white vinegar, 2 parts water) into the open end of the tubing until the cell is nearly filled. **Let it soak for 2-3 minutes only.**
   B. Drain the solution from the cell and flush for 5 minutes with warm (not hot), clean, de-ionized water.
   C. Rinse the exterior of the instrument to remove any spilled solution from the surface.
   D. Fill the cell with a **1%** surfactant solution and let it stand for 5 minutes.
   E. Drain and flush with warm, clean, de-ionized water for 1 minute.
   F. Carefully remove the 0.6 m (2 ft) length of Tygon tubing.
3. With the conductivity cell dry, take and record a raw conductivity reading (in Hz). Compare to the *zero conductivity frequency* on the calibration sheet. The output should be within a few tenths of a Hz of the *zero conductivity frequency*. If not, repeat Steps 1 and 2 with a moderate white vinegar solution (1 part white vinegar, 1 part water) and repeat the test. If still outside the expected range, repeat with a full strength white vinegar solution and repeat the test. If still outside the expected range, return to the factory or see *Hydrochloric Acid (HCl)* below.
4. Prepare for deployment, **or** follow recommendations above for storage.

Hydrochloric Acid (HCl)

Many years ago, Sea-Bird recommended cleaning with a hydrochloric acid (HCl) solution to eliminate bio-organisms or mineral deposits on the inside of the cell. However, bleach cleaning has proven to be effective in eliminating growth of bio-organisms, and is much easier to use and dispose of than acid. Data from many years of use shows that mineral deposits are an unusual occurrence. Sea-Bird recommends that, **in most cases, hydrochloric acid should not be used** to clean the conductivity sensor. ***In rare instances***, it may still be required for mineral contamination of the conductivity cell. ***Sea-Bird recommends that you return the equipment to the factory for this cleaning if it is necessary***. Information below is provided if you cannot return the equipment to Sea-Bird.

CAUTIONS:

- **SBE 37-IMP, SMP, SIP, IMP-IDO, SMP-IDO, SIP-IDO, IMP-ODO, SMP-ODO, MicroCAT; SBE 49 FastCAT; SBE 52-MP Moored Profiler CTD; or other instruments with an integral, internal pump - Do not perform acid cleaning,** which may damage the internal, integral pump. Return these instruments to Sea-Bird for servicing if acid cleaning is required.
- **SBE 9*plus*, 25, or 25*plus* CTD** – Remove the SBE 4 conductivity cell from the CTD and remove the TC Duct before performing acid cleaning.
- **All instruments that include AF24173 Anti-Foulant Devices** – Remove the AF24173 Anti-Foulant Devices before performing acid cleaning; see the instrument manual for details and handling precautions.

WARNING! Observe all precautions for working with strong acid. Avoid breathing acid fumes. Work in a well-ventilated area.

The acid cleaning procedure for the conductivity cell uses approximately 50 - 100 cc of acid. Sea-Bird recommends using a 20% concentration of HCl. However, acid in the range of 10% to full strength (38%) is acceptable.

If starting with a strong concentration of HCl that you want to dilute:
For each 100 cc of concentrated acid, to get a 20% solution, mix with this amount of water -
Water = [(conc% / 20%) – 1] * [100 + 10 (conc% / 20%)] cc
Always add acid to water; never add water to acid.

Example -- concentrated solution 31.5% that you want to dilute to 20%:
[(31.5% / 20%) – 1] * [100 + 10 (31.5% / 20%)] = 66.6 cc of water.
So, adding 100 cc of 31.5% HCl to 66.6 cc of water provides 166.6 cc of the desired concentration.
For 100 cc of solution:
100 cc * (100 / 166.6) = 60 cc of 31.5% HCl   66.6 cc * (100 / 166.6) = 40 cc of water

For acid disposal, dilute the acid heavily or neutralize with bicarbonate of soda (baking soda).

1. Prepare for cleaning:
   A. Place a 0.6 m (2 ft) length of Tygon tubing over the end of the conductivity cell.
   B. Clamp the instrument so that the cell is vertical, with the Tygon tubing at the bottom end.
   C. Loop the Tygon tubing into a U shape, and tape the open end of the tubing in place at the same height as the top of the glass cell.
2. Clean the cell:
   A. Pour **10% to 38% HCl** solution into the open end of the tubing until the cell is nearly filled. **Soak for 1 minute only.**
   B. Drain the acid from the cell and flush for 5 minutes with warm (not hot), clean, de-ionized water.
   C. Rinse the exterior of the instrument to remove any spilled acid from the surface.
   D. Fill the cell with a **1%** surfactant solution and let it stand for 5 minutes.
   E. Drain and flush with warm, clean, de-ionized water for 1 minute.
   F. Carefully remove the 0.6 m (2 ft) length of Tygon tubing.
3. Prepare for deployment, **or** follow recommendations above for storage.

Application Note Revision History

Date	Description
January 1998	Initial release.
October 2002	Remove reference to part number for the small anti-foul cylinders (that have been eliminated) in Tygon tubing.
January 2005	Change in recommendations. Clean with bleach solution as well as Triton. Acid cleaning is not recommended in general, but some information on acid is still provided for the few cases where it is necessary. A section on Materials added, defining water, Triton, etc. in more detail.
July 2005	Include information on common names of commercially available bleach
October 2006	Update manufacturer name and website link for Triton
September 2008	Add SBE 52-MP to list of instruments with integral, internal pump that should not have acid cleaning.
October 2010	• Add reference to IDO MicroCATs, with caution to following cleaning and storage procedures in Application Note 64 instead of in this application note. • Update address.
October 2012	• Update manufacturer information for Triton. • Add information on 25plus. • Add reference to ODO MicroCATs, with caution to following cleaning and storage procedures in ODO manual instead of in this application note. • Eliminate 'new' language regarding cleaning and storing, since recommendations date from 2006.
March 2014	• Add information on cleaning with white vinegar. • Add information on checking zero conductivity frequency to verify cleanliness. • Add information on cleaning if SBE 63 Optical Dissolved Oxygen Sensor on system. • Update language on *recent* recommendations (which dated back to 2005).
June 2016	• Remove information on SBE 37-SIP-ODO (product not released).
August 2021	• Remove references to Triton-X and replace with surfactant

Appendix D: Data Sheet 2

Hypoxia Sensor Master Database - used to track important sensor metadata for each deployment and recovery. Sensor ID, location and last calibration.

Deployment	Site_ID	Sensor_ID	Interaction_date	Interaction_type	Depth_interactio	Int_val_sens	Int_val_cast	Field_data_shee	Note
21_Fall	CB4.3W	XOBH	12/1/2021	deployed	1	19-6913	ctd_filename	2021_1201	
21_Fall	CB4.3W	XOBJ	12/1/2021	deployed	3	19-6913		2021_1201	
21_Fall	CB4.3W	XOBM	12/1/2021	deployed	5	19-6913		2021_1201	
21_Fall	CB4.3W	37-9820	12/1/2021	deployed	8	19-6913		2021_1201	
21_Fall	CB4.3E	XOBA	12/1/2021	deployed	1	19-6913		2021_1201	
21_Fall	CB4.3E	XOBB	12/1/2021	deployed	3	19-6913		2021_1201	
21_Fall	CB4.3E	XOBC	12/1/2021	deployed	5	19-6913		2021_1201	
21_Fall	CB4.3E	XOBE	12/1/2021	deployed	7	19-6913		2021_1201	
21_Fall	CB4.3E	XOBF	12/1/2021	deployed	9	19-6913		2021_1201	
21_Fall	CB4.3E	XOBG	12/1/2021	deployed	11	19-6913		2021_1201	
21_Fall	CB4.3E	XOBP	12/1/2021	deployed	13	19-6913		2021_1201	
21_Fall	CB4.3E	XOBQ	12/1/2021	deployed	15	19-6913		2021_1201	
21_Fall	CB4.3E	XOBN	12/1/2021	deployed	17	19-6913		2021_1201	
21_Fall	CB4.3E	37-9819	12/1/2021	deployed	19	19-6913		2021_1201	
21_Fall	CB4.3W	XOBH	12/15/2021	recovered	1	19-6913			
21_Fall	CB4.3W	XOBJ	12/15/2021	recovered	3	19-6913			
21_Fall	CB4.3W	XOBM	12/15/2021	recovered	5	19-6913			
21_Fall	CB4.3W	37-9820	12/15/2021	recovered	8	19-6913			
21_Fall	CB4.3E	XOBA	12/15/2021	recovered	1	19-6913			
21_Fall	CB4.3E	XOBB	12/15/2021	recovered	3	19-6913			
21_Fall	CB4.3E	XOBC	12/15/2021	recovered	5	19-6913			
21_Fall	CB4.3E	XOBE	12/15/2021	recovered	7	19-6913			
21_Fall	CB4.3E	XOBF	12/15/2021	recovered	9	19-6913			
21_Fall	CB4.3E	XOBG	12/15/2021	recovered	11	19-6913			
21_Fall	CB4.3E	XOBP	12/15/2021	recovered	13	19-6913			
21_Fall	CB4.3E	XOBQ	12/15/2021	recovered	15	19-6913			
21_Fall	CB4.3E	XOBN	12/15/2021	recovered	17	19-6913			
21_Fall	CB4.3E	37-9819	12/15/2021	recovered	19	19-6913			

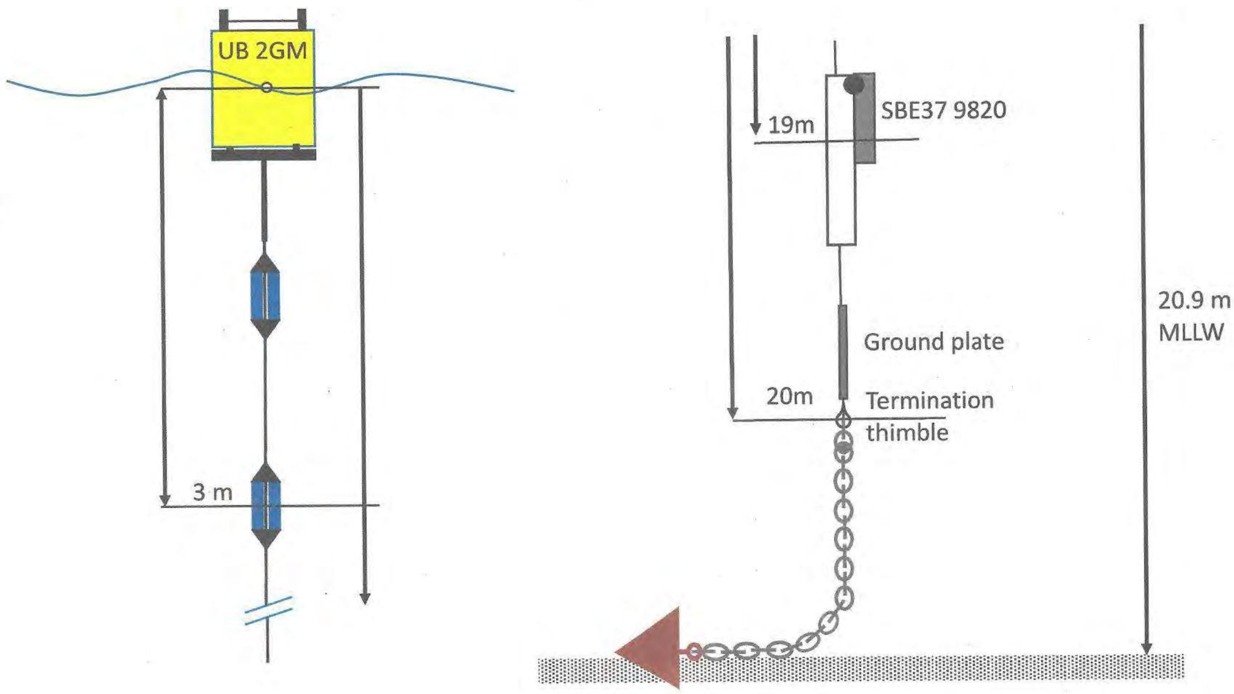
Appendix E: Acronyms

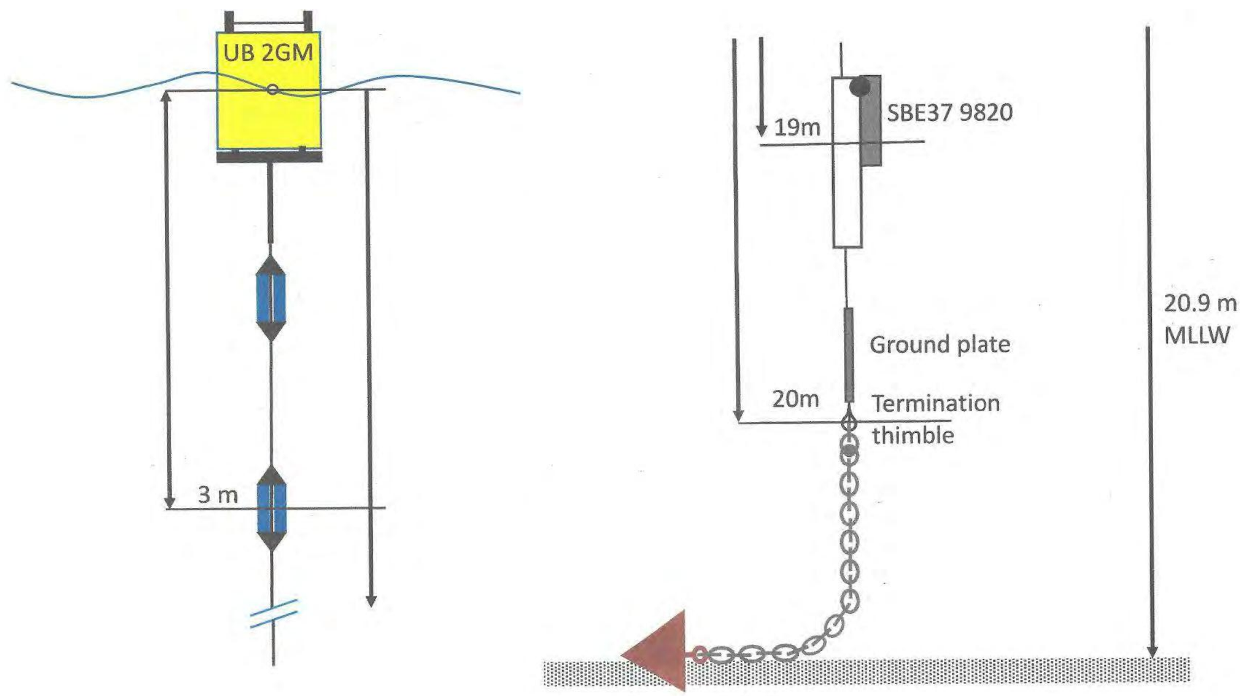
ADF- Automatic Data Flag
CT-DO - Conductivity Temperature - Dissolved Oxygen
CTD-DO; CTDO2 - Conductivity Temperature Depth - Dissolved Oxygen
CBP - Chesapeake Bay Program
CBT - Chesapeake Bay Trust
FLT - Flat Line Test
GRT - Gross Range Test
IOOS - United States Integrated Ocean Observing System Program
MDF - Manual Data Flag
NCBO - NOAA Chesapeake Bay Office
NOAA - National Oceanic and Atmospheric Administration
NCEI - National Centers for Environmental Information
QA/QC - Quality Assurance/Quality Control
QARTOD - Quality Assurance/Quality Control of Real-Time Oceanographic Data
RCT - Rate of Change Test
ST - Spike Test
XIM - Inductive Ultibuoy

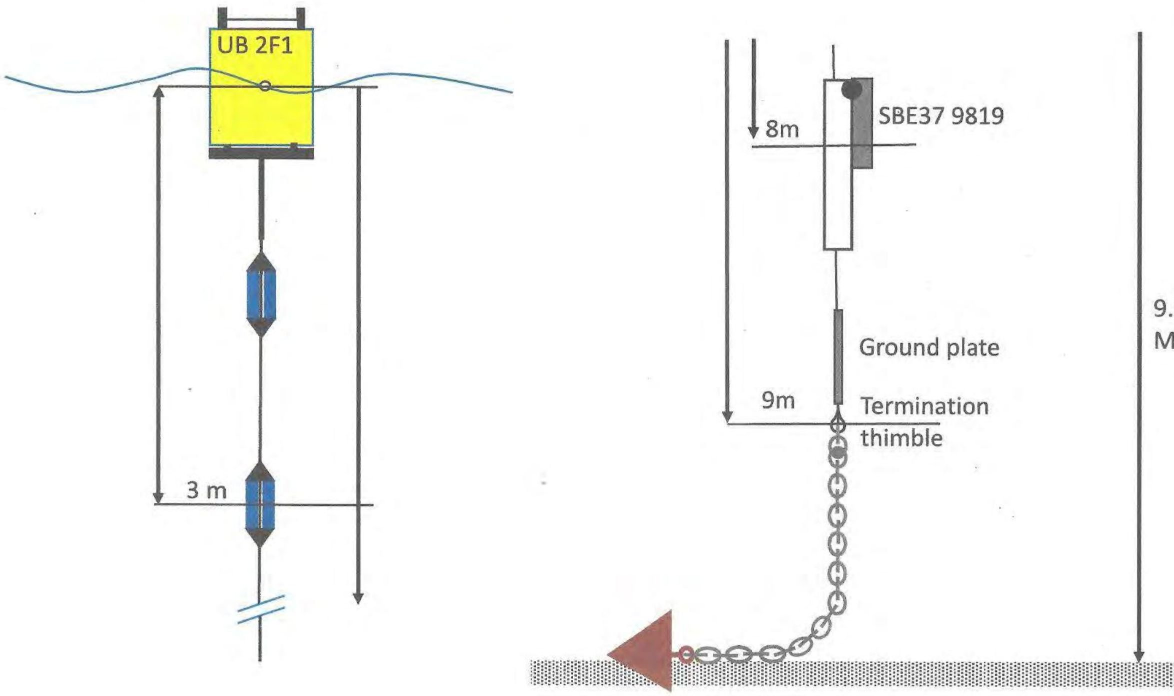
Appendix F: Feasibility Study Technical Report

A technical report resulting from the feasibility study of monitoring hypoxia in the Chesapeake Bay's water column is available at https://cbtrust.org/wp-content/uploads/16793_Caribbean-Wind_Final-Report_Jan2021.pdf.

Appendix G: Termination of Hypoxia Buoys for 2022 Deployment




UB 2GM
3 m
19m
SBE37 9820
Ground plate
20m
Termination
thimble
20.9 m
MLLW


UB 2F1
3 m
8m
SBE37 9819
Ground plate
9m
Termination
thimble
9.8 m
MLLW

Appendix H: CBIBS Hardware Mapping Field Deployment

Maintains a log of serial numbers and photos used in NOAA internal property database.

To be used to track current inventory, not deployment

https://docs.google.com/spreadsheets/d/1bkhfxsrhB34JAEuy4_168gxfH6I8Yoa3hR-JvBiOB0/edit?usp=sharing <- for current deployment

ID	Serial Number	Name	Last Calibration	Location	Parameter	Last/Current Deployment	Last/Current Recovery	Notes	Photo Links
1	X0BA		2023-0207	warehouse	DO-CTD			Returned from repair 2/7/23	
2	X0BB		2023-0207		DO-CTD			Returned from repair 2/7/23	
3	X0BC		2021-1006	HYP_E	DO-CTD	Deployed 2021-1201			
4	X0BE		2021-1015	HYP_E	DO-CTD	Deployed 2021-1201			
5	X0BF		2021-1006	HYP_E	DO-CTD	Deployed 2021-1201			
6	X0BG		2021-1006	HYP_E	DO-CTD	Deployed 2021-1201			
7	X0BH		2021-1006	HYP_W	DO-CTD	Deployed 2021-1201			
8	X0BJ		2023-0207	warehouse	DO-CTD			Returned from repair 2/7/23	
9	X0BM		2021-1006	HYP_W	DO-CTD	Deployed 2021-1201		Shipped for cal	
10	X0BN		2021-1006	HYP_E	DO-CTD	Deployed 2021-1201			
11	X0BP		2021-1006	HYP_E	DO-CTD	Deployed 2021-1201			
12	X0BQ		2023-0207	warehouse	DO-CTD	Deployed 2021-1201		Returned from repair 2/7/23	
13	XOCD		2022_June	HYP_E	DO-CTD	Deployed 2022-0809			
14	XOBD		2022_June	HYP_W	DO-CTD	Deployed 2022-0804		Shipped for cal	
15	X0C7		2023-0207	warehouse	DO-CTD				
16	X0BY		2023-0207	warehouse	DO-CTD				
17	X0C9		2023-0207	warehouse	DO-CTD				
18	X0BX		2023-0207	warehouse	DO-CTD				

Appendix I: Hypoxia Offset File

Used to keep track of file names and time differences between instruments and cloud based systems. Primarily referenced for CTD-DO casts and tracking file names of files generated during site visits.

Folder	File	DO plots	CT plots	First Julian Date	Offset	Converted Date (America/New_York timezone)	Field Notes Time
2022-05-16 E_W Deployment	HYP_E_6913_2022_05_16_0004.cnv	missing	missing	136.338403	2	2022-05-16 10:07:18.019200-05:00	
	HYP_E_Gooses_deploy_6913_2022_05_16_0006.cnv			136.402488	2	2022-05-16 11:39:34.963200-05:00	
	HYP_W_6913_2022_05_16_0005.cnv			136.367086	2	2022-05-16 10:48:36.230400-05:00	
2022-06-01_E_Maintenance	HYP_E_6913_2022_06_01_007	off	off	152.273414	3	2022-06-01 09:33:42.969600-05:00	9:36 AM
	HYP_E_6913_2022_06_01_008			152.337373	3	2022-06-01 11:05:49.027200-05:00	11:13 AM
2022-06-17 E_W Validation Casts	HYP_E_01906398_2022_06_17_0002.cnv	ok	ok	168.584097	-1	2022-06-17 13:01:05.980800-05:00	1:21 PM
	HYP_E_01906913_2022_06_17_0010.cnv			168.583762	-1	2022-06-17 13:00:37.036800-05:00	1:21 PM
	HYP_W_01906398_2022_06_17_0001.cnv			168.557292	1	2022-06-17 14:22:30.028800-05:00	2:01 PM
2022-06-29 East Maintenance	HYP_E_01906398_2022_08_29_0003	ok	ok	180.455613	0	2022-06-29 10:56:04.963200-05:00	10:57 AM
2022-06-30 E&W Maintenance	HYP_E_01906398_2022_06_30_0004	ok	ok	181.401146	0	2022-06-30 09:37:39.014400-05:00	9:38
	HYP_E_01906398_2022_08_30_0005			181.406435	0	2022-06-30 09:45:15.984000-05:00	9:45
	HYP_W_01906398_2022_08_30_0006			181.442384	0	2022-06-30 10:37:01.977600-05:00	10:38
	HYP_W_01906398_2022_06_30_0007			181.51088	0	2022-06-30 12:15:40.032000-05:00	12:15
2022-07-15 East Deployment	HYP_W_01906398_2022_07_15_0008	ok	ok	196.433009	0	2022-07-15 10:23:31.977600-05:00	10:26 AM
	HYP_E_01906398_2022_07_15_0009			196.527813	0	2022-07-15 12:40:03.043200-05:00	12:44 PM
2022-07-26 West Maintenance	HYP_E_01906398_2022_07_26_0010	ok	ok	207.445243	0	2022-07-26 10:41:08.995200-05:00	10:49 AM
	HYP_E_01906398_2022_07_26_0011			207.4514	0	2022-07-26 10:50:00.960000-05:00	10:57 AM
	HYP_W_01906398_2022_07_26_0012			207.470174	0	2022-07-26 11:17:03.033600-05:00	11:20 AM
2022-08-04 West Maintenance	HYP_E_01906398_2022_08_04_0013	ok	ok	216.483993			11:40 AM
2022-08-09 E&W Maintenance	HYP_E_01906398_2022_08_09_0014	ok	ok				950
	HYP_E_01906398_2022_08_09_0016						1005
	HYP_E_01906398_2022_08_09_0017						1014
	HYP_E_01906398_2022_08_09_0018						1259
	HYP_E_01906913_2022_08_09_0011	off	off				950
	HYP_E_01906913_2022_08_09_0013						1005
	HYP_E_01906913_2022_08_09_0014						1014
	HYP_E_01906913_2022_08_09_0015						1259
2022-08-29 HYP E Maintenance	HYP_E_01906913_2022_08_29_0016	missing	missing	241.480243			1133
	HYP_E_01906913_2022_08_29_0017			241.484109			1139

Appendix J: Soundnine XIM-CTD Specification Sheet

SOUNDNINE INC
Tools for Real-time Marine Research and Monitoring

Real-Time Salinity
XIM-CTD

The XIM-CTD delivers accurate real-time conductivity, temperature, depth, and tilt measurements at remarkably low cost in a stand alone instrument with integrated inductive communications.

This sensor enables reasonable cost salinity measurement on expendible platforms like surface drifters and in high-risk environments like under surface ice.

Soundnine's high speed inductive communication allows fast, power efficient, simultaneous sampling and data collection from multiple sensors with a single command. Integrated error detection codes eliminate communication errors from your dataset. Soundnine's Ultimodem inductive modem also supports communication with sensors from Sea-Bird Electronics.

The conductivity sensor is a coated glass three electrode oscillator-based sensor similar to conductivity sensors from Sea-Bird Electronics.

It provides consistent performance in very fresh or very salty water. Unlike other CTDs, there is no loss of resolution in fresh water. It is very power-efficient and its response to changing conductivity is both fast and accurate over the full measurement range.

The XIM-CTD mounts concentrically on on plastic-jacketed wire rope with provided clamps. The tapered ends reduce impact and snagging from nets, lines, and debris. Replaceable copper mesh provides bio-fouling protection.

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R0124

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SOUNDNINE INC

Tools for Real-time Marine Research and Monitoring

Real-Time Salinity

XIM-CTD

Specifications:

	Range	Accuracy	Resolution
Conductivity:	0- 9 S/m	±0.005 S/m	0.0001 S/m
Temperature	-5 - 45° C	±0.005° C	0.00001° C
Pressure Sensor	100 dbar	± 0.5%	0.01%

Pressure rating: 150 dbar
Size: 9.5 cm x 9.5 cm x x 23 cm
Mass: 1500g
Battery: Alkaline 6V, good for at least 5 years
Allowable Cable Size: 3mm to 11mm

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Appendix K: Soundnine Ultibuoy Manual

SOUNDNINE INC

Helping build successful monitoring systems

Ultibuoy Manual

Soundnine Inc Document #R0111
rev 2018-05-01

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R0111

Page 1

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1 Table of Contents

2 Hardware

2.1 Inductive Coupler

The inductive coupler connects the buoy controller to the mooring cable allowing inductive telemetry with sensors on the mooring cable. The connection requires the mooring cable to pass through the ferrite ring of the coupler. There are two types of coupler – swivel couplers and non-swivel couplers. This document describes only non-swivel couplers.

The inductive coupler is a potted assembly with a short cable and M8 connector attached. The M8 connector plugs into the buoy controller.

2.2 Top cable Termination

Buoy are shipped with the top termination in place. The top termination is swaged and potted, it cannot be removed. If it becomes necessary to replace the top termination please contact Soundnine technical support for assistance.

Figure 1 Inductive Coupler

2.3 Bottom Cable Termination

The bottom cable termination uses Nicopress style swaged fittings to hold a wire rope thimble in place. Freshwater deployments using inductive telemetry require a return electrode in the bottom termination.

2.3.1 Before Starting the Bottom Termination

Once the swage fittings are installed they cannot be removed. Removing the termination will require cutting the cable.

Verify all components are properly installed on the mooring cable – including XT & XTP sensors and any cable protectors or other components which must be threaded onto the wire.

Verify the desired termination location. Remember it is best to float three to ten meters of chain under the bottom termination. If the bottom termination drags on the bottom it may fail prematurely. If the bottom electrode is buried in mud the inductive telemetry may not work properly.

Figure 2 Bottom Termination Components

Table 1 Bottom Termination Components (for 1/8" wire rope)

Qty	Description	S9 Part Number
1	3/8"-16 x 1" galvanized steel bolt	
1	3/8"-16 distorted thread lock nut, zinc plated, grade 2	20729
1	3/8" external tooth bronze lock washer	2053A
34cm	Polyurethane tubing, blue, 5mm ID, 8mm OD	20726
1	Bottom electrode, 1"x10.5" galvanized steel with 3/8" eye.	

S9
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6.5cm	Electrode Bumper: Neoprene rubber tube, ¾" OD, ¼" ID	2051C
2	Wire Rope Compression Sleeve - Zinc-Plated Copper; for 1/8" Rope Diameter NOTE: crimp with McMaster-Carr # 3582T1 or equivalent tool.	20713
1	Wire rope thimble for 1/8" wire rope diameter	2051E
1	Ring terminal, 3/8" for wire gauge 8	20717

2.3.2 Bottom Cable Termination procedure

1. Strip the 30 cm of jacket off the cable

2. Thread the electrode bumper and a 34 cm length of cable protector urethane tube on the cable.

3. Thread the electrode on the cable with the bolt attachment facing the end of the cable.

4. Thread two compression sleeves on the cable with a thimble captured in the cable loop.

5. Pull the bottom cable sleeve tight against the thimble and double-crimp both compression sleeves.

6. Securely crimp the 3/8" ring terminal on the end of the cable. When crimping steel cable more force is required than with copper wire – a good ratcheting crimp tool is required. The red insulation may fall off the terminal when crimped properly.
7. Assembly the ring terminal, bronze star washer, electrode and 3/8" bolt. Position the star washer between the electrode and the ring terminal.
8. Fully tighten the lock nut. The star washer must be fully compressed.
9. Wrap the bottom end of the electrode and ring terminal assembly with vinyl electrical tape to prevent any motion between the blue urethane tube and the bolt head.

10. Position the electrode bumper at the end of the electrode pressing against the blue urethane tube (not visible – inside the electrode). There should be about 2-3cm of the bumper visible. Tape the bumper in place with vinyl electrical tape. Cover about 2cm of end of the electrode, the visible portion of the bumper, and 5cm of the cable with tape.

2.4 Anode

The buoy has a sacrificial anode for galvanic corrosion protection. This anode dissolves over time helping preserve the steel components galvanically connected to it. Buoys deployed in freshwater should use an aluminum alloy anode for best protection. Buoys deployed in saltwater should use a zinc alloy anode – the aluminum anode may dissolve too quickly.

Figure 3: Aluminum Alloy Anode

2.4.1 When to Replace the Anode

The anode is an inexpensive component intended to extend the useful life of the buoy. It is appropriate to replace it every time the buoy is serviced. Always replace the anode if it has lost approximately one third of its original mass. The standard anode is about 5cm diameter when new, it should be replaced if the diameter is 4cm or less.

2.4.2 Replacing the Anode

When removing a used anode always wear gloves to protect yourself from sharp edges on any corroded parts.

The anode is held in place with a distorted-thread lock nut. This nut is not reusable.

Be sure the bronze star washer is correctly positioned between the anode and the steel mount plate. Refer to Figure 4 and Figure 5.

Fully tighten the nut to compress the bronze washer tightly between the anode and the mount plate.

Figure 4: Anode installation top view

Table 2 Anode Components

Qty	Description	S9 Part Number
1	3/8"-16 x 1.5" galvanized steel bolt	
1	3/8"-16 distorted thread lock nut, zinc plated, grade 2	20729
2	0.5" ID x 1.25" OD galvanized steel washer	20538
1	3/8" external tooth bronze lock washer	2053A
1	Aluminum alloy anode, 2" diameter, 1" thick	20718

Figure 5 Anode installation side view

2.5 Specifications

Specifications vary with hull design. Soundnine can easily customize buoy hull diameter, thickness, chines, weights and terminations to meet application specific requirements.

2.5.1 Swivel

Standard buoys do not include a swivel in the buoy. The swivel option is available for all Ultibuoy shapes, including buoys with inductive modem communications. We do not recommend swivels in low conductivity freshwater applications with inductive communications – swivels reduce the inductive signal coupling from the cable to the water around the buoy.

2.5.2 UB70P-IM

For fresh or saltwater applications with inductive modem.

Parameter	Value
Materials	Polyethylene, Polyurea, PET, Galvanized steel
Weight in air	50 Lb
Total Buoyancy (submerged)	150 Lb
Natural frequency	1.2 seconds

2.6 Replacement Parts List

Item	Description	Soundnine Part Number	McMaster-Carr Part Number
Anode for fresh water	Aluminum Alloy Corrosion-Inhibiting Pad; 2" Diameter x 1" Thick	20718	3590K2
Anode for salt water	Zinc Alloy Corrosion-Inhibiting Pad; 2" Diameter x 1" Thick		3609K2
Brace w/anode mount	1" x 12" x 0.125" galvanized steel brace with anode mount	50063	NA
Brace	1" x 9" x 0.125" galvanized steel brace	50062	NA
Thimble	Wire rope thimble for 1/8" wire rope diameter	2051E	3494T11
Star washer	3/8" external tooth star washer, bronze	2053A	92164A031
Cable protector tube	Polyurethane tubing, blue, 5mm ID, 8mm OD	20726	
Electrode bumper	Neoprene rubber tube, ¾" OD, ¼" ID, cut to 65mm length	2051C	8637K11
3/32" Compression sleep	Wire Rope Compression Sleeve - Zinc-Plated Copper; for 3/32" Rope Diameter NOTE: crimp with McMaster-Carr # 3582T1 or equivalent tool.	20546	3898T33
1/8" Compression sleeve	Wire Rope Compression Sleeve - Zinc-Plated Copper; for 1/8" Rope Diameter NOTE: crimp with McMaster-Carr # 3582T1 or equivalent tool.	20713	3898T14
Ring terminal	Ring terminal, 3/8" for wire gauge 8	20717	7113K224
Threaded rod	3/8"-16 ASTM A193 B7 STEEL THREADED ROD, HOT DIP GALVANIZED		NA

Appendix L: XIM-CTD Cleaning and Calibration

SOUNDNINE INC
Helping build successful monitoring systems

CTD Cleaning and Calibration

About Soundnine Conductivity Sensors

The Soundnine conductivity sensor is a three-electrode internal field glass cell. Internal field means the electrical current used to measure the conductivity of the water is confined to the area inside the glass tube and there are no electrical fields created outside the glass tube. The area inside the glass tube is referred to as the cell. The three electrodes are the points where electrical current moves into or out of the water. The two outer electrodes are kept at the same electrical potential; this prevents external electrical currents. These electrodes are visible when looking into the cell – they are the black areas at each end. Never touch or mechanically clean the electrodes; doing so may damage the black platinum coating and significantly reduce accuracy.

The electrical current measures the resistance of the water in the conductivity cell. This measurement, combined with calibrated measurements of the geometry of the cell, allows calculation of the conductivity of the water within the cell. Any change to the geometry of the cell or presence of anything other than water within the cell creates an error in the measurement.

Figure 1: Always remove copper mesh before cleaning

About Salinity

Salinity is a parameter calculated from the conductivity, temperature and pressure of the water. Any error in either conductivity, temperature, or pressure will create a salinity error. Pressure has a relatively small effect in this calculation, it may be ignored for shallow sensors and applications with low accuracy requirements.

Calibration Guidelines

In situ performance of the conductivity sensor is highly dependent on the deployed environment and antifouling efforts. Deployments in cold arctic water may see performance better than 0.05 PSU for a year or more. Deployments in productive coastal waters with spawning barnacles and severe fouling may see errors of 0.1 PSU within a few weeks.

Signs Calibration is required

- Visible barnacles, algae, or objects inside the cell not removed by cleaning procedures below
- More than one year deployed (in any environment)
- More than three years since last calibration, even when not deployed.
- Visible damage to the cell such as cracked or chipped glass
- Visible damage to the electrodes or the black platinum coating on the electrodes. Damage may cause the electrode surface to appear silver instead of black. Some visible silver or grey on the edges of the electrodes is normal.
- Lower than expected conductivity or salinity values or sudden decreases in measured values. If the cell is fouled its resistance will increase. When cell resistance increases due to fouling the conductivity and salinity outputs read low.

Cleaning the CTD

Basic Cleaning

This should be performed every time the sensor is recovered from deployment. Ideally this cleaning should be performed before the sensor dries off after recovery.

1. Remove any copper mesh
2. Spray lightly with water and gently brush off any visible external fouling
3. Soak the entire instrument in a solution of 5% household bleach mixed with water (this makes approximately 0.5% sodium hypochlorite solution) for at least 15 minutes. Be sure the conductivity cell is filled with the cleaning solution and does not contain a large air bubble. The easiest way to do this is to orient the sensors vertically in a 5-gallon bucket about half-filled with cleaning solution.
4. Remove and rinse the sensor with clean fresh water, allow water to flow through the conductivity cell for at least ten seconds to remove any cleaning solution.
5. Used cleaning solution is generally considered nonhazardous and can be poured down the drain in most areas. It will decompose into saltwater over time. Do not mix the cleaning solution with any other chemicals or detergents, doing so may allow chemical reactions releasing hazardous chlorine gas.

Figure 2: Cell with newly spawned barnacles; requires cleaning

Cleaning Barnacles (after basic cleaning)

1. Thoroughly rinse the sensor to remove any bleach solution.
2. Soak the sensor in a solution of 10% vinegar mixed with water (this makes a solution of 0.5 to 0.8% acetic acid) for 1-4 hours. Make sure the conductivity cell is filled with the cleaning solution.
3. Remove and rinse the sensor with clean fresh water, allow water to flow through the conductivity cell for at least ten seconds to remove any cleaning solution.
4. It is possible to run a small pipe cleaner through the center of the cell to help remove barnacles, but never touch or attempt to mechanically clean the black electrodes – doing so will reduce the accuracy of the cell.

Appendix M: SeaBird Dissolved Oxygen Specification Sheet

SBE

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APPLICATION NOTE NO. 64 **Revised June 2013**

SBE 43 Dissolved Oxygen Sensor – Background Information, Deployment Recommendations, and Cleaning and Storage

General Description

The SBE 43 is a polarographic membrane oxygen sensor having a single output signal of 0 to +5 volts, which is proportional to the temperature-compensated current flow occurring when oxygen is reacted inside the membrane. A Sea-Bird CTD that is equipped with an SBE 43 oxygen sensor records this voltage for later conversion to oxygen concentration using a modified version of the algorithm by Owens and Millard (1985).

The SBE 43 determines dissolved oxygen concentration by *counting* the number of oxygen molecules per second (flux) that diffuse through the membrane from the ocean environment to the working electrode. At the working electrode (cathode), oxygen gas molecules are converted to hydroxyl ions (OH-) in a series of reaction steps where the electrode supplies four electrons per molecule to complete the reaction. The sensor counts oxygen molecules by measuring the electrons per second (amperes) delivered to the reaction. At the other electrode (anode), silver chloride is formed and silver ions (Ag+) are dissolved into solution. Consequently, the chemistry of the sensor electrolyte changes continuously as oxygen is measured, resulting in a slow but continuous loss of sensitivity that produces a continual, predictable drift in the sensor calibration with time. This *electro-chemical* drift is accelerated at high oxygen concentrations and falls to zero when no oxygen is being consumed. Accordingly, sensor storage and deployment strategies that produce zero- or near zero-oxygen environments when the sensor is not being sampled can be used to substantially reduce electro-chemical drift, improving long-term data quality.

Membrane fouling also contributes to drift by altering the oxygen diffusion rate through the membrane, thus reducing sensitivity. Non-biological fouling, occurring for example if the SBE 43 was profiled through an oil slick, typically produces an immediate jump toward low oxygen. Biological fouling, particularly on moorings, can be troublesome, because the living organisms either consume or create oxygen. Without protection and/or routine cleaning, a micro-environment around the sensor can produce oxygen levels that are different from the true ambient conditions. By recognizing fouling, both episodic and gradual in nature, and promptly cleaning the sensor using the procedures in this application note, accuracy can be restored.

SBE 43s intended for **mooring applications** are plumbed with black Tygon tubing (SBE 43s intended for profiling applications are plumbed with clear tubing). The black tubing minimizes light entering the system, and reduces biological fouling.

The concentration of oxygen in the environment can be computed given the flux of oxygen and the geometry of the diffusion path. The permeability of the membrane to oxygen is a function of temperature and ambient pressure and is taken into account in the calibration equation. The algorithm to compute oxygen concentration requires measurements of **water temperature, salinity, pressure, and oxygen sensor output voltage**. When the oxygen sensor is interfaced with a Sea-Bird CTD, all of these parameters are measured by the CTD system.

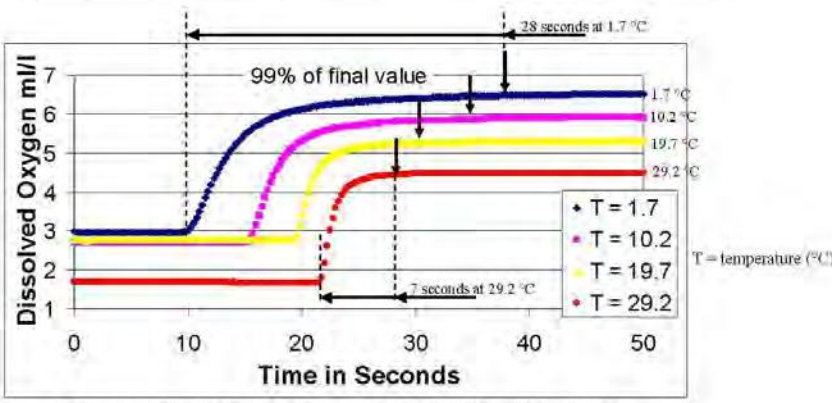
The oxygen sensor consumes the oxygen in the water very near the surface of the sensor membrane. If there is not an adequate flow of new water past the membrane, the sensor will give a reading that is lower than the true oxygen concentration. Additionally, if the flow *rate* is not *constant*, the sensor response time will vary, causing dynamic error, particularly when profiling. Maximum accuracy requires that water be pumped (across the membrane) at rates from 20 to 40 ml/second, as provided on Sea-Bird CTDs with SBE 5T or 5P pumps.

Temperature differences between the water and oxygen sensor can lead to errors in the oxygen measurement. The SBE 43 minimizes this difference by using materials that equilibrate rapidly with the environment and incorporating a thermistor placed under the membrane, at the cathode, for accurate temperature compensation. As a result, the SBE 43 is less susceptible to error when profiling through areas of high temperature gradients than previous oxygen sensors.

Use in Moored Applications

As discussed above, the oxygen sensor consumes the oxygen in the water near the sensor membrane. In moored applications, this requires that water be pumped past the oxygen sensor. When used with a SeaCAT (SBE 16, 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, or 19*plus* or 19*plus* V2 in moored mode), the SBE 43 flow chamber (plenum) is connected in-line between the pump and conductivity sensor. The pump does not run between samples, trapping water in the plenum. Because the sensor is continuously polarized by an internal battery, oxygen continues to be consumed between samples. The sensor depletes oxygen in the water close to the membrane. If you were to observe the sensor output after the pump stopped, the oxygen concentration inside the plenum would approach a steady state well below ambient oxygen levels. When the pump switches on at the beginning of the next sampling interval, you would observe a curve similar to those shown below for a 0.5-mil membrane. The water flow establishes a normal boundary layer at the membrane, and the sensor equilibrates to the ambient oxygen level. The time required to reach 99% of the final equilibrium value depends on temperature (faster equilibration in warmer water) and on the sensor membrane thickness (faster equilibration with a thinner membrane).

Vertical arrows on the plot show the point at which the sensor has achieved 99% of the final value at each temperature.

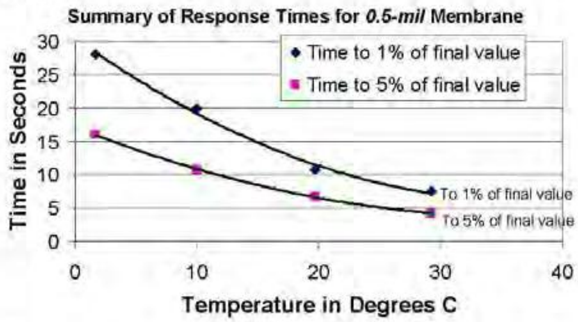


Response Time at Several Temperatures for *0.5-mil* Membrane

Prior to 2007, all SBE 43s were sold with a 0.5-mil thick membrane. Sea-Bird now offers two membrane thicknesses – 0.5 mil (faster response, typically for profiling applications) and 1.0 mil (slower response but more durable, typically for moored applications).

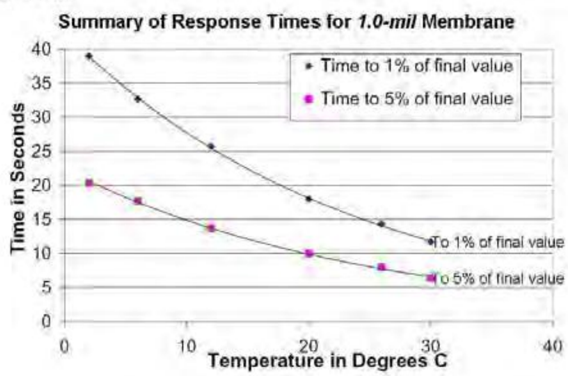
Summary of Response Times for Moored Applications

The first plot below is derived from the preceding plot and may be used to determine the time required from power-up and pump turn-on to the availability of an acceptable dissolved oxygen sample with a **0.5-mil** membrane. For simplicity, we generally recommend a minimum pump time of 15 seconds for 15 °C and warmer water, and reference the 1% curve below for colder water.



- *Example – SBE 16plus with SBE 43 with 0.5-mil membrane:*
  If working in 20 °C water and wanting oxygen data to within 1% of actual oxygen concentrations, pump time of at least 11 seconds is required. Set the SBE 16*plus* to pump during the entire sample (**PumpMode=2**) *, and set the delay before sampling to 15 seconds (**DelayBeforeSampling=15**) *. We have allowed an extra 4 seconds of pump time; this ensures that the sample will still be good if the SBE 16*plus* is in colder than expected water. Note that longer pump times reduce battery endurance.
  ** See the appropriate CTD manual for the exact format of these commands; they vary, depending on the product and the telemetry interface.*

The next plot was derived in a similar fashion, and may be used to determine the time required from power-up and pump turn-on to the availability of an acceptable dissolved oxygen sample with a **1.0-mil** membrane. For simplicity, we generally recommend a minimum pump time of 25 seconds for 15 °C and warmer water, and reference the 1% curve below for colder water.



Use in Hydrogen Sulfide (H_2S) Environments

SBE 43 oxygen sensors can be used for hours in hydrogen sulfide rich environments with no ill effects to sensor elements or signal calibration.

Poisoning of oxygen sensors in hydrogen sulfide environments was a phenomenon common to early sensor designs that used silver as the cathode element. The SBE 43 uses a noble metal (gold) as the cathode and silver as the anode, and shows no degradation of signal or calibration when used for profiling in hydrogen sulfide environments. In particular, a month of intensive hydrographic profiles in the Black Sea using Sea-Bird oxygen sensors has demonstrated that these sensors can operate repeatedly in the H_2S rich depths for durations of hours without any degradation of signal or calibration over that experienced in equivalent profiling work in the open, oxygenated ocean.

We have no laboratory or field evidence of the effect of mooring Sea-Bird oxygen sensors in H_2S rich environments for periods of days to months.

Oxygen Algorithm

Sea-Bird uses an algorithm based on that of Owens and Millard (1985) to convert SBE 43 oxygen sensor data to oxygen concentration. The *Sea-Bird* algorithm incorporates a term related to the offset voltage produced for zero oxygen signal. In addition, there is a third-order polynomial that compensates for changes in sensitivity with temperature and an exponential term that compensates for changes in sensitivity with pressure.

Sea-Bird's algorithm has the following form:

$$Oxygen\ (ml/l) = \left\{ Soc * \left(V + Voffset\ + tau(T,P) * \frac{\partial V}{\partial t} \right) \right\} * Oxsol(T,S)$$

$$* \left(1.0 + A*T + B*T^2 + C*T^3\right) * e^{\left(\frac{E*P}{K}\right)}$$

where.....

Description	Symbol	Definition
Computed	Oxygen	Dissolved oxygen concentration (ml/l)
Measured Parameters	T	CTD Temperature (ITS-90, °C)
	P	CTD Pressure (decibars)
	S	CTD Salinity (psu)
	V	SBE 43 temperature-compensated output oxygen signal (volts)
Calibration Coefficients	Soc	Oxygen signal slope
	Voffset	Voltage at zero oxygen signal
	A, B, C	Residual temperature correction factors
	E	Pressure correction factor
	tau20	Sensor time constant tau (T,P) at 20 °C, 1 atmosphere, 0 PSU; slope term in calculation of tau(T,P)
	D1, D2	Temperature and pressure correction factors in calculation of tau(T,P)
	H1, H2, H3	Hysteresis correction factors
Calculated Value	Oxsol(T,S)	Oxygen saturation value after Garcia and Gordon (1992); see *Appendix A*
	δV/δt	Time derivative of SBE 43 output oxygen signal (volts/second)
	tau(T,P)	Sensor time constant at temperature and pressure = tau20 * exp (D1 * P + D2 * [T – 20])
	K	Absolute temperature

Our software requires you to enter Soc, Voffset, A, B, C, E, tau20, D1, D2, H1, H2, and H3 in the configuration (.con or .xmlcon) file; values are taken from the Calibration Sheet provided with the sensor.

Note: H1, H2, and H3 values are available on calibration sheets for SBE 43s calibrated after October 2008. See *Application Note 64-3: SBE 43 Dissolved Oxygen Sensor Hysteresis Corrections* for the appropriate values to use if your calibration sheet does not show these coefficients.

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Tau Correction

The derivative term [tau(T,P) * δV/δt] function is to improve the response of the measured signal in regions of large oxygen gradients. However, this term also amplifies residual noise in the signal (especially in deep water), and in some situations this negative consequence overshadows the gains in signal responsiveness. In Seasave V7 and SBE Data Processing, this *Tau correction* can be disabled if desired, deleting the entire derivative term from the equation for **calculated oxygen**.

Hysteresis Correction

Under extreme pressure, changes can occur in gas permeable Teflon membranes that affect their permeability characteristics. Some of these changes (plasticization and amorphous/crystalinity ratios) have long time constants and depend on the sensor's time-pressure history. These slow processes result in *hysteresis* in long, deep casts. The hysteresis correction algorithm (using H1, H2, and H3 values entered for the SBE 43 in the configuration [.con or .xmlcon] file) operates through the entire data profile and corrects the **oxygen voltage values** for changes in membrane permeability as pressure varies. At each measurement, the correction to the membrane permeability is calculated based on the current pressure and how long the sensor was at previous pressures.
Hysteresis responses of membranes on individual SBE 43 sensors are very similar, and in most cases the default hysteresis parameters provide the accuracy specification of within 2% of true value. For users requiring higher accuracy (±1 μmol/kg), the parameters can be fine-tuned, if a complete profile (descent and ascent, preferably to greater than 3000 meters) is available. H1, the effect's amplitude, has a default of -0.033, but can range from -0.02 to -0.05. H2, the effect's non-linear component, has a default of 5000, and is a second-order parameter that does not require tuning between sensors. H3, the effect's time constant, has a default of 1450 seconds, but can range from 1200 to 2000. Hysteresis can be eliminated by alternately adjusting H1 and H3 in the configuration file during analysis of the complete profile. Once established, these parameters should be stable, and can be used without adjustment on other casts with the same SBE 43.

Software

Sea-Bird software allows you to select the SBE 43 oxygen sensor (labeled *Oxygen, SBE*) and use the *Sea-Bird* equation documented in this application note when setting up the configuration (.con or .xmlcon) file for the CTD:

- **SBE Data Processing**
  Enable / disable the Tau correction on the Miscellaneous tab in Data Conversion, if you are outputting calculated oxygen at this step. Enable / disable the hysteresis correction on the Miscellaneous tab in Data Conversion, if you are outputting oxygen voltage and/or calculated oxygen at this step.
  You can also enable / disable the Tau correction on the Miscellaneous tab in Derive.
- **Seasave V7**
  Enable / disable the Tau correction and/or the hysteresis correction on the Miscellaneous tab in Configure Inputs. Note that these corrections are applied to data displayed in the software and to **calculated** values output by the software; however, *raw* oxygen voltage output by Seasave V7 to the CTD data file is not corrected.
- **Seasave-Win32**
  The *Sea-Bird* equation is called the *Murphy-Larson* equation in this software, but performs the same *basic* calculation as in Seasave V7 and SBE Data Processing. However, the hysteresis correction is not available. Additionally, to disable the Tau correction, the user must set tau20=0 in the configuration (.con) file; this deletes the term [tau(T,P) * δV/δt] from the calibration equation.

The latest version of the software is available for download from our website (www.seabird.com).

Notes:

1. There are several types of oxygen data that can be calculated, as desired, in all of these software versions:
   - **Oxygen, SBE** (units of ml/l, mg/l, or micromoles/kg, as selected) – measured SBE 43 oxygen, based on the equation shown above in *Oxygen Algorithm*.
   - **Oxygen saturation** (units of ml/l or mg/l, as selected) – theoretical saturation limit of the water at the local temperature and salinity value, but with local pressure reset to zero (1 atmosphere). This calculation represents what the local parcel of water could have absorbed from the atmosphere when it was last at the surface (p=0) but at the same (T,S) value. See *Appendix A* for computation of oxygen saturation.
   - **Oxygen, SBE, percent saturation** – ratio of measured SBE 43 oxygen to oxygen saturation, in percent.
2. When entering calibration coefficients for the SBE 43 in the configuration file for the CTD, you can select the older *Owens-Millard* equation or the recommended *Sea-Bird* equation (documented in this application note).

Data Conversions

Sea-Bird uses the following equations to convert oxygen to various engineering units:

[mg/L] = [ml/L] * 1.42903

[µmole/Kg] = [ml/L] * 44660 / (sigma_theta(P=0,Theta,S) + 1000)

where

Sigma_theta (potential density) is the density a parcel of water would have if it were raised adiabatically to the surface without change in salinity. Sigma_theta is calculated with:

- pressure = 0;
- Theta (potential temperature; temperature a parcel of water would have if it were raised adiabatically to the surface); and
- S (salinity)

(Sigma_theta Discussion: As a water parcel moves within the ocean below the mixed layer, its salt and heat content can change only by mixing with other water. Measurements of temperature and salinity are used to trace the path of the water. The most effective method for doing this is to remove the effect of compressibility. Potential temperature Theta is defined as the temperature a parcel of water would be at the sea surface after it has been raised adiabatically from some depth in the ocean (i.e., without exchanging heat with its surroundings as it is raised).

Because changes in pressure primarily influence the temperature of the water, the influence of pressure on density can be removed, to a first approximation, by using the potential density.

Potential density Sigma_theta is the density a parcel of water would have if it were raised adiabatically to the surface without change in salinity, e.g., calculated using potential temperature.)

For the µmole/Kg conversion, there is disagreement in the scientific community about the 44660 conversion constant:

- The value 44660 is exact for oxygen gas.
- The value 44615 is the average value for atmospheric gas (N2,O2,Ar,H2O,CO2,...). It is not exact for any individual gas, but has been used historically by oceanographers.

The argument distills to exact versus historic, with oceanographers split; Sea-Bird uses 44660 in all calculations.

Oxygen Sensor Cleaning and Storage

Prolonged exposure of the sensor membrane to Triton X-100 is harmful and causes the sensor's calibration to drift. Our recommendation, detailed below, is to use Triton X-100 for degreasing (with a short wash), then use a short wash with a dilute bleach solution to reduce biological growth, and store the sensor in an anoxic (or near zero oxygen) condition. See *Materials* below for a discussion of Triton X-100 detergent, bleach, and water.

Avoid fouling the oxygen membrane with oil or grease, as this causes a calibration shift toward erroneously low readings. An oil-fouled membrane can be cleaned using the following procedures.

CAUTION: During service and storage, maintain temperature at or below 30 °C (86 °F). If temperatures are raised above 40 °C (104 °F), sensors exhibit a temporary increase in sensitivity of a few percent. This relaxes back to historical sensitivity after a few days when temperatures return below 30 °C (86 °F).

- **Preventive Field Maintenance Between Profiles**: After each cast, flush with a **0.1%** solution of **Triton X-100**, using a 60 cc syringe (see *Application Note 34*). Then rinse thoroughly with fresh water. Between casts, ensure that the sensor remains shaded from direct sunlight and stays cool and humidified. Plugging the inlet and exhaust of the plumbing after rinsing will trap sufficient humidity.
- **Routine (post-cruise) Cleaning (no visible deposits or marine growths on sensor)** - Follow this two-step procedure:
  A. **Flush** the sensor for **1 minute** with a **1%** solution of **Triton X-100** warmed to 30 °C (86 °F). **Drain and flush** with warm (not hot) fresh water for **5 minutes**.
  B. **Soak** the sensor for **1 minute** in a **500 – 1000 ppm** solution of **Bleach**. After the soak, **drain and flush** with lukewarm (not hot) fresh water for **5 minutes**.
- **Cleaning Severely Fouled Sensors (visible deposits or marine growths on sensor)**: Soak the sensor in de-ionized water overnight to loosen deposits. Repeat the *Routine Cleaning* procedure up to 5 times. Do **not** attempt to clean the membrane with high pressure flow or by wiping or touching the membrane.
- **Long-Term Storage (after field use)**: **Do not fill the tubing with water, Triton solution, or Bleach solution.**
  - If there is no danger of freezing, loop tubing from inlet to outlet. Place a small piece of clean sponge, *slightly dampened* with fresh, clean water, in the center of the tubing (not near the membrane).
  - **If there is danger of freezing,** shake all excess water out of the plenum and loop tubing from inlet to outlet, leaving the sensor membrane dry.
  - Because the sensor is continuously polarized by an internal battery, oxygen in the plenum and tubing will continue to be consumed, depleting the electrolyte and causing drift. Storing the sensor in a zero-oxygen environment will stop calibration drift between uses. To minimize drift during storage, if possible, connect one end of the tubing loop to the plenum, displace the air in the plenum and tubing with Nitrogen gas, and connect the other end of the tubing to the plenum. If tubing is not available, displace the air in the plenum with Nitrogen gas and close off the plenum with a cap on each end (tape can be used if nothing else is available); do not insert a cap or plug inside the plenum.

Materials

- **Triton X-100: 100%** Triton X-100 is included with every CTD shipment and can be ordered from Sea-Bird; dilute as directed above. Triton X-100 is Octyl Phenol Ethoxylate, a mild, non-ionic surfactant (detergent) manufactured by Avantor Performance Materials (www.avantormaterials.com/commerce/product.aspx?id=2147509608). Other liquid detergents can probably be used, but scientific grades are required (no colors, perfumes, glycerins, lotions, etc.).
- **Bleach:** Bleach is a common household product used to whiten and disinfect laundry. Commercially available bleach is typically 4% - 7% (40,000 ppm – 70,000 ppm) **sodium hypochlorite** (Na-O-Cl) solution that includes stabilizers. Some common commercial product names are Clorox (U.S.) and eau de Javel (French). Clean the SBE 43 with a 500 – 1000 ppm solution of water and sodium hypochlorite. **Dilute** the concentrated household bleach 50 to 1 (50 parts water to 1 part bleach) to produce the proper concentration to clean the oxygen sensor.
- **Water:** We recommend de-ionized (DI) water because it is reliably pure, but commercially distilled water or fresh clean tap water is also sufficient for all uses above. ***On ships, fresh water can occasionally contain traces of oil and should not be used for rinsing, cleaning, or storing sensors, unless there is no alternative.***

Notes:

- Do not use stronger solutions or longer wash times than recommended above.
- Do not place concentrated Triton or bleach **directly** on the sensor membrane. A strong Triton solution can leave a film on the membrane, adversely affecting results.

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Appendix A - Computation of Oxygen Solubility (Oxsol; Garcia & Gordon)

$$\mathbf{Oxsol(T,S)} = \exp\{A0 + A1(Ts) + A2(Ts)^2 + A3(Ts)^3 + A4(Ts)^4 + A5(Ts)^5 + S * [B0 + B1(Ts) + B2(Ts)^2 + B3(Ts)^3] + C0(S)^2\}$$

Where

- Oxsol(T,S) = oxygen saturation value = volume of oxygen gas at standard temperature and pressure conditions (STP) absorbed from humidity-saturated air at a total pressure of one atmosphere, per unit volume of the liquid at the temperature of measurement (ml/l)
- S = salinity (psu)
- T = water temperature (ITS-90, °C)
- $Ts = \ln[(298.15 - T) / (273.15 + T)]$
- A0 = 2.00907 A1 = 3.22014 A2 = 4.0501 A3 = 4.94457 A4 = -0.256847 A5 = 3.88767
- B0 = -0.00624523 B1 = -0.00737614 B2 = -0.010341 B3 = -0.00817083
- C0 = -0.000000488682

The table below contains oxygen saturation values at atmospheric pressure calculated using the Oxsol equation. Units are ml/l. To compute mg/l, multiply the values in the table by 1.42903.

Oxsol: Oxygen Saturation Concentrations in Fresh and Ocean Water (ml/l)									
Temperature (°C)	**Salinity (PSU)**								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**32**	**35**
-2	10.84	10.46	10.10	9.74	9.40	9.07	8.75	8.63	8.45
0	10.23	9.88	9.54	9.21	8.90	8.59	8.30	8.18	8.01
2	9.68	9.35	9.04	8.73	8.44	8.15	7.88	7.77	7.61
4	9.17	8.87	8.58	8.29	8.02	7.75	7.49	7.39	7.24
6	8.71	8.43	8.15	7.89	7.63	7.38	7.14	7.05	6.91
8	8.29	8.02	7.77	7.52	7.28	7.04	6.82	6.73	6.60
10	7.90	7.65	7.41	7.18	6.95	6.73	6.52	6.44	6.31
12	7.54	7.31	7.08	6.86	6.65	6.45	6.25	6.17	6.05
14	7.21	6.99	6.78	6.57	6.37	6.18	5.99	5.92	5.81
16	6.91	6.70	6.50	6.31	6.12	5.93	5.75	5.68	5.58
18	6.62	6.43	6.24	6.06	5.88	5.70	5.53	5.47	5.37
20	6.36	6.18	6.00	5.82	5.65	5.49	5.33	5.27	5.17
22	6.12	5.94	5.77	5.61	5.45	5.29	5.14	5.08	4.99
24	5.89	5.72	5.56	5.41	5.25	5.10	4.96	4.90	4.82
26	5.68	5.52	5.37	5.22	5.07	4.93	4.79	4.74	4.66
28	5.48	5.33	5.18	5.04	4.90	4.77	4.63	4.58	4.51
30	5.29	5.15	5.01	4.87	4.74	4.61	4.49	4.44	4.36
32	5.11	4.98	4.84	4.71	4.59	4.46	4.34	4.30	4.23

Note: As implemented in Sea-Bird software, the Oxsol equation is valid for $-5 < T < 50$ and $0 < S < 60$. Outside of those ranges, the software returns a value of -99 for Oxsol.

References

Carritt, D.E. and J.H. Carpenter. 1966: Comparison and evaluation of currently employed modifications of the Winkler method for determining dissolved oxygen in seawater. J. Mar. Res. 24(3), 286-318.

Clesceri, L.S. A.E. Greenberg, and R.R. Trussell ed. 1989, Standard methods for the examination of water and wastewater, 17th edition, American Public Health Assoc. Washington D.C. ISBN 0-87553-161-X.

Gnaigner, E., and H. Forstner, Ed., 1983: Polarographic Oxygen Sensors: Aquatic and Physiological Applications, Springer-Verlag, 370 pp.

Millard, R, C., Jr., 1982: CTD calibration and data processing techniques at WHOI using the 1978 practical salinity scale. Proc. Int. STD Conference and Workshop, La Jolla, Mar. Tech. Soc., 19 pp.

Owens, W.B., and R.C. Millard Jr., 1985: A new algorithm for CTD oxygen calibration. J. Physical Oceanography, 15, 621-631.

Garcia and Gordon (1992) "Oxygen solubility in seawater: Better fitting equations", Limnology & Oceanography, vol 37(6), p1307-1312.

Application Note Revision History

Date	Description
-	Initial release.
September 2002	• Modify language and equation consistent with Application Note 64-2. • Modify cleaning recommendations (caution about not putting triton directly on membrane).
January 2004	Correct equation at beginning of Appendix A, which was missing a bracket.
December 2004	Change cleaning recommendations: short (1 minute) soak in dilute bleach solution and short (1 minute) soak in dilute Triton solution.
May 2005	Add information on use in hydrogen sulfide rich environments.
August 2005	Add information on "oxygen, SBE" vs. "oxygen saturation" vs "percent saturation" in software.
November 2005	Add information on use in moored mode – discuss equilibration time vs temperature, and pump time.
December 2005	Add information on Nitrogen gas in Tygon tubing for storage.
October 2006	Update name of manufacturer and web link for Triton.
February 2007	• Update temperature for Triton solution cleaning to 30 °C (was 40 °C). • Add caution about storing at temperatures above 30 °C.
July 2007	• Add response time curve for new 1 mil membrane, provide **DelayBeforeSampling=** recommendation of 25 seconds. • Change title of application note to reflect what is covered. • Discuss black plenum and black tubing. • Add information about SBE 5P pump. • Update for Seasave V7. • Software (Seasave V7, Seasave Win32, and SBE Data Processing) was updated to accommodate new DO equation, mention new equation to be released in Fall 2007.
April 2008	• Introduce Sea-Bird equation, update equations, etc. • Update Appendix A (provide Oxsol values instead of Oxsat values).
November 2008	Update to correspond to software changes in SBE Data Processing and Seasave V7 versions 7.18b, providing information on tau and hysteresis corrections.
February 2010	• SBE Data Processing and Seasave V7 version 7.20b: modification to Oxsol equation (Garcia & Gordon only) to extend ranges to ($-5 < t < 50$, $0 < s < 60$) instead of ($-2 < t < 40$, $0 < s < 42$). Outside those ranges, it returns a value of -99.0. • Correct documentation of A4 in Garcia & Gordon Oxsol, should be negative (was listed as positive). • Add information on .xmlcon configuration file. • Update address.
February 2011	Add reference to Application Note 64-3 for information on hysteresis coefficients H1, H2, and H3.
July 2012	• Clarify Temperature used in Oxygen calculation – ITS-90. • Clarify Temperature used in Garcia and Gordon Oxsol calculation – ITS-90. • Triton – update link (now part of Avantor). • Update wording related to changes made years ago: use of black tubing for moorings, cleaning recommendations, version of software to use for tau correction enable/disable and for hysteresis correction. • Correct typos.
June 2013	• Clarify definition of sigma_theta in converting oxygen to various engineering units.