ACT VS04-01
December 1, 2004

PERFORMANCE VERIFICATION STATEMENT

for the Aanderaa Instruments Inc. Dissolved Oxygen Optode 3830/3930/3835

TECHNOLOGY TYPE:	Optical sensors
APPLICATION:	In situ measurements of dissolved oxygen
PARAMETERS EVALUATED:	Accuracy, precision, instrument drift, and reliability
TYPE OF EVALUATIONS:	Laboratory and Field Performance Verification at seven ACT Partner sites
DATE OF EVALUATION:	Testing conducted from May through September 2004

NOTICE:

ACT verifications are based on an evaluation of technology performance under specific, agreed-upon protocols, criteria, and quality assurance procedures. ACT and its Partner Institutions do not certify that a technology will always operate as verified and make no expressed or implied guarantee as to the performance of the technology or that a technology will always, or under circumstances other than those used in testing, operate at the levels verified. ACT does not seek to determine regulatory compliance; does not rank technologies nor compare their performance; does not label or list technologies as acceptable or unacceptable; and does not seek to determine "best available technology" in any form. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements.

This document has been peer reviewed by ACT Partner Institutions and a technology-specific advisory committee and was recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by ACT for use.

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UMCES Technical Report Series: TS-454-04-CBL / Ref. No. [UMCES]CBL 04-116

BACKGROUND:

Instrument performance verification is necessary so that effective existing technologies can be recognized and so that promising new technologies can become available to support coastal science, resource management, and ocean observing systems. To this end, the NOAA-funded Alliance for Coastal Technologies (ACT) serves as an unbiased, third party testbed for evaluating coastal sensors and sensor platforms for use in coastal environments. ACT also serves as a comprehensive data and information clearinghouse on coastal technologies and a forum for capacity building through workshops on specific technology topics (for more information visit www.act-us.info).

This document summarizes the procedures used and results of an ACT Evaluation to verify manufacturer claims regarding the performance of the Aanderaa Dissolved Oxygen (DO) Optode 3830/3930/3835. Detailed protocols, including QA/QC methods, are described in the *Protocols for the ACT Verification of In Situ Dissolved Oxygen Sensors* (ACT TV04-01), which can be downloaded from the ACT website (www.act-us.info/tech_evalvations.php). Appendix 1. is an interpretation of the Performance Verification results from the manufacturer's point of view.

TECHNOLOGY TYPE:

Optical sensors are based on dynamic fluorescence quenching. When a specially-designed chemical complex is illuminated with a blue LED, it will be excited and emit back a red luminescent light with a lifetime that directly depends on the ambient oxygen concentration. Output of the probes is calibrated in the factory for temperature and proportionality with oxygen concentration.

The following is a description of the Aanderaa Optode based on information provided by the vendor and was not verified in this test. The Aanderaa DO Optode 3830/3930/3835 is a life-time based sensor. The DO measurements are based on the ability of selected substances to act as dynamic fluorescence quenchers. For example, for oxygen, if a specially designed metal-complex (e.g. ruthenium or platinum porphyrine) is illuminated with a blue-green light emitting diode (LED) it will become excited and emit back a red luminescent light during its return to the original state. Since energy from the excited metal complex will be transferred to surrounding oxygen molecules (quenching) the lifetime (and intensity) of the returning red light is directly dependent on the oxygen concentration. In the DO Optode the lifetime measurement is made by a phase shift detection of the returning, oxygen quenched red luminescence. The foil is excited with a blue-green light modulated at 5 kHz. The decay time is a direct function of the phase of the received red light that is used directly for oxygen detection, without calculating the decay time. Unlike electrochemical oxygen measurements, optodes do not consume or otherwise remove oxygen from the water during the measurement. As a result this method is not flow sensitive, has no performance drift from normal wear, and has no initial stabilization time. In coastal use this technique is negligibly affected by pressure variations and salinity corrections are made by using standard formulas. Finally, the oxygen response of an optode is exponential, yielding highest sensitivity at low concentrations.

The manufacturer's published performance specifications for the Aanderaa Optodes includes: Range 0 - 500µM (concentration) and 0 - 120% (air saturations), Resolution < 1µM (concentration) and 0.4% (air saturation), Accuracy < 8µM or 5 % (whichever is greater, concentration) and < 5% (air saturation), Response Time < 25 seconds. More information can be found at www.aanderaa.no.

APPLICATION - OBJECTIVES AND FOCUS OF PERFORMANCE VERIFICATION:

The basic application and parameters evaluated were determined by surveying users of in situ DO sensors. The majority of survey respondents indicated that they typically deploy instruments on remote platforms in estuarine and near shore environments, and in relatively shallow water (< 10 meters depth). Therefore, this performance verification was focused on these applications. Accuracy, precision, instrument drift/calibration life, reliability, and operating life were found to be the most important parameters guiding instrument selection decisions. Protocols were therefore developed, with the aid of manufacturers, to evaluate these specific parameters excluding operating life, which is beyond the scope of this program.

PARAMETERS EVALUATED:

Definitions below were agreed upon with the manufacturer as part of the verification protocols.

Accuracy – Accuracy is the absolute value of a mean measured value minus the mean true value. Accuracy was determined in the laboratory at fixed oxygen concentrations by the difference of the mean values from the instrument (I; n=3) from the mean of values determined by Winkler titration (W; n=3) on water samples in proximity to the sensor (accuracy = $\Sigma W/n - \Sigma I/n$). Accuracy was determined on 36 different combinations of salinity, temperature and DO.

Precision – Precision is a measure of the repeatability of a measurement Instrument precision was determined by calculating the coefficient of variation (STD/Mean x 100) of 30 replicate DO measurements at a fixed dissolved oxygen concentration in the laboratory. Thus both accuracy and precision were determined in the laboratory only.

Instrument Drift – Instrument drift is a measure of the error through a month long deployment in the laboratory or the field. The error is the difference between a single instrument measurement and a single Winkler at a single point in time (I-W) is presented as plots of DO values over time. There was one laboratory drift study and seven field studies, representing the seven partner institution sites.

Reliability – Reliability is the ability to maintain integrity of the instrument and data collections over time. Reliability was determined in the laboratory and field by comparing percent of data recovered versus percent of data expected. Comments on the physical condition of the instruments (e.g., physical damage, flooding, corrosion, battery failure, etc.) were also recorded.

TYPE OF EVALUATIONS - SUMMARY OF VERIFICATION PROTOCOLS:

In conference with the participating instrument manufacturers it was determined that the verification protocols would have the following elements A) Winklers chemical titration for dissolved oxygen would serve as the reference standard for evaluating performance characteristics, B) performance would be evaluated across a range of water types in controlled laboratory conditions, C) long term, unattended performance would be evaluated across a range of environmental conditions, and D) performance of the DO sensor in the context of the vendors data acquisition package would be evaluated for instruments with and without manufacturer-designed biofouling prevention solutions.

Winkler titration methods used were based on WOCE protocols; although DO was quantified in mg/L not mol O_2/kg. Water samples collected adjacent to the sensors were analyzed and compared to values collected and reported by test instruments. All laboratory tests were conducted at the NOAA Great Lake Environmental Research Laboratory (in conjunction with the ACT Partner, Cooperative Institute for Limnology & Ecosystems Research) in specially designed water baths that allow the control of temperature, salinity and DO level (by bubbling different oxygen and nitrogen gas mixtures). Field tests were conducted by all seven ACT Partner Institutes at a fixed depth of 1 m from secure deployment sites representing a range of environmental conditions (see Table 2), representative of the range of coastal environments in North America. Field sites included the Chesapeake Biological Laboratory (Solomons, Maryland), French Landing Dam (Belleville Lake, Michigan, CILER/University of Michigan), Darling Marine Center (Walpole, Maine, GoMOOS/University of Maine), Moss Landing Harbor (Moss Landing, California, MLML), western shore of Skidaway Island (Skidaway, Georgia, SkIO), Kaneohe Bay Barrier Reef (Kaneohe Bay, Hawaii, University of Hawaii), and Bayboro Harbor (Tampa Bay, Florida, University of South Florida).

Instruments tested, both in the laboratory and in the field, were incorporated in a stand-alone, pre-calibrated package, which included data logging and independent power provided by the manufacturer. Data was salinity corrected according to the equation provided by Aanderaa. A total of eight sensors were evaluated, four with the manufacturer's biofouling prevention system and four without. Aanderaa provided a copper plate, with a series of small holes that covered the optical window to prevent or reduce biofouling. Two individual sensors (one with a biofouling prevention and one without) were randomly selected for the initial laboratory exercise. One pair of instruments each was then sent out to four of the ACT Partner Institution test sites for four-week field deployments. All instruments were cleaned and reconditioned by the manufacturer prior to the second set of deployments at the remaining ACT Partner test sites.

Prior to deployment, instruments were programmed to record dissolved oxygen data every 5 minutes. Instruments were placed in a water bath and allowed to record three data points with three corresponding Winkler titration values as a baseline reference before placement in the field. This same baseline reference procedure was repeated immediately after the instruments were recovered following the four-week deployment.

Water samples for Winkler titrations were collected (at the same depth and as close as possible to the sensor heads) at least twice a day, Mondays through Fridays during the four-week field test at the time instruments were programmed to sample. In conjunction with each water sample collection, site-specific conditions were also noted (e.g., date, time, barometric pressure, weather conditions, natural or anthropogenic disturbances, and tidal state).

Quality Assurance/Quality Control – This performance verification was implemented according to the test/QA plans and technical documents prepared during planning of the verification test. Prescribed procedures and a sequence for the work were defined during the planning stages, and work performed followed those procedures and sequence. Technical procedures included methods to assure proper handling and care of test instruments, samples, and data. Performance evaluation, technical system, and data quality audits were performed by QA personnel independent of direct responsibility for the verification test. All implementation activities were documented and are traceable to the test/QA plan and to test personnel.

The following is a short summary of QA findings and complete reports are available upon request. The main component to the QA plan included technical systems audits (TSA), conducted by ACT Quality Assurance Specialists at four of the ACT Partner test sites selected at random (Moss Landing Harbor, MLML; Darling Marine Center, GoMOOS; Solomons MD, CBL; Bayboro Harbor, USF). These audits were designed to ensure that the verification test was performed in accordance with the test protocols and the ACT *Quality Assurance Guidelines*. (e.g., reviews of sample collection, analysis and other test procedures to those specified in the test protocols, and data acquisition and handling). During the verification tests, only two deviations from the test protocols were necessary. One involved re-securing test instruments to the field deployment frame and the second involved a set of corrupted samples due to bubbles forming on the tops of the BOD bottles during transport back to the laboratory. Appropriate corrective action was taken (including discarding compromised samples and collecting new ones) and the deviations had no impact on the results of the test.

Finally, in addition to uniform training prior to the tests and employing the identical method for sampling, Winkler titrations, data recording, etc., each site also conducted a Winkler titration precision evaluation of its particular personnel, reagents, and equipment. The precision as a percentage (expressed as coefficient of variation STD/Mean x 100) of each ACT Partner Institution for the Winkler titration analysis (using air saturated bathwater varying in salinity and temperature) is shown below in Table 1.

ACT Partner Institution	Precision
Chesapeake Biological Laboratory	0.21 %
CILER/University of Michigan	0.22 %
GoMOOS/University of Maine	0.11 %
Moss Landing Marine Laboratories	0.20 %
Skidaway Institute of Oceanography	0.40 %
University of Hawaii	0.08 %
University of South Florida	0.29 %

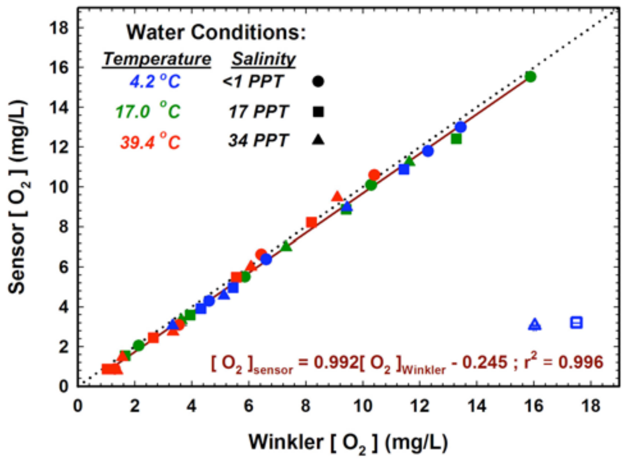
SUMMARY OF VERIFICATION RESULTS, LABORATORY TESTS:

Laboratory Accuracy – Table 2 below presents the mean, standard deviation (STD), and accuracy (Accur) of three replicate DO values in mg/L recorded by two test instruments (one with and one without a copper plate biofouling prevention system, BPS) and the corresponding mean and standard deviation of DO (mg/L) generated by Winkler titrations of three replicate water samples. Instruments were programmed to record DO values every 2 minutes and the mean and STD were calculated from three consecutive values as the reference water samples were collected. The replicate instrument readings and samples were taken under 36 distinct water conditions that varied in temperature, salinity, and DO. The greater absolute accuracy value the less accurate the measurement.

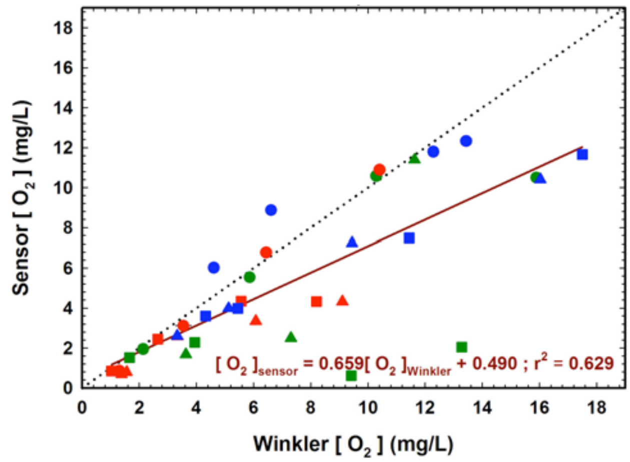
Temp (^oC)	Sal (ppt)	Winkler DO		Aanderaa DO w/out BPS			Aanderaa DO with BPS		
		Mean	STD	Mean	STD	Accur	Mean	STD	Accur
17.0	0.0	15.89	0.02	15.53	0.01	- 0.36	10.50	0.05	- 5.39
17.0	0.0	10.30	0.03	10.09	0.00	- 0.21	10.58	0.02	0.28
17.0	0.0	5.86	0.04	5.50	0.01	- 0.37	5.54	0.00	- 0.32
17.0	0.0	2.14	0.04	2.04	0.02	- 0.10	1.95	0.02	- 0.19
17.0	16.8	1.66	0.00	1.54	0.01	- 0.12	1.53	0.01	- 0.13
17.0	16.8	3.94	0.01	3.58	0.01	- 0.36	2.28	0.01	- 1.65
17.0	16.9	9.42	0.04	8.87	0.02	- 0.54	0.62	0.08	- 8.80
17.0	16.9	13.28	0.06	12.42	0.10	- 0.86	2.05	0.13	-11.23
17.0	34.0	11.62	0.06	11.24	0.03	- 0.38	11.39	0.02	- 0.23
17.0	34.0	7.30	0.02	6.98	0.01	- 0.32	2.49	0.01	- 4.81
17.0	34.0	3.63	0.03	3.32	0.01	- 0.31	1.68	0.02	- 1.96
17.0	34.0	1.56	0.01	1.46	0.01	- 0.10	0.80	0.02	- 0.76
39.4	0.3	10.41	0.05	10.58	0.01	0.18	10.88	0.01	0.48
39.4	0.3	6.44	0.04	6.61	0.00	0.17	6.77	0.01	0.33
39.4	0.3	3.55	0.28	3.07	0.01	- 0.47	3.11	0.01	- 0.43
39.4	0.3	1.31	0.01	0.86	0.01	- 0.44	0.85	0.02	- 0.45
39.4	17.0	1.38	0.04	0.78	0.01	- 0.60	0.68	0.03	- 0.70
39.4	17.0	3.34	0.04	2.75	0.00	- 0.59	2.58	0.02	- 0.76
39.4	17.0	6.08	0.05	6.01	0.00	- 0.07	3.35	0.18	- 2.73
39.4	17.0	9.10	0.04	9.46	0.01	0.36	4.33	0.08	- 4.77
39.4	33.9	8.20	0.02	8.22	0.02	0.02	4.32	0.11	- 3.88
39.4	33.9	5.56	0.09	5.49	0.01	- 0.07	4.35	0.01	- 1.21
39.4	33.8	2.65	0.10	2.45	0.01	- 0.19	2.45	0.01	- 0.19
39.4	33.9	1.03	0.03	0.86	0.01	- 0.17	0.85	0.01	- 0.17
4.2	0.3	13.44	0.09	12.99	0.02	- 0.45	12.33	0.02	- 1.11
4.2	0.3	12.29	0.05	11.79	0.00	- 0.50	11.79	0.02	- 0.50
4.2	0.3	6.62	0.04	6.38	0.01	- 0.24	8.86	0.05	2.25
4.2	0.3	4.61	0.01	4.28	0.02	- 0.32	6.01	0.05	1.40
4.2	16.9	4.32	0.01	3.91	0.00	- 0.41	3.60	0.06	- 0.72
4.2	16.9	5.45	0.04	4.96	0.00	- 0.49	3.98	0.09	- 1.47
4.2	16.9	11.44	0.06	10.88	0.00	- 0.56	7.50	0.01	- 3.94
4.2	16.9	17.50	0.17	3.19	0.01	-14.30	11.66	0.09	- 5.83
4.2	34.1	16.03	0.05	3.05	0.01	-12.98	10.41	0.03	- 5.62
4.2	34.1	9.44	0.05	8.96	0.01	- 0.48	7.23	0.09	- 2.21
4.2	34.1	5.13	0.10	4.56	0.00	- 0.57	3.99	0.06	- 1.14
4.2	34.1	3.33	0.02	3.05	0.01	- 0.28	2.60	0.04	- 0.73

Figures 1A (without Biofouling Prevention System, BPS) and 1B (with BPS) below are plots of the mean of three replicate DO values recorded by the test instrument versus the corresponding mean DO generated by Winkler titrations of three replicate water samples (complete data including standard deviations are presented above in Table 2). The dotted line represents a 1:1 relationship. The two outlying values in Figure 1A were not considered in the regression analysis.

1A



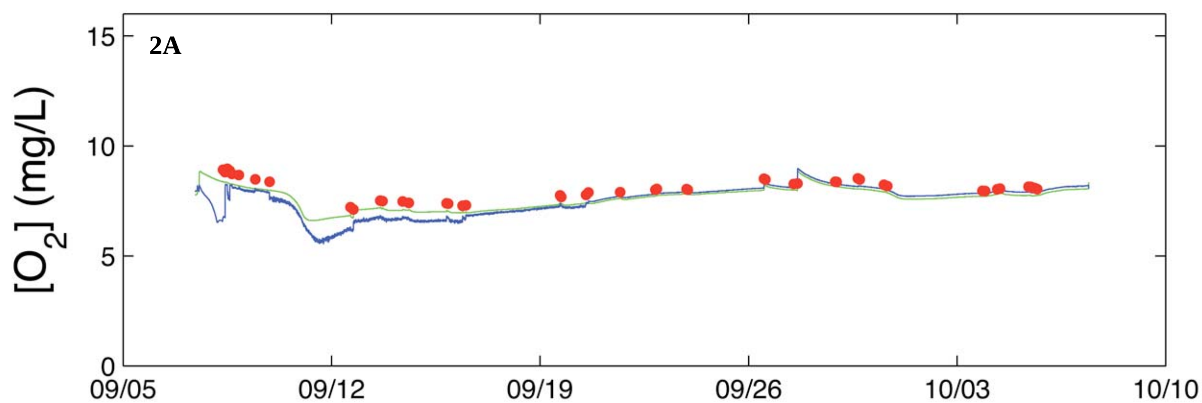
1B

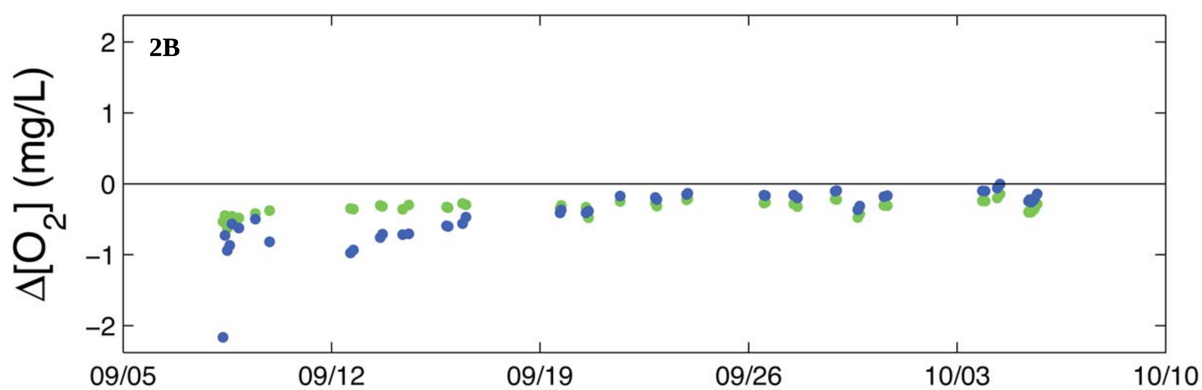


Laboratory Precision – The precision test was conducted in a well-mixed freshwater bath (0.0 ppt) held at 17.2 °C that was continuously aerated (i.e., air saturated). The mean, standard deviation (STD), and coefficient of variance (% CV = STD/Mean x 100) for DO values (mg/L) generated from 30 replicate Winkler titrations of water samples collected from the bath and 30 replicate instrument values taken simultaneously, are listed below in Table 3.

Winkler DO			Aanderaa DO - w/out BPS			Aanderaa DO - with BPS		
Mean	**STD**	**CV**	**Mean**	**STD**	**CV**	**Mean**	**STD**	**CV**
8.97	0.02	0.22 %	8.65	0.01	0.12 %	8.35	0.05	0.60 %

Laboratory Instrument Drift – Figure 2A displays the DO values (mg/L) collected by an instrument without the biofouling system (green line) and a second instrument with the biofouling prevention system (blue line) through time with the corresponding Winkler titration DO (red circles, n = 3, standard deviation are smaller than the thickness of the symbols used in graphs). Figure 2B displays the drift (Instrument value – Winkler mean) of DO (mg/L) recorded by an instrument without the biofouling prevention system (green circles) and with the biofouling prevention system (blue circles).





Optode without the biofouling prevention system after four-week laboratory deployment.

Optode with the biofouling prevention system after four-week laboratory deployment.

Laboratory Reliability – The Aanderaa Optodes were programmed to collect and record DO values every 5 minutes during the four-week laboratory freshwater bath deployment, however we only considered data collected every 15 minutes (on the quarter hour) for this evaluation. All expected data points were successfully downloaded from each test instrument and are plotted above. There were no obvious instrument malfunctions.

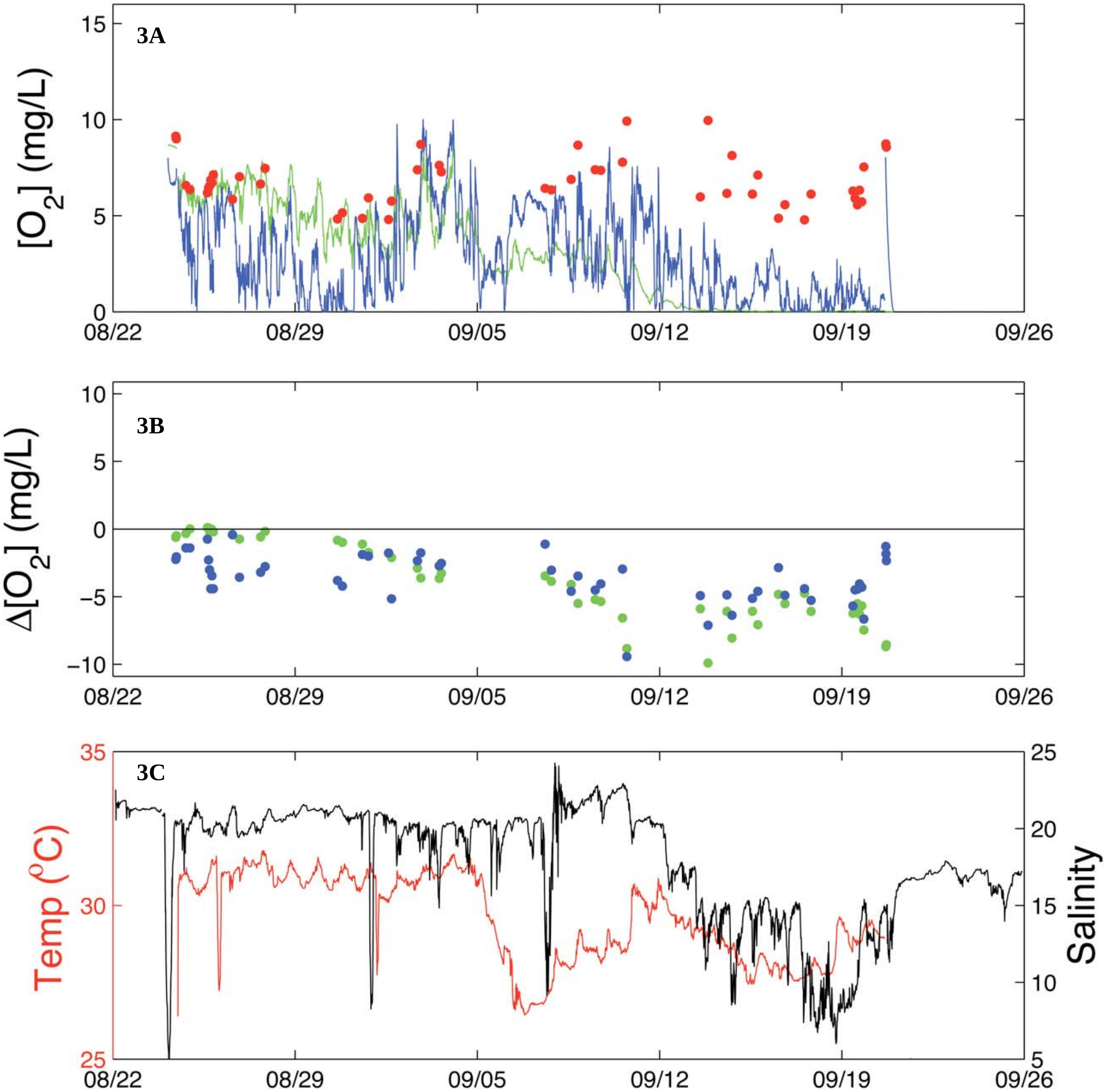
SUMMARY OF VERIFICATION RESULTS, FIELD TESTS:

Table 2. lists the basic test site descriptions and field conditions during testing.

ACT Partner Test Site	Basic Characterization	Range in Water Temperature (^oC)	Range in Salinity (ppt)
Bayboro Harbor, FL	An estuary in the southwestern region of Tampa Bay	26.4 – 31.8	4.4 – 24.2
Belleville Lake, MI	A freshwater impoundment on the Huron River	22.5 – 27.1	0.0 – 0.1
Kaneohe Bay Reef, HI	A high energy barrier coral barrier reef	25.1 – 28.7	34.4 – 34.9
Moss Landing, CA	An estuarine tributary of the Salinas River in Monterey Bay	14.0 – 17.3	30.9 – 33.5
Skidaway Island, GA	A subtropical estuary on the Skidaway River on the western shore of Skidaway Island	23.8 – 29.8	18.4 – 30.9
Solomons, MD	An estuary at the mouth of the Patuxent River in the Chesapeake Bay	24.3 – 28.1	9.8 – 12.0
Walpole, ME	A tide dominated embayment/ Damariscotta River estuary	13.1 – 18.7	29.6 – 31.2

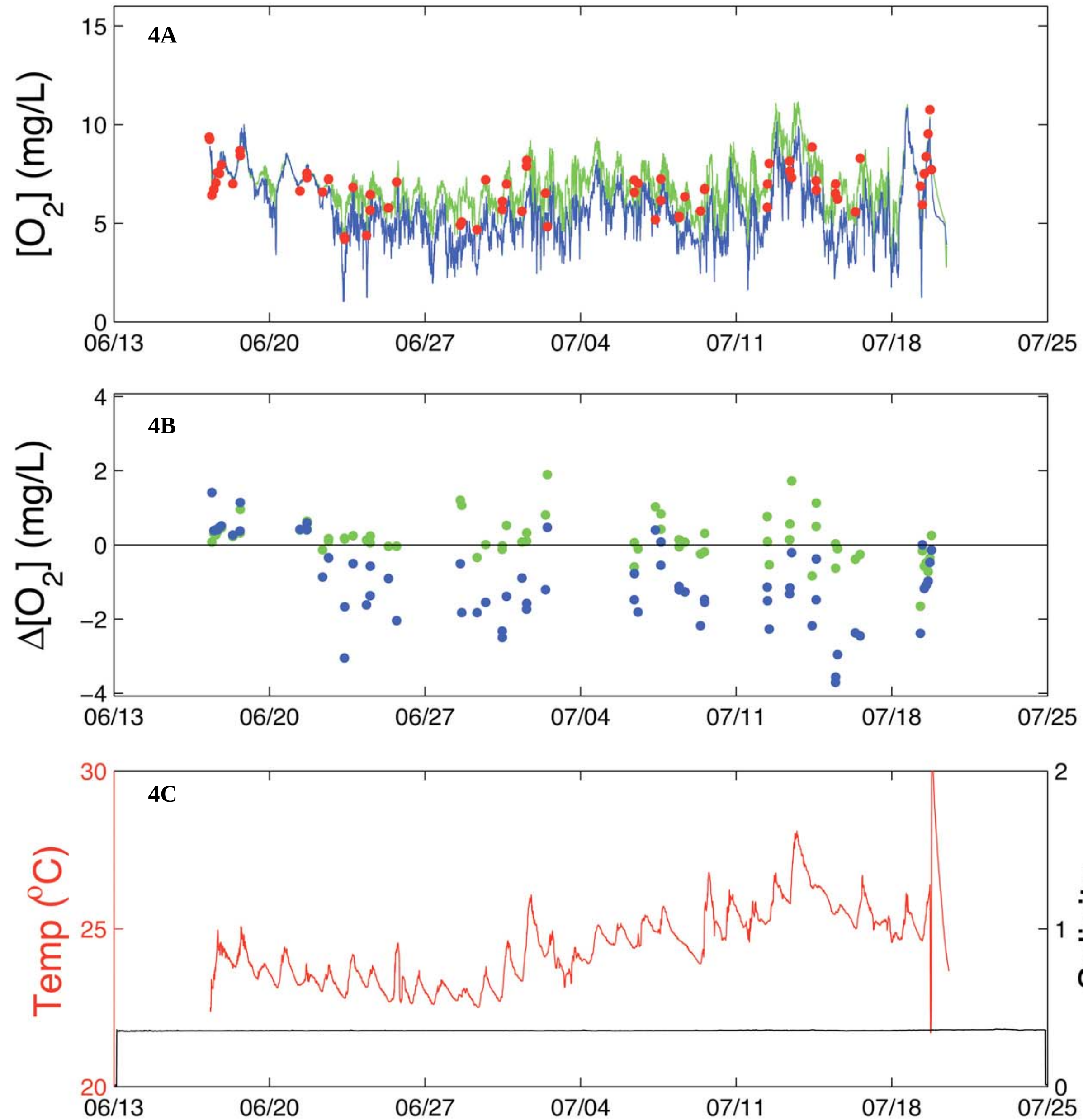
Field Instrument Drift – Figures 3A, 4A, 5A, 6A, 7A, 8A, and 9A on the following pages display the DO values (mg/L) collected by an instrument without the biofouling prevention system (green line) and a second instrument with the biofouling prevention system (blue line) through time (month/day on x axis) with the corresponding Winkler titration DO mean (red circles, n = 3, standard deviation is plotted although values are smaller than symbols used in graphs) taken periodically during the four-week field deployments. Figure 3B, 4B, 5B, 6B, 7B, 8B, and 9B display the drift (Instrument value – Winkler mean) of DO (mg/L) recorded by an instrument without (green circles) and with the biofouling prevention system (blue circles). Figure 3C, 4C, 5C, 6C, 7C, 8C, and 9C shows the corresponding temperature and salinity at field site during deployments.

Figures 3A and 3B. Instrument drift at Bayboro Harbor, FL, 3C (USF).



Sensor without the biofouling prevention system (on the right) and sensor with the biofouling prevention system (on left) after the four-week field deployment.

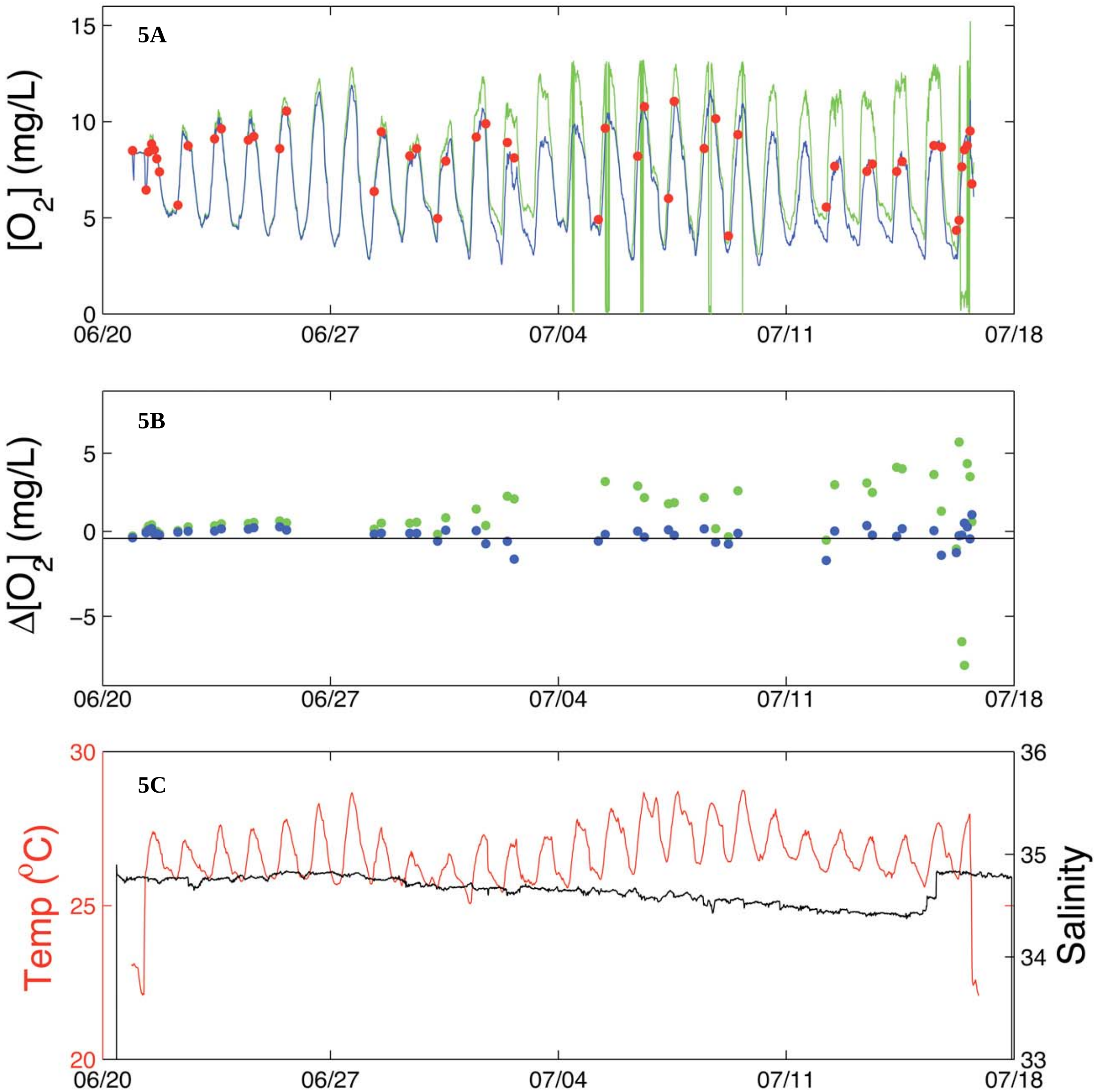
Figures 4A and 4B. Instrument drift at Belleville Lake, MI, 4C (CILER/University of Michigan).



Sensor <u>without</u> the biofouling prevention system after four-week field deployment.

Sensor <u>with</u> the biofouling prevention system after four-week field deployment.

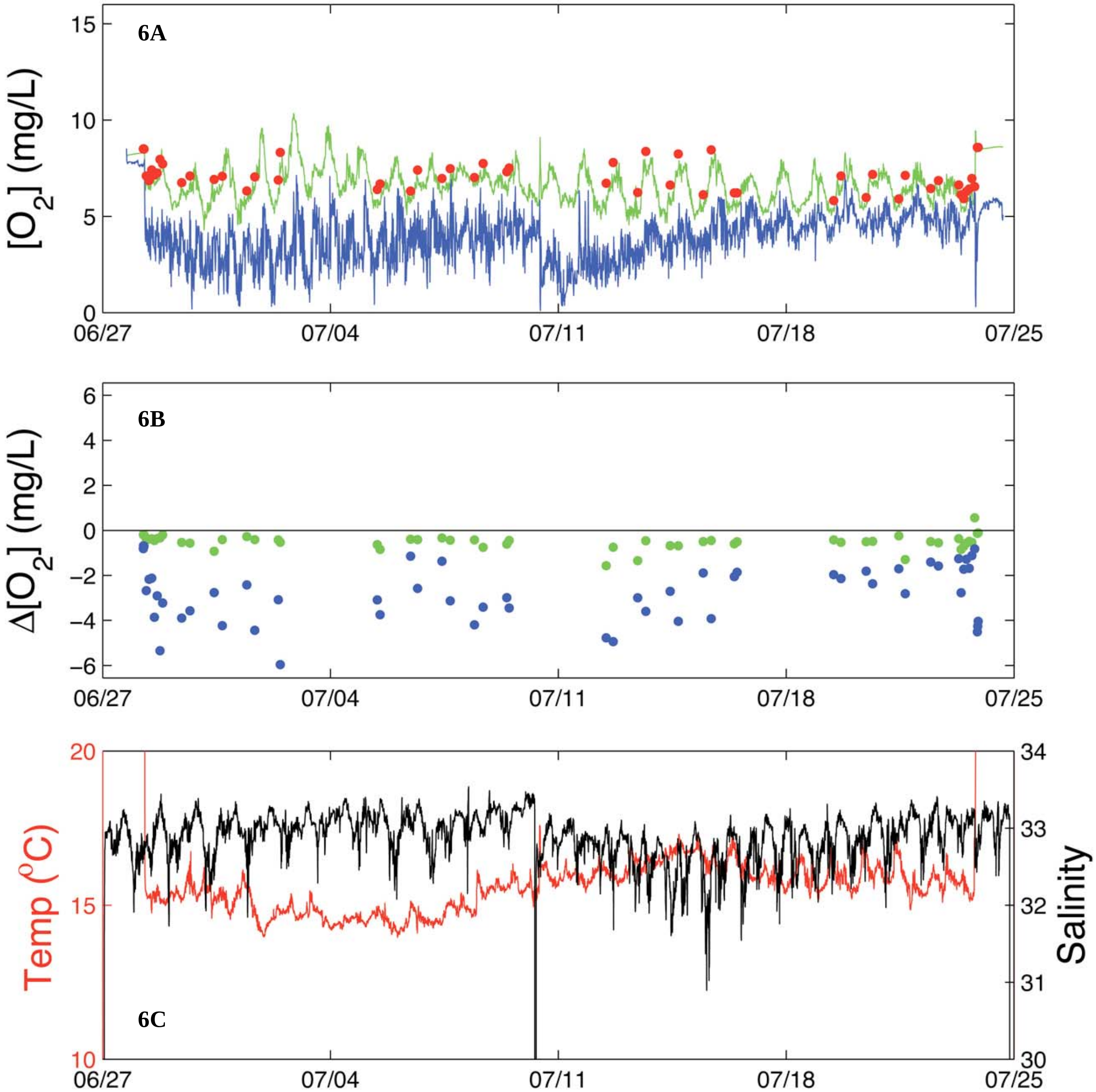
Figures 5A and 5B. Instrument drift at Kaneohe Bay Reef, HI, 5C (University of Hawaii).



Sensor without the biofouling prevention system after four-week field deployment.

Sensor with the biofouling prevention system after four-week field deployment.

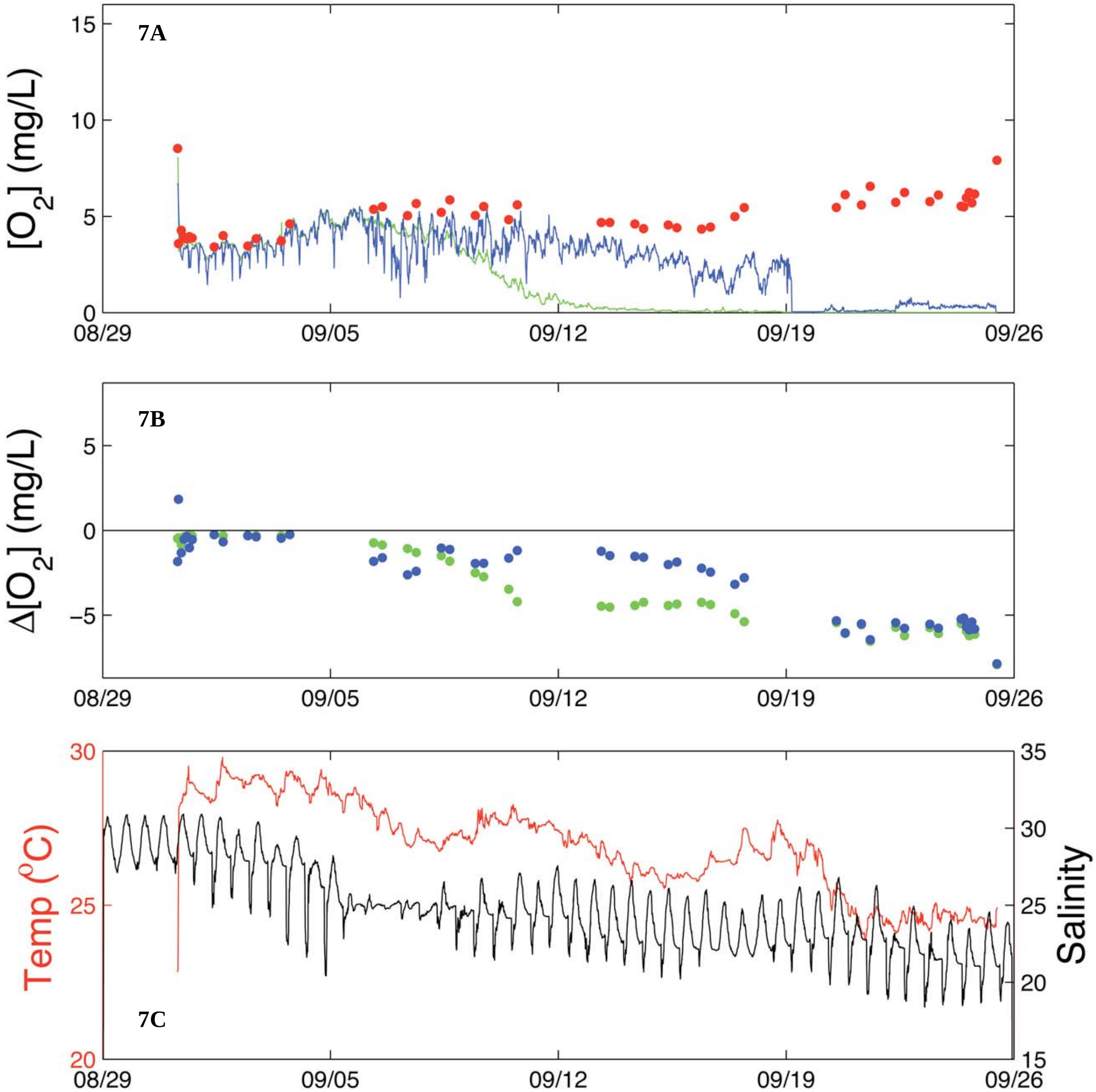
Figures 6A and 6B. Instrument drift at Moss Landing, CA, 6C (MLML).



Sensor without the biofouling prevention system after four-week field deployment.

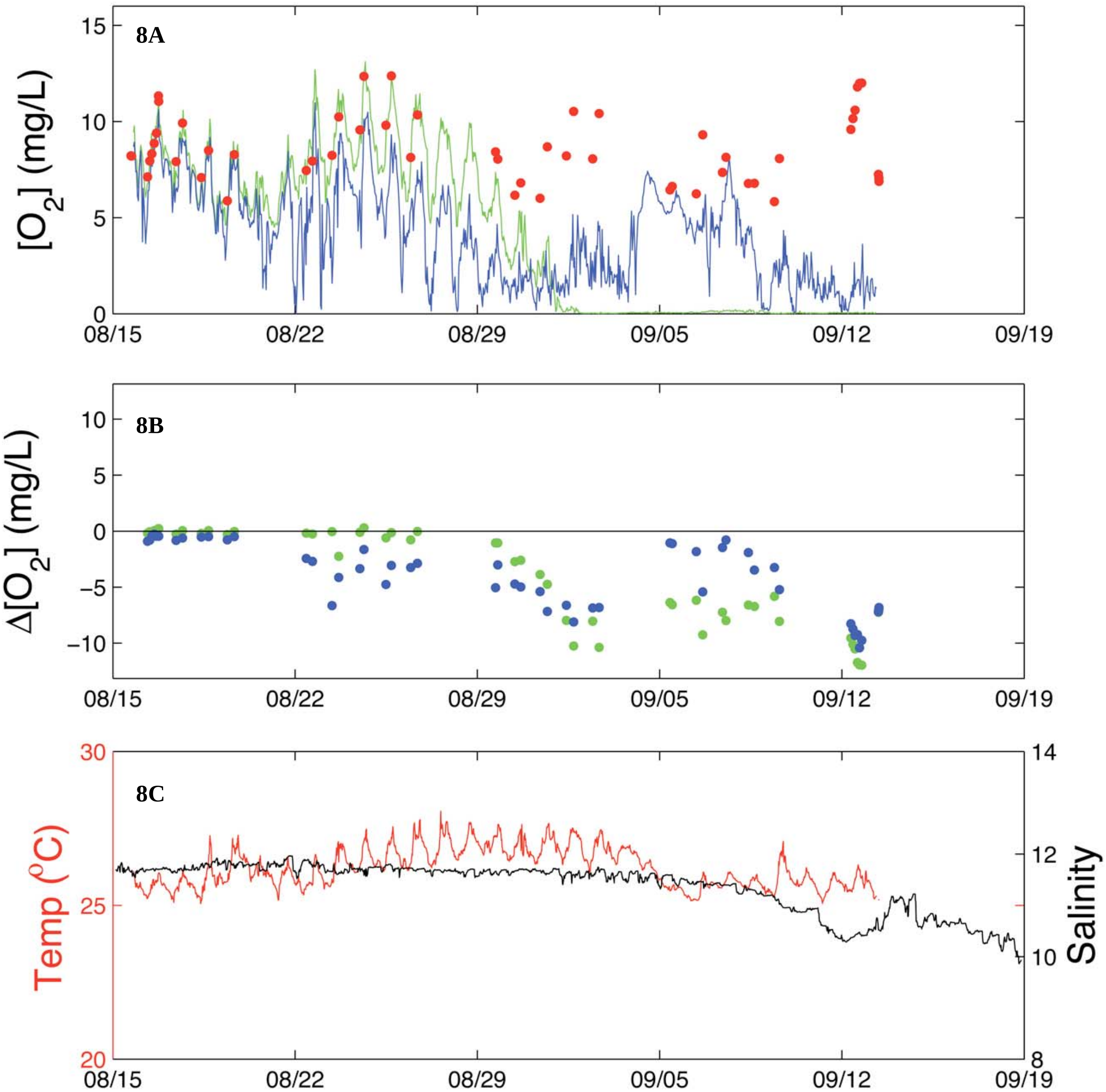
Sensor with the biofouling prevention system after four-week field deployment.

Figures 7A and 7B. Instrument drift at Skidaway Island, GA, 7C (SkIO).



Sensor <u>without</u> the biofouling prevention system (top right corner) and sensor <u>with</u> the biofouling prevention system (bottom left corner) after the four-week field deployment.

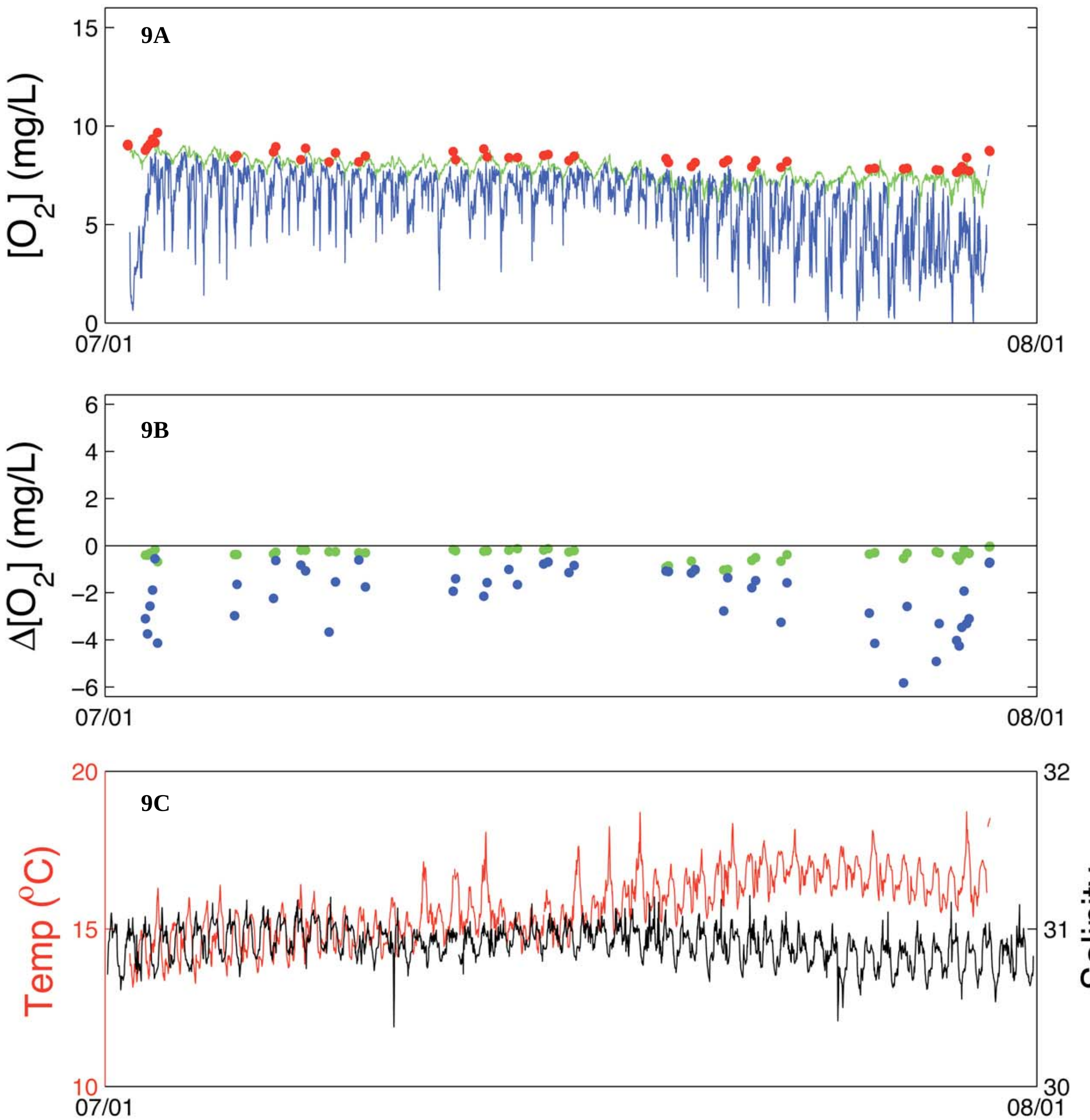
Figures 8A and 8B. Instrument drift at Solomons, MD, 8C (CBL).



Sensor <u>without</u> the biofouling prevention system after four-week field deployment.

Sensor <u>with</u> the biofouling prevention system after four-week field deployment.

Figures 9A and 9B. Instrument drift at Walpole, ME, 9C (GoMOOS/University of Maine).



Sensor without the biofouling prevention system after four-week field deployment.

Sensor with the biofouling prevention system after four-week field deployment.

Table 3. lists the mean instrument drift in measured DO values (mg/L) from Winkler means per week of field deployment. The smaller the absolute number, the less drift.

ACT Partner Test Site	Aanderaa DO - w/out BPS				Aanderaa DO - with BPS			
	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4
Bayboro Harbor, FL	- 0.35	- 2.52	- 5.88	- 6.56	- 2.68	- 2.53	- 4.52	- 4.33
Belleville Lake, MI	0.31	0.22	0.44	0.24	0.00	- 1.54	- 0.83	- 1.36
Kaneohe Bay Reef, HI	0.23	0.79	1.54	1.35	0.00	- 0.39	- 0.26	- 0.24
Moss Landing, CA	- 0.40	- 0.53	- 0.75	- 0.44	- 3.05	- 2.91	- 3.28	- 2.18
Skidaway Island, GA	- 0.43	- 2.76	- 4.80	- 6.06	- 0.64	- 1.67	- 2.91	- 5.82
Solomons, MD	- 0.06	- 0.45	- 5.47	- 8.59	- 0.84	- 3.72	- 5.08	- 5.33
Walpole, ME	- 0.33	- 0.21	- 0.72	- 0.40	- 2.18	- 1.36	- 1.37	- 3.50

Field Reliability – The Aanderaa Optodes were programmed to collect and record DO values every 5 minutes during the four-week field deployments at each of the ACT test sites, however we only considered data collected every 15 minutes (on the quarter hour) for this evaluation. All expected data points were successful downloaded from each test instrument and are plotted above. However, several data sets downloaded after deployments had unreliable time stamps that required manual correction.

ACKNOWLEDGMENTS:

We wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. In particular we would like to thank our Technical Advisory Committee, M. Atkinson, R. Burt, S. McLean and P. Pennington, for their advice and direct participation in various aspects of this evaluations. E. Buckley also provided critical input on all aspects of this work and served as the independent Quality Assurance Manager. This work has been coordinated with, and funded by, the National Oceanic and Atmospheric Administration, Coastal Services Center, Charleston, SC.

December 1, 2004
Date

Approved By: Dr. Kenneth Tenore
ACT Director

December 1, 2004
Date

Approved By: Dr. Mario Tamburri
ACT Chief Scientist

December 1, 2004
Date

Approved By: Dr. Earle Buckley
Quality Assurance Supervisor

November 25, 2004

Objective: Comments on ACT oxygen sensors test report

To whom it may concern,

With pleasure we have taken part in the ACT test program for oxygen sensor technology. We strongly support the basic idea of the ACT program and we have been impressed with how well these investigations have been organized and carried out. To us it was of special value that both users and manufacturers were allowed to contribute during the organizational phase. The rigorousness of these tests and the quality assurance should serve as an example to existing and coming oxygen sensing test protocols. We believe that non-biased investigations like these are of benefit both to manufacturers, to be able to improve our technology, and to users.

The sensors supplied by our company for these examinations were oxygen optode model 3830 that, for the purpose of these tests, were mounted two by two on Recording Current Meters model 9 (RCM9). The Current Sensors were taken off and the instruments were used merely to log data from two optodes at each field and laboratory site.

On the performance of our sensors in these investigations we have the following comments:

- **Accuracy:** As long as there is not heavy fouling the accuracy are within the specifications given. The absolute accuracy of these sensors can be improved by a factor of four if the sensors are calibrated individually in 30 points. However we believe that for costal work the demonstrated accuracy is sufficient and of more importance is a good long-term stability.
- **Precision**: Well within specifications.
- **Stability**: Good, none of the sensors were recalibrated during the whole set of tests. They were only cleaned from the fouling, which affected the sensor response at several sites but never recalibrated. We have many examples of longer (more than 1 year) deployments during which these sensors have been perfectly stable.
- **Copper plate on the sensors to prevent the effects of fouling**: This solution was adopted after positive test results in environments with high flows. Here it turned out that in general this was not a good solution, with the exception of the highly dynamic environment at Hawaii. Based on the experiences gained here and from other deployments we are working on a better and more "universal" antifouling solution. It is our intention to be able to deploy these sensors unattended with a maintained accuracy in the "worst" areas (Chesapeake bay, Skidaway and Florida) for at least 60 days.
- **Reliability**: Ok, see statement in the report.

Yours truly,

Dr Anders Tengberg
Scientific Advisor

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