ACT VS04-03
December 1, 2004

PERFORMANCE VERIFICATION STATEMENT

for the In-Situ Inc. Dissolved Oxygen RDO Sensor

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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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 In-Situ RDO dissolved oxygen optode. 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 In-Situ RDO dissolved oxygen sensor based on information provided by the vendor and was not verified in this test. The RDO sensor is based on the excitation and detection of luminescent material that has a fluorescence lifetime that is directly proportional to the presence of molecular oxygen. Specifically, the measurement of dissolved oxygen is based on the ability of oxygen to act as dynamic fluorescence quencher to a chemical species, which upon photo-excitation produces fluorescent photoemission during its relaxation. For example for oxygen, if a ruthenium-complex is illuminated with a blue light emitting diode (LED) the ruthenium-complex will be excited and emit a red luminescent light during is decay back to the original state. The blue-light excitation is applied during a very short time interval resulting in red luminescent light that is emitted with an intensity that decays over time. The red-light intensity decay rate, or lifetime, is directly proportional to the ambient oxygen concentration. Dissolved oxygen is thus determined by the precise measurement of the luminescent lifetime of the fluorescent chemical species.

Unlike electrochemical dissolved oxygen measurement, luminescent lifetime based dissolved oxygen measurements do not perturb the dissolved oxygen concentrations during the measurement. Luminescent measurement techniques do not consume or otherwise remove oxygen from the water during the measurement. As a result, luminescent dissolved oxygen measurement is not flow sensitive, has no performance drift from normal wear and has no initial stabilization time.

The manufacturer’s published performance specifications for the In-Situ RDO sensor includes: Range 0-20 mg/L or 0-200% saturation; Accuracy +/- 0.1 mg/L, Resolution 0.01 mg/L, and Response Time step change to 63% in 7 seconds or less. More information can be found at www.in-situ.com.

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 a 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 package, which included data logging and independent power provided by the manufacturer. Data was salinity corrected according to the equation provided by In-Situ. A total of eight sensors were evaluated, four with the manufacturer's biofouling prevention system and four without. In-Situ provided a copper screen 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 reconditioned and recalibrated by the manufacturer prior to the second set of deployments at the remaining ACT Partner test sites.

Prior to deployment, instruments were calibrated at the field sites (according to manufactures specified calibration protocols) and programmed to record dissolved oxygen data every 15 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 %

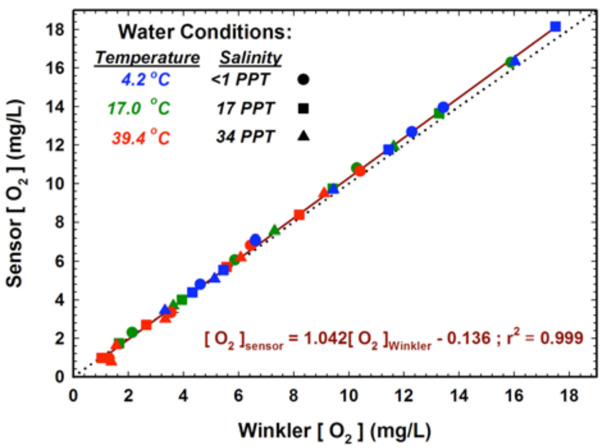
SUMMARY OF VERIFICATION RESULTS, LABORATORY TESTS:

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.

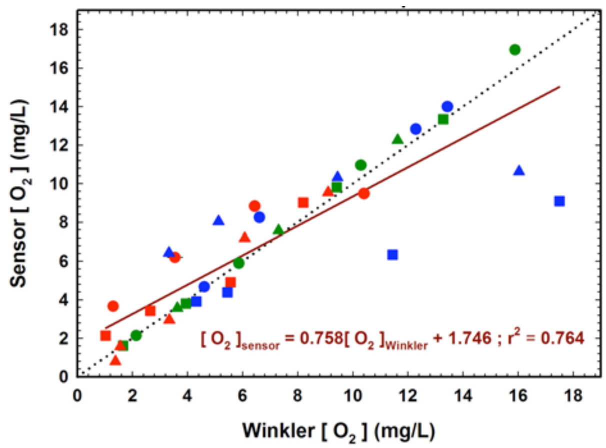
Temp (^oC)	Sal (ppt)	Winkler DO		In-Situ DO w/out BPS			In-Situ DO with BPS		
		Mean	STD	Mean	STD	Accur	Mean	STD	Accur
17.0	0.0	15.89	0.02	16.28	0.02	0.39	16.94	0.01	1.05
17.0	0.0	10.30	0.03	10.79	0.01	0.49	10.95	0.00	0.65
17.0	0.0	5.86	0.04	6.06	0.01	0.19	5.89	0.01	0.03
17.0	0.0	2.14	0.04	2.30	0.03	0.16	2.13	0.02	- 0.01
17.0	16.8	1.66	0.00	1.74	0.01	0.09	1.61	0.01	- 0.05
17.0	16.8	3.94	0.01	4.00	0.01	0.06	3.80	0.01	- 0.14
17.0	16.9	9.42	0.04	9.74	0.01	0.32	9.82	0.03	0.40
17.0	16.9	13.28	0.06	13.64	0.01	0.36	13.35	0.05	0.06
17.0	34.0	11.62	0.06	11.92	0.02	0.30	12.24	0.02	0.62
17.0	34.0	7.30	0.02	7.54	0.00	0.24	7.57	0.00	0.27
17.0	34.0	3.63	0.03	3.69	0.01	0.06	3.56	0.00	- 0.08
17.0	34.0	1.56	0.01	1.62	0.01	0.06	1.58	0.01	0.02
39.4	0.3	10.41	0.05	10.64	0.01	0.24	9.47	0.05	- 0.93
39.4	0.3	6.44	0.04	6.82	0.01	0.37	8.83	0.04	2.38
39.4	0.3	3.55	0.28	3.34	0.01	- 0.21	6.19	0.10	2.64
39.4	0.3	1.31	0.01	0.95	0.02	- 0.36	3.66	0.08	2.35
39.4	17.0	1.38	0.04	0.77	0.01	- 0.61	0.80	0.01	- 0.58
39.4	17.0	3.34	0.04	2.99	0.01	- 0.35	2.94	0.01	- 0.40
39.4	17.0	6.08	0.05	6.19	0.01	0.11	7.17	0.05	1.10
39.4	17.0	9.10	0.04	9.48	0.02	0.38	9.53	0.03	0.43
39.4	33.9	8.20	0.02	8.39	0.02	0.19	9.02	0.03	0.82
39.4	33.9	5.56	0.09	5.70	0.01	0.14	4.90	0.03	- 0.66
39.4	33.8	2.65	0.10	2.70	0.00	0.06	3.43	0.03	0.78
39.4	33.9	1.03	0.03	0.97	0.02	- 0.06	2.14	0.06	1.11
4.2	0.3	13.44	0.09	13.95	0.02	0.52	13.99	0.02	0.56
4.2	0.3	12.29	0.05	12.67	0.00	0.38	12.82	0.02	0.53
4.2	0.3	6.62	0.04	7.08	0.01	0.46	8.24	0.11	1.63
4.2	0.3	4.61	0.01	4.80	0.02	0.19	4.66	0.02	0.06
4.2	16.9	4.32	0.01	4.38	0.01	0.06	3.90	0.01	- 0.42
4.2	16.9	5.45	0.04	5.54	0.01	0.10	4.38	0.01	- 1.07
4.2	16.9	11.44	0.06	11.77	0.01	0.33	6.34	0.04	- 5.10
4.2	16.9	17.50	0.17	18.14	0.01	0.65	9.09	0.09	- 8.41
4.2	34.1	16.03	0.05	16.35	0.01	0.32	10.62	0.08	- 5.41
4.2	34.1	9.44	0.05	9.68	0.00	0.24	10.31	0.01	0.87
4.2	34.1	5.13	0.10	5.09	0.00	- 0.04	8.03	0.07	2.91
4.2	34.1	3.33	0.02	3.44	0.00	0.12	6.43	0.07	3.10

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 in Table 2). The dotted line represents a 1:1 relationship.

1A



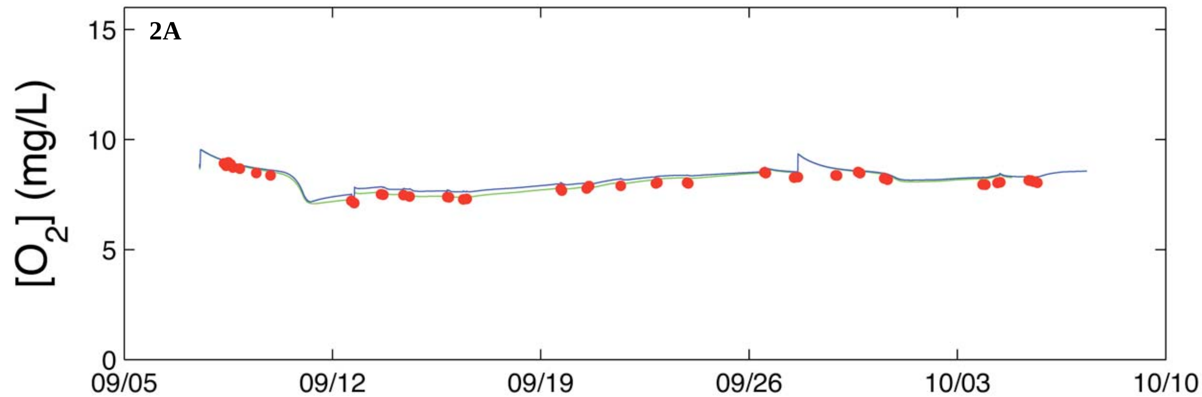
1B

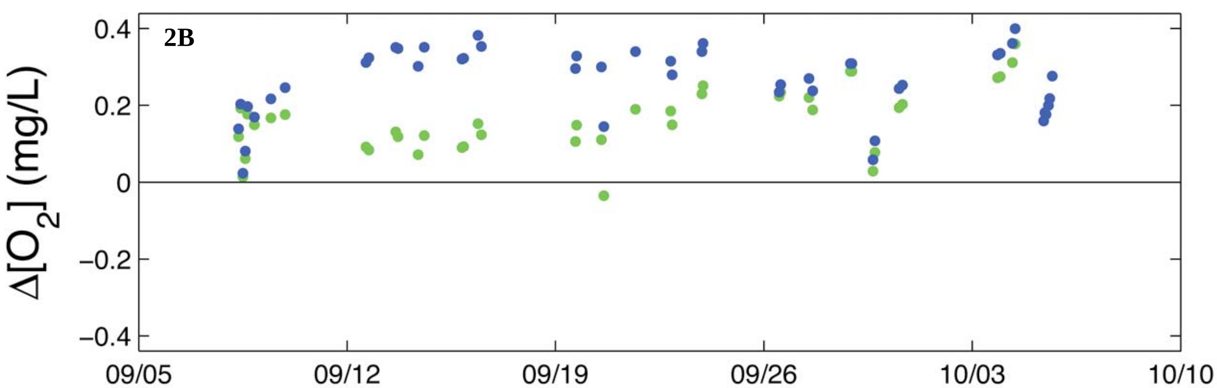


Laboratory Precision – The precision test was conducted in a well-mixed freshwater bath (0.0 ppt) held at 17.2 ^{o}C that was continuously aerated (i.e., air saturated). The mean, standard deviation (STD), and coefficient of variance (% CV = STD/Mean x 100) for DO values (mg/L) generated from 30 replicate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

Winkler DO			In-Situ DO - w/out BPS			In-Situ DO - with BPS		
Mean	**STD**	**CV**	**Mean**	**STD**	**CV**	**Mean**	**STD**	**CV**
8.97	0.02	0.22 %	9.37	0.01	0.11 %	9.40	0.01	0.11 %

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).





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

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

Laboratory Reliability – The In-Situ RDO sensors were programmed to collect and record DO values every 15 minutes during the four-week laboratory freshwater bath deployments. However, the batteries of one instrument lost power during the last day of testing. Therefore, while all data was successfully downloaded from one test instrument, the second did not record during approximately the last 24 hours (plotted above).

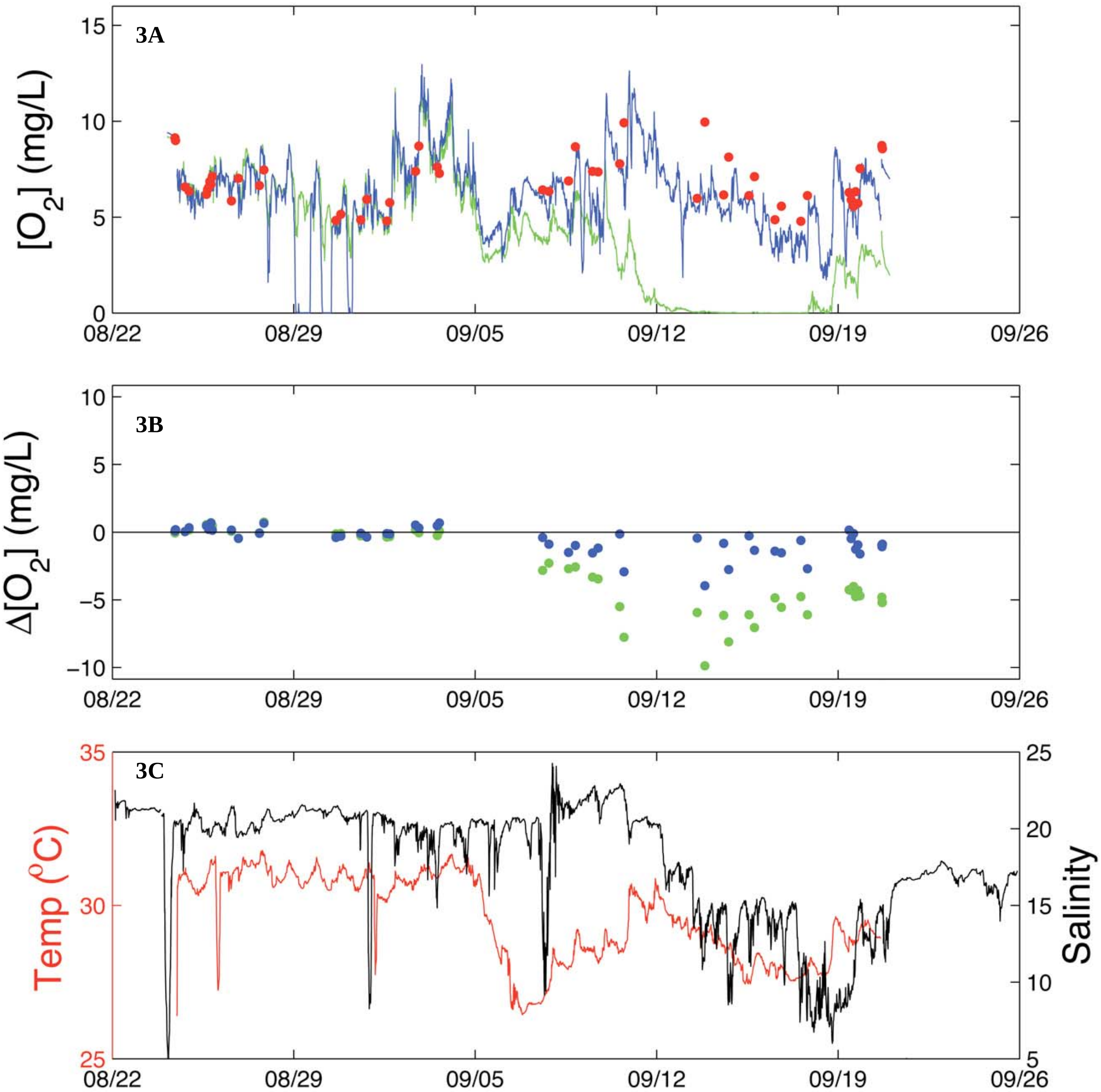
SUMMARY OF VERIFICATION RESULTS, FIELD TESTS:

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

ACT Partner Test Site	Basic Characterization	Range in Water Temperature (°C)	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.

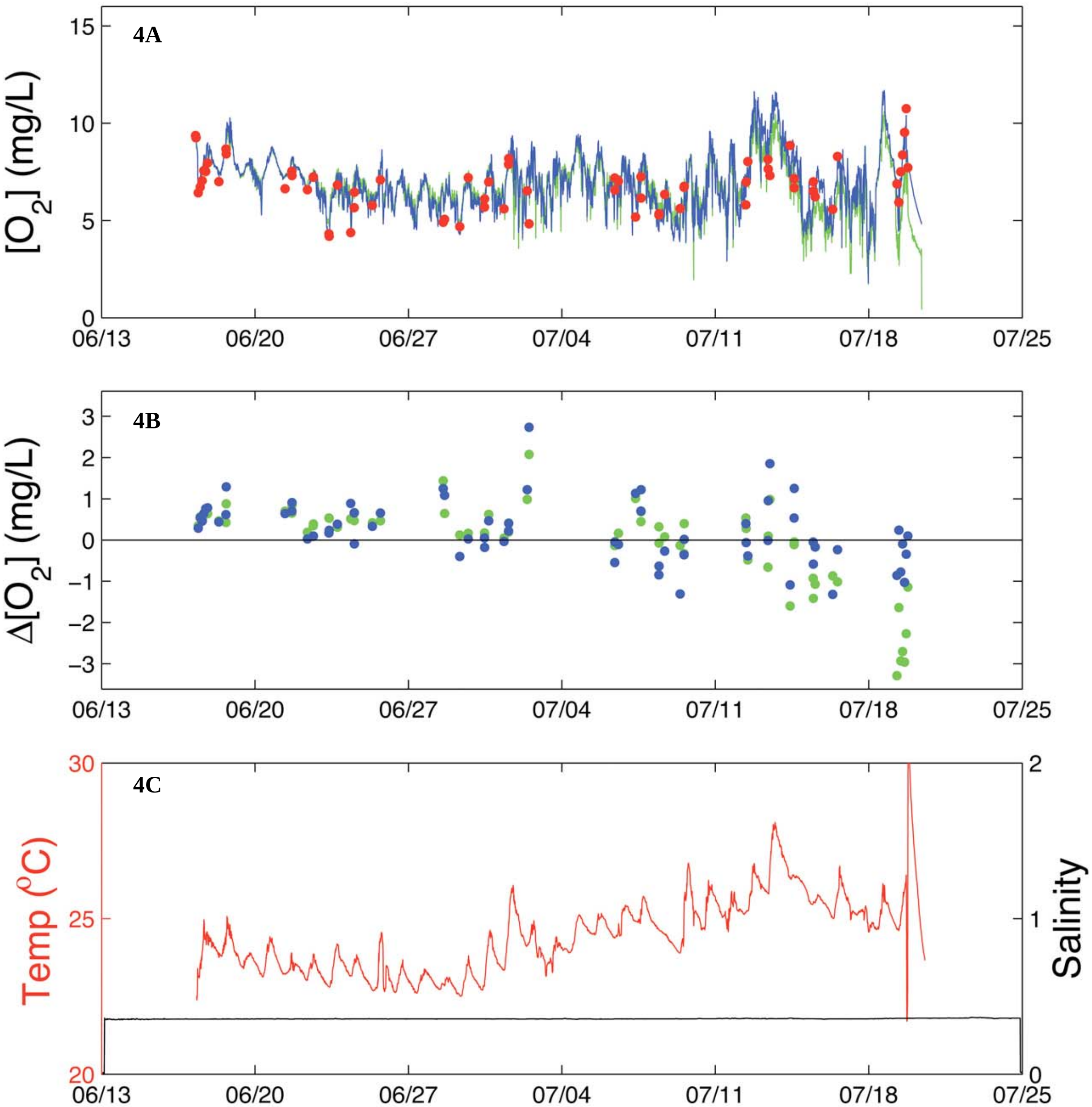
Figures 3A and 3B. Instrument drift at Bayboro Harbor, FL, 3C (USF).



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

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

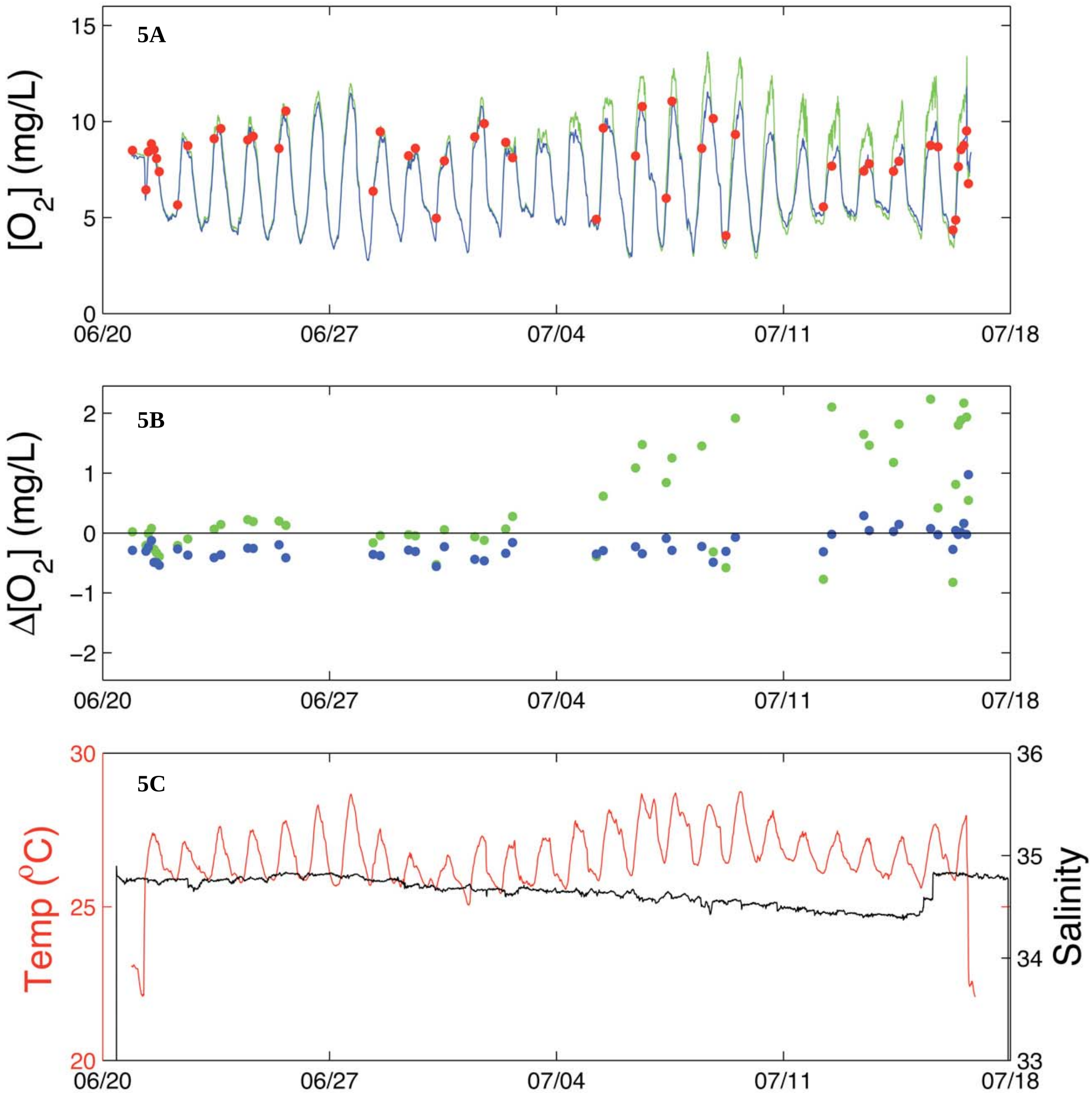
Figures 4A and 4B. Instrument drift at Belleville Lake, MI, 4C (CILER/University of Michigan).



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

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

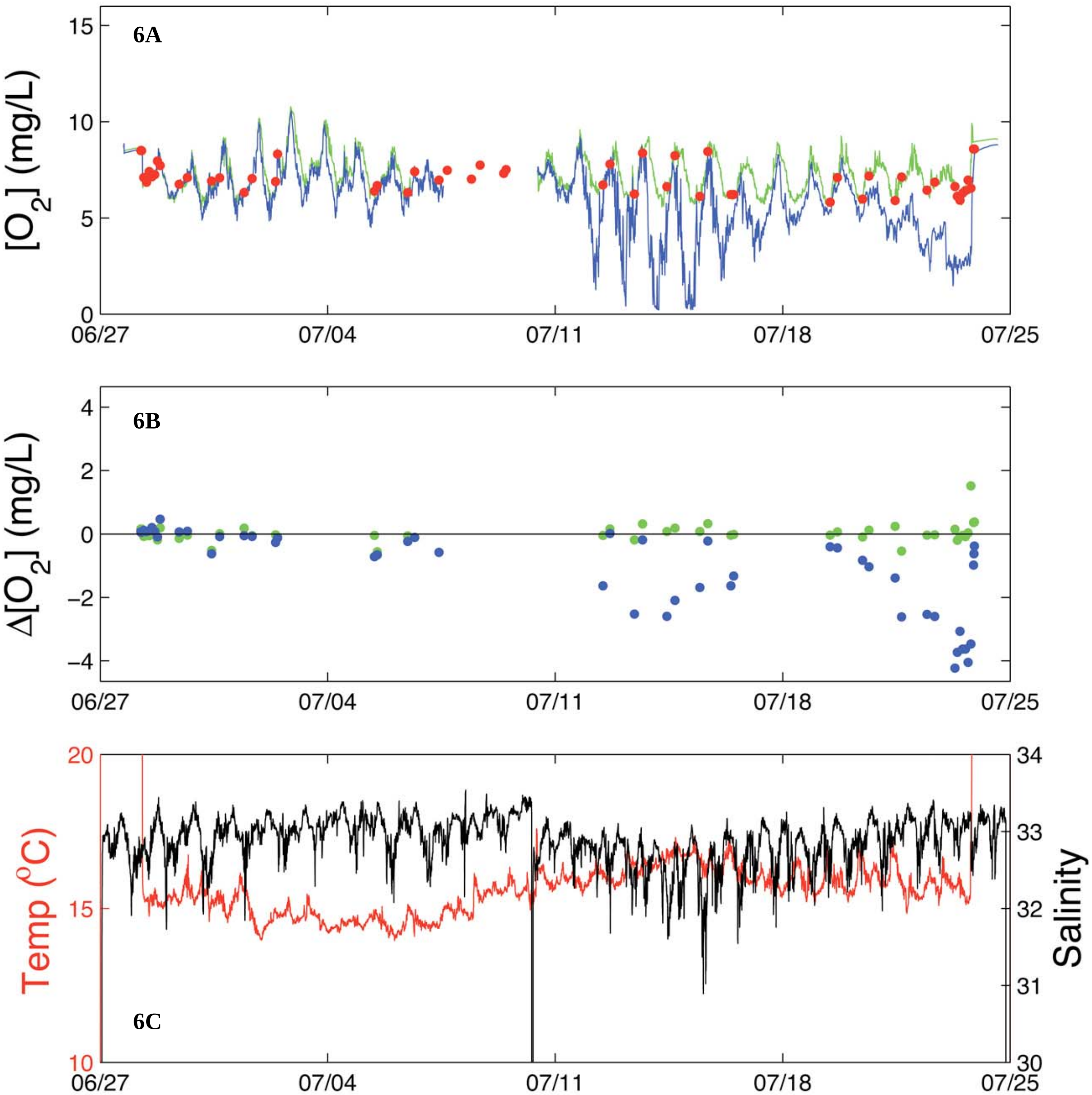
Figures 5A and 5B. Instrument drift at Kaneohe Bay Reef, HI, 5C (University of Hawaii).



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

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

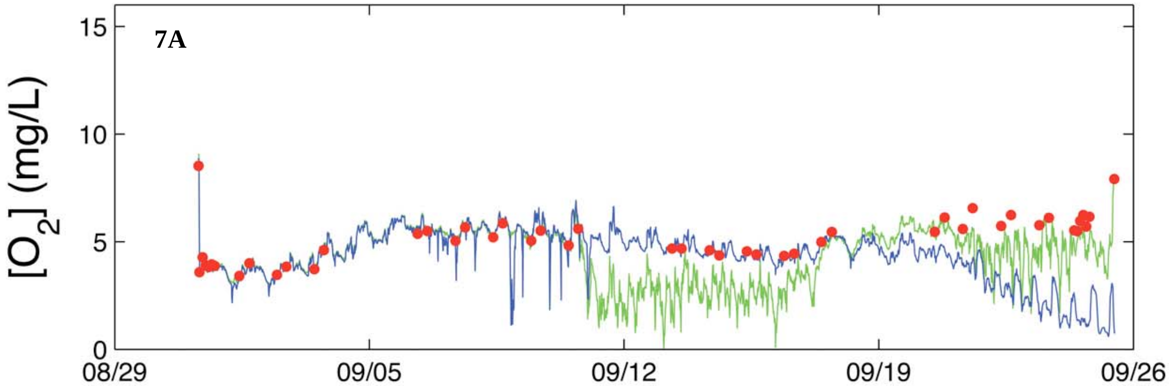
Figures 6A and 6B. Instrument drift at Moss Landing, CA, 6C (MLML).

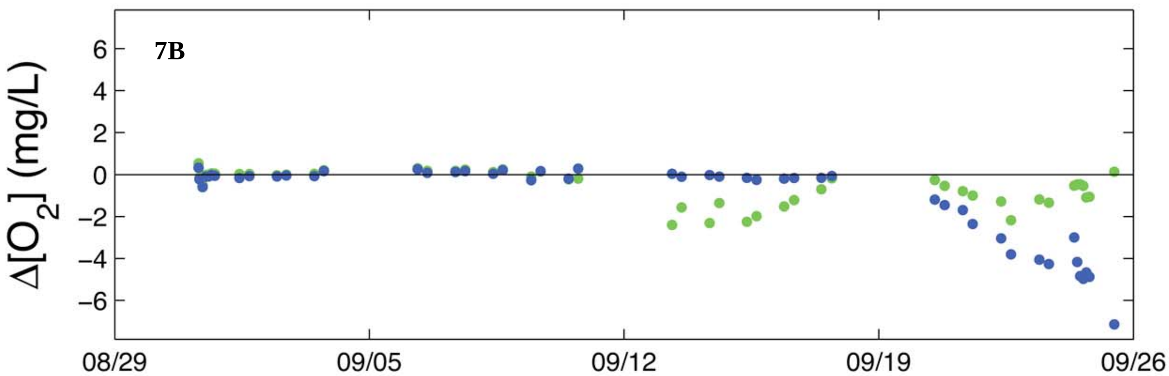


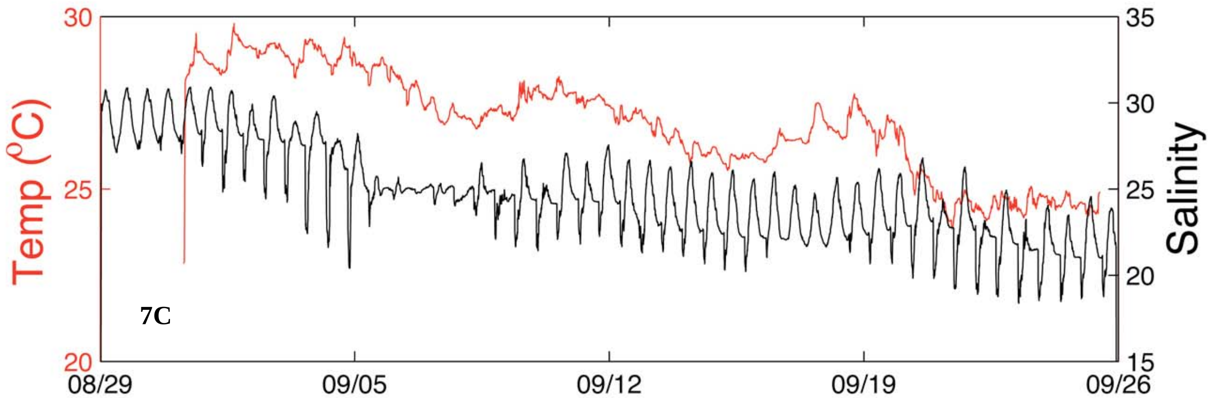
Sensor <u>without</u> the biofouling prevention system after four-week field deployment.

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

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



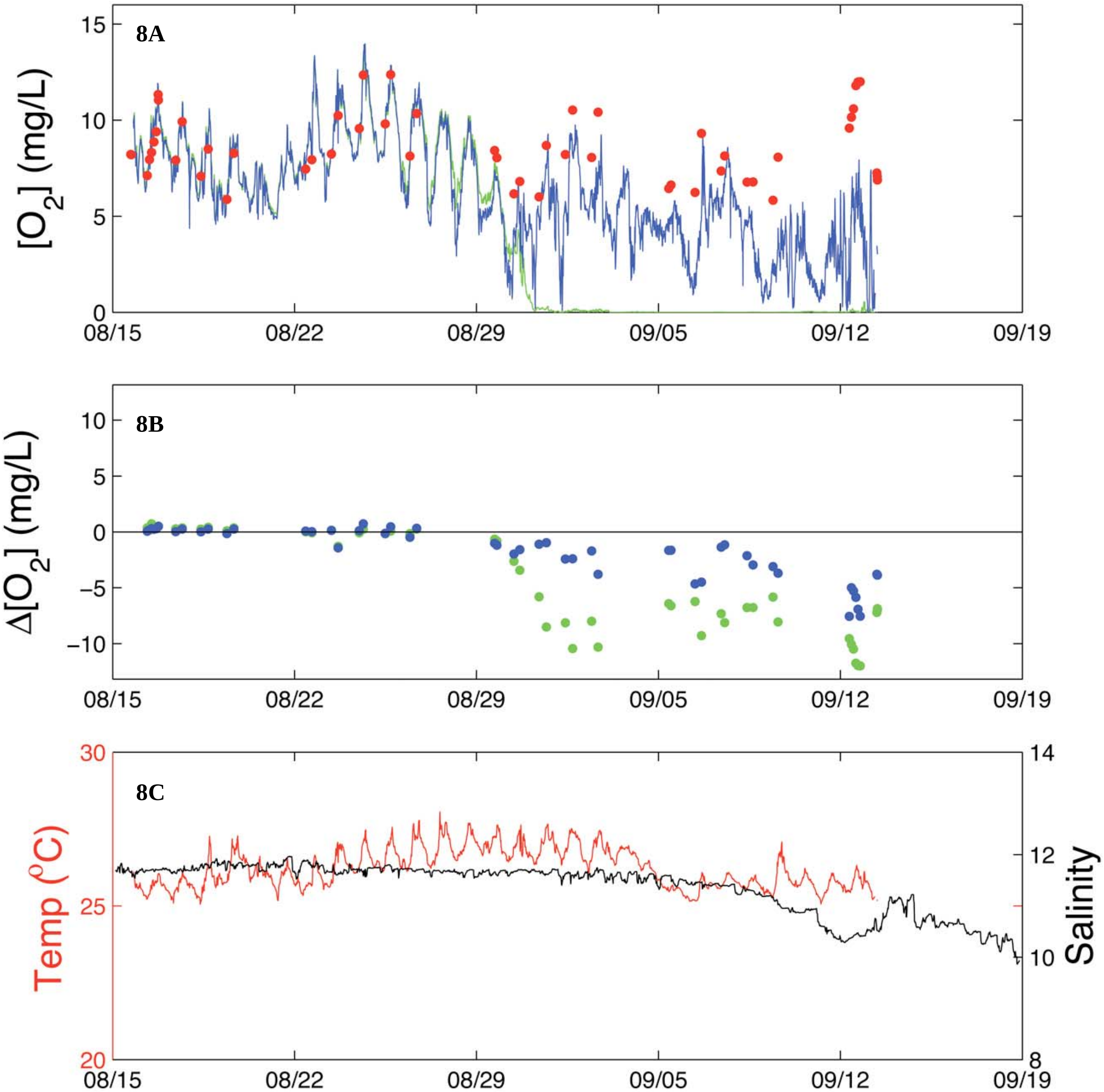




Sensor <u>without</u> the biofouling prevention system after four-week field deployment.

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

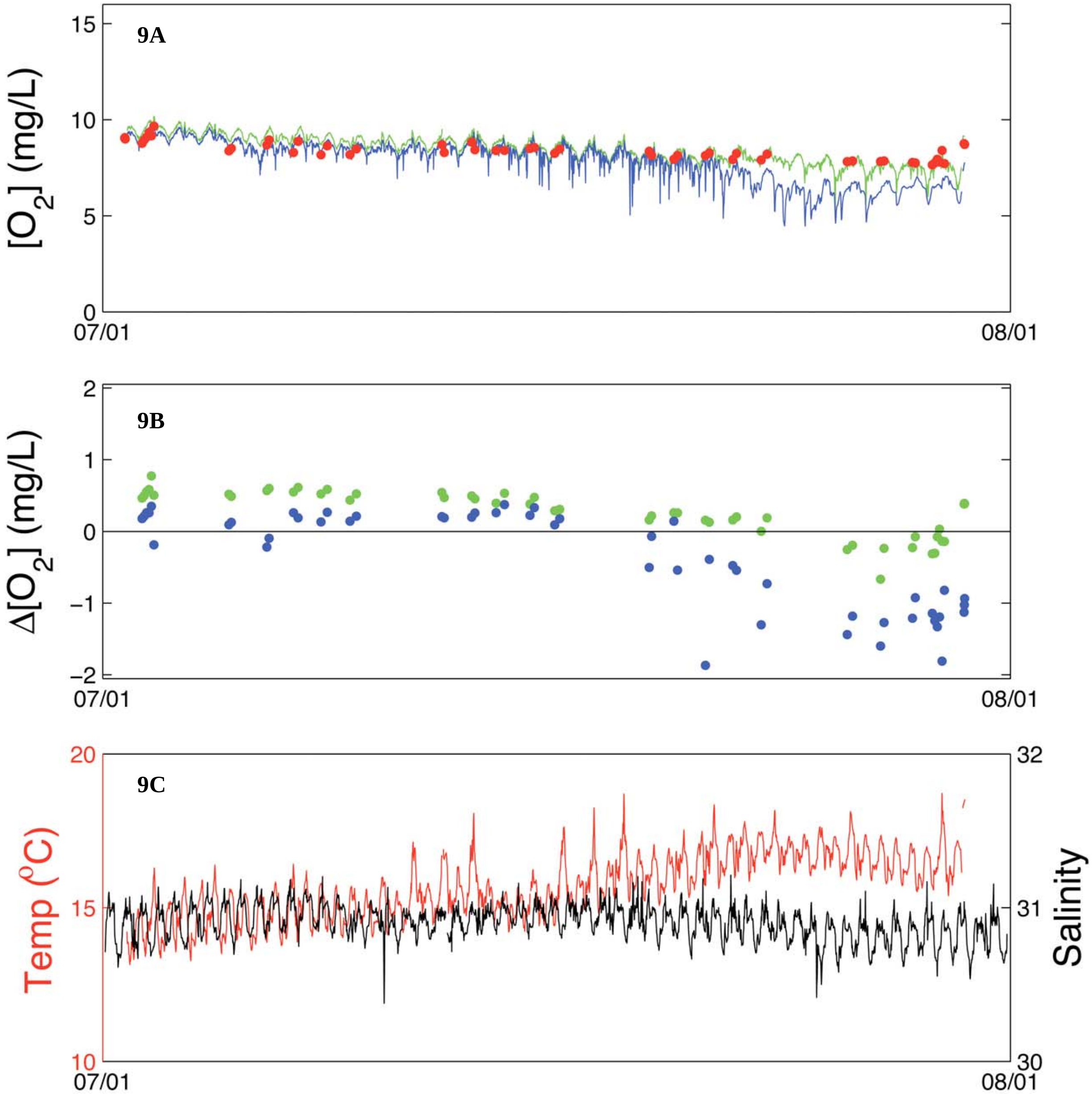
Figures 8A and 8B. Instrument drift at Solomons, MD, 8C (CBL).



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	In-Situ DO - w/out BPS				In-Situ DO - with BPS			
	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4
Bayboro Harbor, FL	0.52	0.18	- 4.45	- 5.28	0.47	0.53	- 1.08	- 0.93
Belleville Lake, MI	0.54	0.49	0.54	-0.04	0.51	0.40	0.63	0.01
Kaneohe Bay Reef, HI	0.19	0.17	0.98	1.45	- 0.11	- 0.12	- 0.03	0.28
Moss Landing, CA	0.06	- 4.78	0.19	0.19	0.08	- 3.76	- 1.29	- 2.14
Skidaway Island, GA	0.36	- 0.03	- 1.00	- 0.65	0.26	0.40	- 0.09	- 3.95
Solomons, MD	0.42	- 0.04	- 5.96	- 8.63	0.27	0.05	- 1.72	- 4.12
Walpole, ME	0.64	0.56	0.31	- 0.07	0.21	0.33	- 0.30	- 1.16

Field Reliability – The In-Situ RDO sensors were programmed to collect and record DO values every 15 minutes during the four-week field deployments at each of the ACT test sites. In one cases, the batteries of an individual instrument lost power as the data was being downloaded just after recovery from the field (SkIO, all data was recovered). The In-Situ instruments also experienced severe corrosion while deployed at two sites (Walpole, ME and Skidaway Island, GA). In both cases, the copper screen biofouling prevention system was absent upon recovery from the field and in Maine, the instrument housing was found to have extensive corrosion and pitting near areas where tape was added to secure the instrument into the test frame.

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
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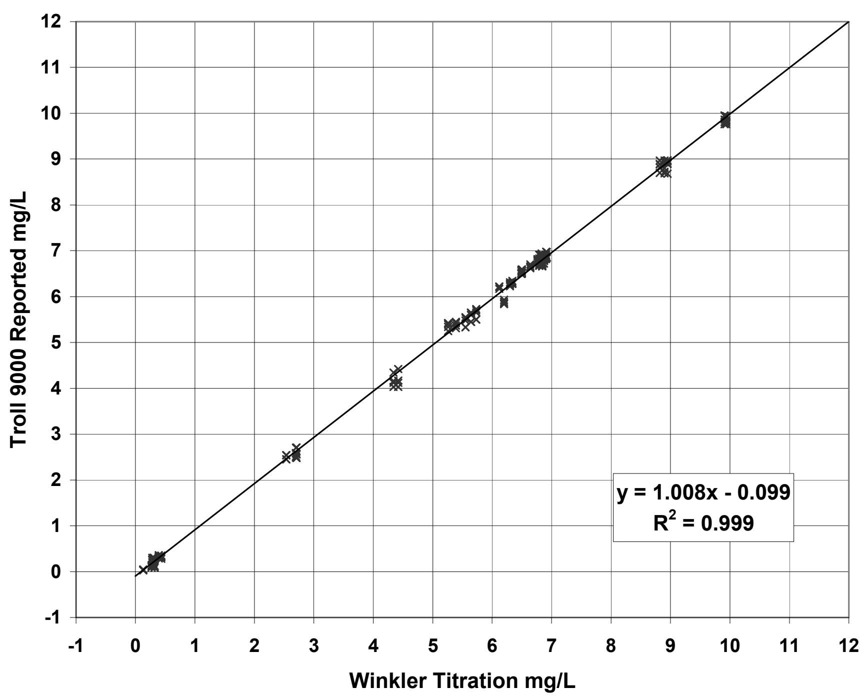
To whom it may concern,

In-Situ was very pleased to participate in the ACT Performance Verification of dissolved oxygen sensors. The In-Situ RDO sensor had only recently been introduced to the market so this was an exciting opportunity to receive additional feedback from experienced end users in the research community. We were impressed with the professional attention to detail in defining and implementing the test plan. We would like to offer our sincere thanks to the participating institutions for their efforts.

We would like to add the following comments:

1. In-Situ does not offer an anti-fouling accessory for sale. Ad-hoc antifouling screens were fabricated and installed for compliance with the test protocol.
2. Win-Situ software incorporates a calibration wizard that autonomously determines the point of stability prior to acceptance of the calibration point. There apparently is an opportunity for us to improve the repeatability of the automatic stability determination, evidenced by the variation in the initial accuracies at the lab and the field sites. Indeed, the mean and standard deviation of these errors are both approximately 0.25 mg/L indicating a minimal statistical significance. We are gratified to see the superb response linearity demonstrated in the lab results but note that in general the data points are high by 4.2%. This is likely the result of an equal and opposite error in the 100% calibration point. The test results we collected prior to the ACT validation project using a manual audit for sensor stability demonstrate our goal for the quality of the hands-off calibration, and we thank ACT for this valuable opportunity to improve our quality.



Sincerely,

Tony Arnerich
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In-Situ, Inc.