PERFORMANCE VERIFICATION STATEMENT for the RBR XR-420 and XR-620 CTD Salinity Sensors

TECHNOLOGY TYPE: Coupled conductivity and temperature sensors with instrument based algorithms for estimation of salinity

APPLICATION: In situ estimates of salinity for coastal moored and profiled deployments

PARAMETERS EVALUATED: Response linearity, accuracy, precision and reliability

TYPE OF EVALUATION: Laboratory and Field Performance Verification

DATE OF EVALUATION: Testing conducted from May through October 2008

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EXECUTIVE SUMMARY:

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. The Alliance for Coastal Technologies (ACT) has therefore completed an evaluation of commercially available in situ salinity sensors. While the sensors evaluated have many potential applications, the focus of this Performance Verification was on nearshore moored and profiled deployments and at a performance resolution of between 0.1 – 0.01 salinity units.

In this Verification Statement, we present the performance results of the RBR XR-420 and XR-620 CTD salinity sensors evaluated in the laboratory and under diverse environmental conditions in moored and profiling field tests. A total of one laboratory site and five different field sites were used for testing, including tropical coral reef, high turbidity estuary, sub-tropical and sub-arctic coastal ocean, and freshwater riverine environments. Quality assurance (QA) oversight of the verification was provided by an ACT QA specialist, who conducted technical systems audits and a data quality audit of the test data.

In the lab tests, the XR-620 exhibited a strong linear response when exposed to 15 different test conditions covering five salinities ranging from 7 – 34 psu, each at three temperatures ranging from 6 - 32 °C with R^2 >0.9999, SE = 0.03330 and slope = 1.001. The overall mean and variance of the absolute difference between instrument measured salinity and reference sample salinity for all treatments was -0.0262 ±0.0351 psu. When examined independently, the relative accuracy of the conductivity and temperature sensors were -0.0375 ±0.0458 mS/cm and -0.0045 ±0.0048.

Across all five field deployments, the range of salinity tested against was 0.14 – 36.97. The corresponding conductivity and temperatures ranges for the tests were 0.27 – 61.69 mS cm^{-1} and 10.75 – 31.14 °C, respectively. Extensive and rapid biofouling at the FL and GA test sites severely impacted instrument performance within approximately one week and more gradually over the eight weeks at the HI test site. The initial relative accuracy of instrument measured salinity during the first few days of deployment period was -0.036, -0.009, -0.003, and -0.004 psu for FL, GA, HI, and MI test sites, respectively. Variability was too great at the AK test site to precisely define a specific offset. Essentially all of the variability and measurement error was traced to the performance of the conductivity cell. The temperature sensor was accurate and stable throughout all of the deployments. The average offset of the measured temperature relative to our calibrated reference temperature logger was -0.0048, -0.0013, 0.0024, 0.0162, and- 0.0037 °C for FL, GA, HI, MI, and AK, respectively. When instrument response for the first 14 days of deployment was compared together for all five field sites, a fairly consistent and linear performance response was observed with R^2 = 0.997, SE = 0.734 and slope = 0.989. For vertical profiling tests, the instrument response was consistent over all depths and all ambient salinity levels. The average offset in measured salinity was -0.0191 ±0.0096 psu.

Performance checks were completed prior to field deployment and again at the end of the deployment, after instruments were thoroughly cleaned of fouling, to evaluate potential calibration drift versus biofouling impacts. In general, there was no strong evidence for calibration drift during the period of deployment and results confirmed that any deterioration in instrument performance during field deployments tests was due to biofouling.

During this evaluation, no problems were encountered with the provided software, set-up functions, or data extraction at any of the test sites. One hundred percent of the data was recovered from the instrument and no outlier values were observed for any of the laboratory tests, field deployment tests, or tank exposure tests. Lastly, a check on the instruments time clocks at the beginning and end of field deployments showed differences of between minus 3 and plus 11 seconds among test sites.

We encourage readers to review the entire document for a comprehensive understanding of instrument performance.

BACKGROUND AND OBJECTIVES

Instrument performance verification is necessary so that effective existing technologies can be recognized and so that promising new technologies can be made 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 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 (visit www.act-us.info).

As part of our service to the coastal community, ACT conducted a performance verification of commercially available, in situ conductivity/temperature sensors that provide a derived measurement of salinity (hereafter referred to as salinity sensors). We focused on commonly used inductive and electrode cell based conductivity sensors with measuring ranges from 0 - 100 mS/cm. Salinity is a composite property of water, originally defined as the total mass of dissolved material in one kilogram of water. The consistency of the ratios of major constituent ions in seawater enabled the successive refinement of the original analytically untractable definition to correspond to the total chlorinity of water. In current use, the practical salinity scale is based on the analytically precise description of the relationship between the conductivity and chlorinity of water at defined temperature and pressure. As a unitless proxy, the practical salinity scale is used for the basic characterization of aquatic habitats, for tracing the mixing of water masses, and for understanding variability in density needed to accurately model physical processes such as sound propagation and geostrophic currents. Frequent short-term forcing or input events (e.g., vertical and horizontal mixing or runoff) are typical of many coastal environments leading to high temporal and spatial variability in salinity. In addition to hydrodynamic considerations, the capacity to acclimate to specific salinity levels is an important constraint of species distributions. Therefore, it is often critically important to be able to generate continuous and accurate in situ observations of salinity.

The basic parameters and application methods to be evaluated in the verification were determined by surveying users of in situ salinity sensors. The two most common applications for users of salinity sensors were moored deployments on remote platforms for continuous monitoring and vertical profiling using CTD/ rosette platforms. The use of salinity sensors among our survey respondents was evenly divided between freshwater, brackish water, and marine environments, but over 75% of the respondents indicated use within shallow, nearshore environments. The greatest use of salinity data was to provide a general description of the environment, followed by identification of water masses and making density calculations for stratification. Approximately 40% of the respondents stated an accuracy requirement of 0.1 salinity, while another 30% stated a requirement of 0.01 salinity. The performance characteristics that ranked highest included reliability, accuracy, precision, ease of calibration, and stability. The verification therefore focused on these types of applications and criteria utilizing a series of field tests at five of the ACT Partner Institution sites, representing marine, estuarine and freshwater environments. In addition, a laboratory component of the verification was performed at the Moss Landing Marine Laboratory Partner site.

The overall objectives of this performance verification were to: (1) highlight the potential capabilities of in situ salinity sensors by demonstrating their utility in a broad range of coastal environments with varying salinity, (2) verify manufacturer claims on the performance characteristics of commercially available salinity sensors when tested in a controlled laboratory setting, and (3) verify performance characteristics of commercially available salinity sensors when applied in real world applications in a diverse range of coastal environments. This document summarizes the procedures and results of an ACT technology evaluation to verify manufacturer claims regarding the performance of the RBR XR-420 and XR-620 salinity probes. Appendix 2 is an interpretation of the performance verification results from the manufacturer's point of view.

TECHNOLOGY TESTED

The XR-420 CTD is a small, autonomous data logger designed to monitor conductivity, temperature and depth. The XR-620 variant offers 6Hz sampling for profiling applications. Both are available with either an inductive conductivity cell for marine environments, or an electrode based cell for fresh water. Standard operating depth is up to 740m, with full ocean depth versions also available. The supplied software computes practical salinity (PSS-78) or specific conductivity from the measured data.

Oceanographic conductivity ranges (0 to 85mS/cm) are measured to an initial accuracy of ±0.003 mS/cm by an inductive cell, using a three-coil system with closed loop feedback. This results in a typical temperature dependence of 0.0005mS/cm/ºC, and the software provided can apply further corrections for the most demanding applications. Critical cell components use ceramic material, yielding excellent long term stability. The response time depends on flow rate through the cell. The normal freshwater conductivity range of 0 to 2 mS/cm is measured by AC excitation of a three electrode cell, with an initial accuracy of ± 0.003 mS/cm and resolution to better than 0.0005 mS/cm. The electrode arrangement minimizes the effect on measurements of objects outside the cell.

Temperature is measured using an aged, hermetically sealed thermistor mounted in a durable 316 stainless steel external housing. Standard response time is 3 seconds, with a 95ms option available for profiling applications. The accuracy is ±0.002°C (ITS-90) over the range -5 to +35°C, with resolution better than 0.00005°C.

The standard pressure measurement option is an internal piezo-resistive strain gauge sensing absolute pressure. These are calibrated to better than ±0.05% full scale using an NIST traceable deadweight pressure generator, and use rugged, reliable technology and construction for long-term stability in harsh environments. The response time is 0.01 ms. A variety of depth ranges is available to suit the application.

An anti-fouling wax was applied to the body of the instrument and the outside of the conductivity cell (except only on the body for the GA test), but not inside the cell in an attempt to reduce biofouling during moored deployment tests.

SUMMARY OF VERIFICATION PROTOCOLS

The protocols used for this performance verification were developed in conference with ACT personnel, the participating instrument manufacturers and a technical advisory committee. The protocols were refined through direct discussions between all parties during a Salinity Sensor Performance Verification Protocol Workshop held on 26 -27 February, 2008 in St. Petersburg, FL. All ACT personnel involved in this Verification were trained on use of instruments by manufacturer representatives and on standardized water sampling, storage, analysis and shipping methods during a training workshop held on 12-16 May 2008 in Moss Landing, CA. During the instrument training workshop, ACT evaluated the current factory calibrations for each test instrument by exposing them to natural seawater in a well-mixed temperature controlled bath and making simultaneous laboratory measurements of triplicate reference samples. This calibration check was performed under the supervision of the manufacturer representatives and instruments were confirmed to be ready for testing. The manufacturer representative and the ACT Chief Scientist verified that all staff were trained in both instrument and sample collection protocols. Lastly, manufacturers worked with ACT to verify that the proposed instrument mounting configuration for the field tests would not produce a measureable effect on sensor performance due to electronic or structural interference. The final mooring arrangement was approved by all parties.

This performance verification report presents instrument-measured conductivity, temperature and derived salinity values reported over time, position, or depth as directly downloaded from the test instruments. The report includes means, standard deviations, and number of replicates of laboratory determined salinity values for corresponding reference samples at the same time, position, or depth of the instrument measurements. The report also includes an independently determined temperature record collected within the water column over corresponding time, position, or depth, by an RBR TR-1060 Temperature Logger which was used for all laboratory and field tests. A summary of the testing protocols is provided below. A complete description of the testing protocols is available in the report, *Protocols for the ACT Verification of In Situ Salinity Sensors* (ACT PV08-01) and can be downloaded from the ACT website (www.act-us.info/evaluation_reports.php).

Reference Standards and Analytical Procedures

State of the art, approved laboratory analytical methods and instrumentation were used to provide the best possible measure of 'true' conductivity and temperature values from laboratory and field reference samples. Reference samples served as the performance standards against which instrument conductivity, temperature and derived salinity estimates were compared. All reference and Quality Assurance and Quality Control (QA/QC) samples were analyzed on a Guildline 8410A Portasal salinometer, which has a reported accuracy of 0.003 and a resolution of 0.0003 equivalent psu. All reference samples for the verification were analyzed at Moss Landing Marine Laboratory (MLML) by the same technician using the same instrument. The Portasal was calibrated with IAPSO certified standard seawater (SSW) purchased from OSIL (Oceanic Scientific International Limited) at the beginning of each analytical batch and fresh SSW were analyzed as samples at the beginning and end of each analytical batch and randomly within the batch (approx. 10% of total volume) to characterize instrument drift. A linear drift correction, based on SSW sample performance, was applied to all reference samples within the SSW sample interval. Each salinity bottle sample generated 30 readings on the Portasal, collected as 3 consecutive readings on 10 aliquots drawn from the bottle. The 30 readings were averaged to a single salinity value per bottle. Variance estimates within our reference method come from replication across salinity bottles as well as a global mean variance for all reference samples collected for the laboratory test.

All reference samples were collected in standardized salinity bottles purchased from OSIL, made of type II borosilicate glass and sealed with polyethylene neck seals and screw caps.

Sample collection bottles were preconditioned for at least one week with ambient water from each test site. All reference samples were collected, stored, and shipped according to approved protocols (see full document at www.act-us.info/evaluation_reports.php). In addition, an independent field reference standard set was made from a single batch collection of ambient water at each test site and immediately sub-sampled into conditioned sample bottles. Sets of three of these reference samples were shipped and analyzed with each batch of field sample bottles to account for any sample bias resulting from storage or shipping and as independent checks on the consistency of the analytical procedures.

Laboratory Tests

Laboratory tests focused on verifying the manufacturers' stated performance characteristics of accuracy and precision using controlled laboratory settings to obtain the highest degree of accuracy and precision for corresponding reference standards. The instrument package was tested at five different salinity levels including 35, 30, 25, 16 and 6 on the practical salinity scale (PSS-78; 60 to 6 mS/cm conductivity), each at three different temperatures including 32 ^{o}C, 16 ^{o}C and 6 ^{o}C. The instrument was pre-equilibrated to the controlled bath test conditions for 60 minutes prior to the start of reference sampling. The instrument was set to measure in situ conductivity and temperature using its own algorithms to derive a practical salinity estimate from these values at 1-minute intervals. Ten reference water samples were collected at sensor depth into sealed pre-rinsed glass salinity bottles at 3 minute intervals over 30 minutes. Each reference sample set was stored at room temperature and analyzed after 24 hours on the Portasal 8410A (Fig. 1).

Figure 1. Analytical instrumentation (Portasal 8410A) used for laboratory analysis of salinity reference samples and one of the test baths and instrument racks used for the laboratory tests.

Moored Field Deployment Tests

Moored deployments were conducted at five ACT Partner sites covering a wide geographic distribution of coastal environments and a range of salinity and temperature conditions (see Table 1). Deployments were conducted over a 4-week duration at four of the test sites including Tampa Bay, FL, Skidaway Island, GA, Clinton River, MI and Resurrection Bay, AK. The deployment in Kaneohe Bay, HI was run over an 8-week duration to examine performance under an extended deployment. The test instrument was set to measure in situ conductivity and temperature using its own algorithms to derive a practical salinity estimate from these values at 15 minute intervals, except at HI where the measurement interval was increased to 30 minutes due to power constraints. Reference sampling for the 4-week test sites consisted of collecting 2 water samples per day on four days of the week and 4 samples per day once per week (Fig. 2). In addition, once each week we collected a replicate field sample by using two Van Dorn water samplers side by side in immediate vicinity of the mooring frame. For the longer deployment at the HI test site, the same pattern was used for the first two weeks, but then the sampling intensity was reduced to 3 collections per week and the intensive 4-per-day sampling every other week. For the Florida offshore site, the sampling schedule was somewhat modified due to vessel and weather constraints; however, all effort was made to produce a consistent number of reference samples as the other sites. Water samples were collected at the same depth and as close as physically possible to the instrument sensors and the water sampler was triggered to match the programmed sampling time of the instrument. Four replicate salinity samples were collected in pre-conditioned (with site water) 200 ml OSIL glass salinity bottles directly from the spigot of the sampler. Three of these salinity sample bottles were shipped to MLML for analysis and the fourth was held back at the collection site as a back up in case of a lost sample or if agreement among triplicates failed to meet a precision target of 0.005 psu. In that case, the remaining sample was also analyzed and the result was included in the final estimate of the reference salinity value. In situ temperature was recorded with an RBR TR-1060 Temperature Recorder which has a stated accuracy of 0.002 ^{o}C and a resolution of < 0.0005 ^{o}C. The calibration and temperature transfer standard of these sensors were independently verified in a NIST-certified laboratory.

As part of each field test, the instrument package was also tested in well-mixed tanks filled with ambient site water immediately before and after the moored deployment. The post-deployment tank test occurred after the instrument was thoroughly cleaned to remove all visible traces of biofouling. The purpose of the tank test was to help differentiate the effects of biofouling from those of instrument drift that may have occurred during the deployment. The instrument was equilibrated to the tank conditions for at least 30 minutes prior to sampling and programmed to sample at 1 minute intervals. Three reference samples were collected and each sub-sampled into triplicate salinity bottles during the instrument sampling interval for comparison.

Lastly, a series of PVC tiles were deployed adjacent to the mooring rack and used to photographically document the amount and rates of biofouling at the site. Each week one tile was retrieved and photographed to characterize the extent of fouling. The weekly photographs are displayed in the field results section of the report.

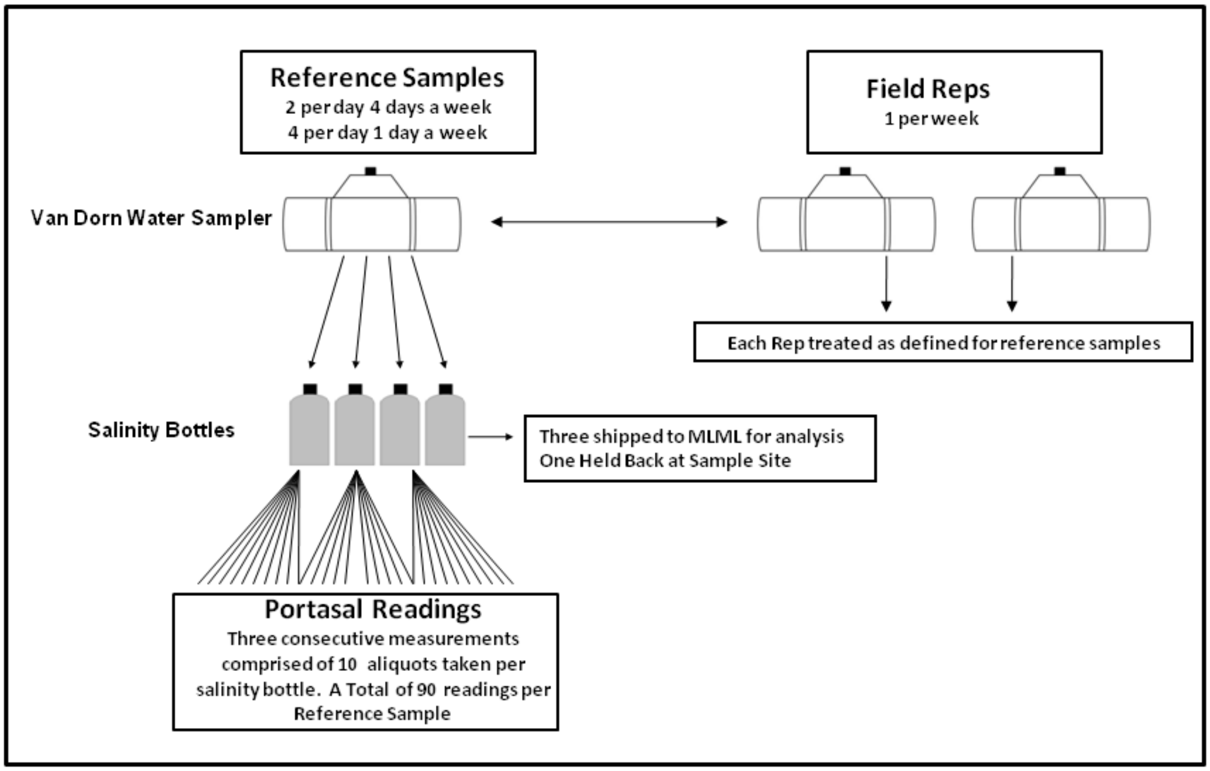


Figure 2. Schematic representation of the reference sampling process conducted during moored deployment field tests.

Veritcal Profiling Field Tests

A vertical profiling application was included at Resurrection Bay, AK for those instruments that are designed to sample at appropriate rates and with appropriate sensor response times. The test consisted of performing vertical profiling casts at 2 locations known to have well defined pycnoclines during a single 1 day cruise. One location was on the shelf just outside the Bay and the other was within the Bay in an area known to be influenced by coastal runoff. The profiling test involved the comparison of simultaneous instrument measurements and discrete samples collected at six discrete depths throughout the water column. Sampling depths were spaced to provide two reference samples in the surface mixed layer, two near or within the pycnocline, and two below the pycnocline in order to capture the maximum variation in salinity. One of the six discrete depths was sampled in replicate with two independent Niskin bottle collections. The XR-620 was included in this portion of the evaluation.

Quality Assurance/Quality Control

This performance verification was implemented according to the QA test plans and technical documents prepared during planning workshops and approved by the manufacturer and the ACT salinity sensor advisory committee. Technical procedures included methods to assure proper handling and use of test instruments, laboratory analysis, reference sample collections, 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 main component to the QA plan included technical systems audits (TSA) conducted by an ACT Quality Assurance Manager of the laboratory tests at MLML and of the field tests at two of the ACT Partner test sites (Florida and Alaska) to ensure that the verification tests were performed in accordance with the test protocols and the ACT *Quality Assurance Guidelines*. All analytical measurements were performed using materials and/or processes that are traceable to a Standard Reference Material. Standard Operating Procedures were utilized to trace all quantitative and qualitative determinations to certified reference materials. Lastly, ACT's QA Manager audited approximately 10% of the verification data acquired in the verification test to assure that the reported data and data reduction procedures accurately represented the data generated during the test.

RESULTS OF LABORATORY TEST

A series of laboratory tests were conducted at Moss Landing Marine Laboratories to examine the response linearity, operational precision and accuracy of the submitted test instruments. Three test baths were established and maintained at temperatures of ca. 6, 16, and 32 ^{o}C. In separate trials, instruments were exposed sequentially to salinity levels of approximately 35, 30, 25, 16, and 6 at each of these temperatures. The response linearity across the exposure trials was assessed by cross plotting average instrument measure against average reference measure obtained for each exposure level. The relative accuracy of the test instrument salinity measurements was assessed as the absolute differences between laboratory measurements of collected reference water samples and independent temperature records. Reference conductivities were derived from the Portasal salinity measurement and concurrent bath reference temperature measure at the time of sampling utilizing the algorithms provided in the ‘Conductivity from Practical Salinity’ module of Lab Assistant V2 (PDMS, Ltd). The accuracy of instrument temperature measurements was determined against a bath reference temperature recorded by calibrated and certified RBR TR-1060 logging thermometers. Two newly calibrated time-synchronized RBR TR-1060 loggers were placed at opposite ends of each laboratory bath at the depth of the instrument conductivity cell and temperature was monitored continuously at 5 second intervals from the top of the minute. For analysis of test results, temperature records were averaged to 1 minute intervals corresponding to the average sampling rate of the test instruments. Comparison of the two reference temperature logs revealed an average temperature difference of 0.005 (± 0.003) ^{o}C across the tank axis with a maximum difference of 0.019 ^{o}C during one of the 16 ^{o}C tests. Average stability of the bath temperatures across the 15 test runs was ± 0.0128 ^{o}C from the mean during reference sampling. Temperature drift associated with the time intervals of reference sampling averaged 0.0123 (± 0.0517) ^{o}C across all tests with a maximum drift of 0.116 ^{o}C encountered during one of the 16 ^{o}C test associated with a cooling line failure.

Analyzed across all five salinity levels and all three temperatures, the XR-620 exhibited a strong linear response to the test solutions with $R^2 > 0.9999$, standard error = 0.033 psu and slope = 1.001 for measured salinity (Fig. 3). The conductivity and temperature regressions also each had $R^2 > 0.9999$ with standard errors of 0.0433 and 0.0050, respectively. The variance in 30 repeated measurements taken at one minute intervals for each of the laboratory trials is shown in Figure 4. The plots are not a measure of engineering precision as environmental conditions within the test baths did change during the sampling process. The variation in instrument derived measurements is plotted relative to the average standard deviation and 3-times the standard deviation upper specification limit of reference salinity, conductivity, and temperature measurements taken over corresponding time intervals for all lab tests. An alternative version of this figure showing a direct comparison of instrument versus reference sample variance for each individual trial is given in Appendix 1. Instrument offsets in salinity, conductivity and temperature were computed for each test run as the difference in the mean instrument measure from the mean reference measure for that test bath condition (Fig. 5). The offset in measured salinity ranged from -0.0076 to -0.1474 psu with an overall mean of -0.0262 ±0.0351 psu for all 15 treatments. Without the one outlier value included the mean of the offsets improved to -0.0175 psu. The mean of the measurement offsets for the conductivity and temperature sensors independently were -0.0375 mS/cm and -0.0045 ^{o}C, respectively.

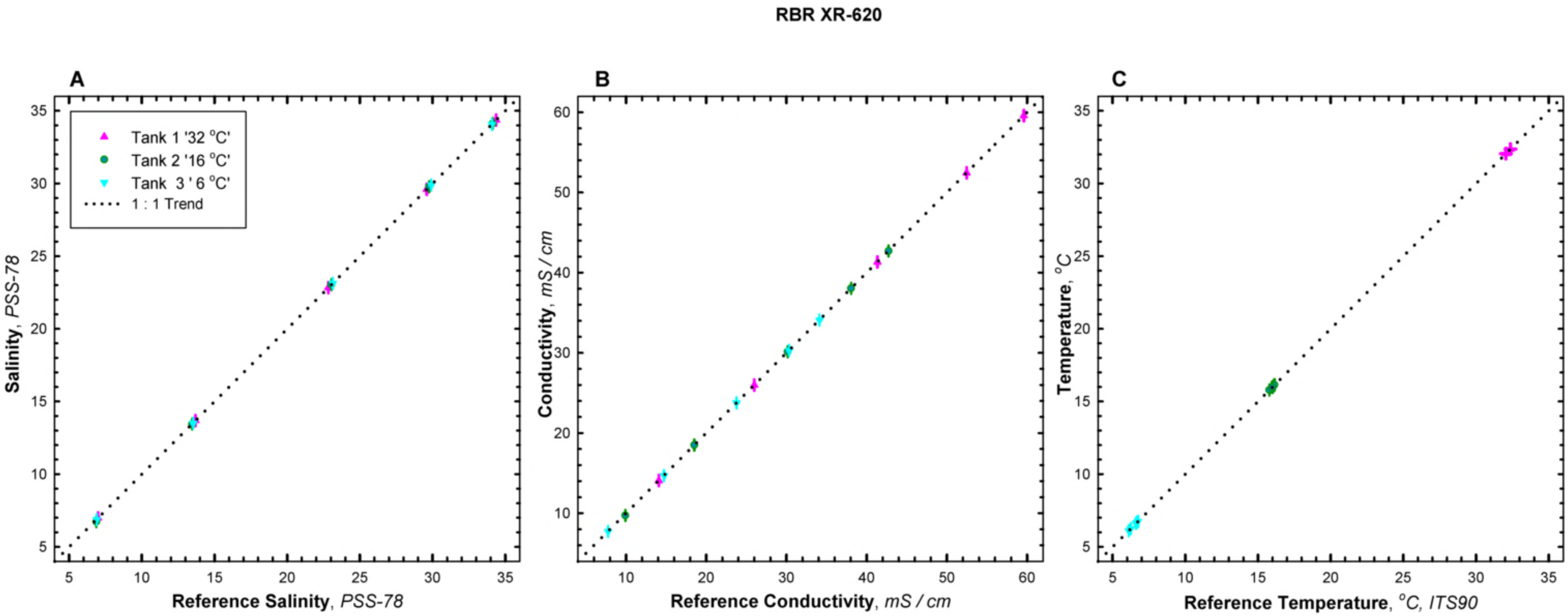


Figure 3. Evaluation of the response linearity for RBR's model XR 620 conductivity and temperature sensor package during controlled laboratory exposures to a combination of natural seawater dilutions and temperatures. Consecutive test exposures ranged between 35 to 6 on the practical salinity scale (PSS-78; 60 to 6 mS/cm conductivity) and 33 to 6 °C. [*A*]Correspondence of instrument derived salinity to Portasal reference measurements; [*B*] Correspondence of instrument in situ conductivity measurement to conductivity estimate derived from the Portasal salinity and reference temperature measurement by inversion of the seawater equations of state (IAPSO PSS-78); [*C*] Correspondence of instrument temperature measurement to bath reference temperature recorded by a calibrated RBR 1060 logging thermometer. Data points are represented as mean ± standard deviation of and 10 reference water samples. Dotted lines represent 1:1 ideal correlation of measures.

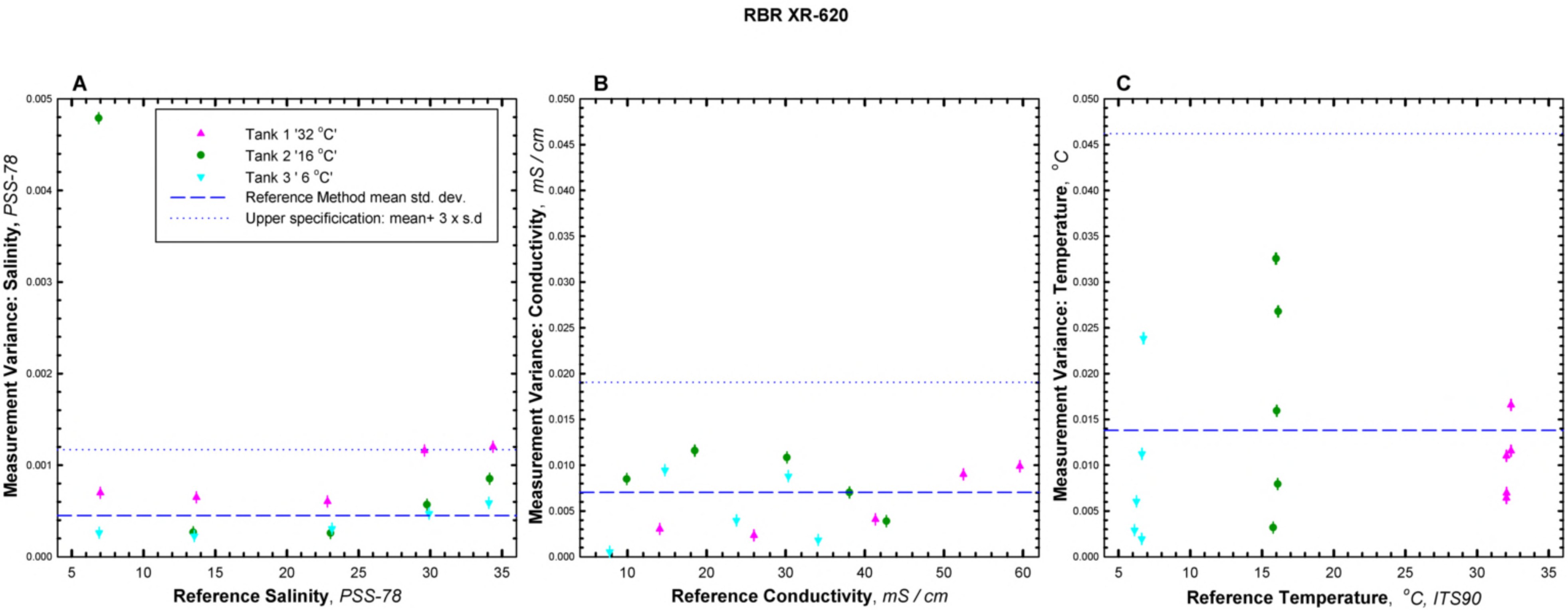


Figure 4. Evaluation of measurement variation of RBR's model XR 620 conductivity and temperature sensor package achieved during the laboratory exposure trials plotted in **Fig. 3**. Relative measurement variance is presented as the standard deviation from 30 consecutive instrument reads associated with each test exposure. The corresponding reference measurement variance range is provided in each plot as the mean standard deviation (dashed line) and 3x s.d. (dotted line) of consecutive reference samples, averaged across all trials. [*A*] Variance of derived salinity estimates; [B] Variance of in situ conductivity measurements; [*C*] Variance of instrument temperature measurements.

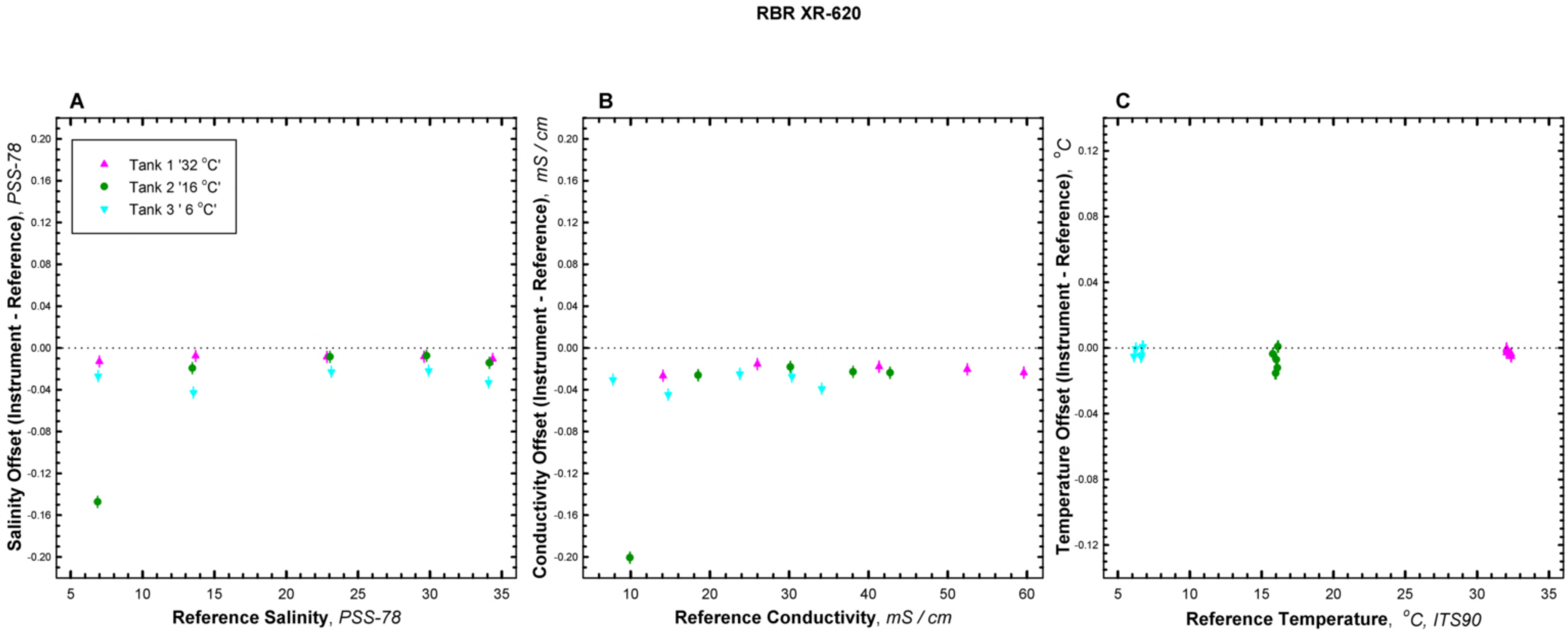


Figure 5. Evaluation of the relative accuracy of RBR's model XR 620 conductivity and temperature sensor package achieved during the laboratory exposure tests plotted in **Fig. 3**. Relative accuracy is estimated as the difference or offset between the mean instrument reading and mean reference reading for each exposure test. [*A*] Relative accuracy of derived salinity estimate; [*B*] Relative accuracy of instrument's in situ conductivity measurement; [*C*] Relative accuracy of instrument's temperature measurements. Dotted horizontal line represents no difference between instrument and reference method measurement.

RESULTS OF MOORED FIELD TEST

Field Site Characterization

Field tests focused on the ability of the instrument to consistently track natural changes in salinity over extended deployment durations of 4-8 weeks. In addition, the field tests examined the reliability of the instrument, i.e., the ability to maintain integrity or stability of the instrument and data collections over time. Reliability of instruments was determined by quantifying the percent of expected data that was recovered and useable. In addition, instrument stability was determined by pre- and post-measures of reference samples in a well mixed test bath after removing any influence from accumulated biofouling.

The performance of the RBR XR-420 or XR-620 salinity sensors was examined in field deployment tests at each of five ACT Partner test sites. The range and mean for temperature and salinity (or conductivity) for each test site is presented in Table 1. Across test sites, temperatures ranged from 10 – 31 ^{o}C, salinity from 19.4 – 37.0 at the coastal ocean test sites and conductivity ranged from 269 – 947 µS/cm at the freshwater test site.

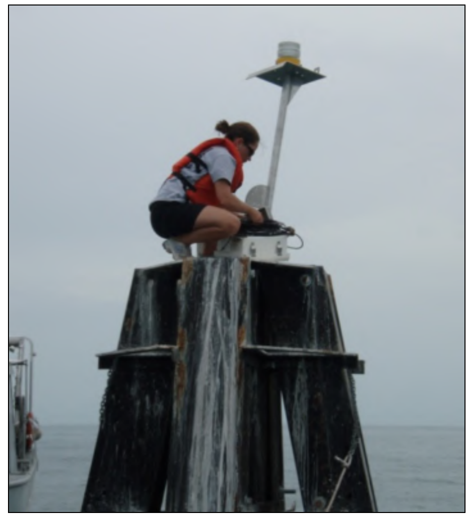
Table 1. Range and average for temperature, conductivity and derived salinity at each of the test sites during the sensor field deployment measured in situ by a SeaBird SBE 26 (or SBE26plus) mounted on the instrument rack and the duration of the deployment.

SITE (deployment period/duration)		**Temperature** (^{0}C)	**Conductivity** (mS cm^{-1})	**Salinity**
Off Tampa Bay, FL	Min.	27.84	58.45	36.01
02Jun – 01Jul	Max.	30.63	61.69	36.97
(n = 30 days)	Mean	29.54	60.17	36.59
Skidaway Island, GA	Min.	27.97	44.48	26.42
09Jun – 03Jul	Max.	31.14	53.88	32.62
(n = 24 days)	Mean	29.48	49.98	29.73
Kaneohe Bay, HI	Min.	26.13	52.73	33.03
10Jun – 19Aug	Max.	29.59	57.47	35.36
(n = 60 days)	Mean	27.51	55.67	35.08
Clinton River, MI	Min.	18.50	0.268	0.137
13Jun – 10Jul	Max.	25.98	0.947	0.505
(n = 28 days)	Mean	22.36	0.522	0.268
Resurrection Bay, AK	Min.	10.75	24.45	19.44
7Aug – 4Sep	Max.	14.69	32.99	28.10
(n = 29 days)	Mean	13.26	30.59	25.15

Moored Deployment in Tampa Bay, FL

The mooring test in Florida took place off a fixed mooring structure located offshore of Tampa Bay. The structure is located on Palatine Shoals at a depth of approximately 6.5m. The instrument rack was attached to the structure at 2.5m below mean sea level to minimize the chances of the instrumentation being exposed to the air during rough sea states. The site exhibited a high and consistent level of salinity, ranging from 36.01 – 36.97 and water temperature ranged between 27.8 – 30.6 ^{o}C.

USF Deployment Site Location



USF Deployment Site

Figure 6. Site map and photo of the field test site located outside of Tampa Bay, Florida.

Time series data of in situ measured conductivity and temperature, and derived salinity, for the FL field test were plotted against corresponding results from the laboratory analyzed reference samples and reference temperature logger (Fig. 7). Instrument measurements appeared to be impacted by fouling after only a few days when absolute differences in measured salinity went from an initial value of 0.036 to -0.224 on day 6 and then continued to decrease sharply (Fig. 8). The offset in measured salinity was clearly related to performance of the conductivity cell, and the temperature sensor response was quite consistent throughout the deployment despite the presence of heavy biofouling with a mean offset of 0.0048 ^{o}C. A test to confirm that changes in instrument performance were due to biofouling and not electronic drift was completed by comparing measurement accuracy in pre- and post- exposures in well mixed reference sampled tanks, after the instrument was cleaned to remove all biofouling (Fig 9). The agreement between instrument and reference sample values was nearly identical between the two suggesting biofouling was the direct cause of the decreased performance. The amount of fouling that developed on the instrument during the deployment is shown in figure 10 and a time-series showing the rate of biofouling captured on PVC tiles in shown in figure 11.

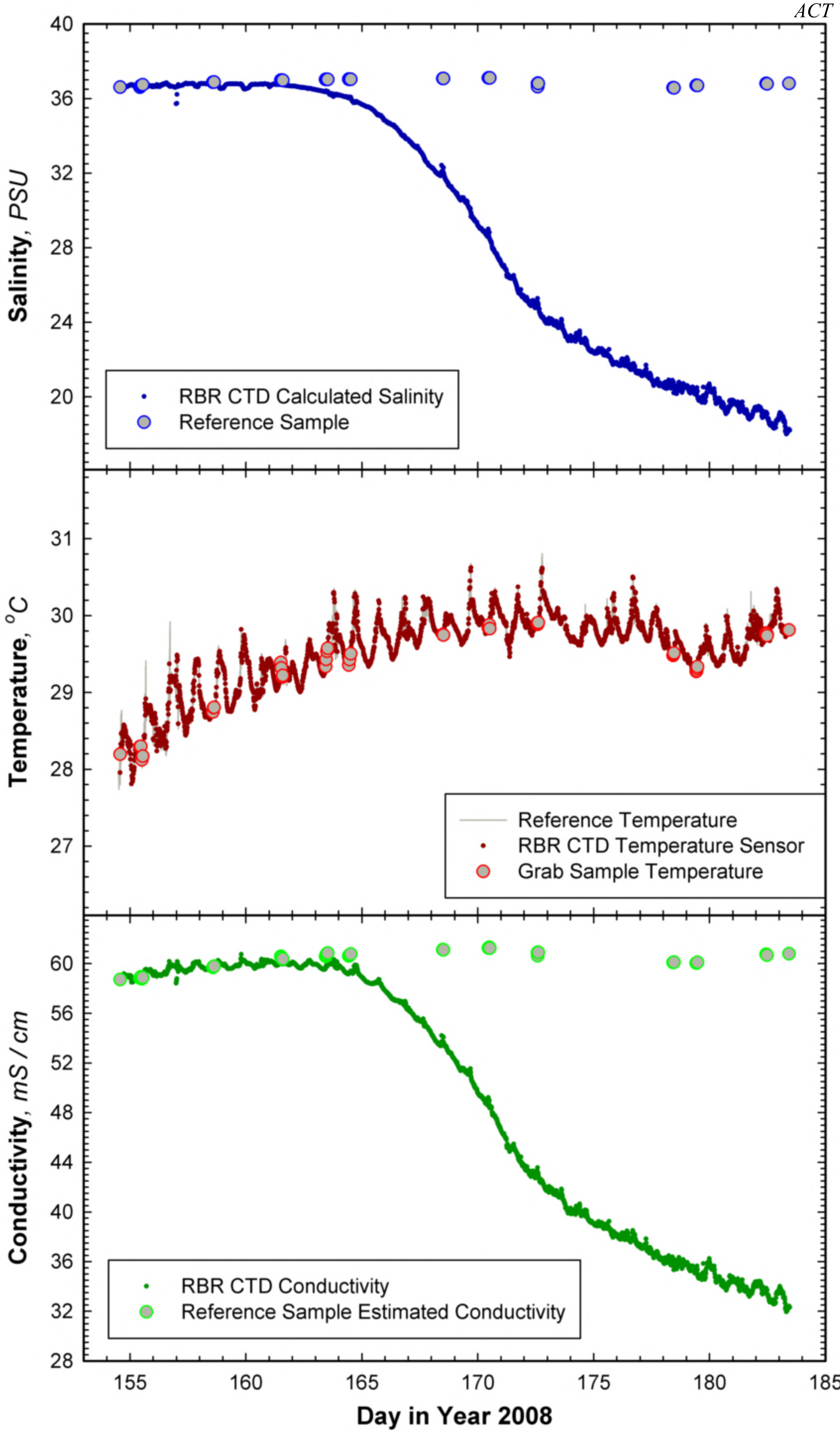


Figure 7. Time series of instrument measurements and corresponding reference samples acquired during USF field deployment.

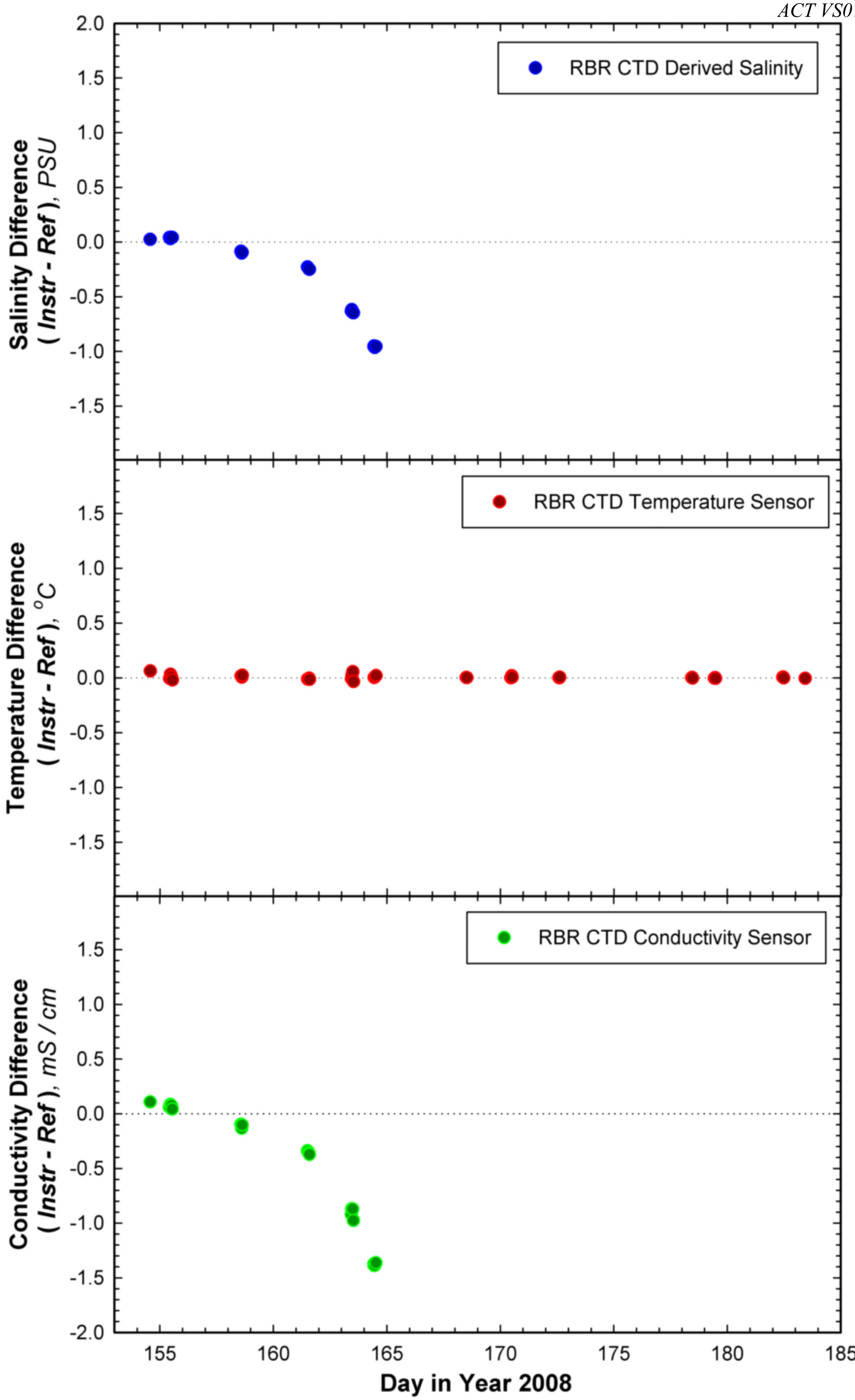


Figure 8. Assessment of relative accuracy of instrument time series measurements during USF field deployment.

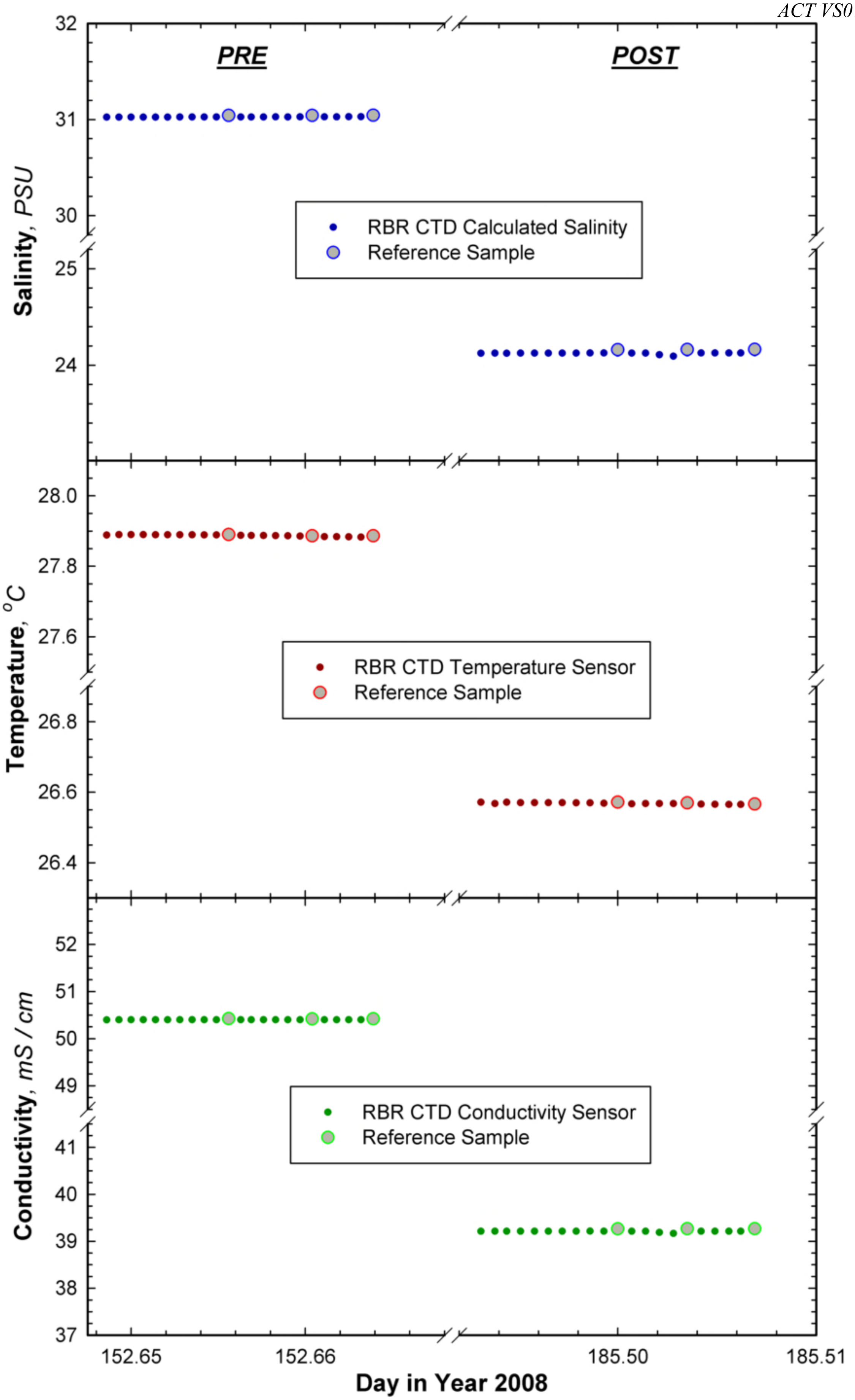


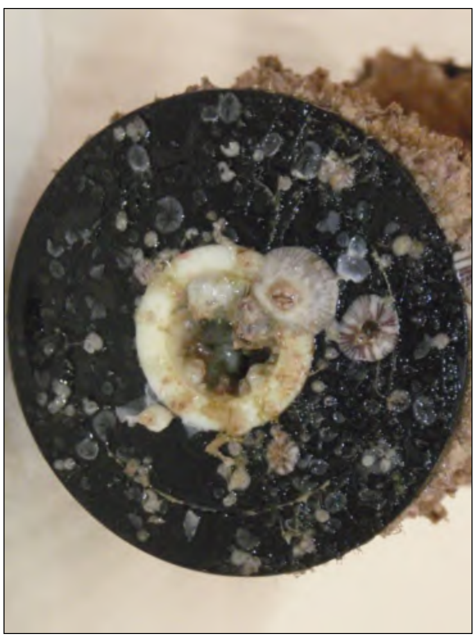
Figure 9. Pre- and Post-deployment reference checks in tanks of natural seawater at USF. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

Instrument Photographs

Before and after photos were taken of the instrument to examine the extent and possible impacts of bio-fouling (Fig. 10). A significant amount of hard, encrusting bio-fouling was evident across most of the instrument body by the end of the deployment despite the application of an anti-fouling wax, and directly within the conductivity cell were no wax was applied.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)



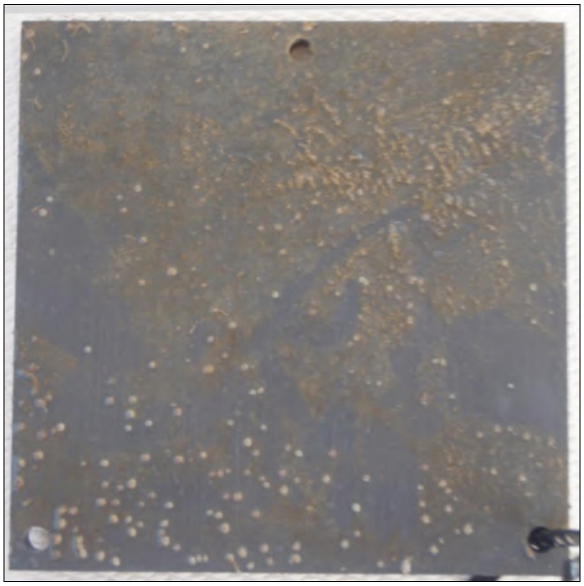
After Deployment (Close-up)

After Deployment (Full View)

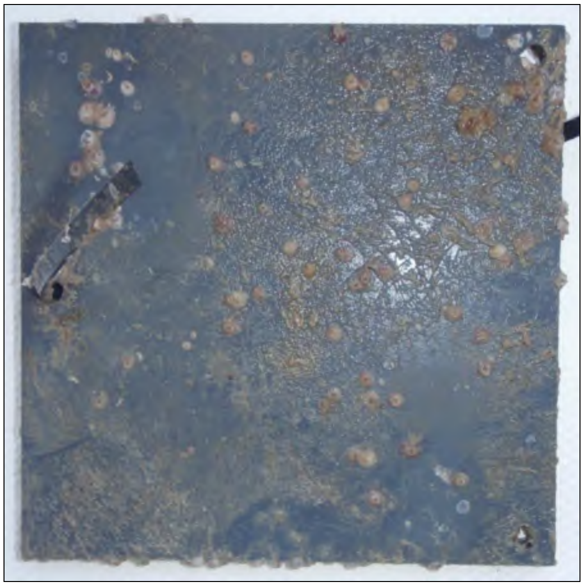
Figure 10. RBR XR-420 instrument photos from Tampa Bay, FL test site before and after deployment

Bio-Fouling Plate Photographs

Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment (Fig. 11). By the third week of deployment there was an extensive amount of hard, encrusting biofouling at the Florida test site.

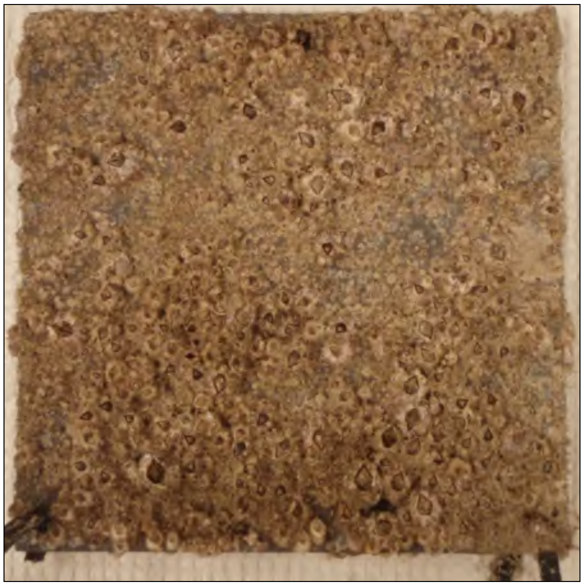


USF Site Week 1



USF Site Week 2

USF Site Week 3



USF Site Week 4

Figure 11. Weekly bio-fouling plates retrieved from the Tampa Bay, FL mooring test site.

Moored Deployment at Skidaway Island, GA

The mooring test in Georgia took place on a floating dock located on Skidaway Island on the Skidaway River (Fig. 12). The water depth of the test site was 2.3 m at minimum. The site exhibited a fairly large fluctuation in salinity, ranging from 26 – 33 PSU, and temperatures ranged from 28 – 31 ^{o}C.

SkIO Deployment Site off Skidaway Island   SkIO Easy Dock with Rack in Center

Figure 12. Site map and deployment arrangement for the field test conducted at Skidaway Island in Savannah, GA.

Time series data of in situ measured conductivity and temperature, and derived salinity, for the GA field test were plotted against corresponding results from the laboratory analyzed reference samples and reference temperature logger (Fig. 13). Similar to the FL test site, instrument performance appeared to be impacted by fouling after only 4 days with a rapid decline starting after 7 days (Fig. 14). The initial offset in salinity measurements was 0.0088 psu. The data plotted is truncated as offsets became meaninglessly large. Again the performance was directly related to the conductivity sensor and the temperature sensor was able to maintain accurate readings with an average offset of -0.0013 over the entire deployment. A test to confirm that changes in instrument performance were due to biofouling and not electronic drift was completed by comparing measurement accuracy in pre- and post- exposures in well mixed reference sampled tanks, after the instrument was cleaned to remove all biofouling (Fig 15). The agreement between instrument and reference sample values was actually better in the post-deployment exposure; however, the rapidly changing conditions in the test tank during the pre-test may have led to greater offset simply from sub-sampling in heterogeneous conditions. The amount of fouling that developed on the instrument during the deployment is shown in figure 16 and a time-series showing the rate of biofouling captured on PVC tiles in shown in figure 17.

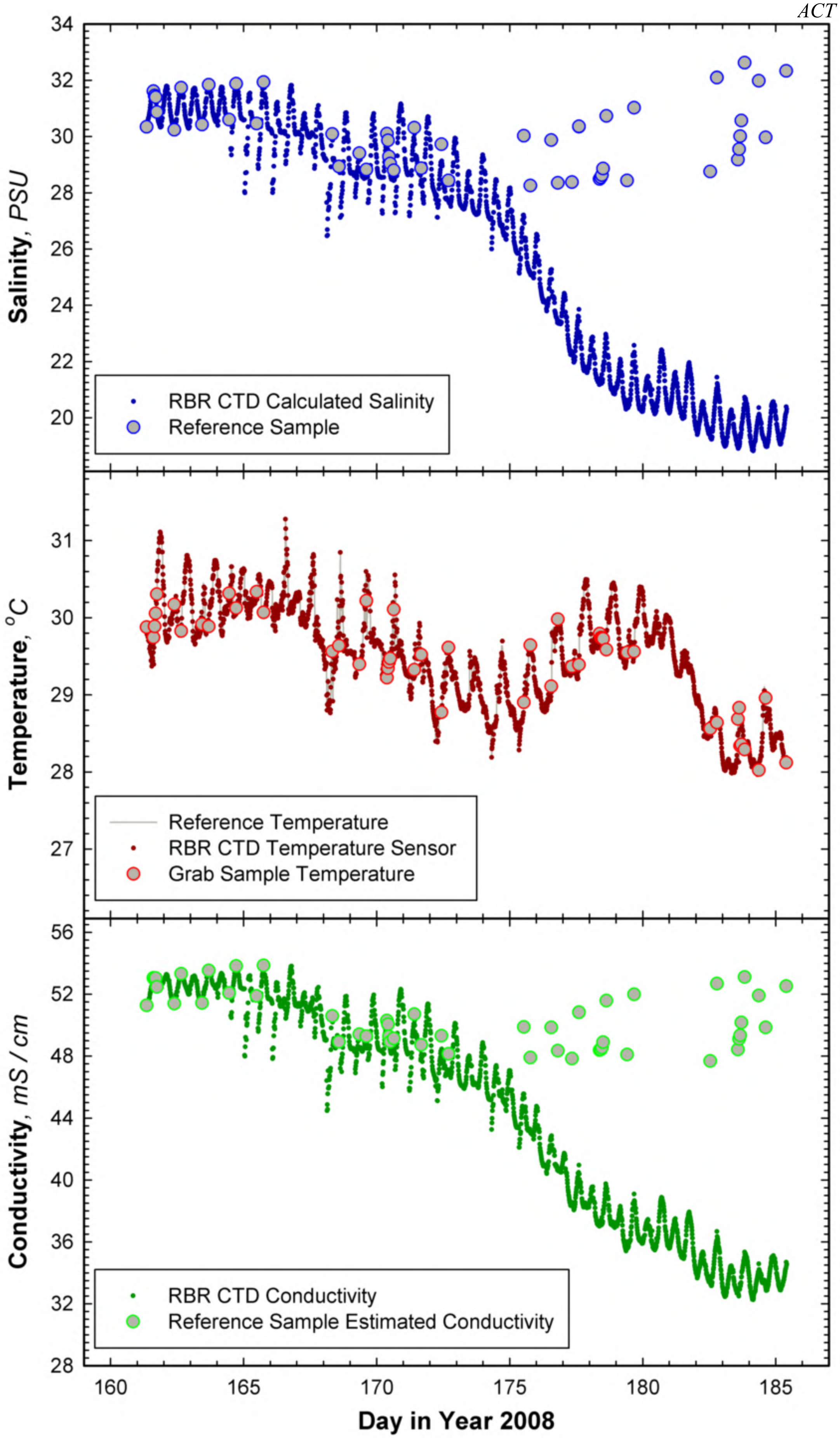


Figure 13. Time series of instrument measurements and corresponding reference samples acquired during the SkIO field deployment.

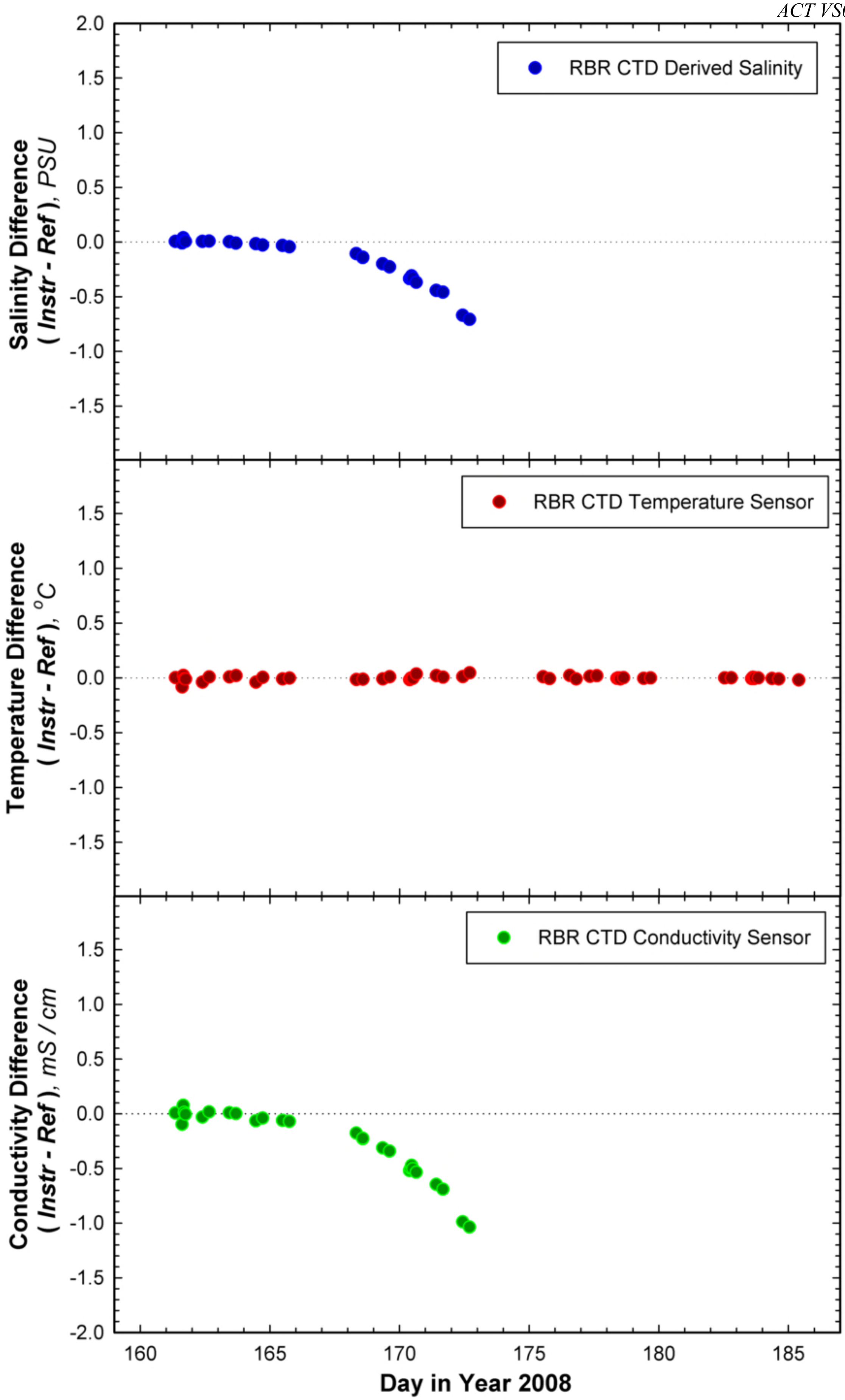


Figure 14. Assessment of relative accuracy of instrument time series measurements during the SkIO field deployment.

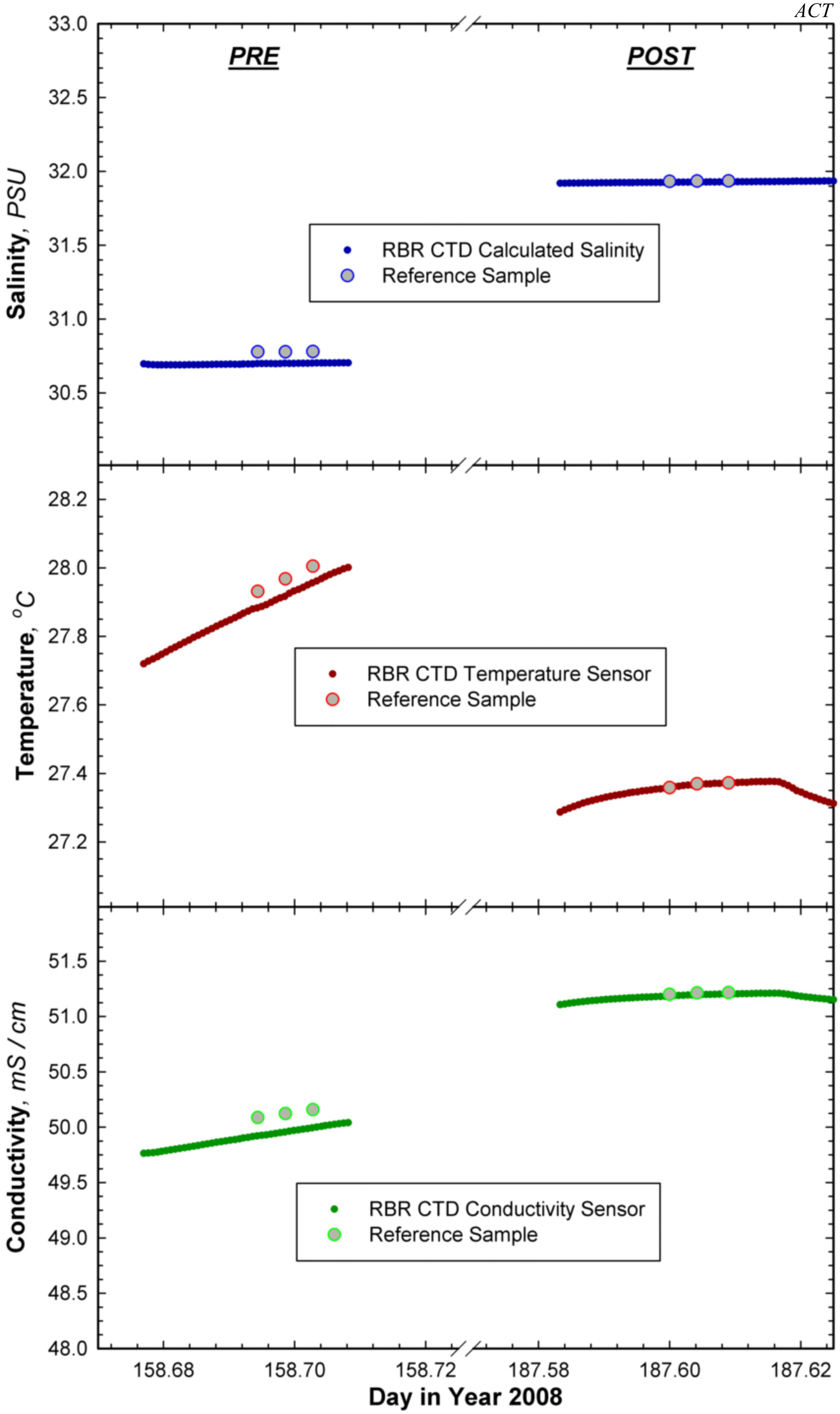


Figure 15. Pre- and Post-deployment reference checks in tanks of natural seawater at SkIO. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

Instrument Photographs

Before and after photos were taken of the instrument to examine the extent and possible impacts of bio-fouling (Fig. 16). A significant amount of soft (plant material) and hard (calcified) bio-fouling was evident across most of the instrument body by the end of the deployment despite the application of an anti-fouling wax, and directly on and within the conductivity cell were no wax was applied.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

After Deployment (Close-up)

After Deployment (Full View)

Figure 16. RBR XR-620 instrument photos from Skidaway, GA test site before and after deployment

Bio-Fouling Plate Photographs

Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment (Fig. 17). Significant amounts of soft biofouling were evident by week 2 and progressed into heavy amounts of hard, encrusting biofouling at the Georgia test site.


SkIO Site Week 1


SkIO Site Week 2


SkIO Site Week 3

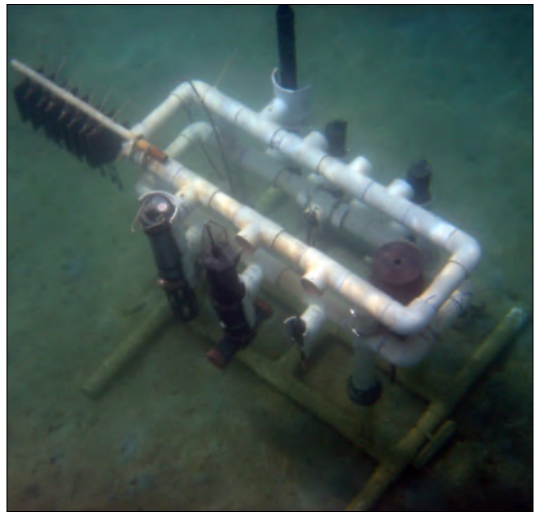

SkIO Site Week 4

Figure 17. Weekly bio-fouling plates retrieved from the Skidaway, GA test site.

Moored Deployment off Coconut Island in Kaneohe Bay, Hawaii

The mooring test in Kaneohe Bay took place on the fringing reef flat surrounding Coconut Island. The instruments were placed on a standing rack (Fig. 18) in a water depth of 3 meters with tidal variations typically less than 0.5 m at this site. During the deployment test, salinity values ranged from 33 to 35.5 and water temperatures from 26.1 to 29.6 ^{o}C.

Deployment Site on Coconut Island



Instruments in Deployment Rack

Figure 18. Site Photos from Field Deployment off Coconut Island, Kaneohe Bay, HI.

Time series data of in situ measured conductivity and temperature, and derived salinity, for the HI field test were plotted against corresponding results from the laboratory analyzed reference samples and reference temperature logger (Fig. 19). The rate of performance decline was slower at this site than FL or GA, but was still noticeable after a few days prevelant by week 3 (Fig. 20). The initial offset in salinity was -0.0027 psu and the mean offset in temperature measurements for the entire duration was 0.0024 ^{o}C. There was a small, but measureable difference in the amount of offset between the pre- and post-exposure tests (Fig. 21). The salinity offset increased by about 0.1 psu for the post-test. The change was again from the conductivity sensor as the temperature sensor response was very consistent between tests. The amount of fouling that developed on the instrument during the deployment is shown in figure 22 and a time-series showing the rate of biofouling captured on PVC tiles in shown in figure 23.

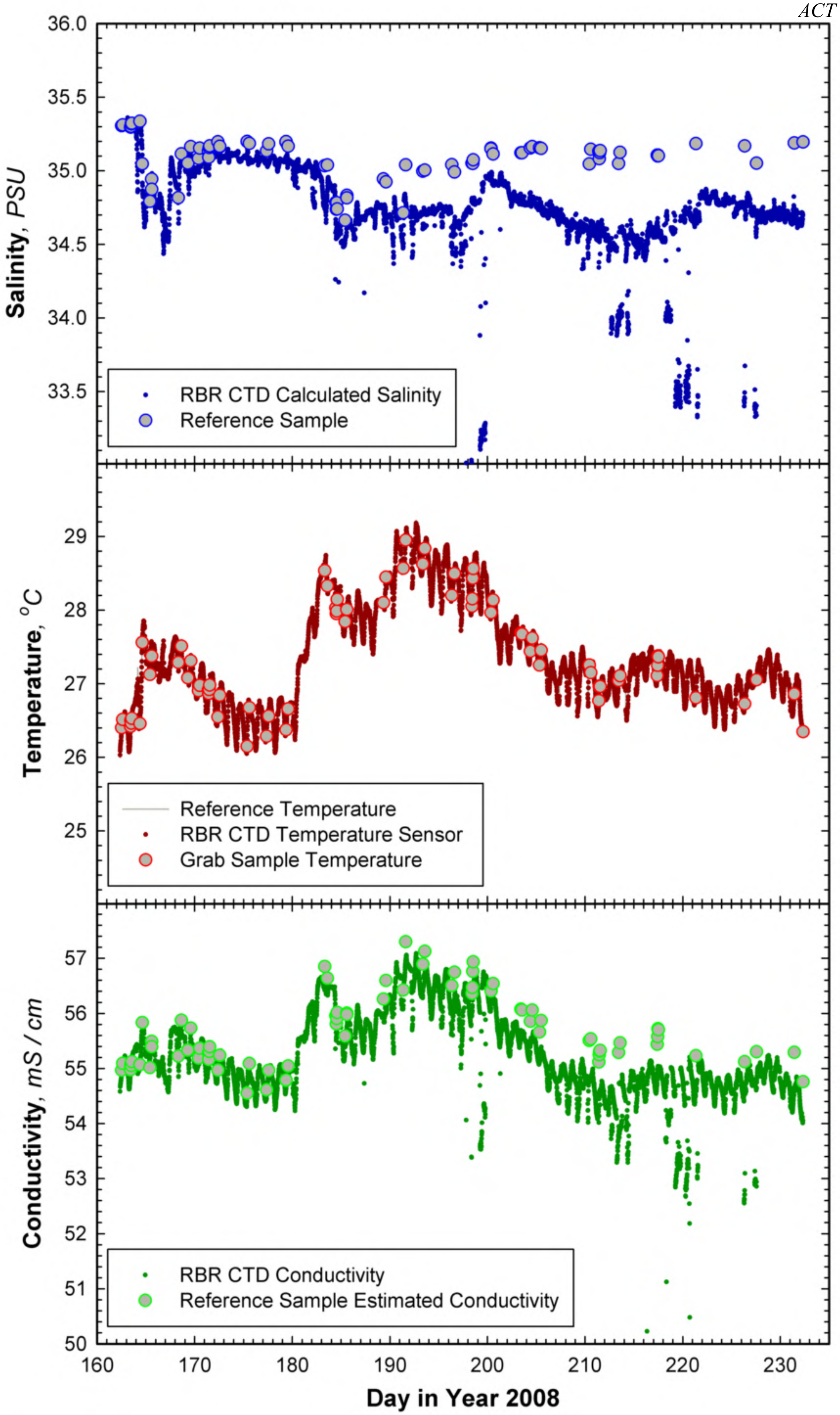


Figure 19. Time series of instrument measurements and corresponding reference samples acquired during the HI field deployment.

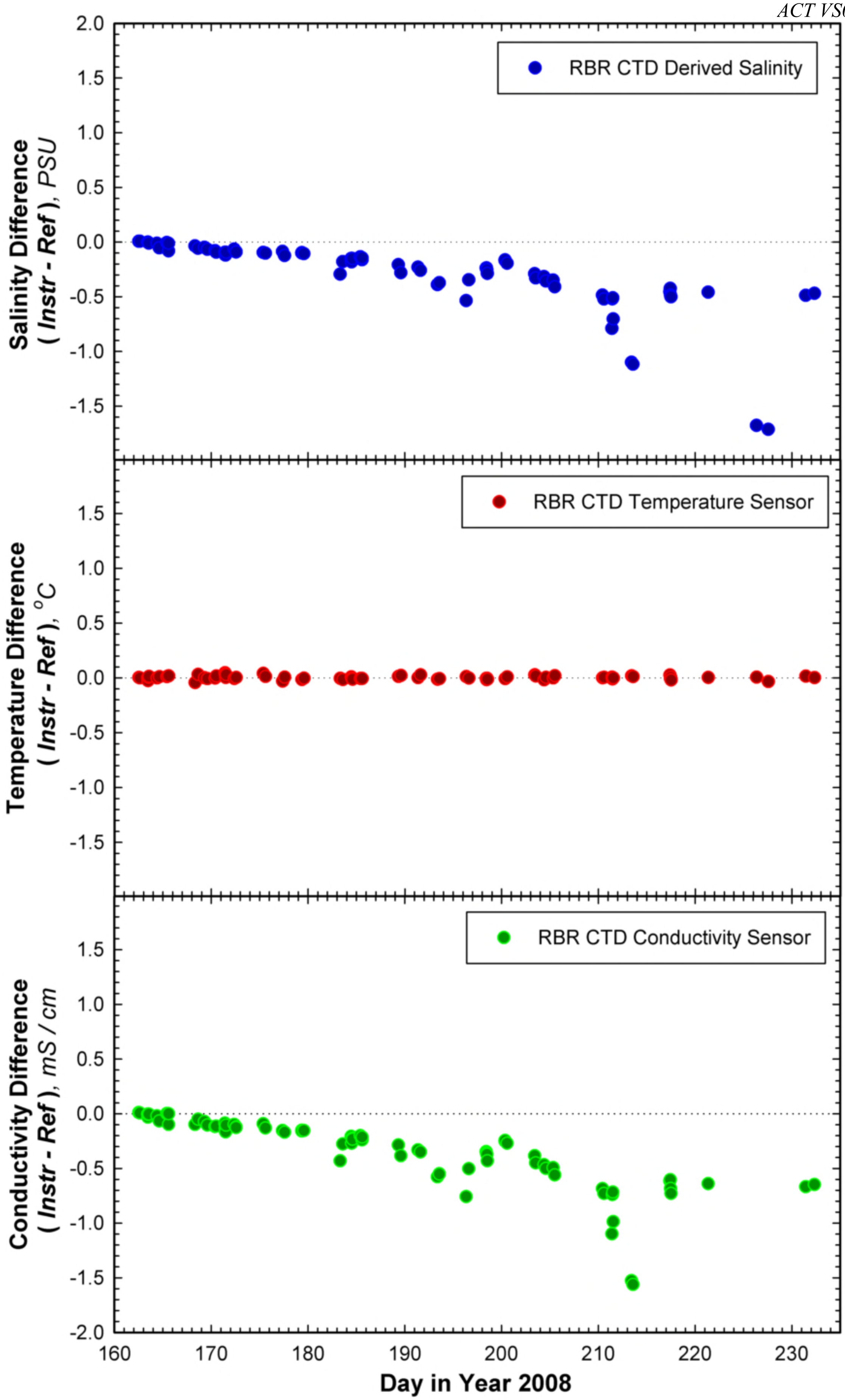


Figure 20. Assessment of relative accuracy of instrument time series measurements during the HI field deployment.

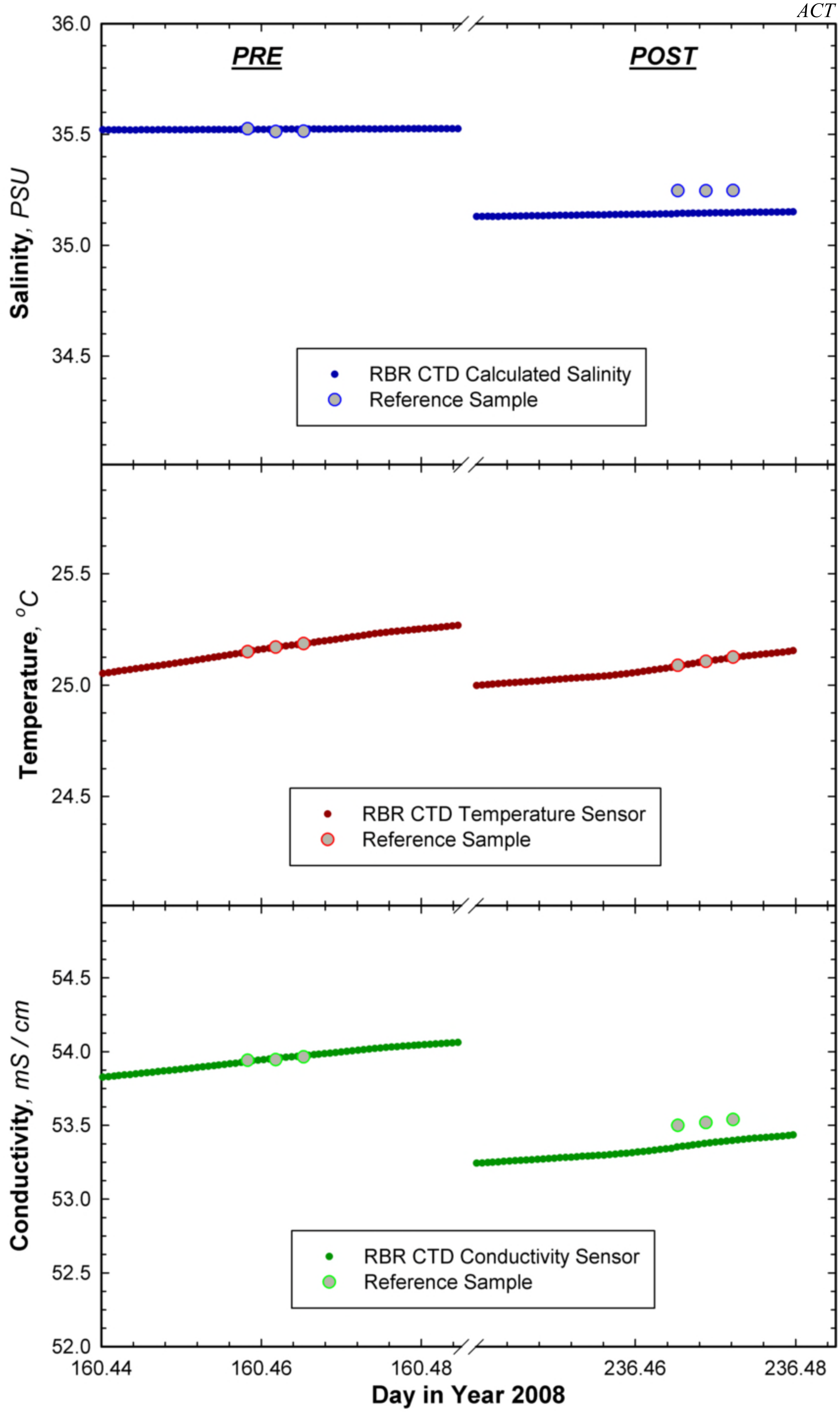


Figure 21. Pre- and Post-deployment reference checks in tanks of natural seawater at HI. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

Instrument Photographs

Before and after photos were taken of the instrument to examine the extent and possible impacts of bio-fouling (Fig. 22). The extent of bio-fouling was significantly less at this test site relative to FL or GA despite the longer deployment period and was mostly comprised of plant material and worm cases.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

After Deployment (Close-up)

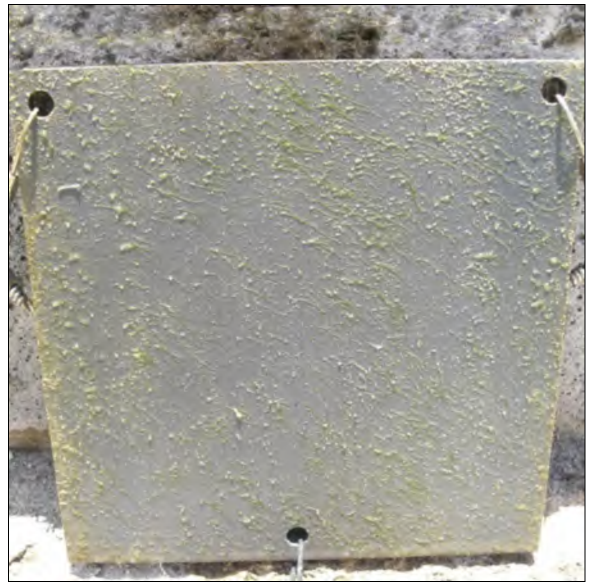
After Deployment (Full View)

Figure 22. RBR XR-420 instrument photos from Coconut Island, HI test site before and after deployment

Bio-Fouling Plates Photographs

Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment. A sub-set of the plate photographs covering weeks 1, 2, 4, and 8 are shown in Figure 23. The extent of bio-fouling was significantly less at this test site relative to FL or GA despite the longer deployment period and was mostly comprised of plant material and worm cases.

HI Site Week 1



HI Site Week 2

HI Site Week 4

HI Site Week 8

Figure 23. Bio-fouling plates for weeks 1, 2, 4, and 8 for the field deployment test off Coconut Island, Kaneohe Bay, HI.

Moored Deployment in Clinton River, MI

The mooring test in Michigan took place at the end of a fixed pier located at the mouth of the Clinton River which drains into Lake St. Clair (Fig. 24). The water depth of the test site was 2.2 m. The site exhibited a fairly large fluctuation in conductivity, ranging from 269 - 947 µS/cm as shifting winds produce a varying mixture of river water and lake water and water temperature ranged from 18.5 – 27 ^{o}C. A freshwater version of the conductivity was mounted on the XR-420 for this test site.

Figure 24. Site map and photo of the Great Lakes field test site located at the mouth of the Clinton River in Mt. Clemens, MI. The test instrument was deployed on a mooring frame attached to the end of a fixed pier.

Time series data of in situ measured conductivity and temperature, and derived salinity, for the GL field test were plotted against corresponding results from the laboratory analyzed reference samples and reference temperature logger (Fig. 25). The RBR XR-420 measurements closely matched reference sample measurements throughout the entire 29 day deployment and captured the temporal gradients experienced at the site from variable mixing of river and lakewater. The amount of offset in salinity, conductivity and temperature averaged -0.0040 psu, -0.0076 mS/cm, and 0.0162 ^{o}C, respectively over the deployment (Fig. 26). The occasional greater offset in temperature could easily be explained by heterogeneity around the mooring and the distance between the instrument and reference temperature logger. The offset in the instrument salinity, conductivity, and temperature measurements was nearly identical between the pre- and post-deployment exposure test (Fig. 27). In general there was very little fouling impact at this site. The amount of fouling that developed on the instrument during the deployment is shown in figure 27 and a time-series showing the rate of biofouling captured on PVC tiles in shown in figure 28.

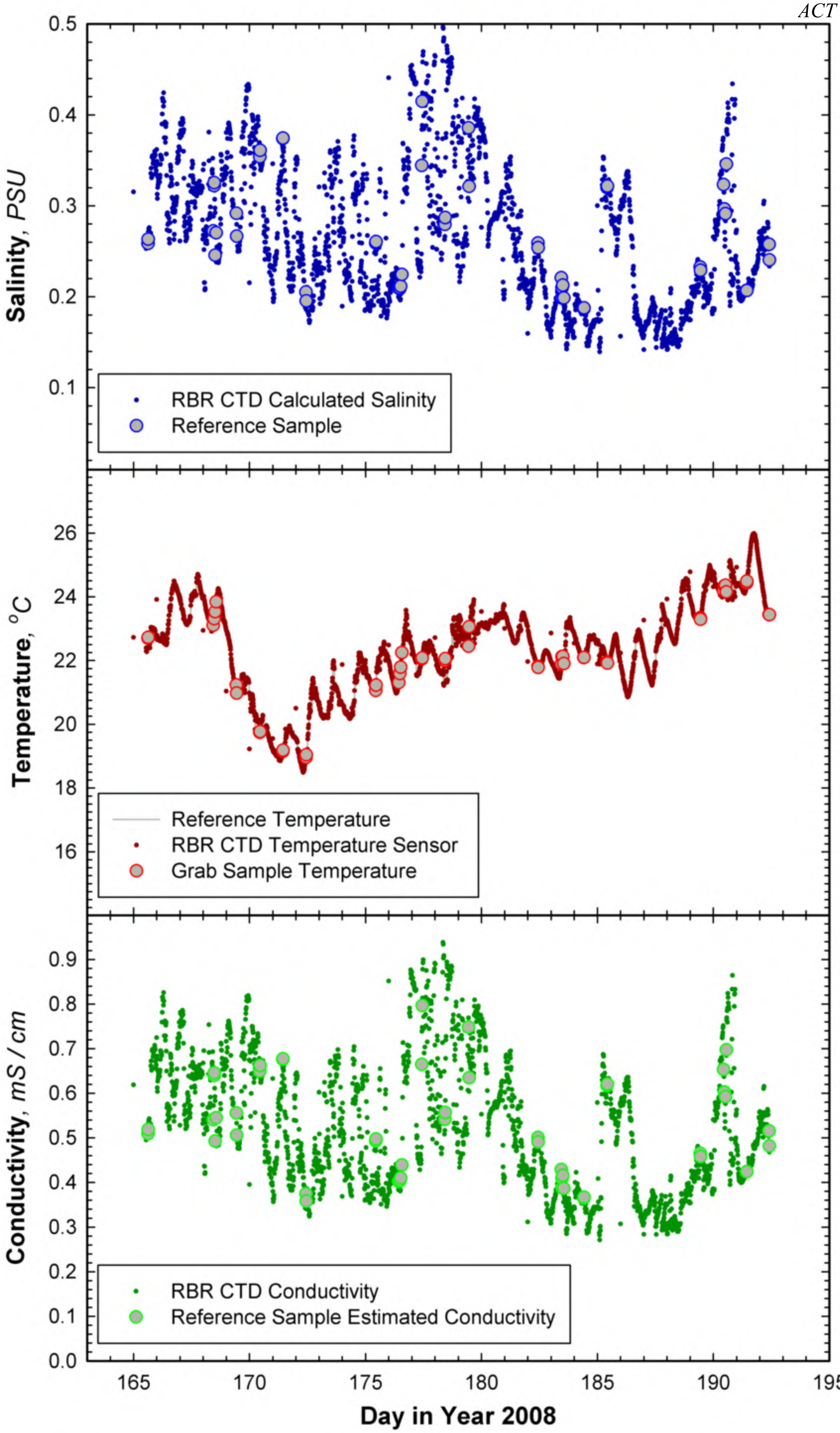


Figure 25. Time series of instrument measurements and corresponding reference samples acquired during the GL field deployment.

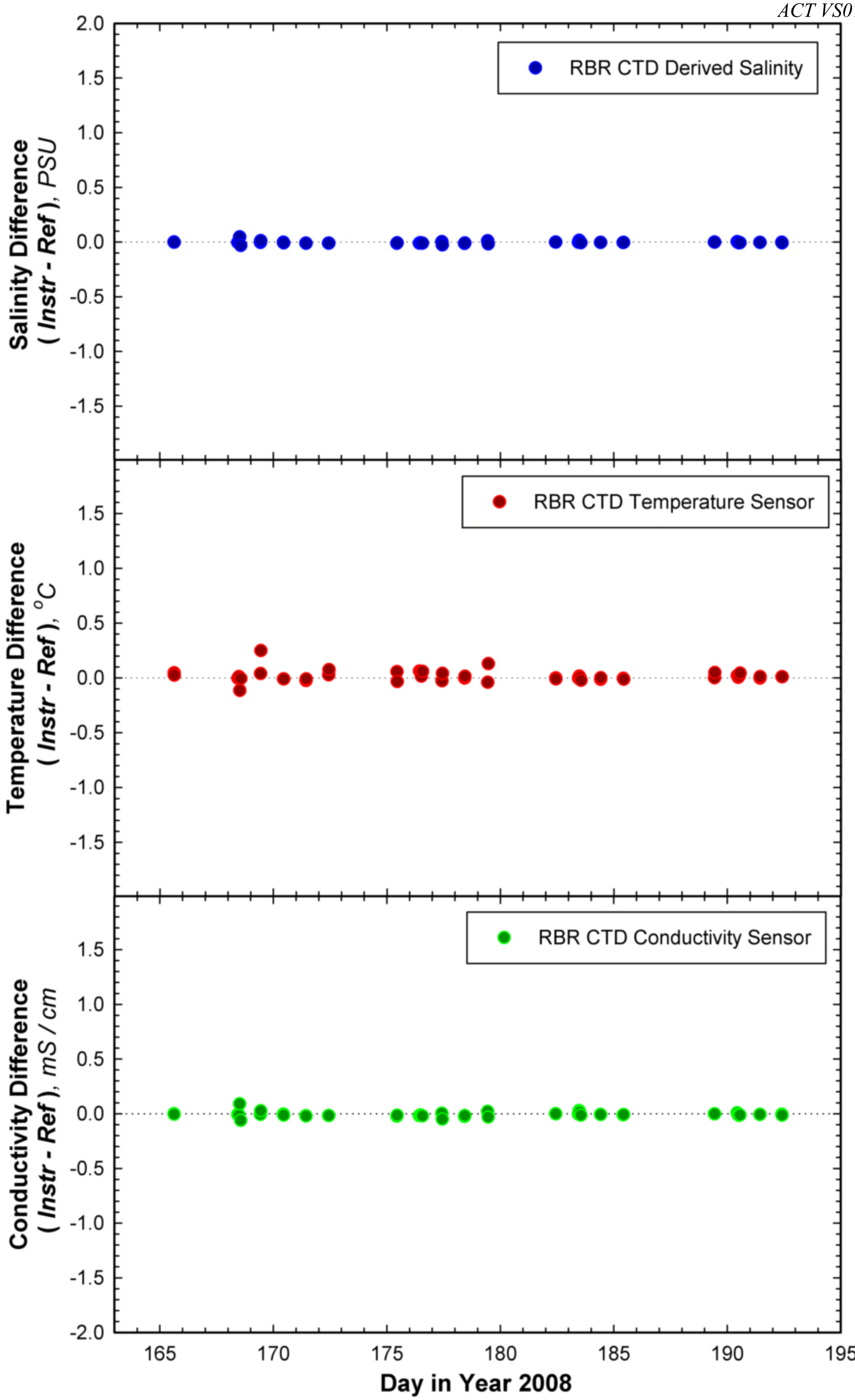


Figure 26. Assessment of relative accuracy of instrument time series measurements during the GL field deployment.

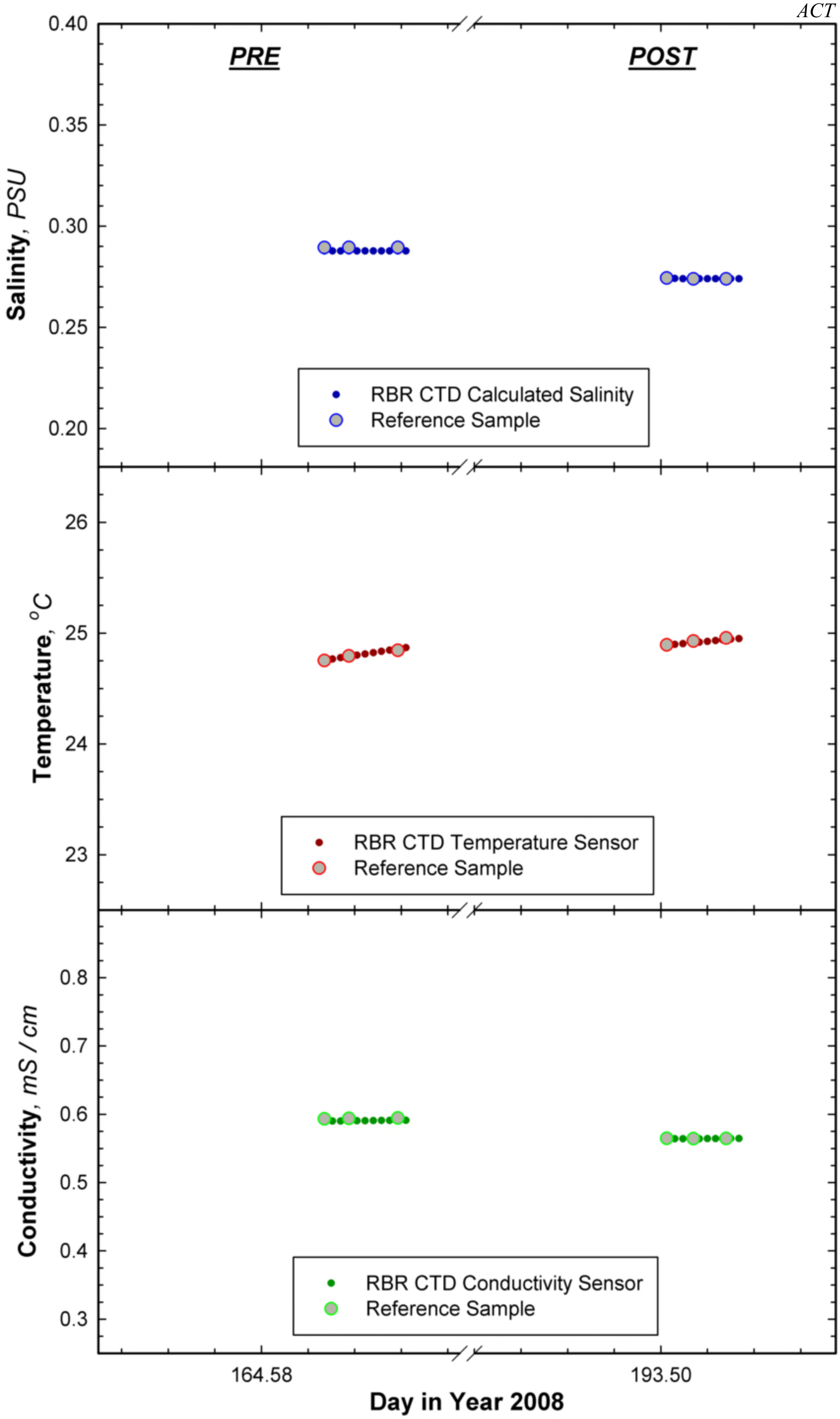


Figure 27. Pre- and Post-deployment reference checks in tanks of river water at GL. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

Instrument Photographs

Before and after photos were taken of the instrument to examine the extent and possible impacts of bio-fouling (Fig. 28). The extent of bio-fouling was quite low at the MI test site and consisted of only soft plant material.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

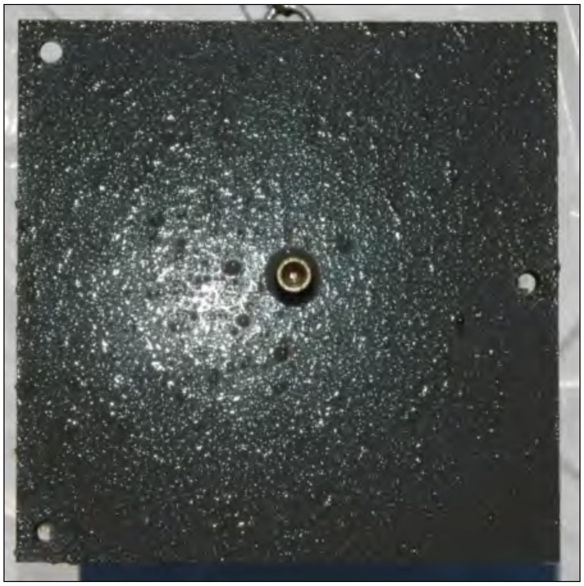
After Deployment (Close-up)

After Deployment (Full View)

Figure 28. RBR XR-420 instrument photos from the Clinton River, MI test site before and after deployment. The instrument was equipped with freshwater version of the conductivity cell.

Bio-Fouling Plate Photographs

Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment (Fig. 29). Biofouling material was mostly comprised of plant material and developed rather quickly but did not appear to accumulate significantly once the original surface was covered.



Great Lakes Site Week 1

Great Lakes Site Week 2

Great Lakes Site Week 3

Great Lakes site Week 4

Figure 29. Weekly bio-fouling plates retrieved from the Great Lakes test site on the Clinton River, MI.

Moored Deployment in Humpy Cove, Resurrection Bay, AK

The mooring test in Resurrection Bay took place within the inlet of Humpy Cove on a floating dock attached to the end of a small fixed pier (Fig 30). The water depth of the test site was 3 m.

Deployment Site in Ressurection Bay

Floating Dock location in Humpy Cove

Figure 30. Site map and photo of the Alaska field test site located in Humpy Cove of Resurrection Bay near Seward, AK. The test instrument was deployed on a mooring frame attached to a floating dock.

Time series data of in situ measured conductivity and temperature, and derived salinity, for the AK field test were plotted against corresponding results from the laboratory analyzed reference samples and reference temperature logger (Fig. 31). Instrument measurements tracked daily and weekly variations throughout the entire deployment; however, mixing events likely resulted in sharp gradients around the mooring and led to greater variability in the relative accuracy of the in situ measurements computed as numerical differences from the reference values (Fig. 32). The fact that measurement accuracy returned to original levels following most large deviations, even at the very end of the test supports the assumption that the greater variability was due to water mass heterogeneity and not instrument performance or biofouling. Also, comparison of instrument accuracy and precision measured during pre- and post- exposure tests, following instrument cleaning, revealed no measureable performance drift over the deployment period of 29 days (Fig 33). The amount of fouling that developed on the instrument during the deployment is shown in figure 34 and a time-series showing the rate of biofouling captured on PVC tiles in shown in figure 35.

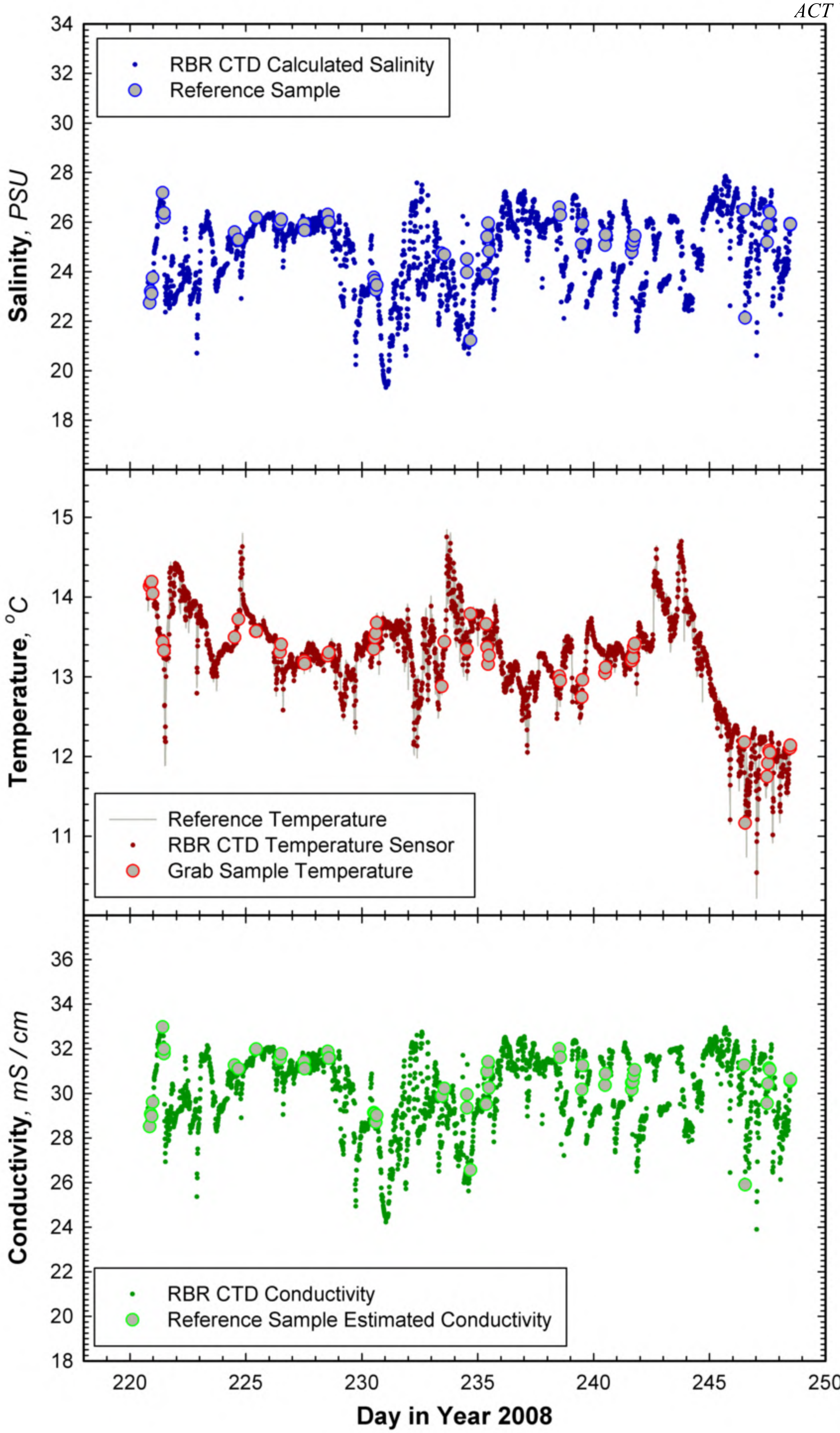


Figure 31. Time series of instrument measurements and corresponding reference samples acquired during the AK field deployment.

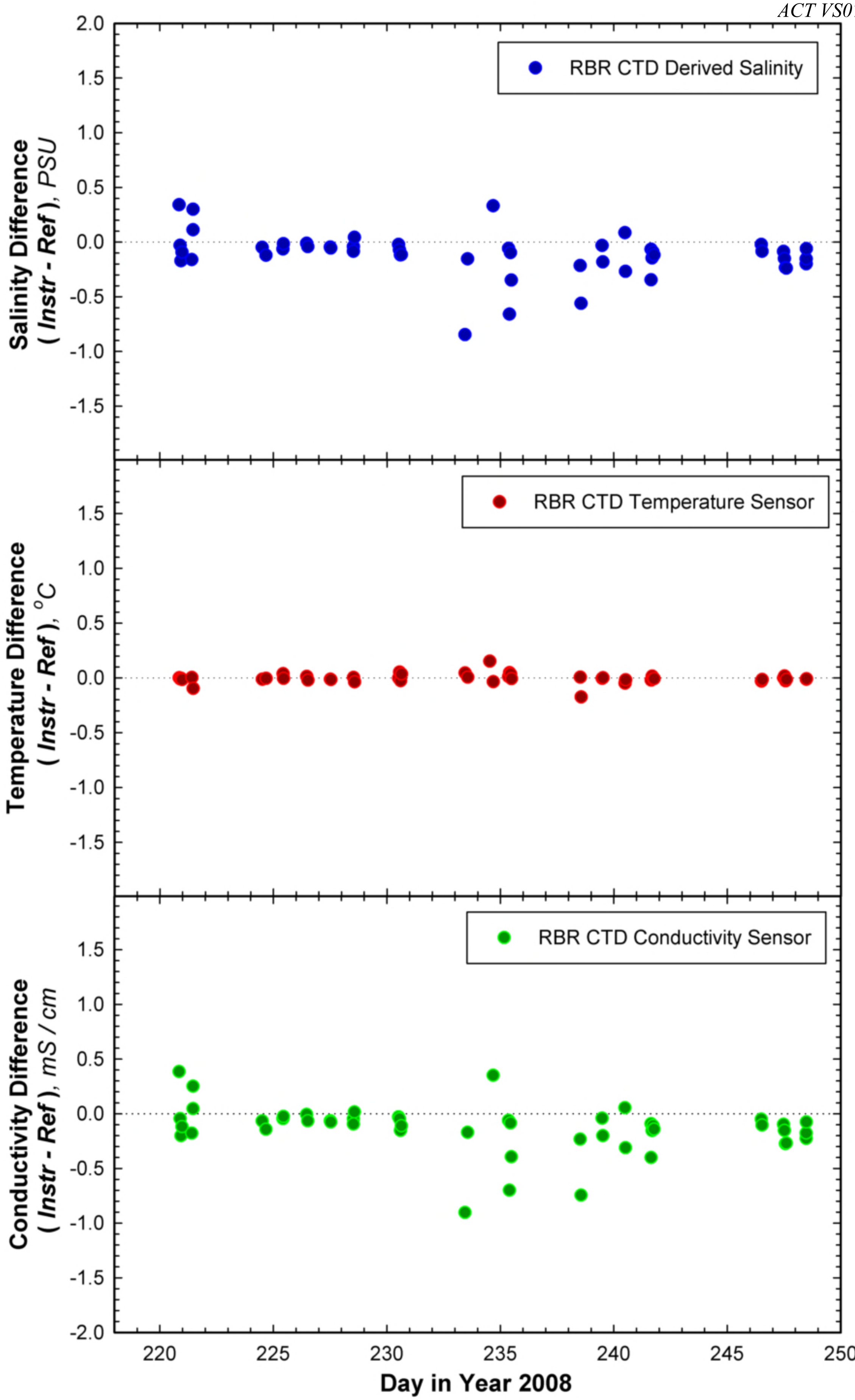


Figure 32. Assessment of relative accuracy of instrument time series measurements during the AK field deployment.

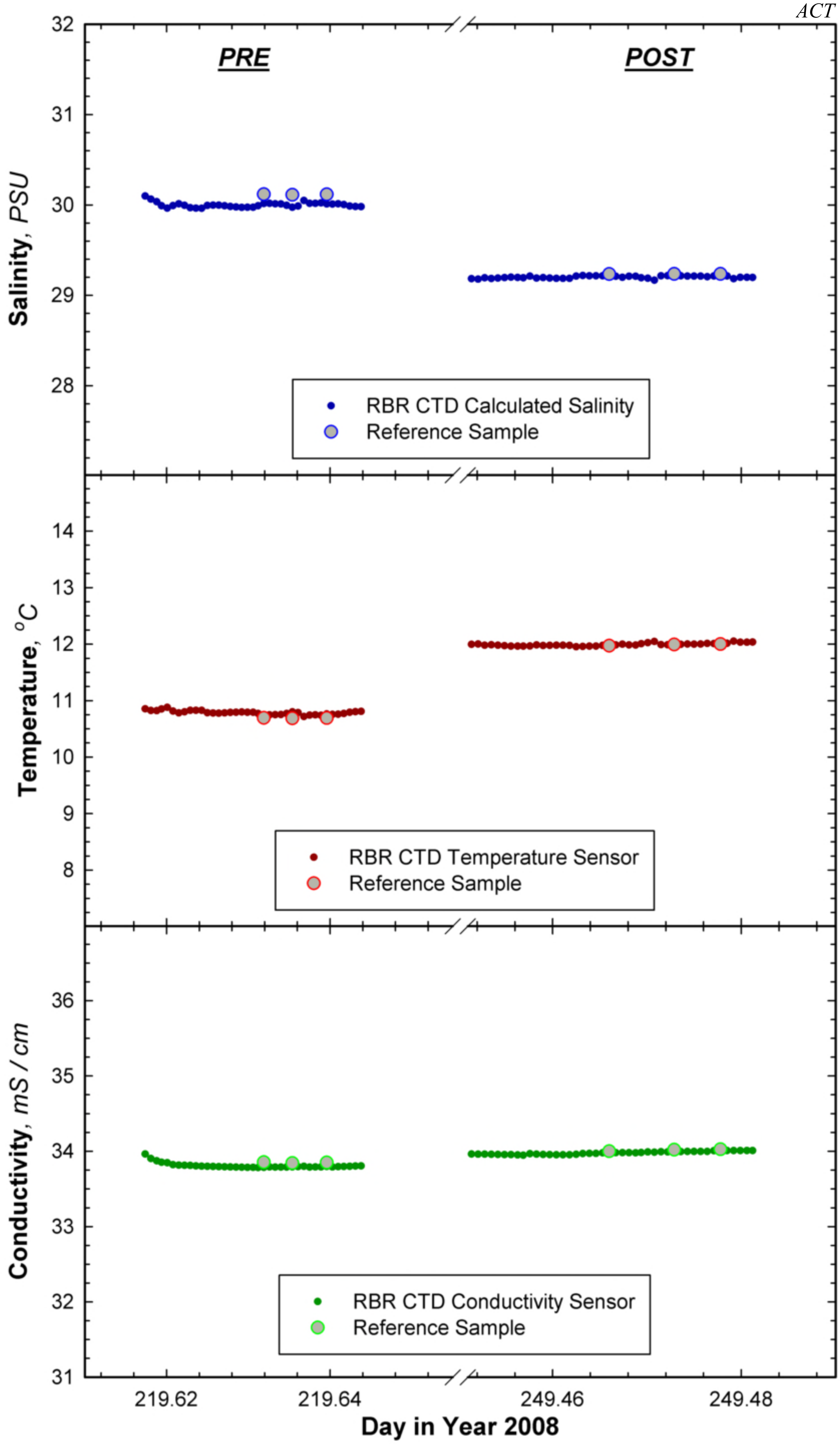
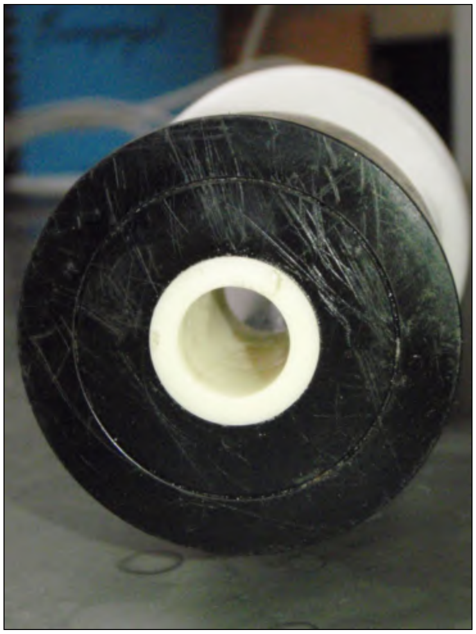


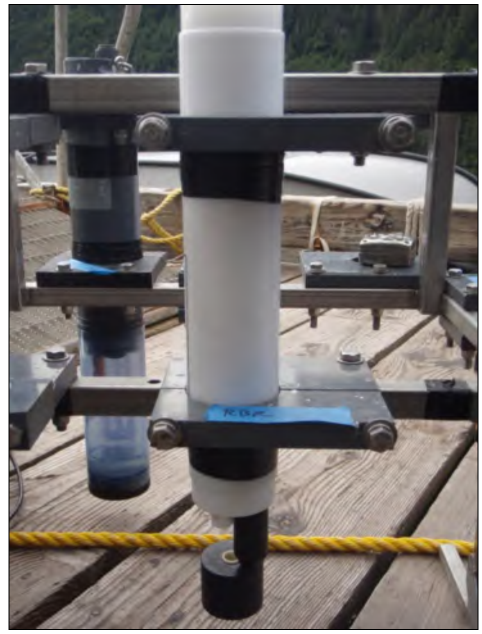
Figure 33. Pre- and Post-deployment reference checks in tanks of natural seawater at AK. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

Instrument Photographs

Before and after photos were taken of the instrument to examine the extent and possible impacts of bio-fouling (Fig. 34). The extent of bio-fouling at the AK test site was very small and the lowest of any of the five test sites. No hard fouling was observed.



Prior to Deployment (Close-up)



Prior to Deployment (Full View)

After Deployment (Close-up)

After Deployment (Full View)

Figure 34. RBR XR-620 instrument photos from the Resurrection Bay, AK test site before and after deployment.

Bio-Fouling Plate Photographs

Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment (Fig. 35). Biofouling material was mostly comprised of plant material and had a slower but consistent rate of fouling until the surface was completely covered.

AK Site Week 1

AK Site Week 2

AK Site Week 3

AK Site Week 4

Figure 35. Bio-fouling plates from the Humpy Cove test site in Seward, AK.

Composite Field Results

Field deployment results were composited for all five test sites to provide an overall comparison of instrument performance across the range of environmental conditions present at out test sites. Data were restricted to the first 14 days of the deployments at each site to minimize the effects of biofouling. The data are analyzed as instrument measurements plotted against reference sample measurements for salinity, conductivity, and temperature (Fig. 36). The responses of the test instruments were highly linear when analyzed across all sites and provide a field confirmation of the performance capability that was determined from the laboratory test solutions. The effects of biofouling, drift, and site heterogeneity can be viewed as the vertical deviations from the 1:1 data correspondence trend line. The mean offsets from this composited, 14-day field site data were -0.2627 psu, -0.3716 mS/cm, and 0.0078 ^{o}C for salinity, conductivity, and temperature, respectively.

RESULTS OF VERTICAL PROFILING FIELD TEST

The RBR XR-620 was tested under a vertical profiling application at 2 locations within Resurrection Bay, AK during a single 1 day cruise. Both locations were known to have well defined pycnoclines, with one site located on the shelf just outside the Bay and the other within the Bay in an area known to be influenced by coastal runoff. The profiling test involved the comparison of simultaneous instrument measurements and discrete samples collected at six discrete depths throughout the water column.

Profiling results showing the instrument measurements and corresponding reference sample comparisons for the nearshore and offshore sites are shown in figure 37 and 38, respectively. The instrument measured salinity closely tracked the salinity profile as defined by the reference sample measurements. The accuracy and precision were similar at all depth for both of the profiles. The average measurement error for all profiling samples was -0.0191 ±0.0096 psu. Separate conductivity and temperature responses were not generated for the profiles.

RELIABILITY

The RBR XR-420 or XR-620 CTD Salinity Sensors were tested under three different applications including: 1) a laboratory test involving 15 different salinity/temperature combinations; 2) in a fixed mooring application at five different field sites including, estuary, coastal ocean, and riverine environments; and 3) in a vertical profiling application at 2 sites within a northern coastal fjord. Complete time series data were successfully retrieved from all test applications and all five testing sites for the deployments. Drift in instrument time clocks were examined at four sites and a change of 1, -1, 0, and 5 seconds was noted for the GA, AK, MI and HI test sites, respectively over the span of the deployment. There was no evidence of electronic drift or calibration response during the 30 – 60 day deployments. Lastly, sites with hard, encrusting biofouling had a significant impact on performance but biofouling of plant material had much less impact.

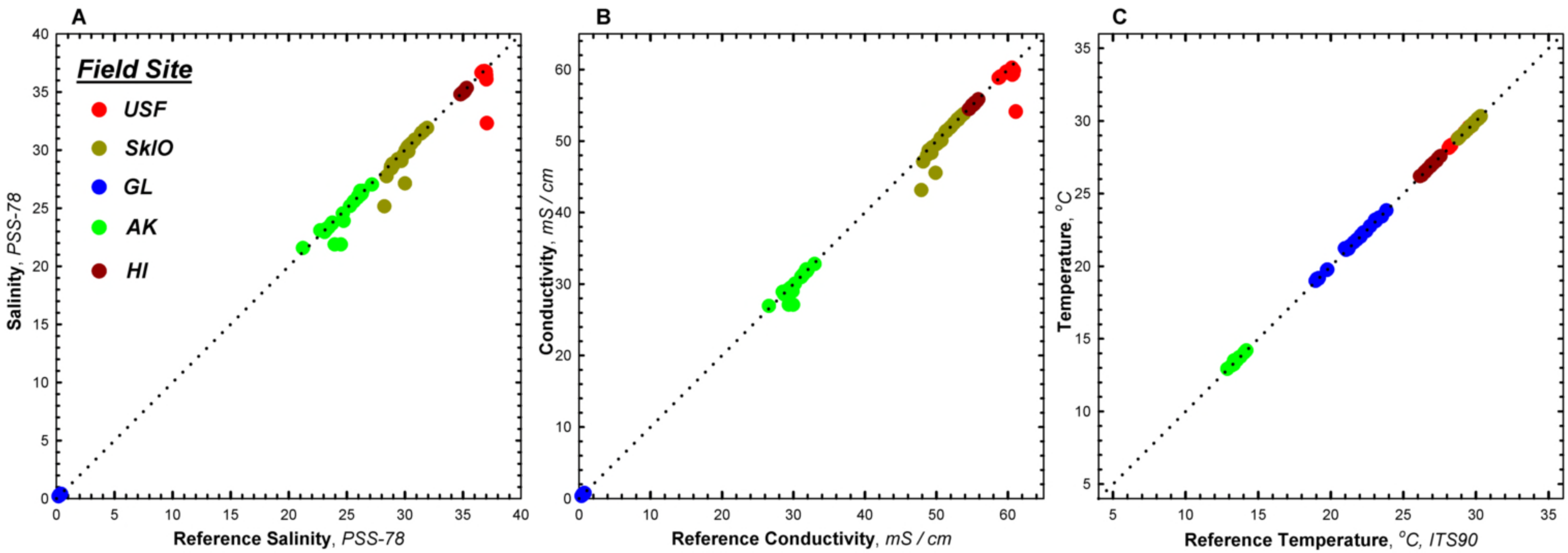


Figure 36. Composite summary of field performance over the first 14 days of deployment for the four RBR 620 CTD units tested during the five evaluation trials. Instrument output plotted against paired field reference sample assay and color indexed by field test site. Dotted line represents 1:1 data correspondence trend line. Scatter around trend line represents occurence of site-specific fouling effects on conductivity cell performance.

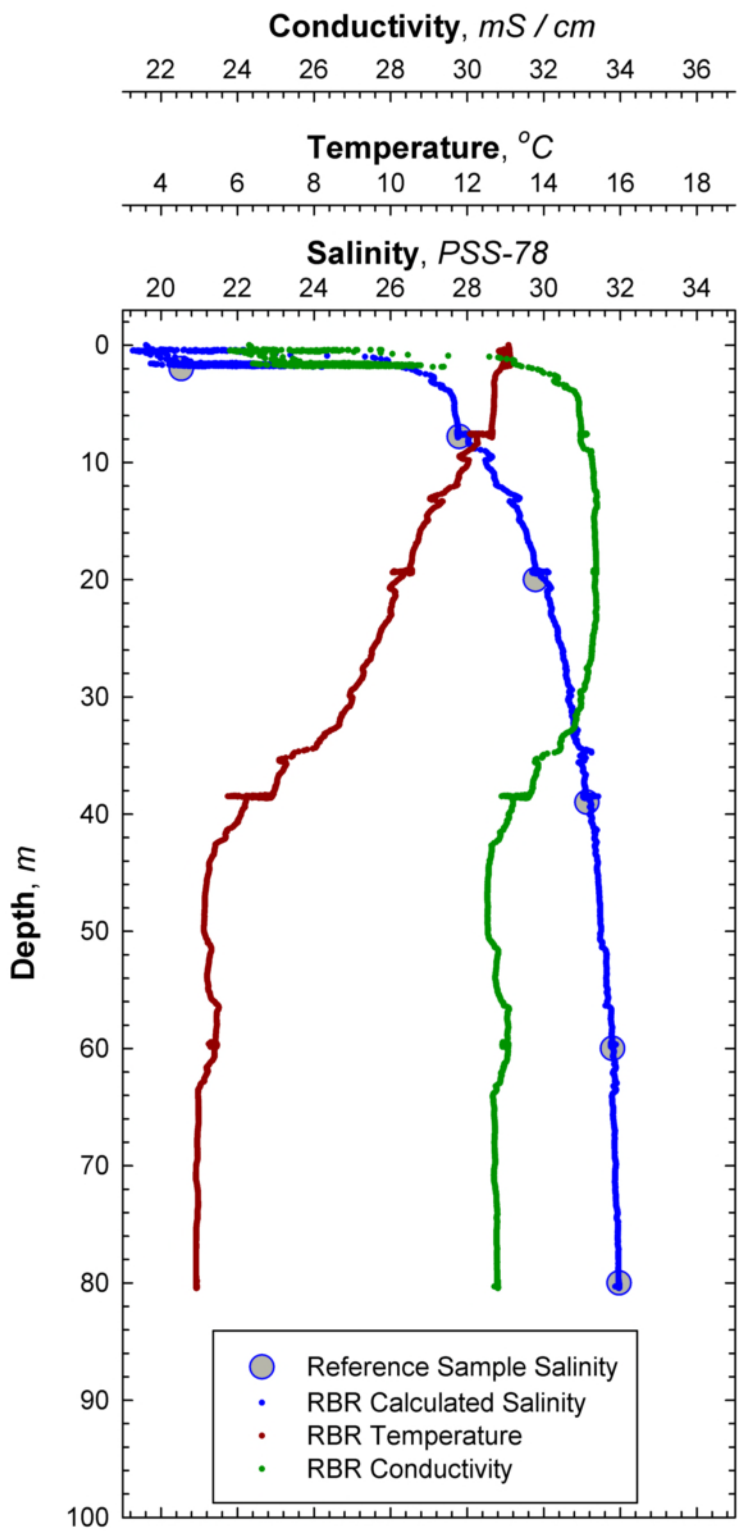


Figure 37. Vertical profile data from the RBR XR620 CTD deployed offshore of the Seward Marine Life Center within Resurrection Bay, AK. Sharp pycnocline at 2 m indicative of influence of glacial runoff at this site.

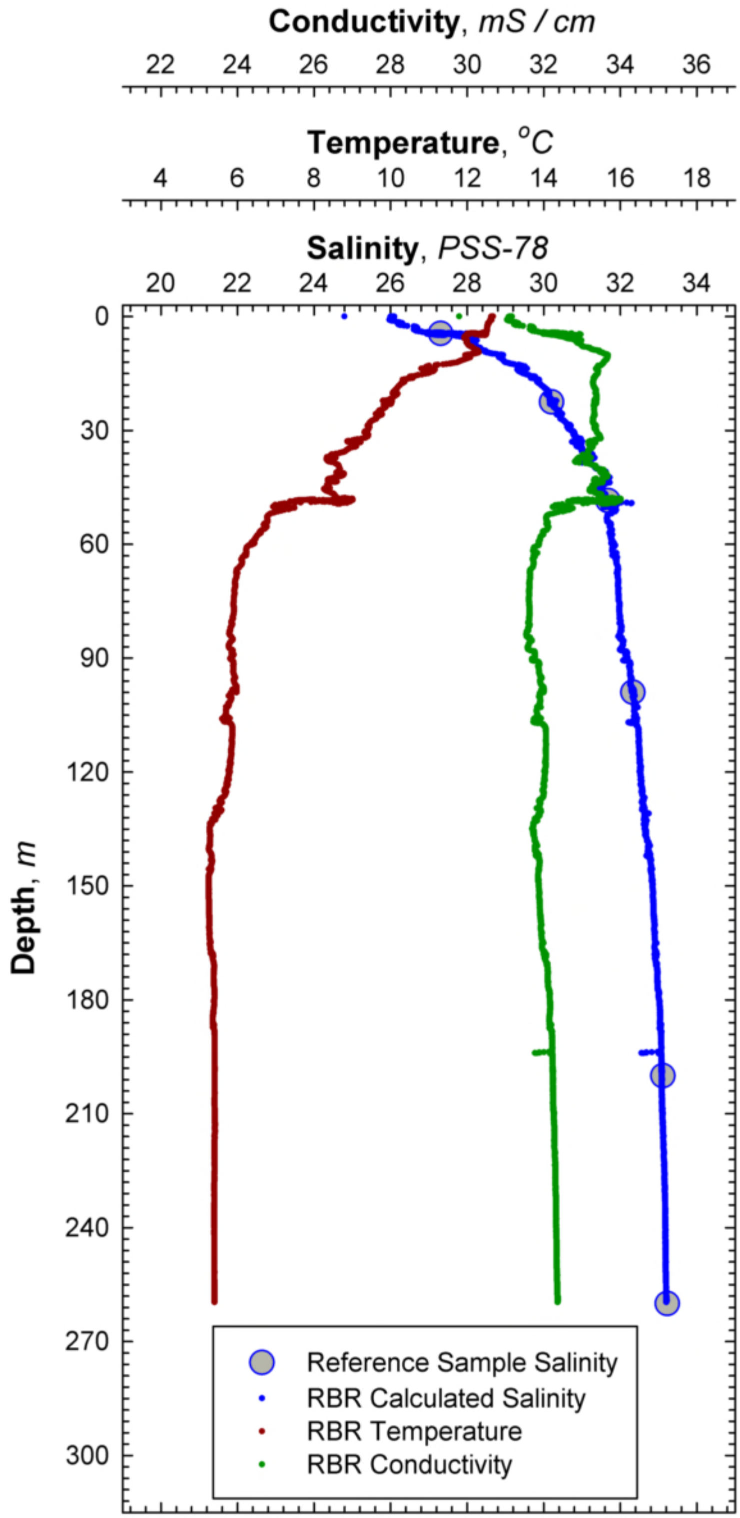


Figure 38. Vertical profile data from the RBR XR620 CTD deployed in deep water off the shelf outside of Resurrection Bay, AK. Deeper and narrower pycnocline reflects mixing of offshore and bay waters.

ANALYSIS OF QUALTIY CONTROL SAMPLES AND REFERENCE SAMPLE PRECISION

Instrument test results should be evaluated relative to the precision estimates of our analysis of laboratory and field reference samples. Precision analyses were performed on readings from individual salinity bottles, triplicate salinity samples drawn from a reference sample collection, globally across lab treatments, replicate field reference sample collections and reference samples stored and shipped over a 4-6 week time course.

Precision Estimates for Laboratory Test Reference Samples

Instrument performance for laboratory tests can be evaluated relative to the global precision estimates for our reference samples and the certified TR-1060 temperature data. We estimated the analytical precision of the Portasal salinity measurements of our reference samples by computing a mean variance for every salinity sample collected during the lab test as well as a mean for the variance obtained across each of the 15 salinity-temperature treatment conditions (Table 2). Our precision results (0.00023 and 0.00045, respectively) were well within the expected performance level of the laboratory instrumentation and confirmed that test protocols were appropriate for providing comparative reference standards.

Table 2. Precision of Portasal-derived reference salinity estimates (in PSS-78) associated with laboratory performance evaluation.

LEVEL	*Mean Variance*	*S.D.*	*n*
Bottle	0.00023	0.00013	150
Treatment	0.00045	0.00024	15

A reference method precision of the temperature control for our test baths was computed for each of the treatment conditions (Table 3). Temperature measurements were recorded at 1-minute intervals at 2 points within each test tank. The mean variance in temperature across the 15 treatment exposures was 0.0138 ^{o}C, indicating relatively well defined test conditions for comparing instrument performance. As the mean bath temperature and Portasal salinity measurements were independent of the test instrument records, the paired bath temperature and analytical salinity measured enabled computation of an independent estimate of in situ conductivity for each bath sample. These computations are based on the inversion of the equations of state for seawater and were performed with Lab Assistant V2 (PDMS, Ltd. 1995).

Table 3. Reference method precision levels obtained during laboratory performance evaluation tests.

LEVEL	*Mean Variance*	*S.D.*	*n*
RBR 1060, *^{o}C*	0.0138	0.0108	15
Portasal, *mS/cm*	0.0070	0.0040	15

Precision Estimates for Field Test Reference Samples

The average analytical precision of salinity measurements taken from a single salinity bottle was 0.00022 for all field test sites with a range of 0.00009 – 0.00034 (Table 4). Similarly, the average analytical precision of salinity measurements taken from replicate (3-4) salinity bottles filled from a single Van Dorn sample collection was 0.00129 for all sites with a range of 0.00013 – 0.00249 (Table 5).

Table 4: Within bottle salinity measurement precision for field reference samples analyzed on a Portasal. S values in PSS-78 scale

Field Site	*Mean Variance*	*S.D.*	*n*
USF	0.00027	0.00016	198
SkIO	0.00018	0.00009	203
GL	0.00009	0.00006	203
HI	0.00034	0.00019	293
AK	0.00023	0.00014	255
Overall	***0.00022***	***0.00013***	***1150***

Table 5: Within Van Dorn sample bottle collection salinity measurement precision for field reference samples analyzed on a Portasal. Estimates derived from the average of 3-4 bottles analyzed for each reference sampling. S values in PSS-78 scale.

Field Site	*Mean Variance*	*S.D.*	*n*
USF	0.00178	0.00250	44
SkIO	0.00067	0.00101	53
GL	0.00013	0.00013	50
HI	0.00139	0.00331	81
AK	0.00249	0.00739	63
Overall	***0.00129***	***0.00287***	***291***

Precision Estimates for Replicate Field Reference Samples

Once per week (except at HI with 6 of 8 weeks) a replicated field reference sample was collected with a second Van Dorn bottle. The two Van Dorn bottles were positioned as close as physically possible to one another when sampling (Table 6). For USF and HI these replicates were collected by divers and were slightly more prone to slight offsets in space and time. At the other field sites bottles were fired by a messenger on a tethered line. The average precision obtained for the field replicates ranged from 0.0030 – 0.2612. The greater variability at the AK test site was likely due to persistent vertical variations in salinity at the test site that were confirmed by occasional vertical profiling. For the other four test sites the variability was less than 0.017 psu.

Table 6: Assessment of environmental heterogeneity based on comparison of simultaneous Van Dorn Bottle Snap samples at each field site. Replicate values represent mean of each Van Dorn Bottle Sample Salinity, comprised of 3 - 4 subsample bottles analyzed on a Portasal, with associated precisions provided in previous tables. Difference values in PSS-78.

Field Site	Year Day 2008	Van Dorn 1	Van Dorn 2	S Difference *absolute*	Overall Mean	Overall s.d.
	158.615	36.86386	36.87139	0.00753		
USF	164.438	37.02441	37.030565	0.00616	0.00295	0.00317
	170.458	37.09299	37.09382	0.00082		
	178.448	36.57010	36.56747	0.00263		
	161.354	30.34166	30.34269	0.00103		
SkIO	168.583	28.92843	28.92578	0.00265	0.00416	0.00413
	177.604	30.34359	30.35383	0.01024		
	182.792	32.09234	32.08964	0.00270		
	168.479	0.32211	0.32530	0.00319		
GL	176.479	0.20867	0.20946	0.00079	0.00388	0.00511
	183.479	0.19835	0.20965	0.01130		
	190.479	0.29647	0.29624	0.00023		
	165.604	34.94302	34.87283	0.07019		
	172.583	35.16459	35.16526	0.00381		
HI	179.375	35.19322	35.19750	0.00428	0.01693	0.02666
	185.604	34.83228	34.81538	0.01690		
	193.583	35.00295	35.00425	0.00130		
	200.375	35.15303	35.14794	0.00509		
	221.469	26.17526	26.36265	0.18739		
AK	228.531	26.25852	26.30227	0.04375	0.26116	0.20593
	234.531	23.96403	24.49750	0.53347		
	241.645	24.79116	25.07116	0.28000		
All Test Sites					**0.0578**	**0.1138**

Reference Sample Storage and Shipping Test

Results of the reference sample storage and shipping test for each site are provided in figures 39 – 43. Values for stored bottles (between 20-80 days from collection) generally agreed with one standard deviation to the values determined for the first set of samples that were shipped and analyzed. There was a noticeable upward trend in salinity values for the storage time series at SkIO. This pattern may have resulted from the initial collection when all of the salinity bottles were being filled from an open bath that was subject to evaporation. The collected samples were numbered and analyzed sequentially instead of first being randomized, thereby allowing for the increasing trend. The other sites filled all bottles from a single well mixed carboy that likely minimized any variation among the storage bottle set.

TECHNICAL AUDITS

Technical Systems Audits

The ACT Quality Manager performed technical systems audits (TSA) of the performance of the laboratory tests conducted at MLML on May 21, 2008 and of the field tests conducted off Tampa Bay, FL, on June 16-18, and in Resurrection Bay, AK, on August 11, 2008. The purpose of the TSAs was to ensure that the verification test was being performed in accordance with the test plan and that all QA/QC procedures were implemented. As part of each audit, ACT's Quality Manager reviewed documentation including relevant standard operating procedures, logbooks tracking actual day-to-day operations, and records of quality control and maintenance checks; observed ACT personnel conduct all activities related to the reference sampling and analysis; compared actual test procedures to those specified in the test/QA plan; and reviewed data acquisition and handling procedures. Observations and findings from these audits were documented and submitted to the ACT Chief Scientist. In summary, there were no adverse findings or problems requiring corrective action in any of the audits. The laboratory and field tests for this verification met or exceeded ACT test requirements. The records concerning the TSAs are permanently stored with the ACT Chief Scientist and Quality Manager.

Data Handling Audits

ACT's Quality Manager audited approximately 10% of the data acquired during the verification test. The data were traced from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked during the technical review process.

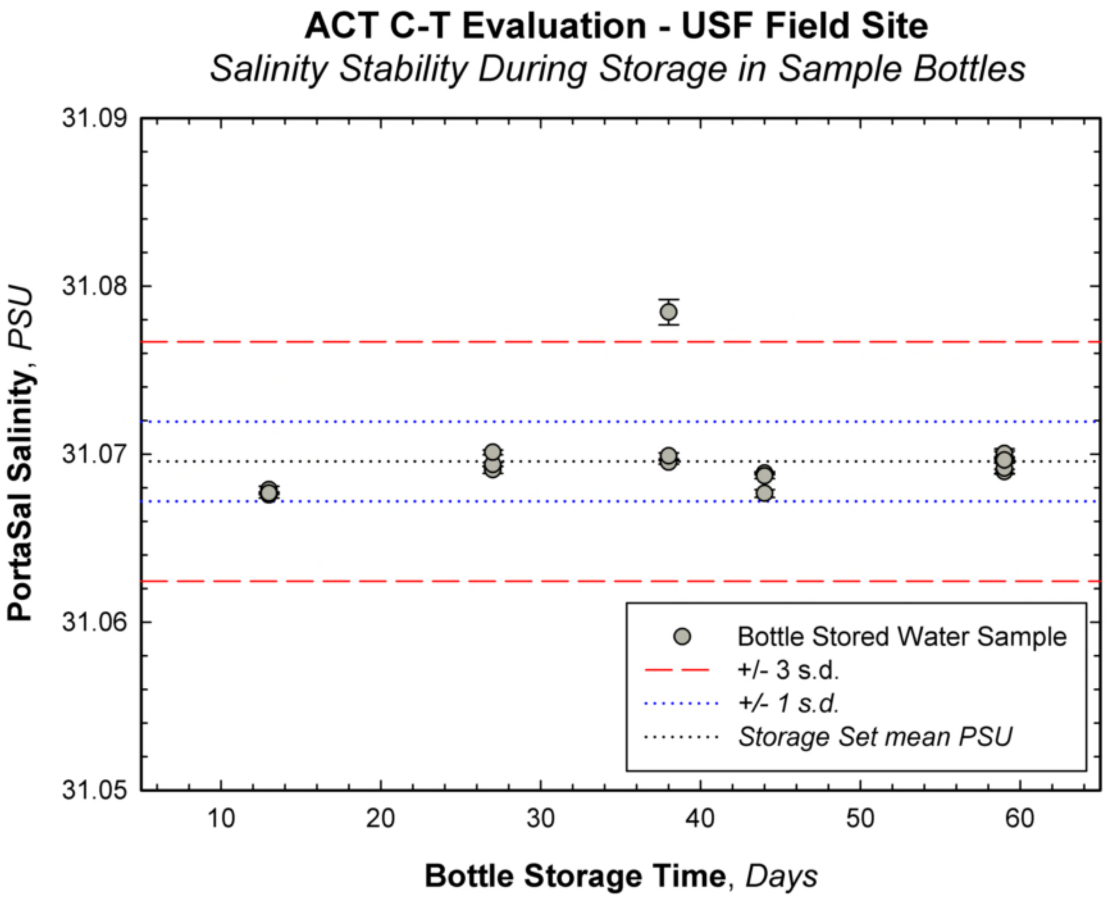


Figure 39. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

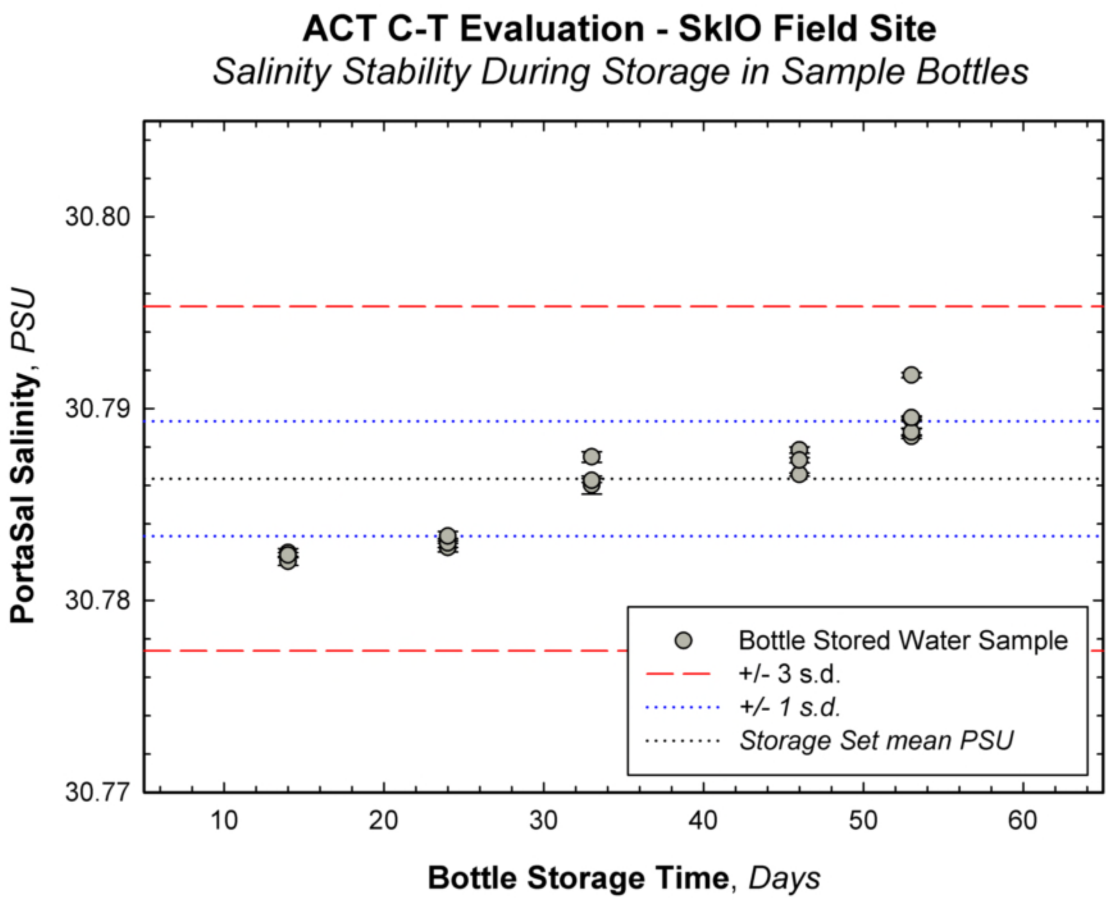


Figure 40. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

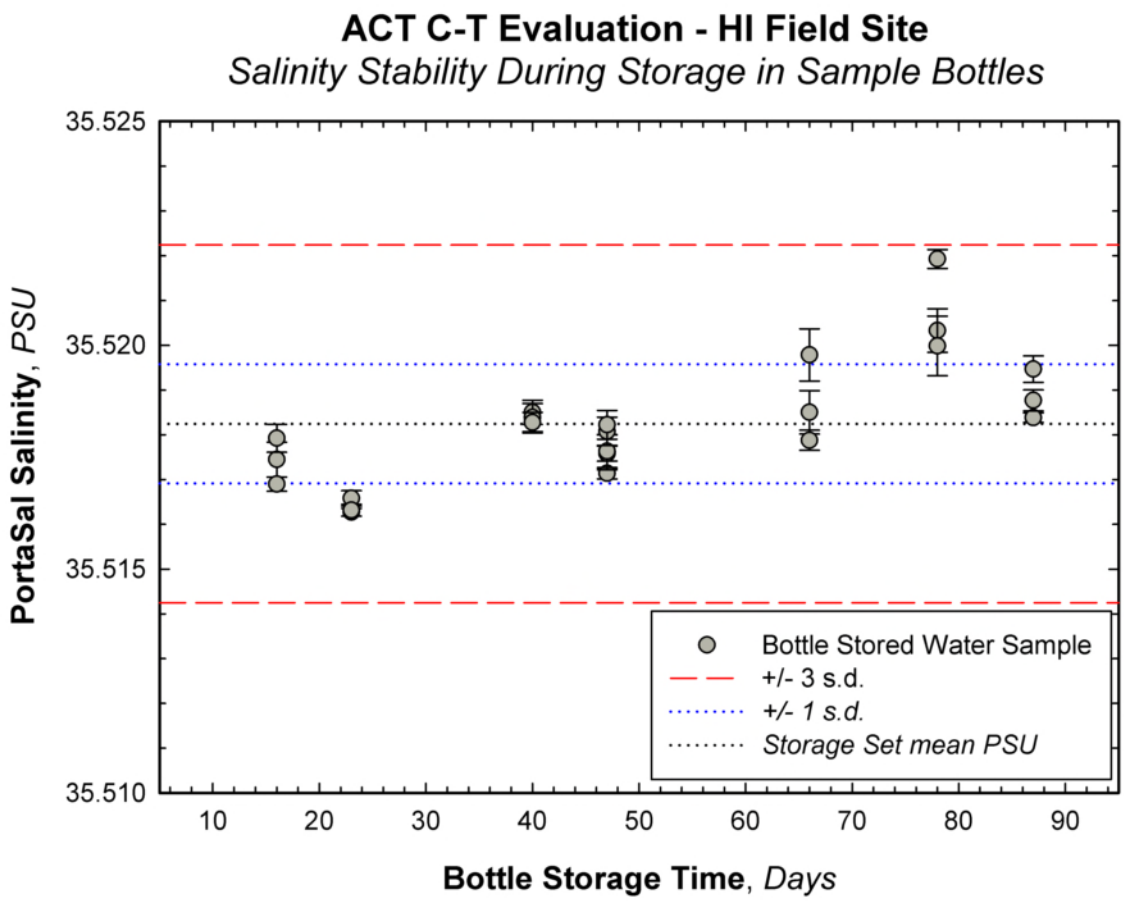


Figure 41. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

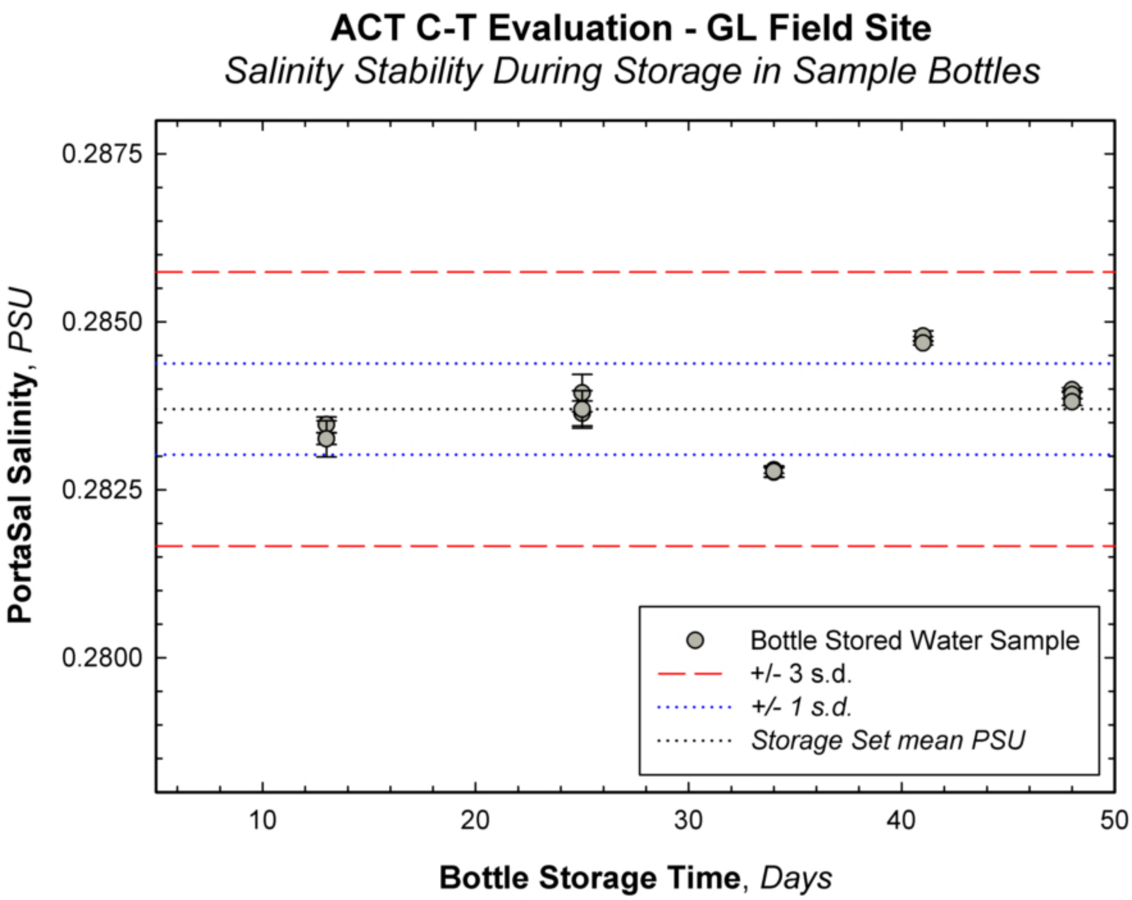


Figure 42. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

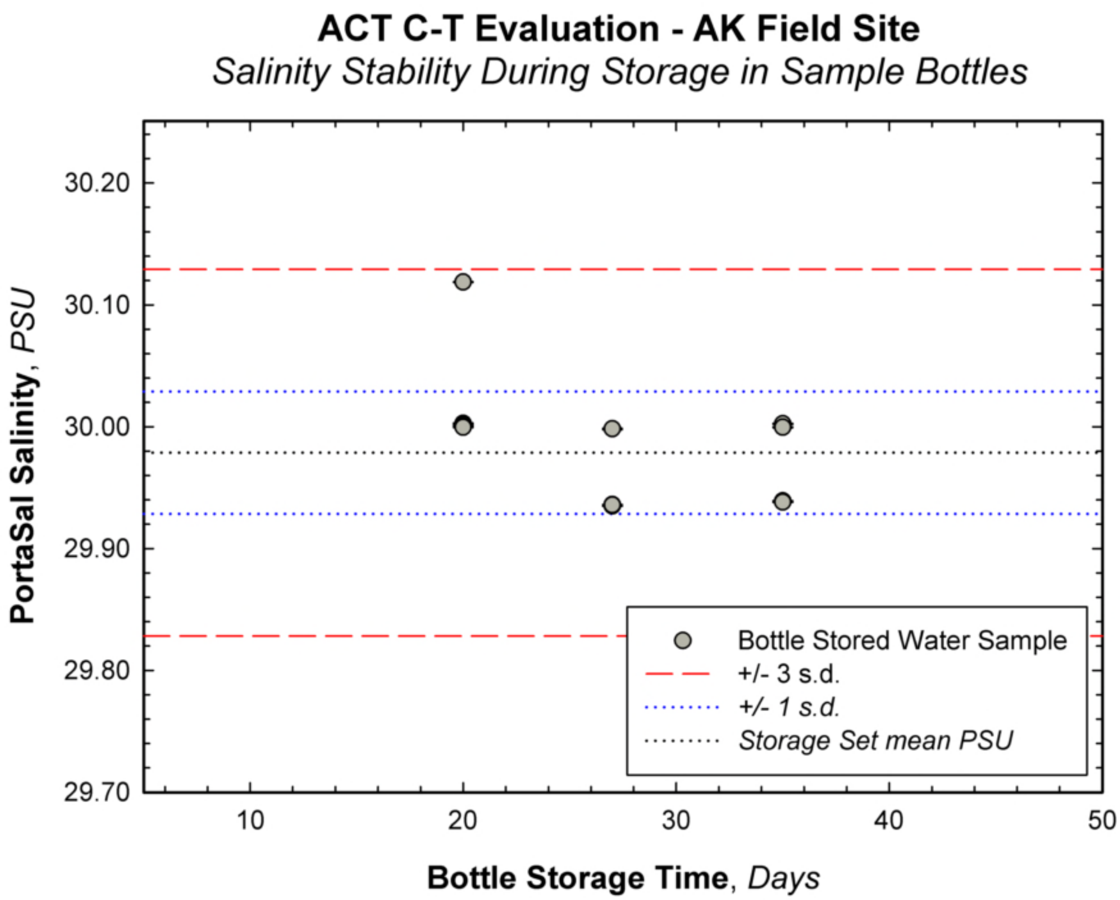


Figure 43. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

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, Geoff Morrison, Robert Millard and Kjell Gundersen for their advice and direct participation in various aspects of this evaluation. 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.

March 15, 2009 — Mario Tam

Date — **Approved By: Dr. Mario Tamburri**
ACT Executive Director

March 15, 2009 — Thomas H. Johengen

Date — **Approved By: Dr. Tom Johengen**
ACT Chief Scientist

March 15, 2009 — Earle N. Buckley

Date — **Approved By: Dr. Earle Buckley**
Quality Assurance Supervisor

APPENDIX 1

Alternative Presentation of Laboratory Test Results for Measurement of Instrument Variance Relative to Reference Sample Variance

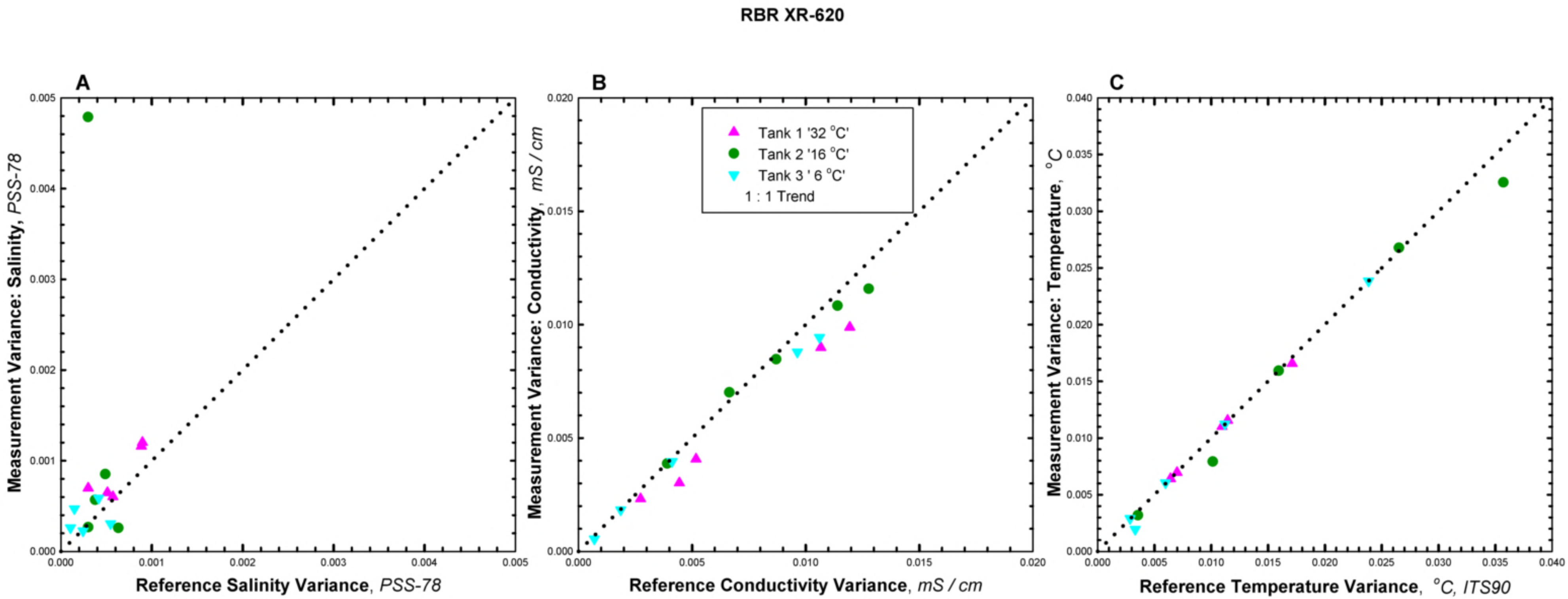


Figure 4. Evaluation of measurement variation of RBR's model XR620 conductivity and temperature sensor package achieved during the laboratory exposure trials plotted in **Fig. 3**. Instrument measurement variance is presented as the standard deviation from 30 consecutive instrument reads recorded during the 30 min reference sampling for each test exposure and plotted against the corresponding variation in the reference measure. The 1:1 correspondence line (dotted) is provided for comparison, with points below the line indicating lower and above higher-instrument measurement variation than obtained by our reference methods and test conditions. [*A*] Co-variation of derived salinity estimates; [B] Co-variation of in situ conductivity measurements; [*C*] Co-variation of instrument temperature measurements.

APPENDIX 2

Company Response Letter to Submitted Salinity Sensor Verification Report

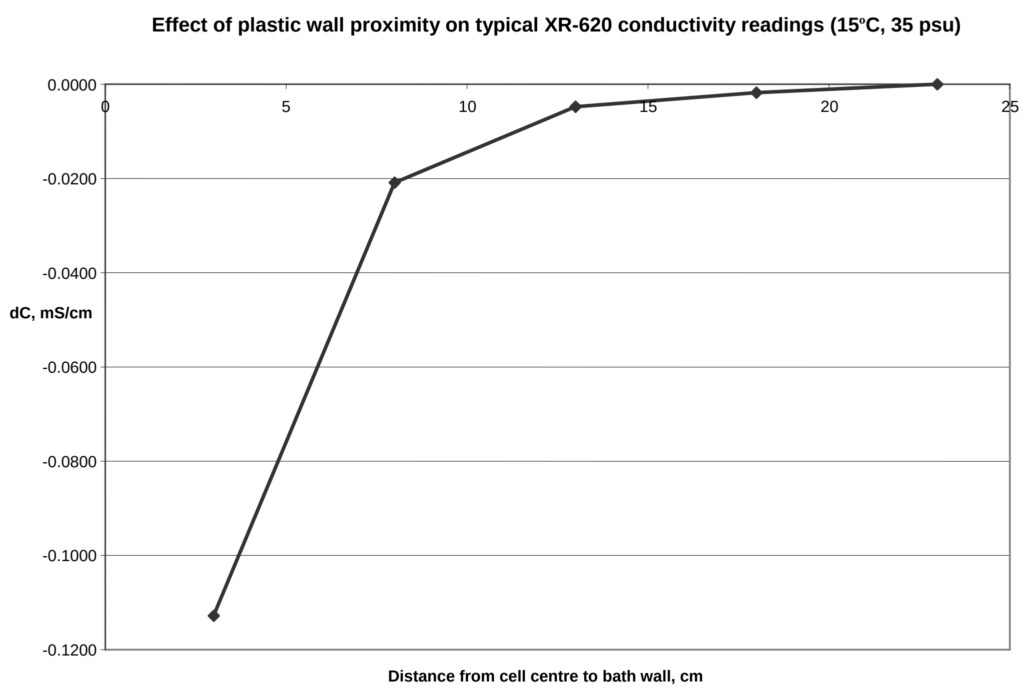
APPENDIX 1 – Manufacturer's Interpretation Of Results

While acknowledging the hard work and diligence of ACT investigators in performing this evaluation and preparing the report, RBR Ltd feels it is necessary to highlight some problems with the laboratory tests, in order to explain the discrepancy between the results presented here and the published specifications of the XR-620. In our opinion:

1. Laboratory tests were performed in a bath with poor thermal uniformity and stability. Data presented show thermal gradients across the bath of up to 0.019°C, and drift during the 30 minute interval used for statistical treatment typically around 0.030°C, and as high as 0.090°C. Attempting to derive a reference conductivity value using averaged data from two reference thermometers in such unstable and varying conditions will produce artificial fluctuations in conductivity residuals. Statistical manipulations using temperature differences (between instrument and reference) and derived conductivity are not valid, as both are affected by thermal non-uniformity. The presented numbers reflect the bath performance, not that of the XR-620.

2. In such thermally non-uniform and unstable laboratory test bath conditions, the only parameter it is reasonable to analyze is practical salinity. The XR-620 shows well harmonized conductivity and temperature measurements, and derived salinity could have been compared with reference sample salinity values. Unfortunately, logistical constraints on time and space during laboratory tests prevented proper placement of the logger in the test bath. On the basis of Figure A1.1 below, RBR requested 20cm clearance around the XR-620, which is the minimum clearance accepted for factory calibration of the instrument. This was maintained for field deployments, but was violated for the laboratory tests, as is clearly seen in Figure 1 on p.7. Close proximity to the bath wall causes conductivity measurement errors which are both large (-0.05±0.04mS/cm), and sensitive to the exact distance from the wall. Thus in each test the error will be different, and can not be eliminated as a systematic error.

Figure A1.1



Based on the presented data, we estimate a temperature bath uniformity of 0.008±0.011°C, and a conductivity error of –0.06±0.06mS/cm, induced mainly by proximity effects. The XR-620 variances in all bath conditions lie within these uncertainties: this data is not meaningful in trying to verify the specification of a high precision instrument such as the RBR XR-620.

3. Statistical analysis using the mean and standard deviation of variables is rigorous only within a single test (at fixed temperature and salinity). Further averaging of these statistics for all temperature and salinity set points is inappropriate due to the non-Gaussian distribution of the residuals of all experimental data. A probability function for variables was not estimated prior to averaging the overall results. In any case, test runs with poor bath performance really should have been excluded as outliers from any overall averaging.

4. The claim that there were problems with the laboratory test configuration is supported by the good results obtained from the same logger shortly afterwards, during the early portion of the field test performed at SkIO (GA). As reported on p.22, the initial salinity offset was 0.0088psu, and an average temperature offset of only -0.0013°C was maintained over the entire deployment. These results are in fact considerably better than those obtained in the laboratory.

5. A post-deployment salinity check performed at RBR in July 2008, after cleaning of the conductivity cell, showed a salinity error of only -0.0076psu.