PERFORMANCE VERIFICATION STATEMENT for the FSI NXIC-CTD-BIO-AUTO Salinity Sensor

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
EVALUATION PERSONNEL:	S. Gilbert, K. Gundersen, T. Johengen, T. McKissack, M. McIntyre, A. Pinchuk, H. Purcell, C. Robertson, D. Schar, G.J. Smith, M. Tamburri and D. Wells.

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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 FSI NXIC 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 NXIC 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 = 0.9996, SE = 0.222 and slope = 0.987. The overall mean and variance of the absolute difference between instrument measured salinity and reference sample salinity for all treatments was -0.2180 ±0.2543 psu. When examined independently, the relative accuracy of the conductivity and temperature sensors were -0.2882 ±0.3303 mS/cm and -0.0073 ±0.0034 °C, respectively.

Across all four 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. The mean absolute difference between instrument measured salinity and reference sample salinity over the entire deployment period was -0.1116, -0.7204, -0.0018, -0.3341 and -0.0179 psu for FL, GA, HI, MI, and AK, respectively. However, these averages include the impacts of biofouling and much higher accuracy was observed at the onset of each field test. Also, the significantly greater offset at the AK test was likely due to fine-scale vertical variation within the water column which resulted in real differences between in situ measured and reference sample salinities and not due to a difference in instrument performance. Despite our best effort to sample as close as possible to the sensors, the collected reference samples may not have been homogeneous with the water mass measured by the sensor. Overall patterns in measured salinity still show excellent agreement at this site. 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 = 0.999, SE = 0.353 and slope = 0.998. These results are quite consistent with those from the laboratory tests.

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. On several occasions results of these tests were compromised, most likely because of entrainment of air bubbles in the conductivity cell. In general, there was no strong evidence for calibration drift during the period of deployment.

During this evaluation, one hundred percent of the data was recovered from the instrument during the laboratory tests, all field deployment tests, and all tank exposure tests. Lastly, a check on the instruments time clocks at the beginning and end of field deployments showed differences of between minus 1 to minus 30 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 FSI NXIC salinity probes. Appendix 2 is an interpretation of the performance verification results from the manufacturer's point of view.

TECHNOLOGY TESTED

The FSI NXIC (Non-eXternal field Inductive Conductivity) CTD-BIO-AUTO Salinity Sensor incorporates an inductive conductivity sensor, an aged thermistor temperature sensor, and a micro-machined silicon pressure sensor. All sensors, including the conductivity sensor, can be cleaned in the field and redeployed without affecting calibration. The inductive method of conductivity measurement operates by inducing a magnetic field in the water enclosed by a transformer. The NXIC conductivity sensor comprises two PEEK tubes mounted parallel to each other. Each tube has a pair of toroidal transformers fitted coaxially over it. Two transformers induce a voltage in the seawater circuit enclosed by the PEEK tubes. The resulting current is directly proportional to the conductivity of the seawater and is measured by a second set of transformers. The NIXC-CTD-BIO-AUTO sensor measures conductivity in mS/cm, temperature in degrees Celsius, and pressure in mbar and computes salinity using an onboard microprocessor implementing International Practical Salinity Scale (IPSS-1978) algorithms recommended in UNESCO Technical Papers in Marine Science, No. 44.

The NXIC-CTD-BIO-AUTO units supplied for verification testing are autonomous units operating off an internal 40AHr battery and providing real-time data output capability as well as internal logging to a 256MB memory. The conductivity and temperature sensors are contained within a controlled area enclosed by copper screening, which provides bio-fouling control. Stated initial accuracies of the various measurements are: Conductivity: ±0.002 mS cm^{-1}; Temperature: ±0.002 degrees C; Pressure: ±0.05% of Full Scale reading; and Salinity: better than ±0.01 PSU.

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).

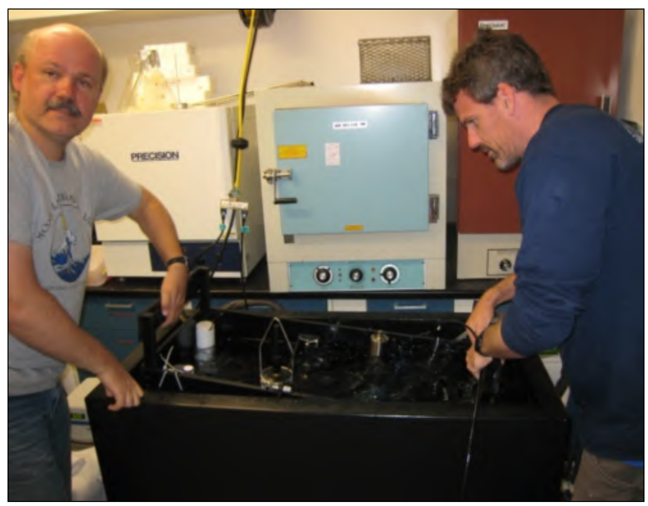


Figure 1. Analytical instrumentation (Portasal 8410A) used for laboratory analysis of salinity reference samples and one of the test baths and instrument racks used for the laboratory tests.

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.

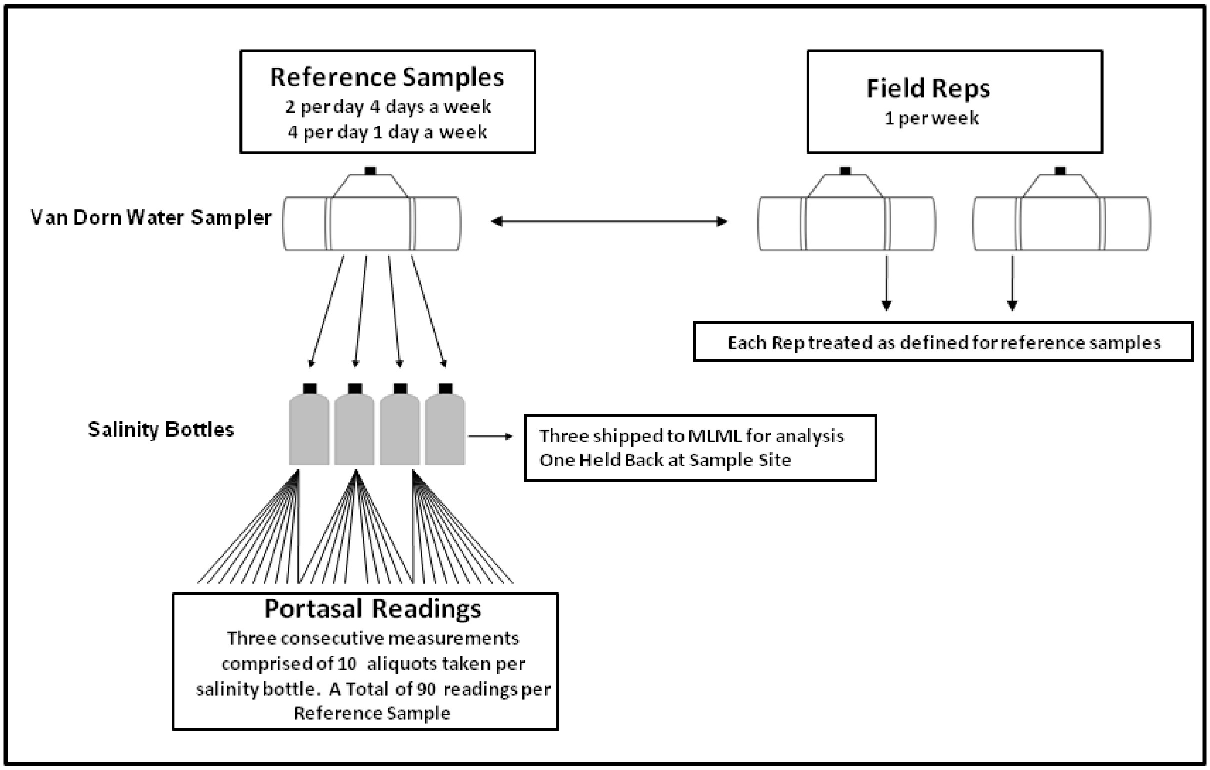


Figure 2. Schematic representation of the reference sampling process conducted during moored deployment field tests.

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 FSI NXIC 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 ^oC. 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) ^oC across the tank axis with a maximum difference of 0.019 ^oC during one of the 16 ^oC tests. Average stability of the bath temperatures across the 15 test runs was ± 0.0128 ^oC from the mean during reference sampling. Temperature drift associated with the time intervals of reference sampling averaged 0.0123 (± 0.0517) ^oC across all tests with a maximum drift of 0.116 ^oC encountered during one of the 16 ^oC test associated with a cooling line failure.

Analyzed across all five salinity levels and all three temperatures, the NXIC exhibited a strong linear response to the test solutions with R^2 = 0.9996, standard error = 0.2225, and slope = 0.9869 (Fig. 3). Most of variability was observed in the conductivity measurements which had a linear response of R^2 = 0.9997, standard error = 0.2737, and slope = 0.987. The temperature response regression was $R^2 > 0.9999$, standard error = 0.0036 and slope = 1.000. 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). There was a slight increase in the amount of offset for salinity and conductivity measurements as the salinity of the test solutions increased. The mean offset in measured salinity for the 15 laboratory test conditions was -0.2180 ±0.2543 psu. When examined independently for conductivity and temperature, the mean offsets were -0.2882 ± 0.3303 mS/cm and -0.0073 ± 0.0034 ^oC, respectively.

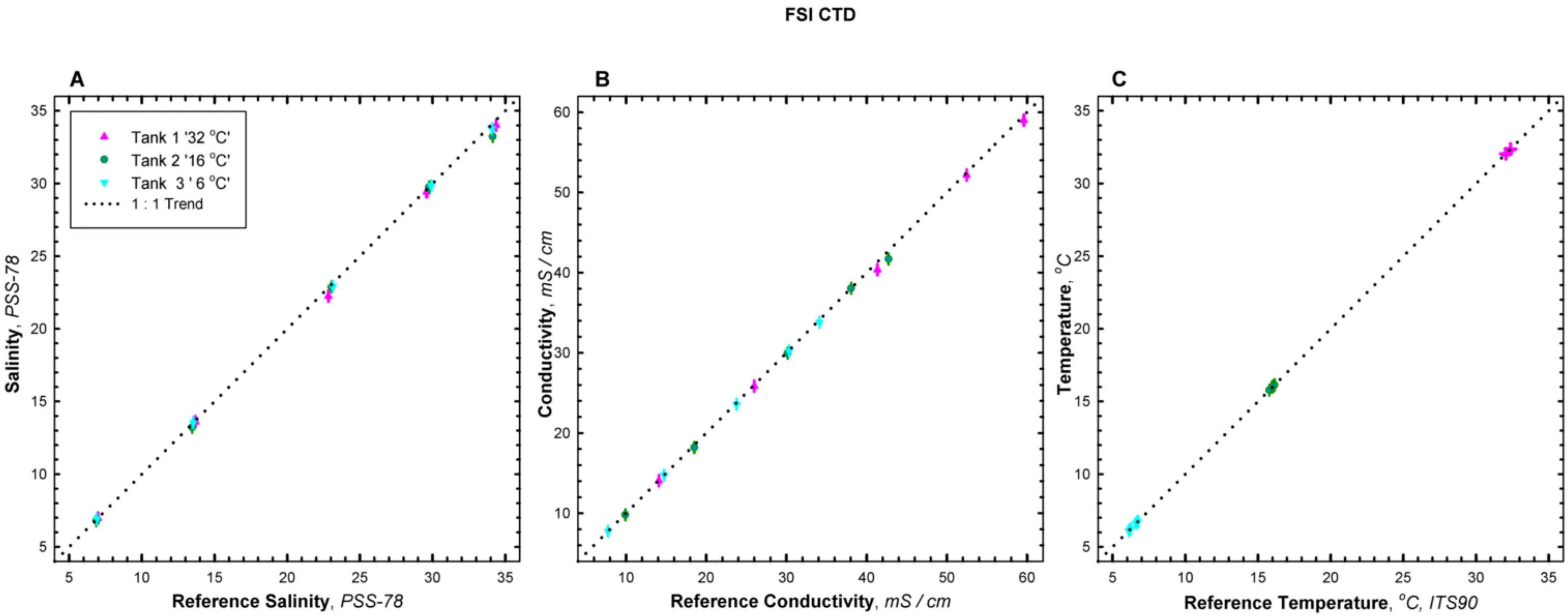


Figure 3. Evaluation of the response linearity for the FSI conductivity and temperature sensor package during controlled laboratory exposures to a combination of natural seawater dilutions and temperatures. Consecutive test exposures ranged between 35 to 6 on the practical salinity scale (PSS-78; 60 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.

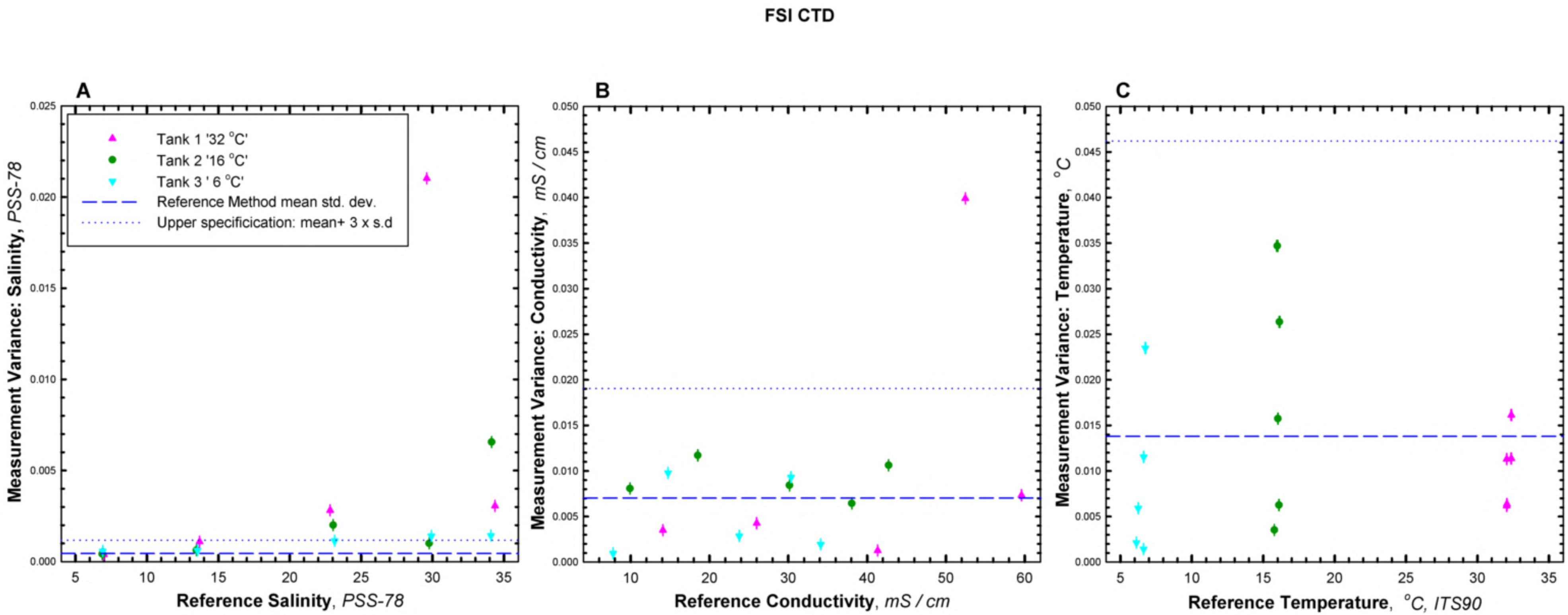


Figure 4. Evaluation of measurement variation of the FSI conductivity and temperature sensor package achieved during the laboratory exposure trials plotted in **Fig. 3**. Relative measurement variance is presented as the standard deviation from 30 consecutive instrument reads associated with each test 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.

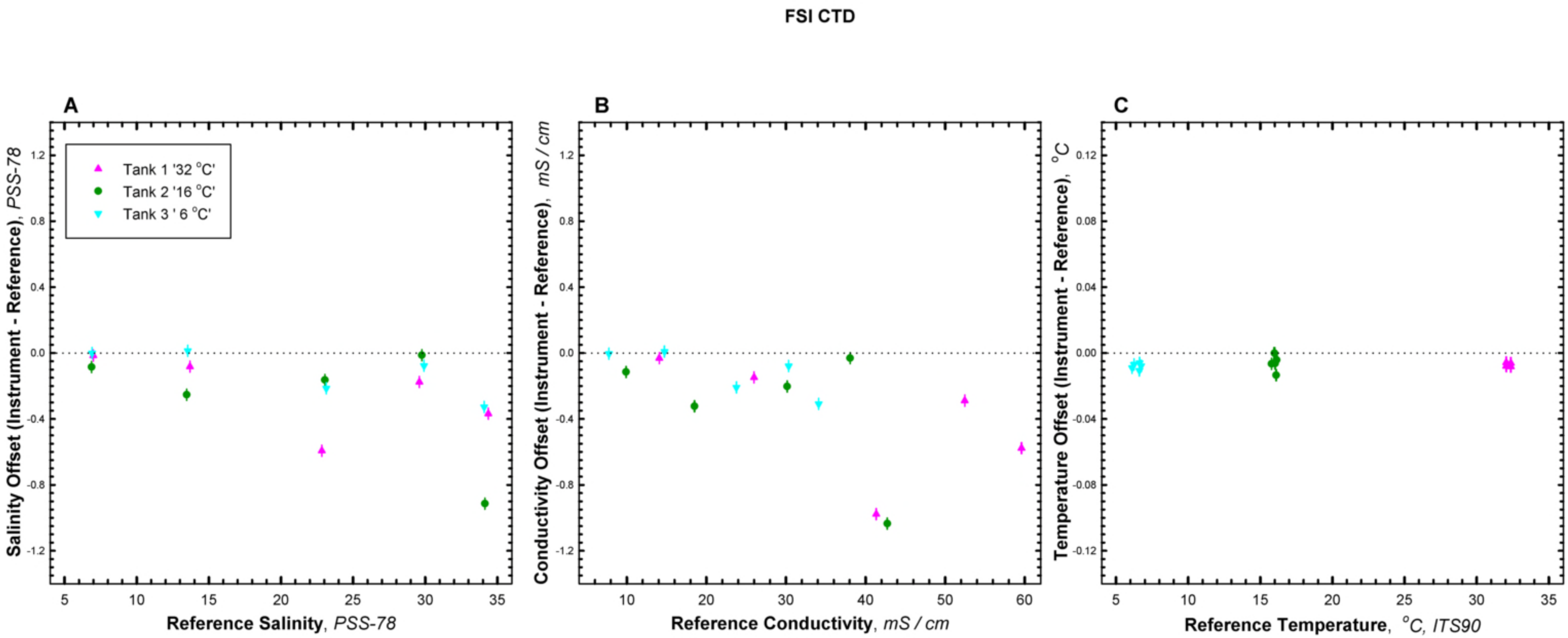


Figure 5. Evaluation of the relative accuracy of the FSI conductivity and temperature sensor package achieved during the laboratory exposure tests plotted in **Fig. 3**. Relative accuracy is estimated as the difference or offset between the mean instrument reading and mean reference reading for each 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 FSI NXIC 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^{-1} at the freshwater test site.

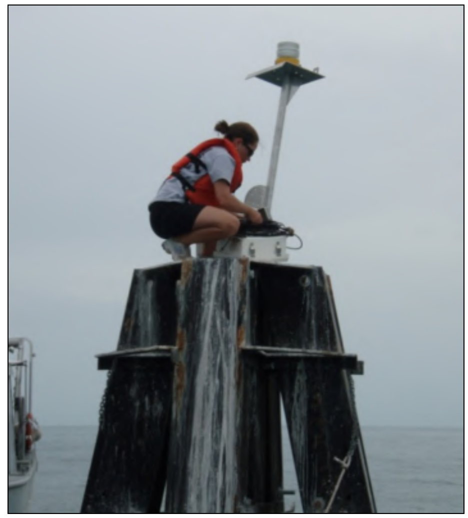
Table 1. Range and average for temperature, conductivity and derived salinity at each of the test sites during the sensor field deployment measured in situ by a SeaBird SBE 26 (or SBE26plus) mounted on the instrument rack and the duration of the deployment.

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 (Fig. 7). The relative accuracy of the instrument measurements were depicted as numerical differences from the reference values and plotted over time (Fig. 8). Instrument measurements appeared to be impacted by fouling after approximately 10 days when a noticeable decrease in accuracy was observed but then offset then remained fairly constant over the last 20 days of the deployment test. The amount of offset in the salinity measurements 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. The mean offset in the salinity measurements over the entire deployment was -0.1116 ± 0.0930 psu. To distinguish between biofouling impacts and potential instrument drift we compared measurement accuracy in pre- and post-exposure tests after the instrument was cleaned to remove any effects of biofouling using well mixed, reference sampled tanks (Fig 9). The agreement between instrument and reference sample values was actually slightly better in the post-deployment exposure, perhaps due a lower salinity of the test solution which better matched the current calibration settings. The amount of fouling that development on the instrument is shown in figure 10 and the rate of fouling was documented with a time-series of photographs showing the accumulation on PVC tiles (Fig. 11).

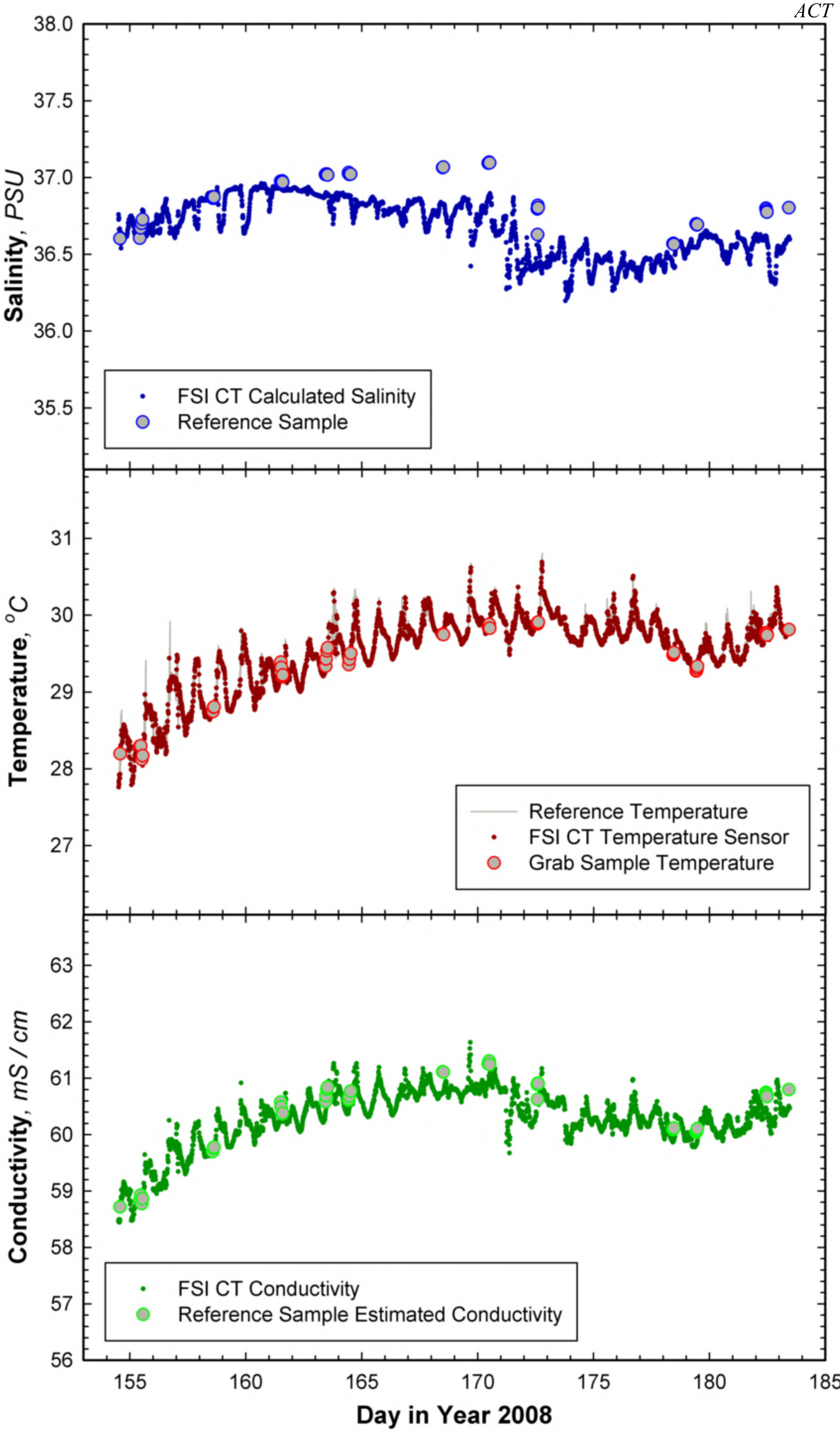


Figure 7. Time series of instrument measurements and corresponding reference samples acquired during USF field deployment.

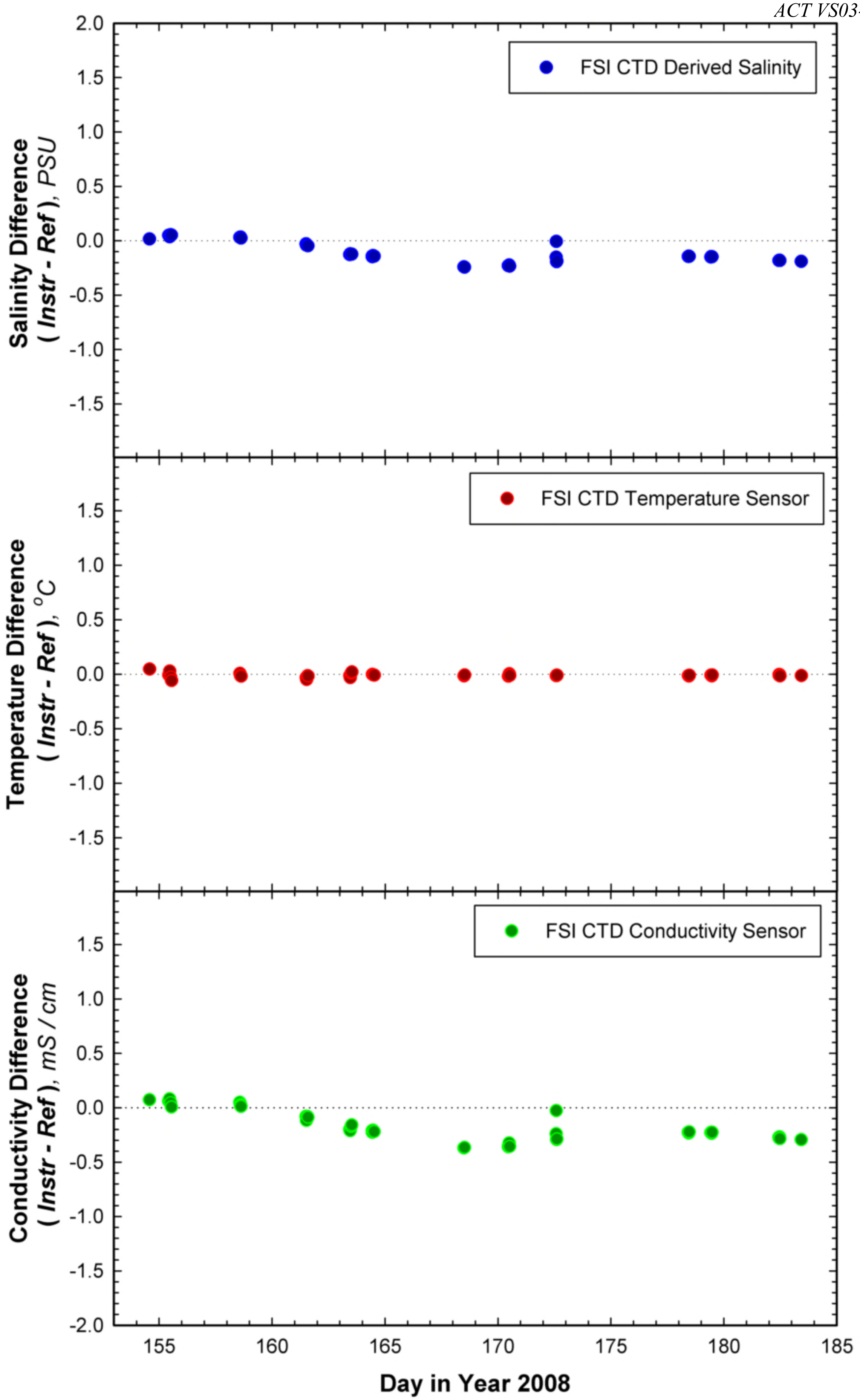


Figure 8. Assessment of relative accuracy of instrument time series measurements during USF field deployment.

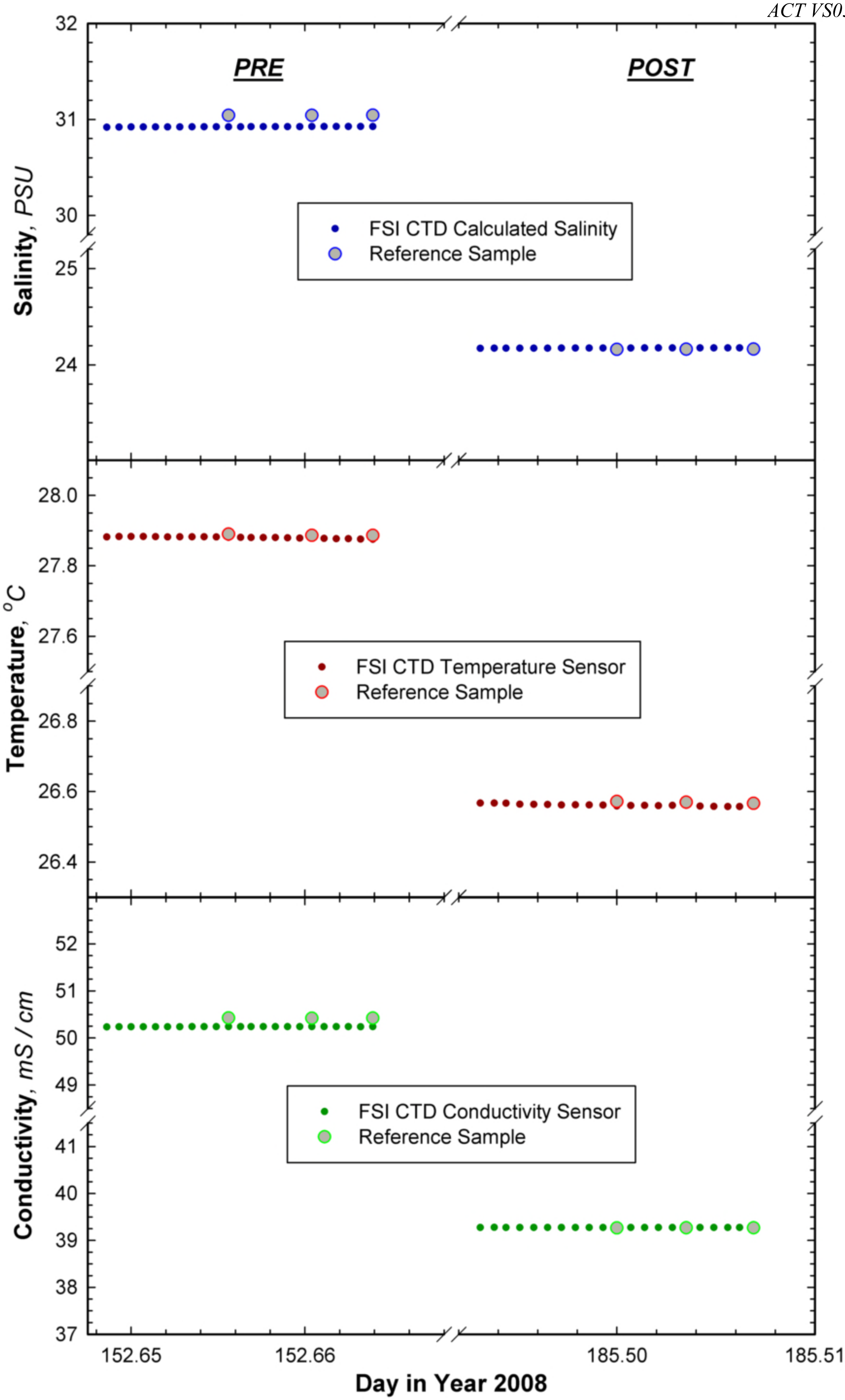


Figure 9. Pre- and Post-deployment reference checks in tanks of natural seawater at USF. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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, and to some extent within the conductivity cell despite the presence of the copper anti-fouling screens.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

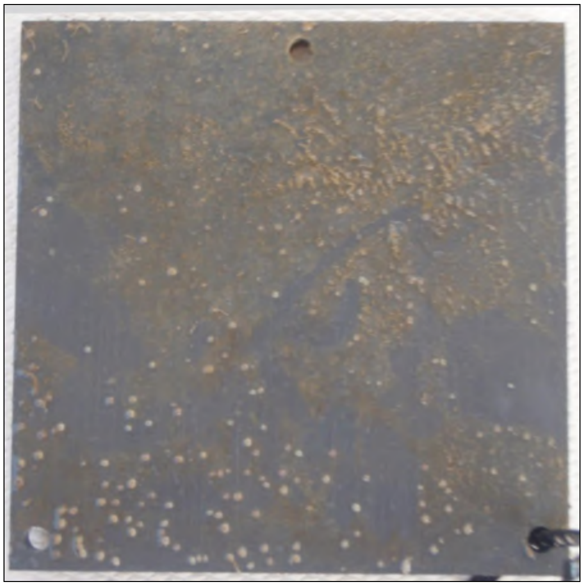
After Deployment (Close-up)

After Deployment (Full View)

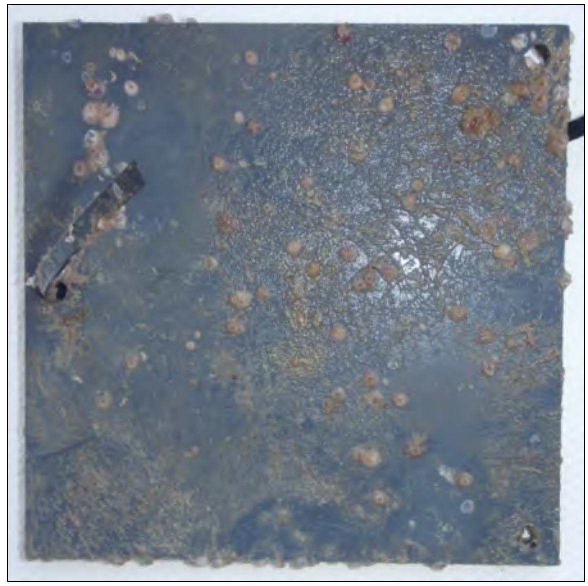
Figure 10. FSI NXIC instrument photos from Tampa Bay, FL test site before and after deployment

Bio-Fouling Plate Photographs

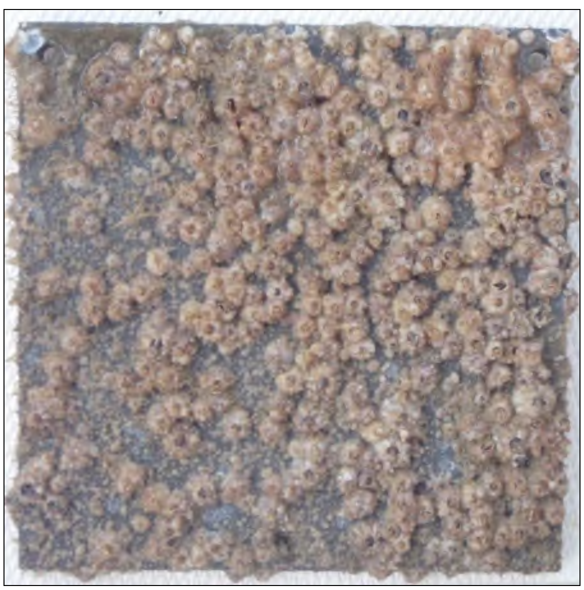
Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment (Fig. 11). By the third week of deployment there was an extensive amount of hard, encrusting biofouling at the Florida test site.



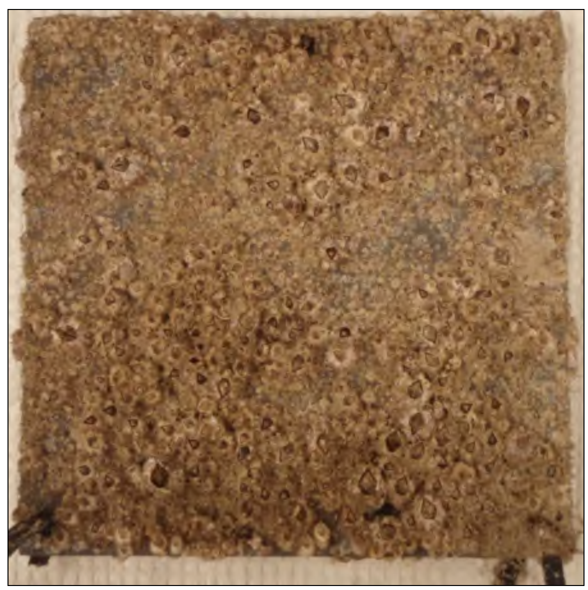
USF Site Week 1



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 (Fig. 13). The initial negative offset for the first 5 readings may have been due to bubbles trapped in the conductivity cells which subsequently were flushed away. Similar to the FL test site, instrument measurements appeared to be impacted by fouling after approximately 10 days when a dramatic decrease in accuracy occurred (Fig. 14). The amount of offset in the salinity measurements was again 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. The mean offset in the salinity measurements over the entire field test was -0.7204 ± 0.6745 psu, however during day 162 – 166 the offset average only 0.001 psu.. 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 significantly better in the post-deployment exposure. As no changes were made in calibration settings, the initial negative offset in instrument readings may again have been due to bubble entrainment. The amount of fouling that developed on the instrument during the deployment is shown in figure 16.

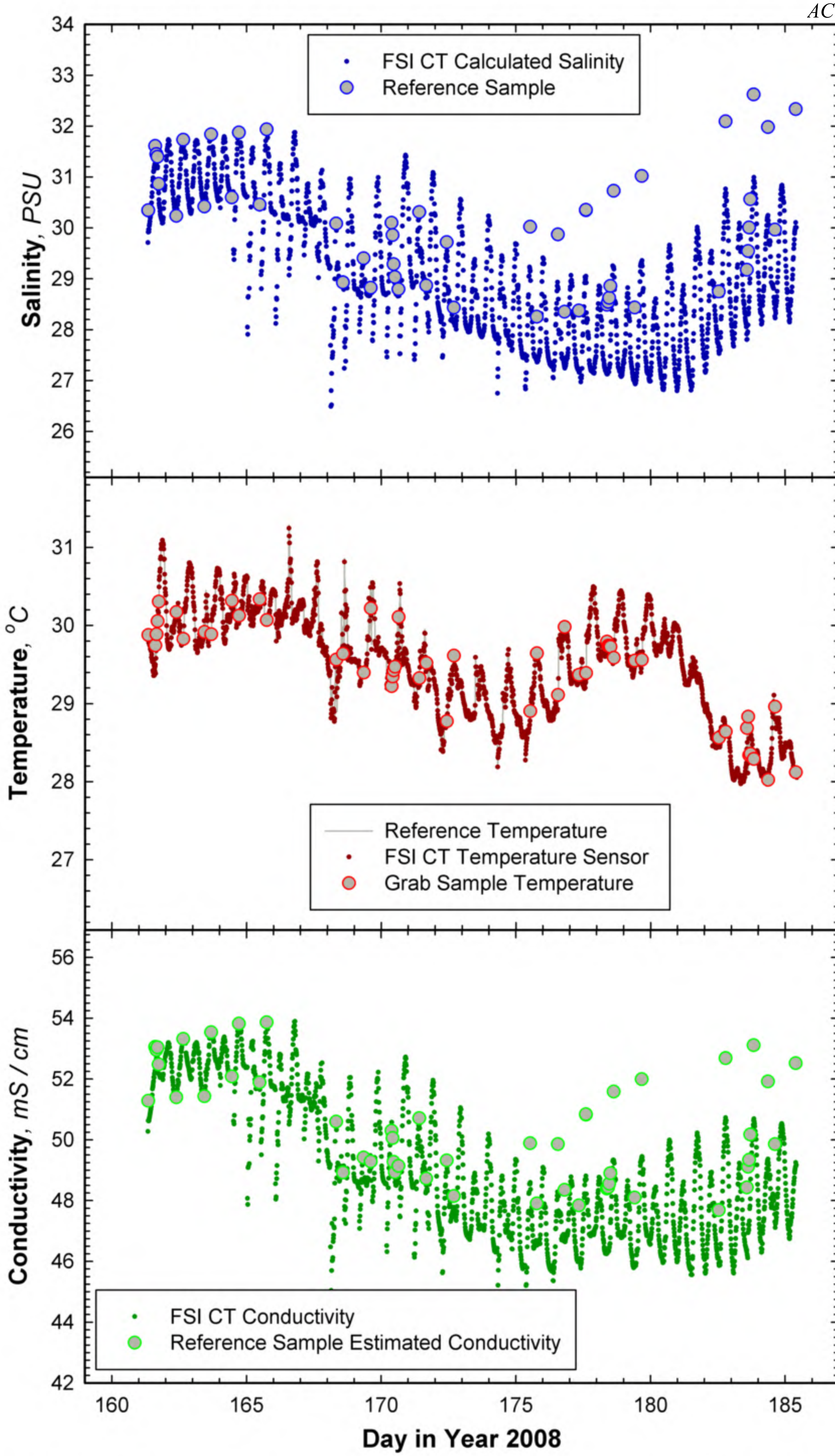


Figure 13. Time series of instrument measurements and corresponding reference samples acquired during the SkIO field deployment.

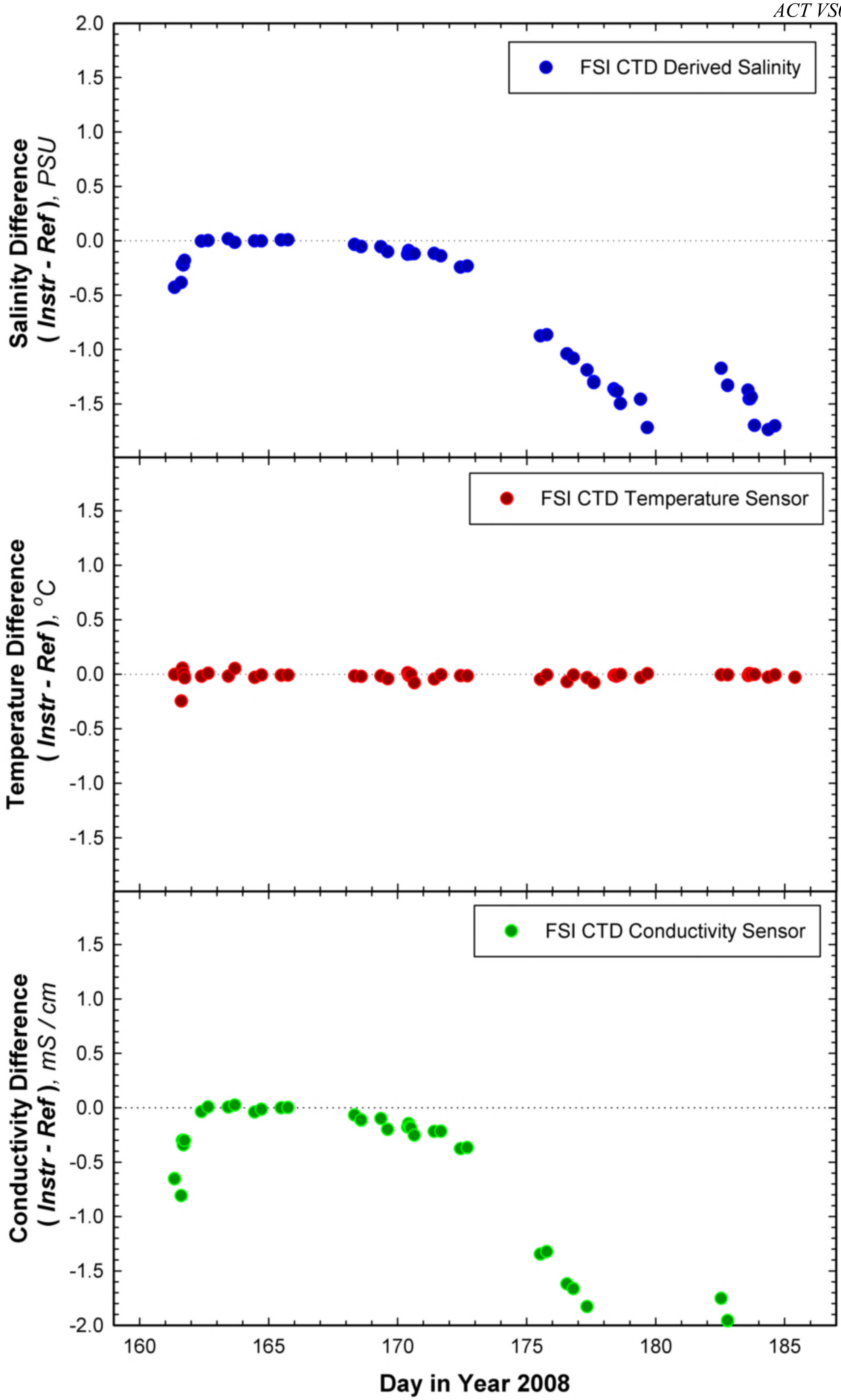


Figure 14. Assessment of relative accuracy of instrument time series measurements during the SkIO field deployment.

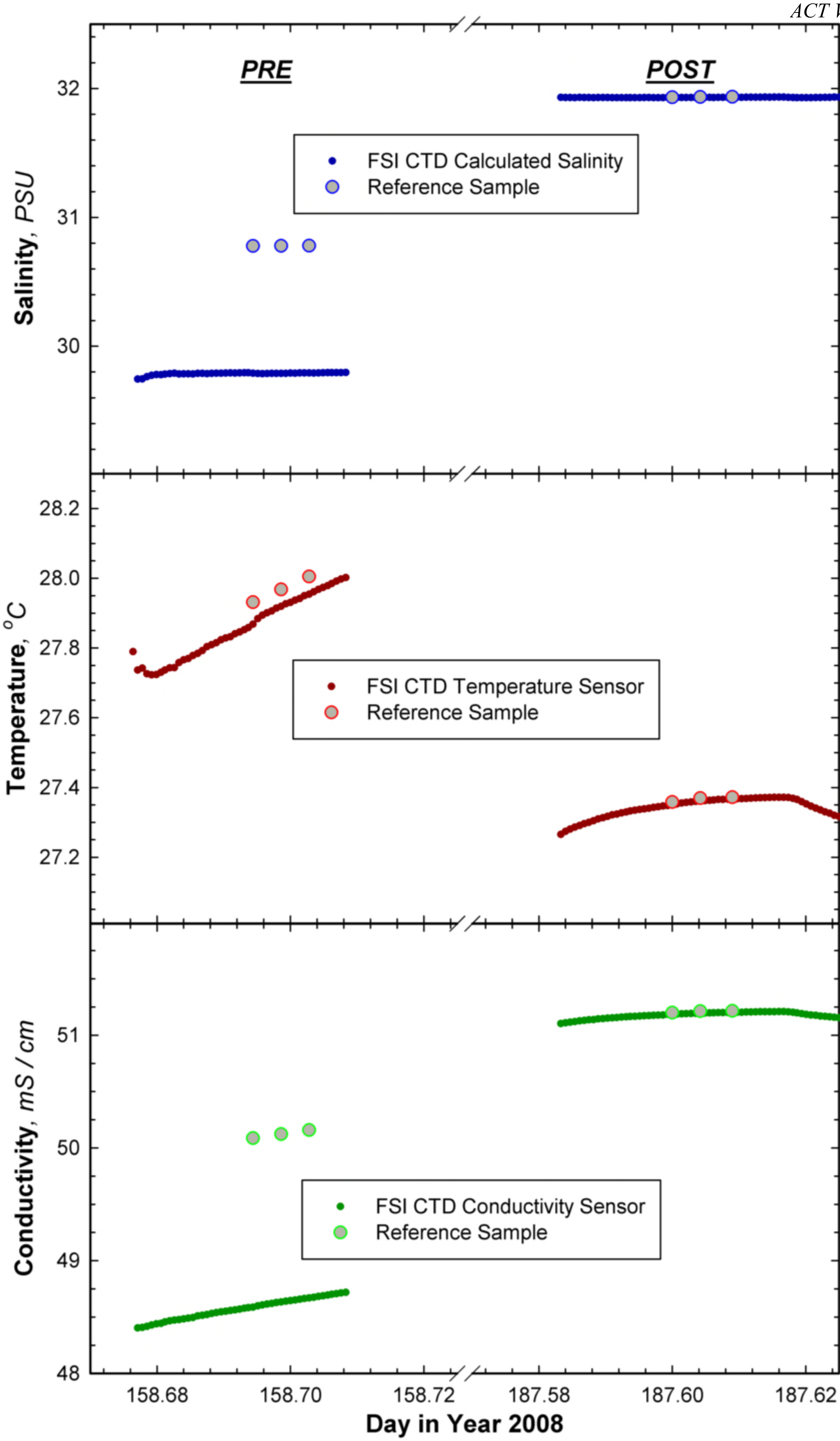


Figure 15. Pre- and Post-deployment reference checks in tanks of natural seawater at SkIO. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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. A significant amount of sediment and fouling occurred within the tube containing the conductivity sensor, aided in part by the orientation that it was moored.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

After Deployment (Close-up)

After Deployment (Full View)

Figure 16. FSI NXIC 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

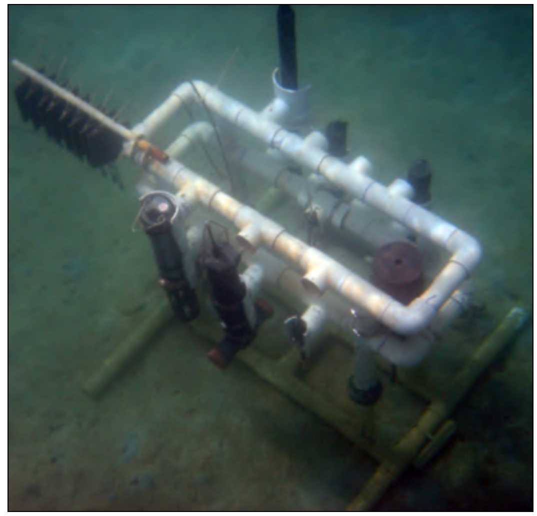
SkIO Site Week 4

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 (Fig. 19). The FSI NXIC salinity measurements closely matched reference sample measurements throughout the entire 60 day deployment. The amount of offset in salinity, conductivity and temperature measurements averaged -0.0179 psu, -0.0073 mS/cm, and 0.0196 ^{o}C, respectively over the deployment (Fig. 20). The offset in the instrument salinity and conductivity measurements for the post-deployment exposure test (Fig. 21) was again likely due to bubble entrainment and not calibration drift; since the instrument was performing significantly (fifty times) better in the field immediately prior to the final tank test. The amount of fouling that developed on the instrument during the deployment is shown in figure 22 and the rate of fouling was documented with a time-series of photographs showing the accumulation on PVC tiles (Fig. 23).

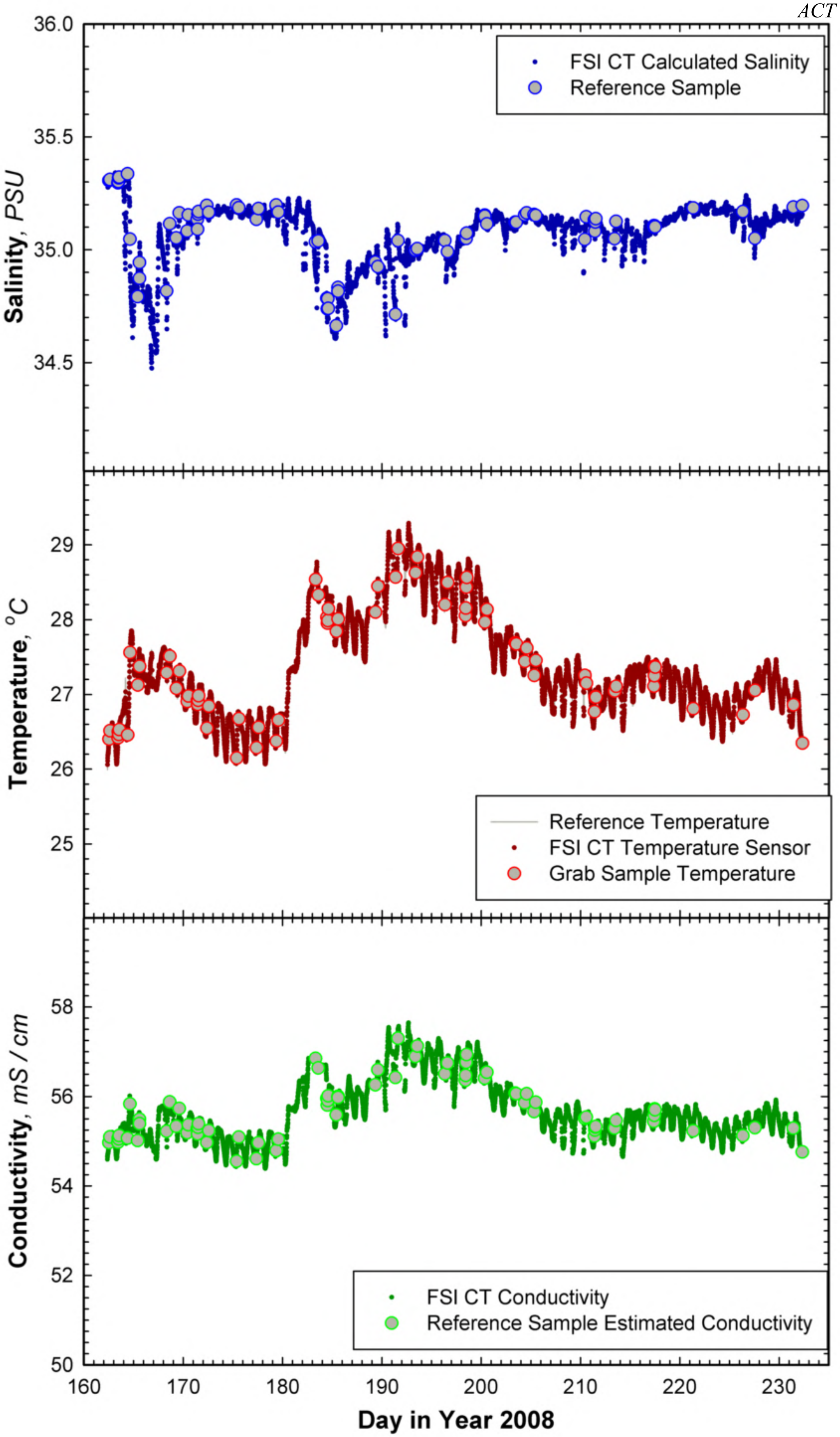


Figure 19. Time series of instrument measurements and corresponding reference samples acquired during the HI field deployment.

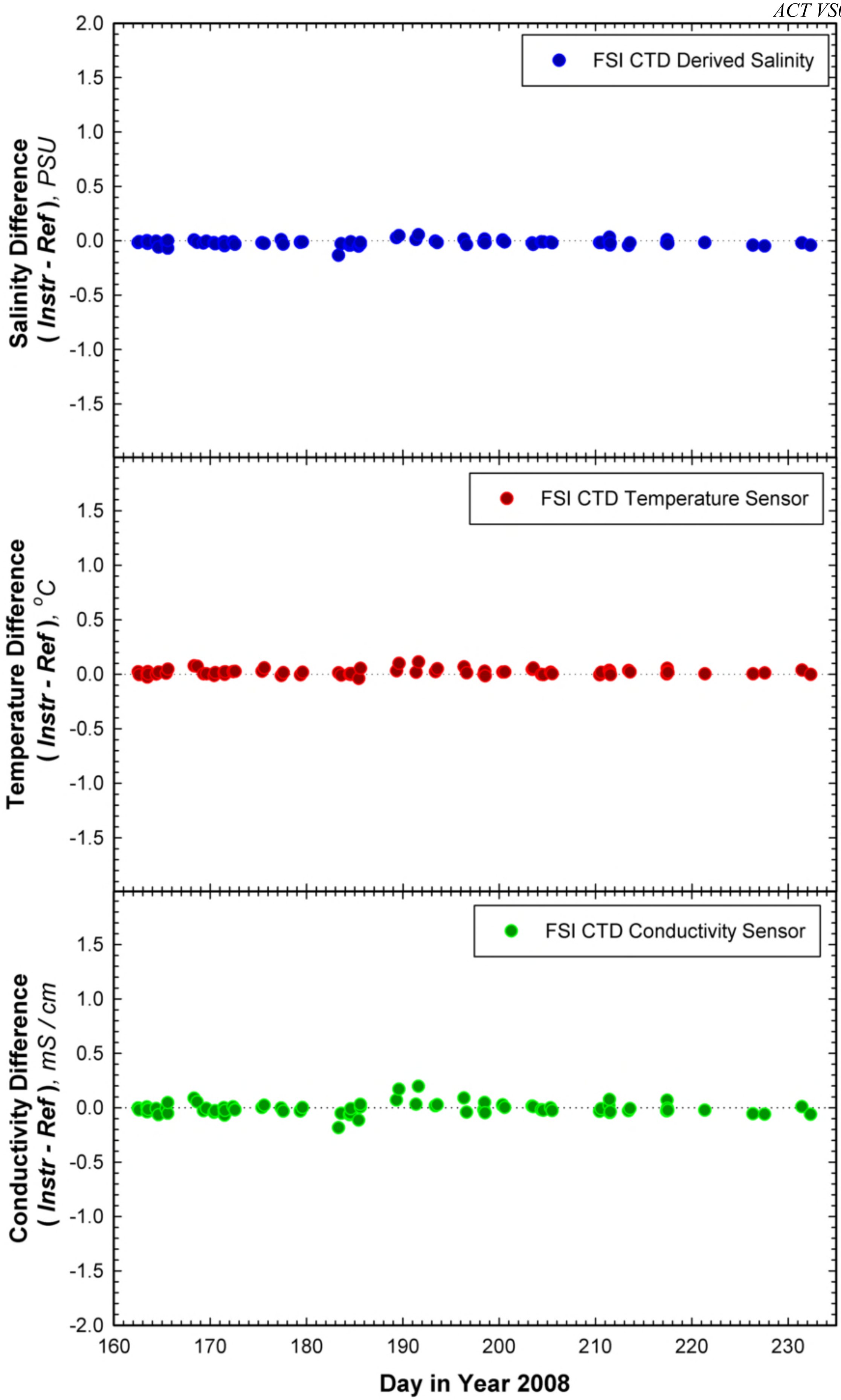


Figure 20. Assessment of relative accuracy of instrument time series measurements during the HI field deployment.

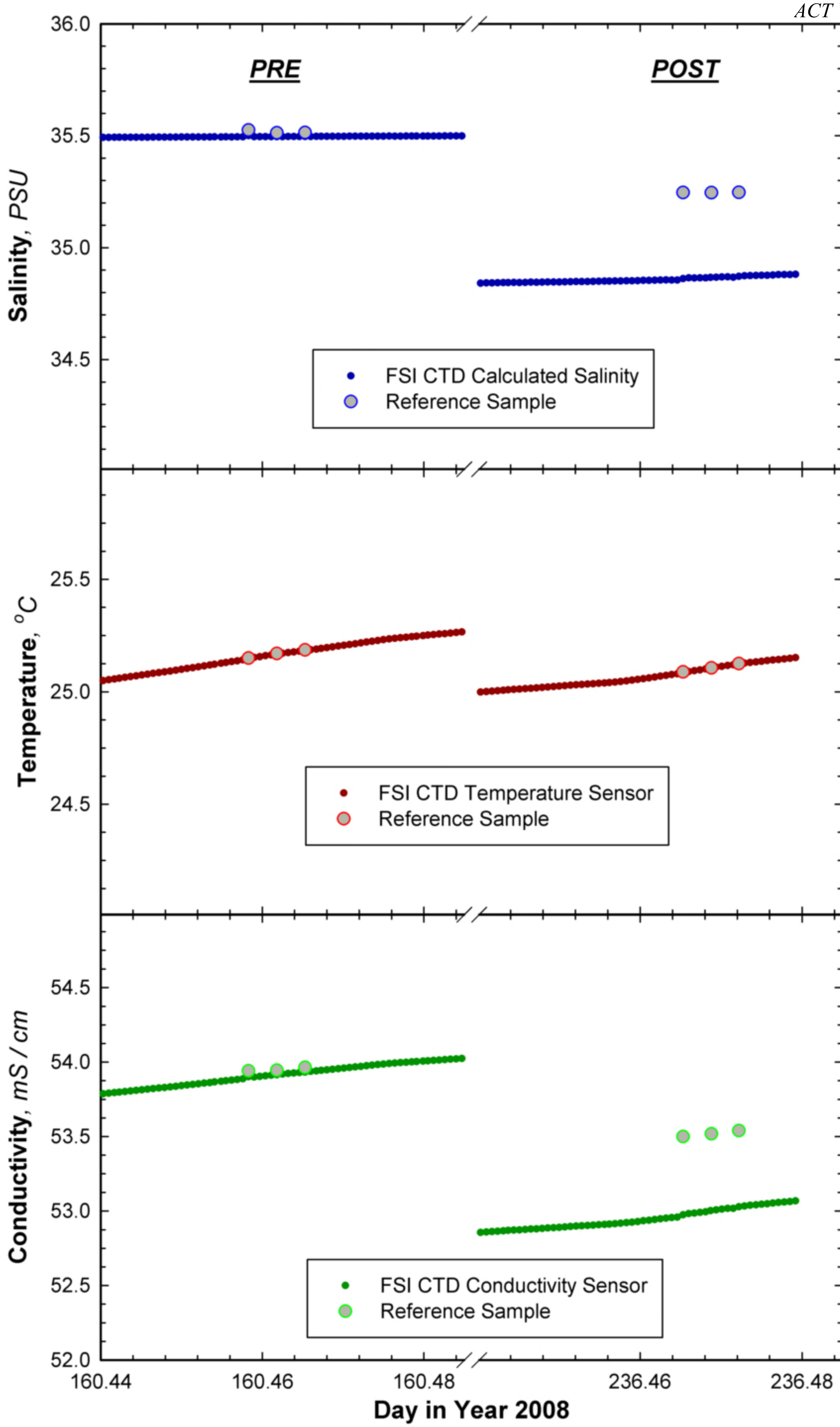


Figure 21. Pre- and Post-deployment reference checks in tanks of natural seawater at HI. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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)

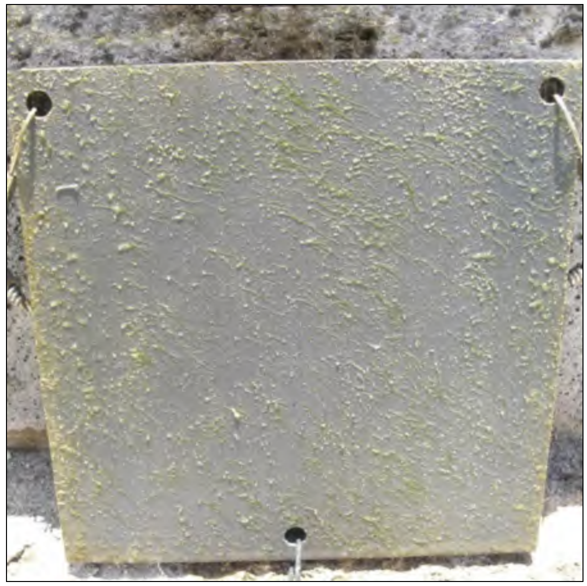
After Deployment (Full View)

Figure 22. FSI NXIC 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. The instrument package used at this test site was the freshwater model, CTW-FS.

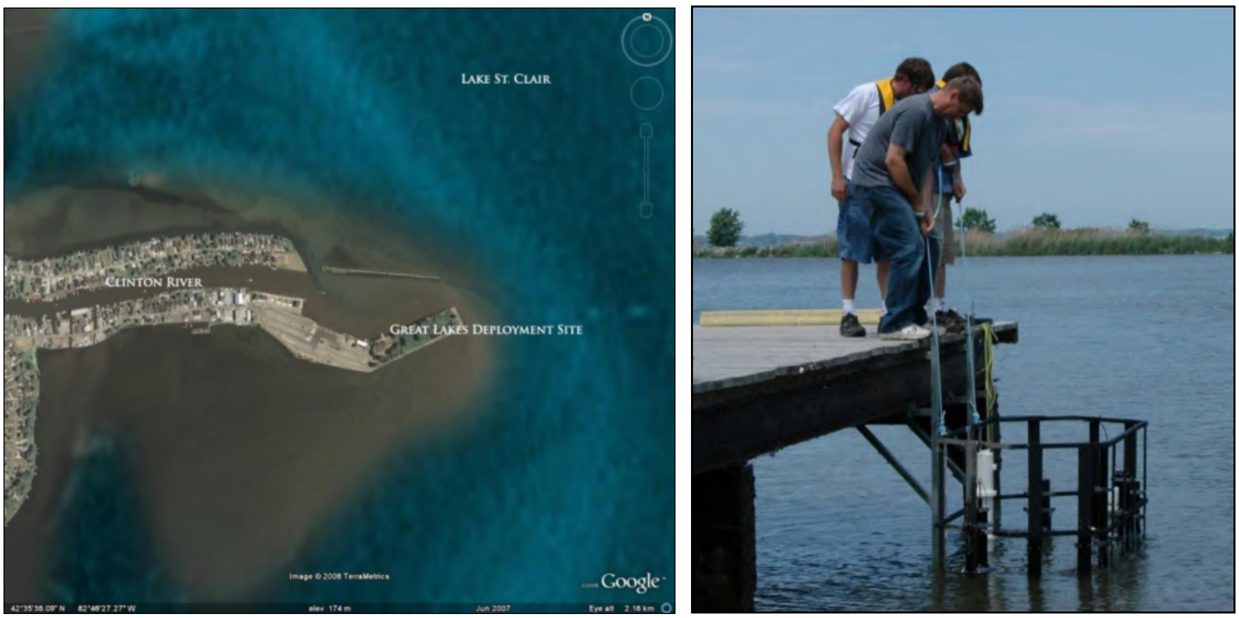


Figure 24. Site map and photo of the Great Lakes field test site located at the mouth of the Clinton River in Mt. Clemens, MI. The test instrument was deployed on a mooring frame attached to the end of a fixed pier.

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 (Fig. 25). The FSI NXIC measurements closely matched reference sample measurements throughout the entire 29 day deployment despite the lower riverine conductivity levels and rather sharp temporal gradients experienced at the site. The amount of offset in salinity, conductivity and temperature averaged -0.0018 psu, -0.0038 mS/cm, and 0.0093 ^{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 tests (Fig. 21). In general there was very little fouling impact at this site and the amount of fouling that developed on the instrument during the deployment is shown in figure 27 and the rate of fouling was documented with a time-series of photographs showing the accumulation on PVC tiles (Fig. 28).

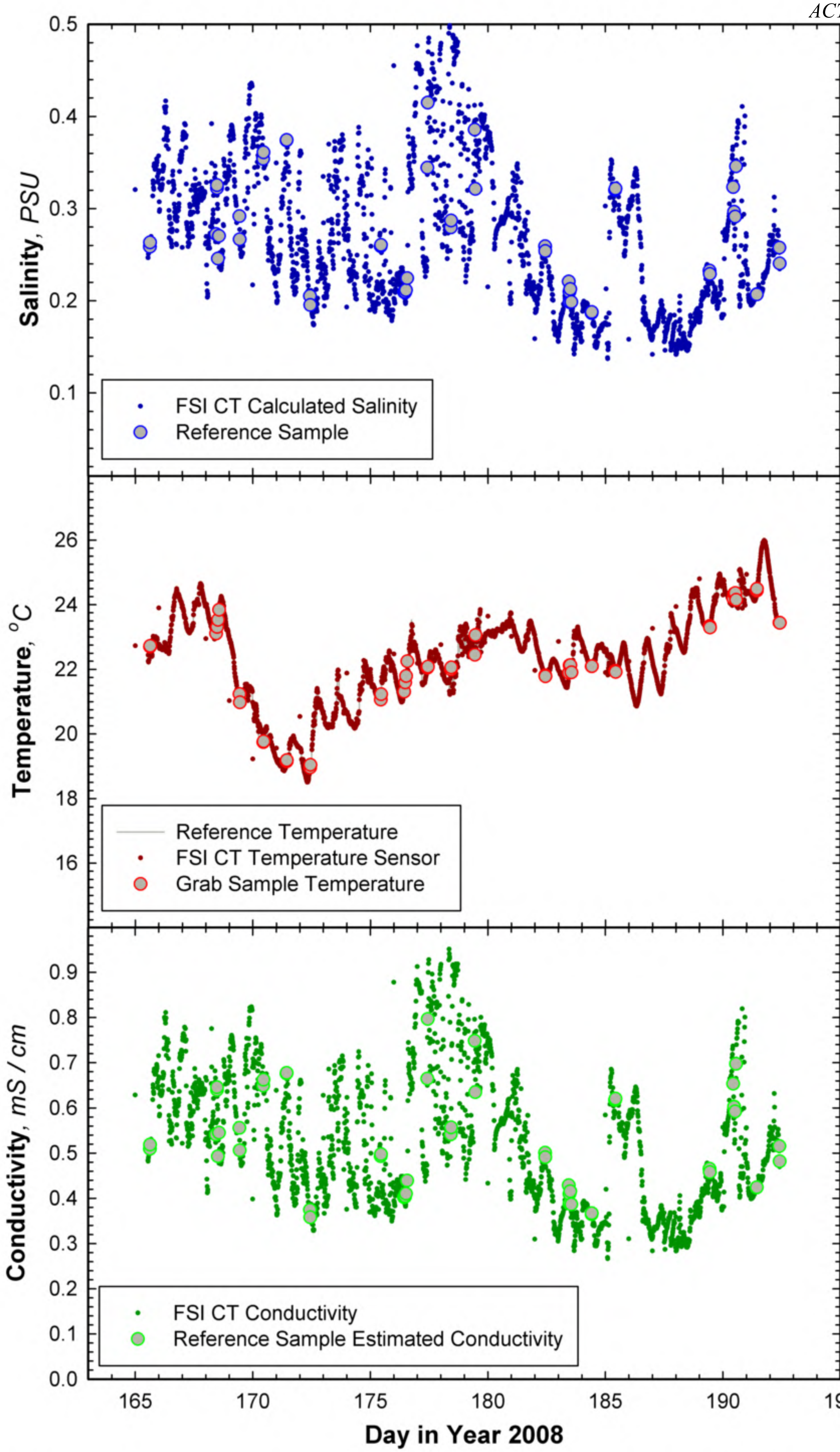


Figure 25. Time series of instrument measurements and corresponding reference samples acquired during the GL field deployment.

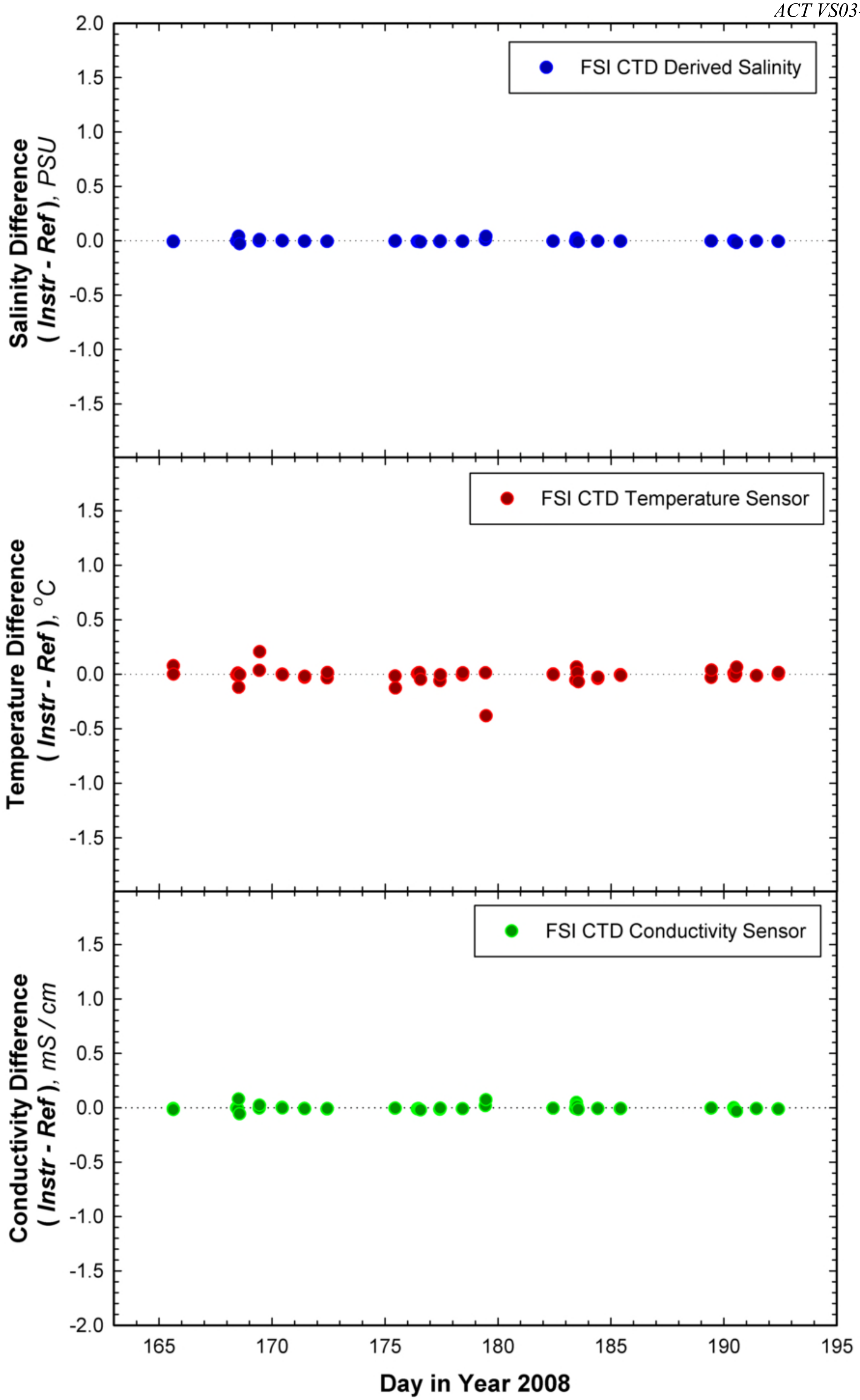


Figure 26. Assessment of relative accuracy of instrument time series measurements during the GL field deployment.

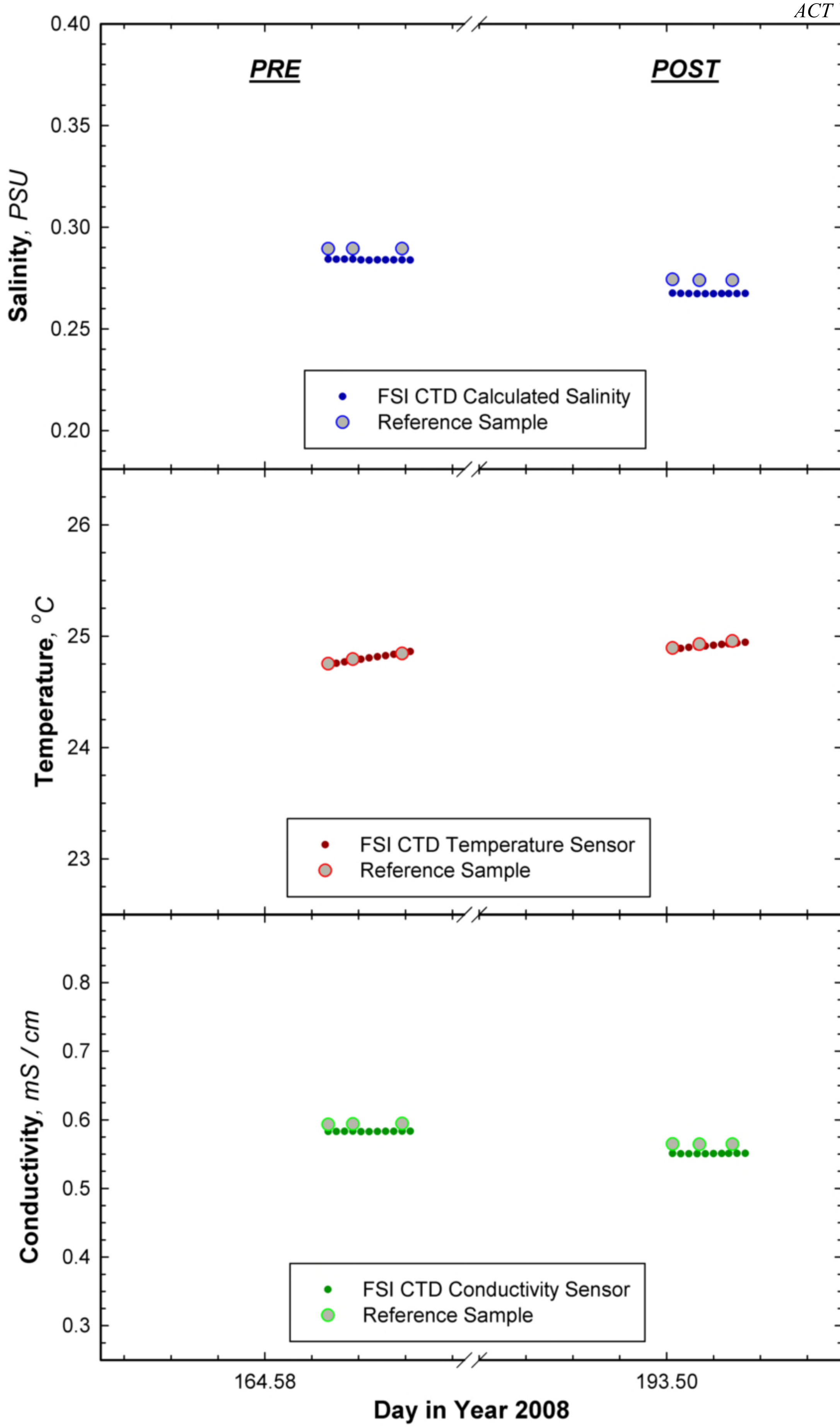


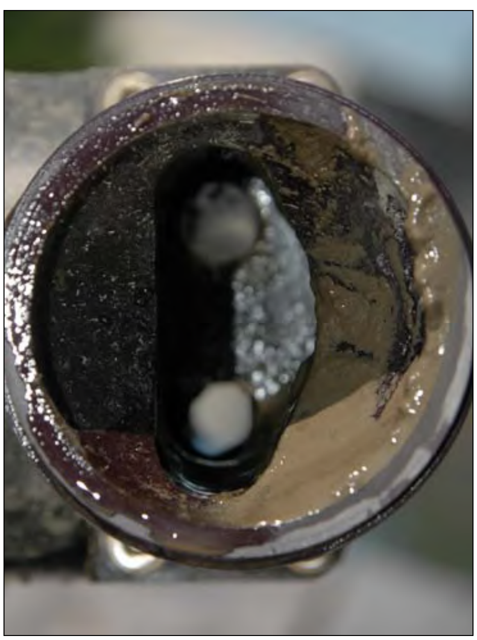
Figure 27. Pre- and Post-deployment reference checks in tanks of river water at GL. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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)

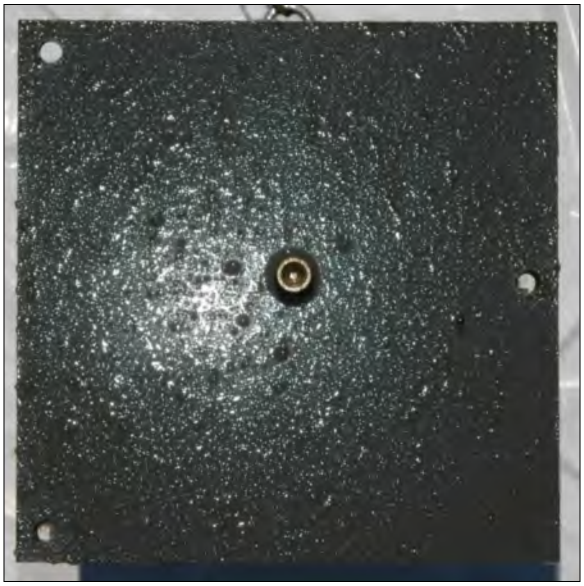

After Deployment (Close-up)


After Deployment (Full View)

Figure 28. FSI NXIC instrument photos from the Clinton River, MI 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. 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 (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 disagreements between instrument and reference sample measurements. The relative accuracy of the in situ measurements were depicted as numerical differences from the reference values and plotted over time (Fig. 32). Several lines of evidence suggest the greater offset was due to heterogeneity and not instrument performance or biofouling. First, measurement accuracy returned to near specifications following most large scale deviations, even at the very end of the test. Secondly, comparison of instrument accuracy and precision measured during pre- and post-deployment exposure tests, following instrument cleaning, revealed no measureable performance drift over the deployment period of 29 days (Fig. 33). Lastly, precision among field replicates was significantly lower at this site than for the other sites. The amount and type of biofouling at this site was similar to observed in HI and MI where very little impact on instrument performance was noted (Fig. 34).

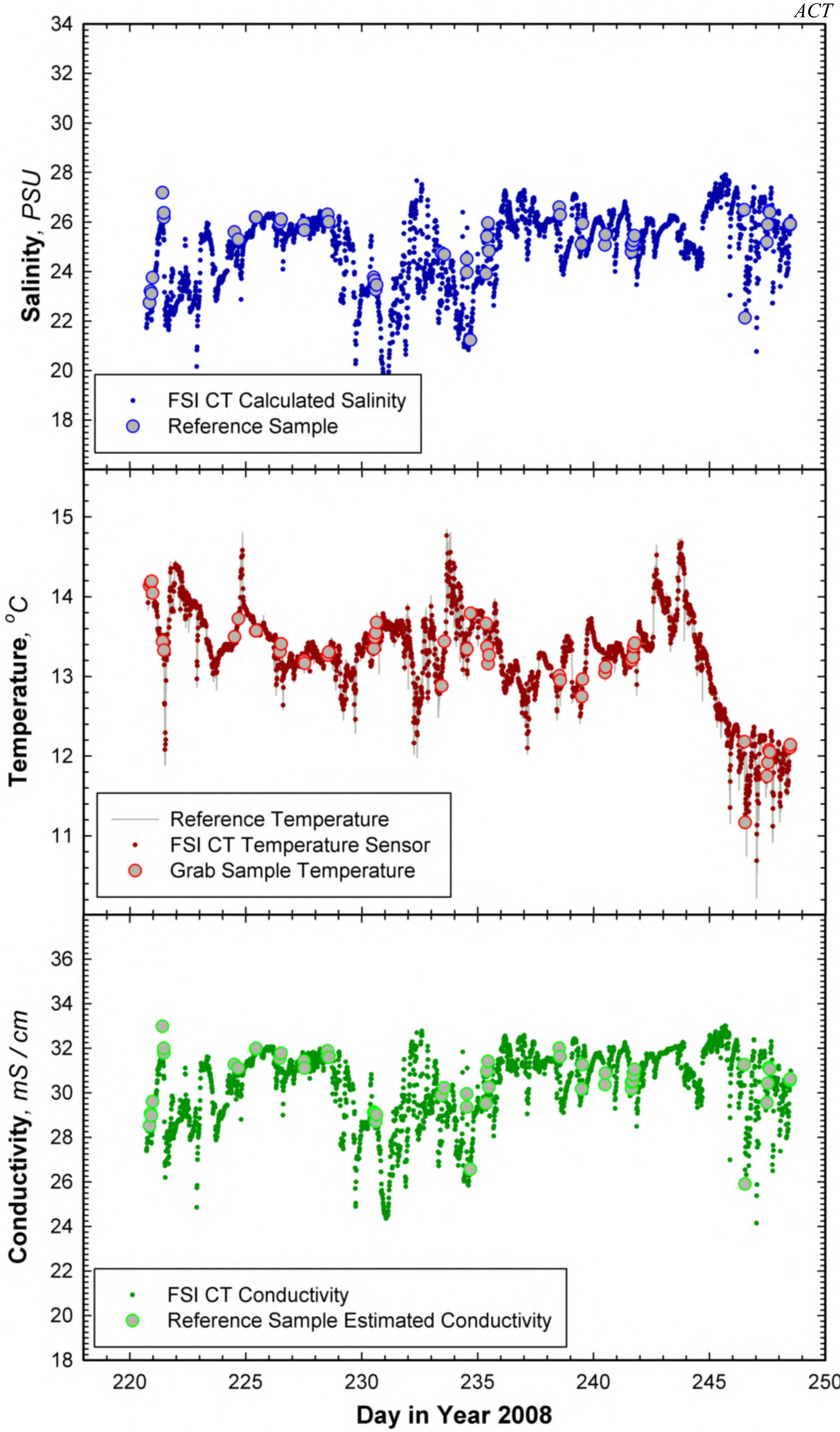


Figure 31. Time series of instrument measurements and corresponding reference samples acquired during the AK field deployment.

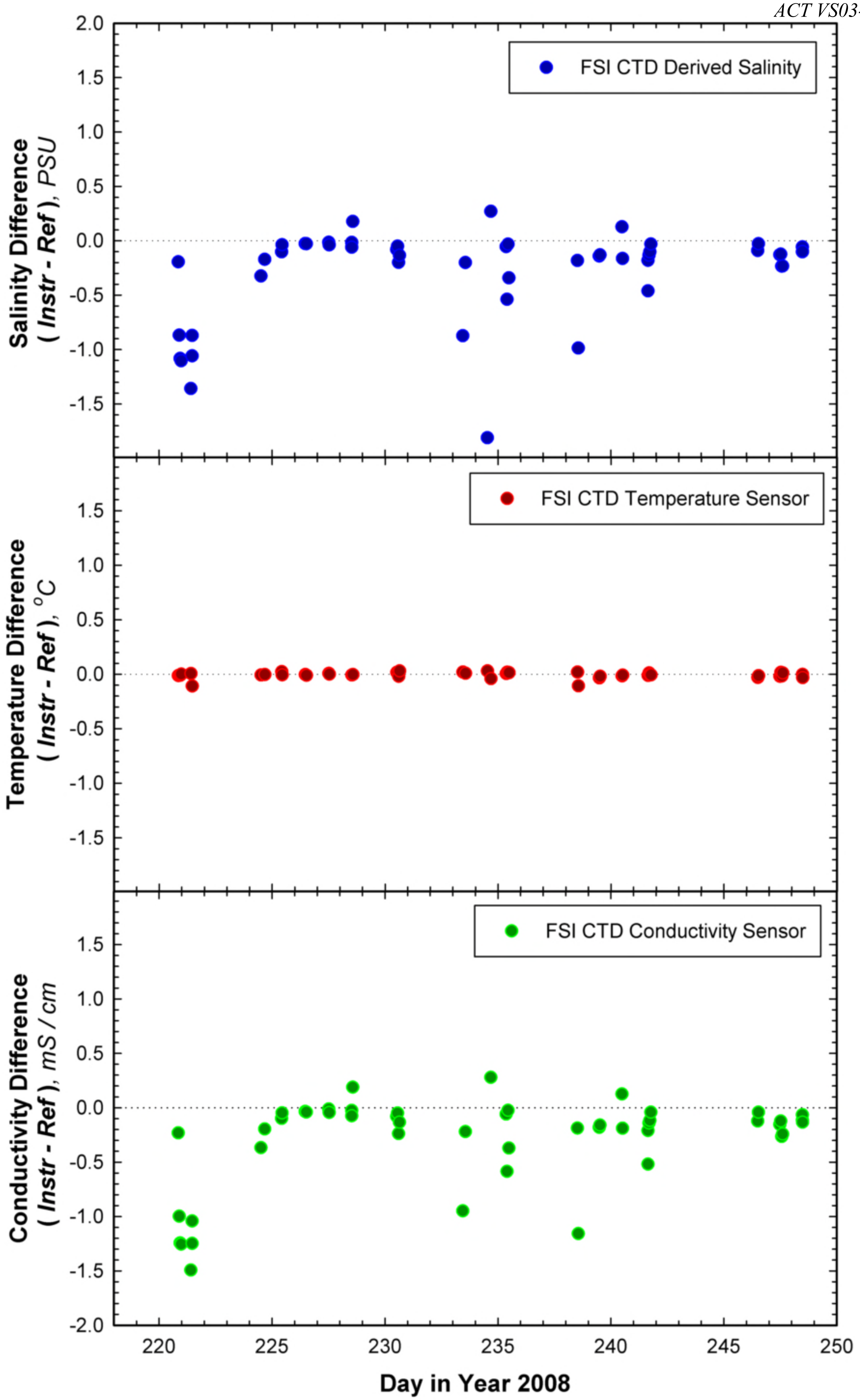


Figure 32. Assessment of relative accuracy of instrument time series measurements during the AK field deployment.

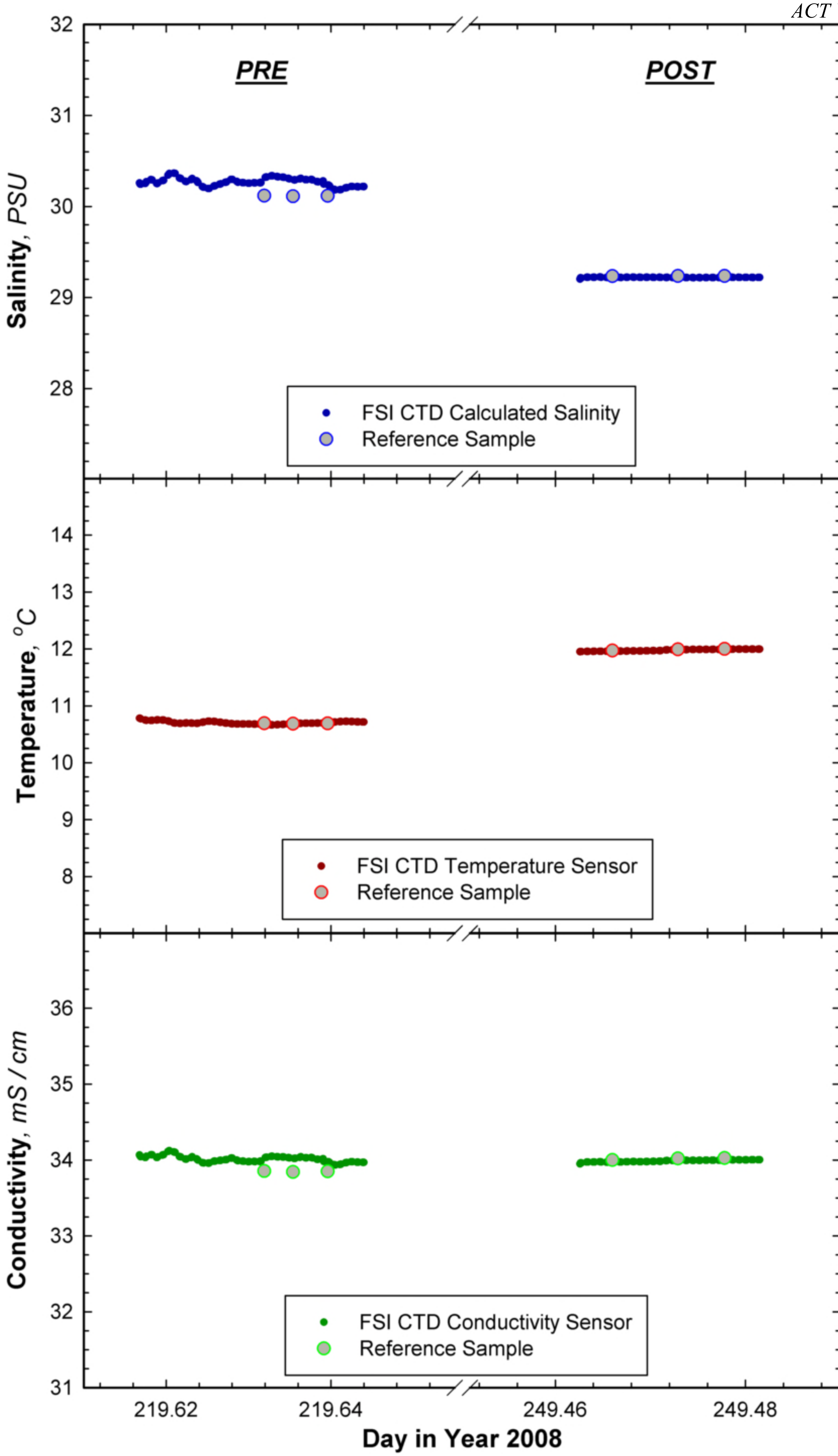


Figure 33. Pre- and Post-deployment reference checks in tanks of natural seawater at AK. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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)

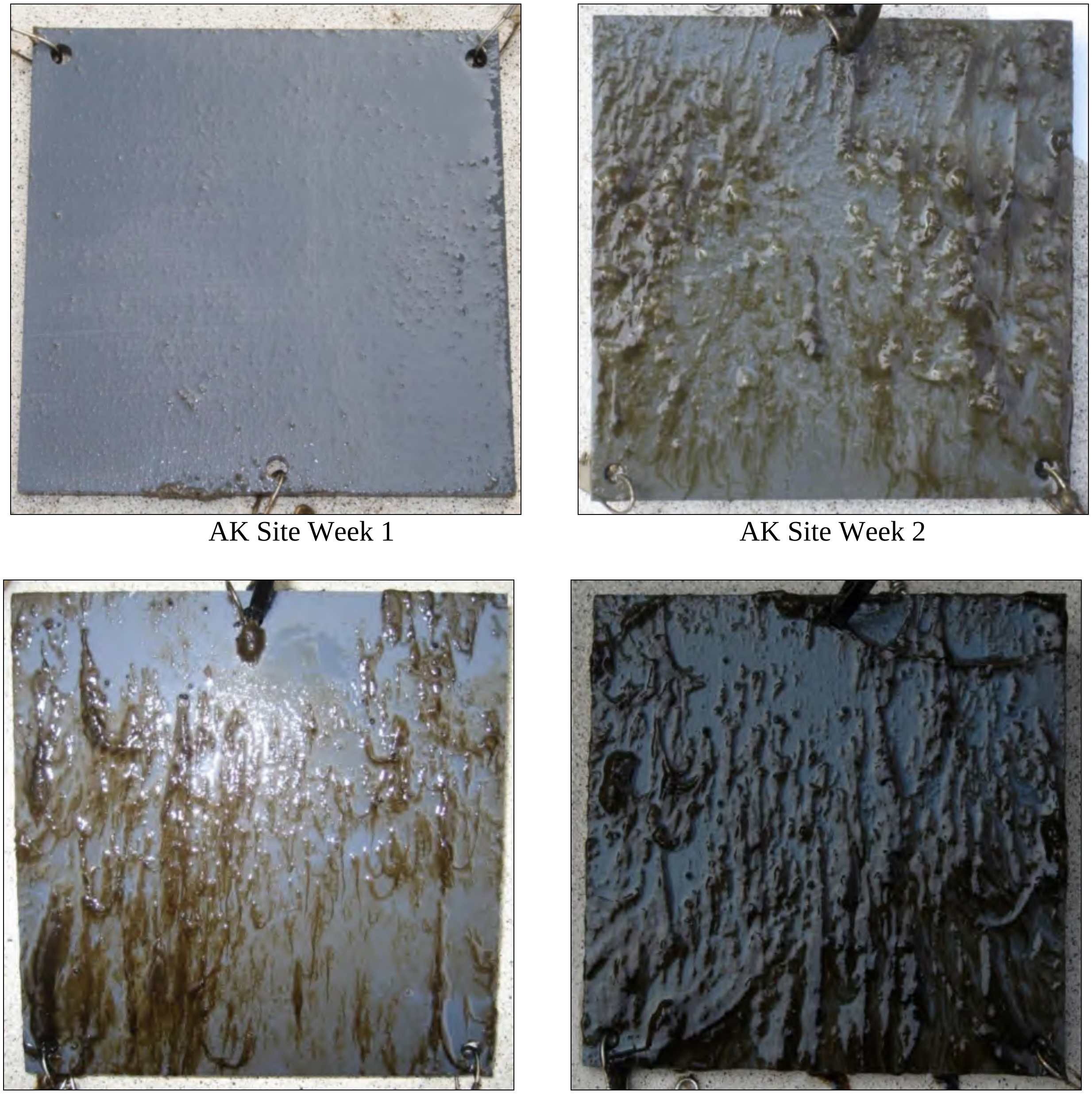
After Deployment (Close-up)

After Deployment (Full View)

Figure 34. FSI NXIC 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 in situ instrument measured plotted against reference sample measurements for salinity, conductivity, and temperature (Fig. 36). These results allow a field-based performance assessment similar to the range of test conditions applied within the laboratory test. The effects of biofouling or calibration offsets can be viewed as the vertical deviations from the 1:1 data correspondence trend line. In general the response of instrument derived salinity was highly linear across the range of field test conditions with an R^2 = 0.999, a standard error of 0.353, and a slope of 0.998. These results are quite comparable to the instrument response observed within the laboratory test. As was noted individually at the test sites, the response of the temperature sensor was more stable than the conductivity sensor and appeared much less impacting by biofouling.

RESULTS OF VERTICAL PROFILING FIELD TEST

The FSI NXIC 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 0.0528 ±0.0207 psu. Separate conductivity and temperature responses were not generated for the profiles.

RELIABILITY

The FSI NXIC CTD-BIO-AUTO Salinity Sensor was 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 loss of 2, 1, 9, and 30 seconds was noted for the GA, AK, MI and HI test sites respectively. Lastly, sites with hard, encrusting biofouling had a significant impact on performance but biofouling of plant material had much less impact. There was no evidence of electronic drift during the 30 – 60 day deployments.

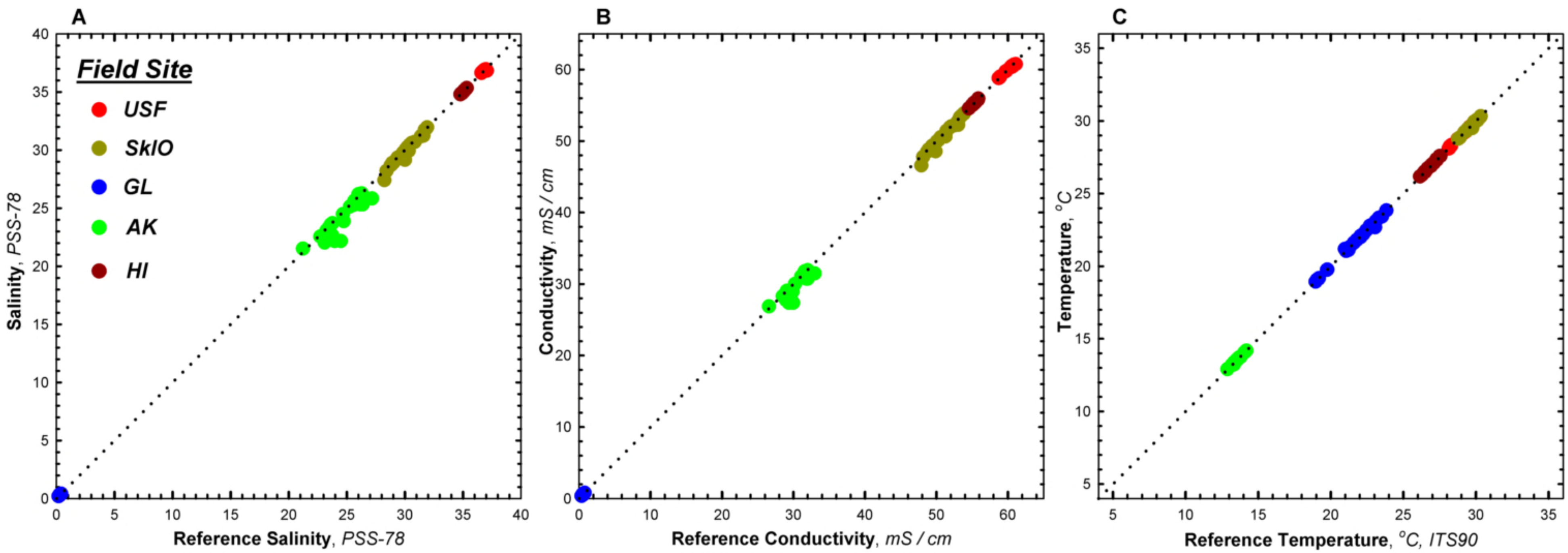


Figure 36. Composite summary of field performance over the first 14 days of deployment for the four Falmouth Scientific CTD units tested during the five evaluation trials. Instrument output plotted against paired field reference sample assay and color indexed by field test site. Dotted line represents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

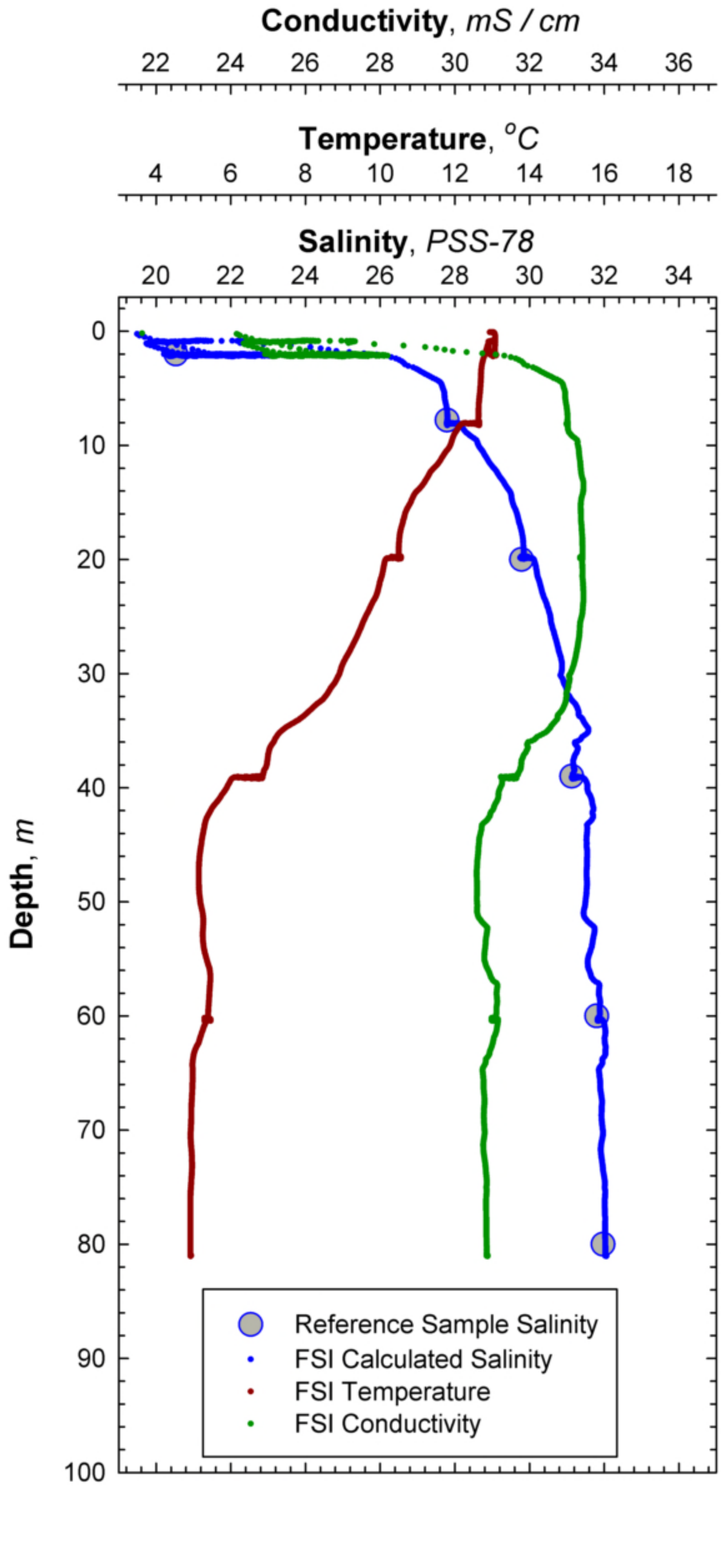


Figure 37. Vertical profile data from the FSI CTD deployed offshore of the Seward Marine Life Center within Resurrection Bay, AK. Sharp pycnocline at 2 m indicative of influence of glacial runoff at this site.

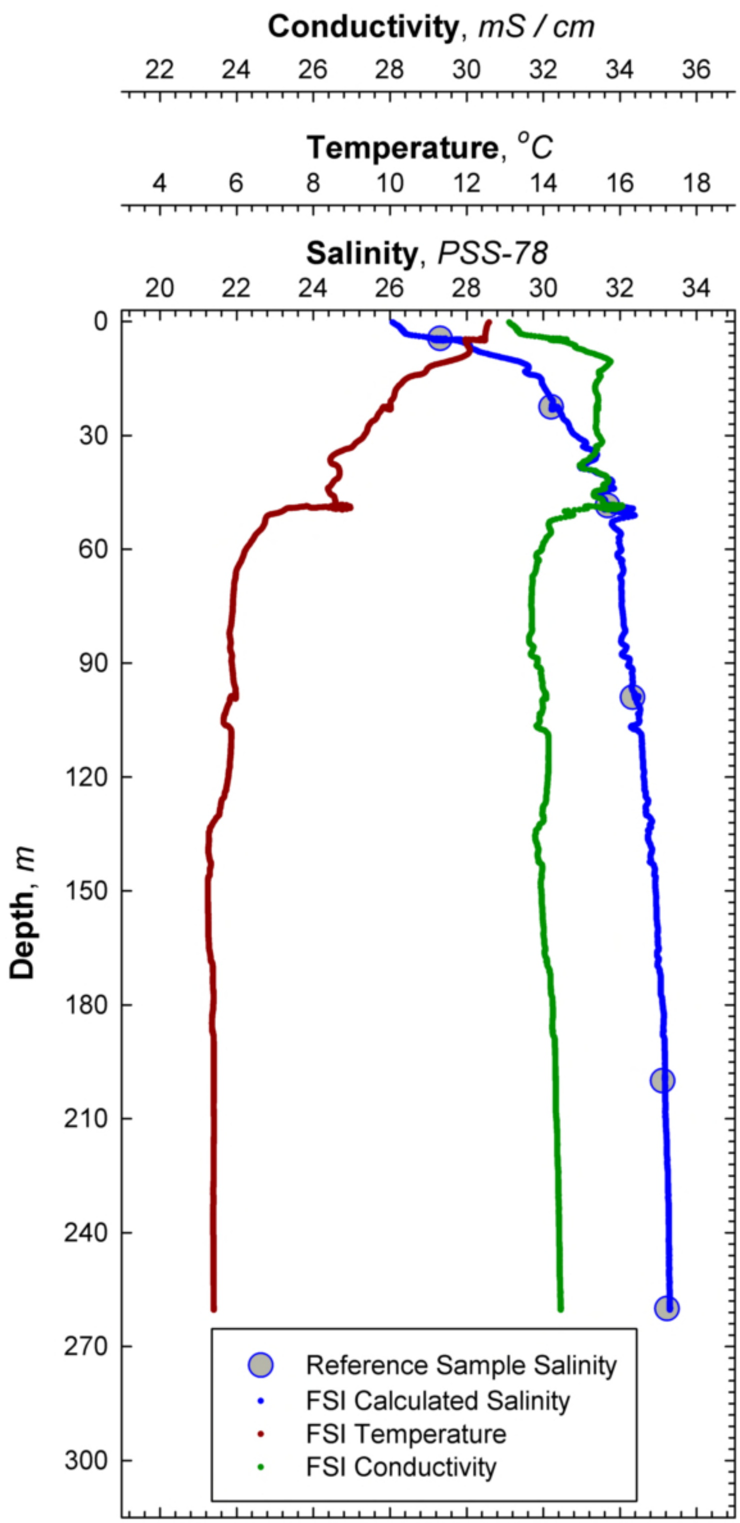


Figure 38. Vertical profile data from the FSI CTD deployed in deep water off the shelf outside of Resurrection Bay, AK. Deeper and narrower pycnocline reflects mixing of offshore and bay waters.

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.

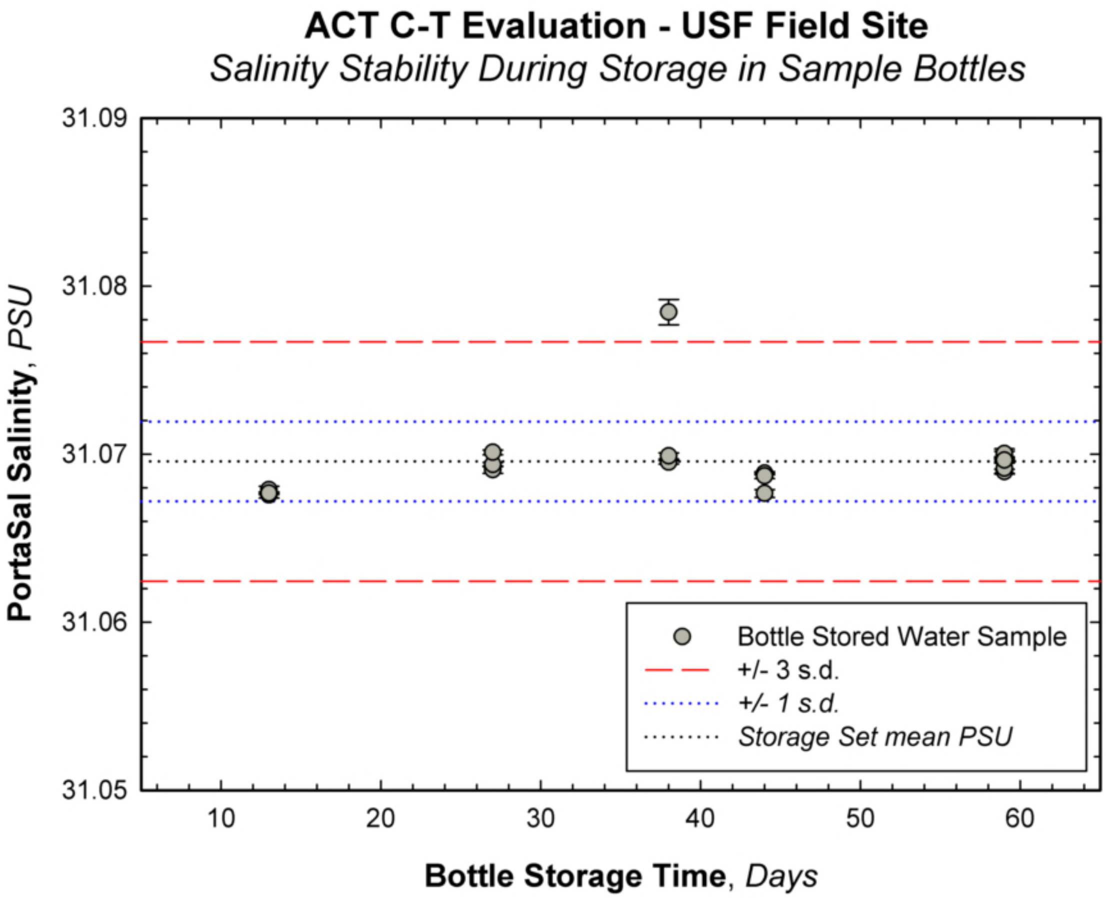


Figure 39. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

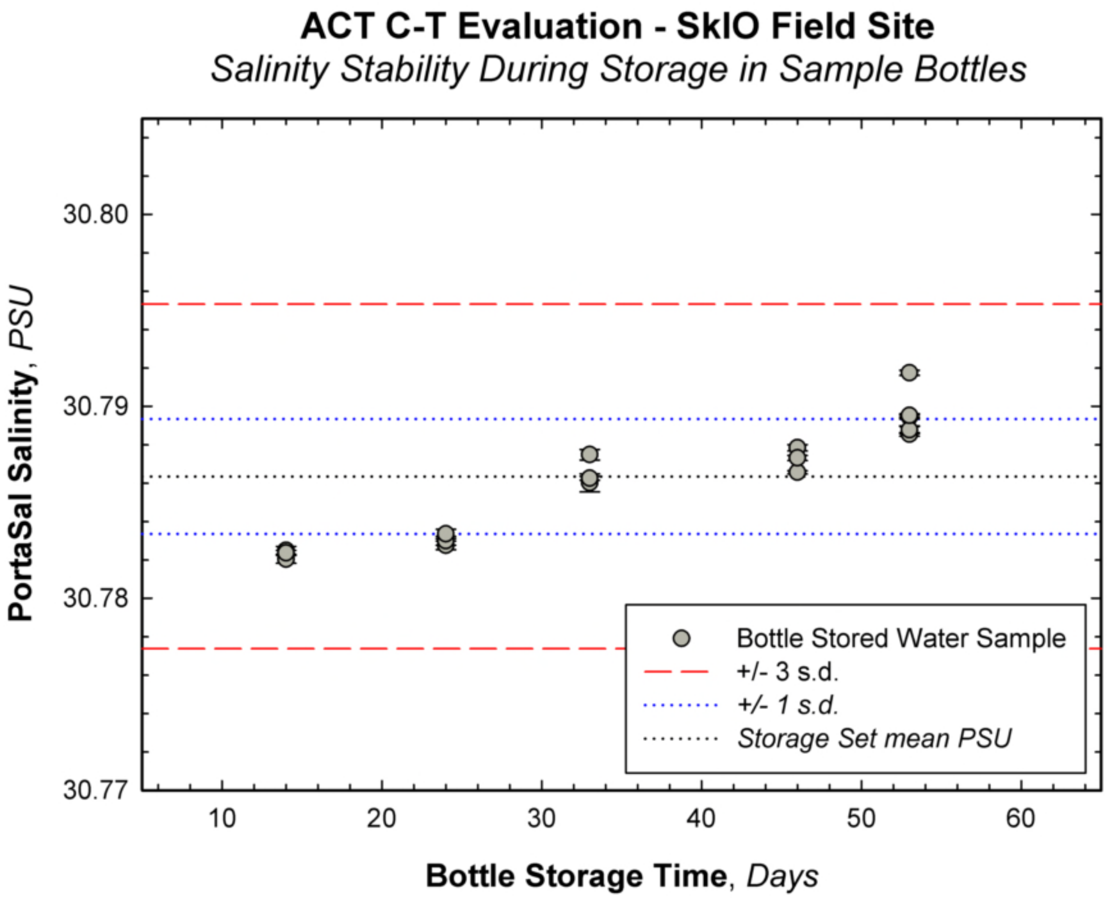


Figure 40. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

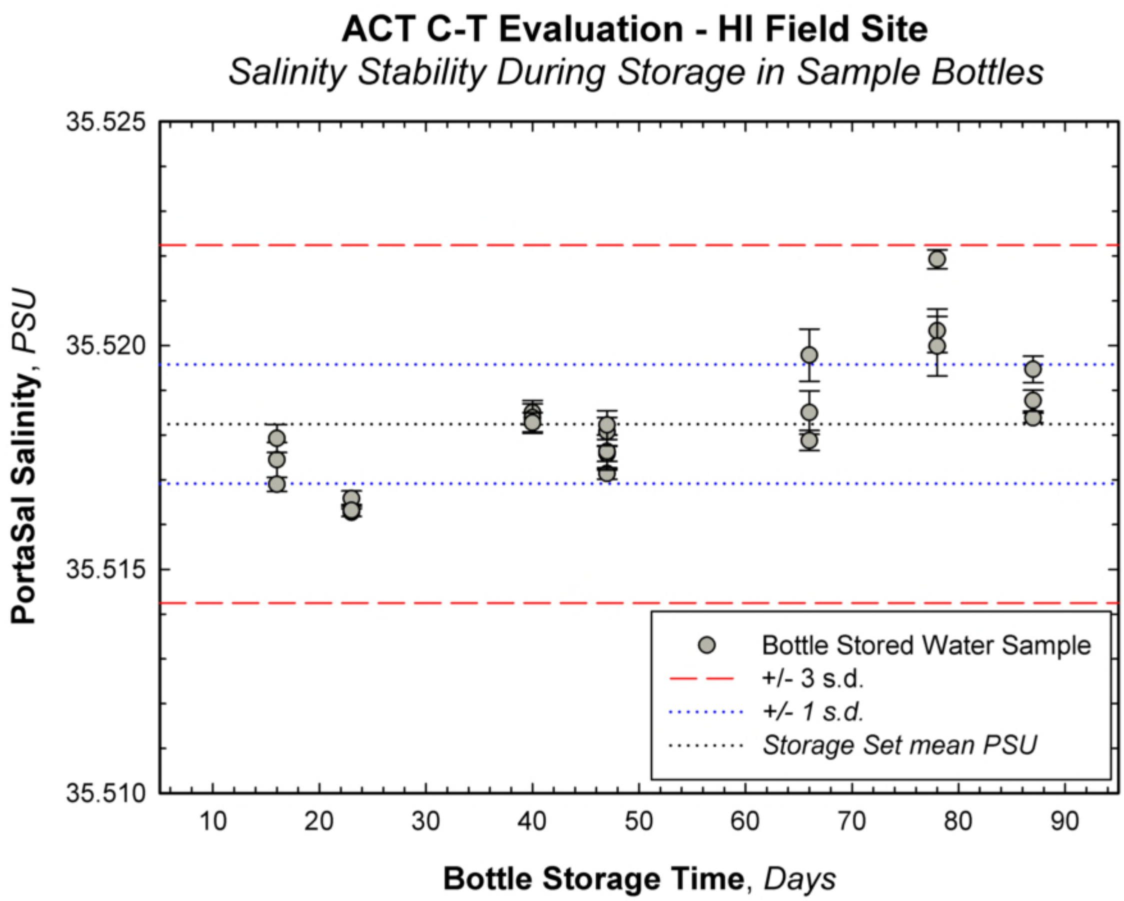


Figure 41. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

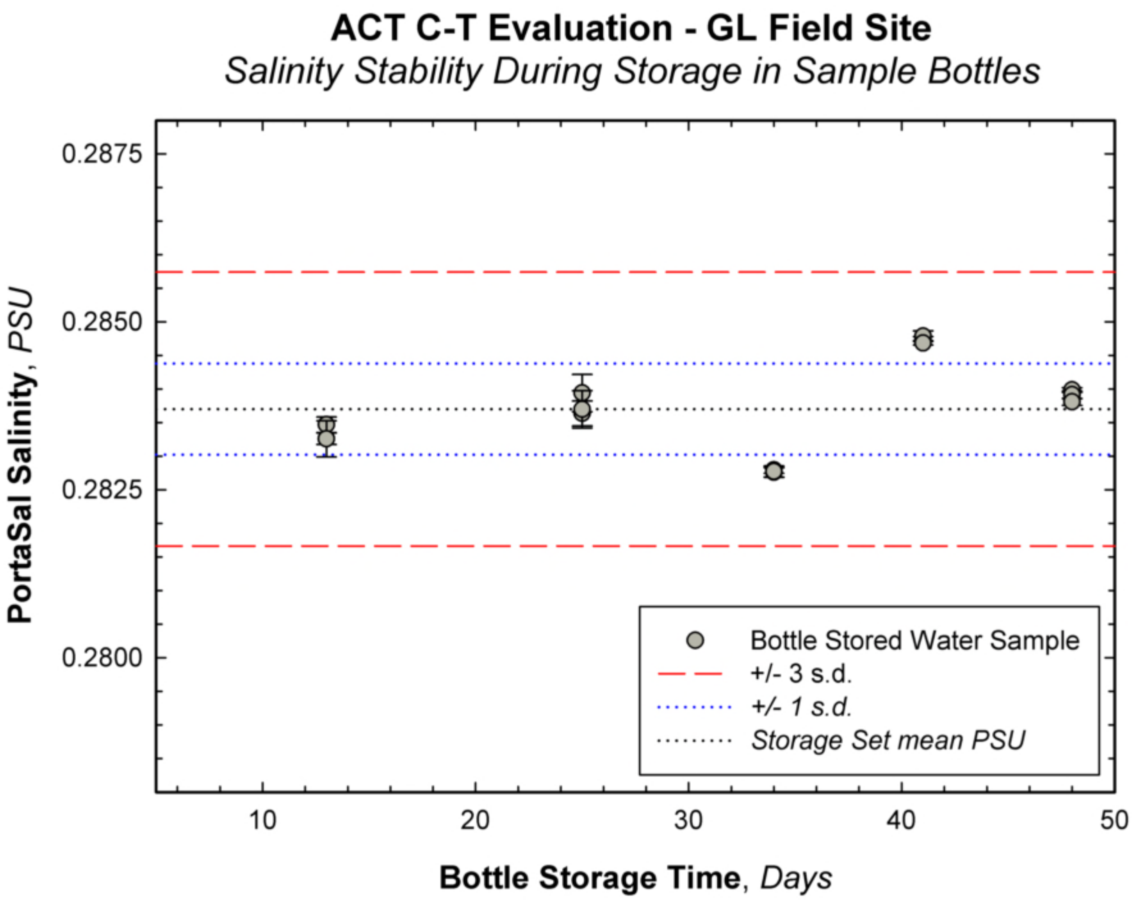


Figure 42. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

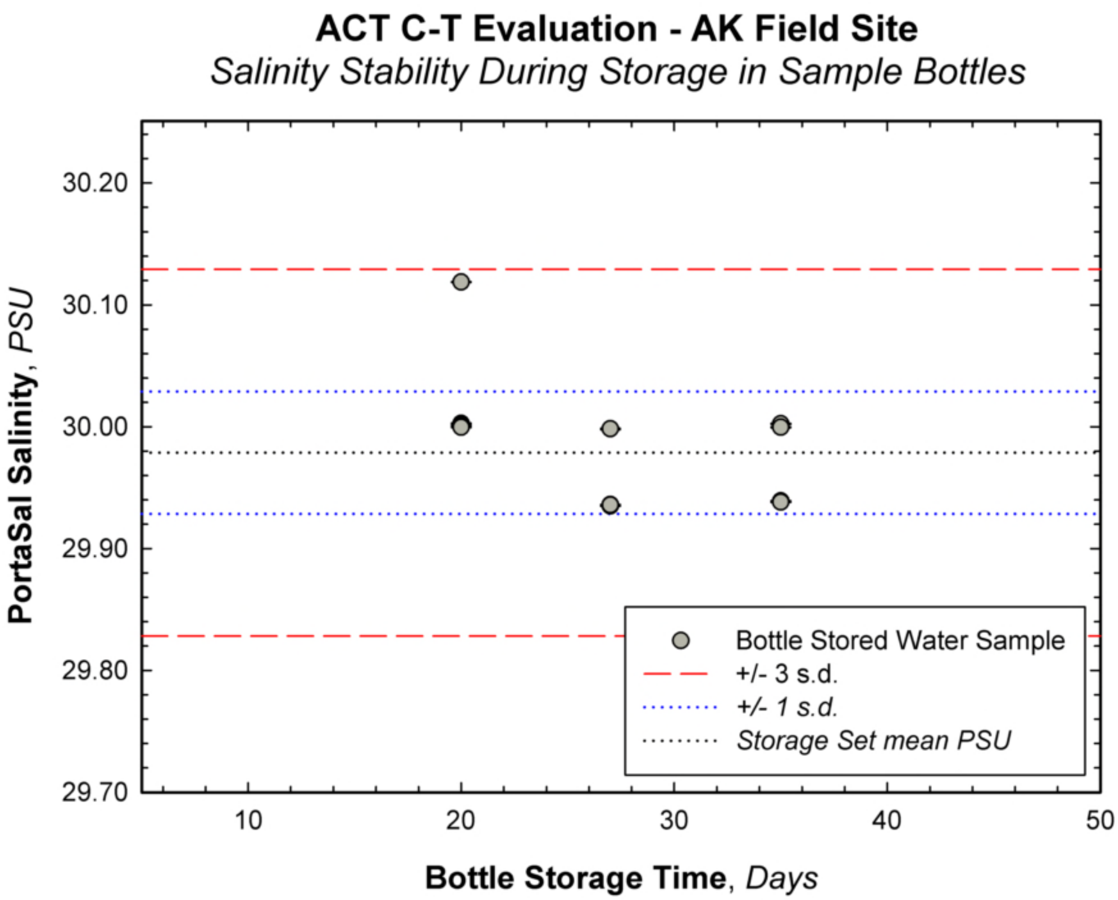


Figure 43. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

Date

Approved By: Dr. Mario Tamburri
ACT Executive Director

March 15, 2009

Date

Approved By: Dr. Tom Johengen
ACT Chief Scientist

March 15, 2009

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

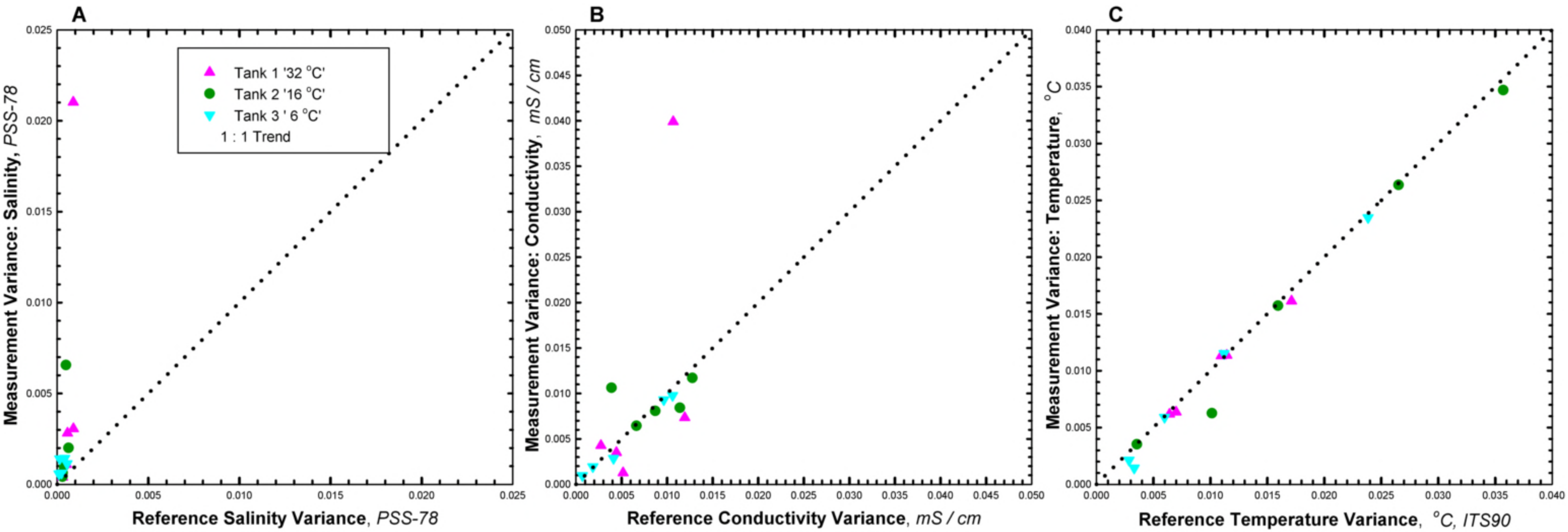


Figure 4. Evaluation of measurement variation of the FSI conductivity and temperature sensor package achieved during the laboratory exposure trials plotted in **Fig. 3**. Instrument measurement variance is presented as the standard deviation from 30 consecutive instrument reads recorded during the 30 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

Falmouth Scientific, Inc.

March 6, 2009

Dr. Thomas Johengen
c/o Alliance for Coastal Technologies
Chesapeake Biological Laboratory
PO Box 38 / One Williams Street
Solomons, Maryland 20688 USA

Re: Performance Verification Statement for the FSI NXIC-CTD-BIO-AUTO Salinity Sensor

Dear Dr. Johengen:

FSI wishes to thank the Alliance for Coastal Technology for the opportunity to participate in the Technology Evaluation of Salinity Sensors.

The evaluation of FSI's NXIC-CTD-BIO-AUTO Salinity sensors showed that, as with all existing conductivity-based salinity measurement technologies, bio-fouling can affect conductivity/salinity readings of inductive sensors by changing the sensor geometry. It was also an effective demonstration that the copper screening is not equally effective in preventing all types of bio-fouling. FSI is in the process of investigating additional bio-fouling control methods.

It should be noted, however, that the evaluation testing also demonstrated that the NXIC-CTD-BIO sensors, once cleaned of bio-fouling, showed "no strong evidence for calibration drift during the period of deployment." (Executive Summary) The ability to clean the conductivity sensors on-site (or in-situ using divers) and to maintain sensor accuracy over a period of several months is one of the advantages of inductive conductivity technology.

The consistently low sensor readings during preliminary laboratory testing, as well as in pre-deployment reference testing at the SkIO and post-deployment reference testing at HI is indicative of air bubbles trapped in the sensor. Although air bubbles may be trapped in the sensor under laboratory or shallow-water conditions, these bubbles would typically be dispersed early in the deployment with increased ambient pressure and as the sensor is flushed by the current, as can be seen by the data at the SkIO site.

Sincerely,

John Baker
President and Chief Technology Officer

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