PERFORMANCE VERIFICATION STATEMENT
for the Greenspan EC3000 Conductivity 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 Greenspan EC3000 conductivity sensor 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 ACT QA specialists, who conducted technical systems audits and a data quality audit of the test data.

In the lab tests, the Greenspan EC3000 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 ^{o}C (R^2 = 0.999, SE = 0.118 and slope = 0.997). The mean of the absolute difference between instrument measured salinity and reference sample salinity for all 15 treatments was -0.0426 ±0.1176 psu. When examined independently, the relative accuracy of the conductivity and temperature sensors were 0.1306 ±0.08902 mS/cm and 0.0935 ±0.1377 ^{o}C, respectively.

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 ^{o}C, respectively. Extensive and rapid biofouling at the FL and GA test sites severely impacted instrument performance within approximately one week. Based on initial relative accuracy of the instrument during the first few days of deployment period, instrument performance was also affected by calibration issues. The initial offsets in measurement salinity were 0.218, 0.200, and -0.210 for the FL, GA, and HI test deployments. The accuracy was much better for the entire MI freshwater deployment and initially for the HI with offsets of -0.0006 and 0.030 psu, 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 = 0.982, SE = 1.789 and slope = 0.982.

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. At the three sites where these tests were successful, field deployment results were largely reflective of biofouling impacts and not calibration drift in the instrument. On one occasion a very low negative offset in instrument readings for the pre-test may have resulted from the entrainment of air bubbles in the conductivity cell.

During this evaluation, significant problems were encountered with the provided software and several interactions with the manufacturer were required before all instruments could be programmed properly for the tests. Several of the test sites had incomplete data records. For the FL field test about 5 % of the data were lost. For the GA field test, a battery failure occurred and only 7% of the deployment record was useable. For the HI field test, we could not get the instrument working properly and lost the pre-deployment test and the first week of the mooring test. Lastly, a check on the instruments time clocks at the beginning and end of field deployments showed differences of between minus 1 and plus 1 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 Greenspan EC3000 salinity sensor. Appendix 2 is an interpretation of the performance verification results from the manufacturer's point of view.

TECHNOLOGY TESTED

The EC3000 Conductivity Sensor is manufactured by Greenspan Analytical (Part of Tyco Environmental) in Warwick, Queensland, Australia. It provides a self contained measurement and data logging system suitable for a wide range of environmental water monitoring applications. The EC3000 sensor utilizes a toroidal sensor for conductivity measurement and a thermistor for temperature measurement. Multi-point linearity and temperature calibration over the full operating ranges is designed to provide stable, repeatable and accurate readings in the field. The internal data logger allows long term data collection at remote sites, as well as options for remote telemetry connection. The sensor can be fitted with an external cable, or with an on board battery pack for stand alone operation. Other cable options can provide serial output in SDI12 format for connection to external Data Logger or process controller. The manufacturer quotes an overall Accuracy (combined linearity, hysteresis and repeatability) of +/- 1% full scale range for EC and +/- 0.2°C for Temperature and long term stability 0.2% full scale per annum.

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).

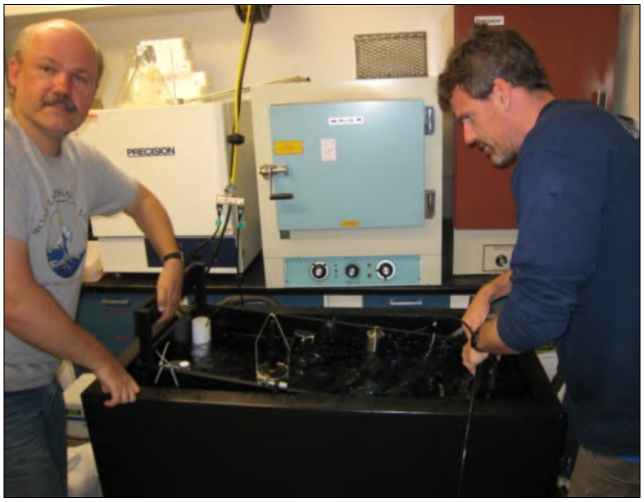


Figure 1. Analytical instrumentation (Portasal 8410A) used for laboratory analysis of salinity reference samples and one of the test baths and instrument racks used for the laboratory tests.

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.

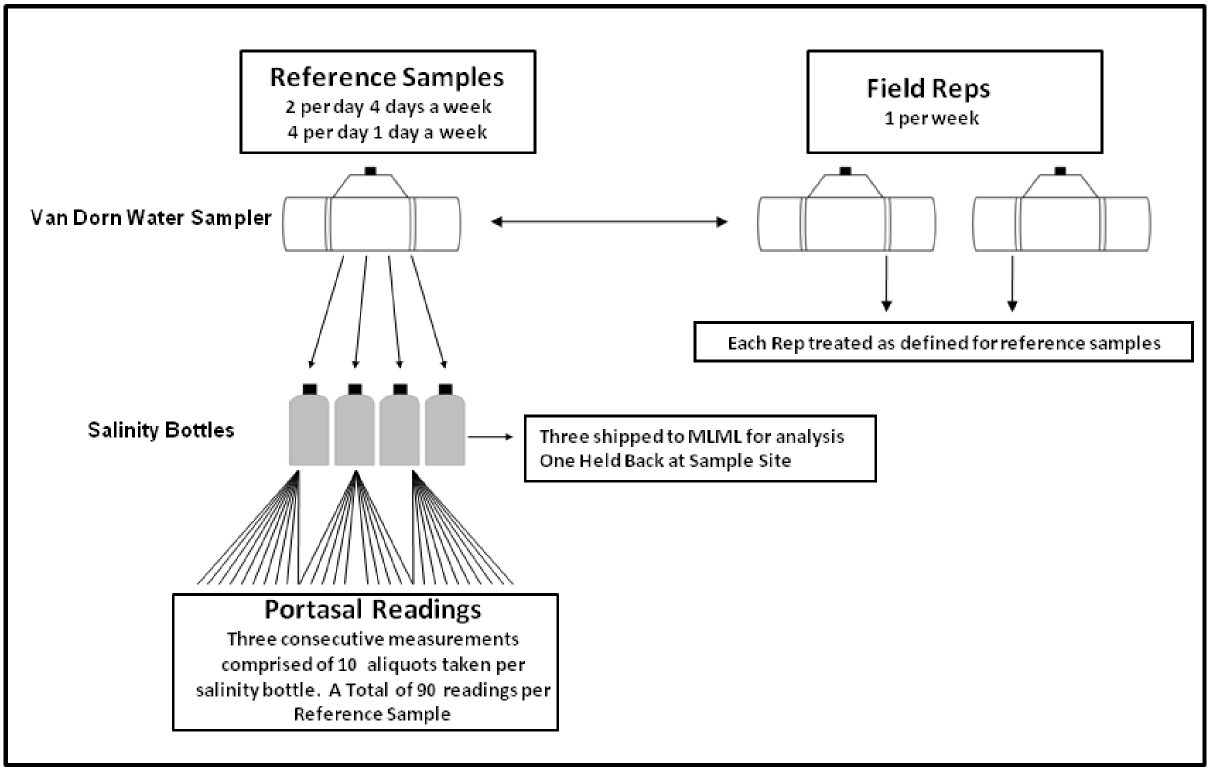


Figure 2. Schematic representation of the reference sampling process conducted during moored deployment field tests.

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 Greenspan EC3000 instrument package was not 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 Greenspan EC3000 exhibited a strong linear response to the test solutions with R^2 = 0.9999, standard error = 0.118 psu and slope = 0.997 (Fig. 3). The conductivity and temperature sensors of the instrument responded with similar linearity and accuracy across the test conditions. 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 noticeable difference in both conductivity and temperature accuracies across the range of test conditions. The response differences resulted in unique error distributions for each test temperature. The overall mean of the salinity offsets for all lab tests was -0.0426 ±0.1176 psu. When examined independently for conductivity and temperature measurements, the mean of the offsets were 0.1306 ±0.0802 mS/cm and 0.0935 ±0.1377 ^{o}C, respectively.

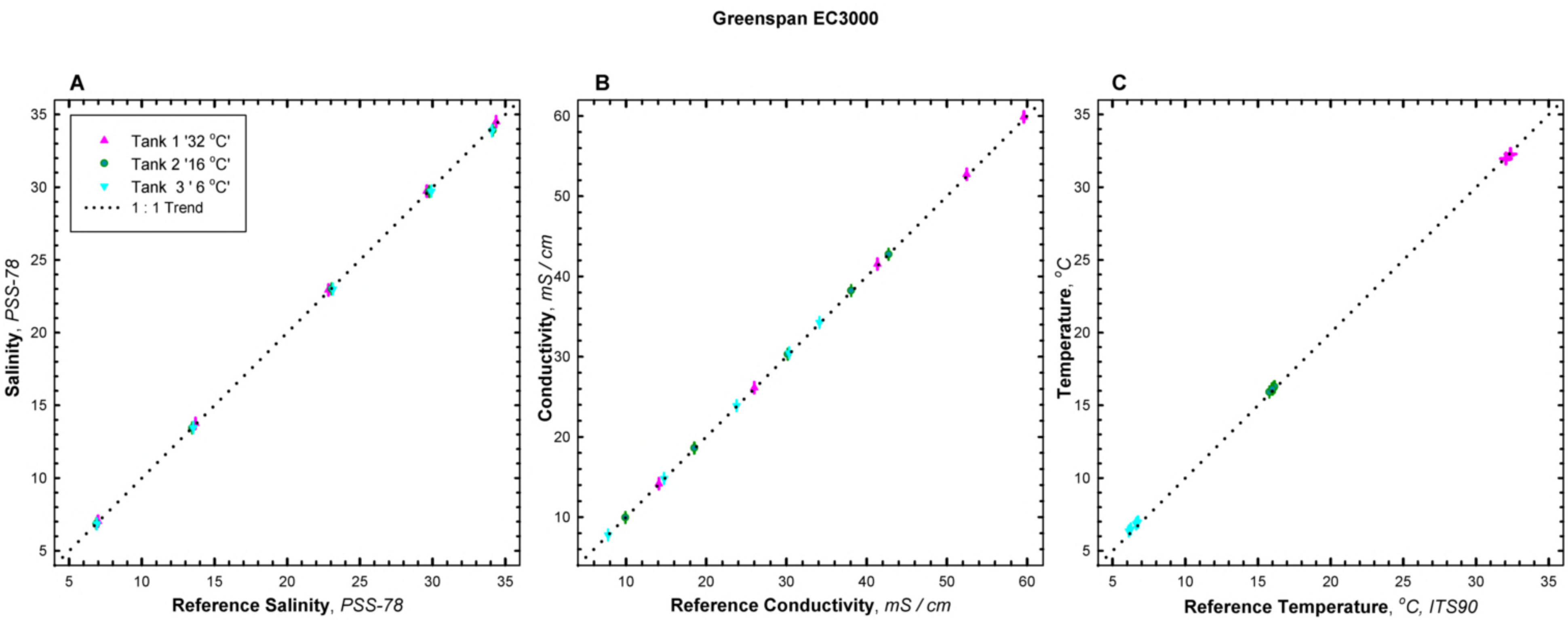


Figure 3. Evaluation of the response linearity for Greenspan Analytical's model EC3000 conductivity and temperature sensor package during controlled laboratory exposures to a combination of natural seawater dilutions and temperatures. Consecutive test exposures ranged between 35 to 6 on the practical 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.

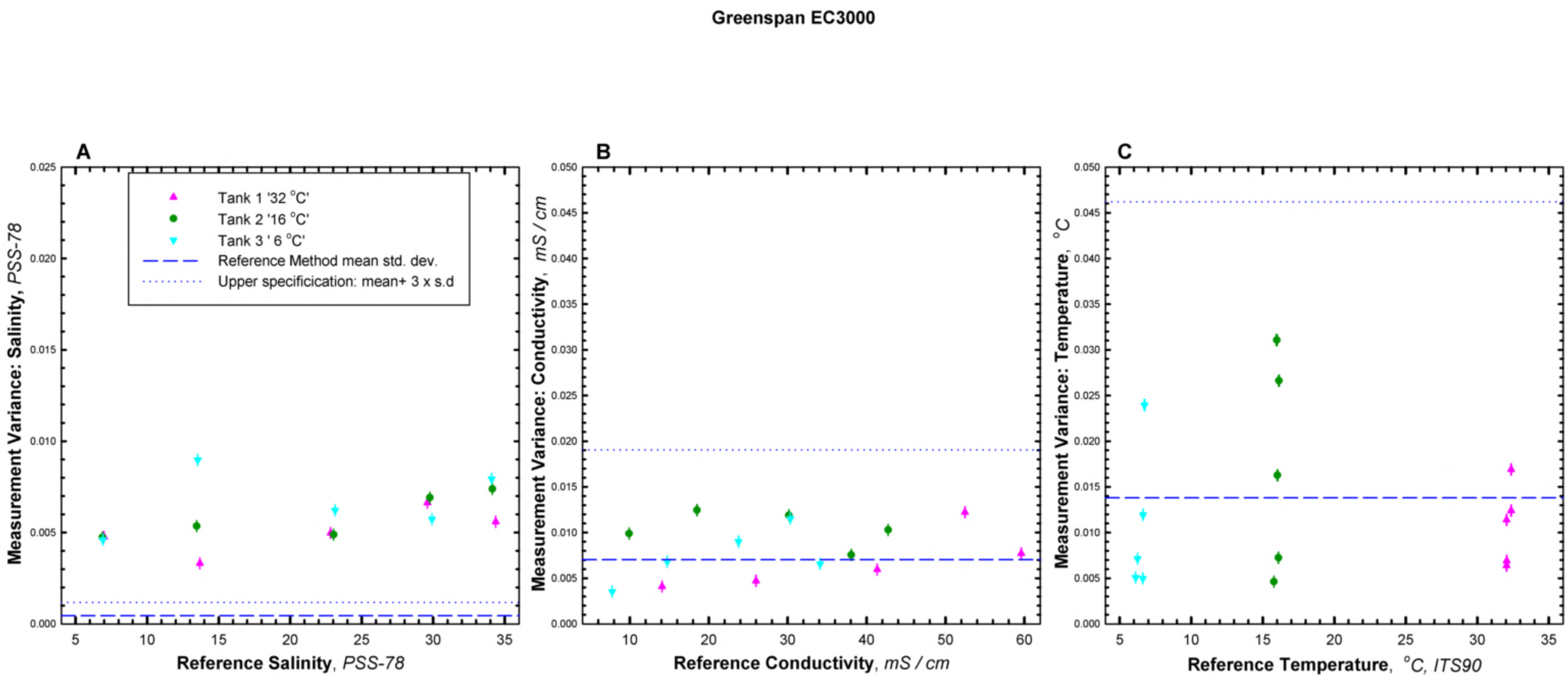


Figure 4. Evaluation of measurement variation of Greenspan Analytical's model EC3000 conductivity and temperature sensor package achieved during the laboratory exposure trials plotted in **Fig. 3**. Relative measurement variance is presented as the standard deviation of 30 consecutive instrument reads 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.

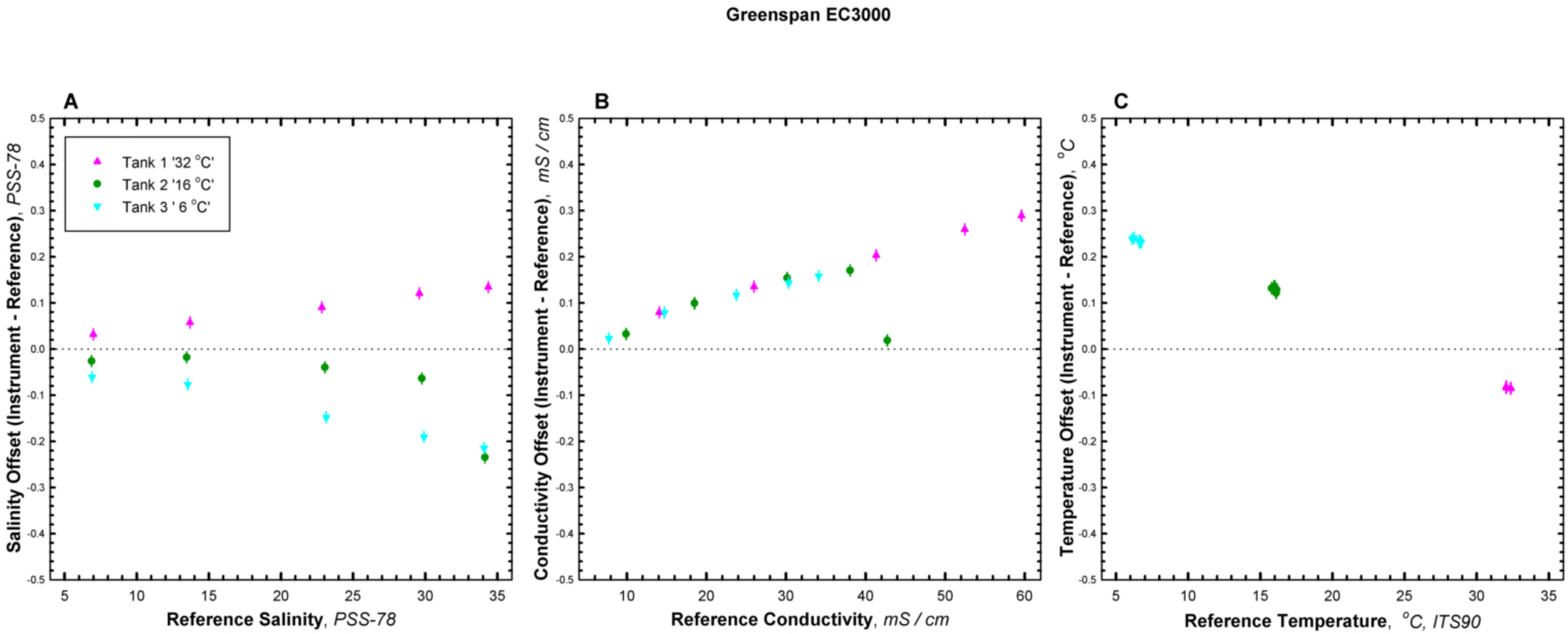


Figure 5. Evaluation of the relative accuracy of Greenspan Analytical's model EC3000 conductivity and temperature sensor package achieved during the laboratory exposure tests plotted in **Fig. 3**. Relative accuracy is estimated as the difference or offset between the mean instrument reading and mean 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 Greenspan EC3000 salinity sensor 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 ^oC, 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** (^0C)	**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 approximately 10 days when a noticeable decrease in accuracy was observed and worsened over the last 20 days of the deployment test. The relative accuracy of the instrument measurements were depicted as numerical differences from the reference values and plotted over time (Fig. 8), but the data plotted was purposely limited by scale and therefore incomplete. 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 first week of the deployment was 0.218 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 calibration factors. 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).

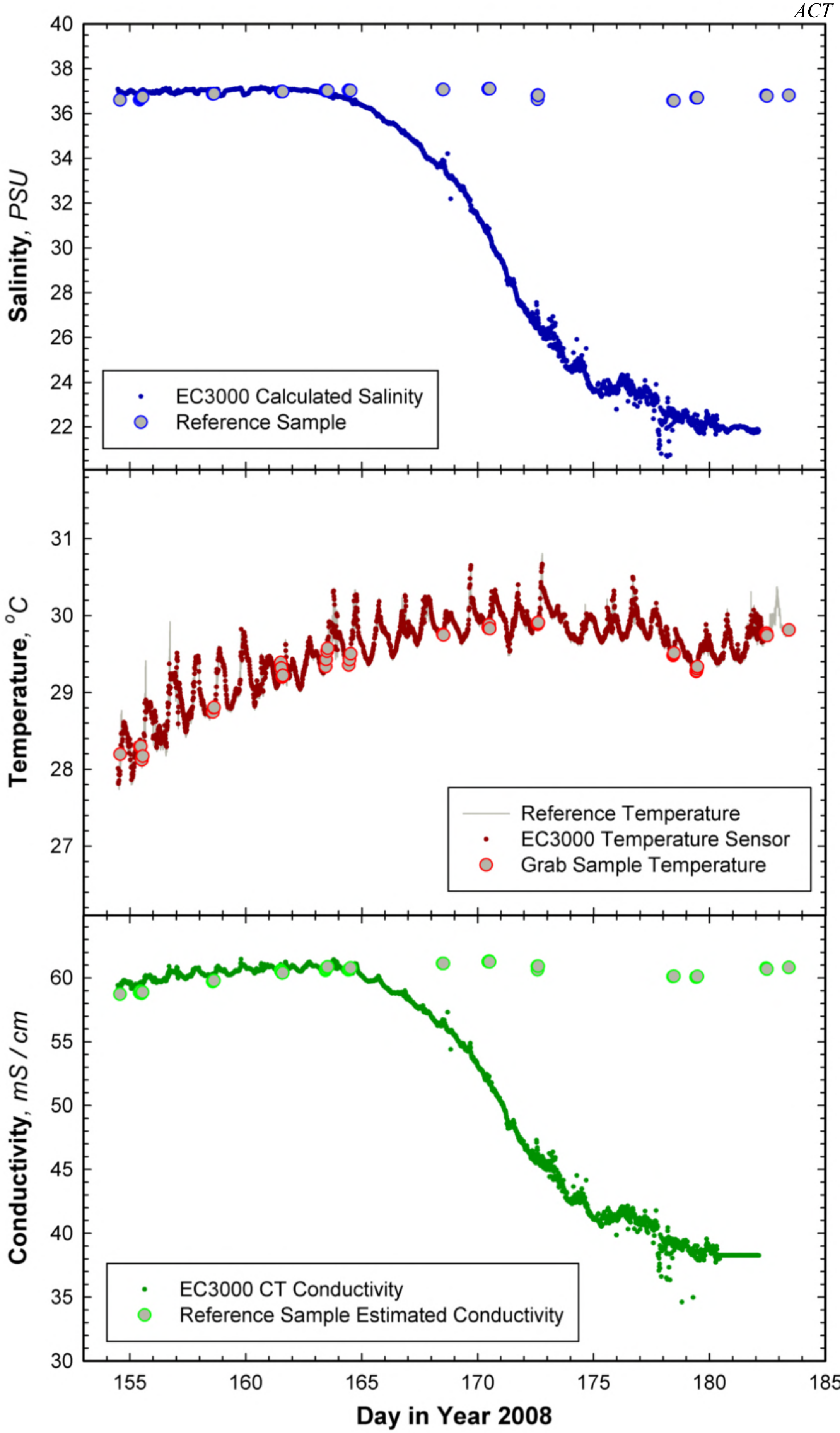


Figure 7. Time series of instrument measurements and corresponding reference samples acquired during USF field deployment.

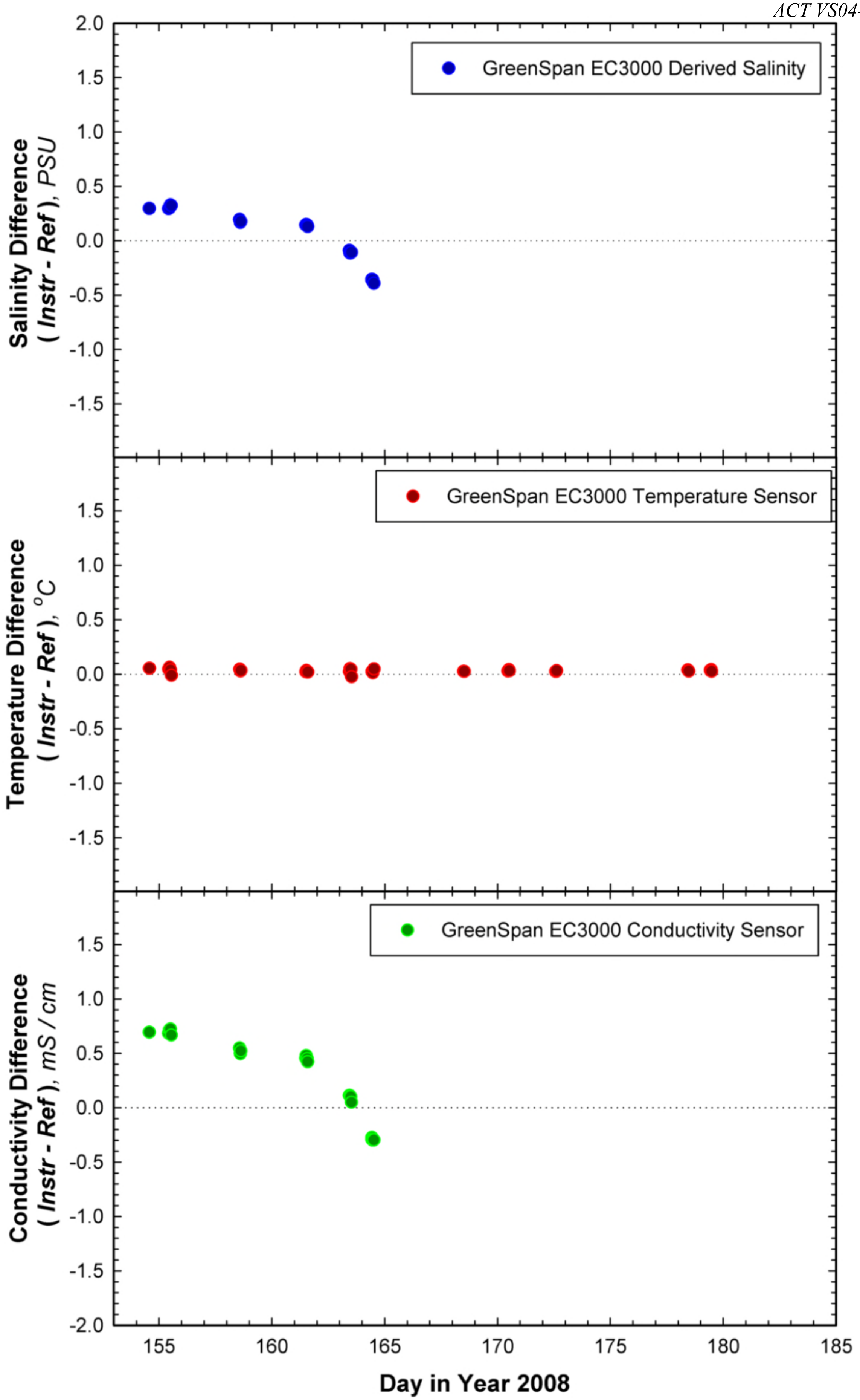


Figure 8. Assessment of relative accuracy of instrument time series measurements during USF field deployment.

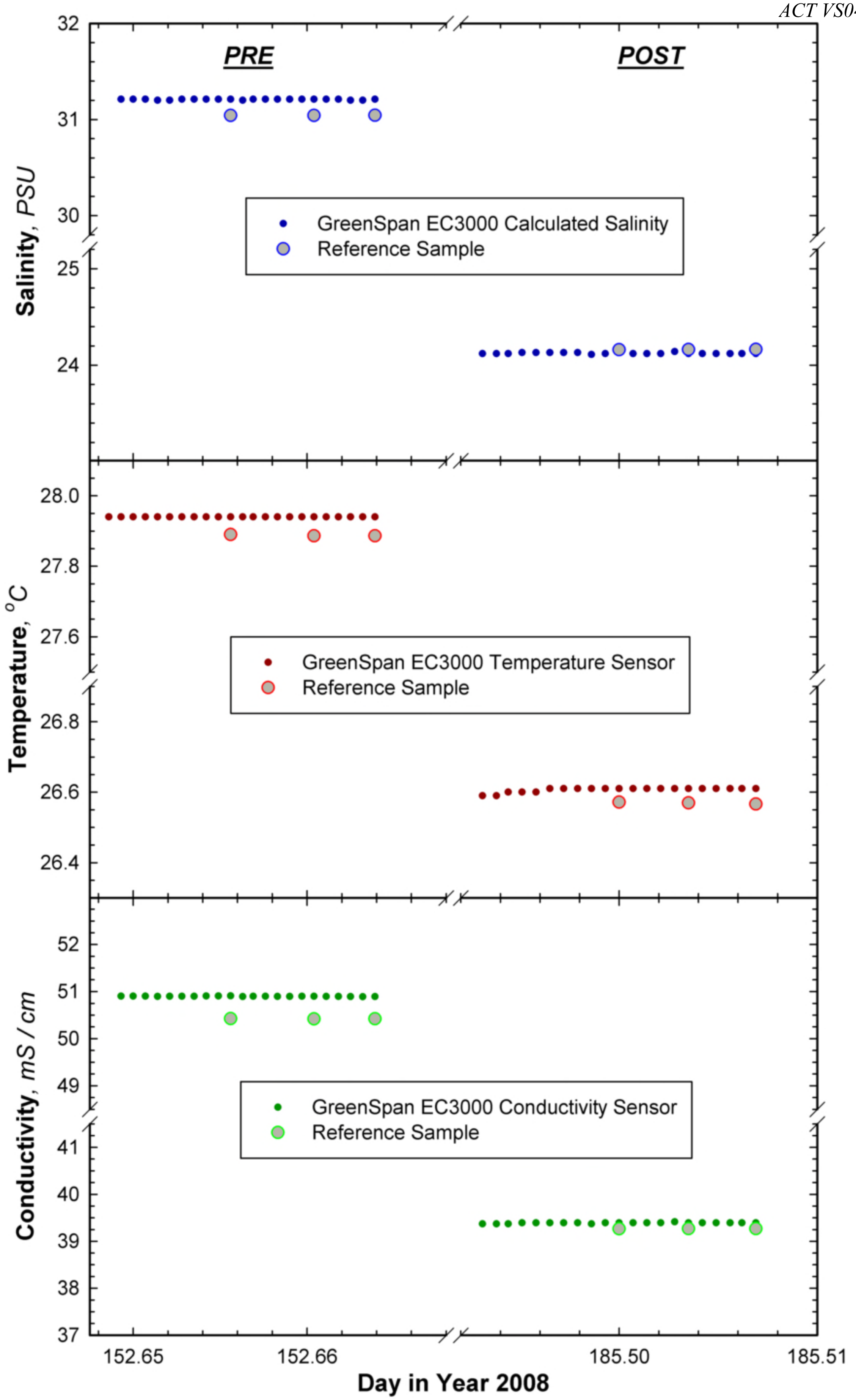


Figure 9. Pre- and Post-deployment reference checks in tanks of natural seawater at USF. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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, including directly within the conductivity cell.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

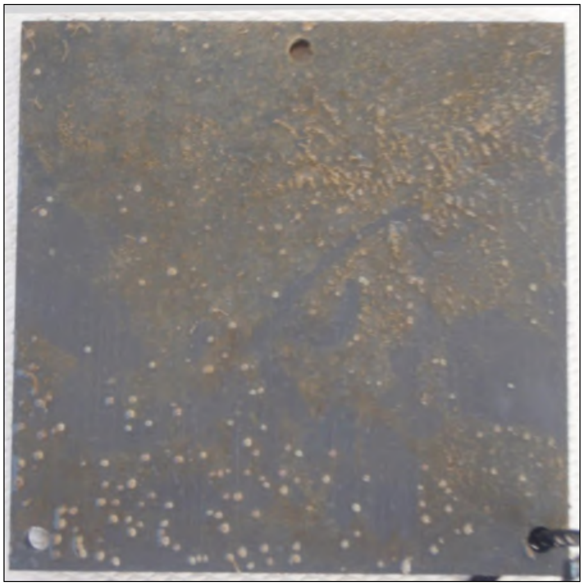
After Deployment (Close-up)

After Deployment (Full View)

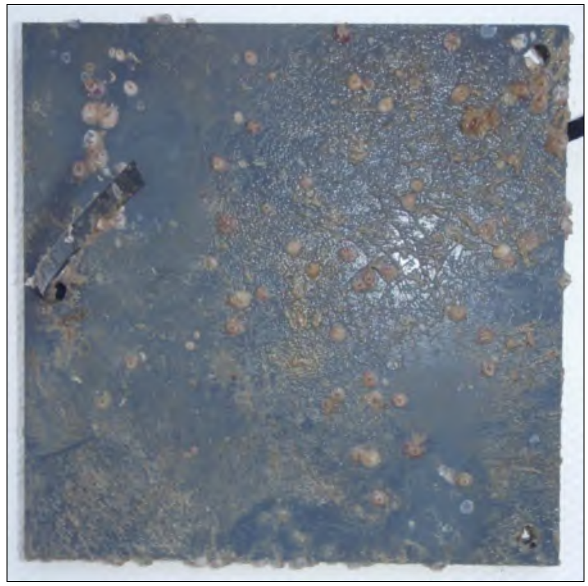
Figure 10. Greenspan EC3000 instrument photos from Tampa Bay, FL test site before and after deployment

Bio-Fouling Plate Photographs

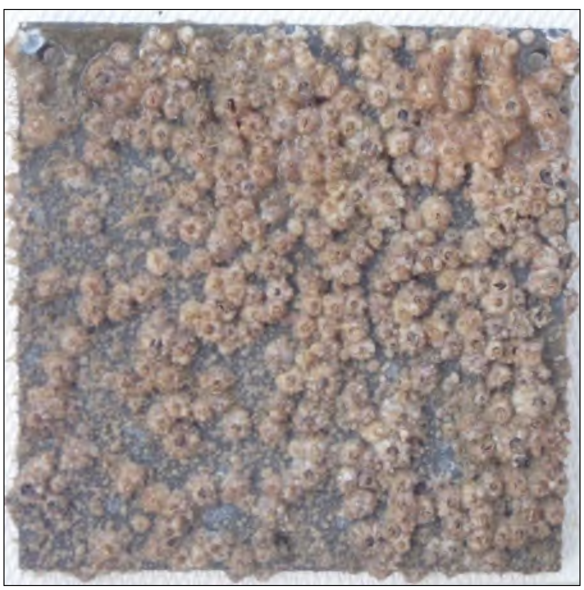
Bio-fouling plates were retrieved and photographed once each week throughout the deployment to help define the rate and extent of biofouling within the test environment (Fig. 11). By the third week of deployment there was an extensive amount of hard, encrusting biofouling at the Florida test site.



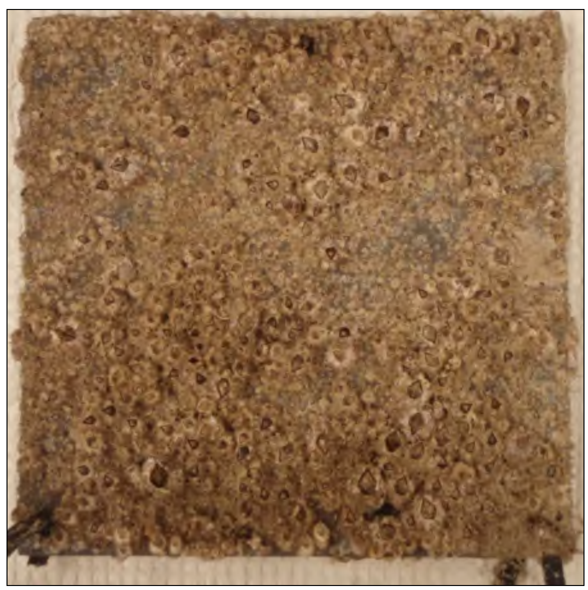
USF Site Week 1



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). We believe a battery failure caused the instrument to stop logging after three days. The relative accuracy of the instrument measurements were depicted as numerical differences from the reference values and plotted over time for the initial period sampled (Fig. 14). The mean offset in the salinity measurements over the first few days of the deployment was 0.200 psu. New batteries were added after retrieval and the instrument came right back to specs as seen in the post-exposure test (Fig 15). It is not clear whether the large initial offset in the pre-test was also due to weak batteries or if perhaps there was an air bubble trapped in the conductivity cell, however, the initial accuracy during the deployment was significantly better so contamination from bubbles are likely. The amount of fouling that development on the instrument is shown in figure 16 and the rate of fouling was documented with a time-series of photographs showing the accumulation on PVC tiles (Fig. 17).

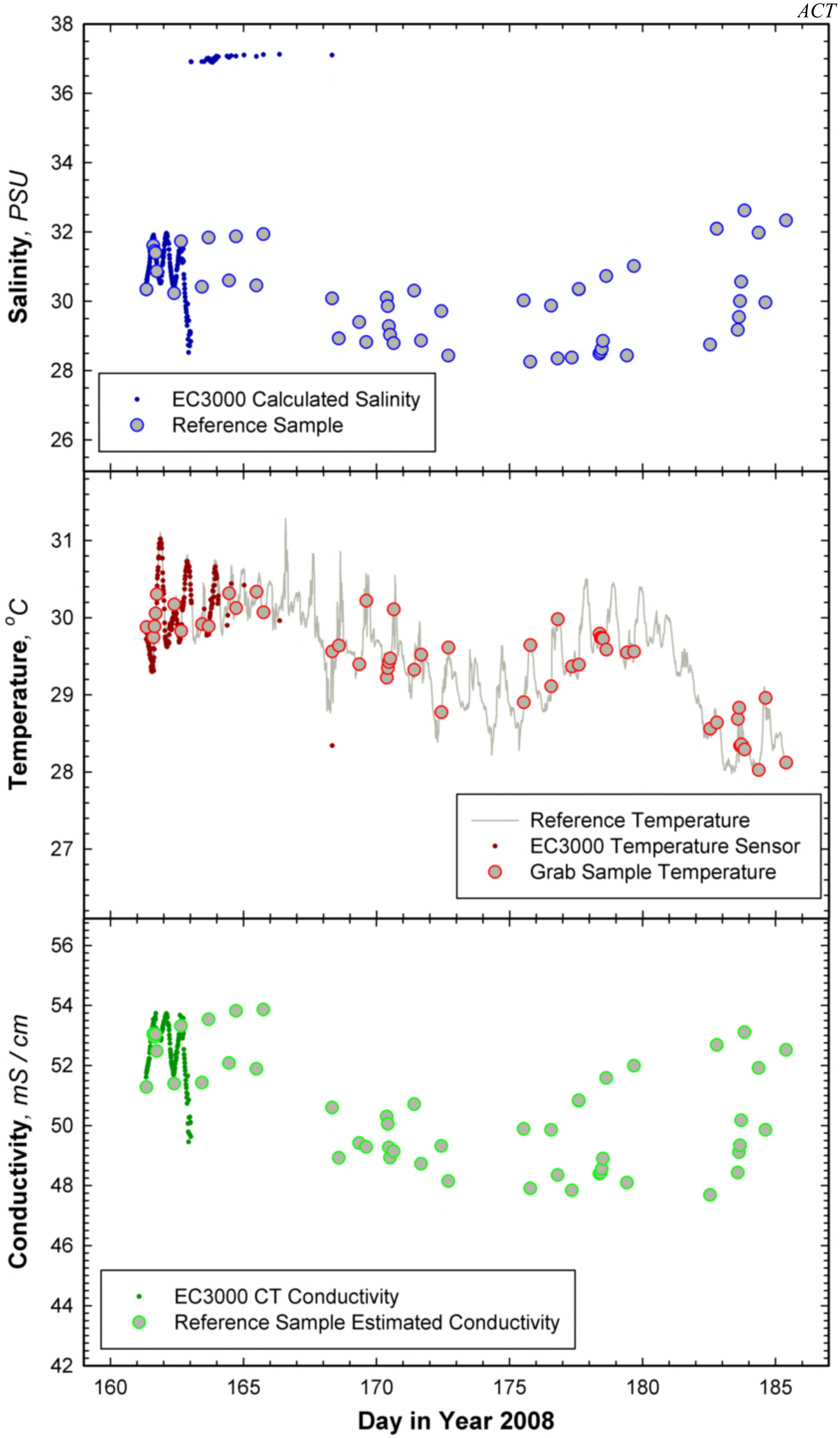


Figure 13. Time series of instrument measurements and corresponding reference samples acquired during the SkIO field deployment.

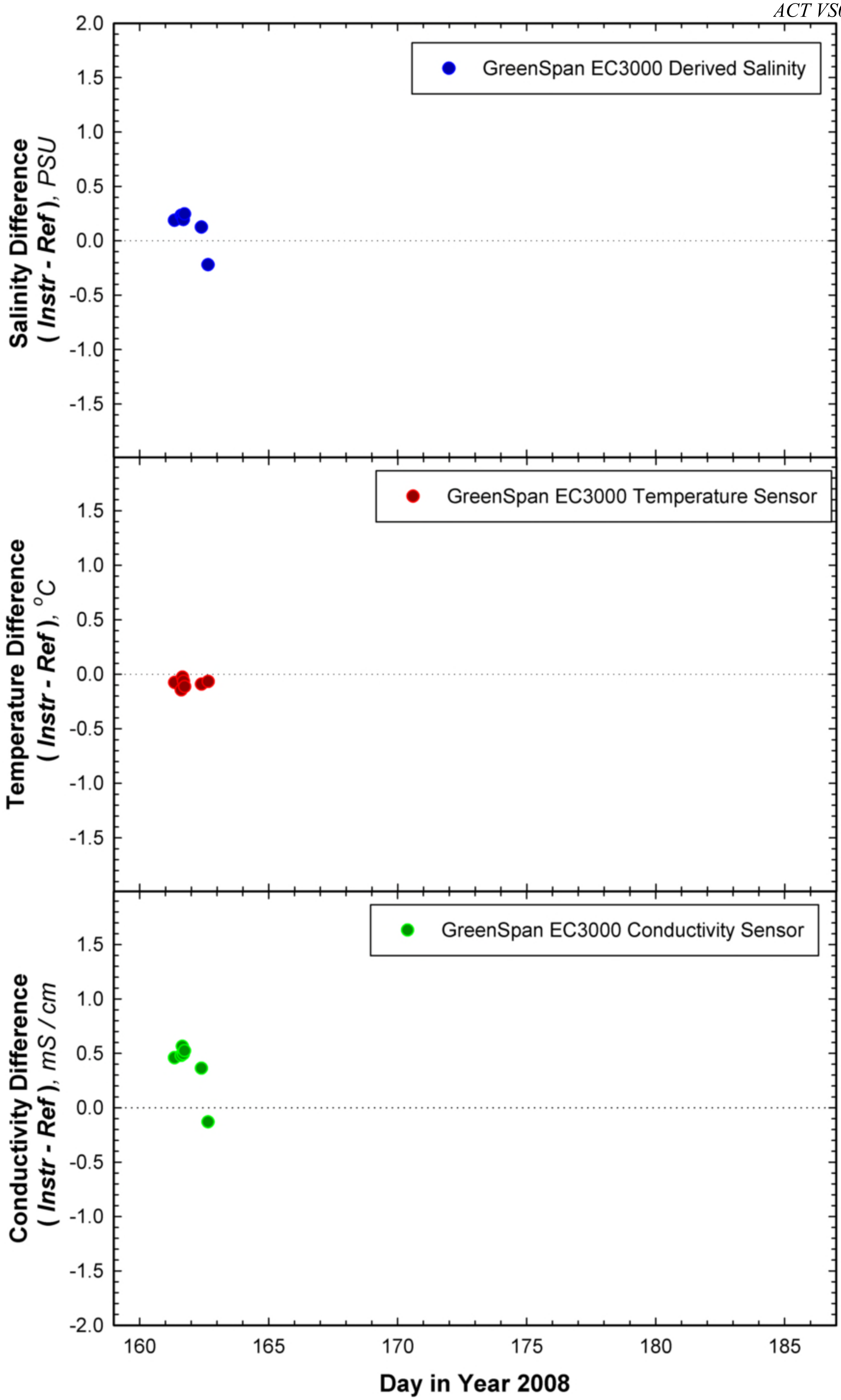


Figure 14. Assessment of relative accuracy of instrument time series measurements during the SkIO field deployment.

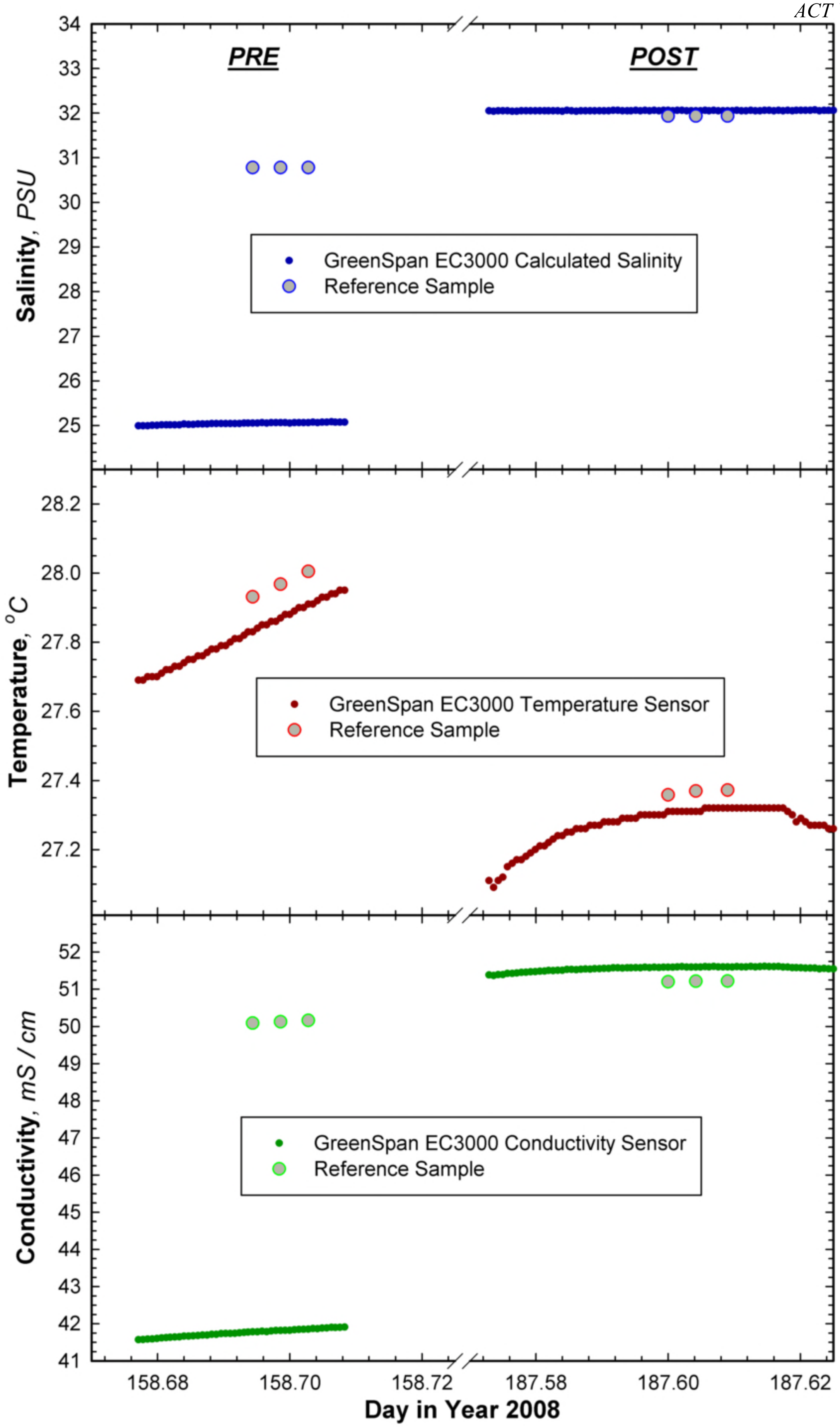


Figure 15. Pre- and Post-deployment reference checks in tanks of natural seawater at SkIO. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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 including directly within the conductivity cell.

Prior to Deployment (Close-up)

Prior to Deployment (Full View)

After Deployment (Close-up)

After Deployment (Full View)

Figure 16. Greenspan EC3000 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

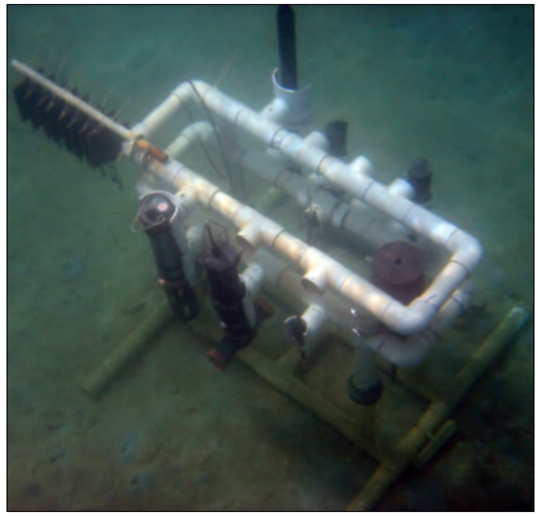
SkIO Site Week 4

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 initial week of the deployment was lost while trouble shooting software issues. Instrument measurements were less impacted by fouling at the site and tracked reference samples for about 40 of the 60 days. The relative accuracy of the instrument measurements were depicted as numerical differences from the reference values and plotted over time (Fig. 20), but the data plotted were purposely limited to ± 2 psu. 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 during the first week it was deployed was -0.210 psu. We were not able to distinguish between biofouling impacts and potential instrument drift since the instrument was not available for the pre-test. The magnitude of offset for the post-deployment exposure tests is again consistent with air bubble contamination in the conductivity cell (Fig 21). The amount of fouling that development on the instrument 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).

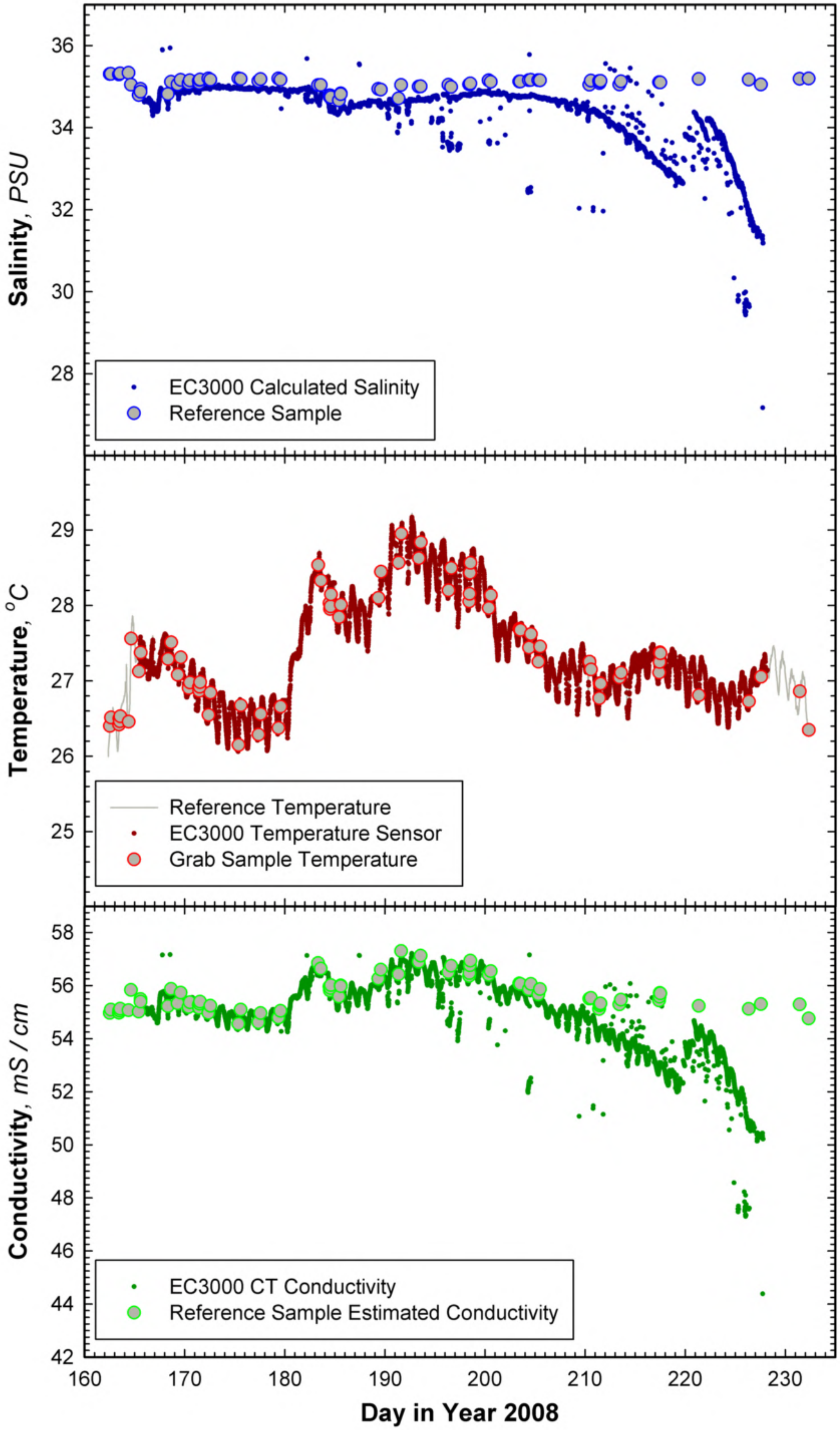


Figure 19. Time series of instrument measurements and corresponding reference samples acquired during the HI field deployment.

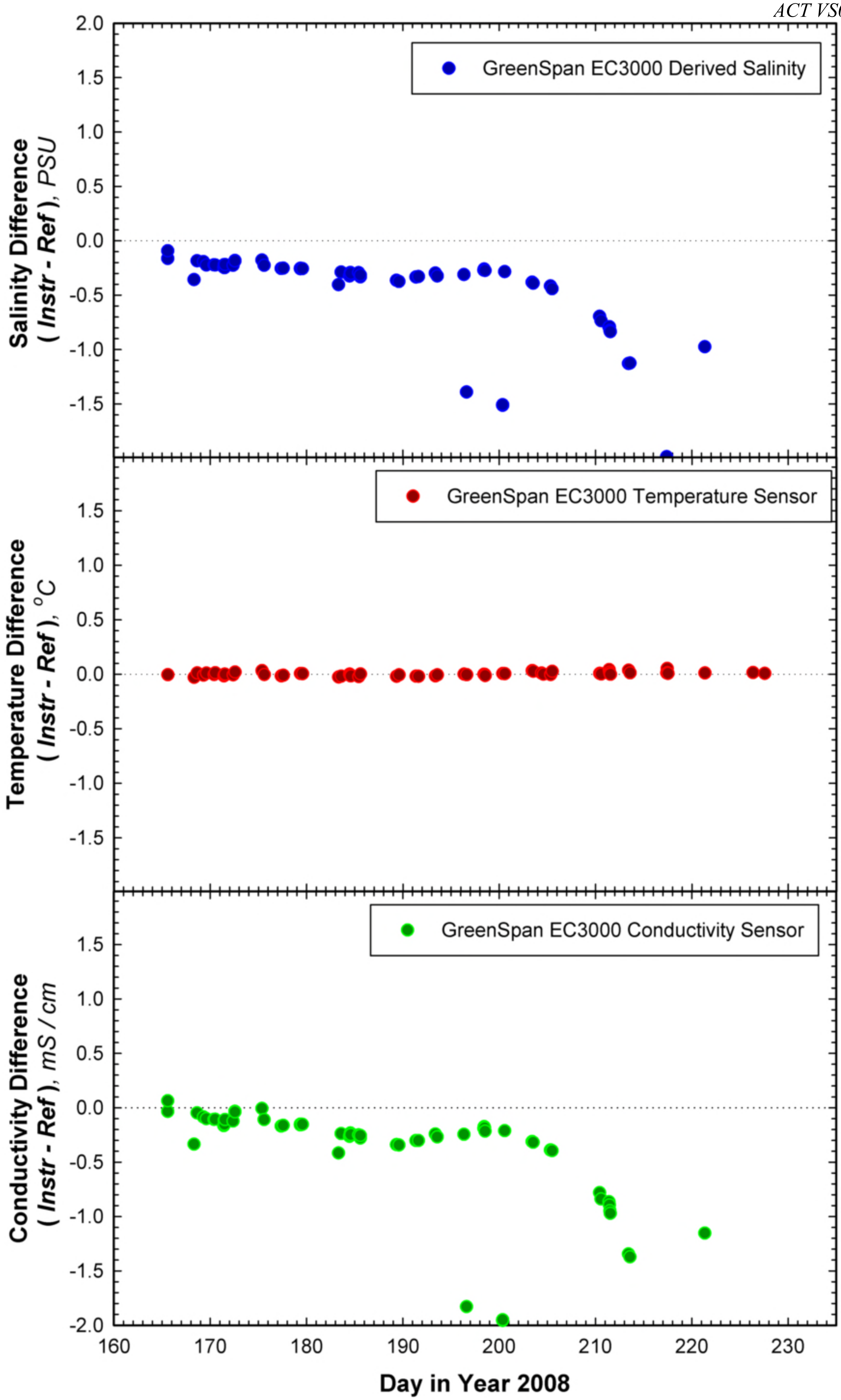


Figure 20. Assessment of relative accuracy of instrument time series measurements during the HI field deployment.

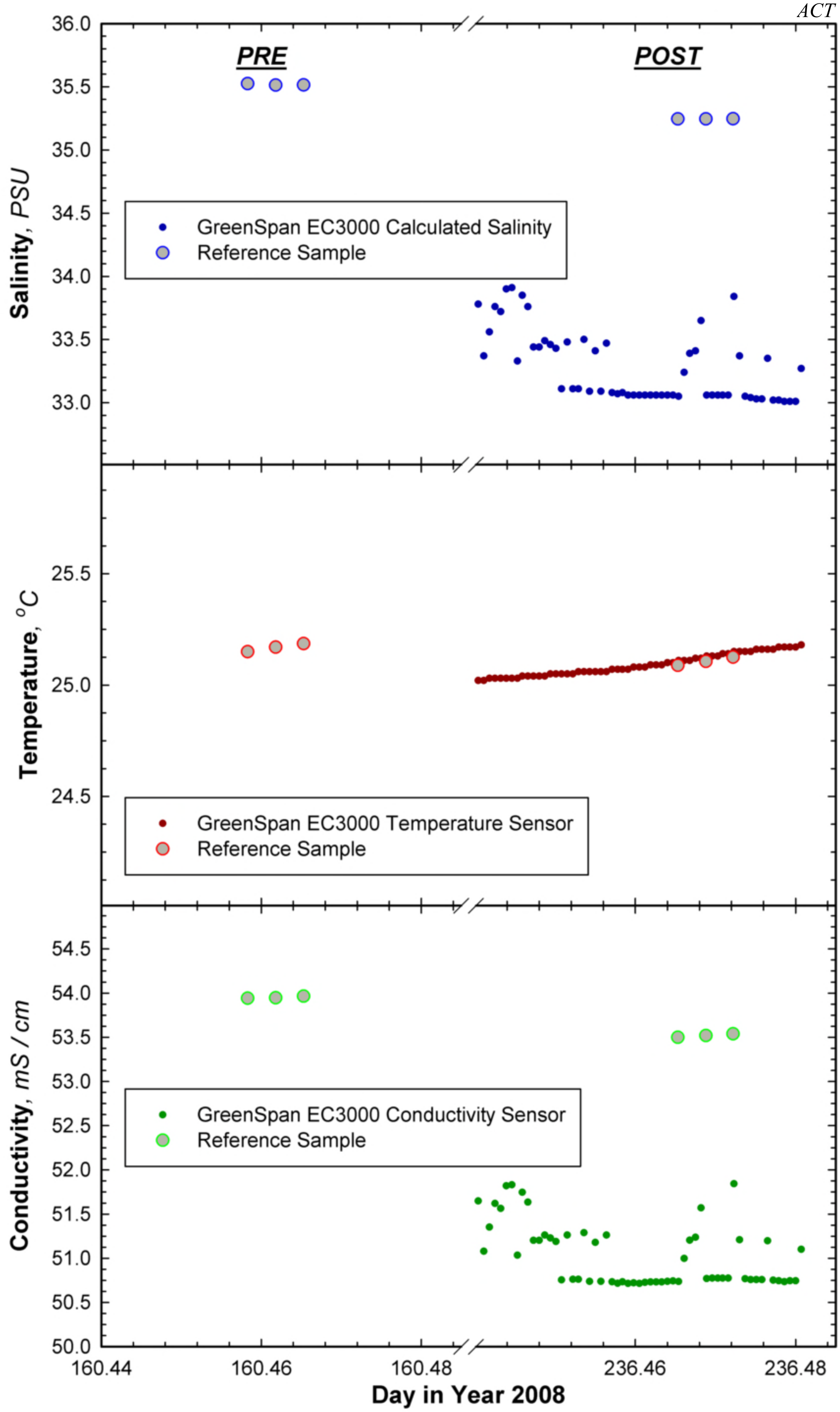


Figure 21. Pre- and Post-deployment reference checks in tanks of natural seawater at HI. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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. Greenspan EC3000 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 °C.

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 MI field test were plotted against corresponding results from the laboratory analyzed reference samples and reference temperature logger (Fig. 25). Instrument measurements closely tracked the sharp gradients in conductivity and temperature throughout the deployment. The relative accuracy of the instrument measurements were plotted over time (Fig. 26) and show little change in performance. The mean offset in the salinity measurements over the entire deployment was -0.0022 psu. The offset in temperature is somewhat higher at this site and averaged 0.2996 °C above the reference temperature logger. This offset was also observed in both the pre- and post-exposure tests in well mixed tanks so appears to be a calibration issue (Fig 27). In general, the agreement between instrument and reference sample values was very similar for the pre- and post-deployment tests. The amount of fouling that development on the instrument is shown in figure 28 and the rate of fouling was documented with a time-series of photographs showing the accumulation on PVC tiles (Fig. 29).

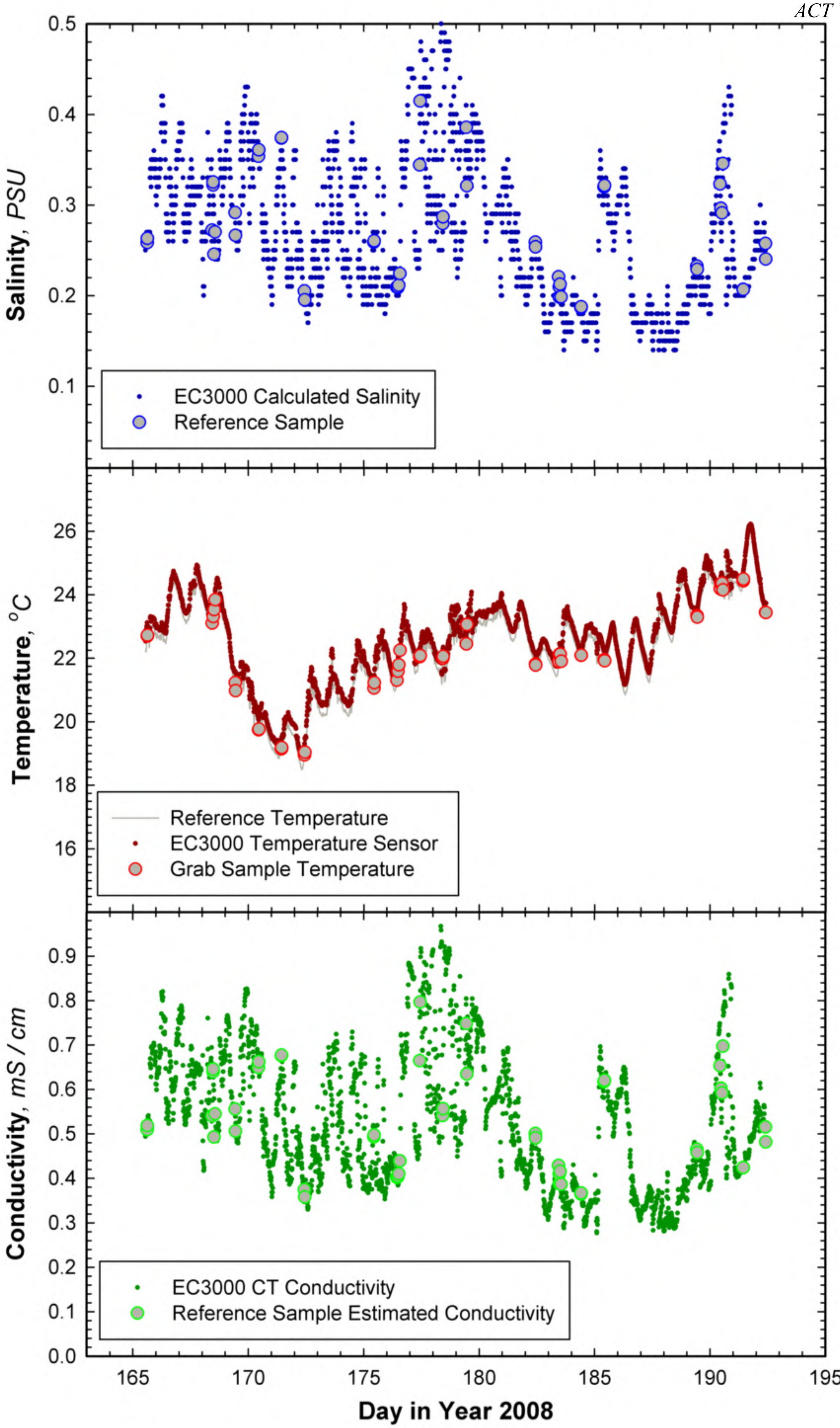


Figure 25. Time series of instrument measurements and corresponding reference samples acquired during the GL field deployment.

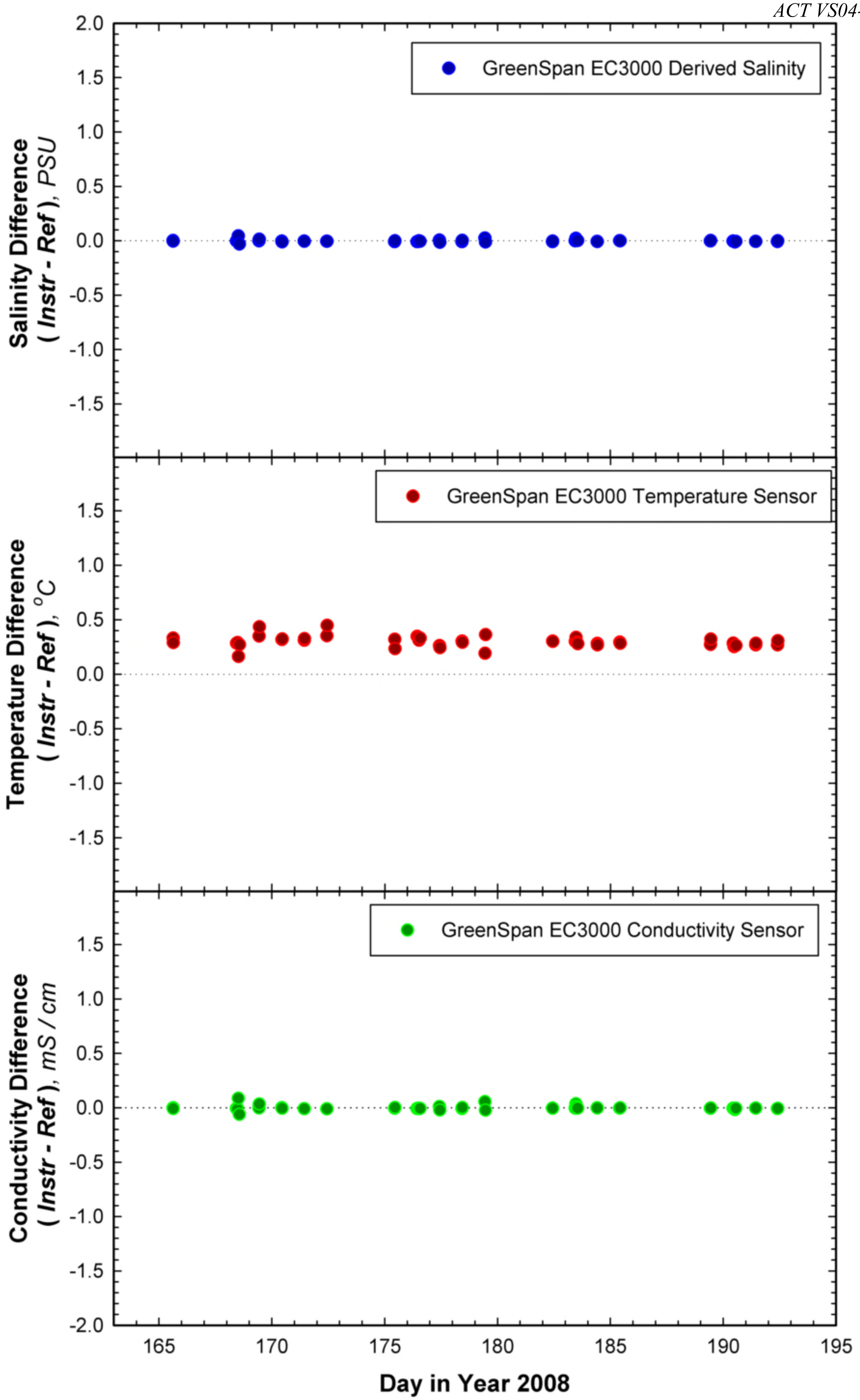


Figure 26. Assessment of relative accuracy of instrument time series measurements during the GL field deployment.

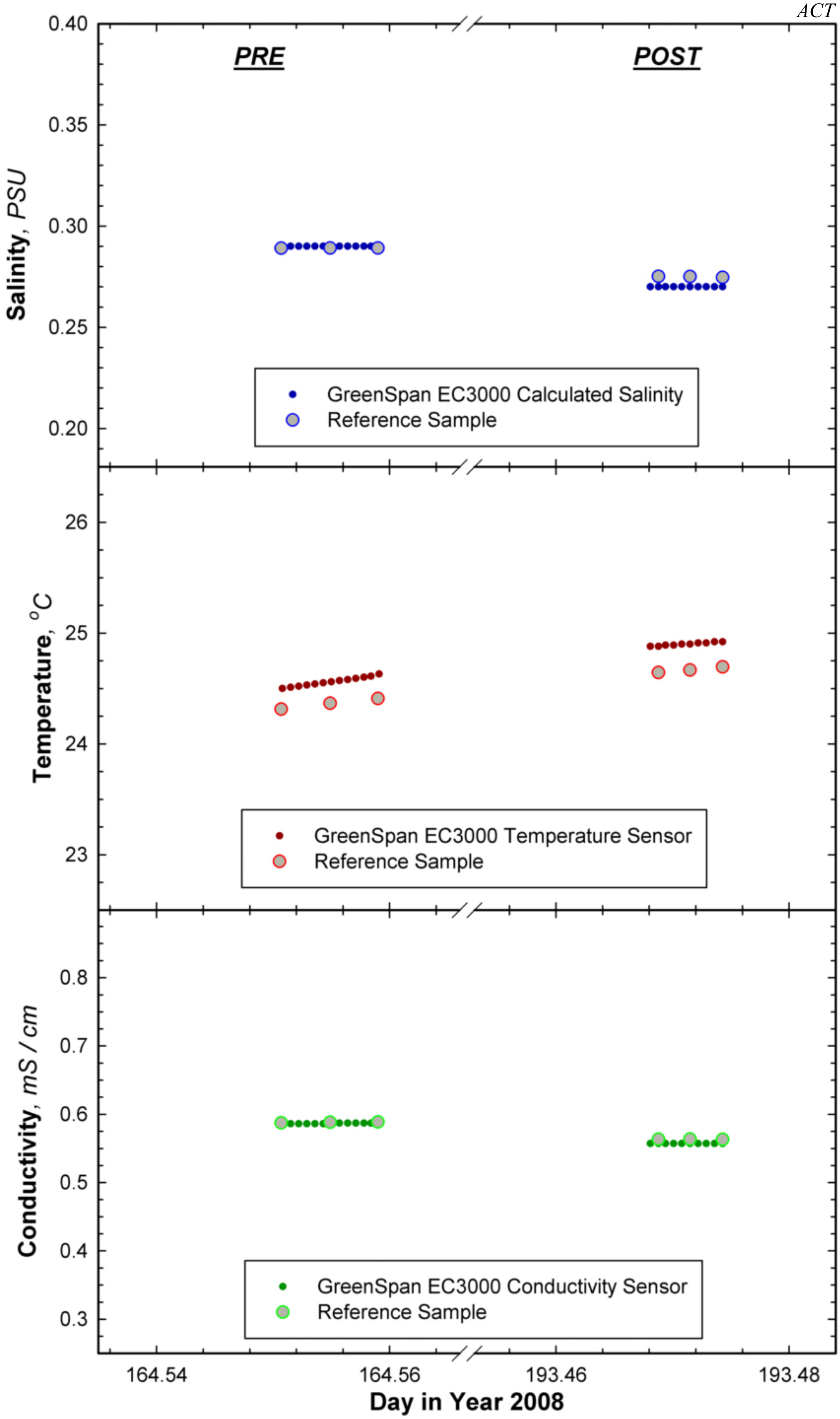


Figure 27. Pre- and Post-deployment reference checks in tanks of river water at GL. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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)

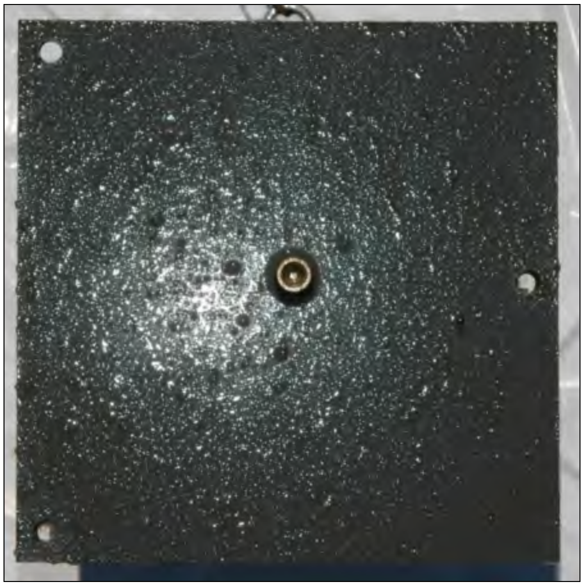
After Deployment (Close-up)

After Deployment (Full View)

Figure 28. Greenspan EC3000 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 and reference temperature logger (Fig. 31). A shipping mishap resulted in a late delivery to the test site and late start to the deployment. Overall, the instrument measurements tracked the sharper gradients and mixing events that occurred daily at this site. The relative accuracy of the in situ measurements were depicted as numerical differences from the reference values and plotted over time (Fig. 32). The average offset in instrument measured salinity was -0.0492 psu over the deployment period. Some of the increased variance may be due to fine-scale vertical gradients which make it difficult to match instrument and reference temperature readings due to spatial heterogeneity around the mooring. We noted greater variance among our own field replicate reference samples at this site (see below). Comparison of instrument accuracy measured during pre- and post-deployment exposure tests, following instrument cleaning, showed small increases in the amount of offset for conductivity and temperature measurements but not in the derived salinity measurement (Fig 33). The amount and rates of biofouling on the instrument and PVC tiles are shown in figures 34 and 35.

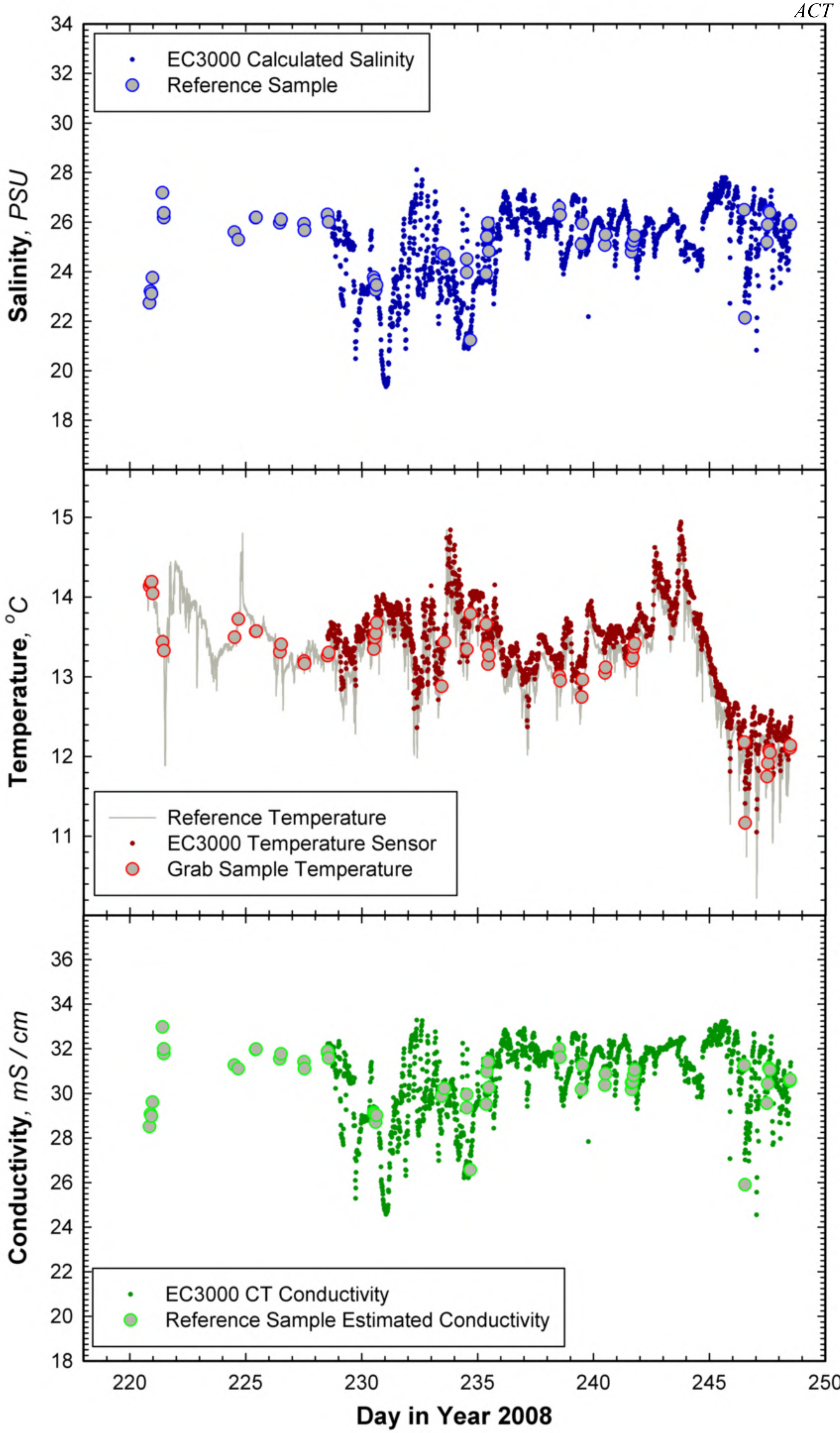


Figure 31. Time series of instrument measurements and corresponding reference samples acquired during the AK field deployment.

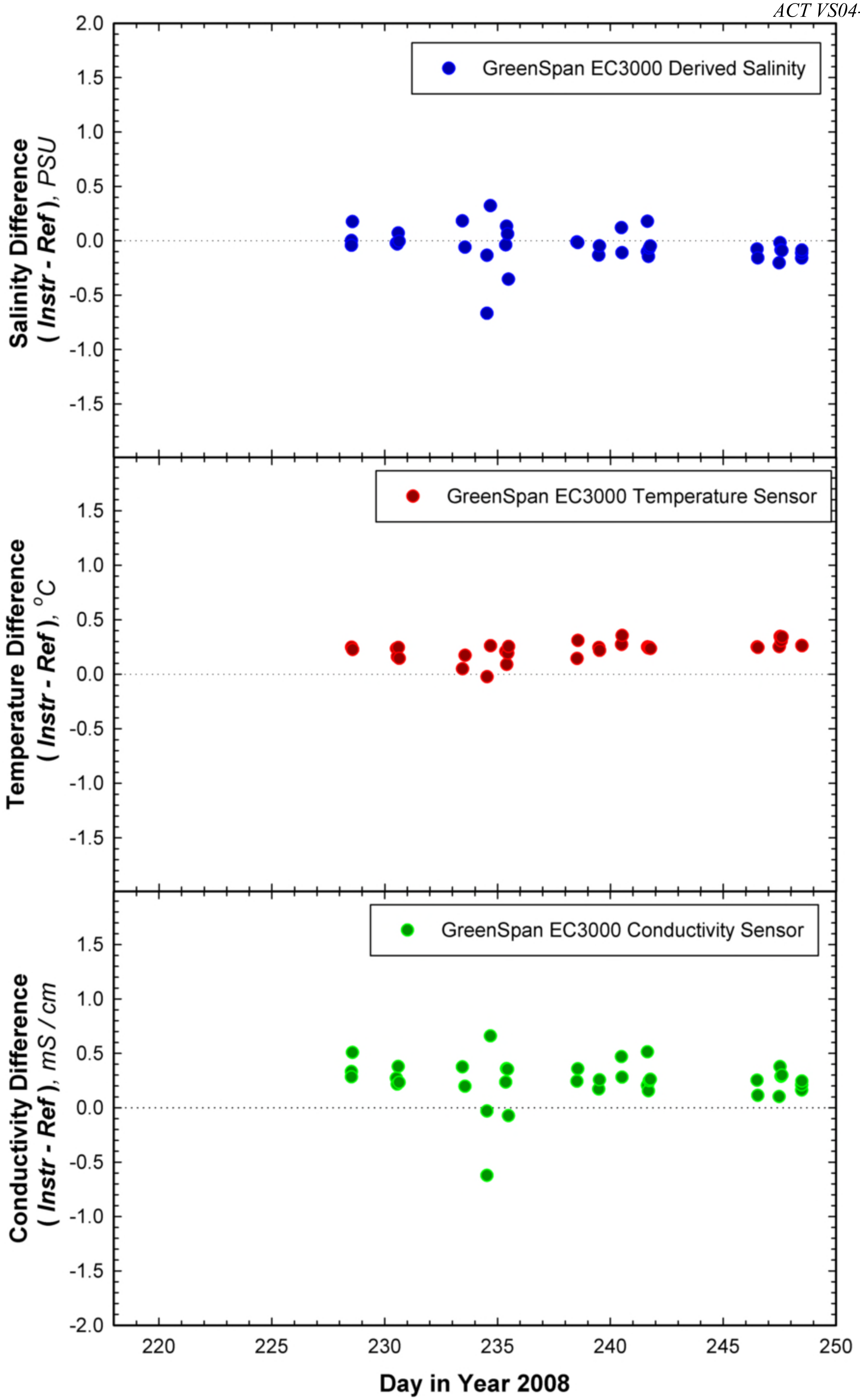


Figure 32. Assessment of relative accuracy of instrument time series measurements during the AK field deployment.

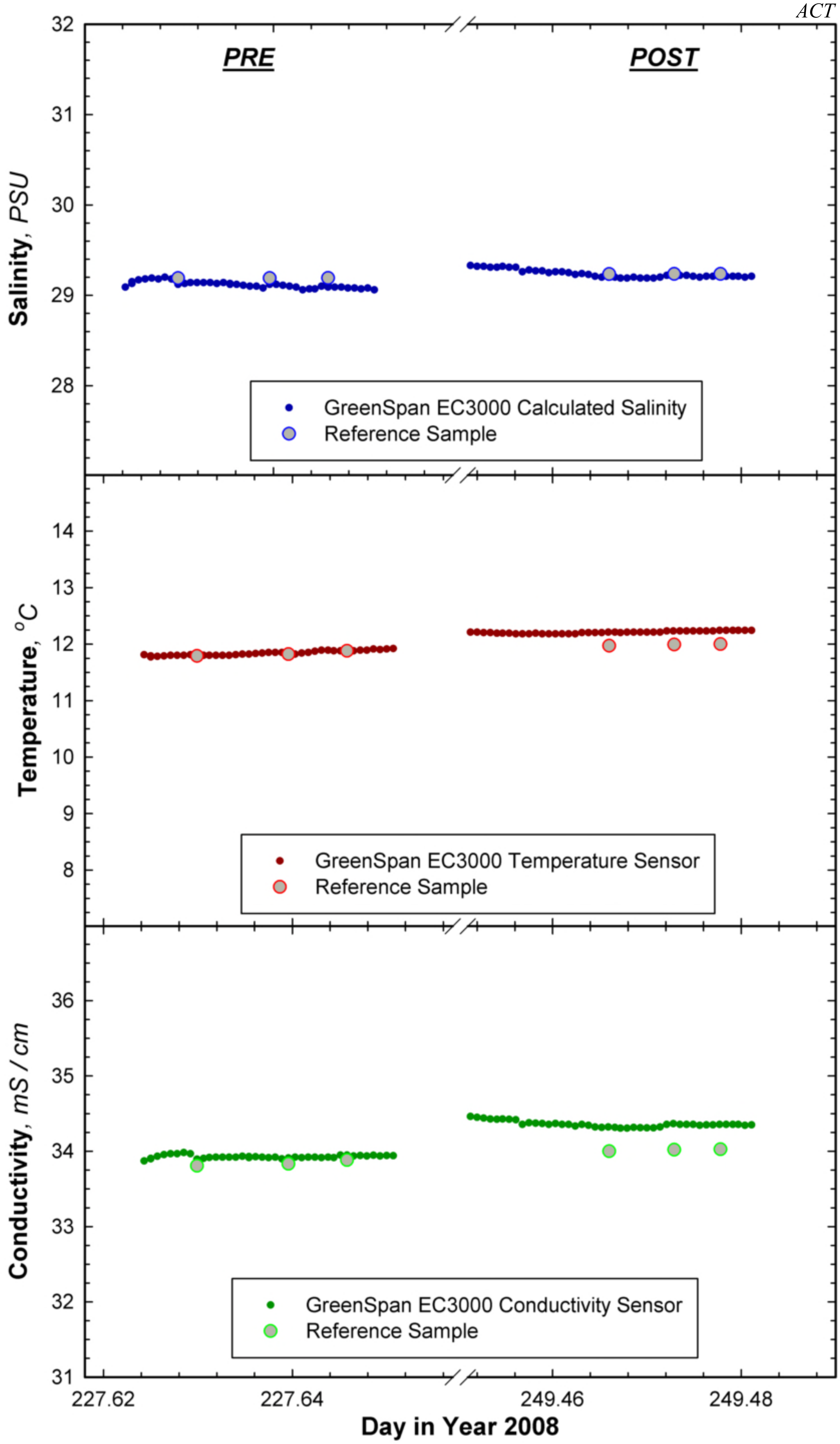


Figure 33. Pre- and Post-deployment reference checks in tanks of natural seawater at AK. Post-deployment tests conducted after cleaning instrument of all fouling material according to manufacturer's recommendations.

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. Greenspan EC3000 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). The responses of the test instruments were highly linear when analyzed across all sites with R^2 = 0.9990, standard error = 0.4997 and slope = 0.995. These results provide a field-based comparison of instrument performance that roughly mimics a similar range of temperature and salinity conditions. The effects of biofouling or drift can be viewed as the vertical deviations from the 1:1 data correspondence trend line. Temperature measurements were more stable than conductivity and probably less prone to fouling impacts.

RELIABILITY

The Greenspan EC3000 salinity sensor was tested in both the laboratory and as a fixed mooring application at five different field sites including, estuary, coastal ocean, and riverine environments. Complete time series data were successfully retrieved for the laboratory test. Data recovery was compromised at three field testing sites. About 5% of the field data was un-reportable from what downloaded at the FL site. About 90% of the data was lost at the GA test site due to a battery failure. Lastly the instrument appeared to run out of battery power on the very last day of the extended HI deployment. Drift in instrument time clocks across the deployment period were examined at three sites and differences of between plus one and minus one second were noted. Lastly, significant problems were encountered trying to use the new version of software provided with the instrument for this test. In particular, the new software did not work if any previous version was present on the same computer. The manufacturer was working on the fix as the verification progressed and eventually we were able to initiate the required set-up procedures.

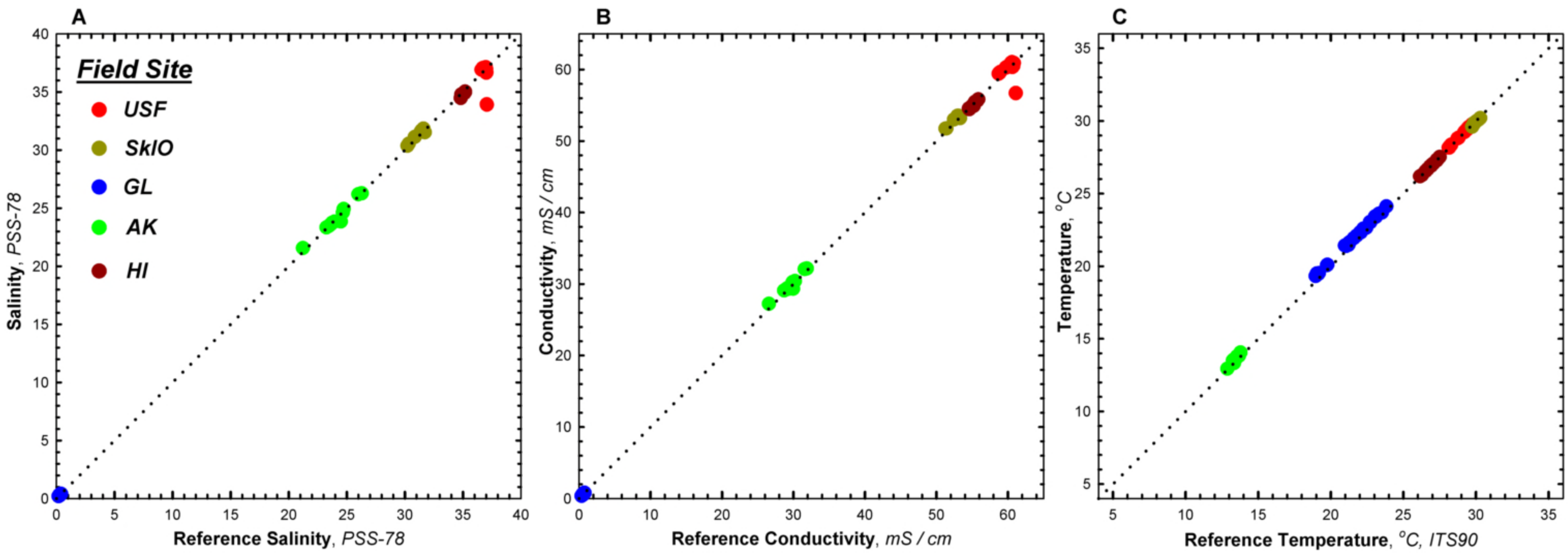


Figure 36. Composite summary of field performance over the first 14 days of deployment for the four Greenspan Analytical EC3000 units tested during the five evaluation trials. Instrument output plotted against paired field reference sample assay and color indexed by field test site. Dotted line represents 1:1 data correspondence trend line. Scatter around trend line represents occurence of site-specific fouling effects on conductivity cell performance.

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 37 – 41. 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.

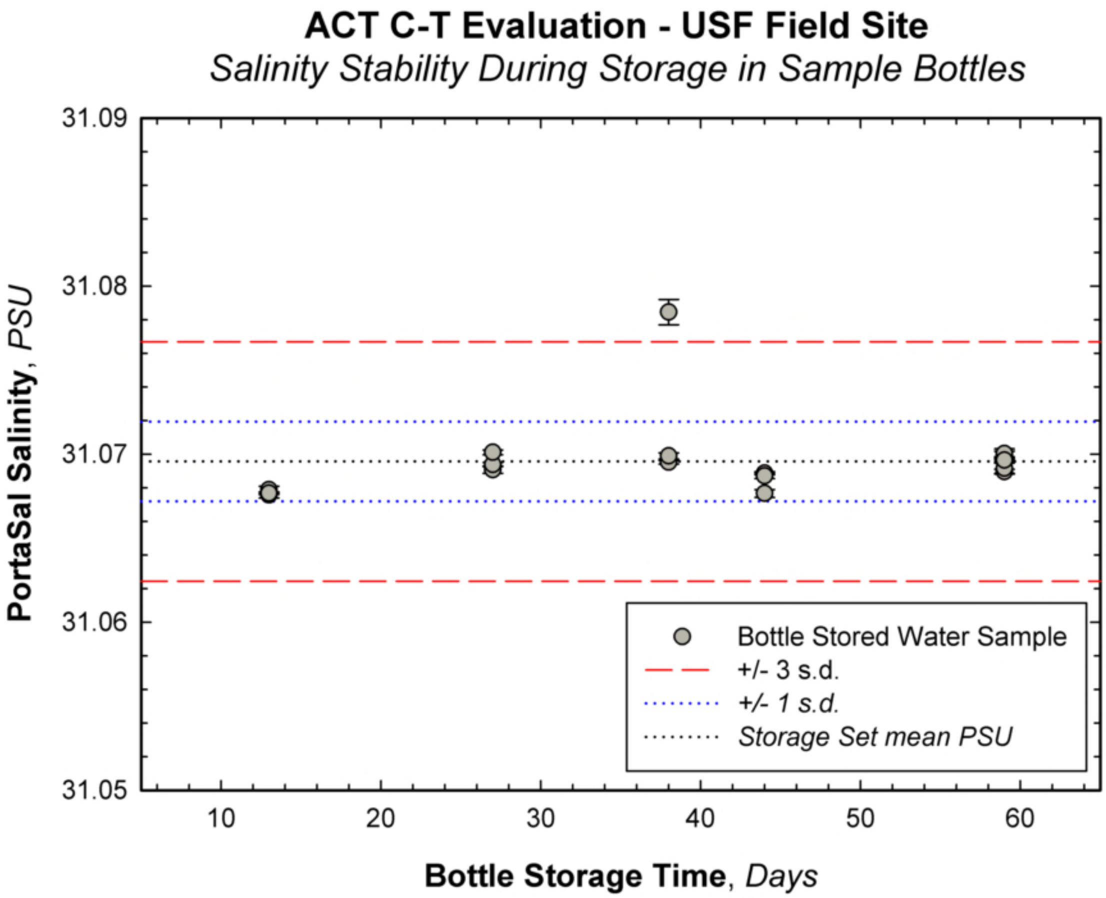


Figure 37. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

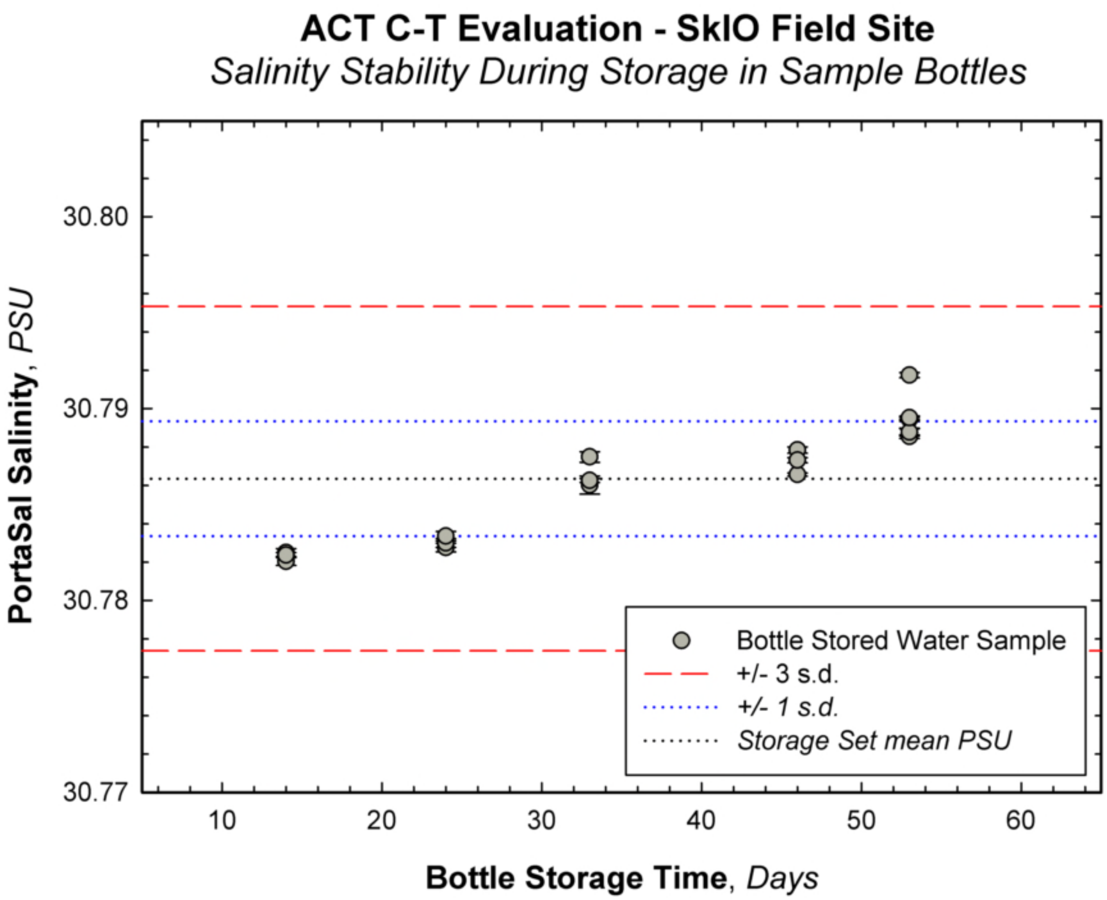


Figure 38. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial water collection.

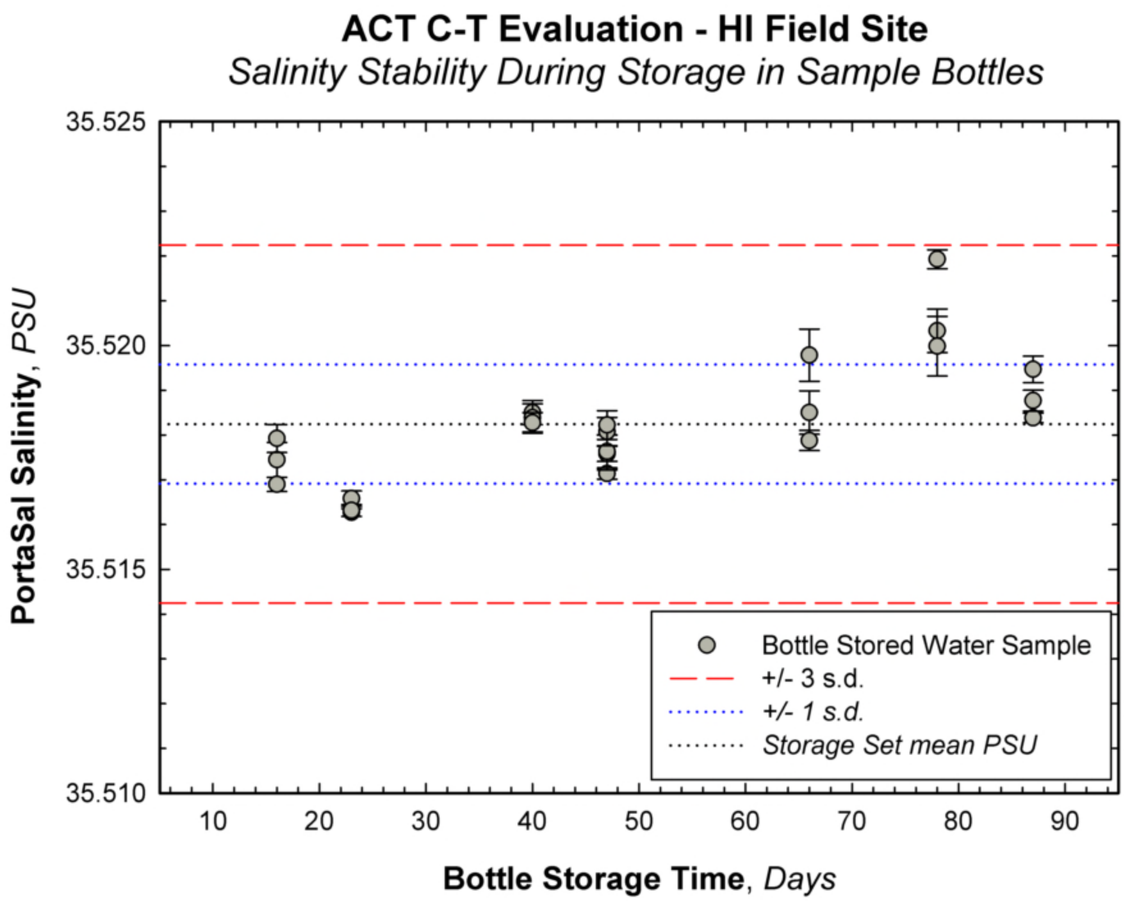


Figure 39. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

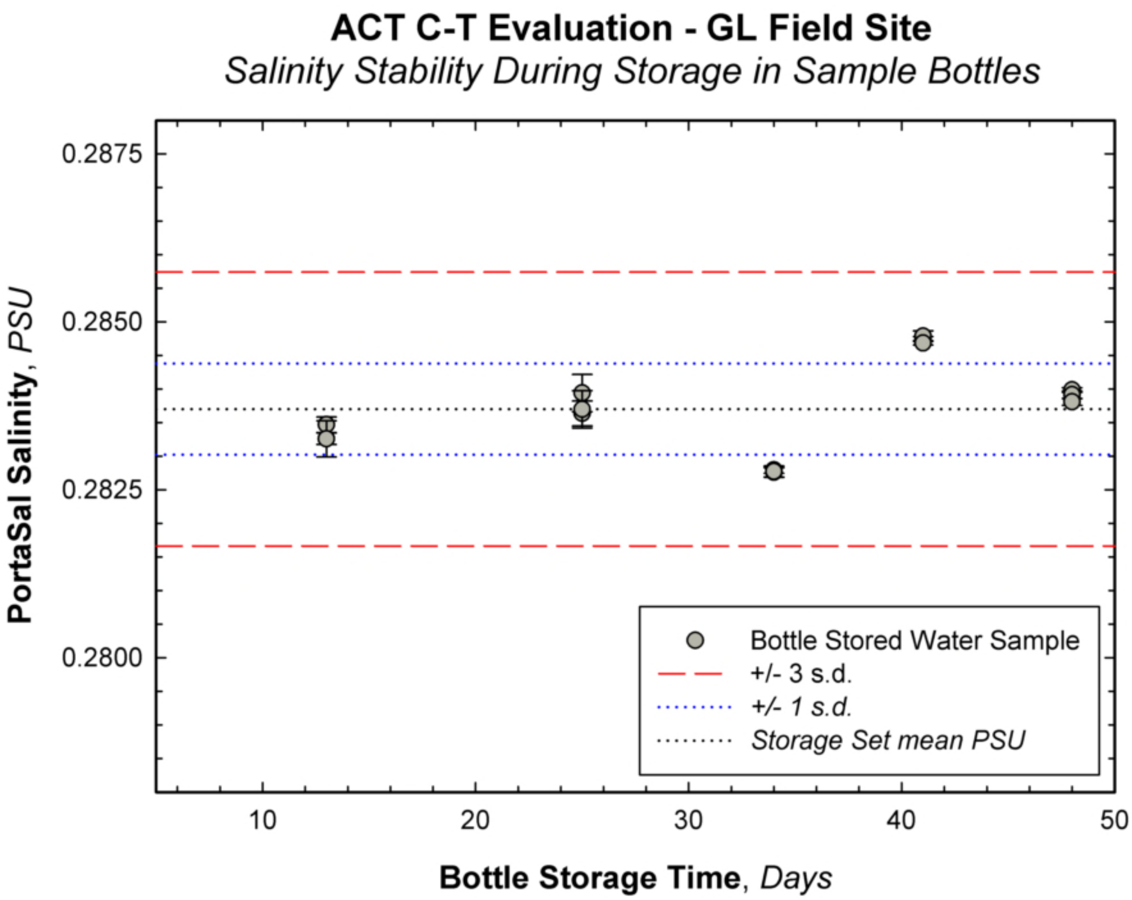


Figure 40. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

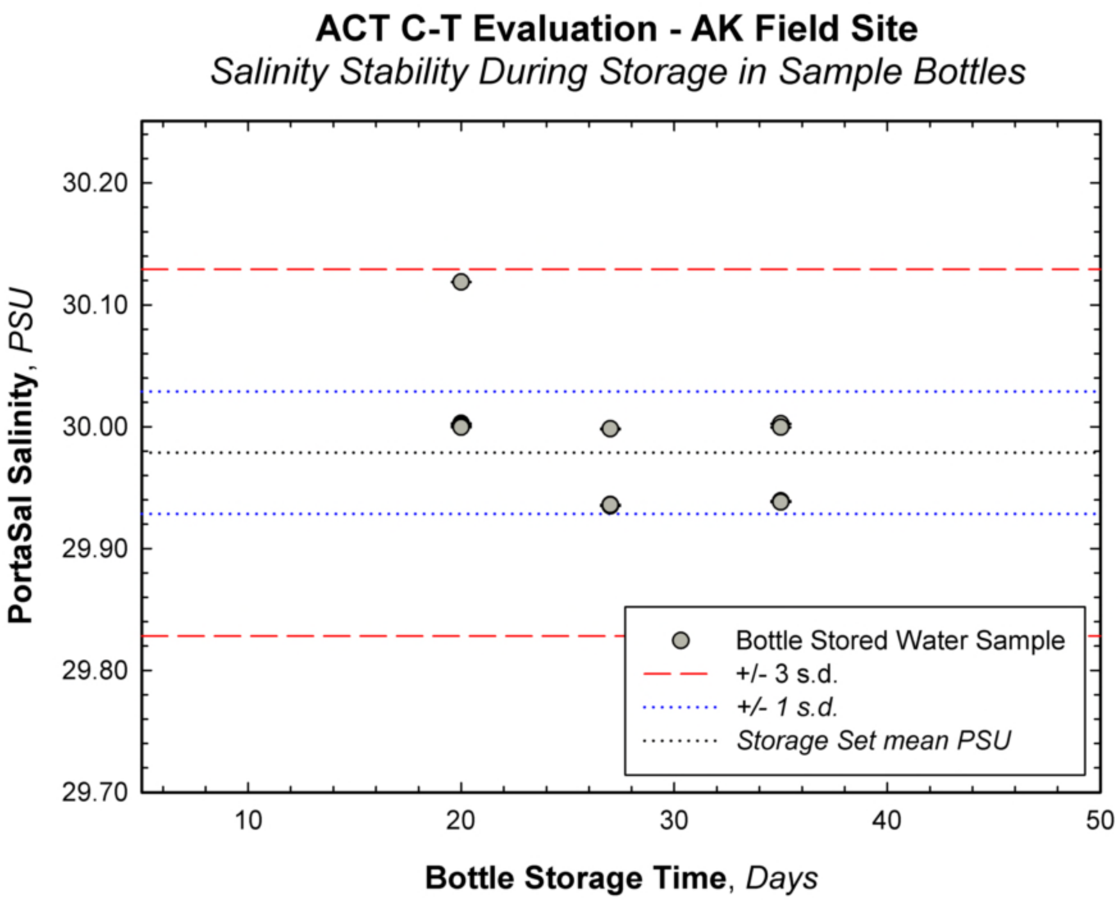


Figure 41. Assessment of drift in laboratory salinity measures associated with sample storage in field reference sample bottles. Sample bottles filled from single batch of test site surface water and subsets included in each sample shipment to MLML. Storage time reflects total time (days) since initial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

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

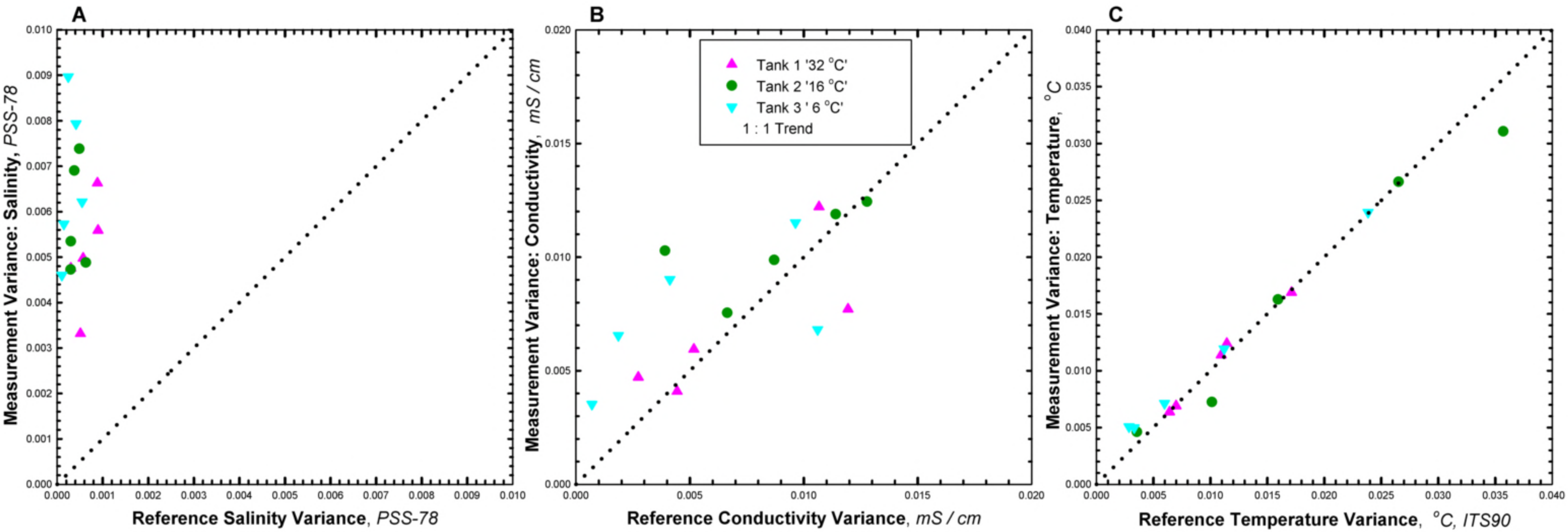


Figure 4. Evaluation of measurement variation of Greenspan Analytical's EC3000 conductivity and temperature sensor package achieved during the laboratory exposure trials plotted in **Fig. 3**. Instrument measurement variance is presented as the standard deviation from 30 consecutive instrument reads 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

Note from the Alliance for Coastal Technologies:

Company representatives at Tyco Environmental Systems - Water Monitoring, Greenspan - Combined Instruments – GTS have reviewed the report and approved its content. They have declined to provide any independent response.