Protocols for Verifying the Performance of In Situ Salinity Sensors

March 2008

ACT PV08-01

Questions and comments should be directed to: Dr. Tom Johengen
c/o Alliance for Coastal Technologies
Chesapeake Biological Laboratory
PO Box 38 / One Williams Street
Solomons, Maryland 20688, USA
Email: Johengen@umich.edu

Table of Contents

Page No.

Protocols for the ACT Demonstration of In Situ Salinity Sensor

1. Background on ACT Technology Evaluations

Instrument performance verification is necessary to effectively evaluate existing technologies and to encourage the development and adoption of promising new technologies that support coastal science, resource management and the long-term development of an Integrated Ocean Observing System. The Alliance for Coastal Technologies (ACT) has therefore been established to provide an unbiased, third party testbed for evaluating coastal sensors and sensor platforms.

The following protocols describe how ACT will examine the environmental performance characteristics of commercially available in situ conductivity/temperature sensors, used to derive salinity, through the evaluation of objective and quality assured data. The goal of ACT's evaluation program is to provide technology users with an independent and credible assessment of instrument performance in a variety of environments. Therefore, the data and information on performance characteristics will focus on the types of information that users most need. ACT will look to the broader community to define the data and operational parameters that are valuable in guiding instrument purchase and deployment decisions.

It is important to note that ACT does not certify technologies or guarantee that a technology will always, or under circumstances other than those used in testing, operate at the levels verified. ACT does not seek to determine regulatory compliance; does not rank technologies or compare performance among specific instruments tested; does not label or list technologies as acceptable or unacceptable; and does not seek to determine "best available technology" in any form. ACT will avoid all potential pathways to picking "winners and losers". Therefore, although the following protocols will apply to all instruments evaluated, no direct comparisons will be made between instruments from different manufacturers and instrument-specific Performance Verification Statements will be released to the public for each instrument type as a final report. Finally, we emphasize that these protocols were developed with the direct assistance of participating manufacturers and an external Technical Advisory Committee and have been agreed upon in singed contracts with ACT.

2. Introduction to Technology

As part of our service to the coastal community, ACT Partner Institutions and Stakeholder Council have chosen the performance verification of commercially available, in situ conductivity/temperature sensors that provide a derived measurement of salinity. Salinity is a fundamental property of water that is used for the basic characterization of environmental habitats, for tracing the mixing of water masses, and for understanding variability in density needed to accurately model sound propagation and geostrophic currents. There are a number of challenges in assessing salinity in coastal aquatic systems that point to the value of sustained in situ observations. High spatial horizontal variability is typical of many coastal, estuarine and fresh water systems, as are strong depth gradients. High temporal variability in natural background concentrations are typical of many locations, often in response to short-term forcing (e.g., vertical mixing) or input events (e.g., runoff, river discharge).

This ACT Technology Evaluation will examine individual sensor performance both in the laboratory and across different field conditions in moored and vertically profiled applications. We will focus specifically on commonly used inductive, conductive, and electrode based conductivity sensors with measuring ranges from 0 - 100 mS/cm. For those instruments that do not internally derive salinity values, we will the use the practical salinity scale approach using the formulas supplied in UNESCO Technical Memo by Fofonoff and Millard (1983). These derived salinity values will be reported without units per recommendations of the International Oceanographic community (reference).

3. Objectives and Focus of Salinity Sensor Performance Verification

The fundamental objectives of this Performance Verification are 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.

ACT has performed a customer needs and use assessments and held a technology workshop on in situ salinity sensors. As part of these reviews, scientists, resource managers, and other users of these technologies were asked about their current use or application of these instruments, their perceptions of limitations or problems with the technology, and the most important criteria they use when selecting a sensor or instrument package. The results of these assessments were used to identify the main applications and key parameters that ACT will evaluate in this Technology Verification.

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 with 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. This ACT Performance Verification will focus on these types of applications and criteria utilizing a series of field tests at up five of the ACT Partner Institution sites, representing marine, estuarine and freshwater environments. A laboratory component of the Verification will be performed at a sixth Partner Institutional site. Complete needs and use assessment and workshop reports can be found at www.act-us.info.

3.1. Parameters to be Investigated

Field tests will focus on reliability and the ability of the instrument to consistently track natural changes in salinity. Laboratory tests will focus on verifying manufacturer's stated performance characteristics to the highest level of accuracy and precision that we can obtain using our testing protocols.

- **Accuracy** – a measure of the closeness of an estimated value to the true value (see below). For this verification, the accuracy of the test instruments will be determined in controlled laboratory tests by comparing the difference between in situ instrument determined salinity values and laboratory measured salinity for collected reference water samples. The amount of disagreement in measurements can be expressed as a percent of the signal or as an absolute difference. Laboratory analyses will follow approved standard operating procedures and be checked against external certified reference standards to ensure they represent the best possible measure of true salinity values. All laboratory analyses will be run in triplicate to assess the precision of these reference measurements.
- **Precision** – Precision is a measure of the repeatability of a measurement. Instrument precision will be determined by calculating coefficients of variation for 10 replicate salinity sensor measurements under each of the specified temperature and salinity conditions defined below in the laboratory test section.
- **Reliability** – Reliability is the ability to maintain integrity or stability of the instrument and data collections over time. Reliability of instruments will be determined in two ways. In field tests, comparisons will be made of the percent of data recovered versus percent of data expected. In addition, instrument stability will be determined by pre- and post-measures of reference standards to quantify drift during deployment periods. Comments on the physical condition of the instruments (e.g., physical damage, flooding, corrosion, battery failure, etc.) will also be recorded.
- **Response Linearity** – Stability of a predetermined response or calibration factor over a range of reference standard concentrations. Response factors will be quantified in the laboratory over a range of 5 - 25 ^{o}C and 5 - 35 salinity.

4. Summary of Basic Verification Approach

Testing protocols are based on an amalgamation of standard procedures for calibrating and testing salinity sensors provided by the participating manufacturers, and protocols recommended by ACT personnel and an external Technical Advisory Committee. The protocols were refined through direct discussions between all parties during an ACT Salinity Sensor Performance Verification Protocol Workshop held on 26 -27 February, 2008. Participants at this workshop included ACT Headquarters Staff, ACT Partner Institution Technical Coordinators, an ACT Quality Assurance Manager, an external Technical Advisory Committee, and representatives from the participating manufacturers. A consensus was reached that the testing protocols will incorporate or require:

- standard, approved laboratory analytical methods to provide best possible measure of the 'true' salinity concentration from field samples, which will serve as performance standards against which instrument estimations will be compared.

- all reference and QAQC samples to be analyzed on a Guildline Portasal salinometer, which has a reported accuracy of 0.003 and a resolution of 0.0003 equivalent psu.
- all samples for the evaluation will be analyzed on the same instrument, which is to be located at Moss Landing Marine Laboratory, and operated by trained technical staff.
- ACT PI's, along with experts from the external Technical Advisory committee will oversee the set-up, training, and use of the Lab instrument during the evaluation.
- all samples will be collected in approved, standardized, salinity bottles
- all samples will be collected, stored, and shipped according to approved Standard Operating Procedures that will be finalized and practiced at the Training Workshop prior to the beginning of the evaluation. The Manufacturers and the Chief Scientist will verify that all staff are trained in both instrument and sample collection SOP's
- the QA manager will conduct technical audits at the field sites to verify compliance with these SOPs during the test.
- field tests will include both a four week and eight week long moored application
- field tests will include a vertical profiling application for those instruments that are designed to sample at appropriate rates and with appropriate sensor response times.
- employ a wide geographic distribution of test sites that includes freshwater, estuarine, and coastal ocean to fully characterize the potential utility of the instruments

All ACT personnel involved in this Verification will be properly trained on use of instruments by manufacturer representatives and on a standardized water sampling, storage and shipping method. All laboratory analysis will be conducted by trained ACT staff at the Moss Landing Marine Laboratory using standardized methods for the Portasal salinometer. ACT will conduct a QA audit of the laboratory during the Verification to assure that all components of established SOPs are being thoroughly followed. Company participants are welcome to visit any of the test sites or MLML at any time during the Verification. Additional agreements for the protocols include:

- all numerical data will be recorded to three or more significant digits where appropriate, with the goal of resolving accuracies of 0.1 salinity in field tests and 0.01 salinity in laboratory tests.
- ACT will do an independent analysis of factory calibration by exposing the instruments to internally established seawater standards. This check will be performed during the training session at MLML and will be monitored by the manufacturer representative to ensure proper handling and expected performance.
- ACT will do an initial and final exposure test of an internally determined reference standard at each field site. The final exposure test will occur after the instruments has been retrieved and cleaned of all removable fouling according to written procedures provided by the manufacturer.
- any post-corrections of data based on improper calibration or drift are the responsibility of the companies.
- post-corrected data can be included in the companies' response page that is included within each report.

- raw conductivity and temperature data along with derived salinity values will be reported over time, position, or depth as directly downloaded from the test instruments
- for those instruments that derive salinity directly, the salinity values will be reported in the default units reported by the instrument, even though we recognize that salinity generated from a conductivity ratio should be reported without units. For those instruments that do not directly derive salinity, salinity will be derived from the recorded conductivity and temperature records using the standard algorithms defined in the UNESCO Technical Papers in Marine Science (Fofonoff and Millard, 1983) and will be reported without units.
- reports will include means, standard deviations, and number of replicates of laboratory determined salinity values for corresponding reference samples at the same time, position, or depth of instrument measurements
- reports will include an independently determined temperature record collected within the water column over corresponding time, position, or depth, recorded with an RBR TR-1060 Temperature Recorder which has a stated accuracy of 0.002 ^{o}C and a resolution of < 0.00005 ^{o}C. The calibration and temperature transfer standard of these sensors will be independently verified in a NIST certified laboratory operated by Geoff Morrison of SeaKeepers International.
- the TR-1060 temperature sensors will be used for laboratory tests, field tests, and initial and final exposure tests at each of the sites.

The goal of this Verification is to test the same model instrument in laboratory tests and field tests covering a range of coastal environments, to the extent that the submitted test instrument is appropriate for each of the testing applications or sites. Where the test instrument specifications are not appropriate for a given environment or application, we will accept a separate instrument package so long as it has been pre-approved and meets all of the original conditions defined in the request for testing. It is also preferred to evaluate instruments incorporated in stand-alone packages, which include features such as data logging, data transformation/conversion equations, independent power supplies, and biofouling prevention. In some cases, however, submitted test instruments may only be tested in one type of field application (if they are designed and sold for one particular use) and some independent sensors will be incorporated into other associated equipment (e.g., datalogger, CTD) owned and operated by ACT Partner Institutions.

Four instrument packages of each particular model, or a single instrument for a site-specific model, will be needed for the field tests and should be delivered to MLML by May 7th to be available for training and confirmation of factory calibration settings. An initial laboratory test, using one of each model instrument package submitted will follow the training workshop and take place during the week of May 19 – 23. ACT will be responsible for shipping the instruments from MLML to the respective field test sites following the training and laboratory testing.

4.1. Laboratory Tests

Laboratory tests of accuracy, response linearity and precision will be conducted at Moss Landing Marine Laboratories, an ACT Partner Institution. A matrix of salinity and temperature conditions will be established in well-mixed (submersible circulating pumps), temperature controlled (monitored at two locations in each bath) water baths where instruments will be submerged for testing. Instrument output will be calibrated as suggested by each manufacturer.

Instrument Setup - Prior to deployment, all instruments will be setup and calibrated as suggested in individual manufacturer manuals or SOPs provided as part of the training workshop. The salinity sensors will then be programmed to record data every 1 minute during the laboratory tests and their internal clocks set to local time using www.time.gov as the time standard.

Accuracy and Precision – For the accuracy and precision tests, a mean and standard deviation of 10 instrument readings taken at 1-minute intervals for each test condition will be collected after the instruments are allowed at least 30 minutes to equilibrate (since response time is not a parameter being tested as part of this evaluation). This instrument mean and standard deviation will be compared to measured salinity from 10 reference samples analyzed in the laboratory. Three test baths will be established and maintained at temperatures of 5, 15, or 30 ^{o}C. In separate trials, instruments will then be exposed sequentially to salinity levels of approximately 35, 30, 25, 20, and 10 at each of these temperatures.

4.2. Field Tests

Moored Deployment

Moored application tests will be conducted at five ACT Partner Institution sites covering freshwater, estuarine, and open-ocean conditions. The test sites include Coconut Island, HA; Resurrection Bay, Seward, AK; Skidaway Island, Savannah, GA; Gulf of Mexico, St. Petersburg, FL; and Clinton River, Mt. Clemens, MI and descriptions are provided at the end of the document. The field tests will occur in two rounds with FL, MI, GA, and HI participating in the first round and AK participating in a second round. A four-week period is provided after the first round of field test to allow individual manufacturers to recondition and recalibrate the instrument packages if they choose to re-use one of the instruments. Alternatively, companies can simply provide 5 sets of instruments to MLML and we will include this in the initial factory calibration test and then have it shipped to the final test site. The duration of the moored deployment tests will be 4 weeks, except at the Hawaii test site where instruments will be deployed for a period of 8 weeks. Instruments will only be removed from the water after the test period is complete, or in the event of an obvious problem or environmental condition that could jeopardize the safety of the instruments.

Instrument Setup - Prior to deployment, all instruments will be set up at the field sites by a trained ACT staff member following established SOPs that will be developed in collaboration with the manufacturers at the Instrument Training workshop to be conducted from May 12-16, 2008. In the event that any initial calibration is required, the manufacturers can either supply their own certified standards for calibration or submit a purchasing requirement list to ACT at least 4 weeks in advance of any initial testing. Instruments will be programmed to record data based on a time interval that will allow for a 30 (or 60) day deployment. Intervals will be selected such that there is a common 30 minute interval achieved by all instruments. This schedule will allow us to coordinate our reference sampling for all instruments. Internal clocks will be set to local time and synchronized against the time standard provided by www.time.gov.

In high flow coastal environments, clock drift could lead to significant bias. We will examine and record any clock drift in the final reports.

Instrument Deployment - A photograph of each individual instrument and the entire instrument rack will be taken just prior to deployment and just after recovery to provide a qualitative estimate of biofouling during the field tests. All instruments will be exposed to an internally defined reference solution made up of ambient field site water with salinity determined by laboratory reference sample analysis both before and after deployment as an estimate drift over time. The post-deployment reading will be taken after the instruments are cleaned according to manufacturer specifications. Instruments are to be set-up as self-recording but should a manufacturer choose, they may add a real-time telemetry component to the test instrument. The manufacturer will be responsible for adding this additional component including all required hardware and software. ACT can facilitate providing server space or web portal access. Manufacturers will train ACT on the protocols on data down-loading and processing during the Instrument Training workshop. All instruments will be returned to the companies containing all of the original data.

Deployment Rack – We will work with the instrument manufacturer to design an appropriate deployment rack for their analyzer. The goal will be to arrange all test instruments in a manner so that we can collect a single representative field sample that is no more than 1 m apart from any of the individual sampling inlets. We will conduct an initial test of the sensor mounting configuration to ensure that there is no interference among instruments. The test will be conducted during the training workshop and will involve the direct participation of the manufacturer representatives. Protocols for this interference test will be developed collectively by ACT and the participating companies. The deployment frames will be arranged so that all of the instruments remain at a fixed depth of 1 m below the water surface (using a float system or fixed dock in environments not affected by tidal changes or strong wave action). A calibrated CTD package will also be attached to the mooring at each test locale and programmed to provide an independent record of temperature at the same depth and the highest required frequency to match any of the test instruments. The sensor rack design will also be standardized as much as possible from site to site. However, physical conditions at particular sites may require specialized modifications. For example, the instrument rack at the offshore site will be mounted approximately 2 meters below MLLW on a fixed piling. This increased depth will ensure that the instruments are not exposed even during extreme conditions.

Biofouling Plates – A series of tiles will be deployed adjacent to the mooring rack and used to photographically document the amount and rates of biofouling at the site. Once each week we will retrieve a tile and photograph the extent of fouling. The photographs will be included in the final Verification reports.

Reference Water Sampling Schedule – The sampling frequency will be structured to examine changes in salinity over daily and weekly time scales. Specifically once each week we will conduct an intensive sampling event that consists of 4 consecutive samples spaced at one-hour intervals. During four additional days of each week we will sample twice per day, at any interval that corresponds with the instrument sampling schedule. The initial intensive sampling event will occur within the first two days of the deployment after all instruments have been deployed, and the final intensive sampling event will occur during the last two days of the deployment. This schedule will provide a higher density of comparative data at the beginning when instruments should be functioning at optimum performance and again after the challenge of a four or eight week deployment. To the extent possible, the middle two intensive sampling events will be selected to correspond to specific meteorological or hydrological events that are likely to correspond to significant changes in the expected salinity values. This sampling schedule will result in at least 48 potential reference samples against which we can compare instrument response and should be sufficient to capture event based scales of variation and provide a 'continuous' check on instrument performance throughout the deployment. The specific timing of when water samples will be collected will be left up to the individual sites, but with the goal of capturing maximum variations in salinity. In the event of weather limitations or un-avoidable schedule conflicts it will be permissible to miss a given sampling day and simply collect additional samples on a subsequent day, with the goal of keeping a similar number of reference points for each test site. Sampling at the offshore test site in Tampa Bay, FL will have a more flexible sampling schedule to accommodate weather and boat availability. It will, however, follow a similar pattern of a weekly intensive sampling event and collect a similar number of overall reference samples. Likewise, the eight week deployment test at HI will modify their sampling scheme to spread out a similar number of samples over the extended time period. Approximately 65 percent of the samples will be collected during the first four weeks, with intensive sampling events staged at week 1, 2, and 4. A final intensive sampling event will occur at week eight. All sampling times will be recorded on logsheets and entered into a database for final data comparisons.

Reference Water Sample Collection - A standard 2L or 4L Van Dorn water sampler will be used at each field test site to collect water samples for reference salinity measurements. These samples will be used to examine instrument performance and stability over time. Water sample collections will be timed to correspond directly with the instrument readings. The water sampler will be lowered to the same depth and as close as physically possible to the sampling inlets and should be no more than 1 m from any of instrument sampling inlets. The water sampler will be soaked at sampling depth for 1 minute prior to sampling. If water is not flowing the sampler should be moved to ensure that it is being flushed with the ambient water. The water sampler will be triggered to match the programmed sampling times of each instrument. Four replicate salinity samples will be collected in pre-conditioned (with site water) 200 ml OSIL glass salinity bottles directly from the spigot. Each sample bottle will be filled one-third with sample water, shaken and emptied three times before collecting a final sample. During emptying, the rinse water will be run over the inside of the vapor seal cap to remove any residual salts if present. Prior to capping the sample bottle, the inside of each vapor seal screw cap and the outside threading of the main body of the sample bottle will be wiped dry with Kimwipes to prevent salt crystals from developing during storage. A specified headspace of approximately 2 ml will be left in each sample bottle. Processed samples will be stored in cool and dark conditions during transport from the field and during shipping to MLML for analysis.

Once each week during the deployment two Van Dorn water samplers will be fired simultaneously and adjacent to each other. These dual samples will help define any potential small-scale variability that may occur in the sampling environment and define a meaningful level of accuracy that can be established under field testing conditions.

Cleaning sampling apparatus – Between every sample taken, the Van Dorn water sampler will be wiped dry to avoid accumulation of salt crystals. The sampler will also be soaked in the environment for 1 minute prior to collecting a new sample.

Sample Shipping – Samples will be shipped unpreserved and at ambient temperatures to MLML for analysis once per week during the deployment. One of the four replicates from each sampling timepoint will be reserved on site as a replacement in the event of loss or damage during shipping. It may also serve as an additional analytical replicate should the variance of the initial 3 replicates be too high. All samples will be recorded onto Chain of Custody forms, and include a description of the condition in which the samples where shipped and received. A copy of the form will be sent with the samples and the receiving laboratory will confirm receipt and condition of samples within 24 hours of their arrival by signing and faxing a copy of the form to the test site. Original copies of these forms will be maintained on site.

Vertical Profiling

The vertical profiling application will only be conducted at the Alaska test site in Resurrection Bay. The test will consist of vertical profiling casts at 2 or 3 test sites known to have well defined pycnoclines and occur during a single 1 day cruise. One site will be located well offshore in open-ocean conditions and one will occur within a few miles of shore in areas known to be influenced by coastal runoff. The profiling test will involve the comparison of simultaneous instrument measurements and discrete samples are collected at six discrete depths throughout the water column. Sampling depths will be spaced to provide two reference samples in the surface mixed layer, two within the pycnocline, and two within the hypolimnion in order to capture the maximum variation in salinity. One of the six discrete depths will be sampled in replicate with two independent bottle collections. The exact depth locations will be determined on the basis of the CTD profile in real-time during the downcast of the rosette system. In the event that the real-time data acquisition fails, the hydrographic profiles will be obtained from a separate initial cast, and the rosette will be deployed immediately after, in AutoFire mode with preprogrammed depths, based on the temperature and salinity profiles from the previous cast. The rosette and test instrument assembly will be lowered and raised at a standard rate of between 0.25 m/sec and the data collected by test instruments will be presented for both down- and up-casts. Test instruments will be mounted within a modified 8 Niskin bottle profiling rosette so that all instruments and bottles measure and sample near the same depth as physically possible. A standard and calibrated CTD package will be attached to the rosette and programmed to provide an independent record of conductivity, temperature, depth and time during each instrument sampling event. For any of the test instruments that cannot be connected directly into the CTD logging unit of the rosette, profiling data will be internally logged and then matched up to the CTD profiles by synchronized time-stamps.

Reference Water Samples - Reference salinity samples will be collected only during the up-cast. At each of the selected depths, the rosette will be paused for 2 minutes to ensure that all test instruments have equilibrated to those conditions and that a sample has been collected at that specific depth. After the delay, one Niskin bottle will be fired at each depth (except where a field duplicate will be taken) in correspondence with the test instruments sampling time. For matching up instrument data to the reference sample we will average the instrument readings for 10 seconds before and after the specific time at which the bottle was fired. Bottle numbers, depth, and profile number will be recorded on the field data log. Water samples will be processed immediately upon retrieving the rosette on deck, following the same procedures defined for the mooring test.

4.3. Analysis of Reference Samples

All reference and QAQC samples will be analyzed on a Guildline 8410A Portasal salinometer, which has a reported accuracy of 0.003 and a resolution of 0.0003 practical salinity units (PSU). All samples for the evaluation will be analyzed on the same instrument, which is to be located at Moss Landing Marine Laboratory, by trained technical staff. ACT PI's, along with experts from the external Technical Advisory committee will oversee the set-up, training, and use of the instrument during the evaluation. The instrument will be calibrated with certified salinity standards from OISL at the beginning, middle, and end of each analytical batch (approx. 10% of total volume analyzed). In addition, a reference sample generated at MLML (see below) will be following each batch of sample bottles as part of the established QA/QC protocols.

4.4. Ancillary Environmental Data

At each of the mooring test sites, a calibrated CTD package will be attached to the test rack and positioned at the same depth as the test instruments to provide an independent record of conductivity and temperature measured at 15-minute intervals. In addition each site will deploy an RBR TR-1060 temperature sensor to establish an accurate temperature history for the site. This sensor has a stated accuracy and resolution of 0.001 ^{o}C and 0.0005 ^{o}C respectively. Each TR-1060 will be independently calibrated and certified prior to the use in this Verification. In conjunction with each water sample collection, technicians will record basic site-specific conditions on standardized log sheets including: date and time, weather conditions (e.g., haze, % cloud cover, rain, wind speed/direction), air temperature, recent large weather event or other potential natural or anthropogenic disturbances, tidal state and distance from bottom of sensor rack, and any obvious problems or failures with instruments. Datasheets will be transmitted on a weekly basis to the ACT Chief Scientist, for data archiving and ACT personnel performance QA/QC.

Each test site will either establish or identify the closest meteorological station (and river discharge gauge where appropriate) that can record air temperature, humidity, directional wind speed, precipitation on a continuous basis to help identify the timing and intensity of any event based changes at the field test locations.

Ancillary data will be used in a qualitative sense to understand the history of weather patterns and changes in ambient water quality conditions. These data will not be used for any direct calibration, correction, or statistical comparison to the reported salinity test data.

5. Verification Schedule

Note that the below schedule is provisional and actual dates for each milestone may vary.

- The Final ACT Salinity Verification Contract will be sent to Manufacturers by April 1, 2008
- Signed contracts are due back to ACT Headquarters by April 25, 2008
- All relevant deployment equipment and 4 sets of complete instrument packages should be delivered to the Moss Landing Marine Lab test site by May 7, 2008.
- A Training Workshop on the actual will be held at MLML on May 12 -16, 2008. Manufacturers will train ACT staff in the set-up, calibration, and use of their instruments during a 2 hour training session for each manufacturer.
- The laboratory test for the verification will take place at MLML from May 19-23, 2008.
- Instruments will be mailed from MLML to the first round of field testing sites by May 20, 2008 except for the one set used in the lab test. This set will be mailed by May 26, 2008.
- Moored field tests will occur at MI, GA, FL during June 2008.
- A long-term field test will occur at HI from late-June to late-August 2008.
- Instruments from MI, GA, and FL will be returned to the companies by July 3, 2008.
- Companies will send instruments to AK by July 31st.
- A vertical profiling test will be conducted in AK on August 4-5, 2008.
- The moored field test in AK will be conducted from August 6 - Sept 3, 2008.
- Instruments from AK will be sent back to Manufacturers by September 10, 2008.
- ACT Chief Scientist, Technical Coordinators, Technical Advisory Committee, and Quality Manager, will meet for 3 days to analyze results and evaluate the Performance Verification processes in November 2008.
- ACT Performance Verification Statements for each individual instrument will be drafted and sent out for review by, Technical Advisory Committee, Technical Coordinators, Quality Manager, Partners, and Stakeholders in January 2009
- Final Performance Verification Statements will be sent to Manufacturers in March 2009
- One page comment letters from Manufacturers are due two weeks after receiving the final reports
- Final Performance Verification will be released to the public in April 2009

6. Data Recording, Processing and Storage

This section describes methods employed during data recording, processing, and storage to minimize errors and assure high quality analyses in the Performance Verification Statements.

6.1. Documentation and Records

A variety of data will be acquired and recorded electronically and manually by ACT staff in this Verification. Operational information and results from the reference method will generally be documented in a field/laboratory record book and on the data sheet/chain-of-custody forms (see below). An electronic copy of these raw data will be transferred to the ACT Chief Scientist weekly, who will store it permanently along with the rest of the study data.

The results from the test instruments will also be recorded electronically. Test data will only be downloaded and analyzed upon completion of the field deployments. Once collected, one copy of these data will reside at the corresponding ACT test facility and a second copy at ACT Headquarters until the entire Verification is finished. The table below summarizes the types of data to be recorded and the process for recording data.

Data to be Recorded	Responsible Party	Where Recorded	How Often Recorded	Purpose of Data
Dates, times of sampling events	Each ACT Partner	Field record books/data sheets	Each reference sample collection and laboratory analysis	Used to organize/check test results; manually incorporate data into spreadsheets - stored in study binder
Test parameters (site conditions)	Each ACT Partner	Field record books/data sheets	Each reference sample collection	Used to define site characteristics; manually incorporate data into spreadsheets - stored in study binder
Test instrument calibration data	Each ACT Partner	Laboratory record Book/data sheets	Start/end of test	Document correct performance of test instrument
Test instrument data - digital display - electronic output	Each ACT Partner	- Data sheets - Instrument data acquisition system (data logger)	After completion of the 26-day field deployments	Used as part of test results; incorporate data into electronic spreadsheets - stored in study binder
Reference analytical results	MLML Lab	Laboratory record Book/data sheets	At the conclusion of each analytical sample batch.	Used to check test results; manually incorporate data into spreadsheets - stored in study binder
Reference calibration data	MLML Lab	Laboratory record books/data sheets	Whenever zero and calibration checks are done	Document correct performance of reference method
Performance evaluation audit results	ACT HQ	Laboratory record books/data sheets	At times of performance evaluation audits	Test reference method with independent standards/ measurements

6.2. Data Review

All data are to be recorded directly in the field/laboratory record book as soon as they are available. Records are to be written in water-proof ink, written legibly, and have any corrections initialed by the person performing the correction. Any corrections will be crossed out with a line (not blackened or white-out), and the correction made, with initials and date of correction. These data will include electronic data, entries in field/laboratory record books, operating data from the ACT Partner test facility, and equipment calibration records. Records will be spot-checked within two weeks of the measurement to ensure that the data are recorded correctly. The checker shall not be the individual who originally entered the data. Data entries shall be checked in general for obvious errors and a minimum of 10 percent of all records shall be checked in detail. Errors detected in this manner shall be corrected immediately. The person performing the review will add his/her initials and the date to a hard copy of the record being reviewed. The ACT Technical Coordinator (TC) will place this hard copy in the files for this Verification. In addition, data generated by each ACT Partner test site will be provided to the ACT Chief Scientist and reviewed before they are used to calculate, evaluate, or report results.

7. Quality Assurance/Quality Control

The Salinity Sensor Verification will be implemented according to the test protocols and technical documents (e.g. Standard Operating Procedures) prepared during the planning stages of the test. Prescribed procedures and a sequence for the work have been defined and all work performed during the Verification shall follow those procedures and sequence. Technical procedures include methods to assure proper handling and care of test instruments. All implementation activities are documented and are traceable to the test/QA plan and SOPs and to test personnel.

7.1. Laboratory Test Quality Control

All laboratory instrumentation at MLML used to measure reference salinity values will be calibrated by a trained technician using established SOPs (eg. JGFOS manuals) along with the instrument manuals supplied by Guildline Instruments. MLML will maintain a log of all calibration and reference QA/QC samples analyzed during the Verification. The logs shall include at least the following information: name and identification number of instrument, date of calibration, and calibration results. These logs shall be provided to the ACT Chief Scientist and maintained in a master calibration file as part of the QA/QC records. QA/QC samples will include:

a. External Certified Standards - An external certified standard will be prepared and analyzed in duplicate at the beginning and end of each set of analyses and once in the middle of the run.

b. Laboratory Storage of Salinity Bottles – Potential bias (due to evaporation during storage of salinity bottles) will be investigated prior to the field deployment tests. A total of 30 salinity bottle will be collected from one batch of seawater collected in Monterey Bay and stored for extended period of time of time. Initially, 5 replicate samples will be analyzed on a Portasal Salinometer, and then 5 additional replicates will be analyzed weekly over the next five weeks.

7.2. Field Quality Control – Mooring and Profiling Deployments

Field quality control represents the total integrated program for assuring the reliability of measurement data. It consists of the daily field logs, quality control samples, and sample custody procedures.

Field Logs

Standard, uniform field logs should be maintained for all fieldwork. These logs should report name of staff conducting fieldwork, date (month, day, and year), operating status of all equipment, and manual readings of environmental conditions.

Field Quality Control Samples

Replicate sample bottles (a total of 4 from each sampling timepoint) will be collected to ensure optimal accuracy and precision of sample collection and analytical procedures. A reference site-water sample will also follow each batch of salinity samples and be measured upon return to MLML with each shipping batch. The QAQC reference sample will be analyzed in the same manner as a salinity sample and should compromise approximately 10% of the total samples collected.

a. Field collected replicates – for moored field tests we will collect replicates of salinity reference samples (duplicate Van Dorn water sampler collections) once per week; for vertical profiling tests we will collect replicate salinity reference samples at one of every 6 depths sampled per cast.
b. Field site QAQC reference samples – Site specific reference salinity samples will be used to account for potential bias due to storage (maximum of 3 weeks) and transport of salinity samples prior to analysis at MLML. Prior to deploying instrument, a batch of well-mixed, unfiltered, ambient water from each respective field site will be processed into 20 salinity bottles following standard protocols. Triplicate of this QAQC reference sample will be immediately shipped to MLML for analysis and then a set of triplicates will accompany each batch of test samples shipped to MLML for analysis. These QAQC samples will help assess any bias due to storage and shipping and consistency of MLML laboratory analysis.

Sample Custody

All reference samples will be accompanied by the sample collection sheet and Chain-of-Custody (COC) forms. The COC specifies time, date, sample location, unique sample number, requested analyses, sampler name, required turnaround time, time and date of transaction between field and laboratory staff, and name of receiving party at the laboratory. Proper labeling of sample bottles is critical. The COC is a mechanism by which a sample can be tracked through the various phases of the process: collection, shipping, receiving, logging, sample prep/extraction, analysis and final data QA/QC review.

Sample Handling

All collected reference samples at each test site will be handled in the same manner. All environmental reference samples should be processed while wearing clean laboratory gloves to minimize potential sources of contamination. Each reference sample should be dated and coded according to site and sample sequence. The actual sample container should be labeled with a number for identification. The reference sample number should be used in all laboratory records and COCs to identify the sample. Transfer of reference samples from field personnel to laboratory personnel is also recorded on the COC and records are maintained in the laboratory with the names and signature of persons leaving and receiving the custody. All logs shall be duplicated weekly. The original shall be retained at the ACT Partner site and a copy shall be sent to the ACT Chief Scientist. Samples stored for any period of time shall be routinely inspected by the TC to assure proper preservation and label integrity. Accumulated samples are to be shipped for analysis each week to minimize holding time.

7.3. Audits

Independent of the QA activities that are being conducted at each Partner test facility, the ACT Chief Scientist will be responsible for ensuring that the following audits are conducted as part of this verification a minimum of two ACT Partner test sites. Audits shall be performed by QA Manager, who shall be independent of direct responsibility for performance of the Verification.

Performance Evaluation Audits

A performance evaluation audit will be conducted of the MLML to assess the extent and compliance of their QA program and adherence to SOPs.

Technical Systems Audits

ACT's QA Manager will perform a Technical Systems Audit (TSA) at least twice during this Verification. The purpose of this audit is to ensure that the Verification is being performed in accordance with the test/QA plan, published reference methods, and any SOPs used by the Partner test facility. In this audit, the ACT QA Manager may review the reference methods used, compare actual test procedures to those specified or referenced in the test/QA plan, and review data acquisition and handling procedures. A TSA report will be prepared, including a statement of findings and the actions taken to address any adverse findings.

Data Quality Audits

ACT's QA Manager will audit at least 10% of the data acquired in the Verification to determine if data have been collected in accordance to the test/QA plan with respect to compliance, correctness, consistency, and completeness. The ACT QA Manager will trace the data from initial acquisition to final reporting.

Assessment Reports

Each assessment and audit will be documented, and assessment reports will include the following:

a. Identification of any adverse findings or potential problems,
b. Response to adverse findings or potential problems,
c. Possible recommendations for resolving problems,
d. Citation of any noteworthy practices that may be of use to others, and
e. Confirmation that solutions have been implemented and are effective.

7.4. Corrective Action

The ACT Chief Scientist, during the course of any assessment, audits, or review of laboratory results will identify to the party performing the specific activities any immediate corrective action that should be taken. If serious quality problems exist, the ACT Chief Scientist is authorized to stop work. Once the assessment report has been prepared, the ACT Chief Scientist will ensure that a response is provided for each adverse finding or potential problem and will implement any necessary follow-up corrective action. The ACT QA Manager will ensure that follow-up corrective action has been taken.

7.5. QA/QC Document Control

It is the responsibility of the ACT Chief Scientist to maintain QA/QC records, which shall include the following:

a. records of the disposition of samples and data.
b. records of calibration of instruments.
c. records of QA/QC activities, including audits and corrective actions.

8. Roles and Responsibilities

The Verification is coordinated and supervised by the ACT Chief Scientist and ACT Partner institution personnel. Staffs from the Partner institutions participate in this test by installing, maintaining, and operating the respective technologies throughout the test; operating the reference equipment, collecting the water samples, downloading the data from the instrument package, and informing the ACT Chief Scientist staff of any problems encountered.

Manufacturer's representatives shall train ACT Partner staffs in the use of their respective technologies and, at their discretion, observe the calibration, installation, maintenance, and operation of their respective technologies throughout the test. QA oversight is provided by the ACT QA Manager. In addition to aiding the development of these protocols, the external Technical Advisory Committee will be consulted during the evaluation in the event problems occur, will assist in the analyses of results, and will review the final Performance Demonstration Statement prior to release. Specific responsibilities are detailed below.

<u>ACT Chief Scientist</u>

The ACT Chief Scientist has the overall responsibility for ensuring that the technical goals and schedule established for the Verification are met. The ACT Chief Scientist shall:

- Prepare the draft Test Protocols/QA Plan and Performance Verification Statements.
- Revise the draft Test Protocols/QA Plan and Performance Verification Statements in response to reviewers' comments.
- Coordinate distribution of the final Test Protocols/QA Plan and Performance Verification Statements.
- Coordinate testing, measurement parameters, and schedules at each ACT Partner institution testing site.
- Ensure that all quality procedures specified in the test/QA plan are followed.
- Respond to any issues raised in assessment reports and audits, including instituting corrective action as necessary.

- Serve as the primary point of contact for manufacturers and ACT Partner Technical Coordinators.
- Ensure that confidentiality of proprietary manufacturer technology and information is maintained.

<u>The ACT QA Manager shall:</u>

- Review the draft Test Protocols/QA Plan and Performance Verification Statements.
- Conduct at least one technical systems audit (TSA) once during the Performance Verification.
- Audit at least 10% of the Verification data.
- Prepare and distribute an assessment report for each audit.
- Verify implementation of any necessary corrective action.
- Notify the ACT Chief Scientist if a stop work order should be issued if audits indicate that data quality is being compromised or if proper safety practices are not followed.
- Provide a summary of the audit activities and results for the Performance Verification reports.
- Review the draft Performance Demonstration reports and statements.
- Have overall responsibility for ensuring that the test/QA plan and ACT QMP are followed.
- Ensure that confidentiality of proprietary manufacturer technology and information is maintained.

<u>ACT Technical Coordinators at each Partner institution shall:</u>

- Assist in developing the Test Protocols/QA Plan.
- Allow facility access to the manufacturers and ACT Headquarters representatives during the field test periods.
- Select a secure location for the tests.
- Install, maintain, and operate the test salinity sensors at their respective test locations according to the specified instructions of the manufactures and these protocols.
- Perform sample collections and analyses as detailed in the test procedures section of the test/QA plan.
- One member of TC team will conduct 10% data audit as described in QA procedures. This will be done on all data logs and electronically entered data.
- Provide all test data to the ACT Chief Scientist electronically, in a mutually agreed upon format.
- Remove sensor systems and other related equipment from the test facility upon completing the Performance Demonstration test.
- Provide the ACT Chief Scientist and Quality Managers access to and /or copies of appropriate QA documentation of test equipment and procedures (e.g., SOPs, calibration data).
- Provide information regarding education and experience of each staff member involved in the demonstration.
- Assist in ACT's reporting of their respective test facility's QA/quality control results.
- Review portions of the draft Demonstration Statements to assure accurate descriptions of their respective test facility operations and to provide technical insight on demonstration results.

The Moss Landing Marine Laboratory shall:

- Perform reference sample measurements.
- Perform all QA/QC analysis as detailed in the these Test Protocols.
- Provide the ACT Chief Scientist and QA Manager access to and /or copies of appropriate QA documentation of test equipment and procedures (e.g., SOPs, calibration data).

- Provide information regarding education and experience of each staff member involved in the demonstration.
- Assist in ACT's reporting of their respective test facility's QA/quality control results.
- Review portions of the draft Demonstration Statements to assure accurate descriptions of their respective test facility operations and to provide technical insight on demonstration results.

Manufacturers shall:

- Review the draft test/QA plan and provide comments and recommendations.
- Approve the revised test/QA plan.
- Work with ACT to commit to a specific schedule for the Verification.
- Provide a operational sensor systems for each of the agreed upon test sites.
- Attend an Instrument Training workshop in MLML to train ACT personnel on the set-up, calibration, use and data management of their instruments.
- Review and comment upon their respective draft Performance Verification Statements.

Note: ACT reserves the right to dismiss any manufacturer from the Verification if it does not comply with agreed upon schedules or requirements.

External Technical Advisory Committee shall:

- Assist in developing the Test Protocols/QA Plan.
- Approve the final Test Protocols/QA Plan.
- Provide specific advice during testing.
- Review and comment upon draft Verification Statements.
- Approve final Verification Statements.

9. External Technical Advisory Committee

- Dr. Earle Buckley, North Carolina State University and ACT Advisor/QA Manager
- Dr. Kjell Gundersen, University of Southern Mississippi
- Dr. Robert Millard, retired, formerly Woods Hole Oceanographic Institute
- Dr. Geoff Morrison, International SeaKeepers Inc.

10. Field Test Site Descriptions

Cooperative Institute of Limnology and Ecosystem Research Field Test Site –

The ACT Partner at the Cooperative Institute for Limnology and Ecosystems Research, University of Michigan, will establish a field test site for this Verification on a fixed pier at the MI-Department of Natural Resources facility located at the mouth of the Clinton River in Malcomb County, MI (43º 13.667 N, 86º 20.333W). The site provides direct access to the Clinton River with water depth at the end of the pier averaging 3m. The pier resides approximately 200m from the confluence with Lake St. Clair. Given this close proximity, shifts in wind direction can bring significant amounts of lake water to the site and provides a greater range in water chemistry than just from the river itself. Water temperatures range from 2 to 24°C annually and roughly between 15 - 20 ºC in June. Conductivity values during the past field test ranged from 325 - 900 μS/cm.

Alaska SeaLife Center Field Test Site –

The ACT Partner at the Alaska SeaLife Center, University of Alaska Fairbanks (UAF) has established its Technology Evaluation Field Site at the Humpy Cove in Resurrection Bay, northern Gulf of Alaska. Resurrection Bay is a long fjord which protects the ice-free port of Seward, allowing for consistent recreational and commercial boat traffic. Humpy Cove is located in the outer bay outside the fjord's sill approximately 11 nautical miles from Seward. The deployment site (59º 58.32 N and 149º 17.54 W) is on a floating dock, which is situated in a small protected area on the southern side of the Cove. These waters have summer temperature range from 6 ºC to 14 ºC. The near-surface salinity varies from 30.5 psu in spring to about 20 psu by the late summer and is strongly dependent on amounts of snow accumulated in winter and summer rainfall. The site experiences a predominantly semidiurnal tide with mean range of 8.33 feet. The minimum depth at the test site is about 5m at MLW.

Skidaway Institute of Oceanography Field Test Site –

The ACT Partner at the Skidaway Institute of Oceanography (SkIO) has established a Technology Verification Field Test Site on a floating dock adjacent to fixed wooden dock located on the western shore of Skidaway Island (Lat: 31° 59.442' N; Lon: 81° 01.298 W). Skidaway Island is sheltered from the Atlantic Ocean by a chain of barrier islands. The site experiences a semi-diurnal tide with a 2 m amplitude. The SkIO site is located within a typical subtropical estuary dominated by *Spartina alterniflora*. The fixed dock is a wooden structure that juts westerly into the north/south running Skidaway River. The minimum depth at test site is 10.5 ft. or 3.2m at MLW. Water temperature ranges from 10 - 32°C, and salinity from 10 – 35 ppt.

University of Hawaii Field Test Site –

The University of Hawaii field site will be on the Kaneohe Bay Barrier Reef flat (157°48'W, 21°28.5') in waters ~2 m deep. Kaneohe Bay sits on the northeast, or windward, side of Oahu. The barrier reef acts as a physical divider separating coastal waters from the Kaneohe Bay lagoon and coastal ocean, as well as impeding the passage of surface wave energy into the bay interior. Significant wave heights at the study site are typically < 1 m with mean cross-reef currents only on the order of a few cm s-1. Both wave heights and cross-reef currents appear to be heavily modulated by the tides. Water temperatures at this site vary between 21 and 29°C with highest values in summer. Tidal variations are typically less than 0.5 m and salinities are between 34.5 and 35.5 psu.

University of South Florida Field Test Site –

The ACT Partner at the University of South Florida (USF) has established its Technology Verification Field Site this year at the start of the Tampa Bay main shipping channel, approximately five miles offshore at the Palatine Shoal. Tampa Bay is the largest Florida estuary and the second largest estuary in the eastern US. The deployment site (27° 35.722 N and 82° 51.516 W) is a piling structure constructed of H-beam extending five meters above the surface. These waters have a May-June temperature range from 23.7.5°C to 31.0°C with a mean of 28.6°C. The salinity during this time varies from 20 psu to about 32 psu and is strongly dependent on rainfall amount. The site has a mean depth of 6.0 m and a mixed tidal range of about 1m. The seabed consists of fine to medium siliclastic quartz and shell hash.