NOAA Technical Report NOS CO-OPS 071
Ocean Systems Test and Evaluation Program

Test and Evaluation Report

For the Greenspan EC3000 Conductivity/Temperature Sensor

Silver Spring, Maryland
January 2013

noaa **National Oceanic and Atmospheric Administration**

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Center for Operational Oceanographic Products and Services

The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. The Center provides the set of water level and tidal current products required to support NOS' Strategic Plan mission requirements and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. For example, CO-OPS provides data and products required by the National Weather Service to meet its flood and tsunami warning responsibilities. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U.S. harbors, and the National Current Observation Program, consisting of current surveys in near shore and coastal areas utilizing bottom mounted platforms, subsurface buoys, horizontal sensors and quick response real-time buoys. The Center: establishes standards for the collection and processing of water level and current data; collects and documents user requirements which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products.

Ocean Systems Test & Evaluation Program

The CO-OPS Ocean Systems Test and Evaluation Program (OSTEP) facilitates the transition of new technology to an operational status, selecting newly developed sensors or systems from the research and development community and bringing them to a monitoring setting. OSTEP provides quantifiable and defensible justifications for the use of existing sensors and methods for selecting new systems. The program establishes and maintains field reference facilities where, in cooperation with other agencies facing similar challenges, devices are examined in a non-operational field setting. Through OSTEP, sensors are evaluated, quality control procedures developed, and maintenance routines generated. The quality of the reference systems used in the field is assured by both rigorous traceable calibrations and redundant sensors.

NOAA Technical Report NOS CO-OPS 071
Ocean Systems Test and Evaluation Program

Test and Evaluation Report

Grace Gray
Robert Heitsenrether

January 2013

U.S. DEPARTMENT OF COMMERCE
Penny Pritzker, Secretary

National Oceanic and Atmospheric Administration
Dr. Kathryn Sullivan, NOAA Administrator and Under Secretary of Commerce for Oceans and Atmosphere

National Ocean Service
Holly Bamford, Assistant Administrator

Center for Operational Oceanographic Products and Services
Richard Edwing, Director

NOTICE

Ocean Systems Test and Evaluation Program

Test and Evaluation Report for the Greenspan EC3000 Conductivity/Temperature Sensor

CO-OPS STATEMENT OF ACCEPTANCE

CO-OPS management personnel have reviewed this document and concur that the evaluated sensor/system, when deployed and implemented as described herein, meets the defined requirements and is suitable for operational use. While additional testing may lead to superior performance or more economical operation, the existing sensor/system configuration is sufficient as described.

OSTEP Program Manager	01/18/12 Date	System Support and Evaluation Branch	18 JAN 13 Date
Chief, Engineering Division	1/23/13 Date	Chief, Field Operations Division	1/22/13 Date
Chief, Oceanography Division	1/25/ , Date	Chief, Information Systems Division	1/29/13 Date
Chief Scientist, CO-OPS	1/29/13 Date		
Director, CO-OPS	1/28/13 Date		

Table of Contents

List of Figures

List of Tables

Acknowledgements

The authors would like to acknowledge CO-OPS personnel for assistance with the design and installation of the field test system at Money Point, including John Stepnowski, Warren Krug, Albert Sanford, Chris Haith, Scott Mowery, and Winston Hensley.

Thanks to Zhong Li and Sudha Sundar from CO-OPS/ISD, who provided valuable information about CO-OPS' calculations of salinity and specific gravity on the PORTS® Web page.

Also, special thanks to Doug Wilson and Eric Stengel from NOAA's Chesapeake Bay Office and Mark Bushnell from Tellus Applied Sciences for coordinating and assisting with the Greenspan CT sensor installation on the Norfolk CBIBS buoy.

Executive Summary

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) maintains a suite of conductivity/temperature (CT) sensors on a select number of its National Water Level Observation Network (NWLON) and Physical Oceanographic Real-Time (PORTS®) stations. The data from these sensors can be used to calculate water salinity and density, which are important tools for safe navigation, especially in the determination of ship draft.

Most CT sensors used on CO-OPS stations are manufactured by Falmouth Scientific, Incorporated (FSI). In a continued effort to explore evolving technology and to expand the suite of instruments available for operational use in its observatories, CO-OPS selected the Greenspan EC3000 CT sensor for test and evaluation. Before an instrument can be approved for operation on a CO-OPS platform, it must first undergo testing by CO-OPS' Ocean Systems Test and Evaluation Program (OSTEP). OSTEP designed a series of laboratory and field tests to evaluate the performance of the Greenspan sensors under a variety of conditions.

In one round of laboratory tests, both the FSI and Greenspan sensors were compared independently to a range of conductivity calibration standard solutions. In a second round of tests, the two sensors were tested concurrently in CO-OPS' seawater test bath facility.

In the first of two field tests, a Greenspan CT sensor was deployed at the Money Point, Virginia NWLON station; data from the instrument were compared to the operational FSI CT sensor at that location. In the second field test, a Greenspan CT sensor was deployed on a NOAA Chesapeake Bay Interpretive Buoy System platform and compared to a Sea-Bird SBE-52 CT sensor.

In laboratory tests with conductivity calibration standards, the Greenspan results were more closely aligned with the standard solutions than the FSI results. However, several laboratory test design details were not ideal for the FSI, including the likelihood that the test container was too small for the sensor. The Greenspan and FSI conductivity and temperature readings were within manufacturer specifications during the seawater bath tests, even though results revealed possible issues due to edge interference and tank stratification. Improvements to the laboratory facility, such as a higher quality reference CT sensor, have been recommended.

During field tests, the Greenspan compared more favorably to the FSI in conductivity (-0.01 versus -0.2 mS/cm) and more favorably to the Sea-Bird in temperature (-0.03 versus -0.4 °C). Some configuration problems were encountered with the Greenspan that delayed the test and evaluation schedule. However, representatives from Greenspan worked with OSTEP personnel to resolve these issues. As a result, the Greenspan CT sensor can now be integrated with a Sutron Xpert Data Collection Platform in an operational real-time CO-OPS observatory.

Overall, Greenspan EC3000 data have compared very well with the data from the FSI and Sea-Bird. Based on test results reported here, the Greenspan EC3000 is recommended for use at operational CO-OPS observatories.

1.0 Introduction/Background

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) has used conductivity/temperature (CT) sensors on a select number of National Water Level Observation Network (NWLON) and Physical Oceanographic Real-Time (PORTS®) stations since 1991. There are now 20 CT sensors in operation at CO-OPS stations; the data from these sensors are used to calculate water salinity and specific gravity (relative density), which are important tools for safe navigation, especially in the determination of ship draft.

Before an instrument can be used operationally, it must undergo testing by CO-OPS' Ocean Systems Test and Evaluation Program (OSTEP). CO-OPS/OSTEP chose the Tyco Environmental Systems Greenspan EC3000 SDI-12 CT sensors for testing, not only because they are a less expensive and potentially reliable replacement for Falmouth Scientific, Incorporated (FSI) sensors that transition out of operation for servicing and repair, but also because Greenspan CT sensors have been used operationally in CO-OPS' systems.

An analog version of the Greenspan CT sensor (EC250) was tested and evaluated by OSTEP in 2006. The sensor performed well, and several sensors were put into operation for a time. When the CO-OPS Chesapeake Instrument Laboratory (CIL) switched to a new version of the Sutron Data Collection Platform (DCP), compatibility issues were encountered with the Greenspan EC250. As a result, the sensors were removed from operation and have not been used since 2008.

Evaluations conducted by the Alliance for Coastal Technologies (ACT) were reviewed as part of the necessary background research for the EC3000 when OSTEP was developing its test and evaluation plan. ACT is a partnership of research institutions, resource managers, and private sector companies that conducts independent testing of freshwater, coastal, and oceanographic sensors. The Greenspan EC3000 was tested by ACT as part of its Salinity Sensor Performance Demonstration and Verification between May and October 2008 [1]. The instrument performed favorably in laboratory tests, with conductivity accuracies of 0.1306 mS/cm (±0.0892 mS/cm) and temperature accuracies of 0.0935 °C (±0.1377 °C) relative to the reference samples. The field tests were less successful, largely due to bio-fouling (evidenced by measurements taken before and after cleaning the instrument) and software issues that resulted in data loss.

When developing the test plan for this project [2], OSTEP assumed that CO-OPS' required accuracies for CT sensors were ±0.1 mS/cm. It was later discovered that these values were actually manufacturer-published accuracies for the FSI. Therefore, OSTEP seeks to better define an acceptable level of accuracy for CO-OPS CT sensors based on user applications. Further discussion of this endeavor is provided in section 4 of this report.

1.1 Sensor Descriptions

Three different CT sensors were used during this test and evaluation. The Greenspan and FSI are toroidal sensors, and the Sea-Bird is an electrode sensor. Toroidal sensors measure the electrical conductivity of water using two wire coils. An electrical current is introduced in one coil and an electromagnetic field that surrounds the adjacent coil is generated. The coils are now inductively coupled, and the current flow between them is proportional to the conductance of the surrounding water [3, 4]. The main benefit of a toroidal system is its robustness and resistance to bio-fouling, while its main drawback is the partly external nature of the electromagnetic field, which leads to interference issues if deployed too closely to nearby objects. Electrode sensors measure the current flow between internal electrodes; this measurement is proportional to the surrounding seawater. Electrode sensors' electromagnetic fields are *mostly* internal, but Sea-Bird sensors are the only ones that are *fully* contained due to their unique electrode design [5]. This highly accurate sensor also has effective anti-fouling measures in place.

Greenspan EC3000

The Greenspan EC3000, like the FSI, is a toroidal sensor. As previously mentioned, a problem inherent to this type of sensor is that nearby objects such as pilings or other mounting structures tend to interfere with the electromagnetic field. Greenspan has avoided this problem by introducing a simple shroud, which is a cap that screws on to the end of the sensor over the toroidal sensing cell and contains the electromagnetic field. The shroud is open at the bottom and has holes in the top to allow water to flow to the toroidal sensing cell [4]. This sensor is capable of both RS232 and SDI-12 communications and can operate using either internal battery power and recording or external AC power and a DCP.

FSI OEM Digital

The FSI OEM Digital CT sensor has been a CO-OPS standard for many years. Its rugged construction and reliable RS232 communications have made it a key element of many NWLON and PORTS® stations.

Sea-Bird SBE 52

The Sea-Bird CT used in this test and evaluation is part of a WET Labs WQM, a sensor suite that measures multiple water quality parameters. This sensor is externally powered and communicates via the RS232 interface.

2.0 Laboratory Test Results

OSTEP designed a series of laboratory and field tests to evaluate the performance of the Greenspan CT sensors under a variety of conditions. The first set of laboratory tests involved comparing the measurement accuracy of both a Greenspan and FSI CT sensor to conductivity standard solutions, which are chemical solutions containing a precisely known concentration of a particular substance. In this case, potassium chloride was used to create a solution with a known conductivity at a specific temperature and then used as a basis of comparison.

The second set of laboratory tests was performed in a seawater test bath at the CO-OPS Chesapeake, Virginia facility. The seawater test bath is used routinely by the CIL to check the accuracy of an instrument before and after field deployments.

The FSI has the option of outputting only raw conductivity values, whereas the Greenspan provides a choice of using either raw conductivity or normalized conductivity (i.e., conductivity normalized to 25 °C, or specific conductance). In this OSTEP test series, all reported sensor conductivity values are raw values; the standard solution values, however, were calculated to account for variation in temperature on each CT sensor's thermistor during the standard solution tests (since the tests were not conducted at 25 °C). This calculation was performed on the standard solution values so that raw values from the sensors were being compared directly to calculated raw values of the standard solutions.

2.1 Standard Solution Tests

Methods

Each instrument was allowed to equilibrate in a beaker of standard solution while conductivity and temperature data were being collected and recorded. The following concentrations of conductivity standard solutions were used: 1.413 mS/cm, 12.890 mS/cm, 15.000 mS/cm, and 58.670 mS/cm. The three higher-concentration standards cover the span of salinities expected in the field, and testing with the lower concentration provides evidence of the sensor's capability to detect very small traces of salinity. Table 1 shows the salinity values associated with these conductivity values at 25 °C.

Table 1. Conductivity standard solutions used in laboratory tests with corresponding salinity values at 25 °C.

Conductivity (mS/cm)	Corresponding Salinity (PSU) at 25 °C
1.413	0.7
12.890	7.4
15.000	8.7
58.670	39.2

Conductivity standard solutions were poured into 1000-mL glass containers (height: 14.48 cm [5.7 in]; diameter: 10.41 cm [4.1 in]). Each sensor was placed in a beaker of new solution and allowed to equilibrate for at least 1 hour (h) (the instrument was collecting and recording data during this time). Raw conductivity values are nearly instantaneous, whereas temperature values need to equilibrate for 1 h [4]. In order to compare raw conductivity sensor values to the conductivity standard solution values, the standard solution value needs to be converted to a raw value (the published standard values are normalized to 25 °C). This conversion requires an accurate temperature measurement. Alternatively, the raw conductivity sensor values can be normalized to 25 °C, a process that also requires an accurate temperature measurement.

The laboratory calibration tests were carried out in two separate rounds. Given the limited container size, only one instrument could be tested at a time. In round one, the Greenspan was first placed into the fresh calibration standard solution (fig. 1). Following the period of equilibration (approximately 15 min) and data collection (approximately 30 min), the Greenspan was removed and the FSI was immediately placed in the solution. To confirm that there was no bias toward the first instrument placed in solution (from evaporation, for example), the Greenspan was placed back in solution during several different tests to ensure that its results had not drifted after the first test.

Figure 1. Greenspan CT sensor in conductivity calibration standard solution.

Results presented in the following section are from tests conducted during round two, after the testing process had been further refined. (See appendix A for laboratory notes for both rounds of testing.) In round two, the FSI was the first sensor in solution; a different Greenspan EC3000 (with internal battery pack) was used for testing. As in round one, tests were performed to ensure that there was no bias against the second sensor in the solution. In round two, each instrument collected data for approximately 1.5 h. Since it is important for both the conductivity and temperature to be measured accurately to ensure a correct salinity calculation, an external thermometer (Hart Scientific 1502A with PRT 5614 probe) was also placed in the beaker during this round to test the operation of each instrument's internal thermistor. The external thermometer was also used to calculate the raw conductivity values of the calibration standard solution.

Results

The Greenspan sensor performed better than the FSI in the conductivity standard tests, staying within its manufacturer-specified accuracies of ±0.7 mS/cm (conductivity) and ±0.2 °C (temperature). Table 2 shows the mean difference between each sensor and the conductivity/temperature references for each of the four tests (shown graphically in 10-min averages for conductivity in fig. 2 through fig. 5 and averaged over each test in fig. 6). Figure 7 shows scatter plots of the sensor conductivity averaged over each test compared to the raw conductivity of the standard solutions.

Table 2. Mean differences between sensors and conductivity standard solution (sensor value minus solution value) and between sensors and external thermometer (sensor value minus thermometer value).

Sensor	Tests	Standard Solution Test 1.413 mS/cm		Standard Solution Test 12.890 mS/cm		Standard Solution Test 15.000 mS/cm		Standard Solution Test 58.670 mS/cm	
		Cond	Temp	Cond	Temp	Cond	Temp	Cond	Temp
FSI		0.06	-0.09	-0.61	-0.12	-0.31	-0.10	-0.85	-0.10
Greenspan		0.00	-0.11	-0.21	-0.11	-0.19	-0.12	-0.37	-0.13

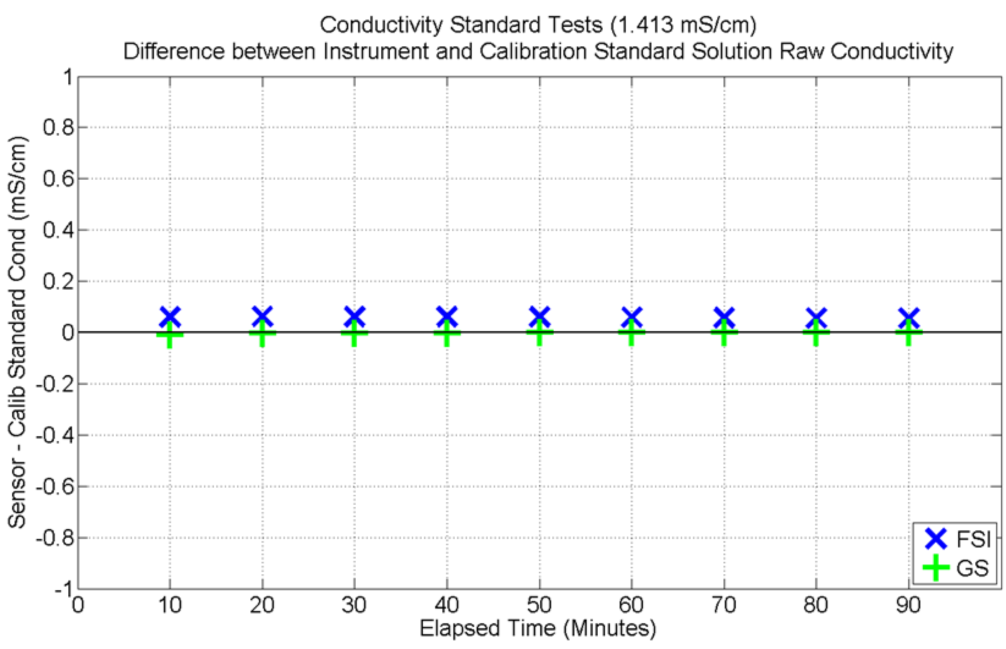


Figure 2. In figs 2-5, a time series of raw conductivity values (0.9 Hz for FSI and 1 Hz for Greenspan) was averaged every 10 min for each calibration standard solution test. The raw (non-normalized) values of the calibration standard were calculated using the data from the external thermometer and also averaged every 10 min. The average calibration standard solution values were subtracted from the average sensor values; the differences between the sensor average values and the black line at zero represent the difference between each sensor and the value of the calibration standard solution.

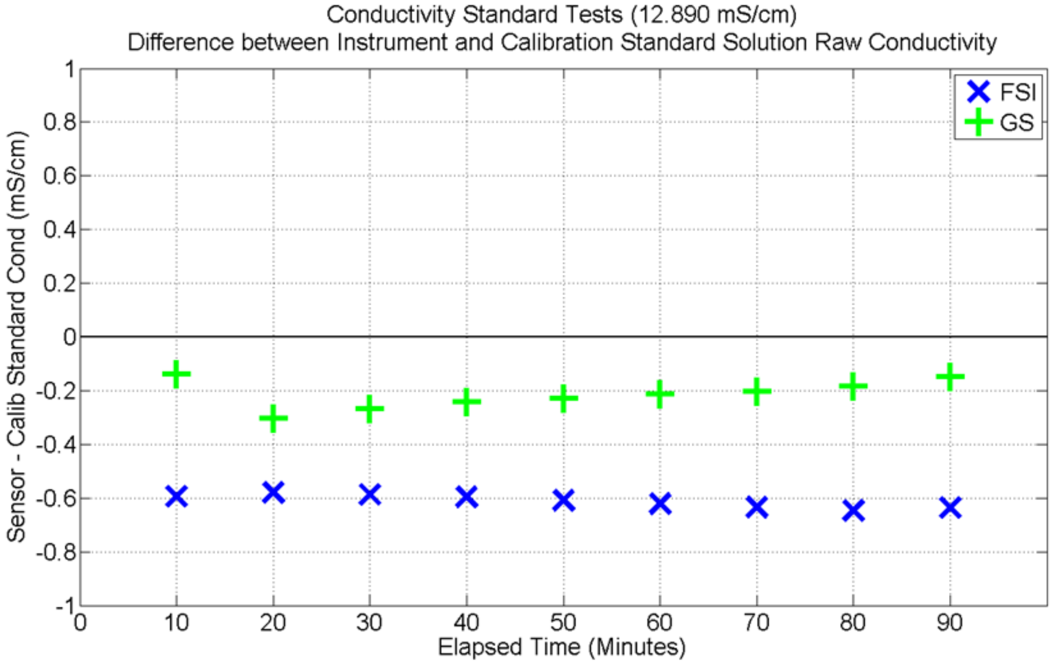


Figure 3. Mean difference between instrument and calibration standard solution at 12.890 mS/cm.

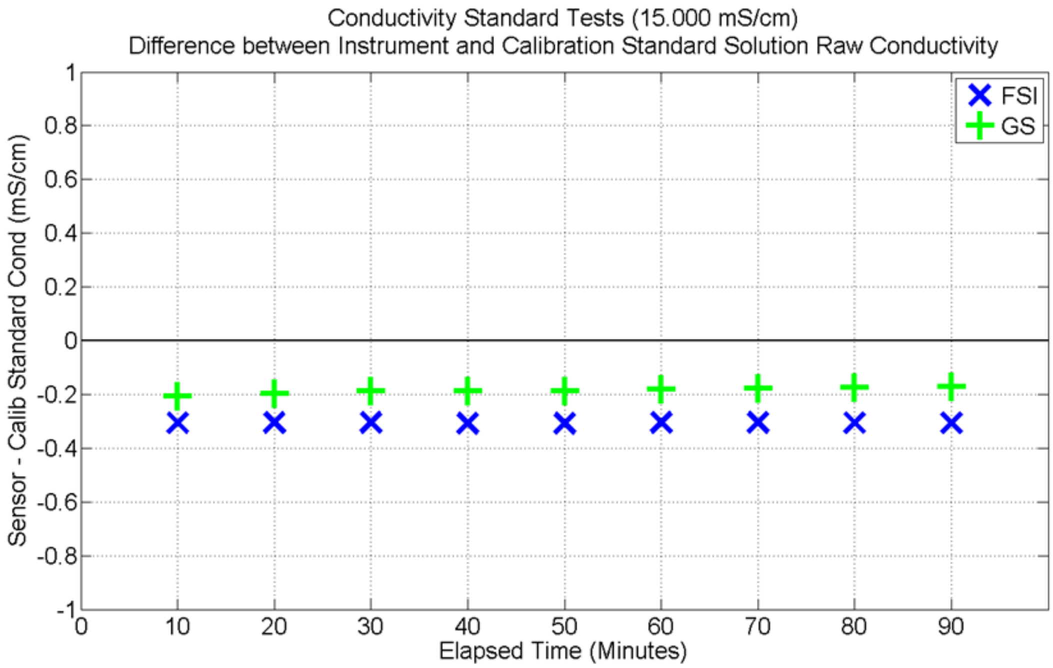


Figure 4. Mean difference between instrument and calibration standard solution at 15.000 mS/cm.

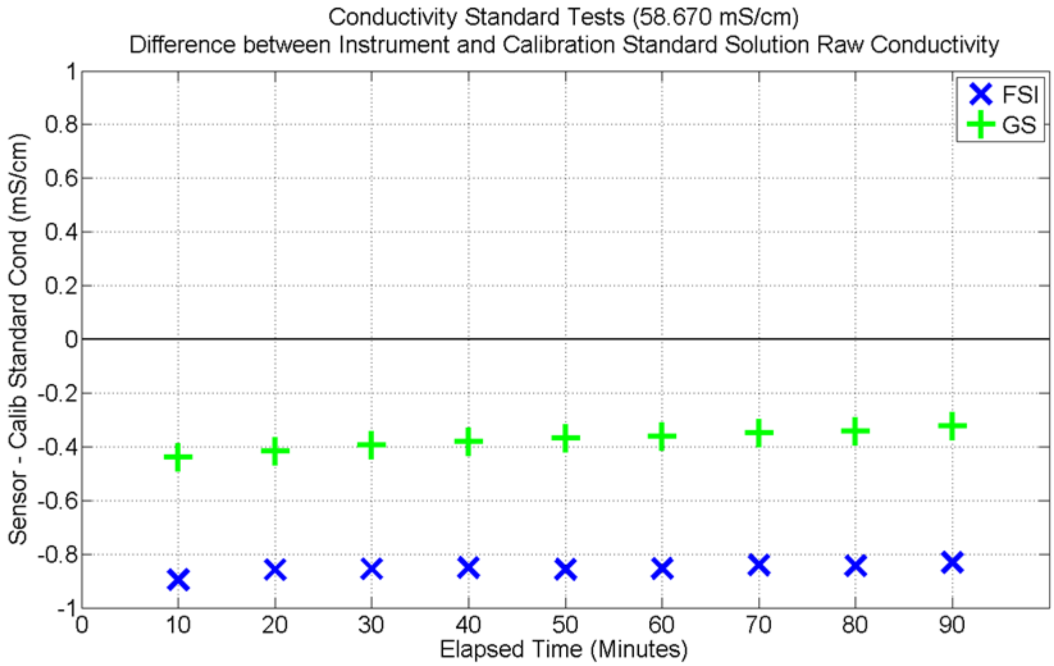


Figure 5. Mean difference between instrument and calibration standard solution at 58.670 mS/cm.

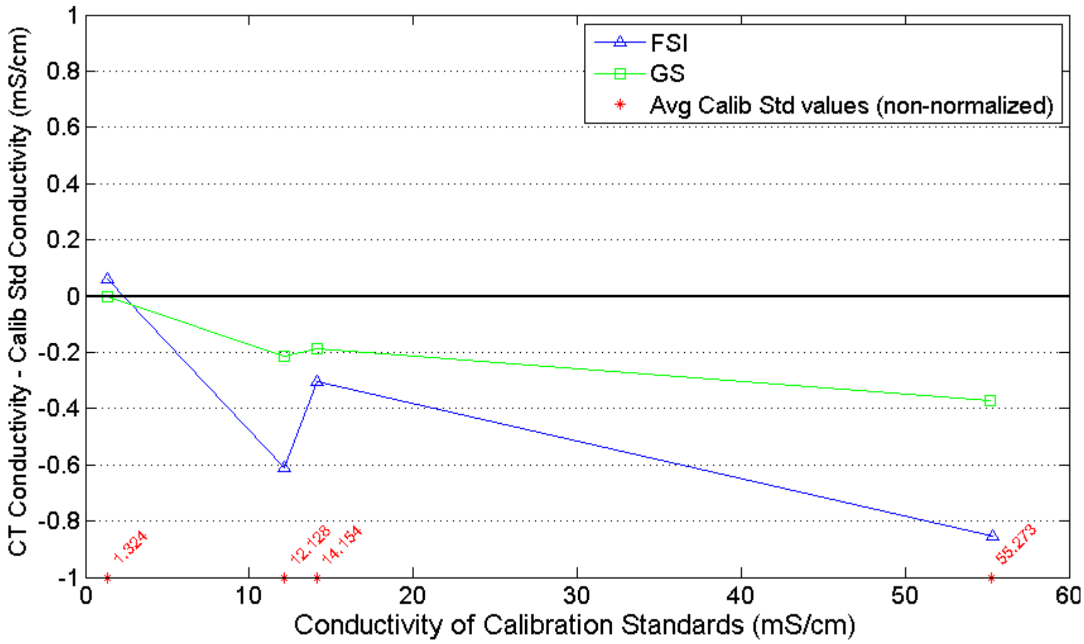


Figure 6. A summary plot of the conductivity differences between each sensor and the raw (normalized) conductivity calibration standard solution for each test. The raw conductivity values were calculated using the external thermometer data from each test and are shown in red along the *x*-axis.

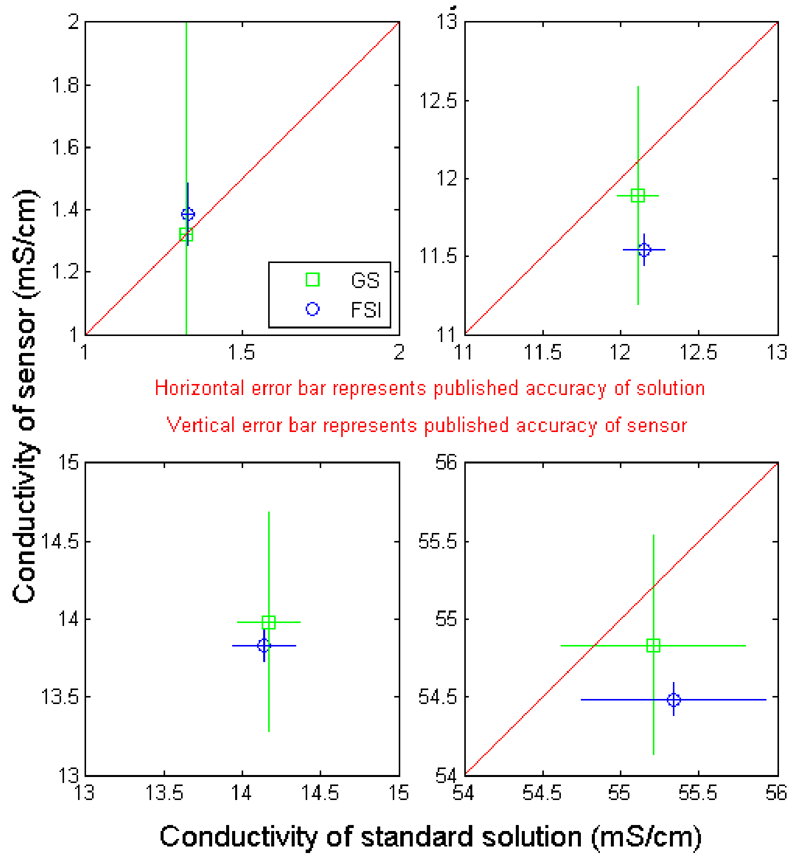


Figure 7. Scatter plots of the sensor conductivity averaged over each test compared to the raw conductivity of the standard solutions.

During the four tests, the Greenspan measurements were within ±0.4 mS/cm of the conductivity reference and ±0.13 °C of the temperature reference. The FSI measurements were within ±0.9 mS/cm of the conductivity reference and ±0.10 °C of the temperature reference, which are outside of the manufacturer-specified accuracies of ±0.1 mS/cm (conductivity) and ±0.05 °C (temperature). During the analysis of results and further review of laboratory notes, however, OSTEP personnel realized that the test container was likely interfering with the sensor's electromagnetic field (referred to as the edge proximity effect). The Greenspan manufacturer solved this problem by enclosing its electromagnetic field within the previously mentioned shroud.

2.2. Seawater Bath Tests

Methods

The seawater bath tests followed the CO-OPS standard calibration check protocol for CT sensors. The test bath (fig. 8a) contained approximately 45 gallons of synthetic seawater prepared by Lake Products Company, Inc. using a simulated sea salt mix [6]. A layer of plastic spheres (approximately 1.9-cm [¾-in] in diameter) resided at the top of the tank to minimize evaporation (fig. 8b). During the calibration test, the water was mixed continuously by a drill outfitted with a stirring bit at the depth of the sensor head. The Greenspan sensor was mounted on a platform at the top of the tank, 15.24 cm (6 in) away from the reference sensor (an FSI OEM Digital CT). Both sensors were allowed to equilibrate for 1 h; data from both sensors were collected, recorded, and compared. Data from an external thermometer (Hart Scientific 1502A) were also recorded to assess the performance of the sensors' internal thermistors.

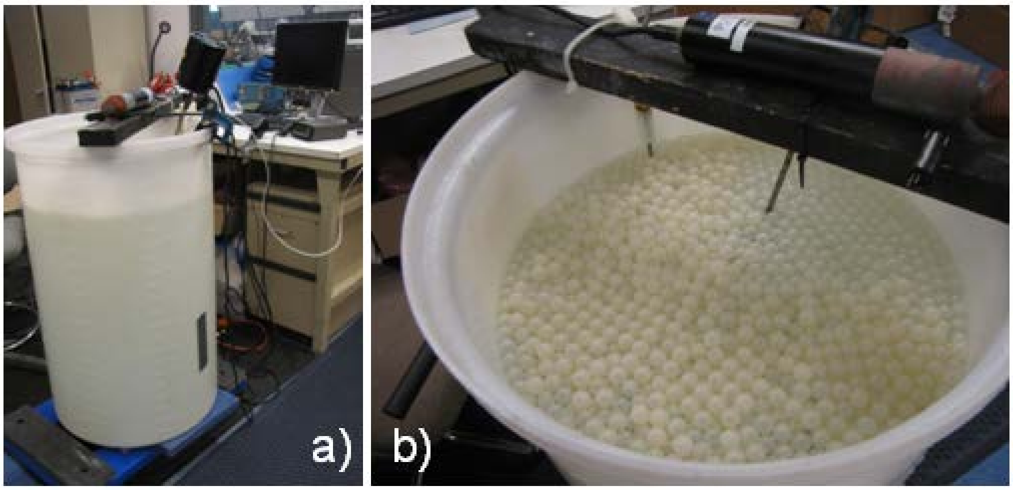


Figure 8. a) Seawater test bath at CO-OPS' Chesapeake Instrument Lab. b) Plastic spheres used to prevent evaporation.

As with the calibration tests, two rounds of seawater bath tests were conducted. In the first round, a series of experiments was performed to determine the effects (if any) of sensor position, mixing, and level of sensor submergence; the findings were used to refine the testing procedures. The results of the round-two test are presented in the next section.

Results

During the seawater test bath, the FSI and Greenspan raw conductivity values were within ±0.3 mS/cm of each other, as shown in fig. 9. This result is within the cumulative manufacturer specifications for both sensors. Temperature measurements for both sensors were within ±0.02 °C, also within cumulative manufacturer specifications. The gap between the sensors and the external thermometer measurements was wider (within ±0.2 °C), but the Greenspan value was consistently closer to the external thermometer value than the FSI value. This value falls within the cumulative manufacturer specifications of the Greenspan and thermometer (±0.2 °C and ±0.007 °C, respectively), but not within FSI specifications (±0.05 °C). During the tests, however, OSTEP personnel discovered that there were uncertainties about the calibration dates of both the external thermometer and the reference FSI CT sensor.

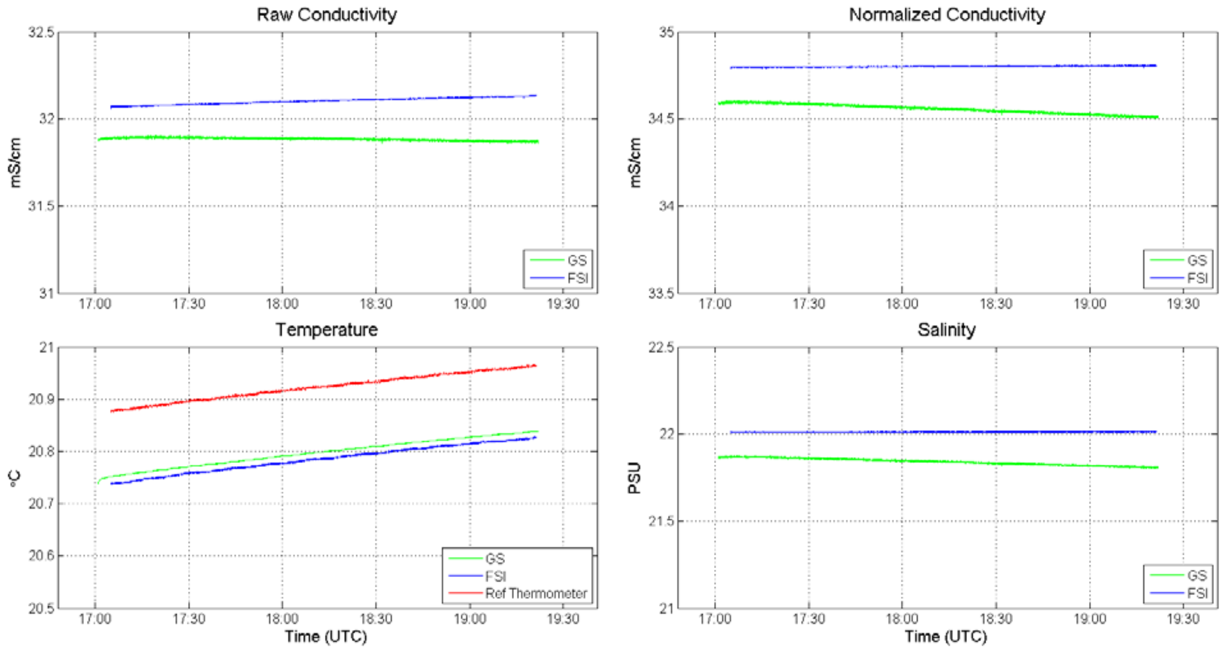


Figure 9. Time series plots of the seawater test bath comparison.

After a status update presentation by OSTEP, the following specific tests were recommended and performed:

- At a fixed salinity, increase and decrease the temperature and evaluate the associated responses from the Greenspan sensor
- Switch sensor positions to identify potential eddies caused by mixing

Both sensors' thermistors and the external thermometer responded appropriately when ice was added to the tank (fig. 10). Switching sensor positions with the drill running showed differences in conductivity, which may indicate non-homogenous mixing; however, results were inconclusive. These tests lead to the recommendation of several improvements to the testing facility, including the annual calibration of the external thermometer and the acquisition of both a higher-accuracy reference CT sensor and new pump/filtration and mixing mechanisms.

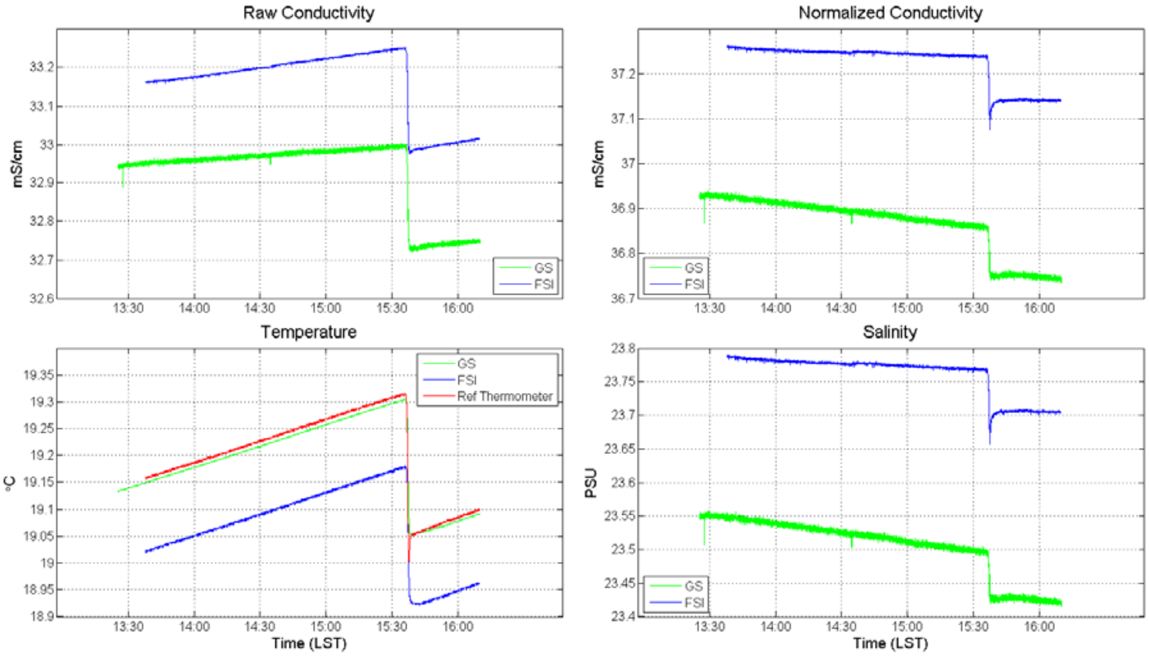


Figure 10. Time series plots of the seawater test bath comparison with the addition of ice.

3.0 Field Test Results

For the field test portion of the CT sensor testing, Greenspan sensors were deployed at two different locations. The first sensor was installed at the Money Point, Virginia, NWLON station (station ID: 8639348), alongside an operational FSI CT sensor. Money Point is located on the Southern Branch of the Elizabeth River.

The second Greenspan sensor was placed on NOAA's Norfolk Chesapeake Bay Interpretive Buoy System (CBIBS) observatory [7] and compared with the Sea-Bird SBE 52 at that location. The Norfolk CBIBS buoy is also located on the Elizabeth River in the heart of downtown Norfolk. Both sites were ideal for a number of reasons, including accessibility and proximity to the CO-OPS Chesapeake facility.

3.1. Money Point NWLON Station

Methods

The Money Point location was chosen for its range of salinity conditions, as well as for its proximity to the CO-OPS Chesapeake facility. The latter criterion proved useful given the troubleshooting trips that were made to the site. A site reconnaissance trip to the Money Point NWLON station was conducted on 24 June 2011. The purpose of the trip was to take measurements and photographs to help determine the best location to mount a test CT well. Figure 11 shows the existing operational instrumentation, as well as locations that were considered for the test CT well. Water depth and water surface measurements were collected from the pier and later referenced to MLLW to ensure that both the test and operational CT sensors would be functioning at the same depth in the water column (fig. 12, table 4).

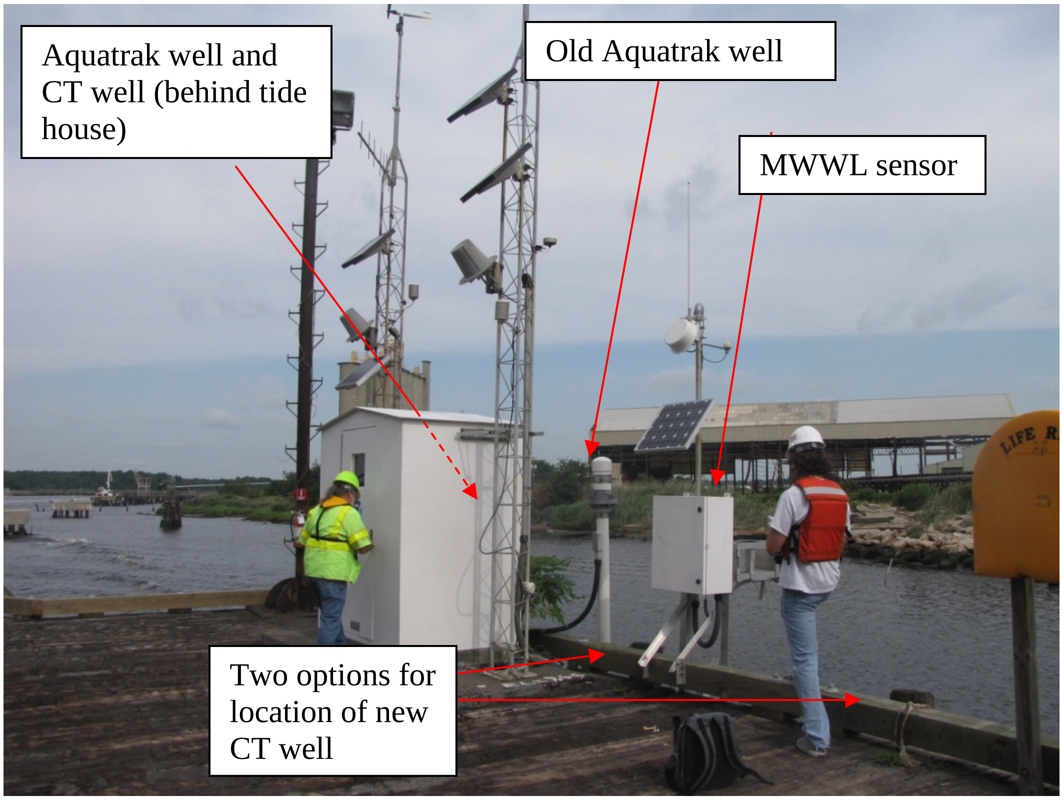


Figure 11. NWLON station at Money Point, Virginia. Locations for a potential new CT well are indicated.

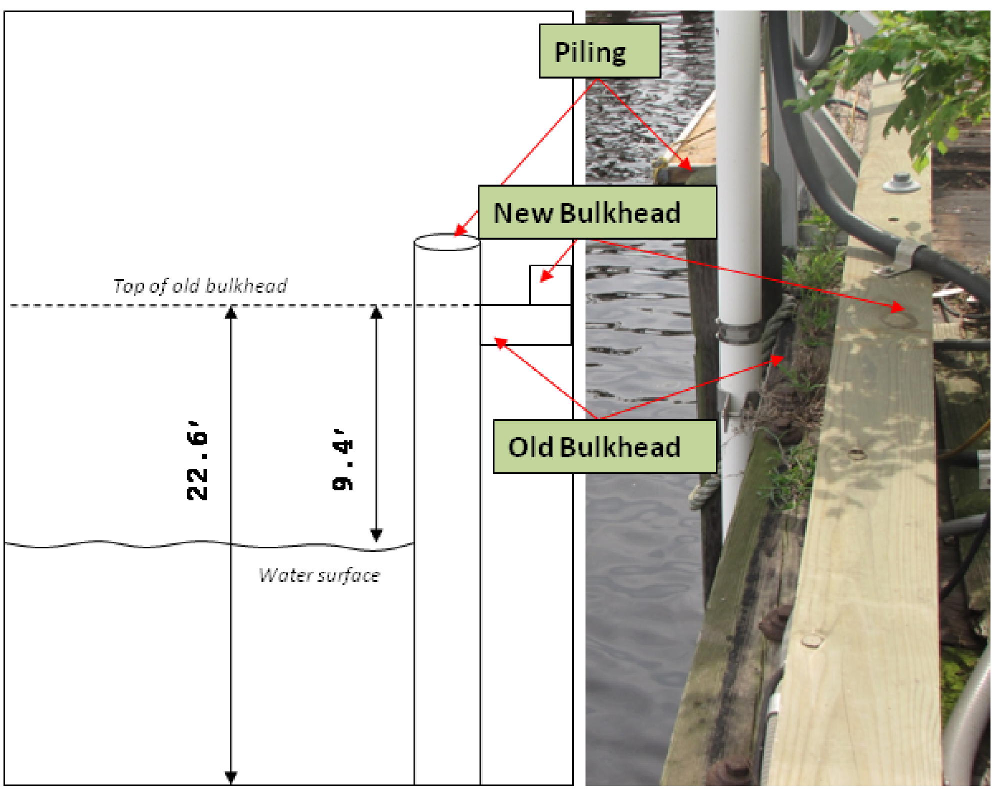


Figure 12. Diagram shows the measured water level and distance to seafloor.

Table 3. Accompanying information and calculations for fig. 12.

Distance from top of old (lower) bulkhead to seafloor Distance from top of old (lower) bulkhead to water surface Diameter of piling	**6.9 m (22.6 ft)** **2.87 m (9.4 ft)** **30.48 cm (12 in)**
Water level (WL) at time of measurement (06/24/2011 13:52 UTC)	**27.74 cm (0.91 ft)** above MLLW **6.86 m (22.52 ft)** above Station Datum
Station Extremes (referenced to Station Datum)	Highest: **9.20 m** (**30.18 ft)** (11/13/2009) Lowest: **5.78 m** (**18.95 ft)** (01/02/1998)
Difference between WL and Station Minimum	6.86 m (22.52 ft) –5.78 m (18.95 ft) = **1.10 m** (**3.57 ft)**
Distance from top of old bulkhead to lowest expected WL	2.87 m (9.4 ft) + 1.09 m (3.57 ft) = **3.97 m** (**13.0 ft)**
Suggested length of CT well (adding 3 ft of depth below lowest expected WL and 4 ft of height above top of old bulkhead)	4.0 m (12.97 ft) + 0.91 m (3 ft) + 1.22 m (4 ft) ≈ **6.1 m** (**20 ft)**
Clearance above seafloor	4.02 m (13.2 ft) – (1.09 m [3.57 ft] + 0.91 m [3 ft]) = **2.01 m (6.6 ft)**

A well for the test CT sensor was assembled in the same manner as CO-OPS' operational PORTS® CT wells. The base of the well extends below the water surface just above the required sensor depth, and the top of the well extends above the fixed structure, where it can be easily accessed for servicing. The sensor body is fitted with a Delrin® clamp (fig. 13), through which a piece of line is run. The line is part of a pulley system that allows the clamp and sensor combination to be raised and lowered from the top of the PVC well. A brass collar at the base of the well inhibits the passage of the Delrin® clamp and allows the exposure of the sensor head and probes to the water column at the requisite measurement depth. The bottom portion of the CT well, like both the operational and test CT sensors, is coated with anti-fouling paint.

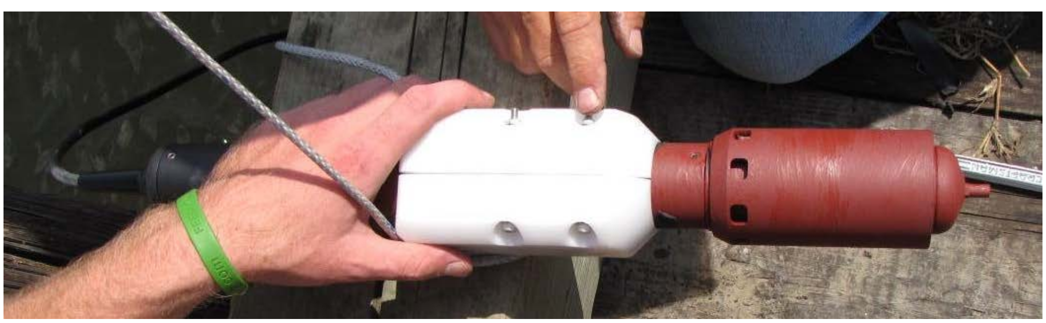


Figure 13. White Delrin® clamp attached to the Greenspan EC3000 CT sensor.

The well and test Greenspan EC3000 CT sensor were installed at Money Point on 16 August 2012 (fig. 14). OSTEP personnel originally intended to install the sensor from CO-OPS' 16-ft Boston Whaler but instead moved an existing floating dock from the pier to the installation site, which greatly improved the ease of operations.

Figure 14. (A) CO-OPS personnel install the bottom bracket of the Money Point test CT well from a floating dock. (B) Installation of the Greenspan sensor into the top of the CT well from the pier.

The sensor was interfaced with a Sutron Xpert DCP in the same way that the operational FSI sensors are configured (albeit with an SDI-12 connection rather than RS232). The sampling regime matched that of the operational FSI: 6-second (s) data averaged over 2 minutes (min), every 6 min. Data were checked and accessed remotely using an IP modem. While the resulting data compared well with data from the FSI, the SDI-12 interface posed problems that were first thought to be power issues. Representatives from Greenspan worked with OSTEP personnel to troubleshoot these issues, upgrading the SDI-12 converter firmware to resolve the problem.

Results

Data are presented in monthly segments over the four months from January through April 2012. Figures 15-16 show the monthly time series of conductivity and temperature from January 2012 (the remaining monthly time series are shown in appendix B). A step in conductivity data was seen each time the FSI was cleaned by the contractor (the Greenspan was not cleaned during the test). Cleaning dates affecting this dataset are: 1 February, 8 March, and 17 April 2012. (The sensor was inspected 5 January 2012 but did not need to be cleaned.) Interestingly, the data steps did not result in an increasing divergence in conductivity data (as might be expected if one sensor is subjected to bio-fouling) but rather a pattern of divergence (beginning 1 February and 18 April) and convergence (beginning 8 March) of the two sensors' data over the four months.

Mean differences between the Greenspan and FSI data were calculated for each month. Over the four months, January 2012 data show the best conductivity agreement between the sensors, with a monthly mean difference of -0.01 mS/cm. The maximum monthly mean difference in conductivity was seen in February (-0.48 mS/cm) and corresponds with the longest period of data divergence as previously described. Mean differences in temperature data remained fairly consistent over the four-month period, with the Greenspan reading 0.2 °C above the FSI for the first three months (January–March 2012) and 0.1 °C above the FSI during April 2012. These data are presented as histograms of differences between the two sensors (figs. 17-18) and scatter plots of the FSI and the Greenspan (figs. 19-20). The agreement between the two sensors is better for temperature than for conductivity. This is reflected in the larger spread of conductivity data both in the histograms and in the scatter plots. The skewness in both types of plots (negative for conductivity, slight positive for temperature) illustrates the fact that the Greenspan routinely reads lower in conductivity and higher in temperature than the FSI.

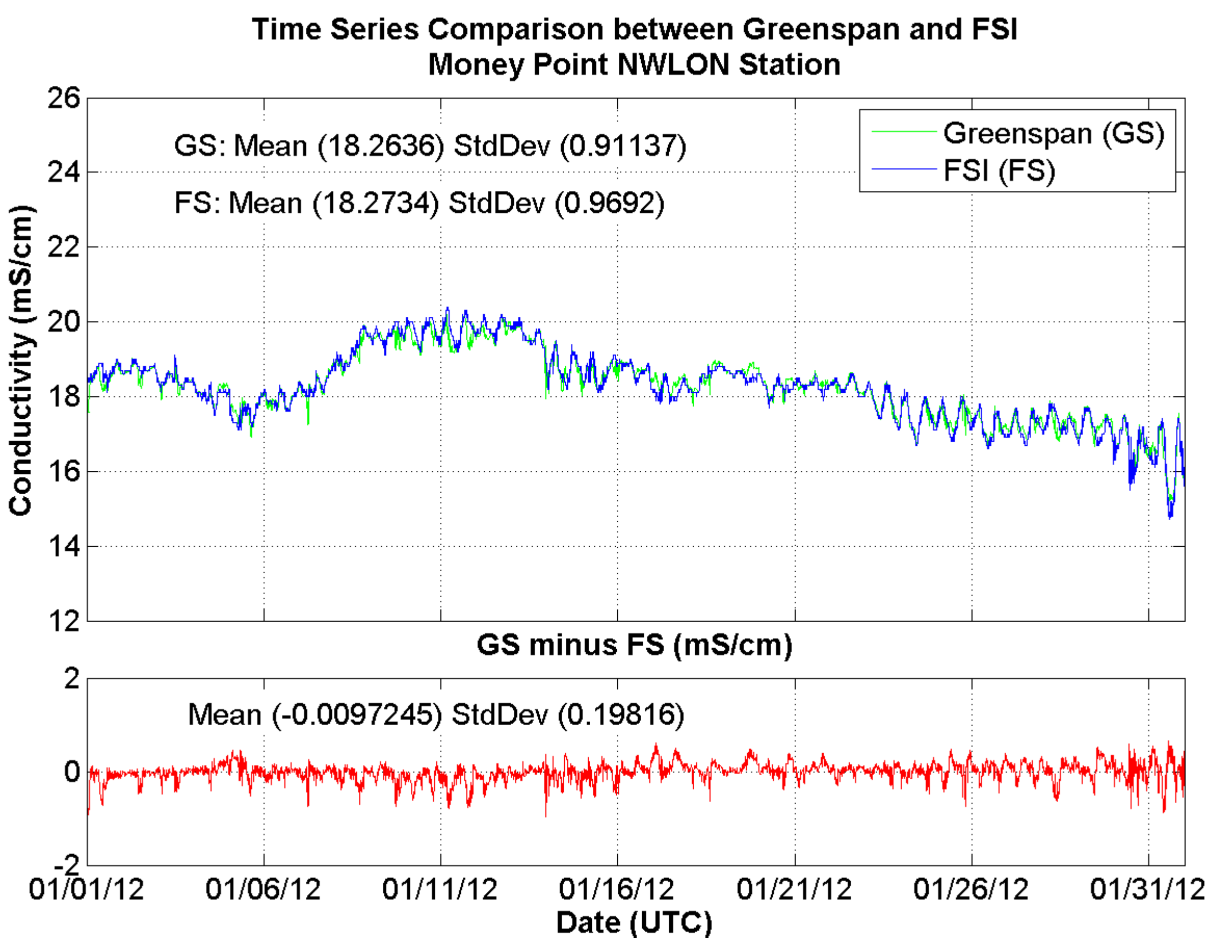


Figure 15. Sample time series of conductivity data collected during January 2012 at Money Point, Virginia NWLON station.

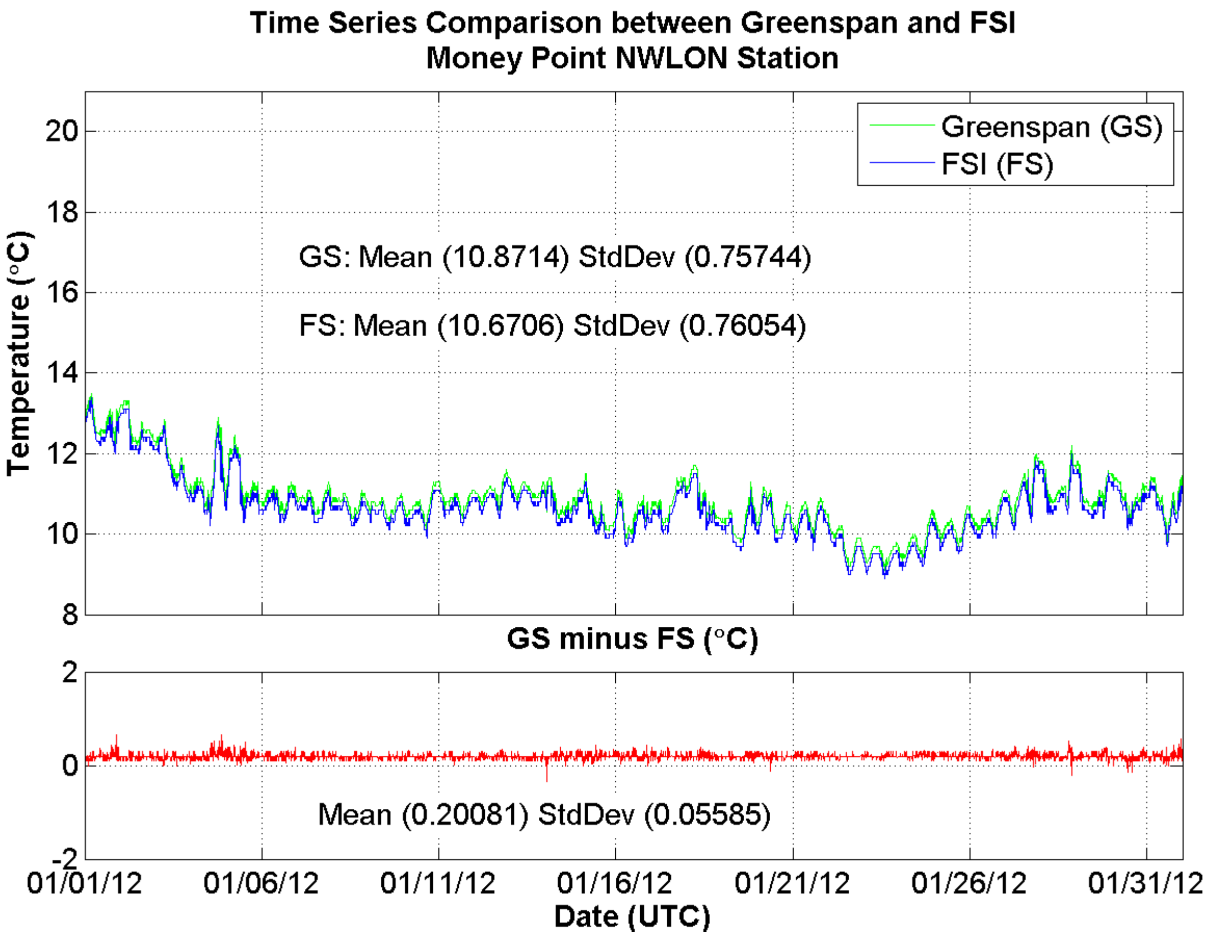


Figure 16. Sample time series of temperature data collected during January 2012 at Money Point, Virginia NWLON station.

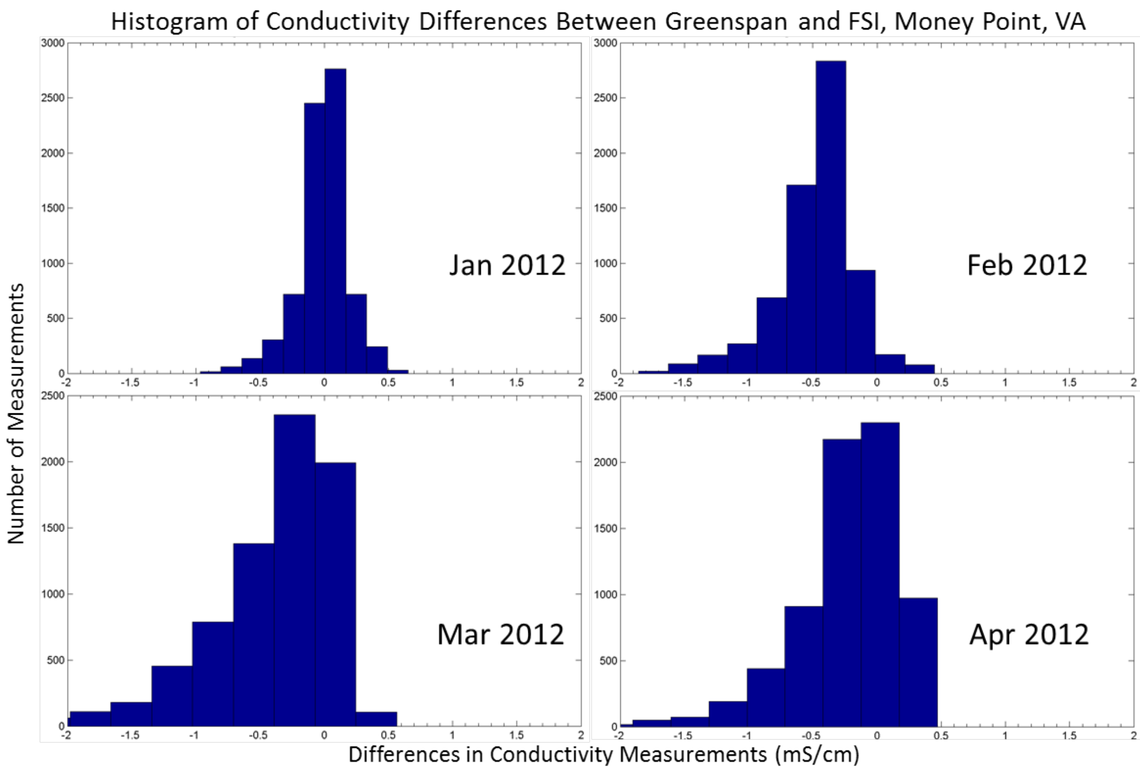


Figure 17. Conductivity histograms showing differences between Greenspan and FSI at Money Point, Virginia NWLON.

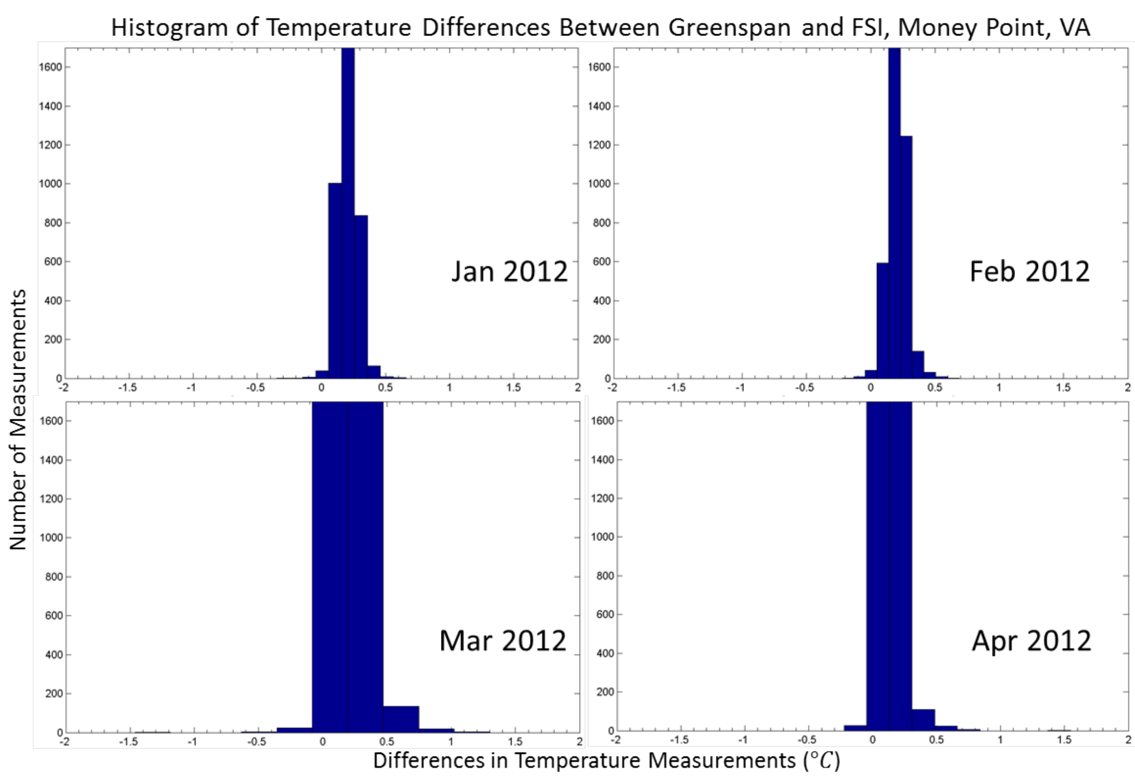


Figure 18. Temperature histograms showing differences between Greenspan and FSI at Money Point, Virginia NWLON.

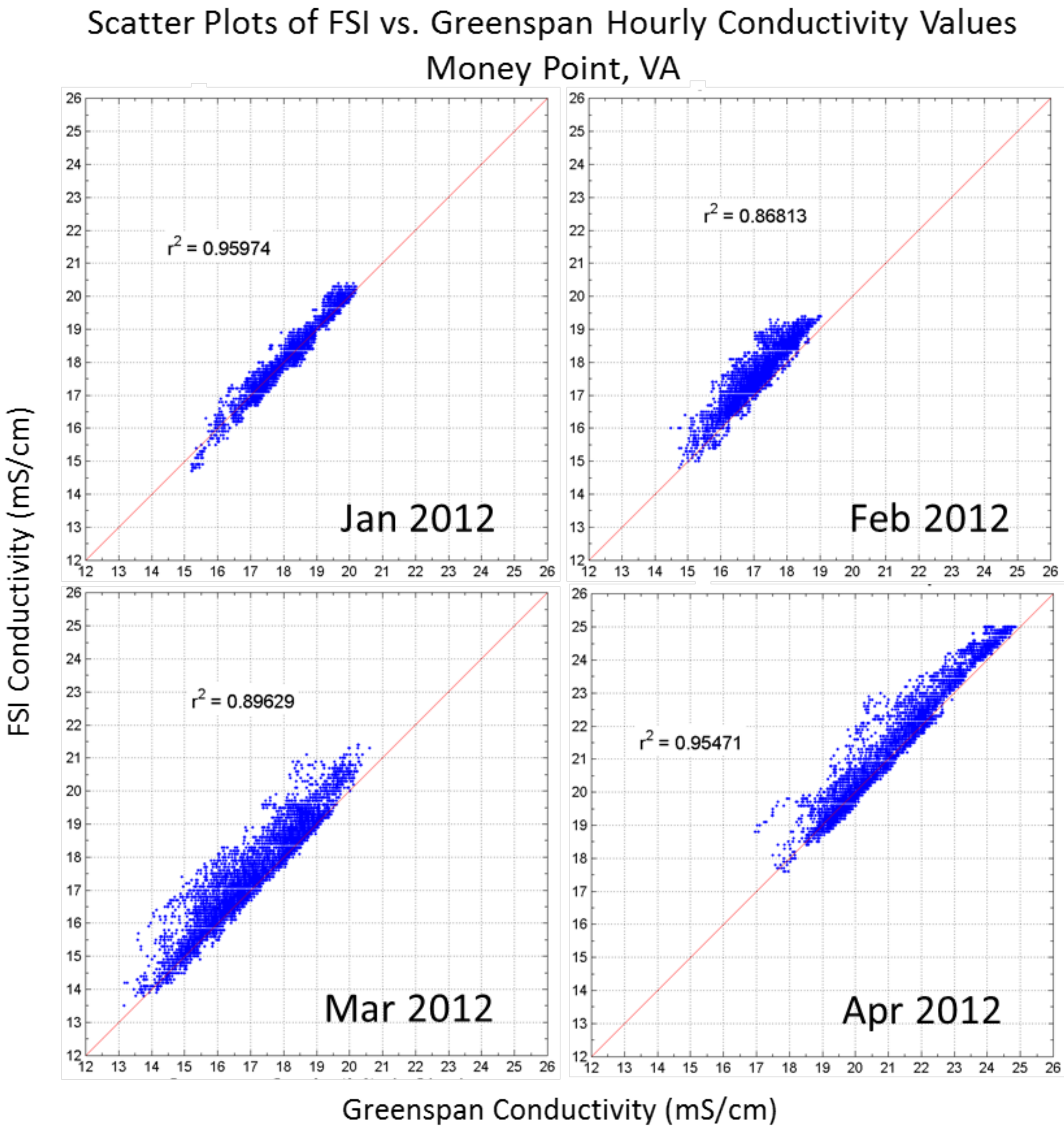


Figure 19. Conductivity scatter plots of FSI versus Greenspan at Money Point, Virginia NWLON.

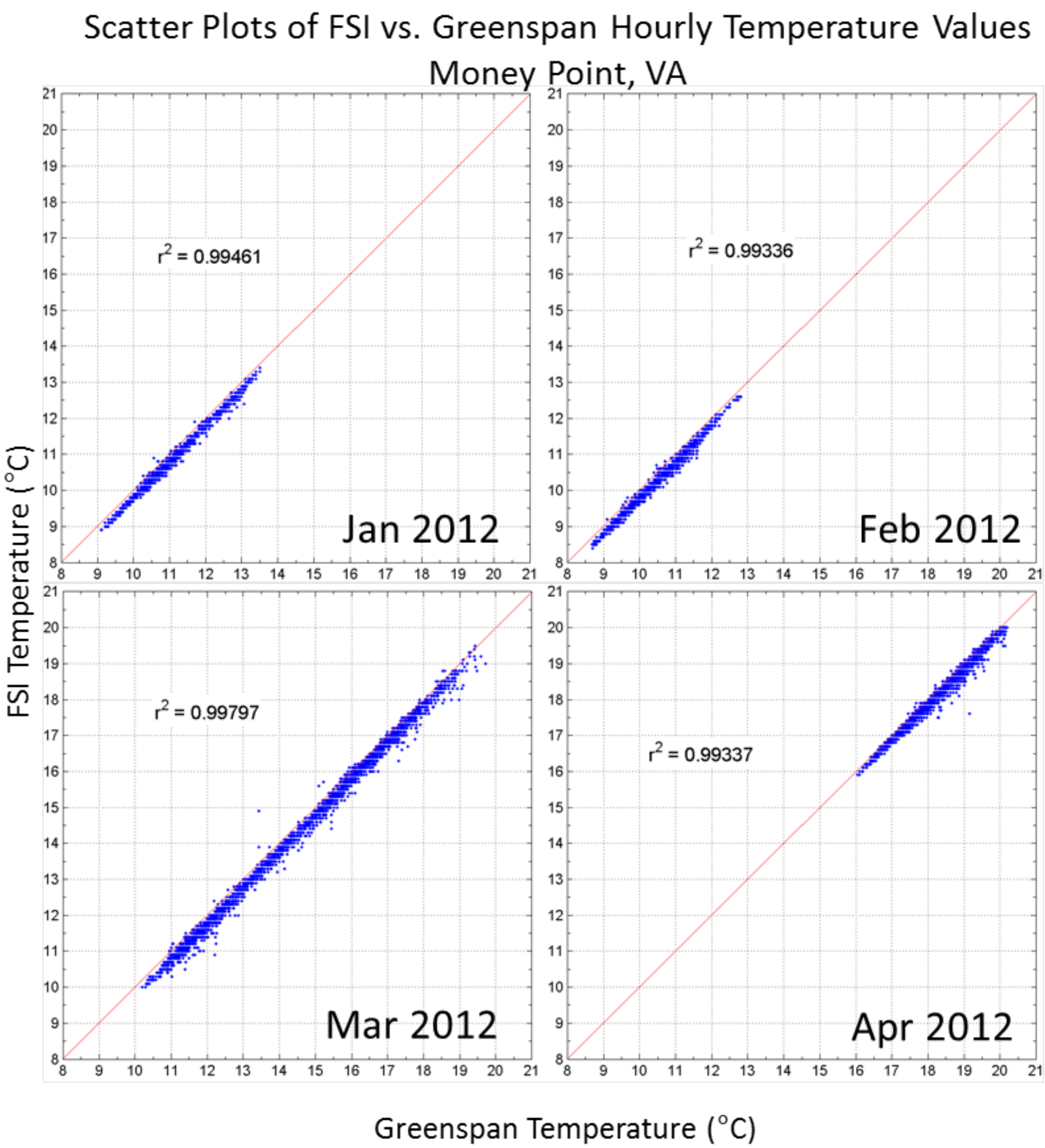


Figure 20. Temperature scatter plots of FSI vs. Greenspan at Money Point, Virginia NWLON.

3.2 CBIBS Buoy

Methods

NOAA's Chesapeake Bay Office in Annapolis, Maryland operates and oversees the CBIBS, a network of observational buoys located throughout the Chesapeake Bay that collect and disseminate oceanographic data. The Norfolk CBIBS buoy is located on the Elizabeth River at 36.8455°N, 76.298°W [7]. The site is ideal for a number of reasons, including its accessibility and proximity to the CO-OPS Chesapeake facility. An empty well on the buoy provided a perfect opportunity to compare the Greenspan to a Sea-Bird SBE 52, an instrument that is considered an industry standard.

The internally powered Greenspan CT sensor was mounted in a well that extended through the hull of the buoy (fig. 21) and was set up to record internally.

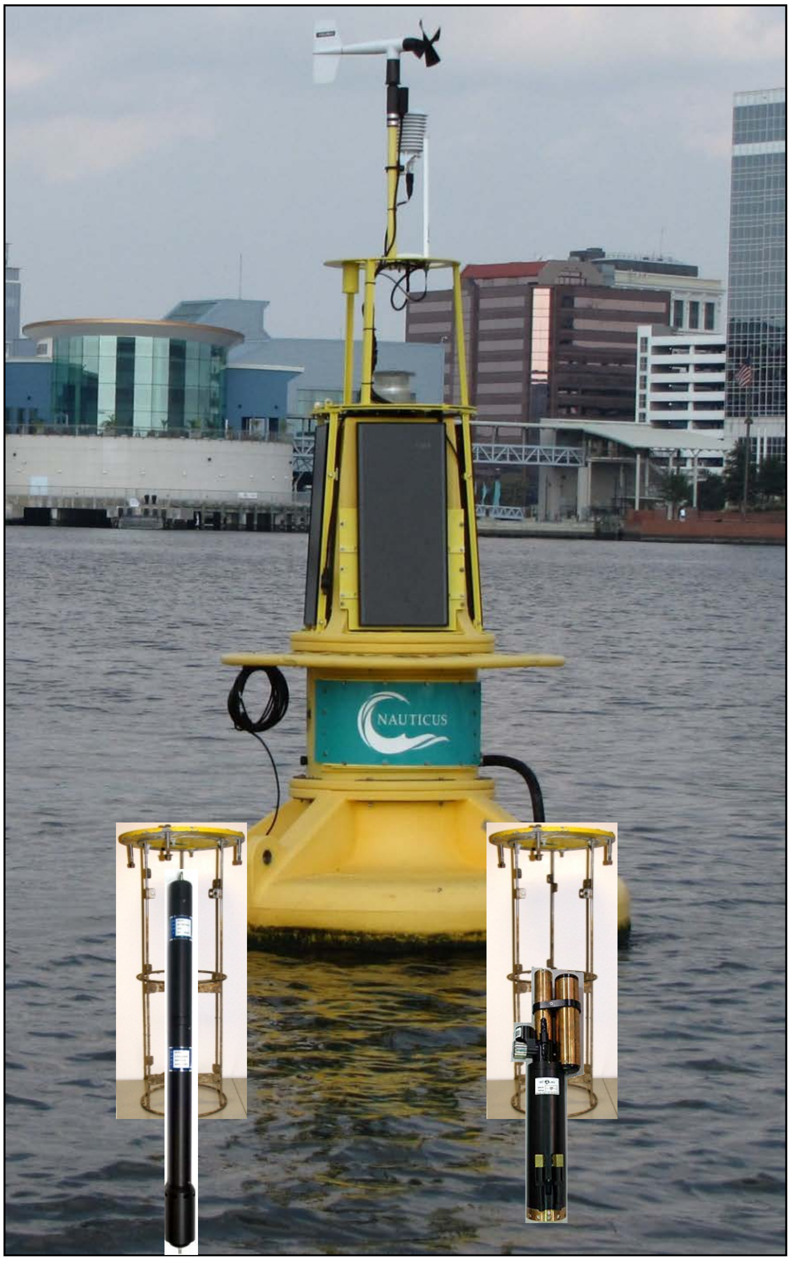


Figure 21. Norfolk CBIBS buoy. Insets show Greenspan (left) and Sea-Bird (right) positioned in mounting brackets. Due to mounting constraints, the Greenspan and Sea-Bird sensors measured conductivity approximately 22 in and 12 in, respectively, below the water surface.

The Greenspan was deployed on 14 September 2011, along with a newly-calibrated Sea-Bird. The intention was to match the sampling regime of the CBIBS Sea-Bird: 5 min of 1-s data are collected from 00:52 to 00:58 of each hour and averaged to provide one measurement per hour available via the CBIBS website. But, due to uncertainties associated with the power consumption of the Greenspan, 5 min of 5-s data were collected for the first month. A site visit was made on 14 October 2011 during which data were downloaded, and the sampling regime was changed to 5 min of 1-s data for the remainder of the test. The Greenspan was recovered on 9 November 2011. Note that neither instrument was cleaned during the seven weeks of testing. Figure 22 shows both sensors upon recovery. While the fouling on the Greenspan appears to have been better controlled than that on the Sea-Bird, the results show that the data quality of the Greenspan deteriorated after approximately five weeks of data collection.

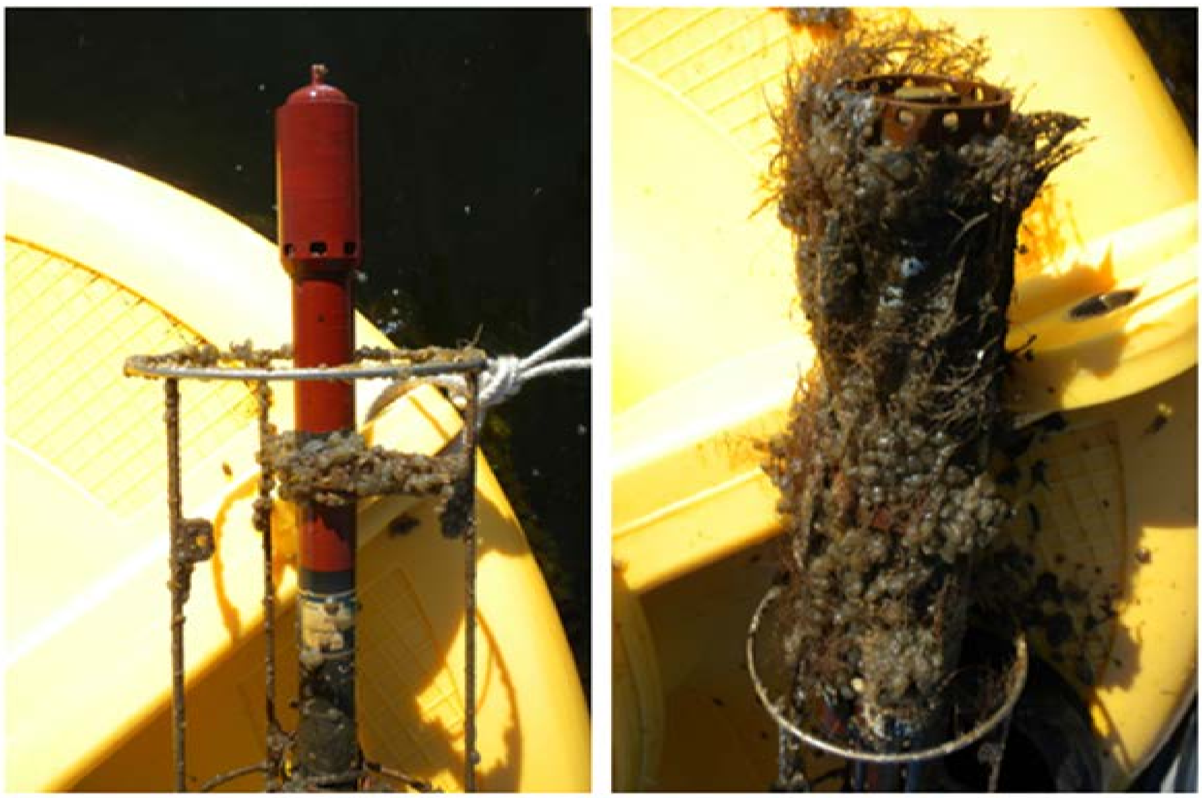


Figure 22. Greenspan (left) and Sea-Bird (right) sensors upon recovery.

Results

The following plots show results from the first month of testing (5-s data). Plots of the 1-s data (final three weeks of testing) can be found in appendix C. The 1-s data are not considered in this evaluation due to the degradation of Greenspan data from bio-fouling after five weeks (in an operational setting, the sensor would be cleaned monthly).

Time series show a monthly mean conductivity difference of -0.22 mS/cm between the Greenspan and Sea-Bird (fig. 23). The anomalous data in the Greenspan record from 4-6 October 2011 were not included in these statistics. (The reason for this drop in data is unknown, but it is speculated that a foreign object became lodged in the toroidal opening.) The temperature records of the two sensors were closely aligned (fig. 24), with a monthly mean difference of -0.03 °C. Histograms of sensor differences (figs. 25 and 26) and scatter plots of the Sea-Bird versus the Greenspan (figs. 27-28) are presented for the same period. The Greenspan consistently registered lower conductivity readings than the Sea-Bird, resulting in the negative skew seen in fig. 25.

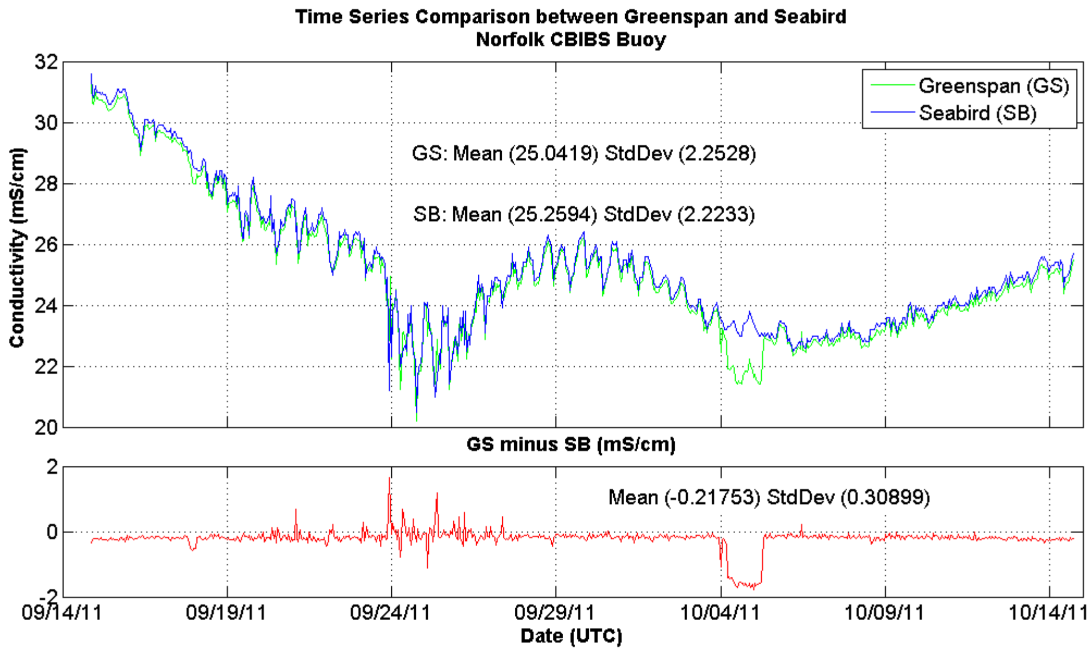


Figure 23. Conductivity time series of Greenspan and Sea-Bird on CBIBS buoy.

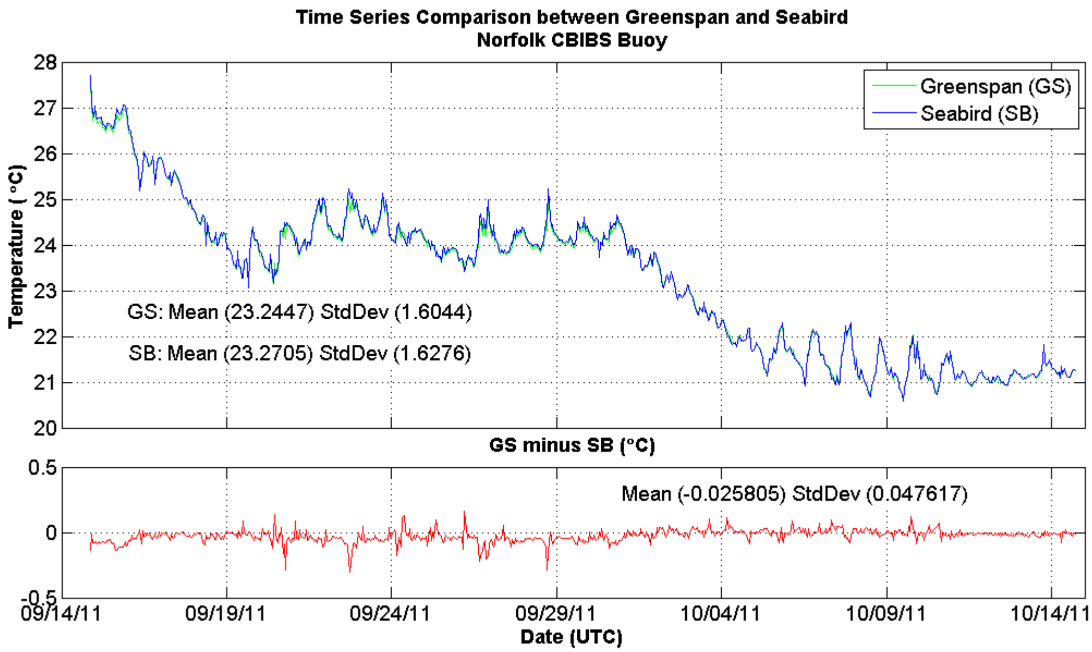


Figure 24. Temperature time series of Greenspan and Sea-Bird on CBIBS buoy.

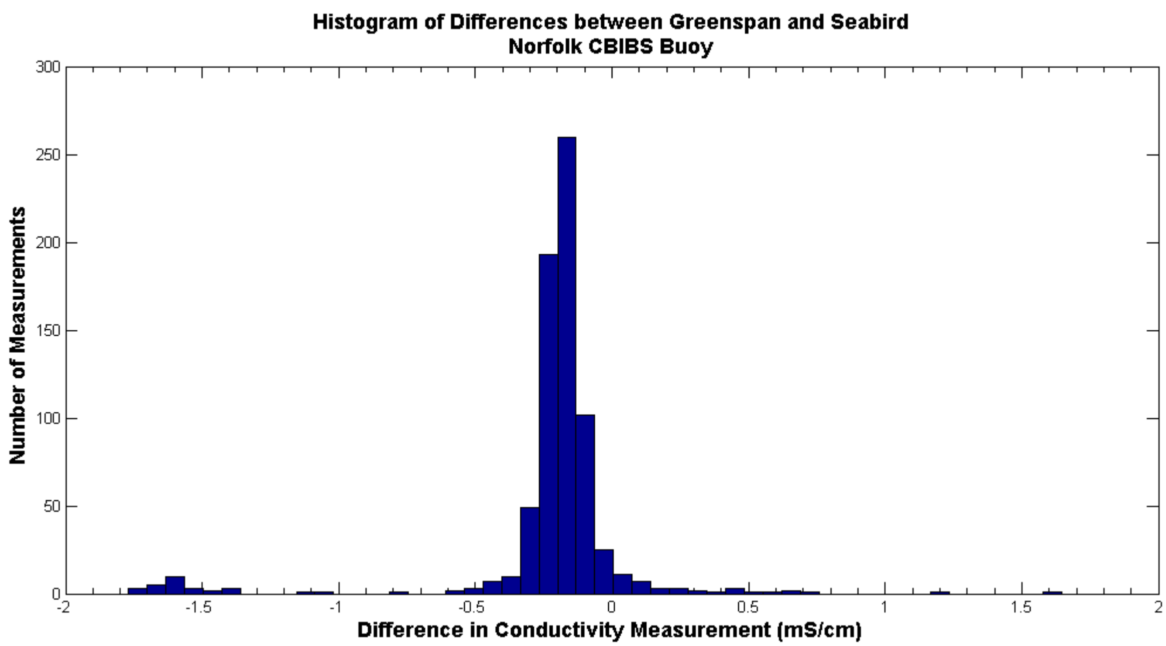


Figure 25. Conductivity histogram showing differences between Greenspan and Sea-Bird on CBIBS buoy.

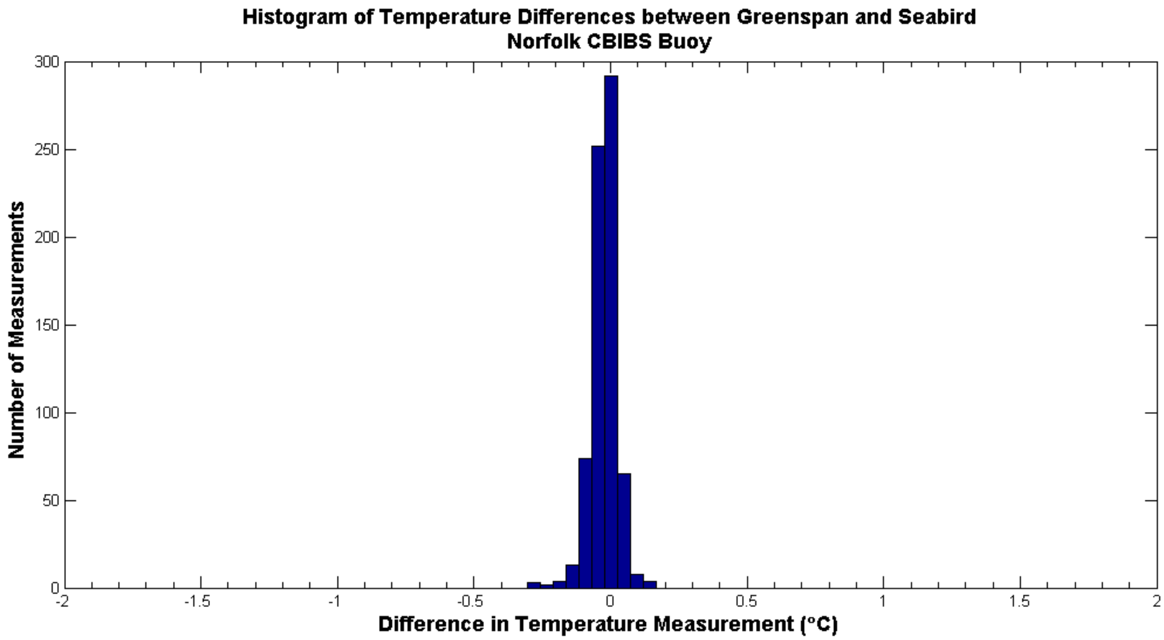


Figure 26. Temperature histogram showing differences between Greenspan and Sea-Bird on CBIBS buoy.

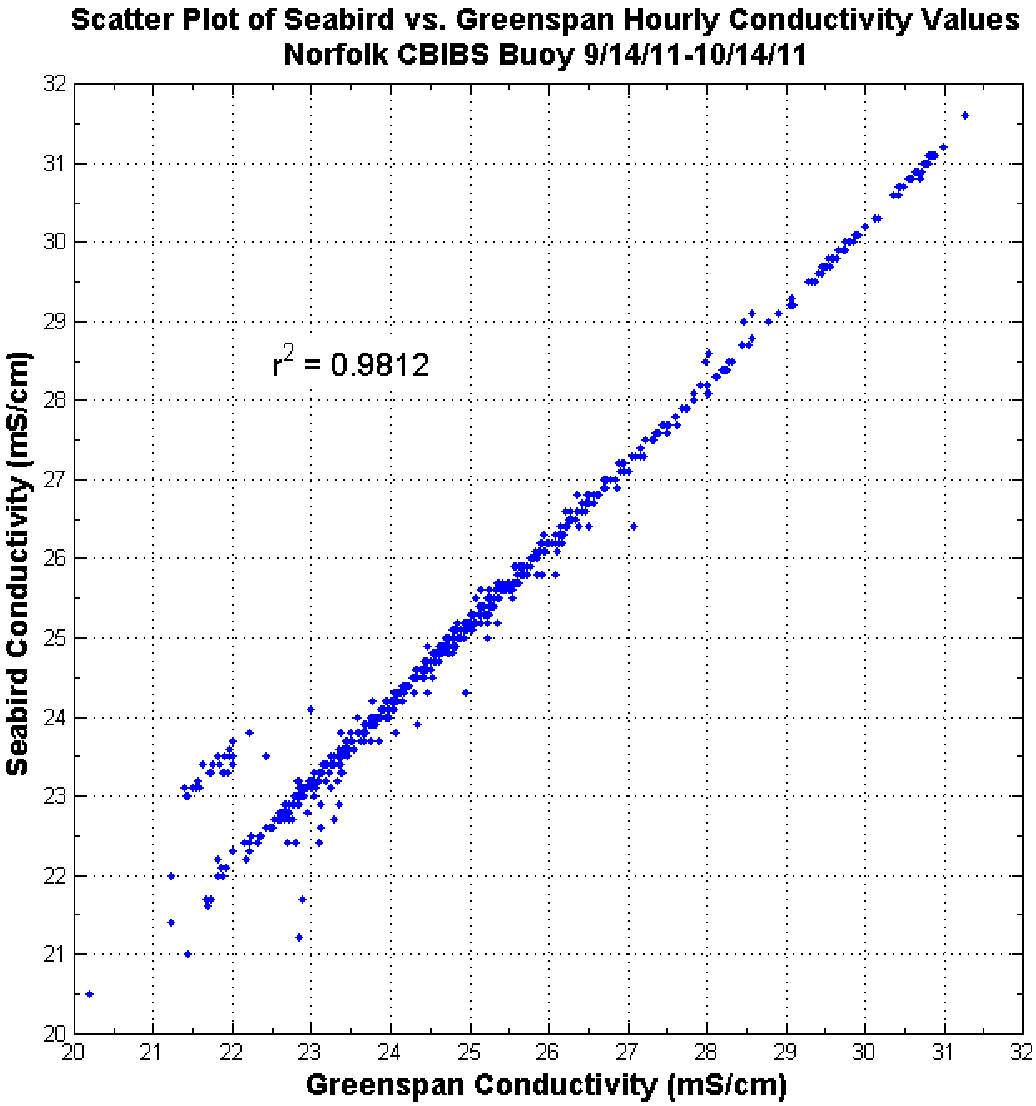


Figure 27. Conductivity scatter plot of Sea-Bird versus Greenspan on CBIBS buoy.

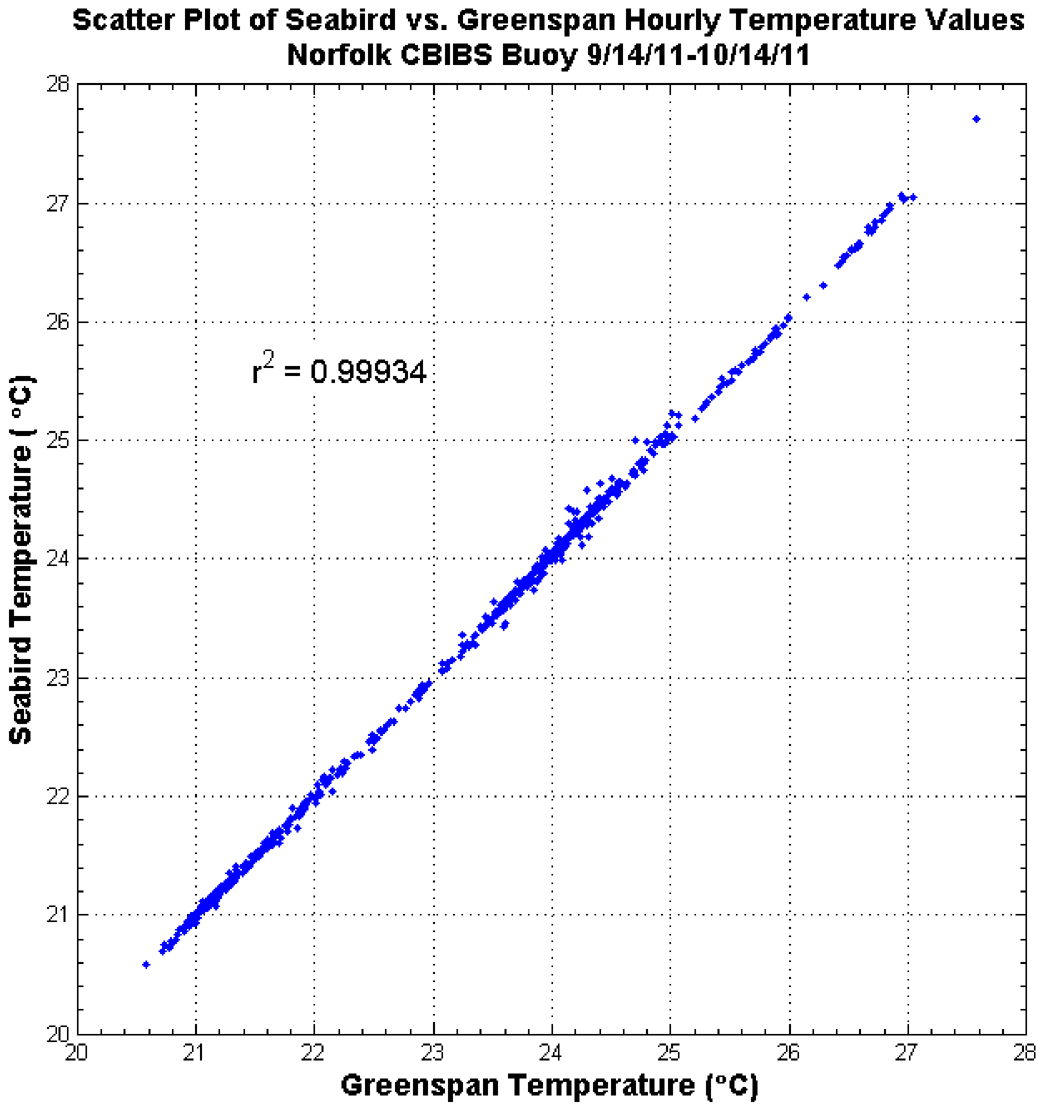


Figure 28. Temperature scatter plot of Sea-Bird versus Greenspan on CBIBS buoy.

4.0 Recommendations for Refining CO-OPS' Conductivity and Temperature Accuracy Requirements

As mentioned earlier, the assumption at the outset of this test and evaluation effort was that CO-OPS' required accuracies for CT sensors were ±0.1 mS/cm for conductivity and ±0.05 °C for temperature. However, since these values are simply manufacturer-published accuracies for the FSI, results from this test and evaluation are being used to refine the CO-OPS requirement for CT sensor accuracy based on user applications. Additionally, the published accuracies for the Greenspan are lower than those for the FSI (table 4), so the task is to determine the optimal accuracy requirement for CT sensors.

Table 4. Published conductivity accuracies for CT sensors and calibration standards.

Test Sensor	Published Conductivity Accuracy	Published Temperature Accuracy
Greenspan EC3000	±1% full scale range *(i.e., 0.7 mS/cm)*	±0.2 °C
FSI CTS-C-1DH	±0.1 mS/cm	±0.05 °C

To determine the optimal conductivity accuracy requirements for CO-OPS applications, the final products of salinity and specific gravity (SG) disseminated via the PORTS® website were considered. Both salinity and specific gravity[1] are derived from the conductivity and water temperature measured by the CT sensor.

From the perspective of CO-OPS user applications, consider a vessel passing from ocean water (SG = 1.025) into a freshwater (SG = 1.000) port and the accompanying increase in draft. A ship's full freshwater allowance (FWA) is essentially a measure of the draft increase that occurs in this scenario [8]. Specific gravity is a unitless quantity reported by CO-OPS with a resolution of 0.001. To give a sense of scale, a 0.001 change in specific gravity equals a 2-cm change in draft for a large containership with a FWA of 50 cm [9].

To better understand the impacts of each sensor's measurement error on the calculated accuracy of specific gravity, worst-case scenarios were created for each sensor.

Methods

Salinity, density, and specific gravity were calculated for two hypothetical sets of conductivity and temperature data. The two sets of hypothetical CT data were chosen to produce examples that bracket the extremes of low and high salinity (tables 5 and 6, respectively) that might be experienced across PORTS® field locations. For each set of hypothetical CT data, two sets of salinity, density, and specific gravity values were calculated using minimum and maximum CT values as input values for each sensor. Each sensor's published accuracy (see legend below each

[1] Here the specific gravity is the ratio of the density of seawater to the density of fresh water.

table) was subtracted from and added to (±) the hypothetical CT values to produce the minimum and maximum input values based on potential sensor measurement error.

The hypothetical output values used in these two examples are shown in blue under each parameter of interest (salinity, density, specific gravity). The test output values resulting from the range of minimum and maximum input values are shown in the boxed sections of the table.

Results

The salinity test output values are ±0.8 PSU for the Greenspan and ±0.15 PSU for the FSI. A ±1 PSU margin of error should be sufficient for salinity. For specific gravity, the potential error of both sensors is ±0.001, on the same order as the resolution. Since the Greenspan's worst-case scenarios (i.e., minimum and maximum inputs) result in the same output accuracy range as the operational sensor, changing the CO-OPS accuracy requirements to match the published accuracy of the Greenspan would not result in any discernible change in the specific gravity data produced at PORTS® observatories.

Table 5. Resulting values of various parameters (salinity, density, specific gravity) in a low-salinity environment, calculated using a range of conductivity and temperature inputs (see legend below table 5) associated with each sensor's published accuracies.

Hypothetical conductivity input: 19.5 mS/cm
Hypothetical temperature input: 16.5 °C

		Salinity (PSU) *Hypothetical value: 14.1*		Density (kg/m^3) *Hypothetical value: 1010*		Specific Gravity *Hypothetical value: 1.011*	
	Inputs	16.45 °C	16.55 °C	16.45 °C	16.55 °C	16.45 °C	16.55 °C
FSI	19.4 mS/cm	14.1	14.0	1010	1010	1.011	1.010
	19.6 mS/cm	14.2	14.2	1010	1010	1.011	1.011
		16.3 °C	16.7 °C	16.3 °C	16.7 °C	16.3 °C	16.7 °C
GS	18.8 mS/cm	13.6	13.5	1009	1009	1.010	1.010
	20.2 mS/cm	14.8	14.6	1010	1010	1.011	1.011

Legend

	Inputs - FSI	Inputs - GS
mS/cm (min)	19.4	18.8
mS/cm (max)	19.6	20.2
°C (min)	16.45	16.3
°C (max)	16.55	16.7
	Cond	**Temp**
FSI Accuracy	±0.1	±0.05
GS Accuracy	±0.7	±0.2

Table 6. Resulting values of various parameters (salinity, density, specific gravity) in a high-salinity environment, calculated using a range of conductivity and temperature inputs (see legend below table 6) associated with each sensor's published accuracies.

Hypothetical conductivity input: 40 mS/cm
Hypothetical temperature input: 15 °C

		Salinity (PSU) *Hypothetical output: 32.4*		Density (kg/m^3)* *Hypothetical output: 1024*		Specific Gravity *Hypothetical output: 1025*	
	Inputs	14.95 °C	15.05 °C	14.95 °C	15.05 °C	14.95 °C	15.05 °C
FSI	39.9 mS/cm	32.3	32.2	1024	1024	1.025	1.025
	40.1 mS/cm	32.5	32.4	1024	1024	1.025	1.025
		14.8 °C	15.2 °C	14.8 °C	15.2 °C	14.8 °C	15.2 °C
GS	39.3 mS/cm	31.9	31.6	1024	1023	1.025	1.024
	40.7 mS/cm	33.2	32.8	1025	1024	1.026	1.025

**Not a product on CO-OPS website*

Legend

	Inputs - FSI	Inputs - GS
mS/cm (min)	39.9	39.9
mS/cm (max)	40.1	40.7
°C (min)	14.95	14.8
°C (max)	15.05	15.2
	Cond	**Temp**
FSI Accuracy	±0.1	±0.05
GS Accuracy	±0.7	±0.2

5.0 Summary and Recommendations

The Greenspan CT sensor performed within its manufacturer-specified accuracies and better than the FSI in the conductivity standard tests. During the four tests, the Greenspan remained within ±0.4 mS/cm of the conductivity reference and ±0.13 °C of the temperature reference. The FSI CT sensor measured within ±0.9 mS/cm of the conductivity reference and ±0.10 °C of the temperature reference. While these values are outside of its manufacturer-specified accuracy, the OSTEP team discovered that the test container was likely too small for the FSI and interfered with the sensor's electromagnetic field. However, the same interference was not seen with the Greenspan, since its electromagnetic field is enclosed within a shroud. This shroud is an important component of the Greenspan sensor and allows deployment close to other objects without interference. Any future tests involving toroidal sensors should be designed with containers that allow a sufficient radius around the conductivity cell, as indicated by manufacturer specifications.

During the seawater test bath, the FSI and Greenspan raw conductivity values were within ±0.3 mS/cm of each other. These results are within the cumulative manufacturer specifications for both sensors. Temperature measurements for both sensors were within ±0.02 °C, also within cumulative manufacturer specifications. The gap between the values of the sensors and the external thermometer was wider (within ±0.2 °C), but the Greenspan values were consistently closer to the external thermometer than those of the FSI. This result falls within the cumulative manufacturer specifications of the Greenspan sensor and the Hart Scientific external thermometer (±0.2 and ±0.007 °C, respectively), but does not for the FSI (±0.05 °C). During the tests, however, the OSTEP team discovered that there were uncertainties about the calibration dates of both the external thermometer and the reference FSI CT sensor.

During the field tests, the Greenspan sensor performed well within its manufacturer specifications. Test results aligned most closely with the Sea-Bird (Norfolk CBIBS Buoy) in terms of both conductivity (within ±0.2 mS/cm) and temperature (within ±0.03 °C), but the values also were within its specifications when compared to the FSI (Money Point NWLON).

The laboratory tests highlighted the container size/edge interference issue with the FSI and several problems with CIL's calibration verification procedures (possible test tank stratification, reference instruments that need to be calibrated, quality of reference sensor). Improvements to the laboratory facility were recommended and implementation has already begun.

Several other issues also emerged during the field tests. The OSTEP team encountered problems with the Greenspan software when setting up the self-contained instrument for the CBIBS deployment; these problems included an erroneous power budget estimate and duplicate schedules (i.e., sampling regimes) that could not be erased. Since CO-OPS will be communicating directly with the instrument through the DCP and not using the Greenspan software, this issue should not be an obstacle to the sensor's operational use. Other issues were encountered with the SDI-12 communications. These communications issues have since been resolved with the upgrade of the SDI-12 converter firmware. It should be noted, however, that direct RS232 communication was not an option, given Greenspan's proprietary RS232 protocol. An alternative (if needed) is to use the Modbus protocol for RS232 communications.

Results of this test and evaluation effort indicate that the accuracy requirements for CO-OPS' CT sensors can be changed to those associated with the Greenspan sensor with no operational impacts on CO-OPS published data. While the published accuracy of the Greenspan (±0.7 mS/cm and ±0.2 °C) is lower than that of the FSI (±0.1 mS/cm and ±0.05 °C), section 4 of this report concludes that this increased error does not have a significant effect on CO-OPS' products (specific gravity, salinity). Additionally, the Greenspan performed better than its stated accuracies in all tests.

Based on the performance of the Greenspan EC3000 under a variety of laboratory and field conditions, the authors recommend this sensor for operational use in CO-OPS observatories.

References

[1] Alliance for Coastal Technologies. http://www.act-us.info/ accessed June 2012.

[2] Gray, G., August 2011. Test Plan for Laboratory and Field Testing of the Greenspan EC3000 Conductivity/Temperature (CT) Sensor, NOAA/NOS/CO-OPS/OSTEP, Silver Spring, Maryland.

[3] Bushnell, M. and Grissom, K., June 2002. Error Sources and Corrective Actions for PORTS Conductivity/Temperature Sensors, NOAA/NOS/CO-OPS/OSTEP, Silver Spring, Maryland.

[4] Greenspan Analytical, Tyco Environmental Systems, (March 2010). Electrical Conductivity Sensor EC3000 User Manual, Version 1.1, 010-UM-700-5100.

[5] Sea-Bird Electronics, Inc., 2003. Conductivity Sensors for Moored and Autonomous Operation, Technical Paper, Revised February 2003. http://www.seabird.com/technical_references/condpaper.htm

[6] Lake Products Company LLC, Florissant, MO. http://lakeproductscompany.com/ accessed June 2011.

[7] Chesapeake Bay Interpretive Buoy System. http://buoybay.noaa.gov/locations/norfolk.html accessed June 2011.

[8] United States Coast Guard, April 2008. USCG Marine Safety Manual: Volume V, Investigations and Enforcement, COMDTINST M16000.10A, Washington, DC.

[9] United States Coast Guard, Naval Architecture Division, September 2008. Load Line Policy Notes, Washington, DC.

List of Appendices

Appendix A: Laboratory Notes

Appendix B: Money Point Conductivity and Temperature Time-Series Plots (February – April 2012)

Appendix C: CBIBS 1-Hz Conductivity and Temperature Plot

Appendix A. Laboratory Notes

Lab tests - R1	**GS1**	SN 027987		procured by CIL
SW tests R3		Range: 0 - 70,000 uS/cm; 0-50° C		
		Sensor ID: 00001080AFB7		
		Firmware version: BE v4.0		
NWLON	**GS2**	SN 027986		procured by CIL
		Range: 0 - 70,000 uS/cm; 0-50° C		sent back to Stevens Water for painting and recalibration 7/18/2011
		Sensor ID: 00001080AFB7		Loop calibration test 08/15/11
		Firmware version: BE v4.0		
Lab tests - R2	**GS3**	SN 028028		procured by OSTEP
CBIBS		Range: 0 - 70,000 uS/cm; 0-50° C		painted intially; has internal battery pack
		Sensor ID: 00001080AFB7		
		Firmware version: BE v4.0		

First Round of Laboratory Calibration Standard Solution Tests

Instruments: GS1 and FSI-Ref

GS1 was tested first in new solution, then FSI was tested in same solution immediately following GS test.

Times are UTC, unless otherwise indicated.

7/6/2011	**Loop Calibration Test (LGS1)**
16:43	Start of test with no loop (Ecraw: 0, -1, -5, -6)
16:56	End of test
16:58	Start of test with loop (Ecraw: 65856; Loop: 65725)
17:10	End of test
Filename: GS1_05Jul11.csv	

7/13/2011	**GS1 in 1.413 mS/cm standard solution (Test_CG1_1.dat)**
18:00	Poured solution
18:41:53	Removed sensor from solution
	Tried to tap sensor to minimize/release air bubbles after submerging; then added more solution
Filename: Test_CG1_1.dat	

7/13/2011	**FSI Ref in old* 1.413 mS/cm std soln (*Test CFR-1)**
18:52:30	Start file
18:55:20	Sensor in soln; shaken to remove bubbles
19:47:15	Sensor removed from soln
19:48:04	Stopped file
	Need to confirm 1Hz sampling for tests using new soln; no time stamp; Dropped to 0.000-0.003 while rinsing with DI water. (*Solution from previous test)
Filename: pw05.cap	

7/13/2011	**GS1 in old** 1.413 mS/cm std soln**
20:17:50	In solution, without shroud
20:30:25	Removed sensor to replace shroud
20:31:55	Back in soln, with shroud
20:48	End of test
	This test was performed to look at the stability of the calibration standard solution, and to compare the operation of the Greenspan with and without the shroud. (Same solution used in two previous tests.)
Filename: GS1_oldstd1413_test.dat	

7/14/2011	**GS1 in 58.670 mS/cm std soln (Test CG1-4)**
15:40	Started log
15:46:00	Added solution
17:17	Realized that log had not been started at 15:40; started log
18:40:50	Removed sensor from solution
	Values when soln was added were 55xxx for ECraw and 58xxx for ECnorm. 1.5 hours equilibration time.
Filename: Test_CG1_4.dat	

7/14/2011	**FSI Ref in old* 58.670 mS/cm std soln (*Test CFR-4)**
18:45:35	Sensor in soln; then started file
21:40	File stopped
Filename: pw06.cap	

7/19/2011	**GS1 in 12.880 mS/cm std soln (Test CG1-2)**
12:32	Sensor in solution
14:04	Sensor out of solution
Filename: Test_CG1_2.dat	

7/19/2011	**FSI Ref in old* 12.880 mS/cm std soln (*Test CFR-2)**
14:17:15	Sensor in soln
16:56:10	File stopped
Filename: pw07.cap	
	[Follow-up tests in same solution]
18:07	Removed FSI from calibration solution
18:18	Returned FSI to calibration solution
18:19	Started file: *pw08.cap*
19:10	Stopped file
19:17	GS1 in calbration solution *(**Changed decimal places on temperature output)*
20:06	Stopped logging and downloaded GS data ("DataDump071911.dat")
	**The above change to the decimal output appears not to have taken effect, for some reason.
Filename: pw08.cap; DataDump071911.dat	

Tests in std 15.000 were not done until 7/26/2011 because calibration standard solution had not arrived.

First Round of Seawater Bath Tests

Instruments: GS1 and FSI-Ref

Times are local, unless otherwise indicated (Times in GS files are UTC).

7/20/2011	**Seawater Bath Tests**
Test 1: No mixing; completely submerged	
Filenames: pw01.cap; GS1_TB1.txt	
10:21	Turned on mixer
10:45	Unplugged mixer to check depth and set instruments (point of measurement is 17.75" bws)
10:56	Started FSI file: *pw01.cap*
10:58	Started GS1 file (Sensor time is 14:59:45 UTC)
11:00	Submerged FSI
11:02	Submerged GS1
11:04	Turned off drill because it was interfering; will leave instruments completely submerged so the thermistors can equilibrate.
11:17	Adjusted the sensors so they were farther from wall of tank.
Test 2: No mixing; instrument positions switched	
Filenames: pw02.cap; GS1_TB2.txt	
12:47	Switched sensor positions; stopped FSI file and started new file: *pw02.cap*
14:38	Stopped logging files.
7/21/2011	
Test 3: Mixed; instruments half submerged	
Filenames: pw03.cap; GS1_TB3.txt	
8:39	T = 20.983°C (temperature readings are from external thermistor)
8:56	Start logging FSI
8:57	Start logging GS
9:09	Both instruments adjusted so they are half-submerged (more stable and no interference with mixer)
9:10	Start mixing; T = 20.872°C
9:29	Slightly adjusted sensors; T = 20.842°C
11:50	T = 20.962°C
13:35	T = 21.052°C
13:38	Downloaded GS data
13:39	Stopped pw03.cap and started pw04.cap

Test 4: Unmixed; instruments fully submerged	
Filenames: pw04.cap; GS1_TB4.txt; T4_therm.txt (thermistor)	
13:47 (GS time)	Stopped mixing; adjusted sensor depth; T = 21.059°C
13:51 (GS time)	Both instruments fully submerged; T = 21.059°C
13:55	Adjusted instruments slightly; T = 21.055°C
14:48	T = 21.040°C
15:12	T = 21.024°C
15:45	Jostled board (instrument mount), by accident; T = 21.014°C
16:05	T = 21.013°C
16:34	T = 21.013°C
17:34	Realized that the extermal thermistor had RS-232 output and began to capture temperature data in "T4_therm.txt"
17:36	Moved thermistor from side of tank to in between two sensors.
18:01	Removed thermistor to rinse in fresh water (accidentally submerged too deeply in salt water.)
18:36	Stopped logging.
7/22/2011	
Test 5: Mixed; instruments fully submerged	
Filenames: pw06.cap; GS1_TB5.txt; T5_therm.txt (thermistor)	
8:00	Turned on mixer; adjusted sensors on new (more stable) mount.
9:16	Started data files (FSI and GS)
9:34	Started thermistor file
9:45	Adjusted thermistor position.
14:12	Stopped logging.

First Round of Laboratory Calibration Standard Solution Tests (CONTINUED)

Changed temperature and salinity output on GS to 4 decimal places.
Added external thermistor to beaker
Greenspan clock changed to LDT

7/26/2011	**GS1 in 15.000 mS/cm std soln (Test CG1-3)**
10:26 (14:26 UTC)	Started files
10:29	Poured soln, then removed to get rid of air bubbles - no luck. When replaced at 10:37, ECnorm had dropped from ~14.5 to 13.2
12:33	Stopped files
Instr: GS1 (SN027987) / Filenames: Test_CG1_3.dat ; pw09.cap (thermistor)	

7/26/2011	**FSI Ref in old* 15.000 mS/cm std soln (*Test CFR-3)**
13:13	Started files: pw10.cap (FSI); pw11.cap (therm)
13:19	Lost power
14:38:45	Started new files: pw12 (FSI); pw13 (therm)
15:37	Started new files to run after hours: pw14 (FSI); pw15 (therm)
7:53	(7/27/11) Stopped files.
Instr: FSI-Ref / Filenames: pw10.cap & pw12.cap (FSI); pw11.cap & pw13.cap (thermistor);	

8/16/2011	**GS2 installed at Money Point NWLON station**

Second Round of Laboratory Calibration Standard Solution Tests

Instruments: FSI-Ref and GS3

FSI-Ref was tested first in new solution, then GS3 was tested in same solution immediately following FSI test.

Times are UTC, unless otherwise indicated.

Note that test names are correct in indicating GS3, but Greenspan filenames erroneously indicate that GS2 was used for these tests.

8/22/2011	**Loop Calibration Test (LGS3)**
17:16:30	Start of test with no loop (Ecraw: 4, -1, 2, 1)
17:48:30	Attached loop (Ecraw: 65975; Ecnorm: 68699; Loop: 65700)
17:53:00	Re-seated connector (Ecraw: 65969)
17:55:56	End of test

8/23/2011	**FSI Ref in 1.413 mS/cm std soln (Test CFR-1)**
10:58:30	Poured solution
11:01:45	Adjusted beaker height
11:09:30	Readjusted beaker height
11:10:50	Adjusted thermistor
11:12:10	Moved beaker
12:46:45	Stopped files (thermistor first to compare times)
	*Thermistor is UTC + 5 hr 8 min 29 sec for this test; fixed before next test.
Filenames: pw16cap (FSI); pw17.cap (thermistor)	
8/23/2011	**GS3 in old* 1.413 mS/cm standard solution (Test CG3-1)**
12:51:26	Sensor in solution
12:55:00	Started logging to both files (GS first)
12:57:10	Adjusted height of sensor
14:30:20	Stopped files (GS first)
	(*Solution from previous test)
Filenames: CG2-1(GS); pw18.cap (thermistor)	

8/23/2011	**FSI Ref in 12.880 mS/cm std soln (Test CFR-2)**
14:41:00	Poured solution then started files.
16:13	Moved beaker so sensor was farther from edge (11.501 -> 11.575 mS/cm)
16:15	Jostled sensor to see if readings would change (11.575 -> 11.800 -> 11.763 mS/cm)
16:16	Repositioned beaker and jostled instrument (11.833 -> 11.815 mS/cm)
16:20:00	Stopped files (FSI first)
Filenames: pw20.cap (FSI); pw19.cap (thermistor)	

8/23/2011	**GS3 in old* 12.880 mS/cm standard solution (Test CG3-2)**
16:26	Poured solution.
16:28:30	Started files: pw21 (thermistor); CG2-2 (GS)
16:35:45	Finished adjusting height, dislodging air bubbles.
18:16:15	Stopped files, then removed shroud.
18:25:18	Started "No shroud" test: pw22 (thermistor); CG2-2_NoShroud (GS)
19:11:55	Stopped files.
	(*Solution from previous test)
Filenames: CG2-2 & CG2-2_NoShroud (GS); pw21.cap & pw22.cap (thermistor)	

8/24/2011	**FSI Ref in 15.000 mS/cm std soln (Test CFR-3)**
14:19	Poured solution; started files: pw23 (thermistor); pw24 (FSI)
16:01	Stopped both files.
16:02	Started new files: pw25 (thermistor) and pw26 (FSI), then removed thermistor to check for interference.
16:55	Removed sensor from solution then stopped files.
Filenames: pw23.cap & pw25.cap (thermistor); pw24.cap & pw26.cap (thermistor)	

8/24/2011	**GS3 in old* 15.000 mS/cm standard solution (Test CG3-3)**
16:55	Poured solution and started files.
18:36:30	Stopped files: pw27 (thermistor); CG2-3 (GS3)
18:42:25	Started new files: pw28 (thermistor) and CG2-3_NoTherm (GS), then removed thermistor to check for interference.
19:30:35	Stopped files.
	(*Solution from previous test)
Filenames: CG2-3 & CG2-3_NoTherm (GS); pw27.cap & pw28.cap (thermistor)	

8/24/2011	**FSI Ref in old** 15.000 mS/cm std soln (Test CFR-3)**
19:37	Put FSI back in 15.000 mS/cm solution after GS test
19:40	Started both files.
	**Same solution used in two previous tests.
Filenames: pw29.cap (thermistor); pw30.cap (thermistor)	

8/25/2011	**FSI Ref in 58.670 mS/cm std soln (Test CFR-4)**
11:47	Poured solution; white flakes in solution.
11:49:30	Started files.
13:34:26	Stopped files.
Filenames: pw31.cap (thermistor); pw32.cap (thermistor)	

8/25/2011	**GS3 in old* 58.670 mS/cm standard solution (Test CG3-4)**
13:44	Poured solution
13:46	Started files
15:20:45	Stopped files
	(*Solution from previous test)
Filenames: CG2-4 (GS); pw33.cap (thermistor)	

Second Round of Seawater Bath Tests

Instruments: FSI-Ref and GS3

Times are local, unless otherwise indicated (Times in GS files are UTC).

8/25/2011	**Seawater Bath Tests**
Filenames: pw13.cap (thermistor); pw14.cap (FSI); SW082511.csv (GS)	
12:50	Both sensors in seawater test bath.
10:45	Started files* pw13 and pw14--(started GS3 a few minutes before.) Moved sensors around the first couple of minutes to check the effect of edge proximity. Moving the FSI closer to the edge of the tank causes the conductivity to decrease (saw the same thi
13:21:10	Stopped FSI file, then thermistor file.
10:58	Stopped GS3 file.

9/14/2011	**GS3 installed on Norfolk CBIBS buoy.**

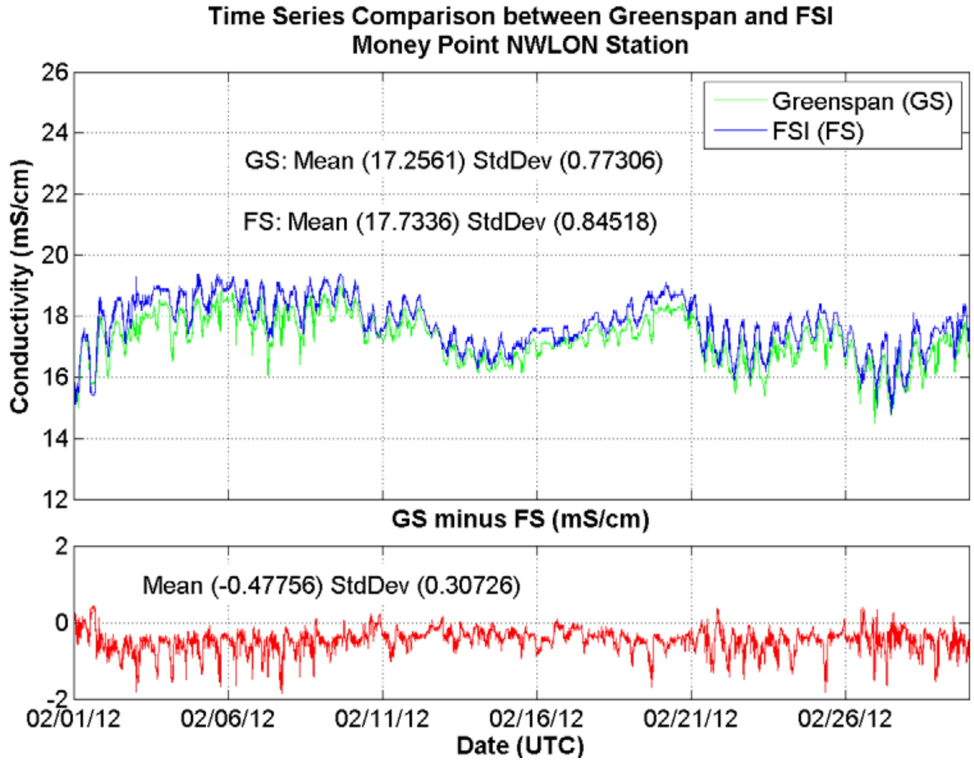
Pad front end of SW_R1 Tests 4 and 5 with Nans:

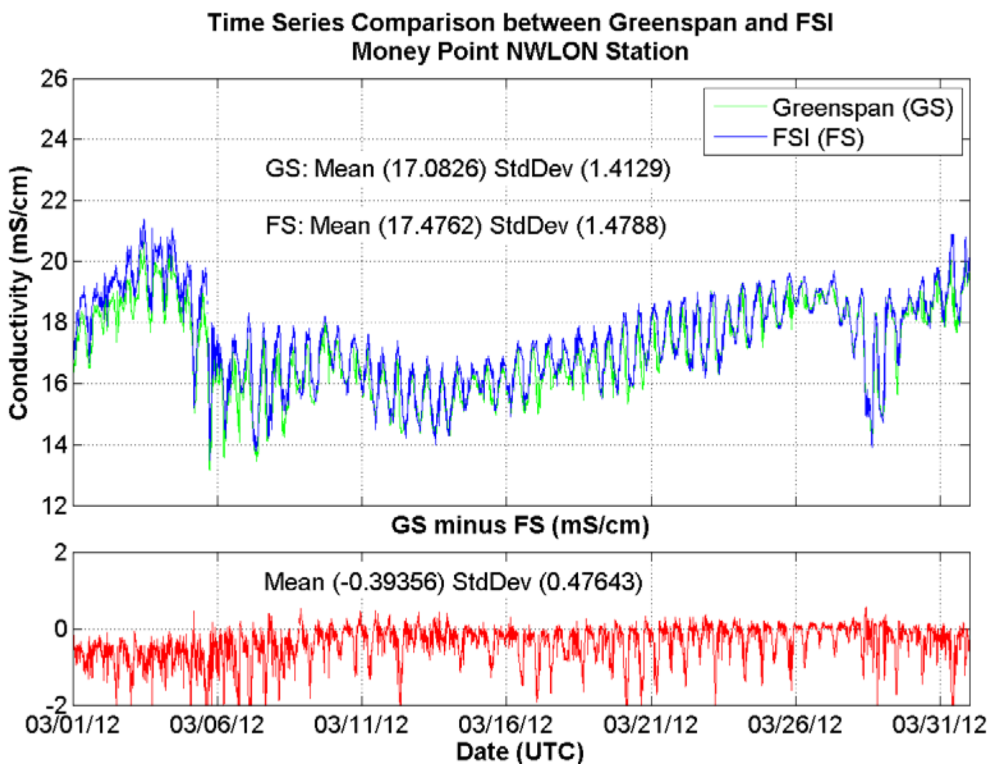
Test 4: start at 13:38 / 17:39

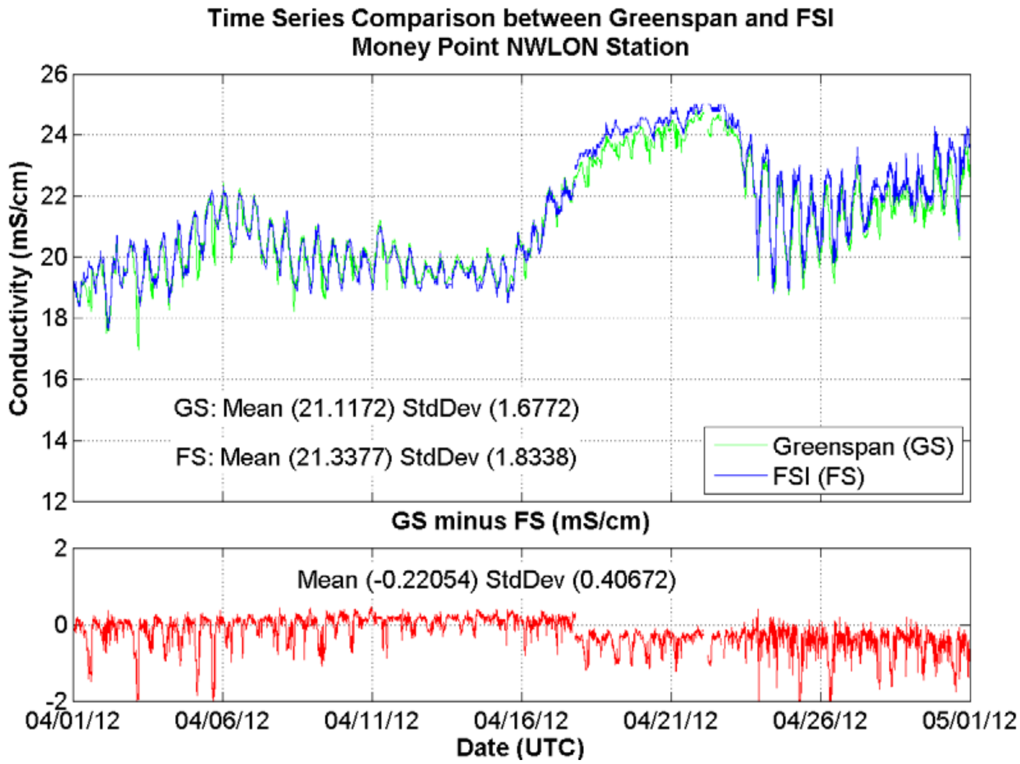
Test 5: start at 09:16 / 13:16

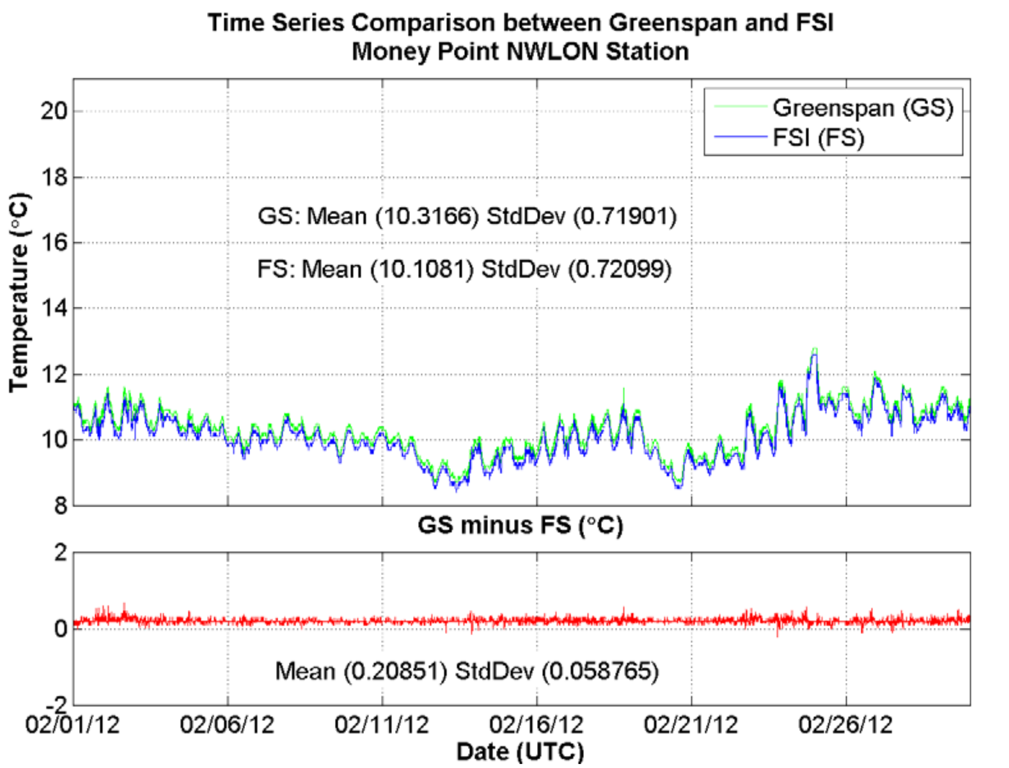
Cut off front end of Test 4?

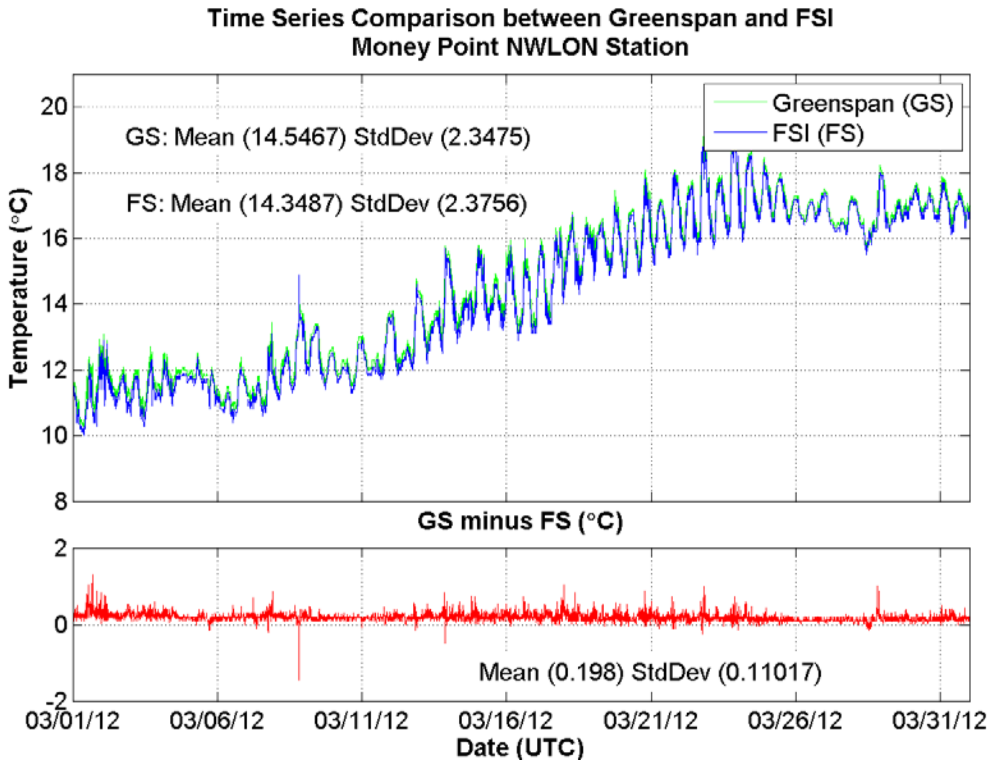
Appendix B. Money Point Conductivity and Temperature Time-Series Plots (February – April 2012)

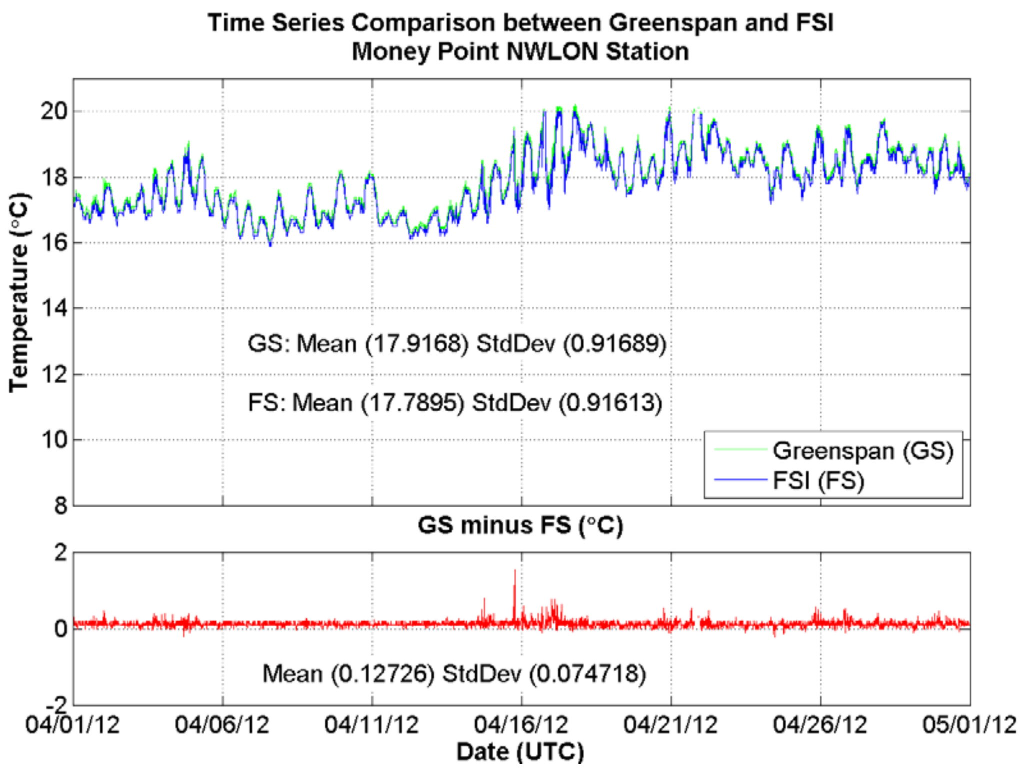




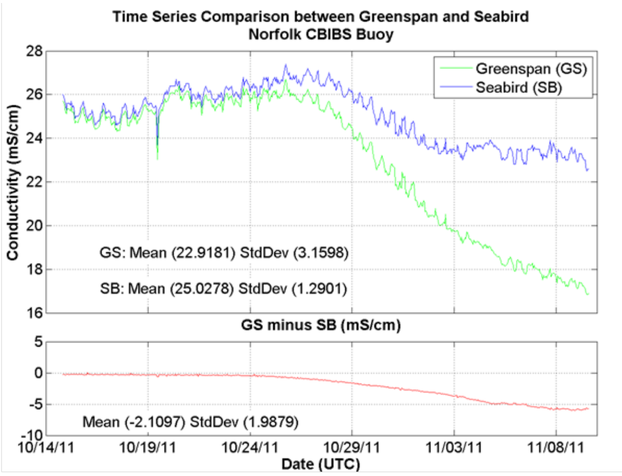

Time Series Comparison between Greenspan and FSI
Money Point NWLON Station
Conductivity (mS/cm)
GS: Mean (21.1172) StdDev (1.6772)
FS: Mean (21.3377) StdDev (1.8338)
Greenspan (GS)
FSI (FS)
GS minus FS (mS/cm)
Mean (-0.22054) StdDev (0.40672)
04/01/12
04/06/12
04/11/12
04/16/12
04/21/12
04/26/12
05/01/12
Date (UTC)

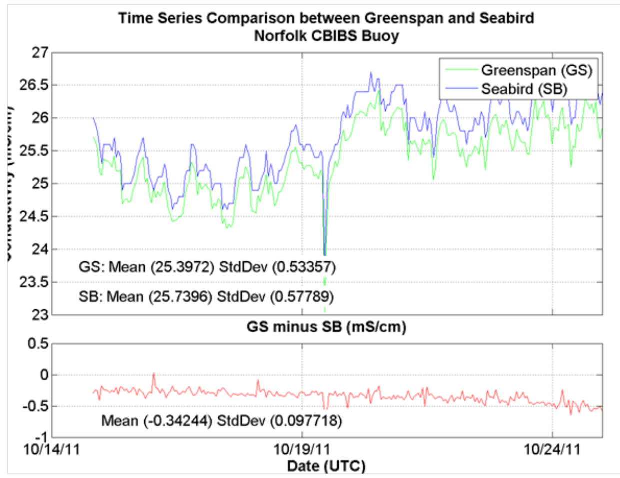

Time Series Comparison between Greenspan and FSI
Money Point NWLON Station
Temperature (°C)
Greenspan (GS)
FSI (FS)
GS: Mean (10.3166) StdDev (0.71901)
FS: Mean (10.1081) StdDev (0.72099)
GS minus FS (°C)
Mean (0.20851) StdDev (0.058765)
02/01/12
02/06/12
02/11/12
02/16/12
02/21/12
02/26/12
Date (UTC)

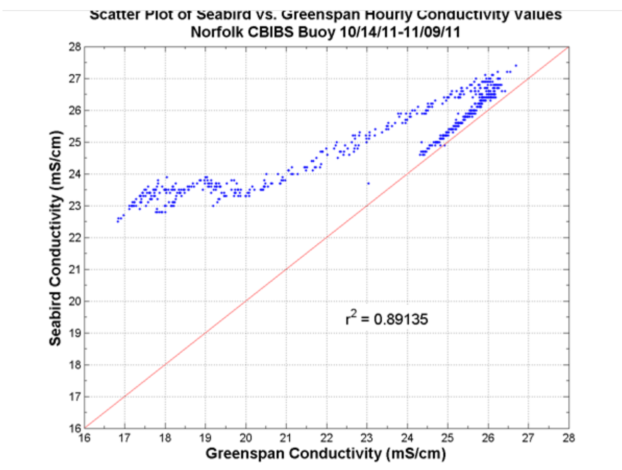

Time Series Comparison between Greenspan and FSI
Money Point NWLON Station
Greenspan (GS)
FSI (FS)
GS: Mean (14.5467) StdDev (2.3475)
FS: Mean (14.3487) StdDev (2.3756)
Temperature (°C)
GS minus FS (°C)
Mean (0.198) StdDev (0.11017)
03/01/12
03/06/12
03/11/12
03/16/12
03/21/12
03/26/12
03/31/12
Date (UTC)

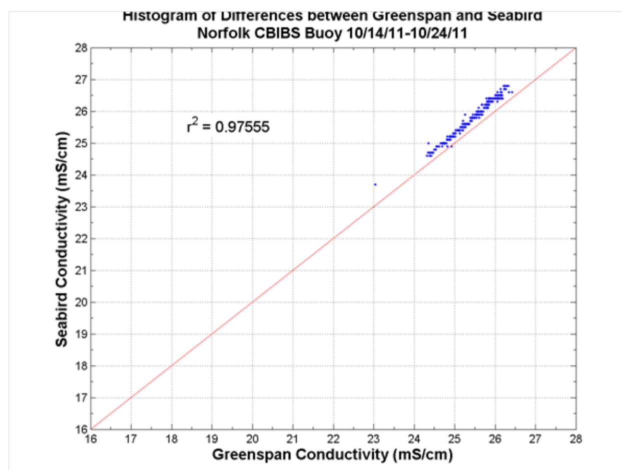

Time Series Comparison between Greenspan and FSI
Money Point NWLON Station
GS: Mean (17.9168) StdDev (0.91689)
FS: Mean (17.7895) StdDev (0.91613)
Greenspan (GS)
FSI (FS)
Temperature (°C)
GS minus FS (°C)
Mean (0.12726) StdDev (0.074718)
04/01/12
04/06/12
04/11/12
04/16/12
04/21/12
04/26/12
05/01/12
Date (UTC)

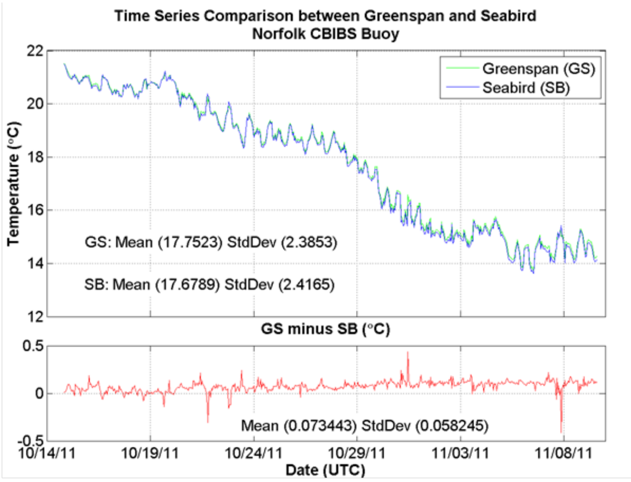
Appendix C. CBIBS 1-Hz Conductivity and Temperature Plots

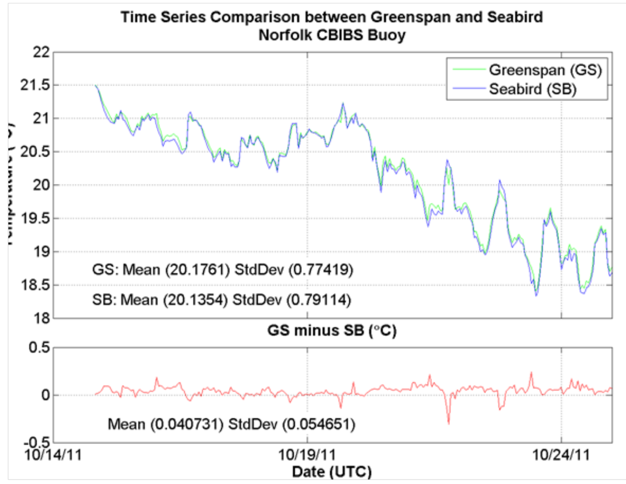


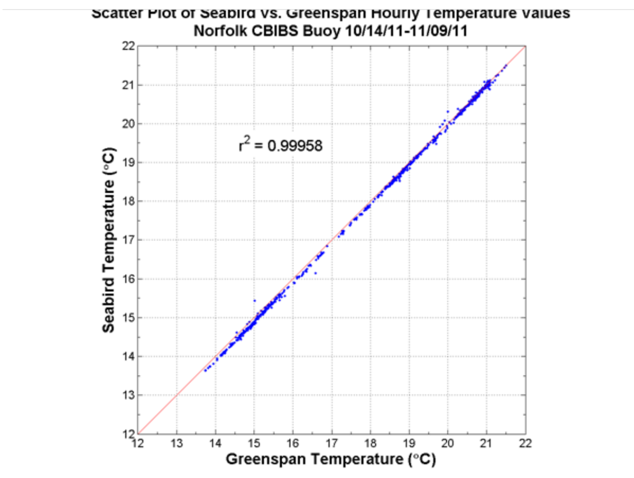


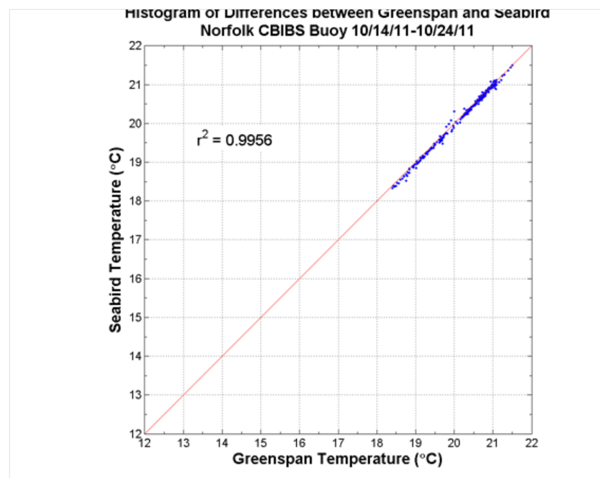


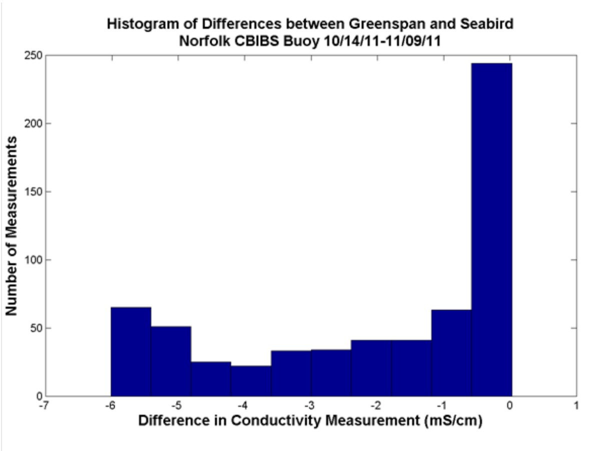


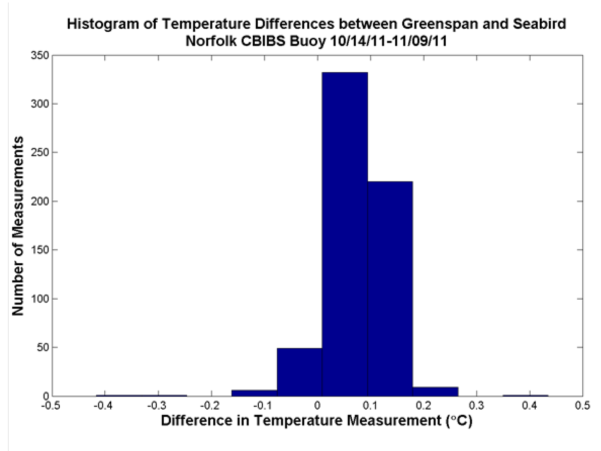

Time Series Comparison between Greenspan and Seabird
Norfolk CBIBS Buoy
Greenspan (GS)
Seabird (SB)
Temperature (°C)
GS: Mean (17.7523) StdDev (2.3853)
SB: Mean (17.6789) StdDev (2.4165)
GS minus SB (°C)
Mean (0.073443) StdDev (0.058245)
Date (UTC)

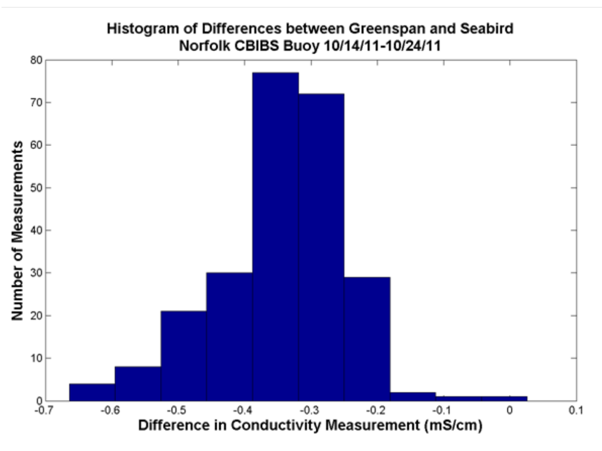

Time Series Comparison between Greenspan and Seabird
Norfolk CBIBS Buoy
Greenspan (GS)
Seabird (SB)
GS: Mean (20.1761) StdDev (0.77419)
SB: Mean (20.1354) StdDev (0.79114)
GS minus SB (°C)
Mean (0.040731) StdDev (0.054651)
Date (UTC)

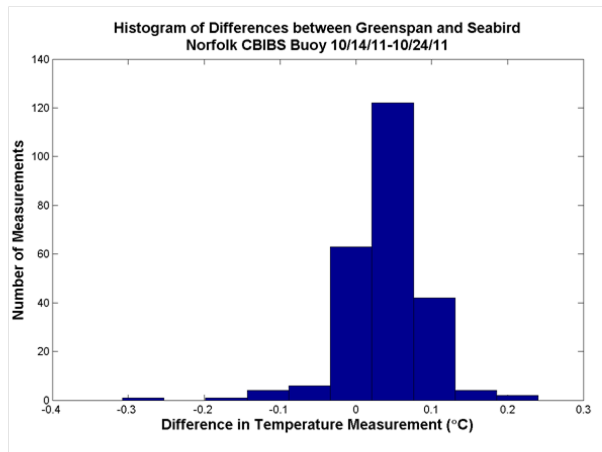

Scatter Plot of Seabird vs. Greenspan Hourly Temperature Values
Norfolk CBIBS Buoy 10/14/11-11/09/11
r2 = 0.99958
Seabird Temperature (°C)
Greenspan Temperature (°C)


Histogram of Differences between Greenspan and Seabird
Norfolk CBIBS Buoy 10/14/11-10/24/11
r2 = 0.9956
Seabird Temperature (°C)
Greenspan Temperature (°C)


Histogram of Differences between Greenspan and Seabird
Norfolk CBIBS Buoy 10/14/11-11/09/11
Number of Measurements
Difference in Conductivity Measurement (mS/cm)


Histogram of Temperature Differences between Greenspan and Seabird
Norfolk CBIBS Buoy 10/14/11-11/09/11
Number of Measurements
Difference in Temperature Measurement (°C)


Histogram of Differences between Greenspan and Seabird
Norfolk CBIBS Buoy 10/14/11-10/24/11
Number of Measurements
Difference in Conductivity Measurement (mS/cm)


Histogram of Differences between Greenspan and Seabird
Norfolk CBIBS Buoy 10/14/11-10/24/11
Number of Measurements
Difference in Temperature Measurement (°C)

Acronyms and Abbreviations

AC	alternating current
ACT	Alliance for Coastal Technologies
CBIBS	Chesapeake Bay Interpretive Buoy System
CIL	Chesapeake Instrument Laboratory
CO-OPS	Center for Operational Oceanographic Products and Services
CT	Conductivity/Temperature
DCP	Data Collection Platform
°C	degrees Celsius
FSI	Falmouth Scientific, Incorporated
ft	feet
FWA	fresh water allowance
h	hour
IP	Internet protocol
ISD	Information Systems Division
min	minute
mL	milliliter
MLLW	mean lower low water
MWWL	microwave water level
mS/cm	milli-siemens per centimeter
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NWLON	National Water Level Observation Network
OSTEP	Ocean Systems Test and Evaluation Program
PORTS®	Physical Oceanographic Real-Time System
PSU	practical salinity unit
PVC	polyvinyl chloride
s	second
SG	specific gravity
stdDev	standard deviation
UTC	Coordinated Universal Time
WL	water level