

A Field Evaluation of the CastAway CTD at the Deepwater Horizon Oil Spill site in the Gulf of Mexico

JENNIFER PATTERSON

SonTek/YSI, San Diego, CA

MARK BUSHNELL AND MANUEL HAENGGI

Tellus Applied Sciences, Williamsburg, VA

I. Introduction

During the Deepwater Horizon spill Tellus Applied Sciences was subcontracted by Fugro GEOS in Houston, Texas to provide shipboard technical support aboard the research vessel *Ocean Veritas* (fig 1). The *Ocean Veritas* was contracted by BP and was one of many vessels employed in tracking and monitoring the Deepwater Horizon leak subsurface plume. Tellus Applied Sciences is headquartered in Williamsburg, Virginia and provides scientific and engineering technical services to federal agencies such as NOAA and NASA, and also contracts with academic and private entities.



FIG. 1. Comparison casts were conducted on Stabbert Maritime's 194 ft. research vessel the *Ocean Veritas*.

Chemical and physical oceanographic profile data were collected in response to the Deepwater Horizon oil spill event on April 20, 2010, by the Subsurface Monitoring Unit (SMU), which consists of multiple government and corporate agencies. Oxygen concentrations, fluorescence, and other chemical analyses from the cast data collected on this cruise aided in the delineation and characterization of the dispersed oil (*SMU Strategic Plan, 2010*). Oil plume

presence was detected by observing anomalous peaks in vertical profile data collected with a WetLabs fluorometer. Plume presence was also identified by anomalously depressed dissolved oxygen, either together with fluorescence anomalies or alone after plume biodegradation.

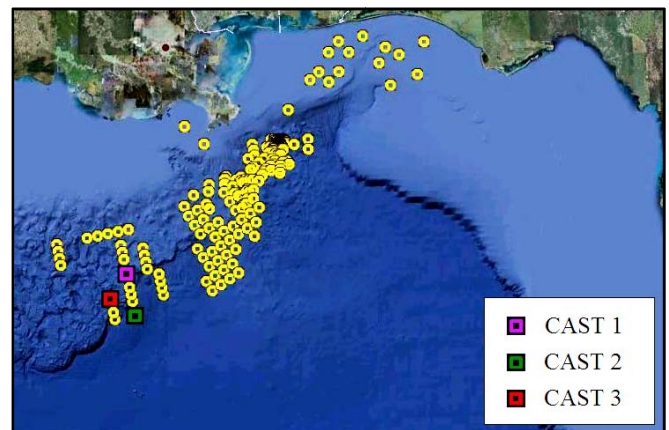


FIG. 2. Locations of the three comparison casts. Yellow markers show the full extent of the monitoring conducted aboard *Ocean Veritas*.

Just prior to this research cruise, SonTek offered to loan a CastAway CTD to Tellus, and the cruise was an easy opportunity to conduct a side-by-side comparison between the CastAway and the shipboard SeaBird CTD. Tellus is interested in the CastAway for characterizing coastal waters for a variety of monitoring projects. A typical application would be to conduct a CTD cast during the reconnaissance of a site prior to deploying a bottom mounted Acoustic Doppler Current Profiler (ADCP) for a current study. Knowledge of the vertical density profile can help to understand observed vertical current shear. Having never used a CastAway, Tellus wanted to test it and see how well it performed in comparison to instruments

that we typically would use in coastal profiling applications.

The SeaBird CTDs used for the oil spill monitoring project were acquired from a variety of sources; they were either borrowed from NOAA, commercially leased, or owned by Fugro GEOS. Each cast utilized a primary and a backup CTD, both of which included a dissolved oxygen sensor. The primary CTD was also configured to accept data from a WetLabs FLCDRTD fluorometer (see www.wetlabs.com/cdomincrude.htm for more details) and to deliver the CTD/DO/fluorometer profile data in real time to the shipboard monitoring and logging computer. The redundant CTD data was downloaded from the instrument directly after the cast and is the data used for this comparison.

a. CTD sensor technology

Salinity is an important variable in research disciplines such as oceanography and climate science and is also important in operational applications such as water quality monitoring and coastal management. There are many commercially available instruments that provide salinity data by measuring conductivity and temperature and then deriving salinity from these measurements. These systems have several key features, each with advantages and disadvantages, which distinguish them from one another. These differences are primarily found in the design of the conductivity cell, with the options of inductive or conductive (electrode) cells, closed cells, pumped cells, and free-flow cells.

Inductive Cells and Electrode Cells - Inductive conductivity cells are typically more rugged and stable than electrode cells, but they have a large thermal mass that can be a challenge to overcome for the most precise observations. They also are not closed cell systems hence they have a relatively large external field which can become a problem when mounting to supporting frames. Electrode based conductivity cells can initially have a high accuracy but tend to drift as their cell characteristics change over time from oxidation caused by direct contact with the water.

Closed Cells - In closed cell conductivity measurement systems the electrodes are configured such that the outer two electrodes are connected together and therefore the electric field is fully contained in the cell.

Closed cells have zero external field and are immune to the influence of nearby metal or other conductive materials. Closed cells must be thermally stable so that volume doesn't change with temperature, or they must compensate for change with a known volume/temperature relationship. Most commercially available conductivity sensors, whether inductive or electrode, do not have fully enclosed cells, however, both of the instruments used in this comparison have closed cells with no external fields.

Pumped and Free-Flow Systems - Salinity calculations rely heavily on a temperature measurement that coincides directly with the conductivity measurement. In most sensors there is a significant lag time between these two measurements which must be compensated for in order to achieve high accuracy and reduce salinity spiking. SeaBird uses a pump and T-C duct system to compensate for this lag time which ensures that conductivity and temperature measurements are made on the same sample of water. Pumping the water sample at a known rate reduces problematic salinity spiking, which occurs when temperature and conductivity observations are not aligned. Pumps add cost and complexity, must be maintained, and are a substantial power draw, but they ensure a known flow rate past the sensors so that sensor lag compensation can be applied.

In contrast, the CastAway conductivity cell and thermistor are collocated inside a flow-through channel. The CastAway is hydrodynamically designed to descend at a rate of 1 m/s. While this does not control the flow as precisely as a pump, it eliminates system complexity and ensures constant flushing of the cell. The flow-through cell design of the CastAway however excludes it from use in stationary long-term monitoring applications. The conductivity cell is not thermally isolated which allows for water to flow directly into the conductivity cell and past the inline external thermistor. The proximity of the sensors and their high response rates minimizes the time lag between measurements reducing salinity spiking. Because the effects of temperature on the volume of the conductivity cell are well defined, measurements from a second internal rapid response thermistor provide the necessary information needed to account for thermal effects and thus eliminate the need for the conductivity cell to be thermally isolated.

II. Comparison

a. Instrumentation

SBE 19plusV2 - The sensor used as a reference instrument for this comparison was a *SBE 19plus V2* which is widely used for high-accuracy ocean research. It incorporates a SBE 4 conductivity cell and an SBE 3F thermistor to provide data at the accuracies required for offshore and deep water oceanography as specified by the Alliance for Coastal Technologies in 2007 (Table 1). The SBE 4 conductivity sensor is a 3 electrode, closed cell system encased in a flow through glass cell (SeaBird, 2007a). The SBE 3F thermistor is coated in glass for thermal isolation and a stainless steel tube for pressure protection (SeaBird, 2007). The *SBE 19plusV2* outputs conductivity, temperature and pressure data at a rate of 4Hz.

TABLE 1. SeaBird *SBE 19plusV2* specifications.

	Range	Resolution	Accuracy
Conductivity (S/m)	0 to 9	0.00005	0.0005
Temperature (°C)	-5 to 35	0.0001	0.005
Pressure (m)	2000	0.002% fs (0.4m)	0.1% fs (2m)

CastAway - The *CastAway* CTD is designed specifically for coastal profiling applications with a maximum profiling depth of 100m (YSI, 2010). It is a small, portable CTD that provides salinity data within the accuracy levels required for coastal monitoring applications (ACT, 2007). In addition to conductivity, temperature and salinity the *CastAway* also outputs the derived parameters of sound velocity, density and specific conductivity.

The conductivity cell has 6 electrodes inside of a flow-through channel and fast response thermistor to provide salinity measurements with an accuracy specification of 0.1 (PSS-78). Similar to the SeaBird conductivity cell design, the outer electrodes are connected, thus the electric field is fully contained in the cell and is immune to the influence of nearby objects. With this six electrode cell design, three electrodes drive the current through the cell and the

other 3 sense the current, improving the accuracy and reliability of the measurements.

TABLE 2. *CastAway* specifications.

	Range	Resolution	Accuracy
Conductivity (S/m)	0 to 10	0.0001	$\pm 0.25\% \pm 0.0005$ ($\sim 0.01 @ 5$ S/m)
Temperature (°C)	-5 to 45	0.01	0.05
Pressure (m)	100	0.01	0.25% full scale (0.25m)

The fast-response thermistor is coated in a thin protective stainless steel tube and is inside the flow-through channel in-line with the conductivity cell. The *CastAway* CTD has a dynamic response time of 5 Hz and outputs conductivity, temperature and pressure at the same frequency.

b. Data Collection

From September 8-10, 2010 three comparison casts were conducted at sites surrounding the location of the Deepwater Horizon oil rig (figure 2) aboard the *Ocean Veritas*. The 194 ft. research vessel is owned and operated by Stabbert Maritime, and is fitted with a winch and cable suitable for conducting CTD casts for the response effort. Two SeaBird CTDs, one primary and one backup, were mounted on a large rosette frame which was outfitted with Niskin bottles for water sampling. The SeaBird casts were lowered by winch through the nominal 1000-1200 meter depth of the subsurface plume. The *CastAway* was deployed in conjunction with the SeaBird casts such that the *CastAway* measurements did not interfere with the primary goal of monitoring the oil plume.

The large CTD rosette with the *SBE 19plusV2* was deployed from the stern A frame, and the ship was oriented with the stern into the wind and seas. *CastAway* profiles were conducted independently from mid-ship on the starboard side, keeping the *CastAway* well away from the CTD cable and the ship's propellers. During *CastAway* profiles the ship was oriented such that the wind and seas were on the starboard quarter to reduce the chance of the *CastAway* getting under the ship.

CastAway downcasts were conducted as close as possible to the start of the SeaBird downcast. For the

first comparison the CastAway downcast began 0.72 minutes before the start of the SeaBird downcast. The CastAway downcast was delayed for comparisons 2 and 3 by 6.85 minutes and 19.38 minutes respectively. These timing differences and hence spatial offsets may result in comparison errors introduced by high frequency spatial and temporal environmental variations. However, this deployment strategy allowed the CastAway to be deployed using the recommended free fall method and therefore it experienced the flow rates for which it was designed, which would not have been the case if had been attached to the larger SeaBird CTD frame. This setup also provided an opportunity to evaluate the recommended deployment and recovery method aboard a ship at sea.

For our first test cast we attached parachute cord to the CastAway and lowered it by hand. We quickly learned that the drag and the buoyancy of the cord was not suitable for full 100 meter deployments. For all subsequent casts including the casts used for this comparison we used 80 pound test braided fishing line (Gorilla Super Sinking Braid, Camo, GTQS80-14, Kmart SKU 28632 16057) on a fishing pole. All casts compared here also had a two pound dive weight suspended from the bottom of the CastAway CTD. This seemed necessary to help maintain a more vertical line, a necessity since the only way to estimate the cast depth is to know how much line was deployed.

c. Data Analysis

Each of the three comparisons was conducted using downcast data within the pressure range of the CastAway profile. Due to the profile start time offsets, data from the SeaBird and the CastAway was aligned by pressure rather than time for each of the three comparisons. The CastAway and SeaBird pressure sensor data have inherent errors within the range of the accuracy specifications of each instrument. The SeaBird pressure sensor has a full scale of 2000 meters with an accuracy specification of 0.1% full scale which equates to an accuracy of 2m. The CastAway pressure sensor has a full scale of 100 meters and an accuracy specification of 0.25% full scale which translates to an accuracy 0.25m.

When compared to the CastAway dataset the SBE 19*plus*V2 had an overall pressure bias of -0.5m. This pressure difference could be associated solely with the

lower pressure sensor accuracy of the SBE 19*plus*V2 or it could be related to pre-deployment zeroing of the pressure sensor to account for variations in atmospheric pressure. The CastAway internally zeroes the pressure sensor to the water surface with each cast, while the SeaBird requires a manual zeroing as part of an on-deck pre-deployment instrument setup. It is possible that the 0.5 dBar offset is associated with the vertical distance between the pressure sensor zeroing locations.

The SBE19*plus*V2 has a sampling rate of 4HZ while the CastAway has an output rate of 5Hz. For statistical comparison purposes the CastAway data was linearly interpolated to the 4Hz sampling rate of the SeaBird reference sensor.

To describe the differences between the SBE 19*plus*V2 and CastAway measurements statistics were calculated for each of the comparison casts. The average difference (AD), standard deviation of the difference, and median absolute deviation (MAD) were calculated for the conductivity and temperature measurements and derived salinity for each of the comparison casts. The median absolute deviation is a more robust statistic than standard deviation which can be significantly impacted by a small number of outliers as typically found in non-normal distributions.

III. Results

a. Conductivity

Figure 3 shows overlays of the conductivity profiles of both of the instruments for the three comparisons. The largest conductivity gradients were observed in the first comparison, with a span of 5.06 – 6.04 S/m. The conductivity differences between the sensors are displayed in Figure 4. As expected, for all casts the largest conductivity differences occur in areas with the largest gradients, with better agreement between sensors when conductivity is more stable throughout the water column. Table 3 presents the summary statistics for the conductivity comparisons. Average conductivity differences ranged from -0.007 to 0.0001 S/m with the median average deviation ranging from 0.004 to 0.01 S/m. The sensors agreed best during Cast 1, which of the three casts also exhibited the largest conductivity range.

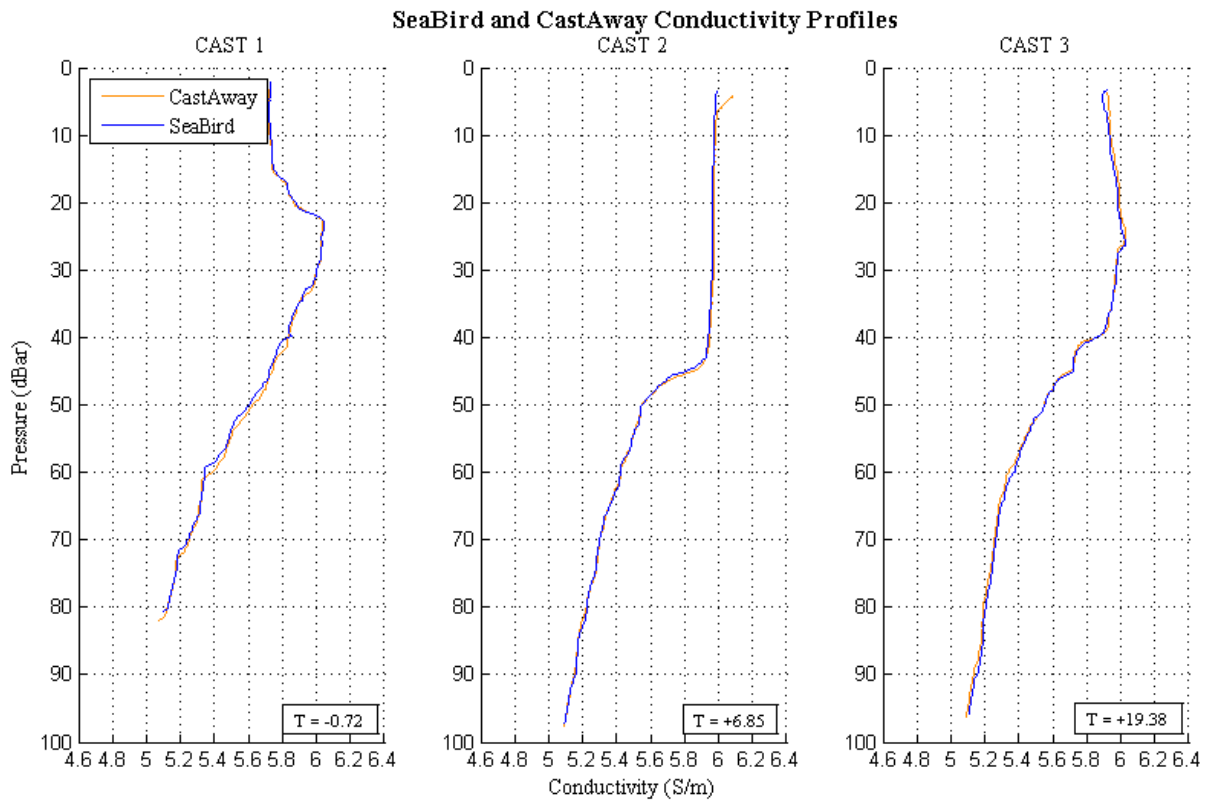


FIG. 3. Conductivity profiles over pressure for each of the three comparison casts. A -0.5 dbar offset has been applied to the SeaBird datasets. T values represent time difference in minutes between the start of the SBE 19plusV2 downcast and the start of the CastAway downcast.

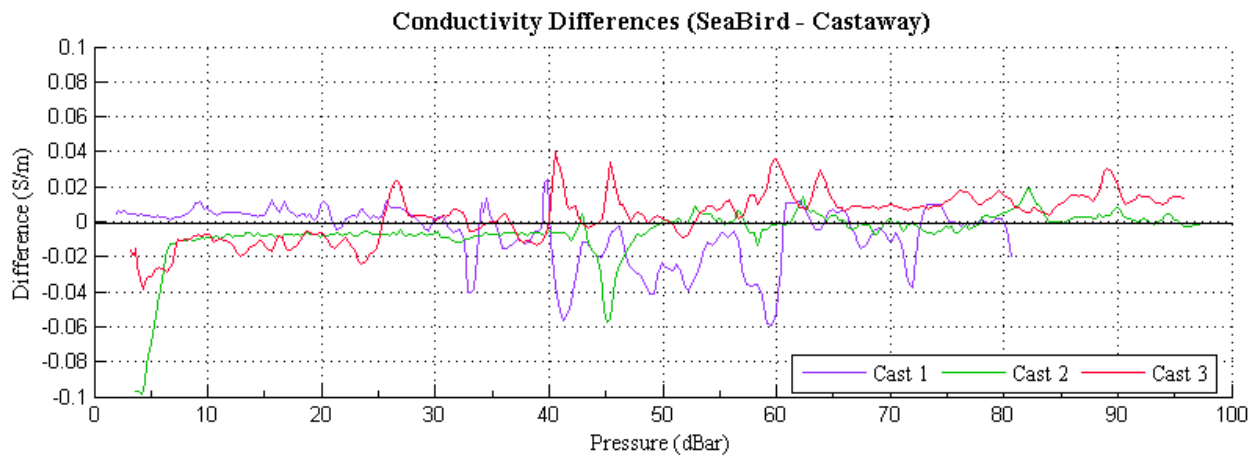


FIG. 4. Conductivity differences in S/m for each of the three comparison casts, SBE 19plusV2 – CastAway.

TABLE 3. Summary statistics for the conductivity comparison. Statistics include average difference in conductivity (AD), standard deviation of AD, number of observations (N), and median average deviation (MAD).

	AD (S/m)	Std dev (S/m)	N	MAD (S/m)
Cast 1	0.0003	0.0127	264	0.0046
Cast 2	-0.0073	0.0164	300	0.0069
Cast 3	0.001279	0.01492	296	0.0106

b. Temperature

The full temperature range was similar for each the three casts with a range from about 21 to 30 °C, as displayed in Figure 5. Again, as expected, the largest temperature differences between the sensors occur in areas of steeper gradients with better agreement when the temperature levels more stable. Figure 6 shows the average temperature differences (SBE 19*plus*V2 – CastAway) with temperature differences ranging from 0.02 to 0.09 °C with the median average deviation ranging from 0.04 to 0.1 °C (Table 4).

TABLE 4. Summary statistics for the temperature comparison casts. Statistics include average difference in temperature (AD), standard deviation of AD, number of observations (N), and median average deviation (MAD).

	AD (°C)	Std dev (°C)	N	MAD (°C)
Cast 1	0.0249	0.1136	264	0.0425
Cast 2	0.0904	0.1524	282	0.0534
Cast 3	0.0887	0.1209	296	0.1019

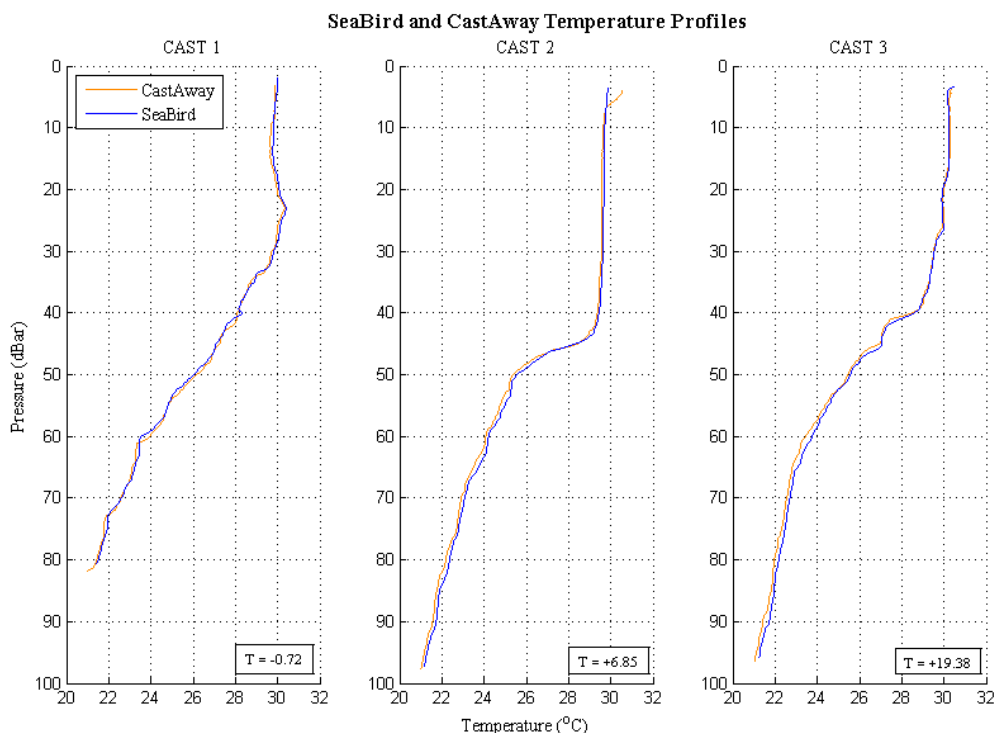


FIG. 5. Temperature profiles over pressure (depth) for each of the three comparison casts. A -0.5 dBar offset has been applied to the SeaBird datasets. T values represent time difference in minutes between the start of the SBE19 downcast and the start of the CastAway downcast.

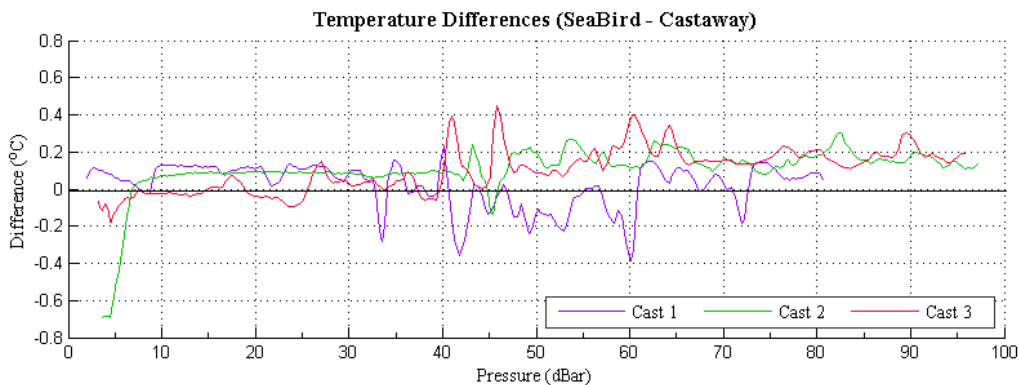


FIG. 6. Temperature differences (°C) for each of the three comparison casts, SeaBird – CastAway.

c. Salinity

Figure 7 shows salinity profiles for both of the instruments for each of the three comparison casts. The largest range in salinity was measured in Cast 1, with a range of 34.2 to 36.5 (PSU). The differences between the sensors (SBE 19*plus*V2 – CastAway) are displayed in Figure 8. The largest salinity differences correlate with the largest differences in temperature. There appears to be a constant offset to the salinity measurements from Cast 2 which likely correlates with the higher average temperature difference of the cast. Table 5 presents the salinity comparison summary statistics. The median average deviation ranged from 0.011 to 0.032 PSU and the first and third casts both had average salinity differences of about 0.05 PSU.

TABLE 5. Summary statistics for salinity comparison. Statistics include average difference in salinity (AD), standard deviation of AD, number of observations (N), and median average deviation (MAD).

	AD (PSU)	Std dev (PSU)	N	MAD (PSU)
Cast 1	-0.0561	0.0623	264	0.0323
Cast 2	-0.1241	0.0384	300	0.0110
Cast 3	-0.0597	0.0447	296	0.0265

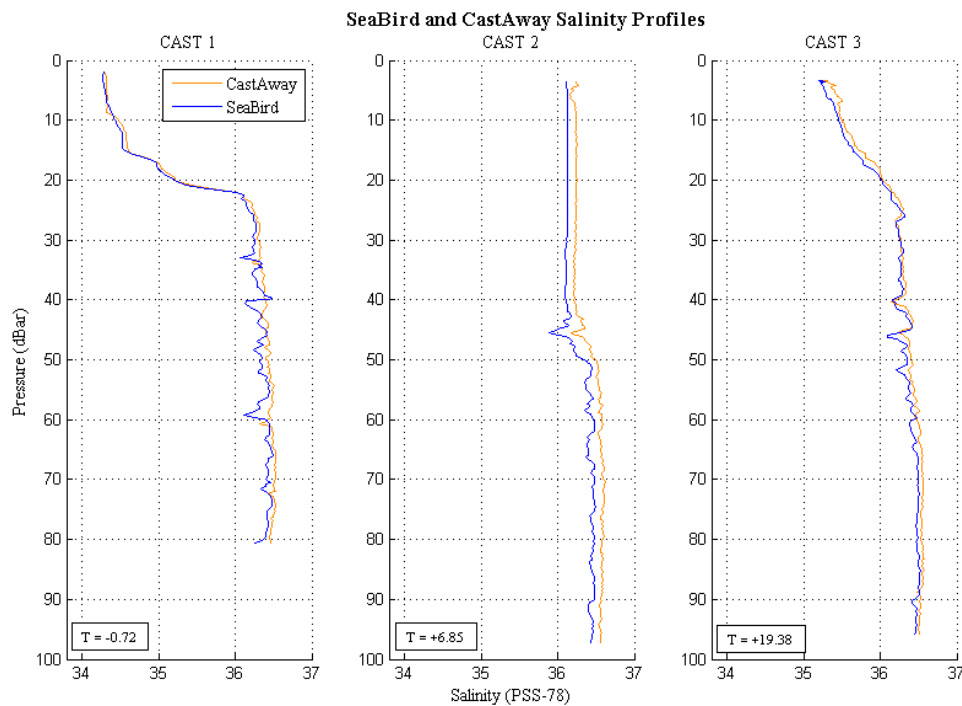


FIG. 7. Salinity profiles over pressure (depth) for each of the three comparison casts. A -0.5 dBar offset has been applied to the SeaBird datasets. T values represent time difference in minutes between the start of the SBE19 and CastAway downcasts.

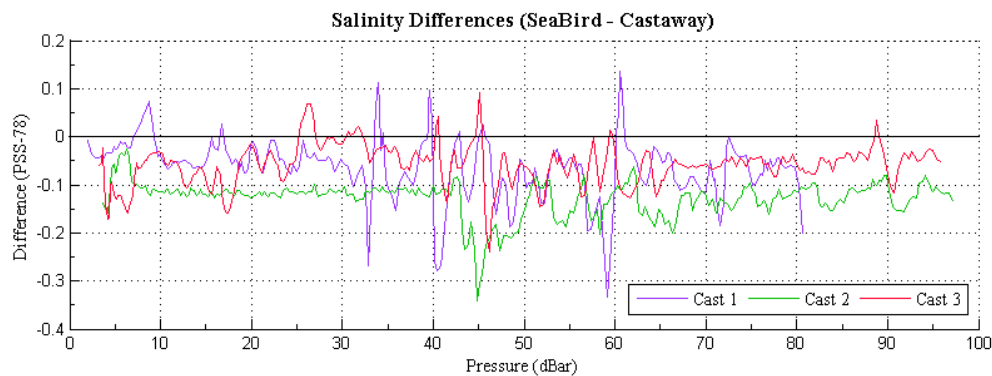


FIG. 8. Salinity differences (PSU) for each of the comparison casts, SBE19 – CastAway.

IV. Discussion

We were fortunate to be able to conduct these comparison tests with very little effort, and we found them to be a worthwhile venture. We focused on the performance of the CastAway and its sensors in comparison to the SeaBird 19*plus*V2, and only glanced at the supporting CastAway PC software. As is usually the case, better ways to conduct such tests became clear during the course of the testing. Future comparisons would ideally be performed as truly coincident casts to minimize time offsets. The much larger depth range and correspondingly larger accuracy specification of the SBE 19*plus*V2 strain-gage pressure sensor made for a less than ideal reference for our pressure aligned comparison. Subsequent tests against a SAIV A/S CTD model SD204 with a 500 meter pressure sensor have been conducted and may provide more comparable results.

The first comparison had the shortest time offset between the start of the instrument downcasts, and as expected it generated the most comparable data indicating that future comparisons would also benefit from minimizing the sensor deployment lag times. Despite our inexact deployment methods, the results of the comparison are encouraging and the CastAway certainly seems to be as accurate as it's quoted specifications for each of the parameters evaluated. However, the true merit of our field evaluation was in testing operational usefulness of the CastAway.

The size and simplicity of the CastAway belies the thoughtful design. The built in GPS ensures there is no confusion regarding time or location of the cast. The onboard data processing and display allows the operator to be confident that useful data has been collected instantaneously. Much thought was given to the onboard data processing (as described in the manual appendix A), relieving the operator of tedious multiple-step data post processing.

The use of standard AA batteries rather than a rechargeable battery pack means that users have the simplest option of all regarding power. They can choose to use alkaline or rechargeable AA batteries, and need only maintain a sufficient supply. It also means that users must open the CastAway to install the batteries, so care must be taken to ensure that the battery compartment remains clean and dry and the O ring seal properly cleaned and lubricated.

Our preliminary testing does not address the stability of the CastAway, nor did it stress the device in ways which could identify flaws. Temperature extremes, impact, low voltage operations and similar tests should be conducted and reported by users.

V. Conclusions

Our simple tests and early working experience with the CastAway have shown it to be a versatile tool, useful for quickly and easily obtaining temperature and conductivity profiles in shallow waters. It also seems to meet and may even exceed its stated specifications. We look forward to conducting further tests to perform a more in depth evaluation of the systems technical qualifications.

Acknowledgements

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Jennifer Patterson
Oceanographer / Ocean Product Manager
SonTek/YSI
San Diego, CA
jpatterson@sontek.com

Mark Bushnell
Senior Oceanographer
Tellus Applied Sciences
Virginia Beach, VA
mbushnell@tellusappliedsciences.com

Manuel Haenggi
Independent Contractor / Oceanographer
Continental Shelf Associates
manuelhaenggi@comcast.net