Northeast Fisheries Science Center Technical Memorandum 448

Processing and Deployment Methods for Conductivity Temperature and Depth (CTD) Instruments Profiles on Northeast Fisheries Science Center Surveys

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Editorial Notes

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1.0 Introduction

This document describes the standard equipment, deployment methods and data processing techniques for conductivity temperature and depth instrument profiles carried out by the Northeast Fisheries Science Center (NEFSC) Oceanography Branch. The NEFSC deploys conductivity, temperature and depth (CTD) instruments on the NEFSC's resource monitoring surveys including, but not limited to, the Ecosystems Monitoring and seasonal Bottom Trawl Surveys. This CTD profile data contributes to a long term, quality controlled hydrographic dataset on the Northeast U.S. Continental Shelf that began in 1977 with the Marine Resources Monitoring and Assessment Program (MARMAP).

Hydrographic data collection methods have evolved with improving technologies since the time series was initiated. From 1977-1987, temperature and salinity were measured using bottle samples and traditional mercury thermometers. In 1981, the NEFSC began using electronic CTD instruments starting with the Neil Brown Mark III. However, bottle sampling remained in active use as a primary source for temperature and salinity data measured by the NEFSC until 1987. Afterward, CTDs took over as the primary instrument for temperature and salinity profiles, with bottle samples being used for calibration of the CTD.

In 1987 the Sea-Bird Electronics SBE-917 was added to the CTD instrument inventory used by the NEFSC. The SBE-917 consisted of an SBE-9 CTD paired with an SBE-17 SeaRAM to provide power and data logging. Both the SBE-917 and the MKIII were used by the NEFSC until 1989.

In 1990 the SBE-19 SeaCat was adopted by the NEFSC. SeaCat variants remain in active use by the NEFSC as of this writing. Between 1992 and 1998 the NEFSC also used the Neil Brown Mk V CTD. Since 1999, the NEFSC's CTD inventory has included the SBE-911plus CTD. The SBE-911plus pairs the SBE-9plus with an SBE-11 deck unit, but unlike the SBE-17 this configuration is deployed on a conducting wire enabling real-time data collection.

This summary of past data collection is provided for historical context, and as reference for users of the full long-term dataset but the focus of this document will be to describe the methods and instruments that are in active use as of 2026. However, many of the general data processing concepts can be applied to any CTD data.

2.0 Current Instrumentation

The NEFSC Oceanography Branch maintains an inventory of profiling CTDs (Table 1). As of 2026, the inventory includes Sea-Bird Electronics SBE-19 SeaCat family and the SBE-911plus. These CTDs differ in their physical size, depth range, sampling rate, external sensor support, and power delivery. The selection of the instrument to use depends on the mission requirements.

Both the SBE-911plus and SBE-19plusV2 can support external sensor inputs. This commonly includes SBE-43 oxygen sensors, PAR sensors, fluorometers or altimeters. This document focuses on the primary CTD sensor capabilities, but this external sensor support is an important mission capability.

These CTD models use ducted temperature and conductivity sensors where an external pump actively delivers water to the sensor duct. The pumps can also supply additional inline instruments such as dissolved oxygen sensors.

Table 1: Profiling CTD Instrument types in active use by the Oceanography Branch 1990–2025

Instrument	Maximum sampling rate	External sensor support	Notes
SBE-911plus	24Hz	Yes	Used with either a 12 or 24 bottle SBE-32 water sampler. Requires conducting wire and slip-ring winch. Supports dual temperature and conductivity sensors for additional quality control and redundancy.
SBE-19plus and 19plusV2	4Hz	Yes	Can deploy in real-time or archive mode with either ship or internal battery power.

SBE-911plus

The SBE-911plus is a multi-part system consisting of an SBE-9plus hub paired with an SBE-11 deck unit, SBE-3 temperature (T) sensor and SBE-4 conductivity (C) sensor. The unit records data at 24Hz. Dual SBE-3 and 4 sensors may be used to provide redundancy.

The SBE-911plus is used in combination with a 12 or 24 bottle SBE-32 Carousel Water Sampler (Figure 1). The SBE-32s used by the NEFSC support 1.7-, 5-, or 10-liter Niskin bottles. The CTD operator triggers the Niskin bottles to close and collect samples at desired depths for later laboratory analysis. Common laboratory analyses include carbonate chemistry, nutrient measurements, chlorophyll, dissolved oxygen or salinity calibration samples.

The SBE-911plus requires a slip-ring winch and conducting wire to operate. Power and communication are provided via the SBE-11 Deck Unit since this CTD lacks onboard data logging and power. Due to the size of the unit and winch requirements, this CTD is generally only suitable for deployment from larger vessels that are equipped for oceanographic operations.

SBE-19/19plus/19plusv2 SeaCat family

The SBE-19 SeaCat (Figure 2) family of CTDs have internal batteries and logging capabilities and can run in a logging mode on their own power or use deck unit power and real

time communications via a conducting cable and slip ring winch. The current SeaCat model used by the NEFSC is the SBE-19plusV2 but the SBE-19plus and 19 have both been used in the past. The SeaCat CTDs are smaller and lighter than the SBE-911plus, but have a slower 4Hz sampling frequency, and lack the ability to have dual T and C sensors.

The SeaCat is used by the NEFSC for both stand-alone vertical profiles and mounted above bongo net frames during plankton net tows operations. During vertical profiles, a water sample may be collected from depth using a Niskin bottle mounted above the CTD that is tripped using a mechanical messenger.

The SBE-19 can be run in different modes depending on the capabilities of the host vessel and deck equipment. The first mode is with real time power and data provided via a power and data interface module (PDIM) and SBE-33 deck unit with the CTD providing real time data. The PDIM unit allows the CTD to send data over greater lengths of wire. The second method is with real-time serial data connection directly from the CTD to a computer, with the CTD using internal battery power. The length of the wire limits the rate of data transmission, which can require averaging samples in the CTD prior to transmission when the CTD is used without a PDIM and deck unit. The final method is with the CTD logging data internally, operating from battery power and with no real time communication. Of these methods, real-time mode is preferred, with the internal logging only used when the host vessel lacks the necessary conducting wire.

A PDIM is typically preferred when real time communication is used, as this allows transmission of data over a greater length of wire, and simplifies operations by allowing a deck unit to power the CTD. Without the PDIM and deck unit, the communication baud rate between the CTD and computer decreases with increasing length of wire, and will often require the CTD to average data prior to transmission rather than transmitting the data at full resolution. This effectively reduces the sampling frequency. Additionally, when external power is provided to the CTD, the CTD can be set to begin data collection as soon as power is provided, whereas when operating from the battery, the CTD must be activated on deck with the magnetic switch.

3.0 Deployment Protocols

The NEFSC uses these instruments for several different deployment types (Table 2) including vertical casts, collection of water samples, and bongo net plankton tows. Deployment of CTDs with nets and water samplers permits the acquisition of temperature and salinity data concurrently with other biological or chemical sampling to support research, environmental monitoring and stock assessments.

Table 2: Standard CTD deployment types used by the NEFSC's Oceanography Branch.

Deployment Type	Gear information	Profile	Notes
SBE-19 vertical profile	SBE-19, 19plus or 19plusV2 CTD	Vertical	CTD mounted on the wire above a weight or in a cage attached to the end of the wire. For profiles performed beyond the shelf break, the maximum sampling depth is typically limited to 500 meters.
SBE-19 vertical water cast	SBE-19, 19plus or 19plusV2 CTD and Niskin bottle	Vertical	CTD mounted on the wire above a weight or in a cage attached to the end of the wire with a Niskin bottle mounted above the CTD to collect a water sample. Primarily used to collect salinity calibration samples. For profiles performed beyond the shelf break, the maximum sampling depth is typically limited to 500 meters.
SBE-911/SBE32 Carousel deployment	SBE-911plus CTD with SBE-32 water sampler with either 12 or 24 bottle configurations	Vertical	Used to collect both vertical CTD profiles and water samples. This is the primary mode of deployment to collect water samples for laboratory analysis. For profiles performed beyond the shelf break, the maximum sampling depth is typically limited to 500 meters.
Bongo Oblique tow	SBE-19, SBE-19plus, or SBE-19plusV2 with a bongo net.	Double oblique tow profile	CTD mounted on the wire above a bongo net frame. In water greater than 200m, this deployment is often paired with a separate vertical CTD profile of the full water column or 500 meters.

CTD Profile Types

The NEFSC performs CTD profiles using either the SBE-19plusV2 or the SBE-911plus CTDs. CTD profiles may be stationary, vertical deployments for water column profiling and sampling or may be towed, oblique deployments for water column profiling to accompany bongo-net plankton collections. Vertical CTD casts may be accompanied by water sampling from a single Niskin bottle attached directly to the wire above an SBE-19plus or from 12 or 24 Niskin bottle configurations within an SBE-911plus/SBE-32 Carousel water sampler system.

The simplest deployment mode is a vertical cast with an SBE-19 CTD. This can be done with the SBE-19 clamped directly to the wire above a weight or with the SBE-19 mounted in a protective cage, which is attached to the end of the wire. Clamping the SBE-19 directly to the wire is the method most commonly used on NEFSC surveys because it facilitates easy transition between SBE-19 vertical casts and bongo-net oblique tows.

Vertical casts with an SBE-911/SBE-32 Carousel water sampler system allow water column profiles accompanied by acquisition of additional sensor data including dissolved oxygen, PAR, fluorescence, or other parameters as well as 12 or 24 water samples.

Bongo-net oblique tows utilize an SBE-19plus CTD mounted directly to the wire above the bongo-net frame. The NEFSC-Oceanography Branch conducts oblique tows to a maximum of 200m. For depths over 200m, an additional vertical cast with the SBE-19 CTD, often with a Niskin bottle, is conducted to a maximum depth of 500m.

Vertical CTD Profiles

The most basic method of CTD deployment is the vertical profile. The NEFSC typically performs vertical profiles using either the SBE-911plus or SBE-19plusV2 CTDs.

The simplest deployment mode for the SBE 19 is a vertical cast attached to the wire. This can be done with the CTD clamped directly to the wire or with the CTD mounted in a protective cage. Clamping directly to the wire is the method most commonly used on NEFSC surveys because it facilitates easy transition to deployments with a CTD and Bongo net.

During a vertical CTD deployment, the instrument is deployed over the side, powered on and then sent down to a safe depth of around 10 meters to soak for 1 minute. This soak period allows the pumps to engage and flush any air from the ducts and plumbing. Once the soak period is complete, the CTD is returned to just beneath the surface, taking care not to allow the CTD to break the surface and pull air into the pump. The user then begins recording data and sends to the CTD to the full depth of the profile. The wire out speed is typically around 50 meters per minute, but this may vary depending on winch capabilities and mission needs.

The ship's depth sounder is used to estimate the water depth and establish the maximum depth of the profile to avoid contact with the seafloor. If the CTD is equipped with an altimeter this may also be used to determine the maximum profile depth. Typically, the CTD will profile to within 5 to 10 meters of the bottom depending on the conditions. When sampling occurs beyond the shelfbreak, the profile depth is often limited to 500 meters rather than the full water column depth. The CTD operator will signal the winch operator to let them know when the CTD is ten meters from the maximum depth. The winch operator will slow the wire payout rate to allow for more precise control at the desired stopping point. Once the target depth is reached, the CTD operator will signal the winch operator to stop and haul back.

As the CTD nears the surface during the upcast, the winch operator will slow the wire, stopping with the instrument just below the surface, allowing for the sea-state, and the CTD operator will then shut down the instrument for recovery.

Water Sampling During a Vertical CTD cast

If water samples are to be collected during a CTD cast, this is done either with an SBE-32 Carousel electronic water sampler or a traditional mechanical Niskin bottle activated using a messenger weight dropped down the wire. The deployment is carried out similarly to a vertical CTD profile but pausing to collect water samples during the upcast.

The carousel sampler allows water samples to be collected at multiple and specific depths in the water column. These samples can be used for a variety of laboratory analyses depending on the scientific mission of a cruise. Some examples include dissolved oxygen, pigment measurements, environmental DNA (eDNA), dissolved inorganic carbon, pH, total alkalinity or nutrients.

Collecting water samples while the CTD is returning on the upcast allows the CTD operator to use the downcast profile to scout the water column and select sampling depths. It also allows for a more continuous profile during the downcast, which typically generates the highest quality CTD data in a vertical cast due to the orientation of the sensor and its plumbing relative to the direction of profile motion.

The Niskin bottles are prepared with end caps opened and attached to the firing mechanism prior to deployment. It is critical that these caps be opened even if water samples are not to be collected to prevent the bottles from imploding under pressure. The bottle's stopcocks and vent knobs are both placed into the closed positions. This will prevent leakage once the bottle end caps are closed at depth.

The CTD operator requests that the CTD be held at each target sampling depth for 1 minute. This time helps ensure that the water sample is representative of the targeted depth. When possible,

multiple bottles are triggered at the same depth to provide redundancy in case of bottle misfires that would otherwise result in a lost sample.

When water is collected during a vertical cast using an SBE-19plus CTD, a single Niskin bottle is mounted on the wire. As with the SBE-32/SBE-911 deployment, the operator holds the CTD at the target depth but the bottle is then triggered by attaching a weighted messenger to the wire and dropping it down the wire. When the weight reaches the sampling bottle, it activates a mechanical trigger that closes the bottle. Upon closure, the bottle and CTD are retrieved.

Once on deck, the water samples are collected and processed. The processing methods will vary depending on the intended purpose of the sample and are beyond the scope of this document.

Double Oblique Net Tows- Real Time CTD

Many of the Northeast Fisheries Science Center's CTD casts are paired with double oblique bongo net tows. Double oblique refers to the V-shaped tow profile through the water. The CTD data is still processed as a vertical profile with an up and down cast. Bongo nets consist of two side by side circular net frames with cone shaped plankton nets attached. The primary bongo nets have a 61 cm opening. A 45 kg depressor weight is hung below the net (Figure 3). This weight is necessary to help the net overcome drag and descend through the water column while it is being towed behind the ship. The CTD is mounted on the wire directly above the primary bongo net frame with the intake facing up. For a vertical deployment without a bongo the intake would normally face down. This difference is because the upcast CTD data is preferred with bongo net tows due to the lack of a surface pre-soak on that type of deployment. Often, a 20 cm-opening bongo is mounted above the CTD to collect additional samples, typically with different net mesh sizes from the primary bongo.

To deploy the net, the vessel first establishes the desired speed and heading. The target speed is generally 1 to 2 knots but will vary with currents. The deck crew raises the wire with the CTD attached, clips on the nets and depressor weight, and begins lowering the assembly over the side. At this point, the CTD operator powers on the CTD using the deck unit, and the assembly is lowered fully into the water to begin the tow. The wire is paid out at a rate which depends on the expected maximum depth of the tow (Appendix A). The maximum depth is either 5-10 meters from the seafloor or 200 meters, whichever is shallower. The maximum depth is limited by the performance of the nets as drag increases with increasing amounts of wire out during the tow. In cases where the water is too deep for the bongo nets to get within 5-10 meters of the bottom, a separate vertical CTD cast is performed after the bongo is recovered to sample the full water column.

The vessel's speed is adjusted to maintain a wire angle of approximately 45 degrees. The exact speed varies depending on the water currents in which the net is travelling. The CTD operator monitors the depth using the real time CTD data, and also monitors depth on the ship's sounder as

the bottom depth often changes as the ship moves during a tow. When the nets approach within ten meters maximum tow depth, the CTD operator alerts the winch operator. When the maximum depth is reached, the CTD operator notifies the winch operator to stop and haul back.

Once the CTD reaches the surface, it is powered off from the deck unit prior to recovery. At this point the deck crew brings the assembly out of the water, unclips the smaller secondary bongo net if present, and brings the rest of the CTD and bongo net assembly aboard.

Because the nets begin to fish as soon as they enter the water, it is not practical to do a surface soak as is done with a vertical cast. This means that the initial CTD data is not usable because the plumbing of the CTD has not been fully primed. For this reason, the upcast data is used in data products from casts collected in this way.

Double Oblique Net Tows: Archive Mode

This is a variation of the double oblique tow used when the host vessel lacks a hydrographic winch to provide real time communication with the CTD. In this case the CTD is switched on using a magnetic switch while on deck and then turned off again on deck after recovery. The other difference is that depth must be estimated from the wire angle and amount of wire out. This makes it important to maintain a consistent wire angle during the tow to ensure the net is at correct target depth. Otherwise, the tow is conducted in the same way as a real time deployment. For this type of deployment, it is particularly important to maintain the target wire angle since the wire angle is used to estimate tow depth.

Bongo Tow-Yo

A tow-yo, named for its similarity to a “yo-yo” is where the bongo net is towed up and down on repeated cycles. Effectively it is a series of back-to-back double oblique tows without removing the net from the water. This type of tow is most often used to collect less abundant larval fish by maximizing the amount of water filtered by the nets. It may also be constrained to a narrow upper and lower depth range to target a species of interest.

Alternate Net Configurations

The various bongo net deployment types described above are sometimes adapted for use with different types of plankton nets, but the CTD portion of the operations are conducted similarly to the above in those cases.

4.0 CTD Calibration

CTDs are sent annually to the manufacturer for calibration and routine maintenance to ensure the collection of high-quality data. To be in the active rotation of sensors deployed in the field, CTDs must have been calibrated within the past year.

In addition to the annual factory calibration, water samples are routinely collected during vertical CTD casts. The conductivity of these water samples is measured in the laboratory with a salinometer and the results are used to correct the slope of the factory conductivity calibration. This is done to account for drift in the conductivity sensor over time.

Calibration samples are taken from isohaline sections of the water column to ensure a good match between the CTD's sensor and the water sample. The water sample is collected using a Niskin bottle. Because the Niskin bottle is not exactly collocated with the CTD (typically within 1 meter), sampling an isohaline section of the water column ensures that the CTD measurement and the calibration samples are comparable.

The laboratory salinometer is calibrated with IAPSO Standard Seawater prior to measuring samples. The sample conductivity values are then compared to the CTD measured conductivity values to derive a new calibration slope. This slope is calculated according to the manufacturer's methods as outlined in Sea-Bird Scientific's Application Note 31- Calculate Temperature and Conductivity Slope and Offset Correction Coefficients. One average slope correction for a given trip and sensor is usually derived using the results from all calibration samples. Using this corrected slope, the final conductivity and derived salinity are recalculated.

For SBE-911plus casts using the SBE-32 carousel, the collection of water samples for calibration can be performed routinely with the built-in water sampling capabilities of that system. For deployments with the SBE-19plus, dedicated calibration casts are performed at regular intervals throughout the cruise. For these dedicated calibration casts, a Niskin bottle is mounted on the wire directly above the CTD.

5.0 Data Processing- Vertical and Double Oblique CTD deployments

Data processing occurs in multiple steps. The descriptions in this section focus on what is being done at each step, but since software versions change over time, please refer to current software manuals for details on how to carry out each step. This section details the data processing methods for vertical CTD casts and double oblique tows, which are both processed as up and down casts using the same general approach. These two types of deployments constitute the bulk of CTD operations conducted by the NEFSC Oceanography Branch.

The initial step is to perform the conversion of the raw CTD data to calibrated values in meaningful units using the Sea-Bird Electronics data processing software. Documentation on the software used and the underlying equations it uses may be found in the Seasoft V2: SBE Data Processing manual. Conversion of the raw data is followed by application of a suite of standard corrections and filters, to be explained in detail later in this section, as well as visual inspection of the data to flag density inversions or other features that indicate a data quality issue. Finally, a conductivity correction is applied using Niskin bottle salinity samples collected in parallel to the CTD.

Figure 4 shows an example of raw CTD data compared to the results after processing with the Sea-Bird data processing software. This includes aligning the sensor channels with pressure in time, a low pass filter, correcting for the cell thermal mass, correcting for vertical reversals and sensor profiling speed, and bin averaging. This does not correct all errors. Therefore, additional visual quality control steps also must be performed. Each of these steps will be detailed in the next sections.

Data conversion

The raw CTD data from the instruments must be converted to calibrated values in meaningful scientific units by applying the factory calibrations. The Sea-Bird software generates several files during a deployment when used in real time mode. These files will have the same file name, chosen at the start of the cast, but different file type extensions. One of these files contains the raw CTD data and will have a ".hex" extension. Another is a configuration file that will have either a ".con" or ".xmlcon" extension.

The configuration file contains the calibration information for the CTD as well as information on any attached secondary sensors. It is a copy of the active "xmlcon" or "con" file at the time the CTD was deployed, effectively archiving a static snapshot in case the master configuration file is later changed. It is critical that the correct calibration file is used. Using the wrong file will produce inaccurate values or may cause processing to fail entirely if the sensor configuration doesn't match. If there is an error in the configuration file, for example the calibration information was outdated and needs to be updated, this should be corrected prior to data conversion.

This initial rough conversion produces values in meaningful units, but with no additional quality control or correction beyond applying the calibration information stored in the configuration file. The data at this stage is treated as preliminary and is subject to uncorrected errors but it is used and made available for limited applications such as real time validation of ocean models.

Wild Edit

Wild Edit is a module in the Sea-Bird software that is run as an optional step with very spiky data. It is not used in most cases. This type of data is usually symptomatic of a technical problem with the instrument. Wild edit will flag the anomalous values with a "bad flag" value. It flags the individual parameters (temperature, conductivity etc), not the entire scan. This flag is used in later processing steps to exclude bad data from analyses and products.

Filter

Using the SeaBird software, the "Filter" step is selected next. This runs a low-pass filter which smooths out rapid changes in the data. Two different time constants can be used, one for pressure and one for temperature and conductivity.

The NEFSC uses the Sea-Bird software's recommended values for each instrument type. For the SBE-19plus instruments this is a 0.5 second window for temperature and conductivity and a 1 second window for pressure. For the SBE-911plus, only a 0.15 second pressure window is used.

Align CTD

The "Align CTD" module of the Sea-Bird software is run next. As water is pumped through the CTD's plumbing, there is lag in the response of temperature, salinity and any other ducted sensors such as dissolved oxygen relative to pressure. This is due to the delay caused by the water moving through the plumbing to ducted sensors, whereas the pressure sensor is exposed to changing ambient conditions instantly.

An obvious symptom of this is that if you plot temperature or conductivity against pressure, the up and down casts at a fixed location will be offset from one another in depth even though they were measuring the same water column (Figure 5). Using misaligned temperature, conductivity and pressure will also result in erroneous calculation of salinity, density or any other derived parameters that combine the misaligned variables.

The align step simply offsets the data in time to account for this lag. For each parameter a constant offset is applied to the entire deployment. The value of this offset depends on the configuration of the individual instrument. Plotting the data allows the user to evaluate whether the selected offset is appropriate by checking alignment between the up and downcast profiles.

Cell Thermal Mass

The "Cell Thermal Mass" module is the next step applied to the data. This step compensates for the effect of the conductivity cell's thermal mass on the conductivity measurements. Thermal mass describes how quickly something can absorb or release heat. As the CTD is exposed to changing temperatures, the conductivity cell's thermal mass can reduce the accuracy of the

measured conductivity if not corrected for. The manufacturer recommended settings are used when correcting each model of CTD.

Loop Edit

Loop edit is used for vertical CTD deployments or oblique CTD tows where the CTD is expected to follow a relatively continuous down and up trajectory through the water. Loop edit simply checks the vertical velocity of the CTD and flags any data that is below a selected minimum or short vertical reversals ("loops") in the profile. The NEFSC Oceanography Branch uses a constant value of 0.05 m/s. This is slower than the manufacturer's default due to account for oblique bongo net tows, where the upcast may be relatively slow compared to a straight vertical CTD profile

The main reason to use loop edit is to remove "loops" in the profile, where the CTD is moving slowly and can even briefly reverse direction momentarily due to rolling seas combined with a slow winch speed. The result is a more continuous upcast and downcast. For example, if the CTD was held momentarily at a depth, such as collecting a water sample, loop edit would filter this pause in the profile

Derive

The "Derive" module is run next. This module calculates derived parameters such as density, salinity or dissolved oxygen. These parameters are calculated from multiple channels; thus, this step is performed only after alignment, and thermal mass corrections have been made. In later steps a conductivity correction may also be applied using bottle samples collected during the profile. In that case, derived parameters affected by the correction are recalculated. These corrections and any resulting recalculations are done outside of the Sea-Bird software, but the same equations are used.

Bin-Average

The final Sea-Bird module applied to the data is "Bin Average". Before further analysis, the full resolution profile data are bin-averaged to 1 decibar bins. Data with "bad flags" from the Sea-Bird software are omitted. In recent years, the bin average step has been applied within MATLAB rather than the Sea-Bird application for convenience, but the underlying calculation used remained identical.

Combine CTD Data with Station Metadata

The bin-averaged CTD data is combined with other station metadata (position, station depth, vessel information, operational information etc.). This merged data is then given additional visual quality control steps and processing that are performed outside of the Sea-Bird software.

Visual Quality Control

The next step is to visually quality control all profiles (Figure 6). Each parameter is plotted. Clearly bad data or profiles are flagged so that they will not be included in final products. This step is currently performed by plotting the bin-averaged data using an interactive MATLAB program that allows the user flag bad data by clicking a data point on the plot. Data flagged in this way will be excluded from final products. Common issues addressed during visual quality control (QC) are:

1. Artificial density inversions in the profile (). These apparent inversions are caused by a misalignment of the temperature, pressure and conductivity data in a gradient. The earlier alignment step minimizes these errors when done properly, but it does not eliminate it completely. Since density and salinity are derived from all three parameters, misalignment, especially in a rapid gradient, produces anomalous values that manifest as an apparent inversion in the profile where less dense water sits below more dense water. These values are flagged and are not included in final data products.

2. Bad surface values. The CTD may be exposed to air if it breaks the surface. Additionally, at the start of the deployment, the CTD ducts may still have trapped air, particularly if a pre-soak could not be performed as in the deployment of bongo net with attached CTD. In these cases, bad surface data, manifested as unusually low or spiky conductivity data, are flagged and not included in final products.

3. Data spikes due to sensor or wiring issues that were not corrected or removed by the prior Sea-Bird software processing.

Comparison of Primary and Secondary Temperature and Conductivity (SBE 911)

The SBE-911 CTD can carry dual, independent channels for temperature and conductivity. This provides redundancy in the event of failures, but it also allows the user to cross check the two sensors for additional quality control. The user will plot and cross check the two profiles. If they are not in agreement, the user will use independent information such as calibration samples to determine which channel should be used in final products. The selected channel will be used in final products. This step is performed during the visual QC process using the same interactive MATLAB program.

Up and Down Cast Selection

The data are split into up and down cast profiles. Only one of these is typically provided in the final quality-controlled product. This selection, similar to the selection of the primary or secondary conductivity and temperature, is made during the visual QC process. The “cleanest” of

the two profiles is selected. This would normally be the downcast for an SBE-911 deployment because the CTD is below the SBE-32 carousel and therefore it is experiencing water that hasn't been disrupted by the rest of the assembly on the way down. For the SBE-19 attached to a bongo frame or other net, the upcast is typically preferred because there is no surface soak and therefore much of the data is not usable due to the time needed to clear trapped air from the CTD.

Conductivity Corrections

As noted in the CTD calibration section, calibration samples are taken during the cruise and a calibration is calculated using the methods in the manufacturer's Application Note 31. If it is determined that the CTD's conductivity sensor has drifted since factory calibration, the corrected calibration value is applied to the data using the MATLAB visual QC program. Conductivity, salinity and any other affected derived parameters such as density are recalculated at this time based on the correction. In most cases, a single "average" correction slope from all calibration samples is applied to a given unique instrument for an entire cruise based on all calibration samples taken. Typically, cruises are short enough that there is not significant conductivity sensor drift within a cruise, and the deployments are short enough to avoid drift due to biofouling.

Final Data

The final results, which are archived and made available from public databases, consist of either the upcast or downcast, and either primary or secondary conductivity and temperature sensors, whichever was deemed to be the higher quality, as noted above. These results reported as one decibar bin-averaged values. Any data flagged during the QC process are omitted. Salinities are reported using the practical salinity scale of 1978 (PSS-78). Temperature is reported in degrees Celsius using the ITIS-90 scale. Densities are calculated using the Thermodynamic Equation of Seawater - 2010 (TEOS-10).

As of this writing, all data are retained in an Oracle database as a long-term archive. Additionally, data are served publicly through the World Ocean Database as well as the Northeast Fisheries Science Center's ERDDAP server.

Appendix A: Wire payout and rate tables for bongo net tows at different depths.

Bottom depth (m)	Sample depth (m)	Wire out (m)	Rate out (m/min)	Rate in (m/min)	Bottom depth (m)	Sample depth (m)	Wire out (m)	Rate out (m/min)	Rate in (m/min)
11	6	11	8	2	109	104	147	50	20
13	8	14	10	3	111	106	150	50	20
15	10	17	12	4	113	108	153	50	20
17	12	19	14	4	115	110	156	50	20
19	14	22	17	5	117	112	158	50	20
20	15	24	18	5	119	114	161	50	20
22	17	26	20	6	120	115	163	50	20
24	19	29	22	7	122	117	165	50	20
26	21	31	24	7	124	119	168	50	20
27	22	33	26	8	126	121	171	50	20
29	24	34	27	8	128	123	174	50	20
31	26	36	29	9	130	125	177	50	20
32	27	38	30	9	131	126	178	50	20
34	29	41	32	10	133	128	180	50	20
36	31	44	35	10	135	130	183	50	20
38	33	47	37	11	137	132	185	50	20
40	35	50	40	12	139	134	188	50	20
41	36	51	40	12	141	136	190	50	20
43	38	54	43	13	142	137	192	50	20
45	40	57	45	13	144	139	194	50	20
47	42	60	48	14	146	141	196	50	20
49	44	62	49	14	148	143	199	50	20
50	45	64	50	15	150	145	202	50	20
52	47	67	50	16	152	147	204	50	20
54	49	69	50	16	153	148	206	50	20
55	50	71	50	17	155	150	208	50	20
57	52	74	50	18	157	152	211	50	20
59	54	76	50	18	159	154	213	50	20
61	56	79	50	19	161	156	215	50	20
62	57	81	50	19	162	157	217	50	20
66	61	86	50	20	166	161	222	50	20
68	63	89	50	20	168	163	225	50	20

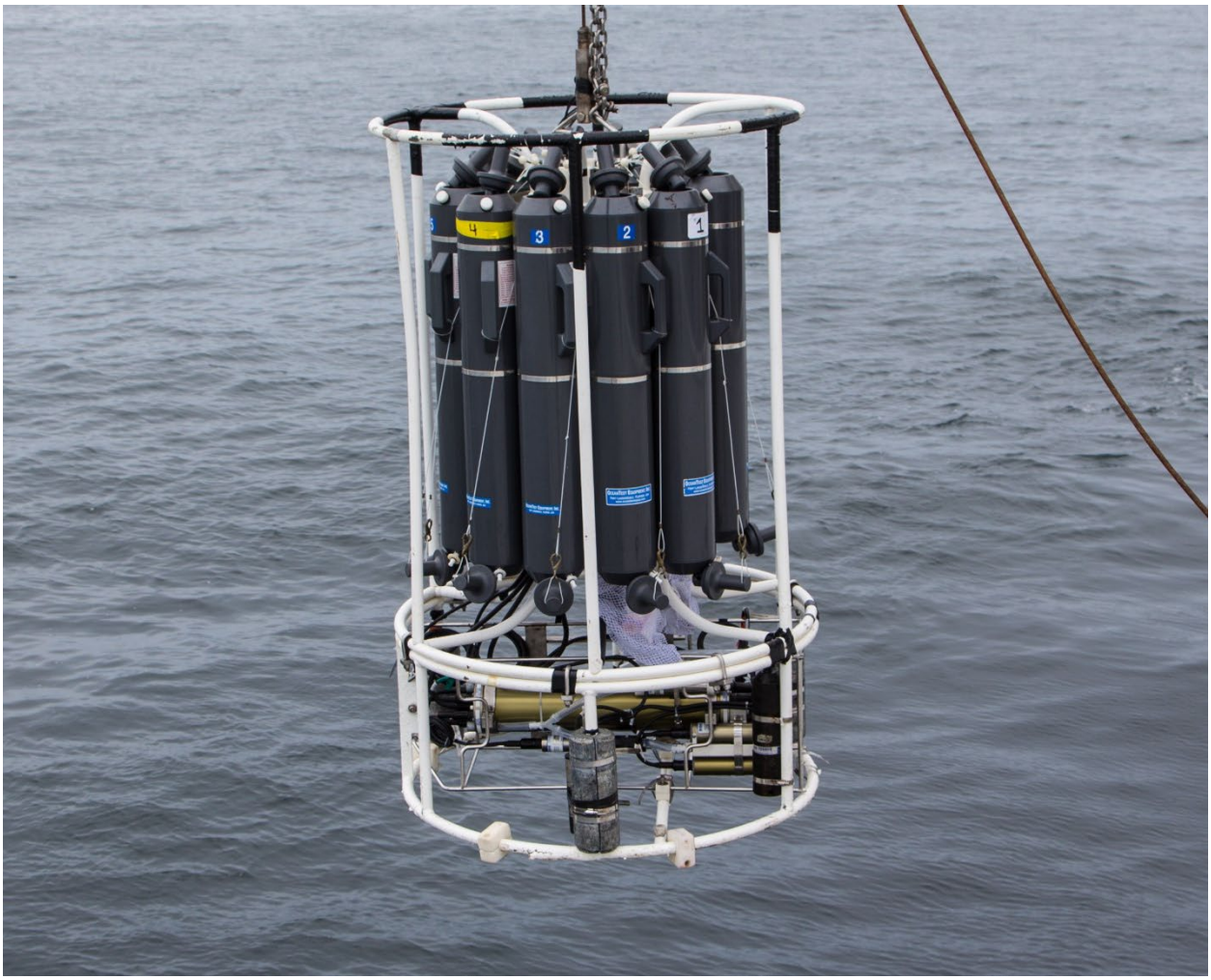

Figure 1: An SBE-32 Carousel with 10-liter Niskin Bottles and an SBE-9plus CTD. Photo Credit: Chris Melrose.

Figure 2: An SBE-19plusV2 SeaCat CTD on deck with attached pump and power and data interface module (PDIM). Photo Credit: Chris Taylor.

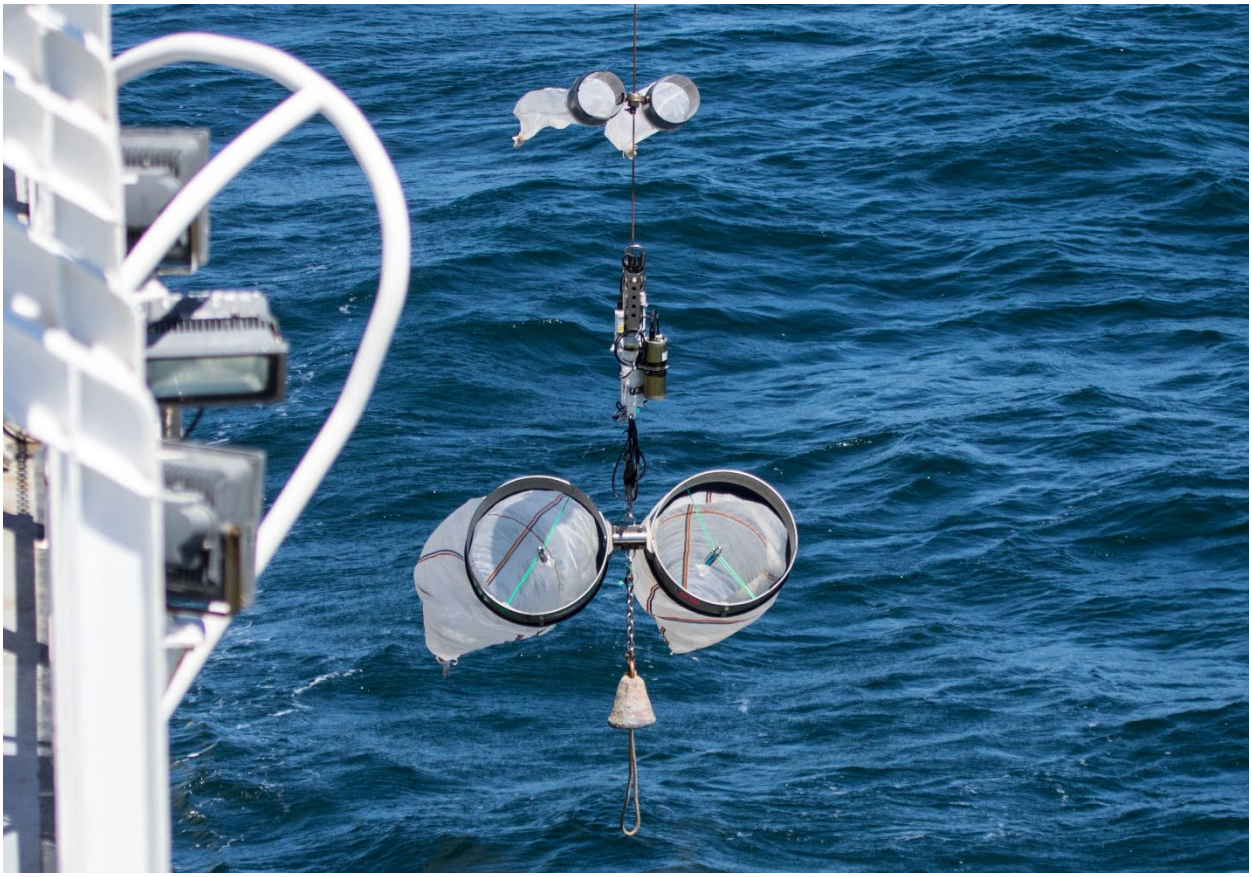

Figure 3: An SBE-19plus V2 CTD mounted with bongo nets and depressor weight for a double oblique towed deployment. Photo Credit: Chris Melrose.

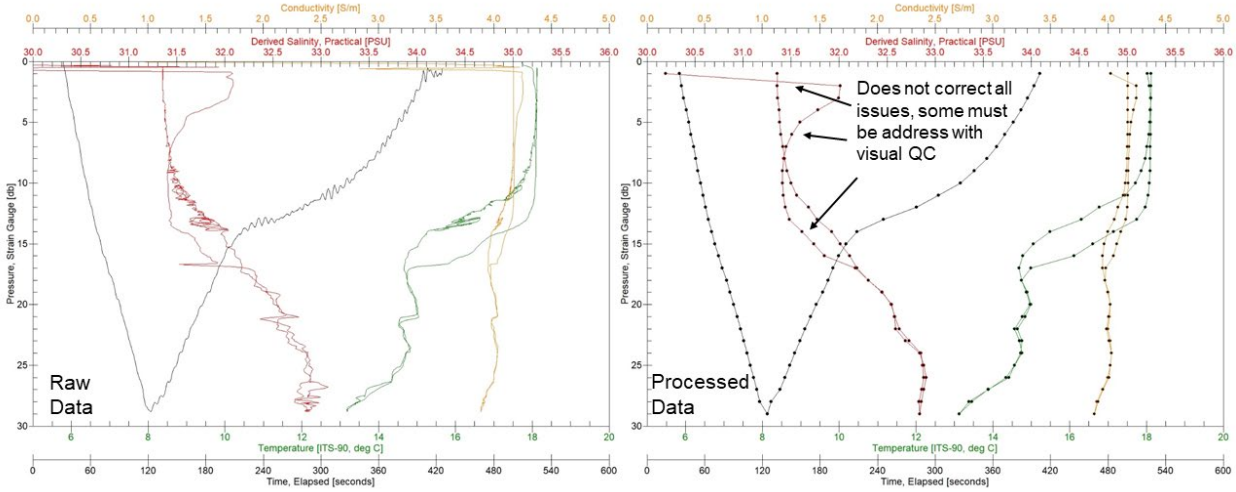

Figure 4: An example of raw compared to processed CTD data. The processed data has undergone sensor alignment, cell thermal mass correction and a low pass filter. The black dots on the processed data represent 1 decibar bin-averaged values. This example shows anomalous surface values on the downcast due to the lack of a surface soak that were not corrected by these automated steps. This type of error is addressed later through visual quality control.

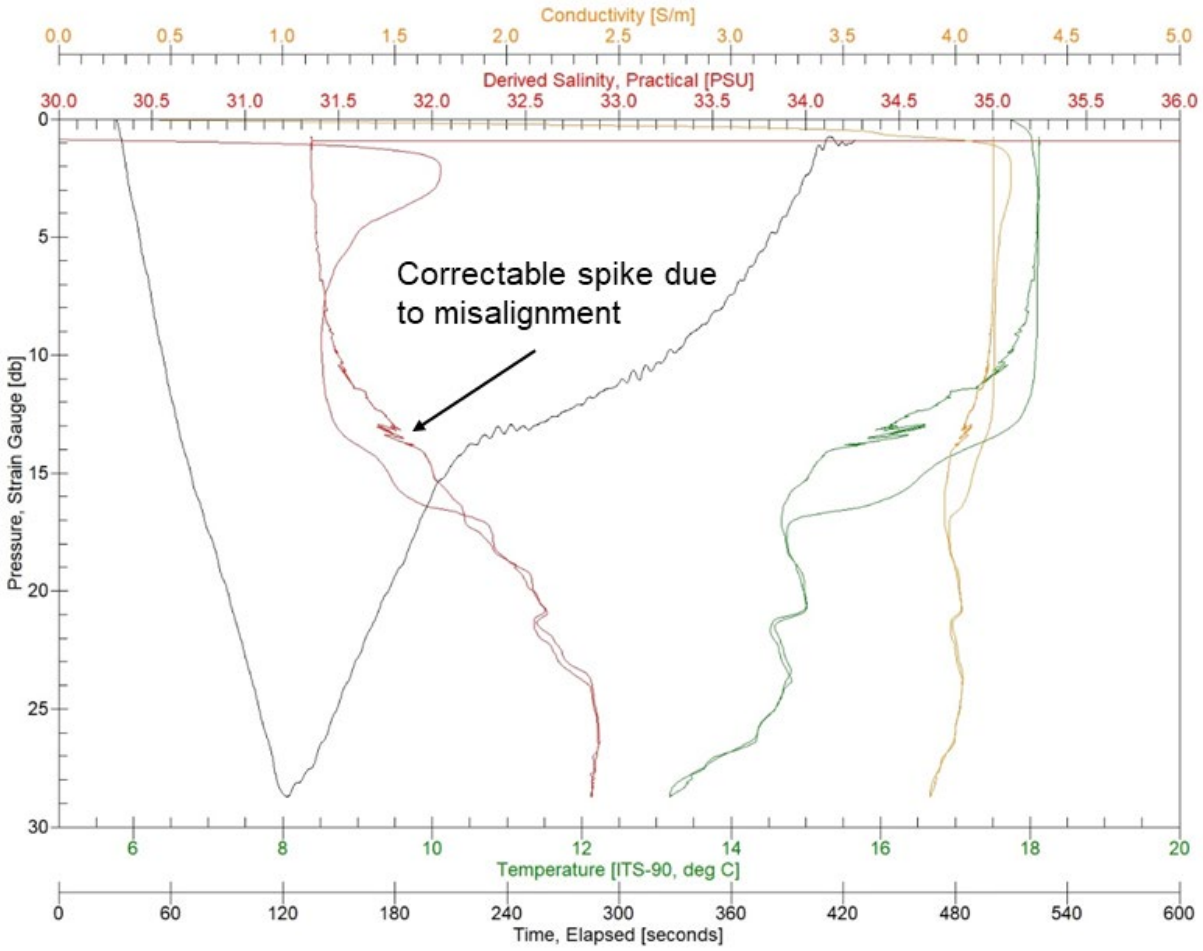

Figure 5: An example of data spikes due to misalignment of data between pressure, temperature and conductivity.

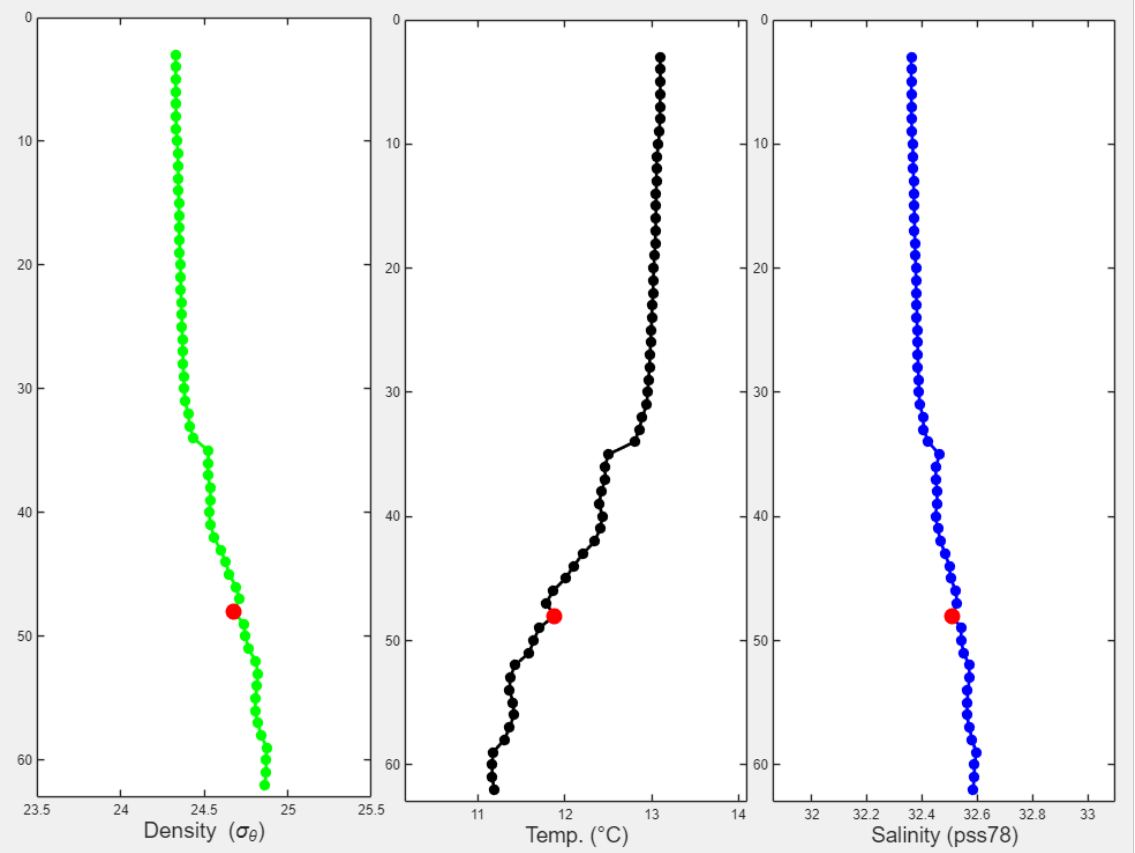

Figure 6: Profiles of density, temperature and salinity are visually inspected and bad values are flagged. The red dot shows a point flagged due to an unrealistic density inversion in the profile.

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