**7. Conductivity, Temperature, Depth (CTD) Stations**

The CTD/rosette system was deployed off the starboard side. The ship's personnel were responsible for the deployment and recovery of the CTD/rosette with assistance of experienced scientific personnel. During recovery, the CTD/rosette package was lowered onto a cart and rail system, maintained by the ship, allowing the CTD/rosette package to be safely brought into the staging bay. One of two 24-position AOML rosette systems with 12-liter Bullister bottles was used for CTD/rosette casts. The second backup package was secured in a readily accessible area, but it was never required. An altimeter was mounted on the rosette system and used during casts to monitor distance from the bottom.

***7.1. CTD Data Acquisition***

The CTD data acquisition system consisted of the ship’s SBE-11*plus* (V2) deck unit s/n 11P111660 and a networked Dell Optiplex 9020 Windows 10 workstation running SBE Seasave V7 version 7.26.7.107 software. NMEA GPS data were received through the deck unit. The workstation was used for data acquisition and to close bottles on the rosette. Raw data files were archived immediately after each cast on a USB drive as well as on Survey and PMEL networked PCs. No real-time data were lost during this cruise.

CTD deployments were initiated by Survey after the Bridge advised that the ship was on station. The FLBB optical sensor was uncapped and cleaned prior to each deployment using lens cleaning pads or deionized water and lens paper. The computer console operator maintained a CTD Cast log recording position and depth information at the surface, depth, and end of each cast; a record of every attempt to close a bottle, and any pertinent comments.

After the underwater package entered the water, the winch operator lowered it to 20 meters. After a 60-second startup delay, the pumps turned on. The console operator watched the CTD data for reasonable values, waited three minutes at the soak depth for sensors to stabilize, instructed the winch operator to bring the package to the surface, paused for 30 seconds, and began the descent to a target depth approximately 10 meters above the sea floor. The descent rate was nominally 30 m/min to 50 m, 45 m/min to 200 m, and 60 m/min deeper than 200 m. These rates could vary depending on sea cable tension and the sea state.

The console operator monitored the progress of the deployment and quality of the CTD data through interactive graphics and operational displays. The chief or co-chief scientist created a sample log for the cast that would be used to record the water samples taken from each Bullister bottle. The altimeter channel, CTD depth, wire-out, and EM122 bathymetric depth were all monitored to determine the distance of the package from the bottom, allowing a safe approach to within 10 meters.

Bottles were closed on the upcast through the software. Each bottle was tripped 30 seconds after the winch stopped at each sample depth to allow the rosette wake to dissipate and the bottles to flush. The winch operator was instructed to proceed to the next bottle stop 15 seconds after closing a bottle to ensure that stable CTD and reference temperature data were associated with the trip.

Near the surface, Survey directed the winch to stop the rosette just beneath the surface. After the surface bottle was closed, the package was recovered. Once on deck, the console operator terminated data acquisition, and turned off the deck unit.

At the end of each cast, primary and secondary CTD/O2 sensors were flushed with a very dilute Triton-X and de-ionized water solution using syringes fitted with tubing. The syringes were left attached to the temperature ducts between casts, with the temperature and conductivity sensors immersed in the rinse solution to guard against airborne contaminants. The rosette carousel was rinsed with warm freshwater. The FLBB optical sensor was rinsed and capped after each cast.

**Table 7.1.** Package component and calibration data

|  |  |  |  |
| --- | --- | --- | --- |
| Manufacturer / Model | Serial Number | Calibration Date | Stations Used |
| Sea-Bird 9plus CTD | 1401 | 4-Sep-19 | 1-8 |
|  |  |  |  |
| Sea-Bird 3Plus primary temperature | 4569 | 02-Jul-19 | 1-8 |
| Sea-Bird 4C primary conductivity | 3068 | 02-Jul-19 | 1-8 |
| Sea-Bird 43 primary oxygen | 3419 | 04-Jul-19 | 1-8 |
| Sea-Bird 5T primary pump | 8774 | n/a | 1-8 |
|  |  |  |  |
| Sea-Bird 3Plus secondary temperature | 4341 | 02-Jul-19 | 1-8 |
| Sea-Bird 4C secondary conductivity | 4600 | 22-Sep-17 | 1-8 |
| Sea-Bird 43 secondary oxygen | 3420 | 04-Jul-19 | 1-8 |
| Sea-Bird 5T secondary pump | 8794 | n/a | 1-8 |
|  |  |  |  |
| Sea-Bird 35 reference temperature | 76 | 19-Jul-19 | 1-8 |
| Sea-Bird 32 24-position carousel | 500 | n/a | 1-8 |
|  |  |  |  |
| Valeport VA500 altimeter | 56634 | 16-Sep-16 | 1-8 |
| WET Labs ECO chlorophyll fluorometer | FLBBRTD-4799 | 9-Aug-17 | 1-8 |

***7.2. CTD Data Processing***

The reduction of profile data began with a standard suite of processing modules using Sea-Bird Data Processing Version 7.26.7 software in the following order:

DATCNV converts raw data into engineering units and creates a ROS bottle file. Both down and up casts were processed for scan, elapsed time(s), pressure, t0, t1, c0, c1, oxvo1, oxvo2, ox1 and ox2. Optical sensor data were converted to voltages and also carried through the processing stream. MARKSCAN was used to skip over scans acquired on deck and while priming the system under water.

ALIGNCTD aligns temperature, conductivity, and oxygen measurements in time relative to pressure to ensure that derived parameters are made using measurements from the same parcel of water. Primary and secondary conductivity were automatically advanced in the V2 deck unit by 0.073 seconds. No further alignment was warranted. It was not necessary to align temperature or oxygen.

BOTTLESUM averages burst data over an 8-second interval (within ± 4 seconds of the confirm bit) and derives both primary and secondary salinity, potential temperature (θ), and potential density anomaly (σθ). Primary and secondary oxygen (in μmol/kg) were derived in DATCNV and averaged in BOTTLESUM, as recommended recently by Sea-Bird.

WILDEDIT makes two passes through the data in 100 scan bins. The first pass flags points greater than 2 standard deviations; the second pass removes points greater than 20 standard deviations from the mean with the flagged points excluded. Data were kept within 0.005 of the mean.

FILTER applies a low pass filter to pressure with a time constant of 0.15 seconds. In order to produce zero phase (no time shift) the filter is first run forward through the file and then run backwards through the file.

CELLTM uses a recursive filter to remove conductivity cell thermal mass effects from measured conductivity. In areas with steep temperature gradients the thermal mass correction is on the order of 0.005 PSS-78. In other areas the correction is negligible. Nominal values of 0.03 and 7.0 s were used for the thermal anomaly amplitude (α) and the thermal anomaly time constant (β-1), respectively, as suggested by Sea-Bird.

LOOPEDIT removes scans associated with pressure slowdowns and reversals. If the CTD velocity is less than 0.25 m s-1 or the pressure is not greater than the previous maximum scan, the scan is omitted.

DERIVE uses 1-dbar averaged pressure, temperature, and conductivity to compute primary and secondary salinity, as well as more accurate oxygen values.

BINAVG averages the data into 1-dbar bins. Each bin is centered on an integer pressure value, e.g. the 1-dbar bin averages scans where pressure is between 0.5 dbar and 1.5 dbar. There is no surface bin. The number of points averaged in each bin is included in the data file.

STRIP removes oxygen that was derived in DATCNV.

TRANS converts the binary data file to ASCII format.

Package slowdowns and reversals owing to ship roll can move mixed water in tow to in front of the CTD sensors and create artificial density inversions and other artifacts. In addition to Seasoft module LOOPEDIT, MATLAB program deloop.m computes values of density locally referenced between every 1 dbar of pressure to compute the square of the buoyancy frequency, N2, and linearly interpolates temperature, conductivity, and oxygen voltage over those records where N2 is less than or equal to -1 × 10-5 s-2. Some profiles failed the criteria near the surface. These data were retained and will be flagged as questionable in the final CCHDO formatted .CSV files.

Program calctd.m reads the delooped data files and applies calibrations to pressure, temperature, conductivity, and oxygen; and computes calibrated salinity.

***7.3. Pressure Calibration***

On-deck pressure readings prior to each cast were examined at sea and the mean offset over eight stations was 0.4702 dbar. This CTD was purchased from Sea-Bird in August 2019, and this was the first cruise using this CTD. Differences between first and last submerged pressures for each cast were also examined and the residual pressure offsets were less than 0.2 dbar.

***7.4. Temperature Calibration***

A viscous heating correction of -0.0006 °C was applied (as recommended by Sea-Bird) prior to preliminary temperature, conductivity, and oxygen calibrations; and to the preliminary data set at the end of the cruise.

SBE 35 reference temperature sensor data were used to correct SBE 3 temperature sensor data. SBE 35 s/n 76 was used for all stations. Primary SBE 3 temperature sensor s/n 4569 and secondary SBE 3 temperature sensor s/n 4341 were used for all stations. At sea, residuals between the reference data and those from the primary SBE 3 were minimized to determine a linearly station-dependent offset, and a linear pressure-dependent correction applied only to temperatures collected at pressures exceeding a value estimated by the minimization. The best fit for primary SBE 3 temperature sensor s/n 4569 applied a slope of 8.180553e-006, an offset of 0.000538 °C, and a pressure correction term of 3.91204e-007.

Temperature corrections were applied to profile data using program calctd.m and to burst data using calclo.m.

***7.5. Conductivity Calibration***

Seasoft module BOTTLESUM creates a sample file for each cast. These files were appended using program sbecal.f. Program addsal.f matched sample salinities to CTD salinities by station/sample number.

Primary conductivity sensor s/n 3068 was used for all stations and calibrated as a single group. Program calcos1.m calculated a linear station-dependent slope and a single conductivity bias that best fit this sensor.

stations 1-8

number of points used 155

total number of points 183

% of points used in fit 84.7

fit standard deviation 0.001738

fit bias -0.0014568269

min fit slope 1.0001636

max fit slope 1.0002448

Conductivity calibrations were applied to profile data using program calctd.m and to burst data using calclo.m. CTD-bottle conductivity differences plotted against station number (Fig. 1) and pressure (Fig. 2) allow a visual assessment of the success of the fit.

***7.6. Oxygen Calibration***

A hybrid of the Owens-Millard (1985) and Murphy-Larson (revised 2010) oxygen sensor modeling equations was used to calibrate the SBE-43 oxygen sensor data from this cruise. The equation has the form

Ox=Soc\*(V+Voff+Tau\*exp(DI\*P+D2\*T).\*dVdt).\*Os.\*exp(Tcor\*T).\*exp(Pcor\*P./(273.15+T));

Where Ox is the CTD oxygen (in μmol/kg), V is the measured oxygen voltage (in volts), dVdt is the temporal gradient of the oxygen voltage (in volts/s estimated by running linear fits made over 5 seconds), P is the CTD pressure (in dbar), T is the CTD temperature (in °C), and Os is the oxygen saturation computed from the CTD data following Garcia & Gordon (1992). Oxygen sensor hysteresis was improved by matching upcast bottle oxygen data to downcast CTD data by potential density anomalies referenced to the closest 1000-dbar interval using program match\_sgn.m. We used the values provided by SBE for each sensor for the constants D1 (1.9263e-4) and D2 (-4.6480e-2) to model the pressure and temperature dependence of the response time for the sensor. For each group of stations fit we determined values of Soc (sometimes station dependent), Voff, Tau, Tcor, and Pcor by minimizing the residuals between the bottle oxygen and CTD oxygen. W represents fitting switches. If the switches are set to 0,0 the fit is a regular L2 (least squares) norm for the entire group. If the switches are set to 1,0 the fit is a regular L2 norm for the entire group but with a slope that is a linear function of station number. If the switches are set to 2,0 the program first fits the entire group, then goes back and fits a slope and bias to individual stations, keeping the other parameters at the group values. If the switches are set to 0,1 the fit is a regular L2 norm for the entire group but it is weighted by the nominal oxygen bottle spacing, thus fitting the deep portion of the water column better.

At sea, program addsal.f matched bottle sample oxygen values to CTD oxygen values by station/sample number. Program run\_oxygen\_cal\_ml.m was used to determine calibration coefficients by visual inspection for primary oxygen sensor s/n 3419 used for all stations.

Stns Soc Voff Tau Tcor Pcor Npts %Used StdDev W

1-8 0.5408 -0.4996 6.9648 -0.0007 0.0408 182 89.0 1.1643 1 1

Oxygen calibration coefficients were applied to profile data using program calctd.m, and to burst data using calclo.m. CTD-bottle oxygen differences plotted against station number (Fig. 3) and pressure (Fig. 4) allow a visual assessment of the success of the fit.