

RV Investigator CTD Data Processing Report

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Voyage Title	Biodiversity Assessment of Australia's Indian Ocean Territories
Depart	Darwin NT, 30 September 2022, 01:38 UTC
Return	Henderson WA, 03 November 2022, 03:50 UTC
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1 Summary

IN2022_V08 voyage was a continuation of IN2021_V04 which was aborted after 10 days of science operations. Operations began approximately where IN2021_V04 left off and focused on the Cocos (Keeling) Island group, 8 seamount clusters, and at three abyssal plains. Most of these territories were previously unmapped.

This report describes the production of quality controlled, calibrated CTD data from RV *Investigator* voyage IN2022_V08.

Data for 44 CTD deployments were acquired using the Sea-Bird SBE911 CTD unit #22 (S/N 1039), fitted with 36 twelve-litre bottles on the rosette sampler. Sea-Bird-supplied calibration factors were used to compute the pressures and preliminary conductivity values. CSIRO-supplied calibrations were applied to the temperature data. The data were subjected to automated QC to remove spikes and out-of-range values.

The final conductivity calibration was based on a single deployment grouping. The final calibration from the secondary sensor had a standard deviation (SD) of 0.0013609 PSU, well within our target of 'better than 0.002 PSU'. The standard product of 1-decibar binned averages were produced using data from the secondary sensors.

The dissolved oxygen data calibration fit had a SD of 0.84263 μ M. The agreement between the CTD and bottle data was good.

Additional sensors include: Altimeter (Tritech PA500), Nephelometer (turbidity Seapoint), Transmissometer (Wetlabs C-Star), CDOM, Chlorophyll-a, Scattering (Wetlabs ECO FLCDRTD) were installed on the auxiliary A/D channels of the CTD.

To access the full voyage plan and other reports and data associated with this voyage, please see the contact information at the end of this report.

1.1 Voyage Track



Figure 1: Voyage track with CTD cast locations

2 Data Processing

2.1 Background Information

44 CTD deployments were conducted on this voyage. The data were acquired with the CSIRO CTD unit #22 (S/N 1039), a Sea-Bird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors including Altimeter, Nepthelometer, Transmissometer, CDOM, chlorophyll-a, and Scattering. These sensors are described in Table 1.

Sensor Description	Model	Serial No.	A/D Channel	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	CTD22#1039	Ρ	21-Apr-2022	Sea-Bird
Primary Temperature	Sea-Bird SBE3plus	4722	то	11-Jun-2022	Sea-Bird
Secondary Temperature	Sea-Bird SBE3plus	6022	Т1	9-Oct-2021	Sea-Bird
Primary Conductivity	Sea-Bird SBE4C	4662	C0	6-Apr-2022	Sea-Bird
Secondary Conductivity	Sea-Bird SBE4C	4685	C1	3-Jun-2022	Sea-Bird
Primary Dissolved Oxygen	SBE43	1794	A0	16-Nov-2021	Sea-Bird
Secondary Dissolved Oxygen	SBE43	3154	A1	11-Jun-2022	Sea-Bird
Altimeter	Tritech PA500	316739	A2	7-May-2019	Tritech
Nephelometer (turbidity)	Seapoint	13142	A3	10-Jun-2022	
Transmissometer	Wetlabs C-Star	CST-1735DR	A4	16-Jun-2021	Wetlabs/Sea-Bird
CDOM	Wetlabs ECO FLBBRTD	7138	A5	8-Dec-2021	Wetlabs
Chlorophyll-a	Wetlabs ECO FLBBRTD	6890	A6	27-Jul-2021	Wetlabs/Sea-Bird
Scattering	Wetlabs ECO FLBBRTD	6890	A7	27-Jul-2021	Wetlabs/Sea-Bird
Additional Payloads					
LADCP Slave (Up)	Teledyne 300 kHz	24502	Internal	N/A	
LADCP Master (Down)	Teledyne 150 kHz	16710	internal	N/A	
LADCP Battery	OceanDeep	2219	N/A	N/A	
MIDAS SVX2	Valeport	73429	N/A	N/A	

Table 1: CTD Sensor configuration on IN2022_V08

Water samples were collected using a Sea-Bird SBE32, 36-bottle rosette sampler. Sampling was from 33 out of the 44 twelve-litre bottles which were fitted to the frame.

The raw CTD data were collected in SBE Seasave version 7.26.7.110, converted to scientific units using SBE Data Processing version 7.26.7.129 and written to NetCDF files with CNV_to_Scan (cnv_to_scan_ui2.py, from the CSIRO MNF Data Acquisition and Processing "marinetech" git repository) for processing using the MATLAB-based CapPro software.

The CapPro software version 2.12 was used to apply automated QC and preliminary processing to the data. This included spike removal, identification of water entry and exit times, conductivity sensor lag corrections, conductivity cell thermal inertia corrections, and the determination of the pressure offsets. It also loaded the hydrology data and computed the matching CTD sample burst

data (i.e., averaged sensor data) for water-sample-to-sensor data comparisons. The automaticallydetermined pressure offsets and in-water points were inspected and verified during data processing.

The bottle sample data were used to compute final conductivity and dissolved oxygen calibrations. These were applied to the data, after which files of binned 1-decibar averaged data were produced.

2.2 Pressure and Temperature Calibration

The pressure offsets for each deployment are plotted in Figure 2. The blue circles refer to initial outof-water values (beginning of downcast) and the red circles the final out-of-water values (end of upcast).





The difference between the primary and secondary temperature sensors at the bottle sampling depths is plotted in Figure 3. Most deployments plot within \pm 0.001 °C of zero – outliers result from

sampling in regions of high vertical temperature gradient. The consistent mean difference (red + markers) between the primary and secondary temperature from deployment to deployment indicates neither sensor has drifted significantly from its calibration. Higher fluctuations in difference presented in the plots represents shallower casts, where the high gradient is present throughout most of the cast.



Figure 3: Difference (primary - secondary) between temperature sensor values on downcast (left) and upcast (right)

2.3 Conductivity Calibration

If any discrepancies or sampling problems occurred during bottle salinity sampling or between primary and secondary CTD conductivity measurements, these would show in the conductivity calibration plots in Figure 4. We observed discrepancies based on these calibration results. These discrepancies were due to a large percentage of points being located within the halocline region The profile plots showing the thermocline and halocline ranges are in Figure 5.

The calibrations were based upon the percent of 'good' sample data (242 good samples from the primary unit and 242 good samples from the secondary unit), out of a total of 376 samples taken during deployments. To perform the calibration with the preferred (default) CapPro calibration settings, a minimum of 70% of the samples need to be in the 'good' range. If there is an insufficient number of good samples for a unit, the conductivity difference 'cutoff' value must be increased to continue with the calibration process in CapPro. For this set of conductivity calibrations, the cutoff values used were 0.003 (primary) and 0.003 (secondary).

Figure 4 plots CTD - bottle salinity differences for both upcast (Hydro bottle) and downcast (CTD SBE43) data. The 'bad' outliers (magenta dots, red dots and red + markers) are excluded from the calibration, the 'suspect' outliers (blue dots) are used in the calibration but are weighted based on their distance from the mean. All green dots are considered 'good' data points and are not weighted based on distance from the mean.



Figure 4: CTD - bottle conductivity difference and salinity calibration error (left: primary, right: secondary)



Figure 5: Temperature, salinity, dissolved oxygen and σT profiles

The box plot (Figure 6) of calibrated downcast conductivities (primary - secondary) at the bottle sampling depths for all deployments shows that the calibrated primary and secondary conductivity cell responses corresponded well to each other.



Figure 6: Difference (primary - secondary) between conductivity sensor values on downcast

The final results for the primary and secondary conductivity sensors with respect to their original calibrations are shown in Table 2 and Table 3.

Sensor	Gensor Deployments Group	Scale Factor		Offset		Salinity (PSU)	
Group		a1	±	a0	±	Residual SD	M.A.D.
Primary	1-44	0.99963	0.00037684	0.0014817	0.0015817	0.0013012	0.0010801
Secondary	1-44	0.99985	0.00035245	0.00045636	0.0014761	0.0013609	0.00082185

Table 2: Conductivity calibration with respect to manufacturer's calibration coefficients and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	1-44	-9.1959e-08	7.6852e-08
Secondary	1-44	-8.4089e-08	7.1118e-08

Table 3: Calculated CPcor (the correction for pressure effects on the conductivity cell) for primary and secondary conductivity units compared to the manufacturer's nominal value of -9.5700e-08 (for pressure in decibars) (Sea-Bird, 2017)

This is a good calibration. We normally aim for a SD of 0.002 PSU for 'typical' oceanographic voyages. The above calibration factors were applied to the indicated deployments. Full plots of residuals before and after calibration are available in A.1.

Data from the secondary conductivity and temperature sensors were used to produce the averaged salinities (these data variables have no suffix) with primary sensors included with a suffix $^{\prime}2^{\prime}$.

2.4 Dissolved Oxygen Sensor Calibration

2.4.1 SBE Calibration Procedure

AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage (Sea-Bird, 2013) describes the SBE43 dissolved oxygen sensor as "a polarographic membrane oxygen sensor having a single output signal of 0 to +5 volts, which is proportional to the temperature-compensated current flow occurring when oxygen is reacted inside the membrane. A Sea-Bird CTD that is equipped with an SBE43 oxygen sensor records this voltage for later conversion to oxygen concentration, using a modified version of the algorithm by Owens and Millard (1985)."

Calibration involves performing a linear regression, as per (Sea-Bird, 2012) to produce new estimates of the calibration coefficients *Soc* and *Voffset*. These new coefficients are used, along with the other, manufacturer-supplied coefficients, to derive oxygen concentrations from the sensor voltages.

2.4.2 Results

Deeper casts (>1000m) are known to be affected by pressure-induced hysteresis with this sensor. This is corrected automatically within CapPro using the method discussed in *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections* (Sea-Bird, 2014).

There is a small mismatch between downcast and upcast dissolved oxygen due to the response time of the sensor. No correction for the sensor lag effect has been applied.

A single calibration group was used with the associated SBE43 upcast data to compute the new *Soc* and *Voffset* coefficients. Figure 7 plots CTD SBE43 - bottle oxygen differences for both upcast (Hydro bottle) and downcast (CTD SBE43) data. The 'bad' outliers (magenta dots, red dots and red + markers) are excluded from the calibration, the 'suspect' outliers (blue dots) are used in the calibration but are weighted based on their distance from the mean. All green dots are considered 'good' data points and are not weighted based on distance from the mean.



Figure 7: CTD SBE43 - bottle dissolved oxygen difference and calibration error (left: primary, right: secondary)

The box plot (Figure 8) of calibrated downcast dissolved oxygen readings (primary - secondary) at the bottle sampling depths for all deployments shows that the calibrated primary and secondary dissolved oxygen sensor responses corresponded well to each other.

Figure 8: Difference (primary - secondary) between dissolved oxygen sensor values on downcast

The old and new *Soc* and *Voffset* values for DO sensors are listed in Table 4. The *Soc* value is a linear slope scaling coefficient; *Voffset* is the fixed sensor voltage at zero oxygen. As expected, over time, the increasing *Soc* scale factors show the SBE43 sensor is losing sensitivity. Full plots of residuals before and after calibration are available in A.2.

The calibrations were applied for each sensor and the averaged files were created using the result from the secondary sensor.

or	Calibration Deployments			Calibration Coefficients			Dissolved Oxygen (µM)	
Sens	Jource		Voffset	±	Soc	±	Residual SD	M.A.D.
ry DO	CapPro	1-44	-0.48072	0.0016507	0.50028	0.001064	0.89145	0.84242
Prima	Sea-Bird	1-44	-0.4772		0.47054			
ary DO	CapPro	1-44	-0.49347	0.0020244	0.42346	0.00094711	0.84263	0.86974
Second	Sea-Bird	1-44	-0.4986		0.40410			

Table 4: Dissolved oxygen calibrations

2.5 Other Sensors

2.5.1 C-Star Transmissometer

The C-Star transmissometer was used on all deployments. It was calibrated by the manufacturer with meter outputs with the beam blocked, in air with a clear beam path and with clean water in the path. These values are used to determine a scale and offset for use in SBE Data Processing software to convert the raw counts to a beam transmittance output of 0 - 100 percent. This sensor worked as expected during this voyage.

2.5.2 WET Labs ECO CDOM Sensor

The WET Labs ECO CDOM (coloured dissolved organic matter) sensor was used for all deployments. The CDOM has been calibrated with manufacturer supplied coefficients. This sensor worked as expected during this voyage.

2.5.3 WET Labs ECO Fluorometer-Scattering Sensor

The WET Labs ECO Fluorometer-Scattering sensor was used for all deployments. The fluorometer (Chlorophyll-*a*) has been calibrated with manufacturer supplied coefficients to give outputs in mg/m³ (= μ g/L). The scattering (optical backscatter, OBS) has been calibrated with manufacturer supplied coefficients to give volume scattering outputs in m⁻¹sr⁻¹. This sensor worked as expected during this voyage.

2.5.4 Nephelometer

The nephelometer was not running on this voyage due to an issue with the internal pump that was identified during IN2022_P05 Quarterly maintenance.

2.6 Bad-Data Detection

The value limits for each sensor are configured in CNV_to_Scan conversion software and are written to the NetCDF scan file. Typical limits used for the sensor range and maximum second difference are in Table 5. The rejection rate is recorded in the CapPro processing log file.

Sensor	Range minimum	Range maximum	Maximum Second Difference
Pressure	-7	6500	0.5
Temperature	-2	40	0.05
Conductivity	-0.01	7	0.01
Dissolved Oxygen	-1	500	0.5
Fluorometer	0	100	0.5
PAR	-5	2000	0.5
Transmissometer	0	100	0.5

Table 5: Sensor limits for bad-data detecti

2.7 Heave Filtering

Sensor data impacted by ship heave impeding the CTD deployment is filtered out in three stages and applied during data binning. The first stage detects negative acceleration of the CTD which can cause trailing mixed water to be pumped through the sensors. The second stage looks at all negative density gradients and flags readings which are above 10 times the standard deviation of all negative gradients, for 2 seconds. The third stage flags any pressure reversals which are greater than the height of the CTD sensor pump inlet above the frame.

2.8 Temperature-Conductivity Lag

To precisely align the temperature and conductivity measurements for a sample of water, a temporal offset can be applied. A manufacturer-recommended nominal offset (Δt_{c_SBE9+}) of -0.073 seconds is initially applied at time of acquisition by the SBE9+ deck unit on both primary and secondary conductivity channels. This offset advances the conductivity sensor readings in time to compensate for the amount of time it takes for the measured water sample to move from the temperature sensor through into the conductivity sensor cell.

Post-voyage inspection of the temperature and conductivity data in CapPro can determine finetuning adjustments to the conductivity sample time (seconds) offset ($\Delta t_{c_{-}CP}$) that will optimally align the data. The final adjustments applied to the conductivity sample time can be found in Table 6 and Table 7. Note that although CapPro can set an offset ('lag', in number of scans, with a scan frequency of 24 Hz) for both temperature and conductivity samples, DAP only sets a lag for the conductivity sample to maintain consistency with the nominal offset applied by the SBE9+ to the conductivity data. The equation governing this conductivity sample time adjustment is given below, where $t_{c_aligned}$ is the best-estimate of the conductivity measurement time (seconds) to align it with the temperature measurement from the same sample of water on the downcast, and t_{c_meas} is the original, uncorrected conductivity measurement time (seconds).

Cast #	Nominal Offset Time Applied by SBE9+, Δt_{c_SBE9+} (sec)	Offset ('Cond lag') Set in CapPro (scans)	Calculated Offset Time from CapPro 'Cond lag', $\Delta t_{c_{-}CP}$ (sec = scans/24 Hz)
1-44	-0.073	-0.66	-0.0275

$$t_{c_aligned} = t_{c_meas} + \Delta t_{c_SBE9+} + \Delta t_{c_CP}$$

Table 6: Primary conductivity sensor offset adjustments

Cast #	Nominal Offset Time Applied by SBE9+, Δt_{c_SBE9+} (sec)	Offset ('Cond lag') Set in CapPro (scans)	Calculated Offset Time from CapPro 'Cond lag', Δt_{c_CP} (sec = scans/24 Hz)
1-44	-0.073	-0.30	-0.0125

Table 7: Secondary conductivity sensor offset adjustments

2.9 Averaging

The calibrated data were 'filtered' to remove pressure reversals and binned into the standard product of 1-decibar averaged NetCDF files. The binned values were calculated by applying a linear, least-squares fit as a function of pressure to the sensor data for each bin, using this to interpolate the value for the bin mid-point. This method is used to avoid possible biases which would result from averaging with respect to time.

Each binned parameter is assigned a quality control (QC) flag (also in the NetCDF files). Our QC flagging scheme is described in (Pender & NCMI Information & Data Centre, 2022).

The QC Flag for each bin is estimated from the values for the bin components. The QC Flag for derived quantities, such as salinity and dissolved oxygen, is taken to be the worst of the estimates for the parameters from which they are derived.

3 References

- Tim O'Hara. (2022). *The RV Investigator. Voyage Plan* IN2022_V08. Retrieved from Marine National Facility: Voyage Plans and summaries: https://mnf.csiro.au/en/Voyages/Voyage-Catalogue
- Pender, L., & NCMI Information & Data Centre. (2022, September 1). Data Quality Control Flags. Retrieved March 28, 2023, from CSIRO NCMI Information and Data Centre - Data Trawler: https://www.marine.csiro.au/data/trawler/download.cfm?file_id=4716

- Sea-Bird. (2012, June). App Note 64.2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections. Retrieved January 18, 2023, from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?id=54627861704
- Sea-Bird. (2013, June). App Note 64: SBE 43 Dissolved Oxygen Sensor Background Information, Deployment Recommendations, and Cleaning and Storage. Retrieved January 18, 2023, from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?id=54627861706
- Sea-Bird. (2014, August). App Note 64.3: SBE 43 Dissolved Oxygen (DO) Sensor Hysteresis Corrections. Retrieved January 18, 2023, from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?id=54627861705
- Sea-Bird. (2017, December 8). Software Manual: Seasoft V2: Seasave V7. Retrieved March 24, 2023, from Sea-Bird Electronics: https://www.seabird.com/assetget.download.jsa?id=55174002257

4 Appendices

A.2 Dissolved Oxygen Calibration Residual Plots

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