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RV *Investigator*

CTD Processing Report

Voyage ID:	in2022_v07
Voyage title:	in2022_v07 CTD Processing Report
Depart:	Brisbane, 0900 Sunday, 14 August 2022
Return:	Cairns, 0700 Wednesday, 7 September 2022

Document History

Date	Version	Author	Comments
13/09/2022	1.0	Francis Chui	Initial version
21/10/2022	1.1	Francis Chui	Minor correction to summary

1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage in2022_v07, from 14 Aug 2022 – 05 Sep 2022.

Data for 21 deployments were acquired using the Sea-Bird SBE911 CTD Report, 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 for the primary channel and two deployment groupings for the secondary channel. The final calibration from the secondary sensor had a standard deviation (SD) of 0.0012964 PSU for casts 1-19 and 0.0011836 for casts 20-21, within our target of 'better than 0.002 PSU'. The standard product of 1 decibar binned averaged were produced using data from the secondary sensors.

The dissolved oxygen data calibration fit was based on two groupings which had a SD of 0.77590 µM for casts 1-16 and 0.90173 µM for casts 17-21 on the secondary channel. The agreement between the CTD and bottle data was good.

An altimeter, PAR, transmissometer, CDOM, chlorophyll and scattering sensors were also installed on the auxiliary A/D channels of the CTD.

2 Voyage Details

2.1 Title

in2022_v07 CTD Processing Report

2.2 Principal Investigators

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2.3 Voyage Objectives

The scientific objectives for in2022_v07 were outlined in the Voyage Plan.

For further details, refer to the Voyage Plan and/or summary which can be viewed on the Marine National Facility web site.

2.4 Area of operation

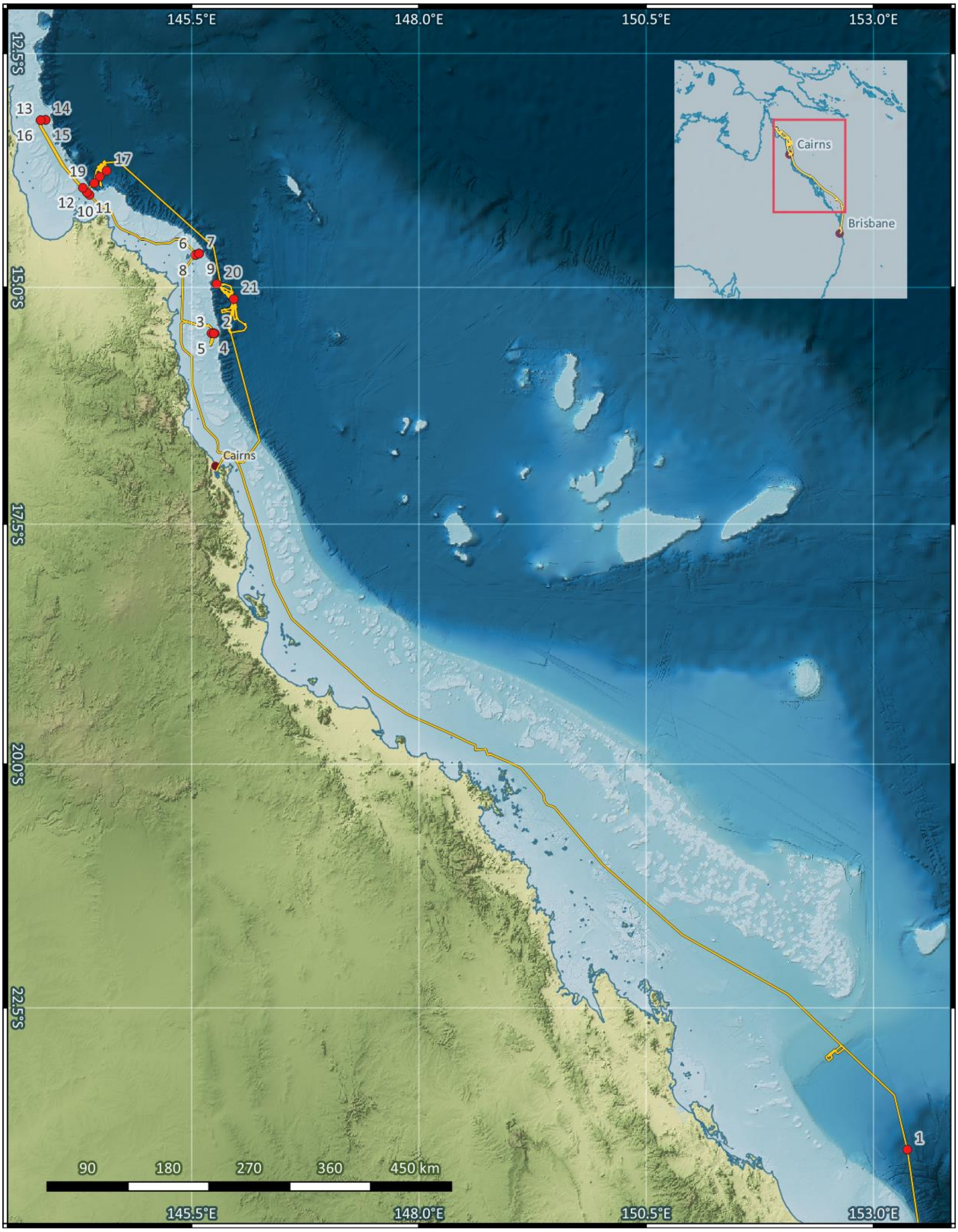


Figure 1 Area of operation for in2022_v07

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with the CSIRO CTD unit Report, a Sea-Bird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors, altimeter, PAR, transmissometer, CDOM, chlorophyll and scattering. These sensors are described in Table 1 for deployments 1-19 and Table 2 for deployments 20-21.

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1039	P	21-Apr-2022	Sea-Bird
Primary Temperature	Sea-Bird SBE3*plus*	4722	T0	11-Jun-2022	Sea-Bird
Secondary Temperature	Sea-Bird SBE3*plus*	6022	T1	9-Oct-2021	Sea-Bird
Primary Conductivity	Sea-Bird SBE4C	4662	C0	6-Apr-2022	Sea-Bird
Secondary Conductivity	Sea-Bird SBE4C	4425	C1	28-Dec-2021	Sea-Bird
Primary Dissolved Oxygen	SBE43	1794	A0	16-Nov-2021	Sea-Bird
Secondary Dissolved Oxygen	SBE43	3155	A1	21-Dec-2021	Sea-Bird
Altimeter	Tri-tech PA500	316739	A2	7-May-2019	Tritech
PAR	Biospherical QCP2300HP	70562	A3	14-Sep-2021	Biospherical
Transmissometer	Wetlabs C-Star	1735DR	A4	16-Jun-2021	Wetlabs
CDOM	Wetlabs ECO FLCDRTD	7138	A5	8-Dec-2021	Wetlabs
Chlorophyll-a	Wetlabs ECO FLBBRTD	6890	A6	27-Jul-2021	Sea-Bird
Scattering	Wetlabs ECO FLBBRTD	6890	A7	27-Jul-2021	Sea-Bird

Table 1 CTD Sensor configuration on in2022_v07

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Secondary Conductivity	Sea-Bird SBE4C	4685	C1	3-Jun-2022	Sea-Bird

Table 2 CTD Sensor configuration on in2022_v07 for deployments 20 & 21

Water samples were collected using a Sea-Bird SBE32, 36-bottle rosette sampler. Sampling was from 36 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 format files with CNV_to_Scan for processing using the Matlab-base, CapPro package version 2.11.

The CapPro software 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. The automatically determined pressure offsets and in-water points were inspected.

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.

3.2 Pressure and temperature calibration

The pressure offsets are plotted in Figure 2 CTD pressure offsets. The blue circles refer to initial out-of-water values and the red circles the final out-of-water values.

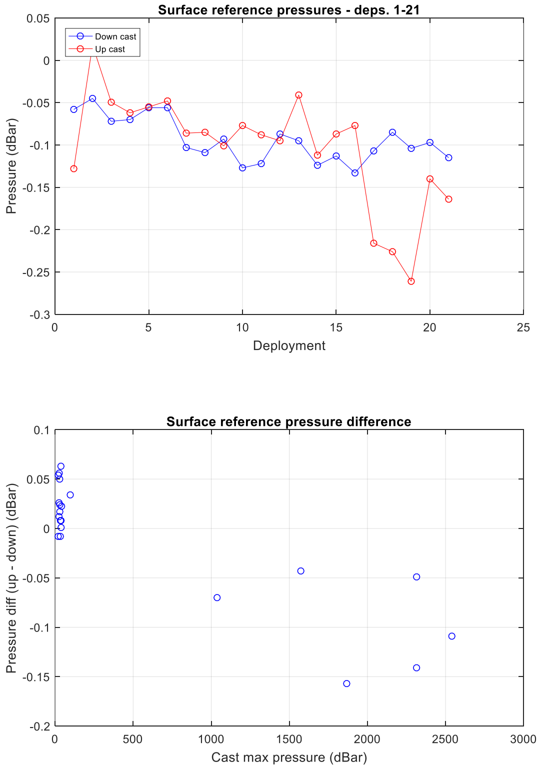


Figure 2 CTD pressure offsets

The difference between the primary and secondary temperature sensors at the bottle sampling depths is plotted below. Most deployments plot within ±0.001°C of zero – outliers result from sampling in regions of high vertical temperature gradient as supported by the similarity between the temperature and conductivity difference shown in Figure 3. This indicates neither sensor has drifted significantly from its calibration.

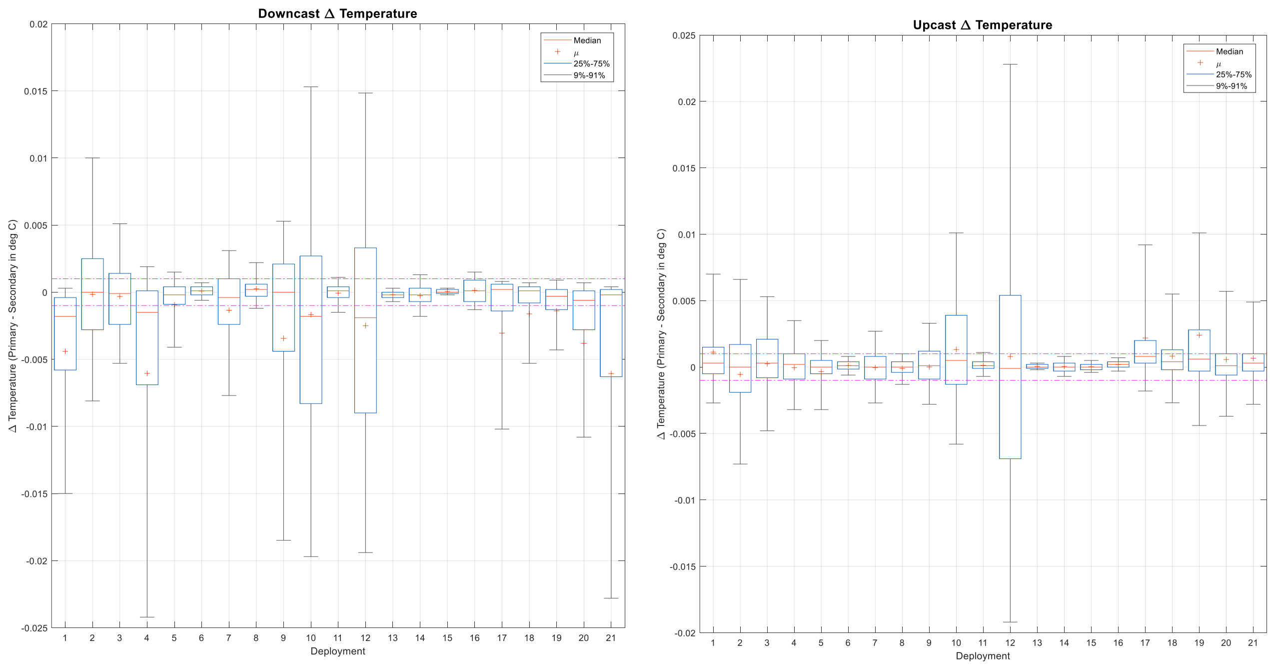


Figure 3 Difference between primary and secondary temperature sensors

3.3 Conductivity Calibration

Discrepancies and possible sampling problems between bottle and CTD salinities for the primary conductivity sensor would show in Figure 4; the plot of calibrated (CTD - Bottle) salinity below. The calibration was based upon the sample data (primary/secondary) for 104/112 of the total of 156 samples taken during deployments which are below our target of 70% for the primary and marginally above for the secondary channel.

The outliers marked in Figure 4 below with magenta dots are excluded from the calibration, the outliers marked with blue dots are used in the calibration but are weighted based on their distance from the mean. Any outliers marked with red crosses or dots are also excluded from the calibration.

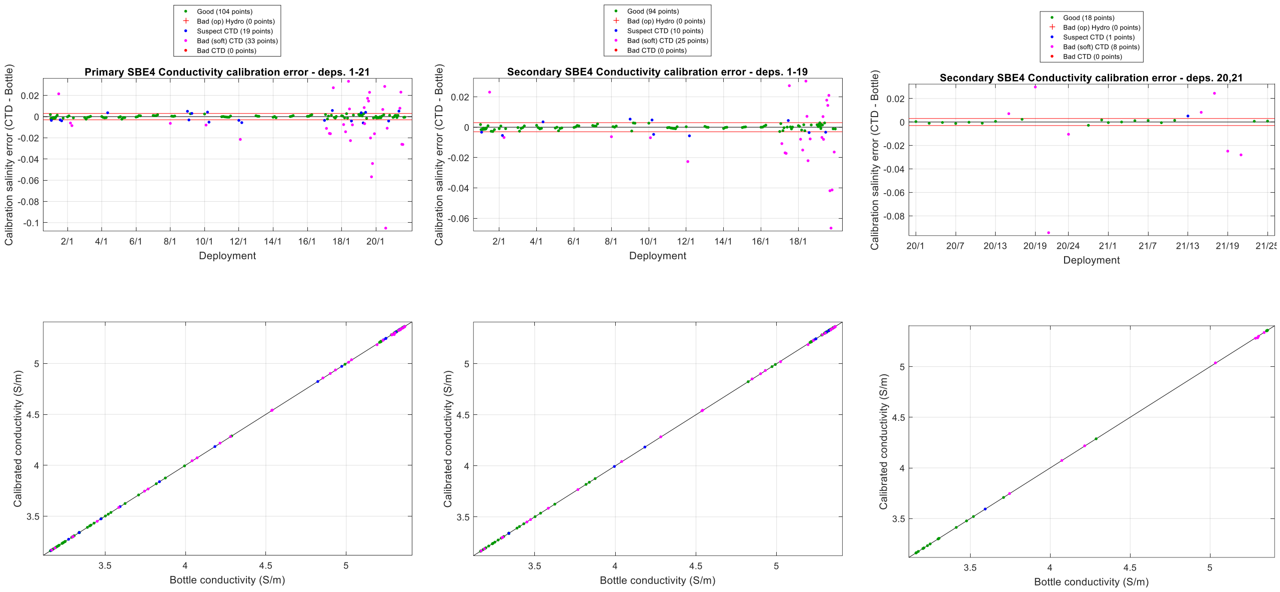


Figure 4 CTD - bottle salinity plot

The box plot of calibrated downcast conductivities (primary - secondary) at the bottle sampling depths for all deployments in Figure 5 shows that the calibrated conductivity cell responses corresponded very well.

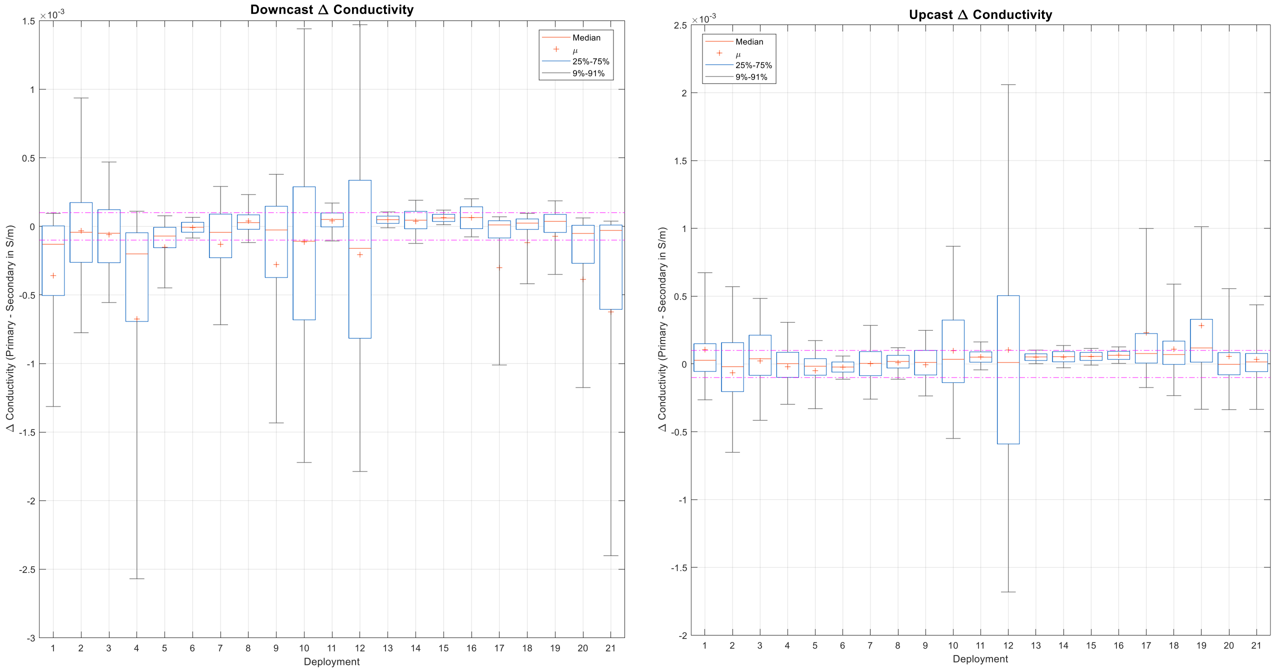


Figure 5 Difference between primary and secondary conductivity sensors

The final result for the primary and secondary conductivity sensors with respect to their original calibrations are shown in Table 3 and Table 4.

Sensor Group	Deployments	Scale Factor		Offset		Salinity (PSU)	
		a1	±	a0	±	Residual SD	M.A.D.
Primary	01-21	0.99957	0.00071848	1.7508e-03	0.0037386	0.0013765	0.0010717
Secondary	01-19	0.99885	0.00077870	4.2046e-03	0.0040794	0.0012964	0.00097899
Secondary	20-21	0.99977	0.00148070	6.2552e-04	0.0072097	0.0011836	0.0010189

Table 3 Conductivity calibration with respect to manufacturers' calibration coefficients and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	01-21	-9.3303e-08	3.2676e-07
Secondary	01-19	-1.0019e-07	3.5930e-07
Secondary	20-21	-8.9990e-08	5.7698e-07

Table 4 Calculated CPcor for primary and secondary compared to the manufacturer nominal value of -9.5700e-08

This is a goodgood calibration. We normally aim for a S.D. of 0.002 PSU for 'typical' oceanographic voyages. The above calibration factors were applied to all deployments. Full plots of residuals before and after calibration are available in Appendix I: Conductivity Calibration Residual Plots.
Data from the secondary conductivity and temperature sensors were used to produce the averaged salinities with primary sensors included with a suffix '_1'.

3.4 Dissolved Oxygen Sensor Calibration

3.4.1 SBE calibration procedure

AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage. Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?code=251036 (Sea-Bird, 2013) describes the SBE43 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.

3.4.2 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.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?code=251035

(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 up-cast data to compute the new *Soc* and *Voffset* coefficients. The plot below is of CTD - bottle oxygen differences for both upcast and downcast data (red indicates ‘bad’ data; + for upcast and square for downcast).

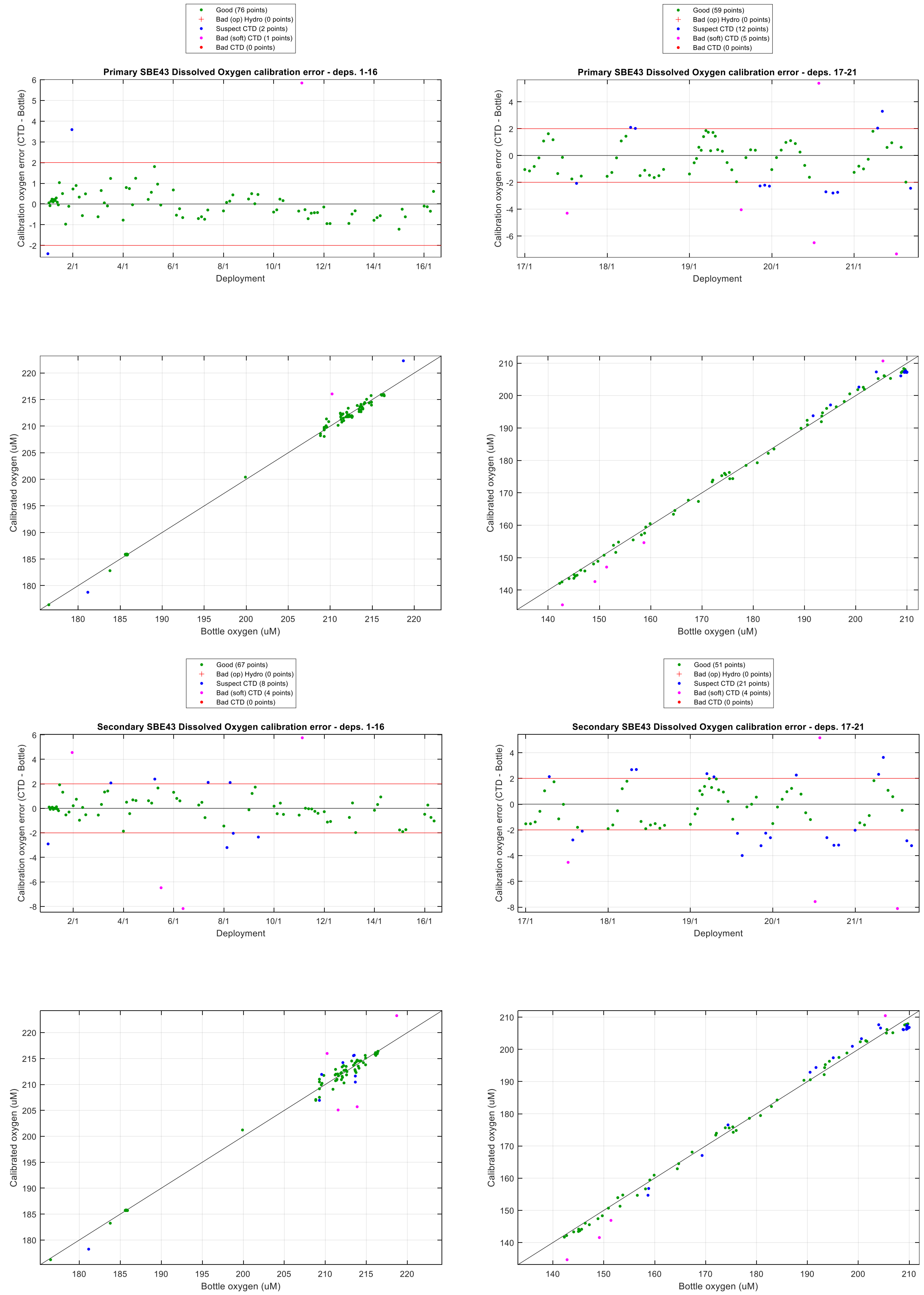


Figure 6 Dissolved Oxygen Difference with upcast CTD data (SBE43 - Bottle)

The box plot of calibrated downcast Dissolved Oxygen readings (primary - secondary) at the bottle sampling depths for all deployments in Figure 7 shows that the calibrated Dissolved Oxygen sensor responses corresponded well for most deployments.

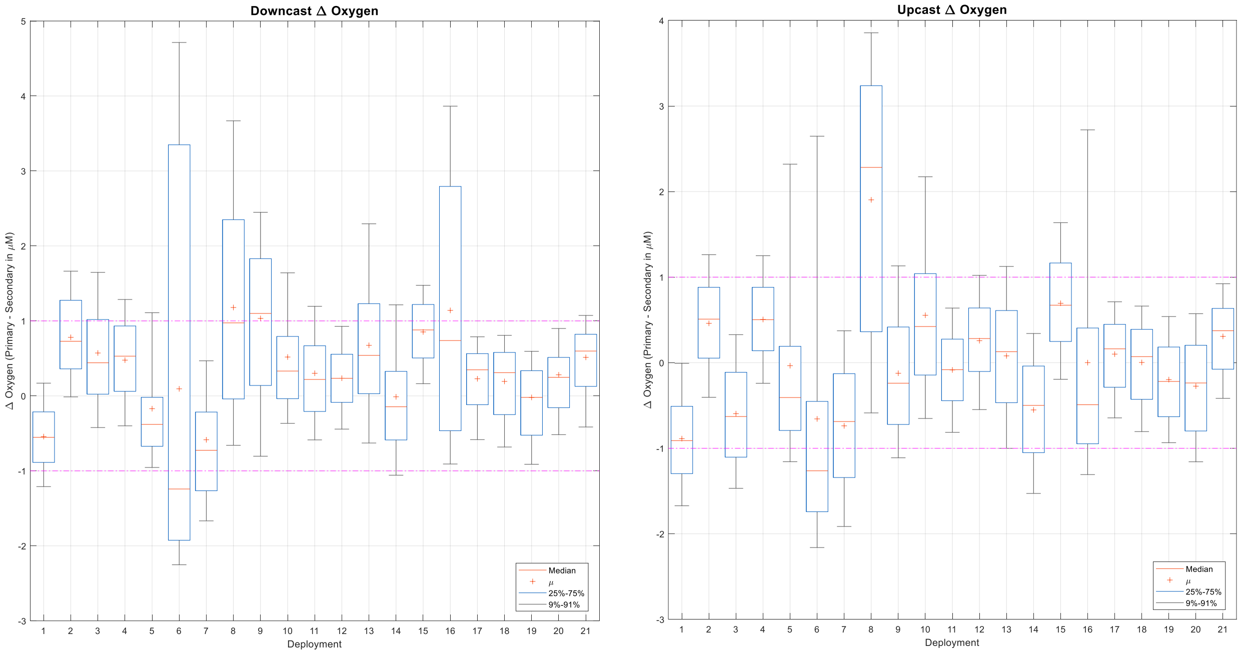


Figure 7 Difference between primary and secondary Dissolved Oxygen sensors

The old and new *Soc* and *Voffset* values for DO sensors are listed in Table 5 below. 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 Appendix II: Dissolved Oxygen Calibration Residual Plots.

The calibrations were applied for each sensor with these values calculated from groupings of deployments less than or equal to 1000 decibar (1-16) and those greater than 1000 decibar (17-21). The averaged files were created using the result from the secondary sensor.

Sensor	Calibration Source	Deployments	Calibration Coefficients				Dissolved Oxygen (µM)	
			Voffset	±	*Soc*	±	Residual SD	M.A.D.
Primary DO	CapPro	01-16	-0.52728	0.0038547	0.50792	0.0011235	0.54034	0.44219
	CapPro	17-21	-0.48383	0.0051547	0.49400	0.0022351	0.74661	1.1519
	Sea-Bird	01-21	-0.4772		0.4705			
Secondary DO	CapPro	01-16	-0.57982	0.0052249	0.57483	0.0019317	0.77590	0.54705
	CapPro	17-21	-0.52500	0.0058158	0.55236	0.0031363	0.90173	1.5259
	Sea-Bird	01-21	-0.5105		0.5095			

Table 5 Dissolved oxygen calibrations

3.5 Other sensors

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.

The WET labs ECO Fluorometer-Scattering sensor was used for all deployments. The fluorometer has been calibrated with manufacturer supplied coefficients to give outputs in mg/m3. The scattering (OBS) has been calibrated with manufacturer supplied coefficients to give outputs in m-1/sr.

The Biospherical PAR sensor was also used for all deployments. The output is a nominal 0-5 volts which is converted to the unit µEinsteins/m2/second using manufacturer supplied wet calibration factor and the dark voltage determined at calibration. This data channel has been included in the output files for all deployments. Clearly, time of day and environmental factors such as sea state and cloud cover impact on these readings. If most or all of the values for a deployment are near zero it indicates a night-time cast. In deployments where the PAR profiles have sub-surface maxima the CTD may have been shaded by the ship.

3.6 Bad data detection

The 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 6 below. 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
Oxygen	-0.1	500	0.5
Fluorometer	0	100	0.5
PAR	-5	2000	0.5
Transmissometer	0	100	0.5
OBS	-5	5000	0.5

Table 6 Sensor limits for bad data detection

3.7 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.

3.8 Averaging

The calibrated data were 'filtered' to remove pressure reversals and binned into the standard product of 111 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 QC flag. Our quality control flagging scheme is described in *Data Quality Control Flags.* Retrieved from Oceans & Atmosphere Information and Data Centre: http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf (Pender, 2000).

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 are taken to be the worst of the estimates for the parameters from which they are derived.

3.9 Data Issues

On deployment 12, a sensor difference was found between the primary and secondary temperature readings, after SIT replaced the pump cable which temporarily resolved the issue was resolved. On deployment 18, the sensor difference issue resurfaced and on retrieval it was discovered the washer on the pump in the secondary had worn away. After the pump was replaced, sensor difference values were settling more rapidly from 19 onwards.

Throughout deployments 1-19, a marginal sensor difference value of +0.0012 S/m between primary and secondary conductivity was observed. The secondary conductivity sensor was replaced before deployment 20 resulting in a lower sensor difference of -0.00024 S/m on deck.

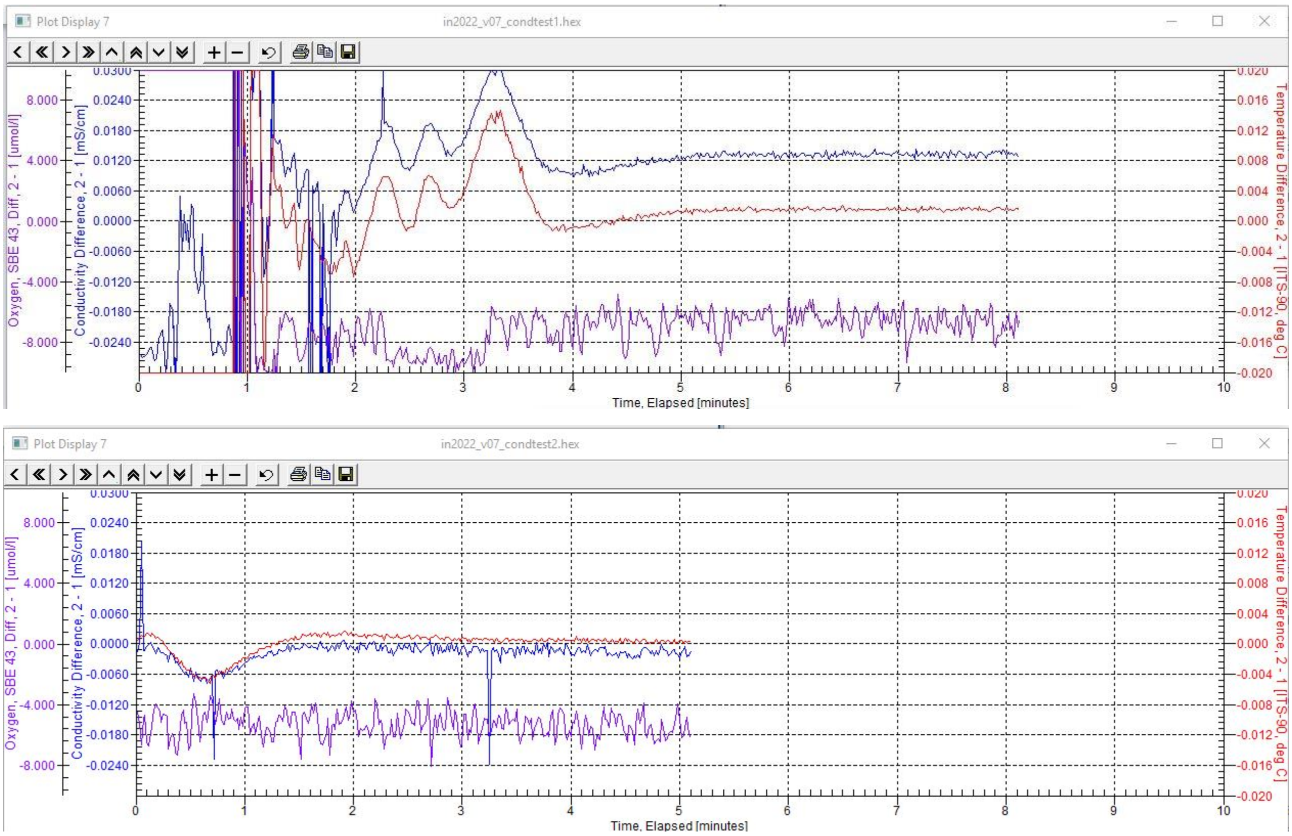


Figure 7 On deck test before and after swapping the secondary conductivity sensor.

Thermohaline staircases were observed on 3 deep deployments (18, 19 and 20) which were in sheltered bays or canyons. Initially we had suspected that there was a sensor issue but both primary and secondary channels agreed and plotting the raw frequency channel values also exhibited the same staircasing effect.

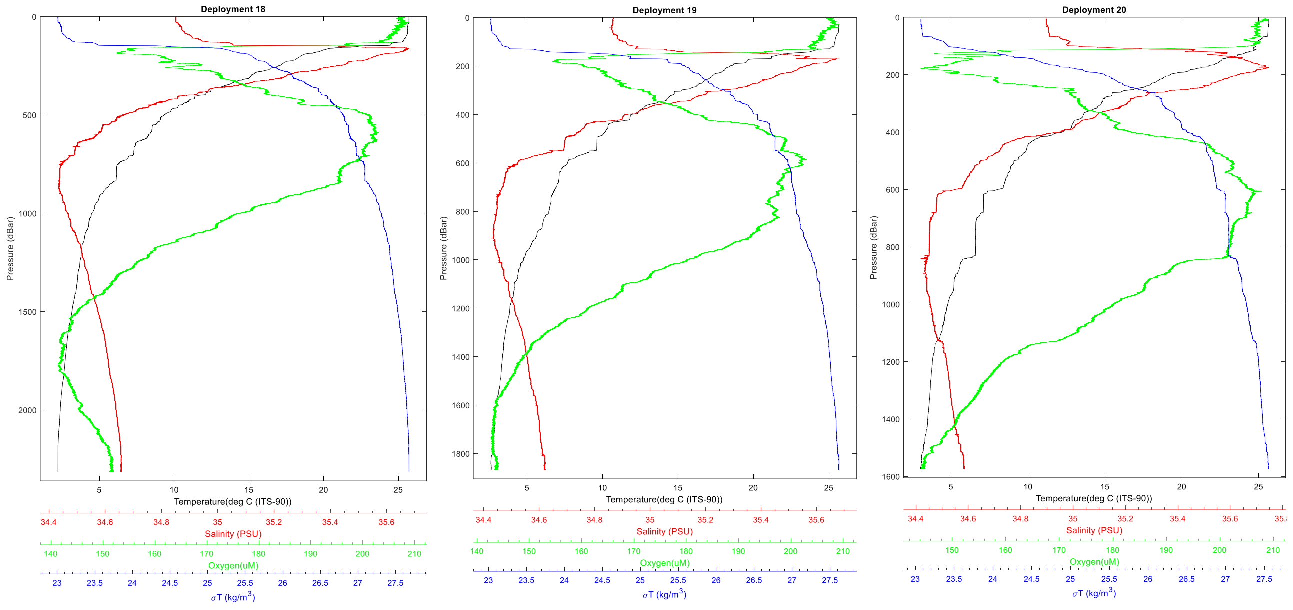


Figure 8 Scan plots with thermohaline staircasing due to salt-fingering observed in deployments 18-20

4 References

Webster, J. (2022). *The RV Investigator. Voyage Plan* in2022_v07*.* Retrieved from Marine National Facility: Voyage Plans and summaries: https://mnf.csiro.au/en/Voyages/Voyage-Catalogue

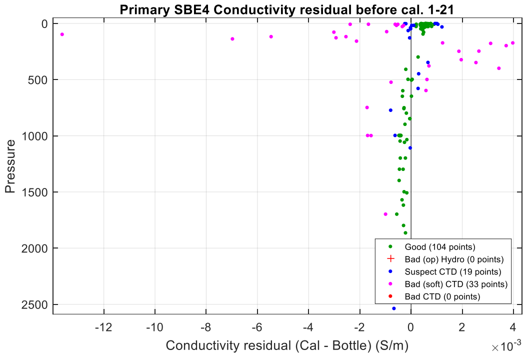
Pender, L. (2000). *Data Quality Control Flags.* Retrieved from Oceans & Atmosphere Information and Data Centre: http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

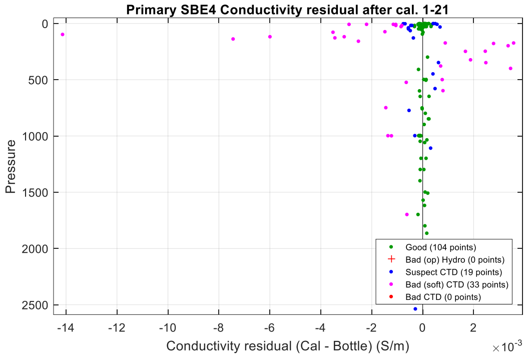
Sea-Bird. (2012). *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?code=251034

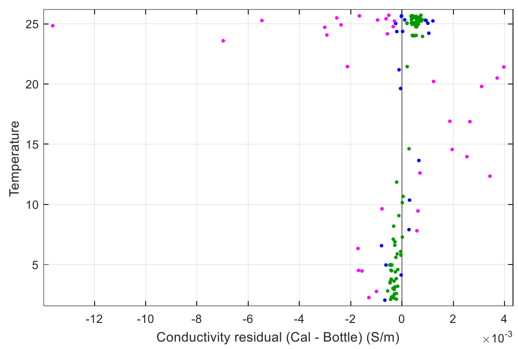
Sea-Bird. (2013). *AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?code=251036

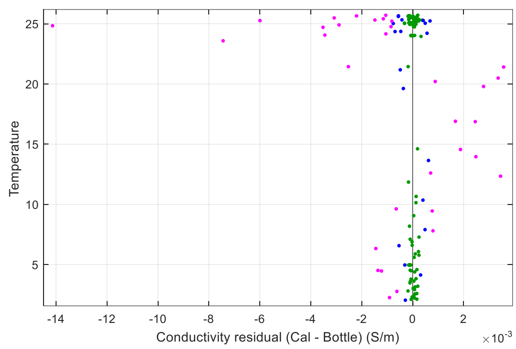
Sea-Bird. (2014). *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?code=251035

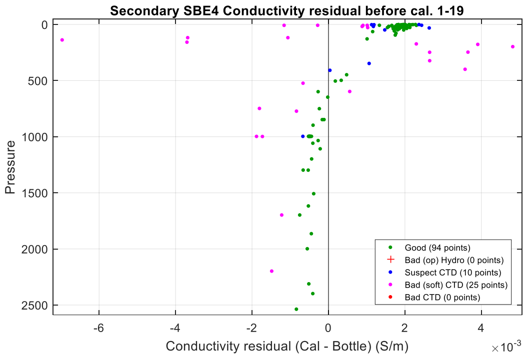
Appendix I: Conductivity Calibration Residual Plots

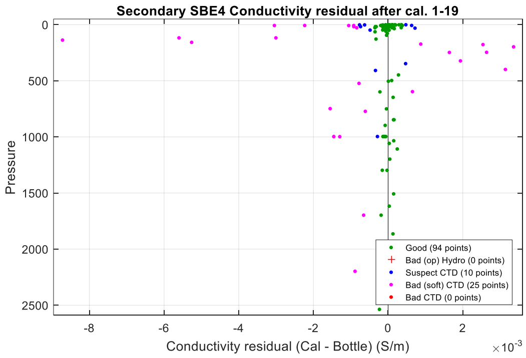


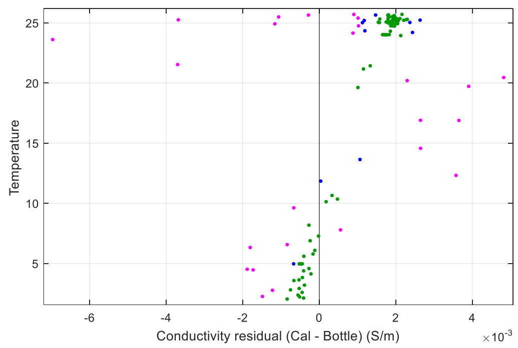


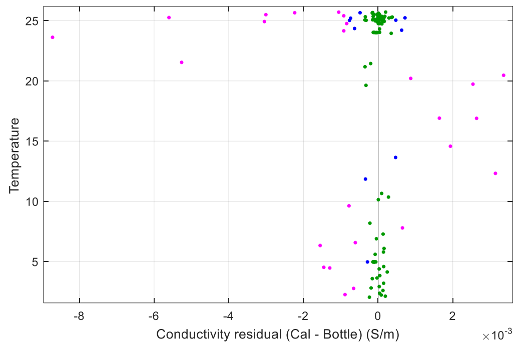


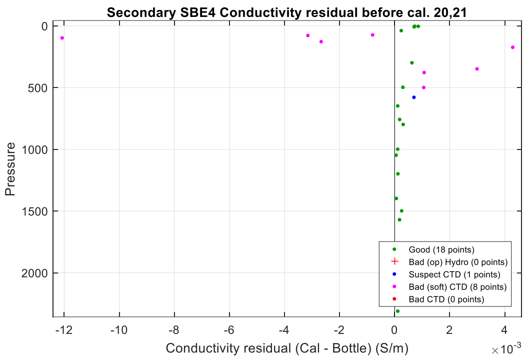


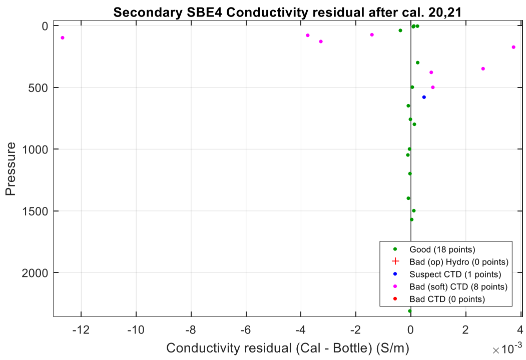









Secondary SBE4 Conductivity residual before cal. 20,21
Pressure
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³
Good (18 points)
Bad (op) Hydro (0 points)
Suspect CTD (1 points)
Bad (soft) CTD (8 points)
Bad CTD (0 points)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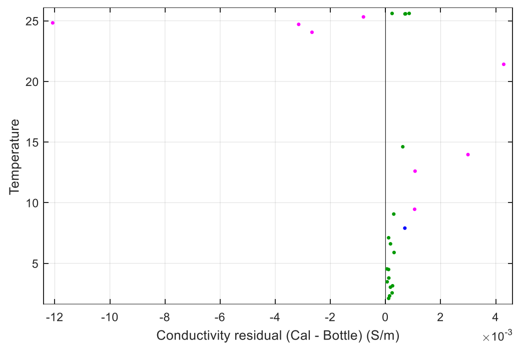
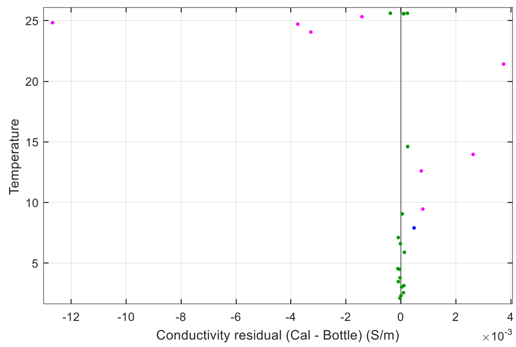
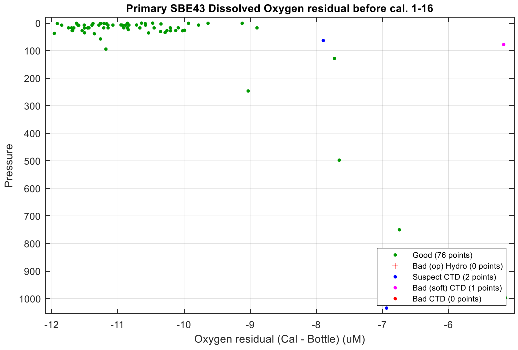
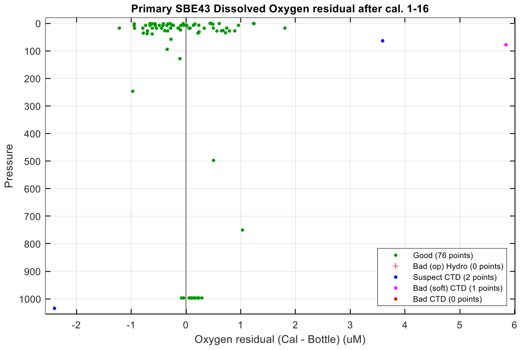
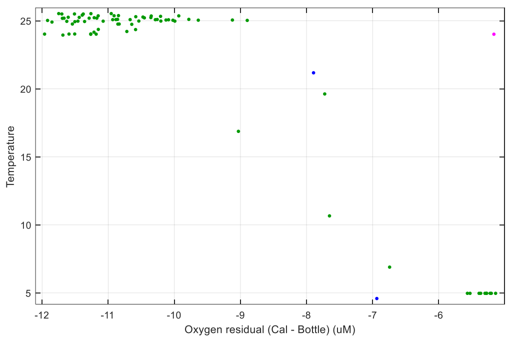

Temperature
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³

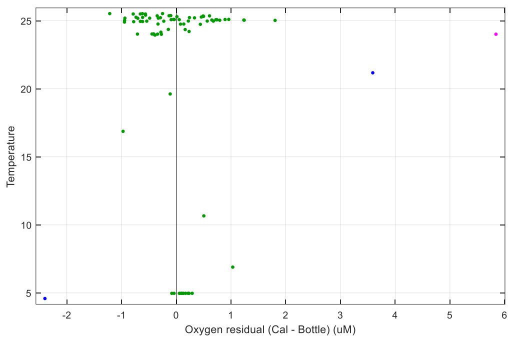

Temperature
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³

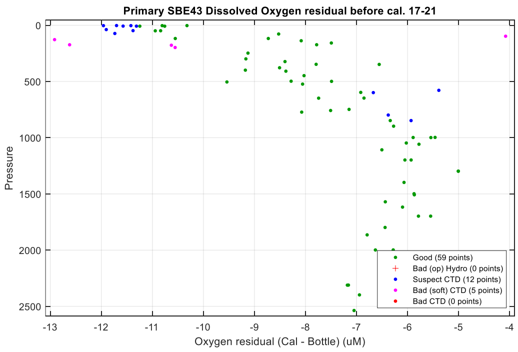
Appendix II: Dissolved Oxygen Calibration Residual Plots

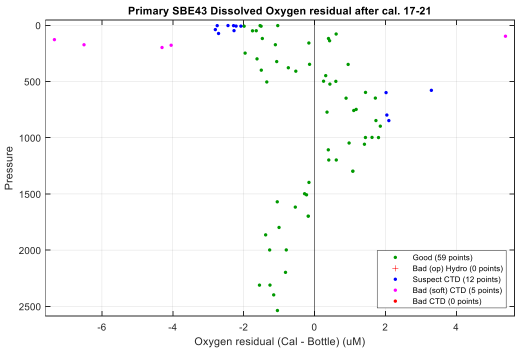


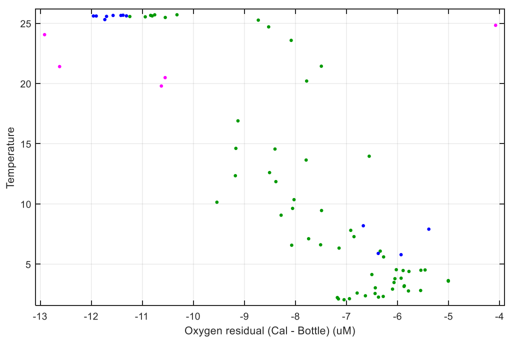


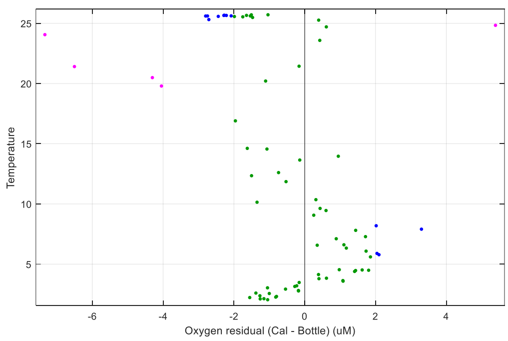


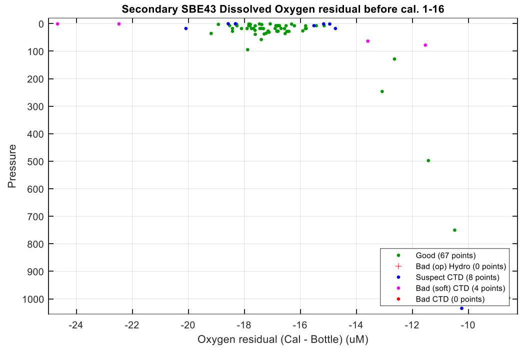


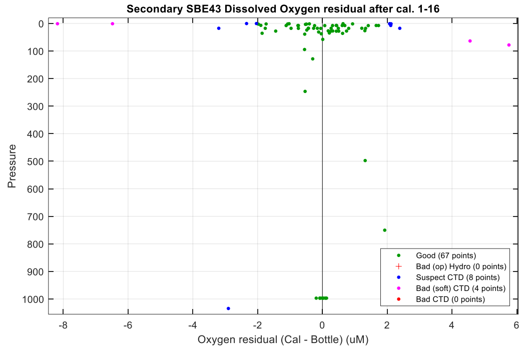









Secondary SBE43 Dissolved Oxygen residual before cal. 1-16
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (67 points)
Bad (op) Hydro (0 points)
Suspect CTD (8 points)
Bad (soft) CTD (4 points)
Bad CTD (0 points)


Secondary SBE43 Dissolved Oxygen residual after cal. 1-16
Pressure
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Good (67 points)
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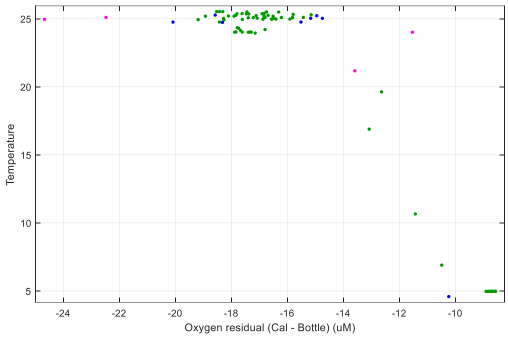
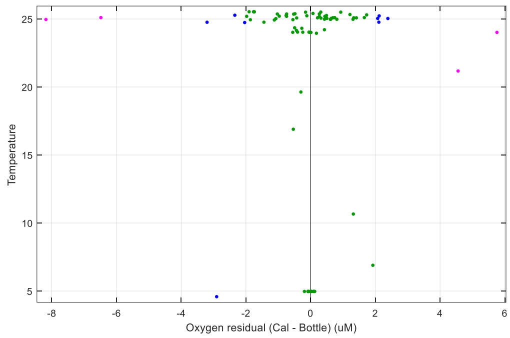
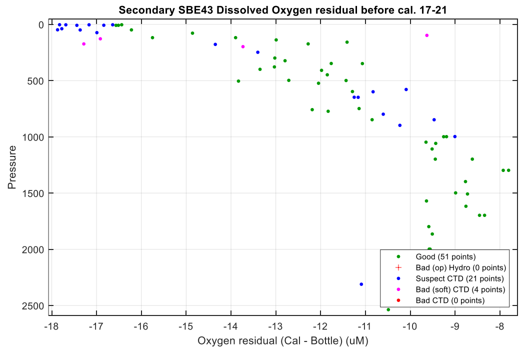
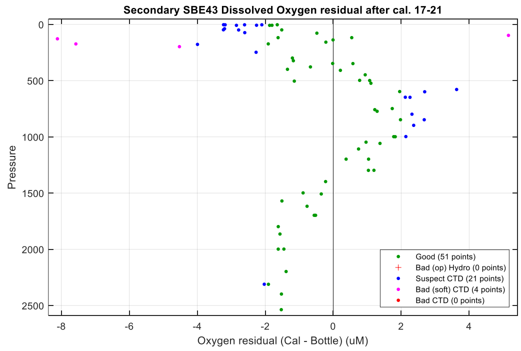
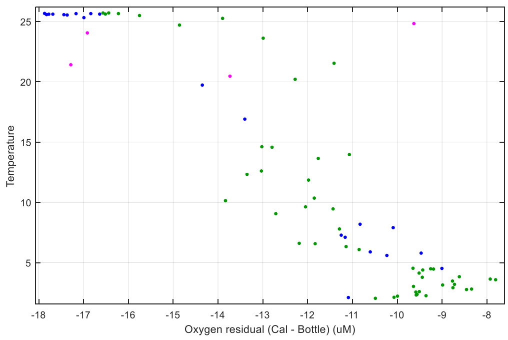
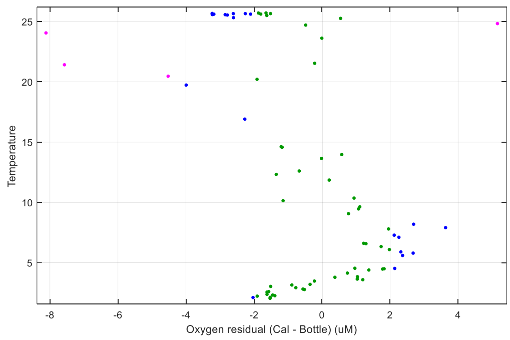

Temperature
Oxygen residual (Cal - Bottle) (uM)


Temperature
Oxygen residual (Cal - Bottle) (uM)


Secondary SBE43 Dissolved Oxygen residual before cal. 17-21
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (51 points)
Bad (op) Hydro (0 points)
Suspect CTD (21 points)
Bad (soft) CTD (4 points)
Bad CTD (0 points)


Secondary SBE43 Dissolved Oxygen residual after cal. 17-21
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (51 points)
Bad (op) Hydro (0 points)
Suspect CTD (21 points)
Bad (soft) CTD (4 points)
Bad CTD (0 points)


Temperature
Oxygen residual (Cal - Bottle) (uM)


Temperature
Oxygen residual (Cal - Bottle) (uM)

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