RV *Investigator*

CTD Processing Report

Voyage ID:	IN2019_T01
Voyage title:	Collaborative Australian Postgraduate Sea Training Alliance (CAPSTAN)
Depart:	Hobart, 0800 Monday, 29 April 2019
Return:	Fremantle, 0800 Thursday, 9 May 2019
Report compiled by:	Francis Chui

Contents

1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage IN2019_T01, from 30 Apr 2019 – 02 May 2019.

Data for 5 deployments were acquired using the Sea-Bird SBE911 CTD 23, 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 0.0021299 PSU, outside 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 had a SD of 0.87858 µM. The agreement between the CTD and bottle data was good.

Biospherical PAR, Tritech Altimeter (100m), Transmissometer, ECO-Chlorophyll and ECO-Scattering sensors were also installed on the auxiliary A/D channels of the CTD.

2 Voyage Details

2.1 Title

Collaborative Australian Postgraduate Sea Training Alliance (CAPSTAN)

2.2 Principal Investigators

Leah Moore, University of Canberra

April Abbott, Macquarie University

2.3 Voyage Objectives

The scientific objectives for IN2019_T01 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

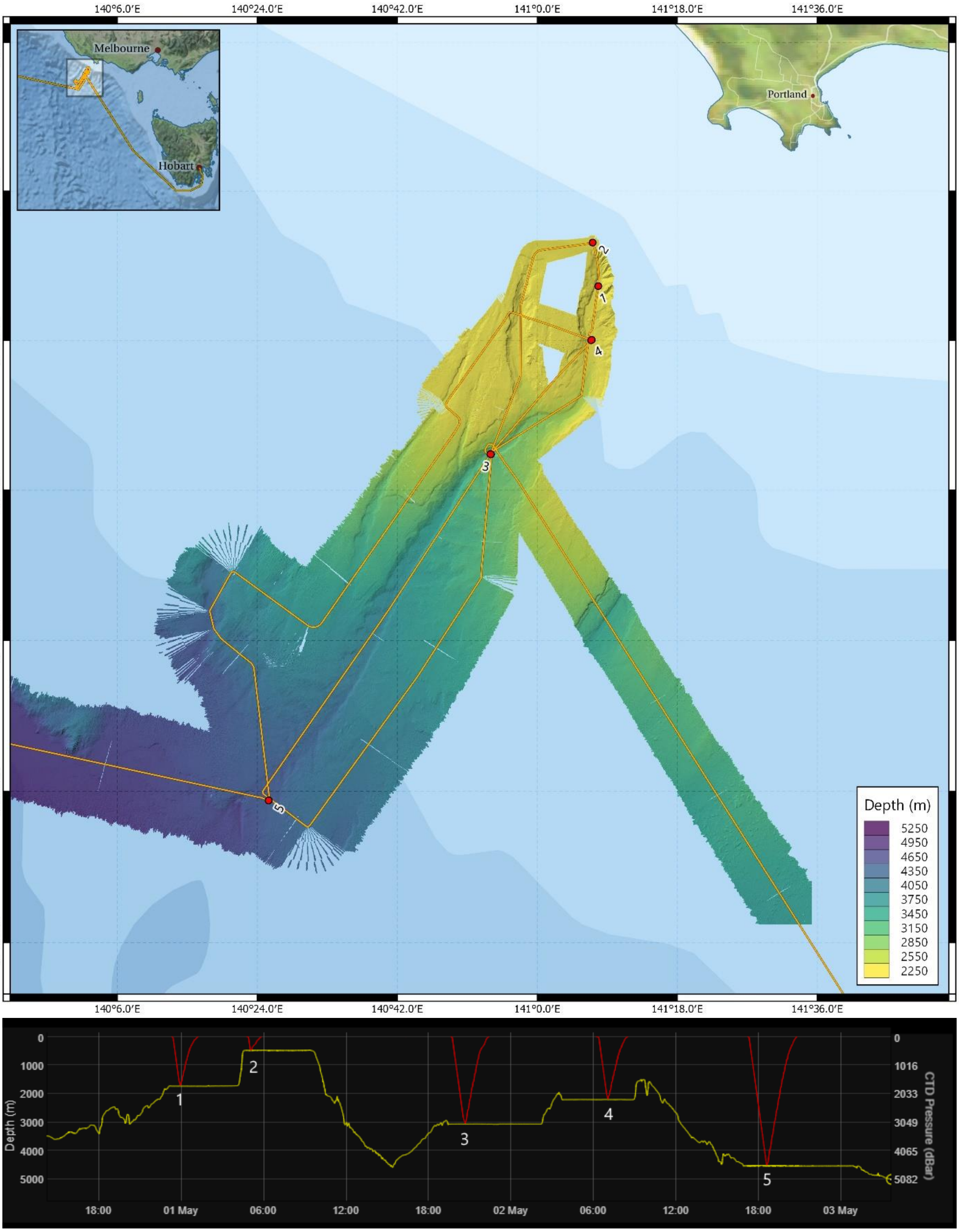


Figure 1 Area of operation for IN2019_T01

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with the CSIRO CTD unit 23, a Sea-Bird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen, Biospherical PAR, Tritech Altimeter (100m), Transmissometer, ECO-Chlorophyll and ECO-Scattering sensors. These sensors are described in Table 1 and Table 2 below.

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1312	P	20-Jul-2018	CSIRO Cal Lab
Primary Temperature	Sea-Bird SBE3*plus*	6130	T0	12-Jan-2019	CSIRO Cal. Lab
Secondary Temperature	Sea-Bird SBE3*plus*	6180	T1	12-Jan-2019	CSIRO Cal. Lab
Primary Conductivity	Sea-Bird SBE4C	4685	C0	14-Jan-2019	CSIRO Cal. Lab
Secondary Conductivity	Sea-Bird SBE4C	4662	C1	14-Jan-2019	CSIRO Cal. Lab
Primary Dissolved Oxygen	SBE43	3154	A0	24-May-2018	Sea-Bird
Secondary Dissolved Oxygen	SBE43	3198	A1	25-May-2018	Sea-Bird
Biospherical PAR	QCP-2300 HP	70111	A3	1-Aug-2018	Biospherical
Tritech 200kHz Altimeter	PA 200	313642	A4	1-Aug-2018	Tritech International
Transmissometer	C-Star	1421	A5	17-Aug-2018	Sea-Bird
Wet labs ECO-Chlorophyll	FLBBNTU	5169	A6	24-Aug-2018	Wet labs
Wet labs ECO-Scattering	FLBBNTU	5169	A7	24-Aug-2018	Wet labs

Table 1 CTD Sensor configuration on IN2019_T01 for deployments 1 and 2

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Primary Dissolved Oxygen	SBE43	1794	A0	30-Jul-2018	CSIRO Cal. Lab

Table 2 CTD Sensor configuration changes on IN2019_T01 for deployments 3, 4 and 5

Water samples were collected using a Sea-Bird SBE32, 36-bottle rosette sampler. Sampling was from 35 twelve litre bottles which were fitted to the frame. Rosette position 14 had issues with the firing mechanism and was not fitted with a bottle for deployments 1 and 2. A bottle was subsequently fitted to this position to test the firing mechanism but the bottle failed to close and from deployment 3 onwards the bottle was not attached. Rosette position 24 had a bottle attached for all 5 deployments but only triggered on deployment 2. On investigation, it was found both firing mechanisms were corroded as shown below.

Figure 2 Corroded rosette firing mechanism at positions 14 (left) and 24 (right)

There were 5 deployments and of these deployments, 0 were on-deck TSG calibration runs.

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-based, CapPro package version 2.9.

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 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 3 below.   The blue circles refer to initial out-of-water values and the red circles the final out-of-water values.

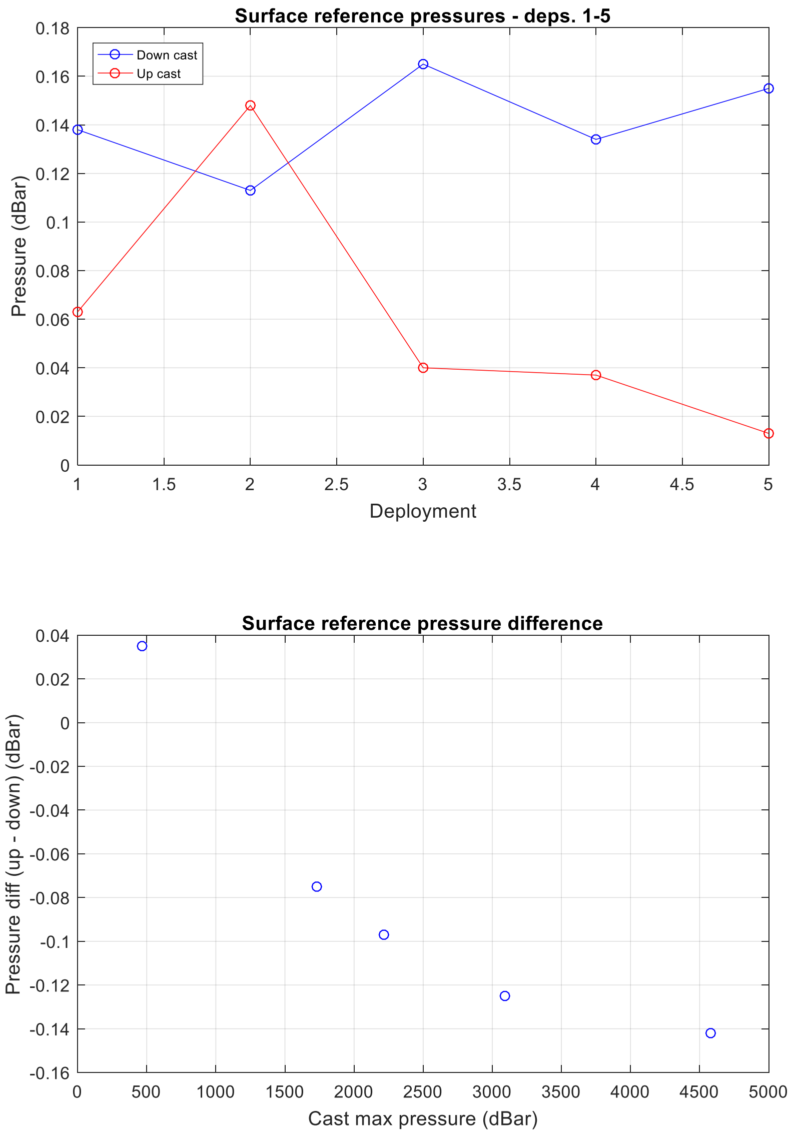


Figure 3 CTD pressure offsets

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 4. This indicates neither sensor has drifted significantly from its calibration.

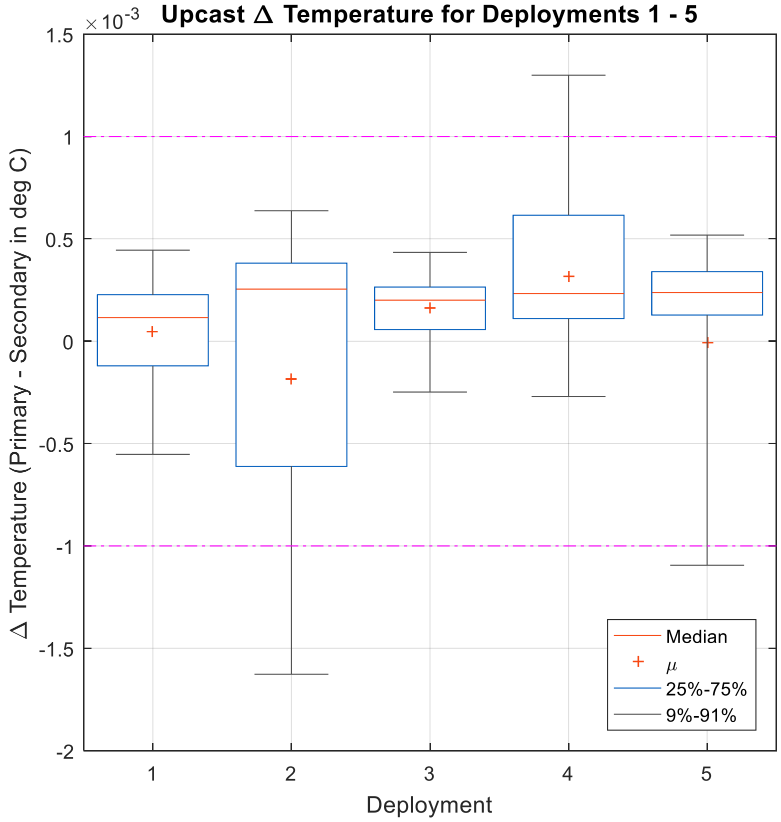


Figure 4 Difference between primary and secondary temperature sensors

3.3 Conductivity Calibration

Discrepancies and possible sampling problems between bottle and CTD salinities for the primary conductivity sensor would show in Figure 5; the plot of calibrated (CTD - Bottle) salinity below. The calibration was based upon the sample data (primary/secondary) for 59/61 of the total of 104 samples taken during deployments which are below our target of 75%.

The outliers marked in Figure 5 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.

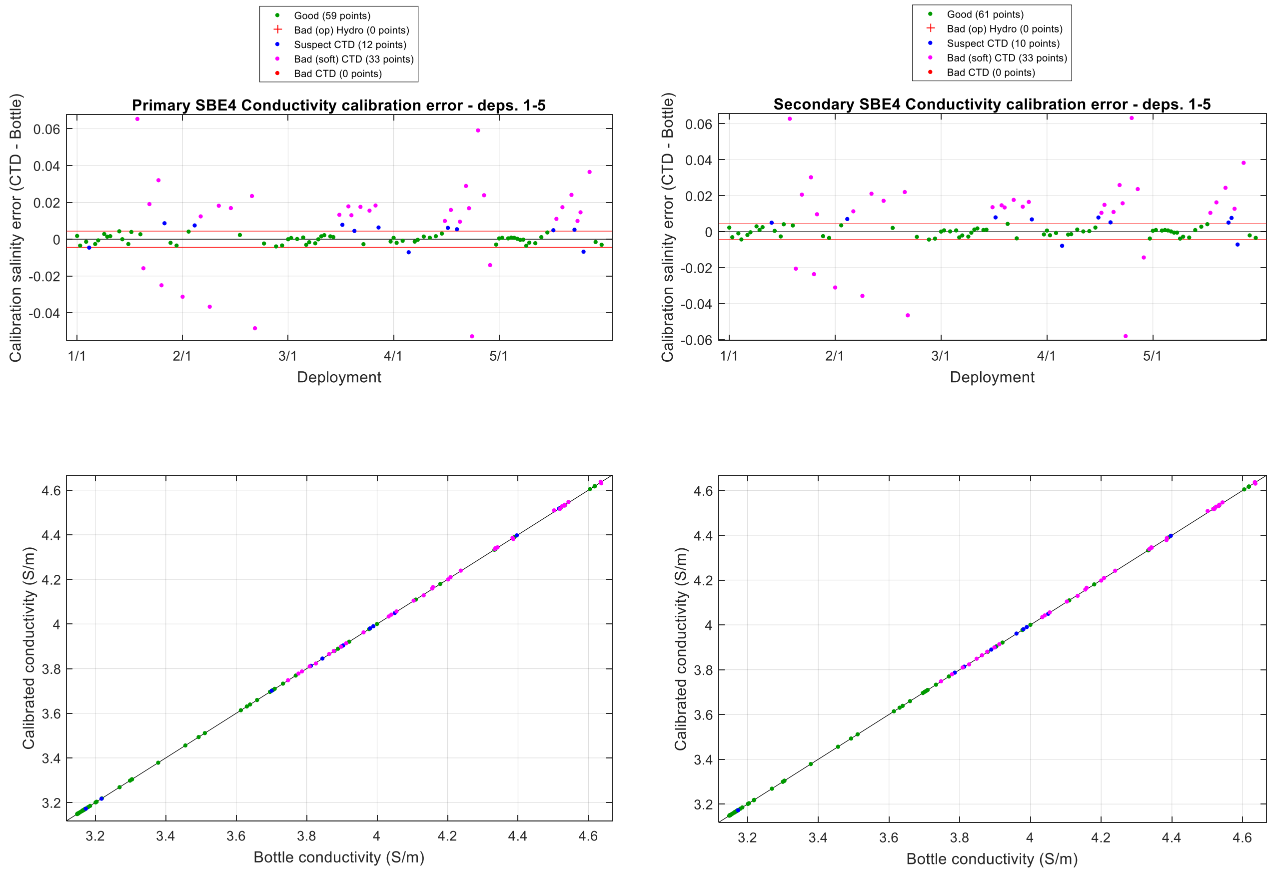


Figure 5 CTD - bottle salinity plot

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

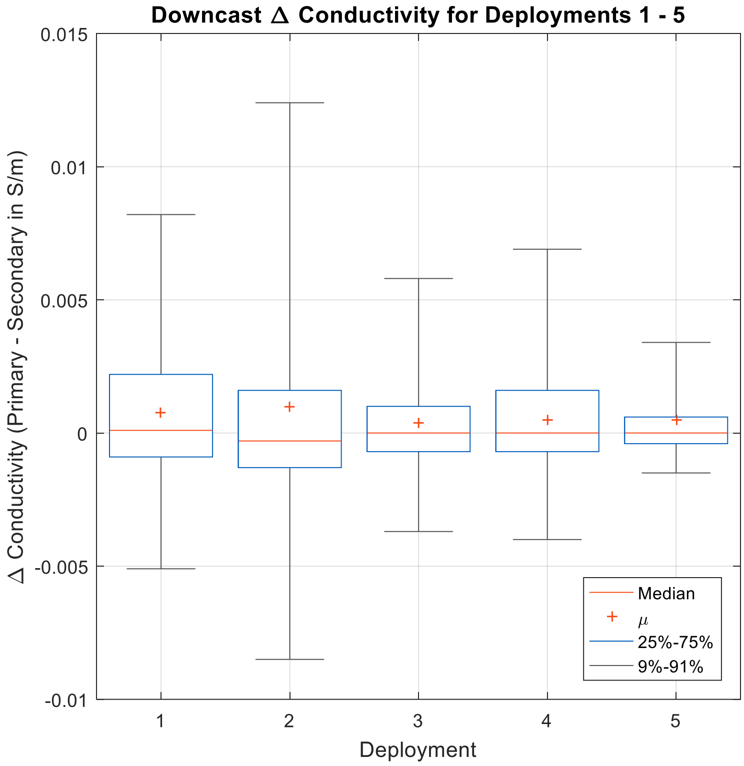


Figure 6 Difference between primary and secondary conductivity sensors

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	Scale Factor		Offset		Salinity (PSU)	
	a1	±	a0	±	Residual SD	M.A.D.
Primary	0.99952	2.8809e-07	0.0012254	0.008184	0.0020725	0.0019516
Secondary	0.99962	0.0021186	0.0011014	0.0085881	0.0021299	0.0023096

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

Conductivity Sensor	CPcor	±
Primary	-9.0083e-08	2.8809e-07
Secondary	-9.7021e-08	2.9807e-07

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

This is a marginal 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 (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 *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections* (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* (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. On deployment 3 the primary oxygen sensor was replaced after a large offset was found between the primary and secondary sensors. During the up-cast of this deployment, sensor readings became erratic from 1000 decibar onwards as shown in Figure 7. The effect of this on calibration can be seen in Figure 8 where bottle values did not match the primary sensor. On deck testing after this deployment showed good agreement between the two sensors and the configuration was kept for the remaining deployments.

Subsequent to the voyage it was found that the incorrect calibration for the primary oxygen sensor was used for deployment 1 and 2. The correct calibration for these two deployments was applied and the data reprocessed.

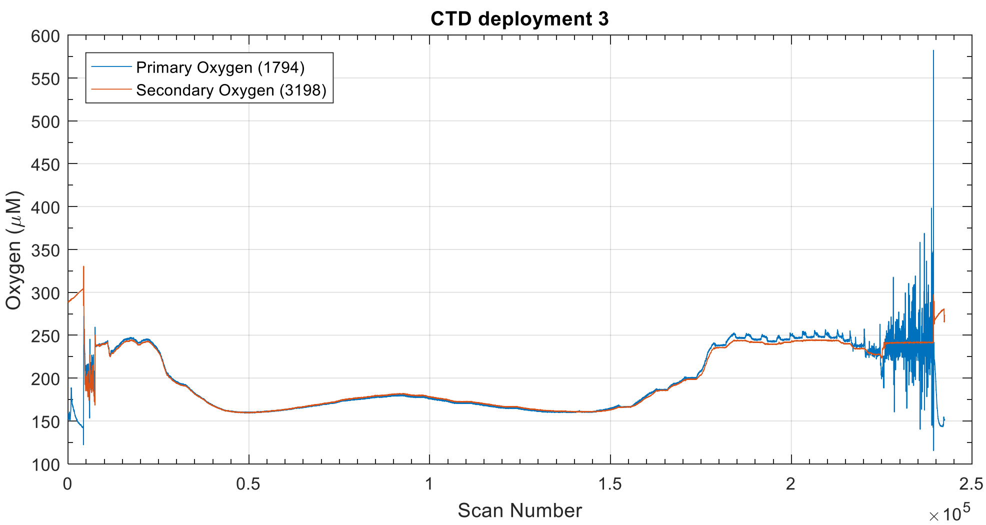


Figure 7 CTD deployment 3 primary and secondary oxygen sensor values plotted over scan showing erratic behaviour of the primary oxygen during the up-cast

Two calibration groups were used for the primary sensor and a single calibration group was used for the secondary sensor 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 (bottles were only fired in the up-cast).

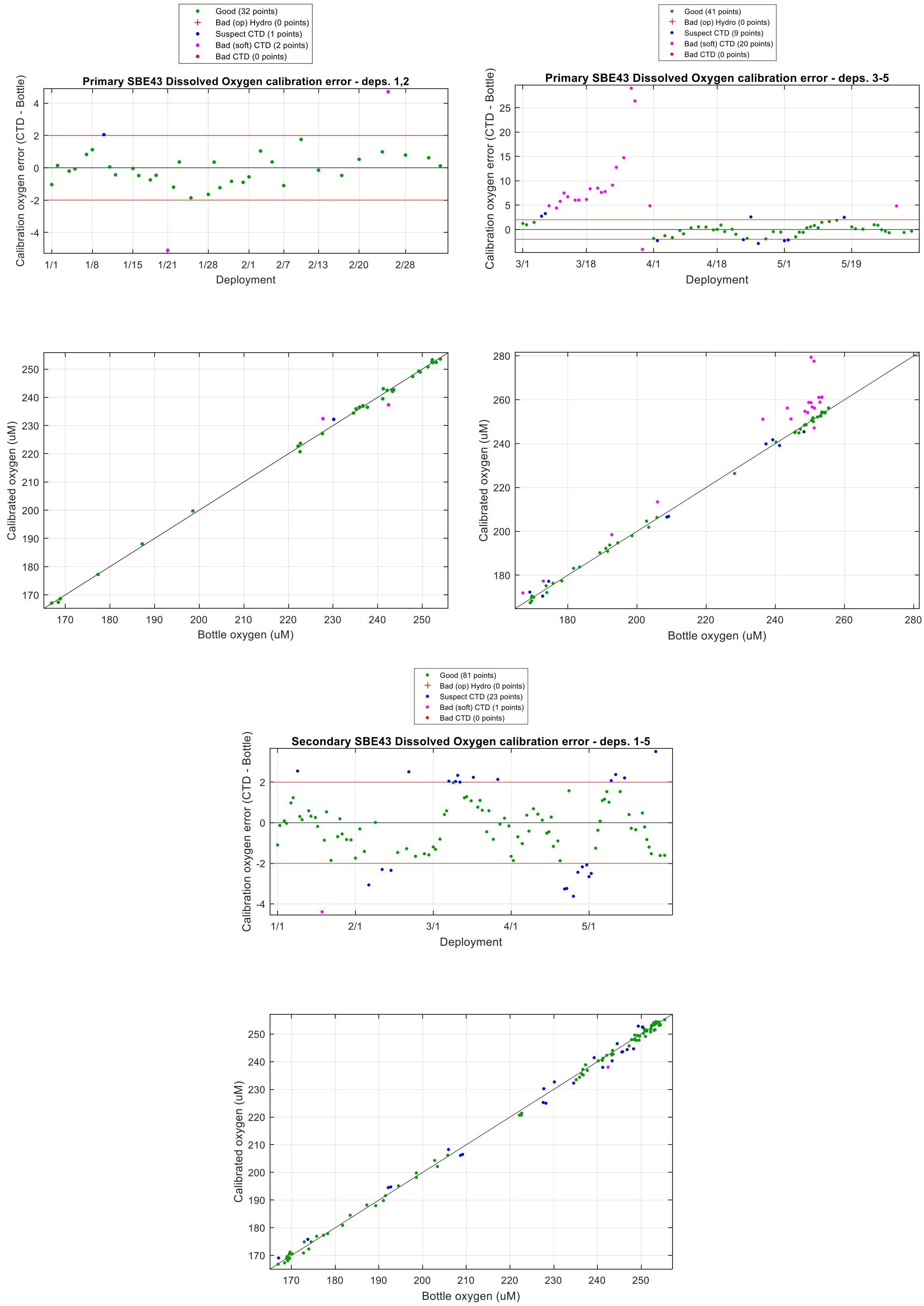


Figure 8 Dissolved Oxygen Difference with upcast CTD data (SBE43 - Bottle)

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 and 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	Hydrochemistry	1-2	-0.47268	0.0082048	0.41303	0.0017724	0.54373	0.61780
	Sea-Bird	1-2	-0.50010		0.40031			
	Hydrochemistry	3-5	-0.48689	0.0039902	0.51457	0.0018773	0.86755	0.88451
	CSIRO Cal. Lab	3-5	-0.50273656		0.49334113			
2nd	Hydrochemistry	1-5	-0.49039	0.0042081	0.42927	0.0011618	0.87858	1.0938
	Sea-Bird	1-5	-0.4989		0.4155			

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
Altimeter	0	100	0.5
Fluorescence	-5	5000	0.5
Turbidity	-5	5000	0.5

Table 6 Sensor limits for bad data detection

3.7 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 QC flag. Our quality control flagging scheme is described in *Data Quality Control Flags* (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.

4 References

Leah Moore. (2019). *The RV Investigator. Voyage Plan* IN2019_T01. Retrieved from Marine National Facility: Voyage Plans and summaries: http://www.csiro.au/~/media/MNF/Files/Voyages/Investigator/Voyage-Plans-summaries/2019/IN2019_T01-CAPSTAN-Voyage-Plan.pdf

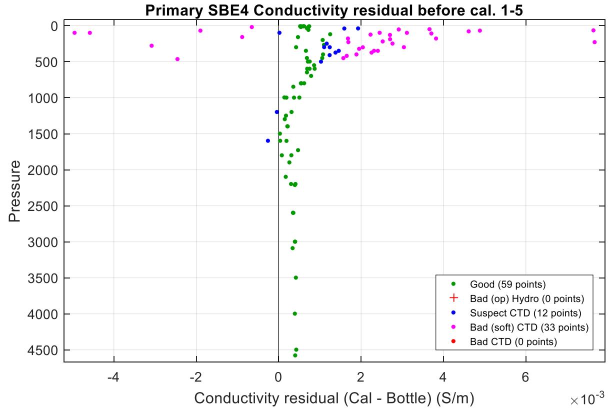
Pender, L. (2000). *Data Quality Control Flags.* Retrieved from Oceans & Atmosphere Information and Data Centre: http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

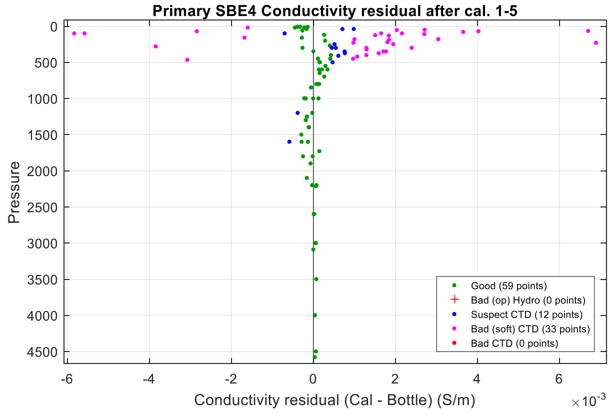
Sea-Bird. (2012). *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-2-sbe-43-dissolved-oxygen-sensor-calibration-and-data-corrections

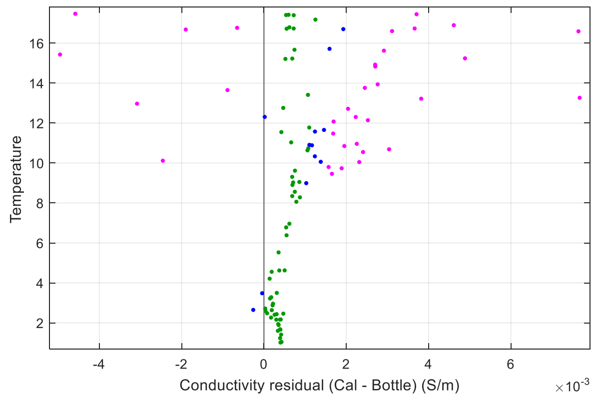
Sea-Bird. (2013). *AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-sbe-43-dissolved-oxygen-sensor-background-information-deployment-recommendations

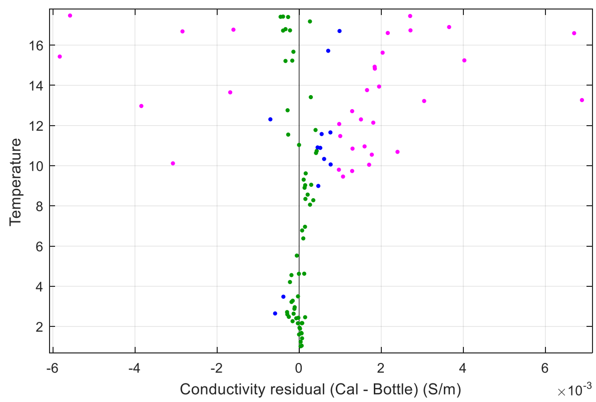
Sea-Bird. (2014). *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-3-sbe-43-dissolved-oxygen-do-sensor-hysteresis-corrections

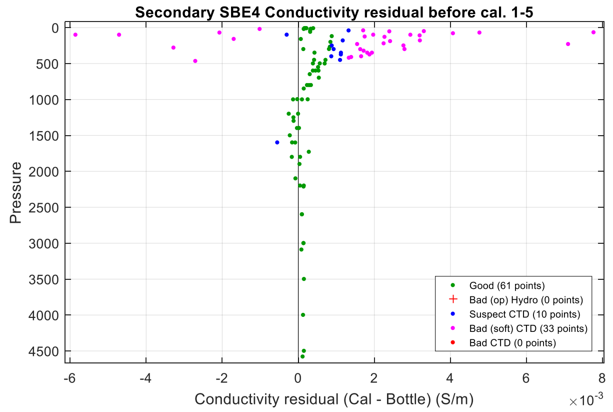
Appendix I: Conductivity Calibration Residual Plots

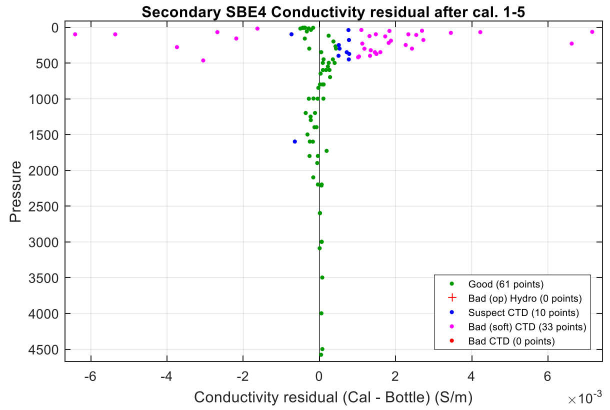


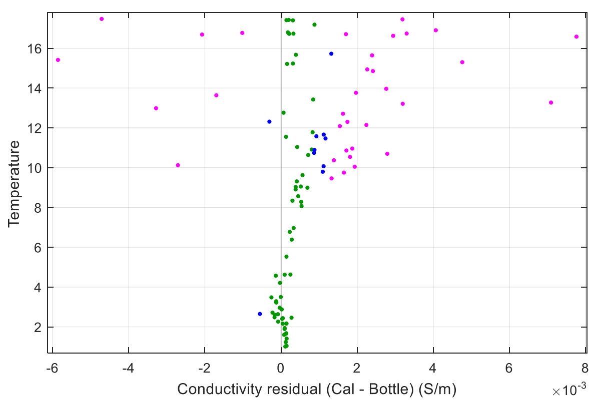


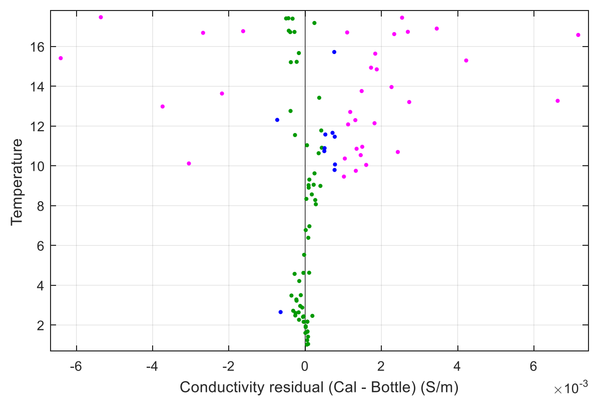




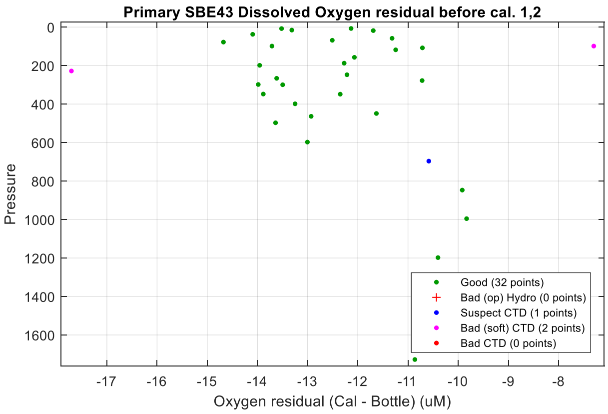


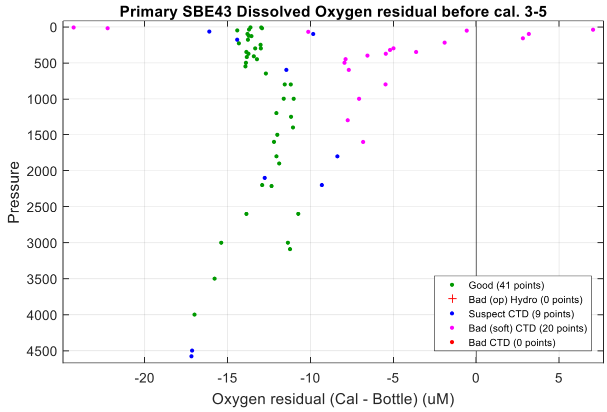


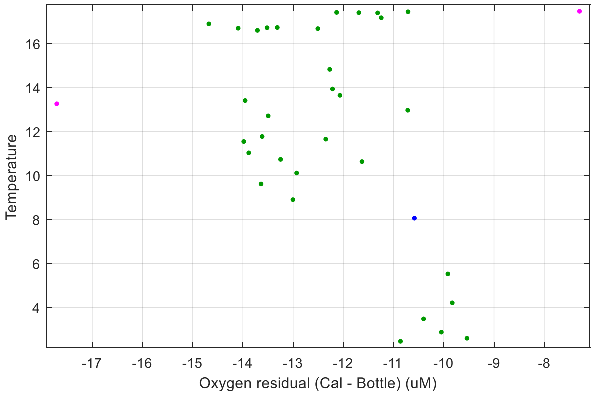


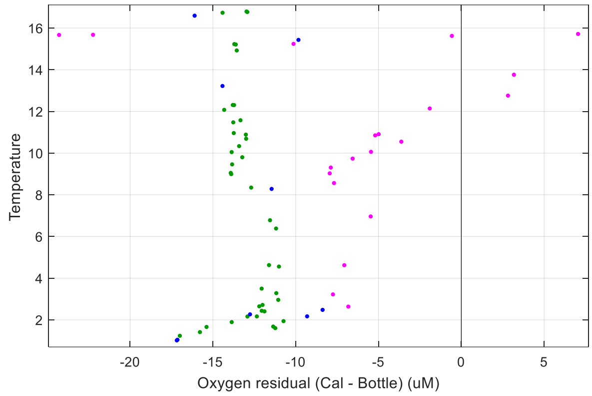


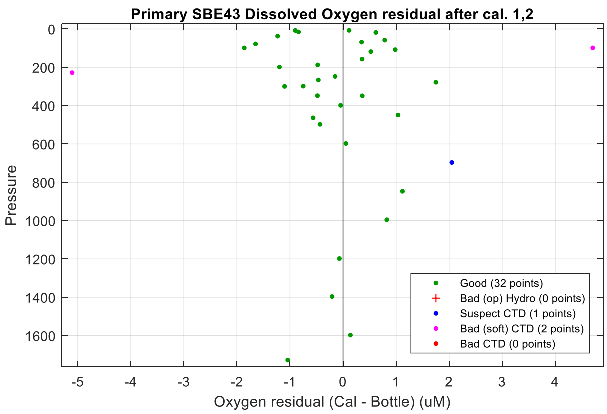
Appendix II: Dissolved Oxygen Calibration Residual Plots

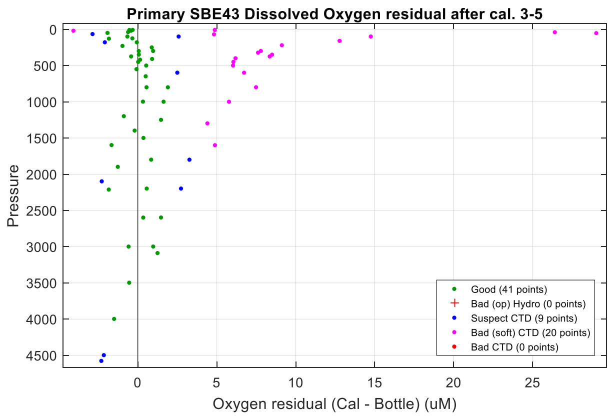


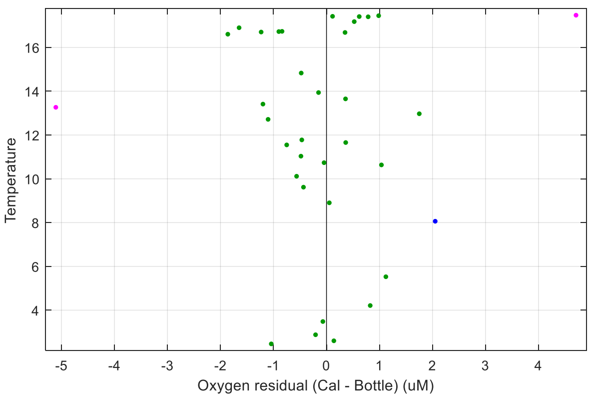


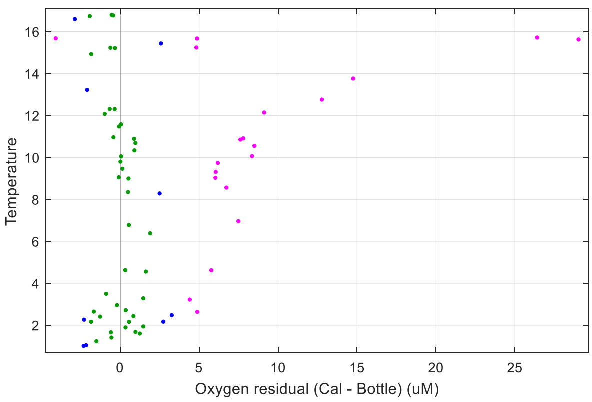


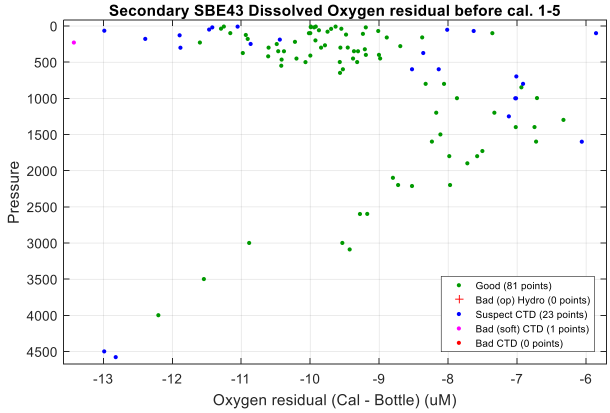


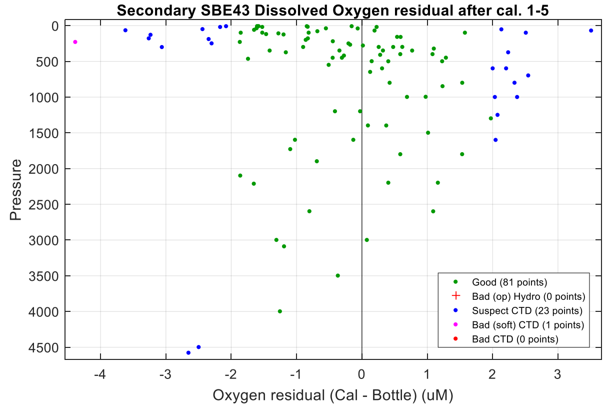









Secondary SBE43 Dissolved Oxygen residual before cal. 1-5
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (81 points)
Bad (op) Hydro (0 points)
Suspect CTD (23 points)
Bad (soft) CTD (1 points)
Bad CTD (0 points)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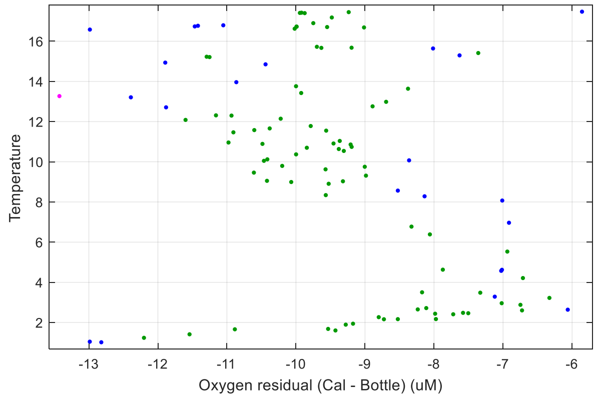
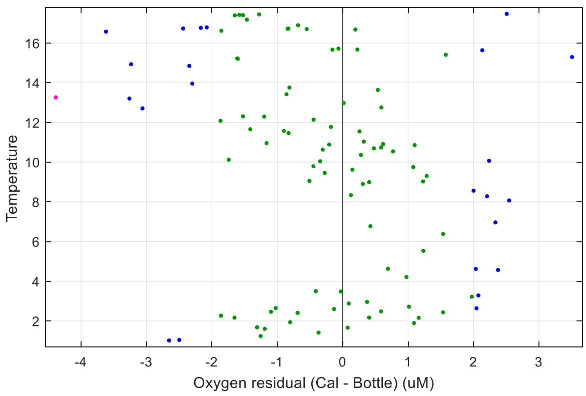

Temperature
Oxygen residual (Cal - Bottle) (uM)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Oxygen residual (Cal - Bottle) (uM)