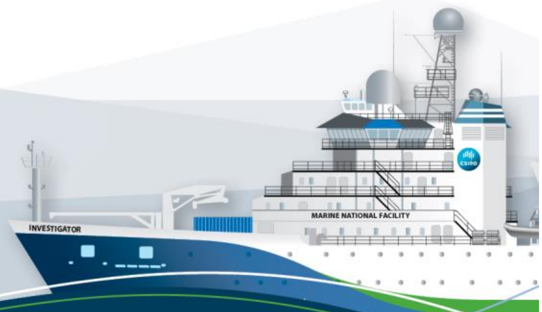
RV *Investigator*

CTD Processing Report

Voyage ID:	IN2019_V06 Leg 1
Voyage title:	Tropical observations of atmospheric convection, biogenic emissions, ocean mixing, and processes generating intra-seasonal SST variability
Depart:	Darwin, 2000 Saturday, 19 October 2019
Return:	Darwin, 0600 Monday, 11 November 2019
Report compiled by:	Stephanie Zeliadt



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1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage IN2019_V06 Leg 1, from 19 Oct 2019 – 11 Nov 2019.

Data for 96 deployments were acquired using the Sea-Bird SBE911 CTD #24, fitted with 24 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 multiple deployment groupings. The deployments were grouped by changes in temperature or conductivity sensor. The final calibrations from the secondary sensor had a standard deviation (SD) of 0.0030308 and 0.0035894 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 0.89666 µM. The agreement between the CTD and bottle data was good.

A Biospherical PAR, Tritech Altimeter, C-Star Transmissometer, Seapoint Nephelometer, WET Labs ECO Scattering, and WET Labs ECO Chlorophyll sensor, were also installed on the auxiliary A/D channels of the CTD. The rosette was also fitted with 3 RBRconcerto³ CTD|ODO sensors measuring temperature, conductivity and oxygen.

2 Voyage Details

2.1 Title

Tropical observations of atmospheric convection, biogenic emissions, ocean mixing, and processes generating intra-seasonal SST variability

2.2 Principal Investigators

Robin Robertson (Xiamen University Malaysia)

2.3 Voyage Objectives

The scientific objectives for IN2019_V06 Leg 1 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

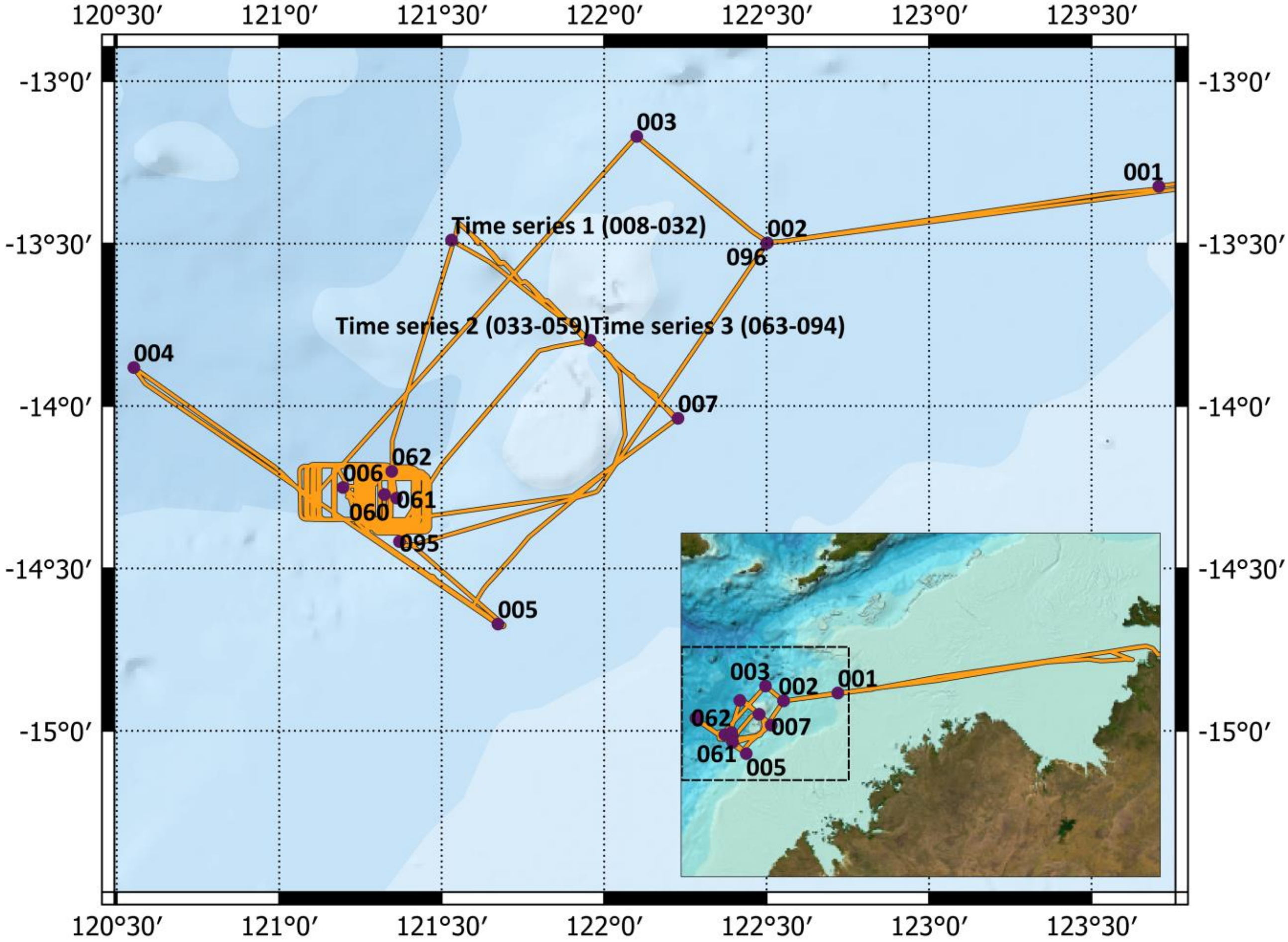


Figure 1 Area of operation for IN2019_V06 Leg 1

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with the CSIRO CTD unit #24, a Sea-Bird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors, Biospherical PAR, Tritech Altimeter, C-Star Transmissometer, Seapoint Nephelometer, WET Labs ECO Scattering, and WET Labs ECO Chlorophyll sensor. These sensors are described in Table 1 – 4 below.

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1332	P	10-Jul-2019	CSIRO
Primary Temperature	Sea-Bird SBE3*plus*	6180	T0	12-Jan-2019	CSIRO
Secondary Temperature	Sea-Bird SBE3*plus*	6130	T1	12-Jan-2019	CSIRO
Primary Conductivity	Sea-Bird SBE4C	4685	C0	14-Jan-2019	CSIRO
Secondary Conductivity	Sea-Bird SBE4C	4662	C1	14-Jan-2019	CSIRO
Primary Dissolved Oxygen	SBE43	3198	A0	12-Aug-2019	CSIRO
Secondary Dissolved Oxygen	SBE43	3159	A1	14-Jun-2019	Manufacturer
Altimeter	PA 500	05301.316739	A2	N/A	Manufacturer
PAR Sensor	QCP2300HP	70111	A3	14-Aug-2019	Manufacturer
Transmissometer	C-Star	1421-DR	A4	17-Aug-2018	Manufacturer
Nephelometer	Seapoint	13142	A5	5-Mar-2012	Manufacturer
Wetlabs ECO - Chlorophyll	FLBB	5169	A6	24-Aug-2018	Manufacturer
Wetlabs ECO - Scattering	FLBB	5169	A7	24-Aug-2018	Manufacturer
LADCP – Upward facing	300kHz	24502			
LADCP – Downward facing	300kHz	16673			

Table 1 CTD Sensor configuration on IN2019_V06 Leg 1 casts 1-33

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Secondary Conductivity	Sea-Bird SBE4C	4426	C1	25-Jun-2019	Manufacturer

Table 2 CTD Sensor configuration changes on IN2019_V06 Leg 1 cast 34 – 96

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Secondary Temperature	Sea-Bird SBE3*plus*	6302	T1	3-Dec-2018	CSIRO

Table 3 CTD Sensor configuration changes on IN2019_V06 Leg 1 casts 35 – 96

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Primary Conductivity	Sea-Bird SBE4C	4662	C1	14-Jan-2019	CSIRO

Table 4 CTD Sensor configuration changes on IN2019_V06 Leg 1 casts 54 – 96

Water samples were collected using a Sea-Bird SBE24, 24-bottle rosette sampler. Sampling was from 24 twelve litre bottles which were fitted to the frame.

There were 96 deployments and of these, deployment 1 was a test deployment which is included in the final dataset.

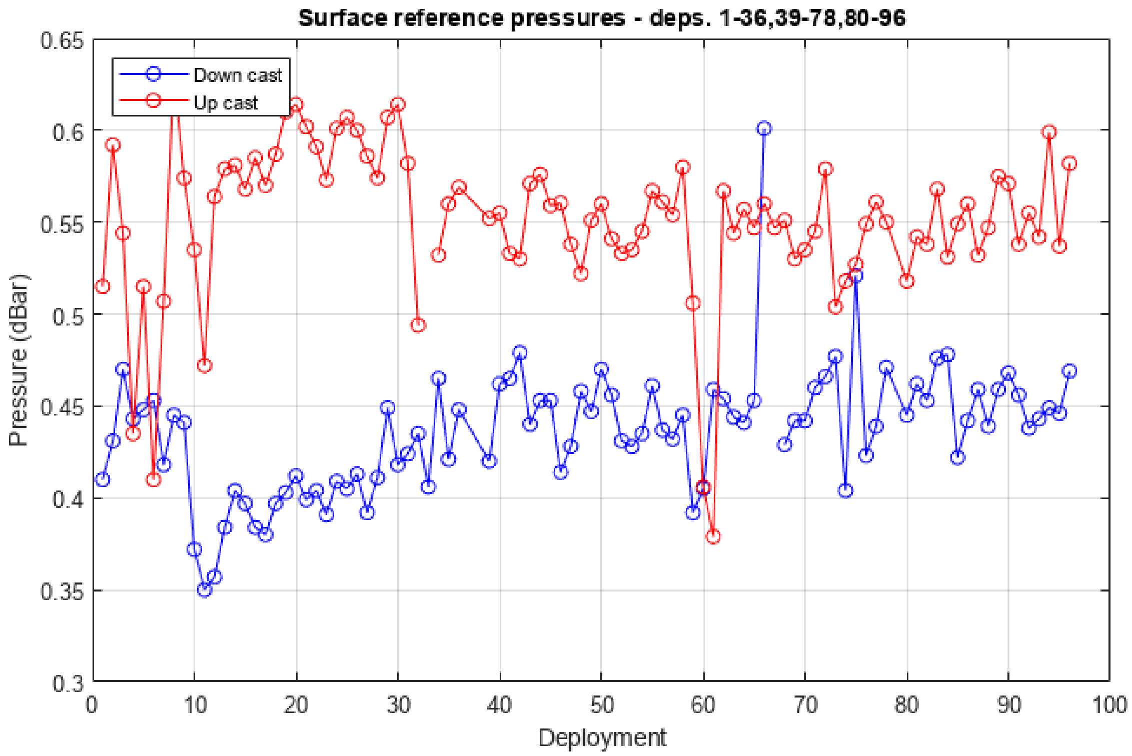
The raw CTD data were collected in SBE SeaSave version 7.26.7.110, converted to scientific units using SBE Data Processing version 7.26.7 and written to netCDF format files with CNV_to_Scan for processing using the Matlab-base, CapPro package version 2.11 dated 23-Aug-2019.

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 2 below. The blue circles refer to initial out-of-water values and the red circles the final out-of-water values. Deployments 37, 38, and 79 have been excluded due to the down cast reference pressure not being available for these deployments.



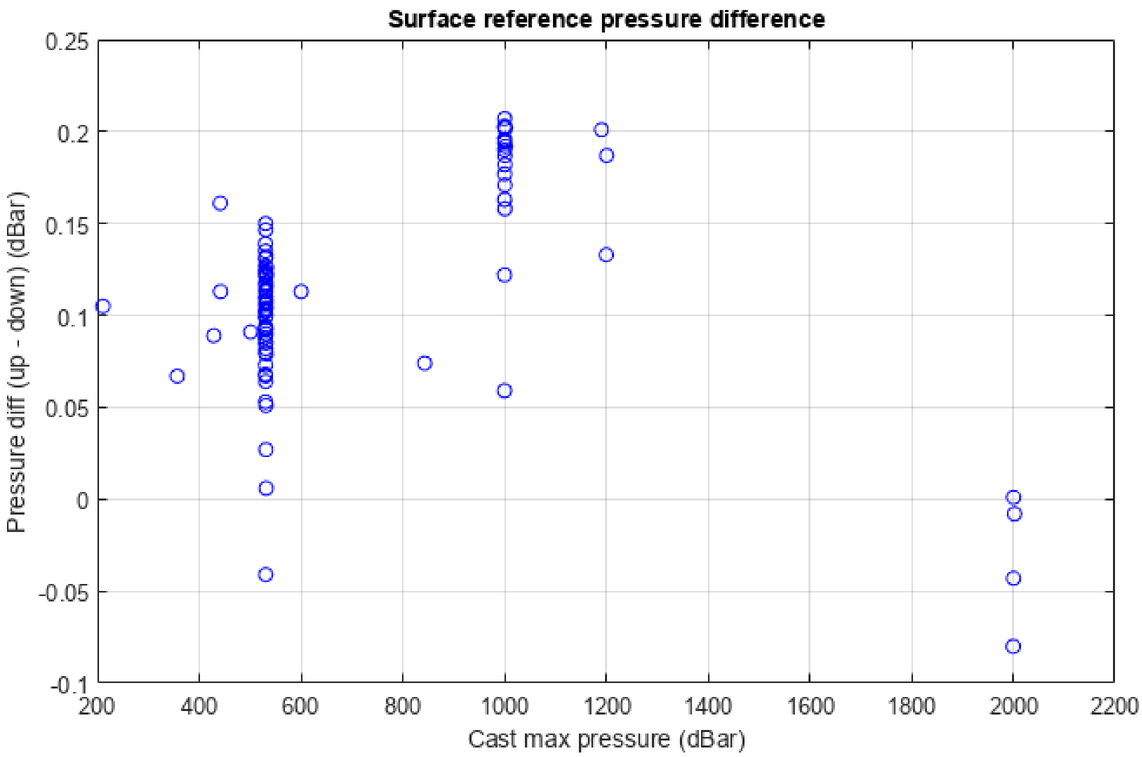


Figure 2 CTD pressure offsets

The difference between the primary and secondary temperature sensors on the downcast is plotted below. Most deployments plot within ±0.005°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. On deployment 36, the pump took a long time to come on and it is suspected it was not fully pumping for the downcast resulting in the outlier in temperature difference for that cast.

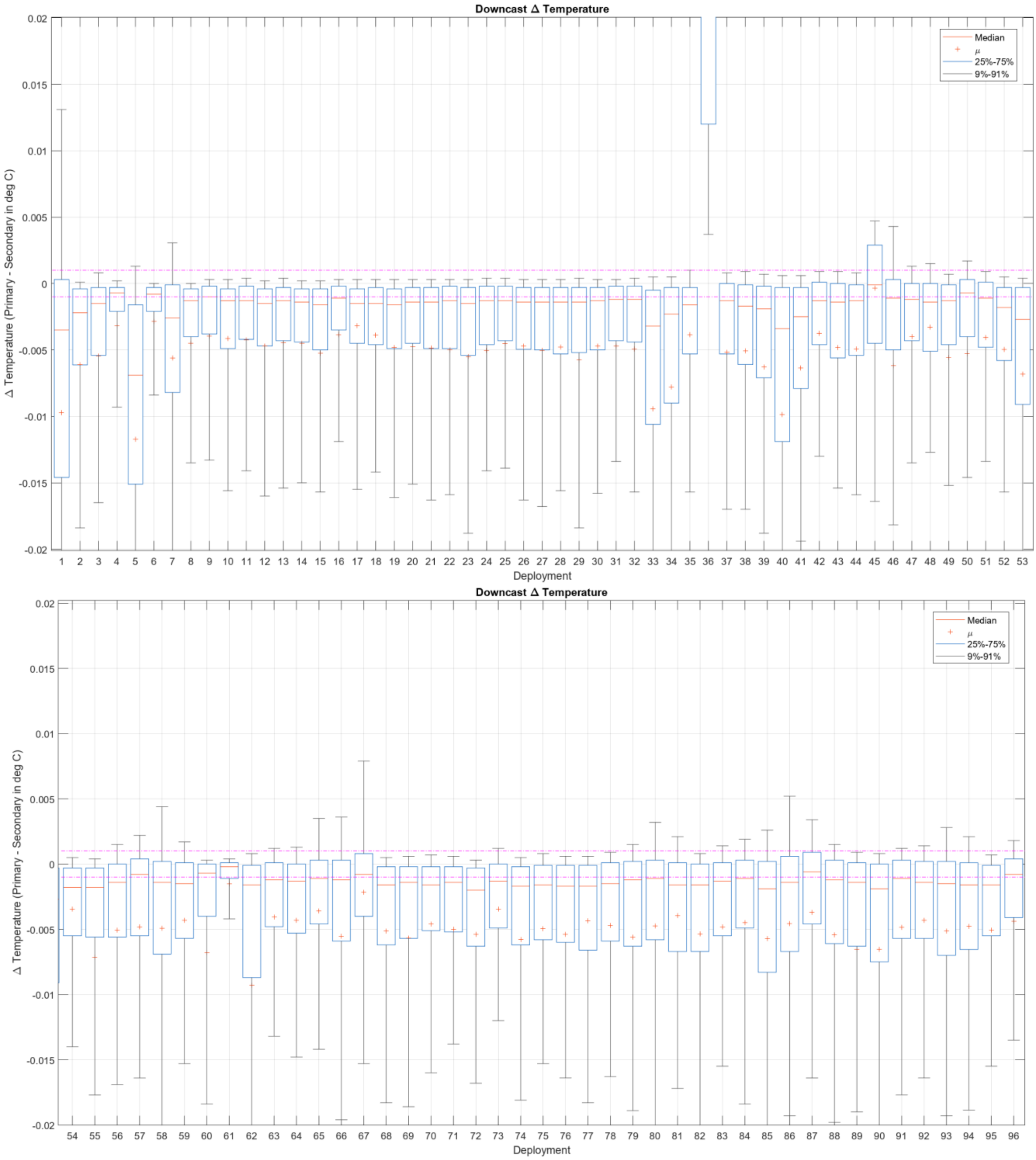
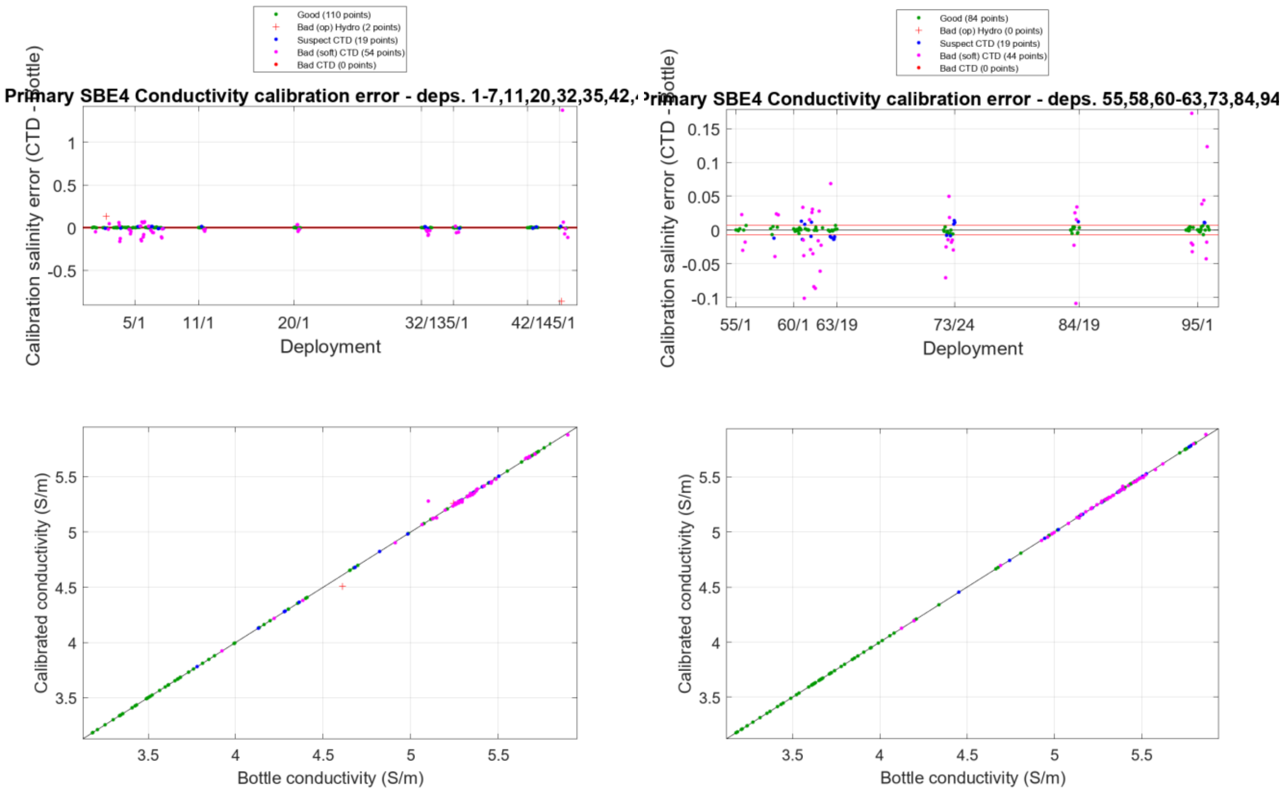


Figure 3 Difference between primary and secondary temperature sensors

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 232/232 of the total of 332 samples taken during deployments which are below our target of 75%.

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.



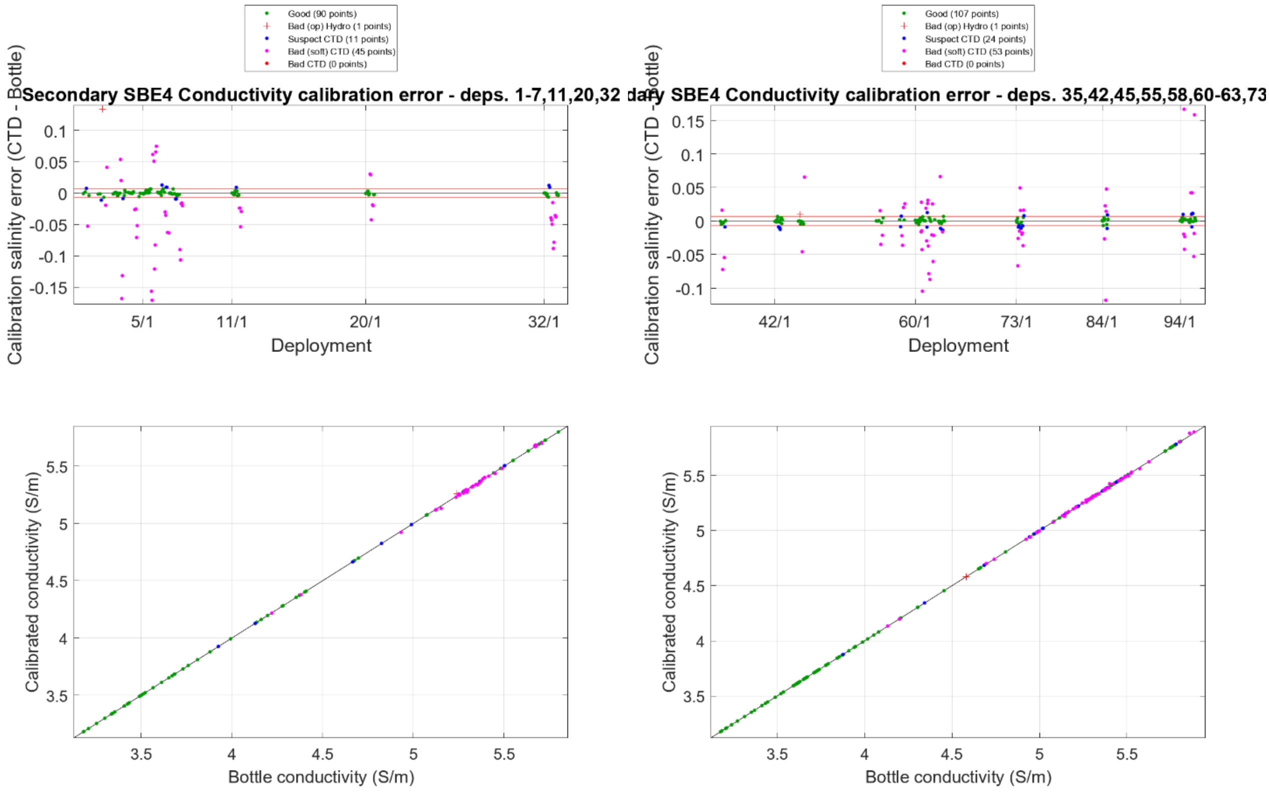
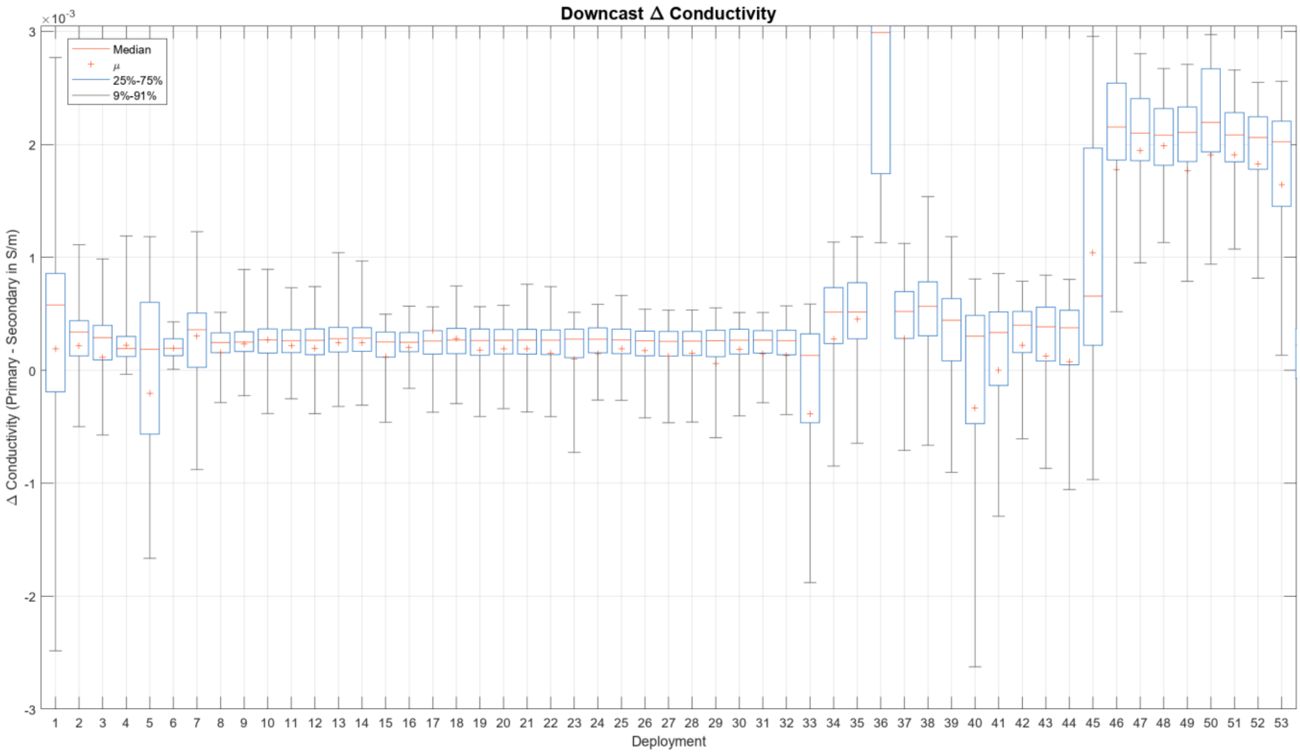


Figure 4 CTD - bottle salinity plot

The box plot of calibrated downcast conductivities (primary - secondary) for all deployments in Figure 5 shows that the calibrated conductivity cell responses corresponded very well. The significant difference on cast 36 resulted from the pump not fully pumping for the downcast and on cast 45 through 53, the primary sensor was cracked, resulting in higher than usual readings.



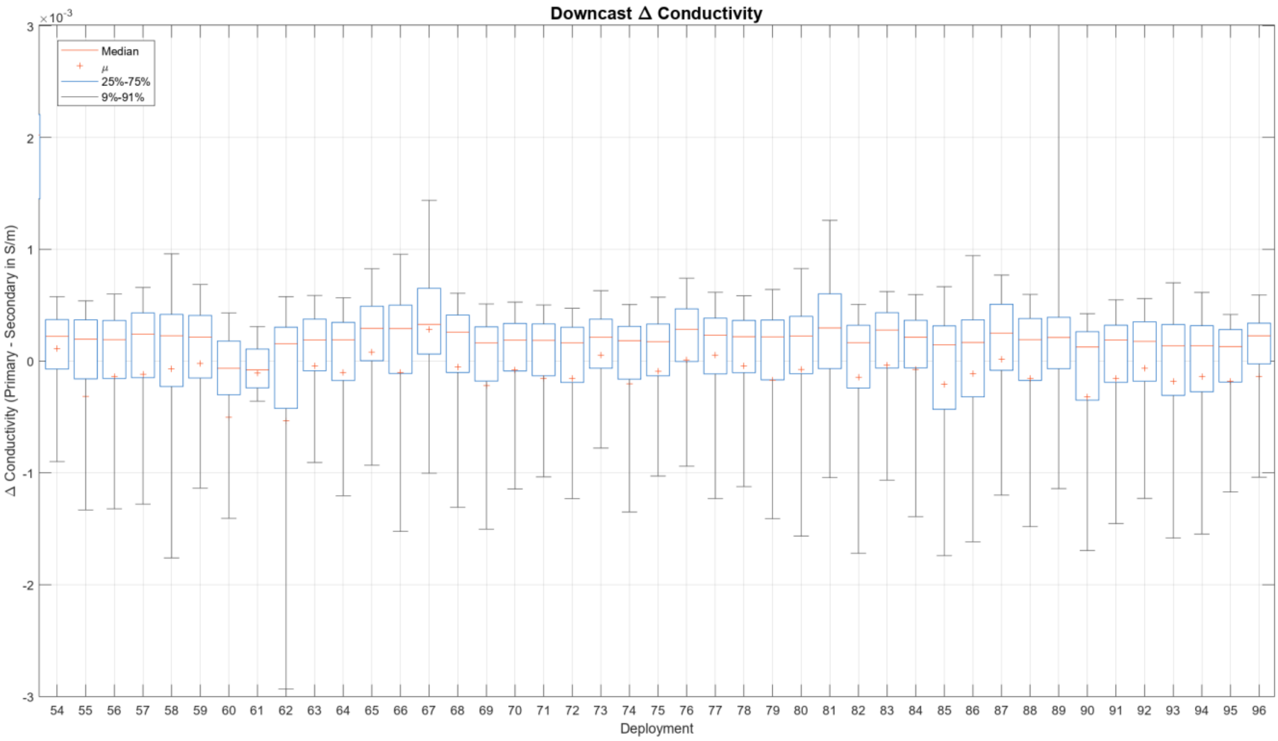


Figure 5 Difference between primary and secondary conductivity sensors

The final result for the primary and secondary conductivity sensors with respect to their original calibrations are shown in Table 5 and Table 6.

Sensor Group	Deployments	Scale Factor		Offset		Salinity (PSU)	
		a1	±	a0	±	Residual SD	M.A.D.
Primary	1-7,11,20,32, 35, 42, 45	0.99962	0.0012018	9.1803e-04	0.0061886	0.0034802	0.0018334
	55, 58, 60-63, 73, 84, 94, 95	0.99994	0.0014314	9.3770e-08	0.0073877	0.0040084	0.0020298
Secondary	1-7,11,20,32	0.99966	0.0012529	9.4028e-04	0.0063748	0.0030308	0.0021217
	35,42,45,55,58,60-63,73,84,94-96	0.99957	0.0012187	1.0012e-03	0.0063206	0.0035894	0.0020212

Table 5 Conductivity calibration with respect to manufacturers' calibration coefficients and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	1-7,11,20,32, 35, 42, 45	-1.2119e-07	7.4657e-07
	55, 58, 60-63, 73, 84, 94, 95	-1.5042e-07	8.9380e-07
Secondary	1-7,11,20,32	-1.2176e-07	7.2405e-07
	35,42,45,55,58,60-63,73,84,94-96	-1.2152e-07	8.0613e-07

Table 6 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)".

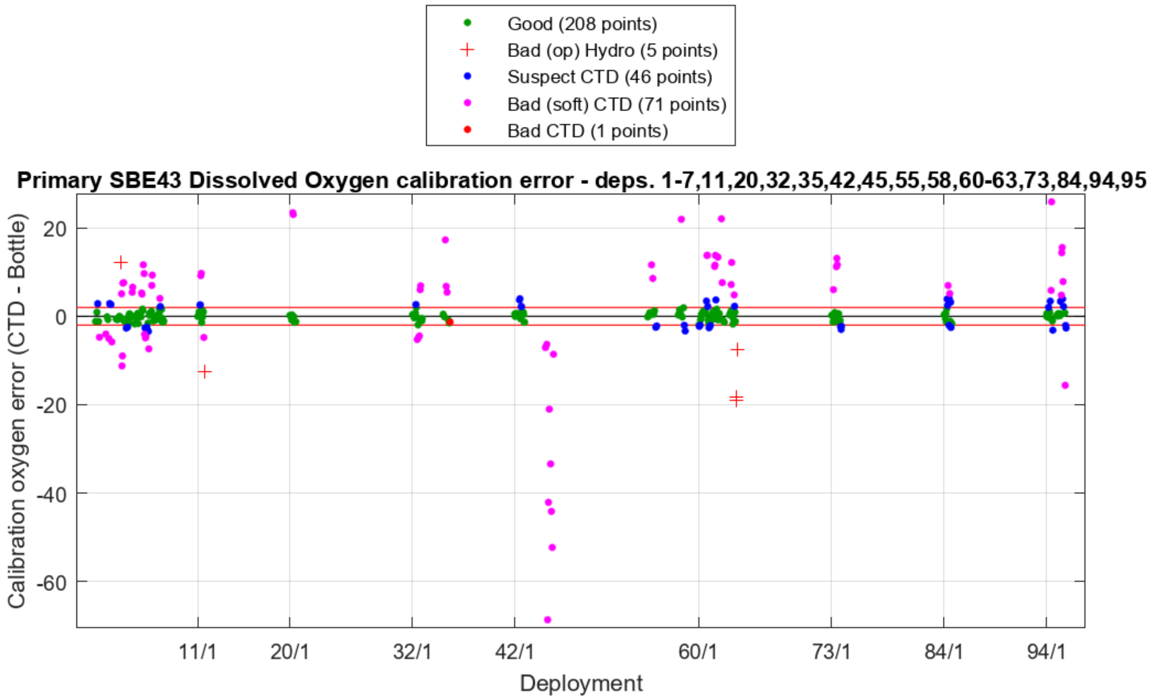
Calibration involves performing a linear regression, as per *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections* (Sea-Bird, 2012) to produce new estimates of the calibration coefficients *Soc* and *Voffset*. These new coefficients are used, along with the other, manufacturer-supplied coefficients, to derive oxygen concentrations from the sensor voltages.

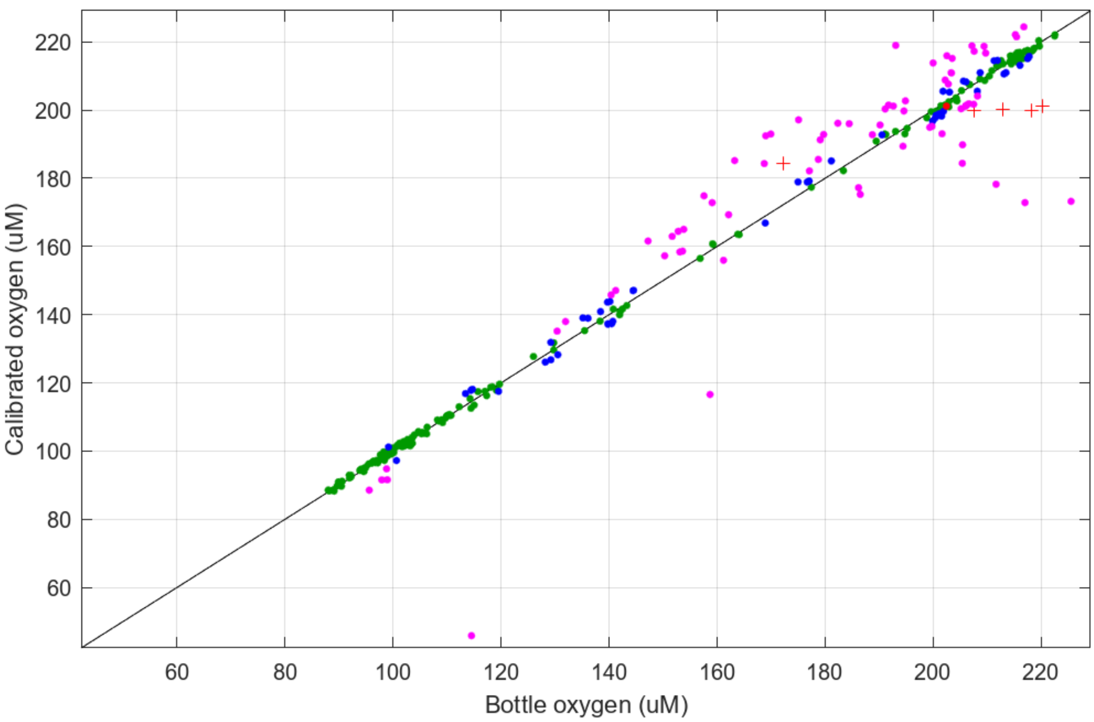
3.4.2 Results

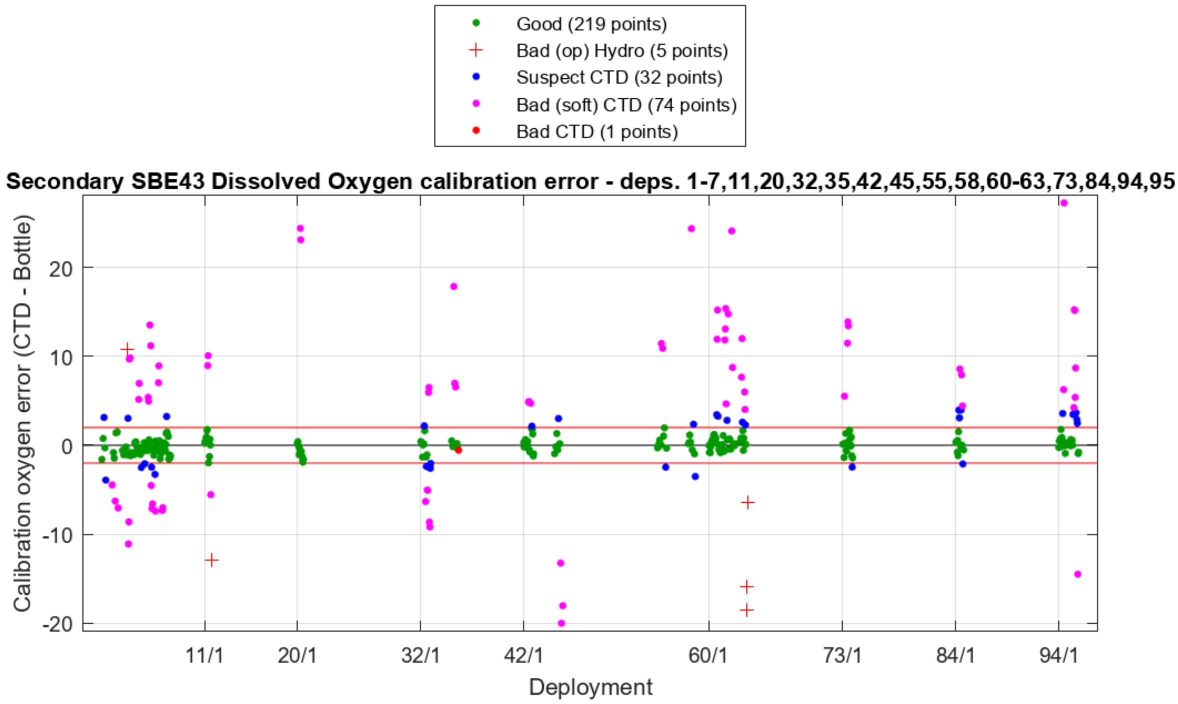
Deeper casts (>1000m) are known to be affected by pressure-induced hysteresis with this sensor. This is corrected automatically within CapPro using the method discussed in *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections* (Sea-Bird, 2014).

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.

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).


Good (208 points)
Bad (op) Hydro (5 points)
Suspect CTD (46 points)
Bad (soft) CTD (71 points)
Bad CTD (1 points)
Primary SBE43 Dissolved Oxygen calibration error - deps. 1-7,11,20,32,35,42,45,55,58,60-63,73,84,94,95
Calibration oxygen error (CTD - Bottle)
Deployment
11/1
20/1
32/1
42/1
60/1
73/1
84/1
94/1


Calibrated oxygen (uM)
Bottle oxygen (uM)



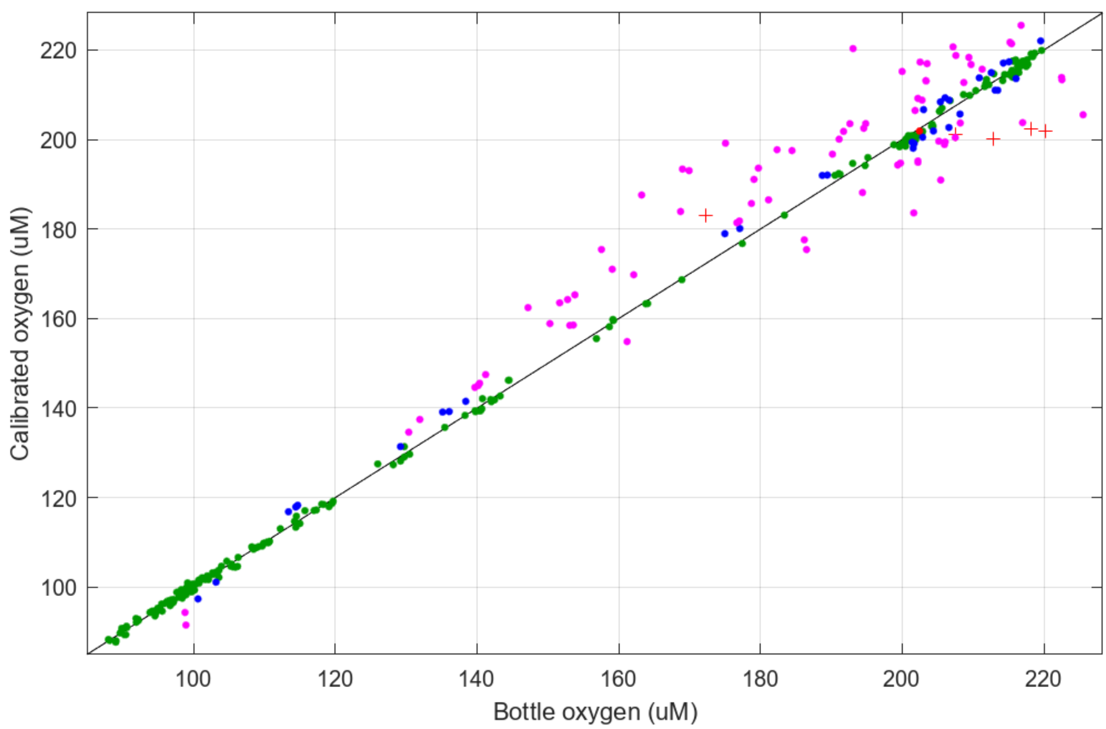


Figure 6 Dissolved Oxygen Difference with upcast CTD data (SBE43 - Bottle)

The old and new *Soc* and *Voffset* values for DO sensors are listed in Table 2 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 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	1-7, 11, 20, 32, 35, 42, 45, 55, 58, 60-63, 73, 84, 94, 95	-0.47633	0.0025355	0.39957	0.00069055	0.93882	0.77415
	Sea-Bird	1-7, 11, 20, 32, 35, 42, 45, 55, 58, 60-63, 73, 84, 94, 95	-0.50190		0.40445			
Secondary DO	Hydrochemistry	1-7, 11, 20, 32, 35, 42, 45, 55, 58, 60-63, 73, 84, 94, 95	-0.49773	0.0018955	0.47528	0.0007401	0.89666	0.66284
	Sea-Bird	1-7, 11, 20, 32, 35, 42, 45, 55, 58, 60-63, 73, 84, 94, 95	-0.49460		0.46210			

Figure 7 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 7 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	-10	40	0.05
Conductivity	-0.01	7	0.01
Oxygen	0	360	0.5
Fluorometer	0	3	0.1
PAR	-3	5000	100
Transmissometer	0	100	0.5
Turbidity, Seapoint	-5	5000	10
Turbidity, Wetlabs OBS	0	3	1e-4

Table 7 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

Protat. (2019). *The RV Investigator. Voyage Plan* IN2019_V06. Retrieved from Marine National Facility: Voyage Plans and summaries: https://www.cmar.csiro.au/data/reporting/get_file.cfm?eov_pub_id=1168

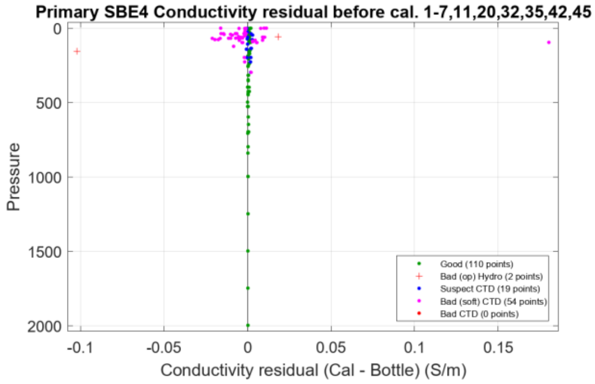
Pender, L. (2000). *Data Quality Control Flags.* Retrieved from Oceans & Atmosphere Information and Data Centre: http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

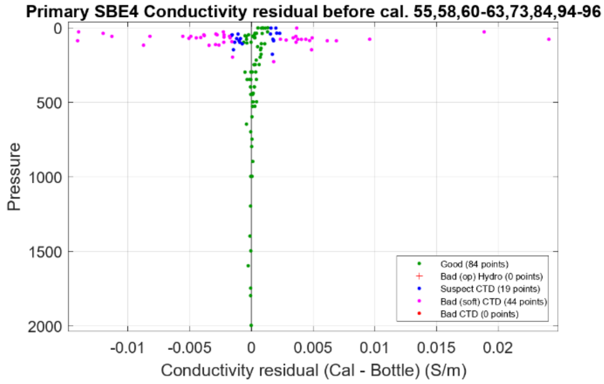
Sea-Bird. (2012). *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?id=54627861704

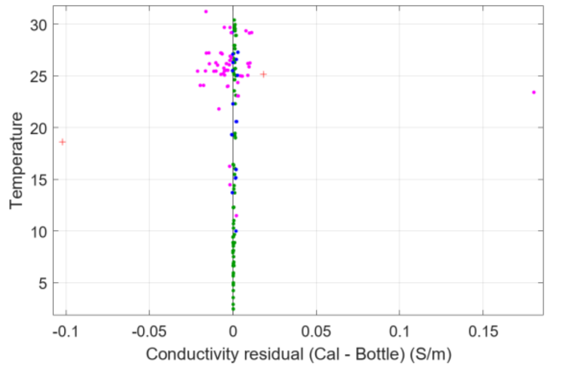
Sea-Bird. (2013). *AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?id=54627861706

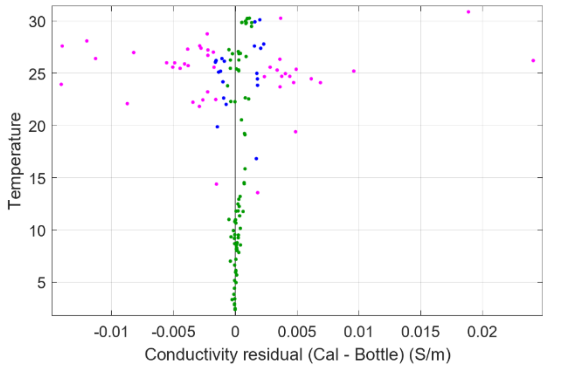
Sea-Bird. (2014). *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections.* Retrieved from Sea-Bird Electronics: https://www.seabird.com/asset-get.download.jsa?id=54627861705

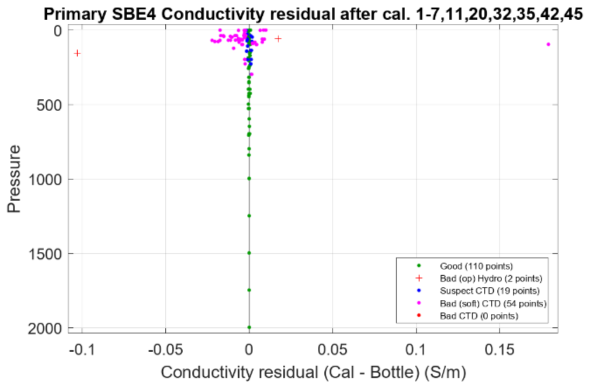
Appendix I: Conductivity Calibration Residual Plots

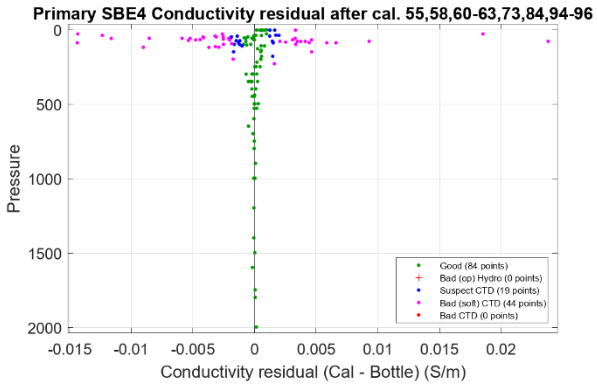


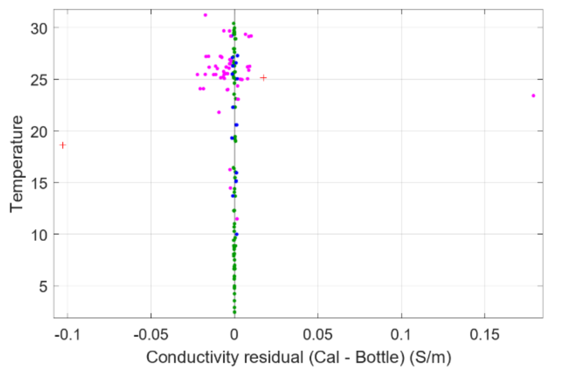


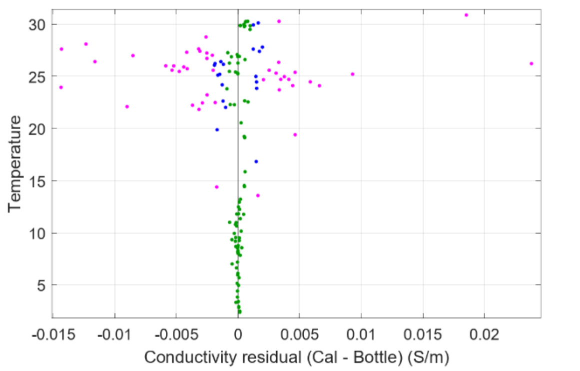


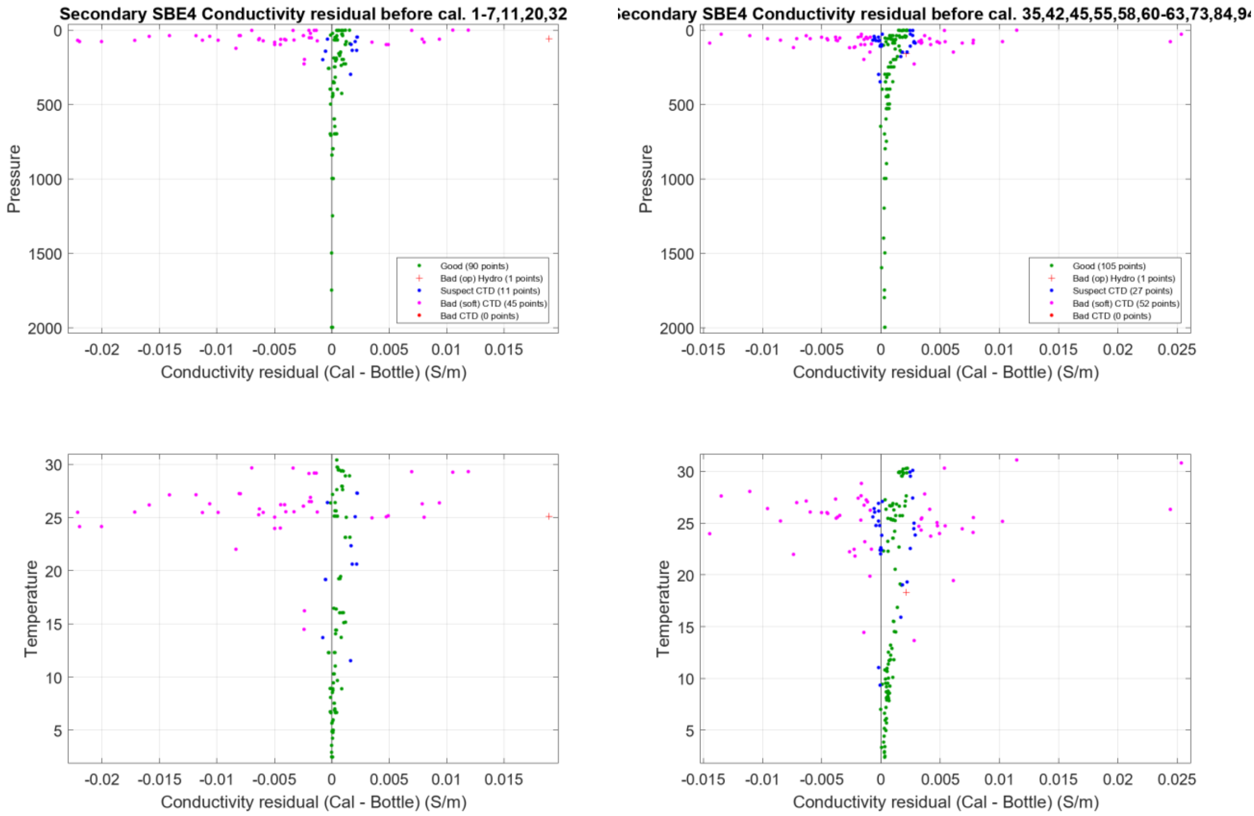


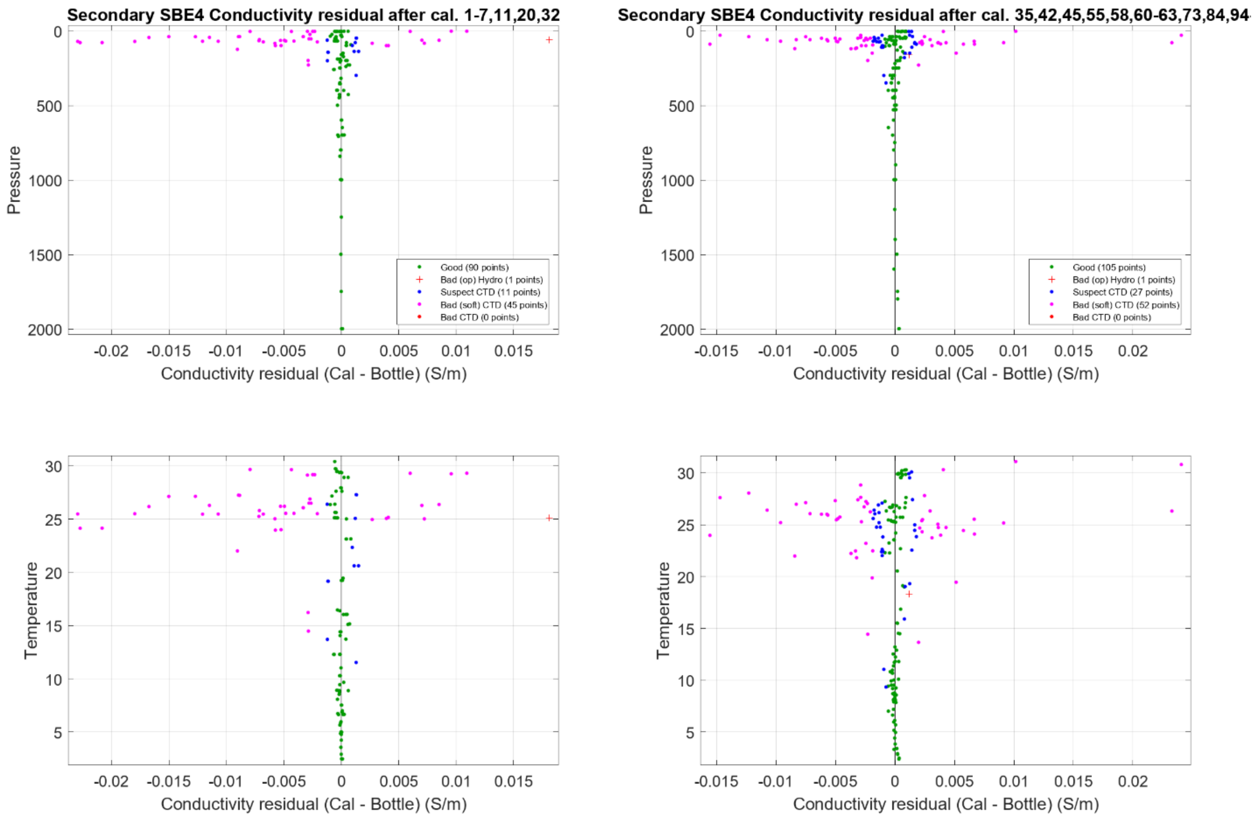









Secondary SBE4 Conductivity residual before cal. 1-7,11,20,32
Secondary SBE4 Conductivity residual before cal. 35,42,45,55,58,60-63,73,84,94
Pressure
Temperature
Conductivity residual (Cal - Bottle) (S/m)
Good (90 points)
Bad (op) Hydro (1 points)
Suspect CTD (11 points)
Bad (soft) CTD (45 points)
Bad CTD (0 points)
Good (105 points)
Bad (op) Hydro (1 points)
Suspect CTD (27 points)
Bad (soft) CTD (52 points)
Bad CTD (0 points)


Secondary SBE4 Conductivity residual after cal. 1-7,11,20,32
Secondary SBE4 Conductivity residual after cal. 35,42,45,55,58,60-63,73,84,94
Pressure
Temperature
Conductivity residual (Cal - Bottle) (S/m)
Good (90 points)
Bad (op) Hydro (1 points)
Suspect CTD (11 points)
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Appendix II: Dissolved Oxygen Calibration Residual Plots