RV *Investigator*

CTD Processing Report

Voyage ID:	in2019_v03
Voyage title:	A coupled bio-physical, ecosystem-scale examination of Australia's International Indian Ocean Expedition Line.
Depart:	Fremantle, 1500 Monday 13 May 2019
Return:	Fremantle, 0800 Friday 14 June 2018
Report compiled by:	Richard Atkinson

Contents

1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage in2019_v03, from 13 May 2019 – 14 Jun 2019.

Data for 54 deployments were acquired using the Sea-Bird SBE911 CTD #23 and #24, fitted with 36 twelve litre bottles on the rosette sampler. CSIRO-supplied calibrations factors were used to compute the pressures, temperature and preliminary conductivity values. The data were subjected to automated QC to remove spikes and out-of-range values.

The final conductivity calibration was based on a single grouping of all the 'deep' (over 500dBar) deployments. The final calibration from the primary sensor had a standard deviation (SD) of 0.0027715 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 0.96258 µM. The agreement between the CTD and bottle data was good.

Chelsea Fluorometer, PAR Sensor, Altimeter, Wetlabs Transmissometer, UVP were also installed on the auxiliary A/D channels of the CTD. Additionally a Teledyne LADCP was installed on the CTD.

2 Voyage Details

2.1 Title

A coupled bio-physical, ecosystem-scale examination of Australia's International Indian Ocean Expedition Line.

2.2 Principal Investigators

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2.3 Voyage Objectives

The scientific objectives for in2019_v03 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

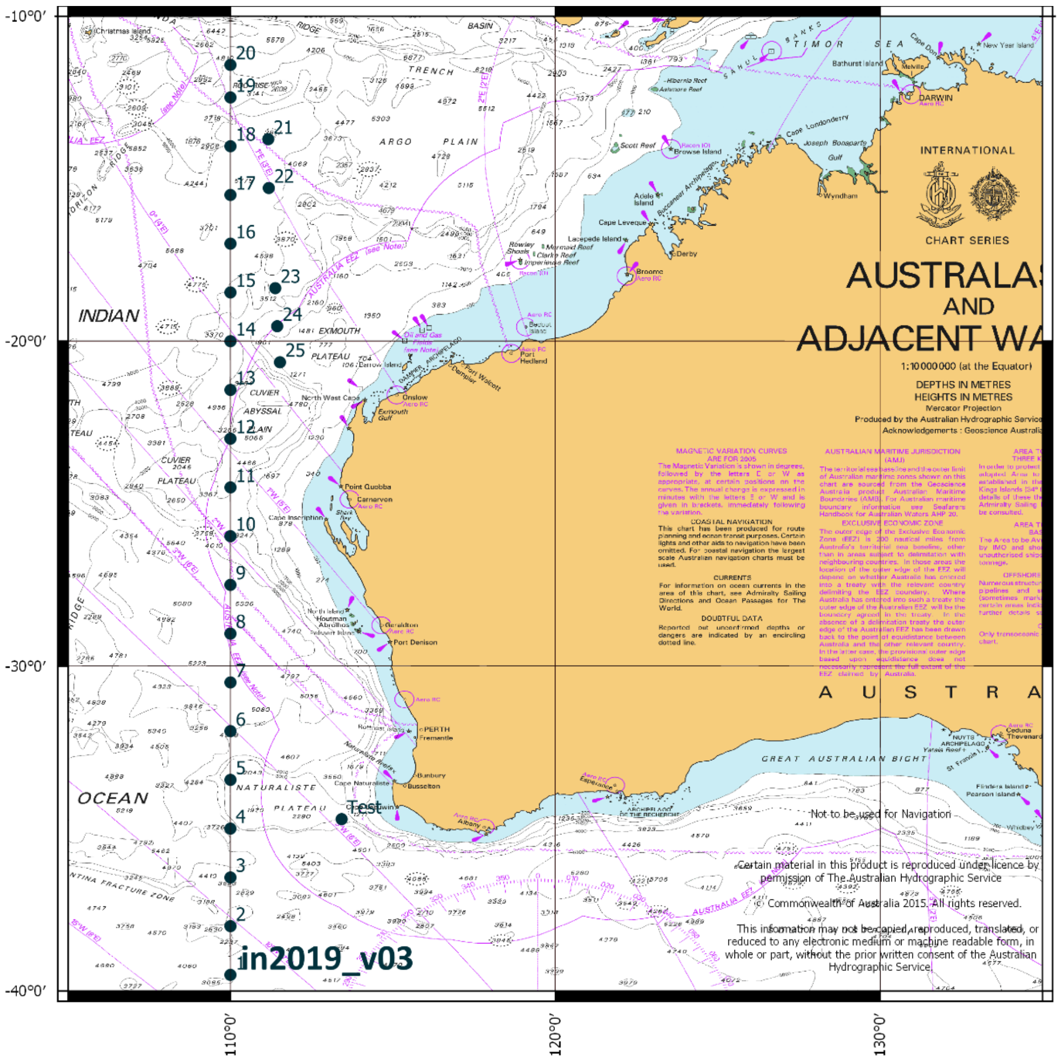


Figure 1 Area of operation for in2019_v03

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with the CSIRO CTD units #23 and #24, both Sea-Bird SBEplus with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors, Chelsea Aquatracka III Fluorometer, PAR, Wetlabs C-Star Transmissometer, upward and downward facing Teledyne Lowered Acoustic Doppler Current Profilers (LADCP), user supplied Underwater Vision Profiler (UVP). These sensors are described in

PAR	QCP – 2300 HP	70111	A3	1-Aug-2018	Manufacturer
LADCP Upward Facing	Teledyne 300kHz	16673	Internal		
LADCP Downward Facing	Teledyne 150kHz	16710	Internal		
UVP	Hydroptics UVP5	01721	A6/A7		

Table 1 below.

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1312	P	20-Jul-2018	CSIRO
Primary Temperature	Sea-Bird SBE3T	6130	T0	12-Jan-2019	CSIRO
Secondary Temperature	Sea-Bird SBE3T	6180	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	1794	A0	30-Jul-2018	CSIRO
Secondary Dissolved Oxygen	SBE43	3198	A1	25-May-2018	Manufacturer
Fluorometer	Chelsea Aquatracka III	11-8206-01	A2	11-Dec-2018	Manufacturer
PAR	QCP – 2300 HP	70111	A3	1-Aug-2018	Manufacturer
LADCP Upward Facing	Teledyne 300kHz	16673	Internal	[Cal. Date]	[Cal. Source]
LADCP Downward Facing	Teledyne 150kHz	16710	Internal	[Cal. Date]	[Cal. Source]
UVP	Hydroptics UVP5	01721	A6/A7	[Cal. Date]	[Cal. Source]

Table 1 CTD Sensor configuration on in2019_v03 - Cast 1

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
PAR	QCP-2300HP	70677	A3	20-Mar-2019	Manufacturer

Table 2 CTD Sensor configuration on in2019_v03 - changes cast 2-54

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1332	P	20-Jul-2018	CSIRO

Table 3 CTD Sensor configuration on in2019_v03 – changes cast 45-54

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.

There were 54 deployments. Deployment 1 was a test deployment which is included in the final dataset. Deployments 45 and 46 were test casts and have been excluded from the final data set.

Deployments 2 to 48 were generally sets of two daily casts at each of 20 stations at 90 nautical mile intervals along the 110 E meridian. At each station one cast was made nominally at 00:00 UTC to near the sea floor and the other nominally at 12:00 UTC to 500 dBar. Station 19 was revisited after station 20 and deployment 49 performed to replace aborted deployment 42.

Deployment 10 onwards release mechanism failed for water bottle 14 so no sample collected.

Deployment 14 onwards release mechanism failed for water bottle 24 so no sample collected.

Deployment 37 collected only 11 water samples due to an equipment failure.

Deployment 38 onwards release mechanism failed for water bottle 17 so no sample collected.

Deployment 39 was aborted a 1500 dBar due to an equipment alarm.

Deployment 40 was undertaken in place of aborted deployment 39.

Deployment 42 was aborted due an equipment alarm and collected no water samples.

Deployment 43 was undertaken in place of aborted deployment 42.

Deployment 44 was aborted at 780 dBar due to an equipment alarm.

Deployments 50 to 54 were undertaken at the start and end of Triaxus tows, at stations 21 to 25.

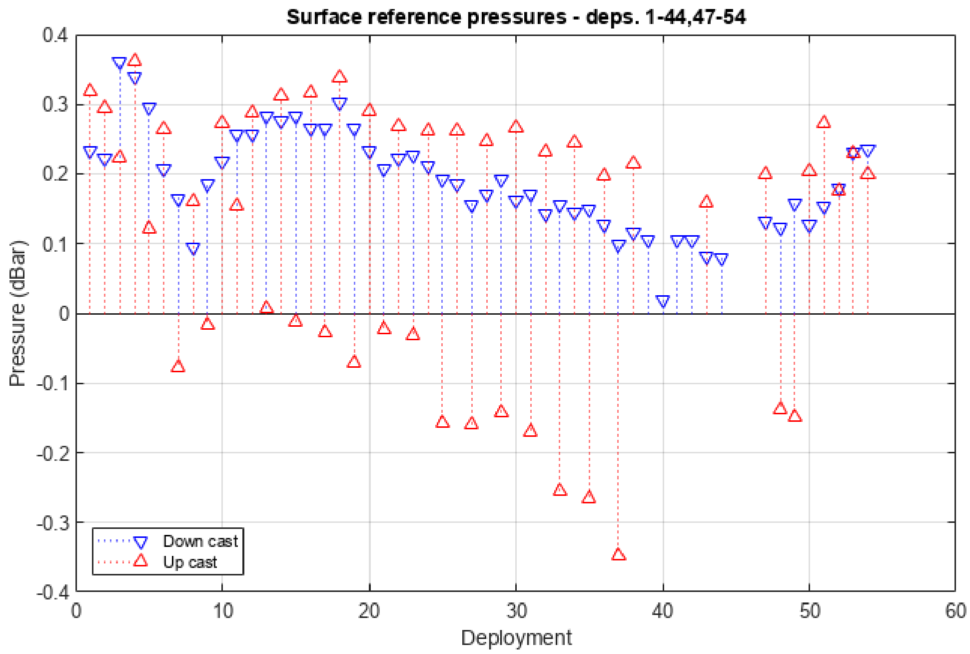
The raw CTD data were collected in SBE SeaSave version 7.26.7.110, converted to scientific units using SBE Data Processing version 7.26.7 and written to netCDF format files with CNV_to_Scan for processing using the Matlab-base, CapPro package version 2.9.

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



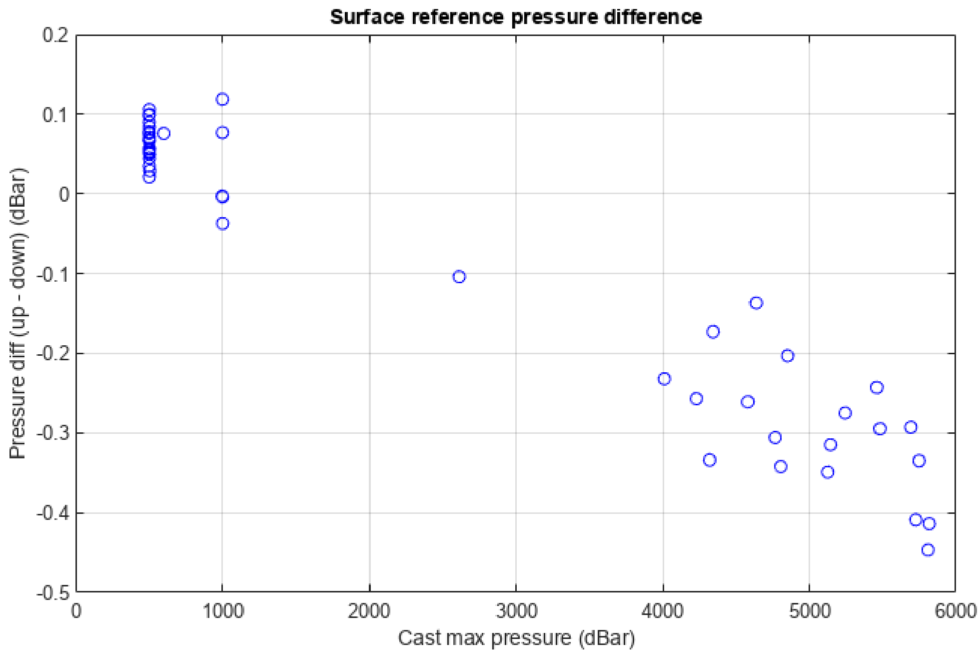


Figure 2 CTD pressure offsets

The difference between the primary and secondary temperature sensors during the downcast is plotted below (Figure 3). The median temperature difference for all casts is 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 (Figure 6). This indicates neither sensor has drifted significantly from its calibration. The alternating nature of the poorer performing casts corresponds to the cycle of deep and shallow casts. The shallow casts show a higher variation in sensor readings due to the higher vertical temperature gradient.

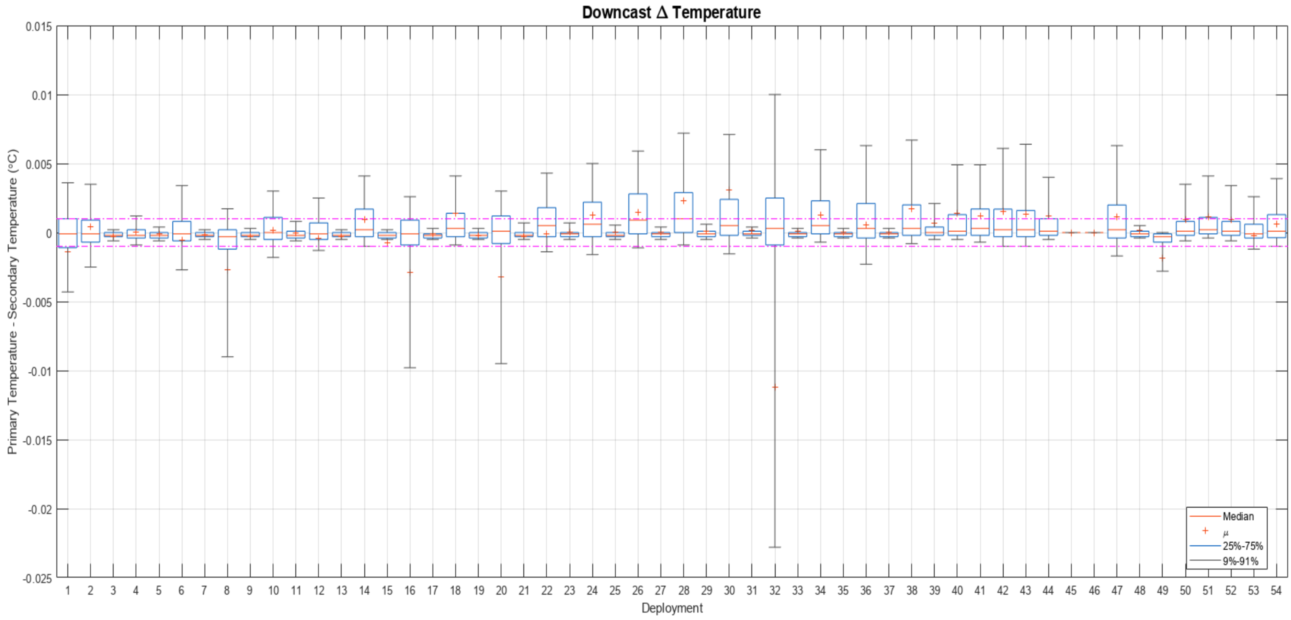


Figure 3 Difference between primary and secondary temperature sensors

3.3 Conductivity Calibration

Initial calibration between bottle and CTD salinities across the full set of deployments where water samples were collected showed larger than expected discrepancies (Figure 4). These were mostly for the 500 dBar deployments where bottle samples were deliberately collected at depths of rapid change in salinity, eg minimum oxygen concentration. The calibration was repeated excluding the 500 dBar deployments to obtain more representative results (Figure 5). These calibrations were then applied to the full set of deployments.

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 220/218 of the total of 731 samples taken for all deployments, which are below our target of 75%.

The outliers marked in Figure 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.

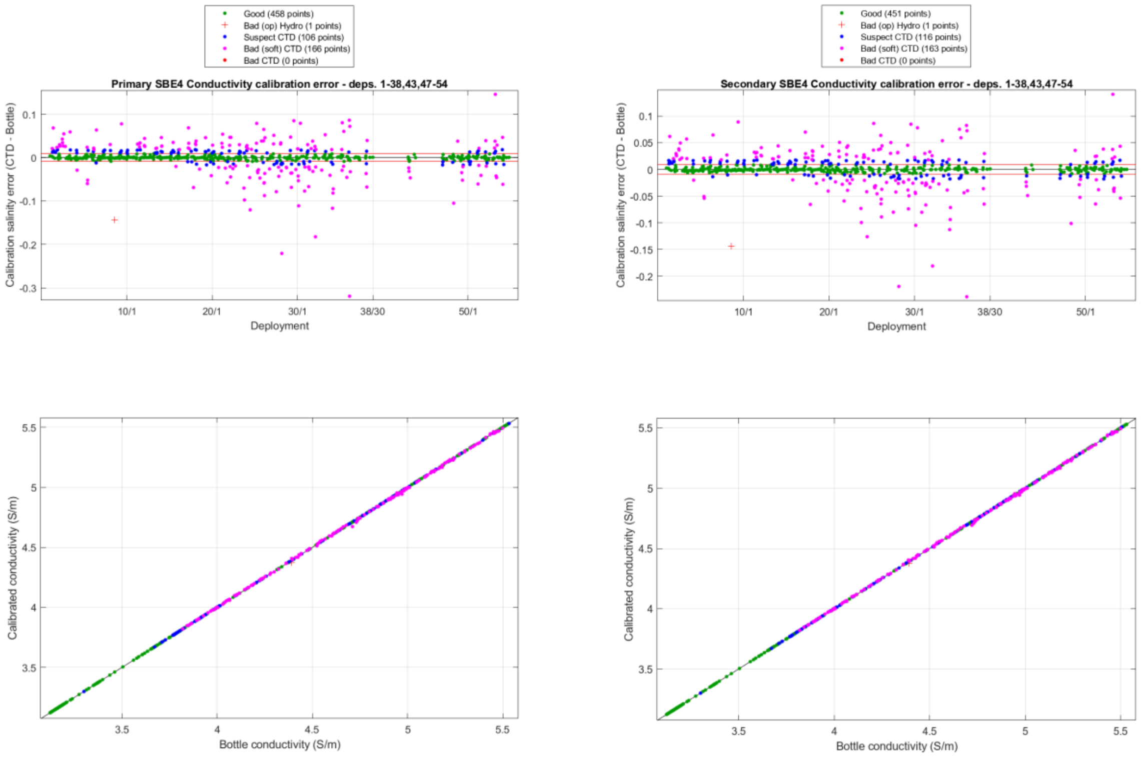


Figure 4 CTD - bottle salinity plot – all deployments

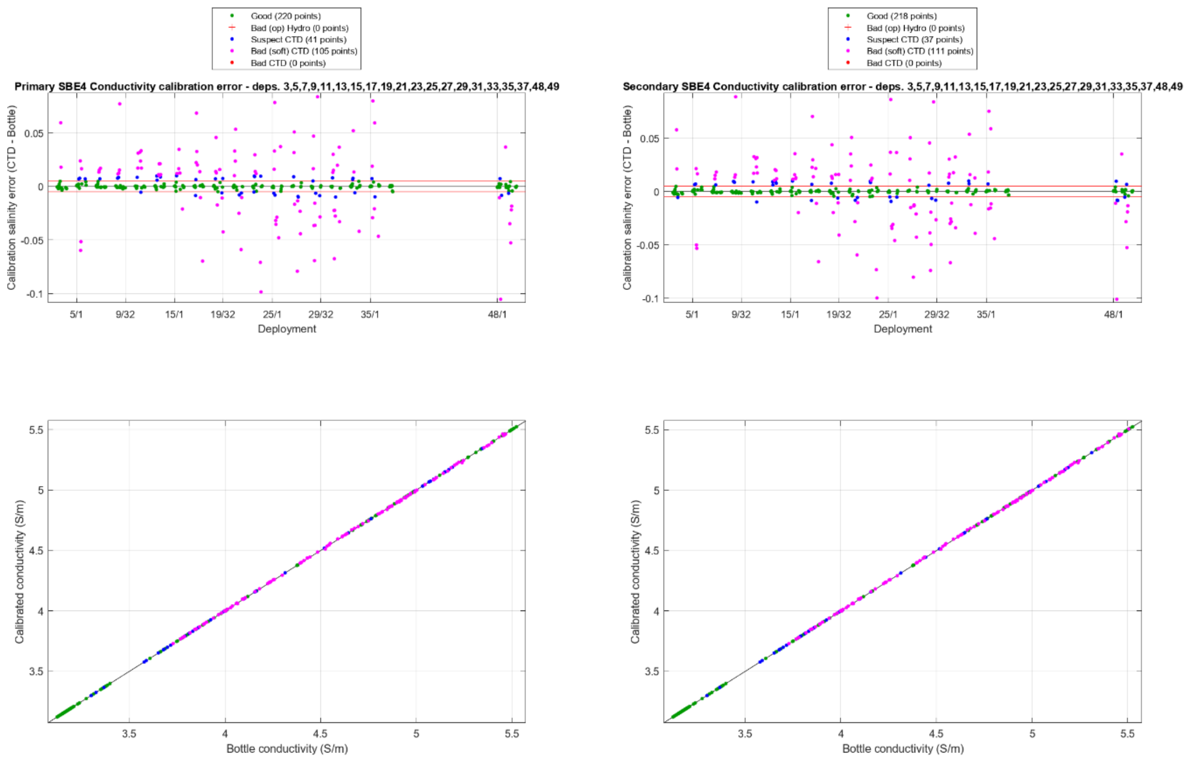


Figure 5 CTD - bottle salinity plot – deep deployments

The box plot of calibrated downcast conductivities (primary - secondary) shows that the calibrated conductivity cell responses corresponded very well (Figure 6).

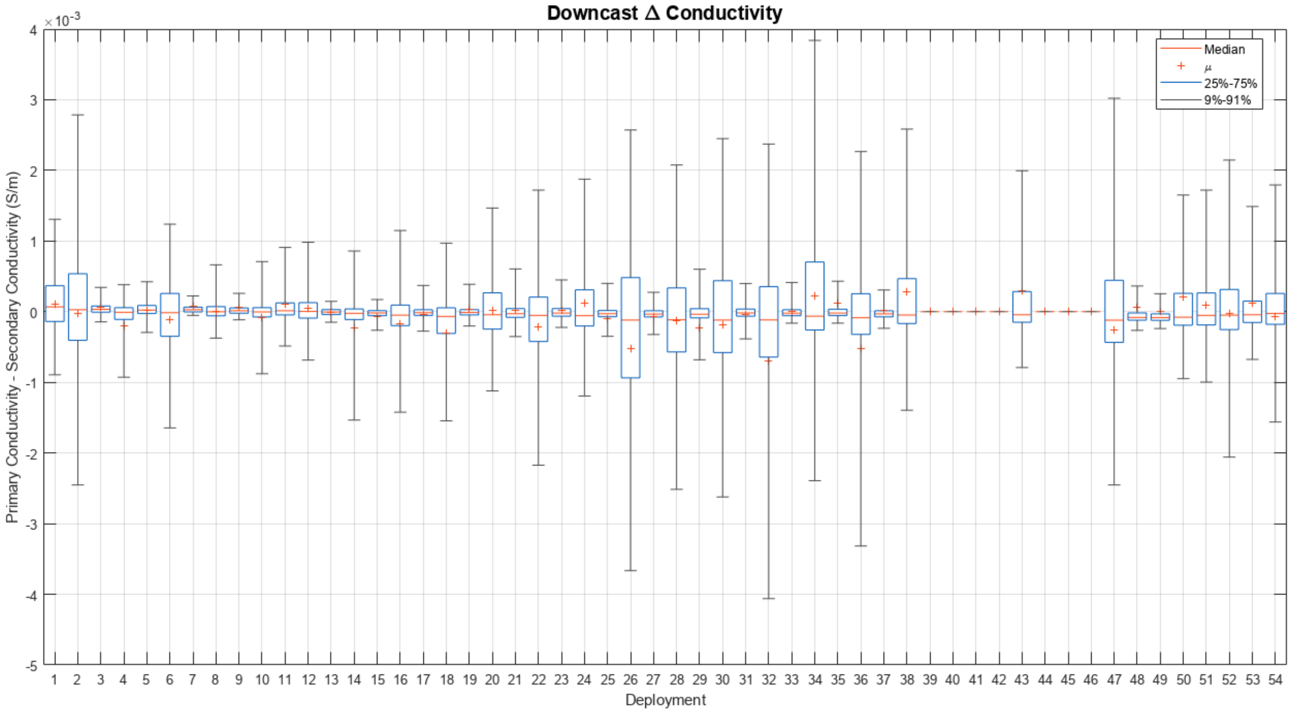


Figure 6 Difference between primary and secondary conductivity sensors

The result for the primary and secondary conductivity sensors with respect to their original calibrations are shown in

Primary	**3,5,7,9,11,13,15,17,19,21 ,23,25,27,29,31,33,35, 37,48,49**	**0.99973**	**0.0021063**	**0.00055468**	**0.002106 3**	**0.0027242**	**0.00075856**
Secondary	3,5,7,9,11,13,15,17,19,21, 23,25,27,29,31,33,35, 37,48,49	0.99984	0.00044941	0.00048147	0.0020524	0.0026019	0.00087535

Table 4 and Table 5.

Sensor Group	Deployments	Scale Factor		Offset		Salinity (PSU)	
		a1	**±**	**a0**	**±**	**Residual SD**	**M.A.D.**
Primary	3,5,7,9,11,13,15,17,19,21, 23,25,27,29,31,33,35, 37,48,49	0.99973	0.0021063	0.00055468	0.0021063	0.0027242	0.00075856
Secondary	3,5,7,9,11,13,15,17,19,21, 23,25,27,29,31,33,35, 37,48,49	0.99984	0.00044941	0.00048147	0.0020524	0.0026019	0.00087535

Table 4 Conductivity calibration with respect to manufacturers' calibration coefficients and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	3,5,7,9,11,13,15,17,19,21,23,25,27,29,31,33,35,37,48,49	-9.3114e-08	7.5609e-08

Table 5 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 Conductivity Calibration Residual Plots.
Data from the secondary conductivity and temperature sensors were used to produce the averaged salinities with secondary sensors included with a suffix '_2'.

3.4 Dissolved Oxygen Sensor Calibration

3.4.1 SBE calibration procedure

AN64: SBE 43 Dissolved Oxygen Sensor (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* (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).

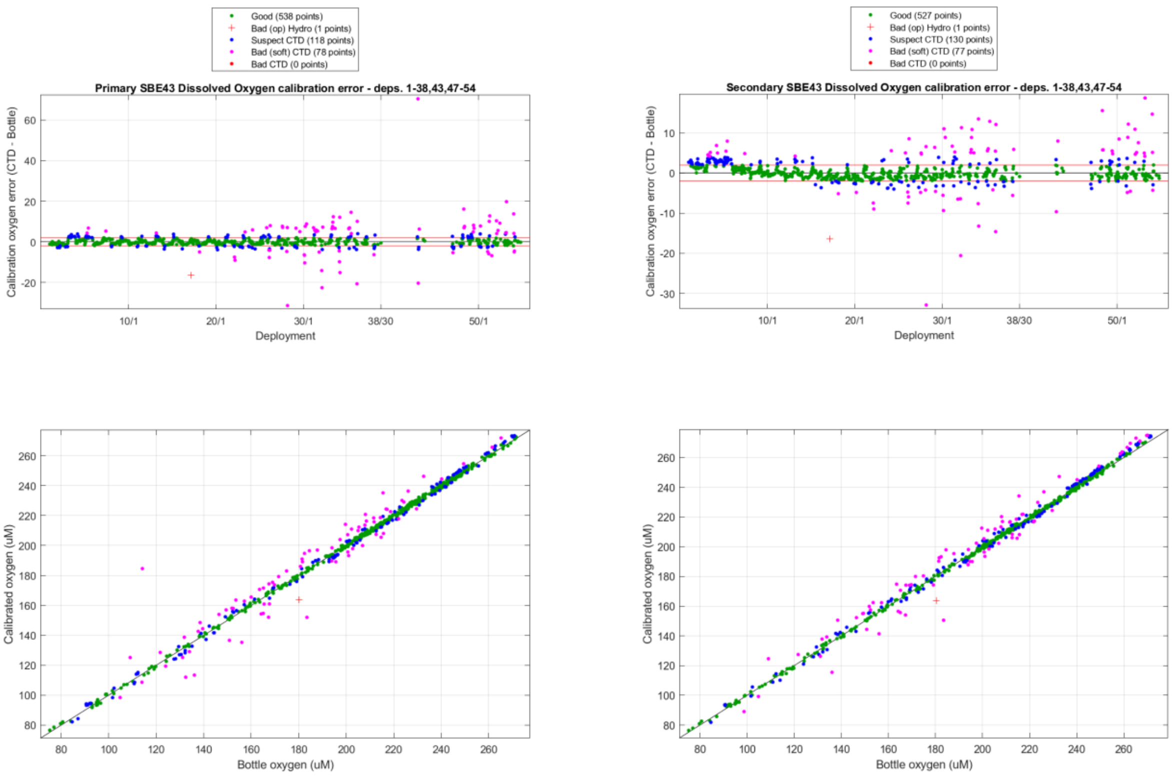


Figure 7 Dissolved Oxygen Difference with upcast CTD data (SBE43 - Bottle)

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 primary sensor.

Sensor	Calibration Source	Deployments	Calibration Coefficients				Dissolved Oxygen (µM)	
			Voffset	±	*Soc*	±	Residual SD	M.A.D.
Primary DO	Hydrochemistry	1-38,43,47-54	-0.47671	0.0010064	0.51884	0.00041351	0.85805	0.7855
	CSIRO	1-38,43,47-54	-0.50273656		0.49334113			
Secondary DO	Hydrochemistry	1-38,43,47-54	-0.48542	0.0014962	0.4372	0.00043039	0.96258	1.0536
	Sea-Bird	1-38,43,47-54	-0.4989		0.4156			

Figure 8 Dissolved oxygen calibrations

3.5 Other sensors

The Chelsea fluorometer was used for all deployments. The fluorometer has been calibrated with manufacturer supplied formula derived from various concentrations of Chlorophyll-a dissolved in acetone in addition to pure water and pure acetone. The coefficients in the formula are used in the SBE Data Processing software to convert the raw counts to fluorophore concentration in µg/L with a range of 0 – 100 micrograms per litre with an uncertainty of 0.02 micrograms per litre plus 3% of value. Please refer to the calibration certificate for more details.

A Biospherical PAR sensor was also used for all deployments. Following the first deployment the PAR sensor was found to be faulty, so a replacement sensor was used for the remainder of the 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	-1	500	0.5

Fluorometer	0	100	0.5
PAR	-5	2000	0.5
Transmissometer	0	100	0.5
[Type]	[Min]	[Max]	[Max Sec Diff]

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

Prof Lynnath Beckley (2019). *The RV Investigator. Voyage Plan* in2019_v03. 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

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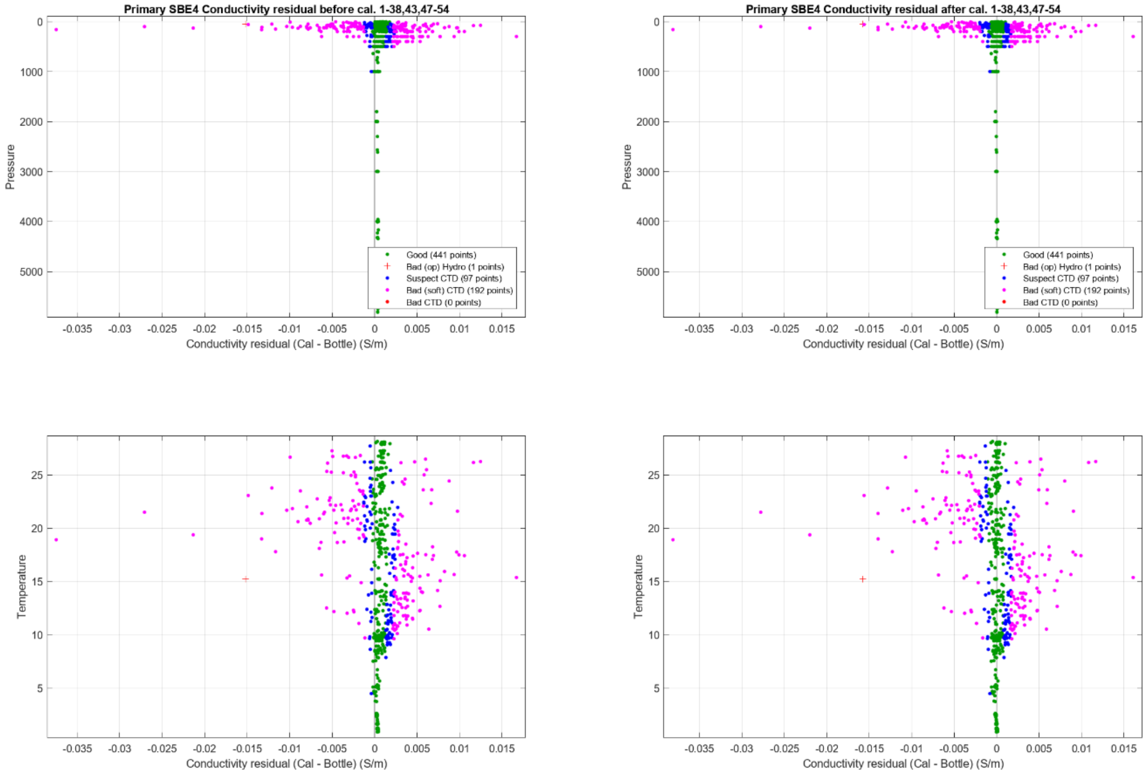
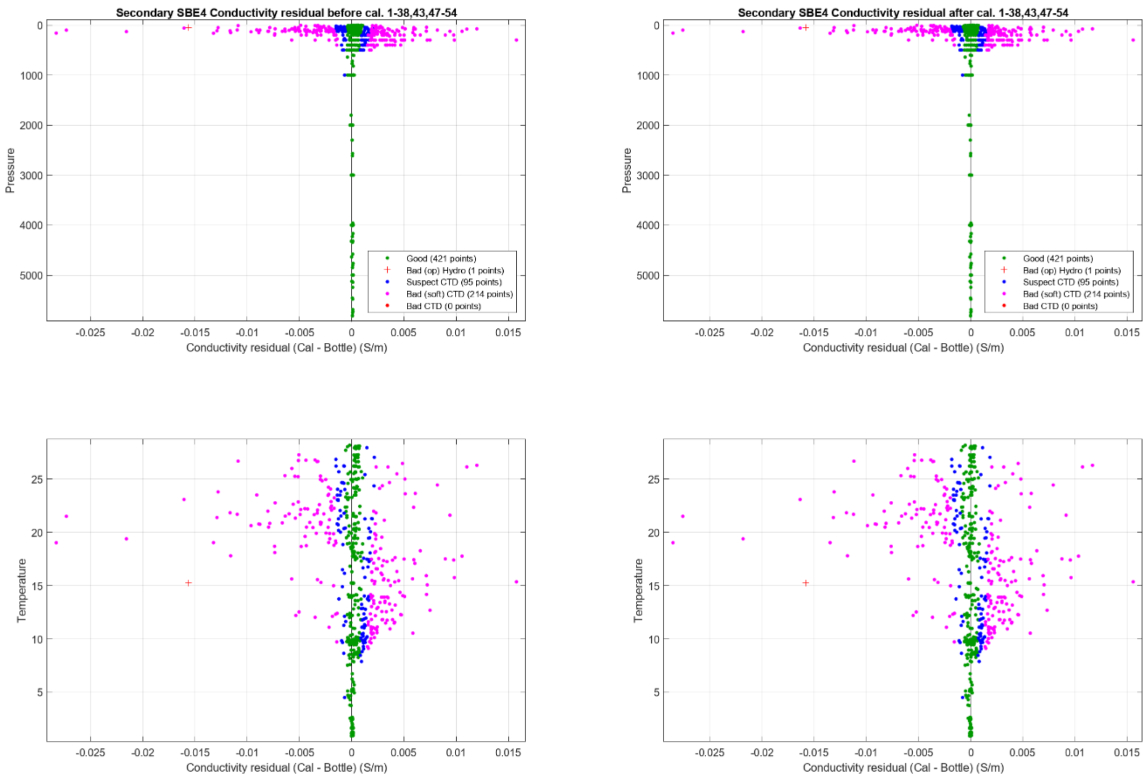
Sea-Bird. (2013). *AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-sbe-43-dissolved-oxygen-sensor-background-information-deployment-recommendations

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