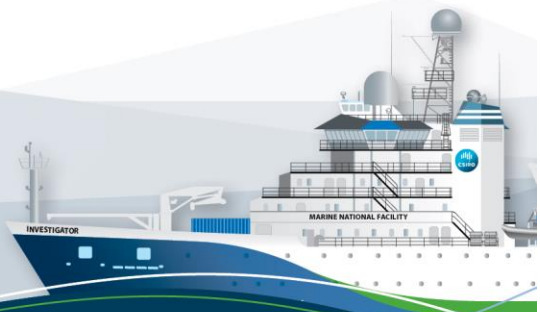
RV *Investigator*

CTD Processing Report

Voyage #:	IN2016_V03
Voyage title:	Monitoring Ocean Change and Variability along 170^{o} W from the ice edge to the equator.
Depart:	Hobart, 0900 Tuesday, 26 April 2016
Return:	Hobart, 0800 Thursday, 30 June 2016
Report compiled by:	Steven Van Graas



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1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage in2016_v03, from 26 Apr 2016 – 30 Jun 2016.

Data for 141 deployments were acquired using the Seabird SBE911 CTD 20, fitted with 36 twelve litre bottles on the rosette sampler. CSIRO supplied calibrations were applied to the temperature, conductivity, oxygen, and pressure data. The data were subjected to automated QC to remove spikes and out-of-range values.

The final conductivity calibration is based on multiple deployment groupings, due to sensor and deck box changes. Processing was performed on each unique sensor configuration in order to best account for the individual characteristics of each sensor. The final calibration from the primary sensor for casts 1-7 had a standard deviation (S.D) of 0.00088 PSU, a S.D of 0.00117 for casts 8-46, and S.D of 0.00114 for casts 47-141, well within our target of 'better than 0.002 PSU'. The standard product of 1 dbar binned averaged were produced using data from the primary temperature and conductivity sensors, and the secondary Oxygen sensor.

Similarly, the dissolved oxygen data were calibrated in groups of deployments due to sensor changes. The agreement between the CTD and bottle data was good.

A Fluorometer, Transmissometer, and altimeter were also installed and logged on the auxiliary A/D channels of the CTD.

2 Voyage Details

2.1 Title

Monitoring Ocean Change and Variability along 170° W from the ice edge to the equator.

2.2 Principal Investigators

Bernadette Sloyan – Leg 1, Susan Wijffels – Leg 2

2.3 Voyage Objectives

The scientific objectives for in2016_v03 were outlined in the Voyage Plan.

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

2.4 Area of operation

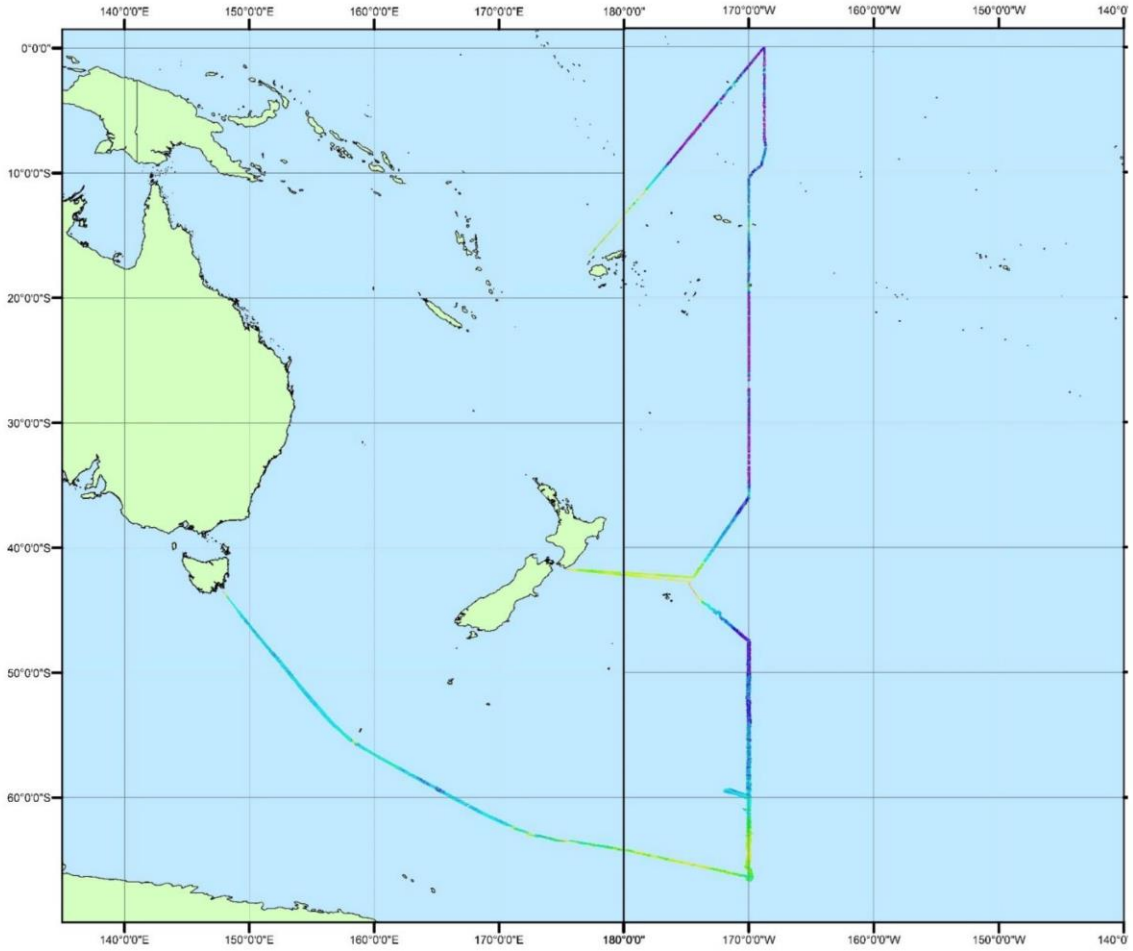


FIGURE 1. Area of operation for in2016_v03

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with the CSIRO CTD unit #20 and #22, Seabird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors, an altimeter, Transmissometer and Fluorometer. Additionally the CTD unit provided power only for two SBE61 units. The sensors that were equipped are described in Table 1 below.

Description	Sensor	Casts	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz SBE9+	1-7, 47-141	552	P	2016-03-09	CSIRO Cal Lab
Pressure	Digiquartz SBE9+	8-46	1243	P	2016-03-09	CSIRO Cal Lab
Primary Temperature	Seabird SBE3*plus*	1-46	4722	T0	2016-03-01	CSIRO Cal Lab

Primary Temperature	Seabird SBE3*plus*	47-141	6022	T0	2015-07-15	CSIRO Cal Lab
Secondary Temperature	Seabird SBE3*plus*	1-46	4522	T1	2016-03-01	CSIRO Cal Lab
Secondary Temperature	Seabird SBE3*plus*	47-93	6024	T1	2015-07-24	CSIRO Cal Lab
Secondary Temperature	Seabird SBE3*plus*	94-141	4718	T1	2015-10-29	CSIRO Cal Lab
Primary Conductivity	Seabird SBE4C	1-46	3868	C0	2016-03-02	CSIRO Cal Lab
Primary Conductivity	Seabird SBE4C	47-141	4425	C0	2015-07-08	CSIRO Cal Lab
Secondary Conductivity	Seabird SBE4C	1-46, 114-141	4426	C1	2015-07-08	CSIRO Cal Lab
Secondary Conductivity	Seabird SBE4C	47-88	2312	C1	2015-11-24	CSIRO Cal Lab
Secondary Conductivity	Seabird SBE4C	89-113	2235	C1	2015-11-24	CSIRO Cal Lab
Primary Dissolved Oxygen	SBE43	1-46	3154	A0	2016-03-10	CSIRO Cal Lab
Primary Dissolved Oxygen	SBE43	47-141	1794	A0	2016-03-10	CSIRO Cal Lab
Secondary Dissolved Oxygen	SBE43	1-46, 111-141	3198	A1	2015-08-12	CSIRO Cal Lab
Secondary Dissolved Oxygen	SBE43	47-111	3199	A1	2015-08-12	CSIRO Cal Lab
Transmissometer	C-Star	1-141	CST-1421DR	A2	2015-08-14	Manufacturer
Altimeter	PA500	1-141	5301. 228403	A3	2015-05-22	Manufacturer
Fluorometer	Chelsea Aquatracka III	57-141	0088-3598C	A6	2014-02-06	Manufacturer

TABLE 1. CTD Sensor configuration on in2016_v03

Water samples were collected using a Seabird SBE32, 24-bottle rosette sampler. Sampling was from 36 twelve litre bottles which were fitted to the frame. There were 141 deployments.

The raw CTD data were converted to scientific units and written to netCDF format files for processing using the Matlab-based, CapPro package.

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. The automatically determined pressure offsets and in-water points were inspected and adjusted where necessary. It also loaded the hydrology data and computed the matching CTD sample burst data. Filtering for bad data caused by ship heave affecting the velocity of the package was also applied to the binned average data.

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 1dB 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. The jump in the plot that is evident at cast 47 is due to changing the pressure sensor.

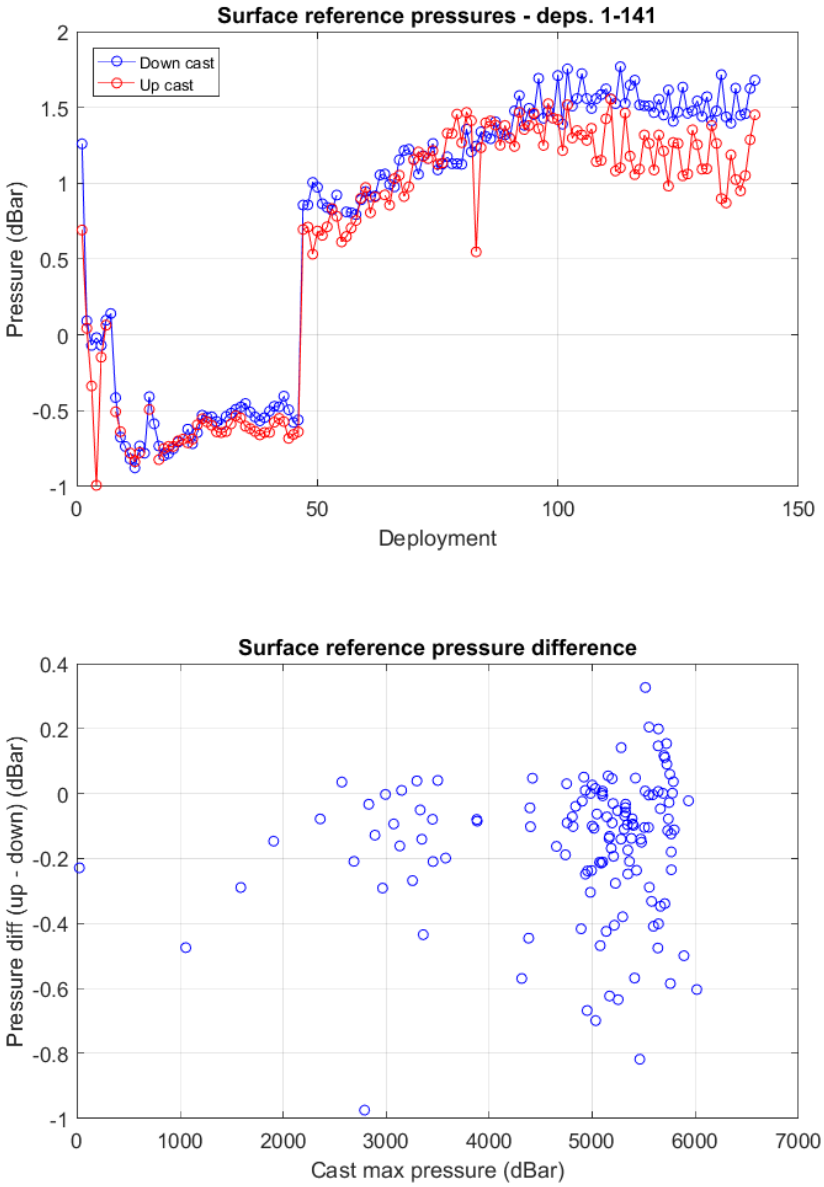
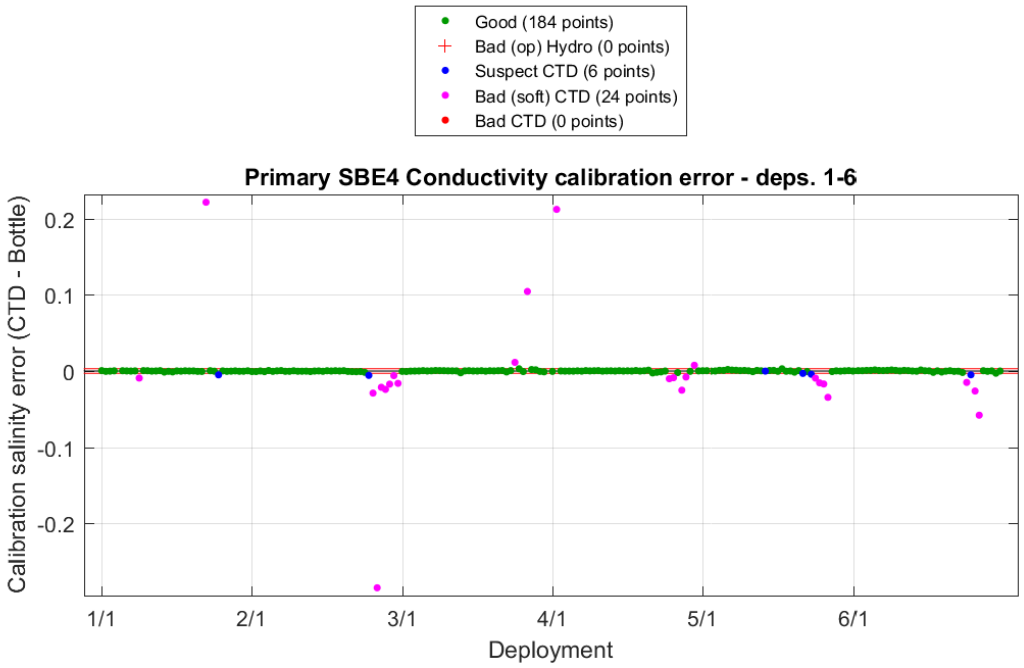
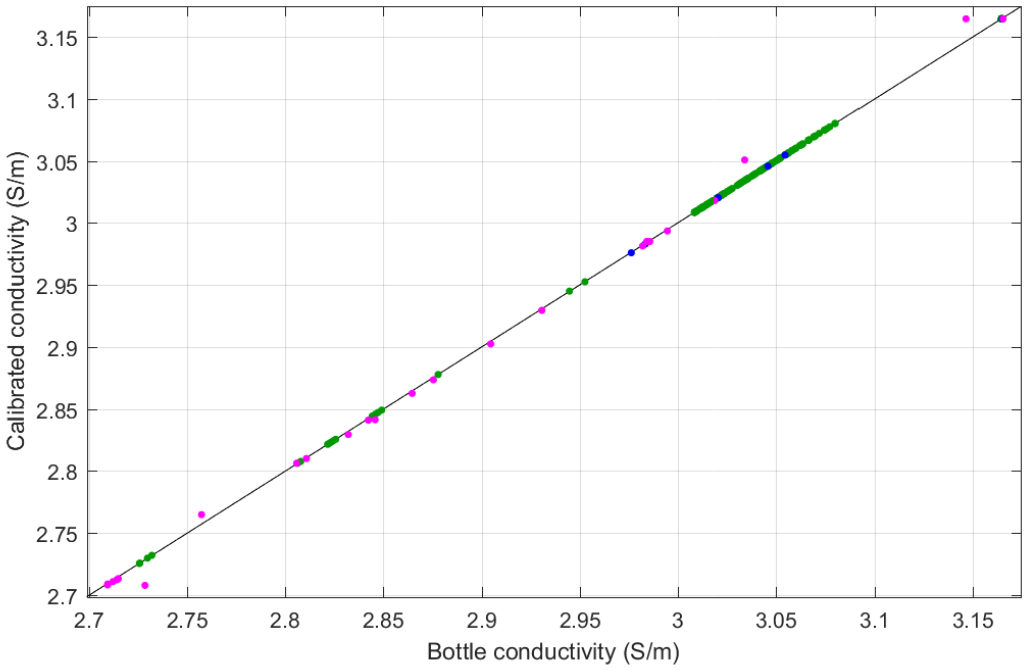


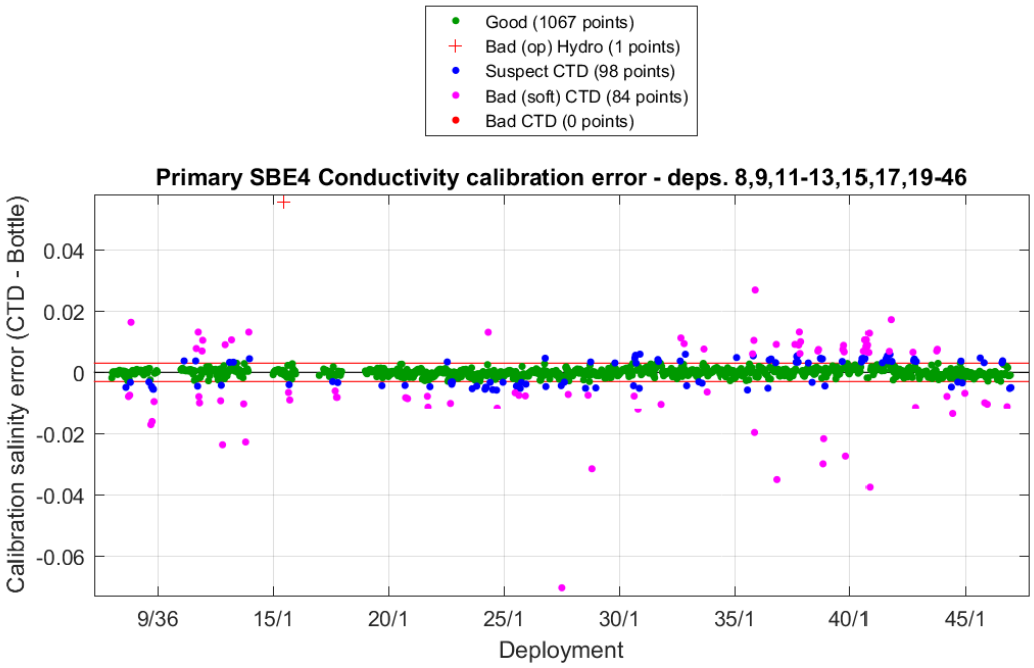
FIGURE 2. CTD pressure offsets

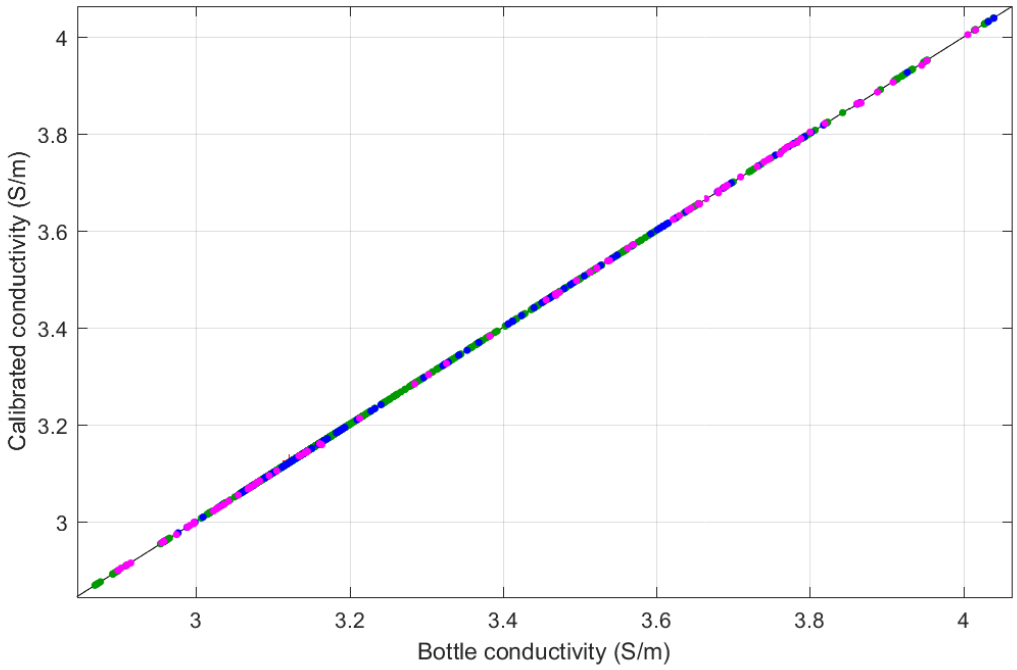
3.3 Conductivity Calibration

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, for all groups of deployments processed. The calibration was based upon the sample data for an overall total of 3654 of the total of 4720 samples taken during deployments (the outliers marked in Figure 4 below with the magenta diamonds are excluded from the calibration).


Good (184 points)
Bad (op) Hydro (0 points)
Suspect CTD (6 points)
Bad (soft) CTD (24 points)
Bad CTD (0 points)
Primary SBE4 Conductivity calibration error - deps. 1-6
Calibration salinity error (CTD - Bottle)
0.2
0.1
0
-0.1
-0.2
1/1
2/1
3/1
4/1
5/1
6/1
Deployment


Calibrated conductivity (S/m)
3.15
3.1
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
2.7
2.75
2.8
2.85
2.9
2.95
3
3.05
3.1
3.15
Bottle conductivity (S/m)


Good (1067 points)
Bad (op) Hydro (1 points)
Suspect CTD (98 points)
Bad (soft) CTD (84 points)
Bad CTD (0 points)
Primary SBE4 Conductivity calibration error - deps. 8,9,11-13,15,17,19-46
Calibration salinity error (CTD - Bottle)
0.04
0.02
0
-0.02
-0.04
-0.06
9/36
15/1
20/1
25/1
30/1
35/1
40/1
45/1
Deployment


Calibrated conductivity (S/m)
4
3.8
3.6
3.4
3.2
3
3
3.2
3.4
3.6
3.8
4
Bottle conductivity (S/m)

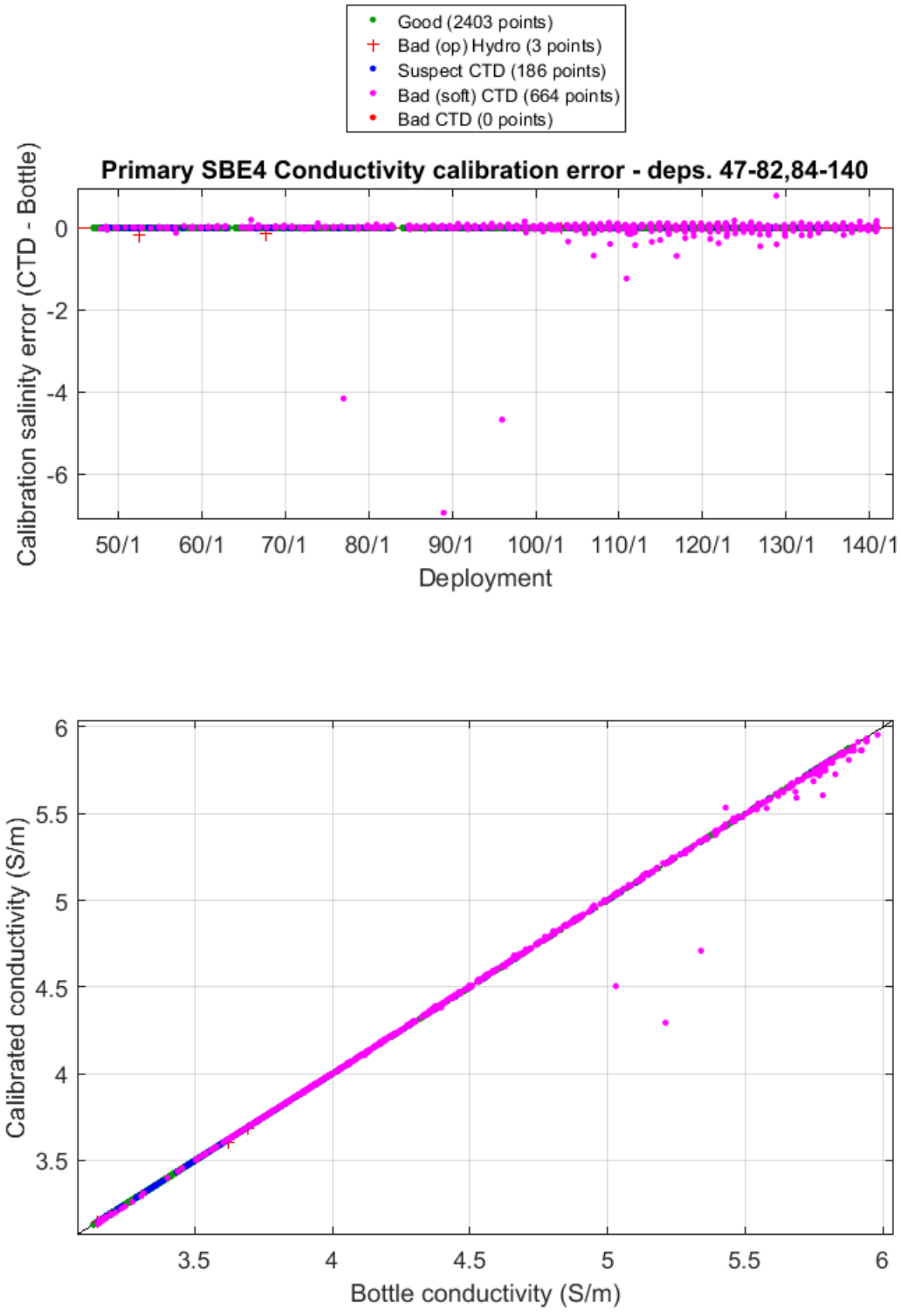


FIGURE 4. CTD - bottle salinity plot.

The final result for the primary conductivity sensor for casts 1 - 7 was –

Scale Factor (a1)	0.99943	wrt. CSIRO calibration
Offset (a0)	-8.6338e-05	ditto
Calibration S.D. (Sal)	0.00087776 PSU	

The final result for the primary conductivity sensor for casts 8 - 46 was –

Scale Factor (a1)	0.99941	wrt. CSIRO calibration
Offset (a0)	-2.4759e-05	ditto
Calibration S.D. (Sal)	0.0011708 PSU	

The final result for the primary conductivity sensor for casts 47 - 141 was –

Scale Factor (a1)	1.0005	wrt. CSIRO calibration
Offset (a0)	-0.00069281	ditto
Calibration S.D. (Sal)	0.0011492 PSU	

This is a good 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 in their respective calibration groups.

Data from the primary conductivity and temperature sensors were used to produce the averaged salinities.

The calibration using the secondary conductivity sensor was well beyond our acceptable standard deviation range, and as such was not applied.

3.4 Dissolved Oxygen Sensor Calibration

3.4.1 SBE calibration procedure

Sea-Bird (2010a) 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 (2010b) 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.

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 by Sea-Bird (2010c).

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.

Multiple deployment calibration groups were used with the associated SBE43 up-cast data to compute the new Soc and Voffset coefficients, due to changes of sensors throughout the voyage.

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.

The calibrations were applied for each sensor and the averaged files were created using the result from the primary sensor for casts 1-83, and the secondary sensor for casts 84 – 141. These groups were divided further due to changing the CTD unit, as shown in Table 2.

Casts		**CSIRO calibration of sensor**	**sensor calibration**	**Primary/Secondary**
1-7	Voffset	-0.50133997	-0.47032	Primary
	Soc	0.47520554	0.49124	
	Fit SD (uM)		0.86539	
8-46	Voffset	-0.50133997	-0.48122	Primary
	Soc	0.47520554	0.50047	
	Fit SD (uM)	--	0.98604	
47-63	Voffset	-0.49845385	-0.44866	Primary
	Soc	0.48405339	0.48468	
	Fit SD (uM)	--	1.1743	
64-83	Voffset	-0.49845385	-0.45711	Primary
	Soc	0.48405339	0.49507	
	Fit SD (uM)	--	0.85613	
84-110	Voffset	-0.4873	-0.44407	Secondary
	Soc	0.5318	0.54158	
	Fit SD (uM)	--	0.87393	
111-141	Voffset	-0.4982	-0.43719	Secondary
	Soc	0.4241	0.41128	
	Fit SD (uM)	--	1.4238	

TABLE 2. Dissolved oxygen calibrations

3.5 Other sensors

The Chelsea Fluorometer was used for deployments 57 onwards. The Fluorometer has been calibrated to give nominal outputs of 0-100 fsd (full scale deflection).

3.6 Bad data detection

The limits for each sensor are configured in the CAP the CTD acquisition software and are written to the NetCDF scan file. Typical limits used for the sensor range and maximum second difference are in Table 3 below. The rejection rate is recorded in the CapPro processing log file.

Sensor	Range min	Range max	Max Second Diff
temperature	-2	40	0.05
conductivity	-0.01	7	0.01
oxygen	-1	500	0.5
Fluorometer	0	100	0.5

TABLE 3. 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 1dbar 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 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

Sloyan, Wijffels., 2016: The RV Investigator. Voyage Plan IN2016_V03 - http://mnf.csiro.au/~/media/Files/Voyage-plans-and-summaries/Investigator/Voyage%20Plans%20summaries/2016/IN2016_V03%20Voyage%20Plan%2020160427%20FINAL.ashx

Pender, L., 2000: Data Quality Control Flags. http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

Sea-Bird Electronics Inc., 2010a: Application Note No 64: SBE 43 Dissolved Oxygen Sensor -- Background Information, Deployment Recommendations, and Cleaning and Storage. http://www.seabird.com/pdf_documents/ApplicationNotes/appnote64Feb10.pdf

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Sea-Bird Electronics Inc., 2010c: Application Note No 64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections. http://www.seabird.com/pdf_documents/ApplicationNotes/Appnote64-3Feb10.pdf