RV *INVESTIGATOR*

HYDROCHEMISTRY DATA PROCESSING REPORT

Voyage:	in2021_v02
Chief Scientist:	Elizabeth Shadwick
Voyage title:	SOTS: Southern Ocean Time Series automated moorings for climate and carbon cycle studies southwest of Tasmania
Report compiled by:	Stephen Tibben

Contents

1 Executive Summary

The main objective of the voyage was to recover and re-deploy SOFS and SAZ moorings. CTD and ISP deployments were also performed for analysis of thorium.

Water samples collected during the voyage were assayed in the ship's hydrochemistry laboratory for nutrients, dissolved oxygen, and salinity. The samples came from deployments of the CTD rosette, underway system, and from experiments run by the science party.

Five nutrients were analysed; silicate, phosphate, nitrate + nitrite, nitrite and ammonium. Certified reference materials for nutrients in seawater were within the specified limits of the certified value.

When using silicate, phosphate, nitrate+nitrite (NOx) and nitrite data set for publication, please cite the paper:

Rees, C., L. Pender, K. Sherrin, C. Schwanger, P. Hughes, S. Tibben, A. Marouchos, and M. Rayner. (2018) "*Methods for reproducible shipboard SFA nutrient measurement using RMNS and automated data processing*." Limnol. Oceanogr: Methods, 17(1): pp. 25-41. doi:10.1002/lom3.10294

When using ammonium dataset for publication, please cite the paper:

Rees, C., J.Janssens, K. Sherrin, P. Hughes, S. Tibben, M. McMahon, J. McDonald, A. Camac, C. Schwanger, and A. Marouchos. (2021) "*Method for Reproducible Shipboard Segmented Flow Analysis Ammonium Measurement Using an In-House Reference Material for Quality Control*." Front. Mar. Sci., 8: p. 316. doi:10.3389/fmars.2021.581901

Final hydrology data, analytical methods, log sheets, and processing notes can be obtained from the CSIRO data centre.

Contact: NCMI_DataLibrarians@csiro.au

2   Itinerary

	Depart	Arrive
Port	Hobart	Hobart
Date	14/04/2021	28/04/2021
Time	1800	0800
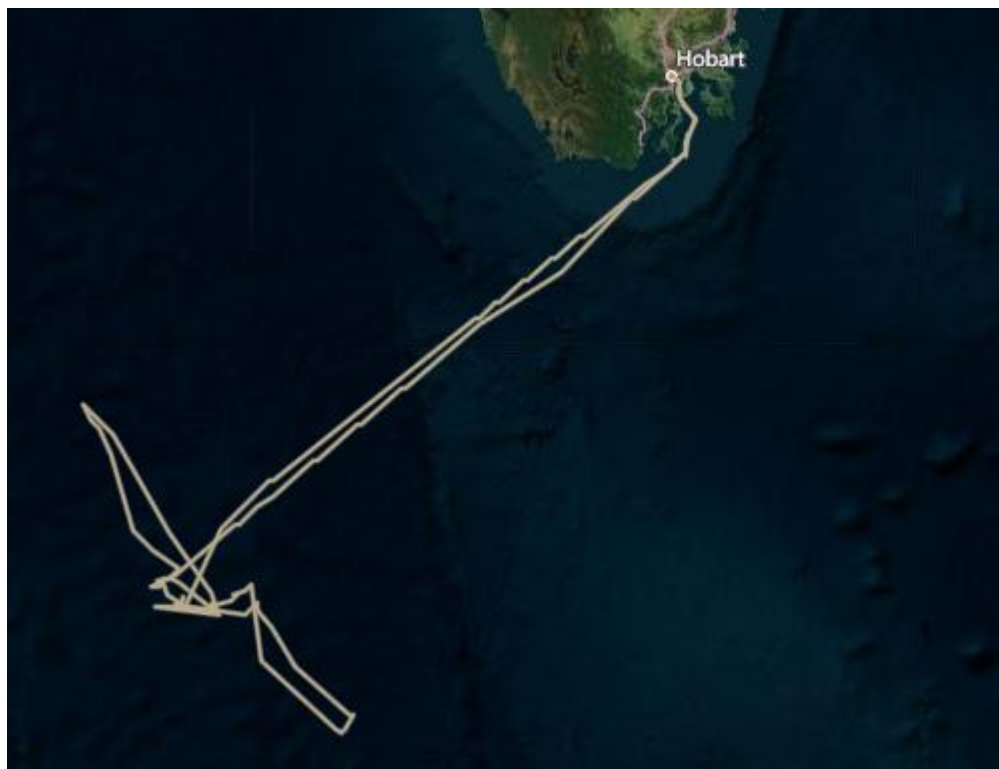
Figure 1: Voyage track:

3   Key personnel list

Name	Role	Organisation
Elizabeth Shadwick	Chief Scientist	CSIRO
Max McGuire	Voyage Manager	CSIRO
Stephen Tibben	Hydrochemist	CSIRO

4 Summary

4.1 Sample Type and Number Assayed

Table 1: Sampling summary.

Analysis (instrument)	Number of Samples	Processing Status at voyage end
Salinity (Guildline Salinometer)	77 CTD	Completed
	15 TSG	Completed
Dissolved Oxygen (automated titration)	77 CTD	Completed
Nutrients (Seal AA3HR)	79 CTD	Completed
	3 UWY	Completed
	38 EXP	Completed

4.1.1 CTD (Conductivity, Temperature, Depth)

- Sampling point, 36 bottle rosette with 12L Ocean Test Equipment bottles (Niskin) deployed at depth for water collection.

- 6 CTD deployments in total.

4.1.2 EXP (Experimental samples)

- Prepared and sampled by the science groups conducting the experiments.

4.1.3 TSG (Thermosalinograph)

- Samples collected by DAP or hydrochemistry from underway lab for calibration of thermosalinograph.

For UWY, EXP, and TSG sample information refer to the eLogs from the voyage.

4.2   Data Processing Overview

The sample meta-data, measured bottle salinity results, dissolved oxygen assay results and the nutrient assay raw data are processed by the CSIRO program HyPro. The final output is the hydrology data set. An overview of this process is illustrated in figure 1.

CTD Deployment

CTD data converted to an xml file for HyPro

CTD Log Editor Software

Sampling log sheet data entered into the CTD deployment xml file. Imported into HyPro

CTD sampling log sheet - paper. Record sample ID and D.O. draw temp

Nutrient Results

Instrument output, two files: CHD (raw peak data) and SLK (peak meta-data). Both files imported into HyPro.

HyPro calculates the nutrient data and applies quality control criteria

HyPro Software

Combines all data and produces profile plots, time series plots, QC charts, sampling and assay summaries. It also compares the salt & D.O. bottle results against the CTD instrument data.

Salinity Results

Instrument output: xlsx file, imported into HyPro. Reported as is.

Dissolved Oxygen Results

Instrument output: LST file, imported into Hypro.

HyPro converts D.O. result from ml l^{-1} to μmole l^{-1} (multiply 44.66)

Output

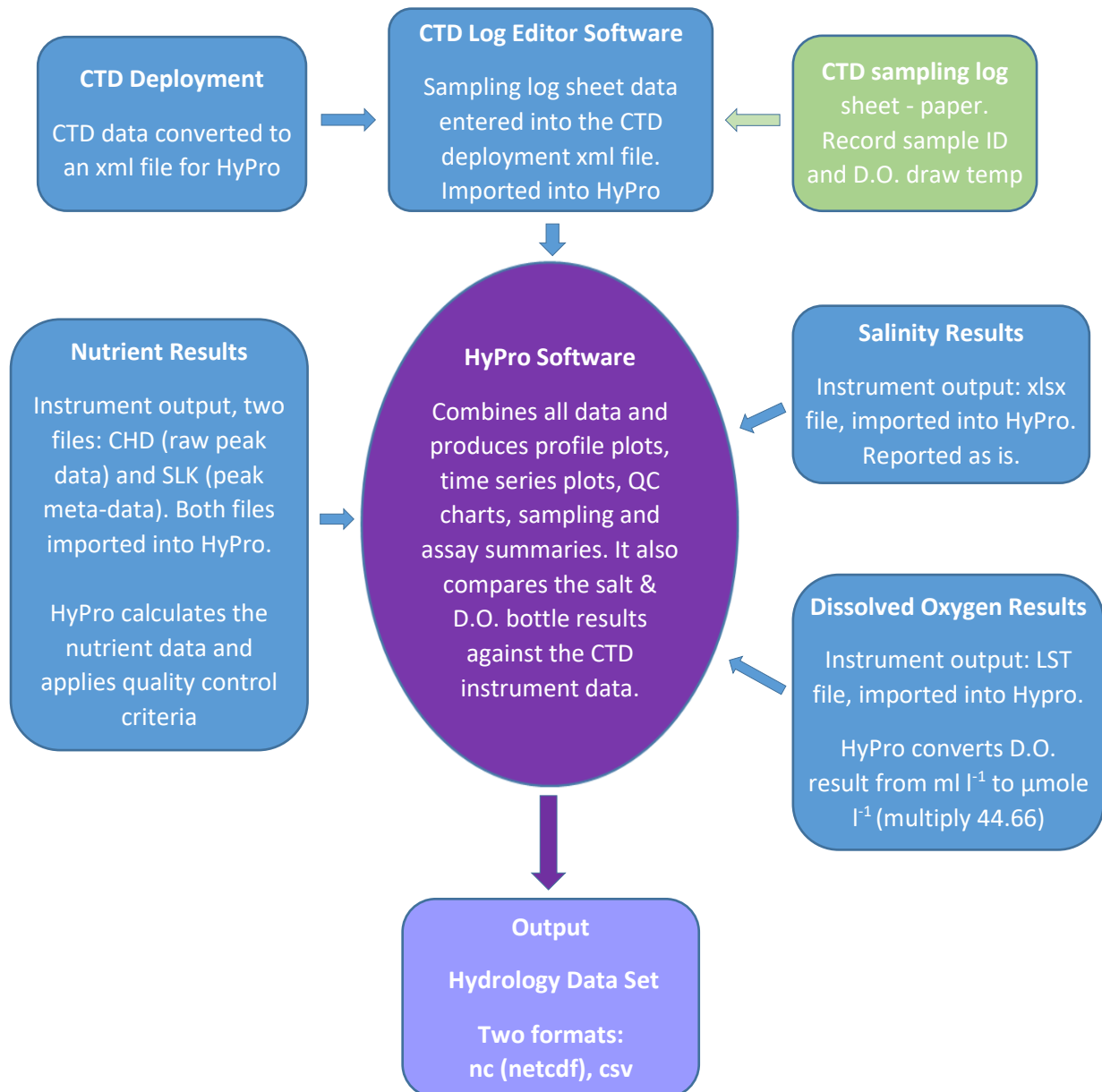**Hydrology Data Set**

**Two formats:
nc (netcdf), csv**

Figure 2: Hydrology Data Processing Flow Diagram.

5   Salinity Data Processing

5.1   Salinity Parameter Summary

Table 2: Salinity parameters

Details	
HyPro Version	5.7
Instrument	Guildline Autosal Laboratory Salinometer 8400(B) – SN 72151
Software	OSIL Data Logger ver 1.2
CSIRO Hydrochem Method.	Sampling: WI_Sal_002 Measurement: SOP006
Accuracy	± 0.001 practical salinity units
Analysts	Stephen Tibben
Lab Temperature (±0.5°C)	21.5 -22.5°C during analysis.
Bath Temperature	24.00°C
Reference Material	Osil IAPSO - Batch P163, use by 23/03/2023, K_{15} = 0.99985
Sampling Container type	200 ml volume OSIL bottles made of type II glass (clear) with disposable plastic insert and plastic screw cap.
Sample Storage	Samples stored in the salinometer room to equilibrate before measurement.
Comments	None.

5.2   Salinity Method

Salinity samples are measured on a high precision laboratory salinometer (Guildline Autosal 8400B) which is operated in accordance with its technical manual.

Practical salinity (S), is defined in terms of the ratio (K_{15}) of the electrical conductivity measured at 15°C 1atm of seawater to that of a potassium chloride (KCl) solution of mass fraction 32.4356 x 10^{-3}.

Before each batch of sample measurements, the Autosal is calibrated with standard seawater (OSIL, IAPSO) of known K_{15} ratio. A new bottle of OSIL solution is used for each calibration. The frequency of calibration is one per set of samples per CTD deployment.

Method synopsis: Salinity samples are collected into 200ml OSIL bottles, filled from the bottom, via a polytetrafluoroethylene (PTFE) straw, till overflowing. The bottle is removed from the straw and the sample is decanted to allow a headspace of approximately 25cm^3. A plastic insert is fitted, the bottle inverted and rinsed with water then capped and stored cap-down until measured. To measure, the Autosal cell is flushed three times with the sample and then measured after the fourth and fifth flush. The OSIL Data logger software captures the conductivity ratio and calculates the practical salinity.

The output from the data logger software is imported into HyPro and collated with the CTD deployment meta-data.

5.3 CTD Salinity vs Bottle Salinity Plot

The difference between the unprocessed (uncorrected) CTD values and the measured bottle salinities is generally less than 0.01 PSU.

Note: dots = bottle samples, circles = CTD instrument (unprocessed)
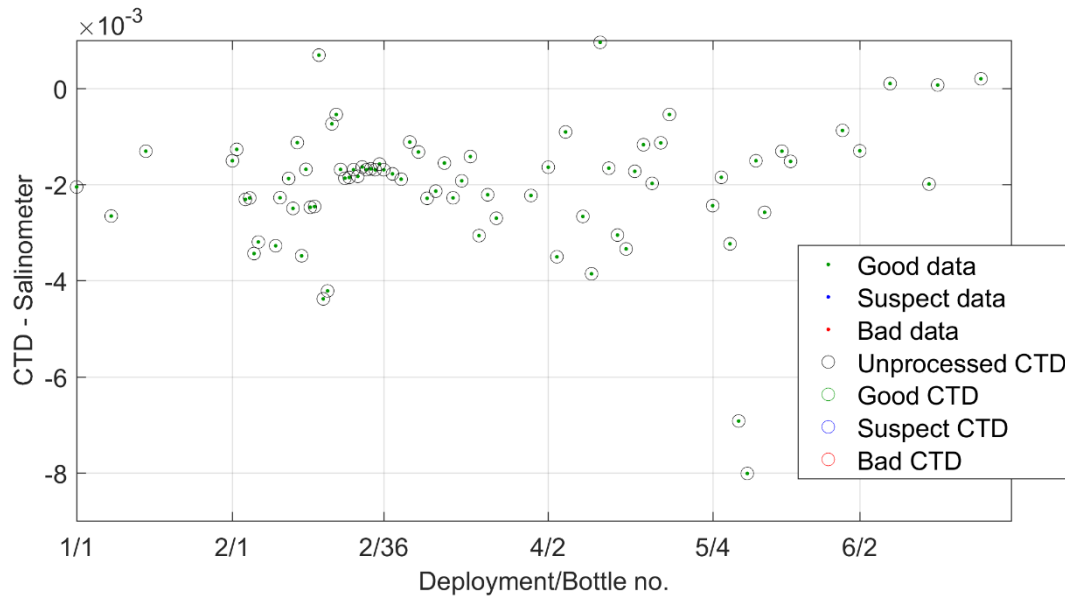

Figure 3: CTD salinity result minus bottle salinity result.

The data quality is coded by colour and represented by a dot for the bottle salinity and a circle for the CTD salinity. Green = GOOD. Black = UNPROCESSED. Units: PSU (dimensionless).

6 Dissolved Oxygen Data Processing

6.1 Dissolved Oxygen Parameter Summary

Table 3: Dissolved Oxygen parameters

Details	
HyPro Version	5.7
Instrument	Automated Photometric Oxygen system (SIO)
Software	SCRIPPS
CSIRO Hydrochem. Method	Sampling: WI_DO_001 Assay: SOP005
Accuracy	± 0.5 µM
Analyst(s)	Stephen Tibben
Lab Temperature (±1°C)	Variable, 19.5 - 21.5°C
Sample Container type	Pre-numbered 140 mL glass iodine determination flasks with glass stopper. 18 flasks per light-proof container.
Sample Storage	Samples stored in the hydrochemistry lab until analysis.
Comments	None.

6.2 Dissolved Oxygen Method

SCRIPPS method used. The method is based on the whole-bottle modified Winkler titration of Carpenter (1965) plus modifications by Culberson *et al* (1991).

Method synopsis: The sample is collected in an iodine determination flask of known volume. 1mL of manganese (II) chloride solution followed by 1 mL of alkaline iodide solution is added to the sample, the flask stoppered and inverted a minimum of 39 times. The dissolved oxygen oxidizes an equivalent amount of Mn (II) to Mn (IV) which precipitates. Just before titration, the sample is acidified, oxidizing the Mn (IV) back to the divalent state liberating iodine twice the original dissolved oxygen content of the sample. The tri-iodine is auto-titrated with a standardised thiosulphate solution using a Metrohm 665 Dosimat fitted with a 1ml burette. The endpoint is determined by measuring changes in the UV absorption of the tri-iodide ion at 365 nm. The point at which there is no change in absorbance is the endpoint.

Before each batch of sample assays, the thiosulphate solution is standardised by using it to titrate a 10ml aliquot of potassium iodate primary standard. A blank correction is also determined from the difference between two consecutive titres for 1ml aliquots of the same potassium iodate solution.

The output from the SIO instrument software is imported into HyPro and collated with the CTD deployment meta-data.

6.3   CTD Dissolved Oxygen vs Bottle Dissolved Oxygen Plot

The CTD values in this plot are unprocessed raw data.

The unprocessed CTD values are adjusted (corrected) by DAP using the bottle results. The corrected values are not reported in the hydrology set. Please contact the DataLibrarians@csiro.au for corrected CTD data.

Note: dots = bottle samples, circles = CTD instrument (unprocessed), units are µmolL^{-1}
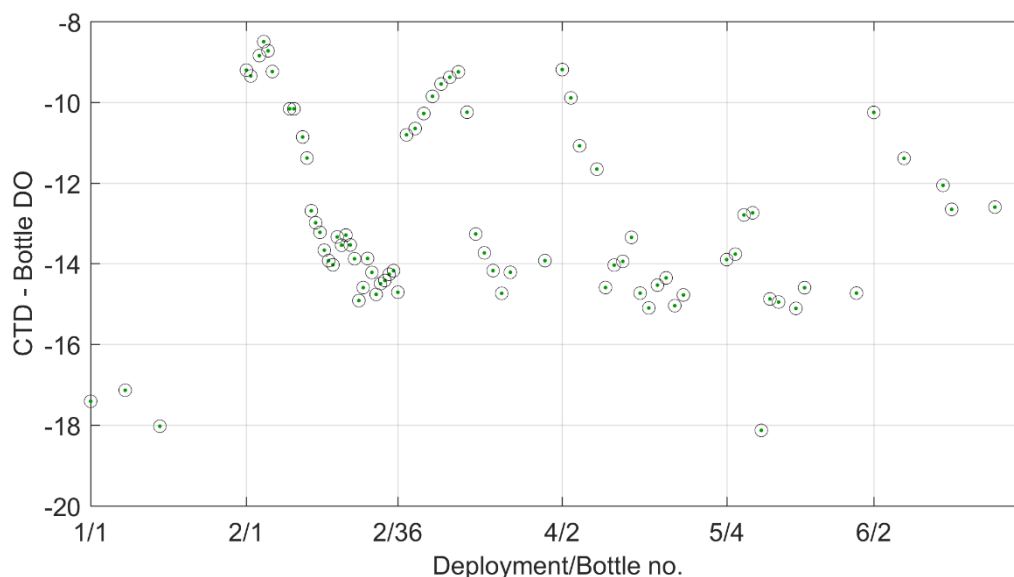

Figure 4: CTD oxygen result minus bottle oxygen result.

The data quality is coded by colour and represented by a dot for the bottle salinity and a circle for the CTD salinity. Green = GOOD. Black = UNPROCESSED. Units: µmolL^{-1}.

7 Nutrient Data Processing

7.1 Nutrient Assay Parameter Summary

Table 4: Nutrient parameters

Details					
CSIRO Software	HyPro 5.7				
Instrument	Seal AA3HR				
Instrument Software	Seal AACE 7.10				
CSIRO Hydrochem. Method, sampling	WI_Nut_001				
CSIRO Hydrochem. Method, nutrient	SOP001	SOP002	SOP003	SOP003	SOP004
Nutrient	Silicate	Phosphate	Nitrate + Nitrite	Nitrite	Ammonium
Concentration range	112 µM	3.0 µM	42 µM	1.4 µM	2.0 µM
Method Detection Limit (MDL)	0.2 µM[1]	0.02 µM	0.02 µM	0.02 µM	0.02 µM
Matrix Corrections	none	none	none	none	none
Analysts	Stephen Tibben				
Lab Temperature (±1°C)	Variable, 19.5– 21.5°C				
Reference Material	KANSO, RMNS lot CC				
Sampling Container type	CTD: 50 mL HDPE with screw cap lids. EXP and UWY: 30 mL PP tubes with screw cap lids.				
Sample Storage	< 2 hrs at room temperature otherwise refrigerated at @ 4°C				

7.2 Nutrient Methods

When using silicate, phosphate, nitrate+nitrite (NOx) and nitrite dataset for publication, please cite the paper:

Rees, C., L. Pender, K. Sherrin, C. Schwanger, P. Hughes, S. Tibben, A. Marouchos, and M. Rayner. (2018) "*Methods for reproducible shipboard SFA nutrient measurement using RMNS and automated data processing.*" Limnol. Oceanogr: Methods, 17(1): pp. 25-41. doi:10.1002/Iom3.10294

When using ammonium dataset for publication, please cite the paper:

Rees, C., J.Janssens, K. Sherrin, P. Hughes, S. Tibben, M. McMahon, J. McDonald, A. Camac, C. Schwanger, and A. Marouchos. (2021) "*Method for Reproducible Shipboard Segmented Flow Analysis Ammonium Measurement Using an In-House Reference Material for Quality Control.*" Front. Mar. Sci., 8: p. 316. doi:10.3389/fmars.2021.581901

Nutrient samples are assayed on a Seal AA3HR segmented flow auto-analyser fitted with 1cm flow-cells for colorimetric measurements and a JASCO FP2020 fluorescence instrument as the ammonium detector.

Silicate (SOP001): colourimetric, molybdenum blue method. Based on Armstrong et al. (1967). Silicate in seawater is reacted with acidified ammonium molybdate to produce silicomolybdic acid. Tartaric acid is added to remove the phosphate molybdic acid interference. Tin (II) chloride is then added to reduce the silicomolybdic acid to silicomolybdous acid and its absorbance is measured at 660nm.

Phosphate (SOP002): colourimetric, molybdenum blue method. Based on Murphy and Riley (1962) with modifications from the NIOZ-SGNOS Practical Workshop 2012 optimizing the antimony catalyst/phosphate ratio and the reduction of silicate interferences by pH. Phosphate in seawater forms a phosphomolybdenum complex with acidified ammonium molybdate. It is then reduced by ascorbic acid and its absorbance is measured at 880nm.

Nitrate (SOP003): colourimetric, Cu-Cd reduction – naphthylenediamine method. Based on Wood et.al (1967). Nitrate is reduced to nitrite by first adding an ammonium chloride buffer then sending it through a copper - cadmium column. Sulphanilamide is added under acidic conditions to form a diazo compound. This compound is coupled with 1-N-naphthly-ethylenediamine di-hydrochloride to produce a reddish purple azo complex and its absorbance is measured at 520 nm.

Nitrite (SOP003): colourimetric, naphthylenediamine method. As per nitrate method without the copper cadmium reduction column and buffer.

Ammonium (SOP004): fluorescence, ortho-phtaldiadehyde method. Based on Roger Kérouel and Alain Aminot, IFREMER (1997 Mar.Chem.57). Ammonium reacted with ortho-phtaldialdehyde and sulphite at a pH of 9.0-9.5 to produce an intensely fluorescent product. Its emission is measured at 460nm after excitation at 370nm.

SOP methods can be obtained from the CSIRO Oceans and Atmosphere Hydrochemistry Group.

7.3 HyPro Processing Parameters

All instrument parameters and reagent batches and operation events are logged for each analysis run. This information is available on request.

Table 5: Nutrient processing parameters

Result Details	Silicate	Phosphate	Nitrate + Nitrite (NOx)	Nitrite	Ammonia
Data Reported as	$\mu mol\ l^{-1}$	$\mu mol\ l^{-1}$	$\mu mol\ l^{-1}$	$\mu mol\ l^{-1}$	$\mu mol\ l^{-1}$
Calibration Curve degree	Linear	Linear	Quadratic	Quadratic	Quadratic
# of points in Calibration	6	6	6	6	6
Forced through zero?	N	N	N	N	N
Matrix correction	N	N	N	N	N
Blank correction	N	N	N	N	N
Peak window defined by	HyPro	HyPro	HyPro	HyPro	HyPro

Result Details	Silicate	Phosphate	Nitrate + Nitrite (NOx)	Nitrite	Ammonia
Carryover correction (HyPro)	Y	Y	Y	Y	Y
Baseline drift correction (HyPro)	Y	Y	Y	Y	Y
Sensitivity drift correction (HyPro)	Y	Y	Y	Y	Y
Data Adj for RMNS variance.	N	N	N	N	N
Medium of Standards	LNSW (bulk on deck of Investigator) sub sampled on 19/01/2021. Sub-lot passed through a 10 micron filter and stored in 20 L carboys in the hydrochemistry laboratory at 20.5°C.				
Medium of Baseline	18.2 Ω water. Dispensed from Milli Q				
Proportion of samples in duplicate.	<10%. CTD: Niskin fired at the greatest depth sampled in duplicate. Single samples collected for remaining depths.				
Comments	The reported data is not corrected to the RMNS. Per deployment RMNS data tabulated in appendix 8.2.1.				

7.4   HyPro Data Processing Summary

After a run, the raw absorbance/ fluorescence data is exported from the instrument and processed by HyPro. For each analyte, HyPro re-creates the peak traces, defines the region on the peak's plateau (peak window) used to determine the peak heights, constructs the calibration curve, applies corrections for carry-over, baseline and sensitive drifts then, derives the nutrient concentrations for each sample. The corrections are quantified using dedicated solutions included in every run.

HyPro uses criteria to identify suspect calibration points, noisy peaks, method detection limits that are above the nominal limit and, duplicate sample results that do not match.

With suspect calibration points, their contribution to the curve is given less weighting dependent on their distance from the final curve. The cut-off limits for good calibration data are:

- ±0.5% of the concentration of the top standard for silicate and nitrate+nitrite (as per WOCE).
- Within 0.02uM for phosphate, nitrite and ammonium.

HyPro classifies the quality of data as good, suspect or bad and flags accordingly. The Flag key is in Appendix 8.3.

7.5   Accuracy - Reference Material for Nutrient in Seawater (RMNS)

Japanese KANSO certified RMNS lot CC was assayed in triplicate in each run to monitor accuracy. The certified values are in table 1.

The majority of RMNS results are within 1% of their certified mean and within 0.02 µM for nitrite. Plots of RMNS values for all runs are below.

The assayed RMNS values per Analysis run and CTD deployments are listed in appendix 8.2.1.

The GO-SHIP criteria (Hyde *et al.*, 2010), appendix 8.6, specifies using 1-3 % of full scale (depending on the nutrient) as acceptable limits of accuracy.

Table 6: RMNS concentrations with expanded uncertainty at 21°C

RMNS	NO$_3$ (µmol L^{-1})	NO$_2$ (µmol L^{-1})	NO$_3$+ NO$_2$ (NO$_X$, µmol L^{-1})	PO$_4$ (µmol L^{-1})	SiO$_4$ (µmol L^{-1})
Lot CC	31.621 ± 0.246	0.119 ± 0.006	31.740 ± 0.252	2.130 ± 0.019	88.228 ± 0.492

KANSO publishes the RMNS nutrient values in µmol kg^{-1}. These are converted to µmol L^{-1} at 21°C. The RMNS is not certified for ammonium. NO$_x$ is derived by adding the NO$_3$ and NO$_2$ values.

Plot key. The green pink and red lines are the 1%, 2% and 3% contours from the RMNS certified mean value. Exception: nitrite, the contours are at 0.02 µM increments from the certified value. The blue line is the expanded uncertainty of the certified value.
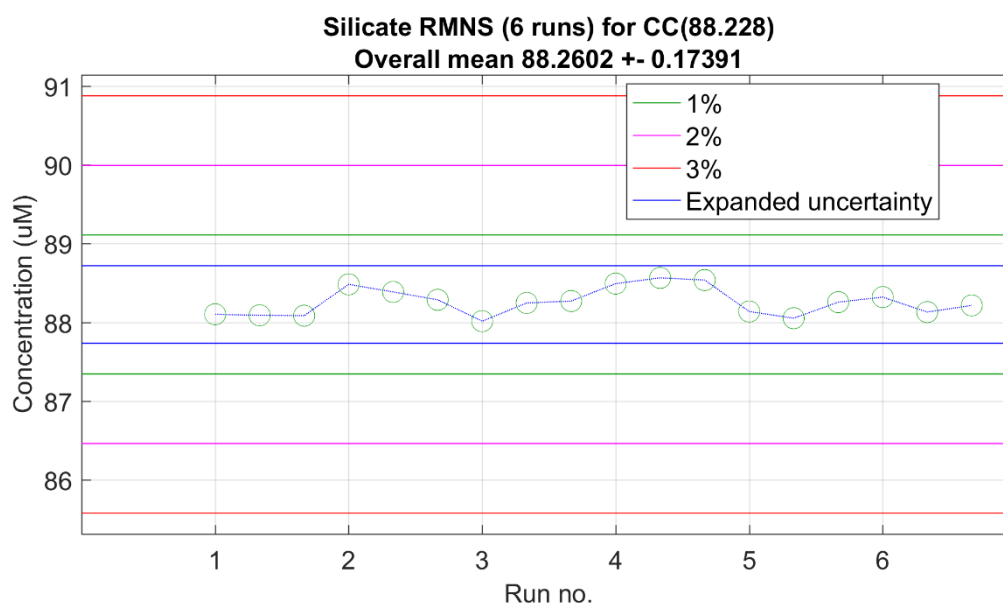
7.5.1   Silicate RMNS Plot (µM)

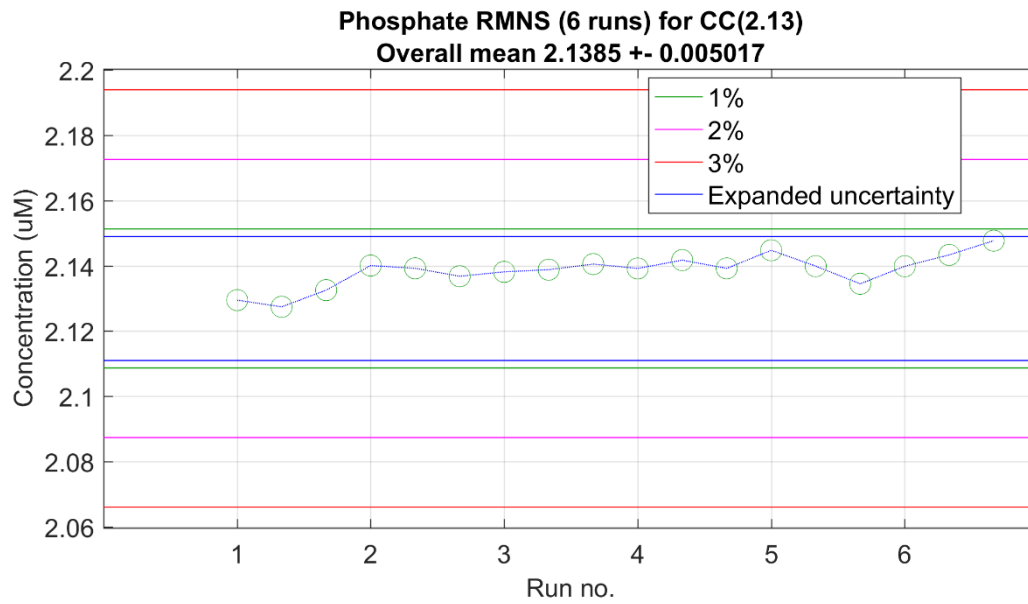**Figure 5: RMNS lot CC plot for silicate**

7.5.2 Phosphate RMNS Plot (μM)

Phosphate RMNS (6 runs) for CC(2.13)
Overall mean 2.1385 +- 0.005017

Figure 6: RMNS lot CC plot for phosphate

7.5.3 Nitrate + Nitrite (NOx) RMNS Plot (μM)

NOx RMNS (6 runs) for CC(31.74)
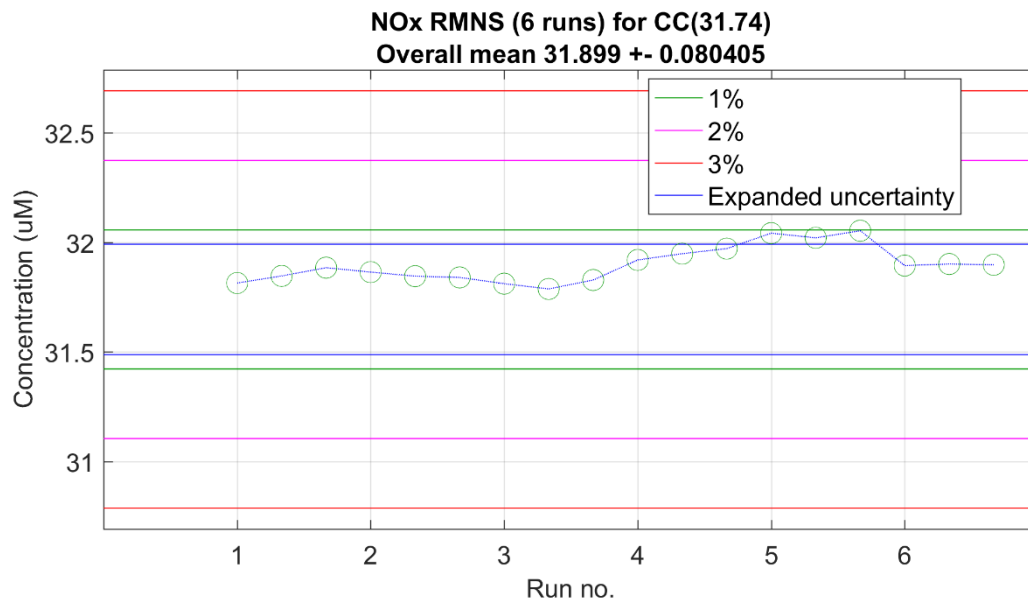**Overall mean 31.899 +- 0.080405**

Figure 7: RMNS lot CC plot for NO$_x$
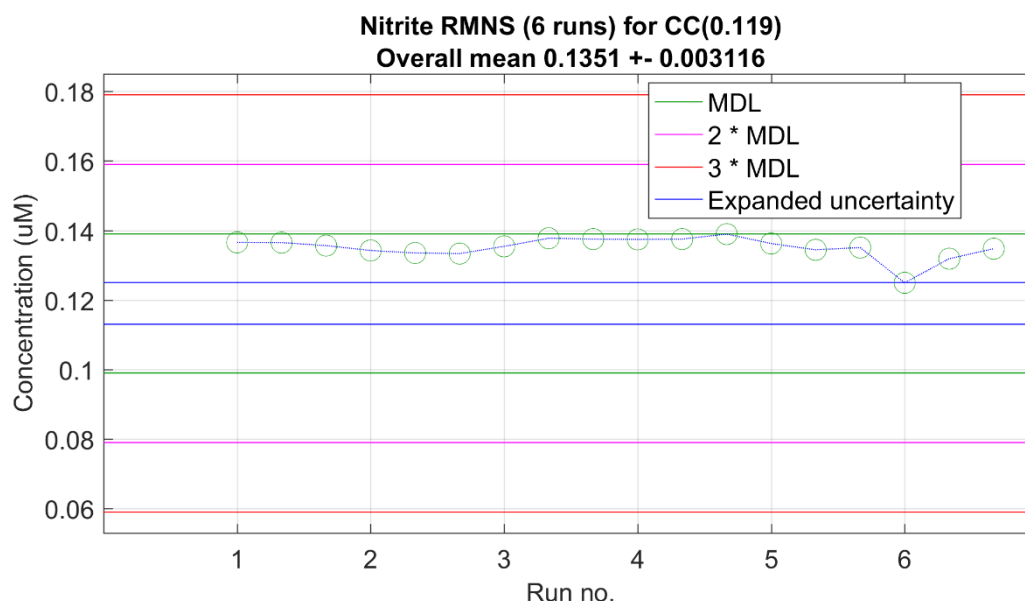
7.5.4   Nitrite RMNS Plot (µM)

Figure 8: RMNS lot CC plot for nitrite

*Please note that there is no certified reference material for ammonia and therefore no plot here.

7.6   Analytical Precision

7.6.1   Nutrient Measurement Uncertainty

The CSIRO Hydrochemistry method measurement uncertainty (MU) has been calculated for each nutrient based on the variation in the calibration curve, calibration standards, pipette and glassware calibration, and precision of the RMNS over time (Armishaw 2003).

Table 7: Nutrient measurement uncertainty

Calculated Measurement Uncertainty @ 1 µmol L^{-1}				
Silicate	Phosphate	Nitrate + Nitrite (NOx)	Nitrite	Ammonia
±0.017	±0.024	±0.019	±0.14	±0.30[¥]

*The reported uncertainty is an expanded uncertainty using a coverage factor of 2 giving a 95% level of confidence.

[¥]The ammonia MU precision does not include data for the RMNS.

7.7   Sampling Precision

Sampling precision is monitored by assaying duplicate samples collected from the greatest depth for each CTD deployment. The sampling precision is good if the difference between the duplicate

concentrations is less than the MDL value. The exception is nitrate+nitrite, which uses 0.06 µM as the MDL boundary.

Plots of the difference between the duplicate and their mean for the CTD deployments are below. The red line is the boundary below which sampling precision is deemed good.

For in2021_v02, the sampling precision is acceptable.
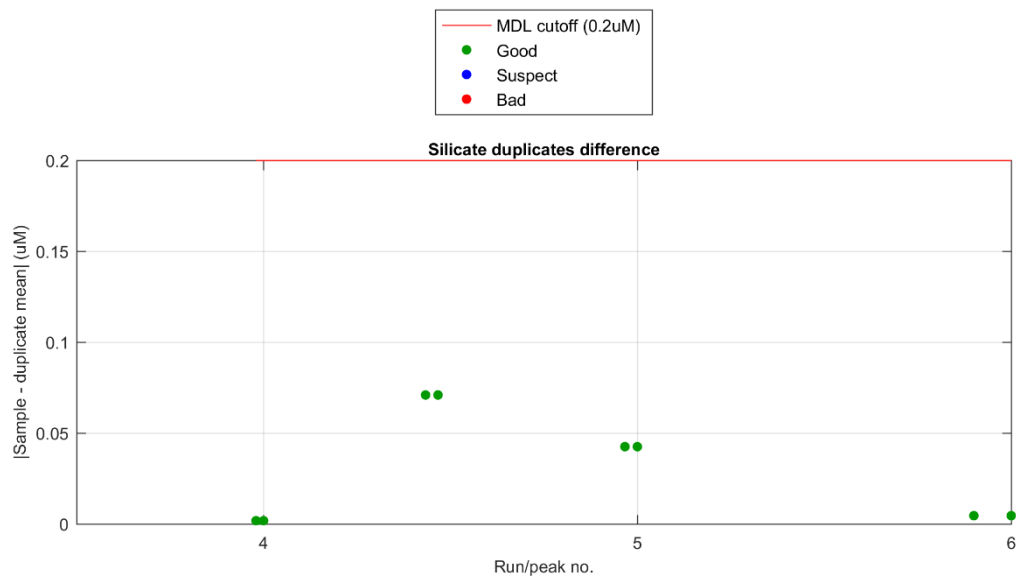
7.7.1 Silicate Duplicates Plot

Figure 9: Duplicate difference plot for silicate

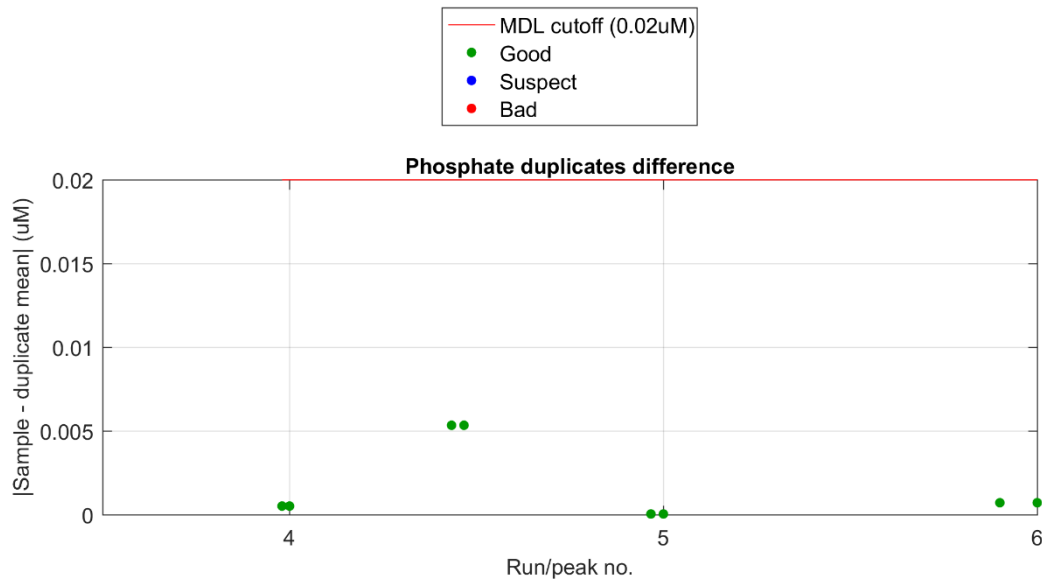### 7.7.2 Phosphate Duplicates Plot

Figure 10: Duplicate difference plot for phosphate

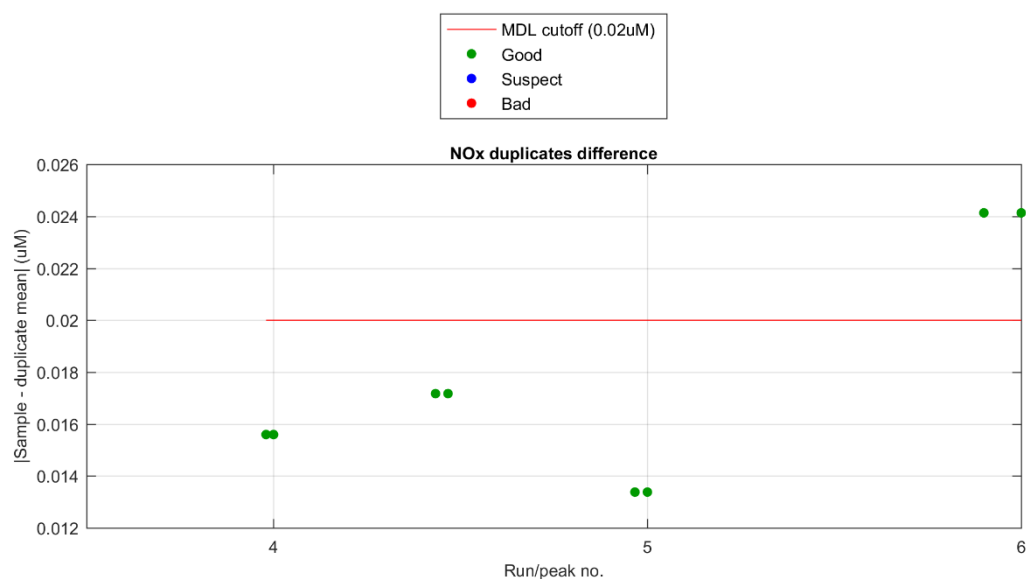### 7.7.3 Nitrate + Nitrite (NOx) Duplicates Plot

Figure 11: Duplicate difference plot for NO$_x$

Note that the method detection limit (MDL) cut off is 0.02 µmolL^{-1} but the acceptable duplicate difference for NO$_x$ is 0.06 µmolL^{-1}, hence the results for run 6 are acceptable.
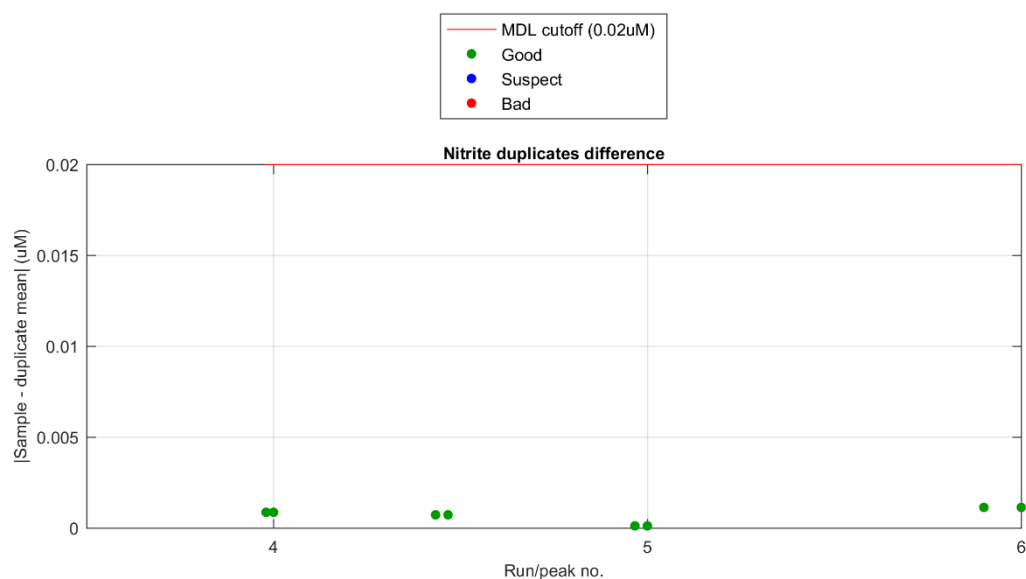
7.7.4 Nitrite Duplicates Plot

Figure 12: Duplicate difference plot for nitrite

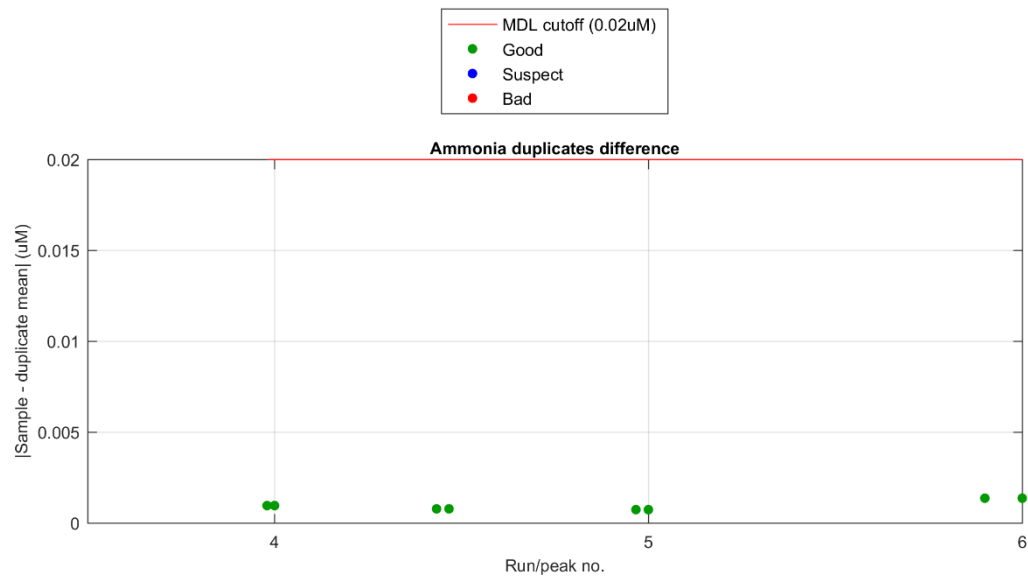### 7.7.5 Ammonia Duplicates Plot

Figure 13: Duplicate difference plot for ammonia

8 Appendix

8.1 Salinity: Reference Material Used

Table 8: Batch information for salinity standard

OSIL IAPSO Standard Seawater	
Batch	P163
Use by date	23/03/2023
K_{15}	0.99985
PSU	34.994

8.2 Nutrients: RMNS results for each Analysis Run & CTD Deployment.

Table 9: RMNS lot CC results

Analysis Run	CTD #	Silicate (Si, $\mu mol\ L^{-1}$)	Phosphate (PO_4, $\mu mol\ L^{-1}$)	Nitrite (NO_2, $\mu mol\ L^{-1}$)	NOx ($NO_2 + NO_3$, $\mu mol\ L^{-1}$)
CC conc. reported	-	88.228 ± 0.492	2.130 ± 0.019	0.119 ± 0.006	31.740 ± 0.252
1	-	88.093	2.130	0.136	31.351
2	-	88.386	2.139	0.134	31.851
3	1, 2	88.178	2.139	0.137	31.810
4	3, 4	88.532	2.140	0.138	31.947
5	5	88.150	2.140	0.135	32.039
6	6	88.223	2.144	0.131	31.898

The submitted nutrient results do <u>NOT</u> have RMNS corrections applied.

<u>**How to use the RMNS for Correction**</u>

Ratio = Certified RMNS Concentration/Measured RMNS Concentration in each run
Corrected Concentration = Ratio x Measured Nutrient Concentration

Or for smoothing data

Ratio = Average RMNS Concentration across voyage/Measured RMNS Conc. in each run
Corrected Concentration = Ratio x Measured Nutrient Concentration

8.3   Flag Key for Hydrology Data Set

The hydrology data were processed using in-house software package, HyPro. An explanation of the flags used is below.

Table 10: HyPro flagging key

Flag	Description
0	Data is GOOD – nothing detected.
192	Data not processed.
63	Below nominal detection limit.
69	Data flagged suspect by operator. Set suspect by software if Calibration or Duplicate data is outside of set limits but not so far out as to be flagged bad.
65	Peak shape is suspect.
133	Error flagged by operator. Data is bad – operator identified by # in slk file or by clicking on point.
129	Peak exceeds maximum A/D value. Data is bad.
134	Error flagged by software. Peak shape is bad - Median Absolute Deviation (MAD) analysis used. Standards, MDL's and Duplicates deviate from the median, Calibration data falls outside set limits.
141	Missing data, no result for sample ID. Used in netcdf file as an array compiles results. Not used in csv file.
79	Method Detection Limit (MDL) during run was equal to or greater than nominal MDL. Data flagged as suspect.

8.4   GO-SHIP Specifications

8.4.1   Salinity

Accuracy of 0.001 is possible with Autosal™ salinometers and concomitant attention to methodology. Accuracy with respect to one particular batch of Standard Sea Water can be achieved at better than 0.001 PSS-78. Autosal precision is better than 0.001 PSS-78. A precision of approximately 0.0002 PSS-78 is possible following the methods of Kawano with great care and experience. Air temperature stability of ± 1°C is very important and should be recorded[2].

8.4.2   Dissolved Oxygen

Target accuracy is that 2 sigma should be less than 0.5% of the highest concentration found in the ocean. Precision or reproducibility (2 sigma) is 0.08% of the highest concentration found in the ocean.

8.4.3   SiO2

Approximately 1-3% accuracy[1], 0.2% precision[3], full scale.

8.4.4   PO4

Approximately 1-2% accuracy[1], 0.4% precision[3], full scale.

8.4.5   NO3

Approximately 1% accuracy[1], 0.2% precision[3], full scale.

8.4.6   Notes

[1] If no absolute standards are available then accuracy should be taken to mean the reproducibility presently obtainable in the better laboratories.

[2] Keeping constant temperature in the room where salinities are determined greatly increases their quality. Also, room temperature during the salinity measurement should be noted for later interpretation, if queries occur. Additionally, monitoring and recording the bath temperature is also recommended. The frequent use of IAPSO Standard Seawater is endorsed. To avoid the changes that occur in Standard Seawater, the use of the most recent batch is recommended. The bottles should also be used in an interleaving fashion as a consistency check within a batch and between batches.

[3] Developments of reference materials for nutrients are underway that will enable improvements in the relative accuracy of measurements and clearer definition of the performance of laboratories when used appropriately and the results are reported with the appropriate meta-data.

9 References

Armishaw, P. (2003) "*Estimating measurement uncertainty in an afternoon. A case study in the practical application of measurement uncertainty*." Accred Qual Assur, 8: pp. 218-224

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