RV *INVESTIGATOR*

HYDROCHEMISTRY DATA PROCESSING REPORT

Voyage:	IN2025_V06
Chief Scientist	Dr. William White
Voyage title:	The Coral Sea Frontier: Deep-sea biodiversity assessment of the Coral Sea Marine Park
Report compiled by:	Alicia Camac & Christine Rees

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Executive Summary

Voyage Objectives

This project conducted the first modern deep-water survey of benthic marine life in the southern and eastern Coral Sea Marine Park, focusing on two key ecological features: the Marion Plateau reefs and the Tasmantid Seamount Chain (200–3600 m). It explored the biodiversity of the northern Tasmantid Seamounts and the Kenn Plateau, which rise over 3000 m from the seabed, providing critical insights into regional marine ecosystems.

A suite of investigative tools—including towed cameras, eDNA sampling, CTDs, trawls, and sleds—was used to assess biodiversity patterns across ecological features and bioregions. The project evaluated endemicity of fishes and key invertebrates, and compared biodiversity between seamounts, atolls, continental slopes, and plateaus. It also assessed the effectiveness of extractive versus non-extractive sampling methods.

New seabed mapping was completed, particularly on the under-surveyed Marion Plateau. The findings supported the Australian Marine Parks' Marine Science Program by enhancing understanding of benthic communities and informing evidence-based management. Crucially, the data will contribute to the 2028 Coral Sea Marine Park Management Plan, especially for Special Purpose Zones and the Tasmantid Seamount Chain.

General Hydrochemistry Information

For this voyage, CTD samples were collected and analysed for nutrients, dissolved oxygen, and salinity by the on-board Hydrochemistry team. Please refer to Hydrochemistry output section for more detail on sample types and analyses. Additionally, Thermosalinograph (TSG) samples were continuously collected throughout the voyage, with on-board measurements of their salinity used to calibrate the ship's underway system.

Please cite the following manuscript when reporting or publishing data for silicate, phosphate, nitrate+nitrite (NO_x) and nitrite:

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.

If publishing ammonium data, please cite the following:

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

The final hydrology dataset, data processing report, analytical methods, related log sheets and processing notes can be obtained from the CSIRO data centre. Please visit CSIRO data trawler, should there be any inquiries on hydrology data please contact CSIRO data centre at NCMI_DataLibrarians@csiro.au.

Itinerary and Voyage track

Table 1: Voyage itinerary

	Depart	**Arrive**
Port	Brisbane	Brisbane
Date	10/10/2025	14/11/2025
Time	2000	0700

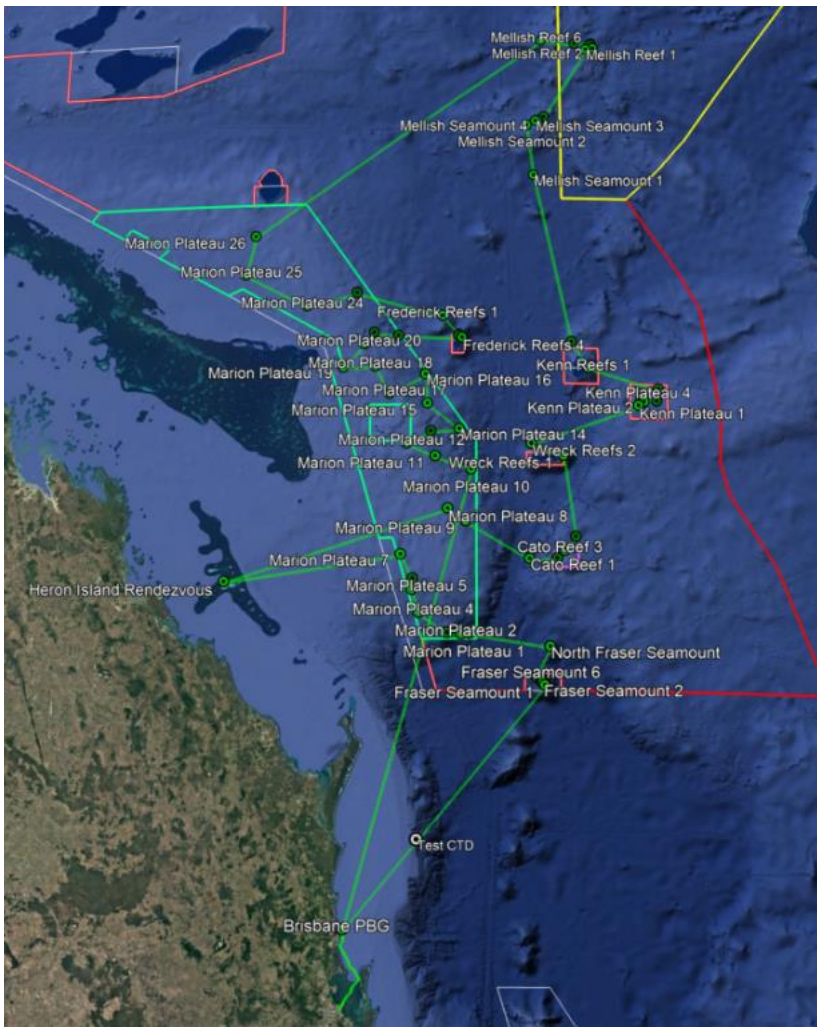


Figure 1. Voyage map of IN2025_V06.

Key personnel list

Table 2: Key Personnel list on IN2025_V06

Name	Role	Organisation
Dr. William White	Chief Scientist	CSIRO
Tegan Sime	Voyage Manager	CSIRO
Alicia Camac	Hydrochemist	CSIRO
Christine Rees	Hydrochemist	CSIRO

Sample Summary

Sample Type and Number Assayed

Table 3: Hydrochemistry sample type and analysis summary for IN2025_V06

Analysis	Instrument	Sample source/type	Number of samples
Nutrients	Seal AA3HR	Conductivity-Temperature-Depth (CTD)	369
Salinity	Guidline Autosal	Conductivity-Temperature-Depth (CTD) Thermosalinograph (TSG)	369 42
Dissolved oxygen (DO)	Scripps	Conductivity-Temperature-Depth (CTD)	369

CTD sample (Conductivity, Temperature, Depth)

Table 4: CTD summary for IN2025_V06

Rosette type	36
Niskin Bottle size	12 L
Number of deployments	41
Number of deployments sampled for hydrochemistry analyses	40
CTD sampling order	Dissolved Oxygen (DO) → Nutrients → Salinity
Sample bottle	DO: 140 mL calibrated glass iodine determination flasks with glass stopper Nutrient: 50 mL HDPE with screw cap lids Salinity: 200 mL volume OSIL bottles made of type II glass (clear) with disposable plastic insert and plastic screw cap
Sample log	CTD deployment paper log sheet and CAP Deployment Log Editor version 1.4.5
Sampling personnel (hydrochemistry)	Christine Rees and Alicia Camac
Sampling personnel (science party)	Cindy Bessey and Bruce Deagle as opposite shift CTD Leads and then occasionally Brodie O'Breza, Gemma Galbraith, Marco Turner and Alison Miller came to assist.

Thermosalinograph sample (TSG)

Table 5: TSG summary for IN2026_V06

TSG source	Instrument clean seawater line supplying the pCO2 instrument in the underway laboratory
Sample bottle	200 mL volume type I (clear) borosilicate bottle with rubber liner lid and aluminium crimp cap
Sample log	TSG Samples Event Logs (available on CSIRO data trawler)
Sampling personnel (hydrochemistry)	Christine Rees and Alicia Camac
Sampling personnel (science party)	NA

Data Processing Overview

The sample meta-data, measured bottle salinity results, dissolved oxygen assay results and the nutrient assay raw data are processed using the CSIRO-developed program HyPro. This processing generates the final hydrology dataset. An overview of this process is illustrated below (fig.2).

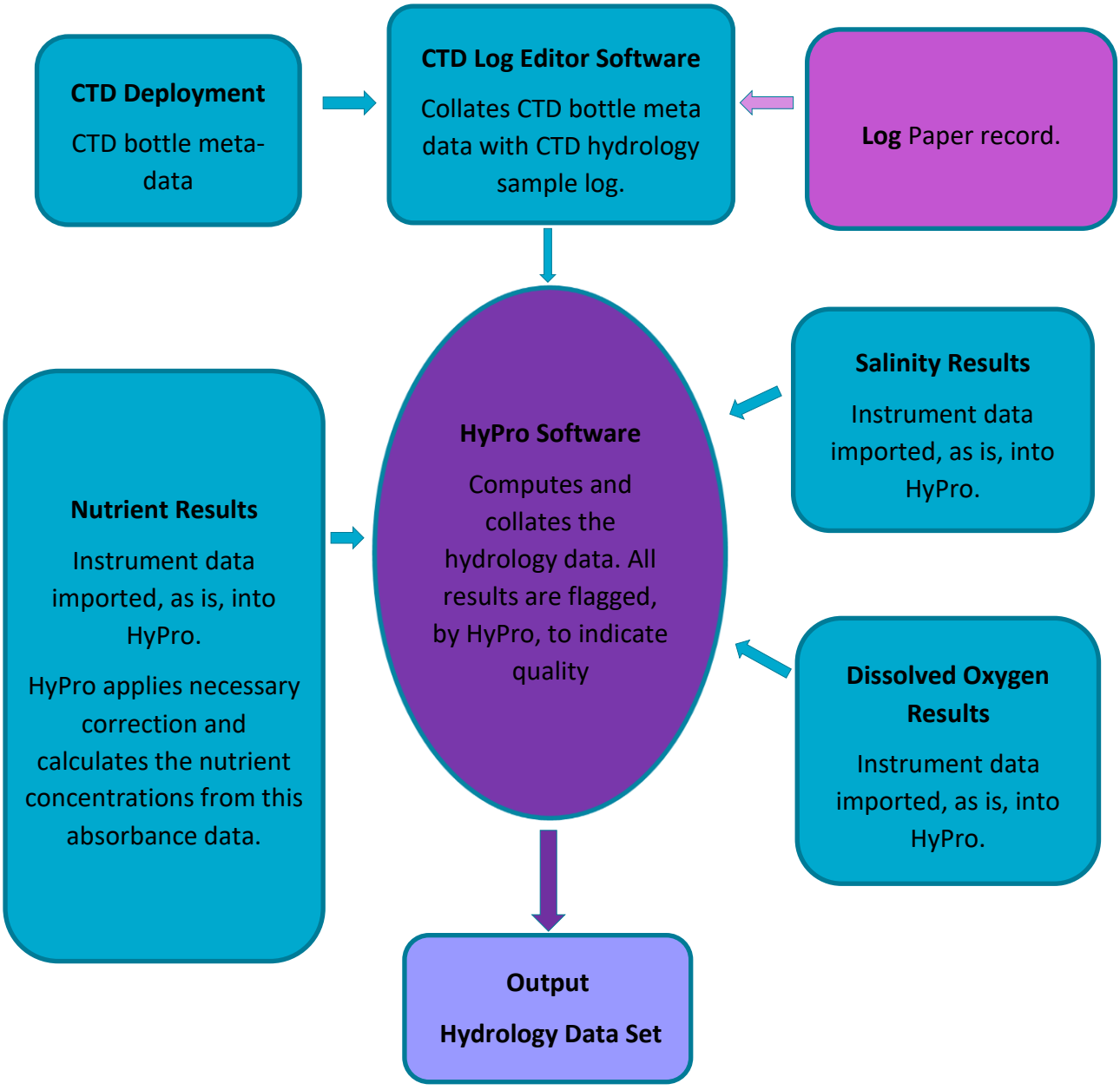


Figure 2. Conventional Hydrology Data Processing Flow Diagram.

Salinity

Salinity Measurement Parameters

Table 6. Salinity Measurement Parameters

Details	
HyPro Version	5.7
Instruments	Guildline Autosal S/N 72873 and 74680. Bath temperature 24.0°C
Software	Ocean Scientific International Ltd (OSIL) Data Logger ver 1.2
Hydrochemistry Methods	Sampling: Salinity - WI_Sal_001, TSG – WI_Sal_004 Analysis: SOP 006
Accuracy	± 0.001 practical salinity units (PSU)
Reference Material	OSIL IAPSO – Batch P167 & P168
Sample Container	CTD: 200 mL volume OSIL bottles made of type II glass (clear) with disposable plastic insert and plastic screw cap. TSG: 200 mL volume type I (clear) borosilicate bottle with rubber liner lid and aluminium crimp cap.
Sample Storage	Stored in salinometer lab for minimum of 8 hrs for temperature equilibration before measurement
Analyst	Alicia Camac

Salinity Method

Salinity samples were measured on a Guildline Autosal 8400B, operated in accordance with the manufacturer's technical manual. The measured value is recorded with an OSIL data logger.

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

Before each lot of sample measurements, the Autosal is calibrated with standard seawater (OSIL, IAPSO) with a known K_{15} ratio. A fresh bottle of OSIL standard is used for each calibration, and calibration is performed at least once per run.

Method summary: The salinity sample is collected in a 200 mL glass bottle. The bottle is rinsed three times with sample, then filled from the bottom, via a polytetrafluoroethylene (PTFE) straw, until

overflowing. The bottle is removed from the straw, and the sample is decanted to allow a headspace of approximately 25 cm^3. A dry plastic insert is fitted, the bottle inverted and rinsed with ultra-pure water, wiped dry, capped and stored upside down until analysis. To measure, the salinometer cell is flushed three times with the sample and then measured after the third and fourth flush. The OSIL data logger software captures the conductivity ratio and calculates the practical salinity.

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

CTD Salinity vs Bottle Salinity

For this voyage, the difference between the unprocessed (uncorrected) CTD value and the measured bottle value is generally less than 0.02 PSU. The larger differences are often observed in shallow samples, where sudden changes in the thermohaline profile occurs. Occasionally, these discrepancies may also be attributed to mismatches between the CTD downcast and upcast profiles. CTD sensor data were recorded on the downcast, while bottle samples were collected on the upcast.

The unprocessed CTD values are adjusted (corrected) by DAP using the salinity bottle results. The corrected values are not reported in the hydrology set. Please refer to IN2025_V06 CTD data on CSIRO marlin metadata system for corrected sensor data.

OSIL Salinity Standard

For each salinity analysis conducted on this voyage, the instrument was calibrated with OSIL standard seawater, lot P167 (PSU = 34.995) and/or P168 (PSU = 34.997).

The mean measured value for the P168 OSIL standard seawater for CTD's 6 – 41 & TSG samples was:

Mean = 34.9971 PSU SD = 0.0002 n = 15

The mean measured value for the P167 OSIL standard seawater for CTD's 1 – 5 was:

Mean = 34.9953 PSU SD = 0.0001 n = 3

Dissolved Oxygen

Dissolved Oxygen Measurement Parameters

Table 7. Dissolved oxygen measurement parameters.

Details	
HyPro Version	5.7
Instrument	Scripps Automated Photometric Oxygen System
Software	Scripps Institution of Oceanography (SIO)
Hydrochemistry Methods	Sampling: WI_DO_001 Analysis: SOP 005
Titrant	50 g/L Sodium Thiosulphate
Primary standard	0.0123510 N and 0.0123519 N Potassium Iodate
Accuracy	± 0.5 µmol L^{-1}
Sample Container type	140 mL glass iodine determination flasks with glass stopper
Sample Storage	Samples stored in the hydrochemistry lab until analysis within 72 hrs.
Analyst	Christine Rees and Alicia Camac

Dissolved Oxygen Method

Scripps Institution of Oceanography (SIO) method is used for dissolved oxygen analysis. The method is based on the whole bottle modified Winkler titration of Carpenter (1965) with modifications by Culberson *et al* (1991).

Method summary: The sample is collected in an iodine determination flask of known volume. To the sample, 1 mL of manganese (II) chloride solution is added, followed by 1 mL of alkaline iodide solution. The flask is then stoppered and inverted at least 30 times. Dissolved oxygen in the sample oxidizes an equivalent amount of Mn (II) to Mn (IV) which forms a precipitate. Just before titration, the sample is acidified (1 mL 5M H_2SO_4), reducing Mn (IV) back to the divalent state and liberating an equivalent amount of iodine. The iodine is titrated with a standardised thiosulphate solution using a Metrohm Dosimat fitted with a 1 mL burette. The titration endpoint is determined by measuring the decrease in the UV absorption at 365 nm.

The thiosulphate solution is standardised by with a 10 mL aliquot of potassium iodate primary standard. A blank correction is also determined from the difference between two titres of consecutive additions of 1 mL aliquots of potassium iodate to the same blank sample. The standardisation is conducted at least once every 24 hours, when samples are being assayed.

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

CTD Dissolved Oxygen vs Bottle Dissolved Oxygen

For this voyage, the difference between the unprocessed (uncorrected) CTD value and the measured bottle value is generally less than 17 µmol L^{-1}. The larger differences are often observed in shallow samples, where sudden changes in the thermohaline profile occurs. Occasionally, these discrepancies may also be attributed to mismatches between the CTD downcast and upcast profiles. CTD sensor data were recorded on the downcast, while bottle samples were collected on the upcast.

The unprocessed CTD values are adjusted (corrected) by DAP using the dissolved oxygen bottle results. The corrected values are not reported in the hydrology set. Please refer to IN2025_V06 CTD data on CSIRO marlin metadata system for corrected sensor data.

Dissolved Oxygen Instrument titrant: thiosulphate normality and blank correction

The variation in thiosulphate concentration remains within the QC parameter of less than 0.0005 N between standardisations. The blank correction, which accounts for oxidisable species in the reagents and in the Milli-Q water that is added to the KIO_3 aliquot before the titration, is used in the calculation of the thiosulphate normality.

The mean normality of first thiosulphate batch and blank for CTD's 1 - 24 were:

Thiosulphate Mean: 0.197830 N SD: 0.000501 n = 16

Blank Mean: 0.000705 N SD: 0.00230 n = 16

The mean normality of second thiosulphate batch and blank for CTD's 25 - 41 were:

Thiosulphate Mean: 0.201592 N SD: 0.000094 n = 5

Blank Mean: 0.001012 N SD: 0.000112 n = 5

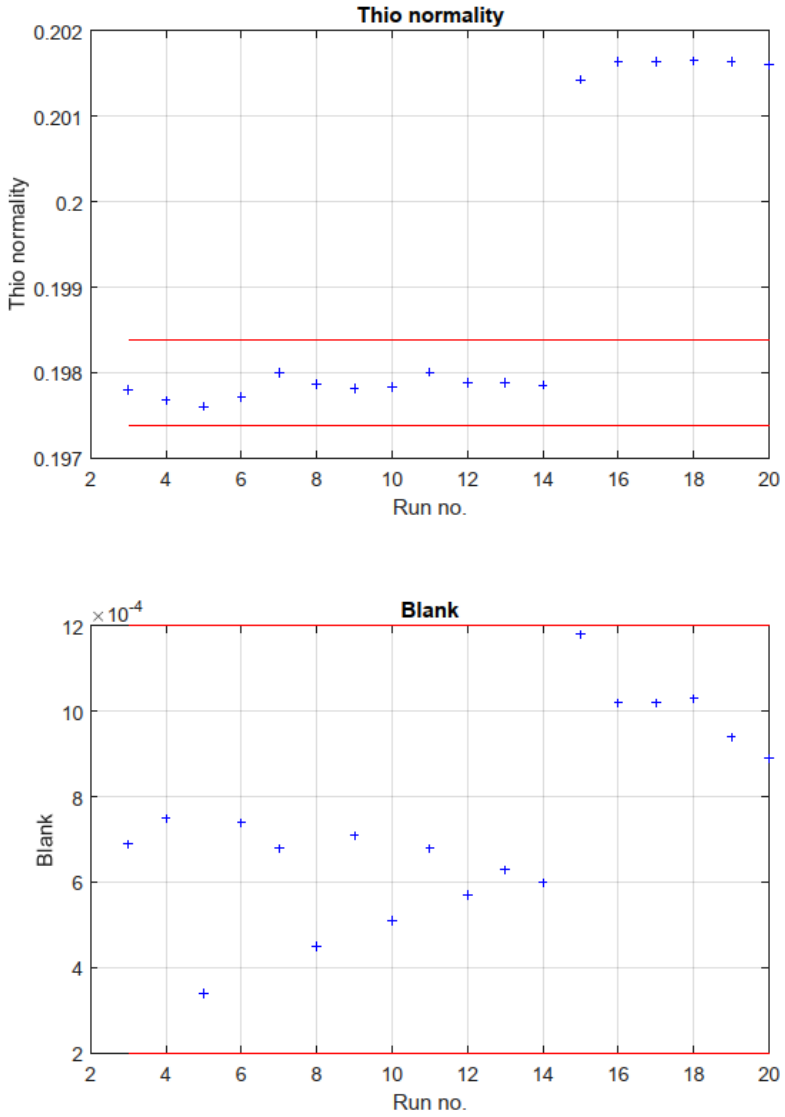


Figure 3. Thiosulphate normality and blank over the voyage IN2025_V06. Noting the thiosulphate solution was changed on run no oxy015, CTD 25.

Nutrients

Nutrient Measurement Parameters

Table 8. Nutrient measurement parameters analysed with Seal AA3HR segmented flow analyser. All instrument parameters, reagent batches, and instrument events are logged for each analysis run. This information is available on request.

Details					
Instrument	Seal AA3HR segmented flow analyser				
HyPro version	5.7				
Operating Software	AACE 7.10				
Hydrochemistry Sampling Method	WI_Nut_001				
Hydrochemistry analysis method	SOP001	SOP002	SOP003	SOP003	SOP004
Nutrients analysed	Silicate (SiO_4^{4-})	Phosphate (PO_4^{3-})	Nitrate + Nitrite (NO_x)	Nitrite (NO_2^-)	Ammonium (NH_4^+)
Top concentration (µmol L^{-1})	112.0	3.0	36.4	1.4	2.0
Method detection limit (MDL) (µmol L^{-1})	0.2	0.02	0.02	0.02	0.02
Stock standards	Made on 20th of August 2025 and prepared for open ocean concentration in 1L HDPE bottle				
Intermediate standards	Prepared every 96 hours in 30 mL polypropylene tubes. Reused after acid wash with 10% hydrochloric acid solution.				
Working standards	Prepared every 72 hours in 30 mL polypropylene tubes. Reused after acid wash with 10% hydrochloric acid solution.				
Reference Material	KANSO RMNS lot CR and CP				
Sample Container	CTD: 50 mL HDPE with screw cap lids. Reused after acid wash with 10% hydrochloric acid solution.				

Sample Storage	< 6 hours at room temperature after collection or < 16 hours at 4°C after collection, samples returned to room temperature prior to analysis.
Sample preparation	No filtration.
Analysts	Christine Rees and Alicia Camac

Nutrient Methods

Nutrient samples are analysed using a Seal AA3HR segmented flow auto-analyser, equipped with 1 cm flow-cells for colorimetric measurements. JASCO FP2020 fluorescence detector was used for ammonium measurement.

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 660 nm.

Phosphate (SOP002): colourimetric, molybdenum blue method. Based on Murphy and Riley (1962) with modifications from the NIOZ-SGNOS[1] 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 880 nm.

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 magenta azo complex, and its absorbance is measured at 540 nm.

Nitrite (SOP003): colourimetric, naphthylenediamine method. As per nitrate method without the copper cadmium reduction column and buffer. Absorbance measured at 520 nm.

Ammonium (SOP004): fluorescence, ortho-phtaldiadehyde method. Based on Kérouel and Aminot (1997). 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 460 nm after excitation at 370 nm.

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

[1] Royal Netherlands Institute for Sea Research – Study Group on Nutrient Standards.

HyPro Processing Summary for Nutrients

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

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

Suspect calibration points are given less weight when fitting the calibration curve. The cut-off limits for acceptable calibration data are as followed:

- ± 0.5% of the concentration of the top standard for silicate and nitrate + nitrite (as per World Ocean Circulation Experiment)
- 0.02 µmol L^{-1} for phosphate, nitrite, and ammonium

HyPro classifies data quality as good, suspect, or bad and flags the results accordingly. The Flag key can be found in Appendix, Data Quality Flag Key. Missing or suspect nutrient data is listed in Appendix, Missing or Suspect Nutrient Data.

Table 9. HyPro 5.7 Processing Parameters. All instrument parameters and reagent batches and operation events are logged for each analysis run. This information is available on request.

Result Details	Silicate	Phosphate	Nitrate + Nitrite	Nitrite	Ammonium
Data Reported as	µmol L^{-1}	µmol L^{-1}	µmol L^{-1}	µmol L^{-1}	µmol L^{-1}
Calibration Curve fit	Linear	Linear	Linear	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
Refractive Index Blank (RIB) correction	N	N	N	N	N
Peak window defined by	HyPro	HyPro	HyPro	HyPro	HyPro

Carryover correction	Y	Y	Y	Y	Y
Baseline drift correction	Y	Y	Y	Y	Y
Sensitivity drift correction	Y	Y	Y	Y	Y
Data Adjusted for RMNS variance	N	N	N	N	N
Medium of Standards	Low nutrient seawater (LNSW) collected in June 2024. Sub-lot passed through a 5-micron filter (filtered in August 2025) and stored in 20 L carboys in the hydrochemistry laboratory at 20°C.				
Medium of Baseline	18.2 MΩ water. Dispensed from the Milli-Q IQ 7010 system.				
Duplicate samples	CTD: Niskin fired at the greatest depth for each CTD deployment were analysed in duplicate. Single samples were analysed for remaining depths.				
Note	The reported data is not corrected to the RMNS. Per deployment RMNS data is provided in supporting document.				

Accuracy - Reference Material for Nutrient in Seawater (RMNS)

Descriptive statistics are used to ascertain the accuracy and precision of the analysis from the repetitive measurement of the RMNS for silicate, phosphate, NOx, nitrite and ammonium in seawater.

For this voyage, Japanese KANSO certified RMNS lot CP was assayed in triplicates in each run to monitor accuracy (Table 10). RMNS CR was only analysed in the characterisation and then randomly throughout the voyage as additional accuracy monitoring at the start of the voyage without samples and specifically for checking Ammonia. An internal bulk quality control (BQC) was also analysed in each analysis run which covers all 5 nutrients.

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

KANSO publishes the RMNS nutrient values in µmol kg^{-1}. These are converted to µmol L^{-1} at 21°C. NO_x is derived by summing the NO_3 and NO_2 values.

Table 10. RMNS certified concentrations ± expanded uncertainty (U) at 21°C. Units: µmol L^{-1}

RMNS	Silicate	Phosphate	Nitrite	Nitrate + Nitrite	Ammonium
Lot CP	62.57 ± 0.31	1.80 ± 0.02	0.32 ± 0.07	25.71 ± 0.38	N/A
Lot CR	14.34 ± 0.31	0.40 ± 0.01	0.99 ± 0.07	6.59 ± 0.24	0.97 ± 0.15

Table 11. RMNS CP statistics for of this voyage. Units: µmol L^{-1}

RMNS CP	Silicate	Phosphate	Nitrite	Nitrate + Nitrite	Ammonium
Mean	62.84	1.813	0.344	25.73	N/A
Standard deviation	0.23	0.008	0.006	0.06	N/A

Table 12. RMNS CR statistics for of this voyage. Units: µmol L^{-1}

RMNS CR	Silicate	Phosphate	Nitrite	Nitrate + Nitrite	Ammonium
Mean	14.23	0.409	1.030	6.49	0.97
Standard deviation	0.07	0.004	0.008	0.02	0.009

RMNS plots

The measured RMNS values for each nutrient analysis run on this voyage is shown in plots below. The green, pink, and red contour lines represent 1%, 2% and 3% or 1*MDL, 2*MDL and 3*MDL (MDL = 0.02 µmol L^{-1}) deviation from the RMNS certified mean value. The blue line is the manufacturer's expanded uncertainty of the certified value. The measured RMNS values per CTD deployments are provided in supporting document available on CSIRO data trawler.

For this voyage, results for RMNS lot CP and CR showed high agreement with certified values, with calculated results falling within the expanded uncertainty. The plot of RMNS lots CP and CR analysed in each channel are shown in figure 4 to figure 8.

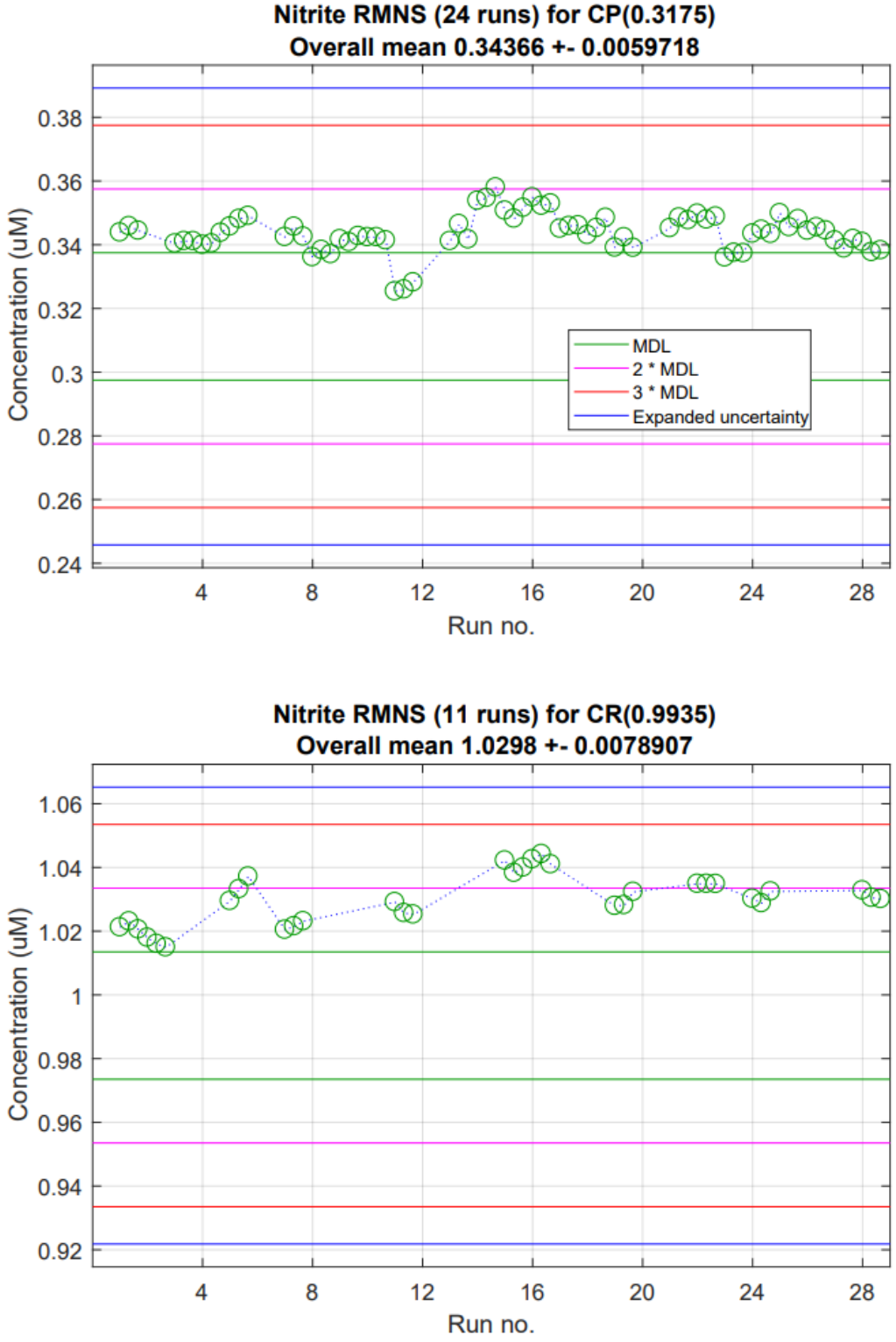
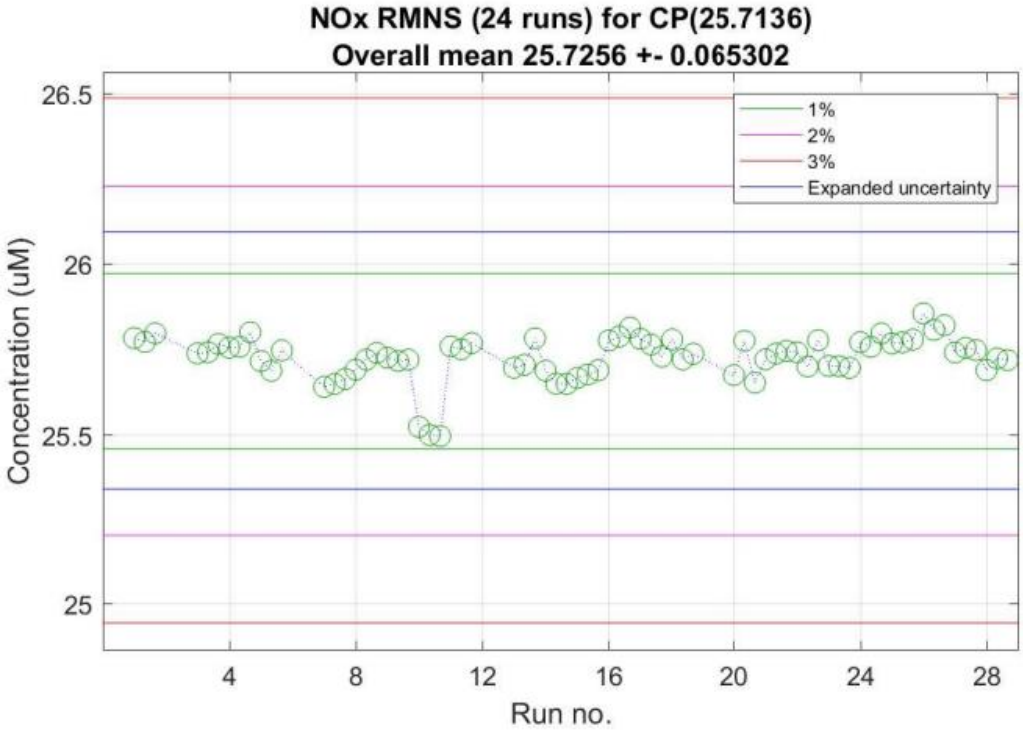


Figure 4. Nitrite RMNS lot CP and CR plot. Concentration in µmol L^{-1}.



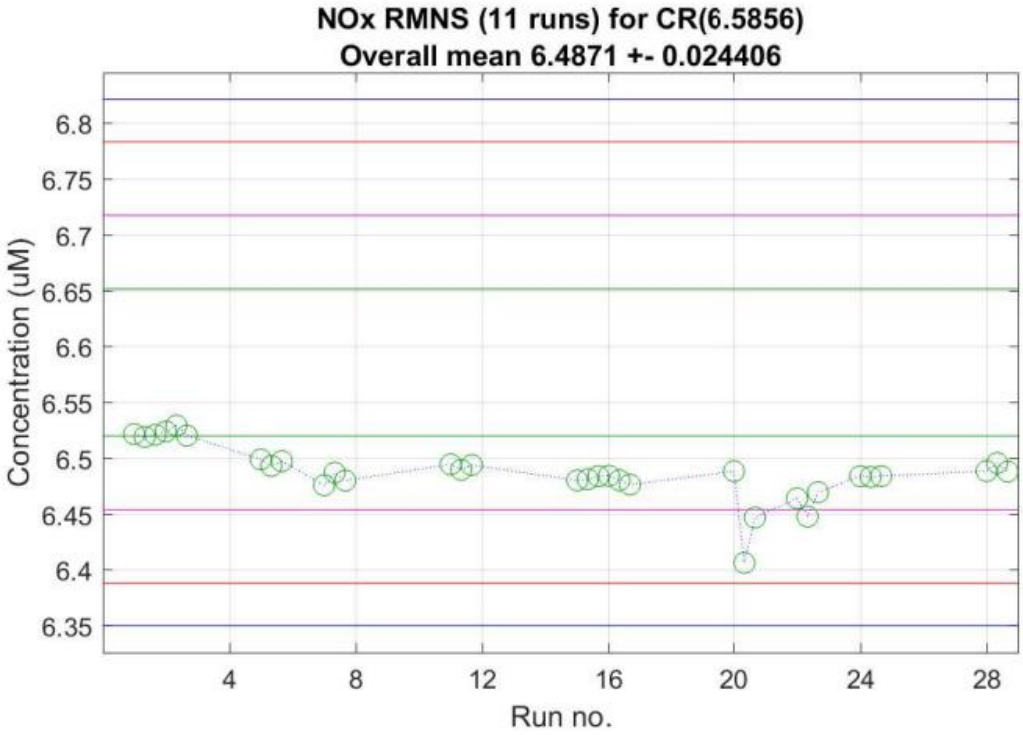
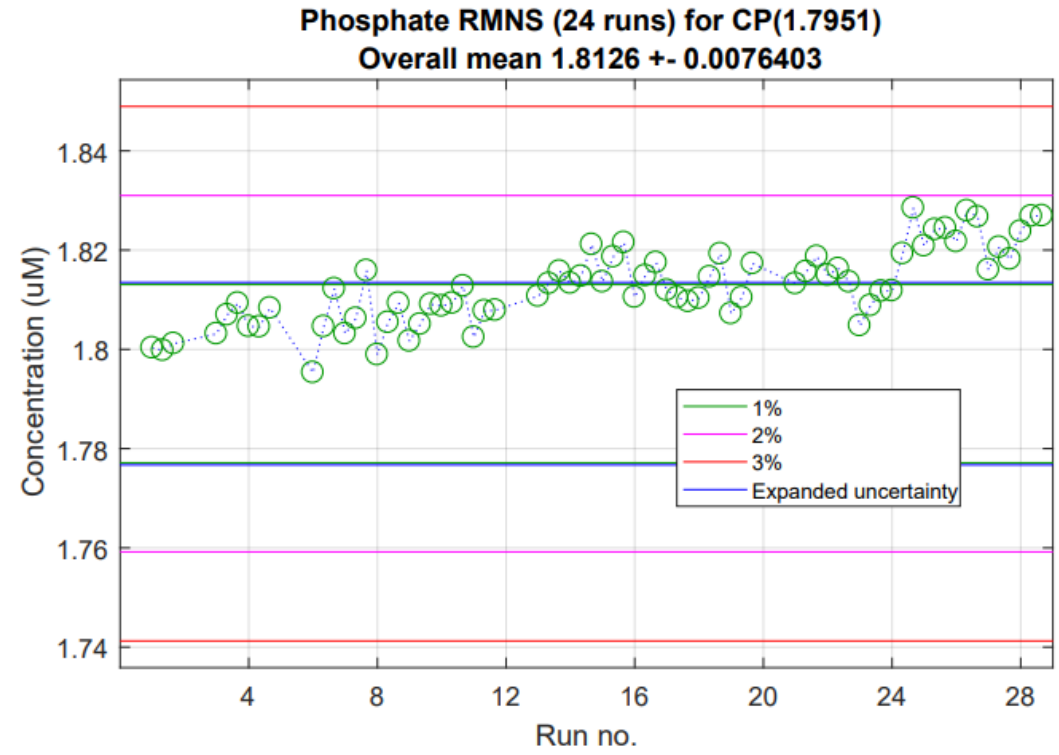


Figure 5. Nitrate + Nitrite (NOx) RMNS lot CP and CR plot. Concentration in µmol L^{-1}.



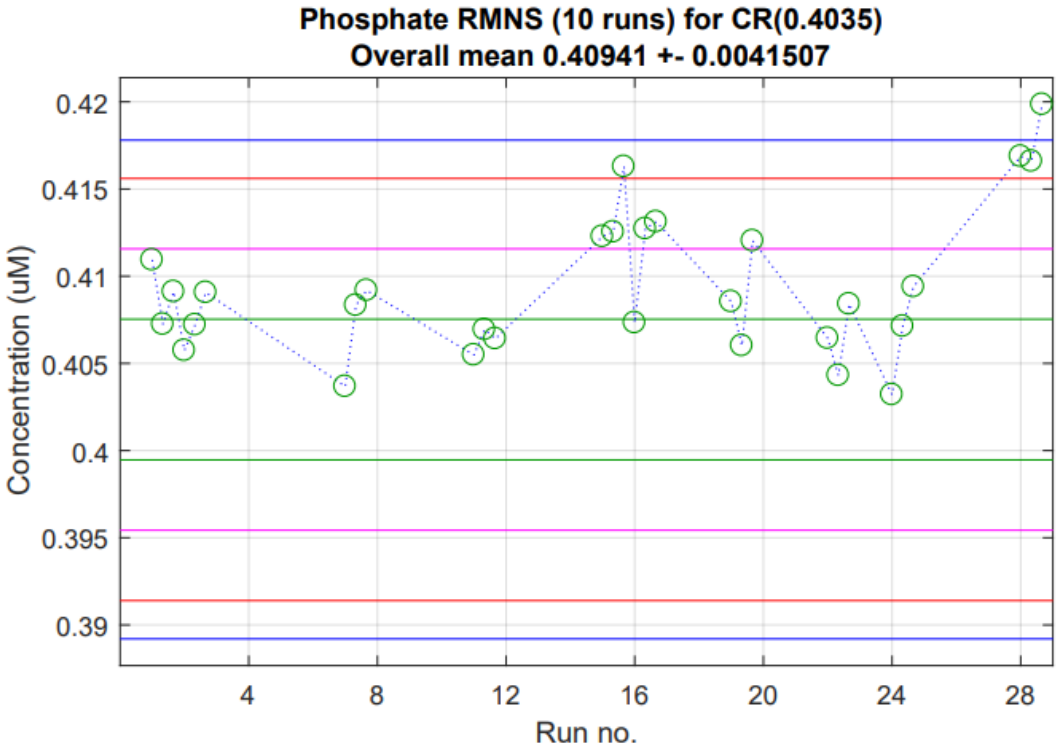


Figure 6. Phosphate RMNS lot CP and CR plot. Concentration in µmol L^{-1}.

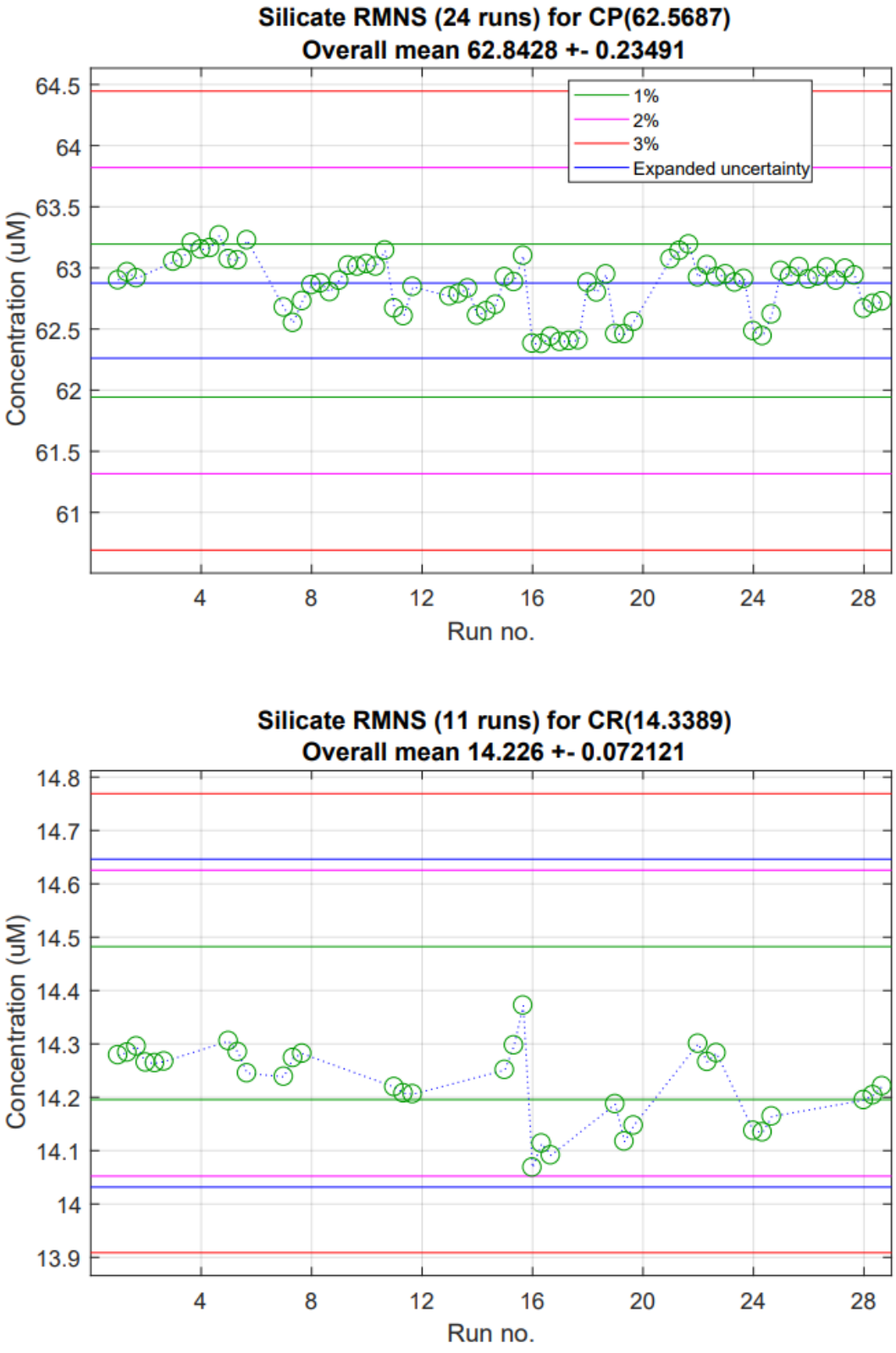


Figure 7. Silicate RMNS lot CP and CR plot. Concentration in µmol L^{-1}.

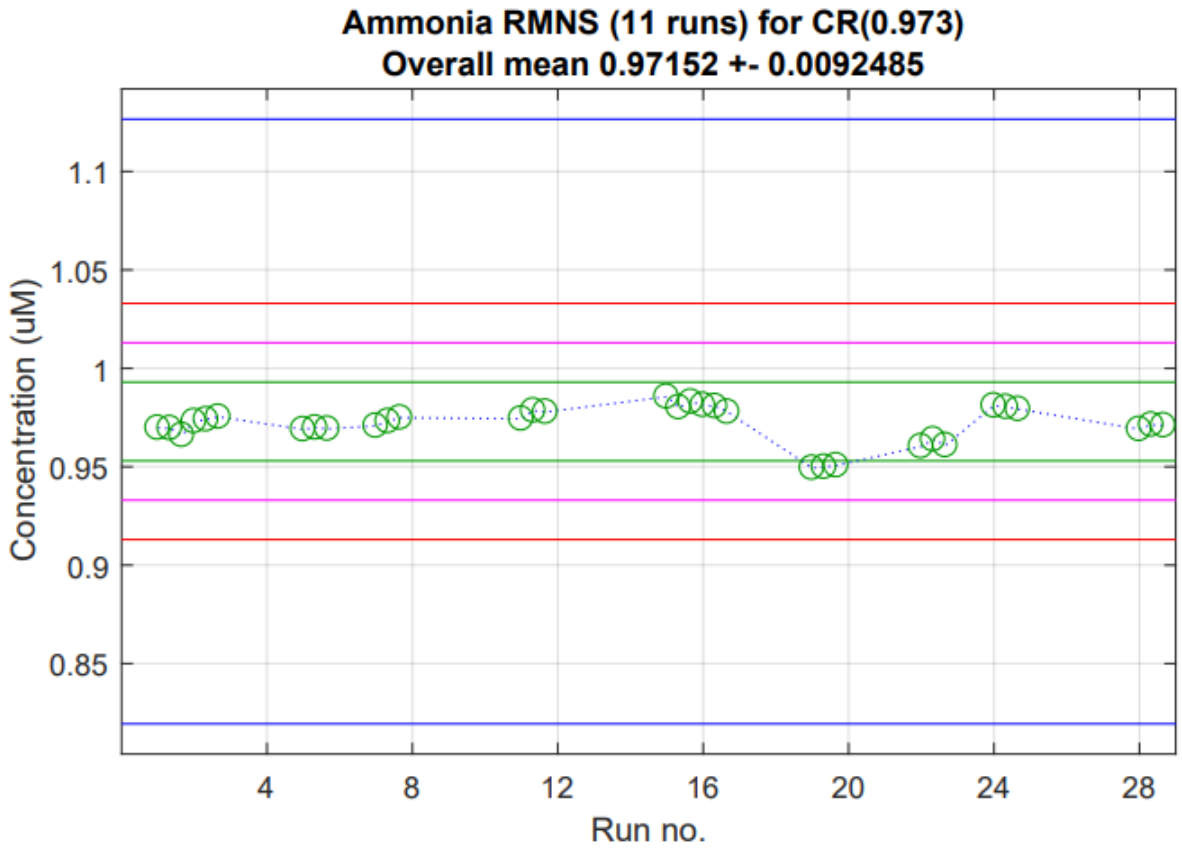


Figure 8. Ammonium RMNS lot CR plot. Concentration in µmol L^{-1}.

Accuracy - Bulk Quality Control (BQC)

For this voyage, Hydrochemistry's in-house Bulk Quality Control (BQC) sample was assayed in duplicates in each run to monitor accuracy and precision. The BQC has now been successfully used on almost every analysis run for over 5 years on both the ship and shore labs. It is intentionally created in an ideal concentration range which is not always achieved for all 5 nutrients from the purchased option. However, this sample is not certified so is used as an additional check but demonstrates a very consistent and reliable reference for all 5 nutrients.

Table 13. Expected BQC concentration for the 2025 September batch at 21°C ± SD. Concentration in µmol L^{-1}. Noting these values are based on the 36 sample results recorded in database so far.

	Silicate	Phosphate	Nitrite	Nitrate + Nitrite	Ammonium
BQC 2025	17.1 ± 0.06	1.55 ± 0.01	0.88 ± 0.003	8.25 ± 0.04	0.89 ± 0.01

Table 14. BQC statistics for of this voyage. Units: µmol L^{-1}

BQC	Silicate	Phosphate	Nitrite	Nitrate + Nitrite	Ammonium
Mean	17.21	1.54	0.89	8.11	0.910
Standard deviation	0.11	0.007	0.009	0.02	0.01

BQC plots

The measured BQC values for each nutrient analysis run on this voyage is shown in plots below. The green lines represent the (World Ocean Circulation Experiment) WOCE line. WOCE was the historic program which is now replaced by GO-SHIP. At the time this software created the WOCE line represented the accuracy of <1% of the top standard or 1*MDL, 2*MDL and 3*MDL (MDL = 0.02 µmol L^{-1}) deviation from the BQC mean value.

For this voyage, results for the BQC showed high agreement, with calculated results falling within the expected WOCE lines and providing a valuable reference material for all nutrients in a mid-concentration. The plots in each channel are shown in figure 9 to figure 13.

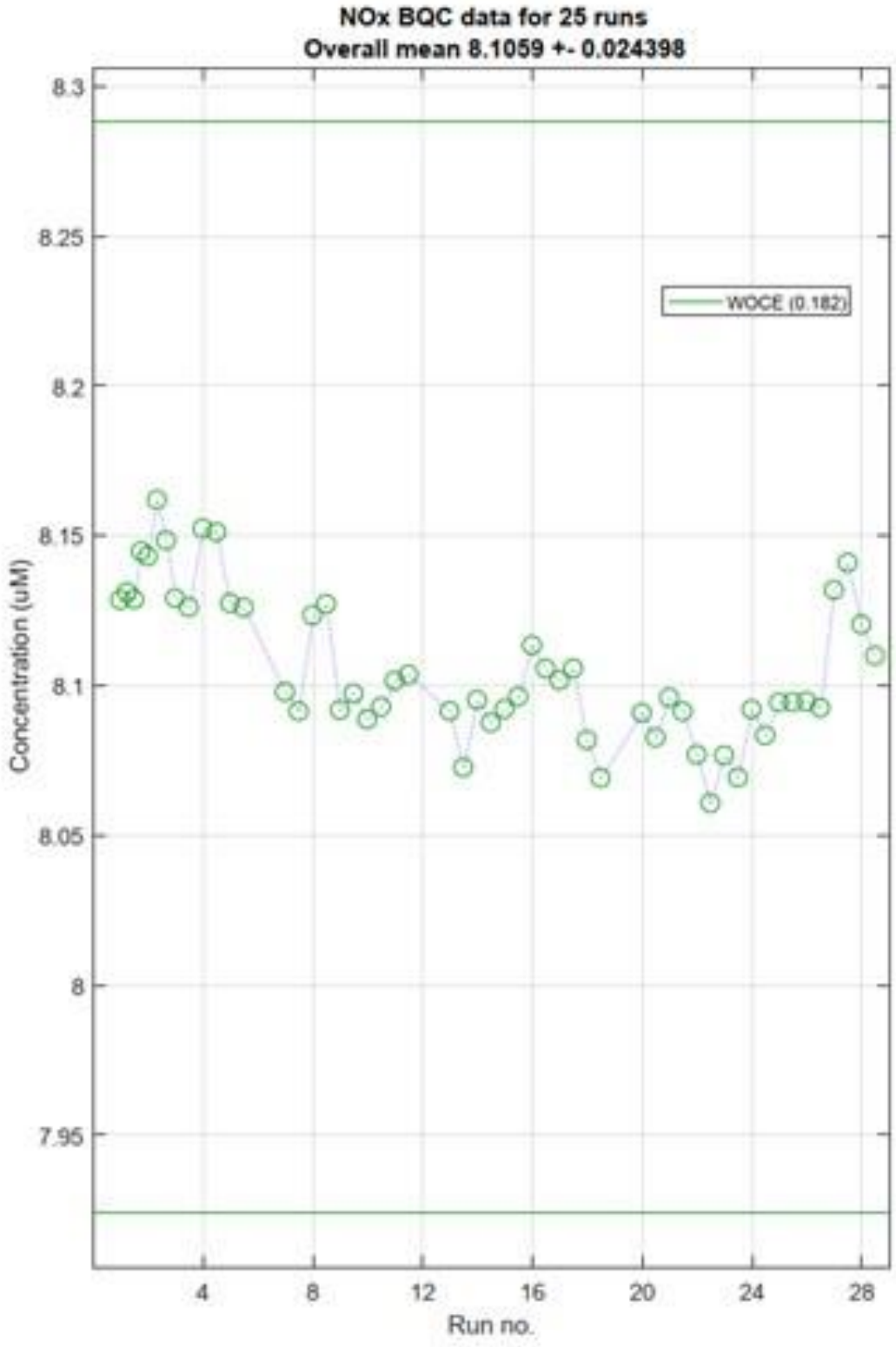


Figure 9. NO_X BQC plot. Concentration in µmol L^{-1}.

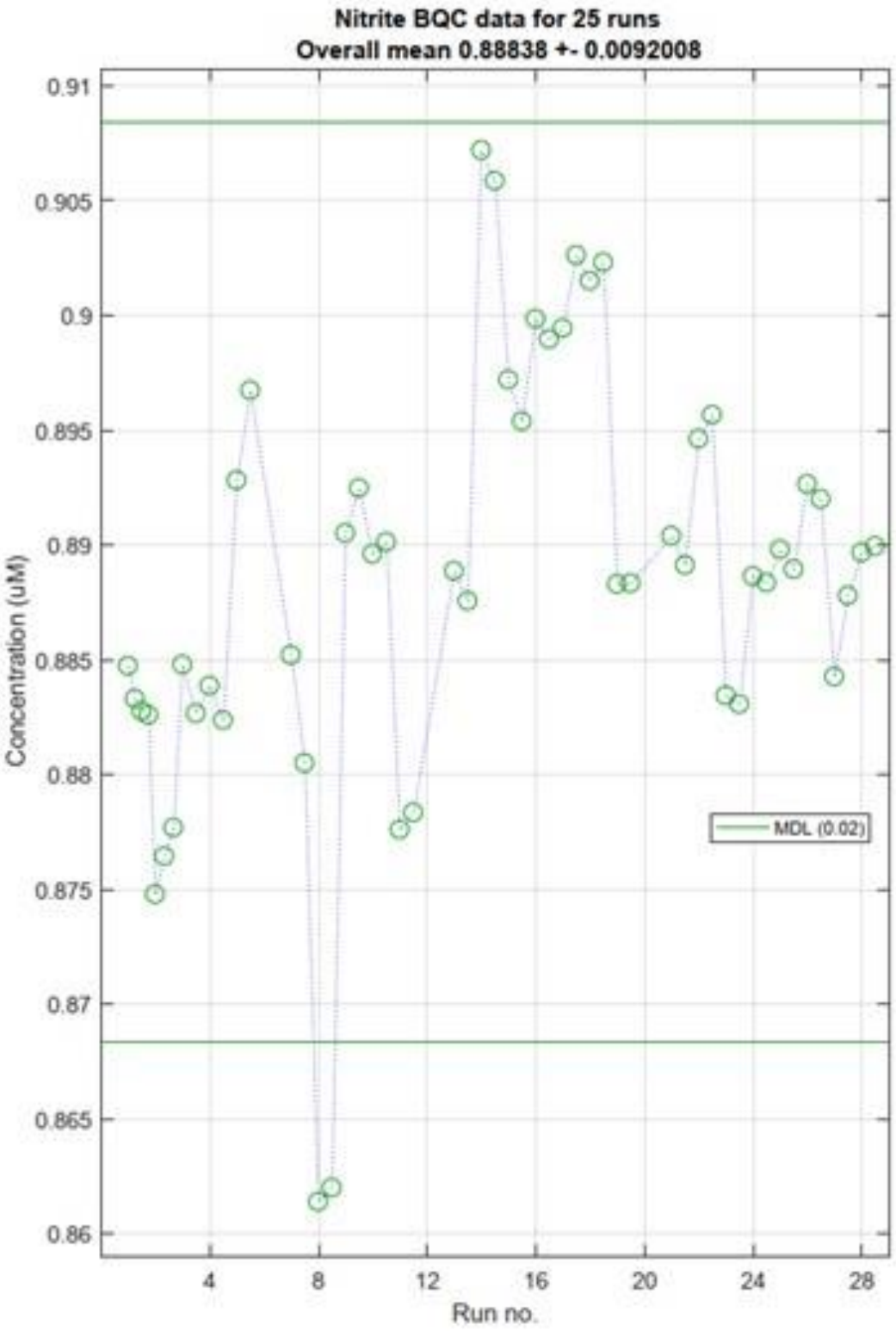


Figure 10. NO_2^- BQC plot. Concentration in µmol L^{-1}.

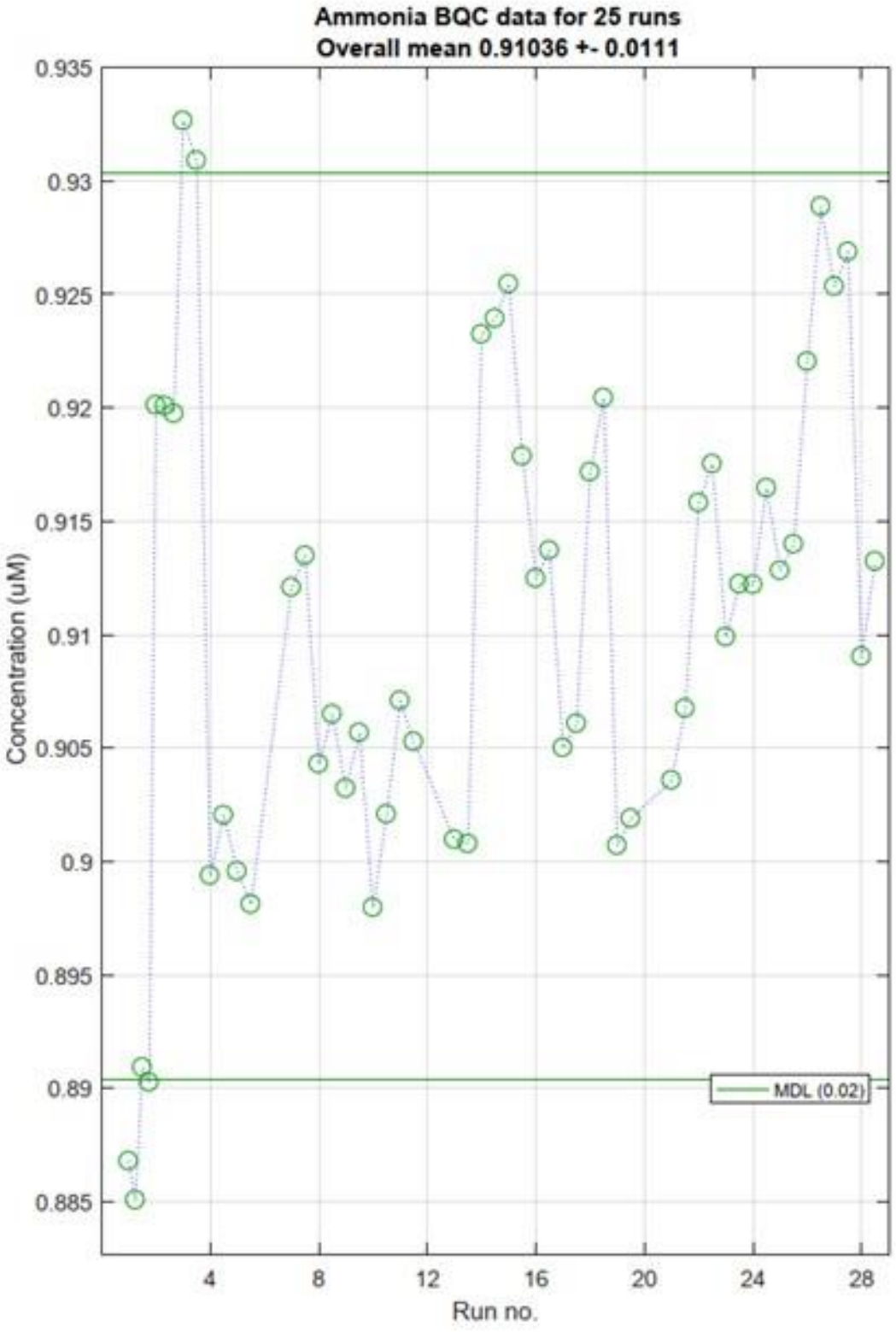


Figure 11. NH_4^+ BQC plot. Concentration in µmol L^{-1}.

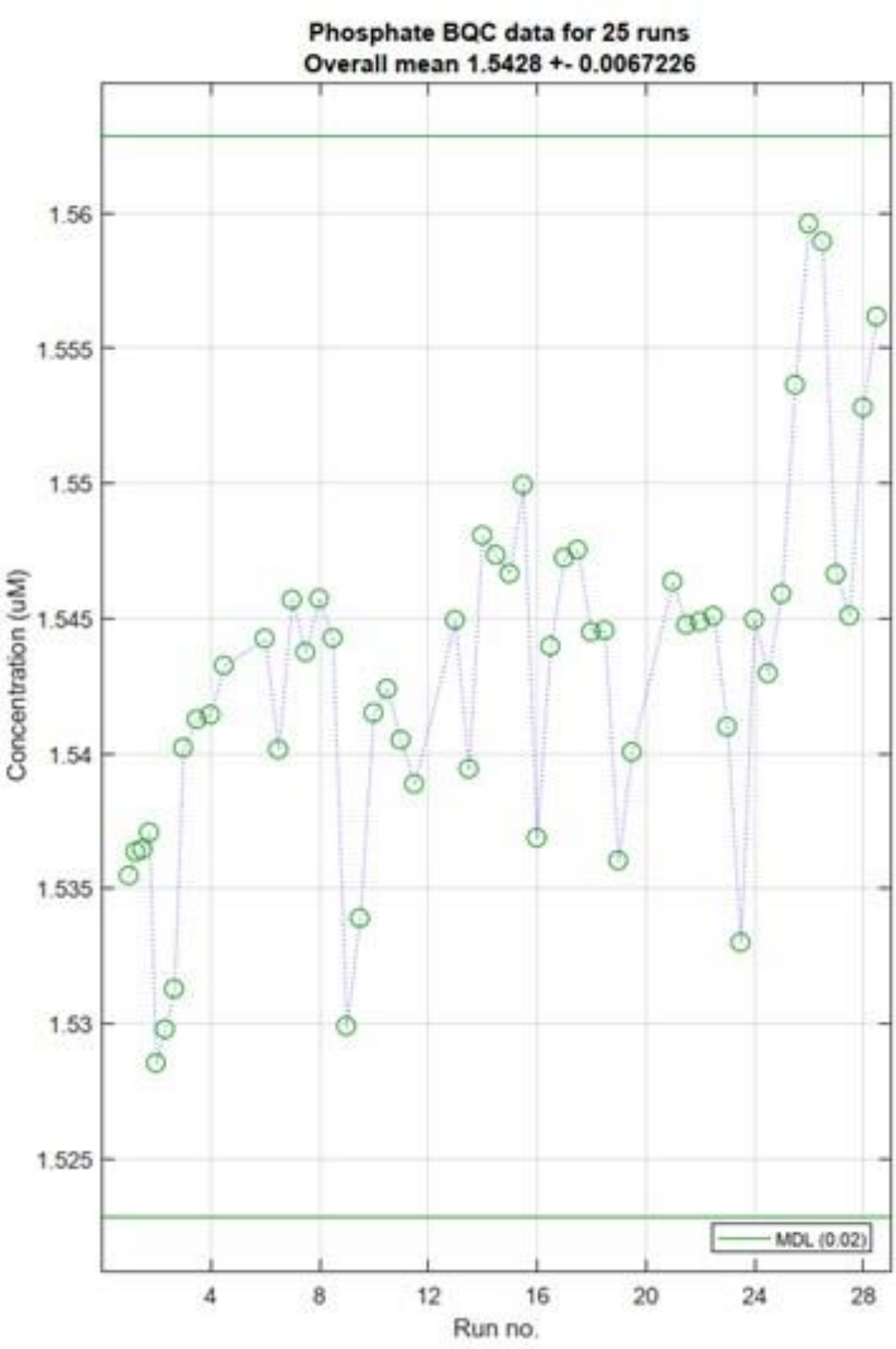


Figure 12. PO_4^{3-} BQC plot. Concentration in µmol L^{-1}.

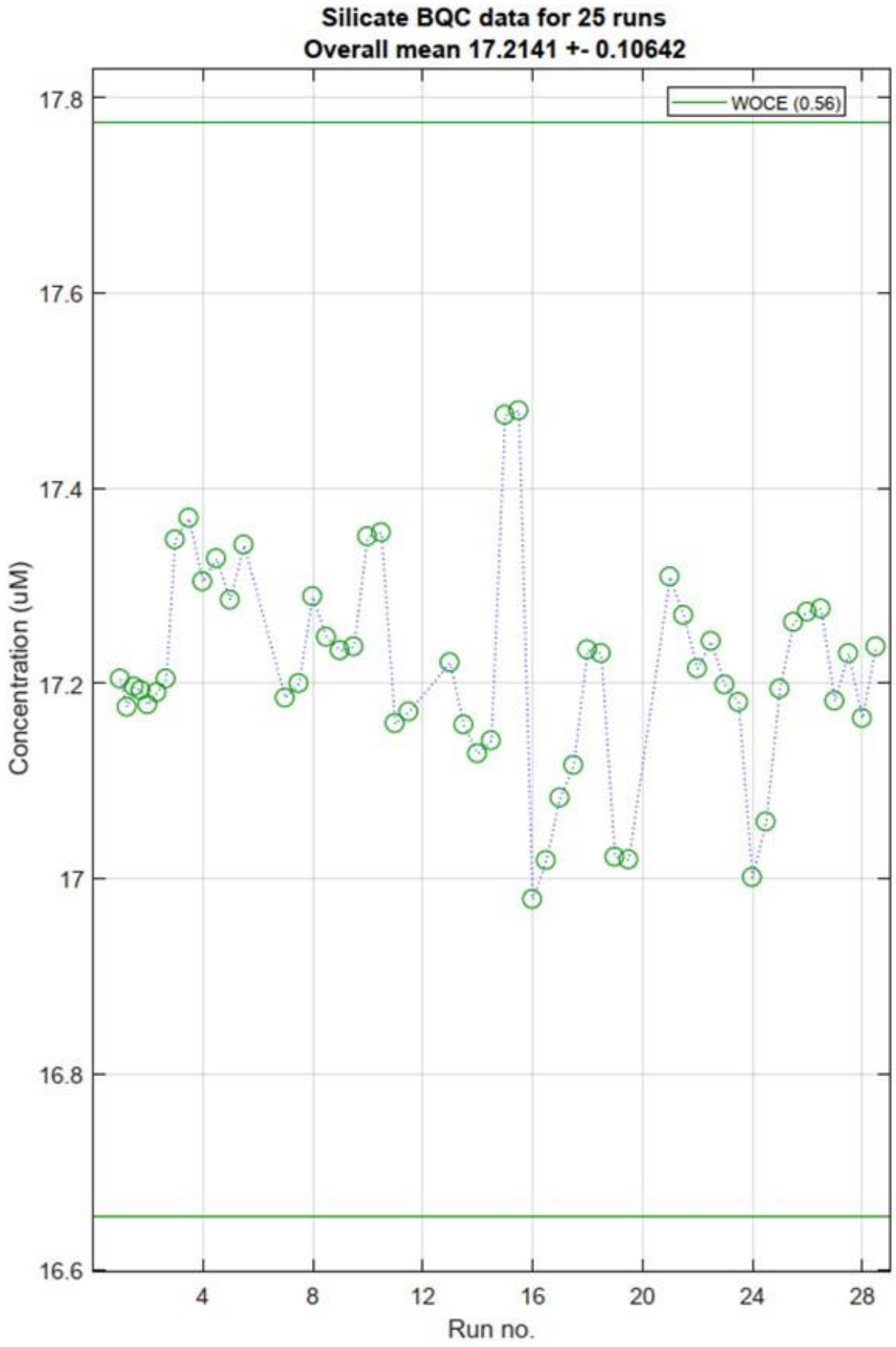


Figure 13. SiO_4^{4-} BQC plot. Concentration in µmol L^{-1}.

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 15. CSIRO Hydrochemistry nutrient analysis uncertainty values. Concentration in µmol L^{-1}.

Calculated Measurement Uncertainty at 1 µmol L^{-1}				
Silicate	**Phosphate**	**Nitrite**	**Nitrate + Nitrite**	**Ammonium**
± 0.017	± 0.024	± 0.140	± 0.019	± 0.30

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

Analytical Precision - Nutrients

The Method Detection Limit (MDL) provides a benchmark for assessing analytical precision at low nutrient concentrations. The nominal MDL is defined as three times the standard deviation (SD) of the Low Nutrient Sea Water (LNSW) measurements (National Association of Testing Authorities, 2013) and was previously determined by multiple measurements of LNSW on shore. During the voyage, each analytical run, had three LNSW samples (referred to as MDL samples) analysed, and the SD of these results were compared with the nominal MDL to confirm that the instrument was operating within expected precision limits. To characterise overall precision across the voyage, the mean of the within-run standard deviations was calculated for each nutrient.

Table 16. AA3HR auto analyser MDL statistics for this voyage. The mean standard deviation (precision) is calculated from every analytical run performed over the voyage. Units: µmol L^{-1}.

MDL	**Silicate**	**Phosphate**	**Nitrite**	**Nitrate + Nitrite**	**Ammonium**
Nominal MDL	**0.2**	**0.02**	**0.02**	**0.02**	**0.02**
Mean SD (precision)	0.014	0.001	0.001	0.002	0.001

Overall, the precision of the MDL (LNSW) demonstrated excellent analytical stability at low concentrations throughout the voyage.

Sampling Precision

Sampling precision is typically assessed using the CTD test deployment (CTD 1), in which all Niskin bottles are fired at the same depth. Each bottle is then sampled as a replicate for hydrochemistry nutrient, dissolved oxygen, and salinity analysis, providing a direct measure of sampling-related variability.

Nutrients

The mean and standard deviation of nutrients analysed during the test deployment are presented in Table 17. Sampling precision is considered acceptable when the standard deviation is equal to or less than the method detection limit (MDL), and no outliers are observed.

Table 17. Test cast deployment at 1000 dbar. Bottle rosette position (RP) 1-36. Units: µmol L^{-1}. *Note: At 1000 dbar the effective concentration of Nitrite and Ammonium is zero.

Replicates	Silicate	Phosphate	Nitrite	Nitrate + Nitrite	Ammonium
Mean	42.34	2.131	0.0154*	31.0697	0.0049*
Standard deviation	0.0498	0.0042	0.0019	0.02754	0.008

Duplicate nutrient samples are also collected from the greatest depth of subsequent CTD deployments. For nutrients analysis, the sampling precision is considered acceptable if the difference from the mean of duplicate measurements is less than the nominal method detection limit (Table 16). The exception is for NO_x (nitrate+nitrite), which uses the limit of 0.06 µmol L^{-1}. Duplicate samples that exceed the limit are flagged. These are tabulated in Appendix, Data Quality Flag Key.

Sampling precision for nutrients was within the specified criteria, demonstrating excellent stability throughout the voyage.

Dissolved Oxygen and Salinity

The mean and standard deviation of dissolved oxygen and salinity analysed during the test deployment are presented in Table 18. Sampling precision is considered acceptable when the standard deviation is equal to or less than the accuracy of the methods (tables: 6 & 7), and no outliers are observed.

Table 18. Test Cast deployment at 1000 dbar. Bottle rosette position (RP) 1-36.

Replicates	**Dissolved Oxygen** μmol L^{-1}	**Salinity** **PSU**
Mean	189.1815	34.43909
Standard deviation	0.416426	0.000661

Sampling precision for dissolved oxygen and salinity was within the specified criteria, demonstrating excellent stability throughout the voyage.

Temperature

Hydrochemistry lab and nutrient analyser

Ambient conditions in the hydrochemistry laboratory and on the segmented flow analyser were monitored at the following locations:

- Hydrochemistry lab temperature: positioned in close proximity to the autoanalyser
- Nutrient sample pump temperature: positioned on the pump tubes where nutrient samples and reagents are introduced into the analyser

Temperature data was measured using Ruuvi temperature logger and monitored in Grafana. A time series plot of hydrochemistry laboratory temperature plot throughout the voyage is shown below. A complete log of temperature is available upon request through CSIRO data centre. The average analyser pump temperature of the analyser during each nutrients analysis is provided in supporting documents available on CSIRO data trawler.

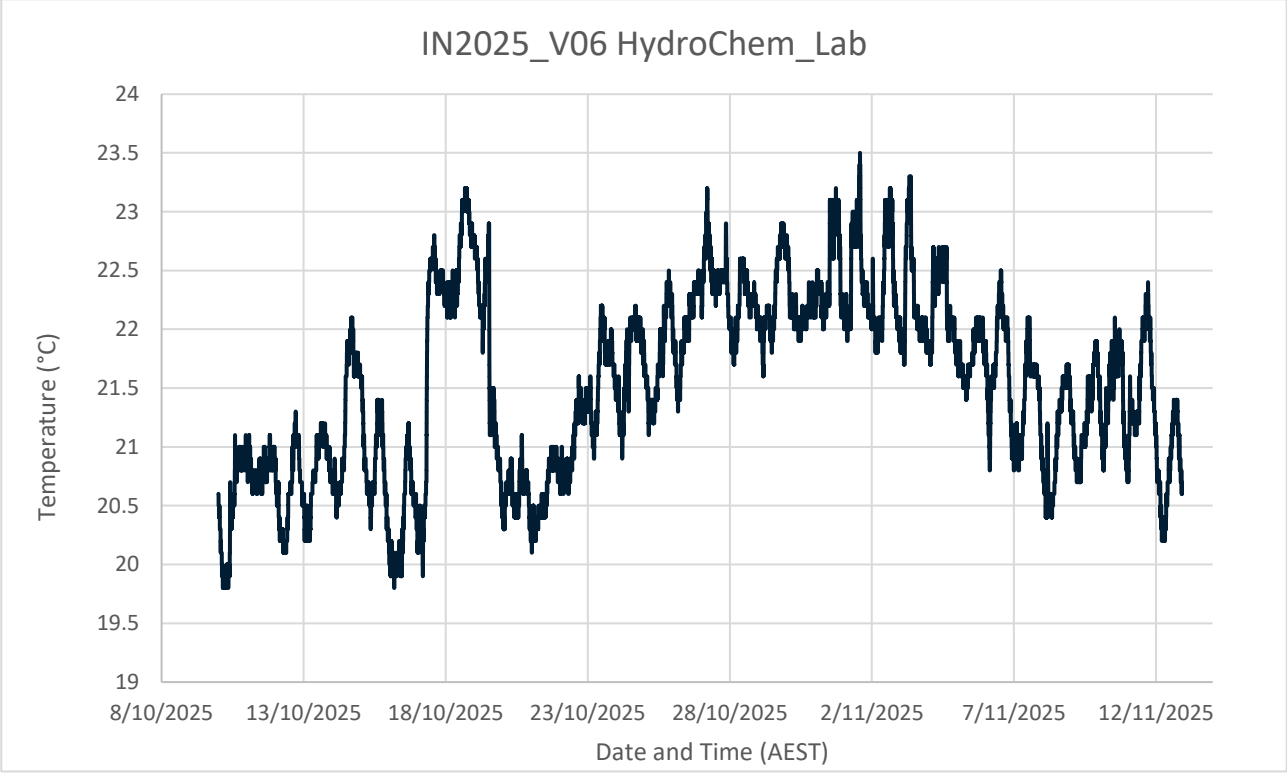


Figure 14. Hydrochemistry lab Ruuvi sensor; scale is 19°C to 24°C, mean: 21.5°C, SD: 0.8°C.

Salinity laboratory

Ambient conditions in the salinity laboratory were monitored using a Ruuvi temperature logger positioned near the area where sample crates were stored. Temperature data was recorded and

visualised in Grafana. A time series plot of salinity lab temperature throughout the voyage is shown below. A complete log of temperature is available upon request through CSIRO data centre.

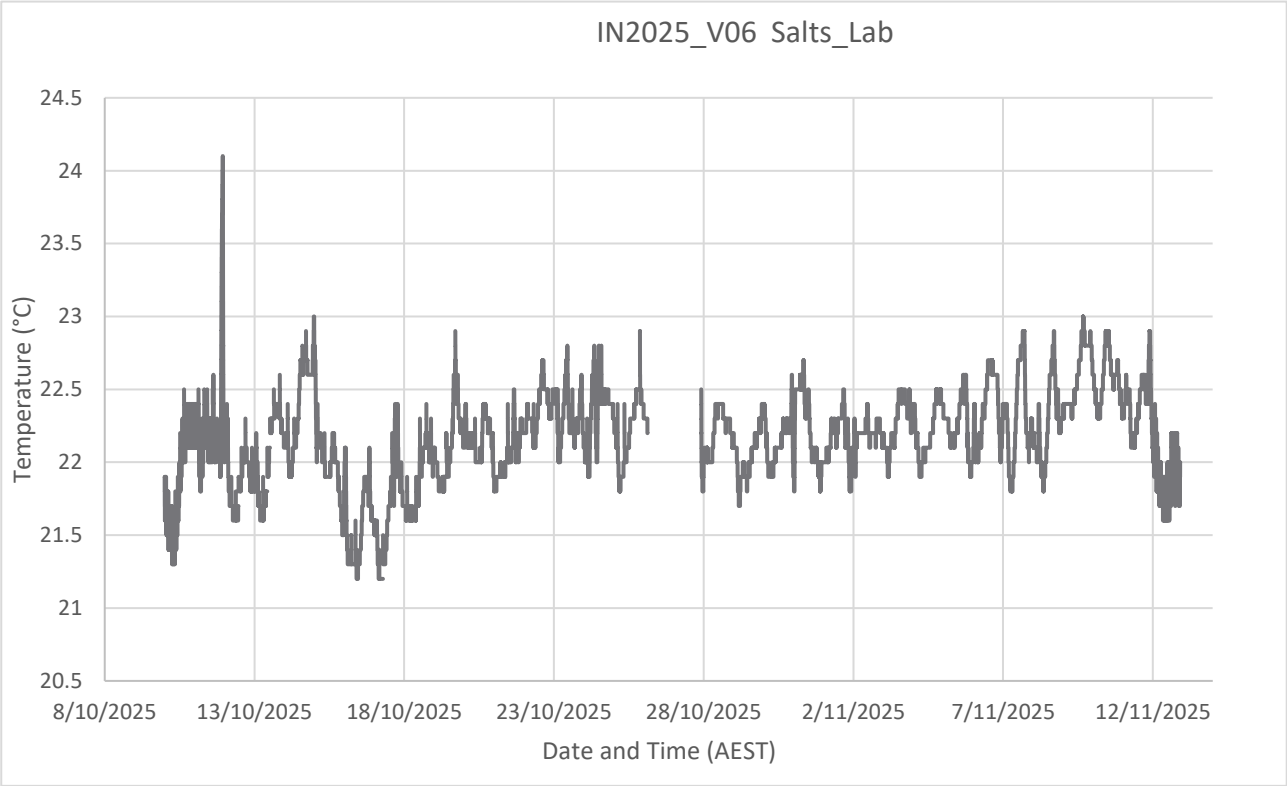


Figure 15. Salinity lab Ruuvi sensor; scale is 20.5°C to 24.5°C, mean: 22.2°C, SD: 0.3°C. Noting that the missing data in centre was from when the Ruuvi battery died.

Appendix

Salinity: Reference material used

OSIL IAPSO Standard Seawater	
Batch	P167 & P168
Use by date	21/2/26 & 1/12/2026
K_{15}	0.99988 & 0.99993
PSU	34.995 & 34.997

Nutrients: RMNS correction

The submitted nutrient results do NOT have RMNS corrections applied. The measured RMNS value per CTD deployment is provided in supporting document available on CSIRO data trawler under the supporting documents.

How to use the RMNS for correction

Ratio = Certified RMNS Concentration/Measured RMNS Concentration in each run

Corrected Concentration = Ratio x Measured Nutrient Concentration

How to use the RMNS for smoothing

Ratio = Average RMNS Concentration across voyage/Measured RMNS Concentration in each run

Corrected Concentration = Ratio x Measured Nutrient Concentration

Missing or Suspect Salinity Data

No salinity data was flagged as missing or suspect. All values passed checks against CTD sampling log notes, analyst observations, and depth-profile diagnostics

Missing or Suspect Dissolved Oxygen Data

No dissolved oxygen data were flagged as missing or suspect. All values passed checks against CTD sampling log notes, analyst observations, and depth-profile diagnostics

Missing or Suspect Nutrient Data

Data is flagged based on CTD sampling log notes, observations during analysis, and examination of depth profile plots (Appendix, Data Quality Flag Key).

Many samples in the .csv file are flagged 63 – below nominal detection limit, particularly for nitrite and ammonium. These nutrients are typically restricted to the upper few hundred metres of the water column and the chlorophyll maximum; at all other depths their concentrations are effectively zero. Because ammonium is analytically challenging to measure in seawater, true zero concentrations are often returned as slightly negative values. This occurs when the Milli-Q baseline becomes slightly contaminated by laboratory air, resulting in a baseline signal that is slightly above zero concentration. All nutrient samples flagged as below detection limit are excluded from this table.

CTD	RP	Analyte	Flag	Reason for Flag
9	54	SiO_4^{4-}	69	Data is suspect, duplicate is outside of set limits.

Data Quality Flag Key

Flag	Description	
0	Data is GOOD	
63	Nutrients only.	Data equal to or below nominal detection limit.
65	Data is SUSPECT.	Nutrients only: Absorbance peak shape, measured by the instrument, is marginally outside set limits.
69	Data is SUSPECT.	Duplicate data is outside of set limits (software). Data point is an outlier on the depth profile plot (operator). Tagged by software or operator
79	Data is SUSPECT.	Nutrients only. Measured Method Detection Limit (MDL) for the analysis run is greater than the nominal MDL. All samples in that run tagged.
129	Data is BAD.	Nutrients Only. Absorbance peak exceeds the maximum value that can be measured by the instrument.
133	Data is BAD.	Set by operator.
134	Data is BAD.	Nutrients Only. Absorbance peak shape of calibrant, measured by the instrument, is outside of set limits (software).

141	NO Data.	Used in netcdf results file. Not used in csv results file.

GO-SHIP Specifications

Salinity

Accuracy of 0.001 is possible with Autosal™ salinometers and concomitant attention to methodology. Accuracy with respect to one particular batch of standard Seawater can be achieved at 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].

Dissolved Oxygen

Target accuracy is that 2 sigma (standard deviation) 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.

$Si(OH)_4$

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

PO_4

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

NO_3

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

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.

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