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FOCUS/SWOT-ACC Data Processing and Inter-Calibration Report

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Author List: Senming Sheng; Annie Foppert; Helen Phillips; Steve Rintoul



Acknowledgment of Country

We acknowledge the Pakana and Palawa people of lutruwita, the traditional owners of the land upon which we live and work.

We pay respects to Elders past and present as the knowledge holders and sharers. We honour their strong culture and knowledges as vital to the self-determination, wellbeing and resilience of their communities.

We stand for a future that profoundly respects and acknowledges Aboriginal perspectives, culture, language and history.

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1. Abstract

The FOCUS/SWOT-ACC observing program collected coordinated multi-platform oceanographic observations in the Southern Ocean south of Tasmania during 2023–2024, including ship-based CTD, Triaxus, Seaglider, EM-APEX and BGC-Argo measurements. This report documents the additional processing, harmonisation and cross-platform inter-calibration undertaken to construct a consistent multi-platform data product. Ship-based CTD observations were used as the primary reference for temperature, salinity and dissolved-oxygen comparisons. Temperature and salinity offsets were evaluated using matched profiles within hydrographically stable comparison layers, with corrections applied only where platform-wide offsets could be distinguished from measurement uncertainty and environmental variability. A systematic temperature and salinity offset was identified and corrected for Seaglider SG681, while the original measurements were retained for Triaxus, SG659 and both EM-APEX floats. Dissolved oxygen from Triaxus, SG659 and SG681 was corrected using platform-specific time-dependent multiplicative gains derived from comparisons with Winkler-calibrated CTD observations. Delayed-mode BGC-Argo observations were retained without further adjustment and used as an independent validation dataset. The released NetCDF files preserve source measurements, quality-control information and metadata while providing harmonised and, where required, inter-calibrated variables for subsequent scientific analysis.

2. Introduction

The FOCUS/SWOT-ACC observing program collected coordinated multi-platform oceanographic observations in the Southern Ocean south of Tasmania during 2023–2024. The ship-based component was conducted during RV Investigator voyage IN2023_V07 from 14 November to 19 December 2023 as part of the Fine-scale Observations of the Antarctic Circumpolar Current Under SWOT (FOCUS) experiment. The experiment was designed to provide in situ observations for the validation and interpretation of high-resolution sea-surface-height measurements from the Surface Water and Ocean Topography (SWOT) satellite, with particular emphasis on ocean variability at horizontal scales of approximately 10–100 km (Legresy, 2023; Tranchant et al., 2025).

The observations were centred on the Polar Front (PF) where it crosses the Southeast Indian Ridge (SEIR), within the standing-meander region targeted by the FOCUS experiment (Legresy, 2023). The region has previously been identified as a hotspot of poleward eddy heat flux across the Antarctic Circumpolar Current (Foppert et al., 2017). A coordinated sampling strategy was used to resolve hydrographic structure and variability across the front and within the overlapping SWOT satellite swaths. The observing system comprised ship-based conductivity–temperature–depth (CTD) casts, shown as black dots in Figure 1; towed Triaxus surveys, shown as grey lines; two Electromagnetic Autonomous Profiling Explorer (EM-APEX) floats, shown as blue dots; two Biogeochemical Argo (BGC-Argo) profiling floats, shown as green dots; and two Seagliders, shown as yellow dots. These platforms provided complementary observations with different spatial coverage, vertical resolution, sampling frequency and deployment duration.

Each source dataset underwent platform-specific processing and quality control before inclusion in the present data product. However, differences in sensor type, processing procedures, variable definitions, units, sampling characteristics and data formats required additional harmonisation before the observations could be used consistently in a common multi-platform framework. Ship-based CTD observations were used as the primary reference for cross-platform comparison because they underwent standard shipboard hydrographic processing and quality control, including bottle-sample calibration of salinity and Winkler-titration calibration of dissolved oxygen (Dirita, 2024a). These calibrated CTD observations therefore provided the reference dataset for evaluating cross-platform consistency. Temperature, salinity and dissolved oxygen were subsequently compared between platforms, and additional corrections were applied only where systematic offsets were considered sufficiently robust. BGC-Argo observations were not recalibrated because delayed-mode adjusted data were available and were instead retained as an independent consistency and validation dataset (Argo, 2026; Wong et al., 2020).

This report documents the additional processing undertaken to construct the FOCUS/SWOT-ACC harmonised multi-platform data product. It describes the source datasets, platform-specific harmonisation, cross-platform inter-calibration and validation, data subsetting, and the structure of the final released files. The original platform-specific processing procedures are not reproduced in full; where appropriate, users are referred to the original processing documentation and

metadata. The objective of the resulting product is to provide a consistent, traceable and citable collection of observations for subsequent scientific analysis.

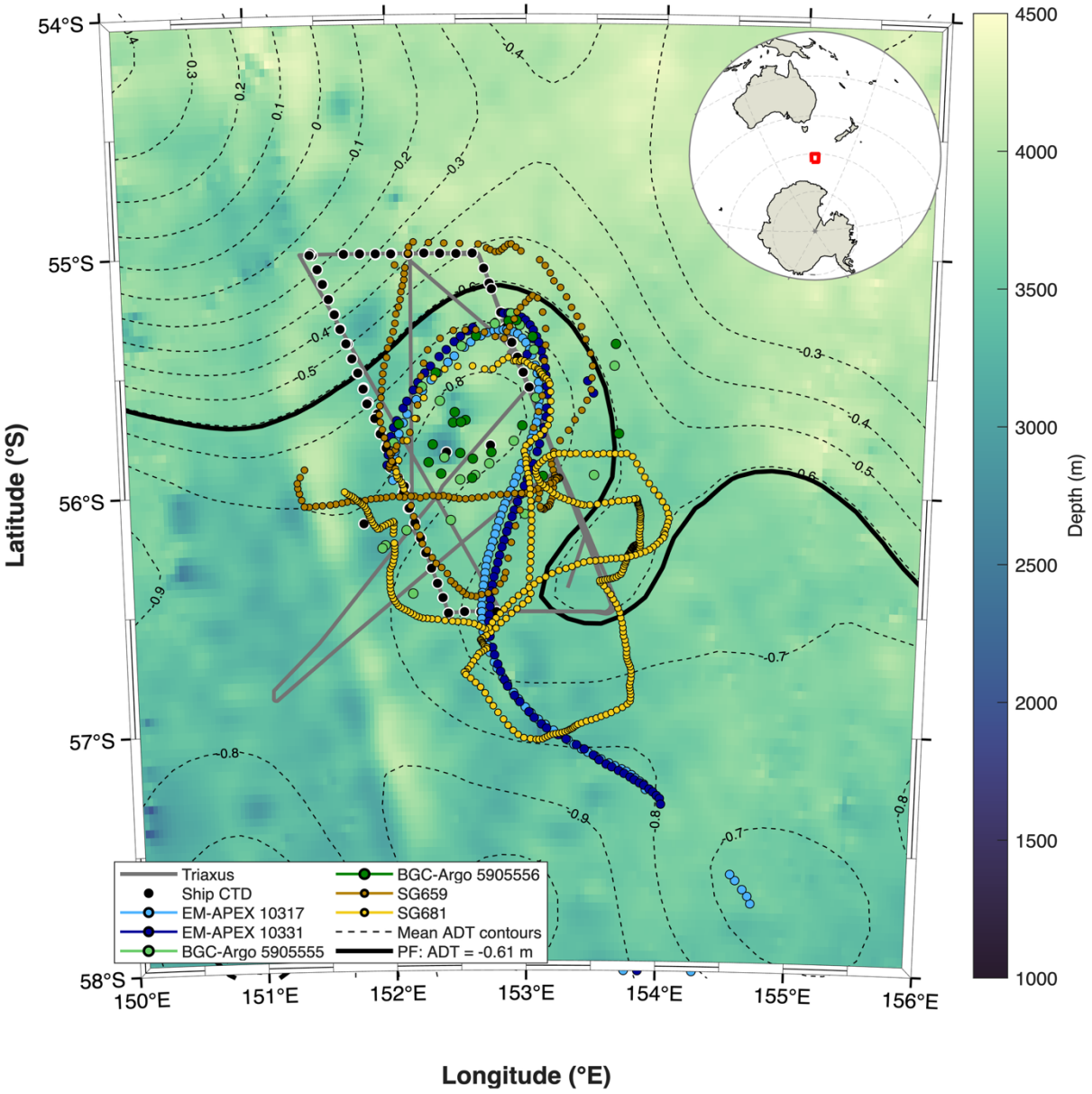


Figure 1 Multi-platform sampling distribution in the FOCUS/SWOT-ACC study region south of Tasmania. Background shading shows bathymetric depth from ETOPO2v2 (NOAA National Centers for Environmental Information, 2022). Dashed black contours show mean absolute dynamic topography (ADT) from the Copernicus Marine Service gridded sea-level product, averaged over 15 November–31 December 2023 and plotted at 0.1 m intervals. The thick solid black contour marks the Polar Front (PF), defined here by the ADT = −0.61 m contour. Grey lines show the Triaxus tow tracks and black circles indicate ship-based CTD casts. Light- and dark-blue symbols show EM-APEX floats f10317 and f10331, respectively; light- and dark-green symbols show BGC-Argo floats 5905555 and 5905556; and brown and yellow symbols show Seagliders SG659 and SG681, respectively. The inset shows the location of the study domain in the Southern Ocean, with the red box indicating the mapped region.

3. Dataset Overview

3.1 CTD

Ship-based hydrographic observations were collected during RV Investigator voyage IN2023_V07 using CSIRO CTD unit #24 (S/N 1332), a Sea-Bird SBE911plus system equipped with duplicate SBE3plus temperature sensors, SBE4C conductivity sensors and SBE43 dissolved-oxygen sensors. The CTD was mounted on a Sea-Bird SBE32 rosette carrying 36 twelve-litre Niskin bottles. A total of 111 CTD deployments conducted during the voyage (Dirita, 2024a; Legresy, 2023), 108 profiles were retained in the harmonised data product. Three deployments were test casts conducted well outside the FOCUS study region and were therefore excluded from the released dataset.

The source CTD data were processed by the CSIRO Marine National Facility using Sea-Bird Seasave and SBE Data Processing together with the MATLAB-based CapPro processing system. The processing workflow included automated quality control, identification of water-entry and water-exit times, pressure-offset correction, conductivity-sensor lag correction and conductivity-cell thermal-inertia correction. Discrete bottle samples collected during the voyage were then used for the final conductivity and dissolved-oxygen calibrations. Conductivity was calibrated against bottle salinity measurements, while dissolved oxygen from the SBE43 sensors was calibrated against Winkler bottle oxygen measurements (Dirita, 2024a).

The final primary-sensor conductivity calibration had a salinity residual standard deviation of 0.0012454, within the CSIRO target of better than 0.002, while the primary dissolved-oxygen calibration had a residual standard deviation of 0.78388 µmol L-1. Calibrated data from the primary temperature, conductivity and dissolved-oxygen sensors were used to generate the standard 1-dbar averaged product, with the corresponding secondary-sensor variables retained separately. Each binned parameter was assigned a quality-control flag following the CSIRO processing scheme (Dirita, 2024a).

The CSIRO-processed CTD profiles were retained as the reference hydrographic dataset for the FOCUS/SWOT-ACC multi-platform inter-calibration. No additional corrections were applied to CTD temperature, salinity or the original dissolved-oxygen measurements. The original variables, associated QC flags and metadata were preserved.

For consistency with the dissolved-oxygen measurements from the other platforms, additional dissolved-oxygen variables expressed in µmol kg-1 were derived from the original CTD dissolved-oxygen concentrations. In-situ seawater density was calculated using TEOS-10 (McDougall & Barker, 2011) from pressure, practical salinity and in-situ temperature, and the original volume-based oxygen concentration was converted to mass-specific concentration using

$$[O_2]_{mass} = \frac{[O_2]_{volume}}{\rho/1000}$$

where ρ is in-situ density in kg m^{-3}. Equivalent derived variables were produced for both the primary and secondary dissolved-oxygen sensors, with their existing QC information retained. No interpolation, additional quality-control filtering or further sensor recalibration was applied.

The complete original CTD processing procedure is documented in the RV Investigator CTD Data Processing Report – IN2023_V07 (CSIRO Marine National Facility, Version 1.1) (Dirita, 2024a).

3.2 Triaxus

Five Triaxus tows were completed during IN2023_V07 using MacArtney Triaxus hull 002 (S/N S1511990), with a total towing duration of 121.75 hours. The vehicle carried a Sea-Bird SBE9plus V2 CTD system with duplicate temperature, conductivity and dissolved-oxygen sensors, together with additional optical and biogeochemical sensors. Only tow legs with regular vertical undulations were retained in the processed dataset (Dirita, 2024b).

The source data were processed by the CSIRO Marine National Facility using Sea-Bird Seasave and SBE Data Processing followed by the MATLAB-based CapPro workflow. Processing included automated quality control, pressure-offset estimation, conductivity lag and thermal-inertia corrections, and comparison of the primary and secondary CTD sensor sets. The released product uses the primary sensors for the default temperature, salinity and dissolved-oxygen variables. Processed observations were binned at 1-dbar intervals, and synthetic vertical casts were generated from the regular undulations (Dirita, 2024b).

For the FOCUS/SWOT-ACC harmonised data product, temperature and salinity were retained without further correction because the observed offsets relative to the shipboard CTD reference did not meet the criteria for a platform-wide adjustment. Dissolved oxygen was converted to μ mol kg^{-1} using TEOS-10 (McDougall & Barker, 2011) in-situ density and corrected using a time-dependent multiplicative gain derived from comparisons with the Winkler-calibrated shipboard CTD observations. The original variables and QC information were retained, with adjusted dissolved-oxygen variables added in both μ mol L^{-1} and μ mol kg^{-1}.

Full details of the original processing are provided in the RV Investigator Triaxus Data Processing Report – IN2023_V07, Version 1.1 (Dirita, 2024b).

3.3 Seaglider

Two Seagliders, SG659 and SG681, were deployed in early December 2023 and sampled the Polar Front region downstream of the SEIR. Both gliders profiled in a V-shaped pattern to approximately 1000 m and carried an unpumped Sea-Bird CTD, an Aanderaa dissolved-oxygen optode and WETLabs optical sensors. The deployments extended from December 2023 into January 2024 and sampled waters on both sides of the Polar Front (Legresy, 2023; Thompson et al., 2025).

The source data were processed using the GliderTools toolbox (Gregor et al., 2019), with individual upcasts and downcasts treated as separate profiles. For the harmonised FOCUS/SWOT-ACC data product, the processed profile-level NetCDF data were retained without additional spatial or vertical interpolation.

The glider temperature, salinity and dissolved-oxygen observations were compared with nearby shipboard CTD profiles. A systematic temperature and salinity offset was identified for SG681 and corrected, while no corresponding adjustment was applied to SG659. Dissolved oxygen from both gliders was corrected using time-dependent multiplicative gains derived from comparisons with the Winkler-calibrated shipboard CTD observations. Original measurements and QC information were retained, with corrected variables added alongside the source data. The inter-calibration procedure and result are described in Section 4.

The original Seaglider observations are archived in Zenodo (Thompson et al., 2025).

3.4 EM-APEX

Two Electromagnetic Autonomous Profiling Explorer (EM-APEX) floats, f10317 and f10331, were deployed during the FOCUS voyage. The floats measured pressure, temperature, salinity and horizontal velocity. During the initial high-frequency sampling phase, profiles were collected approximately every 3–6 h to about 1600 m, followed by lower-frequency sampling cycles extending to approximately 2000 m.

For the harmonised FOCUS/SWOT-ACC data product, data for f10317 and f10331 were extracted from the processed SQUID gridded EM-APEX product. The original gridded variables, metadata and profile structure were retained, and no additional temperature or salinity correction, interpolation or QC filtering was applied. Empty coordinate placeholders associated with unused profile slots were converted to missing values. For f10331, two observations (pid = 11, hpid = 21–22) with anomalous geographic positions were excluded from the released data.

Temperature and salinity from the EM-APEX floats were also compared with nearby shipboard CTD observations as part of the multi-platform inter-calibration assessment. The observed salinity offsets did not meet the criteria for a platform-wide correction, and the original EM-APEX hydrographic measurements were therefore retained unchanged.

3.5 BGC-Argo

Two Biogeochemical Argo (BGC-Argo) profiling floats, WMO 5905555 and 5905556, were deployed during the FOCUS voyage. The floats sampled temperature, salinity, dissolved oxygen and additional biogeochemical variables. They profiled daily during the first 10 days after deployment, then every two days through December 2023 and January 2024, before transitioning to 10-day profiling cycles from February 2024 onward. Most profiles extended to approximately 1000 m, with intermittent deeper profiles reaching 2000 m (Argo, 2026).

For the harmonised FOCUS/SWOT-ACC data product, the delayed-mode Argo Sprof records for both floats were retained through 25 March 2024 (Argo, 2026). The original Argo adjusted variables, quality-control flags and metadata were preserved, with no additional recalibration, QC filtering or interpolation applied. The two floats were retained as separate NetCDF files.

Because the observations had undergone Argo delayed-mode quality control, the adjusted temperature, salinity and dissolved-oxygen variables were used without further correction (Argo, 2026; Wong et al., 2020). The BGC-Argo observations therefore provided an independent reference for assessing the consistency of the inter-calibrated measurements from the other platforms.

4. Multi-Platform Inter-Calibration

To combine observations from the different platforms, temperature, salinity and dissolved-oxygen measurements were compared with the ship-based CTD observations and, where appropriate, adjusted to remove systematic platform offsets. The ship-based CTD observations were used as the primary reference because conductivity and dissolved oxygen had been calibrated against discrete bottle salinity and Winkler oxygen measurements, respectively (Dirita, 2024a). BGC-Argo observations were not recalibrated because delayed-mode adjusted data were available (Owens & Wong, 2009; Wong et al., 2003; Wong et al., 2020); these observations were instead retained as an independent consistency and validation dataset.

Separate procedures were used for temperature and salinity and for dissolved oxygen. Temperature and salinity were assessed using matched profiles within hydrographically stable comparison layers, whereas dissolved oxygen was corrected using time-dependent multiplicative gains. The matching criteria, comparison layers and resulting corrections are summarised in Table 1.

4.1 Temperature and Salinity Inter-Calibration

4.1.1 Profile matching

For each platform, shipboard CTD casts were identified as reference profiles using platform-specific spatial and temporal separation thresholds. These thresholds were selected to account for differences in platform sampling characteristics and the expected displacement of the sampled water between observations.

Triaxus profiles were matched to CTD casts within 5 km and 1 day. The corresponding criteria were 10 km and 3 days for the Seagliders, and 20 km and 5 days for the EM-APEX floats. For each reference CTD cast, all platform profiles satisfying both the spatial and temporal criteria were retained for the inter-calibration analysis. An example of the matching and calibration procedure for Seaglider SG681 is shown in Figure 2a. Three shipboard CTD profiles were identified as reference casts, and 13 SG681 profiles satisfied the corresponding spatial and temporal matching criteria. The matched CTD profiles are shown in red, while the original and corrected SG681 profiles are shown in black and green, respectively.

The matching procedure was designed to provide enough observations for a robust estimate of platform bias while limiting the influence of spatial and temporal hydrographic variability. Because the observations were collected in a dynamically active frontal environment, proximity in space and time alone did not ensure that two profiles sampled directly comparable water. Temperature and salinity differences were therefore evaluated within platform-specific vertical layers selected to minimise the influence of vertical displacement and local water-mass variability.

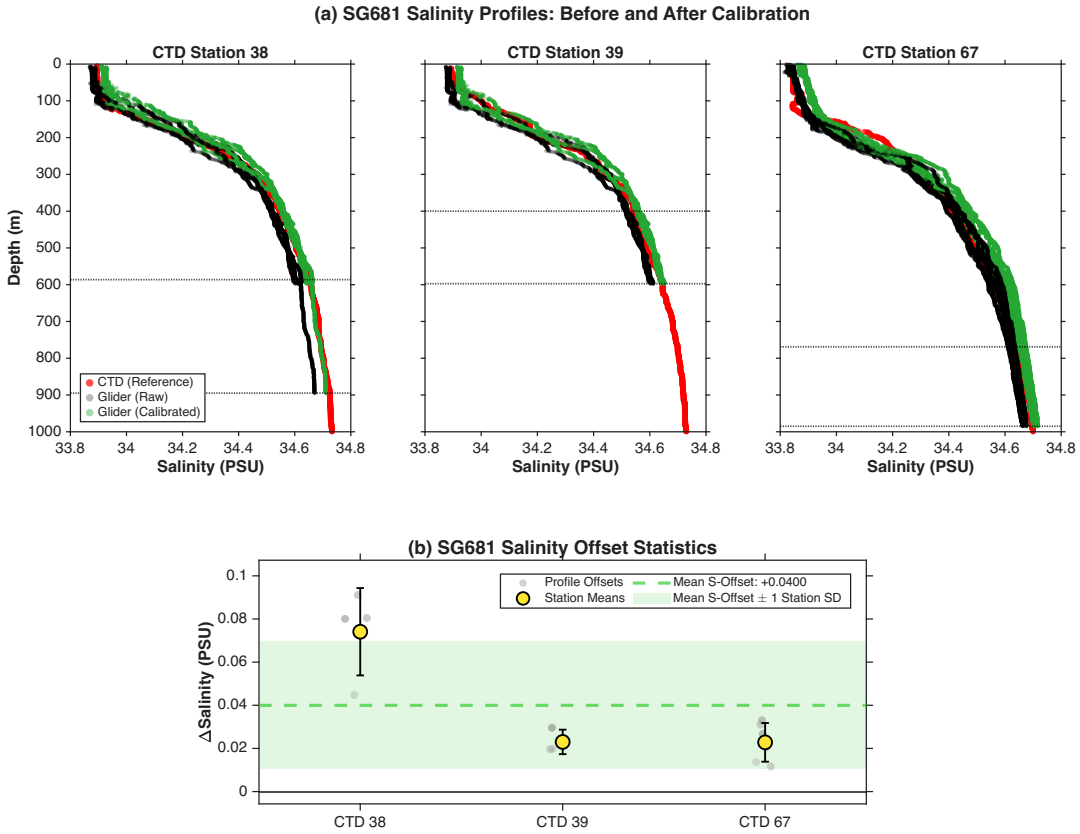


Figure 2 Calibration of temperature and salinity observations from Seaglider SG681 against matched ship-based CTD casts. (a) Salinity profiles for SG681 matched to CTD stations 38, 39, and 67. Red profiles show the reference CTD observations, black profiles show the uncorrected SG681 measurements, and green profiles show the calibrated SG681 measurements. Horizontal dotted lines indicate the depth range of the low-PV layers used to calculate the profile offsets. (b) Salinity offsets calculated for the three matched CTD groups. Grey dots show offsets from individual matched SG681 profiles, yellow points show the mean offset for each CTD group. Green dashed lines and shaded regions indicate the final platform-wide offsets and their standard deviation, respectively.

4.1.2 Comparison layers

For Triaxus, temperature and salinity comparisons were made within the near-surface well-mixed layer, generally shallower than 50 m. The weak vertical gradients in this layer reduced sensitivity to small vertical offsets between the Triaxus and reference CTD profiles.

For the Seagliders, comparison layers were selected individually from regions of low potential vorticity (PV) in each matched CTD cast. Absolute salinity and conservative temperature were calculated using TEOS-10 Gibbs SeaWater toolbox (McDougall & Barker, 2011), and the squared buoyancy frequency, (N^2), was used to define $q = fN\text{^}2 / g$, where f is the Coriolis parameter and g is gravitational acceleration. Low-PV layers were defined using $|q| < 5 \times 10^{-11} m^{-1} s^{-1}$. For shallower casts, the threshold was

relaxed to $|q| < 6 \times 10^{-11} m^{-1} s^{-1}$, where necessary to identify a suitable comparison layer. These low-PV layers were chosen because vertical density and hydrographic-property gradients were relatively weak, reducing the sensitivity of the estimated offset to small differences in profile position or vertical alignment.

EM-APEX comparisons were restricted to a stable deep-water layer, generally deeper than 1500 m and with $\sigma_0 > 27.6$ kg m^{-3}. This approach follows the principles of Argo delayed-mode salinity quality control, in which conductivity-derived salinity is evaluated against high-quality reference hydrography on hydrographically stable surfaces to distinguish instrumental conductivity bias or drift from genuine ocean variability (Owens & Wong, 2009; Wong et al., 2003; Wong et al., 2020). In the standard Argo delayed-mode procedure, reference salinity is estimated from historical hydrographic observations mapped to the float location and compared with float measurements on selected potential-temperature or potential-density surfaces. The resulting differences are expressed in potential-conductivity space, and their evolution through time is used to diagnose conductivity offsets or drift and, where justified, derive salinity adjustments (Owens & Wong, 2009; Wong et al., 2003). The method preferentially uses well-mixed mode waters or deep homogeneous water masses, where natural salinity variability is comparatively small and temperature measurements can provide a stable reference coordinate.

For the present EM-APEX inter-calibration, the same underlying principle was adapted to the available FOCUS observations. Rather than relying on objectively mapped historical hydrography, nearby shipboard CTD profiles provided the reference measurements, and comparisons were restricted to the stable deep-water layer defined above. This reduces the influence of short-scale hydrographic variability and allows persistent salinity differences between EM-APEX and the reference CTD observations to be interpreted primarily as possible conductivity-related offsets. In applying the delayed-mode framework, EM-APEX temperature measurements were assumed to be stable and were not adjusted. Systematic departures of the observed T–S relationship from the CTD reference were therefore attributed to conductivity-derived salinity bias, consistent with the standard Argo delayed-mode treatment of conductivity sensor offset and drift. Salinity adjustments were evaluated on the stable deep-water comparison layers described above.

4.1.3 Offset calculation

Temperature and salinity offsets were calculated hierarchically from individual matched profile pairs to a single platform-wide offset. Within the platform-specific comparison layer, the difference between each matched platform profile and its corresponding reference CTD cast was calculated (grey dots in Figure 2b):

$$\delta X_{ij} = X_i^{\mathrm{CTD}} - X_{ij}^{\mathrm{platform}}$$

For each reference CTD cast, the profile-pair differences were averaged across all associated platform profiles to obtain a CTD-group mean offset (yellow dots in Figure 2b):

$$\delta X_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \delta X_{ij},$$

The platform-wide offset was then calculated as the mean of the CTD-group offsets (green dashed line in Figure 2b):

$$\Delta X = \frac{1}{N_{\mathrm{CTD}}} \sum_{i=1}^{N_{\mathrm{CTD}}} \delta X_i,$$

Where a platform-wide correction was required, the resulting signed offset was added to the platform observations:

$$X^{\mathrm{calibrated}} = X^{\mathrm{platform}} + \Delta X.$$

Here, X represents temperature or salinity; i denotes the reference CTD cast; j denotes the platform profile matched to the ith CTD cast; $X_{ij}^{\mathrm{platform}}$ and X_i^{CTD} are the corresponding layer-mean platform and CTD values within the selected comparison layer; δX_{ij} is the offset for an individual matched profile pair; n_i is the number of platform profiles matched to the ith CTD cast; δX_i is the mean offset associated with that CTD cast; N_{CTD} is the total number of matched reference CTD casts; and ΔX is the final platform-wide offset.

4.1.4 Correction criteria and results

A platform-wide correction was applied only when the estimated offset was sufficiently large and consistent to be distinguished from environmental variability. Two quantitative criteria were used. First, the magnitude of the platform-wide offset had to exceed the adopted measurement-accuracy threshold for the corresponding platform: 0.001 °C for temperature and 0.003 for Practical Salinity for Triaxus (Sea-Bird Scientific, n.d.-a, n.d.-b); 0.002 °C for temperature and 0.01 for Practical Salinity for the Seagliders (OceanGliders, n.d.; University of Washington, 2020); and 0.01 for Practical Salinity for EM-APEX, following the Argo delayed-mode accuracy criterion (Wong et al., 2020). Second, the magnitude of the offset had to exceed the standard deviation of the CTD-group offsets ($|\Delta X| > std(\delta X_i)$). The sign of the individual CTD-group offsets was also examined as a qualitative consistency check; offsets that varied around zero without a persistent sign were interpreted as more likely reflecting environmental variability than a systematic instrumental bias.

The resulting offsets and their standard deviation are summarised in Table 1. Of all platforms examined, only SG681 satisfied the correction criteria for both temperature and salinity. The estimated platform-wide offsets were $\Delta T = -0.0123$℃ and $\Delta S = +0.0400$ for temperature and practical salinity, respectively. The salinity profile comparisons and the corresponding salinity offset statistics for SG681 are shown in Figure 2.

For Triaxus, the between-CTD variability in both temperature and salinity offsets exceeded the corresponding platform-wide mean offsets, and neither offset therefore satisfied the correction criteria (Figure A1). For SG659, the CTD-group offsets did not show a consistent systematic bias, making it difficult to distinguish instrumental offset from environmental variability. The between-CTD standard deviation also

exceeded the magnitude of the platform-wide mean offset for both temperature and salinity, and no correction was therefore applied (Figure A2). For EM-APEX f10317 and f10331, salinity was assessed using the adapted Argo delayed-mode quality-control approach described in Section 4.1.2. The estimated platform-wide salinity offsets were smaller than the stated salinity measurement accuracy and did not satisfy the correction criterion. No additional salinity correction was applied to either float (Figures A4 and A5).

Table 1 Summary of the multi-platform inter-calibration. Platform-specific spatial and temporal matching criteria and vertical comparison layers are shown together with the estimated temperature and salinity offsets and dissolved-oxygen gain corrections. Temperature and salinity offsets are reported as the platform-wide mean offset ± the standard deviation of the CTD-group offsets.

Platform		Matching criteria	Comparison layer	Temperature offset ± std (°C)	Salinity offset ± std	Dissolved-oxygen gain, G(t)
Triaxus		5 km / 1 d	Near-surface well-mixed layer	−0.0148 ± 0.0323	+0.0005 ± 0.0065	**$1.4721 \times 10^{-4}t + 0.9748$**
Seaglider	SG659	10 km / 3 d	Low-PV layer	+0.0127 ± 0.0374	−0.0033 ± 0.0104	**$7.0732 \times 10^{-4}t + 1.163$**
	SG681	10 km / 3 d	Low-PV layer	**−0.0123 ± 0.0111**	**+0.0400 ± 0.0295**	**$-2.7592 \times 10^{-4}t + 1.003$**
EM-APEX	f10317	20 km / 5 d	Stable deep layer, $\sigma_0 > 27.6$ kg m^{-3}	N/A	+0.0003 ± 0.0010	N/A
	f10331	20 km / 5 d	Stable deep layer, $\sigma_0 > 27.6$ kg m^{-3}	N/A	−0.0010 ± 0.0014	N/A

Temperature and salinity offsets are defined as the matched ship-based CTD reference value minus the platform value. The reported uncertainty is the standard deviation of the CTD-group offsets, δX_i. Bold temperature and salinity values indicate offsets that satisfied the correction criteria and were applied to the released observations. For dissolved oxygen, G(t) is the time-dependent multiplicative gain, where t is the number of days since 15 November 2023. EM-APEX did not measure dissolved oxygen. BGC-Argo observations are not listed because they were not recalibrated; delayed-mode adjusted observations were retained as an independent validation dataset.

4.2 Dissolved-Oxygen Inter-Calibration

Dissolved-oxygen measurements were available from the ship-based CTD, Triaxus, Seagliders and BGC-Argo floats; EM-APEX did not measure dissolved oxygen. Before inter-calibration, all dissolved-oxygen observations were expressed in a common unit of μ mol kg^{-1}.

Optical oxygen sensors can exhibit time-dependent changes in sensor sensitivity, which may introduce systematic biases in measured oxygen concentrations (Bittig et al., 2018; Miller et al., 2024). This behaviour is associated with gradual changes in the response of the optode sensing foil over the lifetime of the sensor and may depend on sensor age and use.

For Triaxus, dissolved oxygen was measured using Sea-Bird SBE43 electrochemical oxygen sensors, with SBE43 S/N 3154 used as the primary sensor. Unlike optical oxygen sensors, changes in SBE43 response are primarily expressed as changes in sensor slope rather than as an additive offset. Sea-Bird Scientific recommends correcting such changes through adjustment of the oxygen-signal slope coefficient, (S_{oc}), using the ratio between a reference oxygen measurement and the corresponding SBE43 measurement. Where multiple reference observations are available through time, the slope correction may be represented as a time-dependent factor, including a linear drift rate where appropriate (Sea-Bird Scientific, 2024).

For the relatively short deployment periods considered here, changes in oxygen-sensor response were therefore represented using platform-specific linear, time-dependent multiplicative gains. For the Seaglider optodes, this follows the time-dependent gain approach described by Miller et al. (2024), while for the Triaxus SBE43 sensor it is consistent with the slope-correction procedure recommended by Sea-Bird Scientific (2024).

4.2.1 Time-dependent gain correction

Gain estimates for the Triaxus and Seaglider dissolved-oxygen observations were derived from comparisons with the Winkler-calibrated shipboard CTD oxygen profiles. The same platform-specific spatial and temporal matching criteria used for the temperature and salinity inter-calibration were applied to identify suitable CTD reference profiles (Table 1).

A linear gain function was fitted to the calibration estimates as a function of observation time:

$$G(t) = a + bt$$

where $G(t)$is the multiplicative oxygen correction and t is the number of days since 15 November 2023. The calibrated dissolved-oxygen concentration was then calculated as

$$[O_2]_{\text{calibrated}}(t, z) = G(t)[O_2]_{\text{observed}}(t, z).$$

The fitted gain functions for Triaxus, SG659 and SG681 are listed in Table 1. These functions were applied over the corresponding deployment periods, while the original oxygen variables were retained alongside the corrected measurements in the released data product.

An example of the calibration procedure for SG659 is shown in Figure 3. Each panel compares a SG659 oxygen profile with a spatially and temporally matched shipboard CTD reference profile. The original SG659 measurements (shown in black) and the profiles after application of the time-dependent gain (shown in blue) are shown together with the Winkler-calibrated CTD observations (shown in red), illustrating the improvement in agreement after correction.

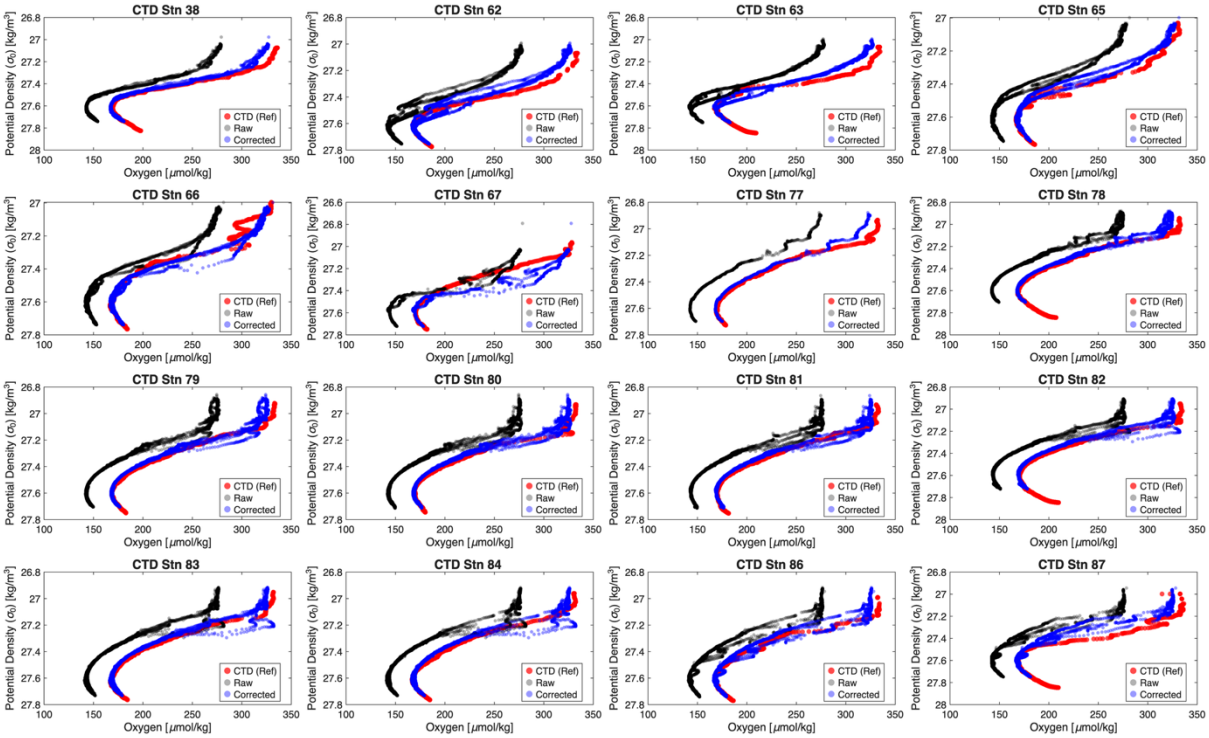


Figure 3 Example of the dissolved-oxygen calibration applied to Seaglider SG659. Each panel compares dissolved-oxygen profiles from SG659 with a matched ship-based CTD cast, plotted against potential density anomaly, σ_0. Red profiles indicate the Winkler-calibrated CTD reference observations, black profiles show the original SG659 measurements, and blue profiles show the SG659 measurements after application of the time-dependent oxygen gain correction.

4.2.2 Independent validation using BGC-Argo

The corrected Triaxus and Seaglider dissolved-oxygen measurements were evaluated against delayed-mode BGC-Argo oxygen observations. Because the BGC-Argo data were not used in the dissolved-oxygen inter-calibration and had already undergone delayed-mode quality control, they were treated as an independent validation dataset.

Candidate validation observations were first required to be separated by less than 5 km and 1 day. Because the study region contains strong frontal and mesoscale hydrographic gradients, spatial and temporal proximity alone does not necessarily indicate that two observations sampled the same water mass. The matched observations were therefore further screened using simultaneous differences in

conservative temperature and absolute salinity. Three progressively stricter hydrographic matching criteria were applied to evaluate the agreement under increasingly similar hydrographic conditions, as summarised in Table 2.

Table 2 Validation of the inter-calibrated dissolved-oxygen observations against delayed-mode BGC-Argo measurements. Candidate observations were required to be separated by less than 5 km and 1 day and were subsequently screened using progressively stricter Conservative Temperature ($|\Delta\Theta|$) and Absolute Salinity ($|\Delta S_A|$) thresholds. The number of retained matched observations and corresponding dissolved-oxygen validation statistics are shown for each threshold.

Hydrographic Threshold	Total N Points	RMSE (µmol/kg)	Median Bias (µmol/kg)	Mean Absolute Error (µmol/kg)	Relative Error (%)
$\lvert\Delta\Theta\rvert < 0.05℃;$ $\lvert\Delta S_A\rvert < 0.05 g\ kg^{-1}$	1906	2.361	-2.235	2.130	1.247
$\lvert\Delta\Theta\rvert < 0.01℃;$ $\lvert\Delta S_A\rvert < 0.01 g\ kg^{-1}$	256	2.214	-1.890	2.057	1.082
$\lvert\Delta\Theta\rvert < 0.005℃;$ $\lvert\Delta S_A\rvert < 0.005 g\ kg^{-1}$	115	2.214	-1.873	2.070	1.069

The three hydrographic criteria retained 1906, 256 and 115 matched observations, respectively (Table 2). Across the three criteria, the RMSE ranged from 2.2137 to 2.3616 µ mol kg^{-1}, the mean absolute error ranged from 2.0571 to 2.1303 µ mol kg^{-1}, and the relative error ranged from 1.0690% to 1.2467%. These values are consistent with the performance reported by Miller et al. (2024), who found that well-calibrated optode dissolved-oxygen measurements showed relative errors of approximately 1% when compared with independent BGC-Argo observations, corresponding to absolute differences of about 2.5–3 µ mol kg^{-1}. The agreement with the independent delayed-mode BGC-Argo observations therefore provides additional support for the reliability of the dissolved-oxygen corrections applied to the Triaxus and Seaglider measurements.

Figure 4 illustrates representative profile comparisons between the corrected SG659 dissolved-oxygen observations and independent delayed-mode BGC-Argo measurements. The correction substantially reduces the offset between the original SG659 observations and the BGC-Argo profiles, while the hydrographically matched observations (blue points) show close agreement with the delayed-mode BGC-Argo oxygen measurements.

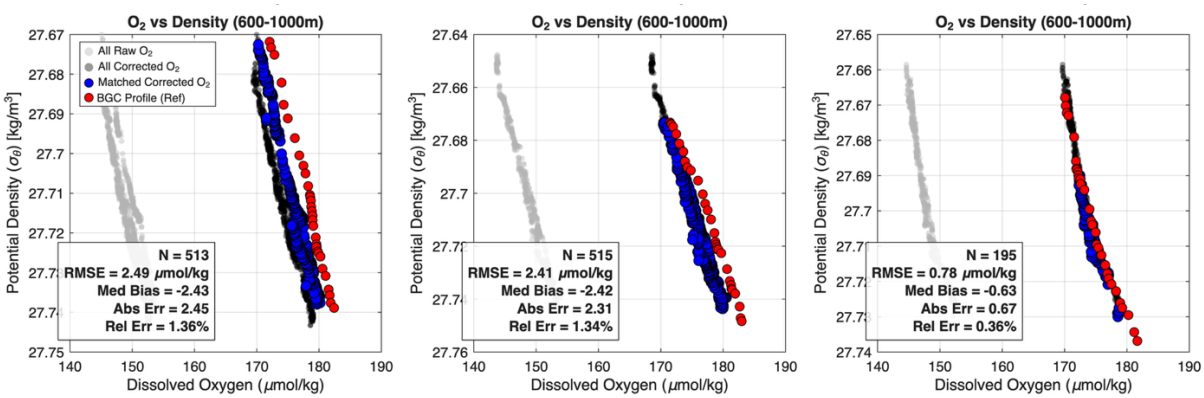


Figure 4 Independent validation of the dissolved-oxygen correction using delayed-mode BGC-Argo observations. Each panel compares dissolved-oxygen profiles from SG659 with a nearby BGC-Argo profile, plotted against potential density anomaly. Grey points show the original SG659 observations, black points show the SG659 observations after application of the time-dependent dissolved-oxygen correction, and red points show the delayed-mode BGC-Argo observations. Blue points indicate corrected SG659 observations that satisfy the hydrographic matching criterion $|\Delta\Theta| < 0.05℃$; $|\Delta S_A| < 0.05\ \mathrm{g\ kg^{-1}}$ relative to the corresponding BGC-Argo observations. Validation statistics for the matched observations are summarised in Table 2.

5. Limitations and Usage Notes

A limitation of the inter-calibration is that the FOCUS voyage was not designed specifically around dedicated cross-platform calibration casts. Consequently, only a limited number of platform profiles were closely co-located with shipboard CTD observations under very strict spatial and temporal criteria. Platform-specific matching thresholds were therefore selected as a compromise between retaining a sufficient number of comparisons and maintaining reasonable spatial and temporal proximity. Wider thresholds were required for platforms with fewer suitable matches. This inevitably increases the potential contribution of environmental variability and water-mass mismatch to the estimated offsets, particularly in the dynamically active Polar Front region. The use of hydrographically stable comparison layers and the requirement that systematic offsets exceed both instrument accuracy and between-CTD variability were intended to reduce, but cannot fully eliminate, this source of uncertainty.

A substantial quality-control issue was identified in the corrected salinity observations from SG659 during the downcast phase. Across the deployment, essentially all corrected downcast salinity measurements (salinity) were flagged as either QC = 3 (probably bad) or QC = 4 (bad), whereas approximately 94% of corrected upcast salinity measurements were flagged as good (QC = 1).

Inspection of the corresponding raw salinity indicated that this was not primarily caused by failure of the conductivity sensor. Approximately 97% of the raw downcast salinity measurements (salinity_raw) were flagged as good. Processing logs indicate that frequent glider stalls during downcasts prevented the standard thermal-inertia salinity correction from being applied reliably. The affected corrected salinity values were consequently assigned poor QC flags by the glider processing software.

Because accurate salinity is required for density-based matching and dissolved-oxygen inter-calibration, SG659 downcast profiles were excluded from the inter-calibration analysis. Only SG659 upcast profiles with valid temperature and salinity

quality-control flags were used. Users of the released dataset should therefore exercise caution when using SG659 corrected salinity from the downcast phase and should retain the supplied QC flags when selecting observations.

Users should note that the Seaglider CTD and Aanderaa dissolved-oxygen sensors may have different sampling times and array lengths. Details of the required time alignment are provided in the accompanying Glider README.

6. Appendix

Appendix A. Inter-Calibration Diagnostics

This appendix presents the diagnostic figures used to assess the consistency of the temperature, salinity and dissolved-oxygen inter-calibration across the observing platforms. For temperature and salinity, individual matched-profile offsets were first grouped by reference CTD cast, and the platform-wide offset was calculated from the CTD-group means. For dissolved oxygen, the temporal evolution of the multiplicative oxygen gain was evaluated from matched shipboard CTD observations.

A.1 Temperature and Salinity Inter-Calibration Diagnostics

For the temperature and salinity diagnostics, offsets are defined as $\Delta X = X^{CTD} - X^{\text{platform}}$, where X represents temperature or salinity. The diagnostic plotting procedure follows the station-based offset calculation described in Section 4.1

A.1.1 Triaxus

For Triaxus, the between-CTD variability in both temperature and salinity offsets exceeded the corresponding platform-wide mean offsets, and neither offset therefore satisfied the correction criteria (Figure A1). No additional temperature or salinity correction was applied.

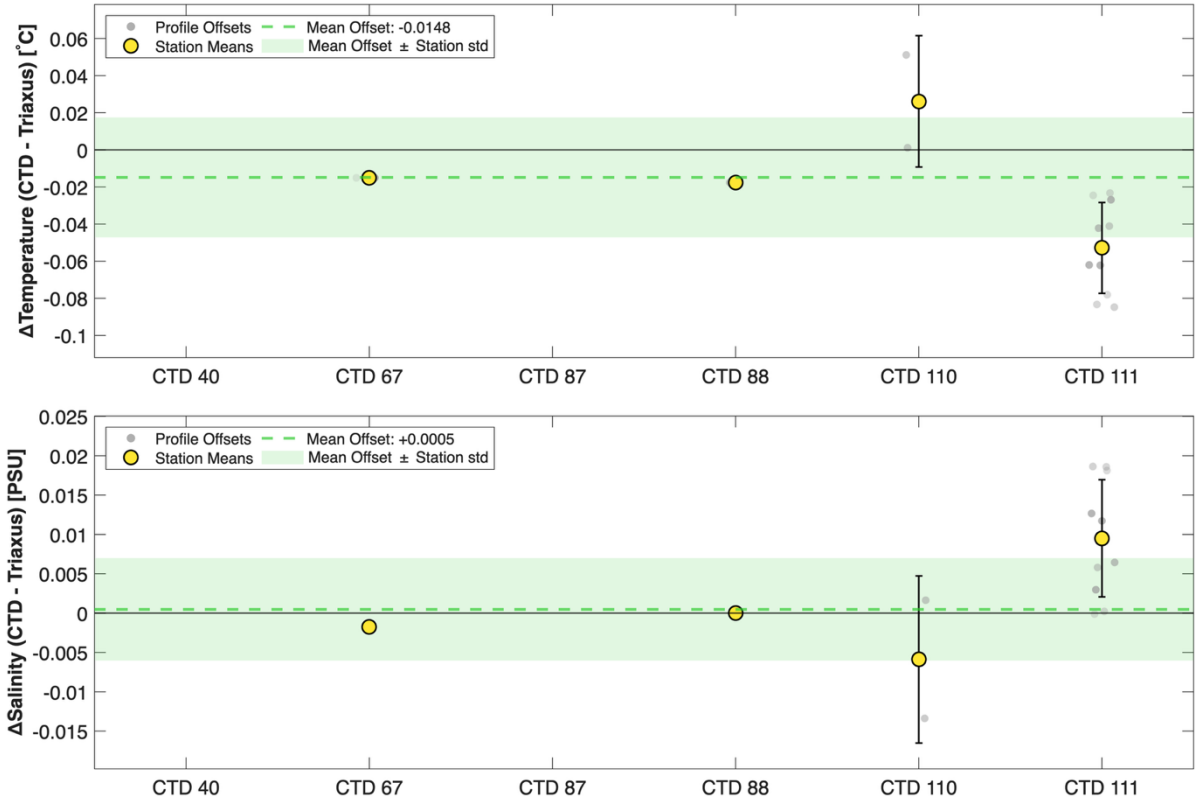


Figure A 1 Temperature and salinity offset diagnostics for Triaxus relative to matched shipboard CTD observations. Comparisons were performed within the near-surface well-mixed layer defined for each reference CTD cast. Grey points show offsets from individual matched Triaxus profiles, yellow points show CTD-group mean offsets, and black

error bars indicate within-group variability. Green dashed lines indicate the platform-wide mean temperature and salinity offsets, while the shaded regions represent standard deviation among the CTD-group means.

A.1.2 Seaglider SG659

For SG659, the CTD-group offsets did not show a consistent systematic bias across the matched reference casts, making it difficult to distinguish instrumental offset from environmental variability. In addition, the between-CTD standard deviation exceeded the magnitude of the platform-wide mean offset for both temperature and salinity. No platform-wide temperature or salinity correction was therefore applied (Figure A2).

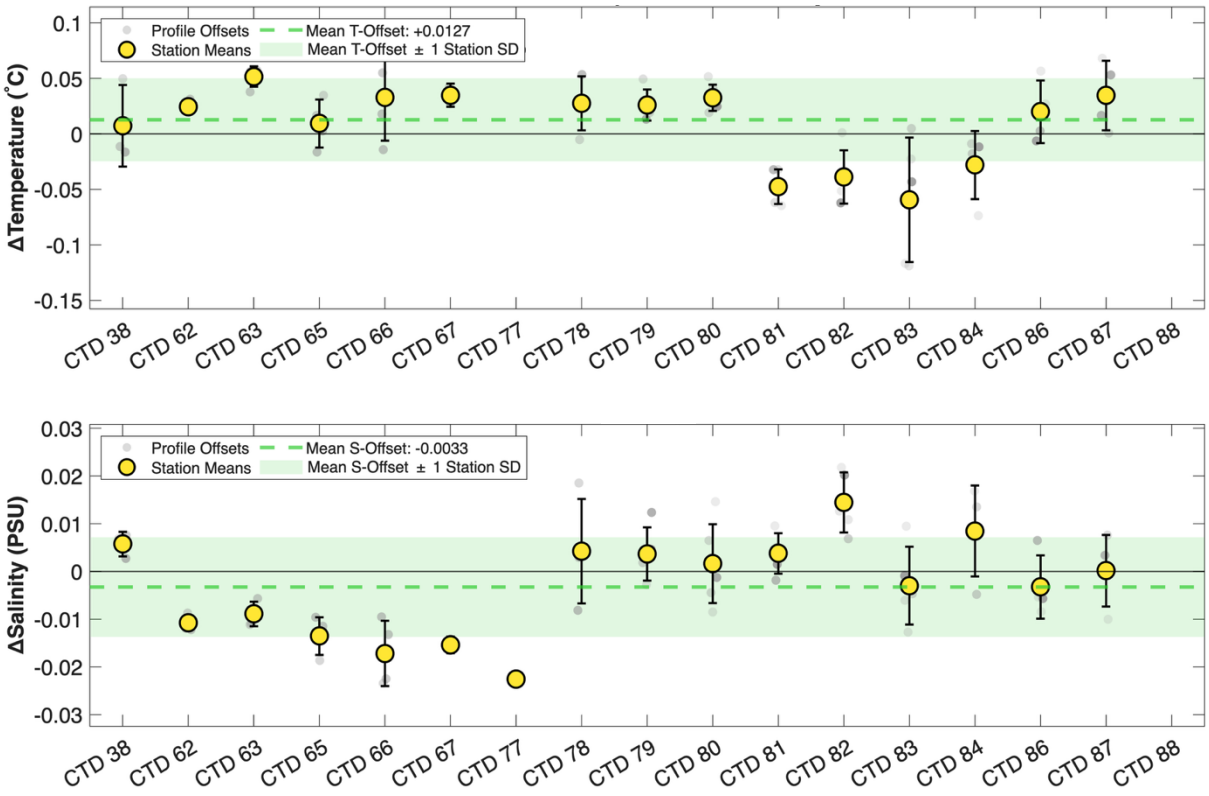


Figure A 2 Similar to Figure A 1 but for SG659.

A.1.3 Seaglider SG681

SG681 showed persistent temperature and salinity offsets that satisfied the correction criteria, and both corrections were applied to the released observations (Figure A3).

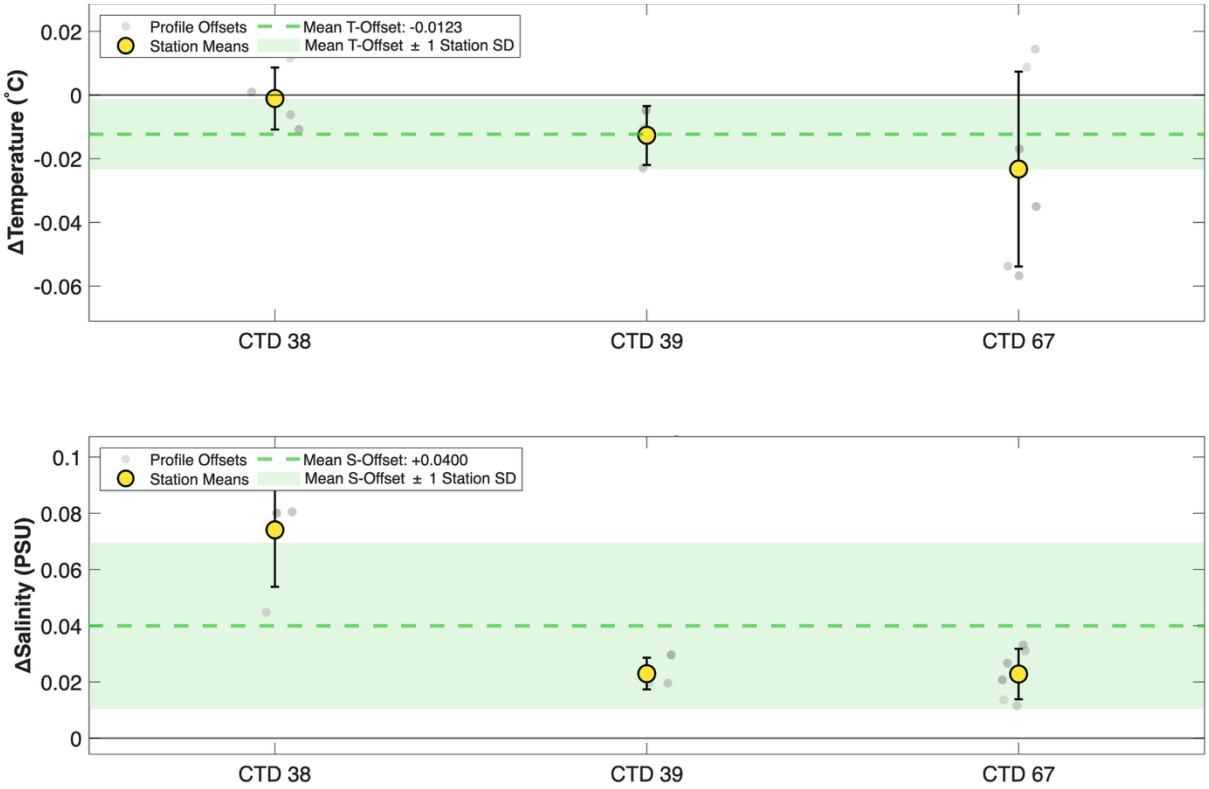


Figure A 3 Similar to Figure A 1 but for SG681.

A.1.4 EM-APEX

For EM-APEX f10317 and f10331, salinity was assessed using the adapted Argo delayed-mode quality-control approach described in Section 4.1.2. The estimated platform-wide salinity offsets were smaller than the stated salinity measurement accuracy of the instruments and were also not distinguishable from the variability among matched CTD comparisons. No additional salinity correction was therefore applied to either float (Figures A4 and A5).

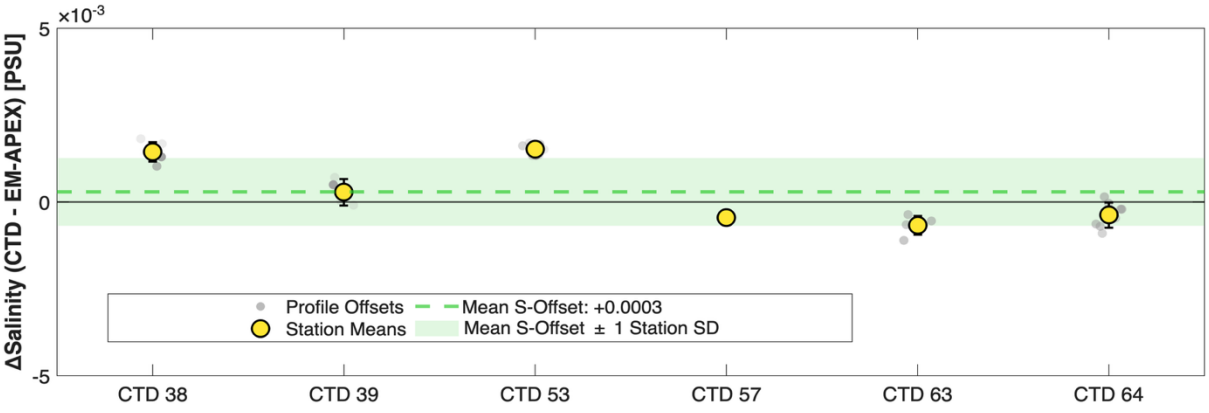


Figure A 4 Salinity offset diagnostic for EM-APEX float f10317 relative to matched shipboard CTD observations.

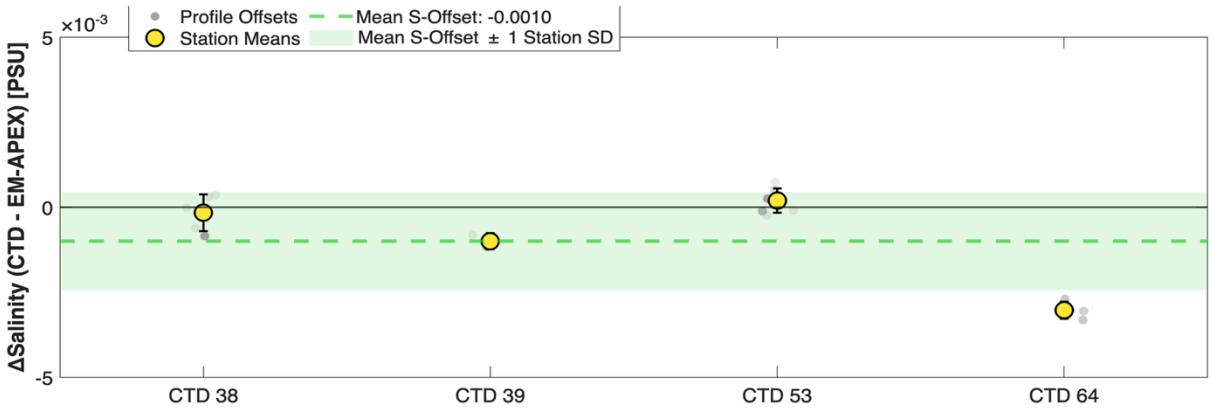


Figure A 5 Salinity offset diagnostic for EM-APEX float f10331 relative to matched shipboard CTD observations.

A.2 Dissolved-Oxygen Inter-Calibration Diagnostics

The following figures provide the diagnostic comparisons used to derive and assess the time-dependent dissolved-oxygen gain corrections for Triaxus, SG659 and SG681. The calibration method is described in Section 4.2.1, and the final gain functions applied to each platform are summarised in Table 1. Individual gain estimates were derived from comparisons between observed dissolved-oxygen and matched Winkler-calibrated shipboard CTD measurements within the comparison layer.

A.2.1 Triaxus

The matched-profile comparisons used to assess the Triaxus dissolved-oxygen correction are shown in Figure A6. The inter-calibration procedure is described in Section 4.2.1, and the final time-dependent gain applied to the Triaxus observations is summarised in Table 1.

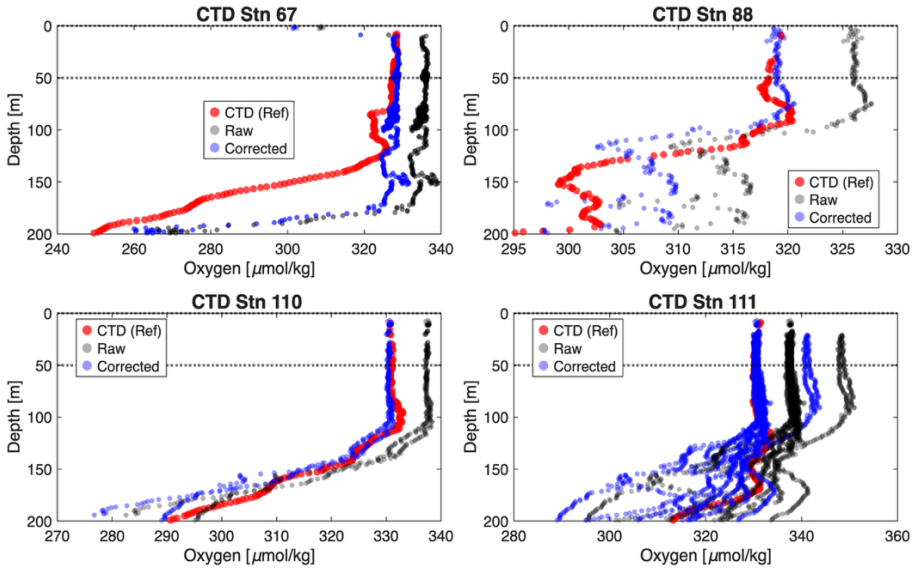


Figure A 6 Matched dissolved-oxygen profiles for Triaxus and the shipboard CTD reference observations. Red profiles show the Winkler-calibrated CTD reference observations, black profiles show the original Triaxus measurements, and blue profiles show the corrected Triaxus measurements. Dashed lines delimit the comparison layer used for the inter-calibration.

A.2.2 Seaglider SG659

The matched-profile comparisons used to assess the SG659 dissolved-oxygen correction are shown in Figure 3. The inter-calibration procedure is described in Section 4.2.1, and the final time-dependent gain applied to SG659 is summarised in Table 1.

A.2.3 Seaglider SG681

The matched-profile comparisons used to assess the SG681 dissolved-oxygen correction are shown in Figure A7. The inter-calibration procedure is described in Section 4.2.1, and the final time-dependent gain applied to SG681 is summarised in Table 1.

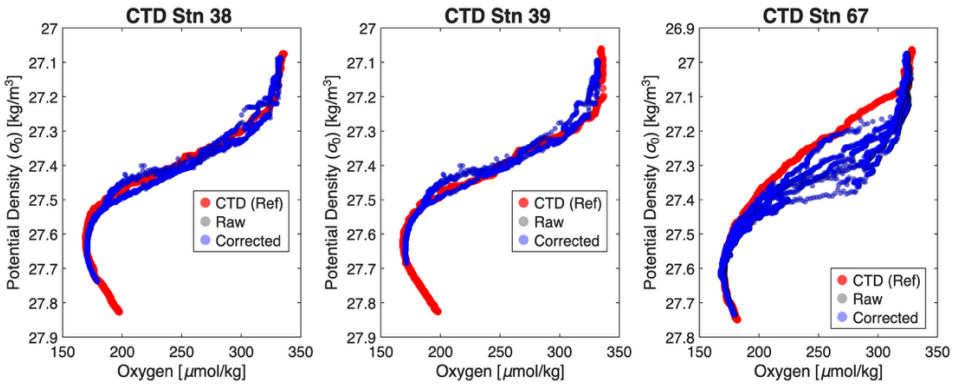


Figure A 7 Matched dissolved-oxygen profiles for Seaglider SG681 and the shipboard CTD reference observations. Red profiles show the Winkler-calibrated CTD reference observations, black profiles show the original SG681 measurements, and blue profiles show the corrected SG681 measurements.

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