



Physical and chemical oceanographic data during *Umitaka-maru* cruise of the 60th Japanese Antarctic Research Expedition in January 2019

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Abstract: The Southern Ocean connects all major ocean basins and plays a pivotal role in the meridional overturning circulation of global oceans. High-quality physical (temperature, salinity, and dissolved oxygen) and chemical (nutrients) oceanographic data from the Southern Ocean are thus critical for an improved understanding of future climates. As part of the 60th Japanese Antarctic Research Expedition, we obtained high-quality conductivity-temperature-depth (CTD) and water sampling data (salinity, dissolved oxygen, and nutrients) at six sites located along a 110°E transect in January 2019. Sea surface temperature and salinity were obtained continuously with a thermosalinograph (TSG) along the cruise track between the ports of Fremantle and Hobart, except within the Australian Exclusive Economic Zone. Data quality was validated by following as far as possible the recommendations for instruments and methods of the Global Ocean Ship-Based Hydrographic Investigation Program.

1. Background & Summary

Connecting all the major ocean basins, the Southern Ocean plays a pivotal role in meridional overturning circulation, and therefore in the global climate¹. In particular, Antarctic Bottom Water

(AABW) production in the Southern Ocean is an integral component of the overturning circulation, making an important contribution to the transport and storage of heat, carbon, and other properties that influence climate².

Since the 1990s, rapid and widespread freshening, possibly linked to enhanced basal melting of the Antarctic Ice Sheet³, has been observed in the Southern Ocean^{4,5}. There is also clear evidence of warming in AABW, which may reflect a reduction in meridional overturning circulation⁶⁻⁸. Furthermore, both freshening and warming have induced a remarkable rise in sea level⁹. In the latest study, however, reversals in AABW freshening trend, possibly due to a decrease in Antarctic Ice Sheet basal melting¹⁰ and/or increase in sea ice formation in the AABW source region¹¹ have been reported. Considering these non-monotonic signals in the Southern Ocean, high-quality data obtained from sustained annual monitoring observations are critical for an improved understanding of future climate.

Oceanographic observations have been taken en route between Japan and the Japanese Antarctic Station, Syowa (69°00'S, 39°35'E), as part of the annual Japanese Antarctic Research Expedition (JARE) routine observations since JARE 7 in 1965/66, when the JARE research programs were re-opened and re-structured in accordance with the decision of the Japanese Cabinet. Between JARE 7 and JARE 50 in 2008/2009, the Hydrographic Division of the Japan Maritime Safety Agency (now re-named the “Hydrographic and Oceanographic Department, Japan Coast Guard”) has been in charge of maintaining and continuing these oceanographic observations, as well as publication of the JARE Data Reports series.

After JARE 51 in 2009/2010, the responsibility for maintaining routine oceanographic observations was transferred to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as the lead agency, but an actual program for restructuring and implementing the oceanographic observations was not established. However, through the efforts of the Japanese Antarctic oceanographic community, oceanographic observations continued within the JARE framework, and were conducted after JARE 52 in 2010/2011 as one of the JARE research projects. The training and research vessel *Umitaka-maru*, which belongs to the Tokyo University of Marine Science and Technology (TUMSAT), has been used as a platform for in situ oceanographic observations under an agreement between TUMSAT and the National Institute of Polar Research (NIPR).

The present report summarizes the routine oceanographic observations made on board the *Umitaka-maru* during the UM-18-08 cruise in 2019, as part of the JARE 60 research project.

2. Observation sites

During the UM-18-08 cruise, in situ oceanographic observations were conducted along a cruise track between the ports of Fremantle and Hobart. Surface monitoring with a thermosalinograph (TSG) and water sampling were carried out along the whole cruise track ([Fig. 1](#)). Top-to-bottom conductivity-

temperature-depth (CTD) profiler observations were conducted at six sites on a meridional transect at 110°E. The geographical settings of the six sites and complementary information on the CTD operations are summarized in [Table 1](#).

3. Materials, methods, and technical validation

The data obtained from CTD observations were conductivity (S/m), temperature (°C), and pressure (dbar), and those obtained from CTD water sampling were salinity (PSS-78), dissolved oxygen ($\mu\text{mol L}^{-1}$), nitrate ($\mu\text{mol L}^{-1}$), nitrite ($\mu\text{mol L}^{-1}$), phosphate ($\mu\text{mol L}^{-1}$), and silicate ($\mu\text{mol L}^{-1}$). TSG observations provided the sea surface conductivity (S/m) and temperature (°C). For both CTD and TSG observations, salinity (PSS-78) was also derived from conductivity, temperature, and pressure, using the algorithm for the practical salinity scale 1978¹². In this section, details of the instruments and methods used to obtain and validate the data are provided.

3.1. TSG

A TSG system developed by CT&C Co. Ltd. was used to observe sea surface temperature and conductivity (and hence salinity) along the complete cruise track, except for within the Australian Exclusive Economic Zone, from the 3rd to 26th, January 2019. The temporal resolution of the TSG system is a minute, and the water intake was approximately 4.3 m below the sea surface. For the conductivity and temperature sensor, an ETSG2 TSG (S/N: 1424-30JULY05), provided by Falmouth Scientific Inc., was used. The nominal accuracies for temperature and salinity are ± 0.1 °C and ± 0.02 PSS-78, respectively. Please note that TSG temperature is likely increased by 0.2–0.8 °C due to warming along the flow path between the water intake and the temperature sensor; the temperature increase is estimated by comparison with near surface temperature (above 10 m) obtained by CTD. We thus plan to deploy the temperature sensor in the proximity of the water intake.

To calibrate TSG salinity, 20 water samples were obtained from the TSG intake (the sampling positions are shown by gray triangles in [Fig. 1](#)). The methods for salinity correction followed the section 3.1. of [reference 13](#). A comparison between TSG and bottle salinity is summarized in [Fig. 2](#).

3.2. CTD

The methods and instruments used to obtain CTD data followed those of MacTaggart *et al.* (2010)¹⁴, as described below.

3.2.1. CTD system configuration

We used a CTD system composed of a CTD SBE9plus and a 24-position carousel water sampler provided by Sea-Bird Electronics (SBE) Inc. with 8-L Niskin bottles mounted on the frame for

sampling water. The CTD system was equipped with pressure, temperature (primary and secondary), conductivity (primary and secondary), and altitude sensors (sensor details are given in [Table 2](#)). The data were acquired at 24-Hz resolution, and the nominal accuracies for pressure, temperature, and conductivity were $\pm 0.015\%$ of the full-scale range (corresponding to ± 1.0 dbar), ± 0.001 °C, and ± 0.0003 S/m (corresponding to ± 0.004 PSS-78), respectively. Please note that the salinity accuracy is derived by applying the typically observed pressure, temperature, and conductivity range in the Southern Ocean to the algorithm for the practical salinity scale 1978¹². Pre-cruise calibrations were performed for the pressure, temperature, and conductivity sensors from August to September 2018 at SBE Inc. Secondary temperature and conductivity sensors were used only to monitor and back up the primary sensors, and an altitude sensor was used to ensure the acquisition of near-bottom data. Therefore, the data obtained using these sensors are not provided.

3.2.2. Data acquisition and processing

The raw CTD data were acquired in real-time using Seasave-Win32 (ver.7.23.2) software, provided by SBE Inc., and stored on the hard disk of a personal computer. Water samples were collected during the upcast by sending firing commands. The CTD system was stopped at each sampling depth for 60 s before bottle closure, so that the water inside and surrounding the bottle to settle to equilibrium. The manner of data processing followed the section 3.2.3. of [reference 13](#), which used SBE Data Processing-Win32 (ver.7.23.2) software provided by SBE Inc. with some originally developed modules.

3.2.3. Post-cruise calibration

Considering pressure sensitivity, the temperature obtained from the primary temperature sensor (03P2863) was corrected according to Uchida *et al.* (2007)¹⁵ as follows:

$$T_{cor} = T_{obs} - 3.20069 \times 10^{-7} \times P \quad \text{Eq. 1}$$

where T_{cor} is corrected temperature, T_{obs} is observed temperature, and P is pressure. The calibration coefficient of -3.20069×10^{-7} (°C /dbar), which implies a subtraction of 1.44×10^{-3} °C at the deepest observation (~4500 dbar), was derived from a direct comparison with SBE 35 (Deep Ocean Standards Thermometer) in January 2015. Ambiguity remained for temporal drift and temperature bias due to viscous heating effect. Regarding temporal drift, based on previous calibration results provided by SBE Inc., and the time elapsed since the pre-cruise calibration, it was expected not to exceed 1×10^{-3} °C during the observation period. Regarding the viscous heating effect, the results of an in situ calibration suggest that it will not exceed 1×10^{-3} °C (Uchida *et al.*, 2007)¹⁵. It is thus likely that the overall temperature accuracy was less than that of the World Ocean Circulation Experiment (WOCE)¹⁶ and the Global Ocean Ship-Based Hydrographic Investigation Program (GO-SHIP)¹⁷ target

$(2 \times 10^{-3} \text{ }^{\circ}\text{C})$.

Considering the pressure sensitivity and temporal drift during the cruise, conductivity was corrected using the following equation:

$$C_{cor} = C_{obs} - (c_0 \times C_{obs} + c_1 \times P + c_2 \times C_{obs} \times P + c_3 \times P^2 + c_4 \times C_{obs} \times P^2 + c_5 \times C_{obs}^2 \times P^2 + c_6) \quad \text{Eq. 2}$$

where C_{cor} is corrected conductivity, C_{obs} is observed conductivity, and P is pressure (dbar).

The coefficients $C_0 - C_6$ are calibration coefficients and were estimated by the least squares method to minimize the sum of the squared differences between the corrected conductivity and the conductivity calculated from bottle salinity (details for determining bottle salinity are given in Section 3.4.). The corrected salinity was then derived from T_{cor} , C_{cor} , and pressure. A comparison between the CTD and bottle salinity is presented in [Fig. 3](#).

The pressure offset from the pre-cruise calibration was also assessed by comparing the on-deck and atmospheric pressures. The on-deck pressure was measured for 2 min both before and after each CTD cast. The mean offset over the whole period, however, was negligible (0.46 dbar), and post-cruise calibration was therefore not conducted.

3.3. Water sampling

Using 8-L Niskin bottles mounted on a CTD frame, water samples for the measurement of salinity, dissolved oxygen, and nutrients were obtained from 23 layers (25, 50, 75, 100, 125, 150, 200, and 250 dbar; 100-dbar intervals from 300 to 1,000 dbar; 1,250 and 1,500 dbar; 500-dbar intervals from 2,000 to 3,500 dbar; the deepest layer; and an arbitrary selected layer) for each cast. The surface-layer water samples were complemented using a bucket sampler at each site. Sampling was omitted if the bottom depth was shallower than the sampling layer. Considering the sensitivity to contamination from air entering the Niskin bottles, samples were collected in the order of dissolved oxygen, salinity, and nutrients. As mentioned in Section 3.1., 20 salinity samples were also obtained from the TSG intake for calibration purposes.

To assess sampling and subsequent measurement repeatability, replicate samples were obtained for the CTD water sampling. For salinity, replicate samples were obtained from four layers: the second, fourth, sixth, and eighth layers from the bottom. For dissolved oxygen, replicate samples were obtained from five layers: the first, third, fifth, seventh, and ninth layers from the bottom. For nutrients, replicate samples were obtained from six layers: 500, 1,000, 1,500, 2,000, 2,500, and 3,000 dbar. In the following subsections, the methods and instruments used for sampling and measurements are described for salinity (Section 3.4.), dissolved oxygen (Section 3.5.), and nutrients (Section 3.6.).

3.4. Salinity

The method of salinity measurement followed that of Kawano (2010)¹⁸ as described below.

3.4.1. Sampling and measurements

During the cruise, 162 samples from Niskin bottles and buckets (including 24 replicate samples) and 20 samples from TSG water were collected with the manner explained in the section 3.4.1. of [reference 13](#).

Sample salinity was determined using a salinometer (Model 8400B “AUTOSAL”, Guildline Instruments Ltd., S/N 63904). The measurable instrument salinity range was 0.005–42 (PSS-78) with an accuracy of ± 0.002 (PSS-78) over 24 h without re-standardization. The salinometer resolution was 0.0002 (PSS-78) at a salinity of 35 (PSS-78).

During the measurements, the salinometer bath and the laboratory temperature were monitored with precision digital thermometers (Model 1502A, FLUKE Co.), with an accuracy of 0.006 °C, and a thermo-recorder (TR-77Ui, T&D Co.) with an error limit of ± 0.1 °C. The temperature of the air-conditioned laboratory on board the ship varied from 20 °C to 24 °C. The salinometer bath temperature was stable and varied by ± 0.001 °C, with a set temperature of 24 °C. We followed the section 3.4.2. of [reference 13](#) for a detailed manner of the measurements.

3.4.2. Quality control

The measurements were validated using IAPSO Standard Sea Water (SSW), which is specified as Batch P162, with a conductivity ratio of 0.99983 (double conductivity ratio 1.99966), salinity of 34.993, and expiration date of April 16, 2021.

The standardization control for the salinometer was 553. The values of STANBY and ZERO were 5861 ± 0001 and $0.0-0002 \pm 0001$, respectively. In total, 14 bottles of SSW (P162) were measured. The time series exhibited a decreasing trend for the measured double conductivity ratio ([Fig. 4a](#)). The linear trend was estimated by the least squares method, and the measured double conductivity ratios of the SSW and samples were corrected to compensate for this. The corrected double conductivity ratios are shown in [Fig. 4b](#); the mean double conductivity ratio was 1.99966, with a standard deviation of 0.00001 (equivalent to 0.0003 in salinity).

To detect sudden salinometer drift between the SSW measurements, the salinity of sub-standard seawater was measured every five to seven samples. Sub-standard seawater was made from filtered sea water and stored in a 20-L polyethylene container, which was stirred for at least 24 h in the laboratory before measurement.

The salinity measurement accuracy was estimated as 0.0003 PSS-78 from the standard deviation of the measured SSW salinity after correction. Precision was assessed using 24 pairs of replicate samples taken from the same Niskin bottle. The root-mean-square of the absolute difference among the 24 pairs ([Fig. 5](#)) was 0.0006 PSS-78. Therefore, both the accuracy and precision of the determined

salinity satisfied the requirements of both WOCE¹⁶ (0.002 PSS-78 for accuracy and 0.001 PSS-78 for precision) and GO-SHIP¹⁷ (0.001 PSS-78 for accuracy and precision).

3.5. Dissolved oxygen

Dissolved oxygen was measured using the Winkler titration method, according to the methods described by Dickson (1996)¹⁹ and Langdon (2010)²⁰ as follows.

3.5.1. Sampling and measurement

During the cruise, 167 samples from Niskin bottles and buckets (including 29 replicate samples) were collected. Details of sampling and measurement methods are same with those given in the sections 3.5.1. and 3.5.2. of [reference 13](#). The instrument and reagent details are summarized in [Table 3](#).

3.5.2. Quality control

The sodium thiosulfate titrant concentration was determined using a potassium iodate solution. Pure potassium iodate was dried in an oven at 130 °C and 1.7835 g was dissolved in deionized water and diluted to a final volume of 5 L in a volume-calibrated flask. The resulting molarity was 0.001667 mol L⁻¹. A standard potassium iodate solution (10 mL) was added to a flask using a volume-calibrated dispenser. Then, 90 mL of deionized water, 1.0 mL of sulfuric acid solution, and 1.0 mL of Winkler reagents II and I were added to the flask in that order. The sodium thiosulfate titrant molarity was calculated from the titrated volume, which was usually the average of five measurements.

The oxygen contents of the Winkler reagents I (1.0 mL) and II (1.0 mL) were assumed to be 7.6×10^{-8} mol²¹. The blank due to anything other than oxygen was determined as follows: 1 and 2 mL of the standard potassium iodate solution were added to two flasks, respectively, using a calibrated dispenser. Then, 100 mL of deionized water, 1 mL of sulfuric acid solution, and 1.0 mL of Winkler reagent solutions II and I were added to the flask in that order. The blank was determined from the difference between the first (1 mL of KIO₃) titrated volume of sodium thiosulfate and the second (2 mL of KIO₃). The results of triplicate blank determinations were averaged ([Table 4](#)).

The overall precision of this procedure was assessed using 29 pairs of replicate samples collected from the same Niskin bottle. The root-mean-square of the absolute difference among the 29 pairs was 0.16 µmol L⁻¹. The precisions stipulated by the WOCE¹⁶ and GO-SHIP¹⁷ requirements are less than 0.1% and 0.08% of the highest concentration observed in ocean, respectively. By using the maximum dissolved oxygen concentration determined during the cruise (400 µmol L⁻¹) as a reference for the highest concentration, the criteria became 0.40 µmol L⁻¹ and 0.32 µmol L⁻¹, respectively. Therefore, our precision satisfied both the WOCE¹⁶ and the GO-SHIP¹⁷ requirements.

3.6. Nutrients

The nutrient (nitrate, nitrite, silicate, and phosphate) concentration measurements followed the methods of Hydes *et al.* (2010)²² as described below.

3.6.1. Sampling, measurement, and data processing

During the cruise, 173 samples from Niskin bottles and buckets (including 35 replicate samples) were collected. Details of sampling and measurement methods are same with those given in the section 3.6.1. of [reference 13](#).

Nutrient concentrations were measured using a QuAAtro 2-HR system (BL Tec K.K.). To measure all the samples within 24 h of collection, we performed QuAAtro runs immediately after leaving station (five runs in total). The analytical methods and subsequent data processing for nutrient concentration determinations (nitrate, nitrite, silicate, and phosphate) were same as those given in the sections 3.6.2. and 3.6.3. of [reference 13](#).

3.6.2. Quality control

For the nitrate standard, we used “potassium nitrate 99.995 Suprapur®”, provided by Merck (Lot 1452165, CAS No. 7757-79-1). For the nitrite standard, we used “nitrous acid iron standard solution (NO₂⁻ 1000, Lot APR5598, Code No. 140-06451)”, provided by Wako (after 2018, the corporation was re-named FUJIFILM Wako Pure Chemical Co.). This standard solution was certified by Wako using ion chromatography. The calibration result was 1003 mg/L at 20 °C. The expanded uncertainty of the calibration ($k = 2$) was 0.7%. For the silicate standard, we used “Silicon standard solution SiO₂ in NaOH 0.5 mol/l CertiPUR®”, provided by Merck (Lot HC73014836, CAS No. 170236). The silicate concentration was certified by NIST-SRM3150, with an uncertainty of 0.7%. The HC73014836 silicate standard was certified to be 1000 mg L⁻¹. For the phosphate standard, we used “potassium dihydrogen phosphate anhydrous 99.995 Suprapur®”, provided by Merck (Lot B1144508, CAS No. 7778-77-0).

Certified reference materials (CRM; provided by KANSO Co. Ltd.) were prepared to maintain the inter-comparability of the measurements. The prepared CRM (CK, CJ, CC, CB, and BZ; details are given in [Table 5](#)) covered the full range of Southern Ocean nutrient concentrations. Lot CB was measured in every run to detect any temporal drift. The calibration curves for the respective nutrient components were obtained for every run using five reference points, which were derived from the CRM and in-house standards, as summarized in [Table 6](#).

The repeatability of all the above methods was assessed based on measurements of the in-house standard, which were made every seven to eight samples. Coefficients of variation (CVs) were then estimated from the means and standard deviations of the in-house standard measurements ([Table 7](#)). These were less than 0.18%, 0.30%, 0.11%, and 0.17% for nitrate, nitrite, silicate, and phosphate, respectively.

4. Data Records

Vertical CTD profiles (temperature and salinity) and CTD water sampling data (salinity, dissolved oxygen, and nutrient concentrations) are shown in [Figs. 6](#), and [7](#), respectively. The sea surface temperature and salinity obtained by TSG are shown in [Fig. 8](#). The CTD and water sampling data were provided in the WHP-Exchange Format²³. The TSG data were provided in the .csv format. The data columns in the TSG file are as follows: Nav Date/Time – date/time derived from the GPS mounted on the ship (UTC); Latitude/Longitude – latitude/longitude derived from the GPS mounted on the ship; C-T Temp – temperature derived from the ETSG2 TSG; and Salinity – salinity derived from the ETSG2 TSG.

5. Competing interests

The authors declare no competing financial interests.

6. Figures

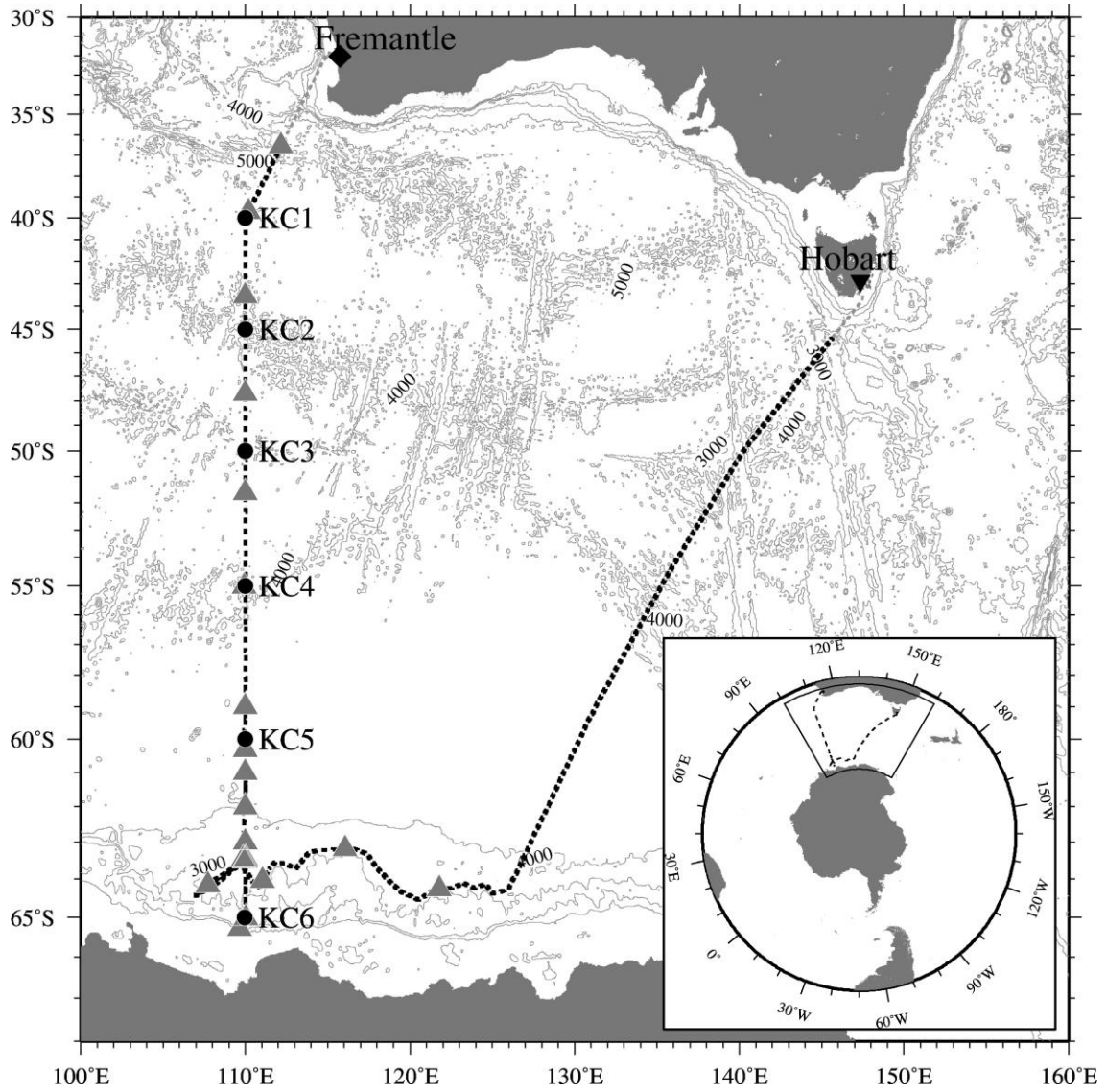


Figure 1. Cruise track and locations of observation sites during the UM-18-08 cruise.

Black circles indicate the locations where the CTD observations were conducted. Gray triangles show the positions where salinity samples were obtained from the TSG. The broken line indicates the cruise track (gray parts indicate Australian Exclusive Economic Zone where TSG data was not obtained). The diamond and inverted triangle indicate the locations of the ports of Fremantle and Hobart, respectively. The bottom-right inset map provides the locations of the observation region (solid line) and cruise track (broken line) in the Southern Ocean.

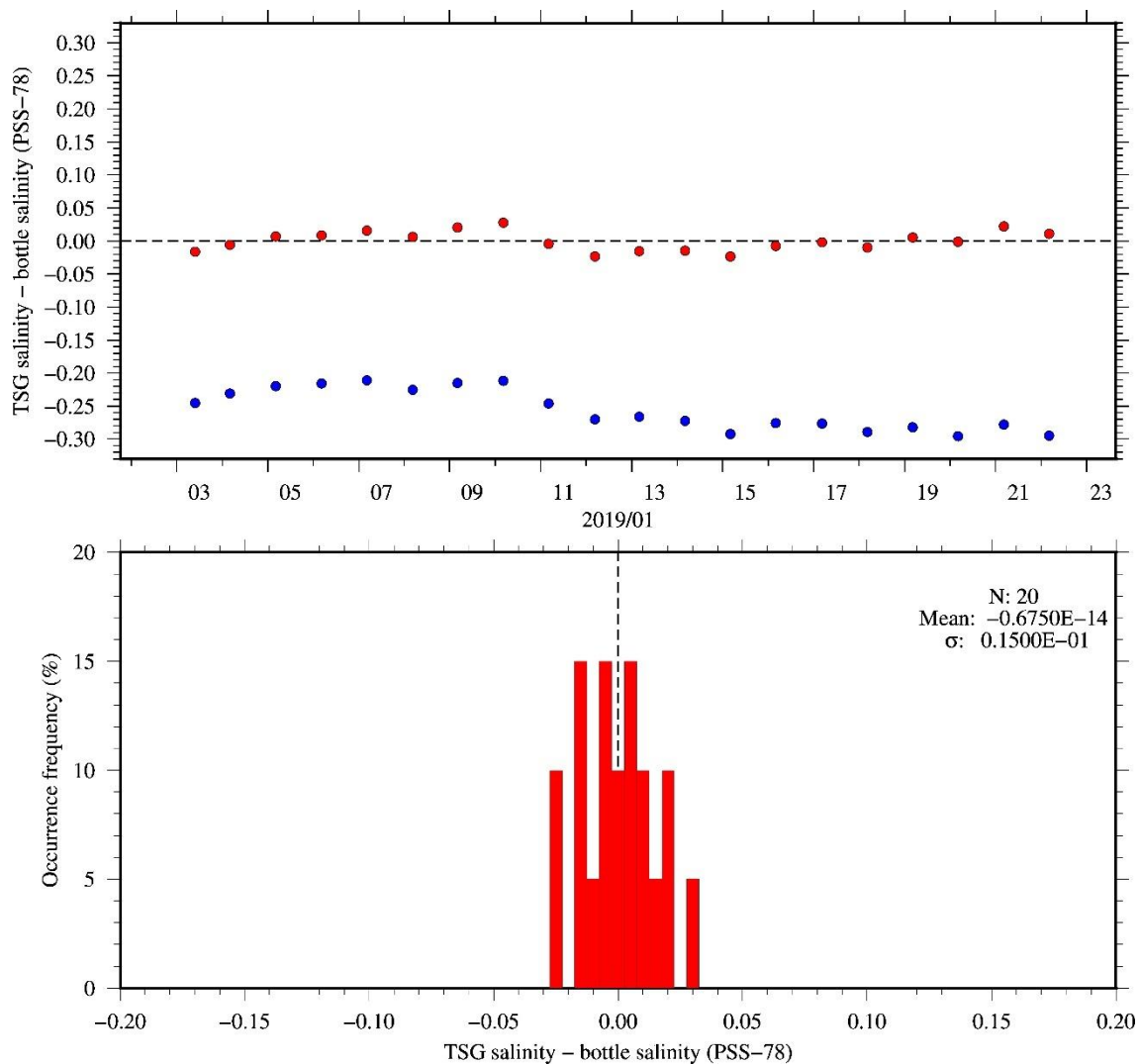


Figure 2. Salinity difference between TSG and bottle salinity.

The upper panel shows the time series of differences between TSG and bottle salinity before (blue) and after (red) post-cruise calibration. The lower panel is a histogram of the differences after the calibration. N and Mean/ σ in the lower panel indicate the number of bottle salinities and average/standard deviation of the difference between the CTD and bottle salinity, respectively.

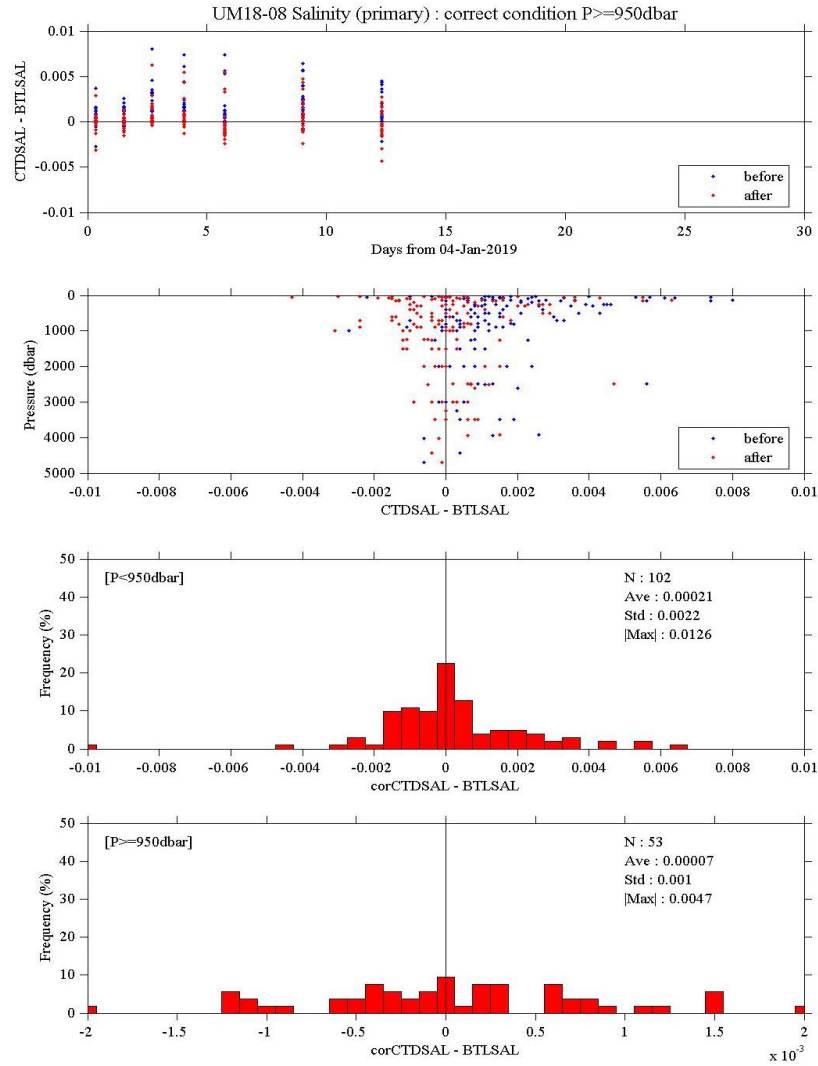


Figure 3. Difference between CTD salinity (primary) and bottle salinity.

The upper two panels are the time series and vertical profile of the differences between the CTD and bottle salinity before (blue) and after (red) post-cruise calibration, respectively. The lower two panels are histograms of the differences after calibration and are divided according to the observed pressure. Here, a separation depth of 950 dbar was chosen because the background vertical salinity gradient, which may influence the salinity difference between the CTD and bottle through the vertical distance between the CTD sensors and Niskin bottles (e.g., ~ 1 m), increases/decreases above/below this depth. N, Ave/Std, and |Max| in the panels indicate the number of bottle salinities, average/standard deviation of the difference between CTD and bottle salinity, and the maximum value for the absolute difference between CTD and bottle salinity, respectively.

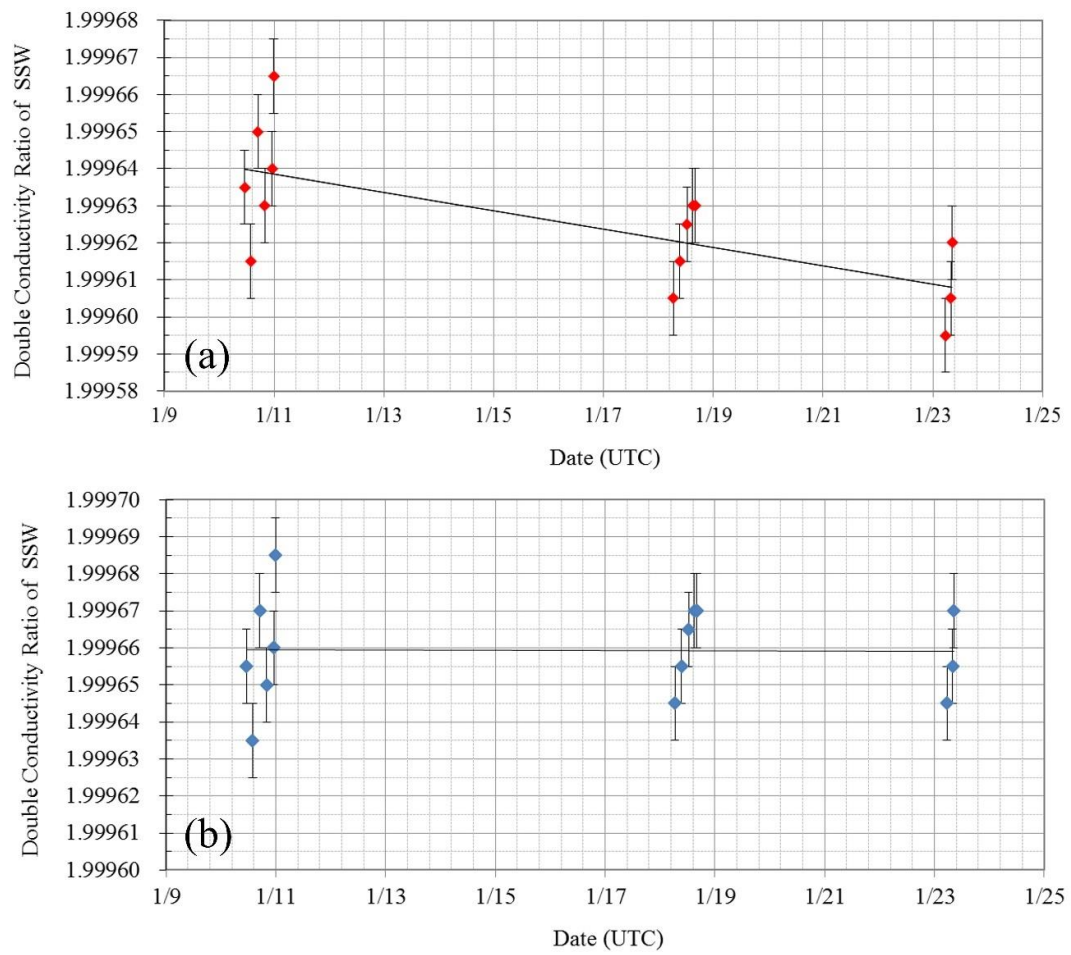


Figure 4. Time series of the double conductivity ratio for Standard Sea Water (SSW) P160. Time series before and after correction are shown in (a) upper and (b) lower panel, respectively. Solid lines indicate regression lines, and error bars indicate standard deviations for each measurement.

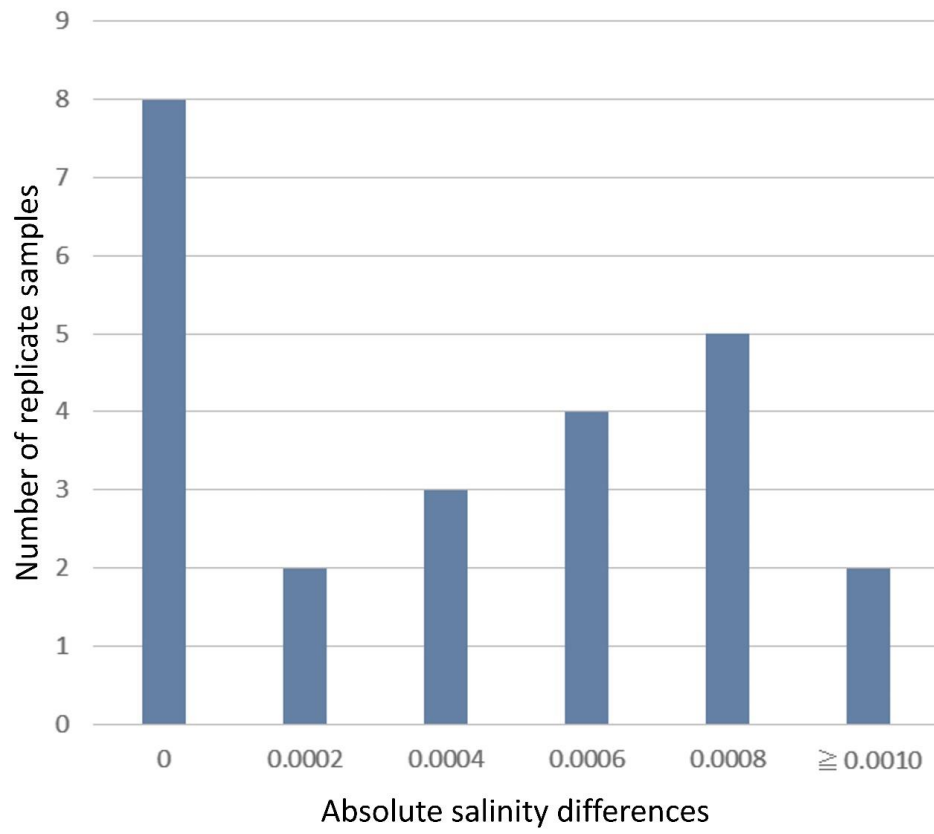


Figure 5. Histogram of the absolute differences between replicate samples.

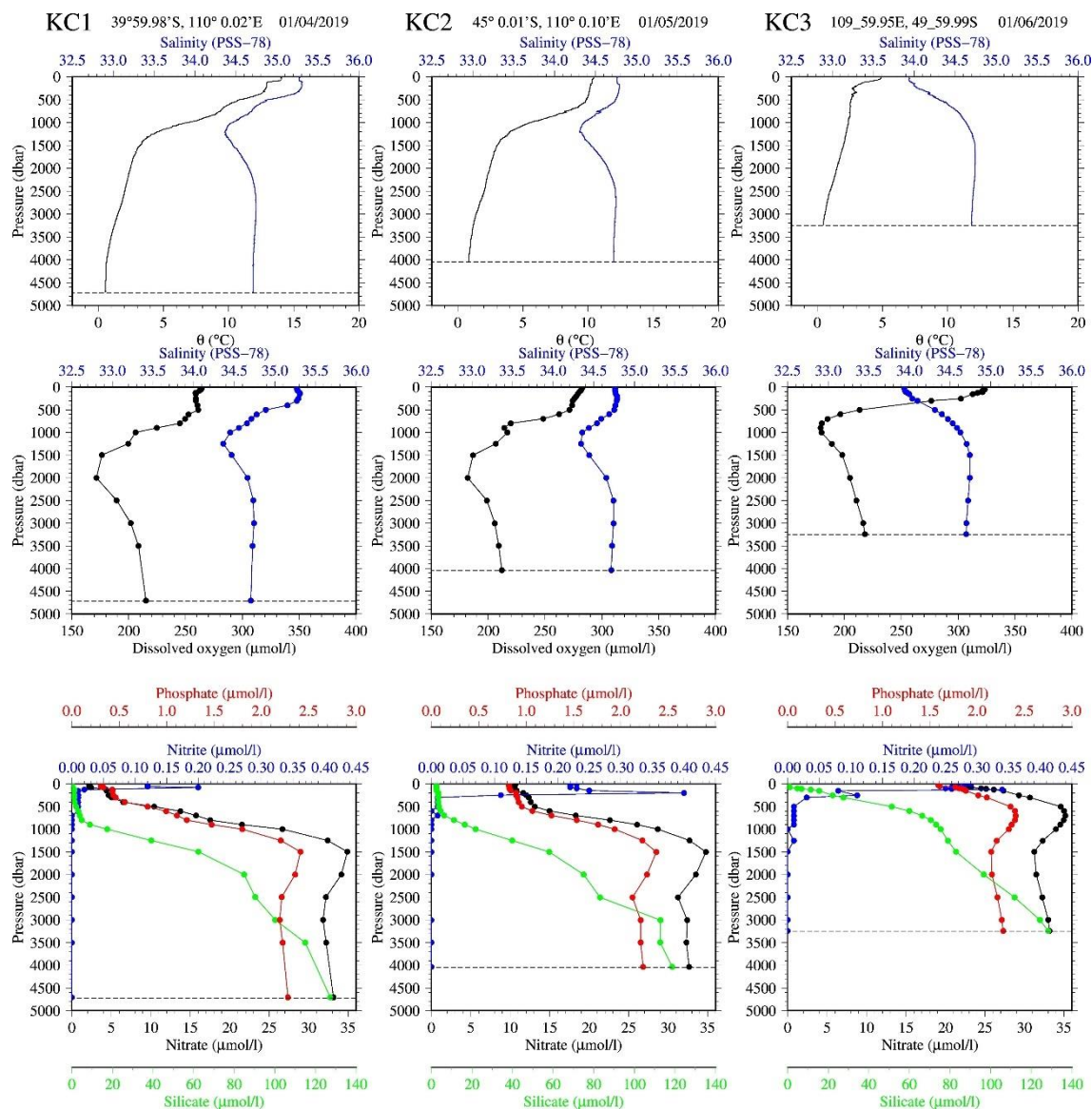


Figure 6. Vertical profiles of CTD and water sampling data.

The left, middle, and right panels show the vertical profiles of KC1, KC2, and KC3, respectively. The upper, middle, and lower panels are vertical profiles of CTD data (temperature and salinity), water sampling data (salinity and dissolved oxygen), and water sampling data (nutrients). The broken line in each panel indicates the pressure at the seafloor.

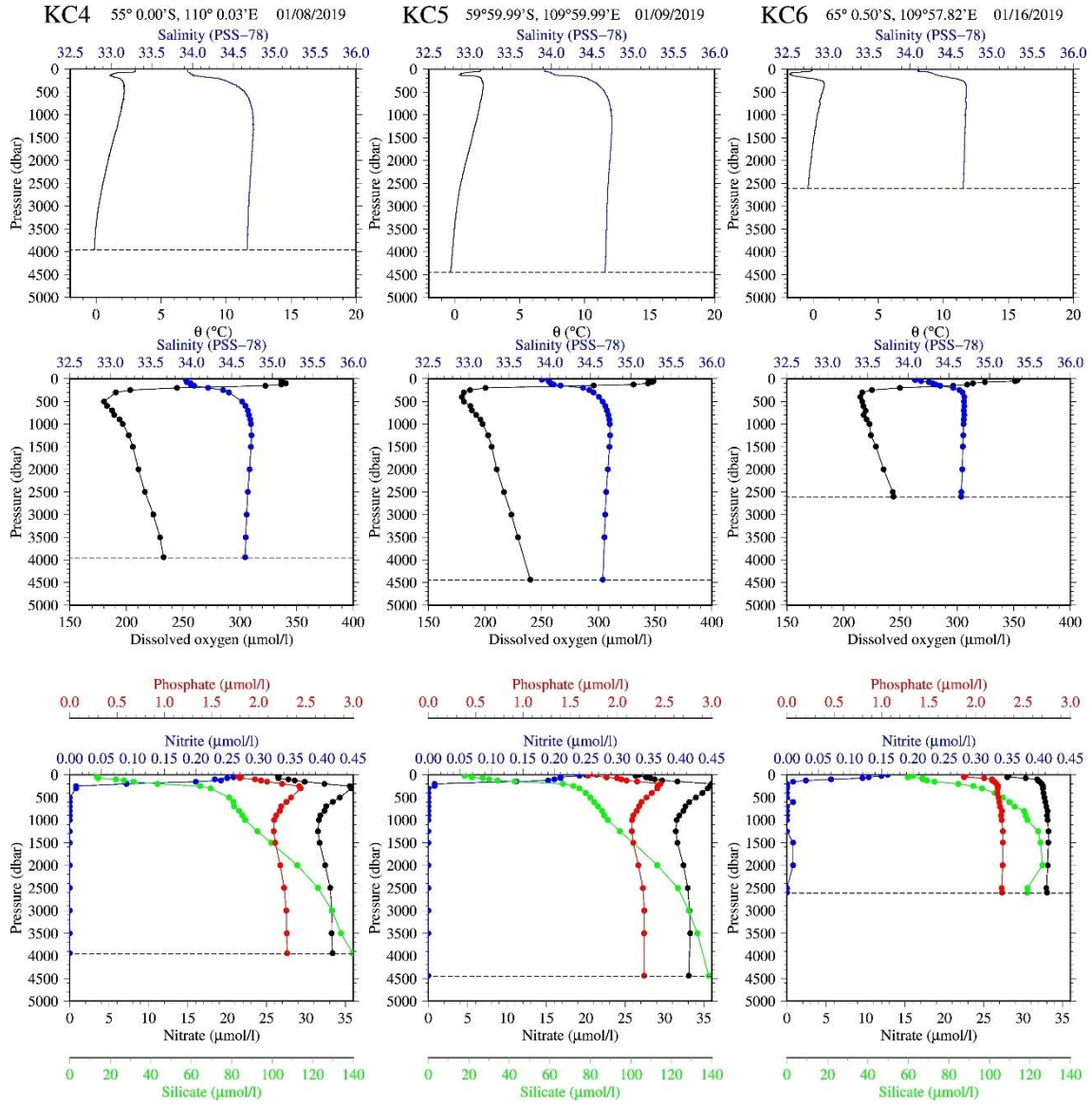


Figure 7. Vertical profiles of CTD and water sampling data.

The left, middle, and right panels show the vertical profiles of KC4, KC5, and KC6, respectively. The upper, middle, and lower panels are vertical profiles of CTD data (temperature and salinity), water sampling data (salinity and dissolved oxygen), and water sampling data (nutrients). The broken line in each panel indicates the pressure at the seafloor.

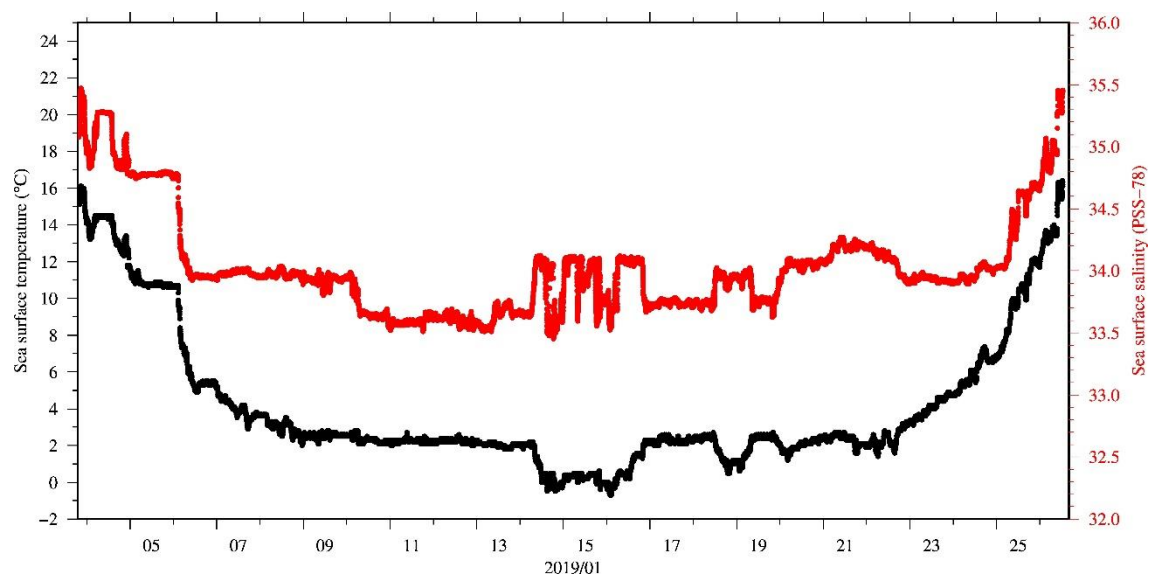


Figure 8. Time series of temperature and salinity obtained by TSG.

7. Tables

Table 1. Summary of CTD observations during the UM-18-08 cruise.

Station name, latitude/longitude (decimal degrees), start date and time, bottom depth estimated from the ship-mounted depth recorder, maximum depth observed, pressure at maximum depth, and minimum distance above bottom are summarized. Please note that bottom depth is defined as sum of the maximum depth observed by CTD and the minimum distance above bottom obtained by altimeter. The differences from bottom depth obtained by ship-mounted depth recorder (sound speed correction is applied using the gridded dataset for the Southern Ocean²⁴) were generally within 10 m.

Station	Latitude (°S)	Longitude (°E)	Date, Time (UTC)				Bottom depth (m)	Max. depth (m)	Max. pressure (dbar)	Min. distance above bottom (m)
			Year	Month	Day	Start time				
KC1	39.9995	110.0003	2019	1	4	6:17	4634	4625	4713	9
KC2	44.9998	110.0002	2019	1	5	11:10	3976	3966	4037	10
KC3	49.9995	110.0003	2019	1	6	14:58	3201	3191	3244	10
KC4	55.0000	109.9998	2019	1	7	23:33	3883	3873	3945	10
KC5	60.0003	109.9993	2019	1	9	16:11	4362	4352	4440	10
KC6	65.0082	109.9630	2019	1	16	6:24	2574	2565	2607	9

Table 2. Specifications of the CTD system used during the UM-18-08 cruise.

Type of instruments, product names, manufacturers, serial numbers, and calibration dates are given.

Type of instrument	Product name	Manufacturer	Serial number	Calibration date
Underwater unit	SBE9plus	Sea-Bird Electronics, Inc.	09P22763-0590	August 21, 2018
Pressure sensor	Digiquartz pressure sensor	Sea-Bird Electronics, Inc.	77509	August 21, 2018
Temperature sensor (primary)	SBE03plus	Sea-Bird Electronics, Inc.	03P2863	September 27, 2018
Temperature sensor (secondary)	SBE03plus	Sea-Bird Electronics, Inc.	03P5679	September 27, 2018
Conductivity sensor (primary)	SBE04C	Sea-Bird Electronics, Inc.	44376	September 27, 2018
Conductivity sensor (secondary)	SBE04C	Sea-Bird Electronics, Inc.	42415	September 28, 2018
Altimeter	PSA-916T	Teledyne Benthos, Inc.	59546	
Carousel water sampler	SBE32	Sea-Bird Electronics, Inc.	3273491-0949	
Submersible Pump (primary)	SBE5T	Sea-Bird Electronics, Inc.	052786	
Submersible Pump (secondary)	SBE5T	Sea-Bird Electronics, Inc.	057891	
Bottom contact switch	Bottom contact switch	Sea-Bird Electronics, Inc.		
Deck unit	SBE11plus	Sea-Bird Electronics, Inc.	11P90698-0969	

Table 3. Details of instruments and reagents used during the UM-18-08 cruise.

Instruments/reagents	Details
Burette used for sodium thiosulfate	808 Titrande (Metrohm Japan Ltd.)
Burette used for potassium iodate	789 MPT Titrimo (Metrohm Japan Ltd.)
Winkler Reagent I	Manganese chloride solution (3 mol dm ⁻³)
Winkler Reagent II	Sodium hydroxide (8 mol dm ⁻³) / sodium iodide solution (4 mol dm ⁻³)
Sulfuric acid solution	5 mol dm ⁻³
Sodium thiosulfate	0.025 mol dm ⁻³
Potassium iodide	0.001667 mol dm ⁻³

Table 4. Results of the standardization and blank determination during the UM-18-08 cruise.

Date, KIO₃ ID, Na₂S₂O₃ ID, end-point reading of titration, estimated blank, and applied station are listed.

Date	KIO ₃ ID	Na ₂ S ₂ O ₃ ID	End point	Blank	Station
1/3/2019	K1805I01	T1806J	3.968	-0.004	KC1, KC2, KC3
1/7/2019	K1805I02	T1806J	3.972	-0.002	KC4, KC5
1/13/2019	K1805I03	T1806J	3.970	0.002	KC6
1/20/2019	K1805I04	T1806J	3.965	-0.001	

Table 5. Certified concentrations and uncertainties of CRMs.

Certified concentrations with uncertainties (coverage factor $k = 2$) of nitrate, nitrite, silicate, and phosphate are given for CRMs CK, CJ, CC, CB, and BZ. All CRMs were provided by KANSO Co. Ltd. All concentrations were expressed in $\mu\text{mol kg}^{-1}$. The values given for nitrite are references. Details are also available on the manufacturer's website (http://www.kanso.co.jp/eng/production/available_lots.html).

Lot	Nitrate	Nitrite*	Silicate	Phosphate
CK	0.02 ± 0.03	0.01 ± 0.01	0.73 ± 0.08	0.048 ± 0.012
CJ	16.20 ± 0.20	0.03 ± 0.01	38.50 ± 0.40	1.190 ± 0.020
CC	30.88 ± 0.24	0.12 ± 0.01	86.16 ± 0.48	2.080 ± 0.019
CB	35.79 ± 0.27	0.12 ± 0.01	109.2 ± 0.62	2.520 ± 0.022
BZ	43.35 ± 0.33	0.22 ± 0.01	161.0 ± 0.93	3.056 ± 0.033

Table 6. CRMs and nominal nutrient concentrations for the in-house standard used for the calibration curves. CRM lots and nominal nutrient concentrations for the in-house standard (expressed in units of $\mu\text{mol L}^{-1}$) are given for the nutrient components. The in-house standard is adopted for C-5, and CRMs are adopted for C-1, C-2, C-3, C-4, and C-6.

	C-1	C-2	C-3	C-4	C-5	C-6
NO_3	CK	CJ	CC	-	36	BZ
NO_2	CK	CJ	CC	-	1.0	BZ
SiO_2	CK	CJ	CC	CB	-	BZ
PO_4	CK	CJ	CC	-	2.4	BZ

Table 7. Descriptive statistics for CV (%) based on the replicate analyses.

Statistics (median, mean, maximum, and minimum) based on five CV estimates are listed for nitrate, nitrite, silicate, and phosphate.

	Nitrate	Nitrite	Silicate	Phosphate
Median	0.13	0.18	0.07	0.14
Mean	0.13	0.19	0.08	0.12
Maximum	0.18	0.30	0.11	0.17
Minimum	0.18	0.12	0.04	0.07
Number of CV estimate	5	5	5	5

Author contributions

K. Shimada performed the sample analysis and wrote the manuscript. K. T. Takahashi, R. Makabe, and M. Moteki conducted field sampling on board the T/V *Umitaka-maru*. T. Odate and J. Kanda directed the monitoring program.

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