Physical and chemical oceanographic data during *Umitaka-maru* cruise of the 58th Japanese Antarctic Research Expedition in January 2017

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Abstract: Connecting all major ocean basins, the Southern Ocean is pivotal in the meridional overturning circulation of the global oceans. High-quality physical and chemical oceanographic data in the Southern Ocean are thus critical for improved understanding of future climates. As a part of the 58th Japanese Antarctic Research Expedition research project, we have obtained high quality Conductivity Temperature Depth (CTD) and water sampling data (salinity, dissolved oxygen, and nutrients) at 5 sites located along 110°E transect, the southern end of which reached the sea ice edge. Sea surface temperature and salinity were continuously obtained with a Thermosalinograph (TSG) along cruise track taken between Ports of Fremantle and Hobart, except for Australian Exclusive Economic Zone. Data quality was validated by following as far as possible the recommendation for instruments and methods of the global Ocean Ship-Based Hydrographic Investigation Program. CTD (including expendable CTD) and water sampling data are provided in Exchange formats for World Ocean Circulation Experiment Hydrographic Program CTD and bottle data; TSG data are in simple .csv format.

1. Background & Summary

Connecting all major ocean basins, the Southern Ocean is pivotal in the meridional overturning circulation and hence, global climate (e.g., Schmitz, 1996[1]). Especially, 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 climate[2].

Recently, widespread freshening of water masses, possibly linked to enhanced basal melting of the Antarctic Ice Sheet (e.g., Rignot *et al*., 2013[3]), has been reported in the Southern Ocean[4, 5]. Furthermore, there has been clear evidence of warming of AABW, which may induce a reduction of meridional overturning circulation[6, 7, 8] and contribution to sea level rise[9]. Therefore, high quality data obtained from annual monitoring observations are critical for improved understanding of future climates.

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

After JARE-51th in 2009/2010, the responsibility for maintaining the routine oceanographic observations was transferred to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as the lead agency, but an actual program of restructuring and implementing the oceanographic observations was not established. However, through the efforts of the Japanese Antarctic communities in oceanography, the oceanographic observations continued within the JARE framework, and observations were carried out during JARE-52th 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), was 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-16-08 cruise in 2017 as a part of the JARE-58th research project.

2. Study sites

During the UM-16-08 cruise, in-situ oceanographic observations were conducted along a cruise track between Ports of Fremantle and Hobart. Surface monitoring with a Thermosalinograph (TSG) and water sampling were carried out all along the cruise track (Fig. 1). Top-to-bottom Conductivity Temperature Depth profiler (CTD) observations were planned at 6 sites on a meridional transect along 110°E (Fig. 1). Due to rough oceanic conditions, however, it was replaced by eXpendable CTD (XCTD) observation at station KC2. Geographical settings of 6 sites and complementary information on CTD operations were summarized in Table 1.

3. Materials, methods, and technical validation

Data obtained from CTD are conductivity (S/m), temperature (℃), and pressure (dbar) and those obtained from CTD water sampling are salinity (PSS-78), dissolved oxygen (μmol L^{-1}), nitrate (μmol L^{-1}), nitrite (μmol L^{-1}), phosphate (μmol L^{-1}), and silicate (μmol L^{-1}). XCTD observation provided conductivity (S/m), temperature (℃), and depth (m) while TSG observation provided sea surface conductivity (S/m) and temperature (℃). For CTD, XCTD, and TSG observations, salinity (PSS-78) was also derived from conductivity, temperature, and pressure using the algorithm for practical salinity scale, 1978[10]. In this section, details on the instruments and methods used to obtain and validate the data are given.

3.1 TSG

A TSG system developed by CT&C Co., Ltd., was used to observe sea surface temperature and salinity, all along the cruise track except for Australian Exclusive Economic Zone (operated from 1st to 24th Jan. 2017). The water intake located roughly 4.3 m below the sea surface. For conductivity and temperature sensor, ETSG2 Thermosalinograph (S/N: 1424-30JULY05) provided by Falmouth Scientific, Inc. was used.

20 water samples were obtained from the TSG intake to calibrate TSG salinity. TSG salinity was corrected by using the following equation.

$$S_{cor} = s_0 \times S_{obs} + s_1 \times T + s_2,$$

where S_{cor} is the corrected salinity, S_{obs} is the observed salinity, and T is the elapsed time since the cruise started. s_0, s_1, and s_2 are calibration coefficients and were estimated by a least square method so that minimize the sum of the squared difference between corrected and bottle salinity (details for determining bottle salinity are given in section 3.2). A comparison between TSG and bottle salinity is summarized in fig. 2.

3.2. CTD

The methods and instruments used to obtain CTD data basically followed those of McTaggart *et al*. (2010)[11] 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 (hereafter referred to as SBE), Inc. 8-liter Niskin bottles were mounted on the frame and were used for sampling water. The CTD system was equipped with pressure, temperature (primary and secondary), conductivity (primary and secondary), and altitude sensor

(detail of sensors are given in table 2). Pre-cruise calibrations were performed for the pressure, primary temperature, and primary conductivity sensors during May 2016 at SBE, Inc. The secondary temperature and conductivity sensors were used only to monitor and backup the primary sensors and altitude sensor was used to ensure acquisition of near bottom data. Data obtained with these sensors are therefore not provided.

3.2.2 Data acquisition

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 the personal computer. Water samples were collected during the upcast by sending a fire command. The CTD system was stopped at each sampling depth for 60 seconds before bottle closure so that water inside and surrounding the bottles to settle to equilibrium.

3.2.3 Data processing

Acquired CTD data were processed mainly using the SBE Data Processing-Win32 (ver.7.23.2.) software provided by SBE, Inc., with some originally developed modules. Details of the processing are given below; the name of the processing modules are enclosed by double quotation marks. The quoted modules are derived from the SBE Data Processing-Win32 (ver.7.23.2.) software, unless otherwise specified.

The raw binary data were converted to engineering unit data by "DATCNV". The "DATCNV" also extracted CTD data in the vicinity of each Niskin bottle closure. The duration and the offset of the data acquisition were set to 3.0 and 0.0 seconds, respectively.

Data were re-aligned from time sequence to pressure (depth) sequence by "ALIGNCTD". This procedure ensured that all the calculations (e.g., salinity) were made using measurements from the same parcel of water.

Extreme outliers were marked by "WILDEDIT". The first pass of "WILDEDIT" is intended to obtain the true standard deviation of the data. For this purpose, data were flagged if they deviated from the mean by more than 10 standard deviations computed over the blocks of 1000 scans. The second pass computed a standard deviation over the same 1000 scans excluding the flagged values. Then, data were marked as bad if they deviated from mean by more than 20 standard deviations. This process was applied to pressure, depth, temperature, and conductivity data.

Conductivity cell thermal mass effects are removed from conductivity data using "CELLTM". Applied values for the thermal anomaly amplitude alpha and the time constant 1/beta are 0.03 and 7.0, respectively.

A low pass filter with a time constant of 0.15 second was applied to the pressure data using "FILTER". To avoid temporal shifts, the filter was first run forward and then backward.

To remove invalid data (e.g., data obtained while the CTD package was above sea surface, or

while the pump was inactive), "SBE_SECTION (an original module developed by author)" was applied. The first and last valid scan were defined to be the first scan after starting the downcast and the last scan with the CTD package beneath the sea surface, respectively. We applied "LOOPEDIT" to remove data obtained while descending motion reversed during downcast because of ship roll.

Finally, salinity was calculated with "DERIVE" and 1-dbar pressure bins averages were obtained with "BINAVG".

3.2.4 Post cruise calibration

Temperature, conductivity, and derived salinity were corrected as follows. Considering pressure sensitivity, temperature obtained from primary temperature sensor (03P2863) is corrected according to Uchida *et al.* (2007)[12] as follows:

$$T_{cor} = T_{obs} - 3.20069 \times 10^{-7} \times P,$$

where T_{cor} is the corrected temperature, T_{obs} is the observed temperature, and P is pressure. The calibration coefficient of -3.20069×10^{-7} (℃/dbar), which implies subtraction of 1.44×10^{-3} ℃ at the deep most observation (⊔ 4500 dbar), was derived from direct comparison with SBE 35 (Deep Ocean Standards Thermometer) in January 2015. Ambiguity remained about temporal drift. However, based on previous calibration results provided by SBE, Inc. and time elapsed since the pre-cruise calibration, it was expected not to exceed 1×10^{-3} ℃ during observation period. It is thus likely that the overall accuracy of temperature was smaller than the World Ocean Circulation Experiment (WOCE)[13] and Global Ocean Ship-Based Hydrographic Investigation Program (GO-SHIP)[14] target (2×10^{-3} ℃).

Considering pressure sensitivity and temporal drift during the cruise, conductivity is corrected by using following equation.

$$C_{cor} = c_0 \times C_{obs} + c_1 \times P + c_2 \times C_{obs} \times P + c_3 \times t + c_4,$$

where C_{cor} is the corrected conductivity, C_{obs} is the observed conductivity, P is pressure (dbar), and t is the elapsed time since the cruise started. The coefficients c_0, c_1, c_2, c_3, and c_4 are calibration coefficients and were estimated by a least squares method so that 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 3.2). Then, corrected salinity was derived from T_{cor}, C_{cor}, and pressure. A comparison between CTD and bottle salinity is summarized in fig. 3.

The pressure offset from the pre-cruise calibration was also assessed by comparison between the on-deck pressure and atmospheric pressure. The on-deck pressure was measured for 2 minutes both before and after each CTD cast. The mean offset over the whole period, however, was negligible (-0.61 dbar) and post-cruise calibration was therefore not conducted.

3.3 Water sampling

This section summarizes how we sampled water during the cruise with several different instruments and depths.

By using 8-liter Niskin bottles mounted on CTD frame, water samples for 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 1000 dbar; 1250 and 1500 dbar; and 500-dbar intervals from 2000 to 3500 dbar, and deep most layer) for each cast. Surface layer water samples were complemented by using bucket sampler at each site. Sampling was omitted if the bottom depth was shallower than the sampling layer. Considering the sensitivity against contamination induced by air that entered the Niskin bottles, samples were collected in order of dissolved oxygen, salinity, and nutrients. Also, as mentioned in section 3.1, 20 salinity samples were also obtained from the TSG intake for calibration purpose.

To assess the repeatability of sampling and subsequent measurement, replicate samples were obtained for CTD water sampling. In the case of salinity/dissolved oxygen, replicate samples were obtained from 4 layers: the second/first, fourth/third, sixth/fifth, and eighth/seventh layers from the bottom. In the case of nutrients, replicate samples were obtained from 6 layers: the third, fifth, sixth, eighth, thirteenth, and twentieth layer from the bottom. 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 measurements followed that of Kawano (2010)[15] as described below.

3.4.1 Sampling

We sampled water with 8-liter Niskin bottles, bucket, and the TSG. A sample bottle of 250 ml clear glass with an inner cap was used and each bottle was rinsed 3 times with sample water and was filled with sample water to the bottleneck. The bottles were stored for more than 24 hours in the laboratory before the measurements.   During the cruise, 138 samples from Niskin bottles and buckets (including 19 replicate samples), and 20 samples from TSG water were measured.

3.4.2 Measurement

Sample salinity was determined using a Salinometer (Model 8400B "AUTOSAL", Guildline Instruments Ltd., S/N 63904). The measuring salinity range of the instrument was 0.005 to 42 (PSS-78) with an accuracy better than ±0.002 (PSS-78) over 24 hours without re-standardization. The maximum resolution of the salinometer was better than ±0.0002 (PSS-78) at salinity of 35 (PSS-78). During the measurements, the temperature of the salinometer bath and laboratory were monitored

with precision digital thermometers (Model 1502A; FLUKE Corporation) with an accuracy of 0.006°C and a thermo-recorder (TR-77Ui; T&D Corp.) with error limits of ±0.1°C, respectively. Air-conditioned ship's laboratory temperature varied in the range of 20 to 24°C. The salinometer bath temperature rarely deviated by more than ±0.001°C away from 23.990°C. The set temperature of the salinometer bath was 24°C.

Measurements were conducted with a double conductivity ratio. Each measurement was started 5 second after the sample water had filled the cell and it took roughly 11 second to determine the stable reading. The cell was rinsed with sample water 5 times before data measurement were made. If the difference between the first and the second measurements was smaller than 0.00002, the mean value was adopted for calculating the bottle salinity with the algorithm for the practical salinity scale 1978[10]. Otherwise, the mean value of the second and third measurements was adopted if the difference satisfied above criteria. In the case when the third measurement did not satisfy the criteria, we added two additional measurements and used the median of the five measurements.

3.4.3 Quality control

The measurements were validated by using two batches of Standard Sea Water (SSW) which are respectively specified as Batch P159: conductivity ratio 0.99988, salinity 34.995, expiration date 15 December 2018 and Batch P158: conductivity ratio 0.99970, salinity 34.988, expiration date 25 March 2018.

The standardization control of the salinometer was set to 536 on 5 January and was changed to 563 on 15 January. The value of STANBY and ZERO were 5847±0001 and 0.0-0000±0001, respectively. In total, 7 bottles of SSW (P159) were measured and the mean of the double conductivity ratio was 1.99565 with a standard deviation being 0.00007 (equivalent to 0.0013 in salinity). Time series exhibit decreasing trend in measured double conductivity ratio (fig. 4a). The trend was estimated by least squares method and the measured double conductivity ratios of the SSW and samples were corrected to compensate it. Corrected time series of the SSW (P159) double conductivity ratios is shown in fig. 4b and the mean of the double conductivity ratio was 1.99976 with standard deviation being 0.00000 (equivalent to 0.0000 in salinity). As for SSW (P158), the mean and standard deviation are estimated from 5 measurements as 1.99941 and 0.00004 (equivalent to 0.0009 in salinity), respectively (fig. 5a). These measurements and sample measurements are corrected in the same manner as that of SSW (P159). The corrected average of the double conductivity ratio was 1.99940, and the standard deviation was 0.00000, which is equivalent to 0.0001 in salinity (fig. 5b).

To detect sudden drift in the salinometer between SSW measurements, the salinity of sub-standard seawater was measured every 6 or 10 samples. Sub-standard seawater was made from filtered sea water and stored in a 20-liter polyethylene container and was stirred for at least 24 hours in the laboratory before measurement.

The accuracy of this overall method was assessed by using 19 pairs of replicate samples taken

from the same Niskin bottle. The average and the standard deviation of the absolute difference among the 19 pairs were 0.00046 and 0.00050 PSS-78, respectively (Fig. 6). The accuracy, which was determined by adding the above average and standard deviation to give 0.00096 PSS-78, satisfied both the WOCE[13] (0.002 PSS-78) and GO-SHIP[14] (0.001 PSS-78) requirements.

3.5. Dissolved oxygen

Dissolved oxygen was measured by Winkler titration method according to the methods described by Dickson (1996)[16] and Langdon (2010)[17] as follows.

3.5.1 Sampling

We sampled water with 8-liter Niskin bottles and buckets. Volume calibrated flask (approximately 100 mL) was used for sampling. The temperature was measured with digital thermometer while three times volume of seawater was overflowed the flask. Then two reagent solutions (Winkler reagent I and II) of 1.0 mL each were added immediately, and the stopper was inserted carefully into the flask. The flask was then shaken vigorously to thoroughly mix the contents. After the precipitate had settled at least halfway down the flask, the flask was re-shaken vigorously to disperse the precipitate. The flasks containing the pickled samples were stored in a laboratory until they were titrated. During the cruise, 139 samples from Niskin bottles and buckets (including 19 replicate samples) were measured.

3.5.2 Measurement

At least two hours after the re-shaking, the pickled samples were measured on board. 1 mL sulfuric acid solution and a magnetic stir bar were added to the sample flask, and stirring began. Samples were titrated with a sodium thiosulfate solution whose molarity was determined as described in the next subsection. The temperature of the sodium thiosulfate during titration was recorded with a thermometer. The dissolved oxygen concentration (μmol L^{-1}) was calculated based on sample temperature obtained during sampling, the flask volume, and the titrated volume of sodium thiosulfate solution. Details for instruments and reagents are summarized in table 3.

3.5.3 Quality control

Concentration of the sodium thiosulfate titrant was determined with potassium iodate solution. Pure potassium iodate was dried in an oven at 130°C. Accurately weighed out 1.7835 g of potassium iodate was dissolved in deionized water and diluted to final volume of 5 L in a volume calibrated flask. The resulting molarity is 0.001667 mol L^{-1}. A 10 mL of the standard potassium iodate solution 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 pickling reagent solutions II and I were added to the flask in that

order. The molarity of sodium thiosulfate titrant was calculated from the volume of titrated sodium thiosulfate. This volume was usually the average of 5 measurements.

The oxygen in the pickling reagents I (1.0 mL) and II (1.0 mL) was assumed to be 7.6 x 10^{-8} mol[18]. 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 pickling 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 KIO_3) titrated volume of sodium thiosulfate and the second (2 mL of KIO_3) one. The results of triplicate blank determinations were averaged (Table 4).

The overall accuracy of this procedure was assessed by 19 pairs of replicate samples obtained from the same Niskin bottle. The standard deviation of the replicate measurement, estimated following Dickson *et al*. (2007)[19], was 0.18 μ mol L^{-1}. The accuracy stipulated by WOCE[13] and GO-SHIP[14] requirements is that twice the standard deviation should be less than 0.5% of the highest concentration found in the ocean. By using the maximum dissolved oxygen concentration determined during the cruise (360.5 μ mol L^{-1}) as a refence for the highest concentration found in the ocean, this criterion becomes 1.8 μ mol L^{-1}. Hence, our accuracy satisfied both WOCE[13] and GO-SHIP[14] requirements.

3.6. Nutrients

The methods of Nutrients concentration (nitrate, nitrite, silicate, and phosphate) measurements followed that of Hydes *et al*. (2010)[20] as described below.

3.6.1. Sampling

We sampled water with 8-liter Niskin bottles and bucket. A previously unused 10 ml polyacrylate vial was used for sampling. Each vial was rinsed 3 times with sample water and was immediately capped after filling. To stabilize the sample temperature, the vials were stored in an air-conditioned laboratory (room temperature was in the range of 20-24℃) before the measurements and were measured within 24 hours after collection. During the cruise, 149 samples from Niskin bottles and buckets (including 30 replicate samples) were measured.

3.6.2. Measurement

Nutrients concentrations were measured with an QuAAtro 2-HR system (provided by BL Tec K.K.). To measure all the samples within 24 hours after collection, we made QuAAtro runs immediately after leaving every station (we made 5 runs in total).

The analytical methods used for determination of nutrient (nitrate, nitrite, silicate and phosphate) concentrations were same as those used by Kawano *et al*. (2009)[21].

For the nitrate+nitrite and nitrite analyses, modification method of Grasshoff (1970)[22] was applied. Nitrate in the sample was reduced to nitrite in a cadmium tube with its inside being coated with metallic copper. The sample stream with its equivalent nitrite was treated with an acidic, sulfanilamide reagent and the nitrite forms nitrous acid which reacted with the sulfanilamide to produce a diazonium ion. N-1-Naphthylethylene-diamine added to the sample stream then coupled with the diazonium ion to produce a red, azo dye. When nitrate is reduced to nitrite, both nitrate and nitrite react, and their sum are measured. In the absence of reduction, only nitrite reacts. No reduction is therefore performed for the nitrite analysis, and an alkaline buffer is not required. Finally, nitrate is computed by difference.

The analytical method used for silicate analysis was analogous to that of phosphate described in next paragraph. The method essentially followed that of Grasshoff *et al.* (1983)[23], wherein silicomolybdic acid is first formed from the silicate in the sample and added molybdic acid; the silicomolybdic acid is then reduced to silicomolybdous acid, or "molybdenum blue", using ascorbic acid as the reductant.

The analytical method for phosphate was a modification of the procedure described by Murphy and Riley (1962)[24]. Seawater sample was added by molybdic acid to form phosphomolybdic acid, which was then, reduced to phosphomolybdous acid by using L-ascorbic acid as a reductant. The flow diagrams and reagents used for each component are given in Fig. 7.

3.6.3. Data processing

The QuAAtro 2-HR raw data were processed as follows:

・Check for baseline shift.

・Check each peak, the shape and position of each peak. Shift position if necessary.

・Apply carry-over correction and baseline drift correction to each peak height. Apply sensitivity correction to peaks

・Use linear regression to apply baseline and sensitivity corrections.

・Calculate nutrient concentrations using seawater density derived from CTD pressure, bottle salinity, and laboratory temperature.

・Apply second order equations to calibration curves, which are used to obtain nutrient concentrations.

3.6.4. Quality control

For the nitrate standard, we used "potassium nitrate 99.995 suprapur®" provided by Merck, Lot. B0771365211, CAS No.: 7757-91-1. For the nitrite standard, we used "nitrous acid iron standard solution (NO_2^- 1000) provided by Wako, Lot ECP4122, Code. No. 140-06451''. This standard solution was certified by Wako using an ion chromatograph method. The calibration result is 999 mg/L at 20 ℃. The expanded uncertainty of calibration (k = 2) was 0.7 %. For the silicate standard, we used

"Silicon standard solution SiO_2 in NaOH 0.5 mol/l CertiPUR®" provided by Merck, CAS No.: 1310-73-2 (lot number: HC54715536). The silicate concentration was certified by NIST-SRM3150 with the uncertainty of 0.5 %. The HC54715536 silicate standard was then certified as 1005 mg L^{-1}. For the phosphate standard, we used "potassium dihydrogen phosphate anhydrous 99.995 suprapur®" provided by Merck, Lot B1144508528, CAS No.: 7778-77-0.

To maintain inter comparability between measurements, we used Reference Material for Nutrients in Seawater (hereafter referred to as RMNS). The prepared RMNS lots (BY, CD, CA, BW, CB and BZ; provided by The General Environmental Technos Co., Ltd.) covered the full range of nutrient concentrations in the Southern Ocean. Details of RMNS lots were available at the web site of the manufacturer (http://www.kanso.co.jp/eng/production/available_lots.html). Lot CB was measured every run to detect temporal drift.

The repeatability of above all methods was assessed based on measurements of in-house standard which were made every 6 to 9 samples. Nominal concentrations of in-house were 36.0, 1.0, 114.0, and 2.4 μ mol L^{-1} for nitrate, nitrite, silicate and phosphate, respectively. Coefficients of variation (CV) were then estimated from mean and standard deviation of in-house standard measurements. They were less than 0.12, 0.39, 0.09 and 0.18% for nitrate, nitrite, silicate and phosphate, respectively.

4. Data Records

Vertical profiles of CTD (temperature and salinity) and CTD water sampling data (salinity, dissolved oxygen, and nutrient concentrations) are shown in fig. 8 and 9, respectively. Sea surface temperature and salinity obtained by TSG are shown in fig. 10. CTD (including XCTD) data and water sampling data are provided in form of WHP-Exchange Format[25]. TSG data are provided in simple .csv format. Data columns in the TSG file are 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 ETSG2 Thermosalinograph; and Salinity– salinity derived from the ETSG2 Thermosalinograph.

5. Author contribution

K. Shimada performed the processing of sample analysis and writing of the manuscript. R. Makabe and S. Takao carried out the field sampling on board the T/V Umitaka-maru. T. Odate directed the monitoring program.

6. Competing interests

The authors declare no competing financial interests.
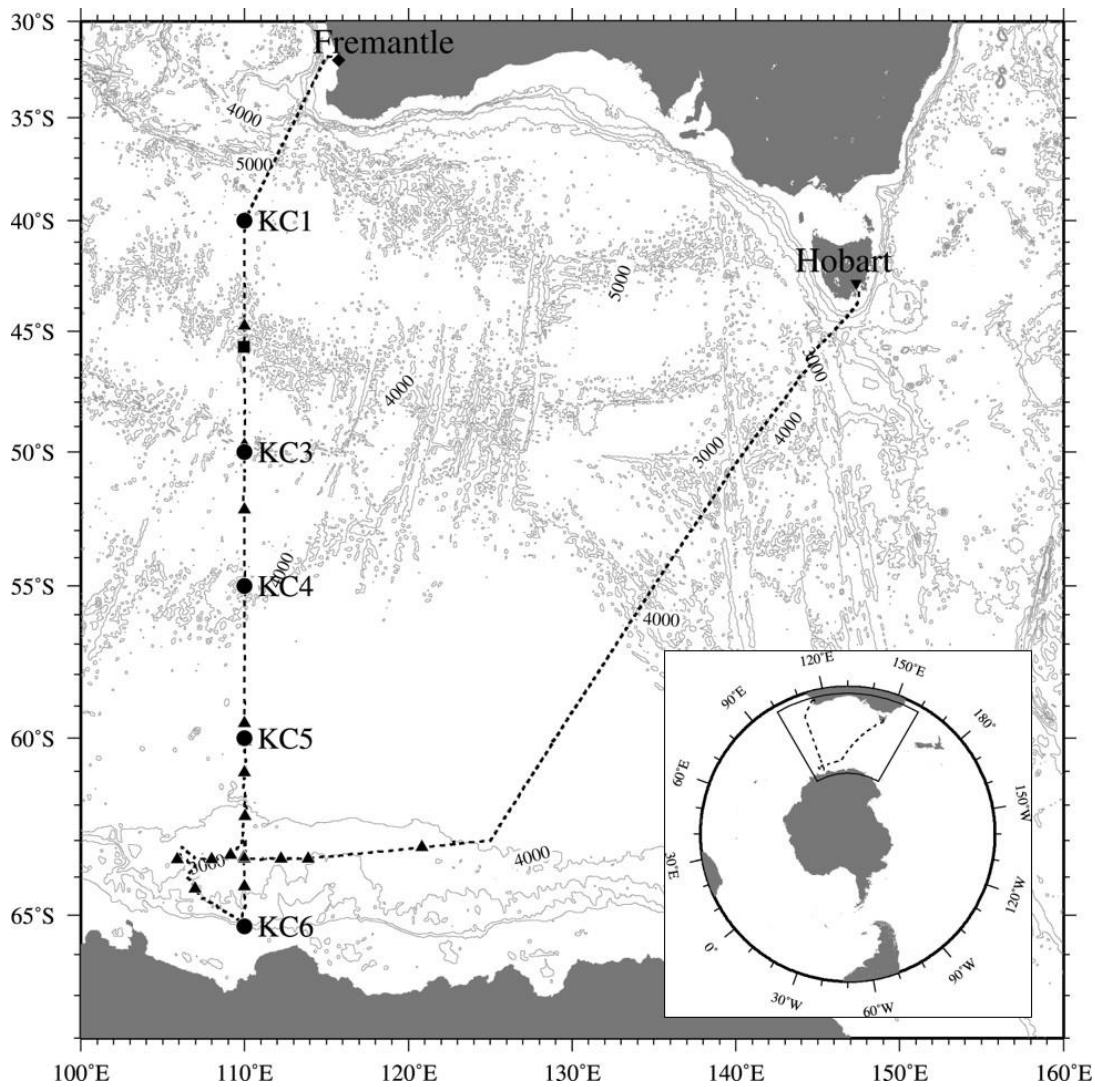
7. Figures

Fig. 1.   Cruise track and location of observation sites during UM16-08 cruise.
Circles indicate locations where CTD observation was conducted and square indicates
location where XCTD observation was conducted, instead, respectively. Triangles show
position where salinity samples were obtained from TSG intake. Broken line indicates cruise
track. Diamond and inverted triangle indicate locations of Ports of Fremantle and Hobart,
respectively. Right-bottom inlet map provides locations of observation site (solid line) and
cruise track (broken line).
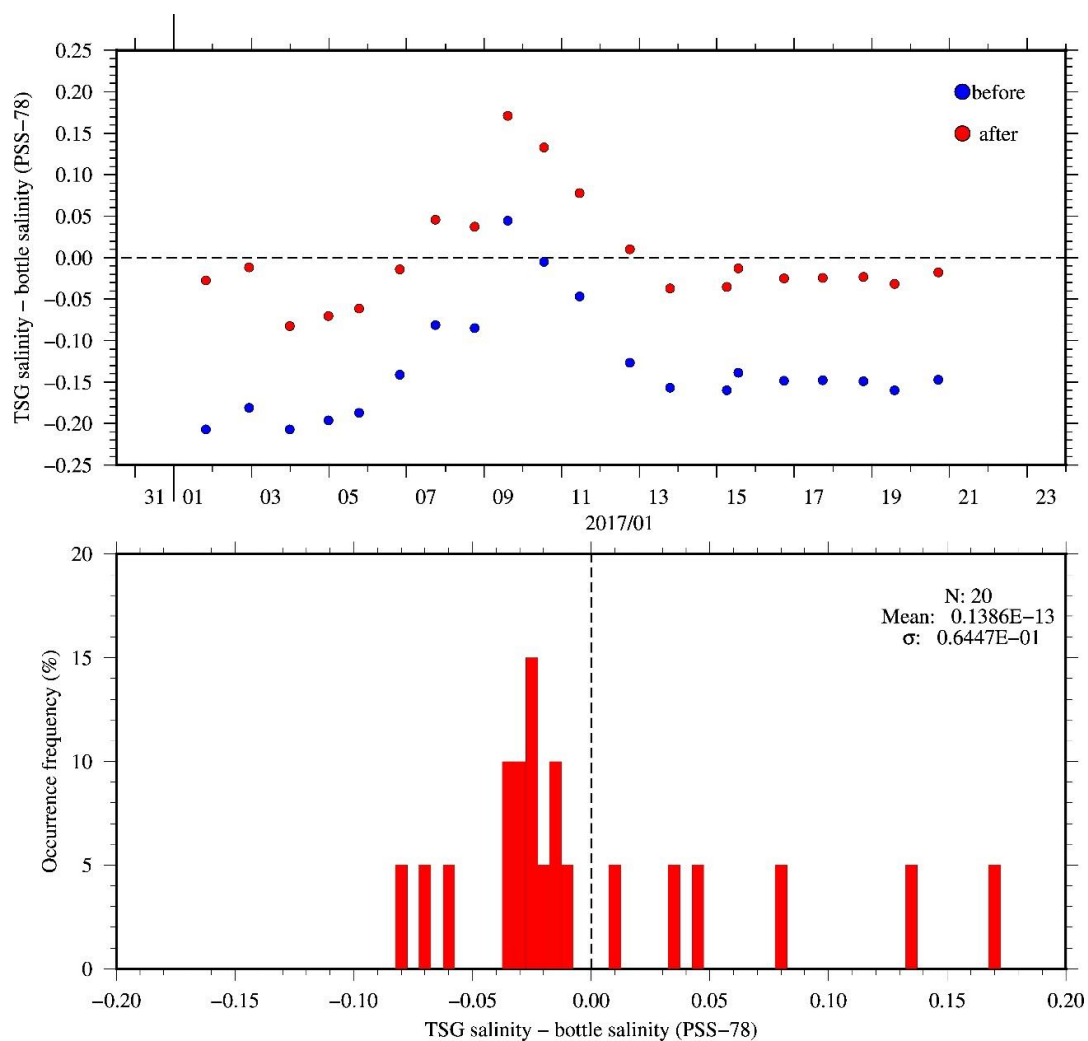
Fig. 2.   Difference between TSG and bottle salinity.

Upper panel is time series of differences between TSG and bottle salinity for before (blue) and after (red) the post-cruise calibration. Lower panel is histogram of the differences after the calibration. N, and Mean/ σ in the lower panel indicate number of bottle salinity, average/standard deviation of difference between CTD and bottle salinity, respectively.
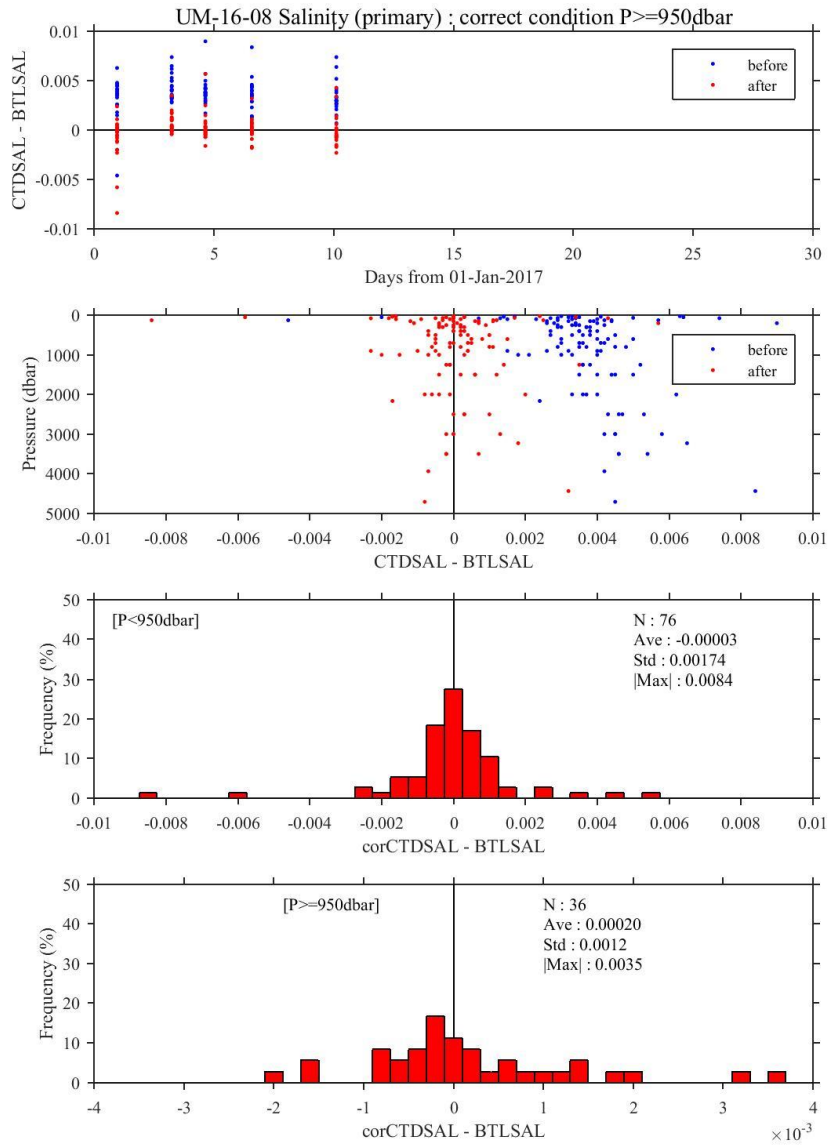
Fig. 3. Difference between CTD salinity (primary) and bottle salinity.
Upper two panels are time series and vertical profile of differences between CTD and bottle salinity for before (blue) and after (red) the post-cruise calibration, respectively. Lower two panels are histogram of the differences after the calibration. Panels are sub-divided according to observed pressure (boundary is 950 dbar) and N, Ave/Std, and |Max| in the panels indicate number of bottle salinity, average/standard deviation of difference between CTD and bottle salinity, and maximum value for absolute difference between CTD and bottle salinity, respectively.
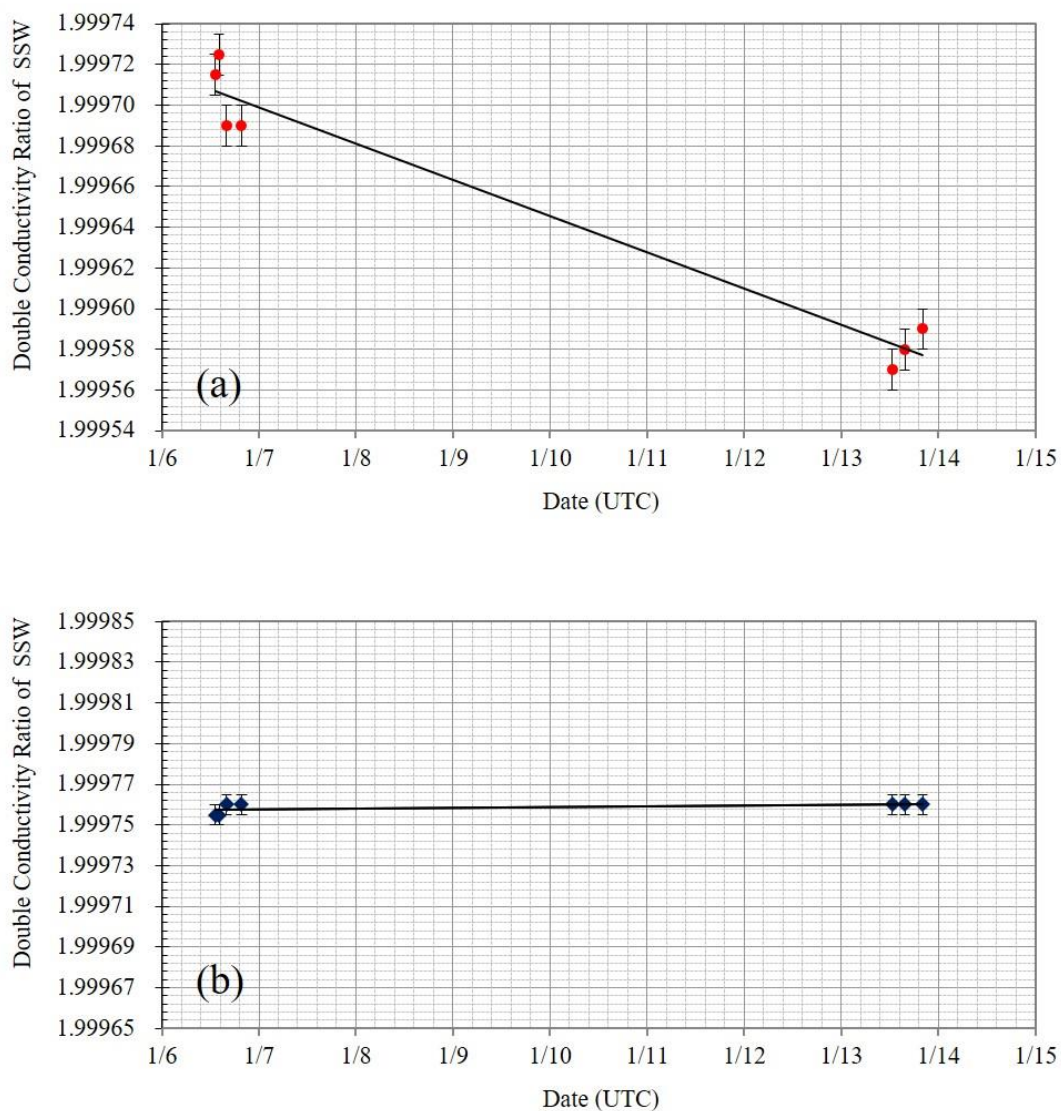
Fig. 4.   Time series of double conductivity ratio for Standard Sea Water P159.
Time series for before and after correction is shown in (a) upper and (b) lower panel,
respectively. Solid lines indicate regression lines and error bars indicate standard deviation
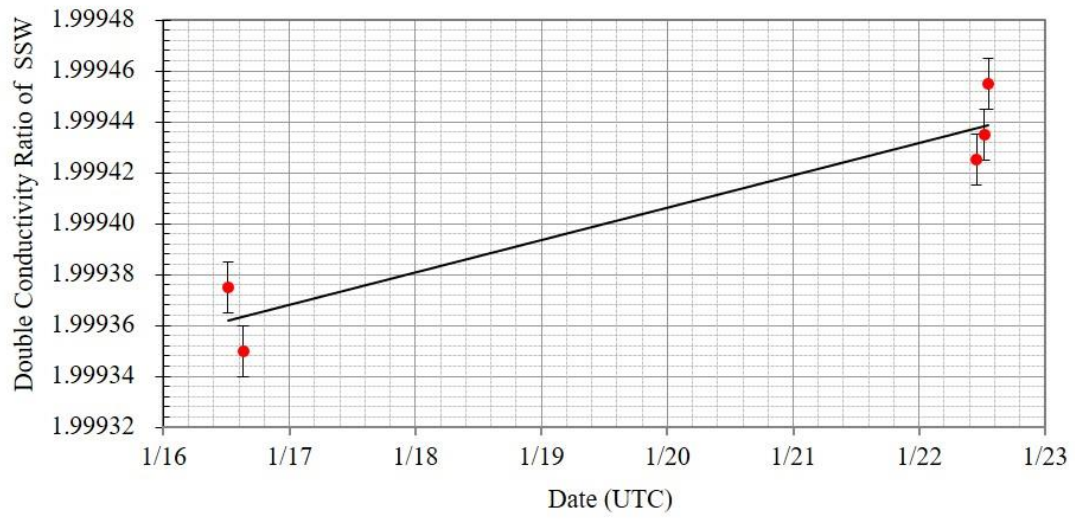for each measurement.
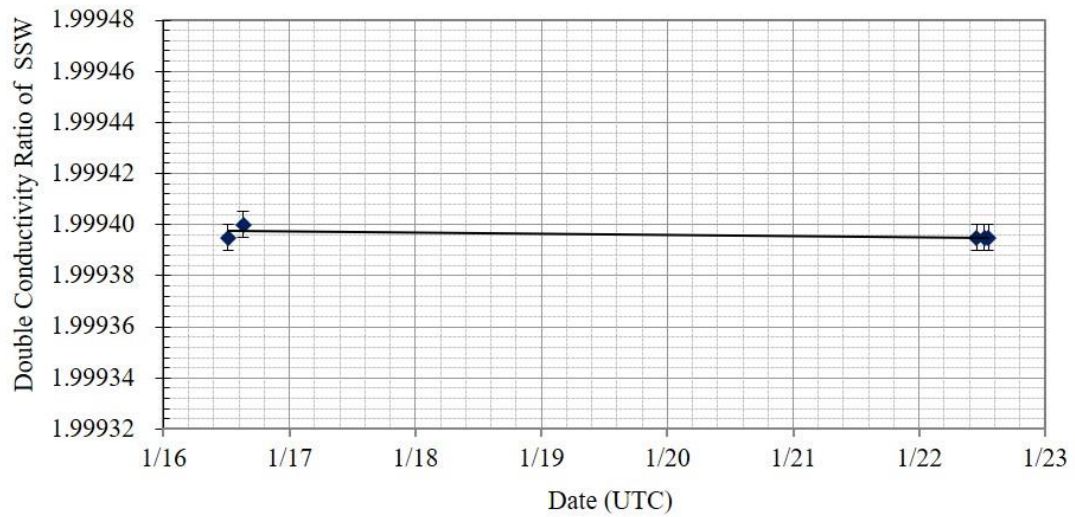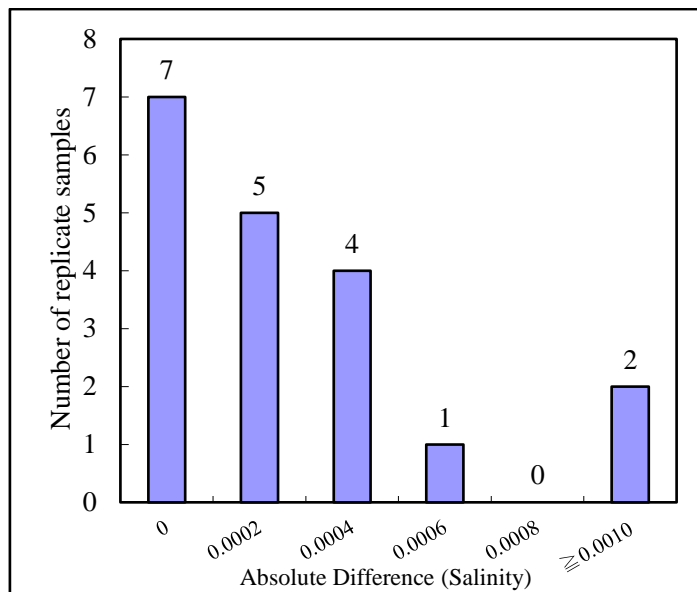
Fig. 5.   Same as fig. 4. but for Standard Sea Water P158.

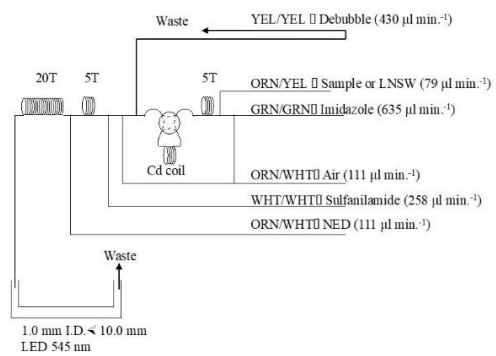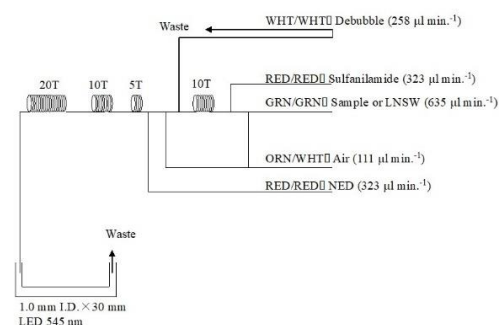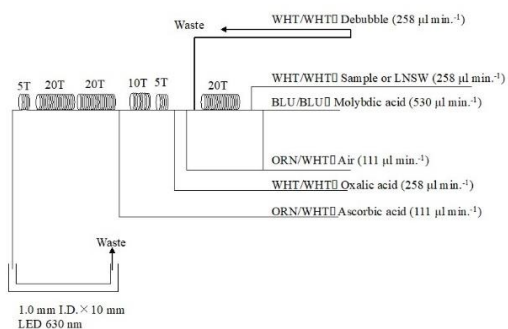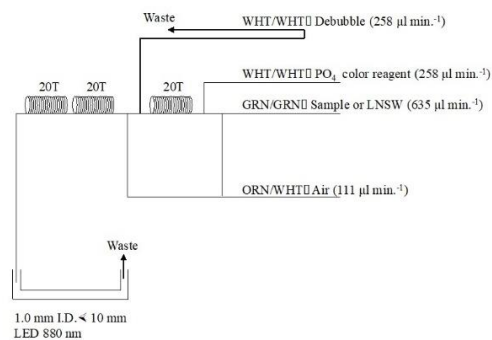Fig. 6.   Histogram of the absolute difference between replicate samples.

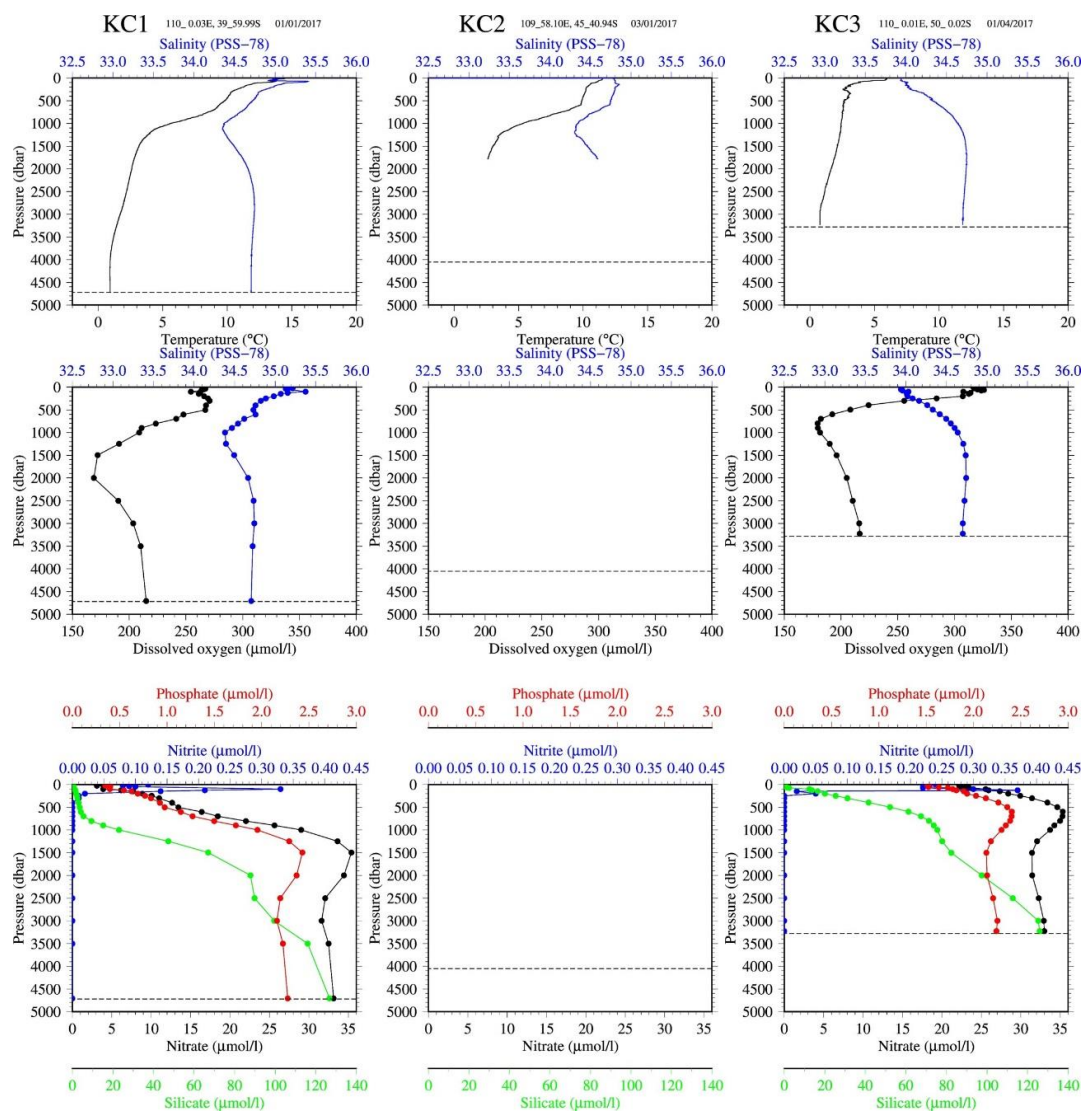Fig. 7.   The flow diagrams and reagents for channel 1 to 4.

Fig. 8. Vertical profiles of CTD and water sampling data.

Left, mid, and right panels are vertical profiles of KC1, KC2, and KC3, respectively. Upper, mid, and lower panels are vertical profiles CTD data (temperature and salinity), water sampling data (salinity and dissolved oxygen), and water sampling data (nutrients). Broken lines in respective panels indicate pressure at sea floor.
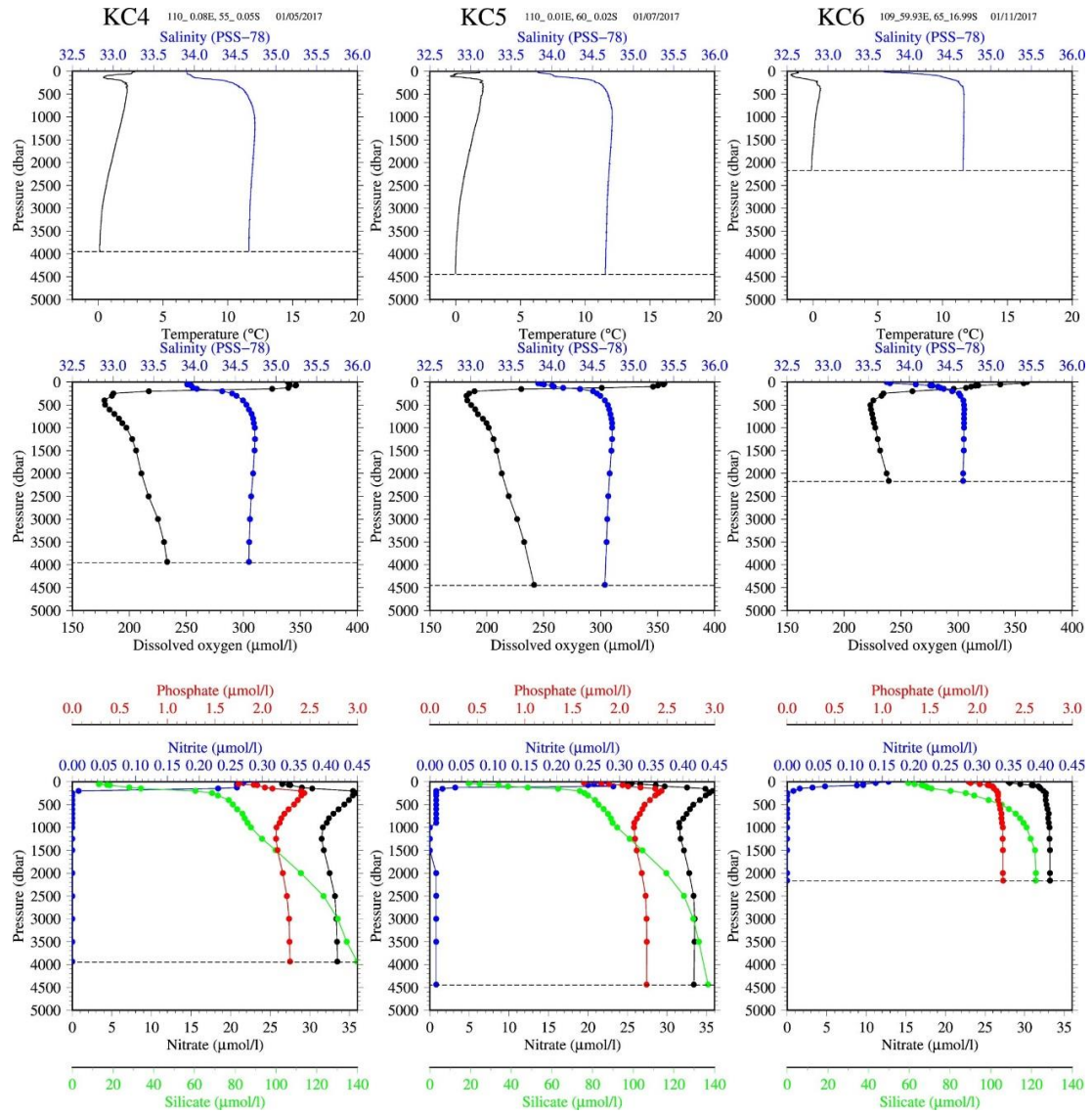
Fig. 9.   Same as fig. 8. but for station KC4 to KC6.

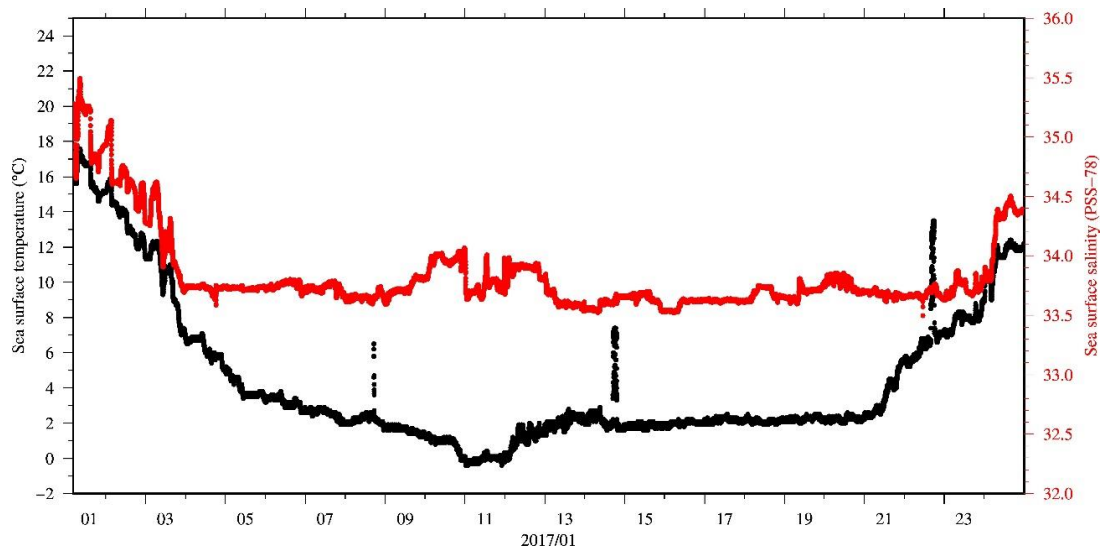Fig. 10.   Time series of temperature and salinity obtained by TSG.

8. Tables

Table 1.   Summary of CTD observations during the UM-16-08 cruise.
Station name, latitude/longitude (decimal degree), start/end date and time, bottom depth estimated from ship mounted depth recorder, maximum depth observed, pressure at maximum depth, and minimum distance above bottom are summarized.

Station name	Latitude (°N)	Longitude (°E)	Date, Time (UTC)					Bottom depth (m)	Max. depth (m)	Max. pressure (dbar)	Min. distance above bottom (m)	Remarks
			Year	Month	Day	Start time	End time					
KC1	-39.9998	110.0005	2017	1	1	21:35	0:55	4630	4624.8	4712.0	8.5	
KC2	-45.6824	109.9684	2017	1	3	5:50		3980	1766	1788	2214	Replaced by XCTD
KC3	-50.0003	110.0001	2017	1	4	4:34	7:16	3229	3180.0	3232.0	50.0	
KC4	-55.0008	110.0013	2017	1	5	14:13	17:10	3868	3868.6	3940.0	10.2	
KC5	-60.0003	110.0001	2017	1	7	12:37	15:49	4365	4352.8	4440.0	8.8	
KC6	-65.2831	109.9988	2017	1	11	1:59	3:55	2141	2132.7	2165.0	8.9	

Table 2.   Specifications of the CTD system used during the UM-16-08 cruise.
Type of instruments, product names, manufacturer, serial number, and, calibrated date are
listed.

Type of instrument	Product name	Manufacturer	Serial number	Calibrated date
Under water unit	SBE9plus	Sea-Bird Electronics, Inc.	09P22763-0590	May 24, 2016
Pressure sensor	Digiquartz pressure sensor	Sea-Bird Electronics, Inc.	77509	May 24, 2016
Temperature sensor primary	SBE03plus	Sea-Bird Electronics, Inc.	03P2863	May 19, 2016
Temperature sensor secondary	SBE03plus	Sea-Bird Electronics, Inc.	03P5679	February 20, 2015
Conductivity sensor primary	SBE04C	Sea-Bird Electronics, Inc.	42415	May 19, 2016
Conductivity sensor secondary	SBE04C	Sea-Bird Electronics, Inc.	44376	February 10, 2015
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-16-08 cruise.

Instruments/reagents	Details
Burette used for sodium thiosulfate	808 Titrando (Metrohm Japan Ltd.)
Burette used for potassium iodate	789 MPT Titrino (Metrohm Japan Ltd.)
Pickling Reagent I	Manganese chloride solution (3 mol dm^{-3})
Pickling 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}
CSK standard of potassium iodade	0.0100N (Wako Pure Chemical Industries Ltd., ID: CSK_KPG6393)

Table 4. Results of the standardization and the blank determination during the UM-16-08 cruise. Date, KIO_3 ID, $Na_2S_2O_3$ ID, end point reading of titration, estimated blank, and applied station are listed.

Date	KIO_3 ID	$Na_2S_2O_3$ ID	End point	Blank	Station
2016/12/31	K1606G05	T1606O	3.968	-0.001	KC1, KC3, KC4
2016/12/31	CSK_KPG6393	T1606O	3.970	-	-
2017/1/6	K1606G06	T1606O	3.962	0.002	KC5, KC6
2017/1/13	K1606G07	T1606O	3.963	0.001	-

Table 5.　Statics of CV (%) based on the replicate analyses.
　　　　　Statics (median, mean, maximum, and minimum) based on 5 CV estimates are listed for
　　　　　nitrate, nitrite, silicate, phosphate.

	Nitrate	Nitrite	Silicate	Phosphate
Median	0.08	0.14	0.06	0.11
Mean	0.08	0.21	0.06	0.12
Maximum	0.12	0.39	0.09	0.18
Minimum	0.05	0.06	0.02	0.09
Number of CV estimate	5	5	5	5

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