# C. Hydrographic Measurement Techniques and Calibration

## CTDO2 Measurements

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### Personnel

Keita KAKUYA (GEMD/JMA)

Kiyoshi TANAKA (GEMD/JMA)

Noriyuki OKUNO (GEMD/JMA)

Togo IDA (GEMD/JMA)

(Leg 1) Yoshikazu HIGASHI (GEMD/JMA)

(Leg 2) Yuma KAWAKAMI (GEMD/JMA)

### CTDO2 measurement system

(*Software*: SEASAVEwin32 ver7.23.2)

|  |  |  |
| --- | --- | --- |
| ***Deck unit*** | ***Serial number*** | ***Station*** |
| SBE 11plus (SBE) | 11P35251 – 0683 | RF6502 – 6571 |
| ***Under-water unit*** | ***Serial number*** | ***Station*** |
| SBE 9plus (SBE) | 09P31345 – 0722  (Pressure : 90574) | RF6502 – 6571 |
| ***Temperature*** | ***Serial number*** | ***Station*** |
| SBE 3plus (SBE)  SBE 3plus (SBE)  SBE 35 (SBE) | 03P4436 (primary)  03P5184 (secondary)  0093 | RF6502 – 6571  RF6502 – 6571  RF6502 – 6571 |
| ***Conductivity*** | ***Serial number*** | ***Station*** |
| SBE 4C (SBE) | 043697 (primary)  042987 (secondary) | RF6502 – 6571  RF6502 – 6571 |
| ***Pump*** | ***Serial number*** | ***Station*** |
| SBE 5T (SBE) | 056552 (primary)  055501 (secondary) | RF6502 – 6571  RF6502 – 6571 |
| ***Oxygen*** | ***Serial number*** | ***Station*** |
| RINKO III (JFE) | 007 (foil number:141304A)  284 (foil numner:164313A) | RF6502 – 6571  RF6502 – 6571 |
| ***Water sampler (36 position)*** | ***Serial number*** | ***Station*** |
| SBE 32 (SBE) | 32 – 1270 | RF6502 – 6571 |
| ***Altimeter*** | ***Serial number*** | ***Station*** |
| PSA-916D (TB) | 40850 | RF6502 – 6571 |
| ***Water sampling bottle*** |  | ***Station*** |
| Niskin Bottle (GO) |  | RF6502 – 6571 |

SBE: Sea- Bird Electronics, Inc., USA JFE: JFE Advantech Co., Ltd., Japan

TB: Teledyne Benthos, Inc., USA GO: General Oceanics, Inc., USA

### Pre-cruise calibration

#### (3.1) Pressure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 09P31345 - 0722, 16 Oct. 2018* | | | | | | |
| *c1* | = | –4.802766 × 104 |  | *t1* | = | 3.012930 × 10 |
| *c2* | = | –2.656902 × 10-1 |  | *t2* | = | –3.769891 × 10-4 |
| *c3* | = | 1.418260 × 10-2 |  | *t3* | = | 4.208190 × 10-6 |
| *d1* | = | 3.830200 × 10-2 |  | *t4* | = | 1.503050 × 10-9 |
| *d2* | = | 0.000000 |  | *t5* | = | 0.000000 |

Formula:



*U* (*degrees Celsius*) *=* *M* × (*12-bit pressure temperature compensation word*) + *B*

*U*: temperature in degrees Celsius

*S/N 0722* coefficients in SEASOFT (configuration sheet dated on 16 *Oct. 2018)*

*M = 1.29410 × 10-2, B = –9.10099*

Finally, pressure is computed as



*t*: pressure period (μsec)

The drift-corrected pressure is computed as



*Slope = 1.00006, Offset = −0.1142*

#### (3.2) Temperature (ITS-90): SBE 3plus

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 03P4436 (primary), 30 Aug. 2018* | | | | | | |
| *g* | = | 4.33647067 × 10-3 |  | *j* | = | 1.75059815 × 10-6 |
| *h* | = | 6.37628029 × 10-4 |  | *f0* | = | 1000.0 |
| *i* | = | 2.08841605 × 10-5 |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 03P5184 (secondary), 30 Aug. 2018* | | | | | | |
| *g* | = | 4.34777201 × 10-3 |  | *j* | = | 1.89805716 × 10-6 |
| *h* | = | 6.36464492 × 10-4 |  | *f0* | = | 1000.0 |
| *i* | = | 2.14978512 × 10-5 |  |  |  |  |

Formula:



*f*: Instrument freq.[Hz]

#### (3.3) Deep Ocean Standards Thermometer Temperature (ITS-90): SBE 35

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 0093, 27 Jun. 2014* | | | | | | |
| *a0* | = | 4.06873596 × 10-3 |  | *a3* | = | –9.25907373 × 10-6 |
| *a1* | = | –1.06370821 × 10-3 |  | *a4* | = | 1.99023461 × 10-7 |
| *a2* | = | 1.65409501 × 10-4 |  |  |  |  |

Formula:



*n*: instrument output

The slow time drift of the SBE 35

*S/N 0093, 25 Feb. 2019 (2nd step: fixed point calibration)*

*Slope = 0.999989, Offset =* 0.000196

Formula:



#### (3.4) Conductivity: SBE 4C

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 043697 (primary), 26 Oct. 2018* | | | | | | |
| *g* | = | –9.73127203 |  | *j* | = | 5.76368338 × 10-5 |
| *h* | = | 1.24473240 |  | *CPcor* | = | –9.5700 × 10-8 |
| *i* | = | –4.11024108 × 10-5 |  | *CTcor* | = | 3.2500 × 10-6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 042987 (secondary), 16 Aug. 2018* | | | | | | |
| *g* | = | –9.92052697 |  | *j* | = | 4.72212263 × 10-5 |
| *h* | = | 1.36213626 |  | *CPcor* | = | –9.5700 × 10-8 |
| *i* | = | 5.27078448 × 10-4 |  | *CTcor* | = | 3.2500 × 10-6 |

Conductivity of a fluid in the cell is expressed as:



*f*: instrument frequency (kHz)

*t*: water temperature (degrees Celsius)

*p*: water pressure (dbar).

#### (3.5) Oxygen (RINKO III)

The RINKO III (JFE Advantech Co., Ltd., Japan) sensor is based on the ability of a selected substance to act as a dynamic fluorescence quencher. The RINKO III model is designed to be used with a CTD system that accepts an auxiliary analog sensor, and it is designed to operate down to 7000 m. The RINKO III output is expressed in voltage from 0 to 5 V.

### Quality control and data correction during the cruise

#### (4.1) Temporal change of deck pressure

The post-cruise drift corrected pressure was computed as follows:



*S/N 09P31345 - 0722, 26 Sep. 2019*

*Slope = 0.99998，Offset = −0.3016*

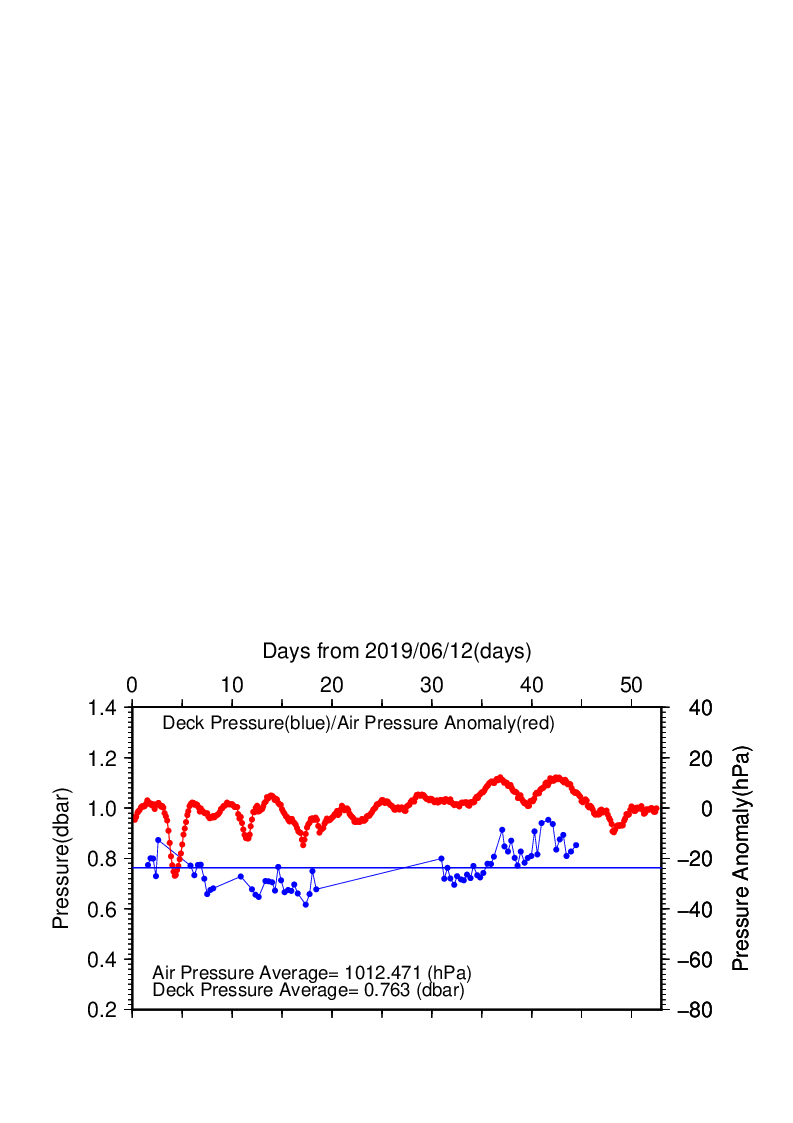


Figure C.1.1. Time series of the CTD deck pressure. Red line indicates atmospheric pressure anomaly. Blue line and dots indicate pre-cast deck pressure and average.

#### (4.2) Temperature sensor (SBE 3plus)

The practical corrections for the CTD temperature data can be made by using a SBE 35 and correcting the SBE 3plus so that it agrees with the SBE 35 (*McTaggart et al., 2010*; *Uchida et al., 2007*).

CTD temperature is corrected as follows:



*T*: CTD temperature (degrees Celsius), *P:* pressure (dbar), and *c0*, *c1*, *c2*: coefficients

Table C.1.1. Temperature correction summary (pressure ≥ 2000dbar). (Bold: accepted sensor)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *S/N* | *Num* | *c0(K)* | *c1(K/dbar)* | *C2(K/dbar2)* | *Stations* |
| **03P4436** | **438** | **1.087056 × 10-4** | **–2.456657 × 10-7** | **2.462016 × 10-11** | **RF6502 – 6533** |
| **03P4436** | **581** | **6.972219 × 10-4** | **–4.596775 × 10-8** | **1.879355 × 10-12** | **RF6534 – 6571** |
| 03P5184 | 438 | 1.480337 × 10-4 | –5.275556 × 10-7 | 4.485962 × 10-11 | RF6502 – 6533 |
| 03P5184 | 581 | 8.288990 × 10-4 | –1.693084 × 10-7 | 0.000000 | RF6534 – 6571 |

Table C.1.2. Temperature correction summary for S/N 03P4436.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stations | Pressure < 2000dbar | | | Pressure ≥ 2000 dbar | | |
| Num | Average  (K) | Std  (K) | Num | Average  (K) | Std  (K) |
| RF6501 – 6533 | 642 | –0.0009 | 0.0190 | 438 | 0.0000 | 0.0001 |
| RF6534 – 6571 | 772 | –0.0003 | 0.0074 | 581 | 0.0000 | 0.0001 |

Table C.1.3. Temperature correction summary for S/N 03P5184.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stations | Pressure < 2000dbar | | | Pressure ≥ 2000 dbar | | |
| Num | Average  (K) | Std  (K) | Num | Average  (K) | Std  (K) |
| RF6501 – 6533 | 642 | –0.0009 | 0.0175 | 438 | 0.0000 | 0.0002 |
| RF6534 – 6571 | 772 | –0.0012 | 0.0082 | 581 | 0.0000 | 0.0002 |

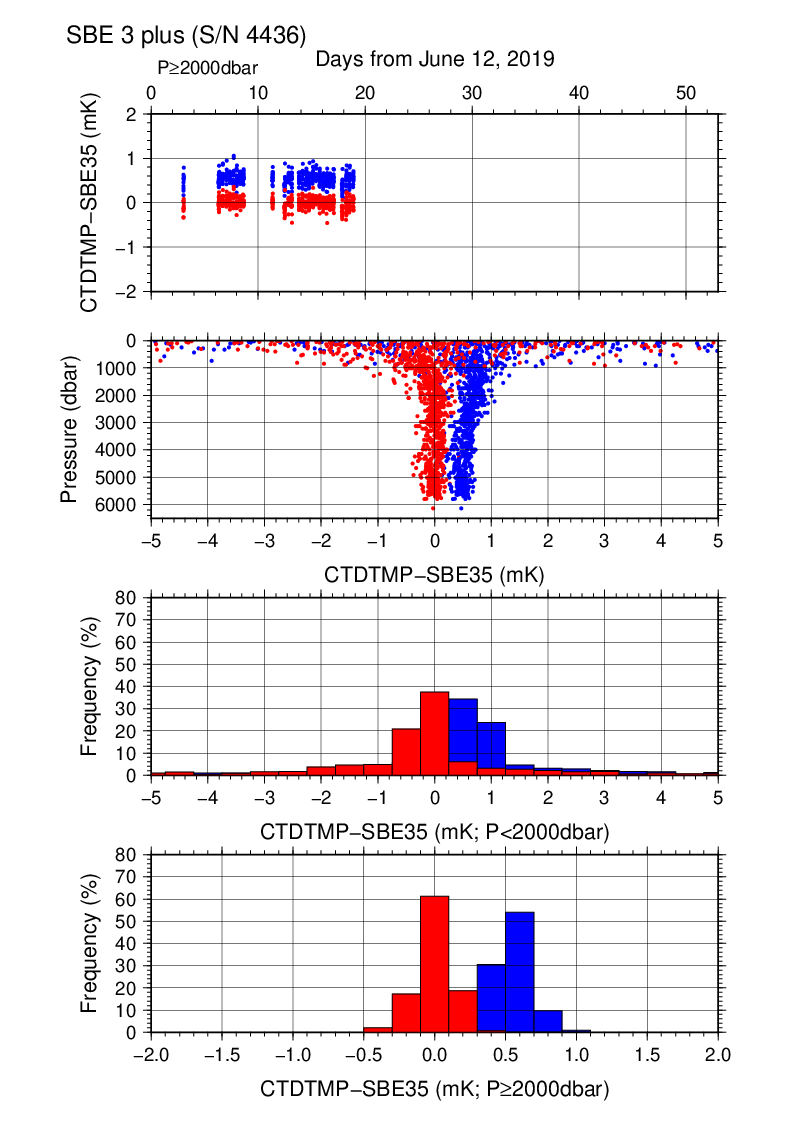


Figure C.1.2. Difference between the CTD temperature (*S/N 03P4436*) and the Deep Ocean Standards thermometer (SBE 35) on Leg 1. Blue and red dots indicate before and after the correction using SBE 35 data, respectively. Lower two panels show histograms of the differences after correction.

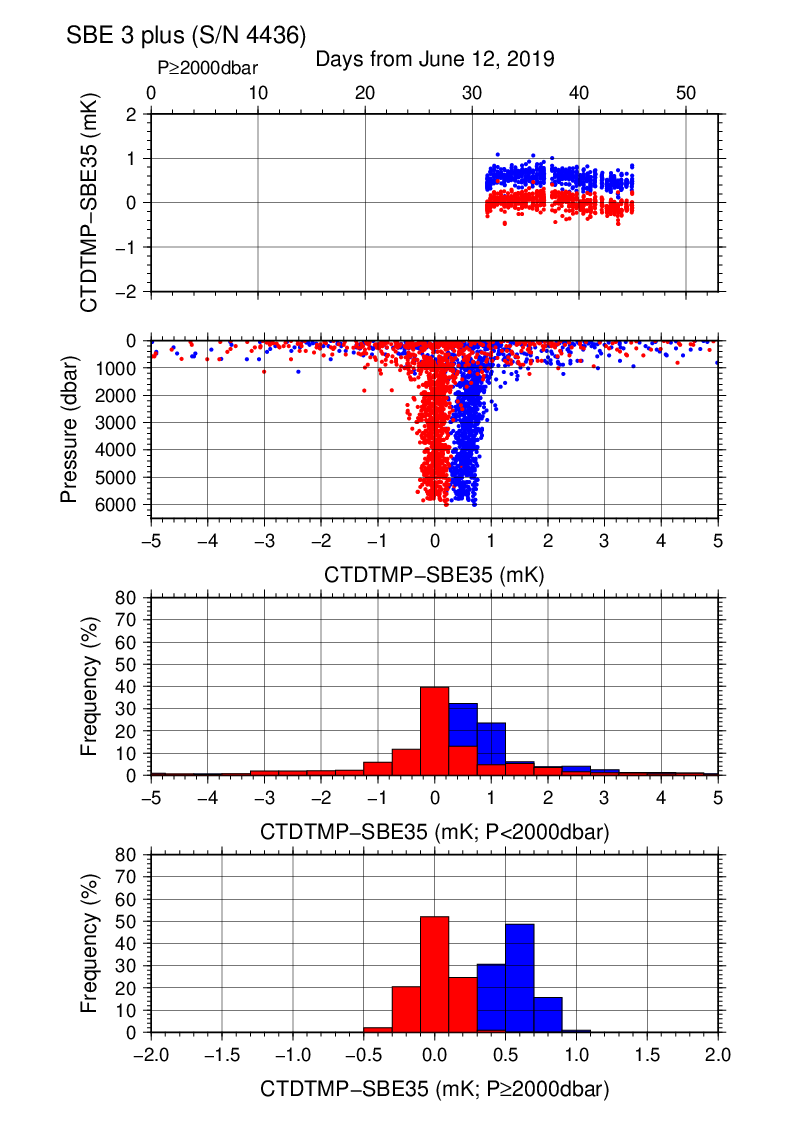


Figure C.1.3. Difference between the CTD temperature (*S/N 03P4436*) and the Deep Ocean Standards thermometer (SBE 35) on Leg 2. Blue and red dots indicate before and after the correction using SBE 35 data, respectively. Lower two panels show histograms of the differences after correction.

#### (4.3) Conductivity sensor (SBE 4C)

The practical corrections for CTD conductivity data can be made by using bottle salinity data to correct the SBE 4C to agree with measured conductivity (*McTaggart et al., 2010*).

CTD conductivity was corrected as follows:



*C*: CTD conductivity, *ci* and *pj*: calibration coefficients

*i, j*: determined by use of the AIC (*Akaike*, 1974). In accord with *McTaggart et al.* (2010), the maximum of *I* and *J* are 2.

Table C.1.4. Conductivity correction coefficient summary. (Bold: accepted sensor)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *S/N* | *Num* | *c0(S/m)* | *c1* | *c2(m/S)* | *Stations* |
|  | *p1(S/m/dbar)* | *p2(S/m/dbar2)* |
| **043697** | **1122** | **3.1142 × 10-3** | **–1.5209 × 10-3** | **1.7101 × 10-4** | **RF6502 – 6533** |
|  | **0.0000** | **0.0000** |
| **043697** | **1340** | **1.0175 × 10-3** | **–3.1676 × 10-4** | **0.0000** | **RF6534 – 6571** |
|  | **2.6605 × 10-8** | **–4.1528 × 10-12** |
| 042987 | 1082 | 2.6413 × 10-3 | –1.3502 × 10-3 | 1.7745 × 10-4 | RF6502 – 6533 |
|  | 1.3335 × 10-8 | 0.0000 |
| 042987 | 1340 | 5.3837 × 10-4 | –1.2321 × 10-4 | 0.0000 | RF6534 – 6571 |
|  | 2.6432 × 10-8 | –2.2120 × 10-12 |

Table C.1.5. Conductivity correction and salinity correction summary for S/N 043697.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stations | Pressure < 1900dbar | | | | | |
| Conductivity | | | Salinity | | |
| Num | Average  (S/m) | Std  (S/m) | Num | Average | Std |
| RF6502 – 6533 | 656 | 0.0000 | 0.0002 | 656 | –0.0001 | 0.0024 |
| RF6534 – 6571 | 820 | 0.0000 | 0.0004 | 820 | 0.0000 | 0.0036 |
| Stations | Pressure ≥ 1900 dbar | | | | | |
| Conductivity | | | Salinity | | |
| Num | Average  (S/m) | Std  (S/m) | Num | Average | Std |
| RF6502 – 6533 | 466 | 0.0000 | 0.0000 | 466 | 0.0001 | 0.0005 |
| RF6534 – 6571 | 520 | 0.0000 | 0.0000 | 520 | 0.0000 | 0.0003 |

Table C.1.6. Conductivity correction and salinity correction summary for S/N 042987.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stations | Pressure < 1900dbar | | | | | |
| Conductivity | | | Salinity | | |
| Num | Average  (S/m) | Std  (S/m) | Num | Average | Std |
| RF6502 – 6533 | 635 | 0.0000 | 0.0002 | 635 | 0.0000 | 0.0024 |
| RF6534 – 6571 | 820 | 0.0000 | 0.0004 | 820 | 0.0000 | 0.0033 |
| Stations | Pressure ≥ 1900 dbar | | | | | |
| Conductivity | | | Salinity | | |
| Num | Average  (S/m) | Std  (S/m) | Num | Average | Std |
| RF6502 – 6533 | 447 | 0.0000 | 0.0000 | 447 | –0.0001 | 0.0005 |
| RF6534 – 6571 | 520 | 0.0000 | 0.0000 | 520 | 0.0000 | 0.0004 |

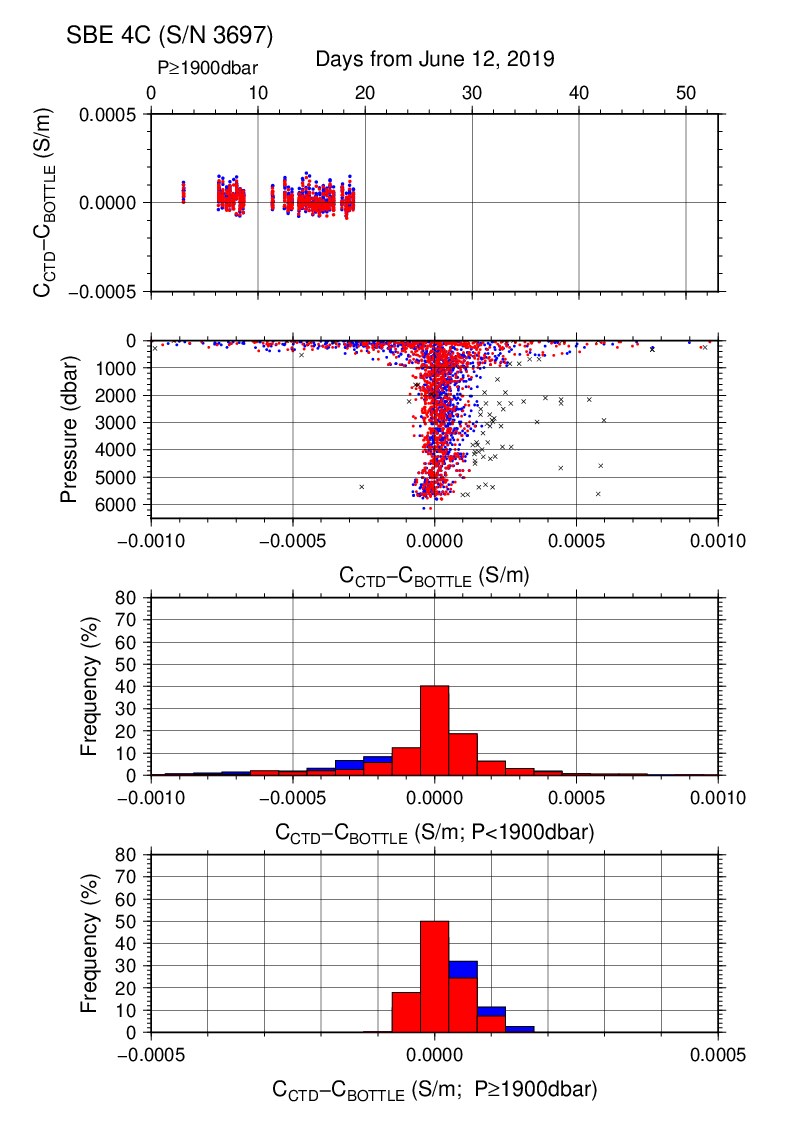


Figure C.1.4. Difference between the CTD conductivity (*S/N 043697*) and the bottle conductivity on Leg 1. Blue and red dots indicate before and after the calibration using bottle data, respectively. Lower two panels show histograms of the differences before and after calibration.

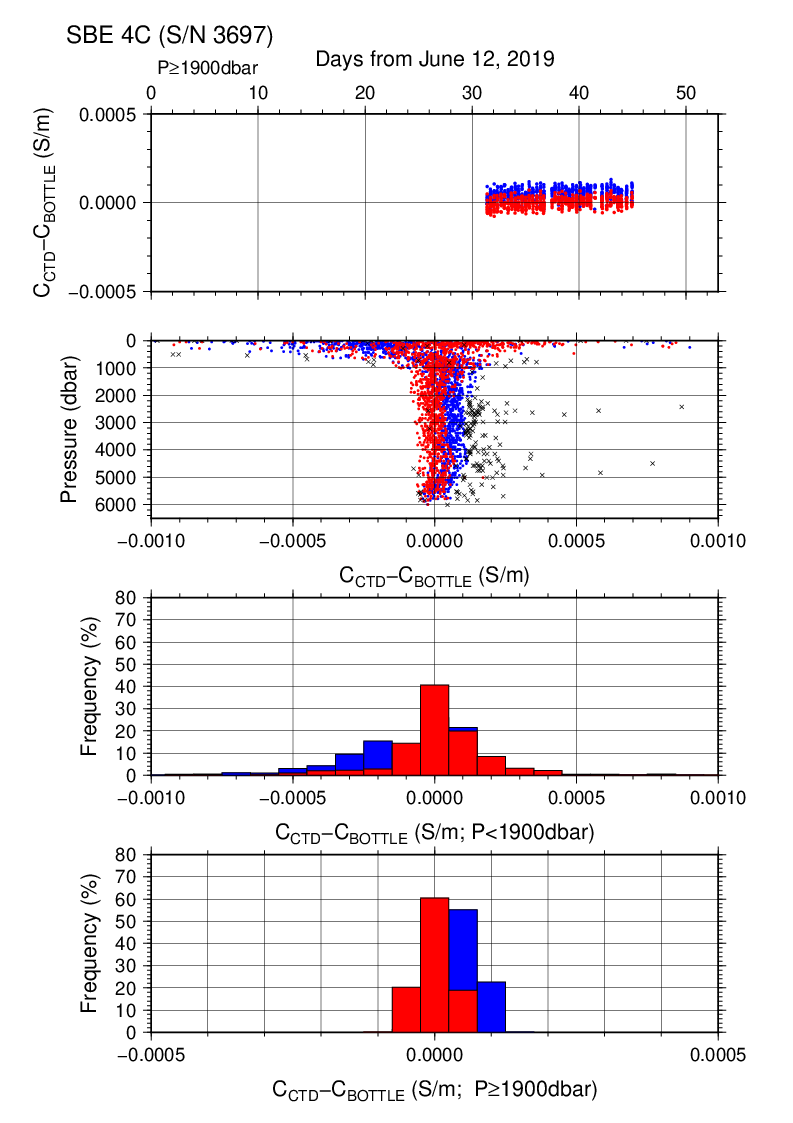


Figure C.1.5. Difference between the CTD conductivity (*S/N 043697*) and the bottle conductivity on Leg 2. Blue and red dots indicate before and after the calibration using bottle data, respectively. Lower two panels show histograms of the differences before and after calibration.

#### (4.4) Oxygen sensor (RINKO III)

The CTD oxygen concentration was calculated using the RINKO III output (voltage) with the Stern-Volmer equation in accord with the method of Uchida et al. (2008) and Uchida et al. (2010). The pressure hysteresis for the RINKO III output (voltage) was corrected in accord with Sea-bird Electronics (2009) and Uchida et al. (2010). The equations were as follows:

*P*: pressure (dbar), *t*: potential temperature, *v*: RINKO output voltage (volt)

*T*: elapsed time of the sensor from the beginning of first station in calculation group in day

O2sat:dissolved oxygen saturation by Garcìa and Gordon (1992) (μmol/kg)

[O2]: dissolved oxygen concentration (μmol/kg)

*c1*–*c9*: determined by minimizing differences between CTD oxygen concentration and bottle dissolved oxygen concentration by quasi-newton method (*Shanno, 1970*).

Table C.1.7. Dissolved oxygen correction coefficient summary. (Bold: accepted sensor)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N* | *Stations* | *c1* | *c2* | *c3* | *c4* | *c5* |
| *c6* | *c7* | *c8* | *c9* |  |
| **0007** | **RF6502 – 6533** | **1.69328** | **3.08942 × 10-2** | **2.58009 × 10-4** | **1.42215 × 10-3** | **–1.50185 × 10-1** |
| **3.23422 × 10-1** | **–6.71890 × 10-4** | **7.53719 × 10-4** | **6.78341 × 10-2** |  |
| **0007** | **RF6534 – 6571** | **1.67409** | **2.39069 × 10-2** | **2.75124 × 10-4** | **2.00501 × 10-4** | **–1.46253 × 10-1** |
| **3.23371 × 10-1** | **7.59088 × 10-4** | **5.29803 × 10-5** | **7.08813 × 10-2** |  |
| 0284 | RF6502 –6533 | 1.65277 | 2.98490 × 10-2 | 3.49575 × 10-4 | 1.78525 × 10-3 | –2.16280× 10-1 |
| 3.12320 × 10-1 | –9.62855 × 10-4 | 7.06602 × 10-4 | 7.69413 × 10-2 |  |
| 0284 | RF6534 –6571 | 1.62357 | 2.14475 × 10-2 | 3.28339 × 10-4 | 3.18233 × 10-4 | –2.06872× 10-1 |
| 3.10692 × 10-1 | 6.78548 × 10-4 | 4.51383 × 10-5 | 8.14780 × 10-2 |  |

Table C.1.8. Dissolved oxygen correction summary for S/N 0007.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stations | Pressure < 950dbar | | | Pressure ≥ 950 dbar | | |
| Num | Average  (μmol/kg) | Std  (μmol/kg) | Num | Average  (μmol/kg) | Std  (μmol/kg) |
| RF6502 – 6533 | 481 | –0.02 | 1.23 | 583 | 0.02 | 0.38 |
| RF6534 – 6571 | 569 | –0.03 | 1.13 | 760 | 0.01 | 0.36 |

Table C.1.9. Dissolved oxygen correction summary for S/N 0284.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Stations | Pressure < 950dbar | | | Pressure ≥ 950 dbar | | |
| Num | Average  (μmol/kg) | Std  (μmol/kg) | Num | Average  (μmol/kg) | Std  (μmol/kg) |
| RF6502 – 6533 | 481 | –0.12 | 1.22 | 583 | 0.02 | 0.42 |
| RF6534 – 6571 | 569 | –0.20 | 1.20 | 760 | 0.02 | 0.38 |

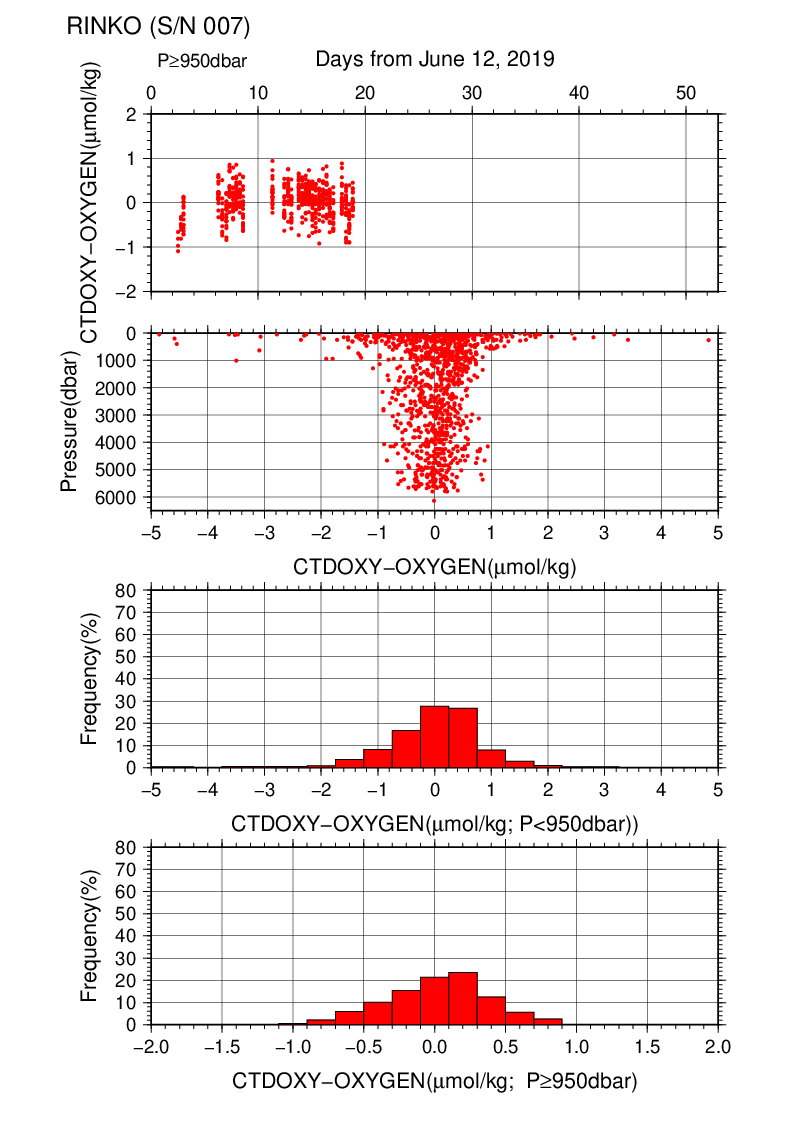


Figure C.1.6. Difference between the CTD oxygen (*S/N 0007*) and bottle dissolved oxygen on Leg 1. Red dots in upper two panels indicate the result of calibration. Lower two panels show histograms of the differences between calibrated oxygen concentration and bottle oxygen concentration.

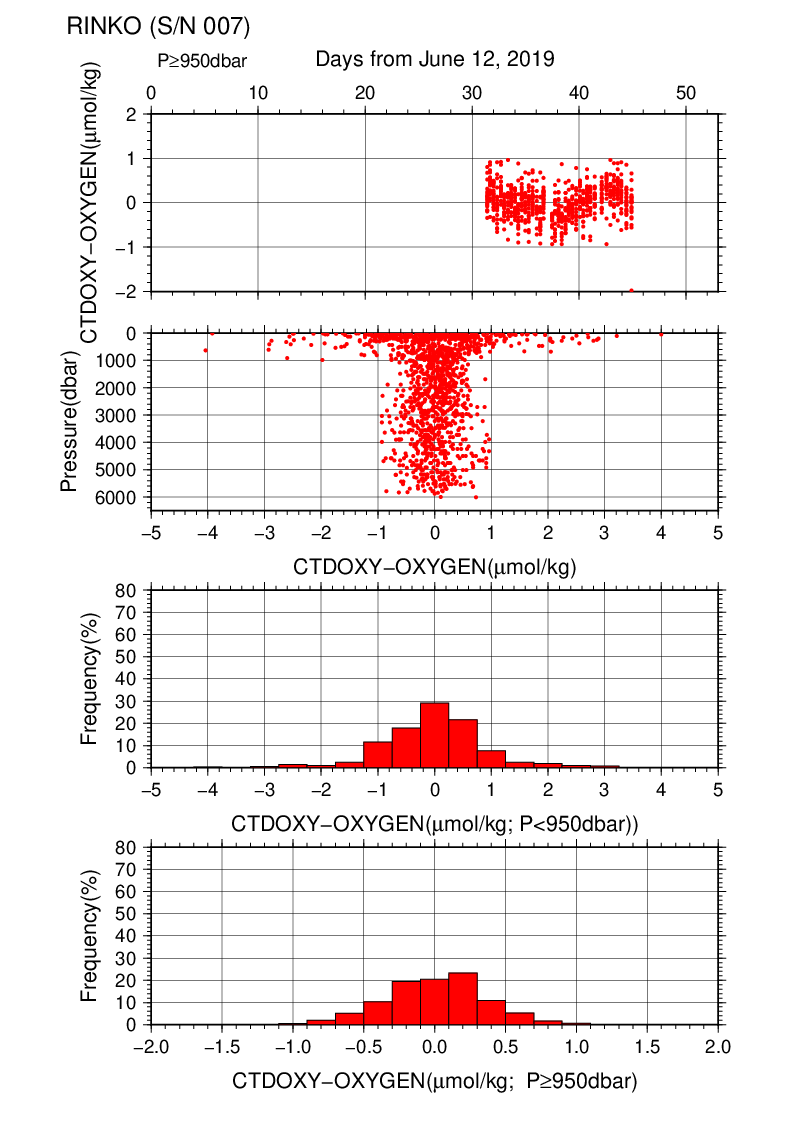


Figure C.1.7. Difference between the CTD oxygen (*S/N 0007*) and bottle dissolved oxygen on Leg 1. Red dots in upper two panels indicate the result of calibration. Lower two panels show histograms of the differences between calibrated oxygen concentration and bottle oxygen concentration.

#### (4.5) Results of detection of sea floor by the altimeter (PSA-916D)

The altimeter detected the sea floor at 65 of 70 stations, the average distance of beginning detecting the sea floor was 45.5 m, and that of final detection of sea floor was 12.7 m. The summary of detection of PSA-916D was shown in Figure C.1.8.

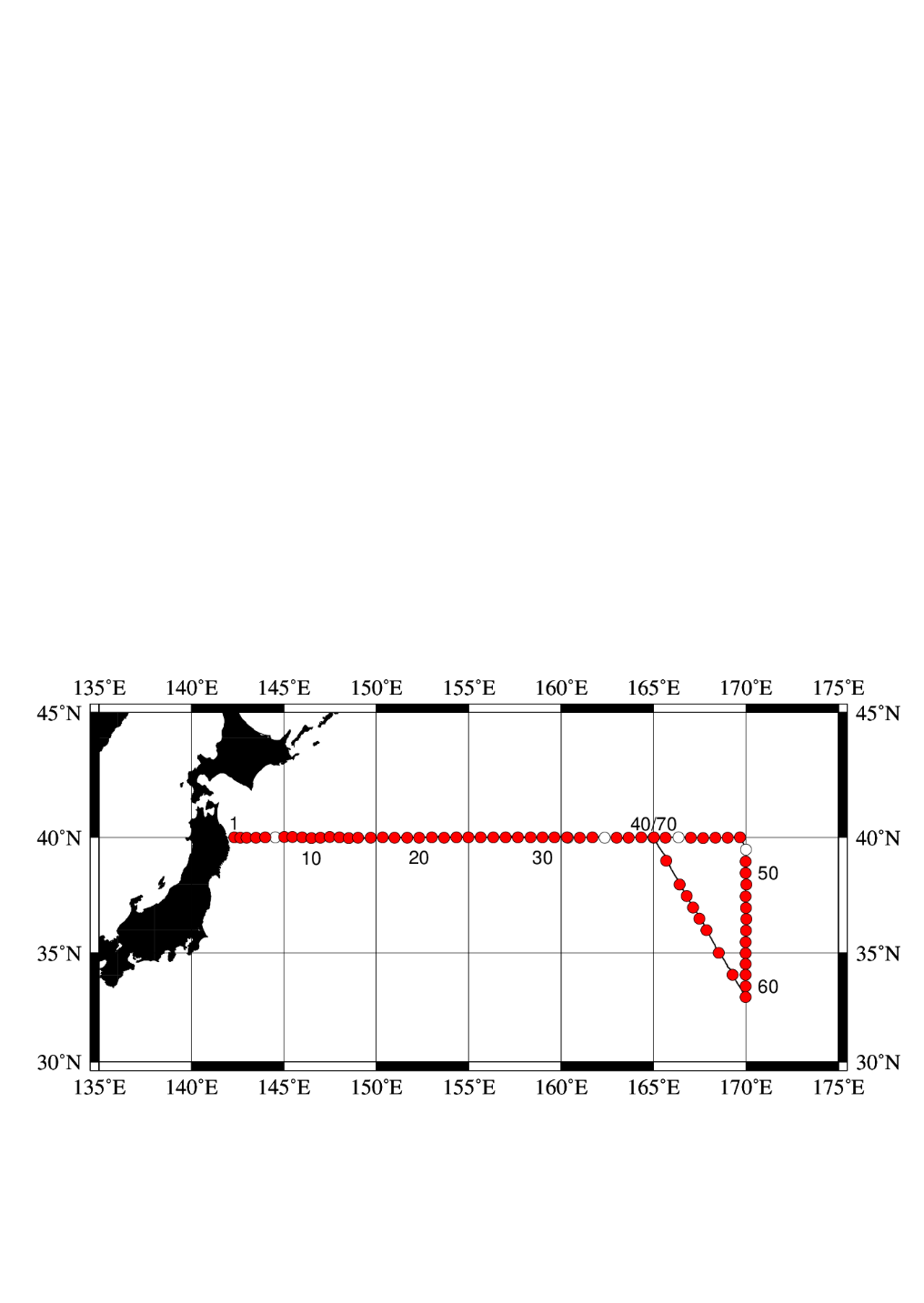
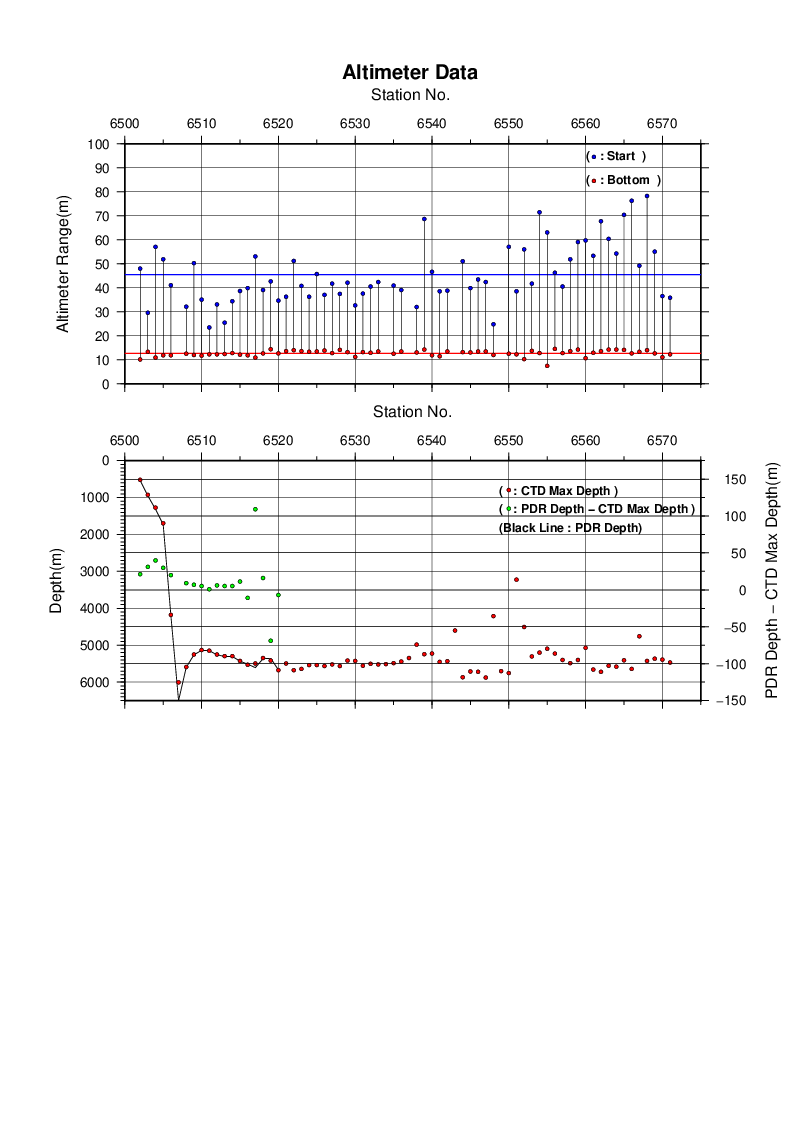


Figure C.1.8. The summary of detection of PSA-916D. The upper panel shows the stations of detection, the lower panel shows the relationship among PSA-916D, bathymetry and CTD depth. In the upper panel, closed and open circles indicate react and no-react stations, respectively.

### Post-cruise calibration

After the cruise, post-cruise calibration of sensors was performed by the manufacturer, as shown below. We confirmed that the calibration of these sensors did not change significantly during the cruise.

#### (5.1) Temperature (ITS-90): SBE 3plus

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 03P4436 (primary), 16 Oct. 2019* | | | | | | |
| *g* | = | 4.33674073 × 10-3 |  | *j* | = | 1.85113437 × 10-6 |
| *h* | = | 6.38225910 × 10-4 |  | *f0* | = | 1000.0 |
| *i* | = | 2.13099806 × 10-5 |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 03P5184 (secondary), 14 Feb. 2020* | | | | | | |
| *g* | = | 4.34795864 × 10-3 |  | *j* | = | 1.96366585 × 10-6 |
| *h* | = | 6.36861968 × 10-4 |  | *f0* | = | 1000.0 |
| *i* | = | 2.17766331 × 10-5 |  |  |  |  |

#### (5.2) Deep Ocean Standards Thermometer Temperature (ITS-90): SBE 35

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 0093, 16 Oct. 2019* | | | | | | |
| *a0* | = | 4.49398478 × 10-3 |  | *a3* | = | –1.00727358 × 10-5 |
| *a1* | = | –1.19680954 × 10-3 |  | *a4* | = | 2.14915542 × 10-7 |
| *a2* | = | 1.81023620 × 10-4 |  |  |  |  |

Formula:



*n*: instrument output

The slow time drift of the SBE 35

*S/N 0093, 10 Oct. 2019 (2nd step: fixed point calibration)*

*Slope = 1.000002, Offset =* –0.000037

Formula:



#### (5.3) Conductivity: SBE 4C

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 043697 (primary), 10 Oct. 2019* | | | | | | |
| *g* | = | –9.73131524 |  | *j* | = | 6.60463693 × 10-5 |
| *h* | = | 1.24469215 |  | *CPcor* | = | –9.5700 × 10-8 |
| *i* | = | –6.70333348 × 10-5 |  | *CTcor* | = | 3.2500 × 10-6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *S/N 042987 (secondary), 22 Nov. 2019* | | | | | | |
| *g* | = | –9.92975809 |  | *j* | = | 1.35274502 × 10-4 |
| *h* | = | 1.36552800 |  | *CPcor* | = | –9.5700 × 10-8 |
| *i* | = | –4.96841577 × 10-4 |  | *CTcor* | = | 3.2500 × 10-6 |

***References***

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Uchida, H., K. Ohyama, S. Ozawa, and M. Fukasawa (2007): In-situ calibration of the Sea-Bird 9plus CTD thermometer. *J. Atmos. Oceanic Technol.,* ***24****, 1961–1967.*

Uchida, H., T. Kawano, I. Kaneko, and M. Fukasawa (2008): In-situ calibration of optode-based oxygen sensors. *J. Atmos. Oceanic Technol.,* ***25****, 2271–2281*.

## Bottle Salinity

*8 June 2020*

### Personnel

Noriyuki OKUNO (GEMD/JMA)

Kiyoshi TANAKA (GEMD/JMA)

Keita KAKUYA (GEMD/JMA)

Togo IDA (GEMD/JMA)

(Leg 1) Yoshikazu HIGASHI (GEMD/JMA)

(Leg 2) Yuma KAWAKAMI (GEMD/JMA)

### Salinity measurement

Salinometer: AUTOSAL 8400B (Guildline Instruments Ltd., Canada ; S/N 69677 for stations before RF6506, S/N 72103 for stations after RF6507)

Thermometer: Guildline platinum thermometers model 9450 (to monitor ambient temperature and bath temperature) (Guildline Instruments Ltd., Canada)

IAPSO Standard Seawater: P162 (K15=0.99983)

### Sampling and measurement

The measurement system was almost the same as the system described by Kawano (2010).

Algorithm for practical salinity scale, 1978 (PSS-78; UNESCO, 1981) was employed to convert the conductivity ratios to salinities.

### Station occupied

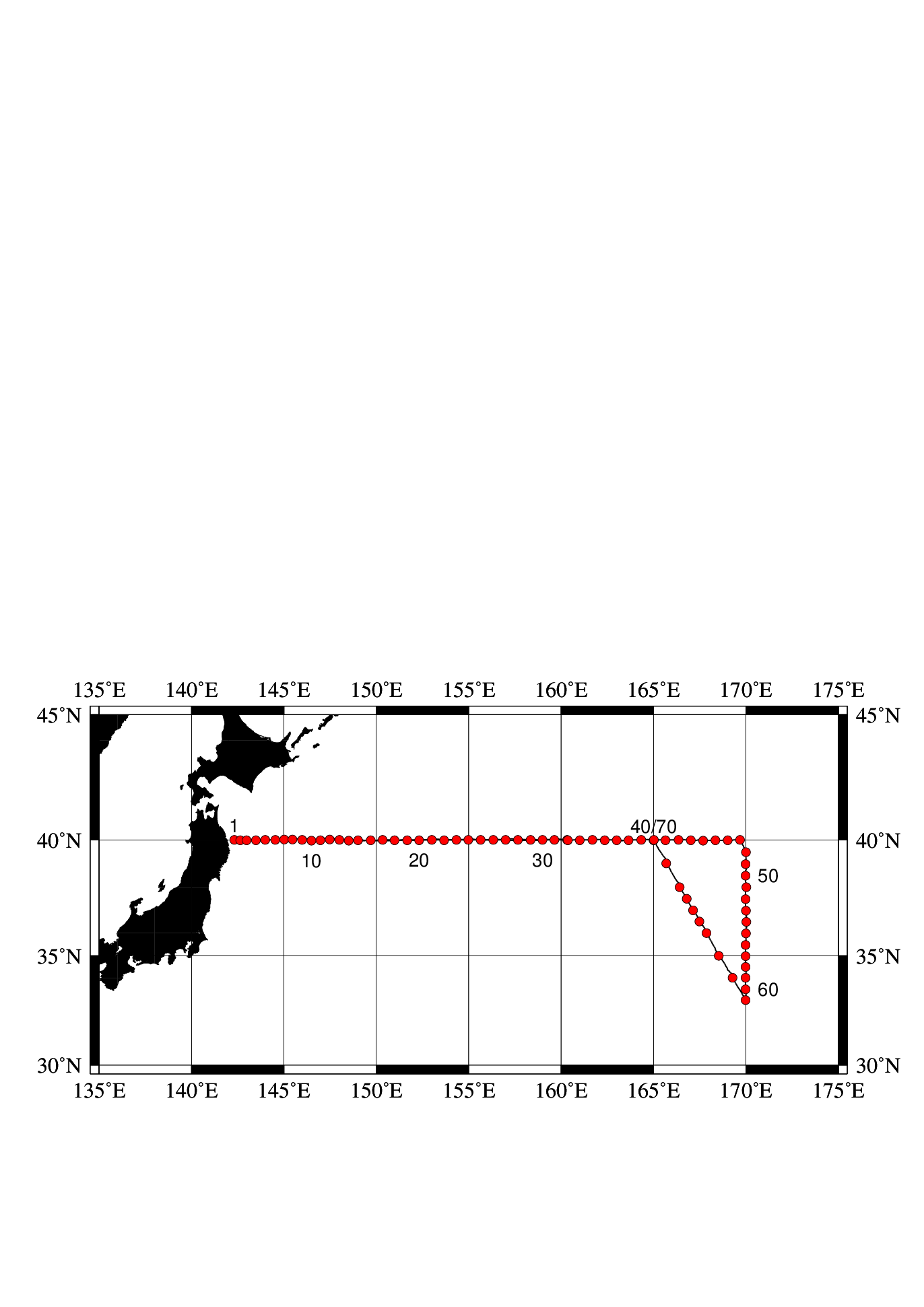


Figure C.2.1. Location of observation stations of bottle salinity.

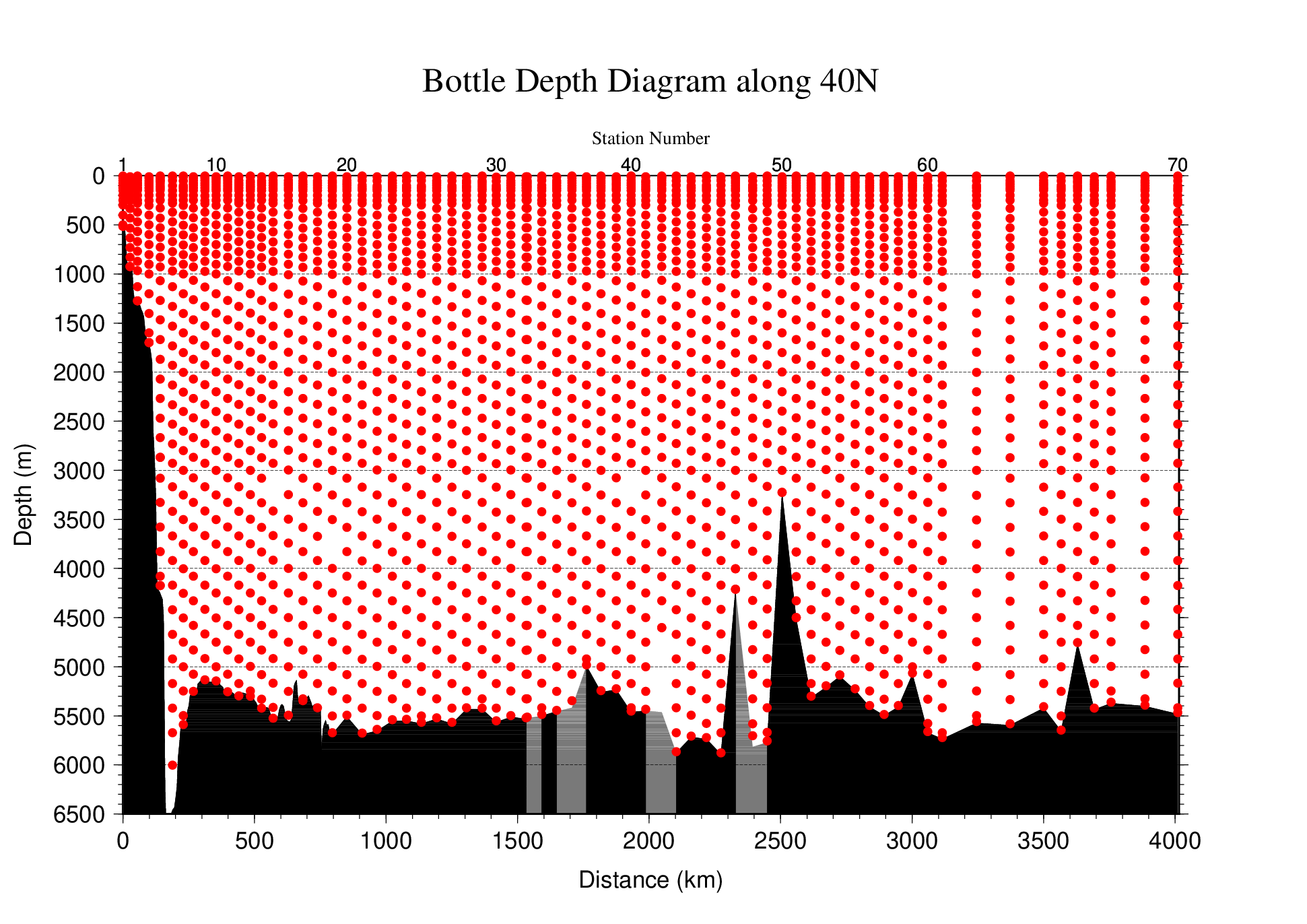


Figure C.2.2. Distance-depth distribution of sampling layers of bottle salinity. Seafloor filled with black before RF6520 station indicates data measured continuously by a single beam echo sounder, and after RF6521 station indicates data estimated by CTD observation with altimeter measurement. Seafloor filled with gray indicates data missing station during this cruise and is referred from our previous cruise in 2012.

### Result

#### (5.1) Ambient temperature, bath temperature and Standard Seawater measurements

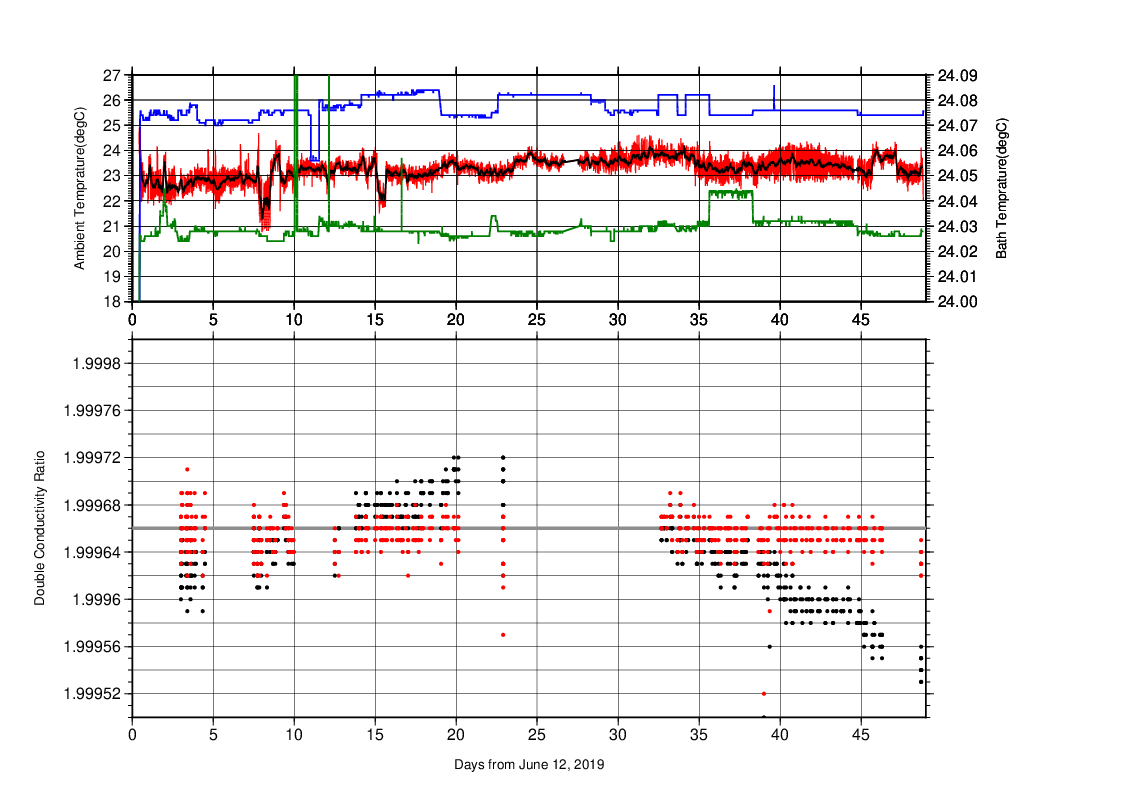


Figure C.2.3. The upper panel, red line, black line, green line, and blue line indicate time-series of ambient temperature, average ambient temperature, bath temperature (Autosal S/N 69677), and bath temperature (Autosal S/N 72103) during cruise. The lower panel, black dots, and red dots indicate raw and corrected time-series of the double conductivity ratio of the standard seawater (P162).

#### (5.2) Replicate and duplicate samples

We took replicate (pair of water samples taken from a single Niskin bottle) and duplicate (pair of water samples taken from different Niskin bottles closed at the same depth) samples for bottle salinity throughout the cruise. Table C.2.1 summarizes the results of the analyses. Figure C.2.4 shows details of the results. The calculation of the standard deviation from the difference of sets was based on a procedure (SOP 23) in DOE (1994).

Table C.2.1. Summary of replicate and duplicate salinity analyses.

|  |  |
| --- | --- |
| **Measurement** | **Average difference ± S.D.** |
| Replicate sample | 0.0002 ± 0.0002 (N = 207) |
| Duplicate sample | 0.0007 ± 0.0008 (N = 14) |

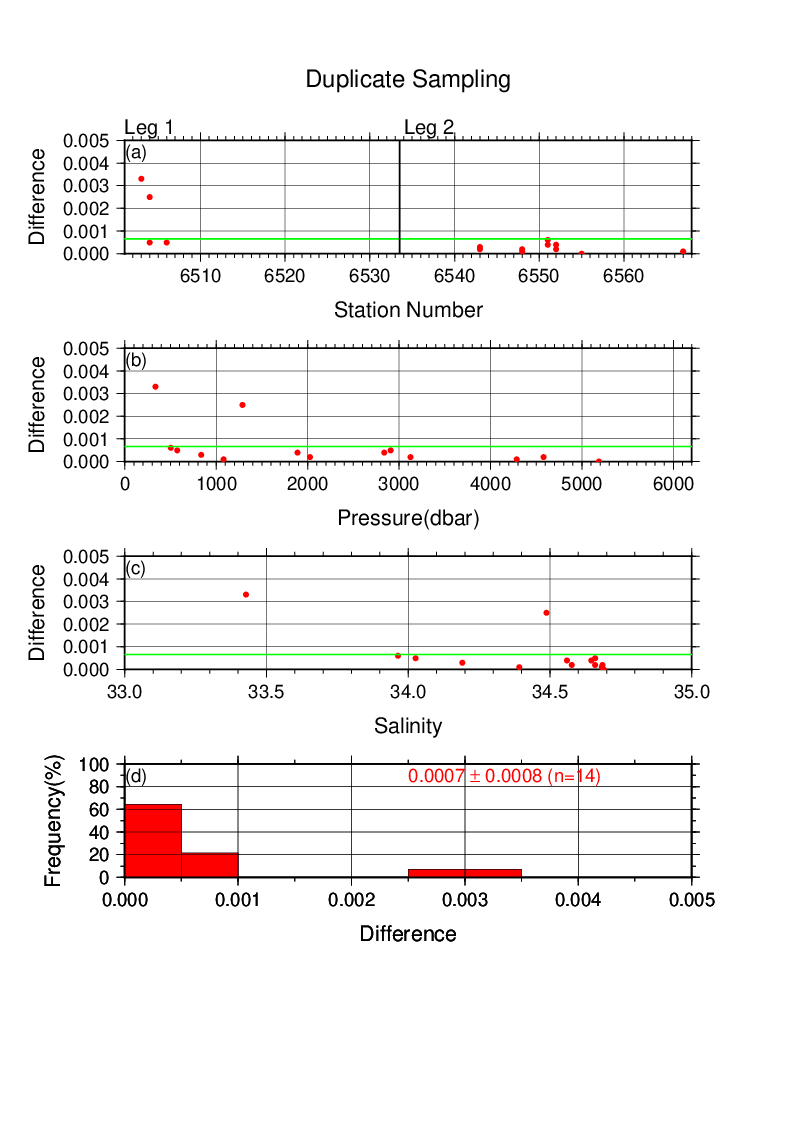
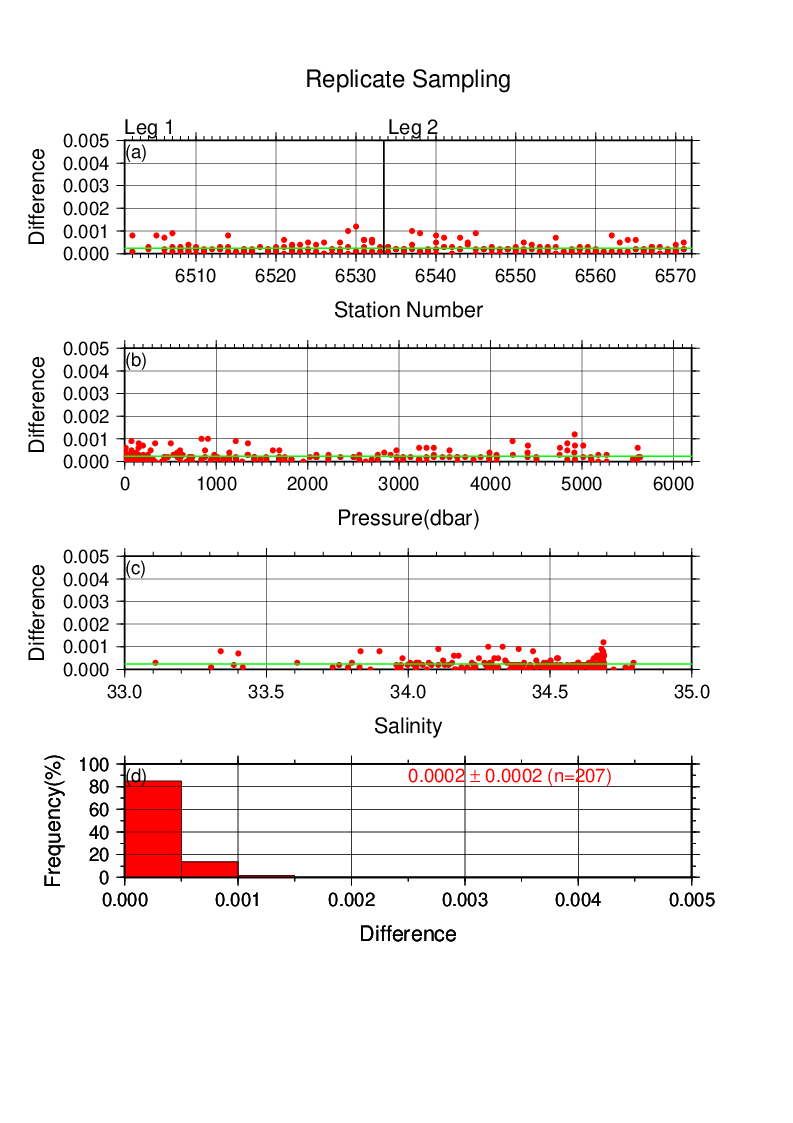


Figure C.2.4. Results of (left) replicate and (right) duplicate analyses during the cruise against (a) station number, (b) pressure, (c) salinity, and (d) histogram of the measurements. Green line indicates the mean of the differences of salinity of replicate/duplicate analyses.

#### (5.3) Summary of assigned quality control flags

Table C.2.2. Summary of assigned quality control flags

|  |  |  |
| --- | --- | --- |
| Flag | Definition | Number |
| 2 | Good | 2036 |
| 3 | Questionable | 0 |
| 4 | Bad (Faulty) | 216 |
| 5 | Not reported | 0 |
| 6 | Replicate measurements | 233 |
| Total number of samples | | 2485 |

***References***

DOE (1994), Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water; version 2. *A. G. Dickson and C. Goyet (eds), ORNL/CDIAC-74.*

Kawano (2010), The GO-SHIP Repeat Hydrography Manual: A Collection of Expert Reports and Guidelines. *IOCCP Report No. 14, ICPO Publication Series No. 134, Version 1.*

UNESCO (1981), Tenth report of the Joint Panel on Oceanographic Tables and Standards. *UNESCO Tech. Papers in Mar. Sci.,* ***36****, 25 pp.*

## Bottle Oxygen

*8 June 2020*

### Personnel

Leg 1

Hiroyuki HATAKEYAMA (GEMD/JMA)

Koichi WADA (GEMD/JMA)

Kei KONDO (GEMD/JMA)

Rie SANAI (GEMD/JMA)

Masakazu TAKAMI (GEMD/JMA)

Leg 2

Hiroyuki HATAKEYAMA (GEMD/JMA)

Tomohiro UEHARA (GEMD/JMA)

Kei KONDO (GEMD/JMA)

Rie SANAI (GEMD/JMA)

Masakazu TAKAMI (GEMD/JMA)

### Station occupied

A total of 70 stations (Leg 1: 32, Leg 2: 38) were occupied for dissolved oxygen measurements. Station location and sampling layers of bottle oxygen are shown in Figures C.3.1 and C.3.2, respectively.

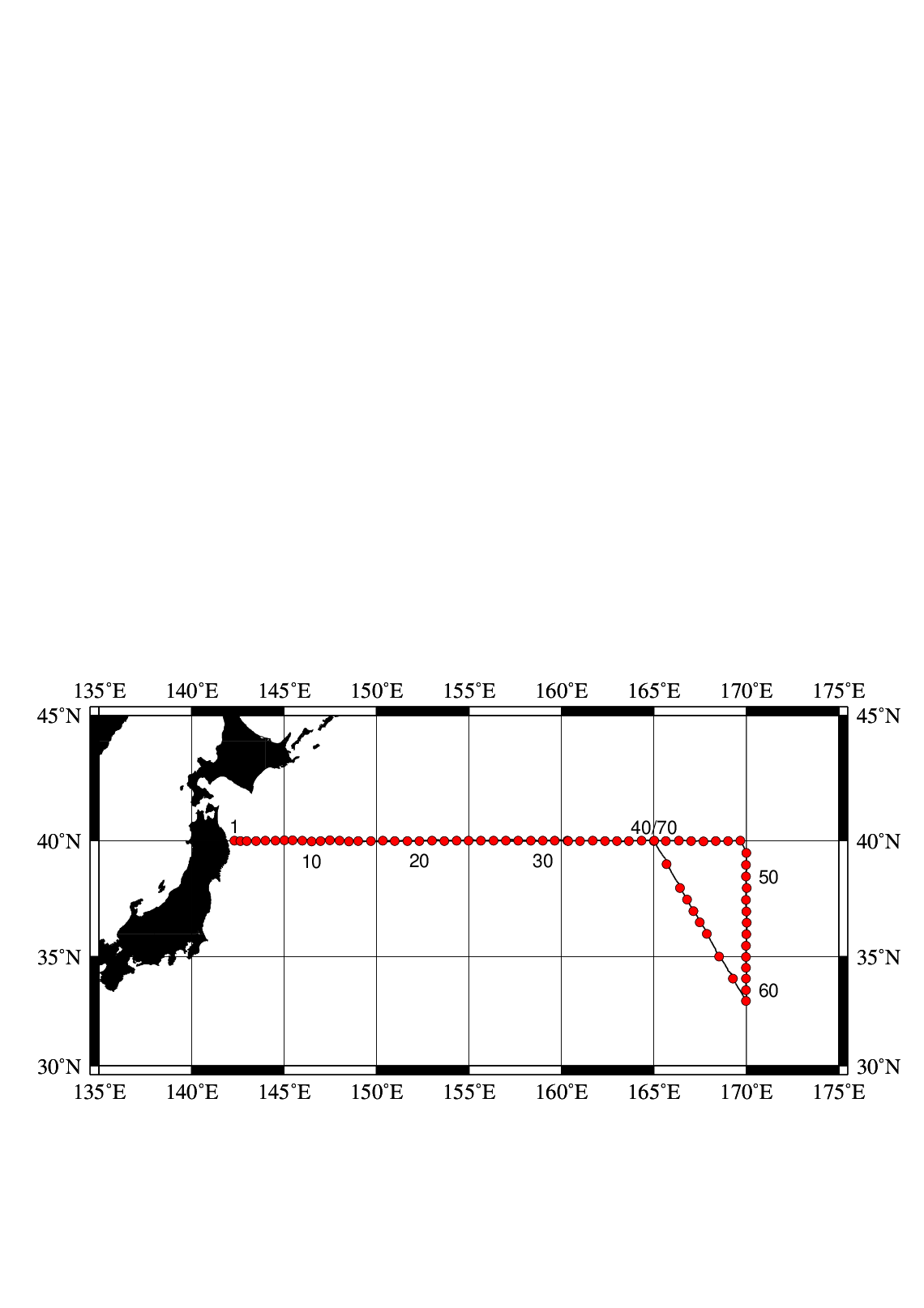


Figure C.3.1. Location of observation stations of bottle oxygen.

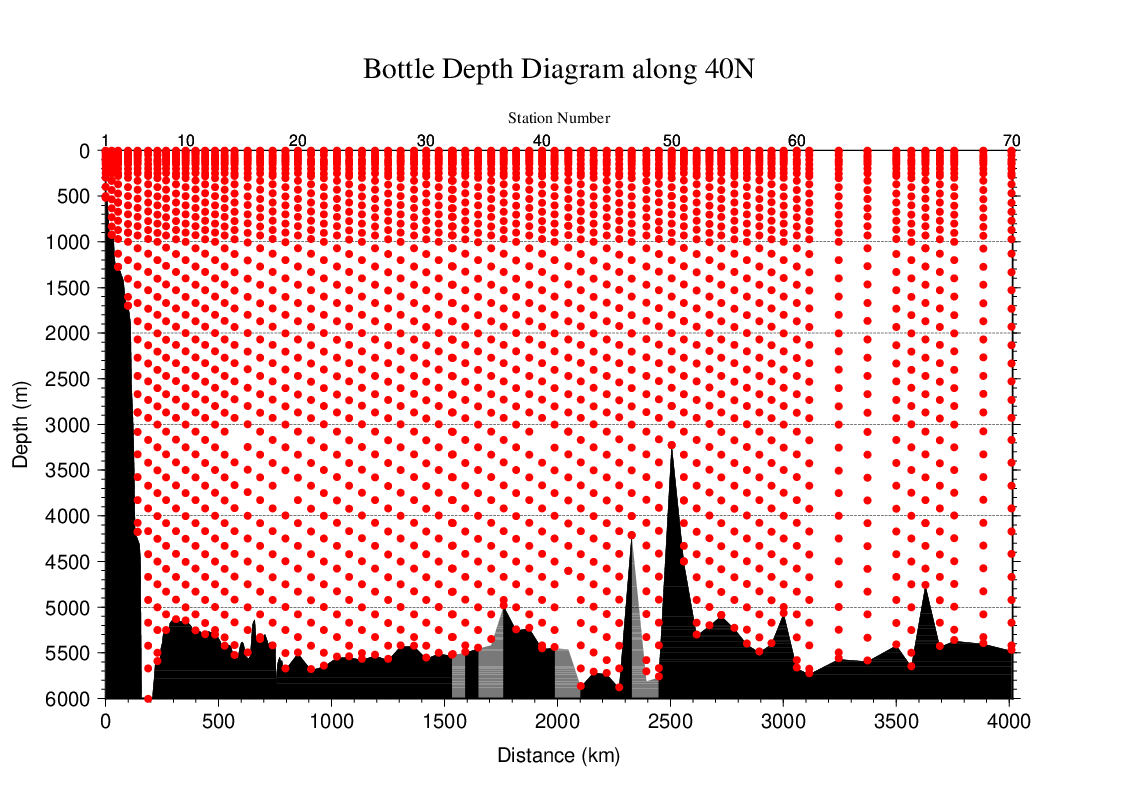


Figure C.3.2. Distance-depth distribution of sampling layers of bottle oxygen.

### Instrument

Detector: DOT-15X (Kimoto Electronic, Japan)

Burette: APB-610 (Kyoto Electronic, Japan)

### Sampling and measurement

Methods of seawater sampling, measurement, and calculation of dissolved oxygen concentration were based on an IOCCP Report (Langdon, 2010). Details of the methods are shown in Appendix A1.

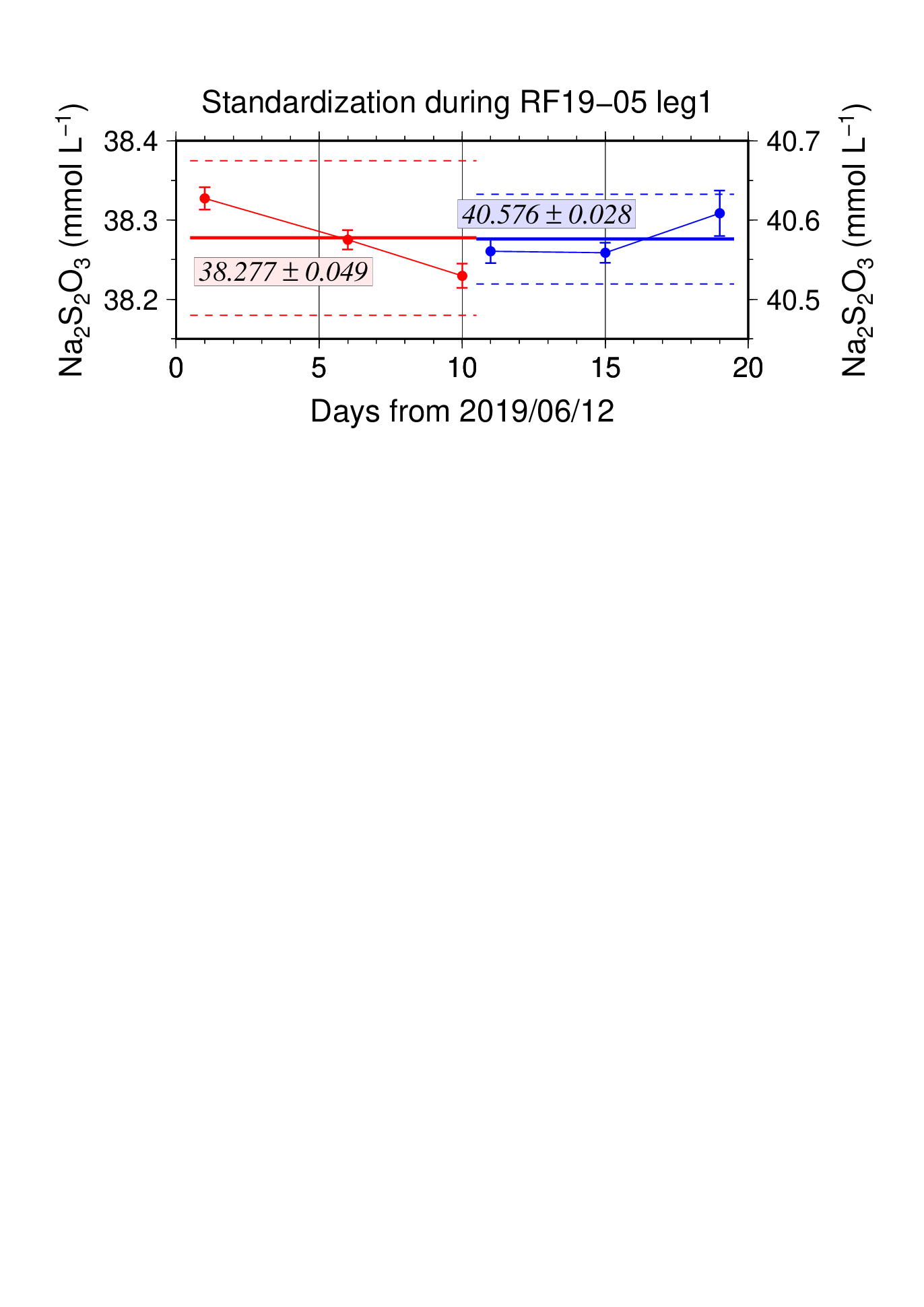
The reagents for the measurement were prepared according to recipes described in Appendix A2. Standard KIO3 solutions were prepared gravimetrically using the highest purity standard substance KIO3 (Lot. No. ECG4358, Wako Pure Chemical, Japan). Table C.3.1 shows the batch list of prepared standard KIO3 solutions.

Table C.3.1. Batch list of the standard KIO3 solutions.

|  |  |  |
| --- | --- | --- |
| **KIO3 batch** | **Concentration and uncertainty (k=2) at 20 °C. Unit is mol L**−**1.** | **Purpose of use** |
| 20181128-2 | 0.0016646±0.0000068 | Standardization (main use) |
| 20181205-2 | 0.0016667±0.0000068 | Mutual comparison |

### Standardization

The concentration of the Na2S2O3 titrant was determined with the standard KIO3 solution “20181128-2”, based on the methods of an IOCCP Report (Langdon, 2010). Figure C.3.3 shows the results of standardization during the cruise. The standard deviation of the concentration at 20 °C was determined through standardization and was used in the calculation of uncertainty.



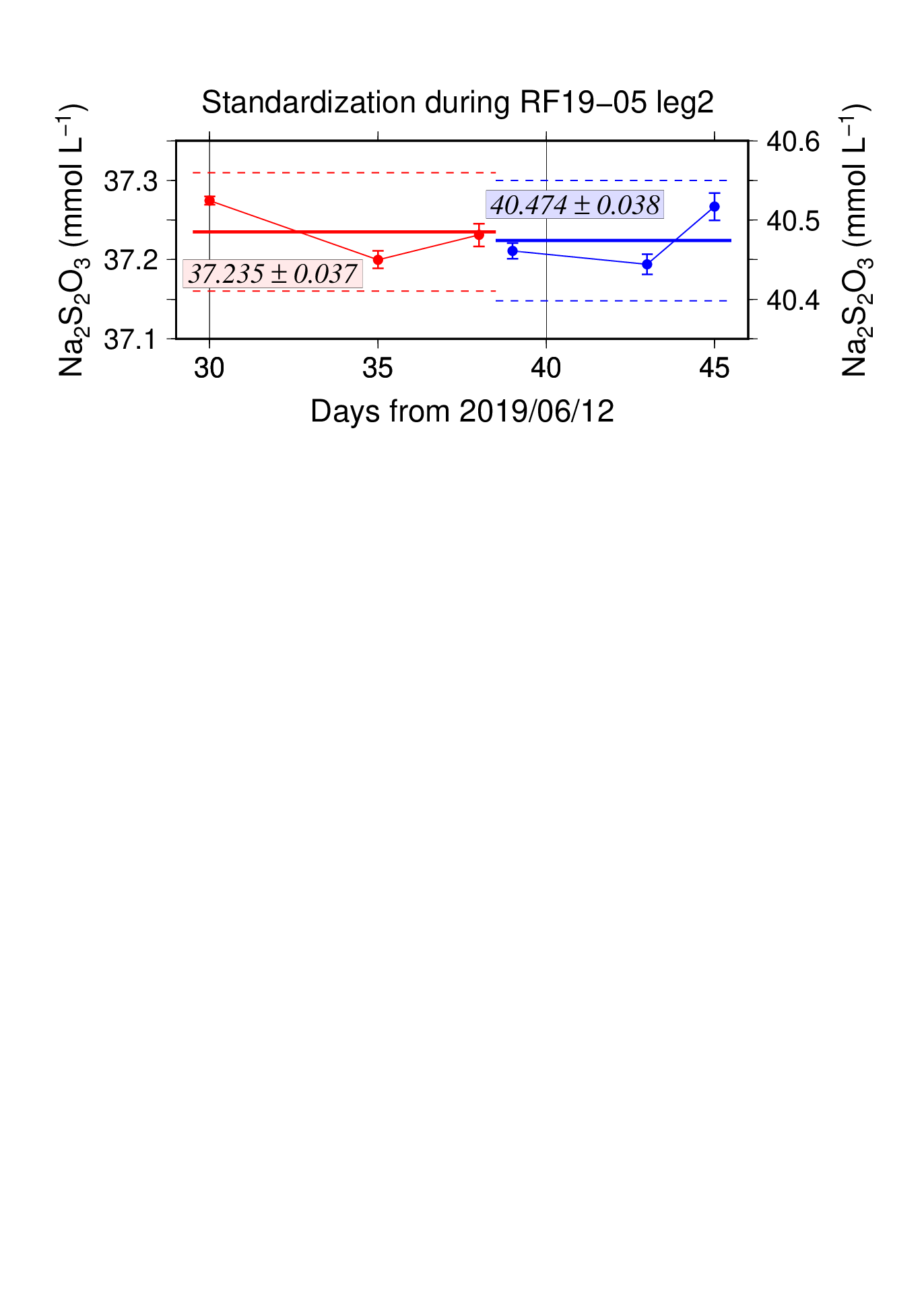
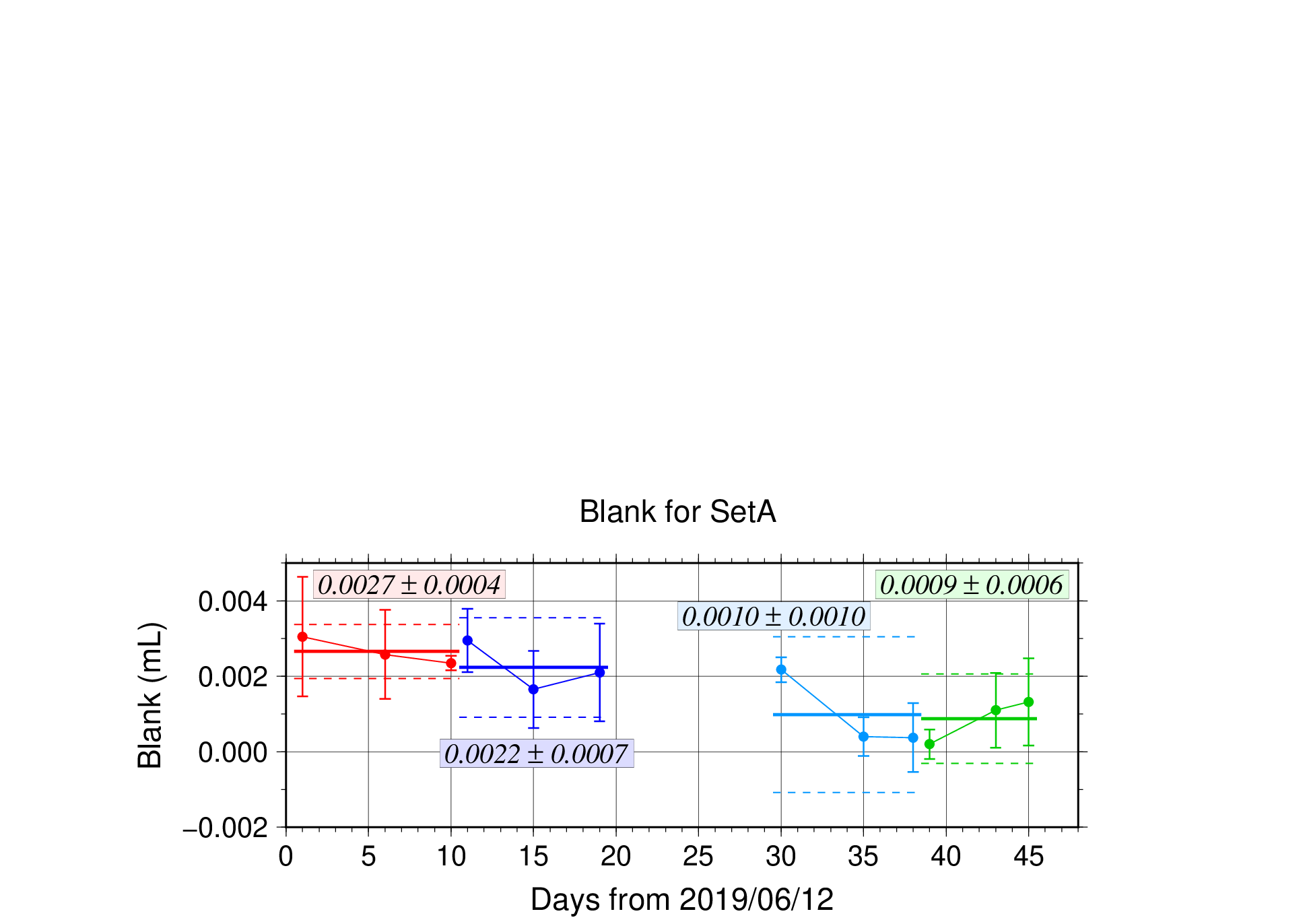


Figure C.3.3. Calculated concentration of Na2S2O3 solution at 20 °C in standardization during RF19-05 Leg 1 (top) and RF19-05 Leg 2 (bottom). Different colors of plots indicate different batches of Na2S2O3 solution; red (blue) plots correspond to the left (right) y-axis. Error bars of plots show standard deviations of concentration of Na2S2O3 in the measurements. Thick and dashed lines denote the mean and twice the standard deviations for the batch measurements, respectively.

### Blank

#### (6.1) Reagent blank

The blank in an oxygen measurement (reagent blank in distilled water; Vreg-blk) was determined by the methods described in the IOCCP Report (Langdon, 2010) using pure water. The blank reflects not only the interfering substances (oxidants or reductants) in the reagents but also the differences between the measured end-point and the equivalence point due to unknown causes in the titrator. Because we used two sets (set A and B) of pickling reagent-I and -II, the blanks in each set were determined separately (Figure C.3.4).



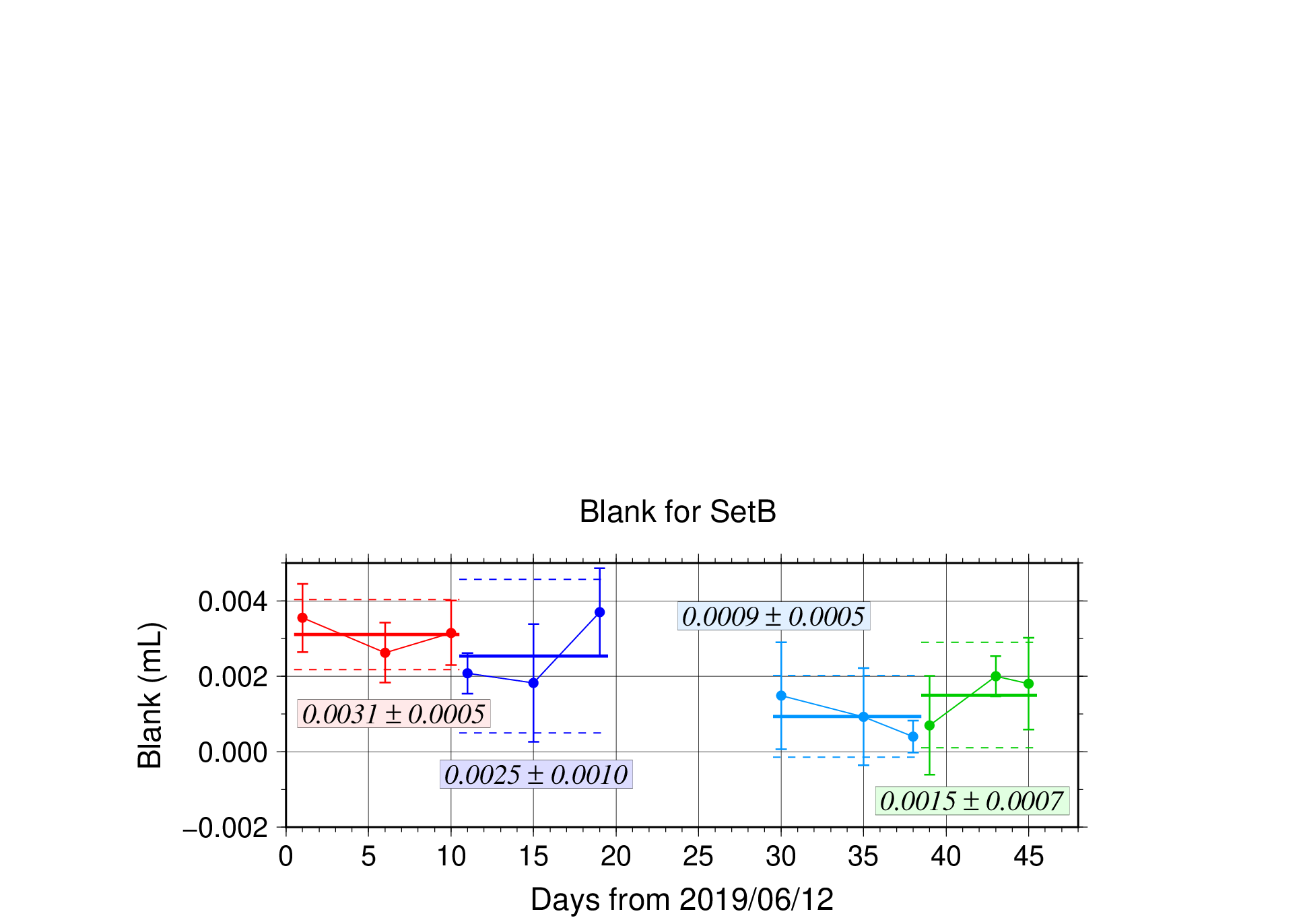


Figure C.3.4. Reagent blank (Vreg-blk) determination for set A (top) and set B (bottom). Error bars of plots show standard deviations of the measurements. Thick and dashed lines denote the mean and the mean ±twice the standard deviation for the batch measurement, respectively.

#### (6.2) Seawater blank

We also determined seawater blank (Vsw-blk) which reflects interfering substances in seawater. Although this blank is not included in determination of oxygen concentration, measurement of the blank would be necessary to improve traceability and comparability in dissolved oxygen concentration. Details are described in Appendix A3.

### Quality Control

#### (7.1) Replicate and duplicate analyses

We took replicate (pair of water samples taken from a single Niskin bottle) and duplicate (pair of water samples taken from different Niskin bottles closed at the same depth) samples of dissolved oxygen throughout the cruise. Table C.3.2 summarizes the results of the analyses. Figure C.3.5 shows details of the results. The calculation of the standard deviation from the difference of sets was based on a procedure (SOP 23) in DOE (1994).

Table C.3.2. Summary of replicate and duplicate measurements.

|  |  |
| --- | --- |
| **Measurement** | **Ave. ± S.D. (mol kg−1)** |
| Replicate | 0.20±0.26 (N=273) |
| Duplicate | 0.57±0.84 (N=23) |

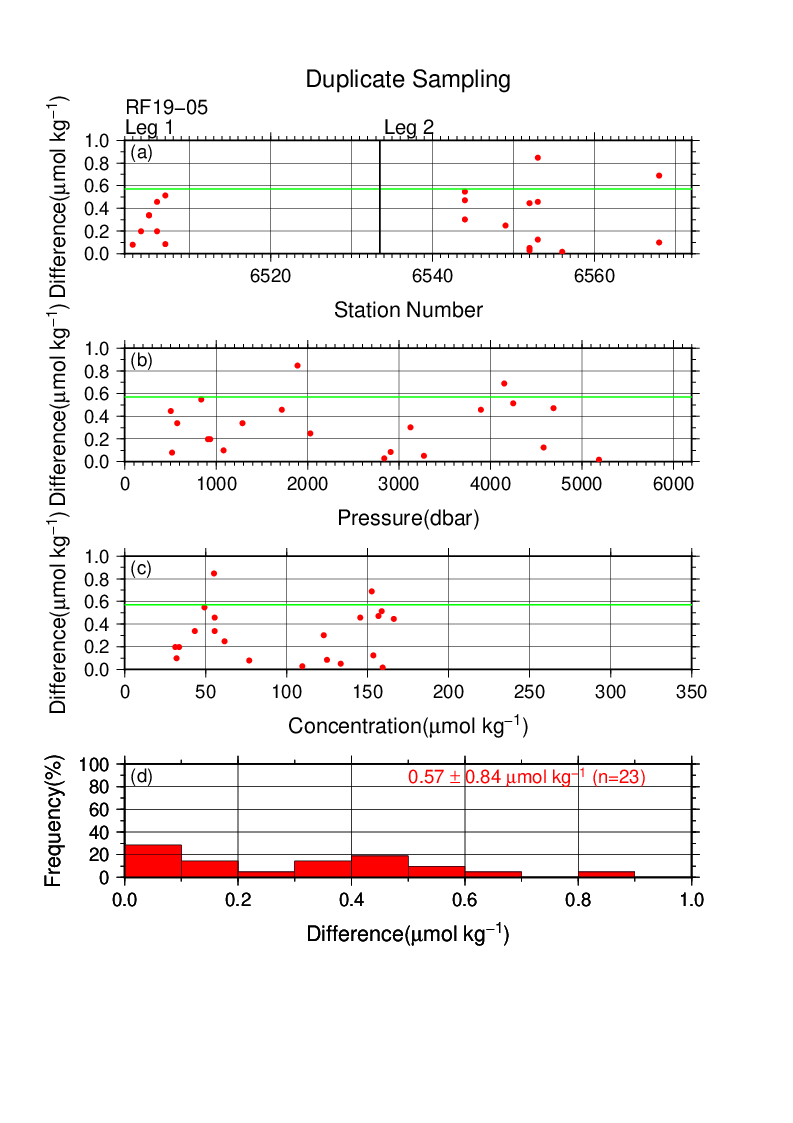
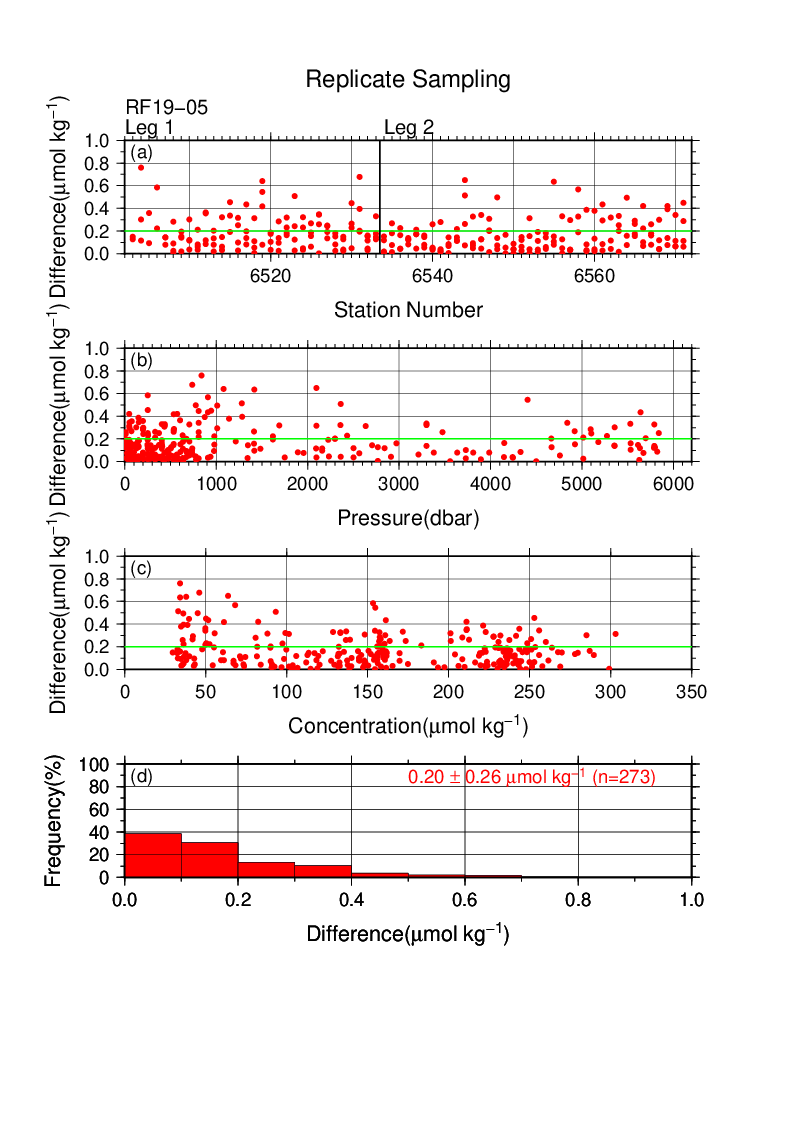


Figure C.3.5. Results of (left) replicate and (right) duplicate measurements during the cruise against (a) station number, (b) pressure, and (c) concentration of dissolved oxygen. Green lines denote the average of the measurements. Bottom panels (d) show histograms of the measurements.

#### (7.2) Comparisons between standard KIO3 solutions

During the cruise, comparisons were made between different lots of standard KIO3 solutions to confirm the accuracy of our oxygen measurements and the bias of a standard KIO3 solution. A concentration of the standard KIO3 solution “20181205-2” was determined using Na2S2O3 solution standardized with the KIO3 solution “20181128-2”, and the difference between the measured value and the theoretical one. Good agreement between two standards confirmed that there was no systematic shift in oxygen measurements during the cruise (Figure C.3.6).

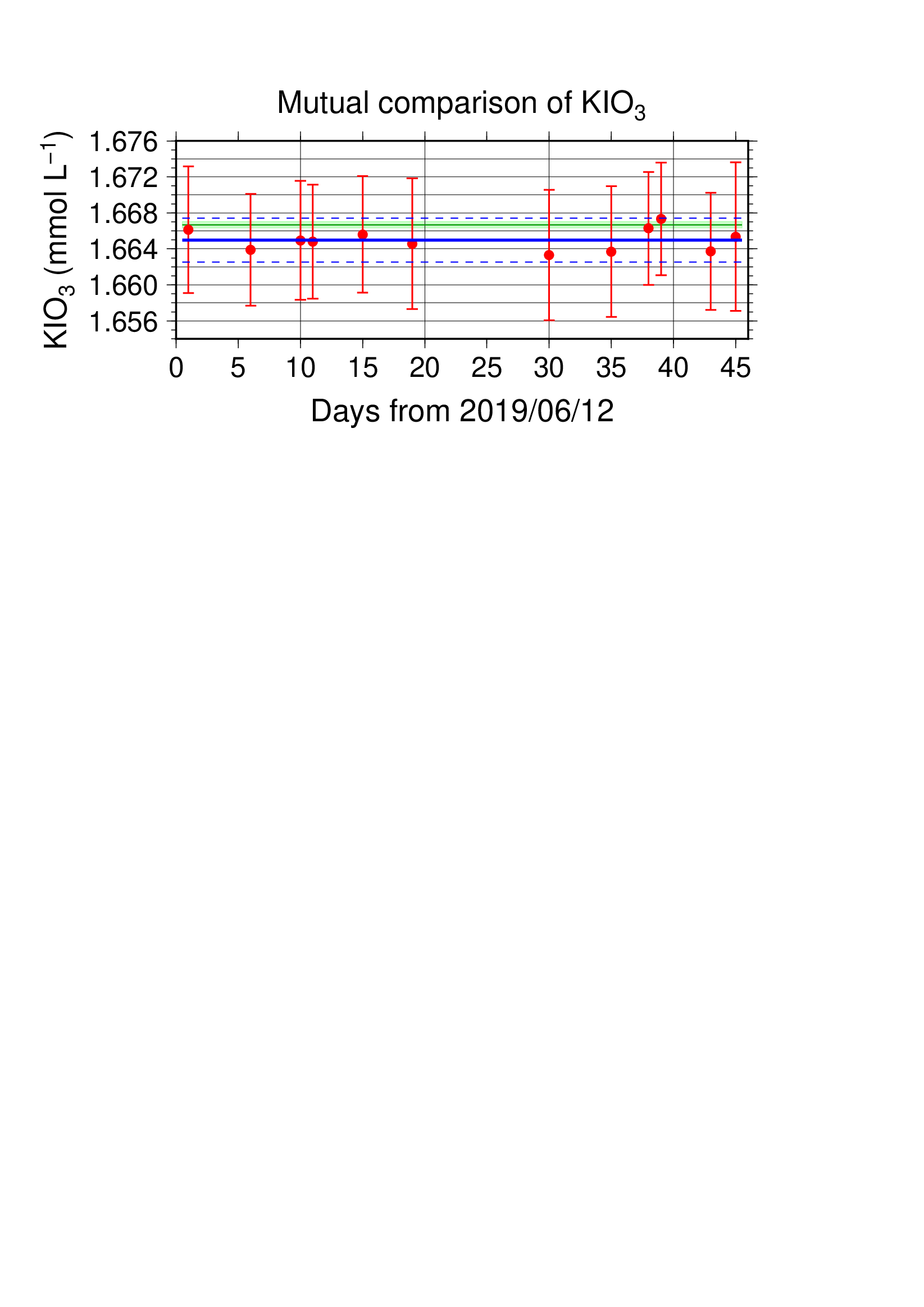


Figure C.3.6. Result of comparison of standard KIO3 solutions during RF19-05. Circles and error bars show mean of the measured value and its uncertainty (k=2), respectively. Thick and dashed lines in blue denote the mean and the mean ± twice the standard deviations, respectively, for the measurements. Green thin line and light green thick line denote the nominal concentration and its uncertainty (k=2) of standard KIO3 solution “20181205-2”.

#### (7.3) Quality control flag assignment

A quality flag value was assigned to oxygen measurements, as shown in Table C.3.3, using the code defined in IOCCP Report No.14 (Swift, 2010).

Table C.3.3. Summary of assigned quality control flags.

|  |  |  |
| --- | --- | --- |
| Flag | Definition | Number of samples |
| 2 | Good | 2189 |
| 3 | Questionable | 28 |
| 4 | Bad (Faulty) | 25 |
| 5 | Not reported | 0 |
| 6 | Replicate measurements | 273 |
| Total number of samples | | 2515 |

### Uncertainty

Oxygen measurement involves various uncertainties; determination of glass bottles volume, repeatability and systematic error of burette discharge, repeatability of pickling reagent discharges, determination of reagent blank, standardization of Na2S2O3 solution, and uncertainty of KIO3 concentration. After taking into consideration the above uncertainties that could be evaluated, the expanded uncertainty of bottle oxygen concentrations (*T*=20, *S*=34.5) was estimated, as shown in Table C.3.4. However, it is difficult to determine a strict uncertainty for oxygen concentration because there is no reference material for oxygen measurement.

Table C.3.4. Expanded uncertainty (k=2) of bottle oxygen during the cruise.

|  |  |
| --- | --- |
| O2 conc. (mol kg−1) | Uncertainty (mol kg−1) |
| 20 | 0.31 |
| 30 | 0.32 |
| 50 | 0.34 |
| 70 | 0.36 |
| 100 | 0.40 |
| 150 | 0.49 |
| 200 | 0.59 |
| 250 | 0.70 |
| 300 | 0.81 |
| 400 | 1.05 |

### Appendix

**A1. Methods**

**(A1.1) Seawater sampling**

Following procedure is based on a determination method in IOCCP Report (Langdon, 2010). Seawater samples were collected from 10-liters Niskin bottles attached the CTD-system and a stainless steel bucket for the surface. Seawater for bottle oxygen measurement was transferred from the Niskin bottle and a stainless steel bucket to a volumetrically calibrated dry glass bottles. At least three times the glass volume water was overflowed. Then, pickling reagent-I 1 mL and reagent-II 1mL were added immediately, and sample temperature was measured using a thermometer. After a stopper was inserted carefully into the glass, it was shaken vigorously to mix the content and to disperse the precipitate finely. After the precipitate has settled at least halfway down the glass, the glass was shaken again. The sample glasses containing pickled samples were stored in a laboratory until they were titrated. To prevent air from entering the glass, deionized water (DW) was added to its neck after sampling.

**(A1.2) Sample measurement**

At least 15 minutes after the re-shaking, the samples were measured on board. Added 1 mL H2SO4 solution and a magnetic stirrer bar into the sample glass, samples were titrated with Na2S2O3 solution whose molarity was determined with KIO3 solution. During the titration, the absorbance of iodine in the solution was monitored using a detector. Also, temperature of Na2S2O3 solution during the titration was recorded using a thermometer. Dissolved oxygen concentration (mol kg−1) was calculated from sample temperature at the fixation, CTD salinity, glass volume, and titrated volume of the Na2S2O3 solution, and oxygen in the pickling reagents-I (1 mL) and II (1 mL) (7.6 × 10−8 mol; Murray *et al.*, 1968).

**A2. Reagents recipes**

Pickling reagent-I; Manganous chloride solution (3 molL−1)

Dissolve 600 g of MnCl2·4H2O in DW, then dilute the solution with DW to a final volume of 1 L.

Pickling reagent-II; Sodium hydroxide (8 molL−1) / sodium iodide solution (4 molL−1)

Dissolve 320 g of NaOH in about 500 mL of DW, allow to cool, then add 600 g NaI and dilute with DW to a final volume of 1 L.

H2SO4 solution; Sulfuric acid solution (5 molL−1)

Slowly add 280 mL concentrated H2SO4 to roughly 500 mL of DW. After cooling the final volume should be 1 L.

Na2S2O3 solution; Sodium thiosulfate solution (0.04 molL−1)

Dissolve 50 g of Na2S2O3·5H2O and 0.4 g of Na2CO3 in DW, then dilute the solution with DW to a final volume of 5 L.

KIO3 solution; Potassium iodate solution (0.001667 mol L−1)

Dry high purity KIO3 for two hours in an oven at 130 °C. After weight out accurately KIO3, dissolve it in DW in a 5 L flask. Concentration of potassium iodate is determined by a gravimetric method.

**A3. Seawater blank**

Blank due to redox species other than oxygen in seawater (Vsw-blk) can be a potential source of measurement error. Total blank (Vtot-blk) in seawater measurement can be represented as follows;

Vtot-blk, = Vreg-blk + Vsw-blk.(C3.A1)

Because the reagent blank (Vreg-blk) determined for pure water is expected to be equal to that in seawater, the difference between blanks for seawater (Vtot-blk) and for pure water gives the Vsw-blk.

Here, Vsw-blk was determined by following procedure. Seawater was collected in the calibrated volumetric glass without the pickling solution. Then 1 mL of the standard KIO3 solution, H2SO4 solution, and reagent solution-II and I each were added in sequence into the glass. After that, the sample was titrated to the end-point by Na2S2O3 solution. Similarly, a glass contained 100 mL of DW added with 1 mL of the standard KIO3 solution, H2SO4 solution, pickling reagent solution-II and I were titrated with Na2S2O3 solution. The difference of the titrant volume of the seawater and DW glasses gave Vsw-blk.

The seawater blank has been reported from 0.4 to 0.8 molkg−1 in the previous study (Culberson *et al*., 1991). Additionally, these errors are expected to be the same to all investigators and not to affect the comparison of results from different investigators (Culberson, 1994). However, the magnitude and variability of the seawater blank have not yet been documented. Understanding of the magnitude and variability is important to improve traceability and comparability in oxygen concentration. The determined seawater blanks are shown in Table C.3.A1.

Table C.3.A1. Results of seawater blank determinations.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Station: RF6533  40°-01′N/160°-20′E | |  | Station: RF6571  40°-01′N/165°-01′E | |  |  | |
| Depth | Blank |  | Depth | Blank |  |  |  |
| (m) | (μmol kg−1) |  | (m) | (μmol kg−1) |  |  |  |
| 11 | 1.83 |  | 101 | 0.70 |  |  |  |
| 248 | 0.92 |  | 280 | 0.64 |  |  |  |
| 428 | 0.91 |  | 672 | 0.74 |  |  |  |
| 631 | 0.85 |  | 672 | 0.77 |  |  |  |
| 930 | 1.03 |  | 973 | 0.72 |  |  |  |
| 1669 | 1.21 |  | 1529 | 0.71 |  |  |  |
| 2270 | 0.84 |  | 2332 | 0.76 |  |  |  |
| 3077 | 1.10 |  | 3170 | 0.70 |  |  |  |
| 3828 | 1.12 |  | 4172 | 0.69 |  |  |  |
| 5327 | 1.69 |  | 4922 | 0.89 |  |  |  |
|  |  |  | 5419 | 0.71 |  |  |  |
|  |  |  | 5419 | 0.75 |  |  |  |

***Reference***

Culberson, A.H. (1994), Dissolved oxygen, in WHPO Pub. 91-1 Rev. 1, November 1994, Woods Hole, Mass., USA.

Culberson, A.H., G. Knapp, M.C. Stalcup, R.T. Williams, and F. Zemlyak (1991), A comparison of methods for the determination of dissolved oxygen in seawater, WHPO Pub. 91-2, August 1991, Woods Hole, Mass., USA.

Langdon, C. (2010), Determination of dissolved oxygen in seawater by Winkler titration using the amperometric technique, *IOCCP Report No.14, ICPO Pub. 134, 2010 ver.1*

Murray, C. N., J. P. Riley and T. R. S. Wilson (1968), The solubility of oxygen in Winkler reagents used for the determination of dissolved oxygen. *Deep-Sea Res*. 15, 237–238.

Swift, J. H. (2010), Reference-quality water sample data: Notes on acquisition, record keeping, and evaluation. *IOCCP Report No.14, ICPO Pub. 134, 2010 ver.1*.

## Nutrients

*10 June 2020*

### Personnel

Leg 1

Hiroyuki HATAKEYAMA (GEMD/JMA)

Koichi WADA (GEMD/JMA)

Kei KONDO (GEMD/JMA)

Rie SANAI (GEMD/JMA)

Masakazu TAKAMI (GEMD/JMA)

Leg 2

Hiroyuki HATAKEYAMA (GEMD/JMA)

Tomohiro UEHARA (GEMD/JMA)

Kei KONDO (GEMD/JMA)

Rie SANAI (GEMD/JMA)

Masakazu TAKAMI (GEMD/JMA)

### Station occupied

A total of 70 stations (Leg 1: 32, Leg 2: 38) were occupied for nutrients measurements. Station location and sampling layers of nutrients are shown in Figures C.4.1 and C.4.2.

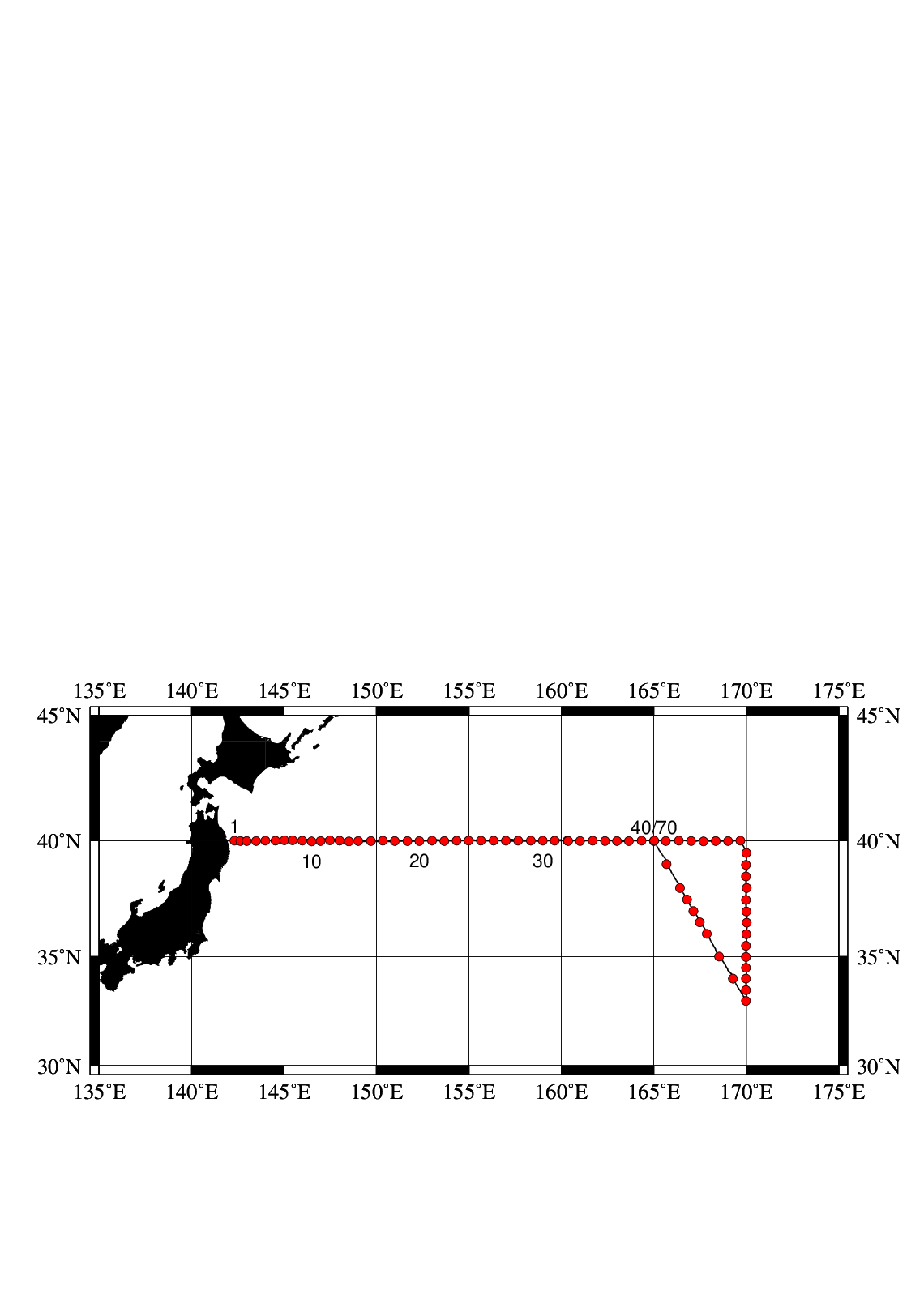


Figure C.4.1. Location of observation stations of nutrients.

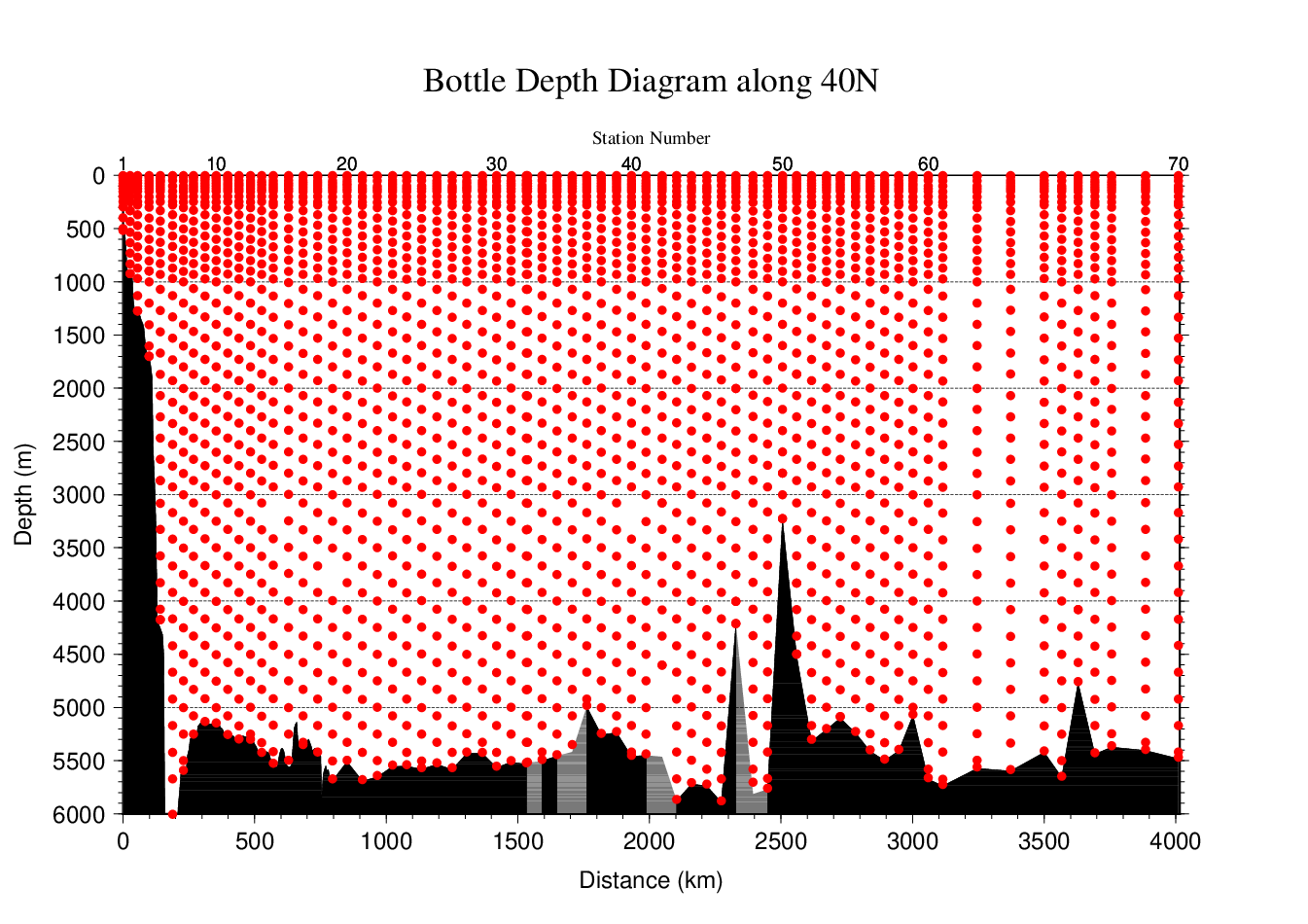


Figure C.4.2. Distance-depth distributions of sampling layers of nutrients.

### Instrument

The nutrients analyses were carried out on a four-channel Auto Analyzer III (BL TEC K.K., Japan) for four nutrients nitrate+nitrite, nitrite, phosphate, and silicate.

### Sampling and measurement

Methods of seawater sampling, measurement, and data processing of nutrient concentration were described in Appendixes A1, A2, and A3, respectively. The reagents for the measurement were prepared according to recipes shown in Appendix A4.

### Nutrients standards

#### (5.1) Volumetric laboratory ware of in-house standards

All volumetric wares were gravimetrically calibrated. The weights obtained in the calibration weighing were corrected for the density of water and for air buoyancy. Polymethylpenten volumetric flasks were gravimetrically calibrated at the temperature of use within 4–6 °C. All pipettes have nominal calibration tolerances of 0.1 % or better. These were gravimetrically calibrated in order to verify and improve upon this nominal tolerance.

#### (5.2) Reagents of standard

The batches of the reagents used for standards are listed in Table C.4.1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table C.4.1. List of reagents for the standards used in the cruise. | | | | |
|  | **Name** | **CAS No** | **Lot. No** | **Industries** |
| **Nitrate** | Potassium nitrate 99.995 suprapur® | 7757-79-1 | B1452165 | Merck KGaA |
| **Nitrite** | Sodium nitrite GR for analysis ACS, Reag. Ph Eur | 7632-00-0 | A1276649 | Merck KGaA |
| **Phosphate** | Potassium dihydrogen phosphate anhydrous 99.995 suprapur® | 7778-77-0 | B1642608 | Merck KGaA |
| **Silicate** | Silicon standard solution 1000 mg/l Si\* | - | HC86788836 | Merck KGaA |

\* Traceable to NIST-SRM3150

#### (5.3) Low nutrient seawater (LNSW)

Surface water with sufficiently low nutrient concentration was taken and filtered using 10 μm pore size membrane filter in our previous cruise. This water was stored in 15 liter flexible container with paper box.

#### (5.4) In-house standard solutions

Nutrient concentrations for A, B and C standards were set as shown in Table C.4.2. A and B standards were prepared with deionized water (DW). C standard (full scale of working standard) was mixture of B-1 and B-2 standards, and was prepared with LNSW. C-1 standard, whose concentrations of nutrient were nearly zero, was prepared as LNSW slightly added with DW to be equal with mixing ratio of LNSW and DW in C standard. The C-2 to -5 standards were prepared with mixture of C-1 and C standards in stages as 1/4, 2/4, 3/4, and 4/4 (i.e., pure “C standard”) concentration for full scale, respectively. The actual concentration of nutrients in each standard was calculated based on the solution temperature and factors of volumetric laboratory wares calibrated prior to use. Nominal zero concentration of nutrient was determined in measurement of DW after refraction error correction. The calibration curves for each run were obtained using 5 levels of C-1 to -5 standards. These standard solutions were periodically renewed as shown in Table C.4.3.

|  |  |  |  |
| --- | --- | --- | --- |
| Table C.4.2. Nominal concentrations of nutrients for A, B, and C standards at 20 °C. Unit is μmol L−1. | | | |
|  | A | B | C |
| Nitrate | 28761 | 575 | 46.0 |
| Nitrite | 12505 | 250 | 2.0 |
| Phosphate | 2202 | 44.0 | 3.52 |
| Silicate | 35819 | 2328 | 186 |

|  |  |
| --- | --- |
| Table C.4.3. Schedule of renewal of in-house standards. | |
| Standard | Renewal |
| A-1 std. (NO3) | No renewal |
| A-2 std. (NO2) | No renewal |
| A-3 std. (PO4) | No renewal |
| A-4 std. (Si) | Commercial prepared solution |
| B-1 std. (mixture of A-1, A-3, and A-4 stds.) | Maximum 8 days |
| B-2 std. (diluted A-2 std.) | Maximum 15 days |
| C-std. (mixture of B-1 and B-2 stds.) | Every measurement |
| C-1 to -5 stds. | Every measurement |

### Certified reference material

Certified reference material for nutrients in seawater (hereafter CRM), which was prepared by the General Environmental Technos company (KANSO Technos, Japan), was used for every analysis at each hydrographic station. Use of CRMs for the analysis of seawater ensures stable comparability and uncertainty of data. CRMs used in the cruise are shown in Table C.4.4.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table C.4.4. Certified concentration and uncertainty (k=2) of CRMs. Unit is μmol kg−1. | | | | |
|  | Nitrate | Nitrite | Phosphate | Silicate |
| CRM-CK | 0.020±0.031\* | 0.011±0.008\* | 0.048±0.012\* | 0.730±0.080 |
| CRM-CJ | 16.2±0.2 | 0.031±0.007 | 1.19±0.02 | 38.5±0.4 |
| CRM-CB | 35.79±0.27 | 0.116±0.0057 | 2.520±0.022 | 109.2±0.62 |
| CRM-BZ | 43.35±0.33 | 0.215±0.011 | 3.056±0.033 | 161.0±0.93 |

\* Reference value because concentration is under limit of quantitation

The CRMs were analyzed every run but were newly opened every two runs. Although this usage of CRM might be less common, we have confirmed a stability of the opened CRM bottles to be tolerance in our observation. The CRM bottles were stored at a laboratory in the ship, where the temperature was maintained at around 25 °C.

It is noted that nutrient data in our report are calibrated not on CRM but on in-house standard solutions. Therefore, to calculate data based on CRM, it is necessary that values of nutrient concentration in our report are correlated with CRM values measured in the same analysis run. The result of CRM measurements is attached as 49UP20190612\_40N\_nut\_CRM\_measurement.csv.

### Quality Control

#### (7.1) Replicate and duplicate analyses

We took replicate (pair of water samples taken from a single Niskin bottle) and duplicate (pair of water samples taken from different Niskin bottles closed at the same depth) samples of nutrients throughout the cruise. Table C.4.5 summarizes the results of the analyses. Figures C.4.3–C.4.5 show details of the results. The calculation of the standard deviation from the difference of sets of samples was based on a procedure (SOP 23) in DOE (1994).

|  |  |  |  |
| --- | --- | --- | --- |
| Table C.4.5. Average and standard deviation of difference of replicate and duplicate measurements throughout the cruise. Unit is μmol kg−1. | | | |
| Samples | Nitrate+nitrite | Phosphate | Silicate |
| Replicate | 0.032±0.033 (N=273) | 0.002±0.002 (N=273) | 0.055±0.055 (N=273) |
| Duplicate | 0.071±0.069 (N=25) | 0.004±0.004 (N=25) | 0.150±0.137 (N=25) |

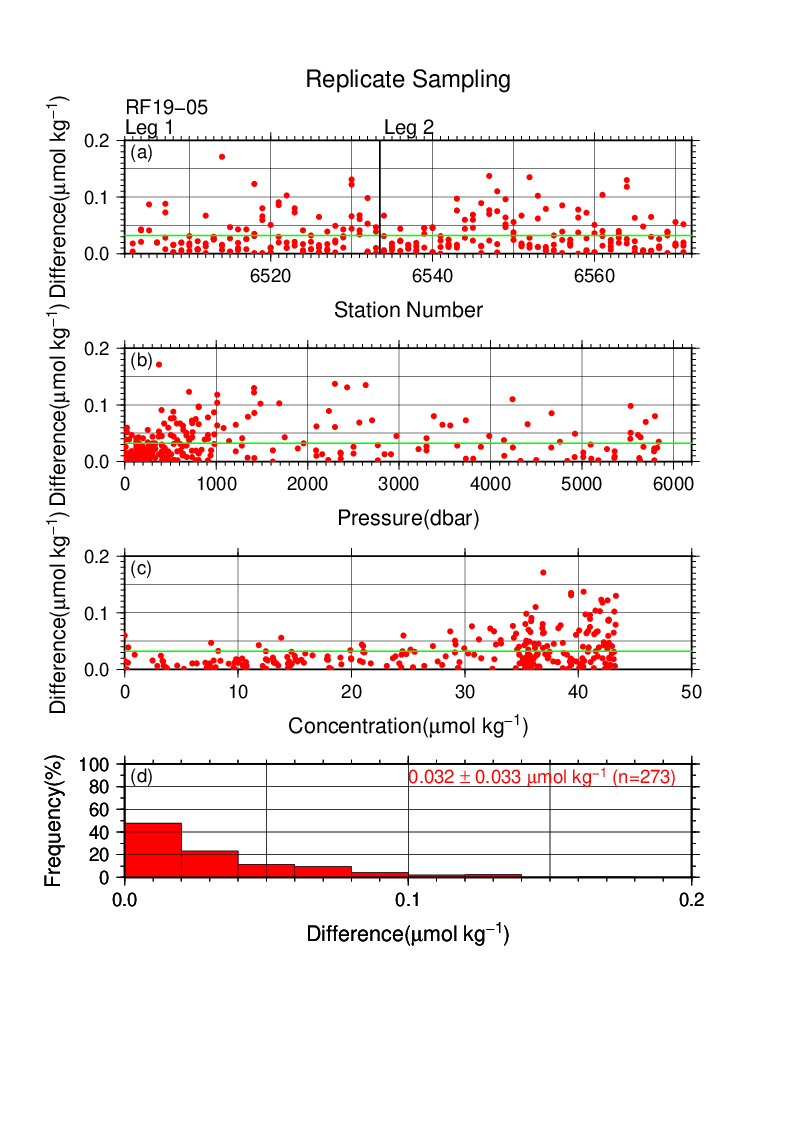
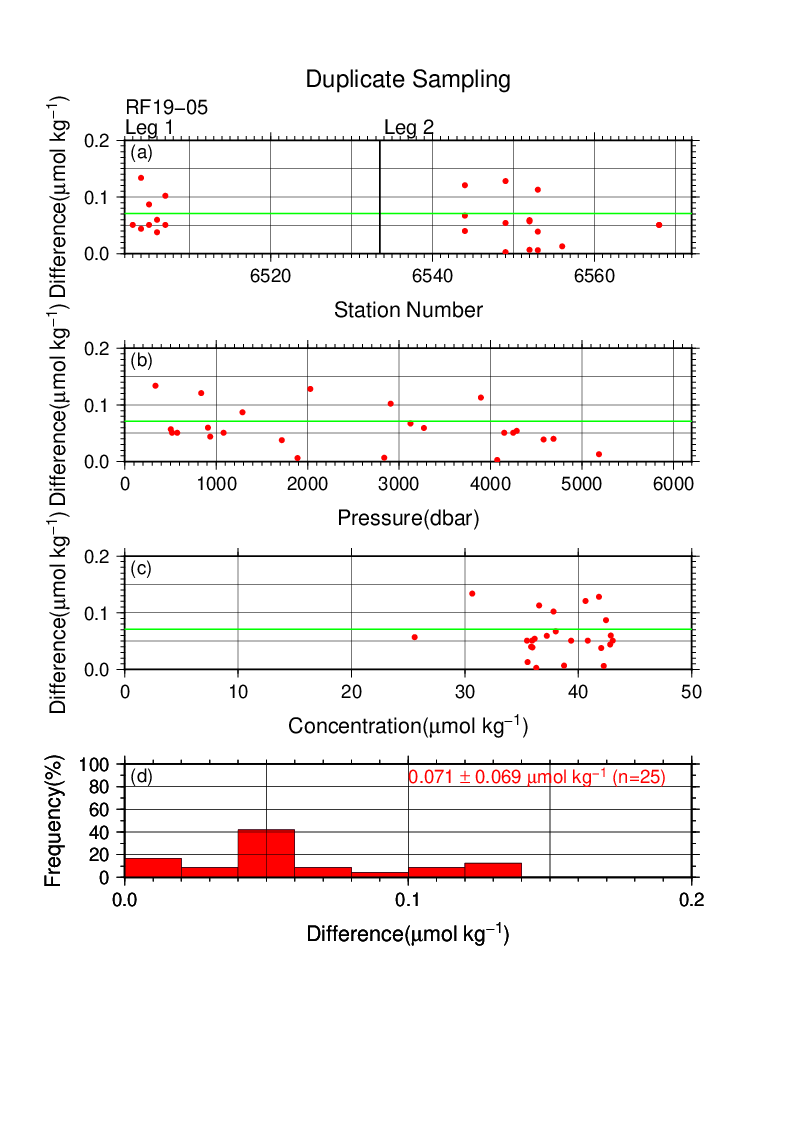
 

Figure C.4.3. Results of (left) replicate and (right) duplicate measurements of nitrate+nitrite throughout the cruise versus (a) station number, (b) sampling pressure, (c) concentration, and (d) histogram of the measurements. Green lines indicates the mean of the differences of concentrations based on replicate/duplicate analyses.

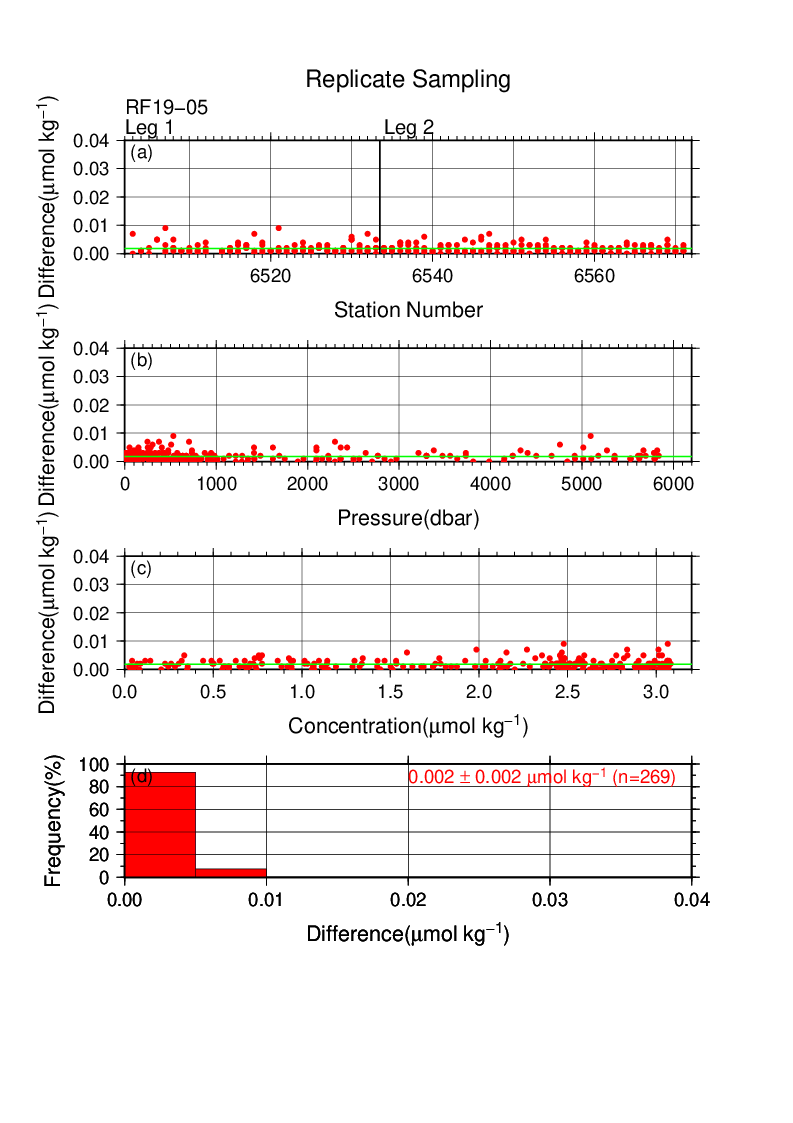
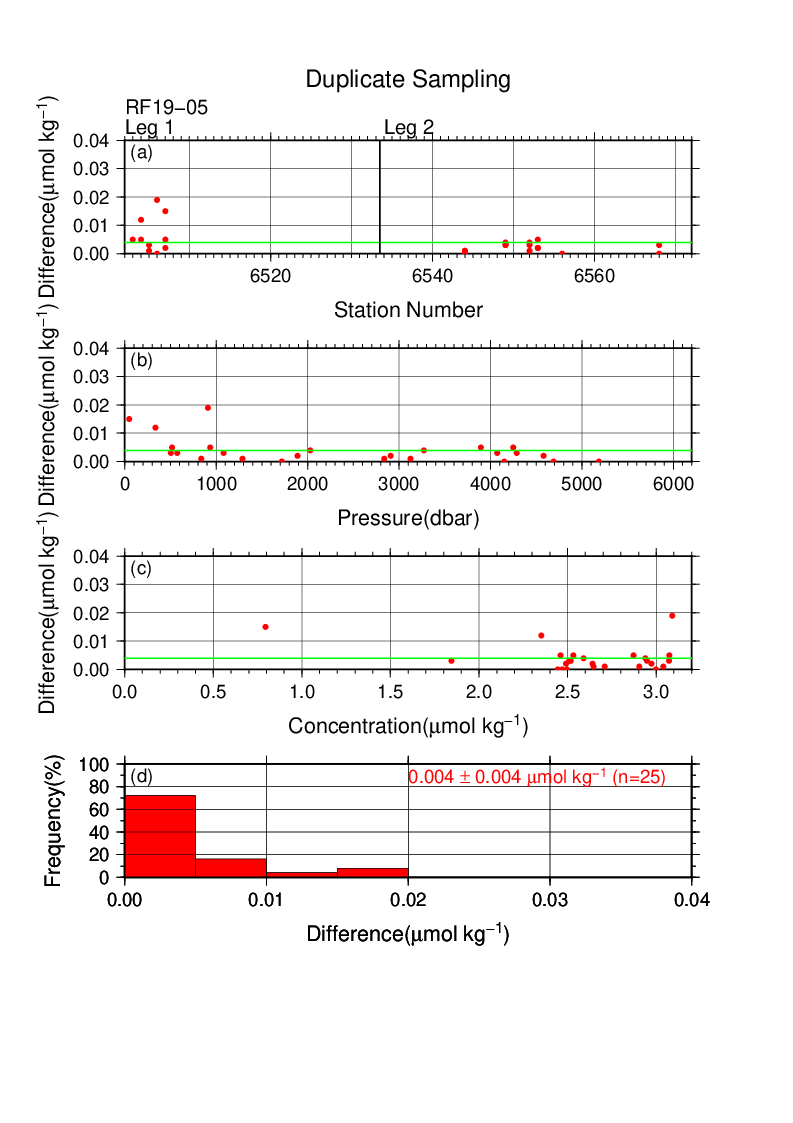
 

Figure C.4.4. Same as Figure C.4.3, but for phosphate.

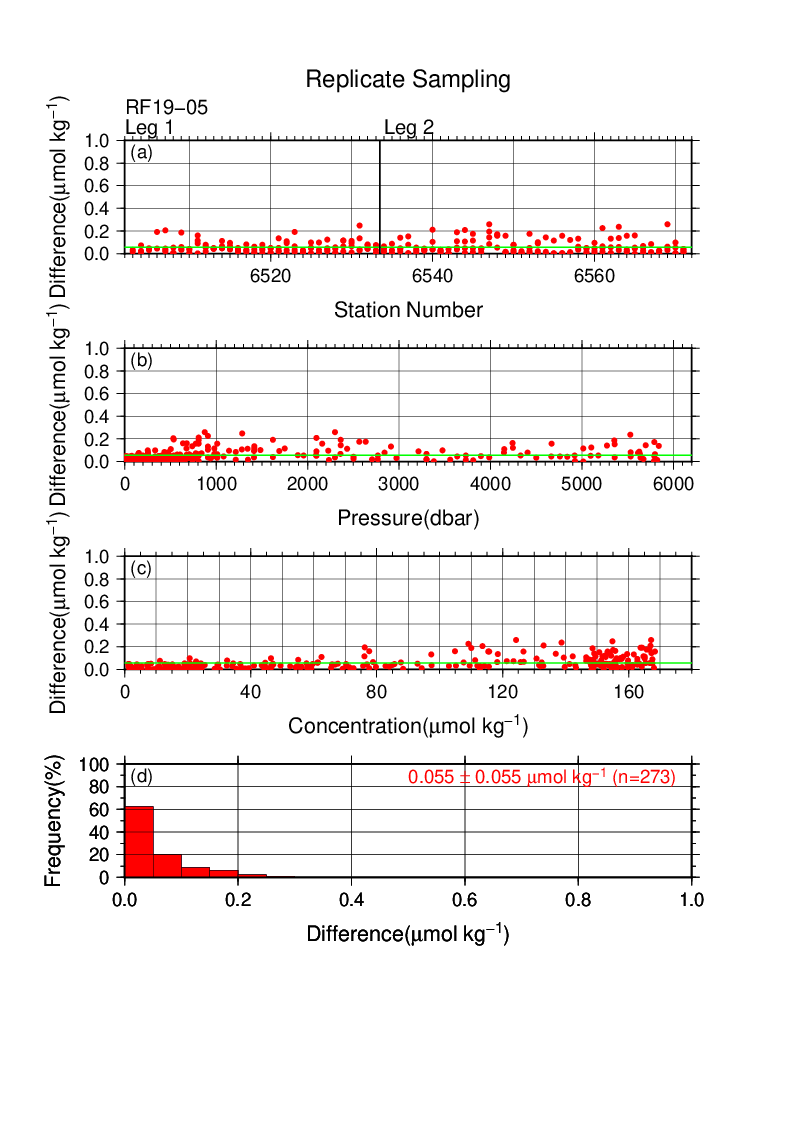
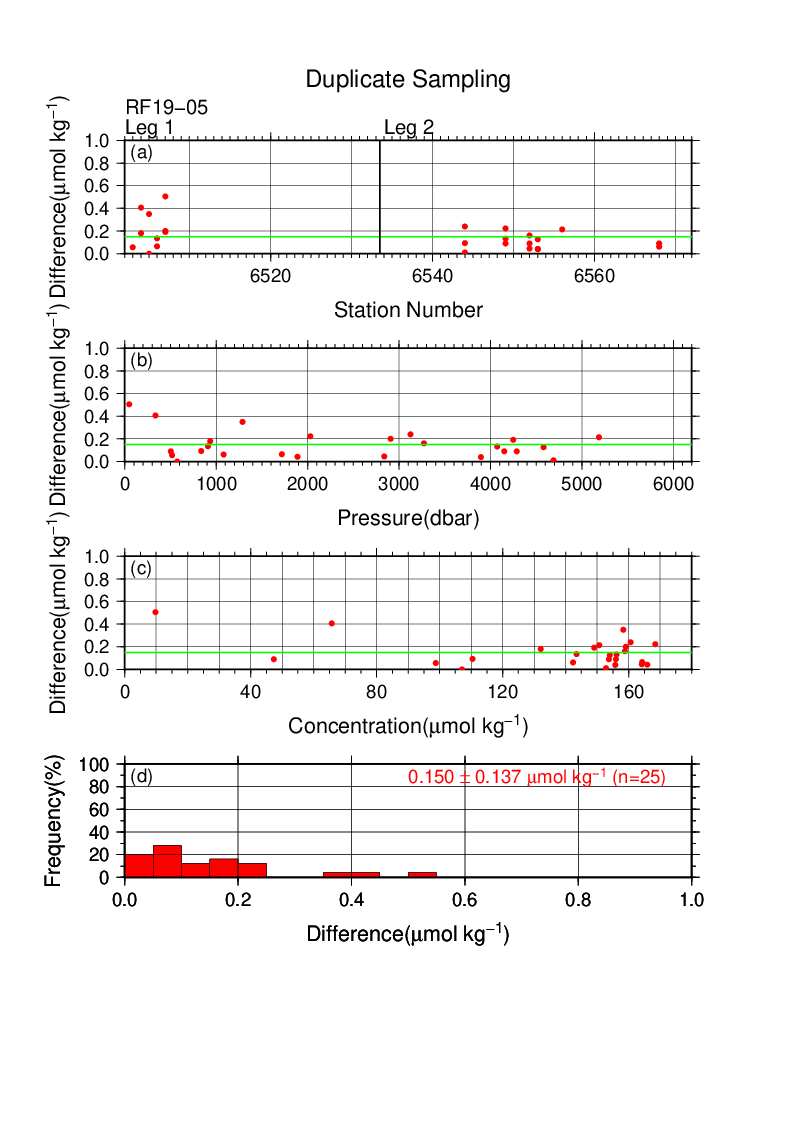
 

Figure C.4.5. Same as Figure C.4.3, but for silicate.

#### (7.2) Measurement of CRMs

Table C.4.6 summarizes the CRM measurements during the cruise. The CRM concentrations were assigned with in-house standard solutions. Figures C.4.6–C.4.9 show the measured concentrations of CRM-BZ throughout the cruise.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table C.4.6. Summary of (upper) mean concentration and its standard deviation (unit: μmol kg−1), (middle) coefficient of variation (%), and (lower) total number of CRMs measurements throughout the cruise. | | | | |
|  | Nitrate+nitrite | Nitrite | Phosphate | Silicate |
| CRM-CK | 0.061±0.022  36.14 %  (N=105) | 0.035±0.002  4.70 %  (N=105) | 0.056±0.003  5.16 %  (N=103) | 0.84±0.05  6.37 %  (N=105) |
| CRM-CJ | 16.20±0.04  0.24 %  (N=105) | 0.045±0.001  2.94 %  (N=104) | 1.19±0.005  0.41 %  (N=103) | 38.88±0.09  0.22 %  (N=105) |
| CRM-CB | 35.93±0.07  0.20 %  (N=105) | 0.133±0.002  1.20 %  (N=105) | 2.53±0.004  0.17 %  (N=103) | 110.72±0.17  0.15 %  (N=105) |
| CRM-BZ | 43.63±0.09  0.21 %  (N=105) | 0.231±0.007  2.85 %  (N=105) | 3.06±0.006  0.21 %  (N=103) | 162.92±0.23  0.14 %  (N=105) |

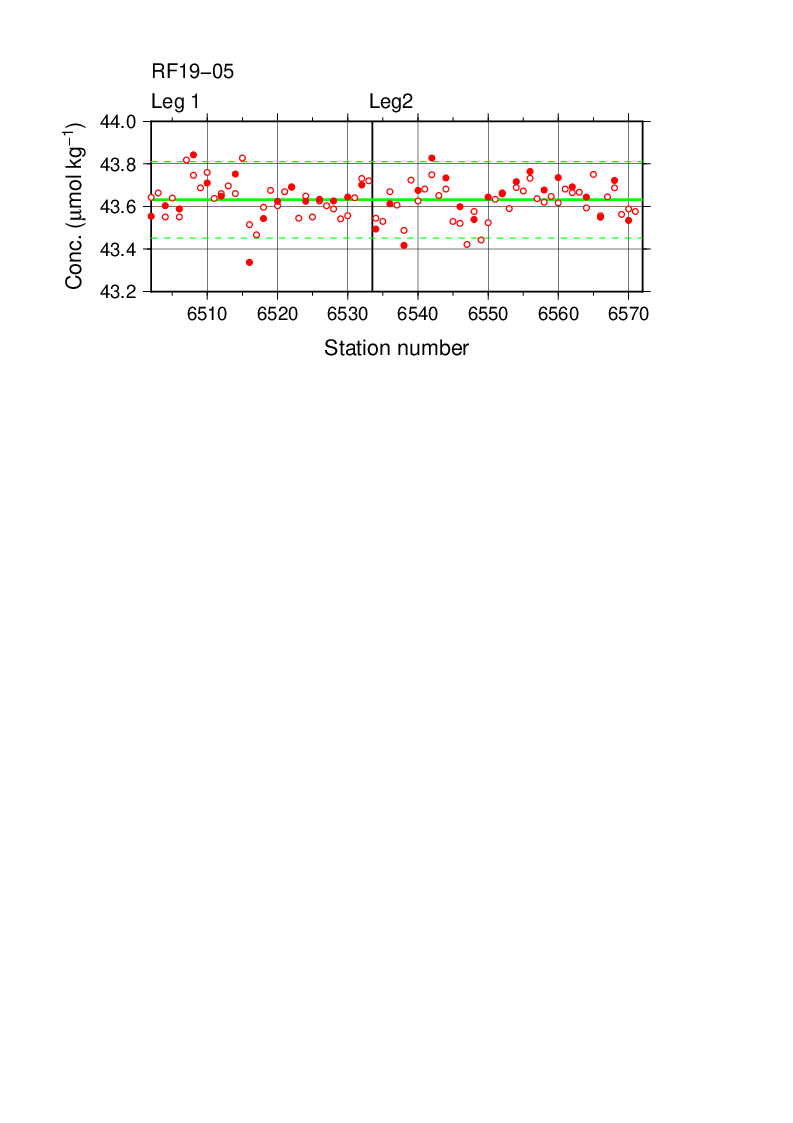


Figure C.4.6. Time-series of measured concentration of nitrate+nitrite of CRM-BZ throughout the cruise. Closed and open circles indicate the newly and previously opened bottle, respectively. Thick and dashed lines denote the mean and the mean ± twice the standard deviations of the measurements throughout the cruise, respectively.

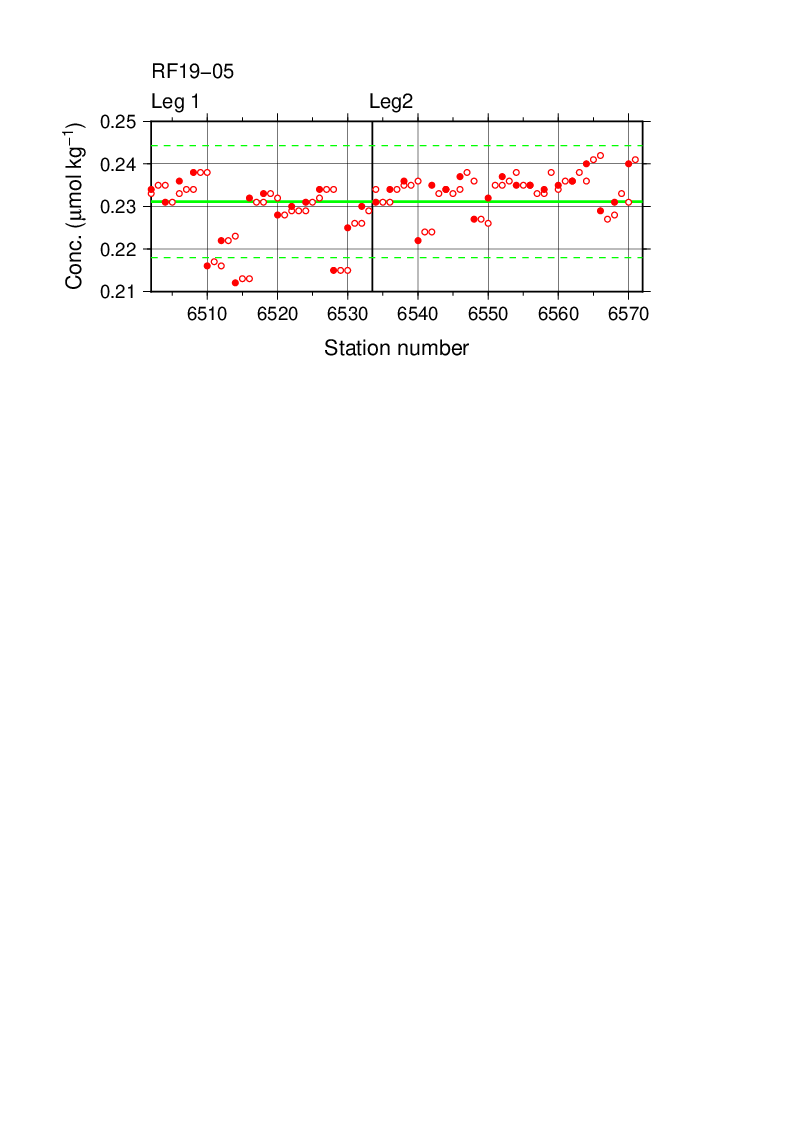


Figure C.4.7. Same as Figure C.4.6, but for nitrite.

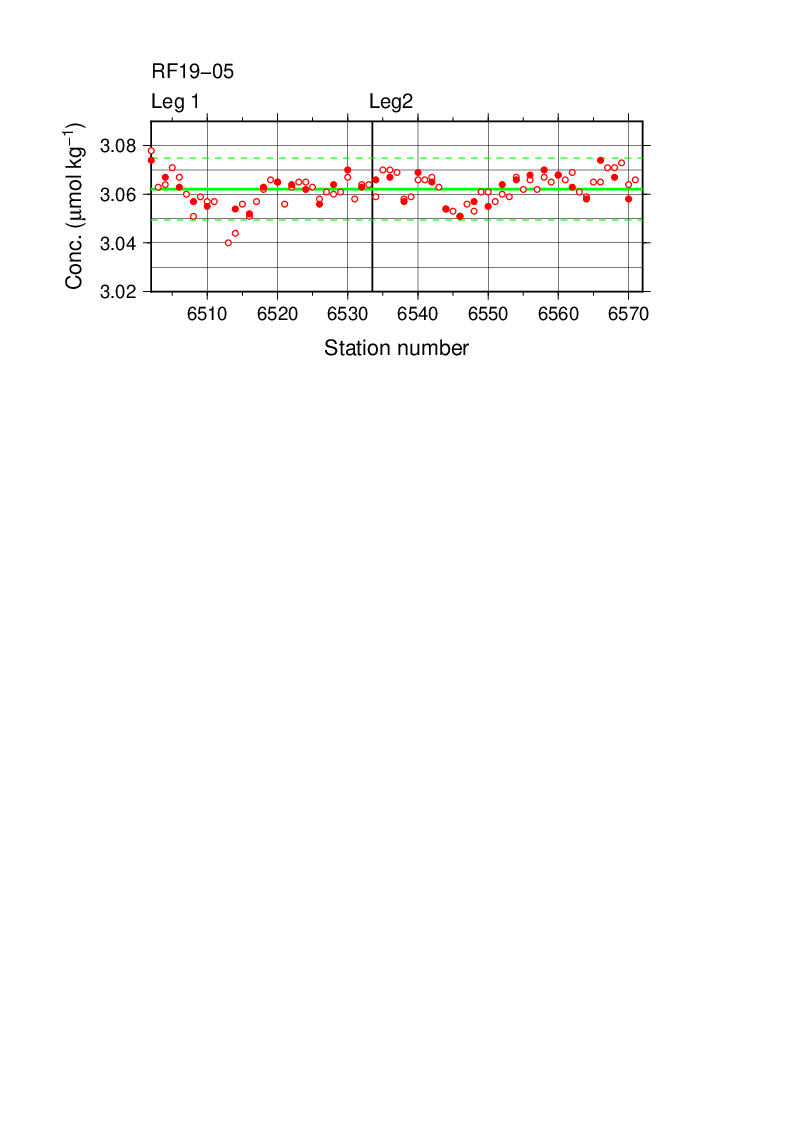


Figure C.4.8. Same as Figure C.4.6, but for phosphate.

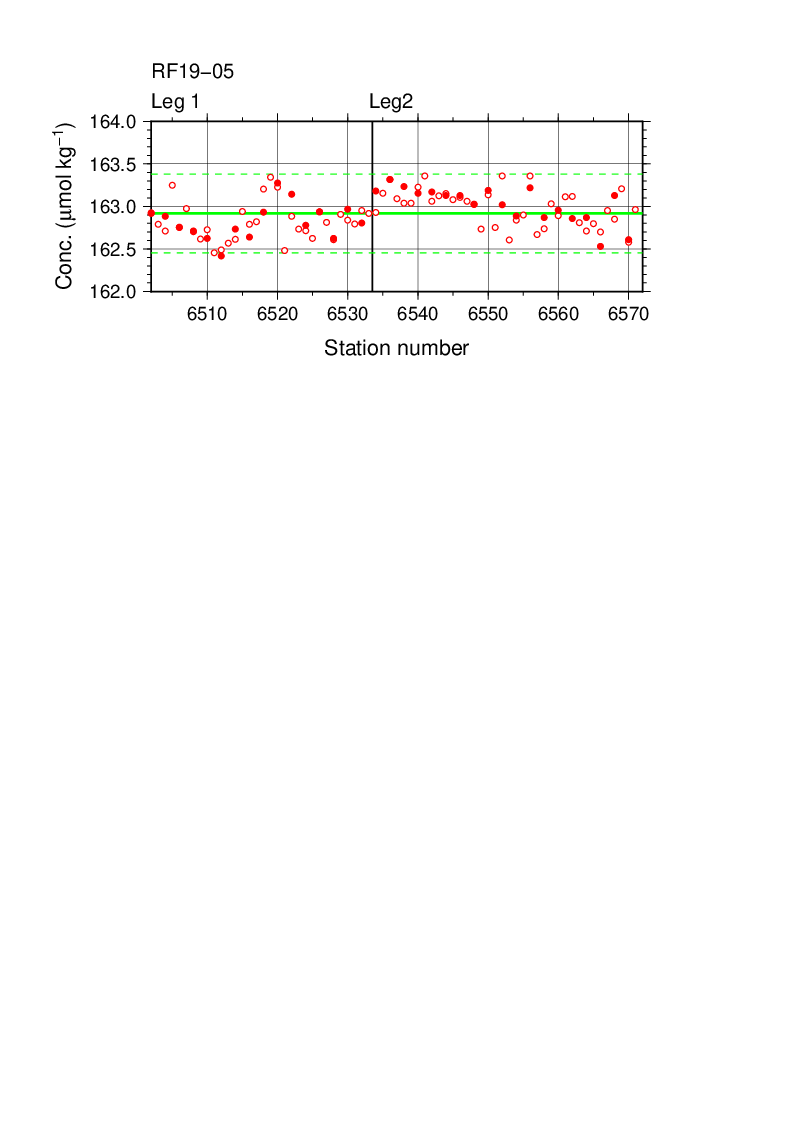


Figure C.4.9. Same as Figure C.4.6, but for silicate.

#### (7.3) Precision of analysis in a run

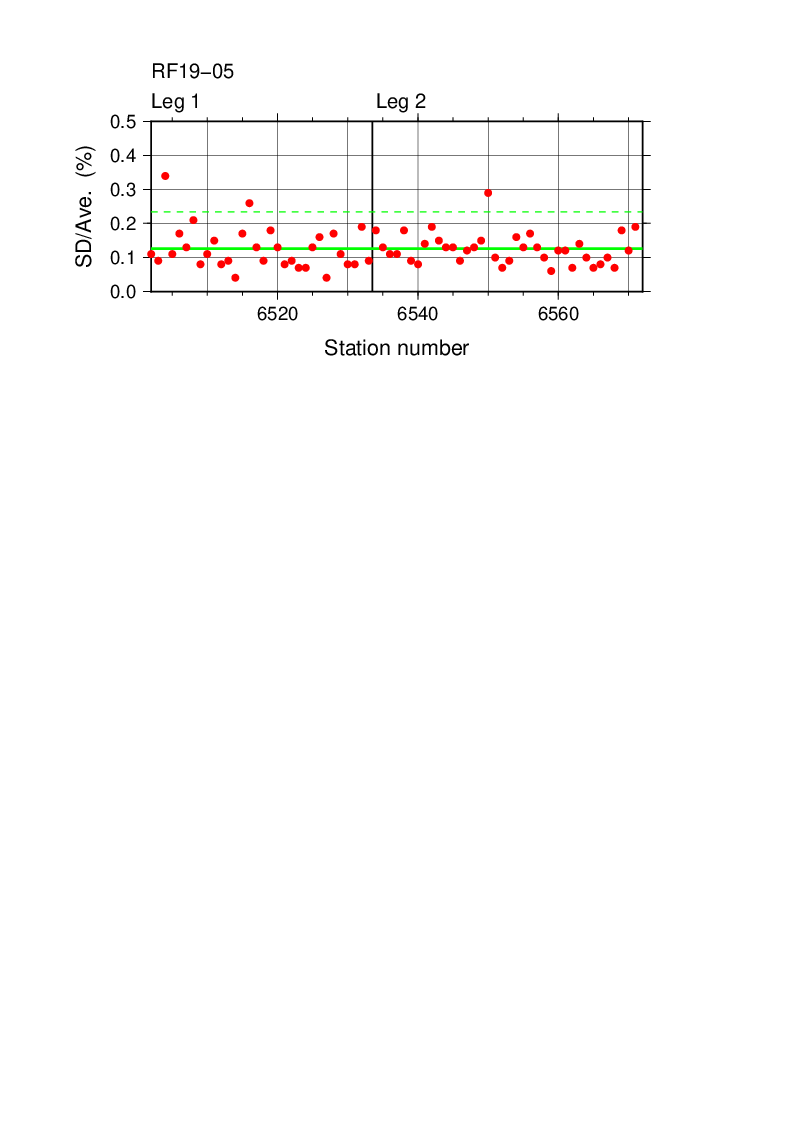
To monitor the precision of the analyses, the same samples were repeatedly measured in a sample array during a run. For this purpose, a C-5 standard solution was randomly inserted in every 2–10 samples as a “check standard” (the number of standards was about 8–9) in the run. The precision was estimated in terms of the coefficient of variation of the measurements. Table C.4.7 summarizes the results. The time series are shown in Figures C.4.10–C.4.13. 

Figure C.4.10. Time-series of the coefficients of variation of “check standard” measurements of nitrate+nitrite throughout the cruise. Thick and dashed lines denote the mean and the mean ± twice the standard deviations of the measurements throughout the cruise, respectively.

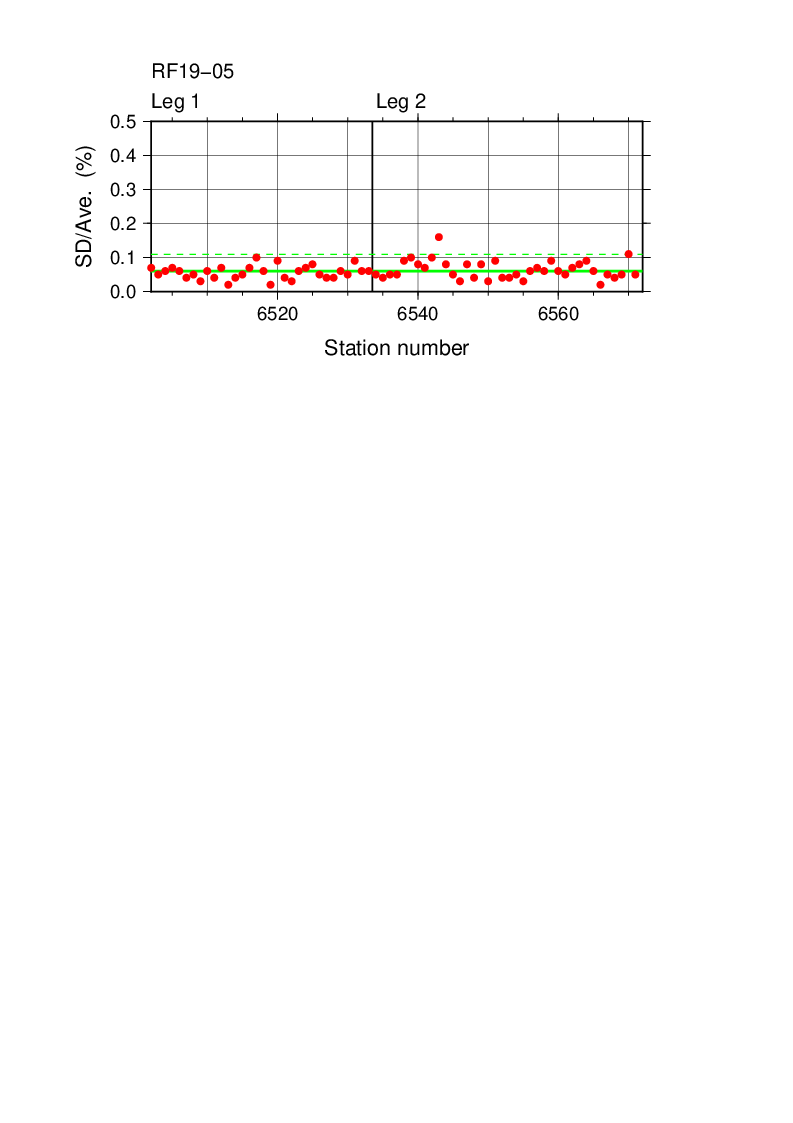


Figure C.4.11. Same as Figure C.4.10, but for nitrite.

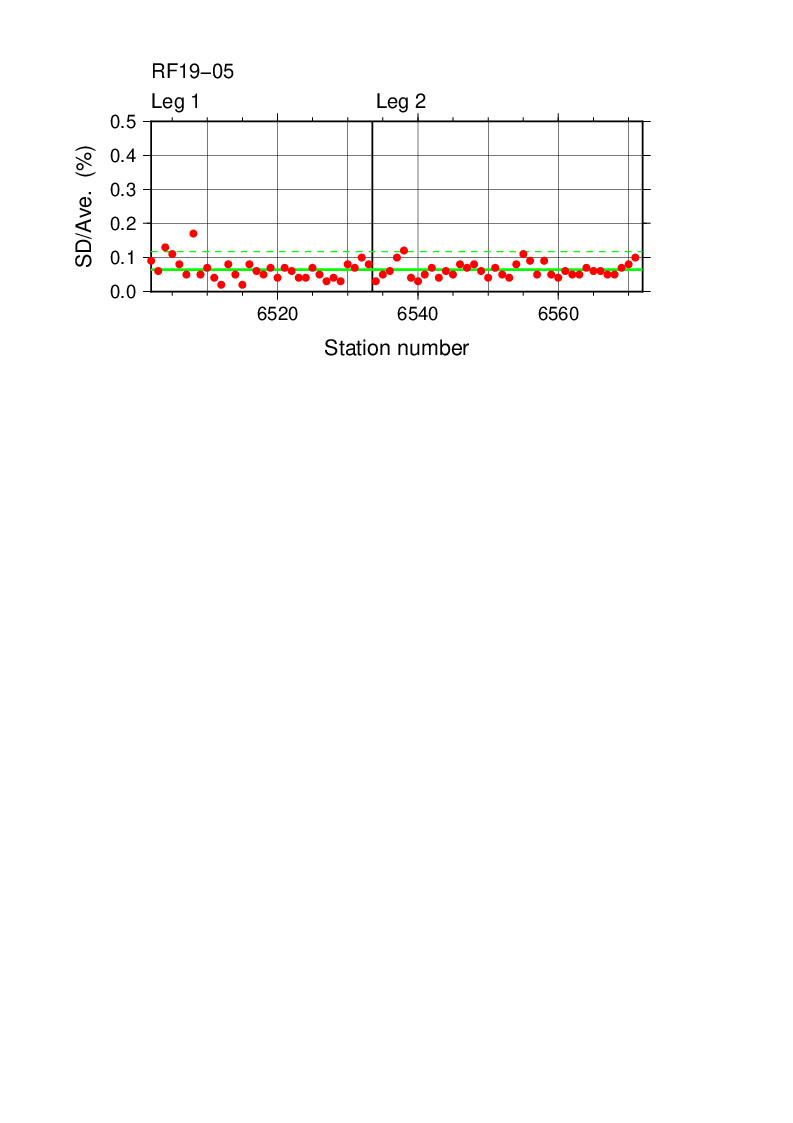


Figure C.4.12. Same as Figure C.4.10, but for phosphate.

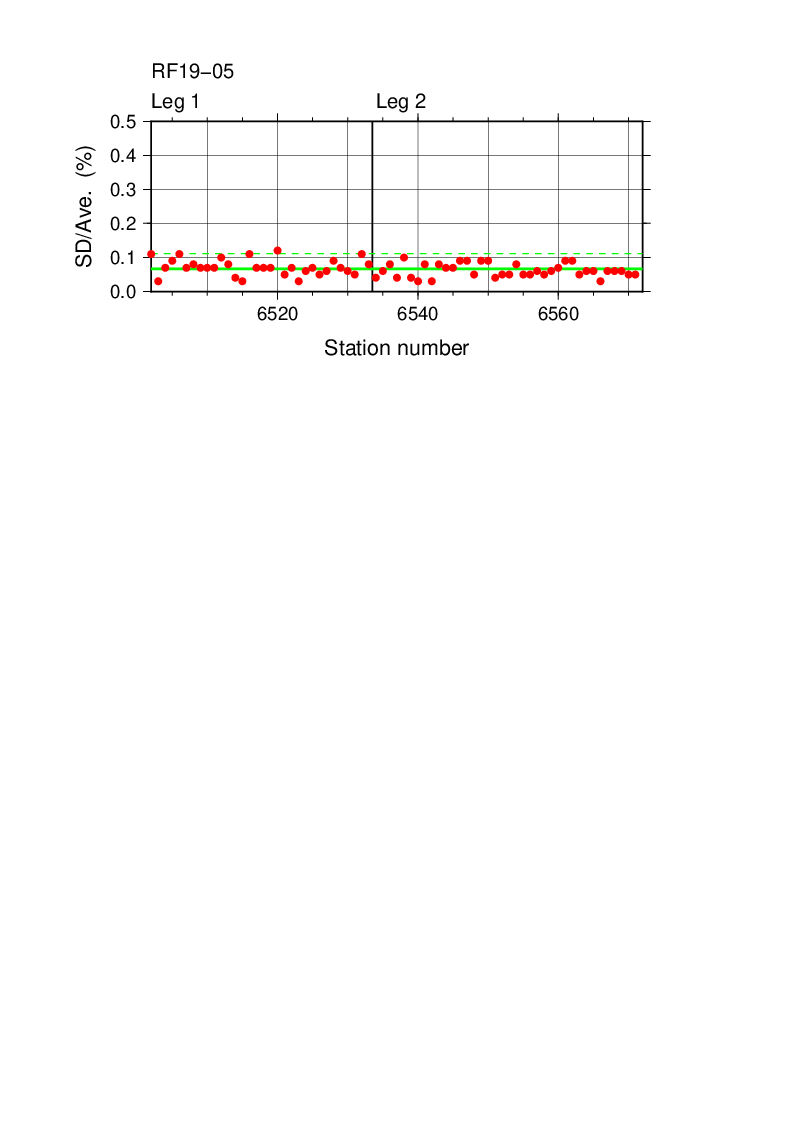


Figure C.4.13. Same as Figure C.4.10, but for silicate.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table C.4.7. Summary of precisions of nutrient assays during the cruise. | | | | |
|  | Nitrate+nitrite | Nitrite | Phosphate | Silicate |
| Median | 0.12 % | 0.06 % | 0.06 % | 0.07 % |
| Mean | 0.13 % | 0.06 % | 0.06 % | 0.07 % |
| Minimum | 0.04 % | 0.02 % | 0.02 % | 0.03 % |
| Maximum | 0.34 % | 0.16 % | 0.17 % | 0.12 % |
| Number | 70 | 70 | 70 | 70 |

#### (7.4) Carryover

Carryover coefficients were determined during each analytical run. The C-5 standard (high standard) was followed by two C-1 standards (low standards). Figures C.4.14–17 show the time series of the carryover coefficients.

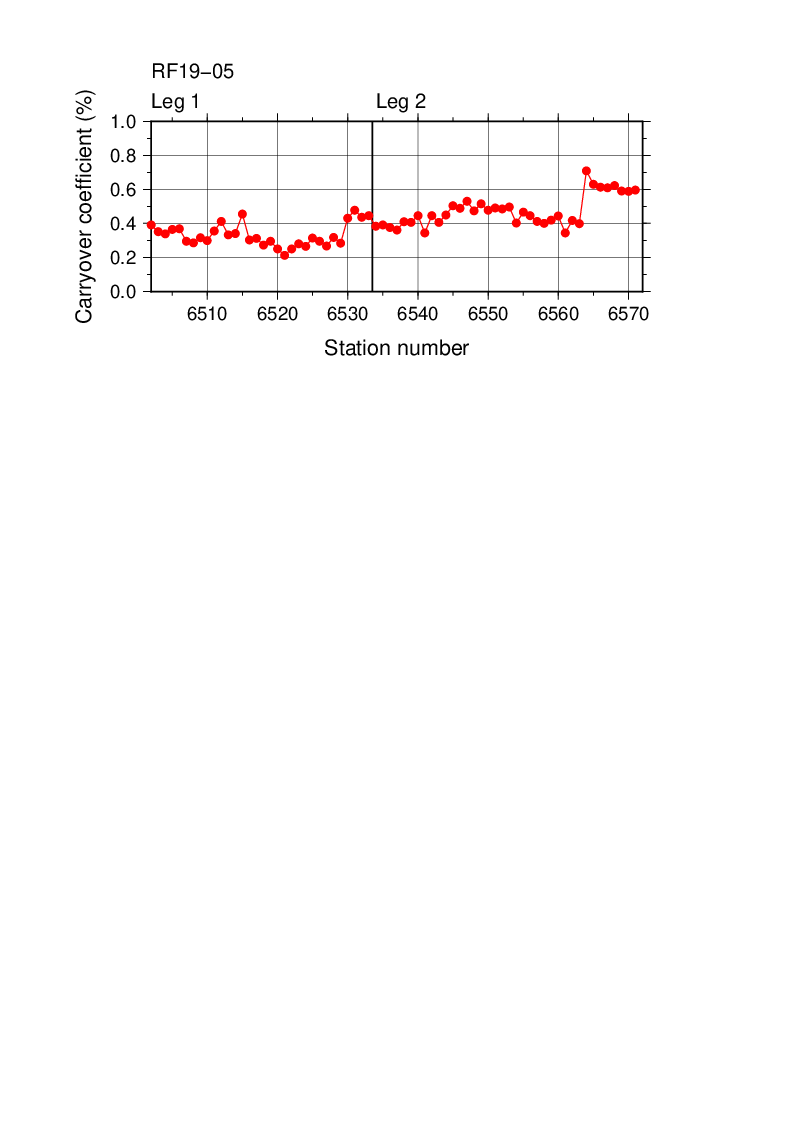


Figure C.4.14. Time-series of carryover coefficients in measurement of nitrate+nitrite throughout the cruise.

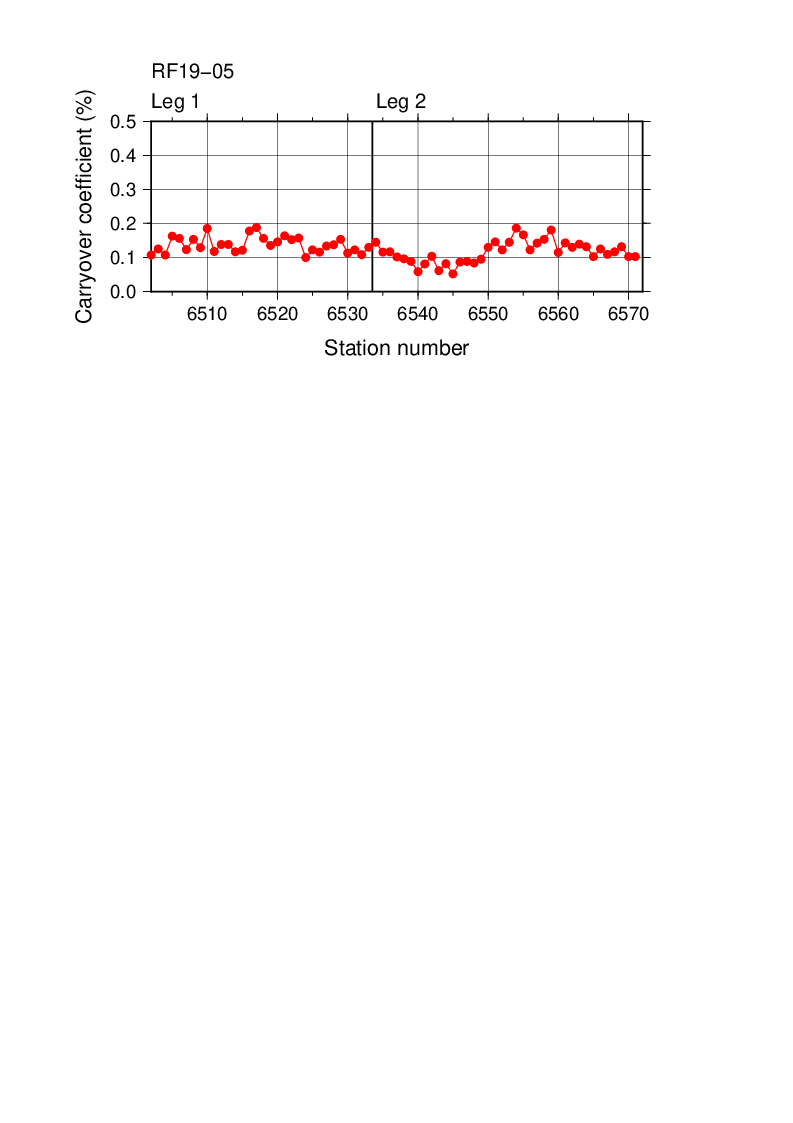


Figure C.4.15. Same as Figure C.4.14, but for nitrite.

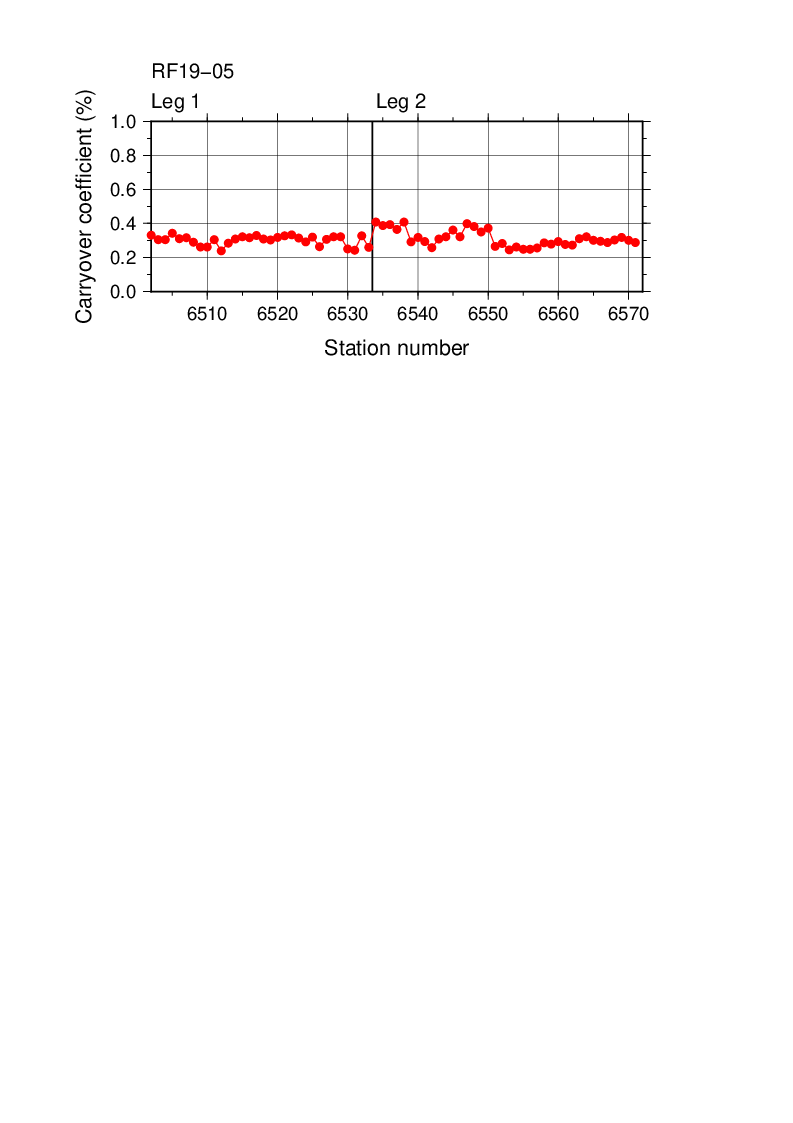


Figure C.4.16. Same as Figure C.4.14, but for phosphate.

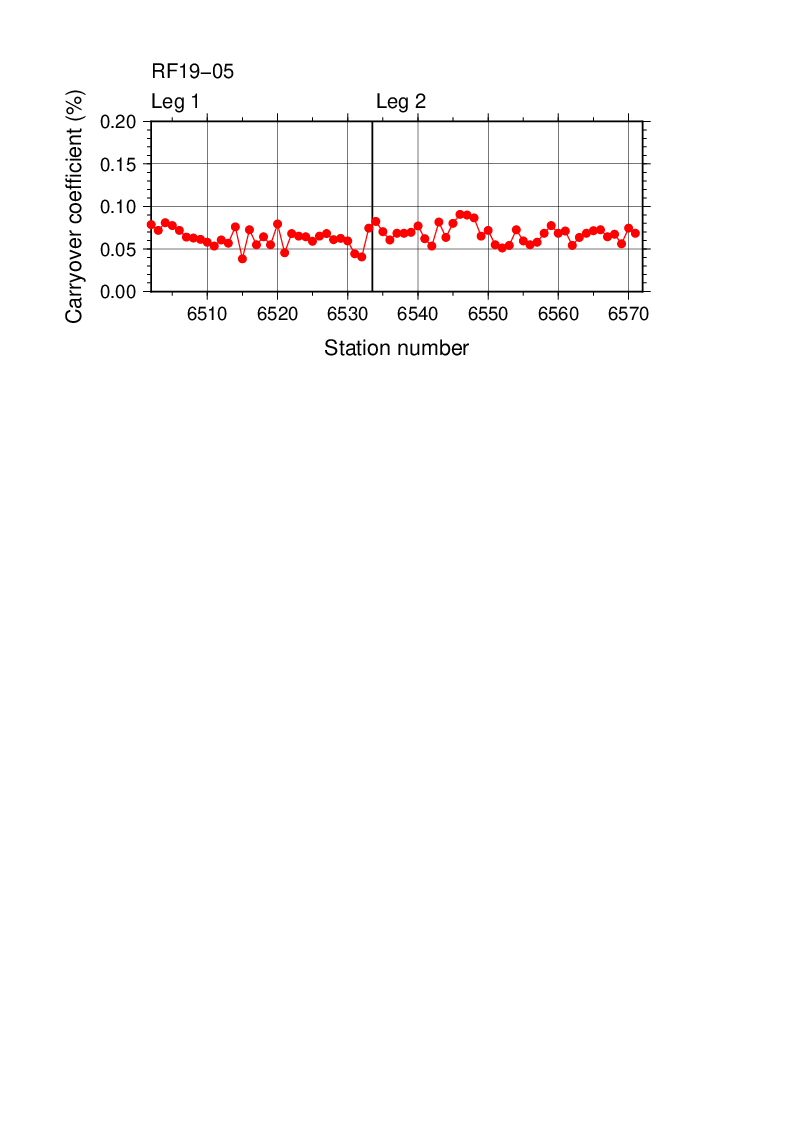


Figure C.4.17. Same as Figure C.4.14, but for silicate.

#### (7.5) Limit of detection/quantitation of measurement

Limit of detection (LOD) and quantitation (LOQ) of nutrient measurement were estimated from standard deviation (σ) of repeated measurements of nutrients concentration in C-1 standard as 3σ and 10σ, respectively. Summary of LOD and LOQ are shown in Table C.4.8.

|  |  |  |
| --- | --- | --- |
| Table C.4.8. Limit of detection (LOD) and quantitation (LOQ) of nutrient measurement in the cruise. Unit is μmol kg−1. | | |
|  | LOD | LOQ |
| Nitrate+nitrite | 0.042 | 0.139 |
| Nitrite | 0.004 | 0.015 |
| Phosphate | 0.007 | 0.023 |
| Silicate | 0.073 | 0.243 |

#### (7.6) Quality control flag assignment

A quality flag value was assigned to nutriment measurements as shown in Table C.4.9, using the code defined in IOCCP Report No.14 (Swift, 2010).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table C.4.9. Summary of assigned quality control flags. | | | | |
| Flag | Definition | Nitrate+nitrite | Nitrite | Phosphate | Silicate |
| 2 | Good | 2236 | 2238 | 2201 | 2237 |
| 3 | Questionable | 2 | 2 | 41 | 0 |
| 4 | Bad (Faulty) | 4 | 3 | 4 | 5 |
| 5 | Not reported | 0 | 0 | 0 | 0 |
| 6 | Replicate measurements | 273 | 272 | 269 | 273 |
| Total number of samples | | 2515 | 2515 | 2515 | 2515 |

### Uncertainty

#### (8.1) Uncertainty associated with concentration level: *Uc*

Generally, an uncertainty of nutrient measurement is expressed as a function of its concentration level which reflects that some components of uncertainty are relatively large in low concentration. Empirically, the uncertainty associated with concentrations level (*Uc*) can be expressed as follows;

, (C4.1)

where *Cx* is the concentration of sample for parameter X.

Using the coefficients of variation of the CRM measurements throughout the cruise, uncertainty associated with concentrations of nitrate+nitrite, phosphate, and silicate were determined as follows:

(C4.2)

(C4.3)

, (C4.4)

where *Cno3*, *Cpo4*, and *Csil* represent concentrations of nitrate+nitrite, phosphate, and silicate, respectively, in μmol kg**−**1. Figures C.4.18–C.4.20 show the calculated uncertainty graphically.

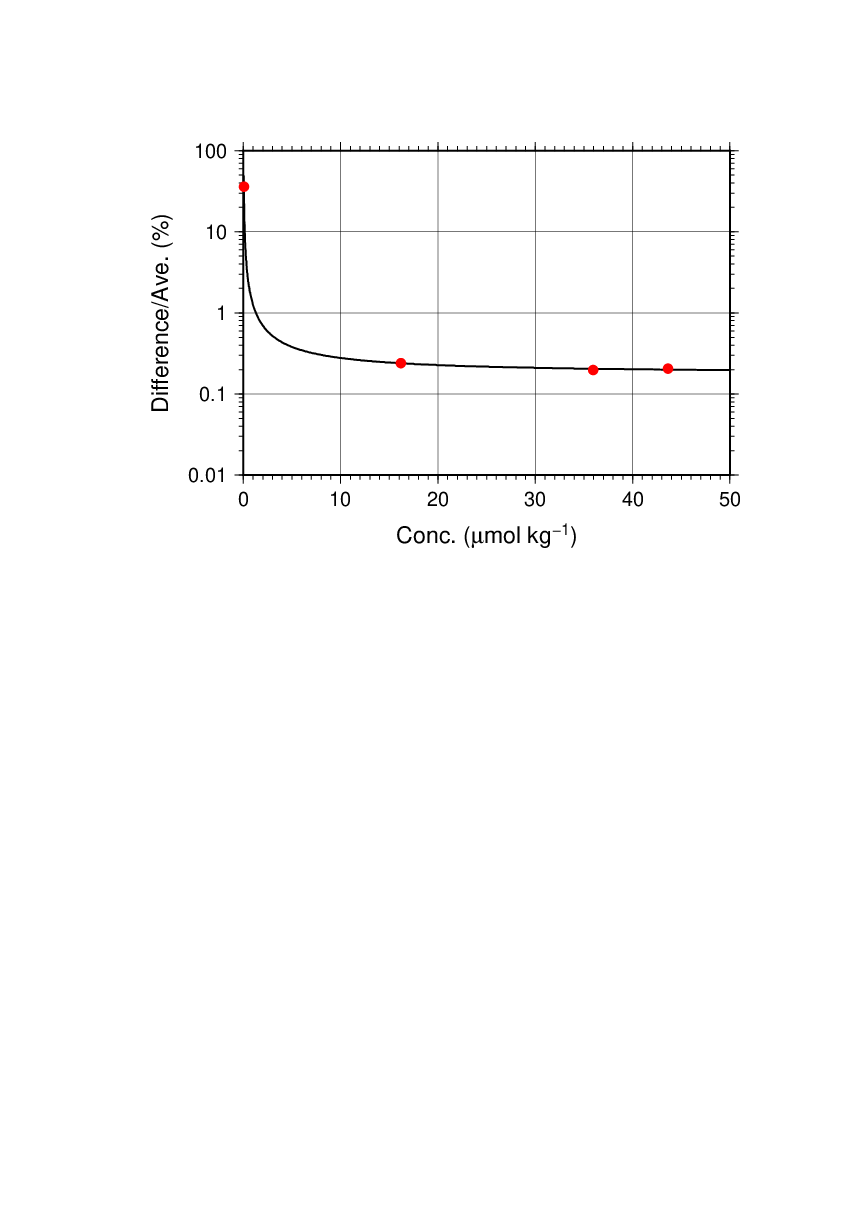


Figure C.4.18. Uncertainty of nitrate+nitrite associated with concentrations.

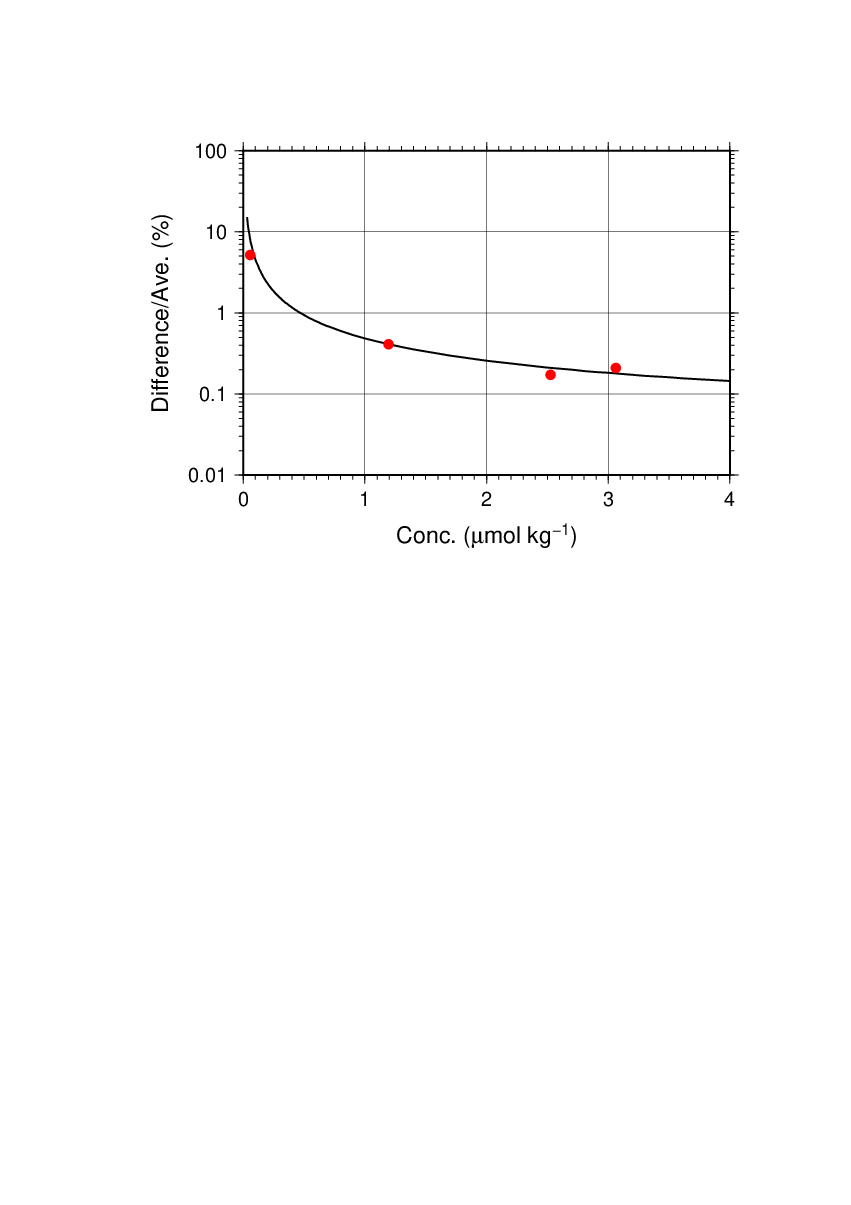


Figure C.4.19. Same as Figure C.4.18, but for phosphate.

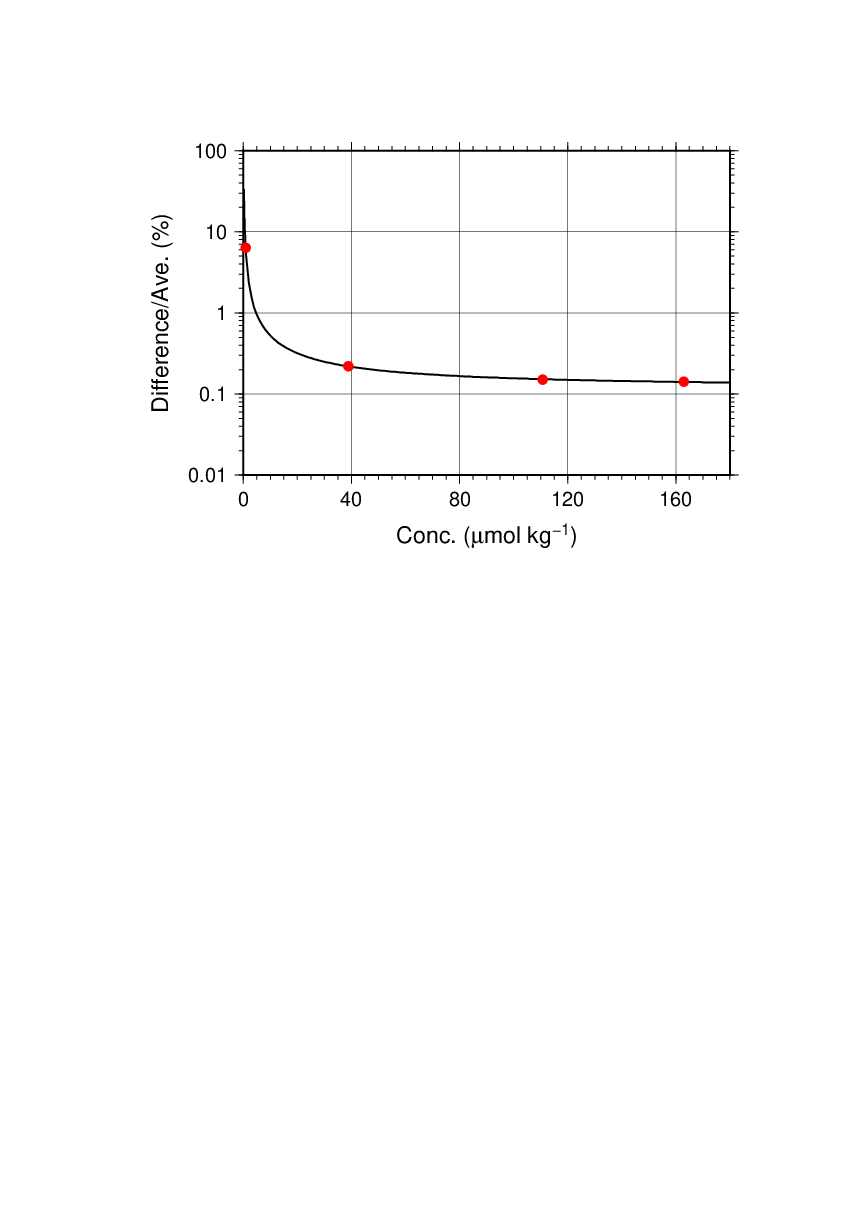


Figure C.4.20. Same as Figure C.4.18, but for silicate.

#### (8.2) Uncertainty of analysis between runs: *Us*

Uncertainty of analysis among runs (*Us*) was evaluated based on the coefficient of variation of measured concentrations of CRM-BZ with the highest concentration among the CRM lots throughout the cruise, as shown in subsection (7.2). The reason for using the CRM lot to state *Us* is to exclude the effect of uncertainty associated with lower concentration described previously. As is clear from the definition of *Uc*, *Us* is equal to *Uc* at nutrients concentrations of the lot. It is important to note that *Us* includes all of uncertainties during the measurements throughout stations, namely uncertainties of concentrations of in-house standard solutions prepared for each run, uncertainties of slopes and intercepts of the calibration curve in each run, precision of measurement in a run (*Ua*), and between-bottle homogeneity of the CRM.

#### (8.3) Uncertainty of analysis in a run: *Ua*

Uncertainty of analysis in a run (*Ua*) was evaluated based on the coefficient of variation of repeated measurements of the “check standard” solution, as shown in subsection (7.3). The *Ua* reflects the conditions associated with chemistry of colorimetric measurement of nutrients, and stability of electronic and optical parts of the instrument throughout a run. Under a well-controlled condition of the measurements, *Ua* might show Poisson distribution with a mean as shown in Figures C.4.10–C.4.13 and Table C.4.7 and treated as a precision of measurement. *Ua* is a part of *Uc* at the concentration as stated in a previous section for *Uc*.

However, *Ua* may show larger value which was not expected from Poisson distribution of *Ua* due to the malfunction of the instruments, larger ambient temperature change, human errors in handling samples and chemistries, and contaminations of samples in a run. In the cruise, we observed that *Ua* of our measurement was usually small and well-controlled in most runs as shown in Figures C.4.10–C.4.13 and Table C.4.7. However, in a few runs, *Ua* showed high values which were over the mean ± twice the standard deviations of *Ua*, suggesting that the measurement system might have some problems.

#### (8.4) Uncertainty of CRM concentration: *Ur*

In the certification of CRM, the uncertainty of CRM concentrations (*Ur*) was stated by the manufacturer (Table C.4.4) as expanded uncertainty at k=2. This expanded uncertainty reflects the uncertainty of the Japan Calibration Service System (JCSS) solutions, characterization in assignment, between-bottle homogeneity, and long term stability. We have ensured comparability between cruises by ensuring that at least two lots of CRMs overlap between cruises. In comparison of nutrient concentrations between cruises using KANSO CRMs in an organization, it was not necessary to include *Ur* in the conclusive uncertainty of concentration of measured samples because comparability of measurements was ensured in an organization as stated previously.

#### (8.5) Conclusive uncertainty of nutrient measurements of samples: *U*

To determine the conclusive uncertainty of nutrient measurements of samples (*U*), we use two functions depending on *Ua* value acquired at each run as follows:

When *Ua* was small and measurement was well-controlled condition, the conclusive uncertainty of nutrient measurements of samples, *U*, might be as below:

. (C4.5)

When *Ua* was relative large and the measurement might have some problems, the conclusive uncertainty of nutrient measurements of samples, *U*, can be expanded as below:

. (C4.6)

When *Ua* was relative large and the measurement might have some problems, the equation of *U* is defined as to include *Ua* to evaluate *U,* although *Ua* partly overlaps with *Uc*. It means that the equation overestimates the conclusive uncertainty of samples. On the other hand, for low concentration there is a possibility that the equation not only overestimates but also underestimates the conclusive uncertainty because the functional shape of *Uc* in lower concentration might not be the same and cannot be verified. However, we believe that the applying the above function might be better way to evaluate the conclusive uncertainty of nutrient measurements of samples because we can do realistic evaluation of uncertainties of nutrient concentrations of samples which were obtained under relatively unstable conditions, larger *Ua* as well as the evaluation of them under normal and good conditions of measurements of nutrients.

### Appendix

**A1. Seawater sampling**

Seawater samples were collected from 10-liters Niskin bottle attached CTD-system and a stainless steel bucket for the surface. Samples were drawn into 10 mL polymethylpenten vials using sample drawing tubes. The vials were rinsed three times before water filling and were capped immediately after the drawing.

No transfer was made and the vials were set on an auto sampler tray directly. Samples were analyzed immediately after collection.

**A2. Measurement**

**(A2.1) General**

Auto Analyzer III is based on Continuous Flow Analysis method and consists of sampler, pump, manifolds, and colorimeters. As a baseline, we used artificial seawater (ASW).

**(A2.2) Nitrate+nitrite and nitrite**

Nitrate+nitrite and nitrite were analyzed according to the modification method of Armstrong(1967). The sample nitrate was reduced to nitrite in a glass tube which was filled with granular cadmium coated with copper. The sample stream with its equivalent nitrite was treated with an acidic, sulfanilamide reagent and the nitrite forms nitrous acid which reacts with the sulfanilamide to produce a diazonium ion. N-1-naphthylethylene-diamine was added to the sample stream then coupled with the diazonium ion to produce a red, azo dye. With reduction of the nitrate to nitrite, sum of nitrate and nitrite were measured; without reduction, only nitrite was measured. Thus, for the nitrite analysis, no reduction was performed and the alkaline buffer was not necessary. The flow diagrams for each parameter are shown in Figures C.4.A1 and C.4.A2. If the reduction efficiency of the cadmium column became lower than 95 %, the column was replaced.

ORN/WHT N-1-naphtylethylene-diamine (0.23)

ORN/WHT sample or ASW (0.23)

5T

10T

20T

WHT/WHT debubble (0.60 cc min−1)

YEL/YEL ammonium chloride (buffer) (1.20)

BLK/BLK air (0.32)

BLK/BLK air (0.32)

ORN/WHT sulfanilamide (0.23)

Waste

Waste

Colorimeter

1.5 mm (I.D.) × 15 mm flow cell

530 nm

Cd tube

10T

Waste

GRY/GRY waste (1.00)

Figure C.4.A1. Nitrate+nitrite (ch. 1) flow diagram.

GRY/GRY sample or ASW (1.00)

ORN/WHT sulfanilamide (0.23)

ORN/WHT N-1-naphtylethylene-diamine (0.23)

Waste

Colorimeter

1.5 mm (I.D.) × 50 mm flow cell

530 nm

10T

20T

10T

Waste

RED/RED waste (0.80)

Waste

WHT/WHT debubble (0.60)

BLK/BLK air (0.32 cc min−1)

Figure C.4.A2. Nitrite (ch. 2) flow diagram.

**(A2.3) Phosphate**

The phosphate analysis was a modification of the procedure of Murphy and Riley(1962). Molybdic acid was added to the seawater sample to form phosphomolybdic acid which was in turn reduced to phosphomolybdous acid using L-ascorbic acid as the reductant. The flow diagram for phosphate is shown in Figure C.4.A3.

Waste

ORN/ORN debubble (0.42)

BLK/BLK ammonium molybdate (0.32)

YEL/BLU sample or ASW (1.40)

BLK/BLK air (0.32 cc min−1)

ORN/WHT ascolbic acid (0.23)

Waste

Colorimeter

1.5 mm (I.D.) × 50 mm flow cell

880 nm

Heating bath

37°C

10T

Waste

RED/RED waste (0.80)

10T

Figure C.4.A3. Phosphate (ch. 3) flow diagram.

**(A2.4) Silicate**

The silicate was analyzed according to the modification method of Grasshoff *et al.* (1983), wherein silicomolybdic acid was first formed from the silicate in the sample and added molybdic acid, then the silicomolybdic acid was reduced to silicomolybdous acid, or "molybdenum blue," using L-ascorbic acid as the reductant. The flow diagram for silicate is shown in Figure C.4.A4.

WHT/WHT ammonium molybdate (0.60)

ORN/YEL sample or ASW (0.16)

BLK/BLK air (0.32 cc min−1)

ORN/ORN oxalic acid (0.42)

Waste

Colorimeter

1.5 mm (I.D.) × 15 mm flow cell

820 nm

Heating bath

37°C

10T

Waste

YEL/YEL waste (1.20)

WHT/WHT ascolbic acid (0.60)

10T

10T

Figure C.4.A4. Silicate (ch. 4) flow diagram.

**A3. Data processing**

Raw data from Auto Analyzer III were recorded at 1-second interval and were treated as follows;

1. Check the shape of each peak and position of peak values taken, and then change the positions of peak values taken if necessary.
2. Baseline correction was done basically using liner regression.
3. Reagent blank correction was done basically using liner regression.
4. Carryover correction was applied to peak heights of each sample.
5. Sensitivity correction was applied to peak heights of each sample.
6. Refraction error correction was applied to peak heights of each seawater sample.
7. Calibration curves to get nutrients concentration were assumed quadratic expression.
8. Concentrations were converted from μmol L−1 to μmol kg−1 using seawater density.

**A4. Reagents recipes**

**(A4.1) Nitrate+nitrite**

Ammonium chloride (buffer), 0.7 μmol L−1 (0.04 % w/v);

Dissolve 190 g ammonium chloride, NH4Cl, in ca. 5 L of DW, add about 5 mL ammonia(aq) to adjust pH of 8.2–8.5.

Sulfanilamide, 0.06 μmol L −1 (1 % w/v);

Dissolve 5 g sulfanilamide, 4-NH2C6H4SO3H, in 430 mL DW, add 70 mL concentrated HCl. After mixing, add 1 mL Brij-35 (22 % w/w).

N-1-naphtylethylene-diamine dihydrochloride (NEDA), 0.004 μmol L −1 (0.1 % w/v);

Dissolve 0.5 g NEDA, C10H7NH2CH2CH2NH2·2HCl, in 500 mL DW.

**(A4.2) Nitrite**

Sulfanilamide, 0.06 μmol L −1 (1 % w/v); Shared from nitrate reagent.

N-1-naphtylethylene-diamine dihydrochloride (NEDA), 0.004 μmol L −1 (0.1 % w/v); Shared from nitrate reagent.

**(A4.3) Phosphate**

Ammonium molybdate, 0.005 μmol L−1 (0.6 % w/v);

Dissolve 3 g ammonium molybdate(VI) tetrahydrate, (NH4)6Mo7O24·4H2O, and 0.05 g potassium antimonyl tartrate, C8H4K2O12Sb2·3H2O, in 400 mL DW and add 40 mL concentrated H2SO4. After mixing, dilute the solution with DW to final volume of 500 mL and add 2 mL sodium dodecyl sulfate (15 % solution in water).

L(+)-ascorbic acid, 0.08 μmol L−1 (1.5 % w/v);

Dissolve 4.5 g L(+)-ascorbic acid, C6H8O6, in 300 mL DW. After mixing, add 10 mL acetone. This reagent was freshly prepared before every measurement.

**(A4.4) Silicate**

Ammonium molydate, 0.005 μmol L−1 (0.6 % w/v);

Dissolve 3 g ammonium molybdate(VI) tetrahydrate, (NH4)6Mo7O24·4H2O, in 500 mL DW and added concentrated 2 mL H2SO4. After mixing, add 2 mL sodium dodecyl sulfate (15 % solution in water).

Oxalic acid, 0.4 μmol L−1 (5 % w/v);

Dissolve 25 g oxalic acid dihydrate, (COOH)2·2H2O, in 500 mL DW.

L(+)-ascorbic acid, 0.08 μmol L−1 (1.5 % w/v); Shared from phosphate reagent.

**(A4.5) Baseline**

Artificial seawater (salinity is ~34.7);

Dissolve 160.6 g sodium chloride, NaCl, 35.6 g magnesium sulfate heptahydrate, MgSO4·7H2O, and 0.84 g sodium hydrogen carbonate, NaHCO3, in 5 L DW.

***References***

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## Phytopigments (chlorophyll-a and phaeopigment)

*8 June 2020*

### Personnel

Leg 1

Hiroyuki HATAKEYAMA (GEMD/JMA)

Koichi WADA (GEMD/JMA)

Kei KONDO (GEMD/JMA)

Rie SANAI (GEMD/JMA)

Masakazu TAKAMI (GEMD/JMA)

Leg 2

Hiroyuki HATAKEYAMA (GEMD/JMA)

Tomohiro UEHARA (GEMD/JMA)

Kei KONDO (GEMD/JMA)

Rie SANAI (GEMD/JMA)

Masakazu TAKAMI (GEMD/JMA)

### Station occupied

A total of 40 stations (Leg 1: 18, Leg 2: 22) were occupied for phytopigment measurements. Station location and sampling layers of phytopigment are shown in Figures C.5.1 and C.5.2.

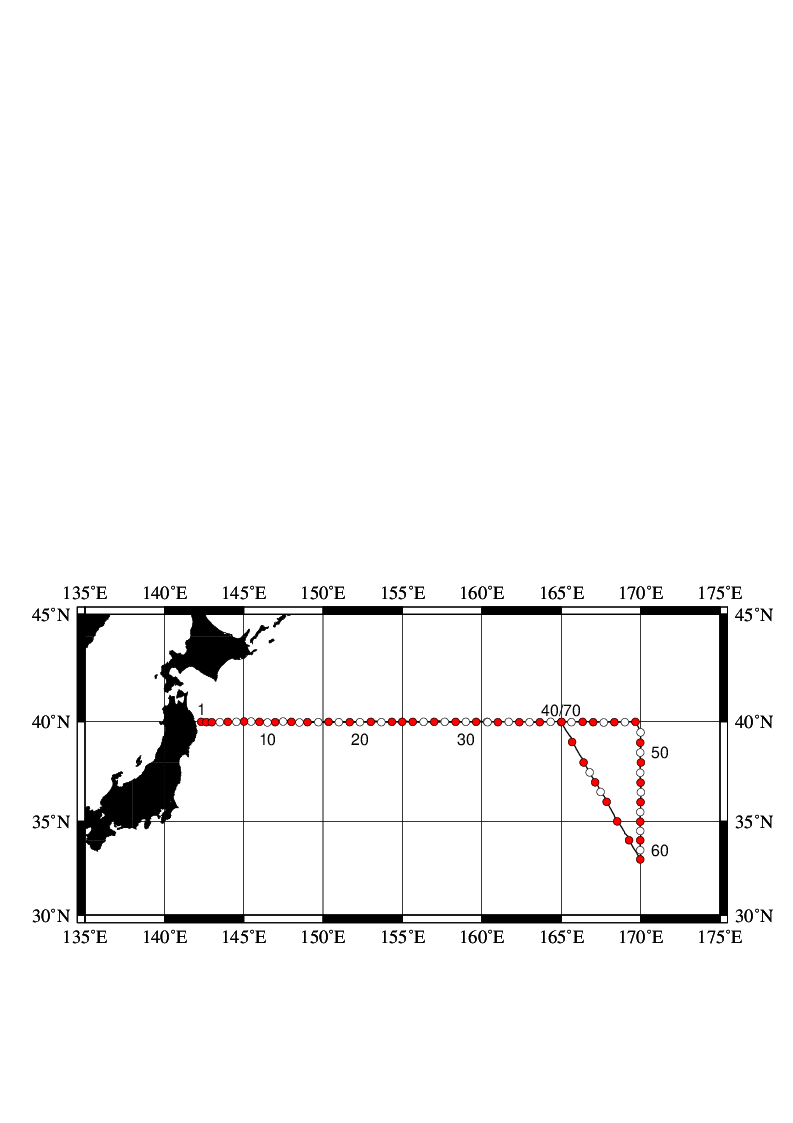


Figure C.5.1. Location of observation stations of chlorophyll-*a*. Closed and open circles indicate sampling and no-sampling stations, respectively.

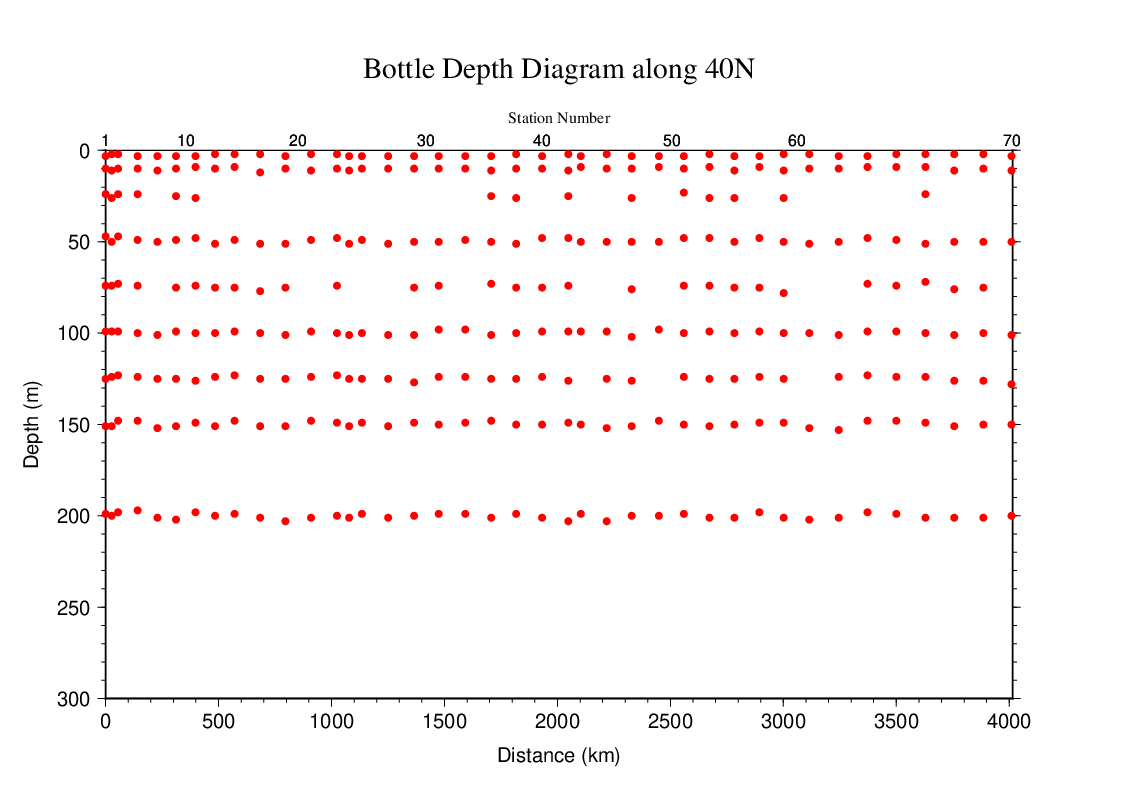


Figure C.5.2. Distance-depth distribution of sampling layers of chlorophyll-*a*.

### Reagents

N,N-dimethylformamide (DMF)

Hydrochloric acid (HCl), 0.5 mol L−1

Chlorophyll-*a* standard from *Anacystis nidulans* algae (Sigma-Aldrich, United States)

Rhodamine WT (Turner Designs, United States)

### Instruments

Fluorometer: 10-AU (Turner Designs, United States)

Spectrophotometer: UV-1800 (Shimadzu, Japan)

### Standardization

#### (5.1) Determination of chlorophyll-*a* concentration of standard solution

To prepare the pure chlorophyll-*a* standard solution, reagent powder of chlorophyll-*a* standard was dissolved in DMF. A concentration of the chlorophyll-*a* solution was determined with the spectrophotometer as follows:

chl. *a* concentration (g mL−1) = Achl / a\*phy (C5.1)

where Achl is the difference between absorbance at 663.8 nm and 750 nm, and a\*phy is specific absorption coefficient (UNESCO, 1994). The specific absorption coefficient is 88.74 L g−1 cm−1 (Porra *et al.*, 1989).

#### (5.2) Determination of R and fph

Before measurements, sensitivity of the fluorometer was calibrated with pure DMF and a rhodamine 1 ppm solution (diluted with deionized water).

The chlorophyll-*a* standard solution, whose concentration was precisely determined in subsection (5.1), was measured with the fluorometer, and after acidified with 1–2 drops 0.5 mol L−1 HCl the solution was also measured. The acidification coefficient (R) of the fluorometer was also calculated as the ratio of the unacidified and acidified readings of chlorophyll-*a* standard solution. The linear calibration factor (fph) of the fluorometer was calculated as the slope of the acidified reading against chlorophyll-*a* concentration. The R and fph in the cruise are shown in Table C.9.1.

Table C.5.1. R and fph in the cruise.

|  |  |
| --- | --- |
| Acidification coefficient (R) | 1.933 |
| Linear calibration factor (fph) | 5.971 |

### Seawater sampling and measurement

Water samples were collected from 10-liters Niskin bottle attached the CTD-system and a stainless steel bucket for the surface. A 200 mL seawater sample was immediately filtered through 25 mm GF/F filters by low vacuum pressure below 15 cmHg, the particulate matter collected on the filter. Phytopigments were extracted in vial with 9 mL of DMF. The extracts were stored for 24 hours in the refrigerator at −30 °C until analysis.

After the extracts were put on the room temperature for at least one hour in the dark, the extracts were decanted from the vial to the cuvette. Fluorometer readings for each cuvette were taken before and after acidification with 1–2 drops 0.5 mol L−1 HCl. Chlorophyll-*a* and phaeopigment concentrations (g mL−1) in the sample are calculated as follows:

 (C5.2)

 (C5.3)

F0: reading before acidification

Fa: reading after acidification

R: acidification coefficient (F0/Fa) for pure chlorophyll-*a*

fph: linear calibration factor

v: extraction volume

V: sample volume.

### Quality control flag assignment

Quality flag value was assigned to oxygen measurements as shown in Table C.5.2, using the code defined in IOCCP Report No.14 (Swift, 2010).

Table C.5.2 Summary of assigned quality control flags.

|  |  |  |  |
| --- | --- | --- | --- |
| Flag | Definition | Chl. *a* | Phaeo. |
| 2 | Good | 302 | 302 |
| 3 | Questionable | 0 | 0 |
| 4 | Bad (Faulty) | 18 | 18 |
| 5 | Not reported | 0 | 0 |
| Total number | | 320 | 320 |

***References***

Porra, R. J., W. A. Thompson and P. E. Kriedemann (1989), Determination of accurate coefficients and simultaneous equations for assaying chlorophylls *a* and *b* extracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absotption spectroscopy. *Biochem. Biophy. Acta,* 975, 384-394*.*

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