3.1.1 CTD Measurements

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(2) Overview of the equipment

The CTD system was SBE 911plus system (Sea-Bird Electronics, Inc., Bellevue, Washington, USA). The SBE 911plus system controls 24-position SBE 24 Carousel Water Sampler. The Carousel accepts 8-litre Niskin-X water sample bottles (General Oceanics, Inc., Miami, Florida, USA, and OceanTec Electronics, Bastrop, Texas, USA). The SBE 9plus was mounted horizontally in a 24-position carousel frame. SBE's temperature (SBE 3) and conductivity (SBE 4) sensor modules were used with the SBE 9plus underwater unit. The pressure sensor is mounted in the main housing of the underwater unit and is ported to outside through the oil-filled plastic capillary tube. A modular unit of underwater housing pump (SBE 5T) flushes water through sensor tubing at a constant rate independent of the CTD's motion, and pumping rate (3000 rpm) remain nearly constant over the entire input voltage range of 12-18 volts DC. Flow speed of pumped water in standard TC duct is about 2.4 m/s. One set of temperature and conductivity modules (two sets of temperature and conductivity modules, stations KC1) were used. An SBE's dissolved oxygen sensor (SBE 43) was placed between the primary conductivity sensor and the pump module. Auxiliary sensors, a Deep Ocean Standards Thermometer (SBE 35), an altimeter (PSA-916T; Teledyne Benthos, Inc., North Falmous, Massachusetts, USA) USA), an oxygen optode (RINKO-III; JFE Advantech Co., Ltd, Kobe Hyogo, Japan) and a fluorometers (Seapoint sensors, Inc., Kingston, New Hampshire, USA) were also used with the SBE 9plus underwater unit.

Summary of the system used in this cruise

24-position Carousel system

Deck unit:

SBE 11plus, S/N 11P90698-0969

Under water unit:

SBE 9plus, S/N 09P22763-0590 (pressure sensor S/N: 77509)

Temperature sensor:

SBE 3plus, S/N 2863 (primary)

SBE 3plus, S/N 2817 (secondary, station KC1)

Conductivity sensor:

SBE 4, S/N 2414 (primary)

SBE 4, S/N 2415 (secondary, stations KC1)

Oxygen sensor:

SBE 43, S/N 1471 (stations KC1)

SBE 43, S/N 1926 (stations KC2 and KC3)

JFE Advantech RINKO-III, S/N 003 (foil batch no. 160008A)

Pump:

SBE 5T, S/N 2786 (primary)

SBE 5T, S/N 2783 (secondary, stations KC1)

Altimeter:

PSA-916T, S/N 59546

Deep Ocean Standards Thermometer:

SBE 35, S/N 0045

Fluorometer:

Seapoint Sensors, Inc., S/N 3590 (measurement range: 0-15 μg/L)

Carousel Water Sampler:

SBE 32, S/N 0949

Water sample bottle:

8-litre Niskin-X model (some were no TEFLON coating, some were TEFLON coating)

(4) Pre-cruise calibration

i. Pressure

The Paroscientific series 4000 Digiquartz high pressure transducer (Model 415K: Paroscientific, Inc., Redmond, Washington, USA) uses a quartz crystal resonator whose frequency of oscillation varies with pressure induced stress with 0.01 per million of resolution over the absolute pressure range of 0 to 15000 psia (0 to 10332 dbar). Also, a quartz crystal temperature signal is used to compensate for a wide range of temperature changes at the time of an observation. The pressure sensor has a nominal accuracy of 0.015 % FS (1.5 dbar), typical stability of 0.0015 % FS/month (0.15 dbar/month), and resolution of 0.001 % FS (0.1 dbar). Since the pressure sensor measures the absolute value, it inherently includes atmospheric pressure (about 14.7 psi). SEASOFT subtracts 14.7 psi from computed pressure automatically.

Pre-cruise sensor calibrations for linearization were performed at SBE, Inc.

S/N 0590, 9 June 2014

ii. Temperature (SBE 3)

The temperature sensing element is a glass-coated thermistor bead in a stainless steel tube, providing a pressure-free measurement at depths up to 6800 m by aluminum housing. The SBE 3 thermometer has a nominal accuracy of 1 mK, typical stability of 0.2 mK/month, and resolution of 0.2 mK at 24 samples per second. The premium temperature sensor, SBE 3plus, is a more rigorously tested and calibrated version of standard temperature sensor (SBE 3).

Pre-cruise sensor calibrations were performed at SBE, Inc

S/N 2863, 7 May 2014

S/N 2817, 5 August 2014

iii. Conductivity (SBE 4)

The flow-through conductivity sensing element is a glass tube (cell) with three platinum electrodes to provide in-situ measurements at depths up to 6800 m by aluminum housing. The SBE 4 has a nominal accuracy of 0.0003 S/m, typical stability of 0.0003 S/m/month, and resolution of 0.00004 S/m at 24 samples per second. The conductivity cells have been replaced to newer style cells for deep ocean measurements.

Pre-cruise sensor calibrations were performed at SBE, Inc.

S/N 2414, 7 May 2014

S/N 2415, 5 August 2014

The value of conductivity at salinity of 35, temperature of 15 °C (IPTS-68) and pressure of 0 dbar is 4.2914 S/m.

iv. Oxygen (SBE 43)

The SBE 43 oxygen sensor uses a Clark polarographic element to provide in-situ measurements at depths up to 7000 m. The range for dissolved oxygen is 120 % of surface saturation in all natural waters, nominal accuracy is 2 % of saturation, and typical stability is 2 % per 1000 hours.

Pre-cruise sensor calibration was performed at SBE, Inc.

S/N 1471, 14 May 2014

S/N 1926, 1 September 2012

v. Deep Ocean Standards Thermometer

Deep Ocean Standards Thermometer (SBE 35) is an accurate, ocean-range temperature sensor that can be standardized against Triple Point of Water and Gallium Melt Point cells and is also capable of measuring temperature in the ocean to depths of 6800 m. The SBE 35 was used to calibrate the SBE 3 temperature sensors in situ (Uchida et al., 2007).

Pre-cruise sensor linearization was performed at SBE, Inc.

S/N 0045, 27 September 2002

Then the SBE 35 is certified by measurements in thermodynamic fixed-point cells of the TPW (0.01 °C) and GaMP (29.7646 °C). The slow time drift of the SBE 35 is adjusted by periodic recertification corrections. Pre-cruise sensor calibration was performed at SBE, Inc. From the end of 2011, the SBE has been applying a NIST correction to the fixed-point cells used for the calibration.

S/N 0045, 11 September 2013 (slope and offset correction)

Slope = 1.000022

Offset = -0.001257

The time required per sample = 1.1 × NCYCLES + 2.7 seconds. The 1.1 seconds is total time per an acquisition cycle. NCYCLES is the number of acquisition cycles per sample and was set to 4. The 2.7 seconds is required for converting the measured values to temperature and storing average in EEPROM.

vi. Altimeter

Benthos PSA-916T Sonar Altimeter (Teledyne Benthos, Inc.) determines the distance of the target from the unit by generating a narrow beam acoustic pulse and measuring the travel time for the pulse to bounce back from the target surface. It is rated for operation in water depths up to 10000 m. The PSA-916T uses the nominal speed of sound of 1500 m/s.

vii. Oxygen optode (RINKO)

RINKO (JFE Alec Co., Ltd.) is based on the ability of selected substances to act as dynamic fluorescence quenchers. RINKO model III is designed to use with a CTD system which accept an auxiliary analog sensor, and is designed to operate down to 7000 m.

viii. Fluorometer

The Seapoint Chlorophyll Fluorometer (Seapoint Sensors, Inc., Kingston, New Hampshire, USA) provides in-situ measurements of chlorophyll-a at depths up to 6000 m. The instrument uses modulated blue LED lamps and a blue excitation filter to excite chlorophyll-a. The fluorescent light emitted by the

chlorophyll-a passes through a red emission filter and is detected by a silicon photodiode. The low level signal is then processed using synchronous demodulation circuitry, which generates an output voltage proportional to chlorophyll-a concentration.

(5) Data collection and processing

i. Data collection

CTD system was powered on at least 20 minutes in advance of the data acquisition to stabilize the pressure sensor and was powered off at least two minutes after the operation in order to acquire pressure data on the ship’s deck.

The package was lowered into the water from the starboard side and held 10 m beneath the surface in order to activate the pump. After the pump was activated, the package was lifted to the surface and lowered at a rate of 1.0 m/s to the bottom. For the up cast, the package was lifted at a rate of 1.0 m/s except for bottle firing stops. As a rule, the bottle was fired after waiting from the stop for 60 seconds to enhance exchanging the water between inside and outside of the bottle and the package was stayed at least 5 seconds for measurement of the SBE 35 at each bottle firing stops.

Water samples were collected using a 24-bottle SBE 32 Carousel Water Sampler with 8-litre Niskin-X bottles.

Data acquisition software

SEASAVE-Win32, version 7.23.2

ii. Data collection problems

(a) Miss trip, miss fire, and remarkable leak

Niskin bottles did not trip correctly at the following stations.

Remarkable leak

KC2, #5 and #21

(b) Bat data of SBE 43 (S/N 1471, 1926)

Bat data was found in the SBE 43 data. Therefore, the SBE 43 was detached after the station KC3.

iii. Data processing

SEASOFT consists of modular menu driven routines for acquisition, display, processing, and archiving of oceanographic data acquired with SBE equipment. Raw data are acquired from instruments and are stored as unmodified data. The conversion module DATCNV uses instrument configuration and calibration coefficients to create a converted engineering unit data file that is operated on by all SEASOFT post processing modules. The following are the SEASOFT and original software data processing module sequence and specifications used in the reduction of CTD data in this cruise.

Data processing software

SBEDataProcessing-Win32, version 7.23.2

DATCNV converted the raw data to engineering unit data. DATCNV also extracted bottle information where scans were marked with the bottle confirm bit during acquisition. The duration was set to 4.4 seconds, and the offset was set to 0.0 second. The hysteresis correction for the SBE 43 data (voltage) was applied for both profile and bottle information data.

ALIGNCTD converted the time-sequence of sensor outputs into the pressure sequence to ensure that all calculations were made using measurements from the same parcel of water. For a SBE 9plus CTD with the ducted temperature and conductivity sensors and a 3000-rpm pump, the typical net advance of the conductivity relative to the temperature is 0.073 seconds. So, the SBE 11plus deck unit was set to advance the primary and the secondary conductivity for 1.73 scans (1.75/24 = 0.073 seconds). Oxygen data are also systematically delayed with respect to depth mainly because of the long time constant of the oxygen sensor and of an additional delay from the transit time of water in the pumped plumbing line. This delay was compensated by 5 seconds advancing the SBE 43 oxygen sensor output (voltage) relative to the temperature data.

WILDEDIT marked extreme outliers in the data files. The first pass of WILDEDIT obtained an accurate estimate of the true standard deviation of the data. The data were read in blocks of 100 scans. Data greater than 2 standard deviations were flagged. The second pass computed a standard deviation over the same 100 scans excluding the flagged values. Values greater than 20 standard deviations were marked bad. This process was applied to pressure, temperature, conductivity, and SBE 43 output.

CELLTM used a recursive filter to remove conductivity cell thermal mass effects from the measured
conductivity. Typical values used were thermal anomaly amplitude alpha = 0.03 and the time constant 1/beta = 7.0.

FILTER performed a low pass filter on pressure with a time constant of 0.15 seconds. In order to produce zero phase lag (no time shift) the filter runs forward first then backwards.

WFILTER performed as a median filter to remove spikes in Fluorometer data. A median value was determined by 49 scans of the window.

SECTION selected a time span of data based on scan number in order to reduce a file size. The minimum number was set to be the start time when the CTD package was beneath the sea-surface after activation of the pump. The maximum number was set to be the end time when the depth of the package was 1 dbar below the surface. The minimum and maximum numbers were automatically calculated in the module.

LOOPEDIT marked scans where the CTD was moving less than the minimum velocity of 0.1 m/s (traveling backwards due to ship roll).

DERIVE was re-used to compute salinity, potential temperature, oxygen (SBE 43) , and density ($\sigma\theta$ and σt) .

BINAVG averaged the data into 1-dbar pressure bins. The center value of the first bin was set equal to the bin size. The bin minimum and maximum values are the center value plus and minus half the bin size. Scans with pressures greater than the minimum and less than or equal to the maximum were averaged. Scans were interpolated so that a data record exist every dbar.

SPLIT was used to split data into the down cast and the up cast. Remaining spikes in the CTD data were manually eliminated from the 1-dbar-averaged data. The data gaps resulting from the elimination were linearly interpolated with a quality flag of 6.

BOTTLESUM created a summary of the bottle data. The data were averaged over 4.4 seconds (or 1 second for the bottle fired without stop).

(6) Post-cruise calibration

i. Pressure

The CTD pressure sensor offset in the period of the cruise was estimated from the pressure readings on the ship deck. For best results the Paroscientific sensor was powered on for at least 20 minutes before the operation. In order to get the calibration data for the pre- and post-cast pressure sensor drift, the CTD deck pressure was averaged over first and last one minute, respectively. Then the atmospheric pressure deviation from a standard atmospheric pressure (14.7 psi) was subtracted from the CTD deck pressure to check the pressure sensor time drift. The atmospheric pressure was measured at the captain deck (5.7 m high from the base line) and sub-sampled one-minute interval as a meteorological data. Time series of the CTD deck pressure is shown in Fig. 3.1.1-1. The CTD pressure sensor offset was estimated from the deck pressure. Mean of the pre- and the post-casts data over the whole period gave an estimation of the pressure sensor offset (0.28 dbar) from the pre-cruise calibration. The post-cruise correction of the pressure data is not deemed necessary for the pressure sensor.

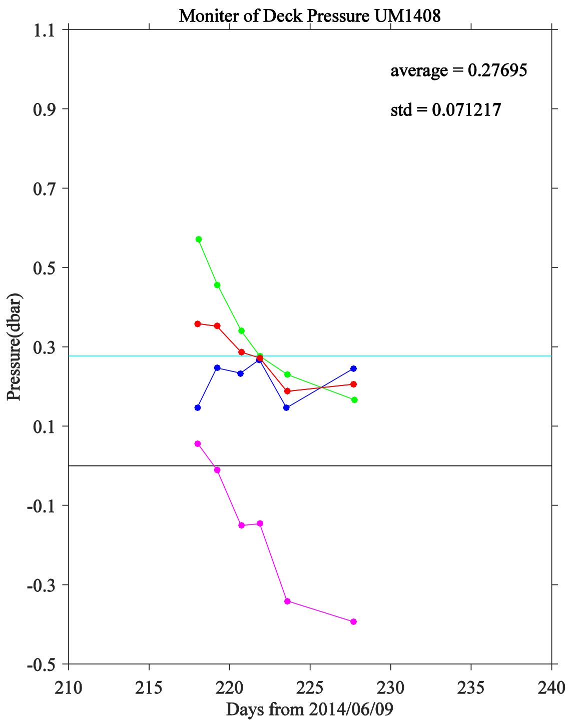

Fig. 3.1.1 Time series of the CTD deck pressure. Atmospheric pressure deviation (magenta dots) from a standard atmospheric pressure was subtracted from the CTD deck pressure. Blue and green dots indicate pre- and post-cast deck pressures, respectively. Red dots indicate averages of the pre- and the post-cast deck pressures.

ii. Temperature

The CTD temperature sensors (SBE 3) were calibrated with the SBE 35 under the assumption that discrepancies between SBE 3 and SBE 35 data were due to pressure sensitivity, the viscous heating effect, and time drift of the SBE 3, according to a method by Uchida et al. (2007).

Post-cruise sensor calibration for the SBE 35 will be performed at SBE, Inc in September 2013.

The CTD temperature was preliminary calibrated as

$$\text{Calibrated primary temperature} = T - (c0 \times P + c1 \times t + c2)$$

$$\text{Calibrated secondary temperature} = T - (c0 \times P + c2)$$

where T is CTD temperature in °C, P is pressure in dbar, t is time in days from pre-cruise calibration date of the CTD temperature and c0, c1, and c2 are calibration coefficients. The coefficients were determined using the data for the depths deeper than 950 dbar.

The primary temperature data were basically used for the post-cruise calibration. The calibration coefficients are listed in Table 3.1.1-1. The results of the post-cruise calibration for the CTD temperature are summarized in Table 3.1.1-2 and shown in Figs. 3.1.1-2 and 3.1.1-3.

Table 3.1.1-1 Calibration coefficients for the CTD temperature sensors.

Serial number	c0 (°C/dbar)	c1 (°C/day)	c2 (°C)
2863	3.20069e–7	8.73035e–5	–0.0229
2817	1.79988e–7		0.0010

Table 3.1.1-2 Difference between the CTD temperature and the SBE 35 after the post-cruise calibration. Mean and standard deviation (Sdev) are calculated for the data below and above 950 dbar. Number of data used is also shown.

Serial number	Pressure ≥ 950 dbar			Pressure < 950 dbar		
	Number	Mean (mK)	Sdev (mK)	Number	Mean (mK)	Sdev (mK)
2863	47	–0.0	0.3	96	–0.0	2.8
2817	8	0.0	0.3	16	2.5	10.0

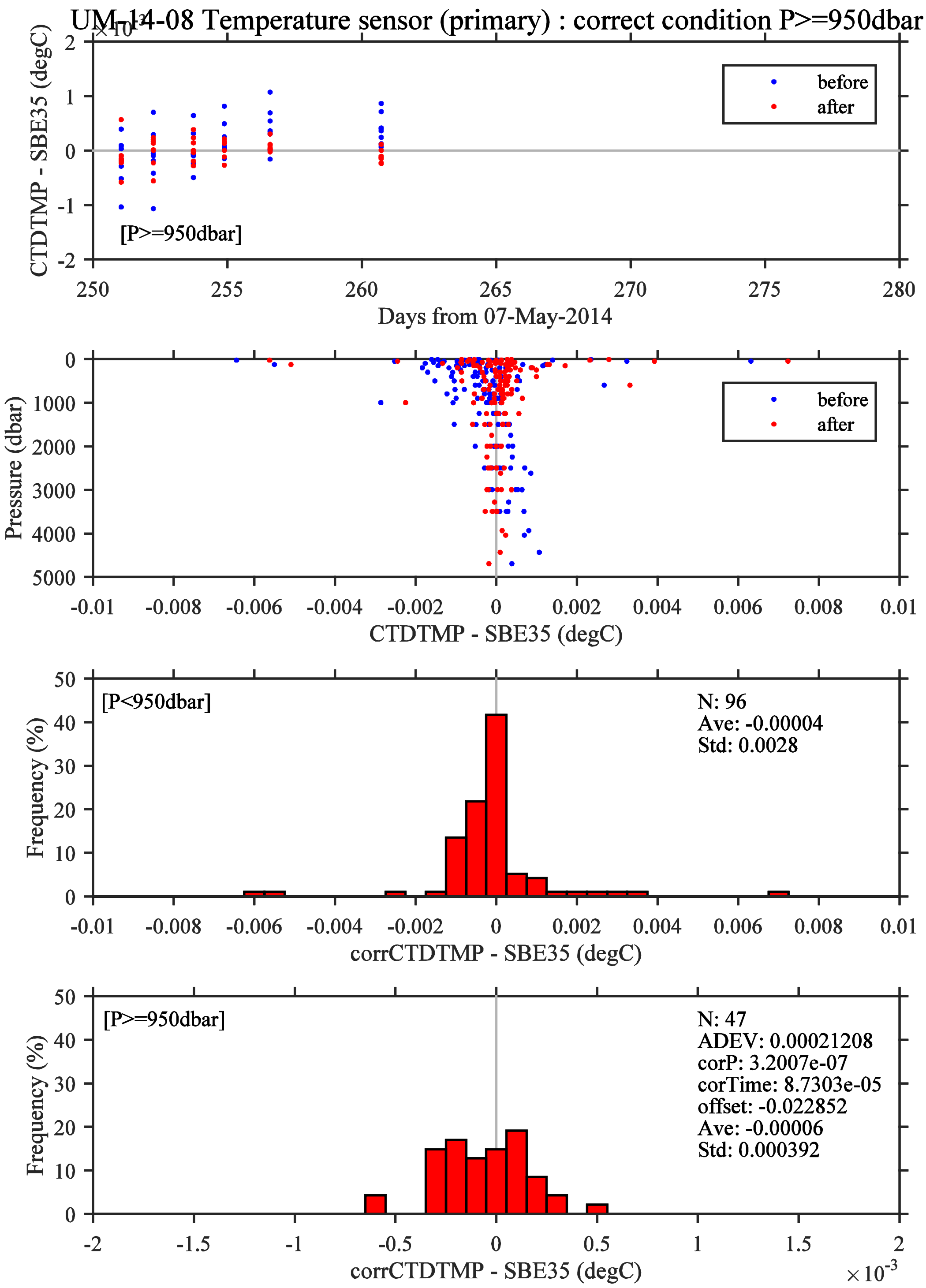

Fig. 3.1.1-2 Difference between the CTD temperature (primary) and the SBE 35. Blue and red dots indicate before and after the post-cruise calibration using the SBE 35 data, respectively. Lower two panels show histogram of the difference after the calibration.

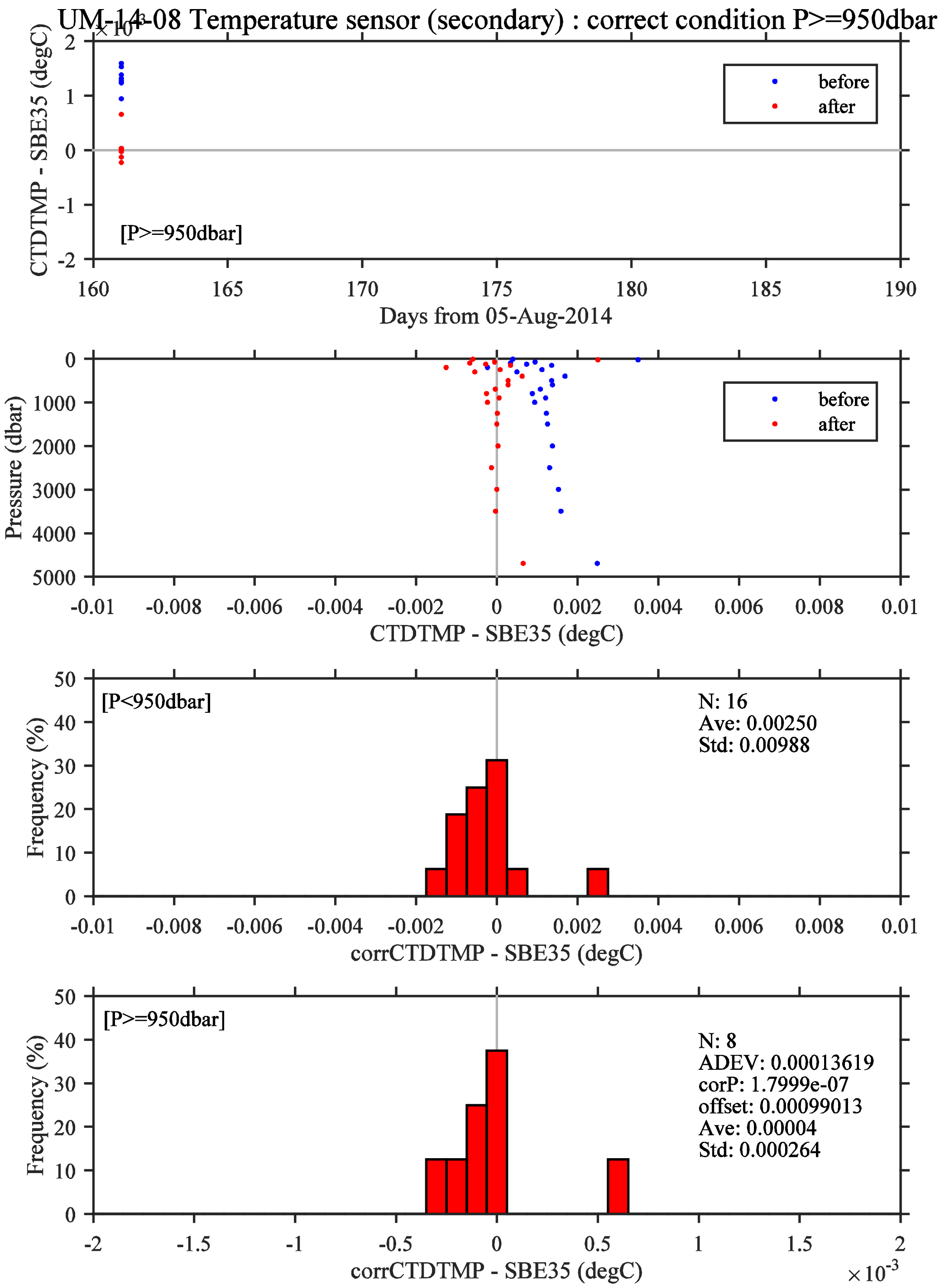

Fig. 3.1.1-3 Same as Fig. 3.1.1-2, but for secondary temperature sensor

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iii. Salinity

The discrepancy between the CTD conductivity and the conductivity calculated from the bottle salinity data with the CTD temperature and pressure data is considered to be a function of conductivity, pressure and time. The CTD conductivity was calibrated as

Calibrated primary conductivity = c0 × C + c1 × P + c2 × C × P + c3 × t + c4

Calibrated secondary conductivity = c0 × C + c1 × P + c2 × C × P + c4

where C is CTD conductivity in S/m, P is pressure in dbar, t is time in days from 12 January 2015, 22:52 (UTC) and c0, c1, c2, c3 and c4 are calibration coefficients. The best fit sets of coefficients were determined by a least square technique to minimize the deviation from the conductivity calculated from the bottle salinity data.

The primary conductivity data created by the software module ROSSUM were basically used after the post-cruise calibration for the temperature data. The secondary conductivity sensor was also calibrated and used instead of the primary conductivity data when the data quality of the primary temperature or conductivity data was bad. The calibration coefficients are listed in Table 3.1.1-3. The results of the post-cruise calibration for the CTD salinity are summarized in Table 3.1.1-4 and shown in Figs. 3.1.1-4 and 3.1.1-5.

Table 3.1.1-3 Calibration coefficients for the CTD conductivity sensors.

Serial Number	c0	c1 [S/(m dbar)]	c2 (1/dbar)	c3 [S/(m day)]	c4 (S/m)
2414	–9.10822e–4	–2.75985e–7	1.03367e–8	–2.471334e–5	4.83325e–4
2415	–1.28878e–4	–1.21793e–6	4.03111e–7		6.54145e–4

Table 3.1.1-4 Difference between the CTD salinity and the bottle salinity after the post-cruise calibration. Mean and standard deviation (Sdev) (in 10–3) are calculated for the data below and above 950 dbar. Number of data used is also shown.

Serial number	Pressure ≥ 950 dbar			Pressure < 950 dbar		
	Number	Mean	Sdev	Number	Mean	Sdev
2414	46	–0.0	0.9	93	–0.0	2.4
2415	8	–0.1	1.1	16	–0.7	3.8

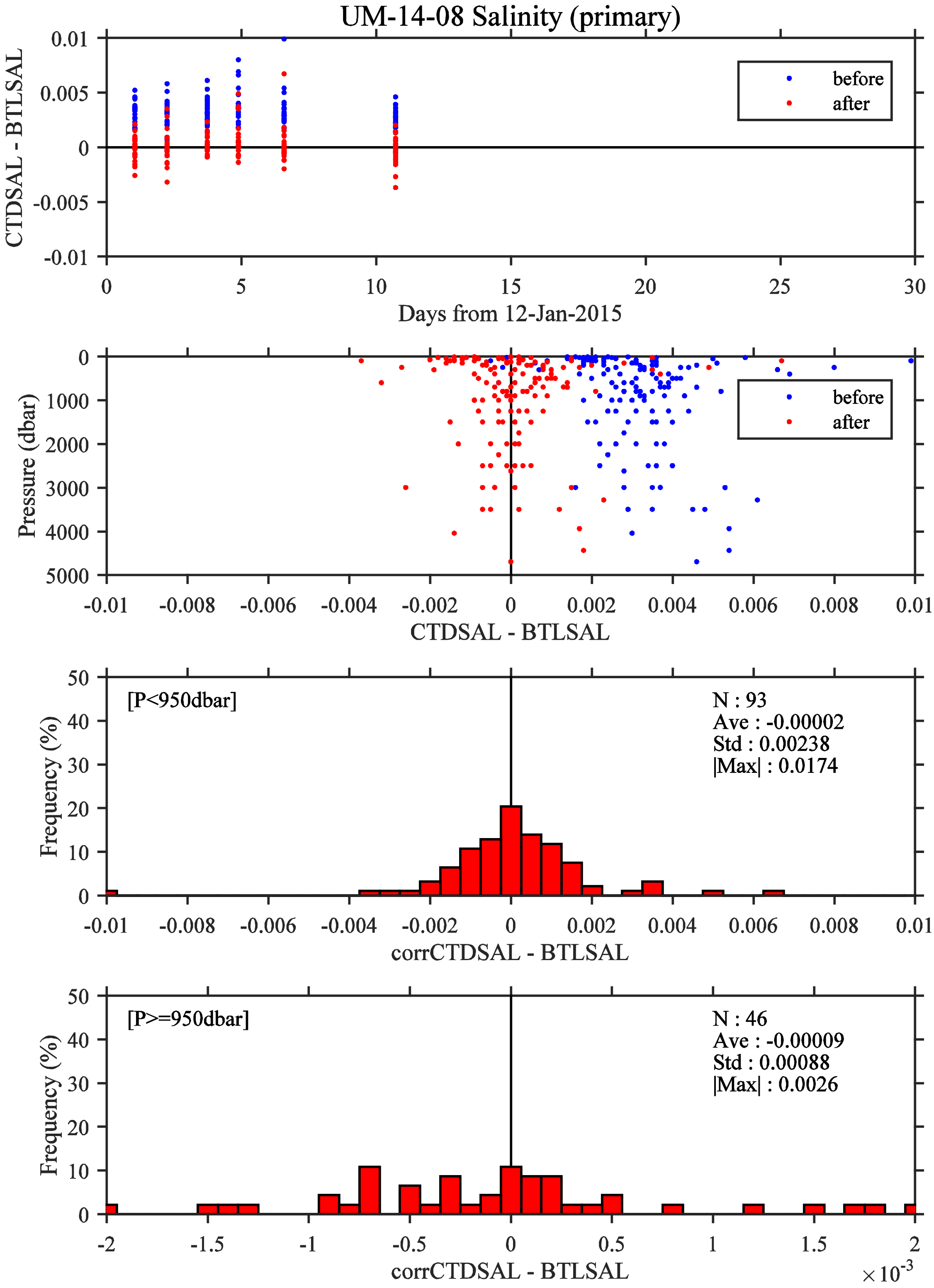

Fig. 3.1.1-4 Difference between the CTD salinity (primary) and the bottle salinity. Blue and red dots indicate before and after the post-cruise calibration, respectively. Lower two panels show histogram of the difference after the calibration.

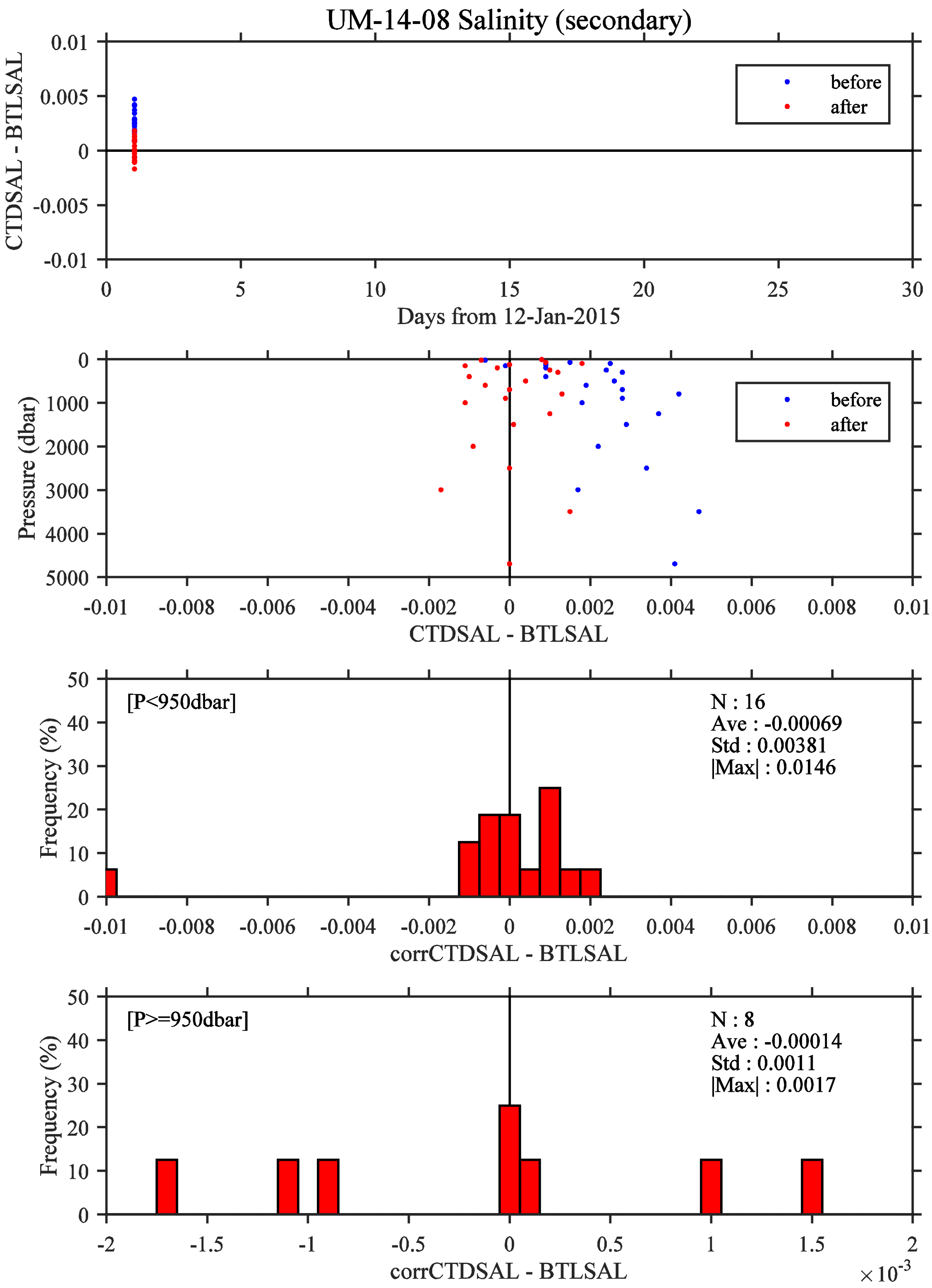

Fig. 3.1.5 Same as Fig. 3.1.4, but for secondary salinity.

(7) References

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