

3.3.1 CTD Measurements

February 13, 2017

(1) Personnel

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(2) Winch arrangements

The CTD package was deployed by using 19.6 kN Winch (Tsurumi-Seiki Co., Ltd., Kanagawa, Japan), which was renewed on the TR/V Umitaka in November 2015. Primary system components include a complete CTD Winch with up to 6000 m of 8.03 mm armored cable.

(3) Overview of the equipment

The CTD system was SBE 911plus system (Sea-Bird Electronics, Inc., Bellevue, Washington, USA). The SBE911plus system controls 24-position SBE 32 Carousel Water Sampler. The Carousel accepts 8-litre Niskin-X water sample bottles (General Oceanics, Inc., Miami, Florida, 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. Two sets of temperature and conductivity modules were used. An SBE's dissolved oxygen sensor (SBE 43) was placed between the primary conductivity sensor and the pump module. Auxiliary sensors, an altimeter (PSA-916T; Teledyne Benthos, Inc., North Falmouth, Massachusetts, USA), an oxygen optodes (RINKO-III; JFE Advantech Co., Ltd, Kobe Hyogo, Japan), a fluorometers (Seapoint sensors, Inc., Kingston, New Hampshire, USA), a transmissometer (C-Star Transmissometer; WET Labs, Inc., Philomath, Oregon, USA) and a Photosynthetically Active Radiation (PAR) sensor (Biospherical Instruments Inc., San Diego, CA, 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 03P2863 (primary)

SBE 3plus, S/N 03P5679 (secondary)

Conductivity sensor:

SBE 4, S/N 042415 (primary)

SBE 4, S/N 044376 (secondary)

Oxygen sensor:

SBE 43, S/N 431926

JFE Advantech RINKO III, S/N 0197 (foil batch no. 142101B)

Pump:

SBE 5T, S/N 052786 (primary)

SBE 5T, S/N 057891 (secondary)

Altimeter:

PSA-916T, S/N 59546

Fluorometer:

Seapoint Sensors, Inc., S/N 3590 (measurement range: 0-10 µg/L)

Transmissometer:

C-Star, S/N CST-1703DR

PAR:

QCP2350, S/N 70590

Carousel Water Sampler:

SBE 32, S/N 3273491-0949

Water sample bottle:

12-litre Niskin-X model 1010X (some 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, 24 May 2016

slope = 0.99995000

offset = -0.79300

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 10500 (6800) m by titanium (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 03P2863, 19 May 2016

S/N 03P5679, 20 February 2015

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 10500 (6800) m by titanium (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 042415, 19 May 2016

S/N 044376, 10 February 2015

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 431926, 09 June 2015

v. 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.

vi. 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.

Data from the RINKO can be corrected for the time-dependent, pressure-induced effect by means of the same method as that developed for the SBE 43 (Edwards et al., 2010). The calibration coefficients, H1 (amplitude of hysteresis correction), H2 (curvature function for hysteresis), and H3 (time constant for hysteresis) were determined empirically as follows.

$$H1 = 0.006 \text{ (for S/N 0197)}$$

$$H2 = 5000 \text{ dbar}$$

$$H3 = 2000 \text{ seconds}$$

Outputs from RINKO are the raw phase shift data. The RINKO can be calibrated by the modified Stern-Volmer equation slightly modified from a method by Uchida et al. (2010):

$$O2 (\mu\text{mol/l}) = [(V0 / V)E - 1] / Ksv$$

where V is voltage, V0 is voltage in the absence of oxygen, Ksv is Stern-Volmer constant. The coefficient E corrects nonlinearity of the Stern-Volmer equation. The V0 and the Ksv are assumed to be functions of temperature as follows.

$$Ksv = C0 + C1 \times T + C2 \times T^2$$

$$V0 = 1 + C3 \times T$$

$$V = C4 + C5 \times Vb$$

where T is CTD temperature (°C) and Vb is raw output (volts). V0 and V are normalized by the output in the absence of oxygen at 0°C. The oxygen concentration is calculated using accurate temperature data from the CTD temperature sensor instead of temperature data from the RINKO. The pressure-compensated oxygen concentration O2c can be calculated as follows.

$$O2c = O2 (1 + Cpp / 1000)$$

where p is CTD pressure (dbar) and Cp is the compensation coefficient. Since the sensing foil of the optode is permeable only to gas and not to water, the optode oxygen must be corrected for salinity. The salinity-compensated oxygen can be calculated by multiplying the factor of the effect of salt on the oxygen solubility (Garcia and Gordon, 1992).

vii. 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.

viii. Transmissometer

The C-Star Transmissometer (WET Labs, Inc., Philomath, Oregon, USA) measures light transmittance at a single wavelength (650 nm) over a known path (25 cm). In general, losses of light propagating through water can be attributed to two primary causes: scattering and absorption. By projecting a collimated beam of light through the water and placing a focused receiver at a known distance away, one can quantify these losses. The ratio of light gathered by the receiver to the amount originating at the source is known as the beam transmittance. Suspended particles, phytoplankton, bacteria and dissolved organic matter contribute to the losses sensed by the instrument. Thus, the instrument provides information both for an indication of the total concentrations of matter in the water as well as for a value of the water clarity.

Light transmission Tr (in %) and beam attenuation coefficient cp are calculated from the sensor output (V in volt) as follows.

$$Tr = M * volts + B$$

$$cp = - (1 / 0.25) \ln(Tr / 100)$$

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

S/N CST-1703DR, 29 December 2014

ix. PAR

Photosynthetically Active Radiation (PAR) sensors (Biospherical Instruments Inc., San Diego, CA, USA) provide highly accurate measurements of PAR (400 – 700 nm) for a wide range of aquatic and terrestrial applications. The ideal spectral response for a PAR sensor is one that gives equal emphasis to all photons between 400 – 700 nm. Biospherical PAR sensors use a high quality

filtered silicon photodiode to provide a near equal spectral response across the entire wavelength range of the measurement.

Pre-cruise sensor calibration was performed at Satlantic, LP.

S/N 70590, 24 November 2014

(5) Data collection and processing

i. Data collection

CTD system was powered on at least 15 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.

Water samples were collected using a 24-bottle SBE 32 Carousel Water Sampler with 8-litre Niskin-X bottles. Before a cast taken water for CFCs, the bottle frame and Niskin-X bottles were wiped with acetone.

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.

Miss trip	Miss fire	Leak
none	KC4_1 #20: accurately setting	KC1_1 #7, #21: Spring Positioning
		KC5_2 #22: rope for captive replaced

(b) Noise in down cast data

Secondary conductivity data were noisy at station KC5_2 from 1426 dbar of down cast. Transmissometer data were noisy at station KC3_1 (from 479 to 3232 dbar), KC4_1 (from 142 to 3940 dbar), KC5_2 (from 109 to 4440 dbar), and the data were removed and linearly interpolated.

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 3 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. Delay of the RINKO data was also compensated by 1 second advancing sensor output (voltage) relative to the temperature data. Delay of the transmissometer data was also compensated by 2 seconds advancing 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 1000 scans. Data greater than 10 standard deviations were flagged. The second pass computed a standard deviation over the same 1000 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 and transmissometer. A median value was determined by 49 scans of the window.

SBE_SECTION (original module) 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 0.0 m/s (traveling backwards due to ship roll).

DERIVE was used to compute oxygen (SBE 43), salinity, potential temperature, 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.

BOTTLESUM created a summary of the bottle data. The data were averaged over 3 seconds.

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.

(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 15 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 (20 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. 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 (-0.61 dbar) from the pre-cruise calibration. The post-cruise correction of the pressure data is not deemed necessary for the pressure sensor.

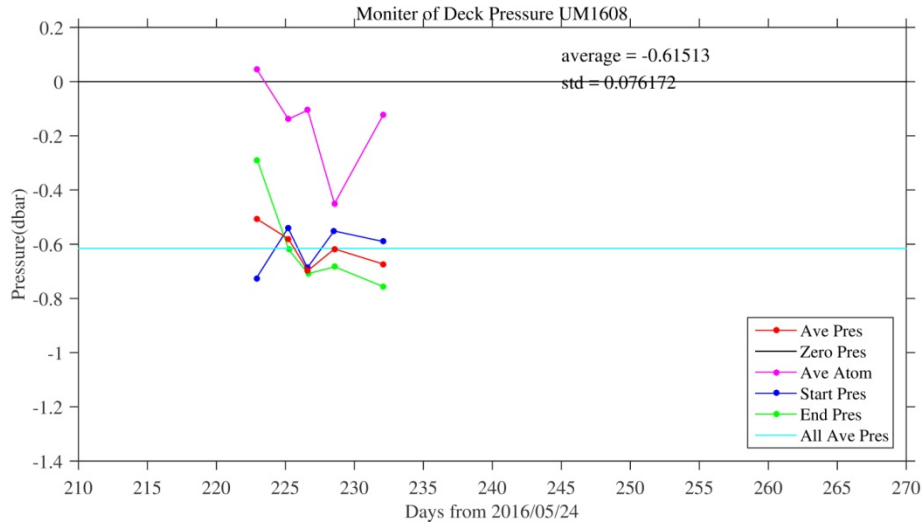


Fig. 3.1.1 Time series of the CTD deck pressure. Atmospheric pressure deviation (magenta dots) from a standard atmospheric pressure was subtracted from the CTD deck pressure. Blue and green dots indicate pre- and post-cast deck pressures, respectively. Red dots indicate averages of the pre- and the post-cast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

ii. Temperature

Pressure sensitivities of SBE 3s were corrected according to a method by Uchida et al. (2007), for the following sensors.

$$\text{S/N 03P 2863, } -3.20069\text{e-}07 \text{ [}^{\circ}\text{C/dbar]}$$

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

$$\text{Calibrated conductivity} = c_0 \times C + c_1 \times P + c_2 \times C \times P + c_3 \times t + c_4$$

where C is CTD conductivity in S/m, P is pressure in dbar, t is time in days, and c_0 , c_1 , c_2 , c_3 and c_4 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 coefficient c_3 was set to zero for this cruise.

The primary conductivity data created by the software module ROSSUM were used after the post-cruise calibration for the temperature data. The calibration coefficients are listed in Table 3.1.3. The results of the post-cruise calibration for the CTD salinity are summarized in Table 3.1.4 and shown in Fig. 3.1.5.

Table 3.1.3 Calibration coefficients for the CTD conductivity sensors.

Serial Number	c_0	c_1 [S/(m dbar)]	c_2 (1/dbar)	c_4 (S/m)
042415	1.26632e	-4 4.50361e-8	4.96820e-9	-1.27936e-4

Table 3.1.4 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 \geq 950 dbar			Pressure < 950 dbar		
	Number	Mean	Sdev	Number	Mean	Sdev
042415	36	0.2	1.2	76	-0.0	1.7

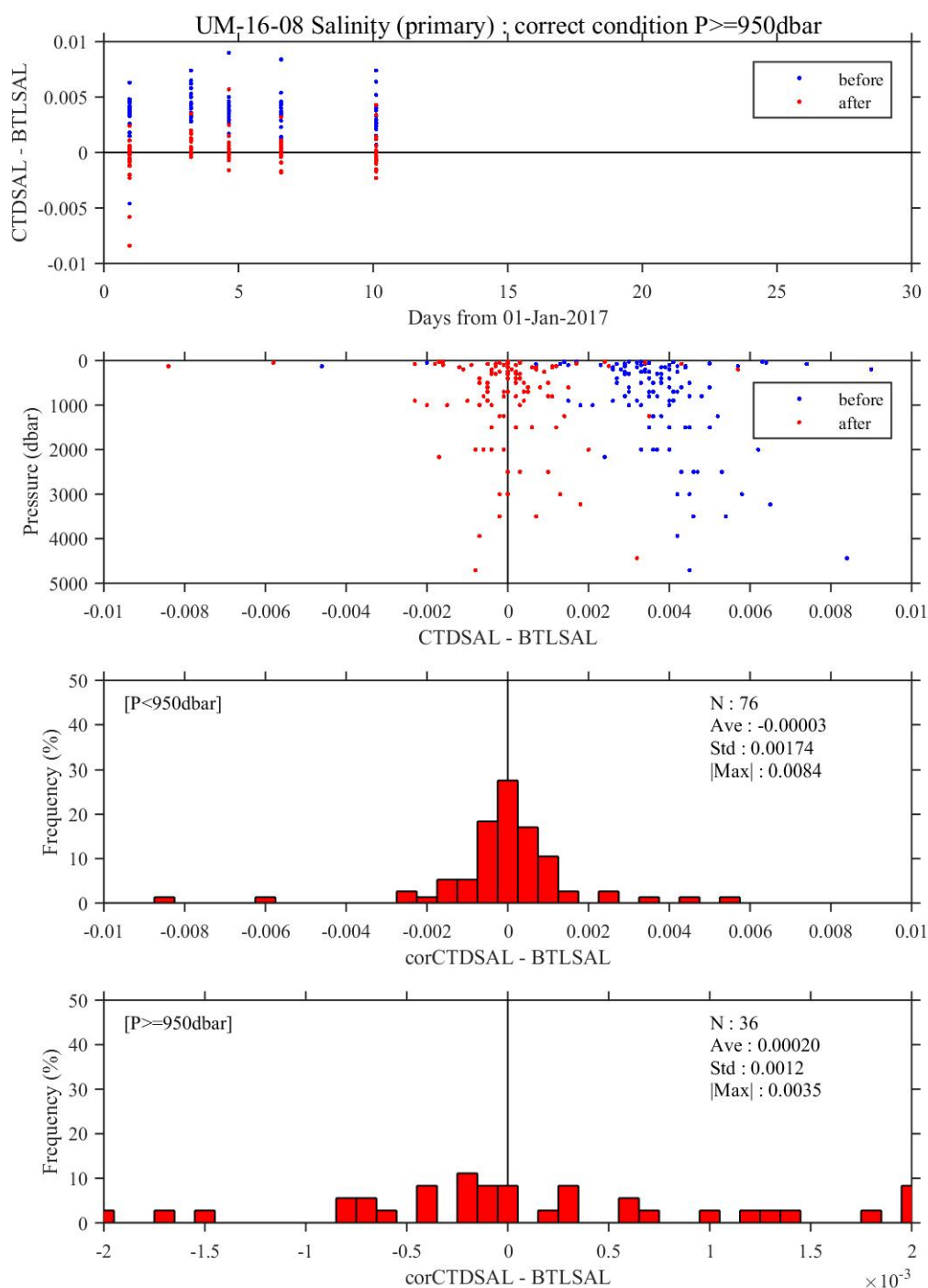


Fig. 3.1.5 Difference between the CTD salinity (primary) and the bottle salinity. Blue and red dots indicate before and after the post-cruise calibration, respectively. Lower two panels show

histogram of the difference after the calibration.

(7) References

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