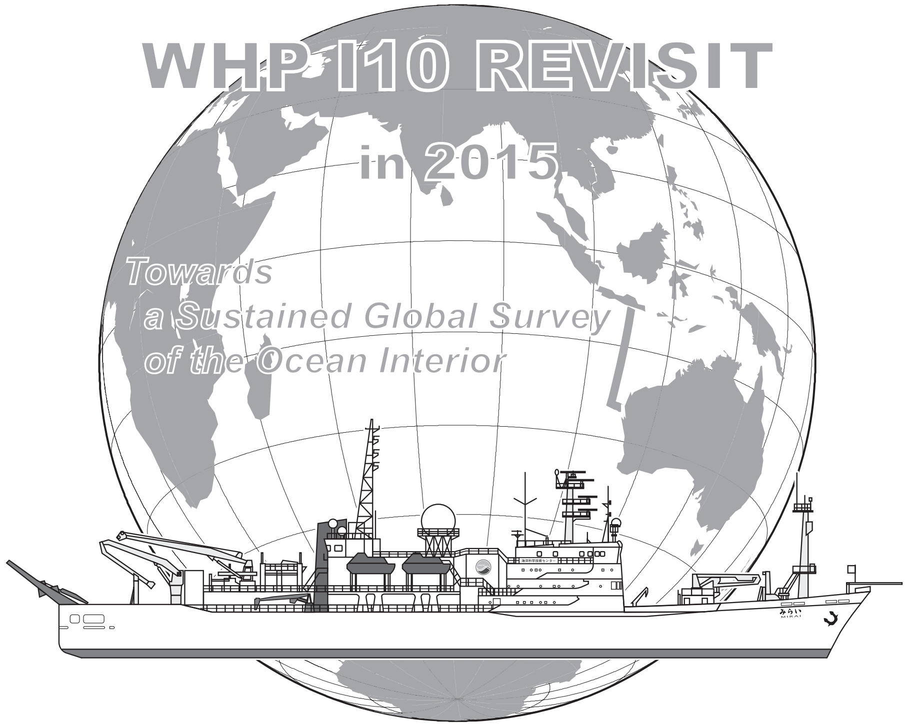
WHP I10 REVISIT IN 2015 DATA BOOK

Field Activity of JAMSTEC towards a Sustained Global Survey of the Ocean Interior

WHP I10 REVISIT IN 2015 DATA BOOK

Edited by
Hiroshi Uchida (JAMSTEC),
Katsuro Katsumata (JAMSTEC),
Toshimasa Doi (JAMSTEC)


The sunrise on New Year's Day



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Edited by Hiroshi Uchida (JAMSTEC), Katsuro Katsumata (JAMSTEC) and Toshimasa Doi (JAMSTEC)

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Preface

I am very happy to be able to announce publication of a new data book. Since the occupation of line P01 of the World Ocean Circulation Experiment (WOCE) Hydrographic Program (WHP) in 1999, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has repeated occupation of WHP lines in the world oceans. The main purpose of this activity is to understand and document large-scale water property distributions and their decadal-scale changes based on high-quality measurements of water property. Our purpose completely meets that of Global Ocean Ship-Based Hydrographic Investigation Program (GO-SHIP, http://www.go-ship.org/index.html), which is an international program subsequent to WOCE WHP. We conduct a re-visit cruise in accordance with the strategy of GO-SHIP accordingly. We collect all the data categorized as level 1 by GO-SHIP (visit http://www.go-ship.org/DatReq.html). This data book reports quality-controlled data from the R/V *Mirai's* cruise (MR15-05) conducted along I10 line of WHP in 2015/16.

The WHP I10 line is located at approximately 120°E in the eastern part of the Indian Ocean, where westward flow from the Pacific through the Indonesian passages exists. As the westward flow is a part of the global thermohaline circulation, description of the westward flow is very important in terms of not only heat and material transport but also of global-scale climate change. The observation of WHP I10 line was first made by a US group using the R/V KNORR in November 1995. Our cruise re-occupied the line after two decades apart. However, there is a difference of cruise track between the two cruises. The cruise track of MR15-05 runs from Shark Bay, Australia to the Indonesian Exclusive Economic Zone (EEZ), while that of the previous WHP cruise turns west along the EEZ boundary. In spite of the difference, we believe that one can detect significant decadal-scale changes of ocean circulation and marine environment with high-quality data obtained by the two cruises. The MR15-05 is also a cruise, which contributes to the 2nd International Indian Ocean Expedition (IIOE-2).

Although the re-occupation was made mostly in the Pacific Ocean because of geographical proximity, our concern is placed at global- or basin-scale changes. In actual, we re-occupied WHP lines of A10 and I03/I04 in the South Atlantic and the South Indian, respectively, in 2003/04. The data collected by our WHP cruises have been used as basic data for basin-scale data synthesis activities such as Carbon in Atlantic Ocean (CARINA), Pacific Ocean Interior Carbon (PACIFICA), Global Ocean Data Analysis Project (GLODAP), etc. We hope that the I10 data from MR15-05 will be helpful for future synthesis activities.

Since the first involvement in WHP in 1999, ocean observation techniques have advanced rapidly. A typical example is the introduction of Argo, which automatically measures temperature and salinity of the upper 2000 m of the ocean. Argo dramatically changed ocean observation and resolved highly under-sampled conditions of the ocean interior. Because of its utility, Argo is now extended into the deeper ocean greater than 2000 m, and Argo with biogeochemical sensors is also developed. Under the circumstances, the WHP cruises are increasing their importance not only because Argo is deployed during the cruises, but also because high-quality data from WHP cruises are indispensable for calibrating sensors mounted on Argo.

All the data listed in this data book are invaluable for research into physical and biogeochemical oceanography. Nevertheless, I would like to emphasize prominent high quality of our nutrient data, which guarantees comparability and traceability. This is attained by consistent measurement based on certified reference materials for nutrients, which was developed in Japan. With the high-quality data for nutrients, detection of basin-scale and long-term changes of marine environment would be made, which has been not possible for a long time due to low quality of nutrients data.

Finally, we would like to express our gratitude to all participants and crews of the R/V *Mirai* for their assistance in conducting the cruise. Furthermore, we would like to extend special thanks to people in BPPT, who made efforts for the R/V *Mirai* to be able to conduct observation within the Indonesian EEZ. We intend to continue our effort to re-occupy WHP lines, having conviction that our data will be useful for understanding and prediction of global climate changes. Data from current and previous WHP cruises are available on the website http://www.jamstec.go.jp/iorgc/ocorp/data/post-woce.html. Updates and corrections will be also found.

Akihiko Murata, Dr.
Group Leader
Global Chemical and Physical Oceanography Group
Research and Development Center for Global Change (RCGC)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

1 Cruise Narrative

January 19, 2018

Katsuro Katsumata (JAMSTEC)

1.1 Highlight

Cruise track:	See Fig. 1.1.1
Cruise code:	MR15-05
Expedition Designation:	Leg 1, 49NZ20140709
	Leg 2, 49NZ20140717
GHPO section designation:	I10
Ship name:	R/V Mirai
Ports of Call:	Leg 1, Jakarta, Indonesia – Bali, Indonesia
	Leg 2, Bali, Indonesia – Yokohama, Japan
Cruise Dates:	Leg 1, 23 December 2015 – 11 January 2016
	Leg 2, 13 January 2016 – 25 January 2016
Chief Scientist and Affiliation:	
	Leg 1, Katsuro Katsumata (k.katsumata@jamstec.go.jp)
	Leg 2, Akihiko Murata (murataa@jamstec.go.jp)
	Research and Development Center for Global Change (RCGC)
	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
	2-15 Natsushima, Yokosuka, Kanagawa, Japan 237-0061
	Fax: +81-46-867-9835
Number of Stations:	Leg 1, 53 stations
	Leg 2, none
Floats and drifter deployed:	16 Argo floats (Leg 1), 1 Argo float (Leg 2)
Mooring recovery:	none

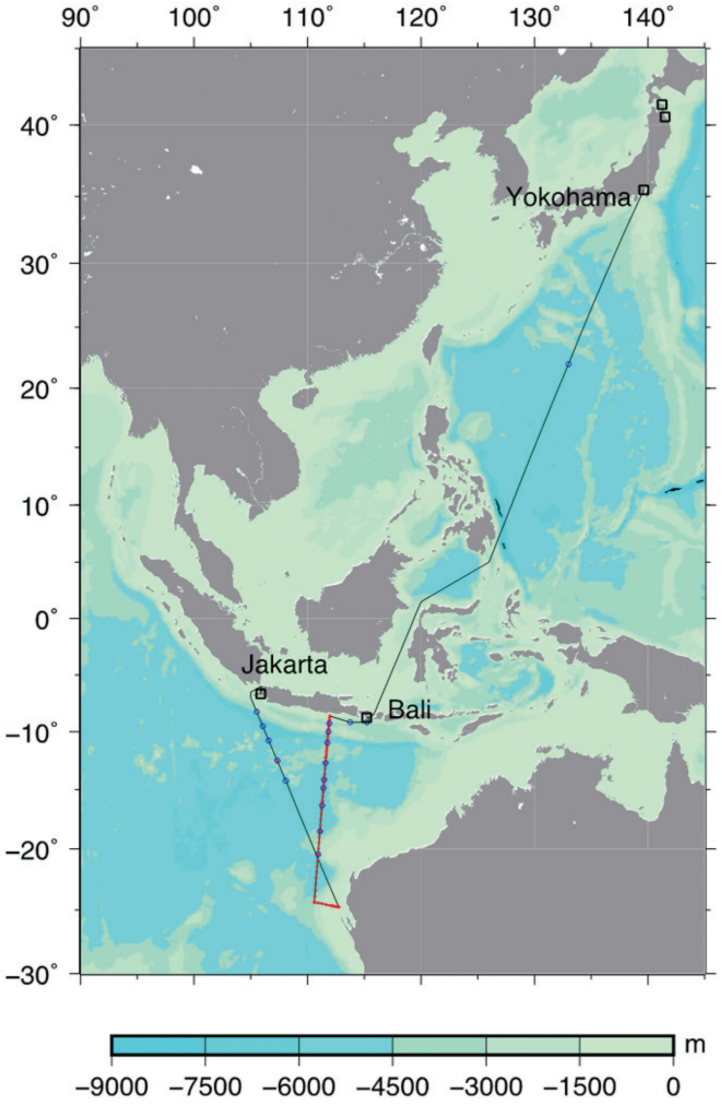

Fig. 1.1.1 MR15-05 cruise. Blue circles show the deployment position of Argo floats. Red dots show CTD/bottle sampling stations.

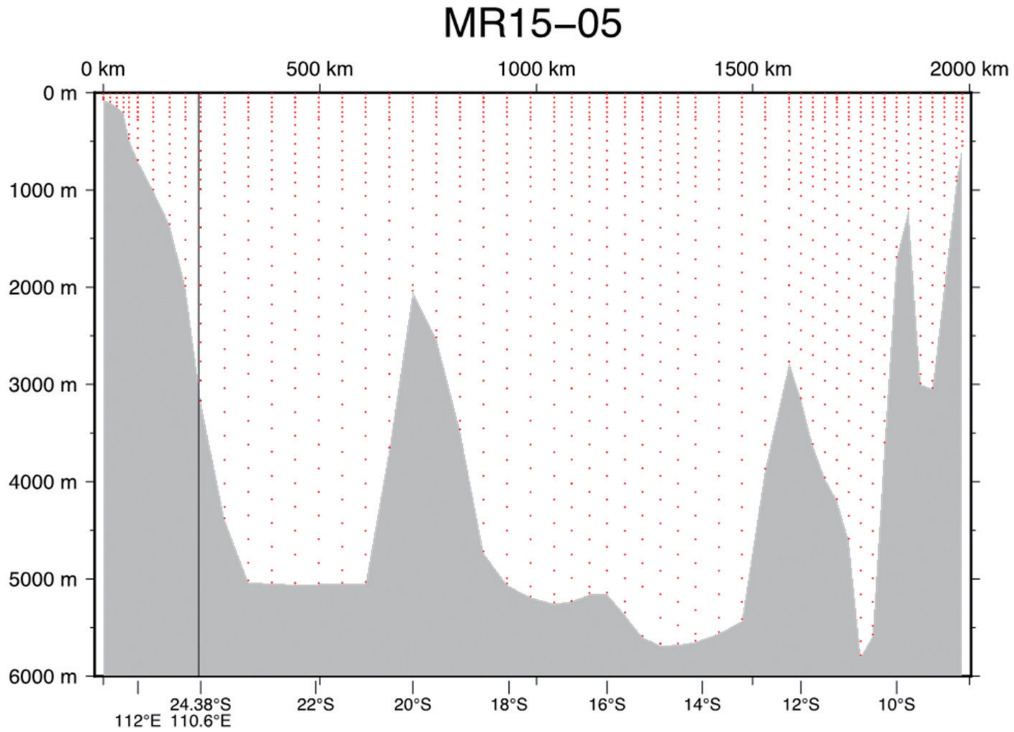

Fig. 1.1.2 Water sampling positions.

1.2 Cruise Description

Indonesian Throughflow is a surface component of the global ocean circulation, which transports fresh Pacific upper water masses into the north Indian Ocean with strong modification from the air-sea interaction and vigorous tidal mixing within the marginal seas. Paucity of observation data in this part of the world ocean has always been a bottleneck in understanding the interaction of the ocean-atmosphere part of the global climate system and its ongoing changes. The main purpose of this cruise is to measure the distribution of properties in this important ocean. The cruise is a contribution to International Indian Ocean Expedition 2. This cruise is also a contribution to and was conducted following the standard methods advocated by the Global Ocean Ship-based Hydrographic Investigation Program (GO-SHIP).

The cruise was blessed with good weather — only a few minor problems with the water sampling and winch systems, and malfunctioning of a meteorological sensor on the fore mast (see main text for the detail). Probably the biggest problem was in the paperworks with Indonesian authorities. In this regard, we owe much to our local colleague Dr. Fadli Syamsudin. He has been with us from the planning stage and this cruise was not possible without his efforts. We would like to repeat our thanks to him.

1.3 Principal Investigators and personnel in charge onboard

The principal investigators (PI) and the persons responsible for major parameters are listed in Table 1.3.1.

Table 1.3.1. List of principal investigator and person in charge on the ship.

Item	Principal Investigator	Person in charge onboard
Underway		
Navigation	Data Management Group (CEIST/JAMSTEC) dmo@jamstec.go.jp	Wataru Tokunaga (GODI) (leg 1) Koichi Inagaki (GODI) (leg 2)
Bathymetry	Data Management Group (CEIST/JAMSTEC) dmo@jamstec.go.jp	Wataru Tokunaga (GODI) (leg 1) Koichi Inagaki (GODI) (leg 2)
Meteorology	Data Management Group (CEIST/JAMSTEC) dmo@jamstec.go.jp	Wataru Tokunaga (GODI) (leg 1) Koichi Inagaki (GODI) (leg 2)
Thermo-salinograph	Hiroshi Uchida (JAMSTEC) huchida@jamtec.go.jp	Masahiro Orui (MWJ)
pCO_2	Akihiko Murata (JAMSTEC) murataa@jamstec.go.jp	Atsushi Ono (MWJ)

Ceilometer	Data Management Group (CEIST/JAMSTEC) dmo@jamstec.go.jp	Wataru Tokunaga (GODI) (leg 1) Koichi Inagaki (GODI) (leg 2)
Surface CO_2 fluxes	Kei Shiomi (JAXA) shiomi.kei@jaxa.jp	None
Sky Radiometer	Kazuma Aoki (Univ. of Toyama) kazuma@sci.u-toyama.ac.jp	None
Radars and Disdrometer	Masaki Katsumata (JAMSTEC) katsu@jamstec.go.jp	None
Aerosol and gases	Yugo Kanaya (JAMSTEC) yugo@jamstec.go.jp	None
Gravity and Magnetic field	Data Management Group (CEIST/JAMSTEC) dmo@jamstec.go.jp	Wataru Tokunaga (GODI) (leg 1) Koichi Inagaki (GODI) (leg 2)
Hydrography		
CTD/O_2	Hiroshi Uchida (JAMSTEC) huchida@jamstec.go.jp	Shinsuke Toyoda (MWJ)
Salinity	Hiroshi Uchida (JAMSTEC) huchida@jamstec.go.jp	Sonoka Wakatsuki (MWJ)
Density	Hiroshi Uchida (JAMSTEC) huchida@jamstec.go.jp	Hiroshi Uchida (JAMSTEC)
Oxygen	Yuichiro Kumamoto (JAMSTEC) kumamoto@jamstec.go.jp	Misato Kuwahara (MWJ) (leg 1) Keitaro Matsumoto (MWJ) (leg 2)
Nutrients	Michio Aoyama (Fukushima Univ.) r706@ipc.fukushima-u.ac.jp	Elena Hayashi (MWJ)
CFCs/SF_6	Ken’ichi Sasaki (JAMSTEC) ksasaki@jamstec.go.jp	Ken’ichi Sasaki (JAMSTEC)
DIC	Akihiko Murata (JAMSTEC) murataa@jamstec.go.jp	Atsushi Ono (MWJ)
Total Alkalinity	Akihiko Murata (JAMSTEC) murataa@jamstec.go.jp	Tomonori Watai (MWJ)
pH	Akihiko Murata (JAMSTEC) murataa@jamstec.go.jp	Tomonori Watai (MWJ)
Calcium and Total Alkalinity 2	Etsuro Ono (JAMSTEC) et_ono@met.kishou.go.jp	Etsuro Ono (JAMSTEC)
Chlorophyll a	Kosei Sasaoka (JAMSTEC) sasaoka@jamstec.go.jp	Kosei Sasaoka (JAMSTEC)
DOC and TDN	Masahito Shigemitsu (JAMSTEC) ma-shige@jamstec.go.jp	Masahito Shigemitsu (JAMSTEC)
CDOM and Absorption coefficient	Kosei Sasaoka (JAMSTEC) sasaoka@jamstec.go.jp	Kosei Sasaoka (JAMSTEC)
Carbon isotopes	Yuichiro Kumamoto (JAMSTEC) kumamoto@jamstec.go.jp	Yuichiro Kumamoto (JAMSTEC)
Radioactive Cesium	Yuichiro Kumamoto (JAMSTEC) kumamoto@jamstec.go.jp	Yuichiro Kumamoto (JAMSTEC)
^{18}O	Hiroshi Uchida (Hokkaido Univ.) huchida@jamstec.go.jp	Hiroshi Uchida (JAMSTEC)
Primary productivity	Kazuhiko Matsumoto (JAMSTEC) matsumotok@jamstec.go.jp	Kazuhiko Matsumoto (JAMSTEC)

LADCP	Shinya Kouketsu (JAMSTEC) skouketsu@jamstec.go.jp	Hiroshi Uchida (JAMSTEC)
XCTD	Hiroshi Uchida (JAMSTEC) huchida@jamstec.go.jp	Wataru Tokunaga (GODI)
Micro Rider	Ichiro Yasuda (AORI) ichiro@aori.u-tokyo.ac.jp	Hiroshi Uchida (JAMSTEC)
Biology		
Microbial abundance etc.		
	Takuro Nunoura (JAMSTEC) takuron@jamstec.go.jp	Taichi Yokokawa (Kochi Univ.)
Floats		
Argo	Ann Thresher (CSIRO) Ann.Thresher@csiro.au	Shungo Oshitani (MWJ)

CEIST	Center for Earth Information Science and Technology
GODI	Global Ocean Development Inc.
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
MWJ	Marine Works Japan, Ltd.
JAXA	Japan Aerospace Exploration Agency
AORI	Atmosphere and Ocean Research Institute, University of Tokyo
CSIRO	Commonwealth Scientific and Industrial Research Organisation

1.4 Cruise Participants

List of Participants for leg 1

Katsuro Katsumata	Chief scientist	RCGC/JAMSTEC
Yuichiro Kumamoto	DO/Sampling chief	RCGC/JAMSTEC
Hiroshi Uchida	Density/^{18}O	RCGC/JAMSTEC
Ken'ichi Sasaki	CFCs	MIO/JAMSTEC
Kosei Sasaoka	CDOM/Absorption coefficient	RCGC/JAMSTEC
Etsuro Ono	Calcium/total alkalinity	RCGC/JAMSTEC
Kazuhiko Matsumoto	Primary productivity	DEGCR/JAMSTEC
Taichi Yokokawa	Biological sampling	RDCMB/JAMSTEC
Chisato Yoshikawa	Biological sampling	DB/JAMSTEC
Shotoku Kotajima	Biological sampling	TUAT
Kanta Chida	Biological sampling	Rakuno Gakuen University
Harun Idham Akbar	Water sampling	BPPT
Gentio Harusono	Security Officer	Indonesian Navy
Hiroshi Matsumaga	Chief technician/Sampling chief	MWJ
Shinsuke Toyoda	CTD	MWJ
Hiroki Ushiromura	Salinity	MWJ
Syungo Oshitani	CTD/Argo	MWJ
Sonoka Wakatsuki	Salinity	MWJ
Keisuke Takeda	CTD	MWJ
Minoru Kamata	Nutrients	MWJ
Tomonori Watai	pH/total alkalinity	MWJ
Makoto Takada	DIC	MWJ

Elena Hayashi	Nutrients	MWJ
Atsushi Ono	pCO_2/DIC	MWJ
Tomomi Sone	Nutrients	MWJ
Katsunori Sagishima	CFCs	MWJ
Hironori Sato	CFCs	MWJ
Misato Kuwahara	DO/Thermo-salinograph	MWJ
Masahiro Orui	Thermo-salinograph/DO	MWJ
Keitaro Matsumoto	DO/Thermo-salinograph	MWJ
Hiroshi Hoshino	CFCs	MWJ
Haruka Tamada	DO/Thermo-salinograph	MWJ
Hiroyuki Hayashi	CTD	MWJ
Kanako Yoshida	pH/total alkalinity	MWJ
Kohei Miura	Nutrients	MWJ
Seika Katayama	Water sampling	MWJ
Naoya Yokoi	Water sampling	MWJ
Kohei Kumagai	Water sampling	MWJ
Naoya Kudo	Water sampling	MWJ
Eri Yoshizawa	Water sampling	MWJ
Kei Takamiya	Water sampling	MWJ
Wataru Tokunaga	Chief technician/meterology/ geophysics/XCTD	GODI
Yutaro Murakami	Meteorlology/geophysics/XCTD	GODI
Tetsuya Kai	Meteorology/geophysics/XCTD	GODI

List of Participants for leg 2

Akihiko Murata	Chief scientist	RCGC/JAMSTEC
Kousei Sasaoka	Chlorophyll a	RCGC/JAMSTEC
Minoru Kamata	Chief marine technician/Nutrients	MWJ
Sinsuke Toyota	CTD	MWJ
Tomonori Watai	pH/Alkalinity	MWJ
Syungo Oshitani	Argo	MWJ
Sonoka Wakatsuki	Salinity	MWJ
Makoto Takada	DIC	MWJ
Elena Hayashi	Nutrients	MWJ
Atsushi Ono	pCO_2/DIC	MWJ
Katsunori Sagishima	CFCs	MWJ
Masahiro Orui	Thermo-salinograph/DO	MWJ
Keitaro Matsumoto	DO	MWJ
Koichi Inagaki	Chief technician/meteorology/geophysics	GODI
Yutaro Murakami	Meteorology/geophysics	GODI

BPPT: Badan Pengkajian dan Penerapan Teknologi (Agency for the Assessment and Application of Technology of the Republic of Indonesia)
DB: Department of Biogeochemistry
DEGCR: Department of Environmental Geochemical Cycle Research
GODI: Global Ocean Development Inc.
MWJ: Marine Works Japan
MIO: Mutsu Institute for Oceanography
RCGC: Research and Development Center for Global Change

RDCMB: Research and Development Center for Marine Biosciences

TUAT: Tokyo University of Agriculture and Technology

2 Underway Measurements

2.1 Navigation

February 5, 2016

(1) Personnel

Katsuro Katsumata	JAMSTEC: Principal investigator	- leg 1 -
Akihiko Murata	JAMSTEC: Principal investigator	- leg 2 -
Wataru Tokunaga	Global Ocean Development Inc., (GODI)	- leg 1 -
Tetsuya Kai	GODI	- leg 1 -
Koichi Inagaki	GODI	- leg 2 -
Yutaro Murakami	GODI	- leg 1, leg 2 -
Ryo Kimura	MIRAI crew	- leg 1 -
Masanori Murakami	MIRAI crew	- leg 2 -

(2) System description

Ship's position and velocity were provided by Navigation System on R/V MIRAI. This system integrates GNSS position, Doppler sonar log speed, Gyro compass heading and other basic data for navigation. This system also distributed ship's standard time synchronized to GPS time server via Network Time Protocol. These data were logged on the network server as "SOJ" data every 5 seconds. Sensors for navigation data are listed below;

(i) GNSS system:

R/V MIRAI has four GNSS systems, all GNSS positions were offset to radar-mast position, datum point. Anytime changeable manually switched as to GNSS receiving state.

(a) StarPack-D (version 1), Differential GNSS system.

Antenna: Located on compass deck, starboard.

(b) StarPack-D (version 1), Differential GNSS system.

Antenna: Located on compass deck, portside.

(c) Standalone GPS system.

Receiver: Trimble SPS751

Antenna: Located on navigation deck, starboard.

(d) Standalone GPS system.

Receiver: Trimble SPS751

Antenna: Located on navigation deck, portside.

(ii) Doppler sonar log:

FURUNO DS-30, which use three acoustic beam for current measurement under the hull.

(iii) Gyro compass:

TOKYO KEIKI TG-6000, sperry type mechanical gyrocompass.

(iv) GPS time server:

SEIKO TS-2540 Time Server, synchronizing to GPS satellites every 1 second.

(3) Data period (Times in UTC)

Leg 1: 03:10, 23 Dec. 2015 to 00:50, 11 Jan. 2016

Leg 2: 01:00, 13 Jan. 2016 to 23:50, 24 Jan. 2016

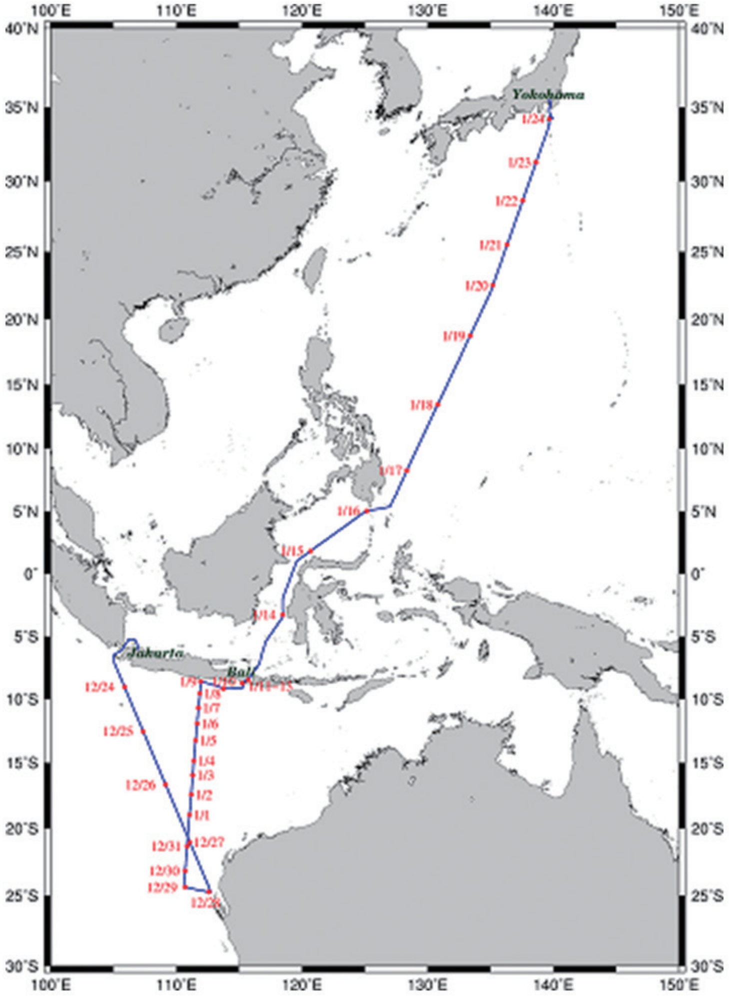

Fig.2.1.1 Cruise track of MR15-05 Leg 1, Leg 2

2.2 Swath Bathymetry

January 29, 2016

(1) Personnel

Katsuro Katsumata	JAMSTEC: Principal investigator	- leg 1 -
Akihiko Murata	JAMSTEC: Principal investigator	- leg 2 -
Wataru Tokunaga	Global Ocean Development Inc., (GODI)	- leg 1 -
Tetsuya Kai	GODI	- leg 1 -
Koichi Inagaki	GODI	- leg 2 -
Yutaro Murakami	GODI	- leg 1, leg 2 -
Ryo Kimura	MIRAI crew	- leg 1 -
Masanori Murakami	MIRAI crew	- leg 2 -

(2) Introduction

R/V MIRAI is equipped with a Multi narrow Beam Echo Sounding system (MBES), SEABEAM 3012 (L3 Communications, ELAC Nautik). The objective of MBES is collecting continuous bathymetric data along ship's track to make a contribution to geological and geophysical investigations and global datasets.

(3) Data Acquisition

The "SEABEAM 3012" on R/V MIRAI was used for bathymetry mapping during this cruise.

To get accurate sound velocity of water column for ray-path correction of acoustic multibeam, we used Surface Sound Velocimeter (SSV) data to get the sea surface sound velocity (at 6.62m), and the deeper depth sound velocity profiles were calculated by temperature and salinity profiles from CTD and XCTD data by the equation in Del Grosso (1974) during this cruise.

Table 2.2.1 shows system configuration and performance of SEABEAM 3012.

Table 2.2.1. SEABEMA 3012 system configuration and performance.

Frequency:	12 kHz
Transmit beam width:	2.0 degree
Transmit power:	4 kW
Transmit pulse length:	2 to 20 msec.
Receive beam width:	1.6 degree
Depth range:	50 to 11,000 m
Number of beams:	301 beams
Beam spacing:	Equi-angle
Swath width:	60 to 150 degrees
Depth accuracy:	< 1 % of water depth (average across the swath)

(4) Data processing

i) Sound velocity correction

Each bathymetry data were corrected with sound velocity profiles calculated from the nearest CTD or XCTD data in the distance. The equation of Del Grosso (1974) was used for calculating sound velocity. The data correction were carried out using the HIPS software version 8.1.8 (CARIS, Canada)

ii) Editing and Gridding

Editing for the bathymetry data were carried out using the HIPS. Firstly, the bathymetry data during ship's turning was basically deleted, and spike noise of each swath data was removed. Then the bathymetry data were checked by "BASE surface (resolution: 50 m averaged grid)".

Finally, all accepted data were exported as XYZ ASCII data (longitude [degree], latitude [degree], depth [m]), and converted to 150 m grid data using "nearneighbor" utility of GMT (Generic Mapping Tool) software.

Table 2.2.2. Parameters for gridding on “nearneighbor” in GMT.

Gridding mesh size:	150 m
Search radius size:	150 m
Minimum number of neighbors for grid:	1

(5) Data Archives

Bathymetric data obtained during this cruise will be submitted to the Data Management Group (DMG) of JAMSTEC, and will be archived there.

(6) Remarks (Times in UTC)

The following periods, the observations were carried out.

Leg 1: 19:35, 23 Dec. 2015 to 09:40, 24 Dec. 2015
11:20, 24 Dec. 2015 to 22:05, 10 Jan. 2016
Leg 2: 14:35, 17 Jan. 2016 to 06:26, 23 Jan. 2016

2.3 Surface Meteorological Observations

February 5, 2016

(1) Personnel

Katsuro Katsumata	JAMSTEC: Principal investigator	- leg 1 -
Akihiko Murata	JAMSTEC: Principal investigator	- leg 2 -
Wataru Tokunaga	Global Ocean Development Inc., (GODI)	- leg 1 -
Tetsuya Kai	GODI	- leg 1 -
Koichi Inagaki	GODI	- leg 2 -
Yutaro Murakami	GODI	- leg 1, leg 2 -
Ryo Kimura	MIRAI crew	- leg 1 -
Masanori Murakami	MIRAI crew	- leg 2 -

(2) Objectives

Surface meteorological parameters are observed as a basic dataset of the meteorology. These parameters provide the temporal variation of the meteorological condition surrounding the ship.

(3) Methods

Surface meteorological parameters were observed during this cruise, except for the Republic of Indonesia territorial waters and Republic of Philippine EEZ. In this cruise, we used two systems for the observation.

i) MIRAI Surface Meteorological observation (SMet) system

Instruments of SMet system are listed in Table 2.3.1 and measured parameters are listed in Table 2.3.2. Data were collected and processed by KOAC-7800 weather data processor made by Koshin-Denki, Japan. The data set consists of 6-second averaged data.

ii) Shipboard Oceanographic and Atmospheric Radiation (SOAR) measurement system

SOAR system designed by BNL (Brookhaven National Laboratory, USA) consists of major five parts.

a) Portable Radiation Package (PRP) designed by BNL – short and long wave downward radiation.
b) Analog meteorological data sampling with CR1000 logger manufactured by Campbell Inc. Canada – wind, pressure, and rainfall (by a capacitive rain gauge) measurement.
c) Digital meteorological data sampling from individual sensors – air temperature, relative humidity and rainfall (by ORG (optical rain gauge)) measurement.
d) Photosynthetically Available Radiation (PAR) and UV (Ultraviolet Irradiance) sensor manufactured by Biospherical Instruments Inc. (USA) - PAR measurement.
e) Scientific Computer System (SCS) developed by NOAA (National Oceanic and Atmospheric Administration, USA) – centralized data acquisition and logging of all data sets.

SCS recorded PRP, CR1000 data, air temperature and relative humidity data, ORG data. SCS composed Event data (JamMet) from these data and ship's navigation data every 6 seconds. Instruments and their locations are listed in Table 2.3.3 and measured parameters are listed in Table 2.3.4.

For the quality control as post processing, we checked the following sensors, before and after the cruise.

a) Young rain gauge (SMet and SOAR)
   Inspect of the linearity of output value from the rain gauge sensor to change input value by adding fixed quantity of test water.
b) Barometer (SMet and SOAR)
   Comparison with the portable barometer value, PTB220, VAISALA
c) Thermometer (air temperature and relative humidity) (SMet and SOAR)
   Comparison with the portable thermometer value, HM70, VAISALA

(4) Preliminary results

Fig. 2.3.1 shows the time series of the following parameters;

Wind (SOAR)
Air temperature (SMet)
Relative humidity (SMet)
Precipitation (SOAR, rain gauge)
Short/long wave radiation (Smet and SOAR)
SMet: 18:51, 23 Dec. 2015 to 00:49, 28 Dec. 2015
SOAR: 00:50, 28 Dec. 2015 to end of cruise
Pressure (SMet)
Sea surface temperature (SMet)
Significant wave height (SMet)

(5) Data archives

These meteorological data will be submitted to the Data Management Group (DMG) of JAMSTEC just after the cruise.

(6) Remarks (Times in UTC)

i) The following periods, the observation were carried out.
Leg1: 18:51, 23 Dec. 2015 to 22:40, 10 Jan. 2016
Leg2: 13:35, 17 Jan. 2016 to 00:00, 25 Jan. 2016

ii) The following periods, sea surface temperature of SMet data were available.
Leg1: 18:51, 23 Dec. 2015 to 22:03, 10 Jan. 2016
Leg2: 13:35, 17 Jan. 2016 to 06:30, 23 Jan. 2016

iii) The following periods, PRP data were invalid due to system trouble.
18:51, 23 Dec. 2015 to 00:49, 28 Dec. 2015
16:42, 21 Jan. 2016 to 20:54, 21 Jan. 2016

iv) The following periods, PRP data acquisition were suspended due to maintenance.
07:27, 24 Jan. 2016 to 07:30, 24 Jan. 2016

v) The following time, increasing of SMet capacitive rain gauge data were invalid due to transmitting for MF/HF or VHF radio.
06:37, 06 Jan. 2016
23:57, 20 Jan. 2016
01:01, 21 Jan. 2016
20:31, 24 Jan. 2016
22:07, 24 Jan. 2016

Table 2.3.1. Instruments and installation locations of MIRAI Surface Meteorological observation system.

Sensors	Type	Manufacturer	Location (attitude from surface)
Anemometer	KE-500	Koshin Denki, Japan	foremast (24 m)
Tair/RH	HMP155	Vaisala, Finland	
with 43408 Gill aspirated radiation shield		R.M. Young, USA	compass deck (21 m)
			starboard side and port side
Thermometer: SST	RFN2-0	Koshin Denki, Japan	4th deck (-1m, inlet -5m)
Barometer	Model-370	Setra System, USA	captain deck (13 m)
			weather observation room
Capacitive rain gauge	50202	R. M. Young, USA	compass deck (19 m)
Optical rain gauge	ORG-815DS	Osi, USA	compass deck (19 m)
Radiometer (short wave)	MS-802	Eko Seiki, Japan	radar mast (28 m)
Radiometer (long wave)	MS-202	Eko Seiki, Japan	radar mast (28 m)
Wave height meter	WM-2	Tsurumi-seiki, Japan	bow (10 m)
			Stern (8 m)

Table 2.3.2. Parameters of MIRAI Surface Meteorological observation system.

Parameter	Units	Remarks
1 Latitude	degree	
2 Longitude	degree	
3 Ship's speed	knot	Mirai log, DS-30, Furuno
4 Ship's heading	degree	Mirai gyro, TG-6000, TOKYO-KEIKI
5 Relative wind speed	m/s	6sec./10min. averaged
6 Relative wind direction	degree	6sec./10min. averaged
7 True wind speed	m/s	6sec./10min. averaged
8 True wind direction	degree	6sec./10min. averaged
9 Barometric pressure	hPa	adjusted to sea surface level 6sec. averaged
10 Air temperature (starboard side)	degC	6sec. averaged
11 Air temperature (port side)	degC	6sec. averaged
12 Dewpoint temperature (starboard side)	degC	6sec. averaged
13 Dewpoint temperature (port side)	degC	6sec. averaged
14 Relative humidity (starboard side)	%	6sec. averaged
15 Relative humidity (port side)	%	6sec. averaged
16 Sea surface temperature	degC	6sec. averaged
17 Rain rate (optical rain gauge)	mm/hr	hourly accumulation
18 Rain rate (capacitive rain gauge)	mm/hr	hourly accumulation
19 Down welling shortwave radiation	W/m^2	6sec. averaged
20 Down welling infra-red radiation	W/m^2	6sec. averaged
21 Significant wave height (bow)	m	hourly
22 Significant wave height (aft)	m	hourly
23 Significant wave period (bow)	second	hourly
24 Significant wave period (aft)	second	hourly

Table 2.3.3. Instruments and installation locations of SOAR system.

Sensors	Type	Manufacturer	Location (attitude from surface)
Meteorological			
Anemometer	05106	R.M. Young, USA	Foremast (25 m)
Barometer	PTB210	Vaisala, Finland	
with 61002 Gill pressure port		R.M. Young, USA	Foremast (23 m)
Capacitive rain gauge	50202	R.M. Young, USA	Foremast (24 m)
Tair/RH	HMP155	Vaisala, Finland	
with 43408 Gill aspirated radiation shield		R.M. Young, USA	Foremast (23 m)
Optical rain gauge	ORG-815DR	Osi, USA	Foremast (24 m)
PRP			
Radiometer (short wave)	PSP	Epply Labs, USA	Foremast (25 m)
Radiometer (long wave)	PIR	Epply Labs, USA	Foremast (25 m)
Fast rotating shadowband radiometer		Yankee, USA	Foremast (25 m)
PAR			
PAR sensor	PUV-510	Biospherical Instruments Inc., USA	Navigation deck (18m)

Table 2.3.4. Parameters of SOAR system (JamMet).

Parameter	Units	Remarks
1 Latitude	degree	
2 Longitude	degree	
3 SOG	knot	
4 COG	degree	
5 Relative wind speed	m/s	
6 Relative wind direction	degree	
7 Barometric pressure	hPa	
8 Air temperature	degC	
9 Relative humidity	%	
10 Rain rate (optical rain gauge)	mm/hr	
11 Precipitation (capacitive rain gauge)	mm	reset at 50 mm
12 Down welling shortwave radiation	W/m^2	
13 Down welling infra-red radiation	W/m^2	
14 Defuse irradiance	W/m^2	
15 PAR	$microE/cm^2/sec$	
16 UV305nm	$microW/cm^2/nm$	
17 UV320nm	$microW/cm^2/nm$	
18 UV340nm	$microW/cm^2/nm$	
19 UV380nm	$microW/cm^2/nm$	

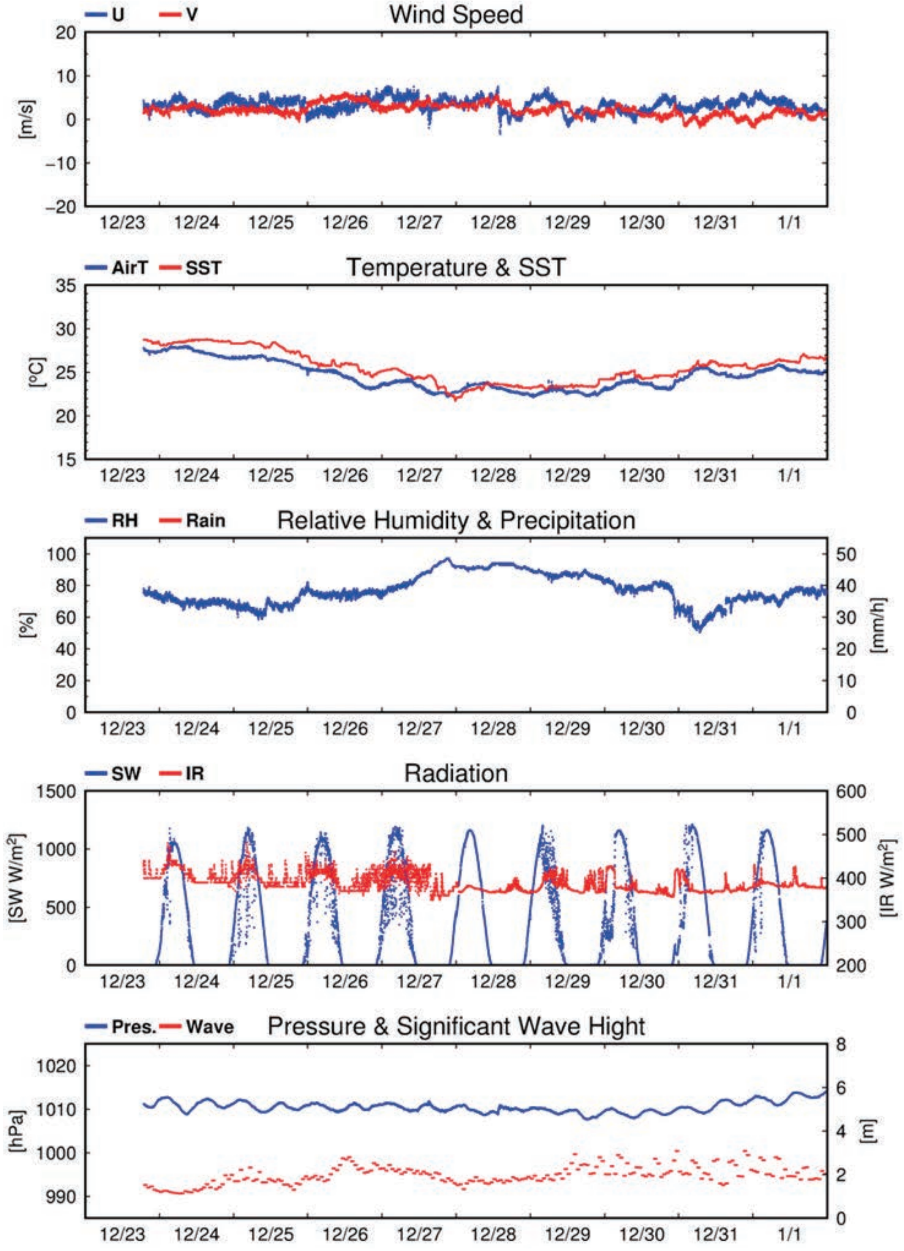

Fig. 2.3.1. Time series of surface meteorological parameters during this cruise (Leg 1).

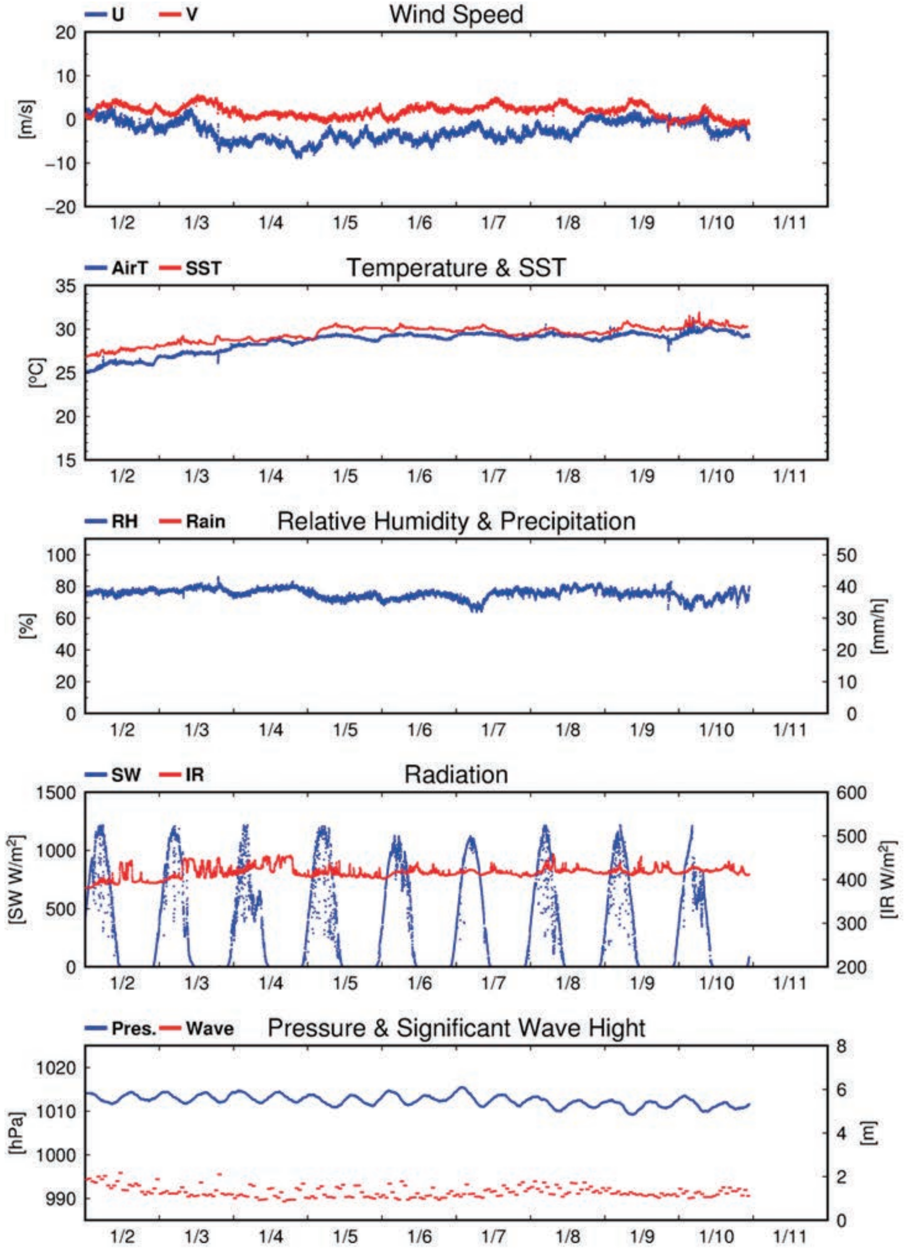

Fig. 2.3.1. Continued (Leg 1).

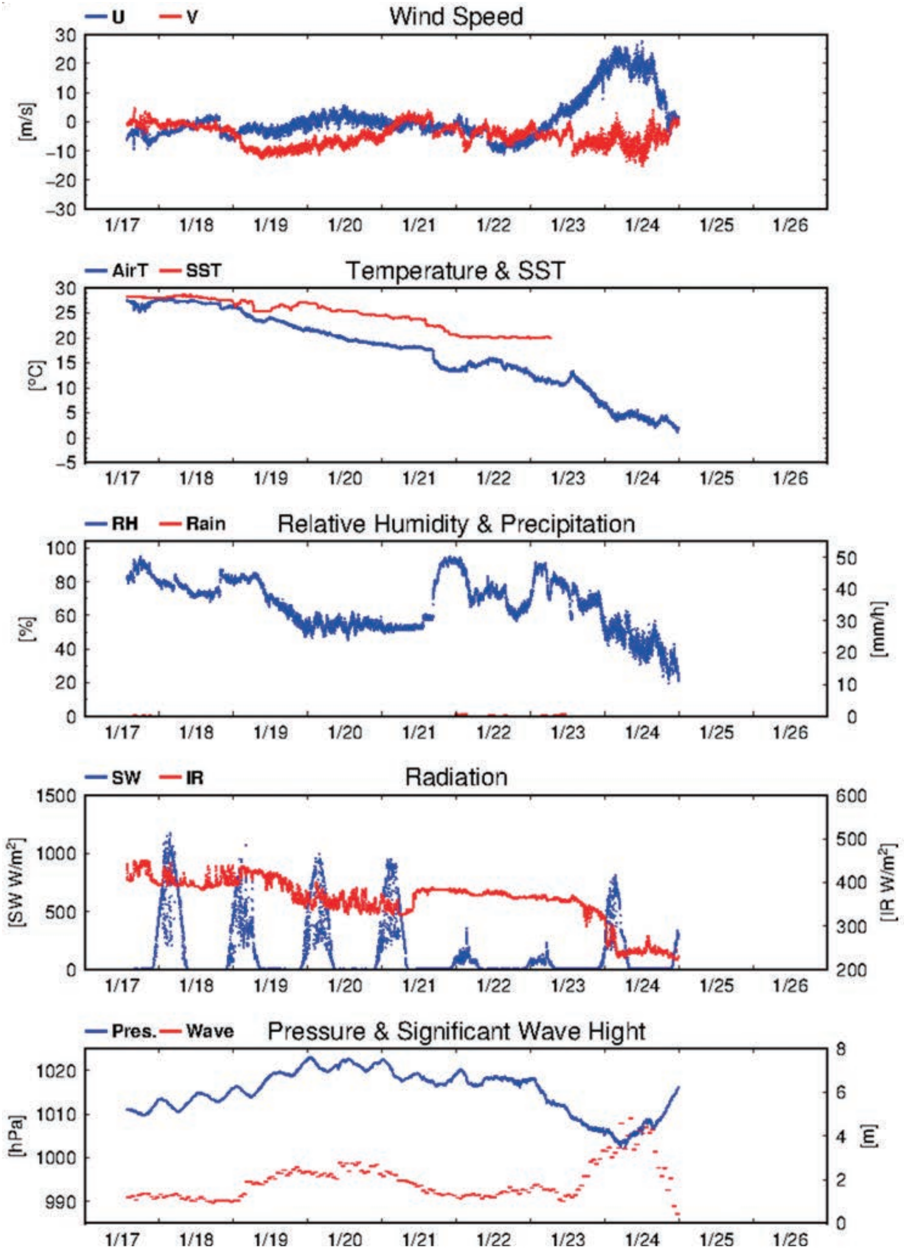

Fig. 2.3.1. Continued (Leg 2).

2.4 Thermo-Salinograph and Related Measurements

February 25, 2018

(1) Personnel

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(2) Objectives

The objective is to collect sea surface salinity, temperature, dissolved oxygen, fluorescence, turbidity, and nitrate data continuously along the cruise track.

(3) Materials and methods

The Continuous Sea Surface Water Monitoring System (Marine Works Japan Co, Ltd.) has seven sensors and automatically measures salinity, temperature, dissolved oxygen, fluorescence, and turbidity in sea surface water every 1 minute. This system is in the sea surface monitoring laboratory and bottom of the ship and connected to shipboard LAN system. Measured data along with time and location of the ship were displayed on a monitor and stored in a desktop computer. The sea surface water was continuously pumped up to the laboratory from about 5 m water depth and flowed into the system through a vinyl-chloride pipe. One thermometer is located just before the sea water pump at bottom of the ship. The flow rate of the surface seawater was controlled to be about 1.2 L/min. Periods of measurement, maintenance and problems are listed in Table 2.4.1.

A chemical-free nitrate sensor was also used with the Continuous Sea Surface Water Monitoring System. The nitrate sensor was attached using a flow cell next to the thermo-salinograph.

Software and sensors used in this system are listed below.

i. Software

Seamoni-kun Ver.1.50

ii. Sensors

Temperature and conductivity sensor
Model: SBE 45, Sea-Bird Electronics, Inc.
Serial number: 4552788-0264
Pre-cruise calibration: 30 August 2014, Sea-Bird Electronics, Inc.

Bottom of ship thermometer
Model: SBE 38, Sea-Bird Electronics, Inc.
Serial number: 3852788-0457
Pre-cruise calibration: 31 October 2014, Sea-Bird Electronics, Inc.

Dissolved oxygen sensor
Model: RINKO-II, JFE Adantech Co. Ltd.
Serial number: 0013
Pre-cruise calibration: 10 May 2015, JAMSTEC

Model: OPTODE 3835, Aanderaa Data Instruments, AS.
Serial number: 1519
Pre-cruise calibration: 13 May 2015, JAMSTEC

Fluorometer and turbidity sensor
Model: C3, Turner Designs, Inc.
Serial number: 2300384

Nitrate sensor

Model:	Deep SUNA, Satlantic, LP.
Serial number:	0385

Table 2.4.1. Events of the Continuous Sea Surface Water Monitoring System operation.

System Date [UTC]	System Time [UTC]	Event
2015/12/23	19:00	Logging for leg 1 start
2015/12/24	05:23–06:07	Flow rate for a line of RINKO and Optode would be small, though both data seem to be normal.
2015/12/29	10:11	Logging stop for C3/filter cleaning
2015/12/29	11:23	Logging restart
2016/01/05	11:27	Logging stop for C3/filter cleaning
2016/01/05	13:05	Logging restart
2016/01/05	13:05–13:25	Optode was unstable.
2016/01/11	22:00	Logging for leg 1 end
2016/01/17	13:35	Logging for leg 2 start
2016/01/23	06:23	Logging for leg 2 end

(4) Pre-cruise calibration

Pre-cruise sensor calibrations for the SBE 45 and SBE 38 were performed at Sea-Bird Electronics, Inc.

Pre-cruise sensor calibrations for the oxygen sensors were performed at JAMSTEC. The oxygen sensors were immersed in fresh water in a 1-L semi-closed glass vessel, which was immersed in a temperature-controlled water bath. Temperature of the water bath was set to 1, 10, 20 and 29°C. Temperature of the fresh water in the vessel was measured by a thermistor thermometer (expanded uncertainty of smaller than 0.01°C, ARO-PR, JFE Advantech, Co., Ltd.). At each temperature, the fresh water in the vessel was bubbled with standard gases (4, 10, 17 and 25% oxygen consisted of the oxygen-nitrogen mixture, whose relative expanded uncertainty is 0.5%) for more than 30 minutes to insure saturation. Absolute pressure of the vessel headspace was measured by a reference quartz crystal barometer (expanded uncertainty of 0.01% of reading) and ranged from about 1040 to 1070 hPa. The data were averaged over 5 minutes at each calibration point (a matrix of 24 points). As a reference, oxygen concentration of the fresh water in the calibration vessel was calculated from the oxygen concentration of the gases, temperature and absolute pressure at the water depth (about 8 cm) of the sensor's sensing foil as follows:

$$O_2\ (\mu mol/L) = \{1000 \times c(T) \times (Ap - pH_2O)\} / \{0.20946 \times 22.3916 \times (1013.25 - pH_2O)\}$$

where c(T) is the oxygen solubility, Ap is absolute pressure [in hPa], and pH_2O is the water vapor pressure [in hPa].

The RINKO was calibrated by the modified Stern-Volmer equation slightly modified from a method by Uchida et al. (2010):

$$O_2\ (\mu mol/L) = [(V_0 / V)^E - 1] / K_{sv}$$

where V is raw phase difference, V_0 is raw phase difference in the absence of oxygen, K_{sv} is Stern-Volmer constant. The coefficient E corrects nonlinearity of the Stern-Volmer equation. The V_0 and the K_{sv} are assumed to be functions of temperature as follows.

$$K_{sv} = C_0 + C_1 \times T + C_2 \times T^2$$

$$V_0 = 1 + C_3 \times T$$

$$V = C_4 + C_5 \times V_b$$

where T is CTD temperature (°C) and Vb is raw output. The oxygen concentration is calculated using accurate temperature data from the SBE 45 instead of temperature data from the RINKO. The calibration coefficients were as follows:

C_0 = 5.048509438066593e-03

C_1 = 2.212851808960770e-04

C_2 = 3.735982971782336e-06

C_3 = -7.847113805097885e-04

C_4 = 3.011495646664952e-02

C_5 = 0.1926948014214438

$$E = 1.5$$

(5) Data processing and post-cruise calibration

Data from the Continuous Sea Surface Water Monitoring System were obtained at 1-minute intervals. Data from the nitrate sensor were obtained at 2-minute intervals and linearly interpolated at 1-minute intervals.

These data were processed as follows. Spikes in the temperature and salinity data were removed using a median filter with a window of 3 scans (3 minutes) when difference between the original data and the median filtered data was larger than 0.1°C for temperature and 0.5 for salinity. Data gaps were linearly interpolated when the gap was ≤ 13 minutes. Fluoromete and turbidity data were low-pass filtered using a median filter with a window of 3 scans (3 minutes) to remove spikes. Raw data from the RINKO oxygen sensor, fluorometer, turbidity and nitrate data were low-pass filtered using a Hamming filter with a window of 15 scans (15 minutes).

A slope correction was applied to the nitrate sensor before post-cruise calibration. RMNS (Reference Material for Nutrients in Seawater, Kanso Technos Co., Ltd., Osaka, Japan) lot BU and CA were measured by the nitrate sensor during the cruise (Fig. 2.4.1 and Table 2.4.2) and a slope (a1) for the correction was estimated to be 0.897966 on average from the following equation:

$$\mathrm{NRA}\ [\mu\mathrm{mol/kg}] = a_0 + a_1\ \mathrm{NRA}_{org}$$

where NRA is corrected nitrate concentration, NRA_{org} is raw data, and a_0 is the offset at the time of RMNS measurement.

Salinity (S [PSU]), dissolved oxygen (O [μmol/kg]), fluorescence (Fl [RFU]), and nitrate (NRA [μmol/kg]) data were corrected using the water sampled data. Details of the measurement methods are described in Sections 3.2, 3.4, 3.5, and 3.10 for salinity, dissolved oxygen, nitrate and chlorophyll-a, respectively. Corrected salinity (S_{cor}), dissolved oxygen (O_{cor}), estimated chlorophyll *a* (Chl-a), and nitrate (NRA_{cor}) were calculated from following equations

$$S_{cor}\ [\mathrm{PSU}] = c_0 + c_1\ S + c_2\ t$$

$$O_{cor}\ [\mu\mathrm{mol/kg}] = c_0 + c_1\ O + c_2\ T + c_3\ t$$

$$\mathrm{Chl\text{-}a}\ [\mu\mathrm{g/L}] = c_0 + c_1\ \mathrm{Fl}$$

$$\mathrm{NRA}_{cor}\ [\mu\mathrm{mol/kg}] = a_1\ \mathrm{NRA}_{org} + c_0 + c_1\ t$$

where S is practical salinity, t is days from a reference time (2015/12/23 19:00 [UTC]), T is temperature in °C. The best fit sets of calibration coefficients (c_0~c_3) were determined by a least square technique to minimize the deviation from the water sampled data. The calibration coefficients were listed in Table 2.4.2. Comparisons between the Continuous Sea Surface Water Monitoring System data and water sampled data are shown in Figs. 2.4.2, 2.4.3, and 2.4.4.

For fluorometer data, water sampled data obtained at night [PAR (Photosynthetically Available Radiation) < 50 μE/(m^2 sec)] were basically used for the calibration, since sensitivity of the fluorometer to chlorophyll *a* is different at nighttime and daytime (Section 2.4 in Uchida et al., 2015). Sensitivity of the fluorometer to chlorophyll *a* may also have regional differences. Therefore, the calibration coefficients are changed between legs 1 and 2.

Post-cruise calibration of the nitrate sensor was not carried out, because nitrate concentration in the surface water was too low (range between 0 and 0.16 μmol/kg) to measure by the nitrate sensor.

(6) References

Uchida, H., G. C. Johnson, and K. E. McTaggart (2010): CTD oxygen sensor calibration procedures, The GO-SHIP Repeat Hydrography Manual: A collection of expert reports and guidelines, IOCCP Rep., No. 14, ICPO Pub. Ser. No. 134.

Uchida, H., K. Katsumata, and T. Doi (2015): WHP P14S, S04I Revisit Data Book, JASTEC, Yokosuka, 187 pp.

Table 2.4.2. Nitrate concentration measured by the nitrate sensor for RMNS lot BU (3.888±0.063 [k=2] μmol/kg) and lot CA (19.66±0.15 [k = 2] μmol/kg). Offset (a_0) of the correction equation (see text for detail) at the time of measurement was also shown.

Date	RMNS lot BU	RMNS lot CA	a_0
2016/01/05 11:40-11:47	−17.71±0.58	−0.20±0.88	19.815
2016/01/05 12:02-12:09	8.70±0.16	26.46±0.17	−4.012
2016/01/10 00:06-00:11	−11.08±0.38	6.11±0.29	14.005
2016/01/17 05:51-05:58	9.65±0.18	27.84±0.20	−5.058
2016/01/23 06:54-07:01	−17.82±0.64	−0.61±0.45	20.049

Table 2.4.3. Calibration coefficients for the salinity, dissolved oxygen, and chlorophyll *a*.

c_0	c_1	c_2	c_3
Salinity			
9.031385e−02	0.9976929	1.379279e−04	
Dissolved oxygen			
9.359068	0.9362957	0.0	-8.934918e−03
Chlorophyll a			
−4.661027e−02	0.2694699	(for leg 1)	
1.281517e−02	0.1385194	(for leg 2)	

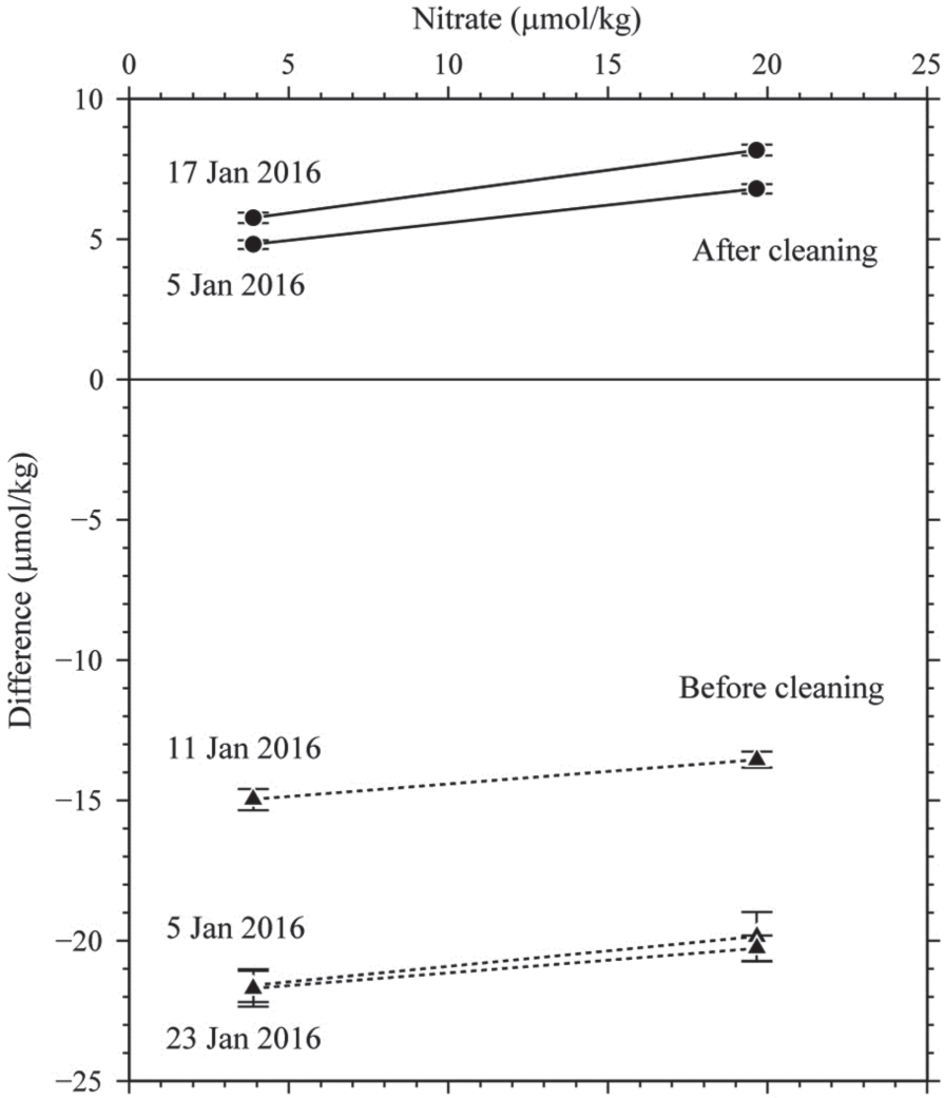

Figure 2.4.1. Results of RMNS measurements by the nitrate sensor. Differences between measured value and certified value are shown. Error bar shows the standard deviation of the measurements.

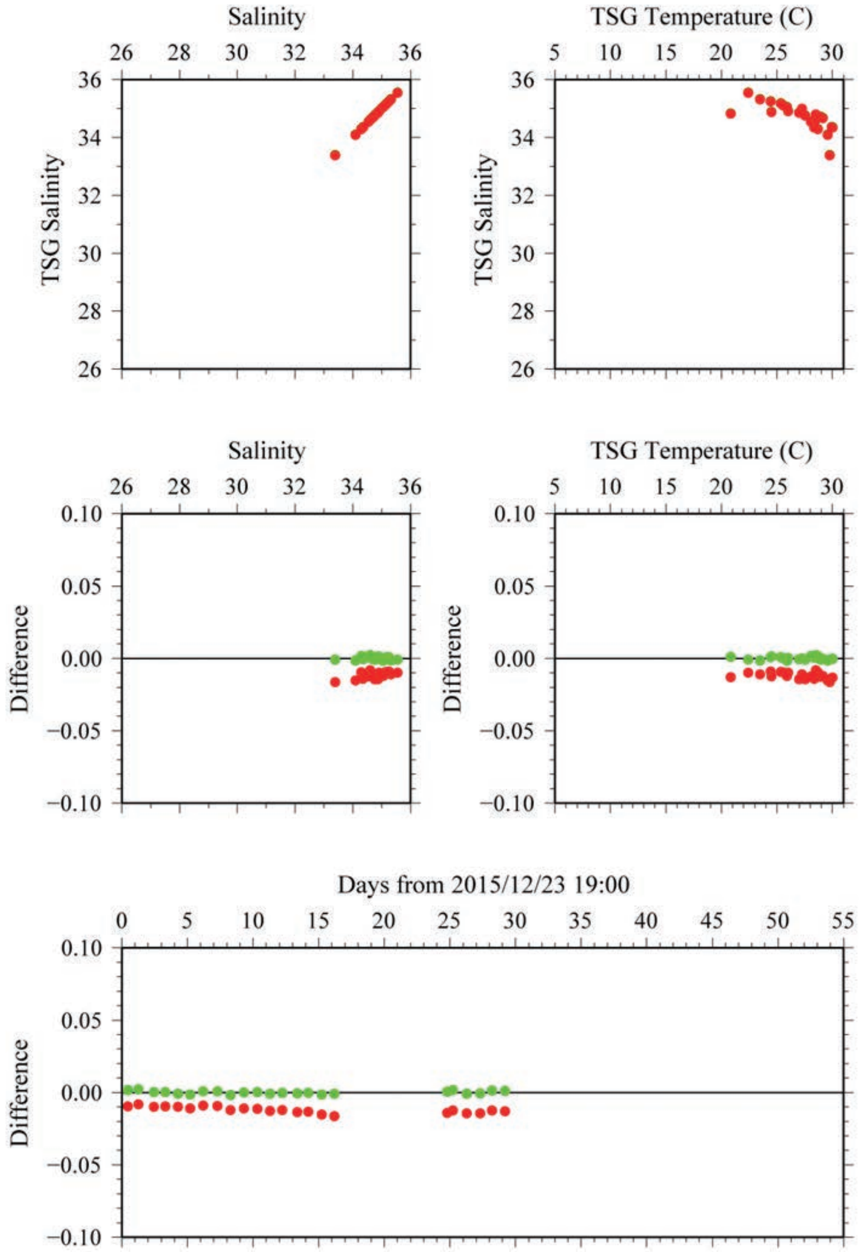

Figure 2.4.2. Comparison between TSG salinity (red: before correction, green: after correction) and sampled salinity.

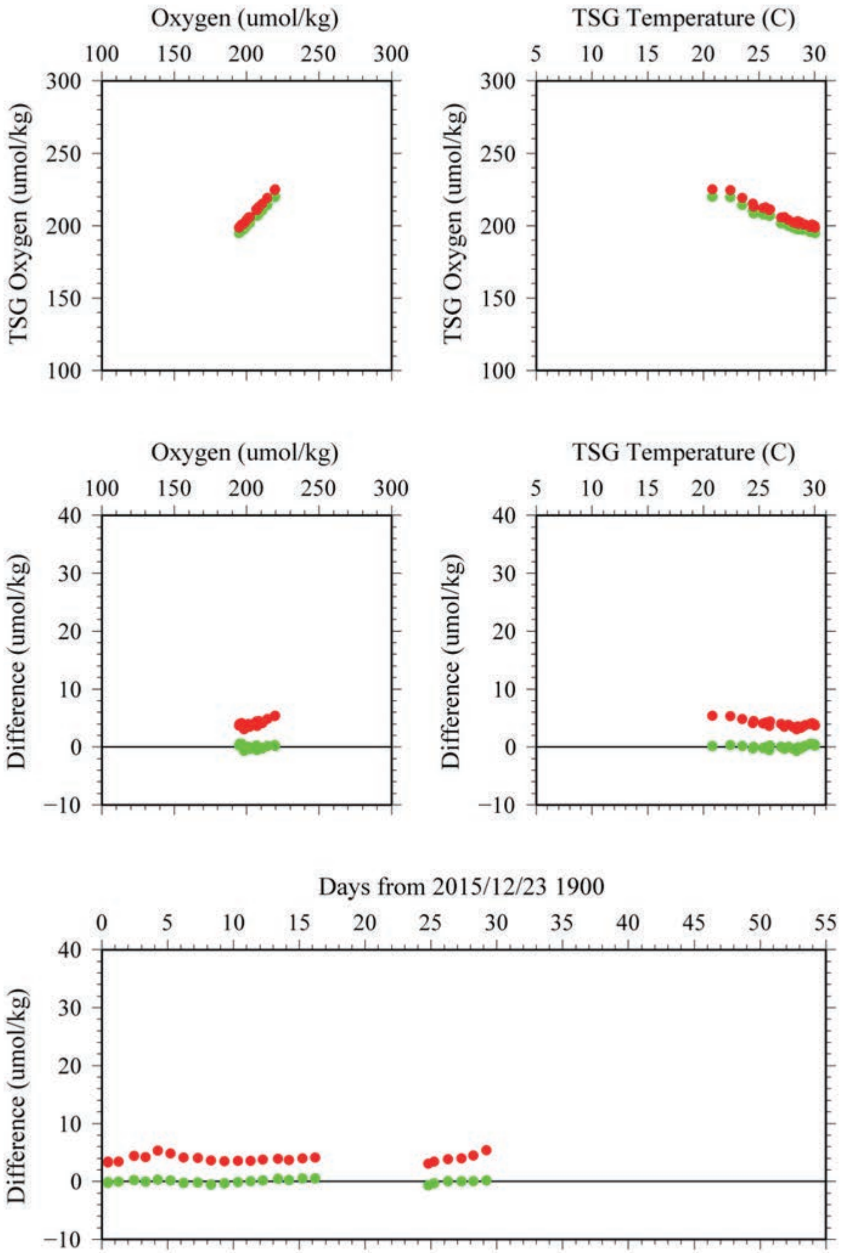

Figure 2.4.3. Comparison between TSG oxygen (red: before correction, green: after correction) and sampled oxygen.

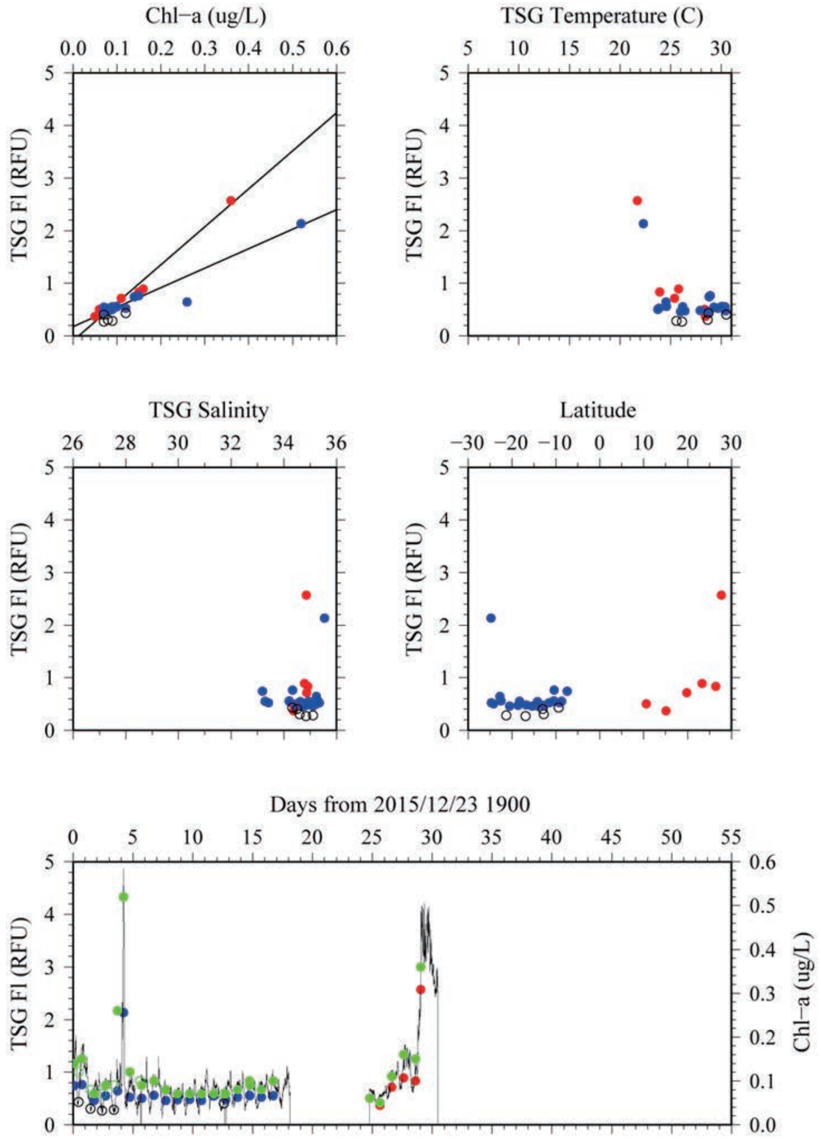

Figure 2.4.4. Comparison between TSG fluorescence and sampled chlorophyll *a*. Open circles indicate the daytime data. Blue dots indicate data obtained during leg 1 and red dots indicate data obtained during leg 2. For bottom panel, blue or red dots indicate fluorescence and green dots indicate water sampled chlorophyll *a*. Line indicates chlorophyll *a* estimated from fluorometer.

2.5 Underway pCO_2

13 November 2017

(1) Personnel

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(2) Introduction

Concentrations of CO_2 in the atmosphere are now increasing at a rate of about 2.0 ppmv yr^{-1} owing to human activities such as burning of fossil fuels, deforestation, and cement production. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO_2, and to clarify the mechanism of the CO_2 absorption, because the magnitude of the anticipated global warming depends on the levels of CO_2 in the atmosphere, and because the ocean currently absorbs 1/3 of the 6 Gt of carbon emitted into the atmosphere each year by human activities.

In this cruise, we were aimed at quantifying how much anthropogenic CO_2 absorbed in the surface ocean in the eastern part of the Indian Ocean and in the western North Pacific. For the purpose, we measured pCO_2 (partial pressure of CO_2) in the atmosphere and surface seawater along the cruise track including WHP I10 line.

(3) Apparatus and shipboard measurement

Continuous underway measurements of atmospheric and surface seawater pCO_2 were made with the CO_2 measuring system (Nippon ANS, Inc.) installed in the R/V *Mirai* of JAMSTEC. The system comprises of a non-dispersive infrared gas analyzer (Li-COR LI-7000, modified by Nippon ANS, Inc.), an air-circulation module and a showerhead-type equilibrator. To measure concentrations (mole fraction) of CO_2 in dry air (xCO_2a), air sampled from the bow of the ship (approx. 13 m above the sea level) was introduced into the NDIR through a dehydrating route with an electric dehumidifier (kept at ~2 °C), a Perma Pure dryer (GL Sciences Inc.), and a chemical desiccant ($Mg(ClO_4)_2$). The flow rate of the air was 500 ml min^{-1}. To measure surface seawater concentrations of CO_2 in dry air (xCO_2s), the air equilibrated with seawater within the equilibrator was introduced into the NDIR through the same flow route as the dehydrated air used in measuring xCO_2a. The flow rate of the equilibrated air was 400 – 900 ml min^{-1}. The seawater was taken by a pump from the intake placed at the approx. 4.5 m below the sea surface. The flow rate of seawater in the equilibrator was 4000 – 5000 ml min^{-1}.

The CO_2 measuring system was set to repeat the measurement cycle such as 4 kinds of CO_2 standard gases (Table 2.5.1), xCO_2a (twice), xCO_2s (7 times). This measuring system was run automatically throughout the cruise by a PC control.

(4) Quality control

Concentrations of CO_2 of the standard gases are listed in Table 2.5.1, which were calibrated before cruise by the JAMSTEC primary standard gases. The CO_2 concentrations of the primary standard gases were calibrated by the Scripps Institution of Oceanography, La Jolla, CA, USA.

In actual shipboard observations, the signals of NDIR usually reveal a trend. The trends were adjusted linearly using the signals of the standard gases analyzed before and after the sample measurements.

Effects of water temperature increased between the inlet of surface seawater and the equilibrator on xCO_2s were adjusted based on Takahashi *et al.* (1993), although the temperature increases were generally slight, being < 0.1 °C.

We checked values of xCO_2a and xCO_2s by examining signals of the NDIR by plotting the xCO_2a and xCO_2s as a function of sequential day, longitude, sea surface temperature and sea surface salinity.

Table 2.5.1. Concentrations of CO_2 standard gases used during the Indian Ocean cruise.

Cylinder no.	Concentrations (ppmv)
CQC00740	269.08
CQC00739	330.17
CQB09461	359.32
CQC00741	419.30

(5) Reference

Takahashi, T., J. Olafsson, J. G. Goddard, D. W. Chipman, and S. C. Southerland (1993) Seasonal variation of CO_2 and nutrients in the high-latitude surface oceans: a comparative study, *Global Biogeochem. Cycles,* 7, 843–878.

3 Hydrographic Measurements

3.1 CTDO$_2$ Measurements

January 22, 2018

(1) Personnel

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Keisuke Takeda (MWJ)
Michinari Sunamura (The University of Tokyo) (CDOM measurement)

(2) Winch arrangements

The CTD package was deployed by using 4.5 Ton Traction Winch System (Dynacon, Inc., Bryan, Texas, USA), which was renewed on the R/V Mirai in April 2014 (e.g. Fukasawa et al., 2004). Primary system components include a complete CTD Traction Winch System with up to 9000 m of 9.53 mm armored cable (Rochester Wire & Cable, LLC, Culpeper, Virginia, USA).

To minimize attitude motion of the CTD package (rotation, pitching and rolling) and twist of the armored cable, a slip ring swivel was introduced between the armored cable and the CTD package.

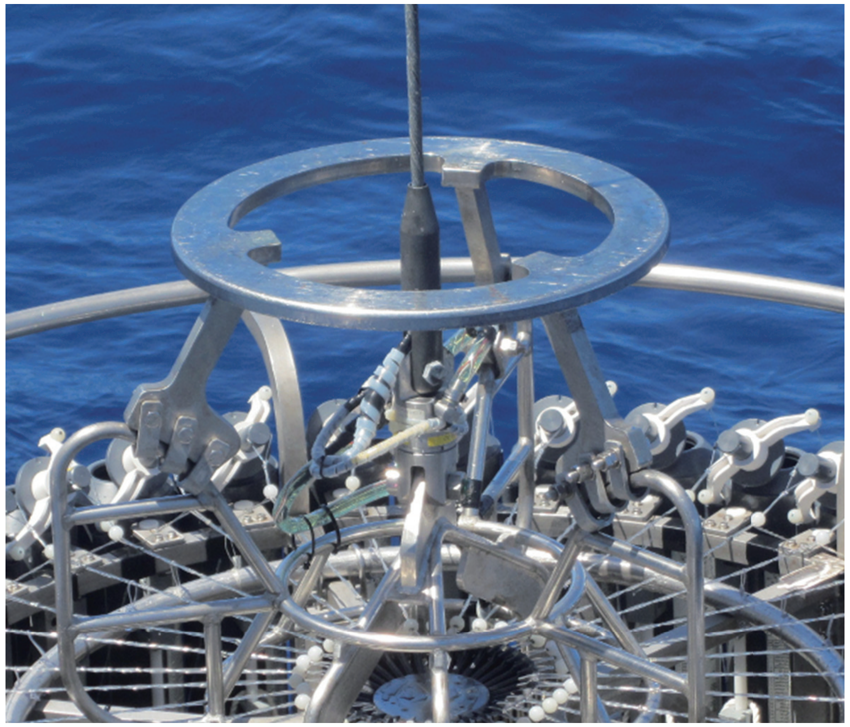

Fig. 3.1.1 A photo of the slip ring swivel attached between the armored cable and the CTD.

(3) Overview of the equipment

The CTD system was SBE 911plus system (Sea-Bird Electronics, Inc., Bellevue, Washington, USA). The SBE 911plus system controls 36-position SBE 32 Carousel Water Sampler. The Carousel accepts 12-litre Niskin-X water sample bottles (General Oceanics, Inc., Miami, Florida, USA). The SBE 9plus was mounted horizontally in a 36-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, a Deep Ocean Standards Thermometer (SBE 35), an altimeter (PSA-916T; Teledyne Benthos, Inc., North Falmous, 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), a Photosynthetically Active Radiation (PAR) sensor (Satlantic, LP, Halifax, Nova Scotia, Canada), and a colored dissolved organic matter (ECO FL CDOM, WET Labs, Inc., Philomath, Oregon, USA) were also used with the SBE 9plus underwater unit. To minimize rotation of the CTD package, a heavy stainless frame (total weight of the CTD package without sea water in the bottles is about 600 kg) was used with an aluminum plate (54 × 90 cm).

Summary of the system used in this cruise

36-position Carousel system

- Deck unit:
  - SBE 11plus, S/N 11P54451-0872
- Under water unit:
  - SBE 9plus, S/N 09P38273_74766 (pressure sensor S/N: 0786)
- Temperature sensor:
  - SBE 3plus, S/N 03P4815 (primary)
  - SBE 3, S/N 031525 (secondary)
- Conductivity sensor:
  - SBE 4, S/N 042435 (primary)
  - SBE 4, S/N 042854 (secondary)
- Oxygen sensor:
  - SBE 43, S/N 430330
  - JFE Advantech RINKO-III, S/N 0024 (foil batch no. 144002A)
- Pump:
  - SBE 5T, S/N 054595 (primary)
  - SBE 5T, S/N 054598 (secondary)
- Altimeter:
  - PSA-916T, S/N 1157
- Deep Ocean Standards Thermometer:
  - SBE 35, S/N 0022
- Fluorometer:
  - Seapoint Sensors, Inc., S/N 3497 (measurement range: 0-10 μg/L)
- Transmissometer:
  - C-Star, S/N CST-1363DR
- PAR:
  - Satlantic LP, S/N 0049
- CDOM:
  - ECO FL CDOM, S/N FLCDRTD-2014 (measurement range: 0-500 ppb)
- Carousel Water Sampler:
  - SBE 32, S/N 0924
- Water sample bottle:
  - 12-litre Niskin-X model 1010X (no 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. The time drift of the pressure sensor is adjusted by periodic recertification corrections against a dead-weight piston gauge (Model 480DA, S/N 23906; Piston unit, S/N 079K; Weight set, S/N 3070; Bundenberg Gauge Co. Ltd., Irlam, Manchester, UK). The corrections are performed at JAMSTEC, Yokosuka, Kanagawa, Japan by Marine Works Japan Ltd. (MWJ), Yokohama, Kanagawa, Japan, usually once in a year in order to monitor sensor time drift and linearity.

S/N 0786, 13 July 2015

slope = 0.99980434

offset = –0.13013

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 03P4815, 16 April 2015

S/N 031525, 28 July 2015

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

S/N 03P4815, –3.4597e–7 [°C/dbar]

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 042435, 1 May 2015

S/N 042854, 1 May 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 430330, 10 May 2015

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 0022, 4 March 2009

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. Since 2014, fixed-point cells traceable to NIST temperature standards is directly used in the manufacturer's calibration of the SBE 35 (Uchida et al., 2015).

S/N 0022, 4 February 2015 (slope and offset correction)

Slope = 1.000007

Offset = 0.000246

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.

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 = 0.0055 (for S/N 0024)

H2 = 5000 dbar

H3 = 2000 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):

$$O_2\ (\mu mol/l) = [(V_0 / V)^E - 1] / K_{sv}$$

where V is voltage, V0 is voltage in the absence of oxygen, K_{sv} is Stern-Volmer constant. The coefficient E corrects nonlinearity of the Stern-Volmer equation. The V_0 and the Ksv are assumed to be functions of temperature as follows.

$$K_{sv} = C_0 + C_1 \times T + C_2 \times T_2$$

$$V_0 = 1 + C_3 \times T$$

$$V = C_4 + C_5 \times V_b$$

where T is CTD temperature (°C) and V_b is raw output (volts). V_0 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 O_{2c} can be calculated as follows.

$$O_{2c} = O_2\ (1 + C_p p / 1000)$$

where p is CTD pressure (dbar) and C_p 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).

Pre-cruise sensor calibrations were performed at RCGC/JAMSTEC.

S/N 0024, 10 May 2015

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.

ix. Transmissometer

The C-Star Transmissometer (WET Labs, Inc., Philomath, Oregon, USA) measures light transmittance at a single wavelength (650 nm) over a know 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 T_r (in %) and beam attenuation coefficient cp are calculated from the sensor output (V in volt) as follows.

$$T_r = (c_0 + c_1 V) \times 100$$

$$c_p = -(1 / 0.25) \ln(T_r / 100)$$

The calibration coefficients were determined by using the data obtained in the R/V Mirai MR15-03 cruise.

x. PAR

Photosynthetically Active Radiation (PAR) sensors (Satlantic, LP, Halifax, Nova Scotia, Canada) 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. Satlantic 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 0049, 22 January 2009

xi. CDOM

The Environmental Characterization Optics (ECO) miniature fluorometer (WET Labs, Inc., Philomath, Oregon, USA) allows the user to measure relative Colored Dissolved Organic Matter (CDOM) concentrations by directly measuring the amount of fluorescence emission in a sample volume of water. The CDOM fluorometer uses an UV LED to provide the excitation source. An interference filter is used to reject the small amount of out-of-band light emitted by the LED. The light from the source enters the water volume at an angle of approximately 55-60 degrees with respect to the end face of the unit. Fluoresced light is received by a detector positioned where the acceptance angle forms a 140-degree intersection with the source beam. An interference filter is used to discriminate against the scattered excitation light.

CDOM (Quinine Dihydrate Equivalent) concentration expressed in ppb can be derived using the equation as follows.

CDOM = Scale Factor * (Output – Dark Counts)

Pre-cruise sensor calibration was performed at WET Labs.

S/N FLCDRTD-2014, 1 September 2015

Dark Counts: 0.025 V

Scale Factor: 106 ppb/V

(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 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 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 200 m (or 300 m when significant wave height was high) then the package was stopped to operate the heave compensator of the crane. The package was lowered again at a rate of 1.2 m/s to the bottom. For the up cast, the package was lifted at a rate of 1.1 m/s except for bottle firing stops. As a rule, the bottle was fired after waiting from the stop for 30 seconds and the package was stayed at least 5 seconds for measurement of the SBE 35 at each bottle firing stops. For depths where vertical gradient of water properties were expected to be large (from surface to thermocline), the bottle was exceptionally fired after waiting from the stop for 60 seconds to enhance exchanging the water between inside and outside of the bottle. At 200 m (or 300 m) from the surface, the package was stopped to stop the heave compensator of the crane.

Water samples were collected using a 36-bottle SBE 32 Carousel Water Sampler with 12-litre Niskin-X bottles. Before a cast taken water for CFCs, the bottle frame and Niskin-X bottles were wiped with acetone. At station 001_1, 012_1, 022_1, 022_2, 030_1 and 037_1, specially washed Niskin-X bottles were used for #2 and #3, since samples for incubation were collected from the 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.

Miss trip	Miss fire	Leak
none	none	007_1 #14 stopcock: O-ring of the stopcock replaced
		025_1 #30 stopcock: O-ring of the end closure replaced
		033_3 #27 end closure: O-ring of the end closure replaced

(b) Failure of the slip ring swivel

The slip ring swivel failed by sea water immersion from the nipple joints at beginning of station 011_1. Therefore, the slip ring swivel was detached from the CTD cast.

(c) Cable replacement

Cables for sensors were replaced after the following stations.

900_1: noise of the secondary temperature
010_2: noise of fluorometer
035_1: noise of transmissometer at station 034_1 and 035_1

(d) Noise in down cast data

Secondary conductivity data were noisy at station 043_1 from 698 dbar of down cast due to a jellyfish. Transmissometer data were noisy at station 016_1 (from 1484 to 2556 dbar), 034_1 (from 539 to 544 dbar), and the data were removed and linearly interpolated. CDOM data were flagged as 4 (bad measurement) for depths deeper than about 4500 m due to noise and large shift of the data

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.

TCORP (original module, version 1.1) corrected the pressure sensitivity of the SBE 3 for both profile and bottle information data.

RINKOCOR (original module, version 1.0) corrected the time-dependent, pressure-induced effect (hysteresis) of the RINKO for both profile data.

RINKOCORROS (original module, version 1.0) corrected the time-dependent, pressure-induced effect (hysteresis) of the RINKO for bottle information data by using the hysteresis-corrected profile data.

BOTTLESUM created a summary of the bottle data. The data were averaged over 4.4 seconds.

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, transmissometer, and CDOM data. A median value was determined by 49 scans of the window. For CDOM data, an additional box-car filter with a window of 361 scans was applied to remove noise.

SECTIONU (original module, version 1.1) 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).

DESPIKE (original module, version 1.0) removed spikes of the data. A median and mean absolute deviation was calculated in 1-dbar pressure bins for both down- and up-cast, excluding the flagged values. Values greater than 4 mean absolute deviations from the median were marked bad for each bin. This process was performed 2 times for temperature, conductivity, SBE 43, and RINKO output.

DERIVE was used to compute oxygen (SBE 43).

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.

BOTTOMCUT (original module, version 0.1) deleted the deepest pressure bin when the averaged scan number of the deepest bin was smaller than the average scan number of the bin just above.

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

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.

(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 (20 m high from the base line) and sub-sampled one-minute interval as a meteorological data.

The pre- and the post-casts deck pressure data showed temperature dependency for the pressure sensor (Fig. 3.1.2). To correct the temperature dependency, the manufacturer's calibration coefficients were slightly modified on board as follows:

T1 = 29.88499
T2 = $-2.565740e^{-4}$
T3 = $4.799030e^{-6}$
Offset = 0.0

Time series of the CTD deck pressure is shown in Fig. 3.1.3. 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 (–0.01 dbar) from the pre-cruise calibration. The post-cruise correction of the pressure data is not deemed necessary for the pressure sensor.

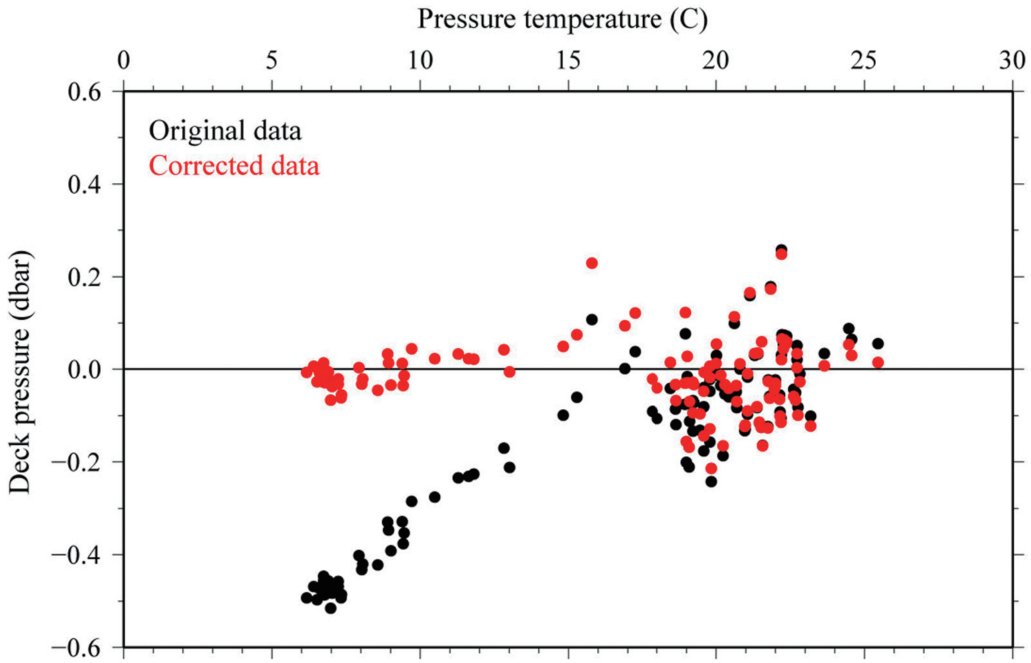

Fig. 3.1.2 Pre- and post-casts CTD deck pressure. Atmospheric pressure deviation from a standard atmospheric pressure was subtracted from the CTD deck pressure. Black dots show the original data and red dots show the data corrected for the temperature dependency of the sensor.

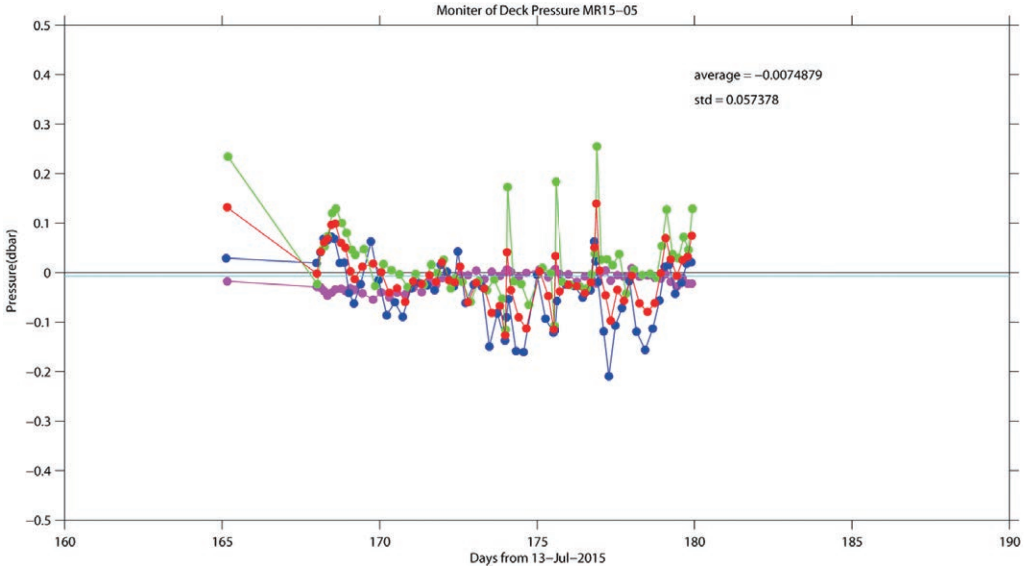

Fig. 3.1.3 Time series of the CTD deck pressure. Atmospheric pressure deviation (magenta dots) from a standard atmospheric pressure was subtracted from the CTD deck pressure. Blue and green dots indicate pre- and post-cast deck pressures, respectively. Red dots indicate averages of the pre- and the post-cast 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 2016

The CTD temperature was preliminary calibrated as

$$\text{Calibrated temperature} = T - (c_0 \times P + c_1 \times t + c_2)$$

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 c_0, c_1, and c_2 are calibration coefficients. The coefficients were determined using the data for the depths deeper than 1950 dbar. The coefficient c1 was set to zero for this cruise.

The primary temperature data were basically used for the post-cruise calibration. The secondary temperature sensor was also calibrated and used instead of the primary temperature data when the data quality of the primary temperature data was bad. The calibration coefficients are listed in Table 3.1.1. The results of the post-cruise calibration for the CTD temperature are summarized in Table 3.1.2 and shown in Fig. 3.1.4.

Table 3.1.1 Calibration coefficients for the CTD temperature sensors.

Serial number	c_0 (°C/dbar)	c_1 (°C/day)	c_2 (°C)
3P4815	−4.79962e−8	0.0	−0.0007

Table 3.1.2 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 1950 dbar. Number of data used is also shown.

Serial number	Pressure ≥ 1950 dbar			Pressure < 1950 dbar		
	Number	Mean (mK)	Sdev (mK)	Number	Mean (mK)	Sdev (mK)
3P4815	467	0.0	0.2	854	−0.0	6.8

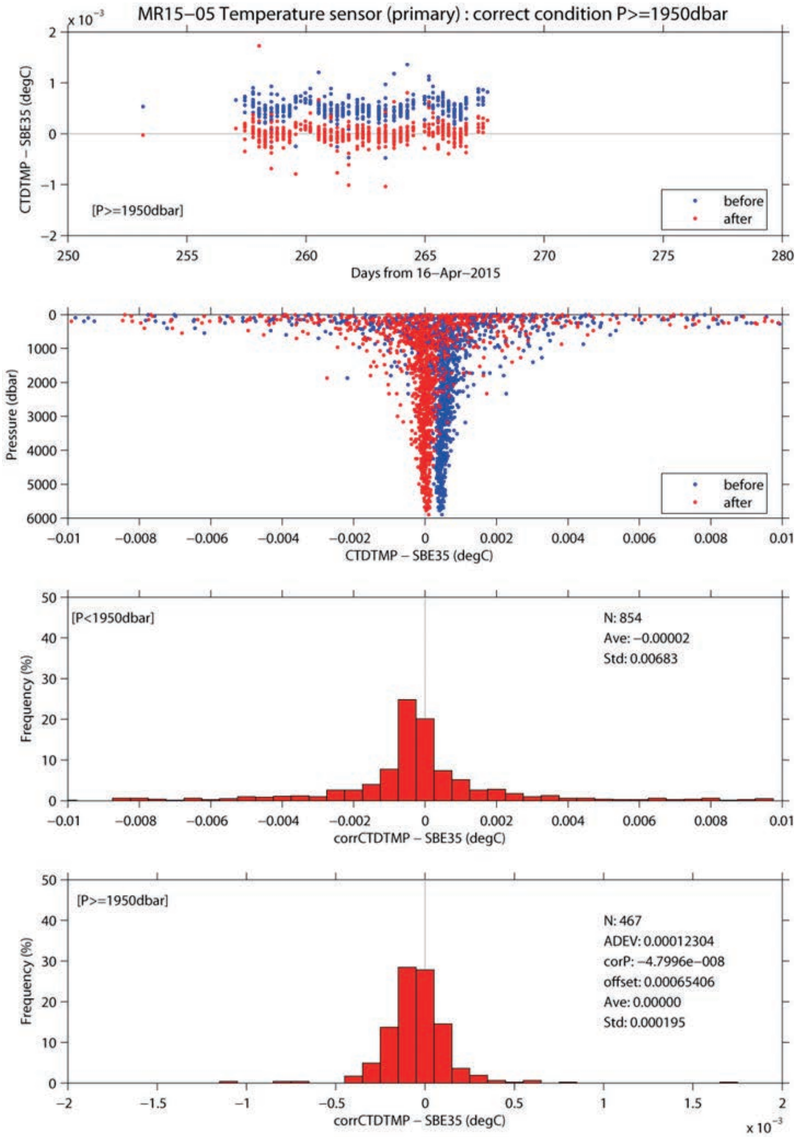

Fig. 3.1.4 Difference between the CTD temperature (primary) and the SBE 35. Blue and red dots indicate before and after the post-cruise calibration using the SBE 35 data, respectively. Lower two panels show histogram of the difference after the calibration.

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 and pressure. The CTD conductivity was calibrated as

$$\text{Calibrated conductivity} = c_0 \times C + c_1 \times P + c_2 \times C \times P + c_3 \times C^2 + c_4$$

where C is CTD conductivity in S/m, P is pressure in dbar, 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 c4 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_3 [1/(S/m)]	c_4 (S/m)
042435	7.56118e−4	5.06987e−7	−1.51008e−7	−1.05904e−4	−1.36503e−3

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 1950 dbar. Number of data used is also shown.

Serial number	Pressure ≥ 1950 dbar			Pressure < 1950 dbar		
	Number	Mean	Sdev	Number	Mean	Sdev
042435	493	–0.0	0.4	861	0.2	4.5

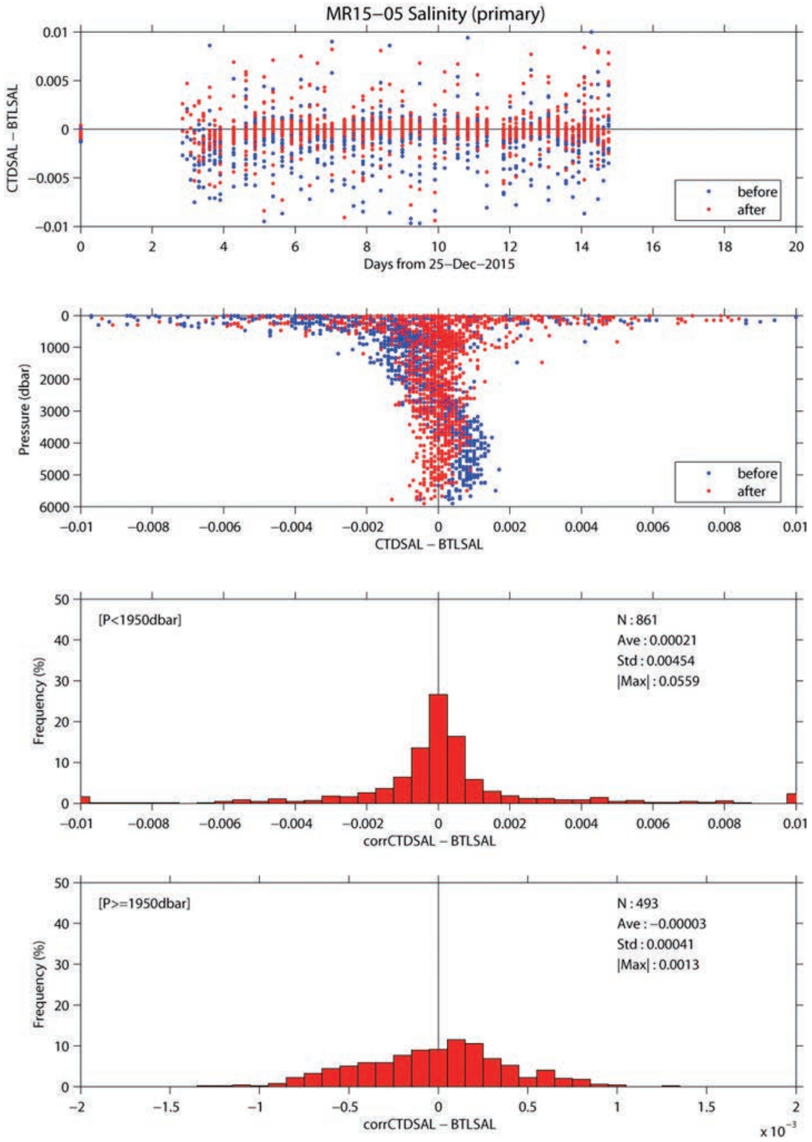

Fig. 3.1.5 Difference between the CTD salinity (primary) and the bottle salinity. Blue and red dots indicate before and after the post-cruise calibration, respectively. Lower two panels show histogram of the difference after the calibration.

iv. Oxygen

The RINKO oxygen optode (S/N 0024) was calibrated and used as the CTD oxygen data, since the RINKO has a fast time response. The pressure-hysteresis corrected RINKO data was calibrated by the modified Stern-Volmer equation, basically according to a method by Uchida et al. (2010) with slight modification:

$$[O_2]\ (\mu mol/l) = [(V_0 / V)^{1.5} - 1] / K_{sv}$$

and

$$K_{sv} = C_0 + C_1 \times T + C_2 \times T^2$$

$$V_0 = 1 + C_3 \times T$$

$$V = C_4 + C_5 \times V_b + C_6 \times t + C_7 \times t \times V_b$$

where Vb is the RINKO output (voltage), V_0 is voltage in the absence of oxygen, T is temperature in °C, and t is exciting time (days) integrated from the first CTD cast. Time drift of the RINKO output was corrected. The calibration coefficients were determined by minimizing the sum of absolute deviation with a weight from the bottle oxygen data. The revised quasi-Newton method (DMINF1) was used to determine the sets.

The post-cruise calibrated temperature and salinity data were used for the calibration. The calibration coefficients are listed in Table 3.1.5. The results of the post-cruise calibration for the RINKO oxygen are summarized in Table 3.1.6 and shown in Fig. 3.1.6.

Table 3.1.5 Calibration coefficients for the RINKO oxygen sensors.

Coefficient	S/N 0024
c_0	5.56160e–3
c_1	2.16834e–4
c_2	2.72251e–6
c_3	–1.03972e–3
c_4	–2.07308e–2
c_5	0.326691
c_6	1.52604e–4
c_7	1.29920e–5
c_p	0.015

Table 3.1.6 Difference between the RINKO oxygen and the bottle ooxygen after the post-cruise calibration. Mean and standard deviation (Sdev) are calculated for the data below and above 1950 dbar. Number of data used is also shown.

Serial number	Pressure ≥ 1950 dbar			Pressure < 1950 dbar		
	Number	Mean	Sdev	Number	Mean	Sdev
		[μmol/kg]			[μmol/kg]	
0024	502	0.11	0.39	859	0.02	0.57

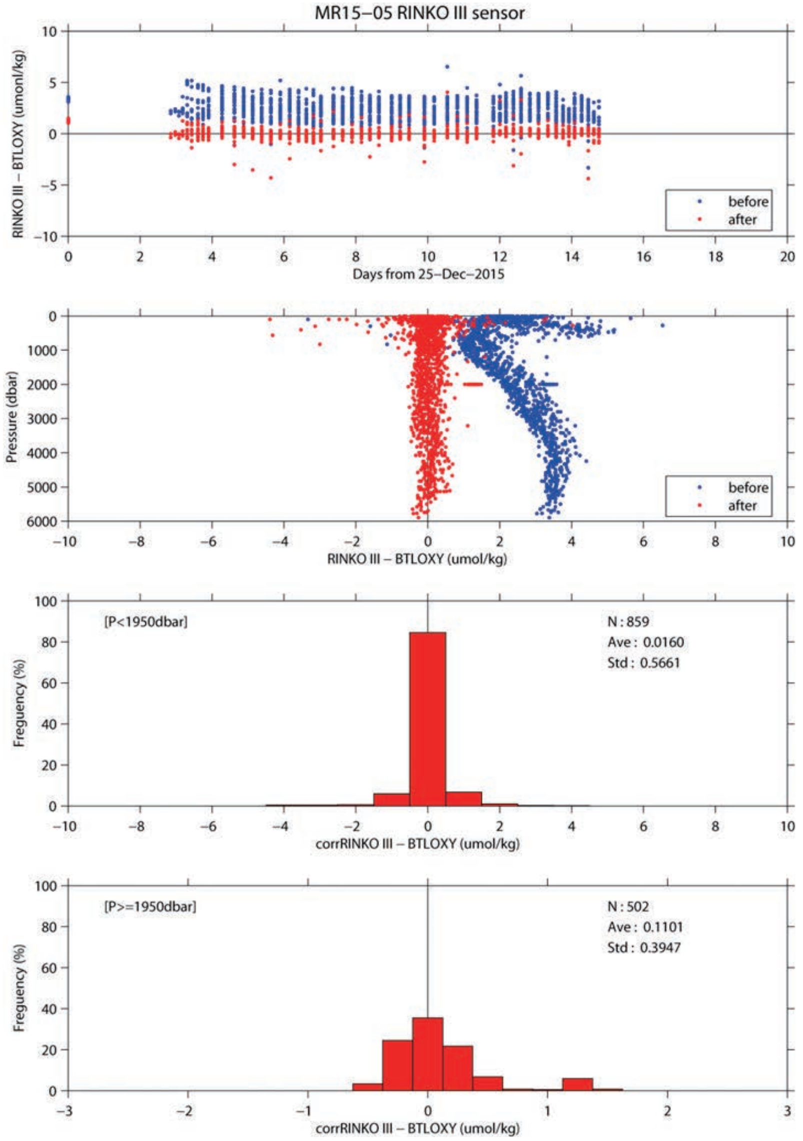

Fig. 3.1.6 Difference between the CTD oxygen and the bottle oxygen. Blue and red dots indicate before and after the post-cruise calibration, respectively. Lower two panels show histogram of the difference after the calibration.

v. Fluorometer

The CTD fluorometer (FLUOR in μg/L) was calibrated by comparing with the bottle sampled chlorophyll-a as

$$\text{FLUORc} = c_0 + c_1 \times \text{FLUOR}$$

where c_0 and c_1 are calibration coefficients. The CTD fluorometer data is slightly noisy so that the up cast profile data which was averaged over one decibar agree with the bottle sampled data better than the discrete CTD fluorometer data obtained at bottle-firing stop. Therefore, the CTD fluorometer data at water sampling depths extracted from the up cast profile data were compared with the bottle sampled chlorophyll-a data. The bottle sampled data obtained at dark condition [PAR (Photosynthetically Available Radiation) < 50 μE/(m^2 sec)] were used for the calibration, since sensitivity of the fluorometer to chlorophyll *a* is different at nighttime and daytime (Section 2.4 in Uchida et al., 2015) (Fig. 3.1.7). The calibration coefficients are listed in Table 3.1.7. The results of the post-cruise calibration for the fluorometer are summarized in Table 3.1.8 and shown in Fig. 3.1.8.

Table 3.1.7. Calibration coefficients for the CTD fluorometer.

c_0	c_1	Note
–2.35932e–3	0.689112	

Table 3.1.8. Difference between the CTD fluorometer and the bottle chlorophyll-a after the post-cruise calibration. Mean, standard deviation (Sdev), and number of data used are shown. Data obtained at daytime are also used in this calculation.

Number	Mean	Sdev
156	–0.00 µg/L	0.07 µg/L

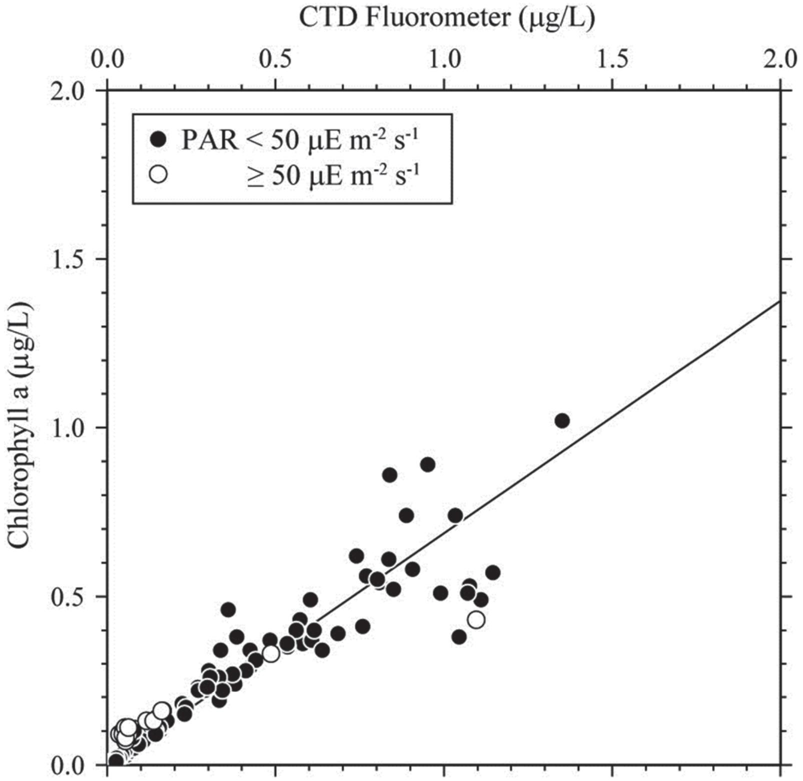

Fig. 3.1.7. Comparison of the CTD fluorometer and the bottle sampled chlorophyll-a. The regression lines are also shown.

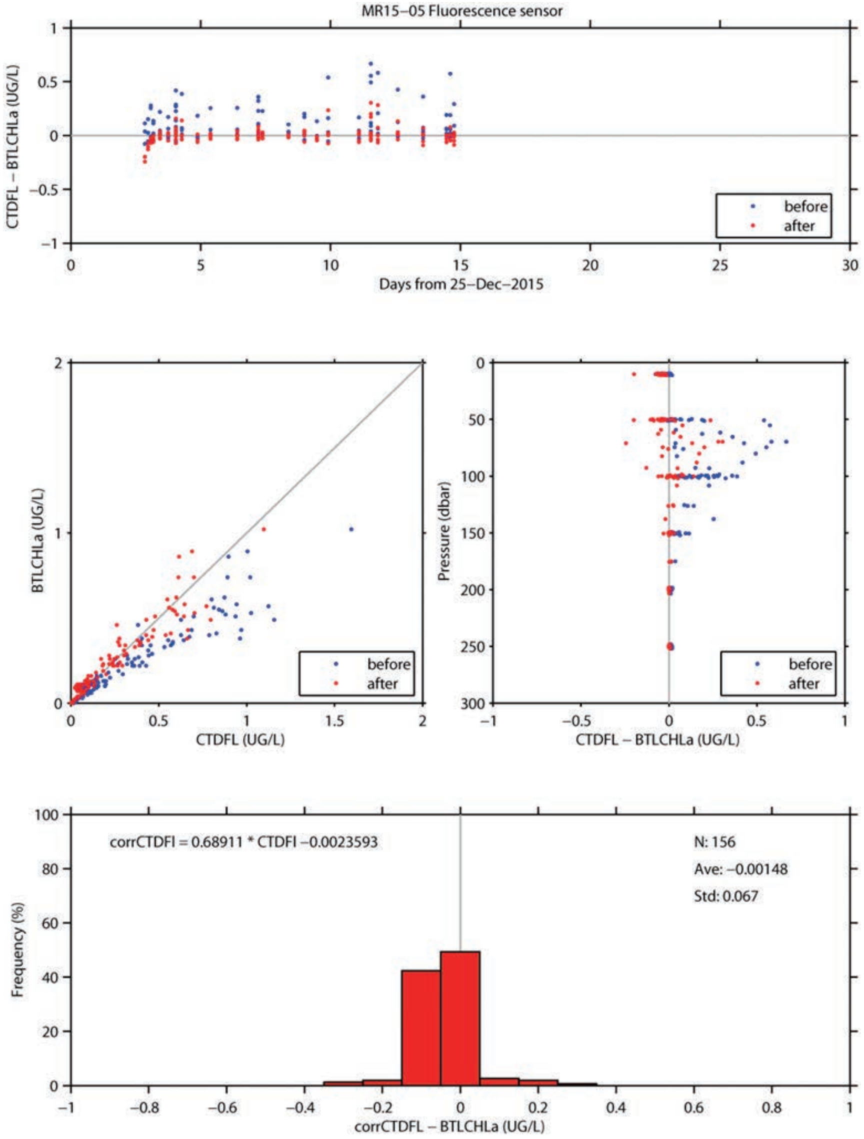

Fig. 3.1.8. Comparison of the CTD fluorometer and the bottle sampled chlorophyll-a. Blue and red dots indicate before and after the post-cruise calibration, respectively. Lower panel shows histogram of the difference after the calibration. Data obtained at daytime are also shown in this figure.

vi. Transmissometer

The transmissometer (T_r in %) is calibrated as

$$T_r = (V - V_d) / (V_r - V_d) \times 100$$

wehre V is the measured signal (voltage), Vd is the dark offset for the instrument, and V_r is the signal for clear water. V_d can be obtained by blocking the light path. V_d and V_{air}, which is the signal for air, were measured on deck before each cast after wiping the optical windows with ethanol. V_d was constant (0.0012) during the cruise. V_r is estimated from the measured maximum signal in the deep ocean at each cast. Since the transmissometer drifted in time (Fig. 3.1.9), V_r is expressed as

$$V_r = c_0 + c_1 \times t + c_2 \times t^2$$

where t is working time (in days) of the transmissometer, and c_0, c_1, and c_2 are calibration coefficients.

Maximum signal was extracted for each cast (Fig. 3.1.9). Data whose depth of the maximum signal was shallower than 200 dbar were not used to estimate V_r (black dots in Fig. 3.1.9). Fits were made iteratively, removing negatively deviated outliers (red dots in Fig. 3.1.9) greater than 2 standard deviations until no more outliers remain. The calibration coefficients thus determined are listed in Table 3.1.9. The coefficient c_2 was set to zero for this cruise.

Maximum signal for the data obtained at station 11 was relatively small compared with the surrounding stations. Therefore, V_r was changed for station 11 to match the average of T_r value for depths between 300 and 400 dbar with that for station 10 and 12 (Table 3.1.9).

Table 3.1.9 Calibration coefficients for the CTD transmissometer.

Leg	c_0	c_1	V_d
1	4.61740	–2.94693e–3	0.0012
	4.6026	0.0	0.0012 (for statoin 11)

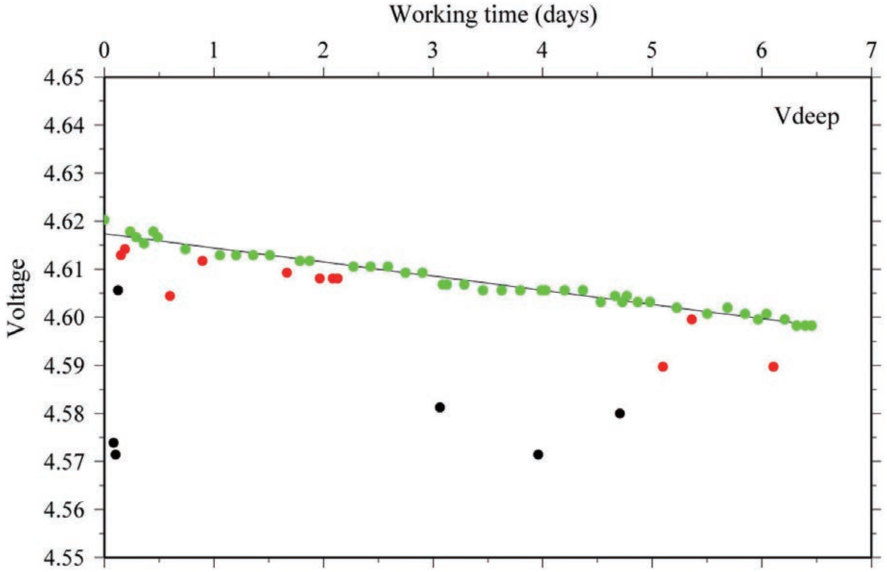

Fig. 3.1.9. Time series of an output signal (voltage) from transmissometer at deep ocean (Vdeep). The black solid line indicates the modeled signal in the deep clear ocean. Black and red dots were not used to estimate the final calibration coefficients (see text for detail).

vii. PAR

The PAR sensor was calibrated with an offset correction. The offset was estimated from the data measured in the deep ocean during the cruise. The corrected data (PARc) is calculated from the raw data (PAR) as follows:

$$PARc\ [\mu E\ m^{-2}\ s^{-1}] = PAR - 0.046.$$

vii. CDOM

The CDOM sensor wasn’t calibrated, since the reference data (see Section 3.9) was not adequate for the in-situ calibration. The data were low-pass filtered by a running mean with a window of 15 seconds (about 13 m) in the data processing mentioned above, since the data was noisy.

(7) References

Edwards, B., D. Murphy, C. Janzen and N. Larson (2010): Calibration, response, and hysteresis in deep-sea dissolved oxygen measurements, *J. Atmos. Oceanic Technol.*, 27, 920–931.

Fukasawa, M., T. Kawano and H. Uchida (2004): Blue Earth Global Expedition collects CTD data aboard Mirai, BEAGLE 2003 conducted using a Dynacon CTD traction winch and motion-compensated crane, *Sea Technology*, 45, 14–18.

García, H. E. and L. I. Gordon (1992): Oxygen solubility in seawater: Better fitting equations. *Limnol. Oceanogr.*, 37 (6), 1307–1312.

Uchida, H., G. C. Johnson, and K. E. McTaggart (2010): CTD oxygen sensor calibration procedures, The GO-SHIP Repeat Hydrography Manual: A collection of expert reports and guidelines, IOCCP Rep., No. 14, ICPO Pub. Ser. No. 134.

Uchida, H., K. Katsumata, and T. Doi (2015): WHP P14S, S04I Revisit Data Book, JASTEC, Yokosuka, 187 pp.

Uchida, H., T. Nakano, J. Tamba, J. V. Widiatmo, K. Yamazawa, S. Ozawa and T. Kawano (2015): Deep ocean temperature measurement with an uncertainty of 0.7 mK, J. Atmos. Oceanic Technol., 32, 2199–2210.

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.

3.2 Bottle Salinity

January 27, 2016

(1) Personnel

Hiroshi Uchida (JAMSTEC)
Sonoka Wakatsuki (MWJ)
Hiroki Ushiromura (MWJ)

(2) Objectives

Bottle salinities were measured to calibrate CTD salinity data.

(3) Instrument and Method

Salinity measurement was conducted basically based on a method by Kawano (2010).

i. Salinity Sample Collection

The bottles in which the salinity samples were collected and stored were 250 ml brown borosilicate glass bottles with screw caps (PTFE packing). Each bottle was rinsed three times with sample water and was filled to the shoulder of the bottle. The caps were also thoroughly rinsed. Salinity samples were stored more than 24 hours in the same laboratory as the salinity measurement was made.

ii. Instruments and Methods

Salinity of water samples was measured with a salinometer (Autosal model 8400B; Guildline Instruments Ltd., Ontario, Canada; S/N 62556), which was modified by adding an peristaltic-type intake pump (Ocean Scientific International Ltd., Hampshire, UK) and two platinum thermometers (Guildline Instruments Ltd., model 9450). One thermometer monitored an ambient temperature and the other monitored a salinometer's bath temperature. The resolution of the thermometers was 0.001 °C. The measurement system was almost same as Aoyama et al. (2002). The salinometer was operated in the air-conditioned laboratory of the ship at a bath temperature of 24 °C.

The ambient temperature varied from approximately 22.3 to 24.3 °C, while the bath temperature was stable and varied within ±0.006 °C. A measure of a double conductivity ratio of a sample was taken as a median of 31 readings. Data collection was started after 10 seconds and it took about 10 seconds to collect 31 readings by a personal computer. Data were sampled for the sixth and seventh filling of the cell. In case where the difference between the double conductivity ratio of this two fillings was smaller than 0.00002, the average value of the two double conductivity ratios was used to calculate the bottle salinity with the algorithm for practical salinity scale, 1978 (UNESCO, 1981). When the difference was greater than or equal to the 0.00003, we measured another additional filling of the cell. In case where the double conductivity ratio of the additional filling did not satisfy the criteria above, we measured other additional fillings of the cell within 10 fillings in total. In case where the number of fillings was 10 and those fillings did not satisfy the criteria above, the median of the double conductivity ratios of five fillings were used to calculate the bottle salinity.

The measurement was conducted about from 2 to 19 hours per day and the cell was cleaned with soap (50 times diluted solution of S-CLEAN WO-23 [Neutral], Sasaki Chemical Co. Ltd., Kyoto, Japan) after the measurement for each day. A total of 1672 water samples were measured during the cruise.

(4) Results

i. Standard Seawater

Standardization control was set to 715. The value of STANDBY was 5216±0001 and that of ZERO was 0.00000 or ±0.00001. We used IAPSO Standard Seawater batch P157 whose conductivity ratio is 0.99985 (double conductivity ratio is 1.99970) as the standard for salinity measurement. We measured 66 bottles of the Standard Seawater during the cruise. History of double conductivity ratio measurement of the Standard Seawater is shown in Fig. 3.2.1.

Time drift of the salinometer was corrected by using the Standard Seawater measurements. Linear time drift of the salinometer was estimated from the Standard Seawater measurement by using the least square method (thin black line in Fig. 3.2.1). No remarkable time drift was estimated from the Standard Seawater measurement. The average of double conductivity ratio was 1.99968 and the standard deviation was 0.00001, which is equivalent to 0.0002 in salinity.

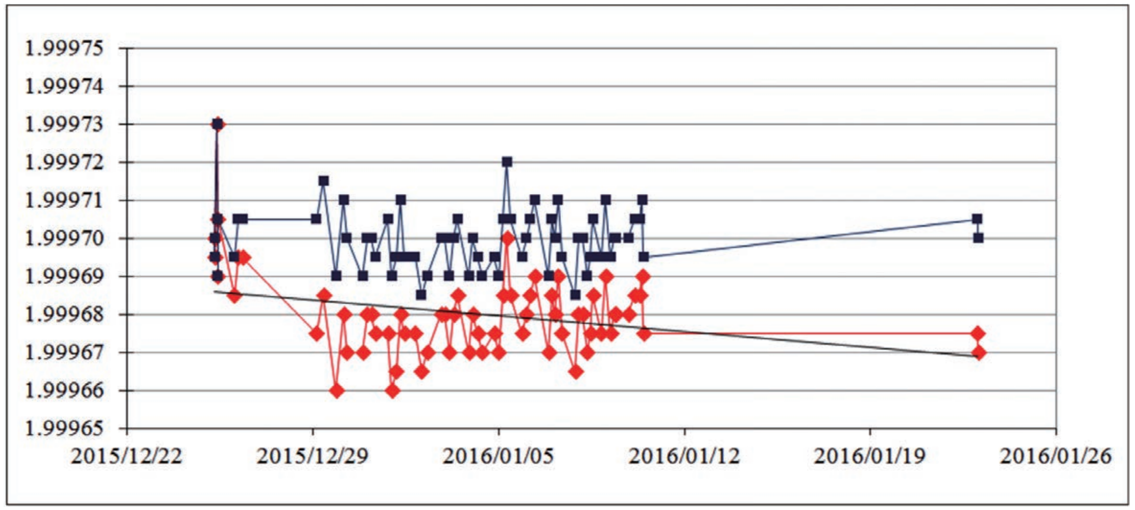

Fig. 3.2.1. History of double conductivity ratio measurement of the Standard Seawater (P157). Horizontal and vertical axes represents date and double conductivity ratio, respectively. Red dots indicate raw data and blue dots indicate corrected data.

ii. Sub-Standard Seawater

We also used sub-standard seawater which was deep-sea water filtered by pore size of 0.45 µm and stored in a 20 liter cubitainer made of polyethylene and stirred for at least 24 hours before measuring. It was measured every 6-8 samples in order to check the possible sudden drift of the salinometer. During the whole measurements, there was no detectable sudden drift of the salinometer.

iii. Replicate Samples

We took 257 pairs of replicate samples collected from the same Niskin bottle. Histogram of the absolute difference between replicate samples is shown in Fig. 3.2.2. The root-mean-square for 256 pairs of replicate samples which are acceptable-quality data was 0.0002.

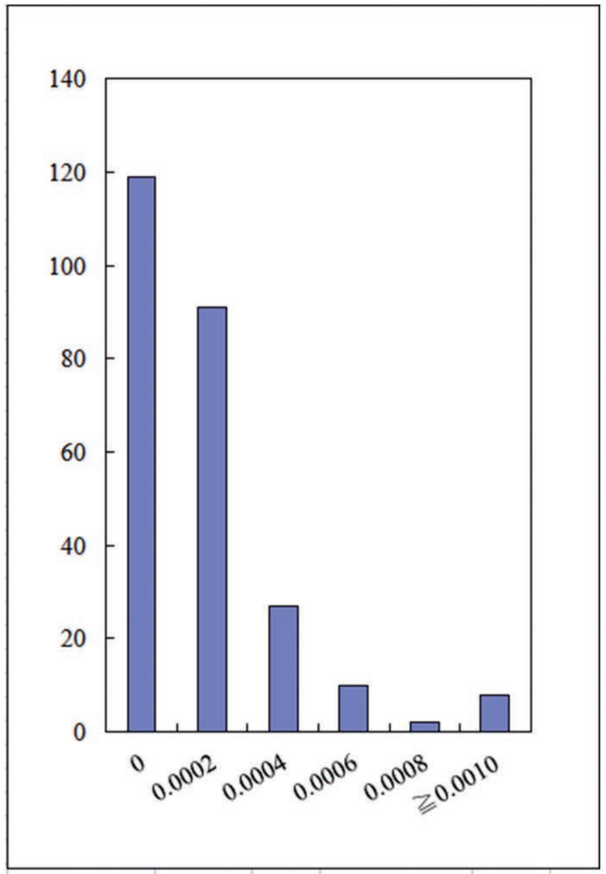

Fig. 3.2.2. Histogram of the absolute difference between replicate samples. Horizontal axis is absolute difference in salinity and vertical axis is frequency.

iv. Duplicate Samples

In this cruise, we took 36 samples collected from the different Niskin bottles at same depth (2000 dbar) of station 900, instead of taking duplicate samples. The average of salinity with the standard deviation was

34.7300 ± 0.0002.

(5) References

Aoyama, M., T. Joyce, T. Kawano and Y. Takatsuki (2002): Standard seawater comparison up to P129. Deep-Sea Research, I, Vol. 49, 1103-1114.

Kawano (2010): Salinity. 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.

3.3 Density

February 18, 2016

(1) Personnel

Hiroshi Uchida (JAMSTEC)

(2) Objectives

The objective of this study is to collect absolute salinity (also called “density salinity”) data, and to evaluate an algorithm to estimate absolute salinity provided along with TEOS-10 (the International Thermodynamic Equation of Seawater 2010) (IOC et al., 2010).

(3) Materials and methods

Seawater densities were measured during the cruise with an oscillation-type density meter (DMA 5000M, serial no. 80570578, Anton-Paar GmbH, Graz, Austria) with a sample changer (Xsample 122, serial no. 80548492, Anton-Paar GmbH). The sample changer was used to load samples automatically from up to ninety-six 12-mL glass vials.

The water samples were collected in 100-mL aluminum bottles (Mini Bottle Can, Daiwa Can Company, Japan). The bottles were stored at room temperature (~23 °C) upside down usually for 12 to 24 hours to make the temperature of the sample equal to the room temperature. The water sample was filled in a 12-mL glass vial and the glass vial was sealed with Parafilm M (Pechiney Plastic Packaging, Inc., Menasha, Wisconsin, USA) immediately after filling. Densities of the samples were measured at 20 °C by the density meter two times for each bottle and averaged to estimate the density. When the difference between the two measurements was greater than 0.002, additional measurements were conducted until two samples satisfying the above criteria were obtained.

Time drift of the density meter was monitored by periodically measuring the density of ultra-pure water (Milli-Q water, Millipore, Billerica, Massachusetts, USA) prepared from Yokosuka (Japan) tap water in October 2012. The true density at 20 °C of the Milli-Q water was estimated to be 998.2042 kg m^{-3} from the isotopic composition ($\delta D = -8.76$ ‰, $\delta^{18}O = -56.86$ ‰) and International Association for the Properties of Water and Steam (IAPWS)-95 standard. An offset correction was applied to the measured density by using the Milli-Q water measurements ($\rho_{\text{Milli-Q}}$) with a slight modification of the density dependency (Uchida et al., 2011). The offset (ρ_{offset}) of the measured density (ρ) was reevaluated in November 2014 as follows:

$$\rho_{\text{offset}} = (\rho_{\text{Milli-Q}} - 998.2042) - (\rho - 998.2042) \times 0.000411 \text{ [kg m}^{-3}\text{]}.$$

The offset correction was verified by measuring Reference Material for Density in Seawater (prototype Dn-RM1) developing with Marine Works Japan, Ltd., Kanagawa, Japan, and produced by Kanso Technos Co., Ltd., Osaka, Japan, along with the Milli-Q water.

Density salinity can be back calculated from measured density and temperature (20 °C) with TEOS-10.

(4) Results

Results of density measurements of the Reference Material for Density in Seawater (Dn-RM1) were shown in Table 3.3.1.

A total of 32 pairs of replicate samples were measured. The root-mean square of the absolute difference of replicate samples was 0.0009 g/kg.

The measured density salinity anomalies (δS_A) are shown in Fig. 3.3.1. The measured δS_A well agree with calculated δS_A from Pawlowicz et al. (2011) which exploits the correlation between δS_A and nutrient concentrations and carbonate system parameters based on mathematical investigation using a model relating composition, conductivity and density of arbitrary seawaters.

(5) References

IOC, SCOR and IAPSO (2010): The international thermodynamic equation of seawater – 2010: Calculation and use of thermodynamic properties. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, United Nations Educational, Scientific and Cultural Organization (English), 196 pp.

Pawlowicz, R., D. G. Wright and F. J. Millero (2011): The effects of biogeochemical processes on ocean conductivity/

salinity/density relationships and the characterization of real seawater. *Ocean Science*, 7, 363–387.

Uchida, H., T. Kawano, M. Aoyama and A. Murata (2011): Absolute salinity measurements of standard seawaters for conductivity and nutrients. *La mer*, 49, 237–244.

Table 3.3.1. Result of density measurements of the Reference Material for Density in Seawater (prototype Dn-RM1).

Date	Stations	Mean density of Dn-RM1 (kg/m^3)	Note
2015/12/29	1,2,3,4,6,10	1024.2631	
2015/12/31	14	1024.2637	
2016/01/01	18	1024.2628	
2016/01/02	22	1024.2627	
2016/01/03	26	1024.2631	
2016/01/04	31	1024.2619	
	33	1024.2622	
2016/01/06	37	1024.2638	
2016/01/07	41	1024.2634	
	42	1024.2624	
2016/01/08	43	1024.2597	
	45	1024.2601	
2016/01/08	46,47	1024.2609	
	48,50	1024.2602	
2016/01/09	51,52	1024.2640	
	Average:	1024.2623 ± 0.0014	

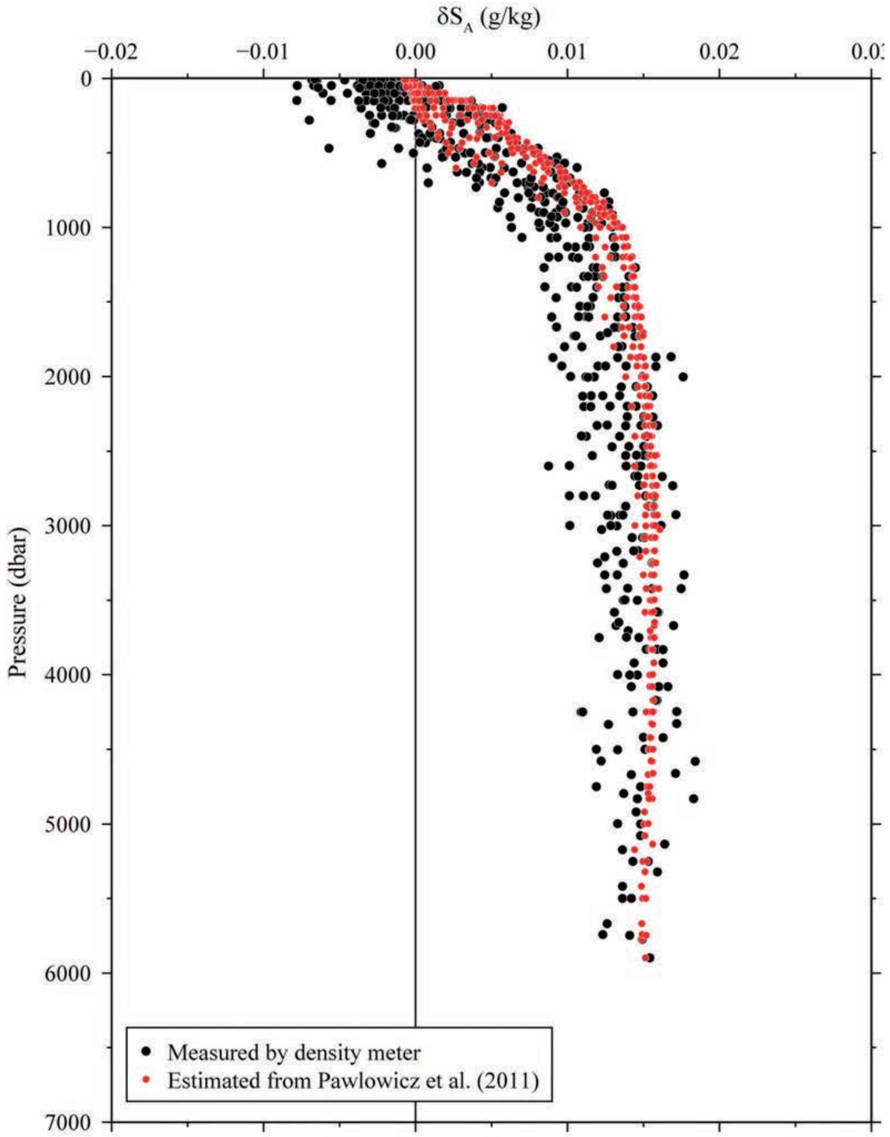

Figure 3.3.1. Vertical distribution of density salinity anomaly measured by the density meter. Absolute Salinity anomaly estimated from nutrients and carbonate parameters (Pawlowicz et al., 2011) are also shown for comparison.

3.4 Oxygen

October 2, 2017

(1) Personnel

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1) Japan Agency for Marine-Earth Science and Technology

2) Marine Works Japan Co. Ltd

(2) Objectives

Dissolved oxygen is one of good tracers for the ocean circulation. Climate models predict a decline in oceanic dissolved oxygen concentration and a consequent expansion of the oxygen minimum layers under global warming conditions, which results mainly from decreased interior advection and ongoing oxygen consumption by remineralization. The mechanism of the decrease, however, is still unknown. During MR15-05 cruise, we measured dissolved oxygen concentration from surface to bottom layers at all the hydrocast stations in the eastern Indian Ocean. All the stations reoccupied the WOCE Hydrographic Program I10 stations in 1995. Our purpose is to evaluate temporal change in dissolved oxygen concentration in the North Pacific Ocean during the past decades.

(3) Reagents

Pickling Reagent I: Manganous chloride solution (3M)

Pickling Reagent II: Sodium hydroxide (8M) / sodium iodide solution (4M)

Sulfuric acid solution (5M)

Sodium thiosulfate (0.025M)

Potassium iodate (0.001667M): NMIJ CRM 3006-a No.028, Mass fraction: 99.973 ± 0.018 % (expanded uncertainty)

CSK standard of potassium iodate: Lot KPG6393, Wako Pure Chemical Industries Ltd., 0.0100N

(4) Instruments

Burette for sodium thiosulfate and potassium iodate;

APB-620 and APB-510 manufactured by Kyoto Electronic Co. Ltd. / 10 cm^3 of titration vessel

Detector;

Automatic photometric titrator, DOT-01X manufactured by Kimoto Electronic Co. Ltd.

(5) Seawater sampling

Following procedure is based on a determination method in the WHP Operations Manual (Dickson, 1996). Seawater samples were collected from 12-liters Niskin sampler bottles attached to the CTD-system. Seawater for bottle oxygen measurement was transferred from the Niskin sampler bottle to a volume calibrated glass flask (ca. 100 cm^3). Three times volume of the flask of seawater was overflowed. Sample temperature was measured using a thermometer. Then two reagent solutions (Reagent I, II) of 0.5 cm^3 each were added immediately into the sample flask and the stopper was inserted carefully into the flask. The sample flask was then shaken vigorously to mix the contents and to disperse the precipitate finely throughout. After the precipitate has settled at least halfway down the flask, the flask was shaken again to disperse the precipitate. The sample flasks containing pickled samples were stored in a laboratory until they were titrated.

(6) Sample measurement

At least two hours after the re-shaking, the pickled samples were measured on board. A magnetic stirrer bar and 1 cm^3 sulfuric acid solution were added into the sample flask and stirring began. Samples were titrated by sodium thiosulfate solution whose molarity was determined by potassium iodate solution. Temperature of sodium thiosulfate during titration was recorded by a thermometer. We measured dissolved oxygen concentration using two sets of the titration apparatus, named DOT-6 and DOT-8. Dissolved oxygen concentration (μmol kg^{-1}) was calculated by the sample temperature during the sampling, CTD salinity, flask volume, and titrated volume of the sodium thiosulfate solution.

(7) Standardization

Concentration of sodium thiosulfate titrant (ca. 0.025M) was determined by potassium iodate solution. Pure potassium iodate was dried in an oven at 130°C. 1.7835 g potassium iodate weighed out accurately was dissolved in deionized water and diluted to final volume of 5 dm^3 in a calibrated volumetric flask (0.001667M). 10 cm^3 of the standard potassium iodate solution was added to a flask using a volume-calibrated dispenser. Then 90 cm^3 of deionized water, 1 cm3 of sulfuric acid solution, and 0.5 cm^3 of pickling reagent solution II and I were added into the flask in order. Amount of titrated volume of sodium thiosulfate (usually 5 times measurements average) gave the molarity of the sodium thiosulfate titrant. Table 3.4.1 shows result of the standardization during this cruise. Coefficient of variation (C.V.) for the standardizations was 0.016 ± 0.005 % (standard deviation, n = 16), c.a. 0.05 μmol kg^{-1}.

(8) Determination of the blank

The oxygen in the pickling reagents I (0.5 cm^3) and II (0.5 cm^3) was assumed to be 3.8×10^{-8} mol (Murray et al., 1968). The blank from the presence of redox species apart from oxygen in the reagents (the pickling reagents I, II, and the sulfuric acid solution) was determined as follows. 1 and 2 cm^3 of the standard potassium iodate solution were added to two flasks respectively. Then 100 cm^3 of deionized water, 1 cm^3 of sulfuric acid solution, and 0.5 cm^3 of pickling reagent solution II and I each were added into the two flasks in order. The blank was determined by difference between the two times of the first (1 cm^3 of KIO_3) titrated volume of the sodium thiosulfate and the second (2 cm^3 of KIO_3) one. The results of 3 times blank determinations were averaged (Table 3.4.1). The averaged blank values for DOT-6 and DOT-8 were 0.002 ± 0.002 (standard deviation, n=8) and 0.000 ± 0.002 (standard deviation, n=8) cm^3, respectively.

Table 3.4.1 Results of the standardization (End point, E.P.) and the blank determinations (cm^3).

Date (UTC)	KIO_3 No.	$Na_2S_2O_3$ No.	DOT-6		DOT-8		Stations
			E.P.	blank	E.P.	blank	
2015/12/27	K1504E02	T1505A	3.962	0.002	3.963	0.000	001-015
2015/12/30	K1504E03	T1505A	3.965	0.003	3.965	0.001	016-026
2016/01/03	K1504E04	T1505B	3.957	0.000	3.959	0.001	027-041
2016/01/06	K1504E05	T1505B	3.957	0.002	3.958	0.000	042-052

(9) Replicate sample measurement

From a routine CTD cast at all the stations, a pair of replicate samples was collected at four layers of 50, 400, 1800, and 3500 db. The total number of the replicate sample pairs in good measurement (flagged 2) was 170 (Fig. 3.4.1). The standard deviation of the replicate measurement was 0.60 μmol kg^{-1} calculated by a procedure (SOP23) in DOE (1994).

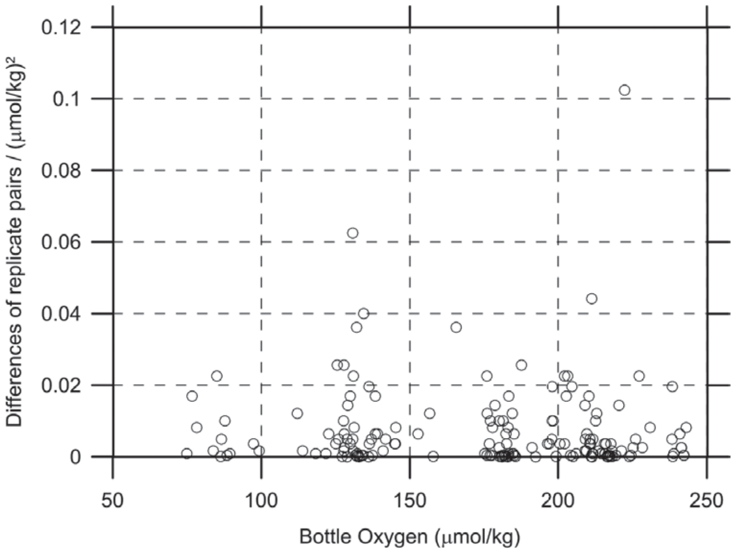

Figure 3.4.1 Oxygen difference between measurements of a replicate pair against oxygen concentration.

(10) Duplicate sample measurement

At Station 900 (test), duplicate sampling were taken at 2000 dbar for all the Niskin bottles (36 bottles, Table 3.4.2). The standard deviation of the duplicate measurements were calculated to be 0.09 μmol kg^{-1}, which were nearly equivalent with that of the replicate measurements (0.06 μmol kg^{-1}, see section 9).

Table 3.4.2 Results of duplicate sample measurements.

Duplicated Niskin #	Niskin	Pres.(db)	Oxygen (μmol kg^{-1})
1	X12J01	2000	139.67
2	X12J02	2000	139.74
3	X12J03	2001	139.73
4	X12104	2001	139.91
5	X12J05	2000	139.78
6	X12J06	2000	139.91
7	X12J07	2000	139.85
8	X12J08	2000	139.93
9	X12J09	2000	139.87
10	X12J10	2000	139.85
11	X12J11	2001	139.96
12	X12J12	2001	139.87
13	X12J13	2001	140.02
14	X12J14	2001	139.86
15	X12J15	2001	139.89
16	X12J16	2001	139.92
17	X12J17	2000	139.97
18	X12J18	1999	139.86
19	X12J19	2000	139.97
20	X12J20	1999	139.99
21	X12J21	2000	139.94
22	X12J22	2001	139.90
23	X12J23	2001	139.97
24	X12J24	2001	139.98
25	X12J25	2000	139.91
26	X12J26	2001	139.94
27	X12J27	2000	139.93
28	X12J28	2001	139.70
29	X12J29	2001	139.89
30	X12J30	2001	139.78
31	X12J31	2001	139.88
32	X12J32	2001	139.79
33	X12J33	2001	140.02
34	X12J34	2001	139.92
35	X12J35	2000	139.77
36	X12J36	2000	139.85

(11) CSK standard measurements

The CSK standard is a commercial potassium iodate solution (0.0100 N) for analysis of dissolved oxygen. We titrated the CSK standard solution (Lot KPG6393) against our KIO3 standard solution (Lot K1504E01) as samples before the cruise on 25 Dec. 2016. Concentration of the CSK solution against that of our KIO_3 solution was calculated to be 0.010006 ± 0.000002 N and 0.010006 ± 0.000002 N for DOT-6 and DOT-8, respectively.

(12) Quality control flag assignment

Quality flag values were assigned to oxygen measurements using the code defined in Table 4.9 of WHP Office Report WHPO 90-1 Rev.2 section 4.5.2 (Joyce *et al*., 1994). Measurement flags of 2 (good), 3 (questionable), 4 (bad), and 5 (missing) have been assigned (Table 3.4.3). For the choice between 2, 3, or 4, we basically followed a flagging procedure as listed below:

a. Bottle oxygen concentration at the sampling layer was plotted against sampling pressure. Any points not lying on a generally smooth trend were noted.

b. Difference between bottle oxygen and CTD oxygen was then plotted against sampling pressure. If a datum deviated from a group of plots, it was flagged 3.

c. Vertical sections against pressure and potential density were drawn. If a datum was anomalous on the section plots, datum flag was degraded from 2 to 3, or from 3 to 4.

d. If there was problem in the measurement, the datum was flagged 4.

e. If the bottle flag was 4 (did not trip correctly), a datum was flagged 4 (bad). In case of the bottle flag 3 (leaking) or 5 (unknown problem), a datum was flagged based on steps a, b, c, and d.

Table 3.4.3 Summary of assigned quality control flags.

Flag	Definition	Number*
2	Good	1363
3	Questionable	0
4	Bad	0
5	Not report (missing)	0
	Total	1363

*Replicate samples (n = 170) were not included.

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3.5 Nutrients

January 22, 2016 (ver.2.3)

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(2) Objectives

The objectives of nutrients analyses during the R/V Mirai MR1505 cruise, GO-SHIP I10 repeat cruise in 2015-2016, in the Eastern Indian Ocean are as follows;

- Describe the present status of nutrients concentration with excellent comparability.
- The determinants are nitrate, nitrite, silicate, phosphate and Ammonium.
- Study the temporal and spatial variation of nutrients concentration based on the previous high quality experiments data of WOCE previous I10 cruises in 1995, GEOSECS, IGY and so on.
- Study of temporal and spatial variation of nitrate: phosphate ratio, so called Redfield ratio.
- Obtain more accurate estimation of total amount of nitrate, silicate and phosphate in the interested area.
- Provide more accurate nutrients data for physical oceanographers to use as tracers of water mass movement.

(3) Summary of nutrients analysis

We made 50 QuAAtro 2-HR runs for the samples at 56 casts, 52 stations in MR1505. The total amount of layers of the seawater sample reached up to 2484 for MR1505. We made duplicate measurement at all layers at all stations.

(4) Instrument and Method

(4.1) Analytical detail using QuAAtro 2-HR systems (BL-Tech)

We applied two units of QuAAtro in this cruise. Unit 1 and Unit 2 were put for R/V Mirai equipment. Configurations of all units are completely same for five parameters, Nitrate, Nitrite, Silicate, Phosphate, and Ammonium.

Nitrate + nitrite and nitrite were analyzed according to the modification method of Grasshoff (1970). The sample nitrate was reduced to nitrite in a cadmium tube inside of which was coated with metallic copper. The sample streamed with its equivalent nitrite was treated with an acidic, sulfanilamide reagent and the nitrite forms nitrous acid which reacted with the sulfanilamide to produce a diazonium ion. N-1-Naphthylethylene-diamine added to the sample stream then coupled with the diazonium ion to produce a red, azo dye. With reduction of the nitrate to nitrite, both nitrate and nitrite reacted and were measured; without reduction, only nitrite reacted. Thus, for the nitrite analysis, no reduction was performed and the alkaline buffer was not necessary. Nitrate was computed by difference.

The silicate method was analogous to that described for phosphate. The method used was essentially that 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 ascorbic acid as the reductant. The analytical methods of the nutrients, nitrate, nitrite, silicate and phosphate, during this cruise were same as the methods used in (Kawano et al. 2009).

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 details of modification of analytical methods for four parameters, Nitrate, Nitrite, Silicate and Phosphate, used in this cruise are also compatible with the methods described in nutrients section in GO-SHIP repeat hydrography manual (Hydes et al., 2010), while an analytical method of ammonium is compatible with Determination of ammonia in seawater using a vaporization membrane permeability method (Kimura, 2000). The flow diagrams and reagents for each parameter are shown in Figures 3.5.1 to 3.5.5.

(4.2) Nitrate Reagents

Imidazole (buffer), 0.06 M (0.4 % w/v)

Dissolve 4 g imidazole, $C_3H_4N_2$, in 1000 mL DIW, add 2 mL concentrated HCl. After mixing, 1 mL Triton^{TM} X-100 (50 % solution in ethanol) is added.

Sulfanilamide, 0.06 M (1 % w/v) in 1.2 M HCl

Dissolve 10 g sulfanilamide, 4-$NH_2C_6H_4SO_3H$, in 900 mL of DIW, add 100 ml concentrated HCl. After mixing, 2 mL Triton^{TM} X-100 (50 %f solution in ethanol) is added.

N-1-Napthylethylene-diamine dihydrochloride, 0.004 M (0.1 %f w/v)

Dissolve 1 g NEDA, $C_{10}H_7NHCH_2CH_2NH_2 \cdot 2HCl$, in 1000 mL of DIW and add 10 mL concentrated HCl. After mixing, 1 mL Triton^{TM} X-100 (50 %f solution in ethanol) is added.

Stored in a dark bottle.

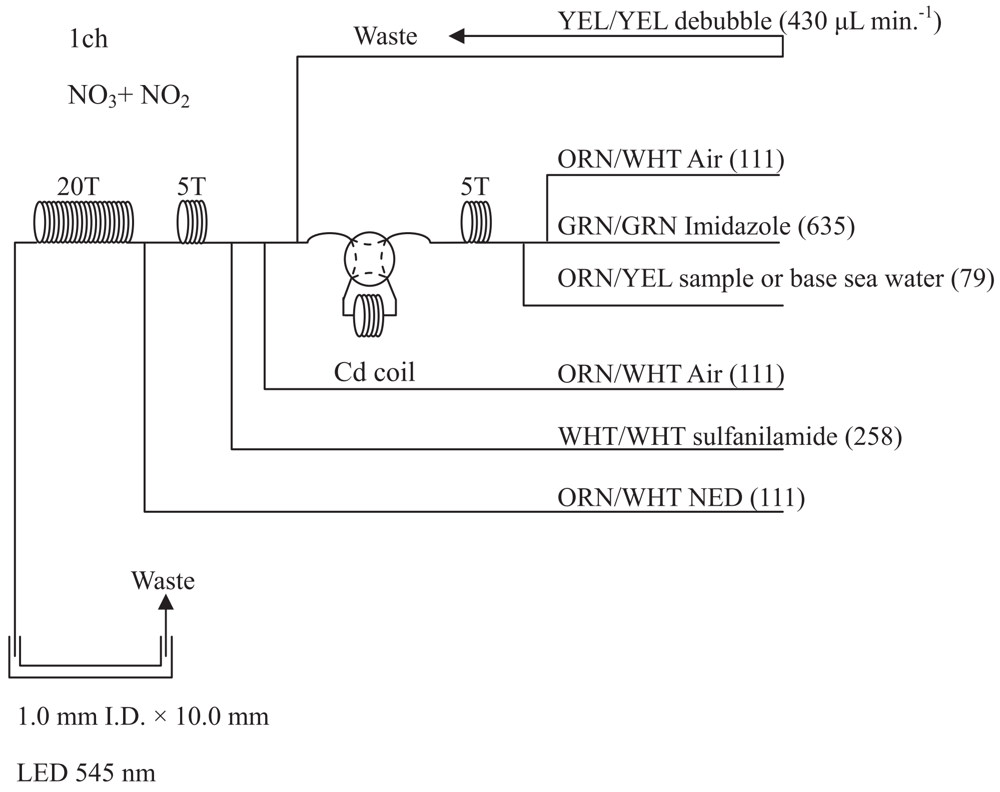

Figure 3.5.1 $NO_3 + NO_2$ (1ch.) Flow diagram.

(4.3) Nitrite Reagents

Sulfanilamide, 0.06 M (1% w/v) in 1.2 M HCl

Dissolve 10 g sulfanilamide, 4-$NH_2C_6H_4SO_3H$, in 900 mL of DIW, add 100 mL concentrated HCl. After mixing, 2 mL Triton^{TM} X-100 (50% solution in ethanol) is added.

N-1-Napthylethylene-diamine dihydrochloride, 0.004 M (0.1% w/v)

Dissolve 1 g NEDA, $C_{10}H_7NHCH_2CH_2NH_2 \cdot 2HCl$, in 1000 mL of DIW and add 10 mL concentrated HCl. After mixing, 1 mL Triton^{TM} X-100 (50% solution in ethanol) is added. This reagent was stored in a dark bottle.

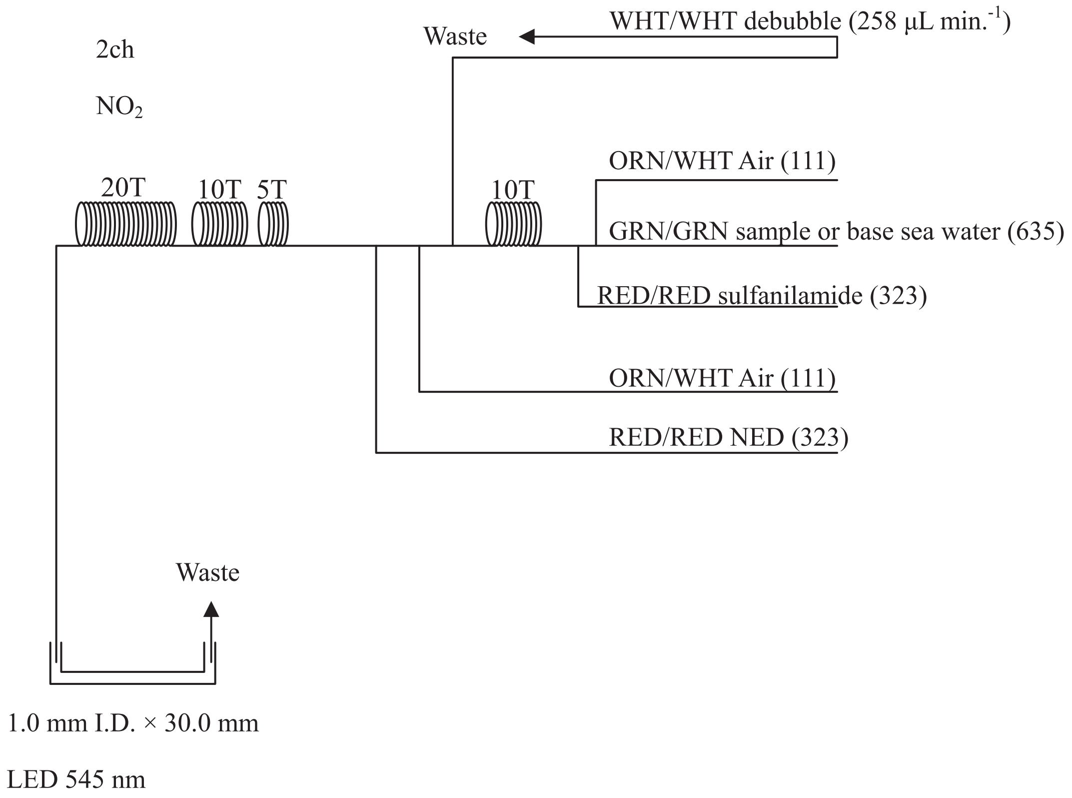

Figure 3.5.2 NO_2 (2ch.) Flow diagram.

(4.4) Silicate Reagents

Molybdic acid, 0.06 M (2% w/v)

Dissolve 15 g disodium Molybdate(VI) dihydrate, $Na_2MoO_4 \bullet 2H_2O$, in 980 mL DIW, add 8 mL concentrated H_2SO_4. After mixing, 20 mL sodium dodecyl sulphate (15% solution in water) is added.

Oxalic acid, 0.6 M (5% w/v)

Dissolve 50 g oxalic acid anhydrous, HOOC: COOH, in 950 mL of DIW.

Ascorbic acid, 0.01 M (3% w/v)

Dissolve 2.5g L(+)-ascorbic acid, $C_6H_8O_6$, in 100 mL of DIW. This reagent was freshly prepared at every day.

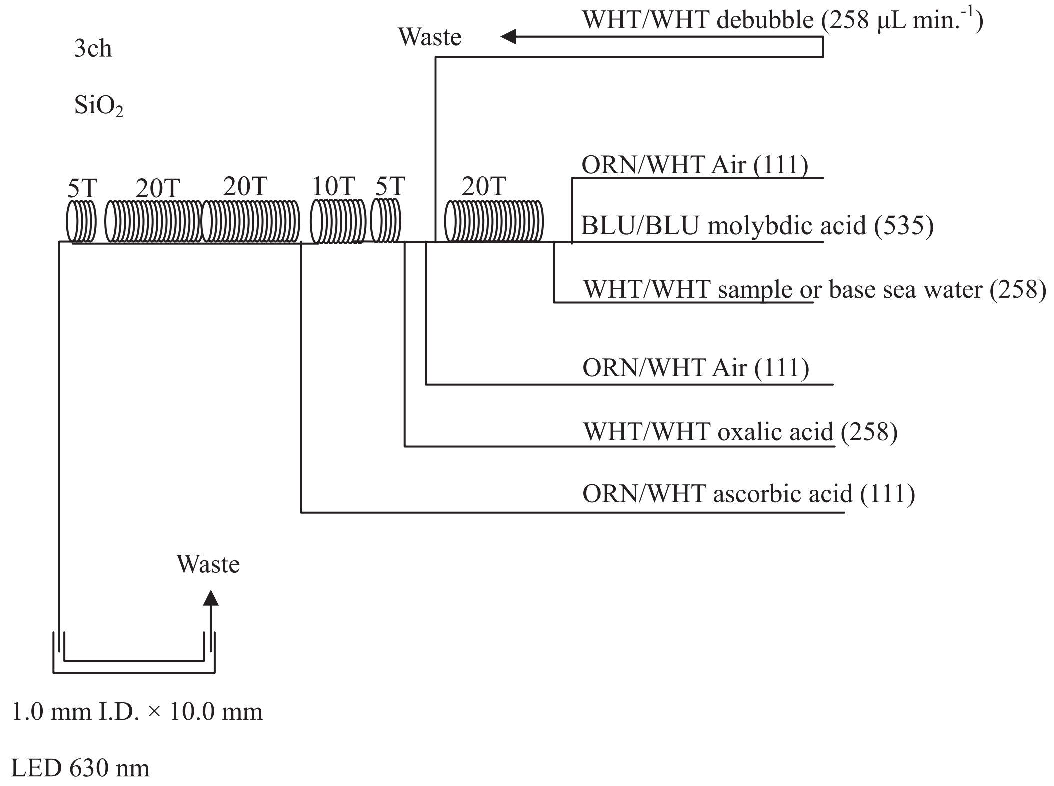

Figure 3.5.3 SiO_2 (3ch.) Flow diagram.

(4.5) Phosphate Reagents

Stock molybdate solution, 0.03 M (0.8% w/v)

Dissolve 8 g disodium molybdate(VI) dihydrate, $Na_2MoO_4 \bullet 2H_2O$, and 0.17 g antimony potassium tartrate, $C_8H_4K_2O_{12}Sb_2 \bullet 3H_2O$, in 950 mL of DIW and added 50 ml concentrated H_2SO_4.

Mixed Reagent

Dissolve 1.2 g L(+)-ascorbic acid, $C_6H_8O_6$, in 150 mL of stock molybdate solution. After mixing, 3 mL sodium dodecyl sulphate (15% solution in water) was added. This reagent was freshly prepared before every measurement.

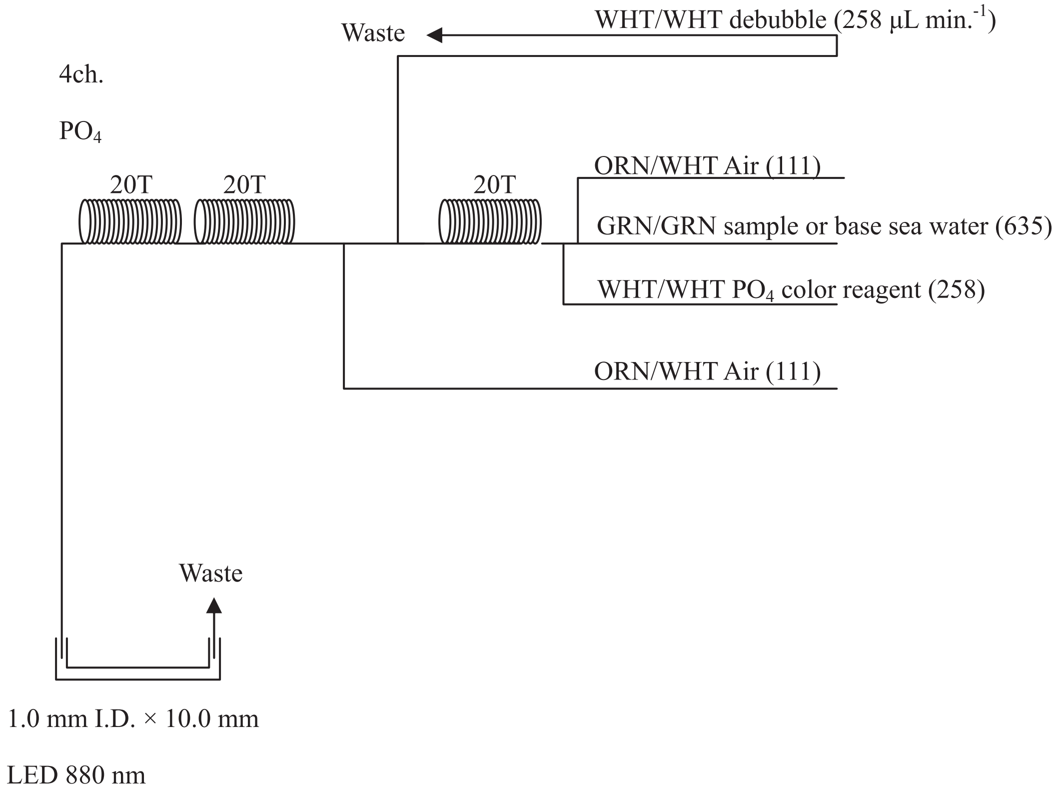

Figure 3.5.4 PO_4 (4ch.) Flow diagram.

(4.6) Ammonium Reagents

EDTA

Dissolve 41 g EDTA (ethylenediaminetetraacetatic acid tetrasodium salt), $C_{10}H_{12}N_2O_8Na_4 \bullet 4H_2O$, and 2 g boric acid, H_3BO_3, in 200 mL of DIW. After mixing, 1 mL Triton^{TM} X-100 (30% solution in DIW) is added. This reagent is prepared at a week about.

NaOH

Dissolve 5 g sodium hydroxide, NaOH, and 16 g EDTA in 100 mL of DIW. This reagent is prepared at a week about.

Stock Nitroprusside

Dissolve 0.25 g sodium pentacyanonitrosylferrate(II), $Na_2[Fe(CN)_5NO]$, in 100 mL of DIW and add 0.2 mL 1N H_2SO_4. Stored in a dark bottle and prepared at a month about.

Nitroprusside solution

Mixed 4 mL stock nitroprusside and 5 mL 1N H_2SO_4 in 500 mL of DIW. After mixing, 2 mL Triton^{TM} X-100 (30% solution in DIW) is added. This reagent is stored in a dark bottle and prepared at every 2 or 3 days.

Alkaline phenol

Dissolve 10 g phenol, C_6H_5OH, 5 g sodium hydroxide and citric acid, $C_6H_8O_7$, in 200 mL DIW. Stored in a dark bottle and prepared at a week about.

NaClO solution

Mix 3 mL sodium hypochlorite solution, NaClO, in 47 mL DIW. Stored in a dark bottle and fleshly prepared before every measurement. This reagent is prepared 0.3% available chlorine.

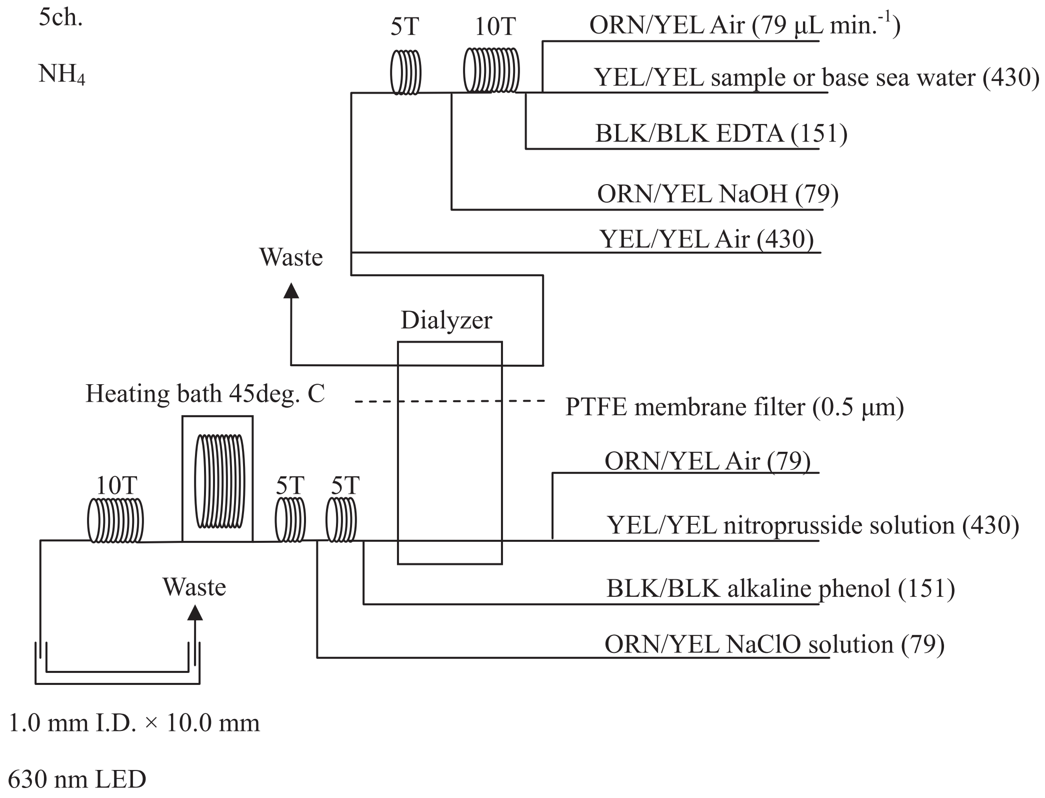

Figure 3.5.5 NH$_4$ (5ch.) Flow diagram.

(4.7) Sampling procedures

Sampling of nutrients followed that oxygen, salinity and trace gases. Samples were drawn into two of virgin 10 mL polyacrylates vials without sample drawing tubes. These were rinsed three times before filling and then vials were capped immediately after the drawing. The vials were put into water bath adjusted to ambient temperature, 23 ± 2 deg. C, in about 30 minutes before use to stabilize the temperature of samples in MR1505.

No transfer was made and the vials were set an auto sampler tray directly. Samples were analyzed after collection basically within 24 hours in principal.

(4.8) Data processing

Raw data from QuAAtro 2-HR was treated as follows:

- Checked baseline shift.
- Checked the shape of each peak and positions of peak values taken, and then changed the positions of peak values taken if necessary.
- Carry-over correction and baseline drift correction were applied to peak heights of each samples followed by sensitivity correction.
- Baseline correction and sensitivity correction were done basically using liner regression.
- Loaded pressure and salinity from CTD data to calculate density of seawater. In case of bucket sample, we generally used bottle salinity from AUTOSAL, while in case of bio-cast we used surface CTD data.
- Calibration curves to get nutrients concentration were assumed second order equations.

(5) Nutrients standards

(5.1) Volumetric laboratory ware of in-house standards

All volumetric glass ware and polymethylpentene (PMP) ware were gravimetrically calibrated. These volumetric flasks were gravimetrically calibrated at the temperature of using in the laboratory within 0 to 4 K.

Volumetric flasks

Volumetric flasks of Class quality (Class A) are used because their nominal tolerances are 0.05 % or less over the size ranges likely to be used in this work. Class A flasks are made of borosilicate glass, and the standard solutions were transferred to plastic bottles as quickly as possible after they are made up to volume and well mixed in order to prevent excessive dissolution of silicate from the glass. High quality plastic (polymethylpentene, PMP, or polypropylene) volumetric flasks were gravimetrically calibrated and used only within 0 to 4 K of the calibration temperature.

The computation of volume contained by glass flasks at various temperatures other than the calibration temperatures were done by using the coefficient of linear expansion of borosilicate crown glass.

Because of their larger temperature coefficients of cubical expansion and lack of tables constructed for these materials, the plastic volumetric flasks were gravimetrically calibrated over the temperature range of intended use and used at the temperature of calibration within 0 to 4 K. The weights obtained in the calibration weightings were corrected for the density of water and air buoyancy.

Pipettes and pipettors

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, general considerations

Specifications

For nitrate standard, "potassium nitrate 99.995 suprapur®" provided by Merck, Lot. B0771365211, CAS No. 7757-91-1, was used.

For nitrite standard, nitrite ion standard solution of JCSS (NO2 1000mg/L) provided by Wako, Lot. ECP4122, CAS No. 7632-00-0, was used. The nitrite concentration was assigned by ion chromatography method using secondary standard solution of nitrite ion. ECP4122 was certified as 999mg L^{-1} (± 0.7 % k=2).

For phosphate standard, "potassium dihydrogen phosphate anhydrous 99.995 suprapur®" provided by Merck, Lot. B0691108204, CAS No.: 7778-77-0, was used.

For the silicate standard, we use "Silicon standard solution SiO_2 in NaOH 0.5 mol/l CertiPUR®" provided by Merck, CAS No. 1310-73-2, of which lot number is HC41358736 are used. The silicate concentration is certified by NIST-SRM3150. HC41358736 was certified as 982 mg kg^{-1} with the expanded uncertainty of ± 5 mg kg^{-1} (k=2). In the previous cruises, we assigned correction factor of merck solutions are shown in table 3.5.1 to ensure internal comparability among WOCE/CLIVAR cruises, we however used merck certified concentration to keep traceability to SI for silicate concentration throughout MR1505 and in the future cruises.

For ammonium standard, we use certified reference material of "ammonium chloride" provided by NMIJ, CAS No. 12125-02-9, of which lot number is NMIJ CRM 3011-a with the expanded uncertainty of ± 0.065 mass fraction % (k=2).

Table 3.5.1 A history of assigned factor of Merck solutions

Lot	Factor	Date	Reference
Merck OC551722	1.004	2005/8/4	
Merck HC623465	1.000	2006/12/4	
Merck HC751838	0.998	2007/4/13	
Merck HC814662	0.999	2008/8/27	
Merck HC074650	0.975	2010/11/5	
Merck HC097572	0.976	2011/12/13	RM Lot. BA, AY, BD, BE, BF
Merck HC382250	0.973	2013/9/14	RM Lot. BS, BU, BT, BD

Treatment of silicate standard due to high alkalinity

Since the silicon standard solution Merck CertiPUR® is in NaOH 0.5 mol/l, we need to dilute and neutralize to avoid make precipitation of $MgOH_2$ etc. When we make B standard, silicon standard solution is diluted by factor 12 with pure water and neutralized by HCl 1.0 mol L^{-1} to be about 7. After that B standard solution is used to prepare C standards.

Ultra pure water

Ultra pure water (MilliQ water) freshly drawn was used for preparation of reagents, standard solutions and for measurement of reagent and system blanks.

Low-Nutrient Seawater (LNSW)

Surface water having low nutrient concentration was taken and filtered using 0.20 μm pore size capsule cartridge filter. This water was stored in 20 liter cubitainer with paper box. After stored for 5 month, a 1000 liter bag were filled with this LNSW filtering once more using 0.20 μm pore size capsule cartridge filter and irradiating by ultraviolet light in August 2015. After circulation of filtering and irradiating for 24 hours, LNSW was drawn into 20 liter cubitainer with paper box. The concentrations of nutrients of this LNSW were measured carefully in September 2015.

Although LNSW was sterilized by filtration and UV irradiation, in-house standard solution prepared with this LNSW showed that concentrations of nitrate, nitrite and phosphate decreased about 2 % after 2 days in November 2015. This should be caused by micro-organismal activity.

Therefore, LNSW was pasteurized at low temperature with 75 deg. C more than 12 hours to suspend micro-organismal activity in December 2015 on board. The concentrations of nutrients of in-house standard solution using pasteurized LNSW became not to decrease after 2 days of preparation as expected. The concentrations of nutrients of pasteurized LNSW were measured again in December 2015.

(5.3) Concentrations of nutrient for A, B and C standards

Concentrations of nutrients for A, B, C and D standards are set as shown in Table 3.5.2. The C standard is prepared according recipes as shown in Table 3.5.3. All volumetric laboratory tools were calibrated prior the cruise as stated in chapter (5.1). Then the actual concentration of nutrients in each fresh standard was calculated based on the ambient, solution temperature and determined factors of volumetric laboratory wares.

The calibration curves for each run were obtained using 6 levels, C-1, C-2, C-3, C-4, C-5 and C-6. C-1, C-2, C-3, C-4 and C-5 were the certified reference material of nutrients in seawater (hereafter CRM) and C-6 was in-house standard.

Table 3.5.2 Nominal concentrations of nutrients for A, B and C standards.

	A	**B**	**D**	**C-1**	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**	**C-7**	**C-8**
NO_3(μM)	22500	900	900	BY	BU	CA	BW	BZ	54	-	-
NO_2(μM)	21700	26	865	BY	BU	CA	BW	BZ	1.0	-	-
SiO_2(μM)	35000	2760		BY	BU	CA	BW	BZ	172	-	-
PO_4(μM)	3000	60		BY	BU	CA	BW	BZ	3.7	-	-
NH_4(μM)	4000	200		-	-	-	-	-	6.0	2.0	0

Table 3.5.3 Working calibration standard recipes.

C std.	**B-1 std.**	**B-2 std.**	**B-3 std**
C-6	30 mL	20 mL	15 mL
C-7	-	-	5 mL
C-8	-	-	0 mL

B-1 std.: Mixture of nitrate, silicate and phosphate
B-2 std.: Nitrite
B-3 std: Ammonium

(5.4) Renewal of in-house standard solutions.

In-house standard solutions as stated in paragraph (5.2) were renewed as shown in Table 3.5.4 (a) to (c).

Table 3.5.4(a) Timing of renewal of in-house standards.

NO_3, NO_2, SiO_2, PO_4, NH_4	**Renewal**
A-1 std. (NO_3)	maximum a month
A-2 std. (NO_2)	commercial prepared solution
A-3 std. (SiO_2)	commercial prepared solution
A-4 std. (PO_4)	maximum a month
A-5 std. (NH_4)	maximum a month
B-1 std. (mixture of A-1, A-3 and A-4 std.)	maximum 8 days
B-2 std. (dilute D-2 std.)	maximum 8 days
B-3 std. (dilute A-5 std.)	maximum 8 days

Table 3.5.4(b) Timing of renewal of in-house standards.

Working standards	**Renewal**
C-6 std. (mixture of B-1, B-2 and B-3 std.)	every 24 hours
C-7 std. (dilute B-3 std.)	
C-8 (LNSW)	

Table 3.5.4(c) Timing of renewal of in-house standards for reduction estimation.

Reduction estimation	**Renewal**
D-1 std. (900 µM NO_3)	maximum 8 days
D-2 std. (870 µM NO_2)	maximum 8 days
36 µM NO_3	when C Std. renewed
34 µM NO_2	when C Std. renewed

(6) CRM

To get the more accurate and high quality nutrients data to achieve the objectives stated above, huge numbers of the bottles of the reference material of nutrients in seawater were prepared and used during the previous cruises (Aoyama et al., 2006, 2007, 2008, 2009, 2012, 2014). In the previous worldwide expeditions, such as WOCE cruises, the higher reproducibility and precision of nutrients measurements were required (Joyce and Corry, 1994). Since no standards were available for the measurement of nutrients in seawater at that time, the requirements were described in term of reproducibility. The required reproducibility was 1%, 1 to 2%, 1 to 3% for nitrate, phosphate and silicate, respectively. Although nutrient data from the WOCE one-time survey was of unprecedented quality and coverage due to much care in sampling and measurements, the differences of nutrients concentration at crossover points are still found among the expeditions (Aoyama and Joyce, 1996, Mordy et al., 2000, Gouretski and Jancke, 2001). For instance, the mean offset of nitrate concentration at deep waters was 0.5 µmol kg^{-1} for 345 crossovers at world oceans, though the maximum was 1.7 µmol kg^{-1} (Gouretski and Jancke, 2001). At the 31 crossover points in the Pacific WHP one-time lines, the WOCE standard of reproducibility for nitrate of 1 % was fulfilled at about half of the crossover points and the maximum difference was 7 % at deeper layers below 1.6 deg. C in potential temperature (Aoyama and Joyce, 1996).

During the period from 2003 to 2014, RMNS were used to keep comparability of nutrients measurement among the 8 cruises of CLIVAR project (Sato et al., 2010), MR1005 cruise for Arctic research (Aoyama et al., 2010) and MR1006 cruise for “Change in material cycles and ecosystem by the climate change and its feedback” (Aoyama et al., 2011).

In this MR1505 cruises, we used 6 lots of CRM (Lot BY, BU, CA, BW, BV, BZ) to ensure comparability and traceability to SI.

(6.1) CRMs for this cruise

5 lot of CRMs were used as calibration standards together with the C-6. Certified concentrations of these lots as shown in table 3.5.4 were used. These bottles were stored at a room in the ship, REAGENT STORE,

where the temperature was maintained around 16 - 25 deg. C.

(6.2) Certified concentration for CRMs

The concentrations for CRM lots BY, BU, CA, BW, BZ, and BV are shown in Table 3.5.4.

Table 3.5.4 Certified concentration and uncertainty (k=2) of CRMs.

unit: μmol kg^{-1}

	Nitrate	Phosphate	Silicate	Nitrite
BY	0.02 ± 0.02	0.039 ± 0.010	1.76 ± 0.06	0.02 ± 0.01
BU	3.94 ± 0.05	0.345 ± 0.009	20.92 ± 0.49	0.07 ± 0.01
CA	19.66 ± 0.15	1.407 ± 0.014	36.58 ± 0.22	0.06 ± 0.01
BW	24.59 ± 0.20	1.541 ± 0.014	60.01 ± 0.42	0.07 ± 0.01
BZ	43.35 ± 0.33	3.056 ± 0.033	161.0 ± 0.93	0.22 ± 0.01
BV	35.36 ± 0.35	2.498 ± 0.023	102.2 ± 1.10	0.05 ± 0.01

(7) Quality control

(7.1) Precision of nutrients analyses during this cruise

Precision of nutrients analyses during this cruise was evaluated based on the 7 to 11 measurements, which are measured every 8 to 13 samples, during a run at the concentration of C-6 std. Summary of precisions are shown as Table 3.5.5 and Figures 3.5.6 to 3.5.8, the precisions for each parameter are generally good considering the analytical precisions during the R/V Mirai cruses conducted in 2009 - 2014. During this cruise, analytical precisions were 0.11% for nitrate, 0.11% for phosphate and 0.10% for silicate in terms of median of precision, respectively.

Table 3.5.5 Summary of precision based on the replicate analyses for all unit.

	Nitrate	Nitrite	Silicate	Phosphate	Ammonium
	CV%	CV%	CV%	CV%	CV%
Median	0.11	0.17	0.10	0.11	0.36
Mean	0.11	0.18	0.10	0.11	0.39
Maximum	0.19	0.34	0.20	0.21	0.83
Minimum	0.03	0.07	0.03	0.04	0.12
N	49	49	49	49	11

Table 3.5.5a Summary of precision based on the replicate analyses for unit 1.

	Nitrate	Nitrite	Silicate	Phosphate	Ammonium
	CV%	CV%	CV%	CV%	CV%
Median	0.10	0.17	0.10	0.09	0.42
Mean	0.11	0.17	0.10	0.10	0.41
Maximum	0.17	0.27	0.20	0.14	0.83
Minimum	0.03	0.07	0.03	0.05	0.12
N	24	24	24	24	9

Table 3.5.5b Summary of precision based on the replicate analyses for unit 2.

	Nitrate	**Nitrite**	**Silicate**	**Phosphate**	**Ammonium**
	CV%	**CV%**	**CV%**	**CV%**	**CV%**
Median	0.11	0.18	0.10	0.13	0.27
Mean	0.12	0.18	0.10	0.13	0.27
Maximum	0.19	0.34	0.15	0.21	0.27
Minimum	0.07	0.07	0.07	0.04	0.26
N	25	25	25	25	2

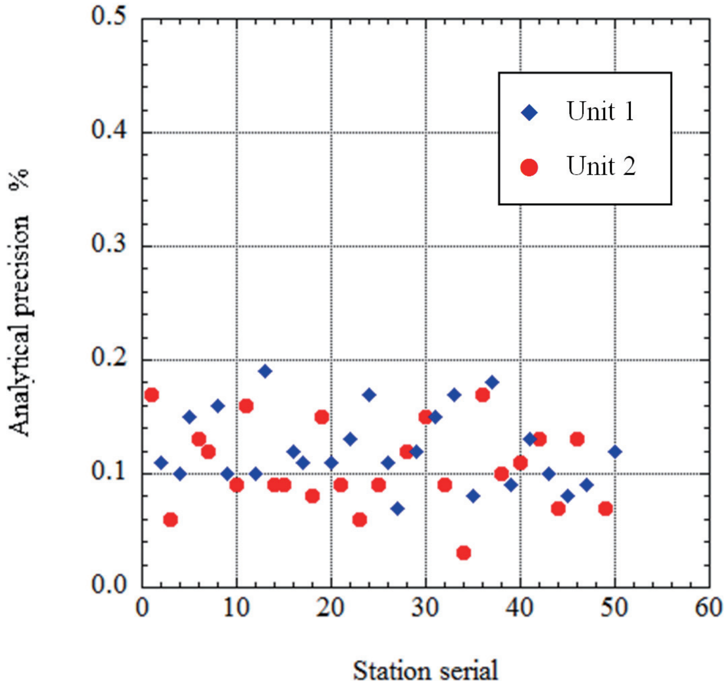

Figure 3.5.6 Time series of precision of nitrate in MR1505.

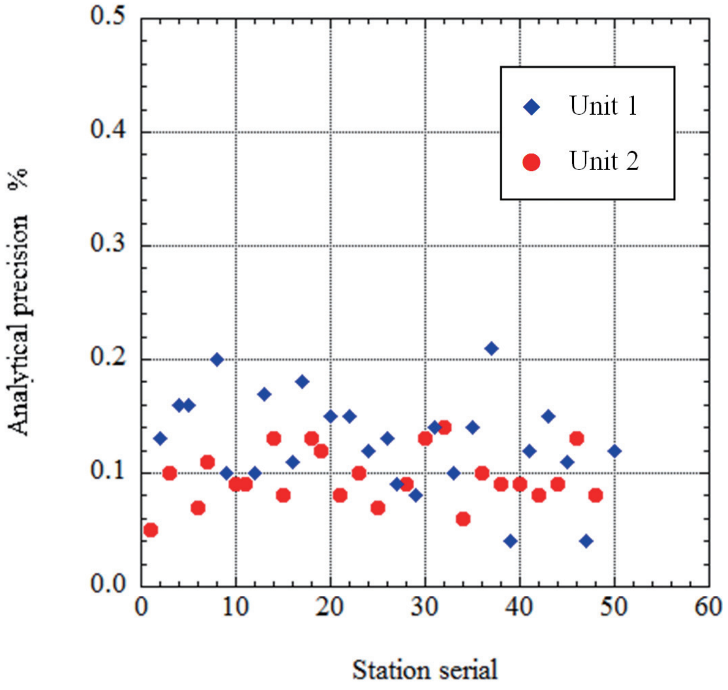

Figure 3.5.7 Time series of precision of phosphate in MR1505.

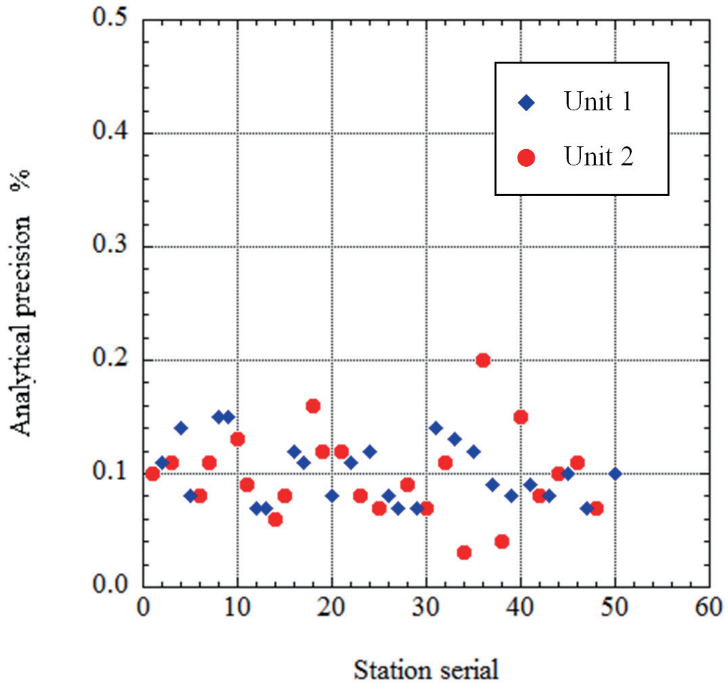

Figure 3.5.8 Time series of precision of silicate in MR1505.

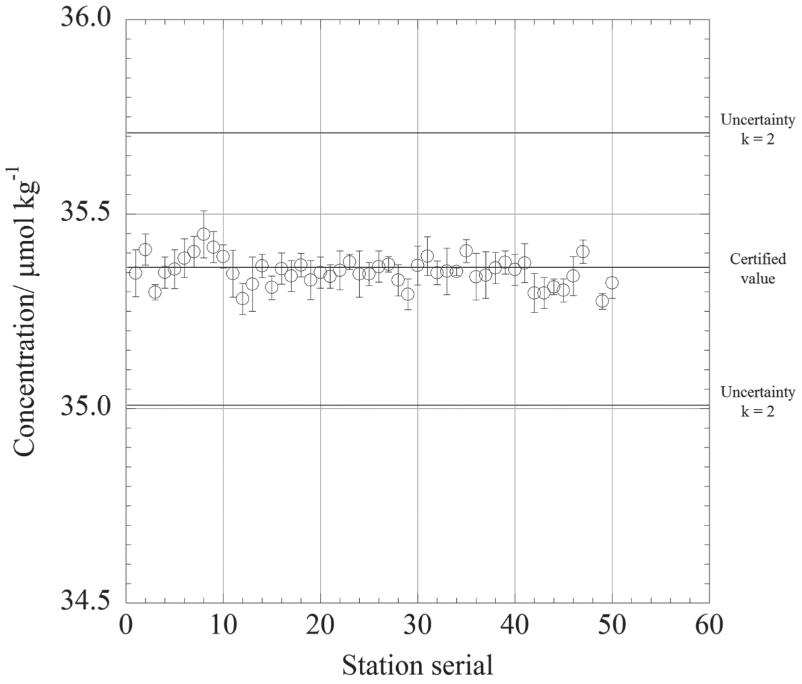

Figure3.5.9 Time series of CRM-BV of nitrate in MR1505.

(7.2) CRM lot. BV measurement during this cruise

CRM lot. BV was measured every run to monitor the comparability among runs. The results of lot. BV during this cruise are shown as Figures 3.5.9 to 3.5.11. Error bars represent analytical precision in figure 3.5.6 to 3.5.8.

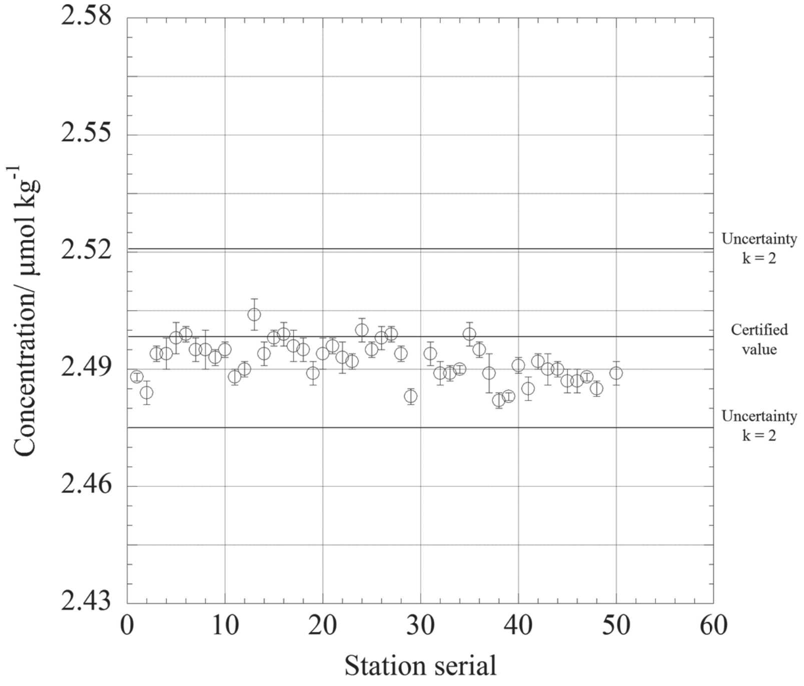

Figure 3.5.10 Time series of CRM-BV of phosphate in MR1505.

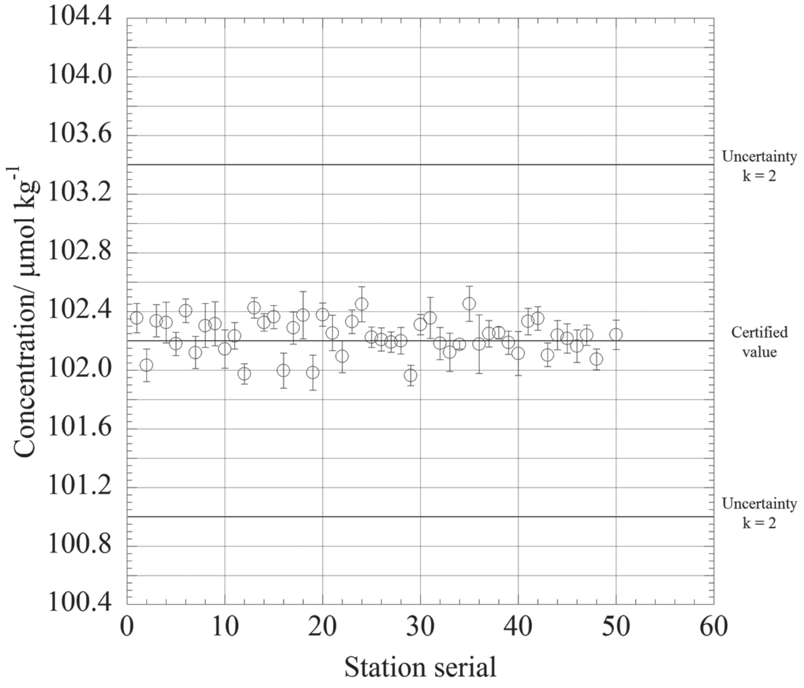

Figure 3.5.11 Time series of CRM-BV of silicate in MR1505.

(7.3) Carryover

We can also summarize the magnitudes of carryover throughout the cruise. These are small enough within acceptable levels as shown in Table 3.5.8 and Figures 3.5.12 to 3.5.14. The carryover in nitrate and silicate had a bias by equipments. It was 0.06% and 0.05%, mean value, at Unit 2. The other hand, it was 0.17% and 0.13%, mean value, at Unit 1. We carried out the maintenance for Unit 1 by changing for new glass coils and new transmission tube before the stn. 22. The bias was clearly solved by the maintenance.

Table 3.5.6 Summary of carry over throughout MR1505.

	Nitrate	Nitrite	Silicate	Phosphate	Ammonium
	CV%	CV%	CV%	CV%	CV%
Median	0.10	0.11	0.07	0.10	0.42
Mean	0.12	0.10	0.09	0.11	0.39
Maximum	0.28	0.40	0.23	0.17	0.67
Minimum	0.03	0.00	0.03	0.05	0.08
N	49	49	49	49	11

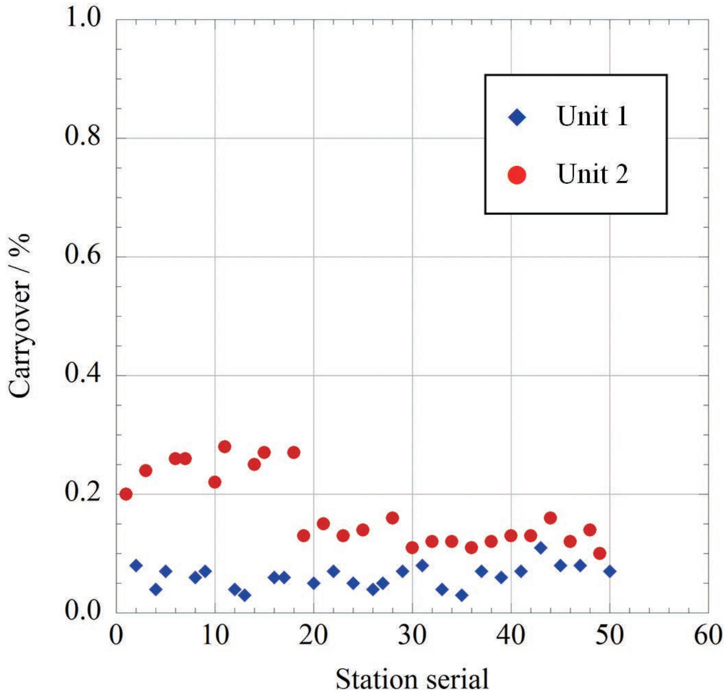

Figure 3.5.12 Time series of carryover of nitrate in MR1505.

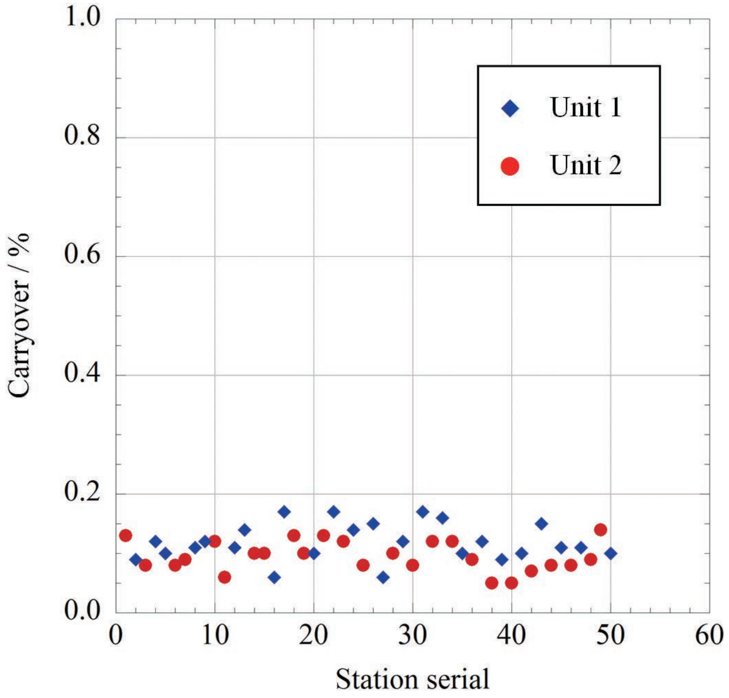

Figure 3.5.13 Time series of carryover of phosphate in MR1505.

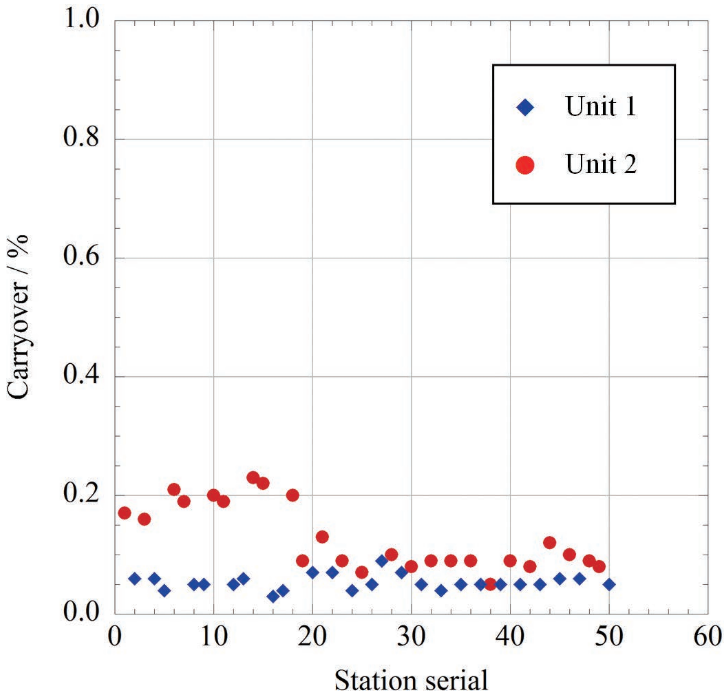

Figure 3.5.14 Time series of carryover of silicate in MR1505.

(7.4) Estimation of uncertainty of phosphate, nitrate and silicate concentrations

Empirical equations, eq. (1), (2) and (3) to estimate uncertainty of measurement of phosphate, nitrate and silicate are used based on measurements of 24 sets of CRMs during this cruise. Empirical equations, eq. (4) and (5) to estimate uncertainty of measurement of nitrite and ammonium are used based on duplicate measurements of the samples. These empirical equations and graphic presentation of equations are as follows, respectively.

Phosphate Concentration Cp in µmol kg^{-1}:

Uncertainty of measurement of phosphate (%) =

$0.142 + 0.136 * (1 / Cp) +0.005 * (1 / Cp) * (1 / Cp)$ — (1)

where Cp is phosphate concentration of sample.

Nitrate Concentration Cno_3 in µmol kg^{-1}:

Uncertainty of measurement of nitrate (%) =

$0.08 + 1.49 * (1 / Cno_3) + 0.02 * (1 / Cno_3) *(1 / Cno_3)$ — (2)

where Cno_3 is nitrate concentration of sample.

Silicate Concentration Cs in µmol kg^{-1}:

Uncertainty of measurement of silicate (%) =

$0.11 + 0.96 * (1 / Cs) + 3.74 * (1 / Cs) * (1 / Cs)$ — (3)

where Cs is silicate concentration of sample.

Nitrite Concentration Cno_2 in µmol kg^{-1}:

Uncertainty of measurement of nitrite (%) =

$- 0.10 + 0.18 * (1 / Cno_2) + 0.000022 * (1 / Cno_2) * (1 / Cno_2)$ — (4)

where Ca is ammonium concentration of sample.

Ammonium Concentration Ca in µmol kg^{-1}:

Uncertainty of measurement of ammonium (%) =

$10.8 + 0.9 * (1 / Ca) + 0.003 * (1 / Ca) * (1 / Ca)$ — (5)

where Ca is ammonium concentration of sample.

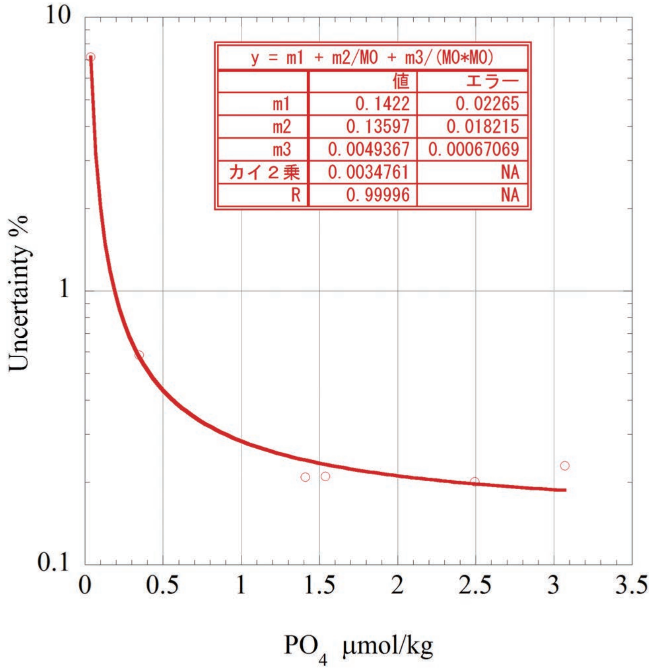

Figure 3.5.15 Estimation of uncertainty for phosphate in MR1505.

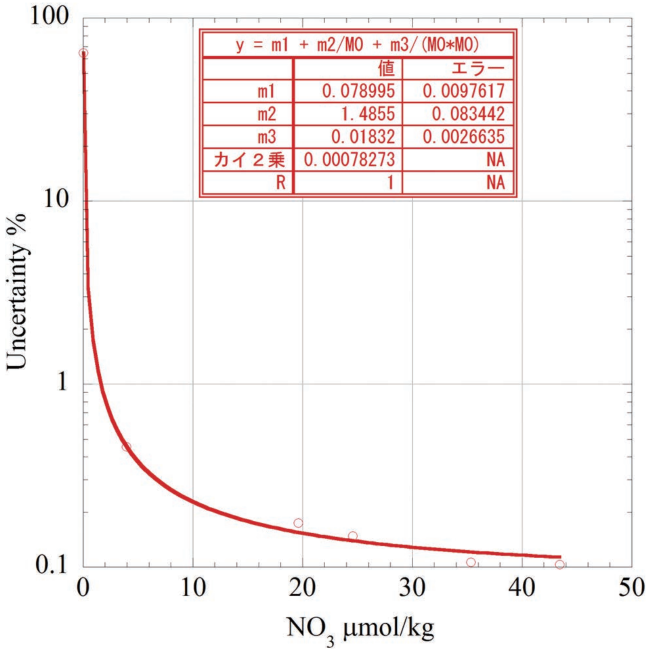

Figure 3.5.16 Estimation of uncertainty for nitrate in MR1505.

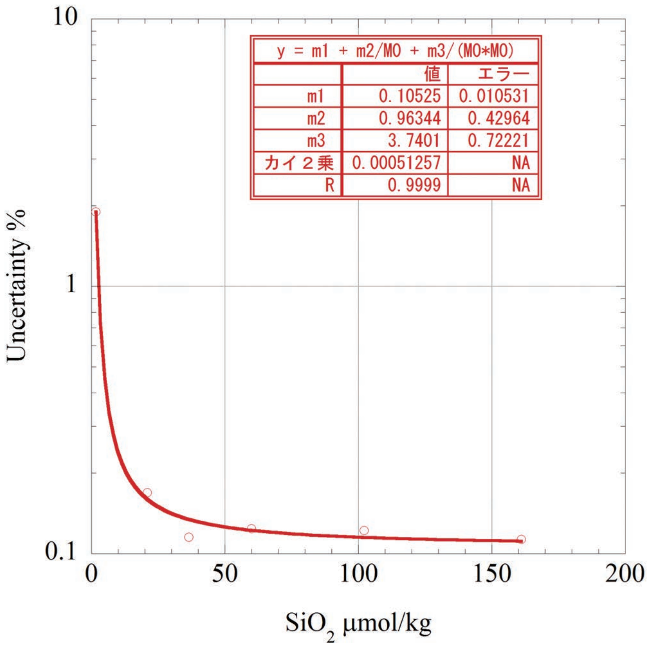

Figure 3.5.17 Estimation of uncertainty for silicate in MR1505.

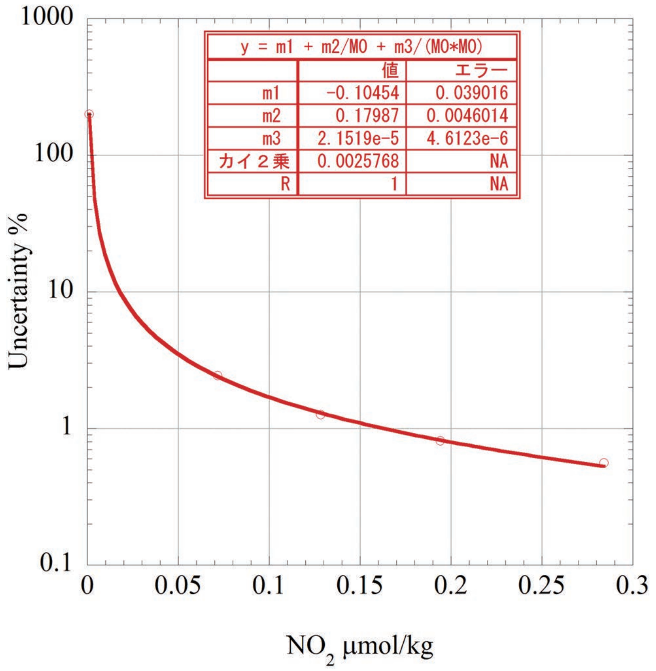

Figure 3.5.18 Estimation of uncertainty for nitrite in MR1505.

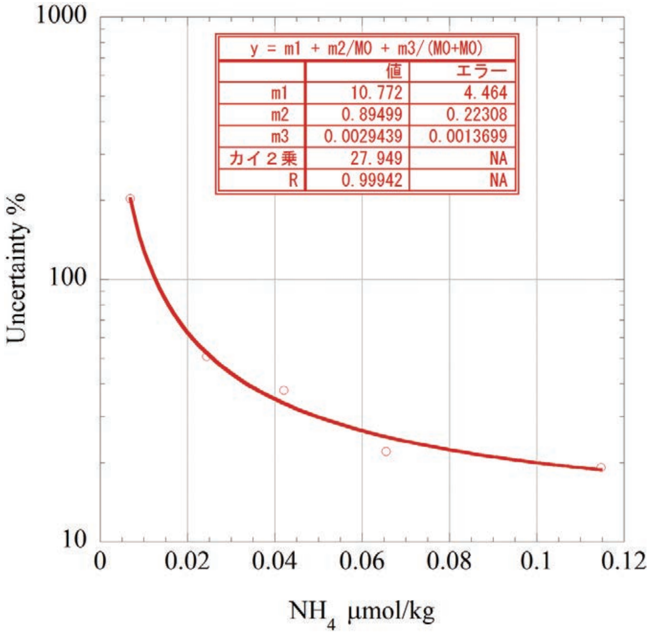

Figure 3.5.19 Estimation of uncertainty for ammonium in MR1505.

(8) Problems / improvements occurred and solutions

(8.1) squashed air tube

We found that peak shape at 1ch became broad in the middle of run for stn. 50. And segment air into inlet were too small. Then we found air tube to inlet was squashed by manifold cover. Because samples concentration of broad peak shape were lower than same samples of normal peak shape, we analysed again all samples of stn. 50. We accepted NO_3 data of second run and others of first run for stn. 50.

(8.2) Phosphate channel

Phosphate channel we observe slightly higher concentration of 0.015 µmol kg^{-1} for lot BZ in terms of average of 49 runs, and slightly lower concentration of 0.006 µmol kg^{-1} for lot BV in terms of average of 50 runs respectively. Most likely reason of these differences we found state above is optics/electronics malfunction of this channel of this analyzers.

(8.3) Improvement of reduction rate at nitrate measurement

Because of decrease of absorbance of maximum concentration of in-house standard solution, we changed a kind of pumptube of sample line at 1ch from ORG/WHT to ORG/YEL. In using ORG/WHT pumptube, absorbance of maximum concentration of In-house standard solution was nearly 0.2. after changed, absorbance was 1.2. As flow rate of sample became more slowly, we achieved a good stable and high reduction rate which was 99.7% (+ 0.4% - 0.7%) in terms of mean of 50 runs during this cruise.

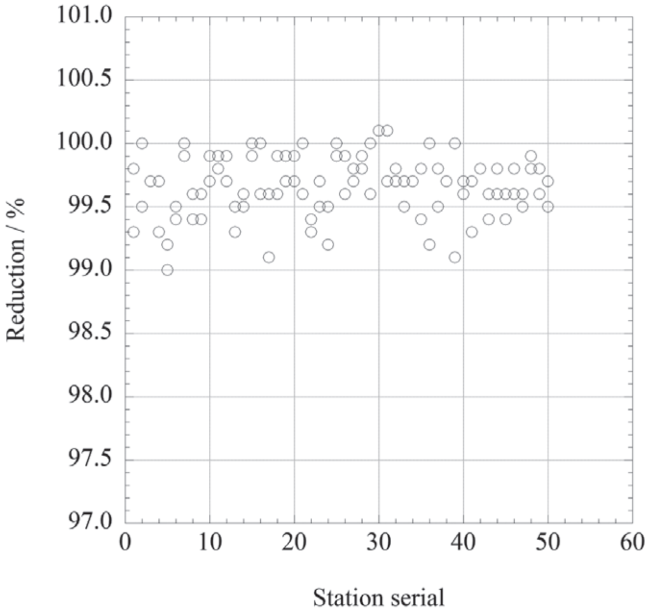

Figure 3.5.20 Time series of reduction of nitrate in MR1505.

(9) Data archive

All data will be submitted to JAMSTEC Data Management Office (DMO) and is currently under its control.

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3.6 Chlorofluorocarbons and Sulfur hexafluoride

January 24, 2018

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(2) Objectives

Chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF_6) are man-made stable gases. These atmospheric gases can slightly dissolve in sea surface water by air-sea gas exchange and then are spread into the ocean interior. So, these dissolved gases could be used as chemical tracers for the ocean circulation. We measured concentrations of three chemical species of CFCs, CFC-11 (CCl_3F), CFC-12 (CCl_2F2), and CFC-113 ($C_2Cl_3F_3$), and SF_6 in seawater on board, and made simultaneous analysis of dissolved nitrous oxide (N_2O) for a certain number of seawater samples as the trial examination.

(3) Apparatus

We used three measurement systems. One of them was CFCs analyzing system (call as system D). Other two were SF_6 – CFCs simultaneous analyzing systems (called as system A and B). Trial analysis of N_2O was made on latter systems. Both systems are based on purging and trapping – electron capture detector (ECD) – gas chromatography. The instruments are summarized in table 3.6.1 and 3.6.2.

Table 3.6.1. Instruments and analytical columns for the system A and B.

Gas Chromatograph:	GC-14B (Shimadzu Ltd.)
Detector 1&2:	ECD-14 (Shimadzu Ltd.)
Analytical Columns:	
Pre-column 1:	Silica Plot capillary column [i.d.: 0.53 mm, length: 6 m, film thickness: 6 µm]
Pre-column 2:	Molesive 5A Plot capillary column [i.d.: 0.53 mm, length: 5 m, film thickness: 15 µm]
Main column 1&2:	Connected two capillary columns (Pora Bond-Q [i.d.: 0.53mm, length: 9 m, film thickness: 10µm] followed by Silica Plot [i.d.: 0.53mm, length: 18 m, film thickness: 6µm])
Purging & trapping:	Developed in JAMSTEC. Cold trap columns are 30 cm length stainless steel tubing packed the section of 5cm with 80/100 mesh Porapak Q and followed by the section of 5cm of 100/120 mesh Carboxen 1000. Outer diameters of the main and focus trap columns are 1/8" and 1/16", respectively.

Table 3.6.2. Instruments and analytical columns for system D.

Gas Chromatograph:	GC-14B (Shimadzu Ltd.)
Detector:	ECD-14 (Shimadzu Ltd.)
Analytical Columns:	
Pre-column:	Silica Plot capillary column [i.d.: 0.53mm, length: 6 m, film thickness: 6µm]
Main column:	Connected two capillary columns (Pora Bond-Q [i.d.: 0.53mm, length: 9 m, film thickness: 10µm] followed by Silica Plot [i.d.: 0.53mm, length: 18 m, film thickness: 6µm])
Purging & trapping:	Developed in JAMSTEC. Cold trap columns are 1/16" SUS tubing packed the section of 5cm with 100/120 mesh Porapak T.

(4) Shipboard measurement

(4.1) Sampling

Seawater sub-samples were collected from 12 liter Niskin bottles to 450 ml of glass bottles developed in JAMSTEC. The glass bottles were filled by CFC free gas (pure nitrogen gas) before sampling. Two times of the bottle volume of seawater sample were overflowed. The seawater samples in the bottle were kept in water bath controlled at 7°C until analysis. The samples were analyzed as soon as possible after sampling (usually within 12 hours).

In order to confirm stabilities of standard gas composition and also to check saturation levels of the components in sea surface water, mixing ratios of the compounds in background air were measured in almost every offshore station. The end of 10 mm OD Dekaron tubing was put on a head of the compass deck and another end was connected onto the air pump in the laboratory. Air samples were continuously led into laboratory by the pump. The tubing was relayed by a T-type union which had a small stop cock. Air sample was collected from the flowing air into a 200ml glass cylinder attached on the cock. The Air samples were analyzed as soon as possible after sampling (usually within 10 minutes).

(4.2) Analysis

i. SF_6 – CFCs (– N_2O) simultaneous analyzing system (System A and B)

Constant volume of sample water (200 ml) was taken into a sample loop. The sample was sent into a stripping chamber and dissolved SF_6, CFCs and N_2O were de-gassed by N_2 gas purging for 8 minutes. The gas sample was dried by magnesium perchlorate desiccant and concentrated on a main trap column cooled down to -80 °C. Stripping efficiencies were frequently confirmed by re-stripping of surface layer samples and more than 99 % of dissolved SF6 and CFCs were extracted on the first purge. As mentioned later, analysis of N_2O had been unsuccessful (and stripping efficiency of N_2O was unknown). Following purging & trapping, the main trap column was isolated and electrically heated to 170 °C. After 1 minute, the desorbed gases were sent onto focus trap cooled down to -80 °C for 30 seconds. Gaseous sample on the focus trap were desorbed by same manner as that on the main trap, and lead onto the pre-column 1 (PC 1). Sample gases were roughly separated on the PC 1. Eluting SF_6 and CFCs onto pre-column 2 (PC 2), PC1 was connected to cleaning line and high boiling point compounds on the PC1 were flushed by counter flow of pure nitrogen gas. SF6 and CFCs were rapidly eluted from PC 2 onto main-column 1 (MC 1) and N_2O was retained on PC 2. Then PC 2 was connected back-flush carrier gas line and N_2O was sent onto main-column 2 (MC 2). SF_6 and CFCs were further separated on MC 1 and detected by ECD 1. N_2O on MC 2 was sent into ECD 2. Nitrogen gases used in these systems was filtered by gas purifier column packed with Molecular Sieve 13X (MS-13X). SF_6 and CFCs measurements were calibrated using gas phase mixture standard prepared by gravimetric method.

Measurement conditions for the systems are listed in table 3.6.3. Standard gas cylinders used in this cruise are listed in table 3.6.4.

Table 3.6.3. Measurement conditions for system A and B.

Temperature	
Analytical Column:	95 °C
Detector (ECD):	300 °C
Trap column:	-80 °C (at adsorbing) & 170 °C (at desorbing)
Mass flow rates of nitrogen gas (99.99995%)	
Carrier gas 1:	10 ml/min
Carrier gas 2:	10 ml/min
Detector make-up gas 1:	27 ml/min
Detector make-up gas 2:	27 ml/min
Back flush gas:	10 ml/min
Sample purge gas:	220 ml/min

Table 3.6.4. Standard gases List (supplied by Japan Fine Products co. Ltd.)

Cylinder No.	Base gas	CFC-11	CFC-12	CFC113	SF_6	N_2O	remarks
		ppt	ppt	ppt	ppt	ppm	
CPB28497	N_2	901	485	78.8	10.10	14.9	for system A&B
CPB26840	N_2	889	81	81.4	9.98	14.9	for system A&B
CPB16993	N_2	300	0	29.9	0.0	0.0	for system D
CPB15651	N_2	300	1	29.8	0.0	0.0	Reference

ii. CFCs analyzing system (System D)

Constant volume of sample water (50 ml) was taken into a sample loop. The sample was send into stripping chamber and dissolved CFCs were de-gassed by N_2 gas purging for 8 minutes. The gas sample was dried by magnesium perchlorate desiccant and concentrated on a trap column cooled down to -50 °C. Stripping efficiencies were frequently confirmed by re-stripping of surface layer samples and more than 99.5 % of dissolved CFCs were extracted on the first purge. Following purging & trapping, the trap column was isolated and electrically heated to 140 °C. The desorbed gases were lead onto the pre-column. Sample gases were roughly separated in the pre-column. When CFC-113 completely eluted from pre-column onto main column, the pre-column was connected onto another line and other compounds were flushed by counter flow of pure nitrogen gas. CFCs sent on MC 1 were further separated and detected by ECD. Nitrogen gases used in this system was also filtered by MS-13X gas purifier column.

Measurement conditions for this system are listed in table 3.6.5.

Table 3.6.5. Measurement conditions for system D

Temperature	
Analytical Column:	95 °C
Detector (ECD):	240 °C
Trap column:	-50 °C (at adsorbing) & 140 °C (at desorbing)
Mass flow rates of nitrogen gas (99.99995%)	
Carrier gas :	10 ml/min
Detector make-up gas :	27 ml/min
Back flush gas:	10 ml/min
Sample purge gas:	130 ml/min

(5) Major problems in analyses

i. CFC-113

For the samples from layers shallower than several hundred meters depth, CFC-113 could not be quantified by system D due to the unknown interference peak (Flag 5). In systems A and B, such interference was not observed. This difference could be due to whether Molesive 5A Plot was incorporated in the analytical column or not.

ii. N_2O

Chromatogram peaks of N_2O for seawater samples were one order of magnitude higher than those for standard gases prepared to usual concentration in seawater (e. g. Weiss and Price, 1980). As a result of experiments after return to a laboratory on land, it turned out to be due to interfering substances.

N_2O measurements are not reported here.

(6) Quality control

i. Blanks

Blank values of SF_6 and CFCs were estimated from the measurements of deep water (sigma-theta > 27.7 kg/m^3) and subtracted from all data. Slightly high concentration of CFC-12 was found in the deep water at stations 22-32, although the reason was unclear. The CFC-12 blank were calculated except data from these stations. Such high concentrations in the deep water were not found in the other compounds. Estimated blank values were 0.023 +/-0.018 fmol kg^{-1} for SF_6 (1 fmol = 1 x 10^{-15} mol), 0.013 +/- 0.002 pmol kg^{-1} for CFC-11 (1 pmol = 1 x 10^{-12} mol), 0.005 +/- 0.001 pmol kg^{-1} for CFC-12, and 0.001+/- 0.001 pmol kg^{-1} for CFC-113.

ii. Background air

In order to check saturation levels of SF_6 and CFCs in surface water, background air samples were analyzed for almost all offshore stations. Average mixing ratios of the compounds were calculated to be 229.1 +/- 5.6 ppt for CFC-11 (n = 48), 522.4 +/- 5.3 ppt for CFC-12 (n = 48), 72.1 +/- 2.7 ppt for CFC-113 (n = 48), and 9.03 +/-0.08 ppt for SF_6 (n = 33),in this cruise.

iii. Precisions

The precisions of measurements were calculated from replicate measurements. The estimated values are +/-0.005 pmol kg^{-1} or 1% (which ever grater) for CFC-11, +/-0.003 pmol kg^{-1} or 1% (which ever grater) for CFC-12, +/-0.003 pmol kg^{-1} or 3% (which ever grater) for CFC-113, and +/-0.03 fmol kg^{-1} or 2% (which ever grater) for SF_6.

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3.7 Carbon Items (C_T, A_T and pH)

December 6, 2017

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(2) Objectives

Concentrations of CO_2 in the atmosphere are now increasing at a rate of about 2.0 ppmv y^{-1} owing to human activities such as burning of fossil fuels, deforestation, and cement production. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO_2, and to clarify the mechanism of the CO_2 absorption, because the magnitude of the anticipated global warming depends on the levels of CO_2 in the atmosphere, and because the ocean currently absorbs 1/3 of the 6 Gt of carbon emitted into the atmosphere each year by human activities.

The eastern part of the Indian Ocean is one of the regions where uncertainty of uptake of anthropogenic CO_2 is large. In this cruise, therefore, we were aimed at quantifying how much anthropogenic CO_2 was absorbed in the ocean interior of the eastern part of the Indian Ocean. For the purpose, we measured CO_2-system parameters such as dissolved inorganic carbon (C_T), total alkalinity (A_T) and pH along the WHP I10 section in the region.

(3) Apparatus

i. C_T

Measurement of C_T was made with a total CO_2 measuring system (called as System D, Nippon ANS, Inc.). The system comprised of a seawater dispensing system, a CO_2 extraction system and a coulometer. In this cruise, we used a coulometer Model 3000, which was constructed by Nippon ANS. The systems had a specification as follows:

The seawater dispensing system has an auto-sampler (6 ports), which dispenses seawater from a 300 ml borosilicate glass bottle into a pipette of about 15 ml volume by PC control. The pipette is kept at 20 °C by a water jacket, in which water from a water bath set at 20 °C is circulated. CO_2 dissolved in a seawater sample is extracted in a stripping chamber of the CO_2 extraction system by adding phosphoric acid (~ 10 % v/v) of about 2 ml. The stripping chamber is approx. 25 cm long and has a fine frit at the bottom. The acid is added to the stripping chamber from the bottom of the chamber by pressurizing an acid bottle for a given time to push out the right amount of acid. The pressurizing is made with nitrogen gas (99.9999 %). After the acid is transferred to the stripping chamber, a seawater sample kept in a pipette is introduced to the stripping chamber by the same method as in adding an acid. The seawater reacted with phosphoric acid is stripped of CO_2 by bubbling the nitrogen gas through a fine frit at the bottom of the stripping chamber. The CO_2 stripped in the chamber is carried by the nitrogen gas (flow rates is 140 ml min^{-1}) to the coulometer through a dehydrating module. The module consists of two electric dehumidifiers (kept at ~2 °C) and a chemical desiccant ($Mg(ClO_4)_2$).

The measurement sequence such as system blank (phosphoric acid blank), ~1.5 % CO_2 gas in a nitrogen base, sea water samples (6) is programmed to repeat. The measurement of ~1.5 % CO_2 gas is made to monitor response of coulometer solutions purchased from UIC.

ii. A_T

Measurement of A_T was made based on spectrophotometry using a custom-made system (Nippon ANS, Inc.). The system comprises of a water dispensing unit, a HCl titration unit (Hamilton No.2), and a detection unit of a spectrophotometer (TM-UV/VIS C10082CAH, Hamamatsu Photonics, Japan) and an optical source (Mikropack, Germany). The system was automatically controlled by a PC. The water dispensing unit had a water-jacketed pipette and a water-jacketed glass titration cell.

A seawater of approx. 42 ml was transferred from a sample bottle (borosilicate glass bottle; maximum

= ~130 ml) into the water-jacketed (25 °C) pipette by pressurizing the sample bottle (nitrogen gas), and was introduced into the water-jacketed (25 °C) glass titration cell. The introduced seawater was used to rinse the titration cell. After dumping the seawater used for rinse, Milli-Q water was introduced into the titration cell to rinse it. The rinse by Milli-Q water is repeated twice. Then, a seawater of approx. 42 ml was weighted again by the pipette, and was transferred into the titration cell. Then, for seawater blank, absorbances were measured at three wavelengths (730, 616 and 444 nm). After the measurement, an acid titrant, which was a mixture of approx. 0.05 M HCl in 0.65 M NaCl and bromocresol green (BCG), was added into the titration cell. The volume of acid titrant solution was changed according to expected values of A_T from approx. 2.2 ml to 2.0 ml. The seawater and acid titrant were mixed for 5 minutes by a stirring tip and bubbling by nitrogen gas in the titration cell. Then, absorbances at the three wavelengths were measured again.

Calculation of A_T was made by the following equation:

$$\mathrm{A_T} = (-[\mathrm{H^+}]_\mathrm{T}\mathrm{V_{SA}} + \mathrm{M_A V_A}) / \mathrm{V_S},$$

where M_A is the molarity of the acid titrant added to the seawater sample, $[H^+]_T$ is the total excess hydrogen ion concentration in the seawater, and V_S, V_A and V_{SA} are the initial seawater volume, the added acid titrant volume, and the combined seawater plus acid titrant volume, respectively. $[H^+]_T$ is calculated from the measured absorbances based on the following equation (Yao and Byrne, 1998):

$$\begin{aligned}\mathrm{pH_T} &= -\log[\mathrm{H^+}]_\mathrm{T} = 4.2699 + 0.002578(35-\mathrm{S}) + \log((\mathrm{R}-0.00131)/(2.3148-0.1299\mathrm{R})) \\ &\quad -\log(1-0.001005\mathrm{S}),\end{aligned}$$

where S is the sample salinity, and R is the absorbance ratio calculated as:

$$\mathrm{R} = (\mathrm{A_{616}} - \mathrm{A_{750}})/(\mathrm{A_{444}} - \mathrm{A_{750}}),$$

where Ai is the absorbance at wavelength i nm.

The HCl in the acid titrant was standardized on land (0.049992 mol L^{-1}). The concentrations of BCG were estimated to be approx. 2.0×10^{-6} mol L^{-1} in the sample seawater, respectively.

iii. pH

Measurement of pH was made by a pH measuring system (Nippon ANS, Inc.). For the detection of pH, spectrophotometry is adopted. The system comprises of a water dispensing unit and a spectrophotometer (Bio 50 Scan, Varian). For an indicator, m-cresol purple (2 mM), which is purified based on Patsavas et al. (2013), is used.

Seawater is transferred from borosilicate glass bottle (250 ml) to a sample cell in the spectrophotometer. The length and volume of the cell are 8 cm and 13 ml, respectively, and the sample cell is kept at 25.00 ± 0.05 °C in a thermostated compartment. First, absorbance of seawater only is measured at three wavelengths (730, 578 and 434 nm). Then the indicator is injected and circulated for about 4 minutes to mix the indicator and seawater sufficiently. After the pump is stopped, the absorbance of seawater + indicator is measured at the same wavelengths. The pH is calculated based on the following equation (Liu et al., 2011):

$$\mathrm{pH_T} = -\log(K_2^T e_2) + \log\left(\frac{R - e_1}{1 - R(e_3/e_2)}\right),$$

where $-\log(K_2^T e_2) = a + (b/T) + c\times\ln T - d\times T$; $a = -246.64209 + 0.315971\times S + 2.86855 \times 10^{-4}\times S^2$; $b = 7229.23864 \times 7.098137 \times S - 0.057034\times S^2$; $c = 44.493382 - 0.052711\times S$; $d = 0.007762$; $e_1 = -0.007762 + 4.5174 \times 10^{-5}T$; $e_3/e_2 = -0.020813 + 2.60262 \times 10^{-4}\times T + 1.0436 + 10^{-4}\times(S - 35)$. The T and S indicate temperature in K and salinity, respectively. The K_2^T is the dissociation constant of HI^-, which is a protonated species of sulfonephthalein indicators. The R is the ratio of sulfonephtalein absorbances (= ${}_{578}A/{}_{433}A$) at wavelengths of 578 nm and 434 nm.

(4) Shipboard measurement

(4.1) Sampling

i. C_T

All seawater samples were collected from depth with 12 liter Niskin bottles basically at every other stations. The seawater samples for C_T were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into a 250 ml DURAN® glass bottle. The glass bottle was filled with seawater smoothly from the bottom following a rinse with seawater of 2 full, bottle volumes. The glass bottle was closed by an inner cap loosely, which was fitted tightly to the bottle mouth after mercuric chloride was added.

At a chemical laboratory on ship, a volume of about 3mL seawater was removed with a plastic pipette from sampling bottles to have a headspace of approx. 1% of the bottle volume. A saturated mercuric chloride of 100 µl was added to poison seawater samples. The seawater samples were kept at 5°C in a refrigerator until analysis. A few hours just before analysis, the seawater samples were kept at 20°C in a water bath.

ii. A_T

All seawater samples were collected from depth using 12 liter Niskin bottles at the same stations as for C_T. The seawater samples for A_T were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into a 100 ml DURAN® glass bottle. The glass bottle was filled with seawater smoothly from the bottom after rinsing it with seawater of 2 full, bottle volume.

The samples were stored at about 5°C in a refrigerator A few hours before analysis, the seawater samples were kept at 25 °C in a water bath.

iii. pH

All seawater samples were collected from depth with 12 liter Niskin bottles at the same stations as for C_T and A_T. The seawater samples for pH were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into a 250 ml borosilicate glass bottle. The glass bottle was filled with seawater smoothly from the bottom following a rinse with a sea water of 2 full, bottle volumes. The glass bottle was closed by a stopper, which was fitted to the bottle mouth gravimetrically without additional force.

A few hours just before analysis, the seawater samples were kept at 25°C in a water bath.

(4.2) Analysis

i. C_T

At the start of each leg, we calibrated the measuring systems by blank and 5 kinds of Na_2CO_3 solutions (nominally 500, 1000 1500, 2000, 2500 µmol/L). As it was empirically known that coulometers do not show a stable signal (low repeatability) with fresh (low absorption of carbon) coulometer solutions. Therefore, we measured ~1.5% CO_2 gas repeatedly until the measurements became stable. Then we started the calibration.

The measurement sequence such as system blank (phosphoric acid blank), ~1.5% CO_2 gas in a nitrogen base, seawater samples (6) was programmed to repeat. The measurement of ~1.5% CO_2 gas was made to monitor response of coulometer solutions (from UIC, Inc. or in-house made). For every renewal of coulometer solutions, certified reference materials (CRMs, batch 149, certified value = 2011.67 µmol kg^{-1}) provided by Prof. A. G. Dickson of Scripps Institution of Oceanography were analyzed. In addition, in-house reference materials (RM) (batch Q32) were measured at the initial, intermediate and end times of a coulometer solution's lifetime.

The preliminary values were reported in a data sheet on the ship. Repeatability and vertical profiles of C_T based on raw data for each station helped us check performances of the measuring systems.

In the cruise, we finished all the analyses for C_T on board the ship.

ii. A_T

We analyzed reference materials (RM), which were produced for C_T measurement by JAMSTEC, but were efficient also for the monitor of A_T measurement. In addition, certified reference materials (CRM, batches 149, certified value = 2224.69 µmol kg^{-1}) were analyzed periodically to monitor systematic differences of measured A_T. The reported values of A_T were set to be comparable to the certified value of the batch 149.

The preliminary values were reported in a data sheet on ship. Repeatability calculated from replicate samples and vertical profiles of A_T based on raw data for each station helped us check performance of the measuring system.

In the cruise, we finished all the analyses for A_T on board the ship.

iii. pH

For an indicator solution, purified *m*-cresol purple (2 mM) was used. The indicator solution was produced on board a ship, and retained in a 1000 ml DURAN® laboratory bottle. The absorbance ratios of the indicator solution were kept between 1.56 and 1.62 by adding acid or alkali solution appropriately.

It is difficult to mix seawater with an indicator solution sufficiently under no headspace condition. However, by circulating the mixed solution with a peristaltic pump, a well-mixed condition came to be attained rather shortly, leading to a rapid stabilization of absorbance. We renewed a TYGON® tube of a peristaltic pump periodically, when a tube deteriorated. We measured absorbances at 25°C.

Absorbances of seawater only and seawater + indicator solutions were measured 5 times each after stable absorbances were attained, and the averaged values were used for the calculation of pH.

The preliminary values of pH were reported in a data sheet on the ship. Repeatability calculated from replicate samples and vertical profiles of pH based on raw data for each station helped us check performance of the measuring system.

We finished all the analyses for pH on board the ship.

(5) Quality control

i. C_T

We conducted quality control of the data after return to a laboratory on land. With calibration factors, which had been determined on board a ship based on blank and 5 kinds of Na_2CO_3 solutions, we calculated C_T of CRM (batches 149), and plotted the values as a function of sequential day, separating legs and the systems used. There were no statistically-significant trends of CRM measurements.

The repeatability of measurements was estimated to be 0.76 µmol kg^{-1}, which was calculated from 91 differences of replicate measurements.

ii. A_T

Temporal changes of A_T, which originate from analytical problems, were monitored by measuring A_T of CRM. We found no abnormal measurements during the cruises.

The repeatability of measurements was estimated to be 0.91 µmol kg^{-1} which was calculated from 80 differences of replicate measurements.

iii. pH

It is recommended that correction for pH change resulting from addition of indicator solutions is made (Dickson et al., 2007). To check the perturbation of pH due to the addition, we measured absorbance ratios by doubling the volume of indicator solution and added it to a replicate seawater sample. We corrected absorbance ratios based on an empirical method (Dickson et al., 2007), although the perturbations were small. The correction was made by subtracting 0.0028 from measured absorbances. The repeatability of measurements was estimated to be 0.0004 pH unit, which was calculated from 120 differences of replicate measurements.

We evaluated accuracy of pH values by comparing the corrected values with those computed from measured C_T and A_T. The averaged difference (measured – computed) of pH values was 0.0030 ± 0.0073 (n = 816). In addition, we also measured pH of Dickson's CRM batch 149, and compared the calculated pH from the certified C_T and A_T. The averaged difference was 0.0031 ± 0.0010 (n = 3). As a whole, the reported pH values (total scale at 25°C) have a systematic error of ~0.003 pH unit.

References

Clayton T. D. and R. H. Byrne (1993) Spectrophotometric seawater pH measurements: total hydrogen ion concentraion scale calibration of m-cresol purple and at-sea results. Deep-Sea Research 40, 2115-2129.

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Yao, W. and R. B. Byrne (1998) Simplified seawater alkalinity analysis: Use of linear array spectrometers. Deep-Sea Research 45, 1383-1392.

3.8 Calcium and Total alkalinity 2

September 29, 2017

Calcium

(1) Personnel

Etsuro Ono (JAMSTEC)

(2) Objectives

According to the recent IPCC report, concentrations of CO_2 in the atmosphere have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

Ocean acidification is characterized by an increase of H^+ (i.e., a decrease of pH) and a concurrent decrease of carbonate ion concentration (CO_3^{2-}). The decrease of CO_3^{2-} is unfavorable to marine calcifying organisms, which utilize CO_3^{2-}, together with Ca^{2+}, to produce their calcium carbonate ($CaCO_3$) shells and skeletons. To evaluate dissolution and precipitation of calcium carbonate, we measured directly the concentration of calcium in the sea water in the subtropical region of the eastern part of the Indian Ocean.

(3) Apparatus

Measurement of calcium was made by a modified Dissolved Oxygen Titrator DOT-01 (Kimoto Electronic Co. Ltd.). Bandpass filter was replaced to f0=620nm.

Added reagents are as follows.

NH_3/NH_4buffer: 0.4 mol/l NH_4Cl/ 0.4 mol/l NH_3 buffer

Masking agent: 0.05 mol/l 2,2',2''-nitrotriethanol solution

Zincon solution: 0.004 mol/l Zincon

0.0925g Zincon was dissolved 0.8 ml 1M NaOH and was diluted to 50 ml

Zn/EGTA solution: 0.004 mol/l $ZnSO_4$/ 0.004 mol/l EGTA

EGTA titrant: 0.02 mol/l EGTA

The system comprises of a light source, photodiode detectors, auto-burette and control unit. Seawater of accurate 10 ml was transferred from a sample bottle (60ml HDPE bottle) into 100 ml tall beaker by volumetric pipet. A magnetic stirrer bar was added into beaker. 1ml NH_3/NH_4 buffer, 1 ml masking agent, 1 ml Zincon solution, 1 ml Zn/EGTA solution and about 60 ml H_2O were added into the beaker. The seawater samples were titrated by the EGTA titrant. The EGTA titrant was calibrated by 1000 mg/l Ca standard solution (produced by Wako Pure Chemical Industries, Ltd.).

(4) Performances

The system worked well no troubles. The repeatability was estimated to be 0.009±0.008 (n=17 pairs) mmol kg^{-1}.

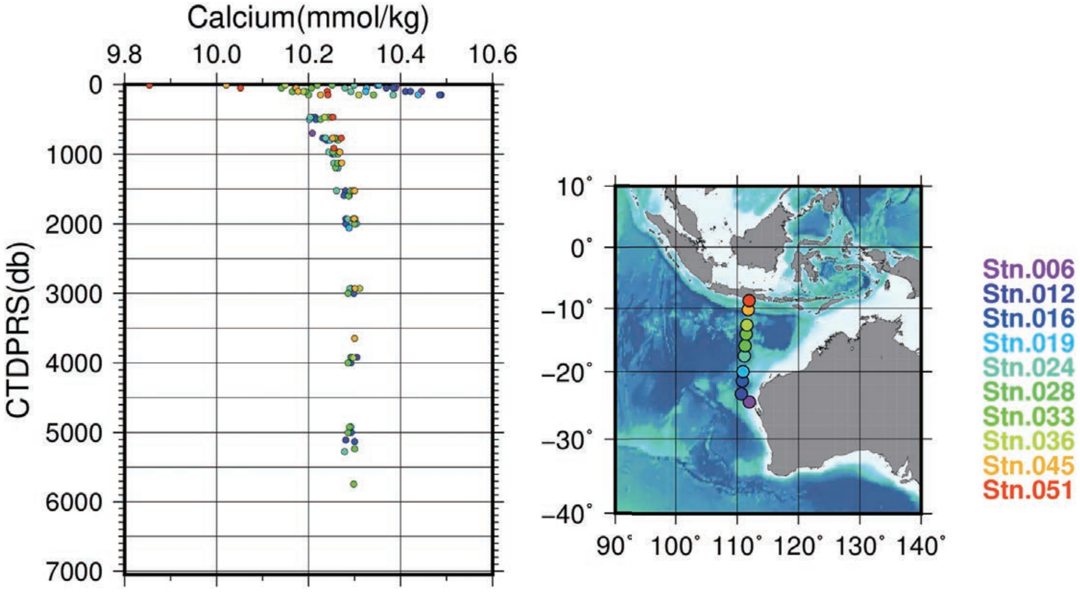

Fig.3.8.1 Vertical profiles of calcium.

Total alkalinity 2

(1) Personnel

Etsuro Ono (JAMSTEC)

(2) Objectives

For the determination of Total Alkalinity (A_T), spectrophotometry is known as more precise and more accurate procedure than potentiometry. On the other hands, potentiometry is still described as recommended standard operating procedures while spectrophotometry is not. The objective of this study is to evaluate the measuring procedures of A_T. At several stations during this cruise, A_T values were measured potentiometrically and compared with that were measured spectrophotometrically.

(3) Instruments

Measurement of A_T was made based on potentiometry with Total Alkalinity Titrator ATT-05 (Kimoto Electronic Co. Ltd.). The system comprises of an auto-burette, combination electrode (pHC2001-8 S/N:13242-F17, S/N:13282-F11, Radiometer analytical) and control unit. The in-house acid solution (approx.0.1 M HCl in 0.6 M NaCl) was prepared as a titrant in advance of this cruise.

(4) Analytical methods

All measurements were carried out with open cell method. Seawater of accurate 50ml was transferred from a sample bottle (glass bottle) into 100 ml tall beaker by volumetric pipet. A magnetic stirrer bar was added into a beaker. A combination electrode and a temperature sensor were immersed in the sample. The seawater samples were titrated by the acid titrant. The acid titrant was calibrated by measuring Dickson's CRM (Batch 149). First, the acid titrant was added until pH of the sample under 3.8 and stirred for 300 seconds. Second, the acid titrant was added by 20 µl at intervals of 15 seconds until reaching pH of 2.8. Values of A_T were computed with a program incorporated in the equipment.

(5) Performances

The electrode of S/N:13242-17, at first, was used at station 06, 12, 16 and 24. However, S/N:13242-17 was replaced with S/N:13282-F11 after the measurements at station 24, because S/N:13242-17 showed such slow a response that some measured values were not computed accurately. The measurements worked well with S/N:13282-F11 at station 28, 33, 36, 45 and 51.

The repeatability was estimated to be 2.5±2.2 (n=15 pairs) µmol kg^{-1}. Differences of A_T (spectrophotometry - potentiometry) were 3.2 ±3.6 µmol kg^{-1}(n=99 pairs).

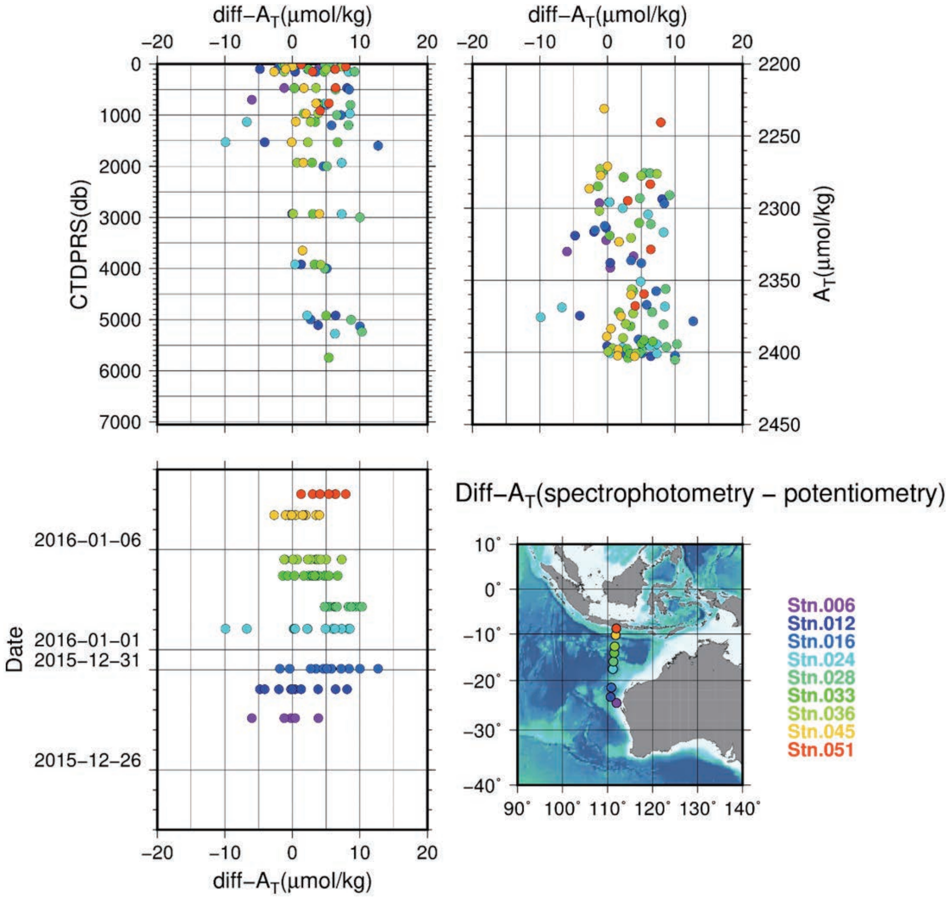

Figure 3.8.2 A_T differences between measurement techniques.

(6) Reference

Dickson, A. G., C. L. Sabine and J. R. Christian eds. (2007), Guide to best practices for ocean CO_2 measurements, PICES Special Publication, Chapter 4, SOP 3b.

3.9 DOC and TDN

October 25, 2017

(1) Personnel

Masahito Shigemitsu	(JAMSTEC): Principal investigator
Chisato Yoshikawa	(JAMSTEC)
Masahide Wakita	(JAMSTEC)
Akihiko Murata	(JAMSTEC)

(2) Objective

Dissolved organic carbon (DOC) and an organic fraction of total dissolved nitrogen (TDN), i.e., dissolved organic nitrogen (DON), are considered to be important reservoirs of carbon and nitrogen in the ocean. They can be substrates for heterotrophic microbial communities and DON can also serve as a source of nitrogenous nutrient to autotrophs in the sunlit nitrogen-deficient regions.

In this cruise, we aimed to gain insights into the amount of DOC and DON transported via the Indonesian throughflow from the Pacific to the Indian ocean, and the interactions between dissolved organic matter (DOC and DON) and heterotrophic/autotrophic micro-organisms in the Indian Ocean.

(3) Sampling

Seawater samples were obtained from Niskin bottles on a CTD-rosette system at 9 stations (Fig. 3.9.1). Each sample taken in the upper 500 m was filtered using a pre-combusted (450 °C for 4 hours) 47-mm Whatman GF/F filter. The filtration was carried out by connecting a spigot of the Niskin bottle through silicone tube to an inline plastic filter holder. Filtrates were collected in acid-washed 60 mL High Density Polyethylene (HDPE) bottles, in duplicate or triplicate, and were immediately stored frozen until analysis. Other samples taken below 500 m were unfiltered and stored in the same way.

(4) DOC and TDN concentrations

The frozen samples were thawed at room temperature, and acidified to pH < 2 with hydrochloric acid. Then, concentrations of DOC and TDN were measured by using a Shimadzu TOC-L system coupled with a Shimadzu Total N analyzer. The instrument conditions were as follows:

Combustion temperature	720 °C
Carrier gas	G1 Air
Carrier flow rate	150ml/min
Ozone generator gas	G3 Oxygen
Ozone flow rate	500ml/min
Sample sparge time	~10min
Minimum number of injections	4
Maximum number of injections	6
CV maximum	2.0%
Injection volume	100µL

Standardization was achieved using glucose for DOC and potassium nitrate for TDN. All DOC and TDN analyses were referenced against reference material provided by Hansell Laboratory, University of Miami. The repeatabilities of DOC and TDN were calculated to be ~1.0 µmol kg^{-1} and ~0.7 µmol kg^{-1}, respectively, by using a statistical procedure (SOP23) in DOC (1994).

(5) Reference

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.

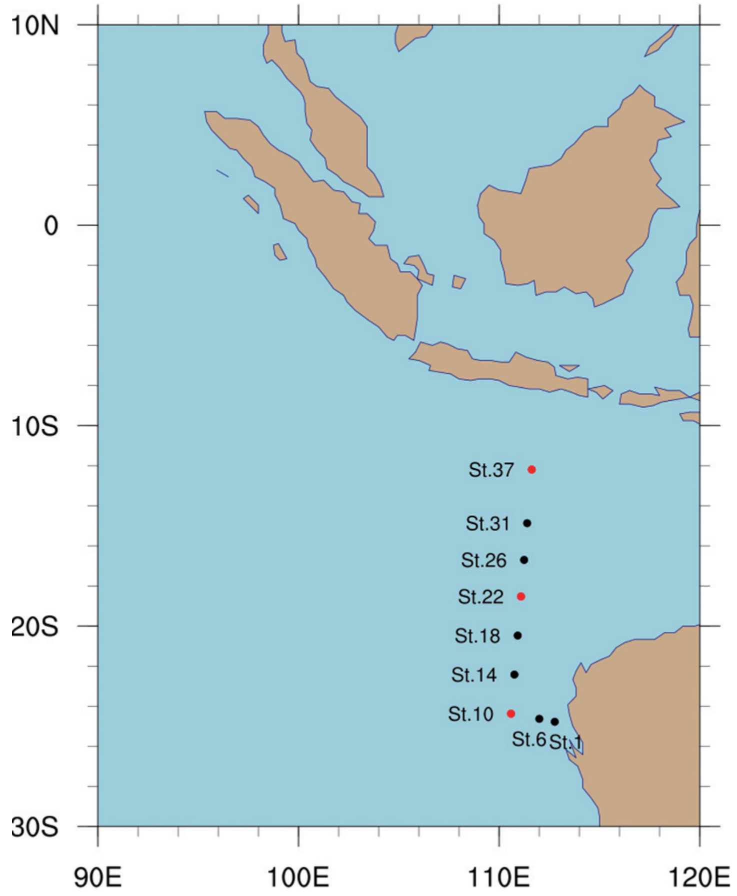

Figure 3.9.1 Map showing the location where samples for DOC and TDN were collected. Filled circles in red indicate the stations where a special cast in addition to a routine cast was carried out.

3.10 Chlorophyll *a*

October 10, 2017

(1) Personnel

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Misato Kuwahara (MWJ)
Masahiro Orui (MWJ)
Haruka Tamada (MWJ)

(2) Objectives

Chlorophyll *a* is one of the most convenient indicators of phytoplankton stock, and has been used extensively for the estimation of phytoplankton abundance in various aquatic environments. In this study, we investigated horizontal and vertical distribution of phytoplankton along the I10 section in the Eastern Indian Ocean. The chlorophyll *a* data is also utilized for calibration of fluorometers, which were installed in the surface water monitoring and CTD profiler system.

(3) Instrument and Method

Seawater samples were collected in 250 ml brown Nalgene bottles without head-space. The whole samples were gently filtrated by low vacuum pressure (< 0.02 MPa) through Whatman GF/F filter (diameter = 25 mm) in the dark room. Whole volume of each sampling bottle was precisely measured in advance. After filtration, phytoplankton pigments were immediately extracted in 7 ml of N,N-dimethylformamide (DMF), and samples were stored at -20°C under the dark condition to extract chlorophyll a more than 24 hours. Chlorophyll *a* concentrations were measured by the Turner fluorometer (10-AU-005, TURNER DESIGNS), which was previously calibrated against a pure chlorophyll *a* (Sigma-Aldrich Co., LLC) (Fig. 3.10.1). To estimate the chlorophyll *a* concentrations, we applied to the fluorometric "Non-acidification method" (Welschmeyer, 1994).

(4) Results

Vertical profiles and cross section of chlorophyll *a* concentrations along the I10 section during the cruise are shown in Figure 3.10.2 and Figure 3.10.3 respectively. To estimate the measurement precision, 48-pairs of replicate samples were obtained from hydrographic casts. All pairs of the replicate samples were collected in 250 ml bottles. Standard deviation calculated from 48-pairs of the replicate samples was 0.078 µg/L and absolute difference values between 45-pairs of the replicate samples were smaller than 0.01 µg/L.

(5) Reference

Welschmeyer, N. A. (1994): Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. Limnor. Oceanogr., 39, 1985-1992.

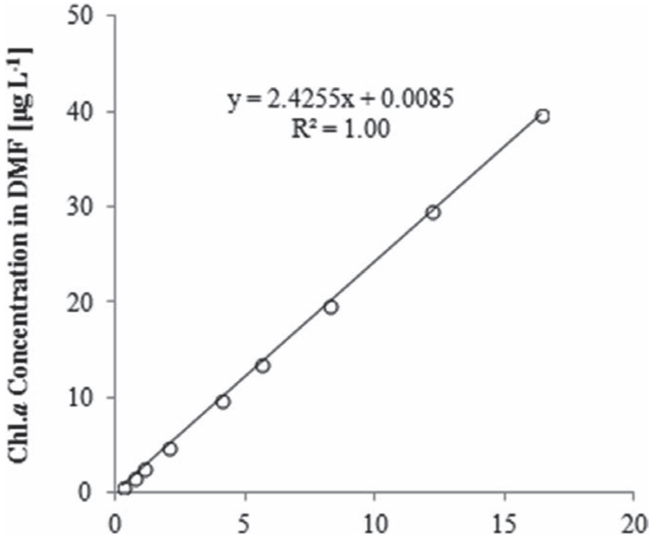

Figure 3.10.1 Relationships between pure chlorophyll *a* concentrations and fluorescence light intensity.

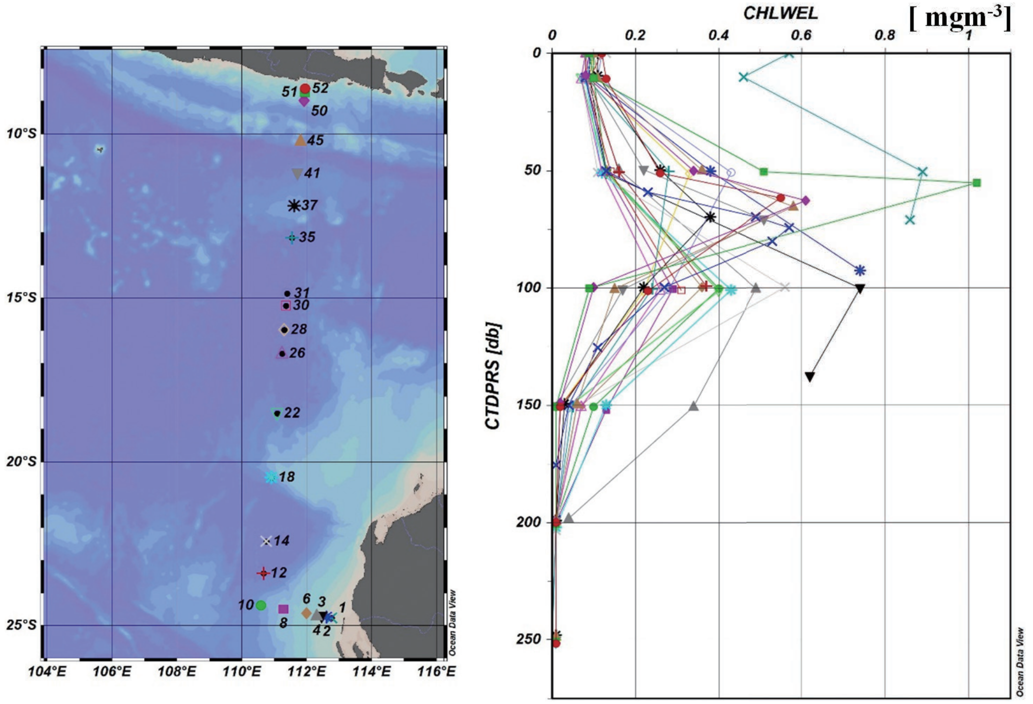

Figure 3.10.2 Vertical profiles of chlorophyll *a* concentrations along the I10 section obtained from hydrographic casts.

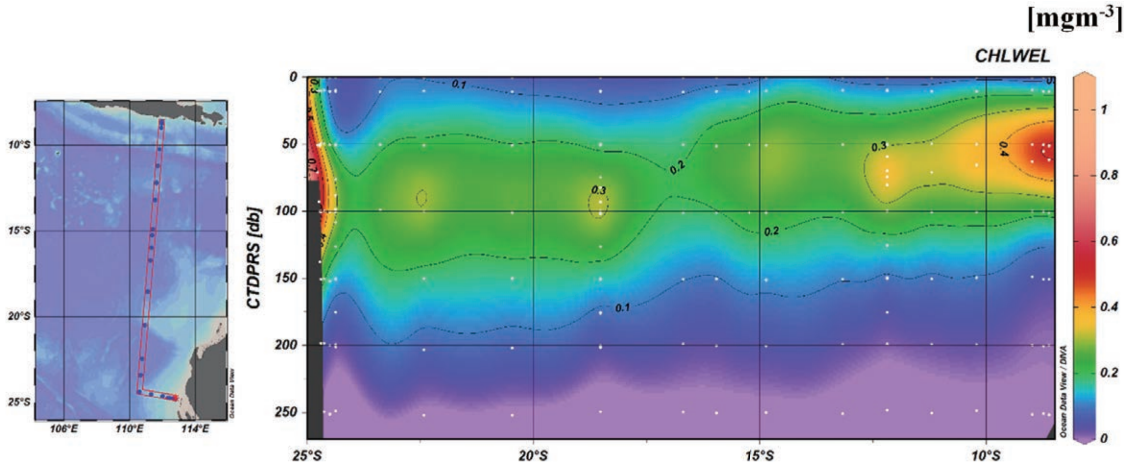

Figure 3.10.3 Cross section of chlorophyll *a* concentrations along the I10 section obtained from hydrographic casts.

3.11 Absorption coefficients of particulate matter and colored dissolved organic matter (CDOM)

October 10, 2017

(1) Personnel

Kosei Sasaoka (JAMSTEC)

(2) Objectives

Absorption coefficients of particulate matter (phytoplankton and non-phytoplankton particles, defined as 'detritus') and colored dissolved organic matter (CDOM) play an important role in determining the optical properties of seawater. In particular, light absorption by phytoplankton is a fundamental process of photosynthesis, and their chlorophyll *a* (Chl-*a*) specific coefficient, a^*_{ph}, can be essential factors for bio-optical models to estimate primary productivities. Absorption coefficients of CDOM are also important parameters to validate and develop the bio-optical algorithms for ocean color sensors, because the absorbance spectrum of CDOM overlaps that of Chl-*a*. The global colored detrital and dissolved materials (CDOM) distribution appears regulated by a coupling of biological, photochemical, and physical oceanographic processes all acting on a local scale, and greater than 50% of blue light absorption is controlled by CDOM (Siegel et al., 2002). Additionally, some investigators have reported that CDOM emerges as a unique tracer for diagnosing changes in biogeochemistry and the overturning circulation, similar to dissolved oxygen (e.g., Nelson et al., 2010). The objectives of this study are to understand the North-South variability of light absorption by phytoplankton and CDOM along the I10 section in the Eastern Indian Ocean.

(3) Methods

Seawater samples for absorption coefficient of total particulate matter ($a_p(\lambda)$) were performed using Niskin bottles and a bucket above 100m depth along the I10 section (Fig. 3.11.1, Table 3.11.1). Samples were collected in 3000ml dark bottles and filtered (1000 - 3000 ml) through 25-mm What-man GF/F glass-fiber filters under a gentle vacuum (< 0.02 MPa) on board in the dark room. After filtration, the optical density of total particulate matter on filter ($OD_{fp}(\lambda)$) between 350 and 750 nm at a rate of 1.0 nm was immediately measured by an UV-VIS recording spectrophotometer (UV-2400, Shimadzu Co.), and absorption coefficient was determined from the OD according to the quantitative filter technique (QFT) (Mitchell, 1990). A blank filter with filtered seawater was used as reference. All spectra were normalized to 0.0 at 750nm to minimize difference between sample and reference filter. To determine the optical density of non-pigment detrital particles ($OD_{fd}(\lambda)$), the filters were then soaked in methanol for a few hours and rinsed with filtered seawater to extract and remove the pigments (Kishino et al., 1985), and its absorption coefficient was measured again by UV-2400. These measured optical densities on filters ($OD_{fp}(\lambda)$ and $OD_{fd}(\lambda)$) were converted to optical densities in suspensions ($OD_{sp}(\lambda)$ and $OD_{sd}(\lambda)$) using the pathlength amplification factor of Cleveland and Weidemann (1993) as follows:

$$OD_{sp}(\lambda) = 0.378\ OD_{fp}(\lambda) + 0.523\ OD_{fp}(\lambda)^2 \text{ and}$$

$$OD_{sd}(\lambda) = 0.378\ OD_{fd}(\lambda) + 0.523\ OD_{fd}(\lambda)^2.$$

The absorption coefficient of total particles ($a_p(\lambda)$ (m^{-1})) and non-pigment detrital particles ($a_d(\lambda)$ (m^{-1})) are computed from the corrected optical densities ($OD_s(\lambda)$):

$$a_p(\lambda) = 2.303 \times OD_{sp}(\lambda) / L \quad (L = V / S), \text{ and}$$

$$a_d(\lambda) = 2.303 \times OD_{sd}(\lambda) / L \quad (L = V / S),$$

where S is the clearance area of the filter (m^2) and V is the volume filtered (m^3). Absorption coefficient of phytoplankton ($a_{ph}(\lambda)$) was obtained by subtracting $a_d(\lambda)$ from $a_{ph}(\lambda)$ as follows:

$$a_{ph}(\lambda) = a_p(\lambda) - a_d(\lambda).$$

Finally, we calculated chl-*a* normalized specific absorption spectra (a^*_{ph}) to divide a_{ph} by chl-*a* concentrations obtained from same hydrographic casts.

Seawater samples for absorption coefficient of CDOM ($a_y(\lambda)$) were collected in 250ml bottles using Niskin bottles and a bucket from surface to bottom (Fig. 3.11.1, Table 3.11.1). CDOM samples were filtered using 0.2 µm Nuclepore polycarbonate filters on board. Optical densities of the CDOM ($OD_y(\lambda)$) in this filtered seawater were recorded against UV-2400 in the range from 300 to 800 nm using 10-cm pathlength glass cells. Milli-Q water was used as a base line. A blank (Milli-Q water versus Milli-Q water) was subtracted from each wavelength of the spectrum. The absorption coefficient of CDOM ($a_y(\lambda)$ (m^{-1})) was calculated from measured optical densities ($OD_y(\lambda)$) as follows:

$$a_y(\lambda) = 2.303 \times OD_y(\lambda) \;/\; L \text{ (L is the cuvette path-length (m))}.$$

(4) Preliminary results

Chl-*a* normalized specific absorption spectra (a^*_{ph}) at each station were shown in Fig. 3.11.2. Cross section and vertical profiles of CDOM absorption coefficient at 325 nm (unit = m^{-1}) along the I10 section were shown in Fig. 3.11.3 and Fig. 3.11.4, respectively.

(5) References

Cleveland, J.S. and Weidemann, A.D., 1993, Quantifying absorption by aquatic particles: a multiple scattering correction for glass fiber filters, Limnology and Oceanography, 38, 1321-1327.

Kishino, M., Takahashi, M., Okami, N. and Ichimura, S., 1985, Estimation of the spectral absorption coefficients of phytoplankton in the sea, Bulletin of Marine Science, 37, 634-642.

Mitchell, B.G., 1990, Algorithms for determining the absorption coefficient of aquatic particulates using the quantitative filter technique (QFT), Ocean Optics X, SPIE 1302, 137-148.

Nelson, N. B., D. A. Siegel, C. A. Carlson, and C. M. Swan, 2010, Tracing global biogeochemical cycles and meridional overturning circulation using chromophoric dissolved organic matter, Geophys. Res. Lett., 37, L03610, doi:10.1029/2009GL042325.

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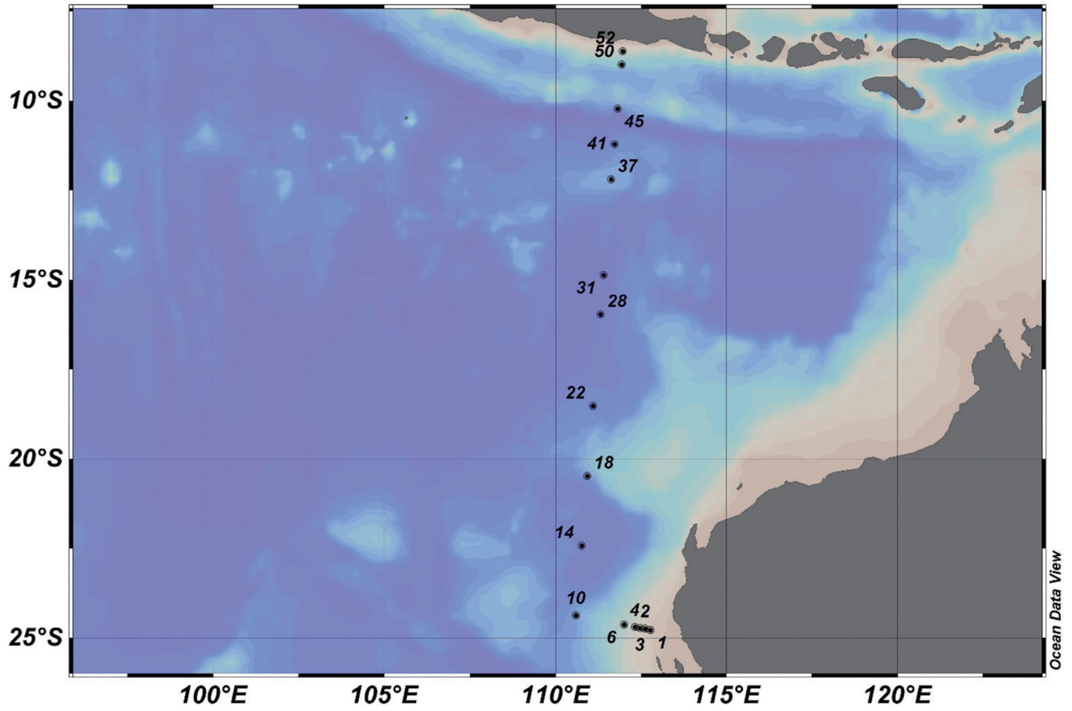

Fig. 3.11.1 Location of sampling stations for absorption coefficients of phytoplankton and CDOM along the I10 section in the Indian Ocean during MR15-05.

Table 3.11.1 List of sampling stations for absorption coefficients of phytoplankton (Ap) and CDOM during MR15-05.

Station	Date (UTC)	Time (UTC)	Latitude		Longitude		Sampling type	Cast No.	Sampling depth (db)	
									Particle absorbance	CDOM absorbance
1	12/28/2015	0:12	24.78	S	112.77	E	CTD + Bucket	1	0, 10, 50, 71	0, 10, 50, 71
2	12/28/2015	3:06	24.74	S	112.62	E	CTD + Bucket	1	none	93, 50, 10, 0
3	12/28/2015	5:38	24.73	S	112.47	E	CTD + Bucket	1	none	138, 100, 50, 10, 0
4	12/28/2015	8:08	24.70	S	112.31	E	CTD + Bucket	1	none	198, 100, 50, 10, 0
6	12/28/2015	14:05	24.63	S	112.00	E	CTD + Bucket	1	0, 10, 50, 100	698, 570, 370, 280, 200, 100, 50, 10, 0
10	12/29/2015	10:30	24.38	S	110.59	E	CTD + Bucket	3	0, 10, 50, 100	3210, 3000, 1000, 800, 600, 400, 300, 200, 100, 50, 10, 0
14	12/30/2015	12:55	22.42	S	110.76	E	CTD + Bucket	1	0, 10, 50, 100	5135, 3080, 1070, 830, 630, 430, 330, 200, 100, 50, 10, 0
18	12/31/2015	13:33	20.48	S	110.92	E	CTD + Bucket	1	0, 10, 50, 100	3704, 2930, 970, 770, 570, 370, 280, 200, 100, 50, 10, 0
22	01/01/2016	12:50	18.53	S	111.09	E	CTD + Bucket	2	0, 10, 50, 100	4797, 3000, 1000, 800, 600, 400, 300, 200, 100, 50, 10, 0
28	01/03/2016	3:36	15.97	S	111.30	E	CTD + Bucket	3	0, 10, 50, 100	5235, 5000, 3000, 1000, 800, 600, 400, 300, 200, 100, 50, 10, 0
31	01/04/2016	1:30	14.87	S	111.39	E	CTD + Bucket	1	none	5774, 5000, 3000, 1000, 800, 600, 400, 300, 200, 100, 50, 10, 0
37	01/05/2016	23:33	12.19	S	111.62	E	CTD + Bucket	4	0, 10, 50, 100	2800, 1000, 800, 600, 400, 300, 200, 100, 50, 10, 0
41	01/06/2016	18:03	11.21	S	111.72	E	CTD + Bucket	1	0, 10, 50, Chl_{max}(71), 100	4246, 3080, 1070, 830, 630, 430, 330, 200, 100,Chl_{max}(71), 50, 10, 0
45	01/07/2016	17:25	10.22	S	111.81	E	CTD + Bucket	1	0, 10, 50, Chl_{max}(65), 100	3648, 2930, 970, 770, 570, 370, 280, 200, 100, Chlmax(65), 50, 10, 0
50	01/08/2016	14:51	8.99	S	111.93	E	CTD + Bucket	1	0, 10, 50, Chl_{max}(63), 100	2005, 1070, 830, 630, 430, 330, 200, 100, Chl_{max}(63), 50, 10, 0
52	01/08/2016	21:57	8.62	S	111.96	E	CTD + Bucket	1	0, 10, 50, Chl_{max}(62), 100	549, 400, 300, 200, 100, Chl_{max}(62), 50, 10, 0

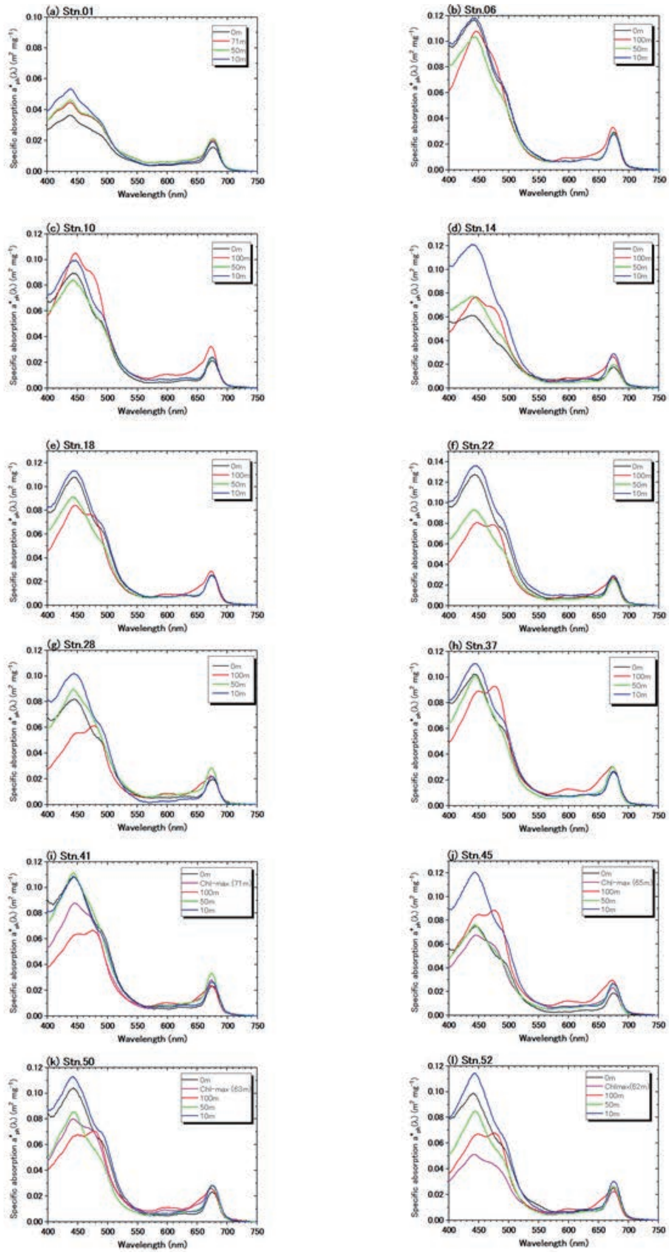

Fig. 3.11.2 Chlorophyll-specific phytoplankton absorption coefficient spectra ($a^*_{ph}(\lambda)$) at 400-750 nm. All spectra were normalized to 0.0 at 750nm.

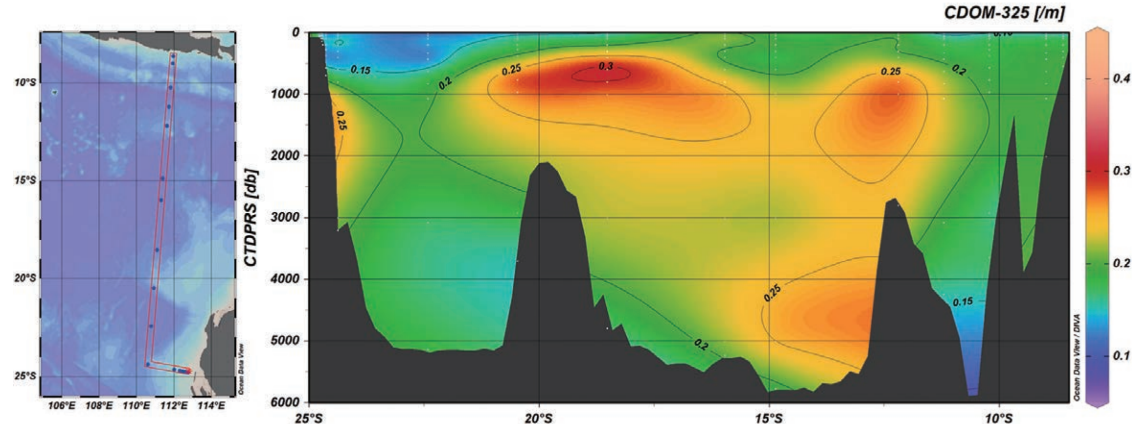

Fig. 3.11.3 Contours showing distribution of CDOM (as absorption coefficient at 325 nm, unit = m^{-1}) along the I10 section during MR15-05.

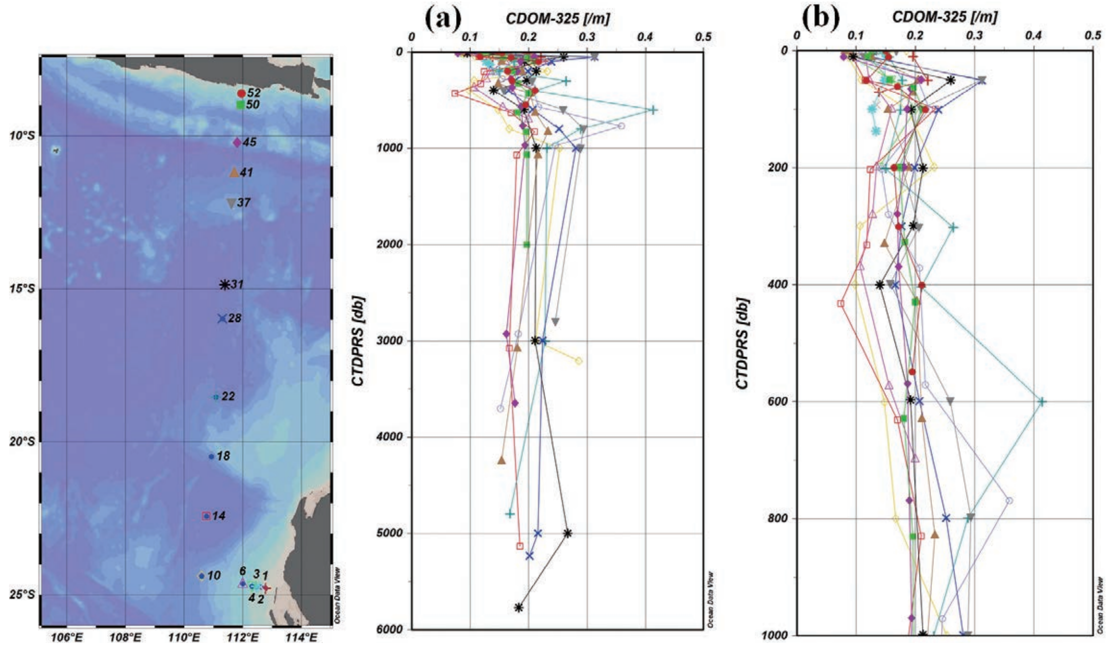

Fig. 3.11.4 Vertical profiles of CDOM absorption coefficient at 325 nm (unit = m^{-1}) along the I10 section obtained from hydrographic casts. (a) plotted against depth of all sample collection. (b) above 1000db.

3.12 Lowered Acoustic Doppler Current Profiler

October 3, 2017

(1) Personnel

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(2) Overview of the equipment

An acoustic Doppler current profiler (ADCP) was integrated with the CTD/RMS package. The lowered ADCP (LADCP), Workhorse Monitor WHM300 (Teledyne RD Instruments, San Diego, California, USA), which has 4 downward facing transducers with 20-degree beam angles, rated to 6000 m. The LADCP makes direct current measurements at the depth of the CTD, thus providing a full profile of velocity. The LADCP was powered during the CTD casts by a 48 volts battery pack. The LADCP unit was set for recording internally prior to each cast. After each cast the internally stored observed data was uploaded to the computer on-board. By combining the measured velocity of the sea water and bottom with respect to the instrument, and shipboard navigation data during the CTD cast, the absolute velocity profile can be obtained (e.g. Visbeck, 2002).

The instrument used in this cruise was as follows.

Teledyne RD Instruments, WHM300
S/N 20754(CPU firmware ver. 50.40)

(3) Data collection

In this cruise, data were collected with the following configuration.

Bin size: 4.0 m
Number of bins: 25
Pings per ensemble: 1
Ping interval: 1.0 sec

(4) Processing problems

As ship-board ADCP (SADCP) was not available during this cruise, the LADCP profiles were processed without surface velocities with SADCP. Especially, we could not estimate the velocities well at the first cast in St. 900 (aborted cast).

Reference

Visbeck, M. (2002): Deep velocity profiling using Lowered Acoustic Doppler Current Profilers: Bottom track and inverse solutions. *J. Atmos. Oceanic Technol.*, **19**, 794-807.

3.13 XCTD

February 1, 2016

(1) Personnel

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Ryo Kimura (MIRAI crew)

(2) Objectives

XCTD (eXpendable Conductivity, Temperature and Depth profiler) measurements were carried out to examine a hydrographic structure along south coast of Java Island and to evaluate the fall rate equation and the thermal bias by comparing with CTD (Conductivity, Temperature and Depth profiler) measurements.

(3) Instrument and Method

The XCTD used was XCTD-4 (Tsurumi-Seiki Co., Ltd., Yokohama, Kanagawa, Japan), except for XCTD-1 (Tsurumi-Seiki Co., Ltd.) at station I10_0, with an MK-150N deck unit (Tsurumi-Seiki Co., Ltd.). The manufacturer's specifications are listed in Table 3.13.1. In this cruise, the XCTD probes were deployed by using 8-loading automatic launcher (Tsurumi-Seiki Co., Ltd.). For comparison with CTD, XCTD was deployed at about 10 minutes after the beginning of the down cast of the CTD (I10_44, 45, 46, 48, 49 and 50). For correction of the sound velocity profile used in the bathymetry observation, XCTD-1 was deployed near station I10_1.

The fall-rate equation provided by the manufacturer was initially used to infer depth Z (m), $Z = at - bt^2$, where t is the elapsed time in seconds from probe entry into the water, and a (terminal velocity) and b (acceleration) are the empirical coefficients (Table 3.13.2).

(4) Data Processing and Quality Control

The XCTD data were processed and quality controlled based on a method by Uchida et al. (2011). Differences between XCTD and CTD depths were shown in Fig. 3.13.1. The terminal velocity error was estimated for the XCTD-4 (Table 3.13.2). The XCTD-4 data were corrected for the depth error by using the estimated terminal velocities. Differences of temperature on pressure surfaces were examined by using side-by-side XCTD and CTD data (Table 3.13.3). Average thermal bias below 900 dbar was –0.003 °C. The XCTD data were corrected for the thermal bias. Differences of salinity on reference temperature surfaces were examined by using CTD data (Table 3.13.4). The XCTD data were corrected for the estimated salinity bias.

(5) Results

Temperature-salinity plot using the quality controlled XCTD data is shown in Fig. 3.13.3. Potential temperature cross section is shown in Fig. 3.13.4.

(6) References

Kizu, S., H. Onishi, T. Suga, K. Hanawa, T. Watanabe, and H. Iwamiya (2008): Evaluation of the fall rates of the present and developmental XCTDs. *Deep-Sea Res I*, **55**, 571–586.

Uchida, H., K. Shimada, and T. Kawano (2011): A method for data processing to obtain high-quality XCTD data. *J. Atmos. Oceanic Technol.*, **28**, 816–826.

Uchida, H., A. Murata, and T. Doi (eds.) (2014): WHP P10 Revisit in 2011 Data Book, 179 pp., JAMSTEC.

Uchida, H., K. Katsumata, and T. Doi (eds.) (2015): WHP P14S/S04I Revisit in 2012/2013 Data Book, 187 pp., JAMSTEC.

Uchida, H and T. Doi (eds.) (2016): WHP P01 Revisit in 2014 Data Book, 149 pp. JAMSTEC

Table 3.13.1. Manufacturer's specifications of XCTD-4.

Parameter	Range	Accuracy
Conductivity	0 ~ 60 mS cm^{-1}	±0.03 mS cm^{-1}
Temperature	–2 ~ 35 °C	±0.02 °C
Depth	0 ~ 1850 m	5 m or 2%, whichever is greater *

* Depth error is shown in Kizu et al (2008).

Table 3.13.2. Manufacturer's coefficients for the fall-rate equation.

Model	a (terminal velocity, m/s)	b (acceleration, m/s^2)	e (terminal velocity error, m/s)
XCTD-4	3.43898	0.00031	–0.0198

Table 3.13.3. Thermal biases of the XCTD temperature data.

Cruise	Average thermal bias (°C)	Depth range	Source
MR09-01	0.016	>= 1100 dbar	Uchida et al. (2011)
KH-02-3	0.019	>= 1100 dbar	Uchida et al. (2011)
MR11-08	0.014	>= 1100 dbar	Uchida et al. (2014)
MR12-05	0.009	>= 400 dbar	Uchida et al. (2015)
MR14-04	0.011	>= 900 dbar	Uchida et al. (2016)
MR15-05	–0.003	>= 900 dbar	This report
Mean	0.011 ± 0.008		

Table 3.13.4. Salinity biases of the XCTD data.

XCTD station	Salinity bias	Reference temperature (°C)	Reference salinity	Reference CTD stations
44	–0.008	3.0	34.7209	44,45,46,48,49,50
45	–0.003	3.0	34.7209	44,45,46,48,49,50
46	–0.022	3.0	34.7209	44,45,46,48,49,50
48	–0.016	3.0	34.7209	44,45,46,48,49,50
49	–0.015	3.0	34.7209	44,45,46,48,49,50
50	–0.010	3.0	34.7209	44,45,46,48,49,50
901	–0.035	6.0	34.6558	51
902	–0.034	4.2	34.6532	44,45,46,48,49,50
903	–0.023	4.2	34.6532	44,45,46,48,49,50
904	–0.040	3.0	34.7209	44,45,46,48,49,50
905	–0.034	3.0	34.7209	44,45,46,48,49,50
906	–0.035	3.0	34.7209	44,45,46,48,49,50
907	–0.033	3.0	34.7209	44,45,46,48,49,50
908	–0.030	3.0	34.7209	44,45,46,48,49,50
909	–0.042	3.0	34.7209	44,45,46,48,49,50
910	–0.022	3.0	34.7209	44,45,46,48,49,50
911	–0.022	3.0	34.7209	44,45,46,48,49,50
912	–0.037	3.0	34.7209	44,45,46,48,49,50
913	–0.035	4.2	34.6532	44,45,46,48,49,50

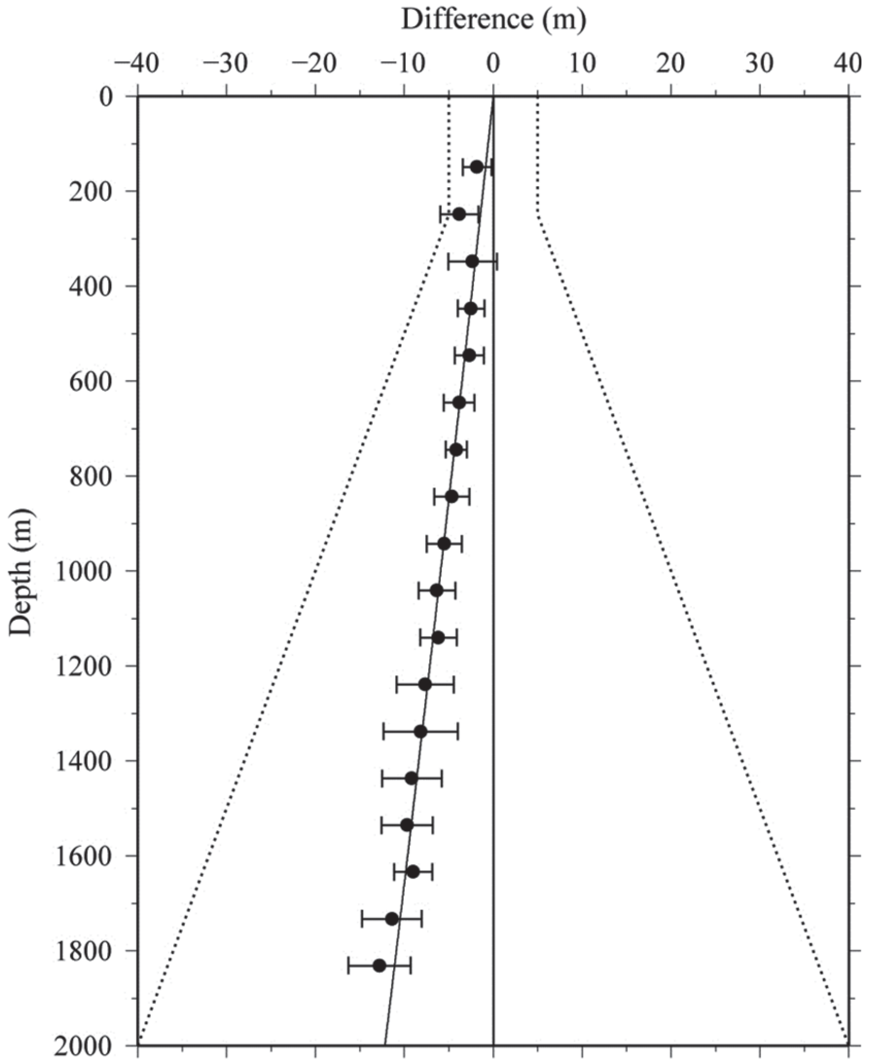

Figure 3.13.1. Differences between XCTD and CTD depths for XCTD-4. Differences were estimated with the same method as Uchida et al. (2011). Standard deviation of the estimates (horizontal bars) and the manufacturer’s specification for XCTD depth error (dotted lines) are shown. The regression for the data (solid line) is also shown.

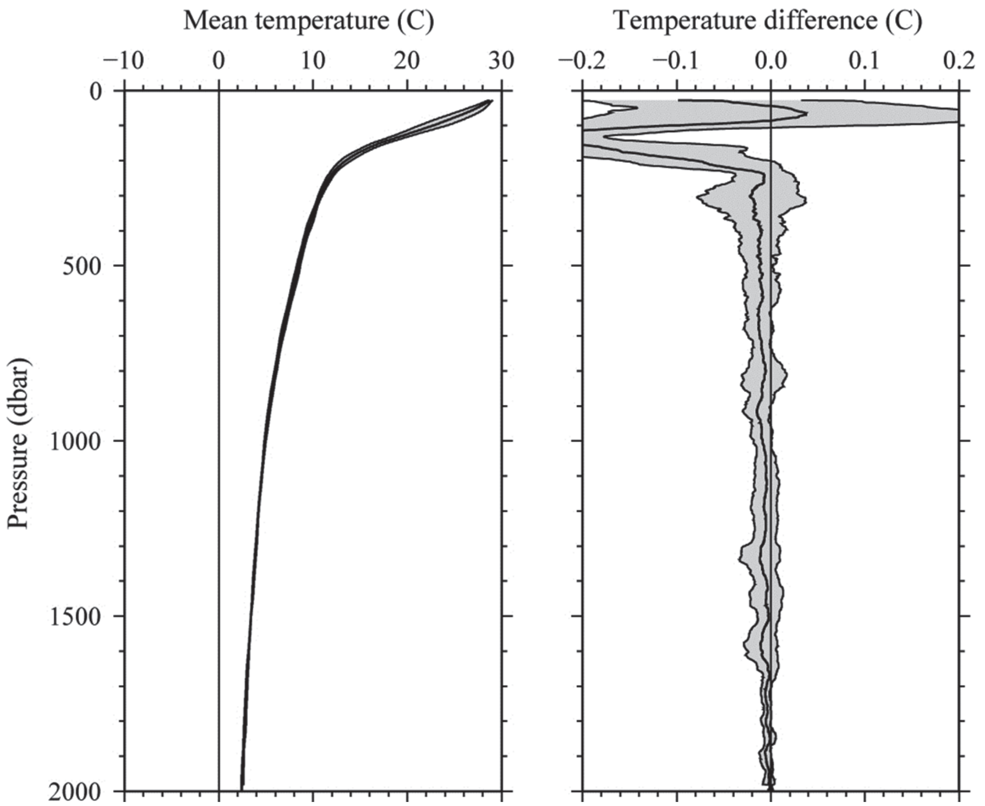

Figure 3.13.2. Comparison between XCTD and CTD temperature profiles. (a) Mean temperature of CTD profiles with standard deviation (shade) and (b) mean temperature difference with standard deviation (shade) between the XCTD and CTD. Mean profiles were low-pass filtered by a running mean with a window of 51 dbar.

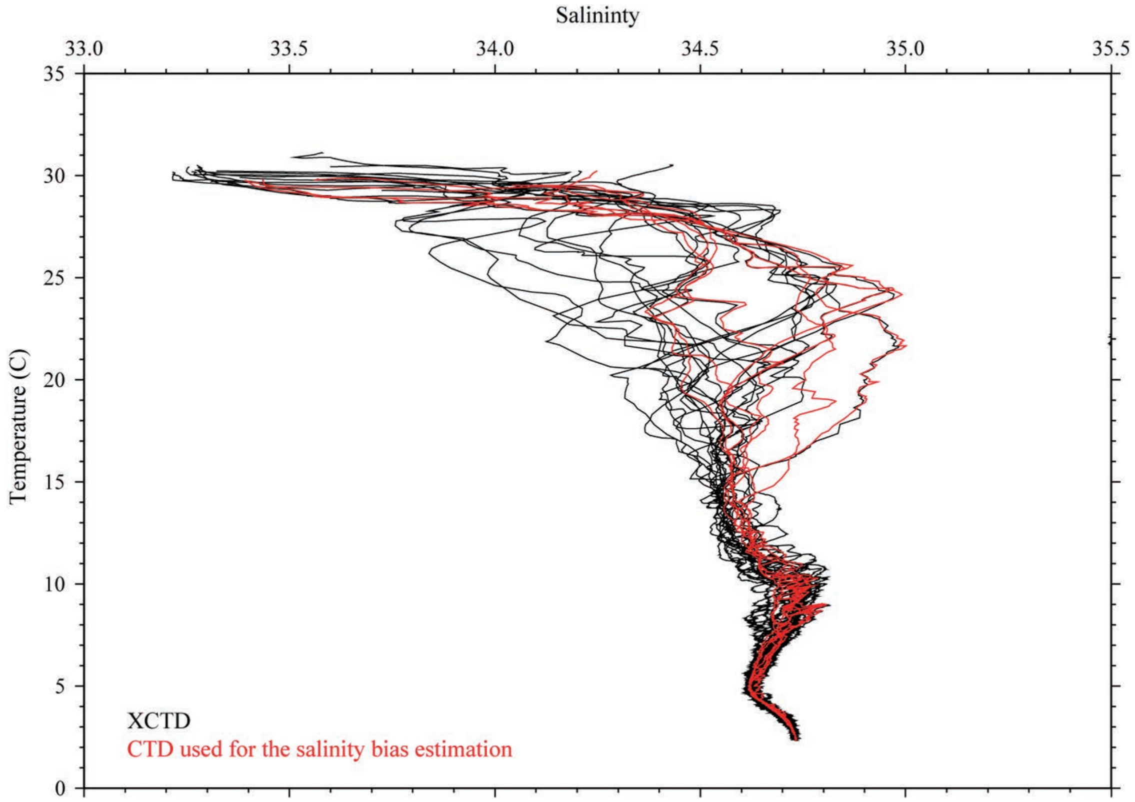

Figure 3.13.3. Comparison of temperature-salinity profiles of CTD data (red lines) used for the XCTD salinity bias estimation and salinity bias-corrected XCTD data (black lines).

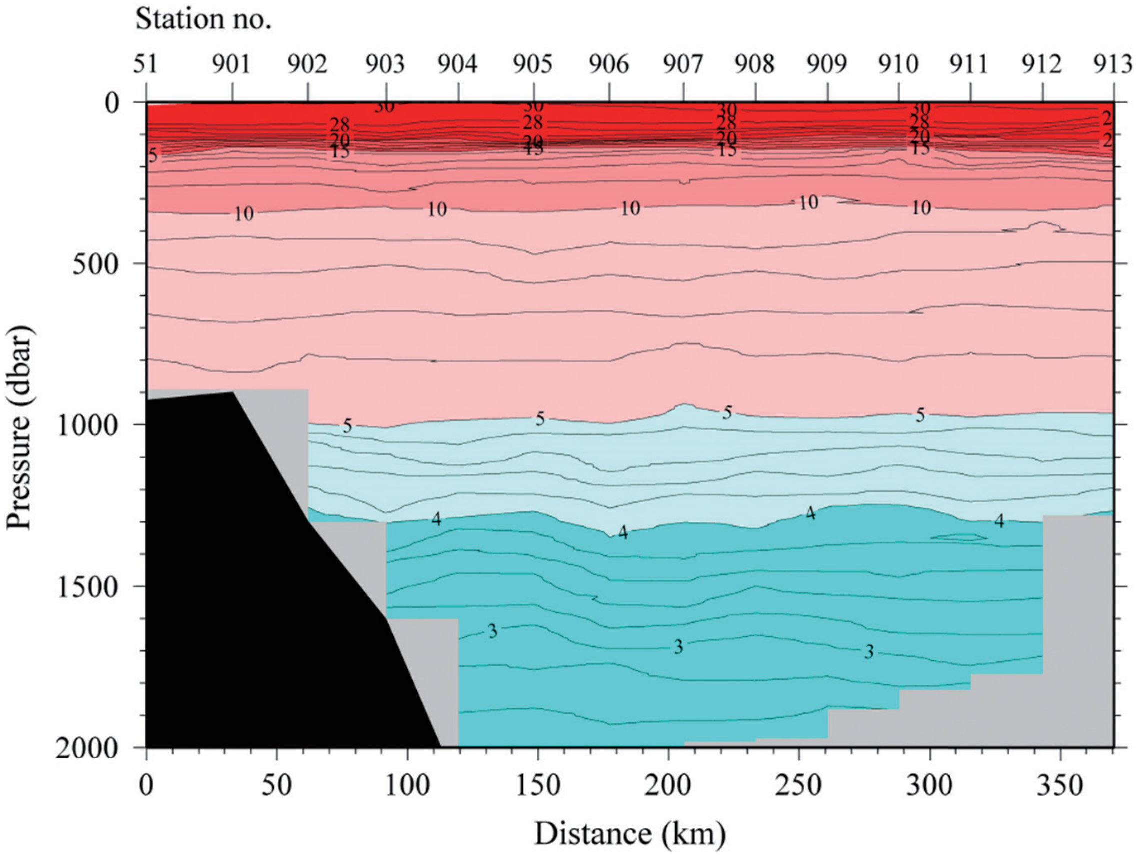

Figure 3.13.4. Potential temperature (°C) section along south coast of Java Island.

Station Summary

```
R/V MIRAI CRUISE MR1505 LEG1
SHIP/CRS    WOCE                 CAST          UTC EVENT               POSITION         UNC   COR HT ABOVE    WIRE    MAX  NO. OF
EXPOCODE    SECT   STNNBR CASTNO TYPE DATE    TIME  CODE   LATITUDE   LONGITUDE NAV  DEPTH  DEPTH   BOTTOM     OUT  PRESS BOTTLES PARAMETERS                                                   COMMENTS
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
49NZ20151223 I10      894      1  FLT 122415 0034    DE 08 14.84 S 105 31.45 E GPS      -9    3410                                                                                             ARGO HULL NUMBER 7435i
49NZ20151223 I10      895      1  FLT 122415 0736    DE 09 29.75 S 106  2.96 E GPS      -9    6258                                                                                             ARGO HULL NUMBER 7426i
49NZ20151223 I10      896      1  FLT 122415 1533    DE 10 45.06 S 106 35.02 E GPS      -9    5855                                                                                             ARGO HULL NUMBER 6542i
49NZ20151223 I10      900      1  ROS 122515 0127    BE 12 29.85 S 107 20.19 E GPS      -9    4696
49NZ20151223 I10      900      1  ROS 122515 0135    EN 12 29.85 S 107 20.19 E GPS      -9    4693                                                             CAST CANCELLED AT WOUT=110M DUE TO CTD CABLE LEAK ON TEMP2
49NZ20151223 I10      900      2  ROS 122515 0311    BE 12 29.97 S 107 20.16 E GPS      -9    4674
49NZ20151223 I10      900      2  ROS 122515 0345    BO 12 30.05 S 107 20.25 E GPS      -9    4676        -9   1975   2002      36 1,2
49NZ20151223 I10      900      2  ROS 122515 0426    EN 12 30.06 S 107 20.37 E GPS      -9    4693
49NZ20151223 I10      897      1  FLT 122515 0438    DE 12 30.15 S 107 20.25 E GPS      -9    4668                                                                                             ARGO HULL NUMBER 7041i
49NZ20151223 I10      898      1  FLT 122515 1413    DE 14 15.03 S 108  5.04 E GPS      -9    5331                                                                                             ARGO HULL NUMBER 7042i
49NZ20151223 I10      899      1  XCT 122715 2321    DE 24 40.27 S 112 43.38 E GPS      -9      85                                                                                             TSK XCTD-1 #14088884
49NZ20151223 I10        1      1  BUC 122815 0005    UN 24 46.84 S 112 46.12 E GPS      -9      82                                 1,3-6,20,31,33,34,43,48,82,86,95,98,99,100,101,102,104,106  22.2C
49NZ20151223 I10        1      1  ROS 122815 0006    BE 24 46.84 S 112 46.13 E GPS      -9      81
49NZ20151223 I10        1      1  ROS 122815 0012    BO 24 46.80 S 112 46.15 E GPS      -9      82        10     67     71      10 1-9,20,23,24,26,27,31,33,34,43,48,82,86,92,95,98,99,100,101,102,104,106
                                                                                                                                                                                               #2,3 CLEAN NISKIN

49NZ20151223 I10        1      1  ROS 122815 0023    EN 24 46.74 S 112 46.20 E GPS      -9      81
49NZ20151223 I10        2      1  BUC 122815 0259    UN 24 44.72 S 112 36.97 E GPS      -9     104                                 1,3-6,20,34,98,102                                          22.9C
49NZ20151223 I10        2      1  ROS 122815 0300    BE 24 44.69 S 112 36.97 E GPS      -9     100
49NZ20151223 I10        2      1  ROS 122815 0306    BO 24 44.60 S 112 36.99 E GPS      -9     104        11     89     92       3 1-9,20,23,24,26,27,34,92,98,102
49NZ20151223 I10        2      1  ROS 122815 0316    EN 24 44.44 S 112 37.03 E GPS      -9     104
49NZ20151223 I10        2      1  UNK 122815 0328    BE 24 44.33 S 112 36.69 E GPS      -9     104                                                                                             MAGNETOMETER CALIBRATION
49NZ20151223 I10        2      1  UNK 122815 0354    EN 24 43.71 S 112 36.00 E GPS      -9     112                                                                                             MAGNETOMETER CALIBRATION
49NZ20151223 I10        3      1  ROS 122815 0532    BE 24 43.60 S 112 27.97 E GPS      -9     147
49NZ20151223 I10        3      1  BUC 122815 0532    UN 24 43.59 S 112 27.97 E GPS      -9     148                                 1,3-6,20,34,98,102                                          23.1C
49NZ20151223 I10        3      1  ROS 122815 0538    BO 24 43.56 S 112 28.02 E GPS      -9     145         9    134    138       4 1-9,20,23,24,26,27,34,92,98,102
49NZ20151223 I10        3      1  ROS 122815 0550    EN 24 43.48 S 112 28.11 E GPS      -9     146
49NZ20151223 I10        4      1  ROS 122815 0800    BE 24 42.16 S 112 18.74 E GPS      -9     208
49NZ20151223 I10        4      1  BUC 122815 0801    UN 24 42.16 S 112 18.74 E GPS      -9     208                                 1,3-6,20,31,33,34,86,98,102                                 23.0C
49NZ20151223 I10        4      1  ROS 122815 0808    BO 24 42.18 S 112 18.78 E GPS      -9     208         8    193    199       5 1-9,20,23,24,26,27,31,33,34,86,92,98,102
49NZ20151223 I10        4      1  ROS 122815 0824    EN 24 42.19 S 112 18.88 E GPS      -9     206
49NZ20151223 I10        5      1  BUC 122815 1059    UN 24 40.06 S 112 11.81 E GPS      -9     480                                 1,3-6                                                       23.8C
49NZ20151223 I10        5      1  ROS 122815 1059    BE 24 40.06 S 112 11.81 E GPS      -9     480
49NZ20151223 I10        5      1  ROS 122815 1112    BO 24 40.04 S 112 11.86 E GPS      -9     482         9    466    473       9 1-9,27
49NZ20151223 I10        5      1  ROS 122815 1144    EN 24 40.07 S 112 11.99 E GPS      -9     484
49NZ20151223 I10        6      1  ROS 122815 1348    BE 24 37.99 S 111 59.87 E GPS      -9     705
49NZ20151223 I10        6      1  BUC 122815 1356    UN 24 38.01 S 111 59.91 E GPS      -9     705                                 1,3-6,20,31,33,34,43,82,98-102,104,106                       23.7C
49NZ20151223 I10        6      1  ROS 122815 1405    BO 24 38.01 S 111 59.95 E GPS      -9     704        11    690    699      21 1-9,20,23,24,26,27,31,33,34,43,82,98-102,104,106
49NZ20151223 I10        6      1  ROS 122815 1441    EN 24 38.06 S 112  0.05 E GPS      -9     702
49NZ20151223 I10        7      1  ROS 122815 1758    BE 24 34.44 S 111 39.12 E GPS      -9    1009
49NZ20151223 I10        7      1  BUC 122815 1806    UN 24 34.44 S 111 39.20 E GPS      -9    1007                                 1,3-6,102                                                    23.5C
49NZ20151223 I10        7      1  ROS 122815 1821    BO 24 34.45 S 111 39.24 E GPS      -9    1008        11    994   1005      14 1-9,27,102
49NZ20151223 I10        7      1  ROS 122815 1910    EN 24 34.68 S 111 39.48 E GPS      -9    1003
49NZ20151223 I10        8      1  ROS 122815 2119    BE 24 30.06 S 111 17.03 E GPS      -9    1368
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49NZ20151223  I10        8      1  BUC 122815 2128    UN 24 30.07 S 111 17.12 E GPS       -9   1364                                   1,3-6,20,31,33,34,102                                      23.3C
49NZ20151223  I10        8      1  ROS 122815 2148    BO 24 30.10 S 111 17.16 E GPS       -9   1364         9   1349   1364       16 1-9,20,23,24,26,27,31,33,34,86,102
49NZ20151223  I10        8      1  ROS 122815 2242    EN 24 30.10 S 111 17.35 E GPS       -9   1360
49NZ20151223  I10        9      1  ROS 122915 0047    BE 24 25.30 S 110 56.05 E GPS       -9   2001
49NZ20151223  I10        9      1  BUC 122915 0056    UN 24 25.32 S 110 56.08 E GPS       -9   2002                                   1,3-6,102                                                  23.3C
49NZ20151223  I10        9      1  ROS 122915 0126    BO 24 25.41 S 110 56.20 E GPS       -9   1999         9   1985   2011       20 1-9,27,102
49NZ20151223  I10        9      1  ROS 122915 0237    EN 24 25.60 S 110 56.38 E GPS       -9   1994
49NZ20151223  I10       10      1  BUC 122915 0433    UN 24 22.58 S 110 35.41 E GPS       -9   3191                                   3-6,13,31,33,34,43,82,86,100-102,104,106,115               23.4C
49NZ20151223  I10       10      1  ROS 122915 0433    BE 24 22.58 S 110 35.41 E GPS       -9   3191                                                                                              FOR BIO
49NZ20151223  I10       10      1  ROS 122915 0445    BO 24 22.60 S 110 35.41 E GPS       -9   3184        -9    494    501       29 3-6,13,31,33,34,43,82,86,100-102,104,106,112,113,115,116
49NZ20151223  I10       10      1  ROS 122915 0522    EN 24 22.68 S 110 35.43 E GPS       -9   3181
49NZ20151223  I10       10      2  ROS 122915 0727    BE 24 22.59 S 110 35.41 E GPS       -9   3190
49NZ20151223  I10       10      2  BUC 122915 0735    UN 24 22.60 S 110 35.41 E GPS       -9   3190                                   1,3-6,20,31,33,34,43,98,99,102                             23.4C
49NZ20151223  I10       10      2  ROS 122915 0818    EN 24 22.60 S 110 35.50 E GPS       -9   3179                                                                             CAST CANCELLED AT WOUT=1300M DUE TO FL ERROR
49NZ20151223  I10       10      3  ROS 122915 0938    BE 24 22.64 S 110 35.39 E GPS       -9   3191                                                                                              ATTACHED 5KG WEIGHT
49NZ20151223  I10       10      3  ROS 122915 1030    BO 24 22.72 S 110 35.51 E GPS       -9   3180         9   3162   3211       35 1-9,20,23,24,26,27,31,33,34,43,82,92,98,99-102,104,106
49NZ20151223  I10       10      3  ROS 122915 1203    EN 24 22.77 S 110 35.50 E GPS       -9   3181
49NZ20151223  I10       11      1  ROS 122915 1728    BE 23 53.01 S 110 38.12 E GPS       -9   4403                                                                                          DETTACHED SWIVEL AND 5KG WEIGHT
49NZ20151223  I10       11      1  BUC 122915 1737    UN 23 53.03 S 110 38.17 E GPS       -9   4395                                   1,3-6,102                                                  23.5C
49NZ20151223  I10       11      1  ROS 122915 1838    BO 23 53.08 S 110 38.31 E GPS       -9   4389         9   4370   4452       30 1-9,27,102
49NZ20151223  I10       11      1  ROS 122915 2041    EN 23 53.22 S 110 38.24 E GPS       -9   4388
49NZ20151223  I10       12      1  ROS 122915 2325    BE 23 23.68 S 110 40.49 E GPS       -9   5033
49NZ20151223  I10       12      1  BUC 122915 2333    UN 23 23.67 S 110 40.45 E GPS       -9   5032                                   1,3-6,20,34,48,86,95,102                                   24.2C
49NZ20151223  I10       12      1  ROS 123015 0044    BO 23 23.63 S 110 40.34 E GPS       -9   5034        10   5003   5109       35 1-9,20,23,24,26,27,34,48,86,95,97,102                       #2,3 CLEAN NISKIN
49NZ20151223  I10       12      1  ROS 123015 0253    EN 23 23.54 S 110 40.10 E GPS       -9   5035
49NZ20151223  I10       13      1  ROS 123015 0528    BE 22 54.64 S 110 42.80 E GPS       -9   5053
49NZ20151223  I10       13      1  BUC 123015 0536    UN 22 54.58 S 110 42.83 E GPS       -9   5053                                   1,3-6,102                                                  24.7C
49NZ20151223  I10       13      1  ROS 123015 0649    BO 22 54.45 S 110 43.17 E GPS       -9   5052         8   5040   5132       33 1-9,27,102
49NZ20151223  I10       13      1  ROS 123015 0905    EN 22 53.84 S 110 43.68 E GPS       -9   5052
49NZ20151223  I10       14      1  ROS 123015 1138    BE 22 25.47 S 110 45.30 E GPS       -9   5055
49NZ20151223  I10       14      1  BUC 123015 1147    UN 22 25.49 S 110 45.30 E GPS       -9   5056                                   1,3-6,20,31,33,34,43,82,98,99,101,102,104,106              24.3C
49NZ20151223  I10       14      1  ROS 123015 1255    BO 22 25.47 S 110 45.50 E GPS       -9   5058         9   5034   5137       35 1-9,20,23,24,26,27,31,33,34,43,82,98,99,101,102,104,106
49NZ20151223  I10       14      1  ROS 123015 1502    EN 22 25.50 S 110 45.80 E GPS       -9   5056
49NZ20151223  I10       15      1  ROS 123015 1741    BE 21 56.18 S 110 48.03 E GPS       -9   5059
49NZ20151223  I10       15      1  BUC 123015 1750    UN 21 56.20 S 110 48.02 E GPS       -9   5058                                   1,3-6,102                                                  24.7C
49NZ20151223  I10       15      1  ROS 123015 1902    BO 21 56.28 S 110 48.22 E GPS       -9   5055        10   5033   5136       33 1-9,27,102
49NZ20151223  I10       15      1  ROS 123015 2113    EN 21 56.55 S 110 48.53 E GPS       -9   5054
49NZ20151223  I10       16      1  ROS 123015 2358    BE 21 27.01 S 110 50.33 E GPS       -9   5055
49NZ20151223  I10       16      1  BUC 123115 0005    UN 21 27.03 S 110 50.34 E GPS       -9   5055                                   1,3-6,20,86,102                                            25.0C
49NZ20151223  I10       16      1  ROS 123115 0116    BO 21 27.10 S 110 50.56 E GPS       -9   5055         9   5030   5131       33 1-9,12,13,20,23,24,26,27,86,97,102
49NZ20151223  I10       16      1  ROS 123115 0323    EN 21 27.53 S 110 51.10 E GPS       -9   5053
49NZ20151223  I10       17      1  ROS 123115 0615    BE 20 57.91 S 110 52.88 E GPS       -9   5050
49NZ20151223  I10       17      1  BUC 123115 0624    UN 20 57.95 S 110 52.93 E GPS       -9   5049                                   1,3-6,102                                                  25.9C
49NZ20151223  I10       17      1  ROS 123115 0735    BO 20 57.96 S 110 53.34 E GPS       -9   5048         9   5037   5126       32 1-9,27,102
49NZ20151223  I10       17      1  ROS 123115 0945    EN 20 58.26 S 110 53.97 E GPS       -9   5047
49NZ20151223  I10       18      1  ROS 123115 1235    BE 20 28.55 S 110 55.41 E GPS       -9   3651
49NZ20151223  I10       18      1  BUC 123115 1243    UN 20 28.55 S 110 55.41 E GPS       -9   3654                                   1,3-6,20,31,33,34,43,82,98-102,104,106                     26.0C
49NZ20151223  I10       18      1  ROS 123115 1333    BO 20 28.55 S 110 55.37 E GPS       -9   3664         6   3643   3704       36 1-9,20,23,24,26,27,31,33,34,43,82,92,98-102,104,106
49NZ20151223  I10       18      1  ROS 123115 1513    EN 20 28.52 S 110 55.36 E GPS       -9   3664
49NZ20151223  I10       18      1  FLT 123115 1518    DE 20 28.37 S 110 55.37 E GPS       -9   3673                                                                                              ARGO HULL NUMBER 7040i
49NZ20151223  I10       19      1  ROS 123115 1802    BE 19 59.34 S 110 57.77 E GPS       -9   2052
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49NZ20151223  I10       19       1  BUC 123115 1810    UN 19 59.35 S 110 57.77 E GPS     -9    2053                                  1,3-6,20,102                                                   25.9C
49NZ20151223  I10       19       1  ROS 123115 1840    BO 19 59.42 S 110 57.76 E GPS     -9    2051      10   2032   2059      20 1-9,20,23,24,26,27,97,102
49NZ20151223  I10       19       1  ROS 123115 1953    EN 19 59.62 S 110 57.90 E GPS     -9    2044
49NZ20151223  I10       20       1  ROS 123115 2240    BE 19 30.15 S 111  0.04 E GPS     -9    2528
49NZ20151223  I10       20       1  BUC 123115 2248    UN 19 30.18 S 111  0.06 E GPS     -9    2529                                  1,3-6,102                                                      25.5C
49NZ20151223  I10       20       1  ROS 123115 2324    BO 19 30.31 S 111  0.13 E GPS     -9    2528       9   2514   2545      22 1-9,27,102
49NZ20151223  I10       20       1  ROS 010116 0039    EN 19 30.56 S 111  0.24 E GPS     -9    2520
49NZ20151223  I10       21       1  ROS 010116 0323    BE 19  0.73 S 111  2.78 E GPS     -9    3515
49NZ20151223  I10       21       1  BUC 010116 0331    UN 19  0.76 S 111  2.83 E GPS     -9    3524                                  1,3-6,20,102                                                   25.8C
49NZ20151223  I10       21       1  ROS 010116 0422    BO 19  0.91 S 111  3.03 E GPS     -9    3470      31   3464   3513      28 1-9,12,13,20,23,24,26,27,102    BOTTOM NOT DETECTED BY ALTIMETER (MEASURED BY LADCP)
49NZ20151223  I10       21       1  ROS 010116 0603    EN 19  1.24 S 111  3.31 E GPS     -9    3445
49NZ20151223  I10       22       1  ROS 010116 0840    BE 18 31.57 S 111  5.16 E GPS     -9    4735                                                                                              FOR BIO
49NZ20151223  I10       22       1  ROS 010116 0854    BO 18 31.58 S 111  5.23 E GPS     -9    4735      -9    497    503      30 3-6,13,31,33,34,43,82,86,95,100-102,104,106,112,113,115,116
49NZ20151223  I10       22       1  ROS 010116 0933    EN 18 31.58 S 111  5.38 E GPS     -9    4733
49NZ20151223  I10       22       1  UNK 010116 0942    BE 18 31.92 S 111  5.38 E GPS     -9    4729                                                                                              MAGNETOMETER CALIBRATION
49NZ20151223  I10       22       1  UNK 010116 1005    EN 18 32.15 S 111  5.23 E GPS     -9    4728                                                                                              MAGNETOMETER CALIBRATION
49NZ20151223  I10       22       2  ROS 010116 1137    BE 18 31.66 S 111  5.13 E GPS     -9    4731
49NZ20151223  I10       22       2  BUC 010116 1145    UN 18 31.64 S 111  5.15 E GPS     -9    4737                                  1,3-6,20,31,33,34,43,48,82,86,95,98,99,102                     26.3C
49NZ20151223  I10       22       2  ROS 010116 1250    BO 18 31.63 S 111  5.21 E GPS     -9    4736      11   4705   4798      34 1-9,20,23,24,26,27,31,33,34,43,48,82,86,92,95,98-102,104,106
49NZ20151223  I10       22       2  ROS 010116 1450    EN 18 31.64 S 111  5.42 E GPS     -9    4735
49NZ20151223  I10       22       1  FLT 010116 1457    DE 18 31.68 S 111  5.57 E GPS     -9    4737                                                                                              ARGO HULL NUMBER 7039i
49NZ20151223  I10       23       1  ROS 010116 1732    BE 18  2.41 S 111  7.71 E GPS     -9    5065
49NZ20151223  I10       23       1  BUC 010116 1740    UN 18  2.43 S 111  7.70 E GPS     -9    5067                                  1,3-6,102                                                      26.7C
49NZ20151223  I10       23       1  ROS 010116 1852    BO 18  2.35 S 111  7.71 E GPS     -9    5065      10   5036   5138      33 1-9,27,102
49NZ20151223  I10       23       1  ROS 010116 2107    EN 18  2.54 S 111  8.24 E GPS     -9    5079
49NZ20151223  I10       24       1  ROS 010116 2350    BE 17 33.27 S 111 10.06 E GPS     -9    5193
49NZ20151223  I10       24       1  BUC 010116 2357    UN 17 33.30 S 111 10.06 E GPS     -9    5193                                  1,3-6,20,102                                                   26.7C
49NZ20151223  I10       24       1  ROS 010216 0111    BO 17 33.30 S 111 10.12 E GPS     -9    5190       9   5169   5276      34 1-9,20,23,24,26,27,102
49NZ20151223  I10       24       1  ROS 010216 0321    EN 17 33.50 S 111 10.21 E GPS     -9    5180
49NZ20151223  I10       25       1  ROS 010216 0602    BE 17  3.87 S 111 12.51 E GPS     -9    5257
49NZ20151223  I10       25       1  BUC 010216 0610    UN 17  3.88 S 111 12.54 E GPS     -9    5258                                  1,3-6,102                                                      27.3C
49NZ20151223  I10       25       1  ROS 010216 0725    BO 17  3.97 S 111 12.74 E GPS     -9    5258      10   5230   5338      34 1-9,27,102
49NZ20151223  I10       25       1  ROS 010216 0940    EN 17  4.04 S 111 13.00 E GPS     -9    5260
49NZ20151223  I10       26       1  ROS 010216 1142    BE 16 42.07 S 111 14.33 E GPS     -9    5240
49NZ20151223  I10       26       1  BUC 010216 1150    UN 16 42.06 S 111 14.35 E GPS     -9    5240                                  1,3-6,20,31,33,34,43,82,100-102,104,106                        27.7C
49NZ20151223  I10       26       1  ROS 010216 1304    BO 16 42.11 S 111 14.56 E GPS     -9    5233       8   5217   5322      36 1-9,20,23,24,26,27,31,33,34,43,82,92,100-102,104,106
49NZ20151223  I10       26       1  ROS 010216 1513    EN 16 42.07 S 111 15.06 E GPS     -9    5202
49NZ20151223  I10       27       1  ROS 010216 1747    BE 16 20.04 S 111 16.33 E GPS     -9    5158
49NZ20151223  I10       27       1  BUC 010216 1754    UN 16 19.97 S 111 16.35 E GPS     -9    5157                                  1,2-6,102                                                      27.9C
49NZ20151223  I10       27       1  ROS 010216 1907    BO 16 20.12 S 111 16.36 E GPS     -9    5159       9   5135   5239      34 1-9,27,102
49NZ20151223  I10       27       1  ROS 010216 2125    EN 16 20.18 S 111 16.47 E GPS     -9    5181
49NZ20151223  I10       27       1  FLT 010216 2136    DE 16 19.92 S 111 16.59 E GPS     -9    5186                                                                                              ARGO HULL NUMBER 7430i
49NZ20151223  I10       28       1  ROS 010216 2333    BE 15 58.15 S 111 18.34 E GPS     -9    5155
49NZ20151223  I10       28       1  ROS 010216 2339    BO 15 58.13 S 111 18.37 E GPS     -9    5150      -9     98    101      36 22,89                                                          CESIUM SAMPLING I
49NZ20151223  I10       28       1  ROS 010216 2353    EN 15 58.11 S 111 18.42 E GPS     -9    5150
49NZ20151223  I10       28       2  ROS 010316 0037    BE 15 58.17 S 111 18.19 E GPS     -9    5162
49NZ20151223  I10       28       2  ROS 010316 0055    BO 15 58.18 S 111 18.22 E GPS     -9    5159      -9    794    802      36 22,89                                                          CESIUM SAMPLING II
49NZ20151223  I10       28       2  ROS 010316 0123    EN 15 58.15 S 111 18.28 E GPS     -9    5160
49NZ20151223  I10       28       3  ROS 010316 0215    BE 15 58.25 S 111 18.13 E GPS     -9    5162
49NZ20151223  I10       28       3  BUC 010316 0223    UN 15 58.23 S 111 18.16 E GPS     -9    5159                                  1,3-6,20,31,33,34,98,99,102                                    28.2C
49NZ20151223  I10       28       3  ROS 010316 0336    BO 15 58.24 S 111 18.22 E GPS     -9    5157       9   5128   5235      36 1-9,12,13,20,23,24,26,27,31,33,34,97-99,102
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49NZ20151223 I10      28      3  ROS 010316 0551    EN 15 58.28 S 111 18.22 E GPS     -9   5162
49NZ20151223 I10      29      1  ROS 010316 0753    BE 15 36.17 S 111 20.04 E GPS     -9   5357
49NZ20151223 I10      29      1  BUC 010316 0800    UN 15 36.17 S 111 20.07 E GPS     -9   5360                                 1,3-6,102                                                 28.8C
49NZ20151223 I10      29      1  ROS 010316 0914    BO 15 36.14 S 111 20.22 E GPS     -9   5373       10   5335   5446      34 1-9,27,102
49NZ20151223 I10      29      1  ROS 010316 1149    EN 15 35.70 S 111 20.73 E GPS     -9   5419
49NZ20151223 I10      30      1  ROS 010316 1348    BE 15 14.35 S 111 21.73 E GPS     -9   5602
49NZ20151223 I10      30      1  BUC 010316 1356    UN 15 14.32 S 111 21.76 E GPS     -9   5598                                 1,3-6,20,34,48,86,95,102                                  28.5C
49NZ20151223 I10      30      1  ROS 010316 1514    BO 15 14.34 S 111 21.92 E GPS     -9   5601        9   5569   5694      36 1-9,20,23,24,26,27,34,48,86,95,102
49NZ20151223 I10      30      1  ROS 010316 1739    EN 15 14.30 S 111 21.96 E GPS     -9   5599
49NZ20151223 I10      31      0  UNK 010316 1945    BE 14 52.32 S 111 23.52 E GPS     -9   5680                                                                                           RELEASE WIRE TWIST
49NZ20151223 I10      31      0  UNK 010316 2107    BO 14 52.39 S 111 23.58 E GPS     -9   5684            5580                                                                           HOLD 5 MIN. AT BOTTOM
49NZ20151223 I10      31      0  UNK 010316 2237    EN 14 52.13 S 111 23.64 E GPS     -9   5687
49NZ20151223 I10      31      1  ROS 010416 0001    BE 14 52.24 S 111 23.59 E GPS     -9   5684
49NZ20151223 I10      31      1  BUC 010416 0010    UN 14 52.23 S 111 23.61 E GPS     -9   5683                                 1,3-6,20,31,33,34,43,82,98,100,101,102,104,106           28.7C
49NZ20151223 I10      31      1  ROS 010416 0130    BO 14 52.14 S 111 23.66 E GPS     -9   5684        9   5644   5774      36 1-9,20,23,24,26,27,31,33,34,43,82,92,98,100,101,102,104,106
49NZ20151223 I10      31      1  ROS 010416 0355    EN 14 52.21 S 111 23.74 E GPS     -9   5682
49NZ20151223 I10      31      1  FLT 010416 0404    DE 14 52.02 S 111 23.75 E GPS     -9   5682                                                                                           ARGO HULL NUMBER 7431i
49NZ20151223 I10      32      1  ROS 010416 0632    BE 14 30.43 S 111 25.61 E GPS     -9   5679
49NZ20151223 I10      32      1  BUC 010416 0640    UN 14 30.43 S 111 25.59 E GPS     -9   5677                                 1,3-6,102                                                 28.7C
49NZ20151223 I10      32      1  ROS 010416 0800    BO 14 30.34 S 111 25.63 E GPS     -9   5680        9   5648   5773      35 1-9,27,102
49NZ20151223 I10      32      1  ROS 010416 1021    EN 14 30.30 S 111 25.56 E GPS     -9   5680
49NZ20151223 I10      33      1  ROS 010416 1232    BE 14  8.68 S 111 27.56 E GPS     -9   5656
49NZ20151223 I10      33      1  ROS 010416 1237    BO 14  8.70 S 111 27.55 E GPS     -9   5653       -9     97    100      36 22,89                                                            CESIUM SAMPLING I
49NZ20151223 I10      33      1  ROS 010416 1255    EN 14  8.77 S 111 27.51 E GPS     -9   5647
49NZ20151223 I10      33      2  ROS 010416 1337    BE 14  8.52 S 111 27.51 E GPS     -9   5650
49NZ20151223 I10      33      2  ROS 010416 1355    BO 14  8.49 S 111 27.47 E GPS     -9   5649       -9    763    773      36 22,89                                                            CESIUM SAMPLING II
49NZ20151223 I10      33      2  ROS 010416 1422    EN 14  8.50 S 111 27.36 E GPS     -9   5650
49NZ20151223 I10      33      1  UNK 010416 1430    BE 14  8.19 S 111 27.60 E GPS     -9   5648                                                                                           MAGNETOMETER CALIBRATION
49NZ20151223 I10      33      1  UNK 010416 1456    EN 14  8.36 S 111 27.72 E GPS     -9   5652                                                                                           MAGNETOMETER CALIBRATION
49NZ20151223 I10      33      3  ROS 010416 1517    BE 14  8.54 S 111 27.66 E GPS     -9   5655
49NZ20151223 I10      33      3  BUC 010416 1525    UN 14  8.53 S 111 27.64 E GPS     -9   5650                                 1,3-6,20,102                                              29.1C"
49NZ20151223 I10      33      3  ROS 010416 1645    BO 14  8.42 S 111 27.42 E GPS     -9   5650       10   5622   5743      36 1-9,20,23,24,26,27,97,102
49NZ20151223 I10      33      3  ROS 010416 1915    EN 14  8.37 S 111 27.13 E GPS     -9   5651
49NZ20151223 I10      33      3  FLT 010416 1925    DE 14  8.15 S 111 27.15 E GPS     -9   5650                                                                                           ARGO HULL NUMBER 7429i
49NZ20151223 I10      34      1  ROS 010416 2206    BE 13 39.36 S 111 29.98 E GPS     -9   5580
49NZ20151223 I10      34      1  BUC 010416 2214    UN 13 39.36 S 111 29.95 E GPS     -9   5569                                 1,3-6,102                                                 29.0C
49NZ20151223 I10      34      1  ROS 010416 2333    BO 13 39.26 S 111 29.89 E GPS     -9   5560        9   5533   5651      35 1-9,27,102
49NZ20151223 I10      34      1  ROS 010516 0151    EN 13 39.05 S 111 29.68 E GPS     -9   5537
49NZ20151223 I10      35      1  ROS 010516 0440    BE 13 10.19 S 111 32.45 E GPS     -9   5434
49NZ20151223 I10      35      1  BUC 010516 0447    UN 13 10.19 S 111 32.45 E GPS     -9   5431                                 1,3-6,20,31,33,34,102                                     30.2C
49NZ20151223 I10      35      1  ROS 010516 0604    BO 13 10.23 S 111 32.64 E GPS     -9   5432        9   5403   5516      34 1-9,20,23,24,26,27,31,33,34,102
49NZ20151223 I10      35      1  ROS 010516 0824    EN 13 10.30 S 111 32.79 E GPS     -9   5431
49NZ20151223 I10      36      1  ROS 010516 1111    BE 12 41.26 S 111 35.00 E GPS     -9   3879
49NZ20151223 I10      36      1  BUC 010516 1119    UN 12 41.30 S 111 34.94 E GPS     -9   3883                                 1,3-6,20,102                                              30.4C
49NZ20151223 I10      36      1  ROS 010516 1214    BO 12 41.24 S 111 35.04 E GPS     -9   3878        8   3859   3926      28 1-9,12,13,20,23,24,26,27,102
49NZ20151223 I10      36      1  ROS 010516 1406    EN 12 41.18 S 111 35.02 E GPS     -9   3873
49NZ20151223 I10      36      1  FLT 010516 1412    DE 12 41.08 S 111 35.04 E GPS     -9   3868                                                                                           ARGO HULL NUMBER 7428i
49NZ20151223 I10      37      1  ROS 010516 1654    BE 12 11.74 S 111 37.30 E GPS     -9   2779                                                                                           FOR BIO
49NZ20151223 I10      37      1  ROS 010516 1705    BO 12 11.71 S 111 37.24 E GPS     -9   2780       -9    495    501      30 3-6,13,31,33,34,43,82,86,95,100,101,102,104,106,112,113,115,116
49NZ20151223 I10      37      1  ROS 010516 1745    EN 12 11.77 S 111 37.15 E GPS     -9   2779
49NZ20151223 I10      37      2  ROS 010516 1951    BE 12 11.69 S 111 37.52 E GPS     -9   2777
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49NZ20151223	I10	37	2	ROS	010516	1956	BO	12 11.70 S	111 37.49 E	GPS	-9	2778	-9	97	101	36	22,89	CESIUM SAMPLING I
49NZ20151223	I10	37	2	ROS	010516	2011	EN	12 11.74 S	111 37.35 E	GPS	-9	2777						
49NZ20151223	I10	37	3	ROS	010516	2055	BE	12 11.68 S	111 37.38 E	GPS	-9	2780						
49NZ20151223	I10	37	3	BUC	010516	2103	UN	12 11.67 S	111 37.33 E	GPS	-9	2781					48,86,95	NO TEMP MEASUREMENTS
49NZ20151223	I10	37	3	ROS	010516	2113	BO	12 11.64 S	111 37.33 E	GPS	-9	2780	-9	794	803	36	22,89	CESIUM SAMPLING II
49NZ20151223	I10	37	3	ROS	010516	2144	EN	12 11.60 S	111 37.25 E	GPS	-9	2783						
49NZ20151223	I10	37	4	ROS	010516	2246	BE	12 11.70 S	111 37.43 E	GPS	-9	2782						
49NZ20151223	I10	37	4	BUC	010516	2254	UN	12 11.69 S	111 37.39 E	GPS	-9	2780					1,3-6,13,20,31,33,34,43,82,98,99,100,101,102,104,106,115	30.1C
49NZ20151223	I10	37	4	ROS	010516	2333	BO	12 11.57 S	111 37.34 E	GPS	-9	2779	9	2763	2801	31	1-9,20,23,24,26,27,31,33,34,43,48,82,92,95,98,100,101,102,104,106	
49NZ20151223	I10	37	4	ROS	010616	0059	EN	12 11.37 S	111 37.12 E	GPS	-9	2784						
49NZ20151223	I10	38	1	ROS	010616	0301	BE	11 56.95 S	111 38.74 E	GPS	-9	3152						
49NZ20151223	I10	38	1	BUC	010616	0308	UN	11 56.95 S	111 38.69 E	GPS	-9	3154					1,3-6,102	29.8C
49NZ20151223	I10	38	1	ROS	010616	0354	BO	11 56.92 S	111 38.70 E	GPS	-9	3156	9	3130	3184	25	1-9,27,102	
49NZ20151223	I10	38	1	ROS	010616	0530	EN	11 56.91 S	111 38.57 E	GPS	-9	3166						
49NZ20151223	I10	39	1	ROS	010616	0702	BE	11 42.16 S	111 40.12 E	GPS	-9	3629						
49NZ20151223	I10	39	1	BUC	010616	0709	UN	11 42.17 S	111 40.06 E	GPS	-9	3626					1,3-6,102	30.4C
49NZ20151223	I10	39	1	ROS	010616	0800	BO	11 42.19 S	111 40.03 E	GPS	-9	3633	10	3603	3665	27	1-9,23,24,26,27,102	
49NZ20151223	I10	39	1	ROS	010616	0941	EN	11 42.15 S	111 40.10 E	GPS	-9	3625						
49NZ20151223	I10	40	1	ROS	010616	1154	BE	11 27.31 S	111 41.75 E	GPS	-9	3974						
49NZ20151223	I10	40	1	BUC	010616	1202	UN	11 27.34 S	111 41.70 E	GPS	-9	3970					1,3-6,102	30.1C
49NZ20151223	I10	40	1	ROS	010616	1258	BO	11 27.35 S	111 41.66 E	GPS	-9	3971	8	3947	4018	28	1-9,27,102	
49NZ20151223	I10	40	1	ROS	010616	1443	EN	11 27.38 S	111 41.53 E	GPS	-9	3979						
49NZ20151223	I10	41	1	ROS	010616	1657	BE	11 12.55 S	111 43.05 E	GPS	-9	4194						
49NZ20151223	I10	41	1	BUC	010616	1704	UN	11 12.57 S	111 43.04 E	GPS	-9	4200					1,3-6,34,98,99,102	30.1C
49NZ20151223	I10	41	1	ROS	010616	1803	BO	11 12.62 S	111 43.02 E	GPS	-9	4196	9	4171	4246	32	1-9,23,24,26,27,34,92,98,99,102	
49NZ20151223	I10	41	1	ROS	010616	2000	EN	11 12.52 S	111 42.88 E	GPS	-9	4197						
49NZ20151223	I10	42	1	ROS	010616	2237	BE	10 57.81 S	111 44.50 E	GPS	-9	4600						
49NZ20151223	I10	42	1	BUC	010616	2245	UN	10 57.80 S	111 44.48 E	GPS	-9	4601					1,3-6,102	29.7C
49NZ20151223	I10	42	1	ROS	010616	2351	BO	10 57.78 S	111 44.64 E	GPS	-9	4607	9	4577	4662	31	1-9,23,24,26,27,92,102	
49NZ20151223	I10	42	1	ROS	010716	0149	EN	10 57.91 S	111 44.75 E	GPS	-9	4596						
49NZ20151223	I10	42	1	FLT	010716	0156	DE	10 57.86 S	111 44.82 E	GPS	-9	4606						ARGO HULL NUMBER 7432i
49NZ20151223	I10	43	1	ROS	010716	0358	BE	10 42.95 S	111 45.88 E	GPS	-9	5791						
49NZ20151223	I10	43	1	BUC	010716	0406	UN	10 42.97 S	111 45.85 E	GPS	-9	5793					1,3-6,102	30.1C
49NZ20151223	I10	43	1	ROS	010716	0533	BO	10 42.88 S	111 45.76 E	GPS	-9	5803	9	5772	5901	36	1-9,23,24,26,27,92,102	
49NZ20151223	I10	43	1	ROS	010716	0811	EN	10 42.77 S	111 45.63 E	GPS	-9	5819						
49NZ20151223	I10	44	1	ROS	010716	1032	BE	10 28.11 S	111 47.30 E	GPS	-9	5585						
49NZ20151223	I10	44	1	BUC	010716	1040	UN	10 28.12 S	111 47.28 E	GPS	-9	5582					1,3-6,102	30.1C
49NZ20151223	I10	44	1	XCT	010716	1044	DE	10 28.11 S	111 47.28 E	GPS	-9	5576						TSK XCTD-2 #12099593
49NZ20151223	I10	44	1	ROS	010716	1158	BO	10 28.15 S	111 47.31 E	GPS	-9	5587	10	5561	5678	35	1-9,27,102	
49NZ20151223	I10	44	1	ROS	010716	1411	EN	10 28.09 S	111 46.89 E	GPS	-9	5579						
49NZ20151223	I10	45	1	ROS	010716	1627	BE	10 13.33 S	111 48.67 E	GPS	-9	3609						
49NZ20151223	I10	45	1	BUC	010716	1634	UN	10 13.34 S	111 48.71 E	GPS	-9	3609					1,3-6,34,98,99,102	29.4C
49NZ20151223	I10	45	1	XCT	010716	1638	DE	10 13.34 S	111 48.73 E	GPS	-9	3611						TSK XCTD-2 #12099592
49NZ20151223	I10	45	1	ROS	010716	1725	BO	10 13.37 S	111 48.71 E	GPS	-9	3615	10	3589	3648	29	1-9,23,24,26,27,34,92,97,98,99,102	
49NZ20151223	I10	45	1	ROS	010716	1909	EN	10 13.47 S	111 48.79 E	GPS	-9	3633						
49NZ20151223	I10	46	1	ROS	010716	2132	BE	09 58.56 S	111 50.18 E	GPS	-9	1707						
49NZ20151223	I10	46	1	BUC	010716	2140	UN	09 58.60 S	111 50.22 E	GPS	-9	1702					1,3-6,102	29.3C
49NZ20151223	I10	46	1	XCT	010716	2146	DE	09 58.59 S	111 50.21 E	GPS	-9	1703						TSK XCTD-2 #12099591
49NZ20151223	I10	46	1	ROS	010716	2204	BO	09 58.60 S	111 50.24 E	GPS	-9	1701	11	1686	1706	18	1-9,23,24,26,27,92,102	
49NZ20151223	I10	46	1	ROS	010716	2310	EN	09 58.72 S	111 50.36 E	GPS	-9	1698						
49NZ20151223	I10	46	1	FLT	010716	2340	DE	10 2.72 S	111 49.84 E	GPS	-9	2122						ARGO HULL NUMBER 7427i

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49NZ20151223 I10      47      1  ROS 010816 0132    BE 09 43.89 S 111 51.56 E GPS     -9   1212
49NZ20151223 I10      47      1  BUC 010816 0140    UN 09 43.94 S 111 51.60 E GPS     -9   1191                                1,3-6,102                                                  29.7C
49NZ20151223 I10      47      1  ROS 010816 0159    BO 09 43.91 S 111 51.62 E GPS     -9   1215       10   1194   1205      15 1-9,23,24,26,27,92,102
49NZ20151223 I10      47      1  ROS 010816 0247    EN 09 44.04 S 111 51.75 E GPS     -9   1218
49NZ20151223 I10      48      1  ROS 010816 0456    BE 09 29.00 S 111 52.95 E GPS     -9   3026
49NZ20151223 I10      48      1  BUC 010816 0504    UN 09 29.04 S 111 52.97 E GPS     -9   3021                                1,3-6,86,102                                               30.1C
49NZ20151223 I10      48      1  XCT 010816 0507    DE 09 29.05 S 111 52.96 E GPS     -9   3010                                                                                           TSK XCTD-2 #12099594
49NZ20151223 I10      48      1  ROS 010816 0547    BO 09 29.12 S 111 52.96 E GPS     -9   3001        8   2984   3028      25 1-9,23,24,26,27,92,102
49NZ20151223 I10      48      1  ROS 010816 0717    EN 09 29.19 S 111 52.82 E GPS     -9   2981
49NZ20151223 I10      49      1  ROS 010816 0931    BE 09 14.06 S 111 54.27 E GPS     -9   3045
49NZ20151223 I10      49      1  BUC 010816 0939    UN 09 14.07 S 111 54.22 E GPS     -9   3047                                1,3-6,102                                                  29.7C
49NZ20151223 I10      49      1  XCT 010816 0942    DE 09 14.06 S 111 54.23 E GPS     -9   3045                                                                                           TSK XCTD-2 #12099595
49NZ20151223 I10      49      1  ROS 010816 1021    BO 09 14.09 S 111 54.26 E GPS     -9   3053        8   3039   3076      25 1-9,27,102
49NZ20151223 I10      49      1  ROS 010816 1153    EN 09 14.17 S 111 54.15 E GPS     -9   3054
49NZ20151223 I10      49      1  FLT 010816 1200    DE 09 14.05 S 111 54.13 E GPS     -9   3045                                                                                           ARGO HULL NUMBER 7434i
49NZ20151223 I10      50      1  ROS 010816 1415    BE 08 59.37 S 111 55.73 E GPS     -9   2008
49NZ20151223 I10      50      1  BUC 010816 1422    UN 08 59.35 S 111 55.72 E GPS     -9   2000                                1,3-6,34,98,99,102                                         29.6C
49NZ20151223 I10      50      1  XCT 010816 1426    DE 08 59.35 S 111 55.71 E GPS     -9   1998                                                                                           TSK XCTD-2 #12099596
49NZ20151223 I10      50      1  ROS 010816 1451    BO 08 59.29 S 111 55.66 E GPS     -9   1988        7   1989   2006      22 1-9,23,24,26,27,34,92,98,99,102
49NZ20151223 I10      50      1  ROS 010816 1554    EN 08 59.05 S 111 55.55 E GPS     -9   1979
49NZ20151223 I10      51      1  ROS 010816 1814    BE 08 44.56 S 111 57.16 E GPS     -9    924
49NZ20151223 I10      51      1  BUC 010816 1822    UN 08 44.56 S 111 57.06 E GPS     -9    923                                1,3-6,34,102                                               29.6C
49NZ20151223 I10      51      1  ROS 010816 1835    BO 08 44.52 S 111 57.07 E GPS     -9    926        9    907    915      15 1-9,23,24,26,27,34,92,97,102
49NZ20151223 I10      51      1  ROS 010816 1930    EN 08 44.50 S 111 57.00 E GPS     -9    924
49NZ20151223 I10      52      1  ROS 010816 2141    BE 08 37.21 S 111 57.76 E GPS     -9    557
49NZ20151223 I10      52      1  BUC 010816 2142    UN 08 37.20 S 111 57.75 E GPS     -9    558                                1,3-6,34,98,99,102                                         29.4C
49NZ20151223 I10      52      1  ROS 010816 2157    BO 08 37.18 S 111 57.63 E GPS     -9    556        9    544    550      12 1-9,23,24,26,27,34,92,98,99,102
49NZ20151223 I10      52      1  ROS 010816 2228    EN 08 37.08 S 111 57.49 E GPS     -9    553
49NZ20151223 I10     901      1  XCT 010916 1247    DE 08 42.27 S 112 14.99 E GPS     -9    897                                                                                           TSK XCTD-2 #12026202
49NZ20151223 I10     902      1  XCT 010916 1421    DE 08 46.73 S 112 30.00 E GPS     -9   1299                                                                                           TSK XCTD-2 #12026199
49NZ20151223 I10     903      1  XCT 010916 1600    DE 08 51.29 S 112 45.00 E GPS     -9   1602                                                                                           TSK XCTD-2 #12026196
49NZ20151223 I10     904      1  XCT 010916 1736    DE 08 55.98 S 113  0.00 E GPS     -9   2121                                                                                           TSK XCTD-2 #12026193
49NZ20151223 I10     905      1  XCT 010916 1910    DE 09  0.61 S 113 15.00 E GPS     -9   2419                                                                                           TSK XCTD-2 #12026195
49NZ20151223 I10     906      1  XCT 010916 2042    DE 09  5.54 S 113 30.14 E GPS     -9   2123                                                                                           TSK XCTD-2 #12026198
49NZ20151223 I10     907      1  UNK 010916 2208    BE 09  9.93 S 113 45.06 E GPS     -9   2235                                                                                           MAGNETOMETER CALIBRATION
49NZ20151223 I10     907      1  UNK 010916 2229    EN 09  9.93 S 113 45.39 E GPS     -9   2238                                                                                           MAGNETOMETER CALIBRATION
49NZ20151223 I10     907      1  FLT 011016 0055    DE 09  9.68 S 113 44.97 E GPS     -9   2232                                                                                           ARGO HULL NUMBER 7425i
49NZ20151223 I10     907      1  XCT 011016 0058    DE 09  9.82 S 113 44.99 E GPS     -9   2235                                                                                           TSK XCTD-2 #12026201
49NZ20151223 I10     908      1  XCT 011016 1355    DE 09  9.94 S 113 59.99 E GPS     -9   3377                                                                                           TSK XCTD-2 #12026194
49NZ20151223 I10     909      1  XCT 011016 1521    DE 09 10.06 S 114 15.00 E GPS     -9   3469                                                                                           TSK XCTD-2 #12026200
49NZ20151223 I10     910      1  XCT 011016 1647    DE 09 10.01 S 114 30.01 E GPS     -9   3164                                                                                           TSK XCTD-2 #12099598
49NZ20151223 I10     911      1  XCT 011016 1818    DE 09 10.00 S 114 45.00 E GPS     -9   2307                                                                                           TSK XCTD-2 #12099597
49NZ20151223 I10     912      1  XCT 011016 1948    DE 09  9.98 S 115  0.00 E GPS     -9   2489                                                                                           TSK XCTD-2 #11021994
49NZ20151223 I10     913      1  FLT 011016 2155    DE 09  9.91 S 115 14.77 E GPS     -9   3095                                                                                           ARGO HULL NUMBER 7433i
49NZ20151223 I10     913      1  XCT 011016 2159    DE 09  9.94 S 115 14.93 E GPS     -9   3101                                                                                           TSK XCTD-2 #12026197
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R/V MIRAI CRUISE MR1505 LEG2
SHIP/CRS     WOCE                CAST         UTC EVENT             POSITION         UNC    COR HT ABOVE   WIRE    MAX  NO. OF
EXPOCODE     SECT  STNNBR CASTNO TYPE DATE   TIME  CODE LATITUDE    LONGITUDE NAV  DEPTH  DEPTH   BOTTOM    OUT  PRESS BOTTLES PARAMETERS                                                COMMENTS
-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
49NZ20160113          914      1  FLT 011916 2303   DE 21 95.84 N 134 59.91 E GPS     -9   5462                                                                                          ARGO WMO-ID: 5901937
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Water sample parameters:

Number	Parameter	Mnemonic	Mnemonic for expected error
1	Salinity	SALNTY	
2	Oxygen	OXYGEN	
3	Silicate	SILCAT	SILUNC *1
4	Nitrate	NITRAT	NRAUNC *1
5	Nitrite	NITRIT	NRIUNC *1
6	Phosphate	PHSPHT	PHPUNC *1
7	Freon-11	CFC-11	
8	Freon-12	CFC-12	
9	Tritium		
10	Helium		
11	He-3/He-4		
12	14Carbon	DELC14	C14ERR
13	13Carbon	DELC13	C13ERR
14	Kr-85		
15	Argon		
16	Ar-39		
17	Neon		
18	Ra-228		
19	Ra-226		
20	Ratio of O18 to O16	O18/O16	
21	Sr-90		
22	Cesium-137	CS-137	CS137ER *2
23	Total carbon	TCARBN	
24	Total alkalinity	ALKALI	
25	pCO2		
26	pH	PH	
27	Freon-113	CFC113	
28	Carbon tetrachloride	CCL4	
29	Iodate/Iodide		
30	Ammonium	NH4	
31	Methane	CH4	
32	Dissolved organic nitrogen	DON	
33	Nitrous oxide	N2O	
34	Chlorophyll-a	CHLORA	
35	Phaeophytin		
36	Halocarbons		
37	Biogenic sulfur compounds	DMS	
38	Hydrocarbons		
39	Barium		
40	Particulate organic carbon	POC	
41	Particulate organic nitrogen	PON	
42	Abundance of bacteria	BACT	
43	Dissolved organic carbon	DOC	
44	Carbon monoxide		
45	Nitrogen (gas)		
46	Total organic carbon	TOC	
47	Plutonium	PLUTO	PLUTOER *2
48	Primary productivity		
64	Incubation		
81	Particulate organic matter	POM	
82	15N-Nitrate	15NO3	
83	Particulate inorganic matter	PIM	
84	Dissolved organic phosphate		
85	Ratio of O-17 to O-16	O17/O16	
86	Flowcytometry		
87	Genetic analysis		
88	Nitrogen fixation		
89	Cesium-134	CS-134	CS134ER
90	Perfluoroalkyl substances	PFAS	
91	Iodine-129	I-129	
92	Density salinity	DNSSAL	
93	Sulfur hexafluoride	SF6	
94	Isoprene		
95	Pigment		
96	Microscope		
97	Calcium		
98	Colored dissolved organic matter	CDOM	
99	Absorption coefficients of particulate matter	AP	
100	Nitrification		
101	13C-CH4		
102	Prokaryotic abundance		
103	Fluorescence in situ hybridization		
104	Prokaryotic activity		
105	Viral production		
106	Microbial diversity		
107	N2O 15N-isotope		
108	Nitrogen fixation		
109	NH4 15N-isotope		
110	Urea		
111	NO2 15N-isotope		
112	Coenzyme F430		
113	Chlorophyll 15N-isotope		

Figure captions

Figure 1 Station locations for WHP I10 revisit in 2015 cruise with bottom topography.

Figure 2 Bathymetry (m) measured by Multi Narrow Beam Echo Sounding system.

Figure 3 Surface wind (m/s) measured at 25 m above sea level. Wind data is averaged over 6-hour.

Figure 4 (a) Sea surface temperature (°C), (b) sea surface salinity (psu), (c) sea surface oxygen (μmol/kg), and (d) sea surface chlorophyll *a* (mg/m^3) measured by the Continuous Sea Surface Water Monitoring System.

Figure 5 Difference in the partial pressure of CO_2 between the ocean and the atmosphere, ΔpCO_2 (ppmv).

Figure 6 Potential temperature (°C) cross sections calculated by using CTD temperature and salinity data calibrated by bottle salinity measurements. Vertical exaggeration of the 0-6500 m section is 1000:1, and expanded section of the upper 1000 m is made with a vertical exaggeration of 2500:1.

Figure 7 CTD salinity (psu) cross sections calibrated by bottle salinity measurements. Vertical exaggeration is same as Fig. 6.

Figure 8 Absolute salinity (g/kg) cross sections calculated by using CTD salinity data. Vertical exaggeration is same as Fig. 6.

Figure 9 Density (upper: σ_0, lower: σ_4) (kg/m^3) cross sections calculated by using CTD temperature and salinity data. Vertical exaggeration of the 0-1500 m and 1500-6500 m section are 2500:1 and 1000:1, respectively. (a) EOS-80 and (b) TEOS-10 definition.

Figure 10 Neutral density (γ^n) (kg/m^3) cross sections calculated by using CTD temperature and salinity data. Vertical exaggeration is same as Fig. 6.

Figure 11 CTD oxygen (μmol/kg) cross sections. Vertical exaggeration is same as Fig. 6.

Figure 12 CTD chlorophyll *a* (mg/m^3) cross section. Vertical exaggeration of the upper 1000 m section is same as Fig. 6.

Figure 13 CTD beam attenuation coefficient (m^{-1}) cross sections. Vertical exaggeration is same as Fig. 6.

Figure 14 Bottle sampled dissolved oxygen (μmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 15 Silicate (μmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 16 Nitrate (μmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 17 Nitrite (μmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration of the upper 1000 m section is same as Fig. 6.

Figure 18 Phosphate (µmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 19 Dissolved inorganic carbon (µmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 20 Total alkalinity (µmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 21 pH cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 22 Dissolved organic carbon (µmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 23 Calcium (mmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 24 CFC-11 (pmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 25 CFC-12 (pmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 26 CFC-113 (pmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 27 SF_6 (fmol/kg) cross sections. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Fig. 6.

Figure 28 Cross sections of current velocity (cm/s) normal to the cruise track measured by LADCP (eastward or northward is positive). Vertical exaggeration is same as Fig. 6.

Figure 29 Difference in potential temperature (°C) between results from the WOCE cruise in 1995 and the revisit in 2015. Red and blue areas show areas where potential temperature increased and decreased in the revisit cruise, respectively. On white areas differences in temperature do not exceed the detection limit of 0.002 °C. Vertical exaggeration is same as Fig. 6.

Figure 30 Same as Fig. 29, but for salinity (psu). CTD salinity data with SSW batch correction[1] were used. On white areas differences in salinity do not exceed the detection limit of 0.002 psu.

Figure 31 Same as Fig. 29, but for dissolved oxygen (µmol/kg). CTD oxygen data were used. On white areas differences in dissolved oxygen do not exceed the detection limit of 2 µmol/kg.

Note

1. As for the traceability of SSW to Kawano’s value (Kawano et al., 2006), the offset for the batches P126 (WOCE I10 in 1995) and P157 (WOCE I10 revisit in 2015) are 0.0006 and −0.0007, respectively. The offset values for the recent batches are listed in Table A1 (Uchida et al., in preparation).

Table A1. SSW batch to batch differences from P145 to P160 (Uchida et al., in preparation). The difference of P145 is reevaluated.

Batch no.	Production date	K15	Sp	Batch to batch difference ($\times 10^{-3}$)	
				Mantyla's standard	Kawano's standard
P145	2004/07/15	0.99981	34.9925	–2.3	–1.0
P146	2005/05/12	0.99979	34.9917	–2.8	–1.5
P147	2006/06/06	0.99982	34.9929	–1.9	–0.6
P148	2006/10/01	0.99982	34.9929	–1.3	0.0
P149	2007/10/05	0.99984	34.9937	–0.6	0.7
P150	2008/05/22	0.99978	34.9913	–0.6	0.7
P151	2009/05/20	0.99997	34.9984	–1.7	–0.4
P152	2010/05/05	0.99981	34.9926	–1.3	0.0
P153	2011/03/08	0.99979	34.9918	–0.9	0.4
P154	2011/10/20	0.99990	34.9961	–0.7	0.6
P155	2012/09/19	0.99981	34.9925	–1.2	0.1
P156	2013/07/23	0.99984	34.9937	–0.9	0.4
P157	2014/05/15	0.99985	34.9941	–2.0	–0.7
P158	2015/03/25	0.99970	34.9883	–1.5	–0.2
P159	2015/12/15	0.99988	34.9953	–1.6	–0.3
P160	2016/07/20	0.99983	34.9933	–1.3	0.0

References

Kawano, T., M. Aoyama, T. Joyce, H. Uchida, Y. Takatsuki and M. Fukasawa (2006): The latest batch-to-batch difference table of standard seawater and its application to the WOCE onetime sections, *J. Oceanogr.*, 62, 777–792.

Figure 1
Station locations for WHP I10 revisit in 2015

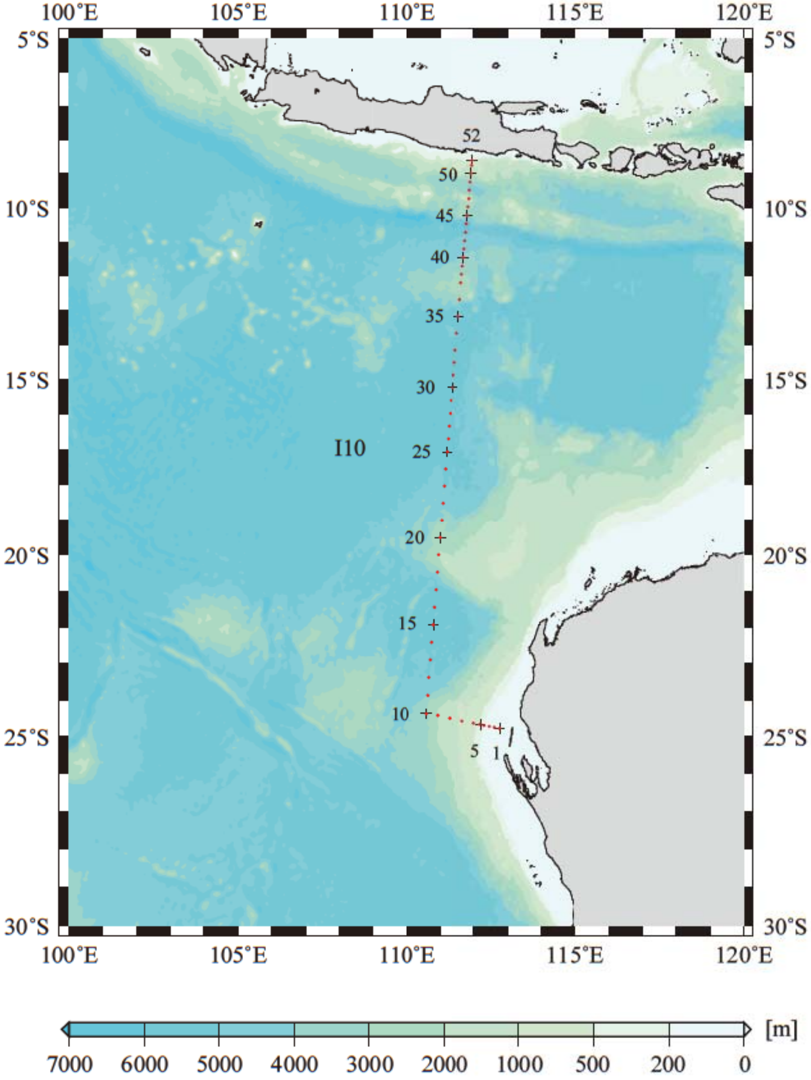


Figure 2
Bathymetry measured by Multi Narrow Beam Echo Sounding system

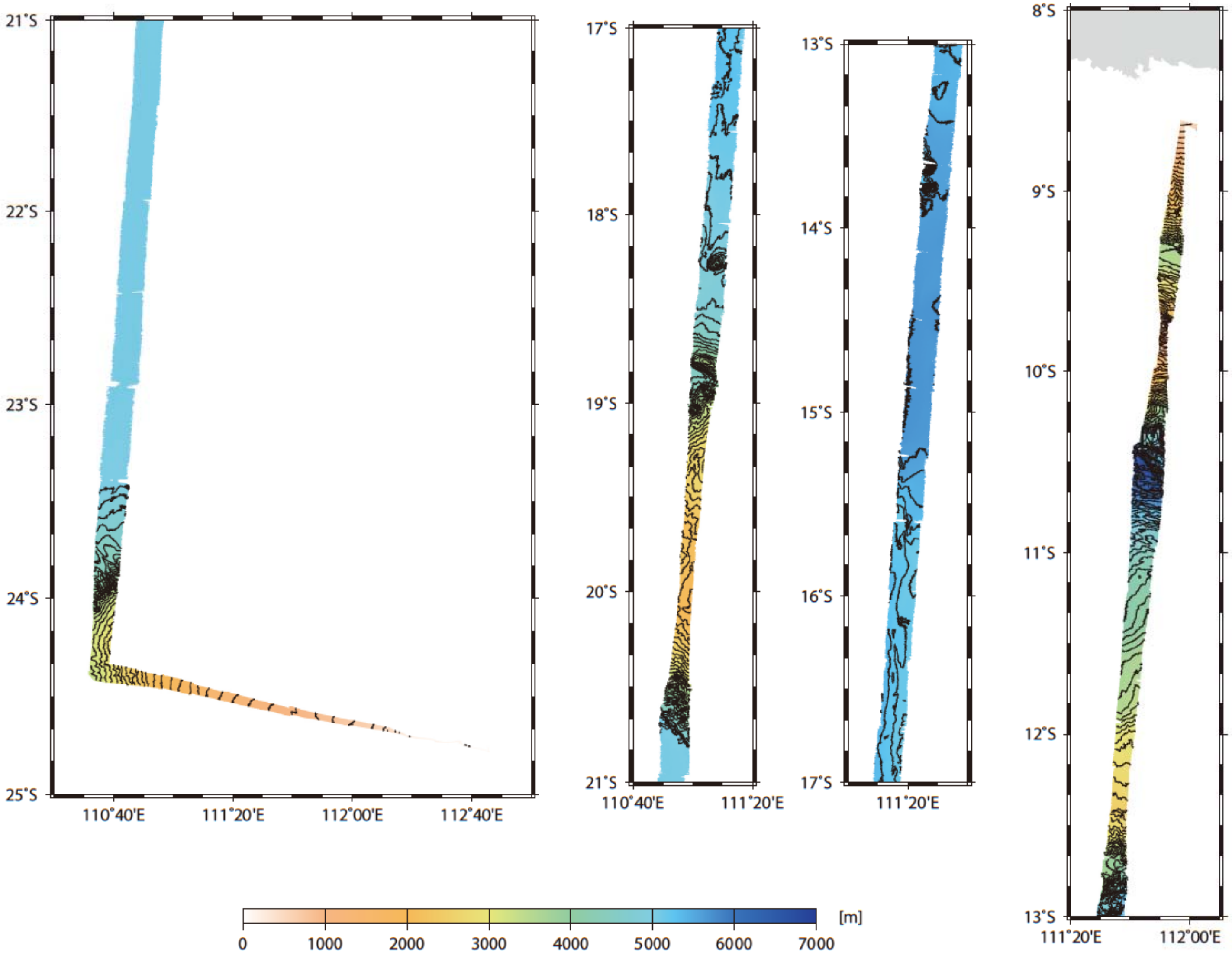


Figure 3

Surface wind measured at 25 m above sea level

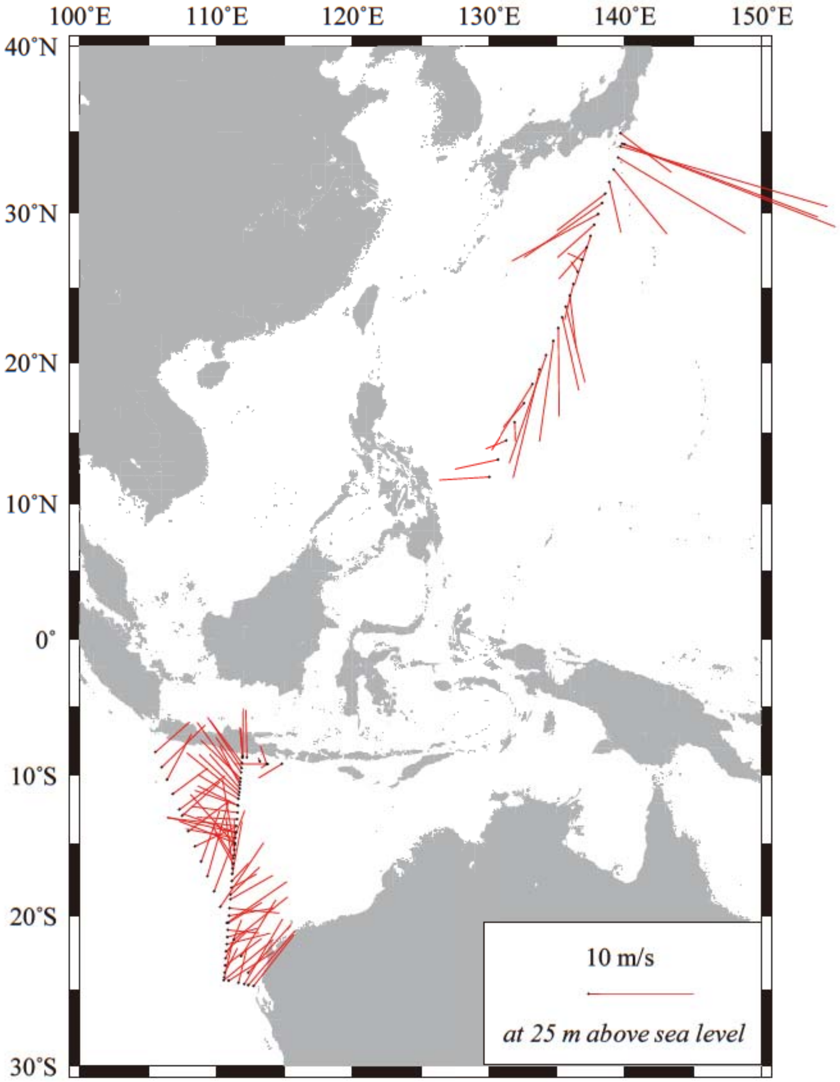


Figure 4a

Sea surface temperature (°C)

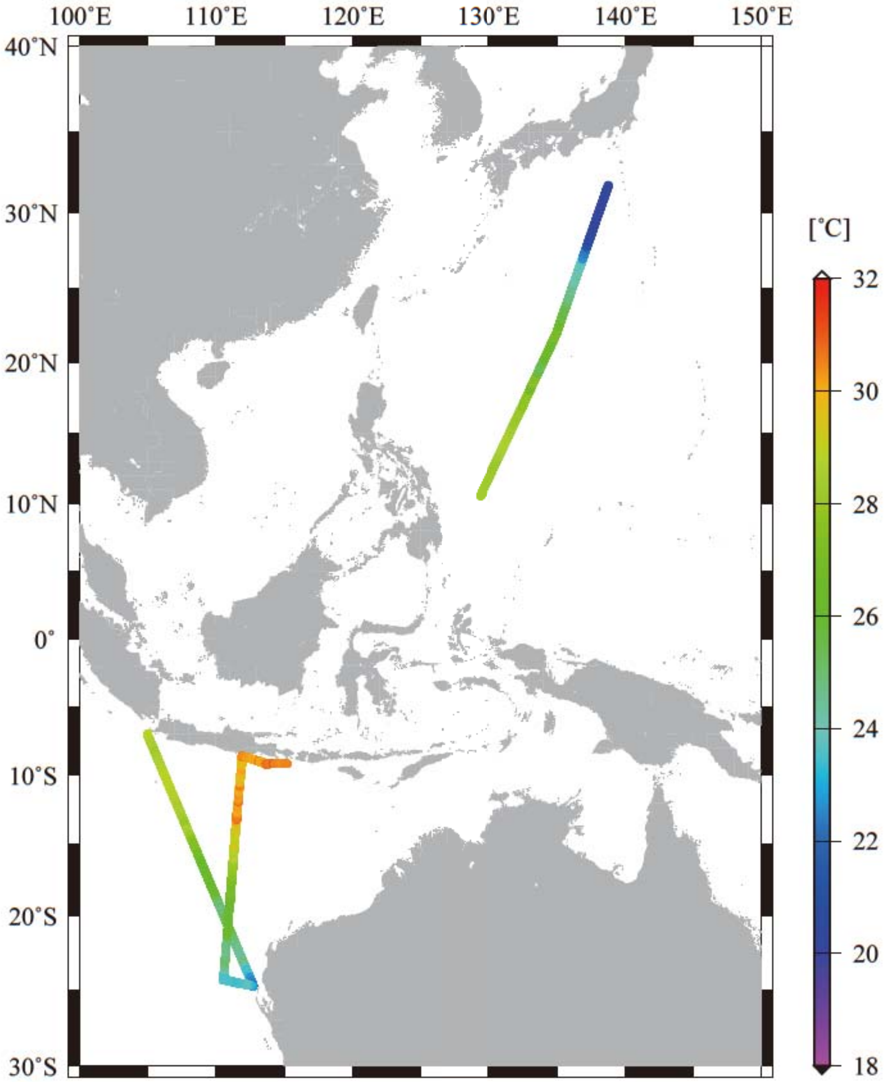


Figure 4b
Sea surface salinity (psu)

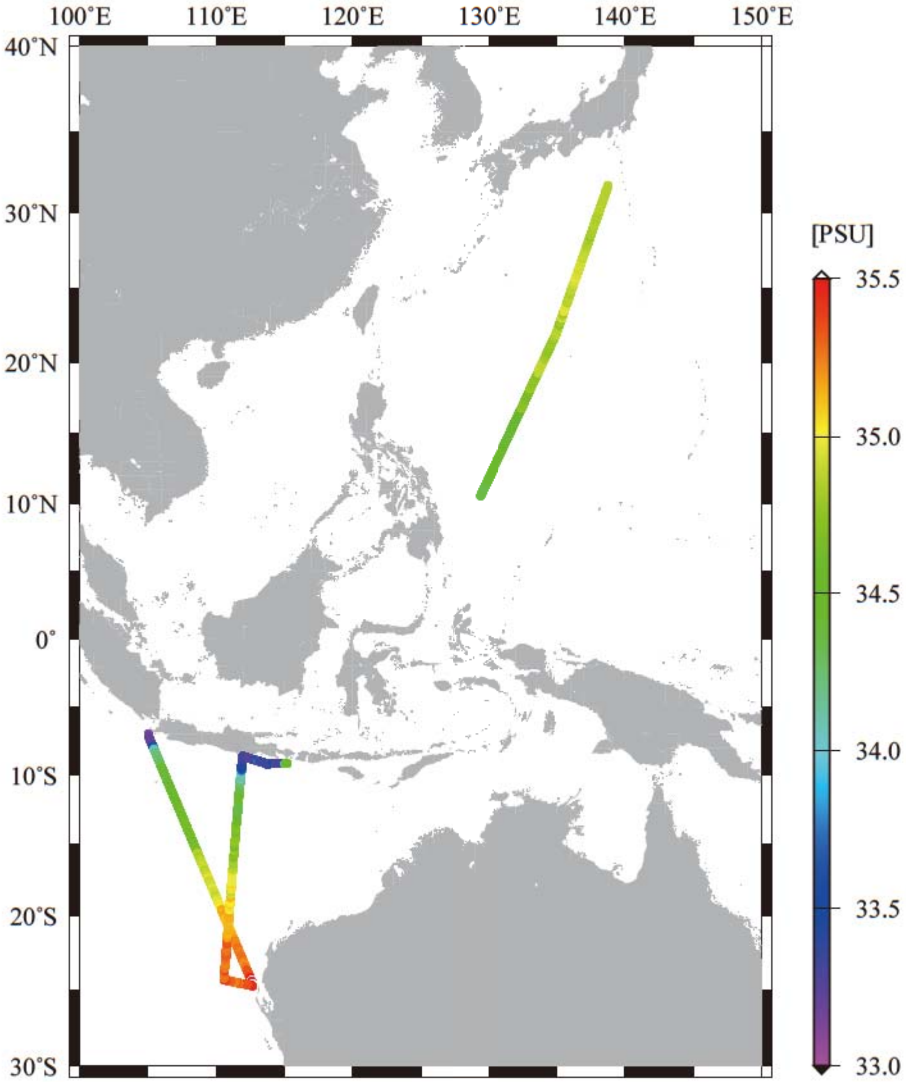


Figure 4c
Sea surface oxygen (μmol/kg)

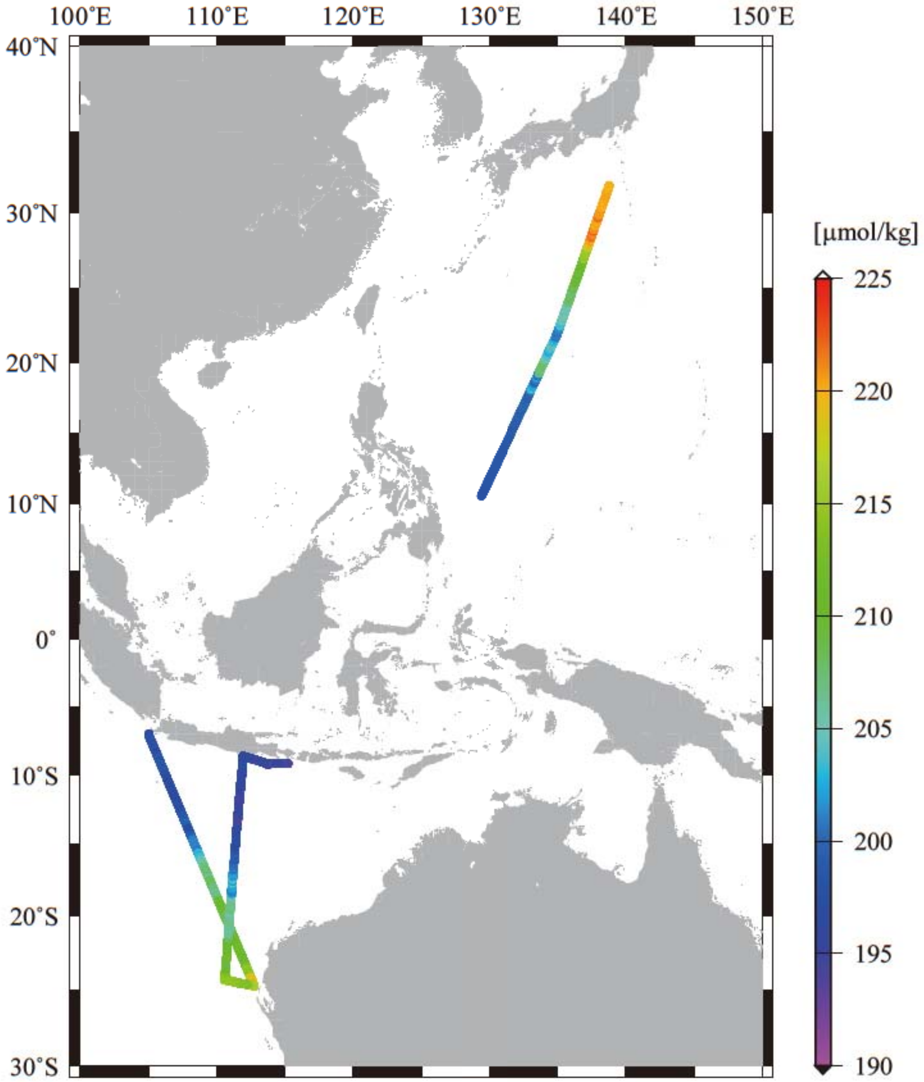


Figure 4d

Sea surface chlorophyll *a* (mg/m^3)

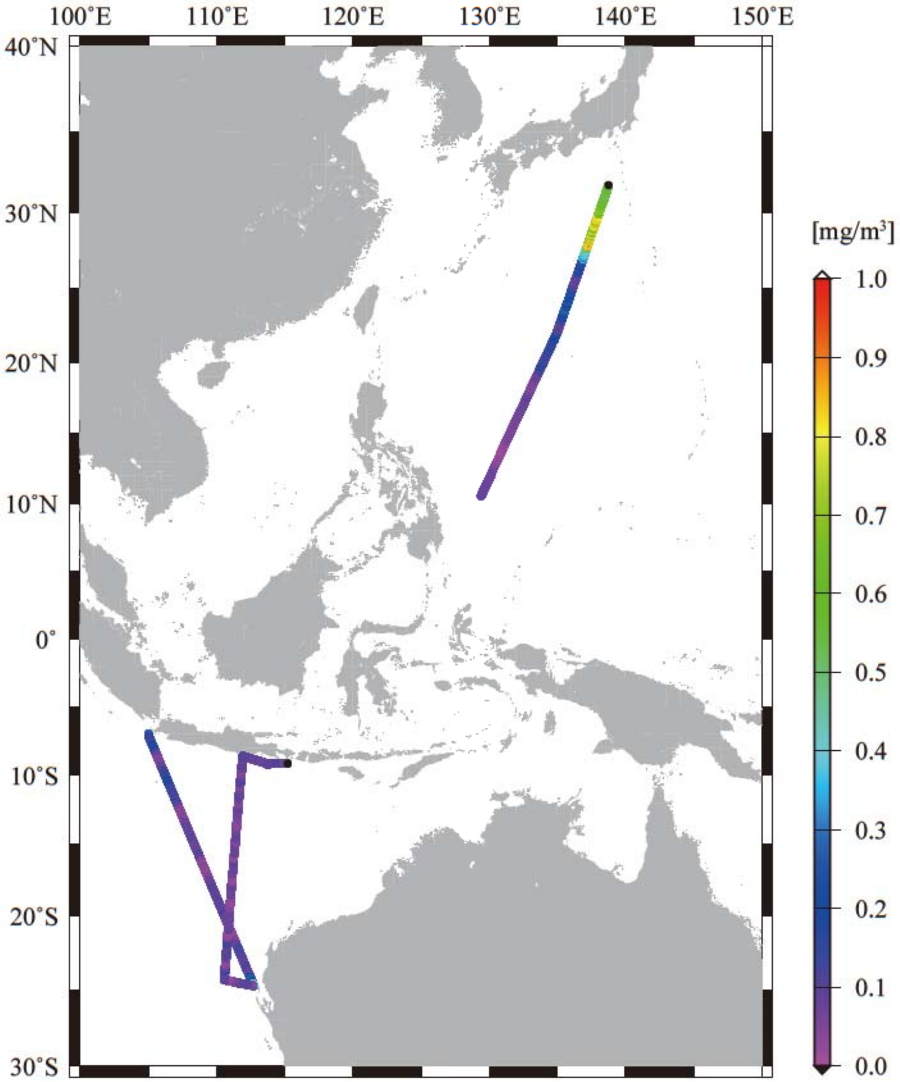


Figure 5

ΔpCO_2 (ppmv)

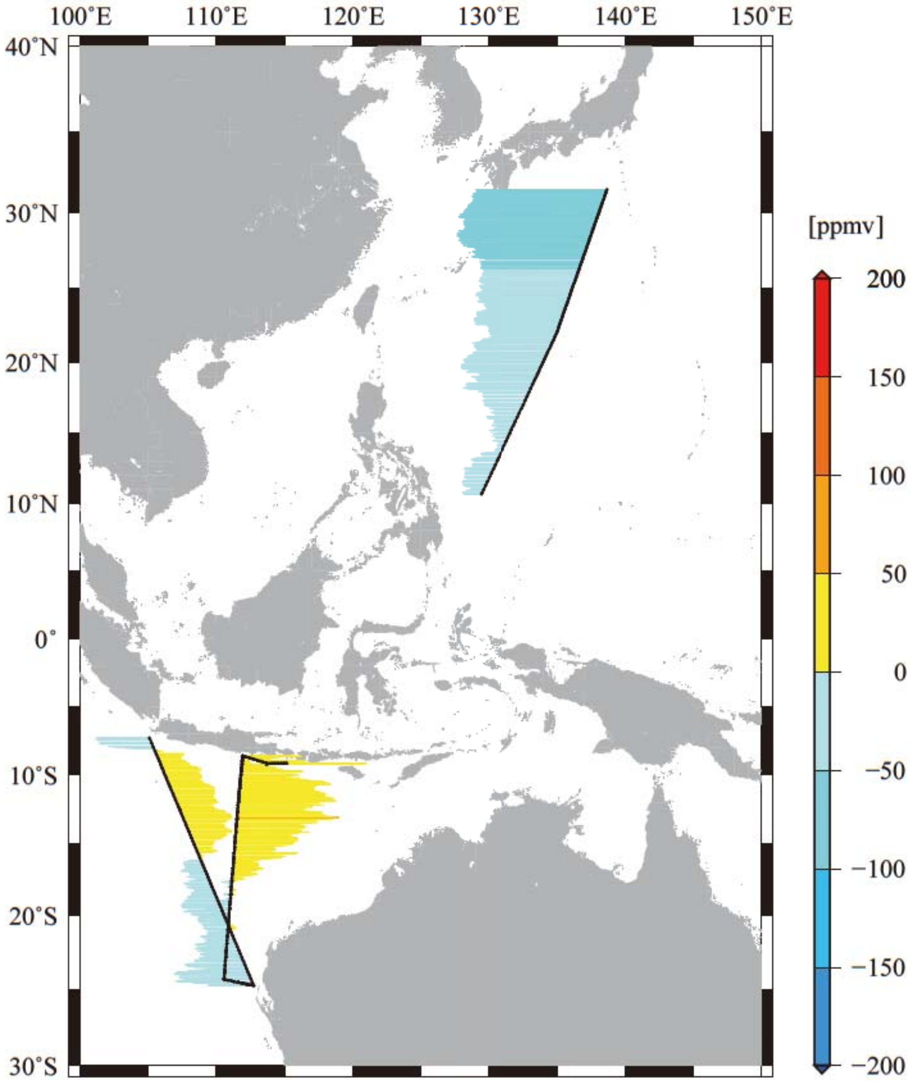


Figure 6

Potential temperature (°C)

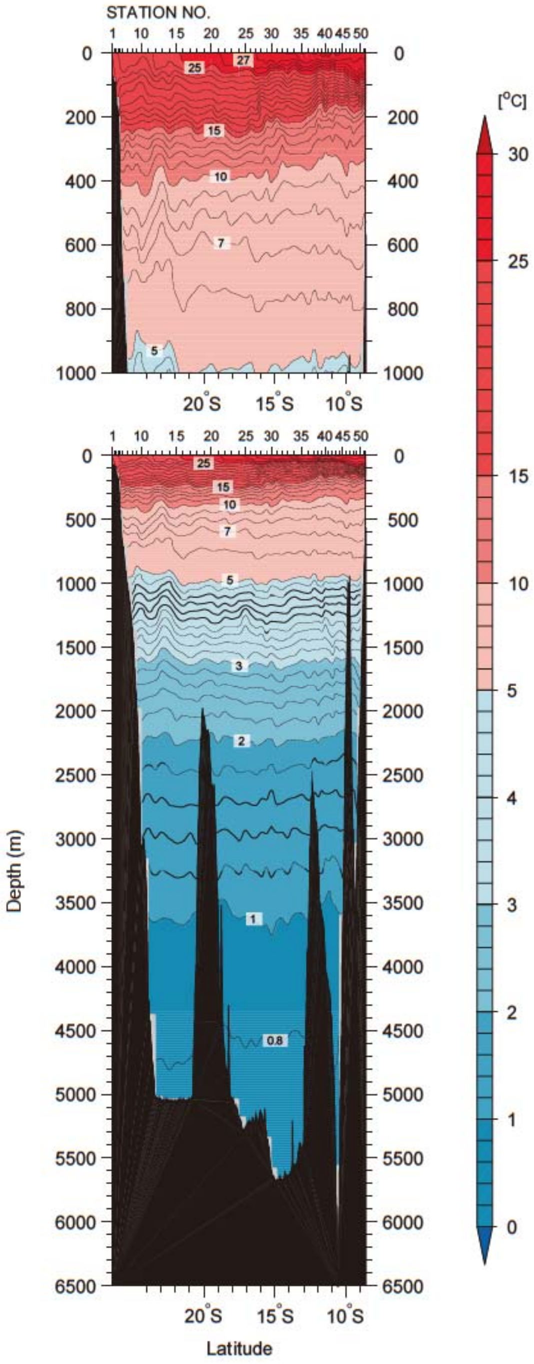


Figure 7
CTD salinity (psu)

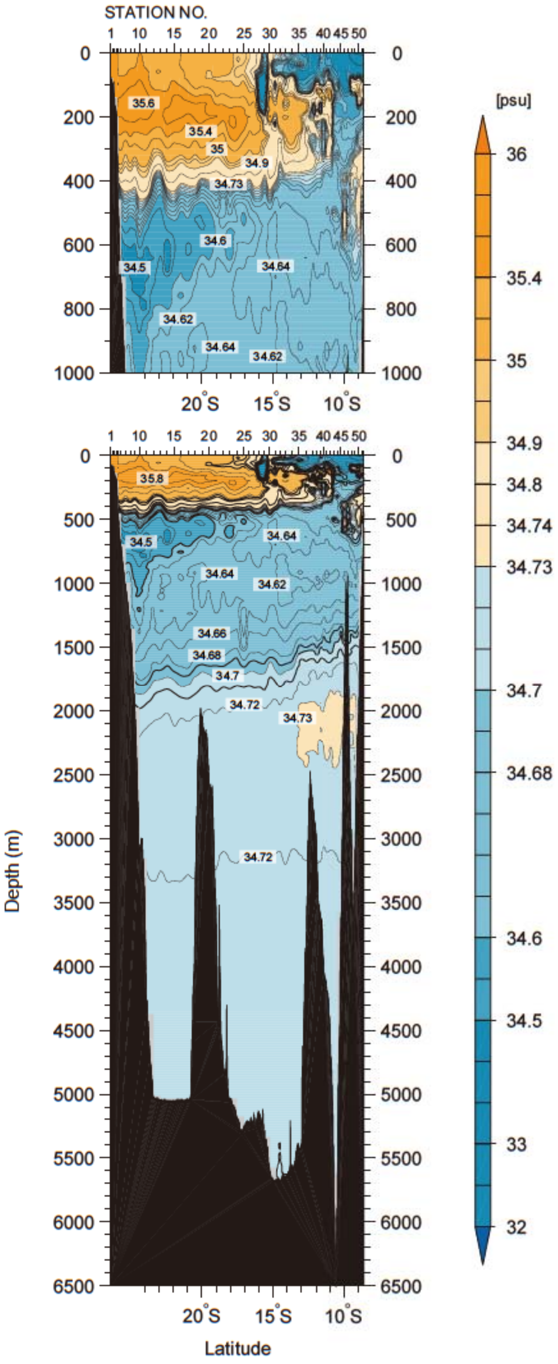


Figure 8
Absolute Salinity (g/kg)

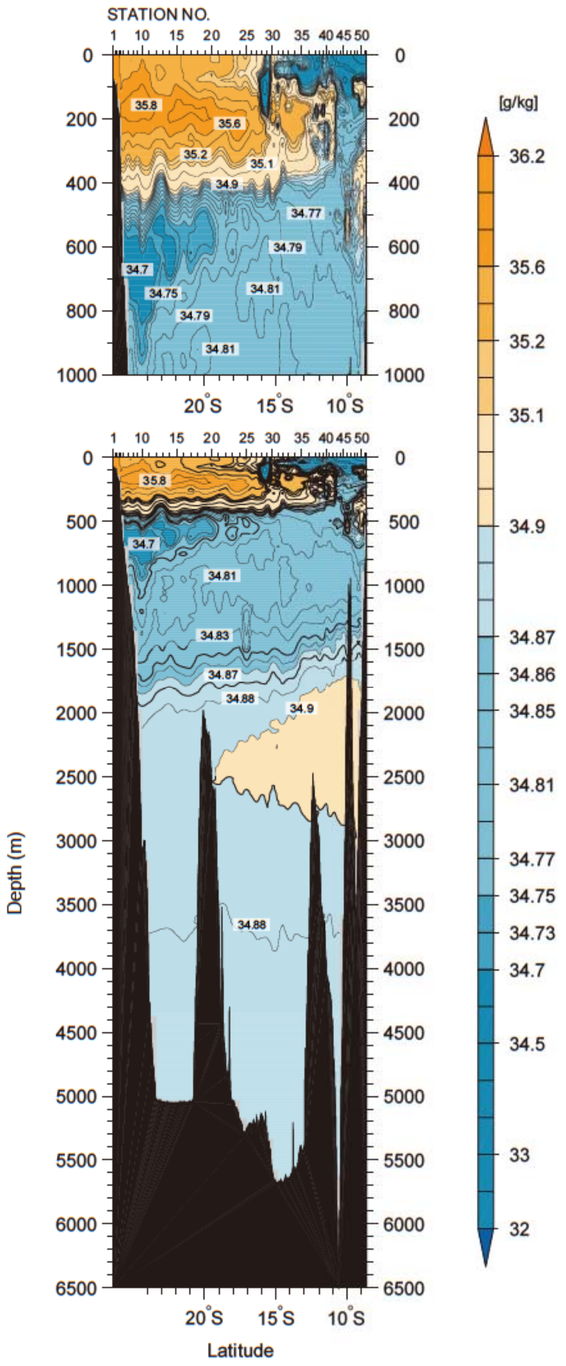


Figure 9a

Density (upper: σ_0, lower: σ_4) (kg/m^3) (EOS-80)

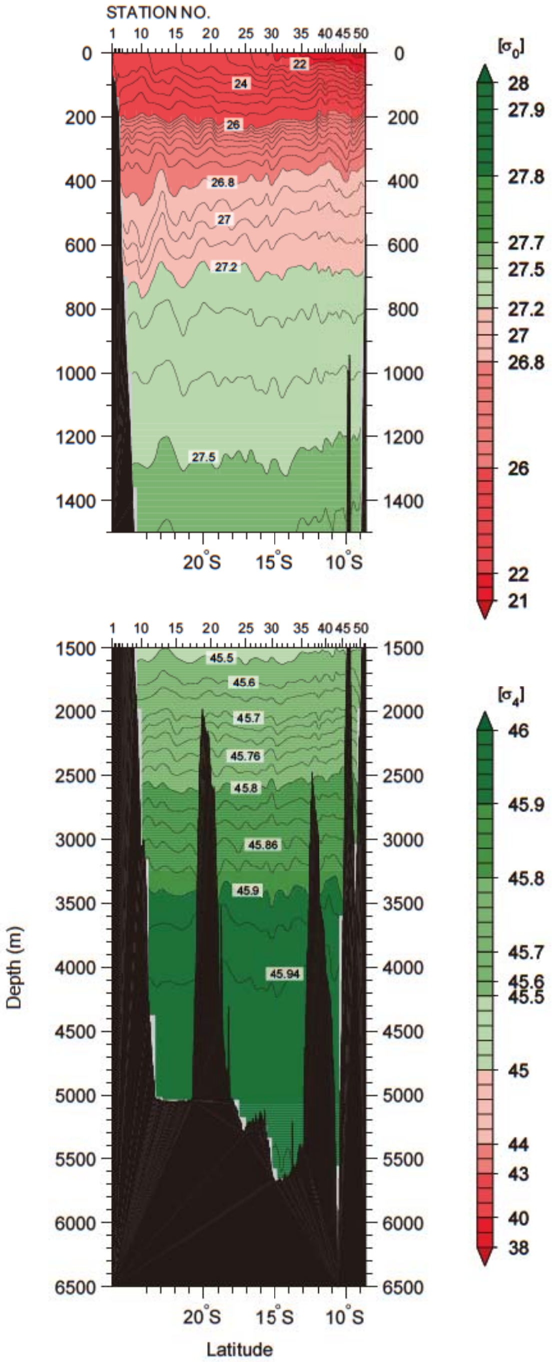


Figure 9b

Density (upper: σ_0, lower: σ_4) (kg/m^3) (TEOS-10)

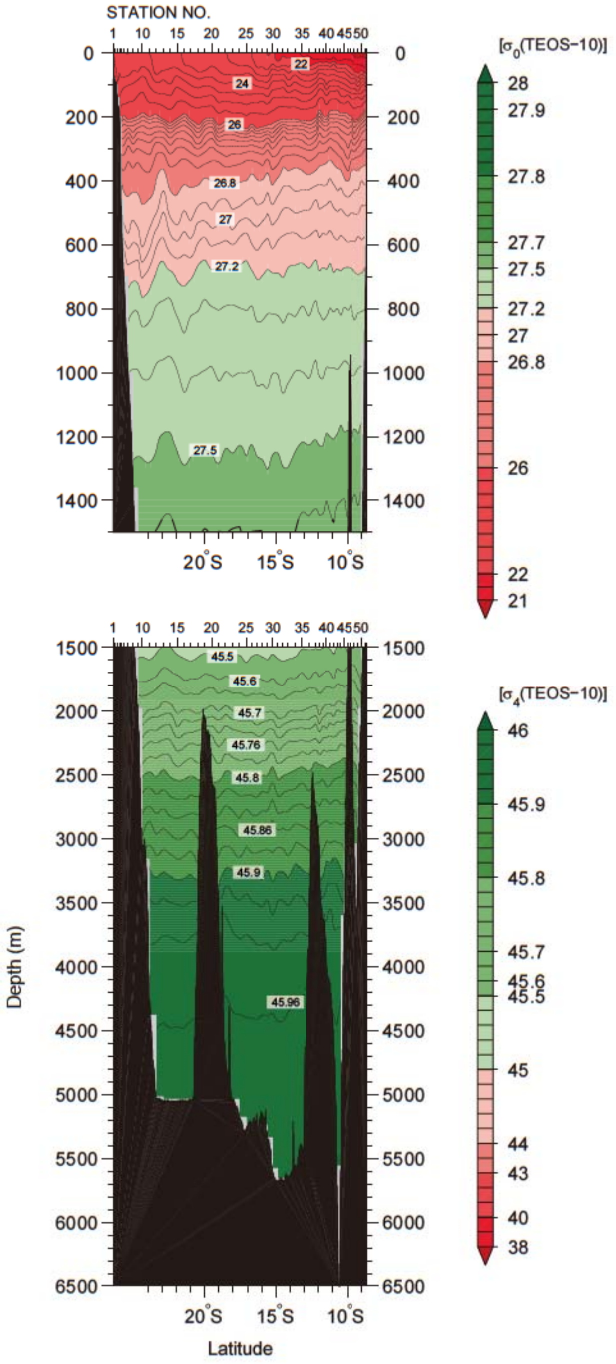


Figure 10

Density (γ^n) (kg/m^3)

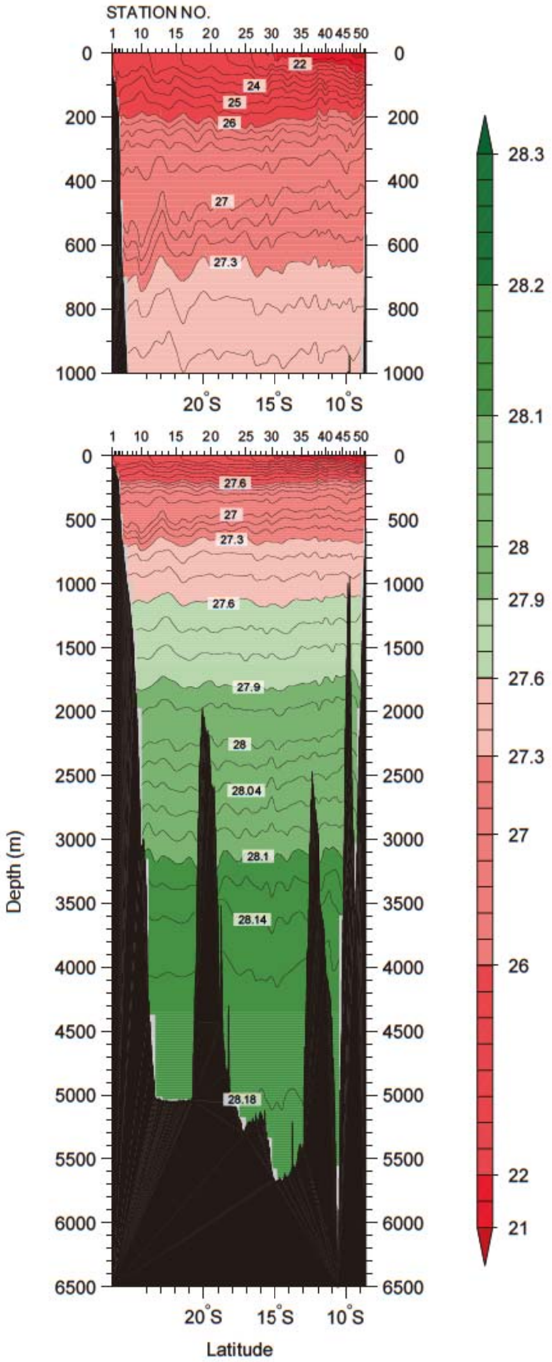


Figure 11
CTD oxygen (μmol/kg)

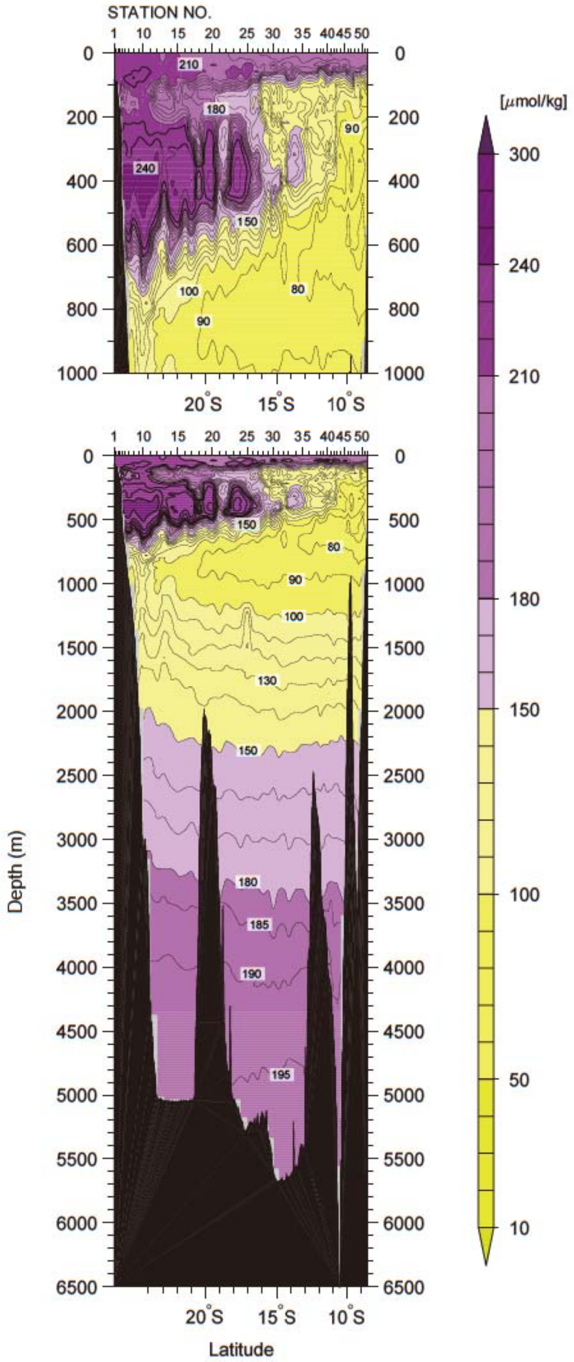


Figure 12

CTD chlorophyll *a* (mg/m^3)

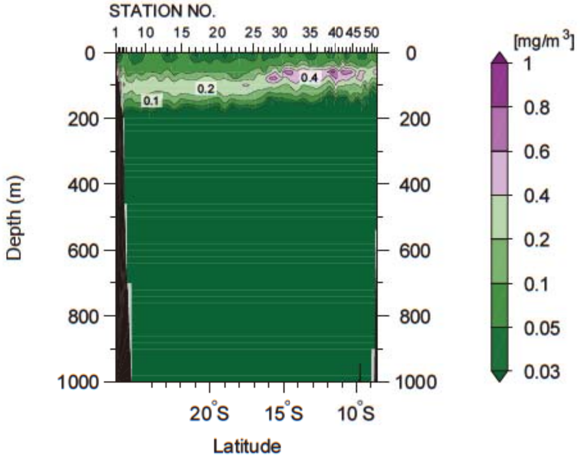


Figure 13
CTD beam attenuation coefficient (m^{-1})

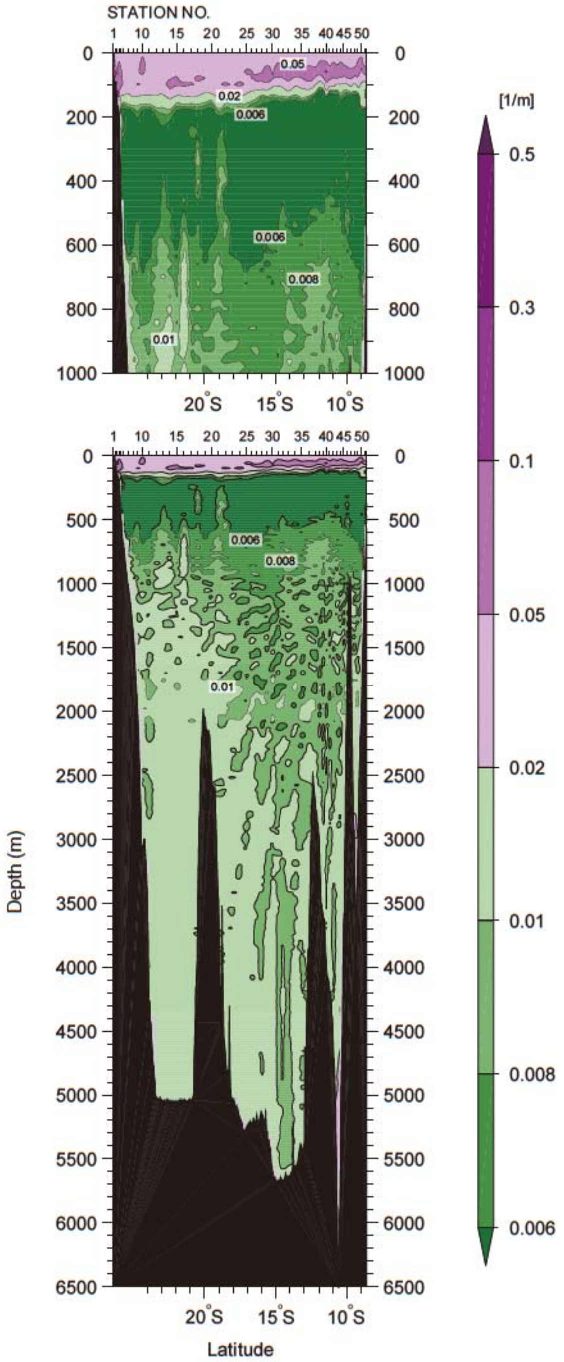


Figure 14
Bottle sampled dissolved oxygen (μmol/kg)

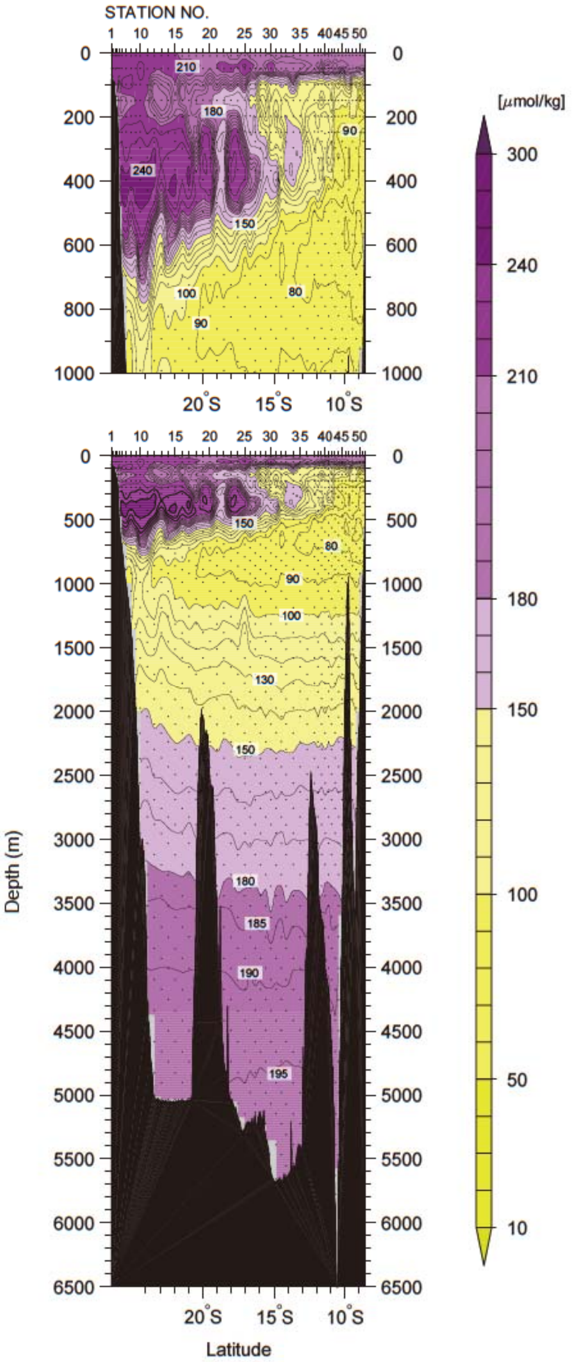


Figure 15
Silicate (µmol/kg)

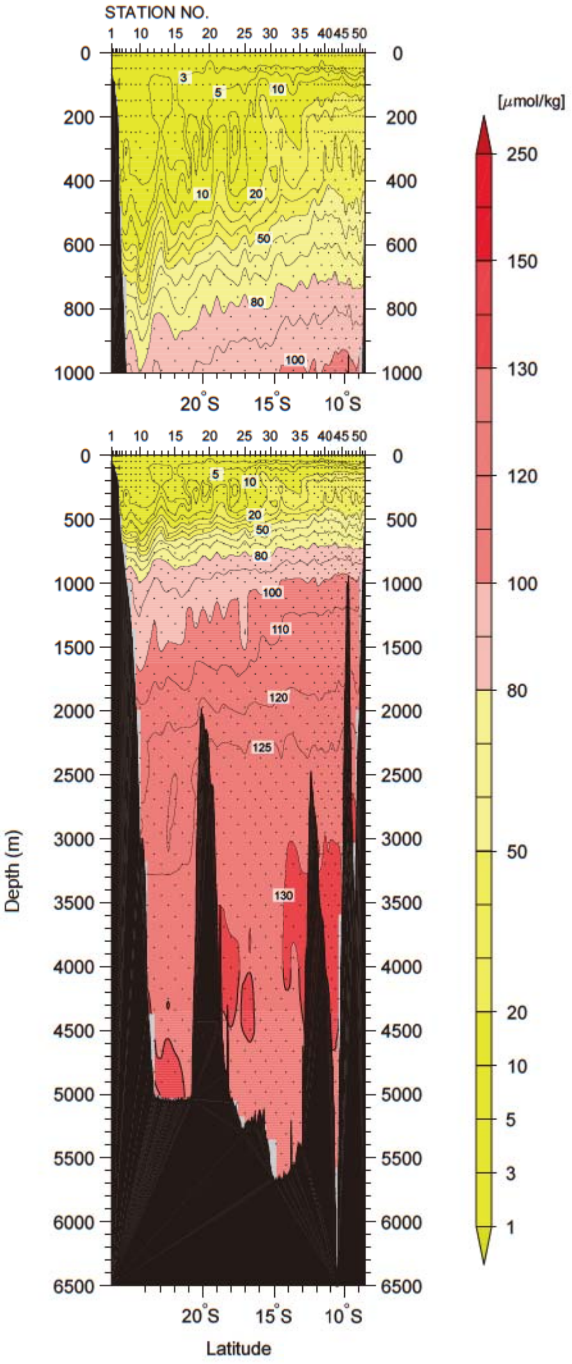


Figure 16

Nitrate (μmol/kg)

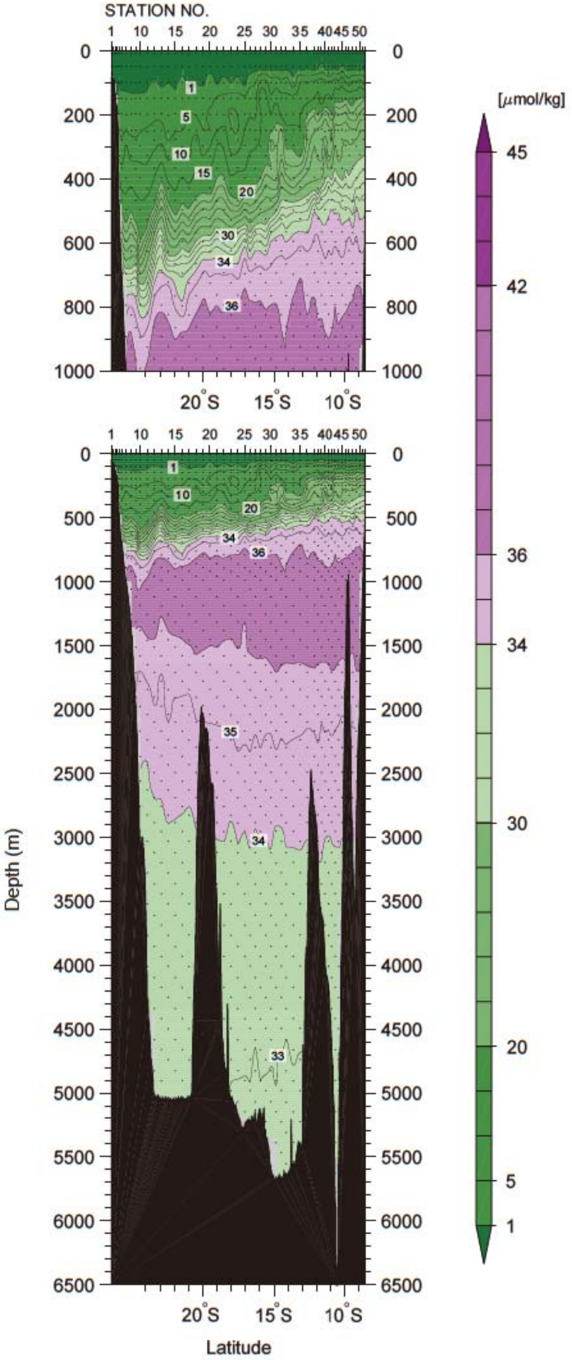


Figure 17
Nitrite (µmol/kg)

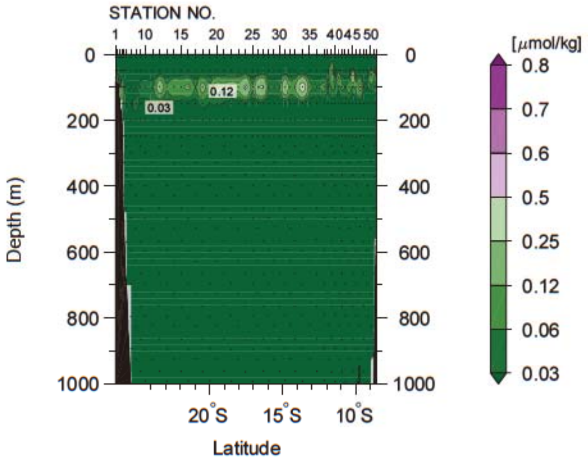


Figure 18

Phosphate (μmol/kg)

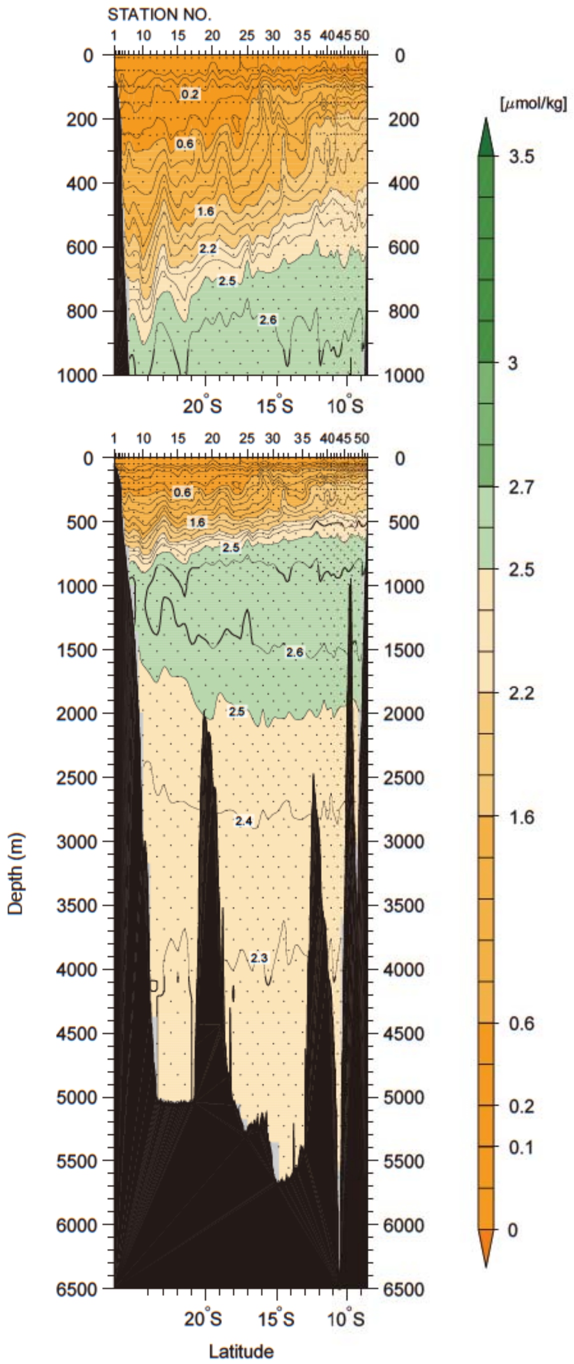


Figure 19

Dissolved inorganic carbon (C_T) (µmol/kg)

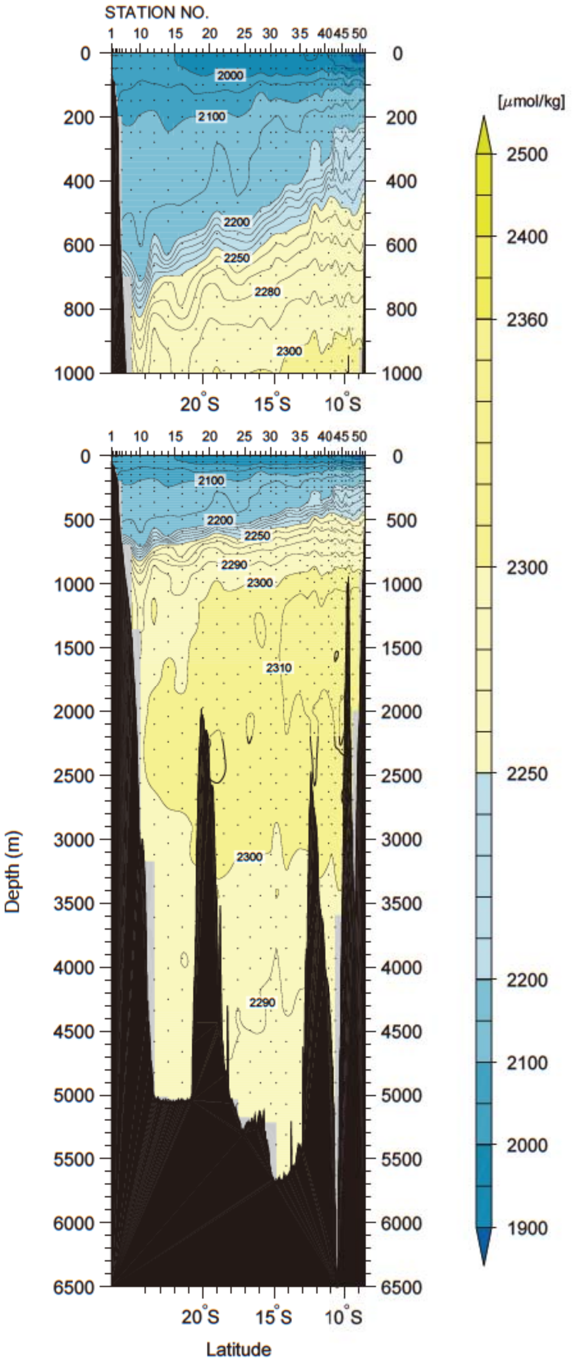


Figure 20

Total alkalinity (A_T) (μmol/kg)

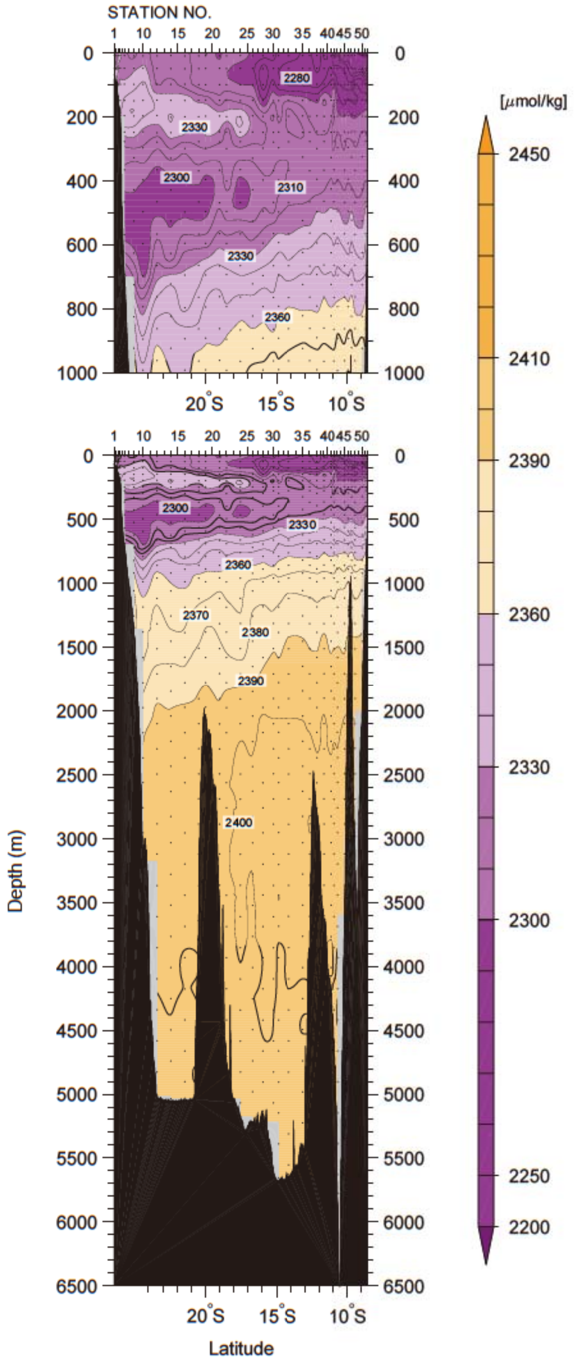


Figure 21
pH (pH_T)

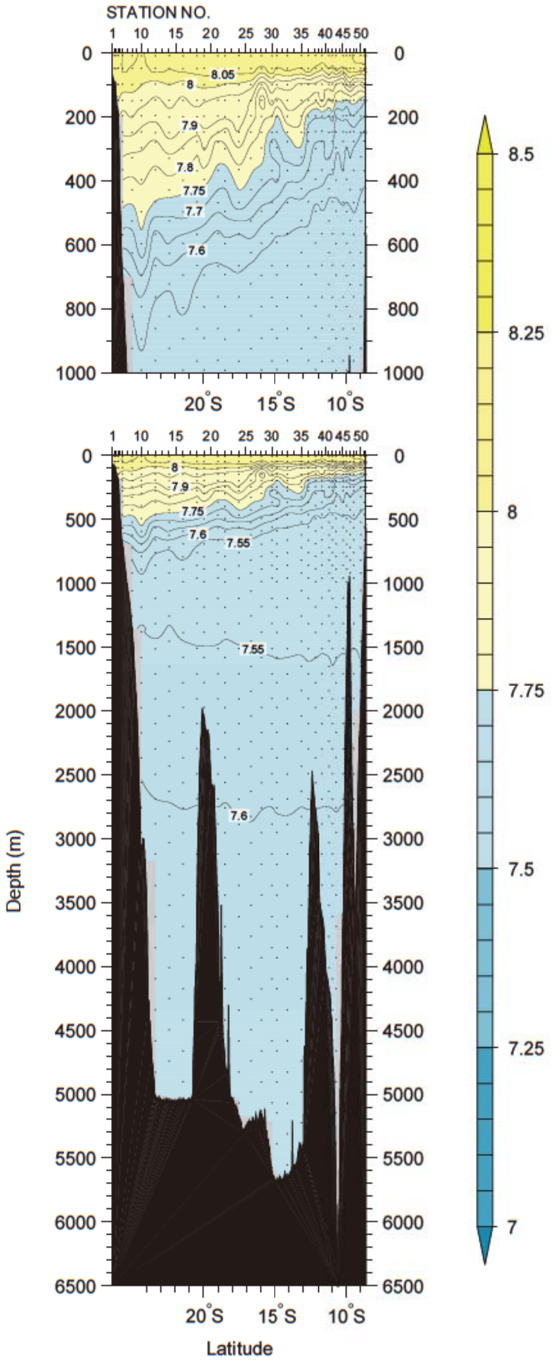


Figure 22
Dissolved organic carbon (μmol/kg)

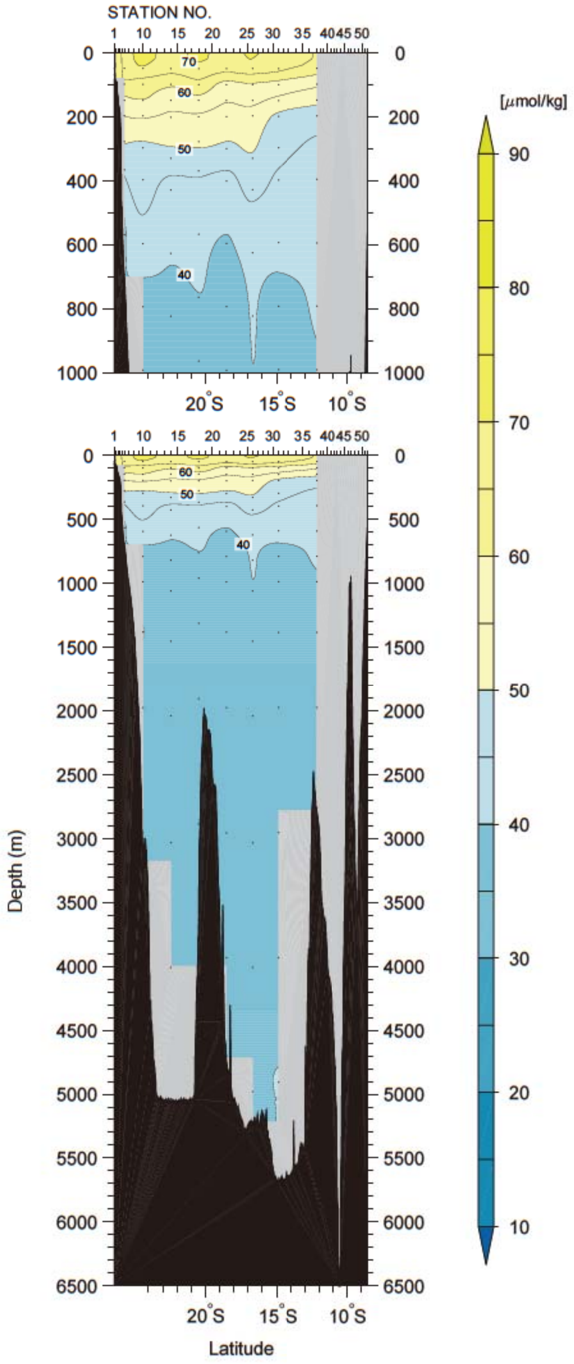


Figure 23
Calcium (mmol/kg)

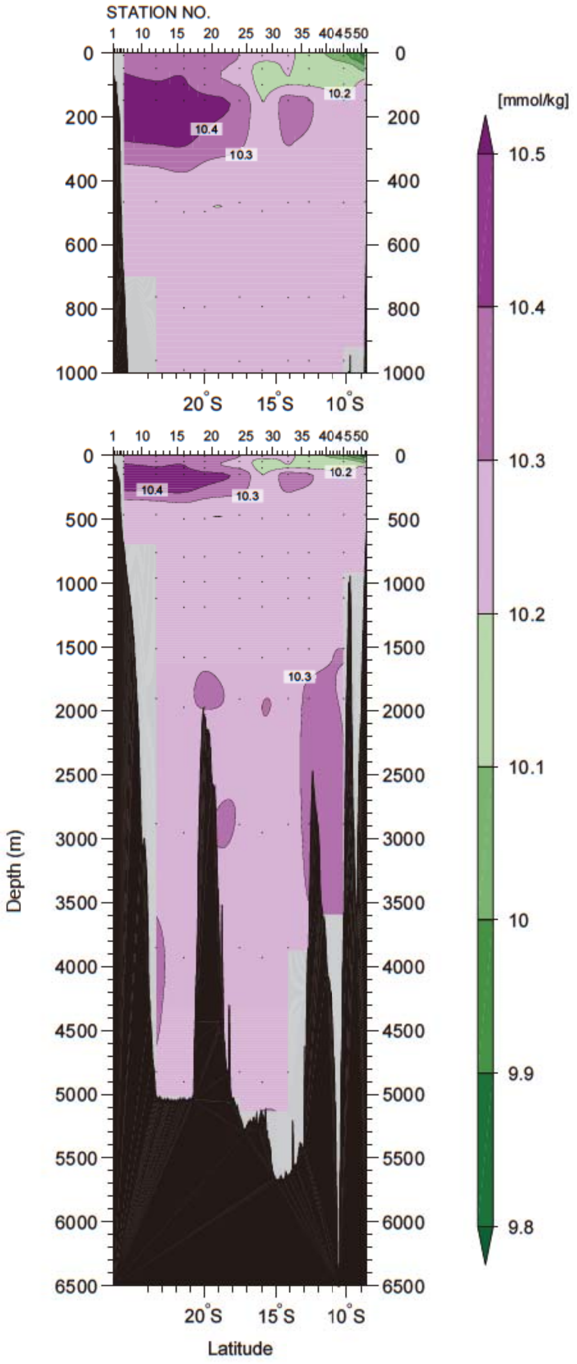


Figure 24
CFC-11 (pmol/kg)

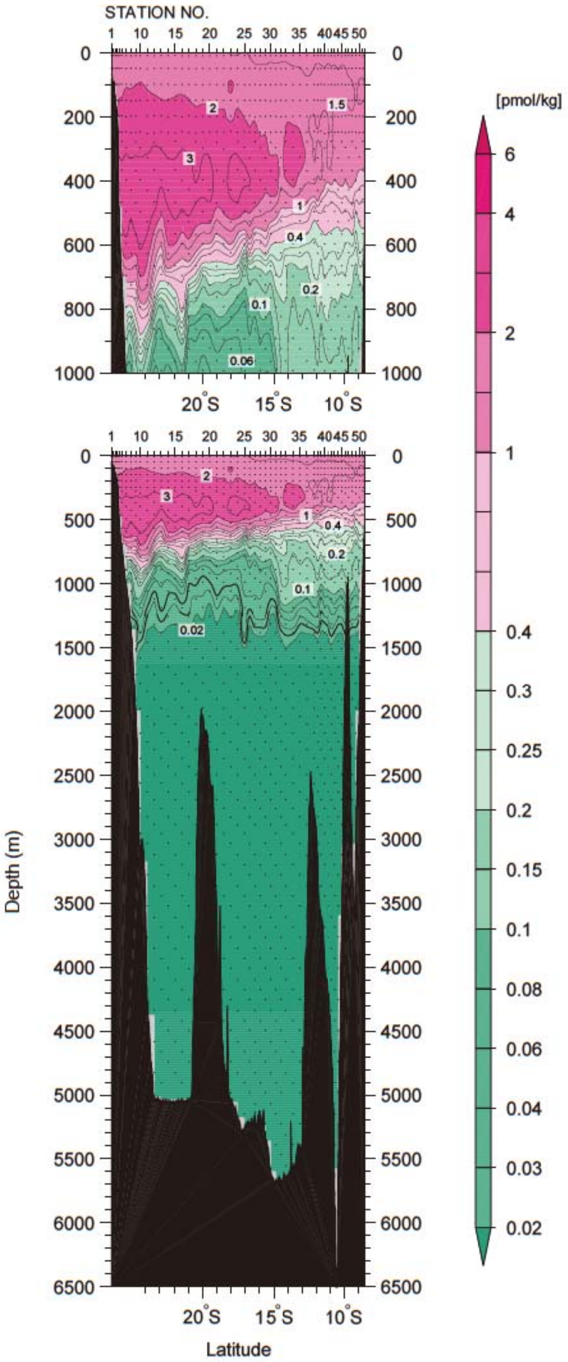


Figure 25

CFC-12 (pmol/kg)

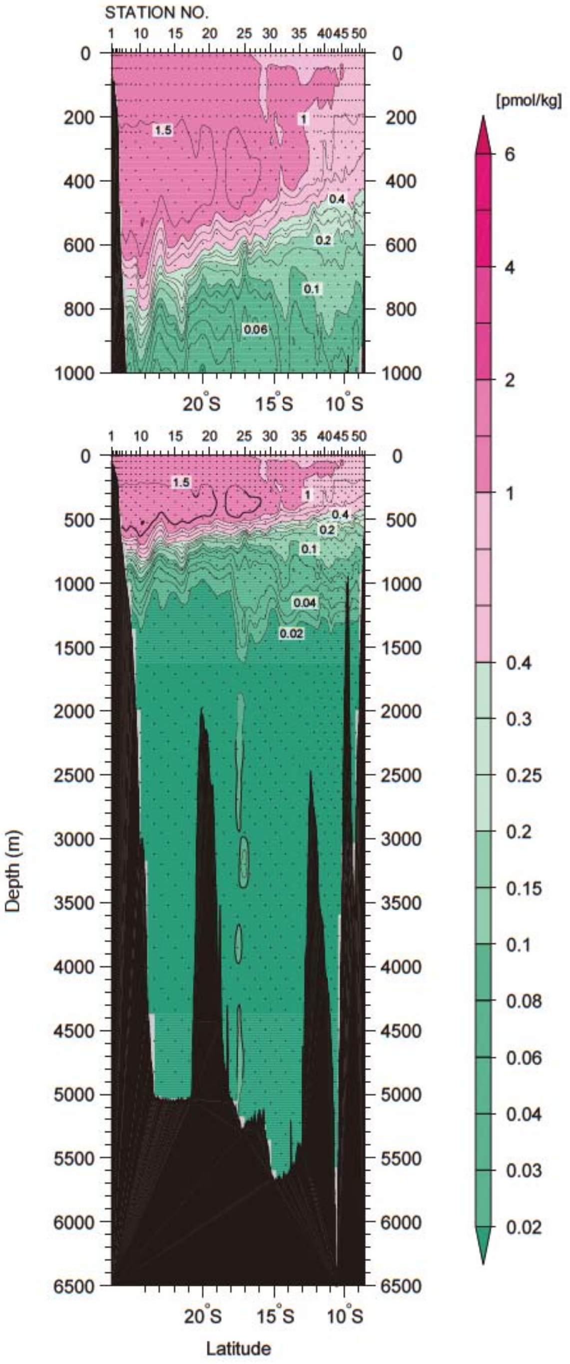


Figure 26
CFC-113 (pmol/kg)

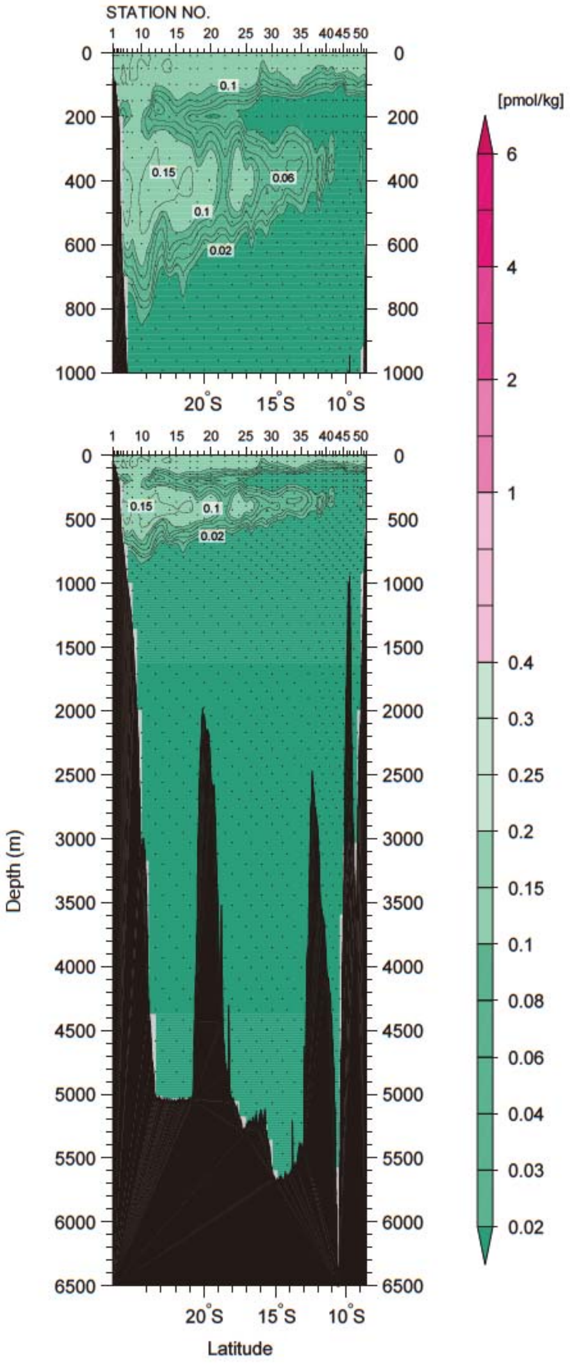


Figure 27

SF$_6$ (fmol/kg)

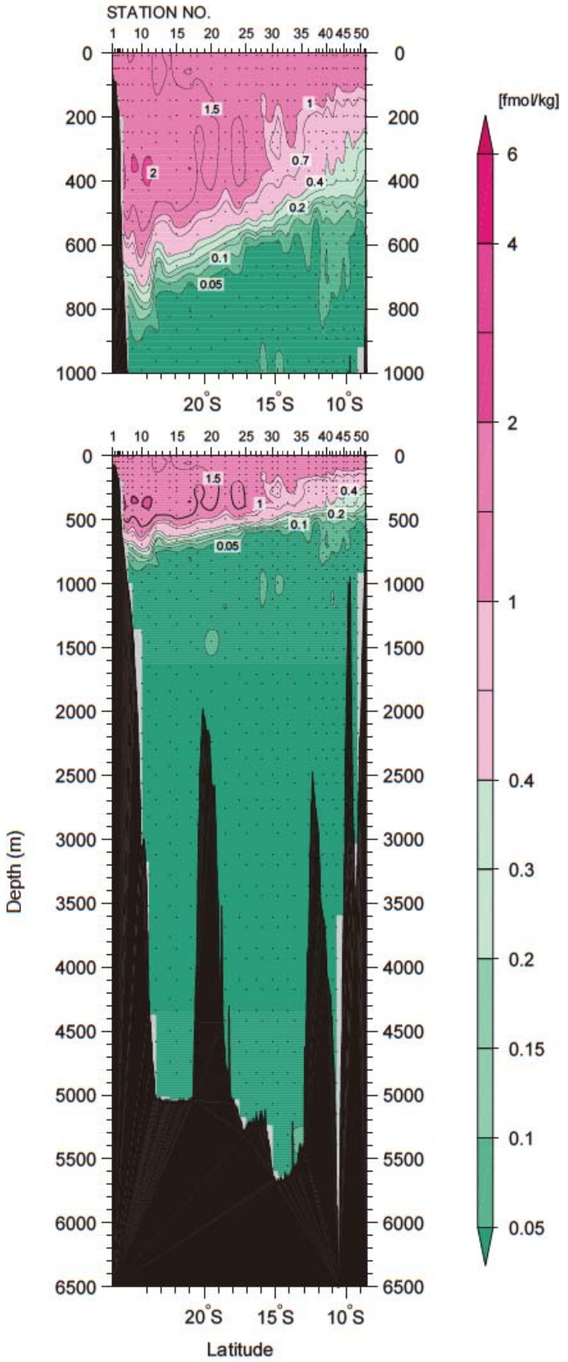


Figure 28
Current velocity (cm/s) normal to the cruise track measured By LADCP (eastward or northward is positive)

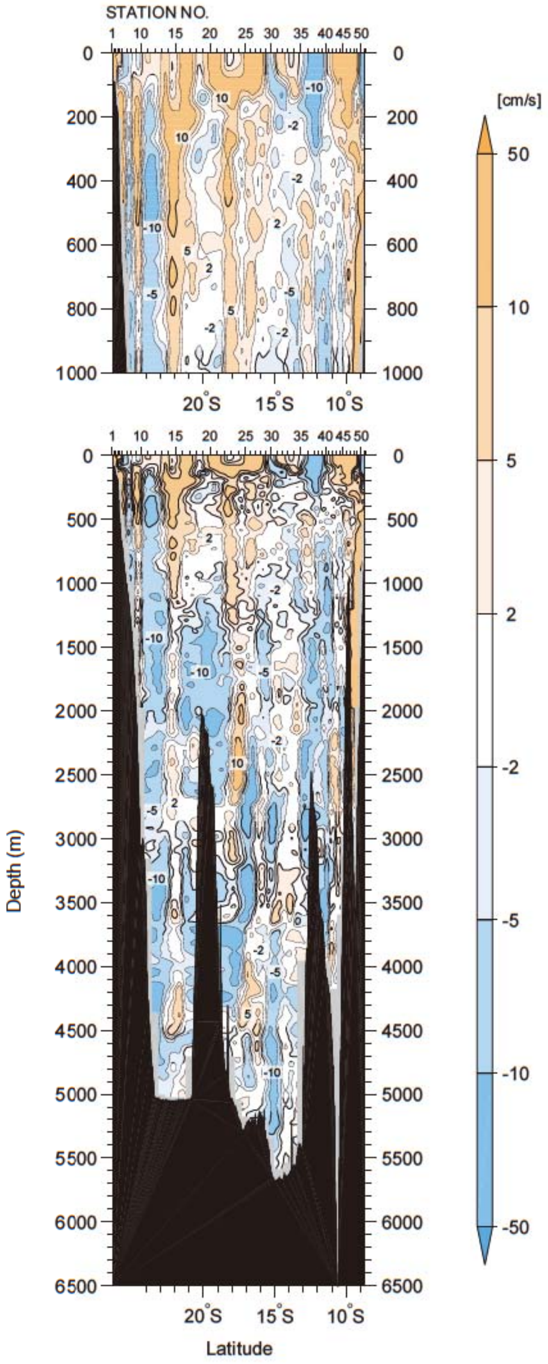


Figure 29
Difference in potential temperature (°C) between results from WHP I10 in 1995 and the revisit in 2015

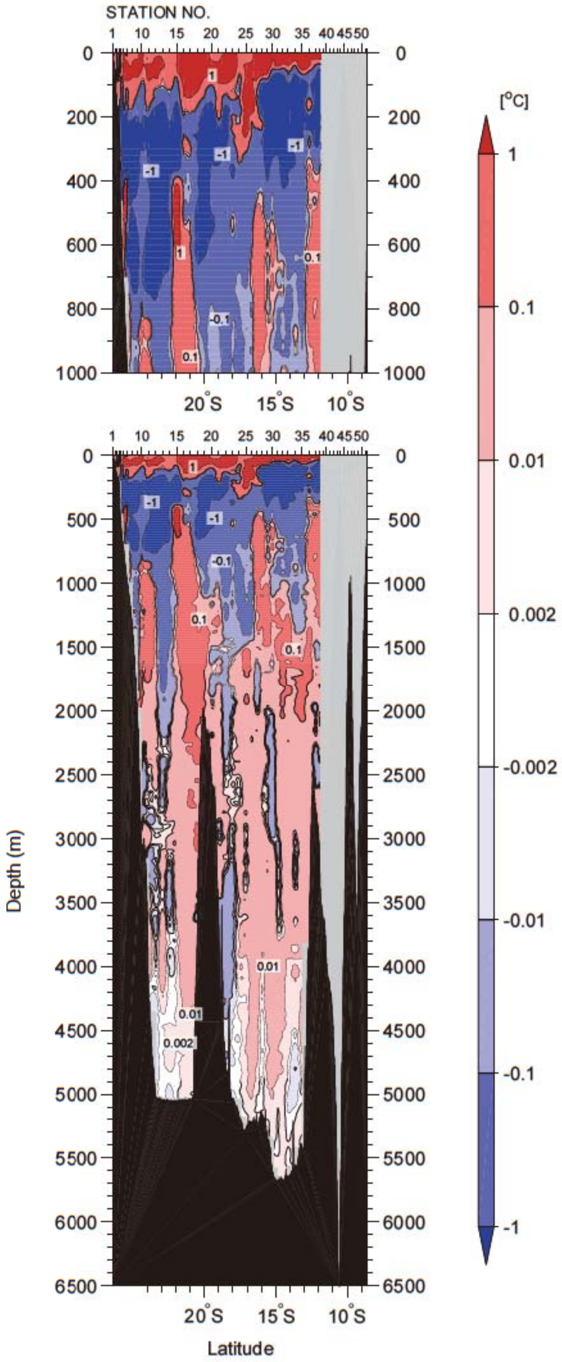


Figure 30
Difference in CTD salinity between results from WHP I10 in 1995 and the revisit in 2015

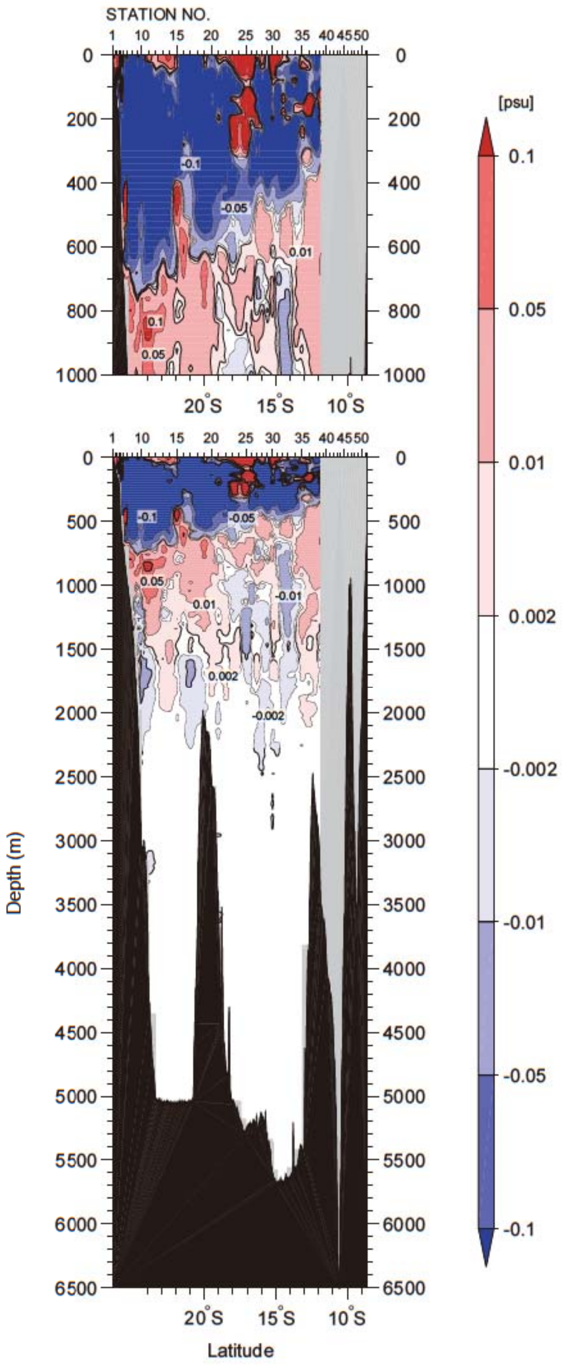
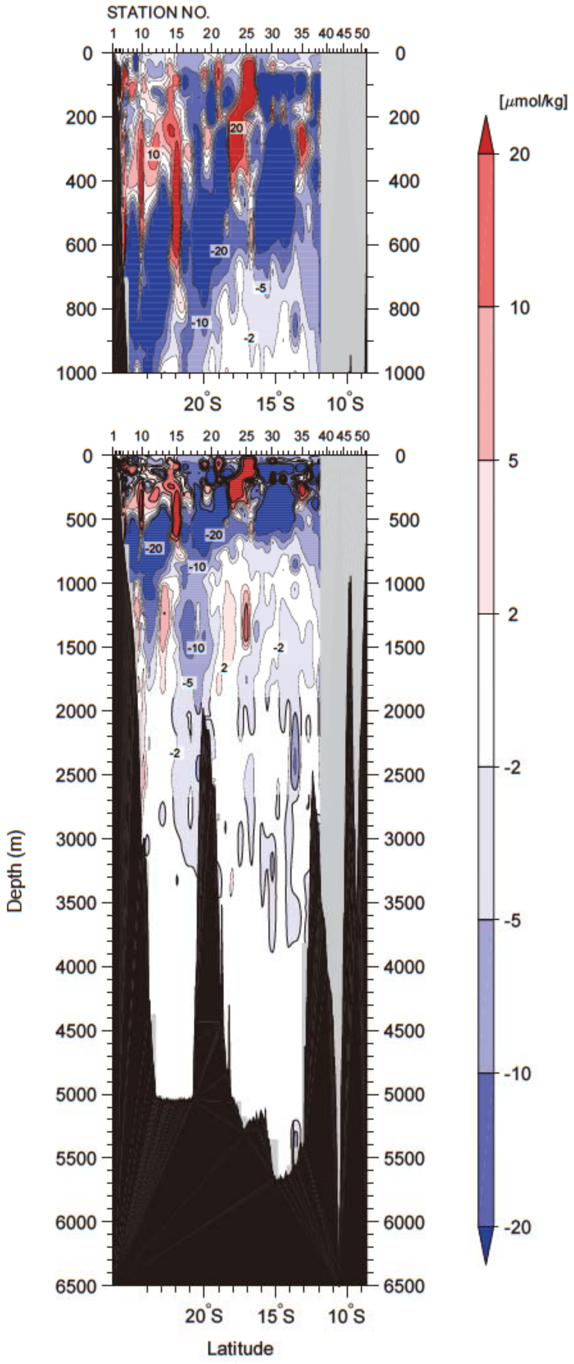
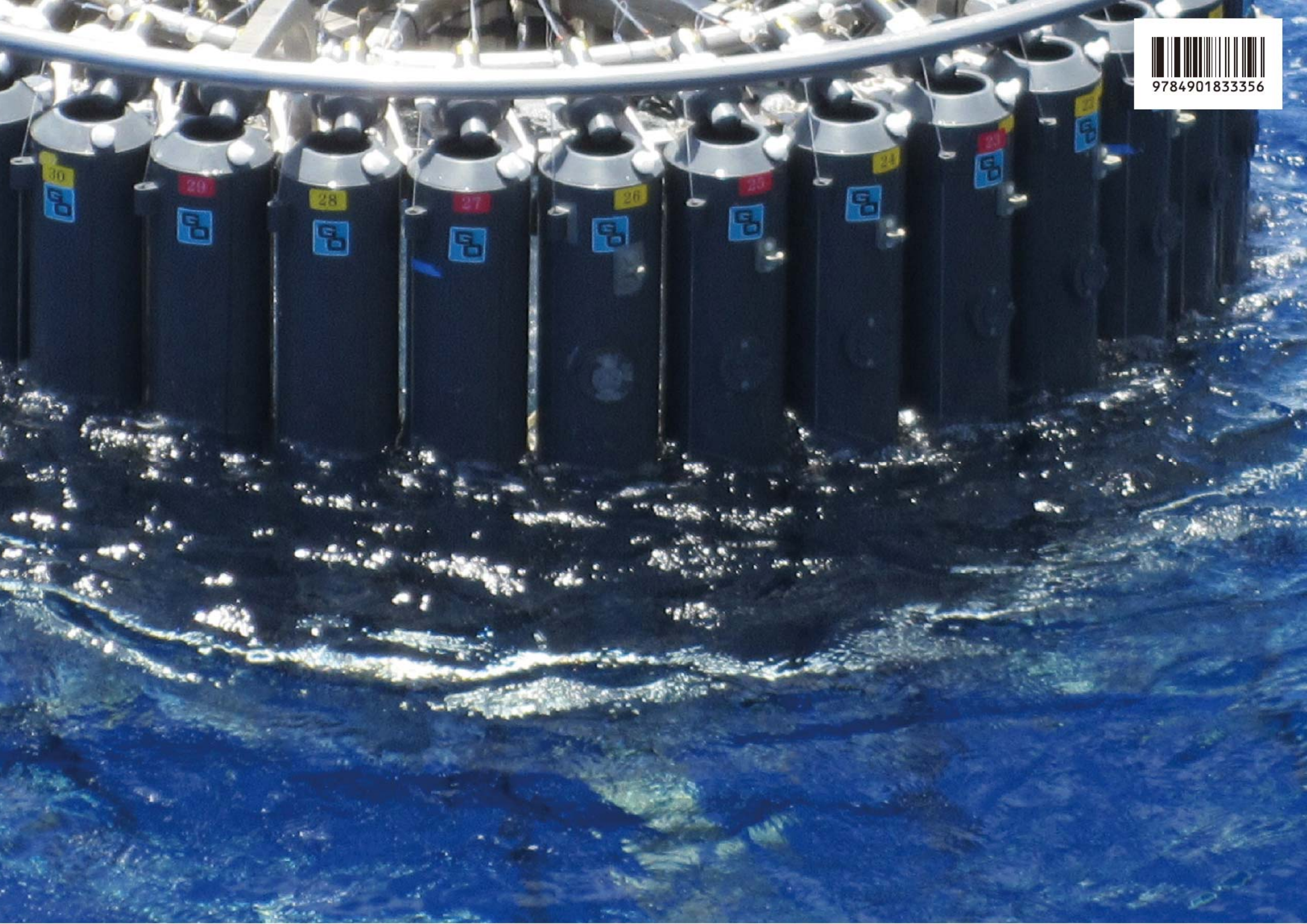


Figure 31
Difference in CTD oxygen (µmol/kg) between results from WHP I10 in 1995 and the revisit in 2015





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