

WHP P10 REVISIT IN 2011 DATA BOOK

Field Activity of JAMSTEC towards International Repeat Hydrography and Carbon Program

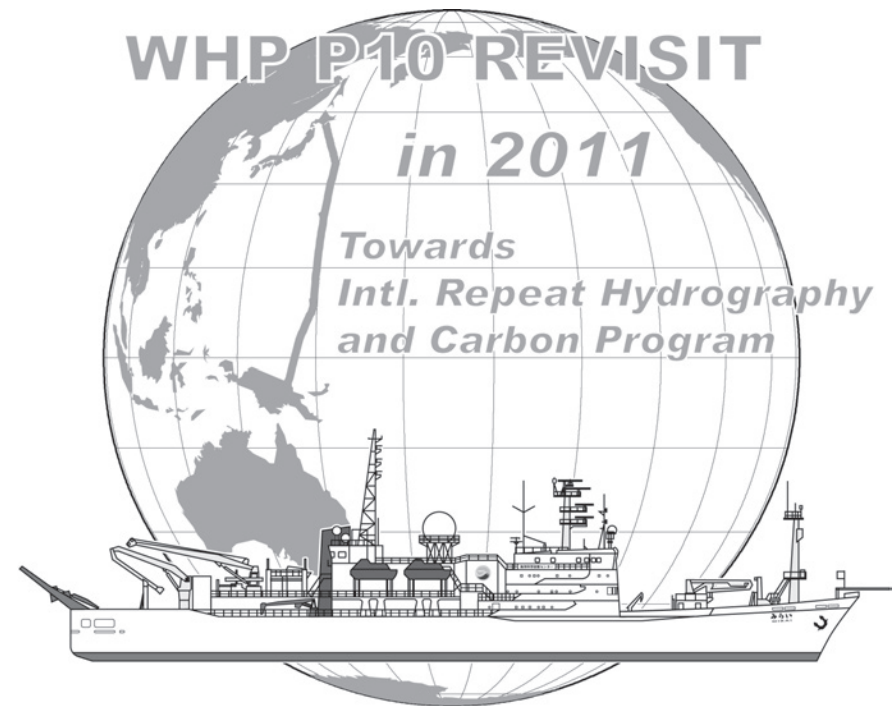
WHP P10 REVISIT *in 2011*

*Towards
Intl. Repeat Hydrography
and Carbon Program*



WHP P10 REVISIT IN 2011 DATA BOOK

*Edited by
Hiroshi Uchida (JAMSTEC),
Akihiko Murata (JAMSTEC),
Toshimasa Doi (JAMSTEC)*



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Edited by Hiroshi Uchida (JAMSTEC), Akihiko Murata (JAMSTEC) and Toshimasa Doi (JAMSTEC)

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Preface

At 14:46 on 11 March 2011, Japan was attacked by the huge catastrophe earthquake with magnitude of 9.0. The epicenter of the earthquake widely distributed along the Japan trench off the east coasts of Tohoku district. Unprecedented tragedies were brought about by the Tsunami which attacked the Pacific coast of eastern Japan twenty minutes after the earthquake. More than 18,000 people were killed or lost by this Tsunami. Moreover, the Fukushima First Nuclear Power Plant was destroyed by the Tsunami and considerable amount of radio nuclides were discharged from the power plant into the atmosphere and the ocean.

Right after the earthquake, we, Research Institute for Global Change started to monitor and forecast the dispersion of the discharged radio nuclides off coast of Fukushima under the request from the Japanese government. It was very hard task for scientists in RIGC/JAMSTEC to conduct ocean monitoring and prediction, nevertheless, RIGC/JAMSTEC was expected to be deeply engaged in the task because RIGC is the only institute which has the ability to pursue the governmental requests.

Facing the Fukushima Disaster brought about by the earthquake, RIGC/JAMSTEC changed the cruise plan for GO-SHIP hydrographic observation. As the result, RIGC/JAMSTEC decided to re-occupy P10 in the western North Pacific Ocean instead of I08N/I05E in the Indian Ocean since we believed this change of our plan made it possible for the world GO-SHIP community to build a data network on radio nuclides in the western North Pacific within three years together with US cruise along P02 in 2013 and RIGC/JAMSTEC cruise along P01 in 2014. The preparation for the original plan to re-occupy the line in the Indian Ocean had been proceeded under collaboration with Sri Lanka and India. Thus, here, I would like to express my heartfelt thanks to all those concerned in both countries for their kind acceptance of our sudden changes of the cruise at that time.

The cruise along P10 was started on 20 December 2011 from Palau. Stations were set to reoccupy the stations which were observed in 2005 by IORG, a predecessor of RIGC/JAMSTEC, namely 124 stations on the cruise track from Papua New Guinea to Hokkaido. We completed the cruise on 9 February 2012, however, bad weather and sea condition forced us to decrease the number of CTD/water sampling stations in the northern part of the cruise.

Of course, this cruise was carried out as Japanese activity within the framework of GO-SHIP. On the other

hand, we had our specific objective for this cruise that was to prepare data network for radio nuclides in the western North Pacific Ocean after the Fukushima Disaster. It was the reason why we placed larger priority on the northern part of P10 in the cruise. Now, the data including results from chemical analysis can be used by anyone through this data book and websites of JAMSTEC, CCHDO and CDIAC.

Lastly, I would like to ask favors of all scientists to refer our data book as often as possible. Such reference from scientists proves the scientific importance of GO-SHIP and consequently helps RIGC/JAMSTEC to continue GO-SHIP activity.

On the memorial day after three years of the Tragic Earthquake and Tsunami

Masao Fukasawa

Research Director RIGC/JAMSTEC

*Acronym

RIGC	Research Institute for Global Change
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
GO-SHIP	Global Ocean Ship-Based Hydrographic Investigation Program
CCHDO	CLIVAR and Carbon Hydrographic Data Office
CDIAC	Carbon Dioxide Information Analysis Center

1 Cruise Narrative

Akihiko Murata (RIGC/JAMSTEC)

Yuichiro Kumamoto (RIGC/JAMSTEC)

1.1 Highlight

GHPO Section Designation: P10

Cruise code: MR11-08

Expedition Designation: 49NZ20111220
49NZ20120113

Chief Scientists and Affiliation:

Leg 2: Akihiko Murata

murataa@jamstec.go.jp

Leg 3: Yuichiro Kumamoto

kumamoto@jamstec.go.jp

Ocean Climate Change Research Program

Research Institute for Global Change (RIGC)

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

2-15 Natsushima, Yokosuka, Kanagawa, Japan 237-0061

Fax: +81-46-867-9835

Ship: R/V Mirai

Ports of Call: Leg 2: Koror, Palau – Guam, USA

Leg 3: Guam, USA – Sekinehama, Japan

Cruise Dates: Leg 2: December 20, 2011 – January 12, 2012

Leg 3: January 13, 2012 – February 9, 2012

Number of Stations: 102 stations for CTD/Carousel Water Sampler
(Leg 2: 59, Leg 3: 43)

Geographic Boundaries (for hydrographic stations):

10°S - 43°N

140°E - 151°E

Floats and Drifters Deployed:

2 Argo floats

Mooring Deployed or Recovered Mooring:

None

1.2 Cruise Summary

It is well known that climate changes of a timescale more than a decade are influenced by changes of oceanic conditions. Among various oceanic changes, we conducted shipboard observations focusing on storage and transport of anthropogenic CO₂, heat and freshwater in the ocean, which are important for global warming and relevant climate changes. Our observation line (Figs. 1.2.1 and 1.2.2) is a meridional line, which is set in the western Pacific, and traverses the main subtropical gyre in the ocean. By occupying the observation line, we intended to clarify: (1) storage of anthropogenic CO₂, distributions of dissolved oxygen, etc. in the subtropical gyre and the temporal changes, (2) temperature rise and transport of dissolved substances along the route of Circumpolar Deep Water, and (3) current degree of ocean acidification in the western Pacific. This study was conducted under the Global Ocean Ship-based Hydrographic Investigations Program (abbreviated as GO-SHIP, <http://www.go-ship.org/>).

In addition to the objectives listed above, we were also aimed at elucidating dispersion of radioactive substances, released into the sea unfortunately from the Fukushima Dai-ichi nuclear power plant.

During the 2nd leg, we could conduct hydrographic observations steadily. But during the 3rd leg, we had to give up some hydrographic casts due to big waves.

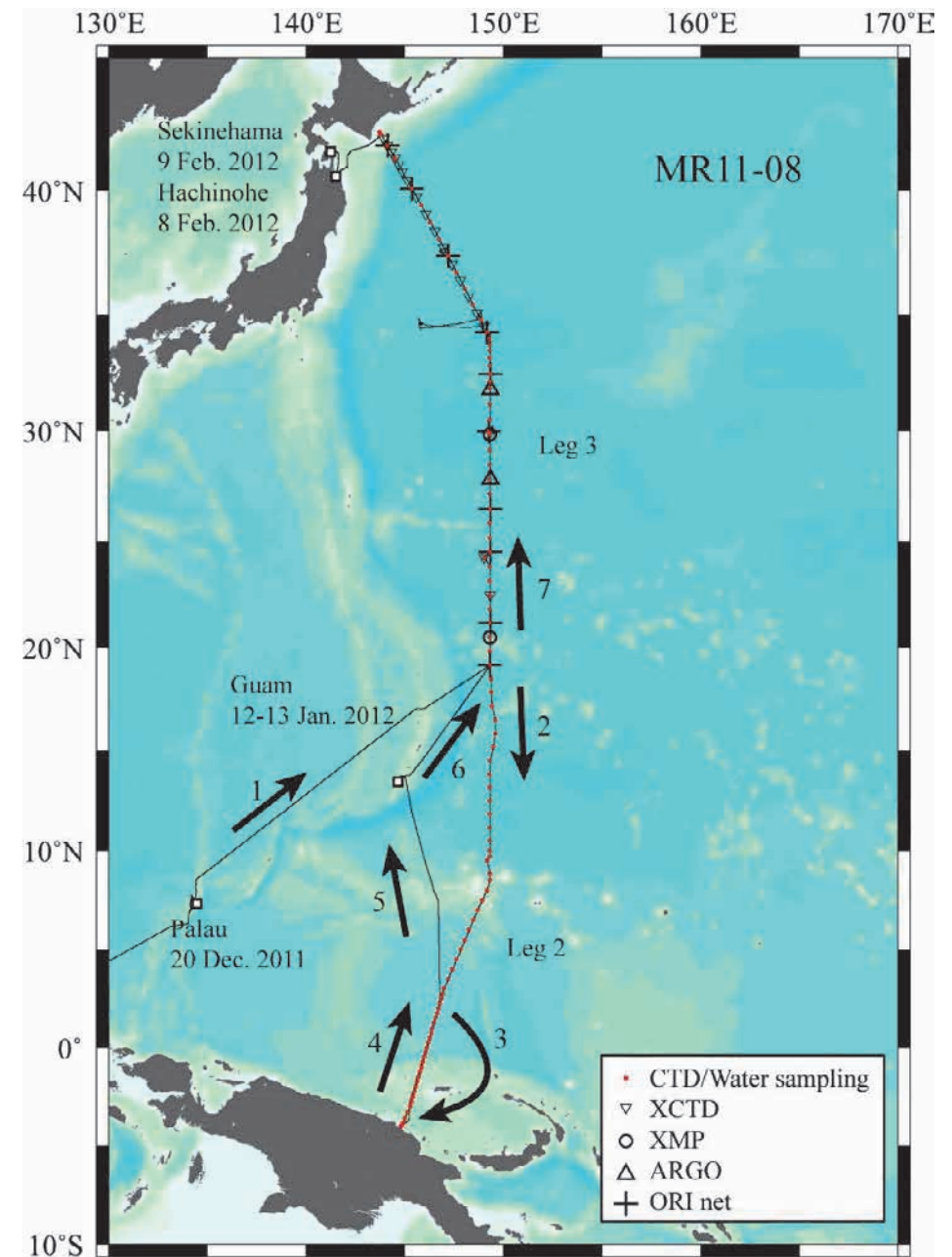


Figure 1.2.1. Cruise track and hydrographic stations.

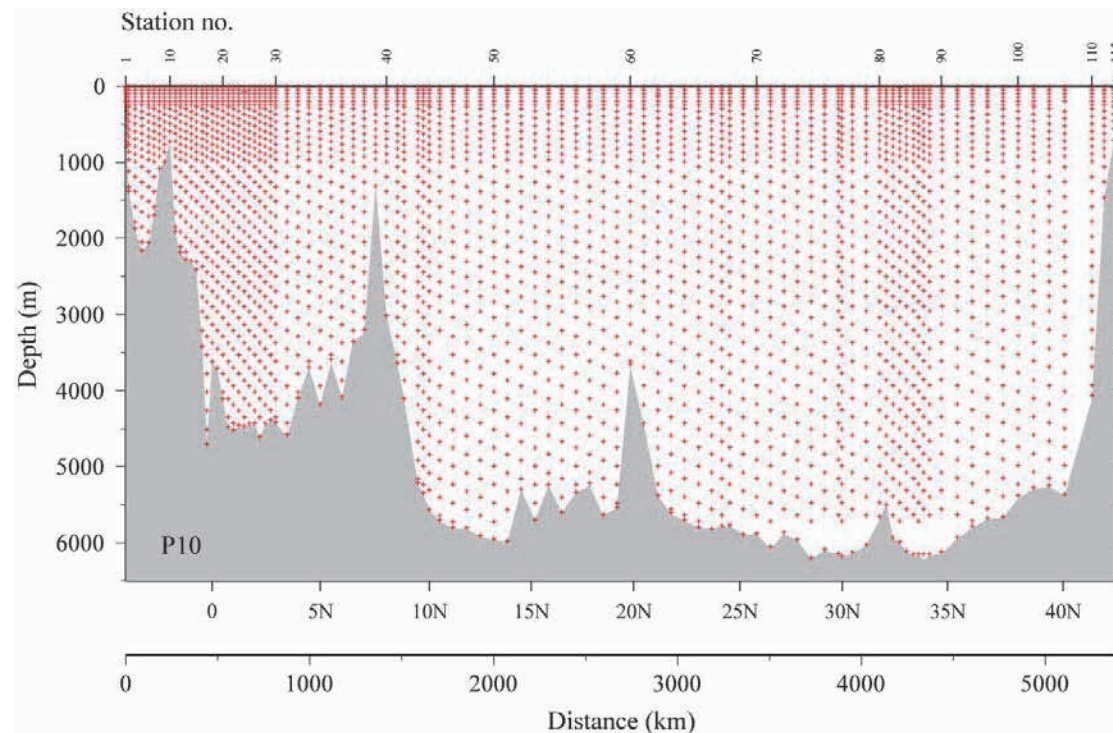


Figure 1.2.2. Bottle depth diagram.

1.3 List of Principal Investigator and Person in Charge on the Ship

The principal investigator (PI) and the person in charge responsible for major parameters measured on the cruise 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 on the Ship
<i>Underway</i>		
ADCP	Shinya Kouketsu (JAMSTEC) <i>skouketsu@jamstec.go.jp</i>	Kazuho Yoshida (GODI) (leg 2) Katsuhisa Maeno (GODI) (leg 3)
Bathymetry	Takeshi Matsumoto (Univ. of Ryukyus) <i>tak@sci.u-ryukyu.ac.jp</i> Naoto Hirano (Tohoku Univ.) <i>nhirano@cneas.tohoku.ac.jp</i>	Kazuho Yoshida (GODI) (leg 2) Katsuhisa Maeno (GODI) (leg 3)
Meteorology	Kunio Yoneyama (JAMSTEC) <i>yoneyamak@jamstec.go.jp</i>	Kazuho Yoshida (GODI) (leg 2) Katsuhisa Maeno (GODI) (leg 3)
T-S	Hiroshi Uchida (JAMSTEC) <i>huchida@jamstec.go.jp</i>	Miyo Ikeda (MWJ) (leg 2) Misato Kuwahara (MWJ) (leg 3)
pCO ₂	Akihiko Murata (JAMSTEC) <i>murataa@jamstec.go.jp</i>	Yoshiko Ishikawa (MWJ)
<i>Hydrography</i>		
CTD/O ₂	Hiroshi Uchida (JAMSTEC) <i>huchida@jamstec.go.jp</i>	Shinsuke Toyoda (MWJ) (leg 2) Kenichi Katayama (MWJ) (leg 3)
XCTD	Hiroshi Uchida (JAMSTEC) <i>huchida@jamstec.go.jp</i>	Katsuhisa Maeno (GODI)
LADCP	Shinya Kouketsu (JAMSTEC) <i>skouketsu@jamstec.go.jp</i>	Shinya Kouketsu (JAMSTEC) (leg 2) Katsuro Katsumata (JAMSTEC) (leg 3)

Salinity	Hiroshi Uchida (JAMSTEC) <i>huchida@jamstec.go.jp</i>	Fujio Kobayashi (MWJ) (leg 2) Tatsuya Tanaka (MWJ) (leg 3)	PFCs	Nobuyasu Yamashita (AIST) <i>nob.yamashita@aist.go.jp</i>	
Density	Hiroshi Uchida (JAMSTEC) <i>huchida@jamstec.go.jp</i>	Hiroshi Uchida (JAMSTEC)	Plankton	Minoru Kitamura (JAMSTEC) <i>kitamura@jamstec.go.jp</i>	Minoru Kitamura (JAMSTEC)
Oxygen	Yuichiro Kumamoto (JAMSTEC) <i>kumamoto@jamstec.go.jp</i>	Miyo Ikeda (MWJ) (leg 2) Misato Kuwahara (MWJ) (leg 3)	Floats		
Nutrients	Michio Aoyama (MRI) <i>maoyama@mri-jma.go.jp</i>	Minoru Kamata (MWJ)	ARGO float	Toshio Suga (JAMSTEC) <i>sugat@jamstec.go.jp</i>	Kenichi Katayama (MWJ)
DIC	Akihiko Murata (JAMSTEC) <i>murataa@jamstec.go.jp</i>	Yoshiko Ishikawa (MWJ)			
Alkalinity	Akihiko Murata (JAMSTEC) <i>murataa@jamstec.go.jp</i>	Tomonori Watai (MWJ)		GODI	Global Ocean Development Inc.
pH	Akihiko Murata (JAMSTEC) <i>murataa@jamstec.go.jp</i>	Tomonori Watai (MWJ)		JAMSTEC	Japan Agency for Marine-Earth Science and Technology
CFCs	Ken'ichi Sasaki (JAMSTEC) <i>ksasaki@jamstec.go.jp</i>	Ken'ichi Sasaki (JAMSTEC)		MRI	Meteorological Research Institute, Japan Meteorological Agency
$\Delta^{14}\text{C}/\delta^{13}\text{C}$	Yuichiro Kumamoto (JAMSTEC) <i>kumamoto@jamstec.go.jp</i>	Yuichiro Kumamoto (JAMSTEC)		MWJ	Marine Works Japan, Ltd.
$^{134}\text{Cs}/^{137}\text{Cs}$	Yuichiro Kumamoto (JAMSTEC) <i>kumamoto@jamstec.go.jp</i>	Yuichiro Kumamoto (JAMSTEC)		NIRS	National Institute of Radiological Sciences
Tritium	Tatsuo Aono (NIRS) <i>t_aono@nirs.go.jp</i>			JAEA	Japan Atomic Energy Agency
Iodine-129	Shigeyoshi Otsuka (JAEA) <i>otsuka.shigeyoshi@jaea.go.jp</i>			RGU	Rakuno Gakuen University
Chlorophyll <i>a</i>	Osamu Yoshida (RGU) <i>yoshida@rakuno.ac.jp</i> Hiroshi Uchida (JAMSTEC) <i>huchida@jamstec.go.jp</i>	Osamu Yoshida (RGU) (leg 2) Hiroshi Uchida (JAMSTEC) (leg 3)		AIST	National Institute of Advanced Industrial Science and Technology
$\text{N}_2\text{O}/\text{CH}_4$	Osamu Yoshida (RGU) <i>yoshida@rakuno.ac.jp</i>	Osamu Yoshida (RGU) (leg 2) Yuki Okazaki (RGU) (leg 3)			

1.4 List of Cruise Participants

Table 1.4.1. List of cruise participants for leg 2.

Name	Responsibility	Affiliation			
Akihiko Murata	Chief Scientist/CTD/water sampling	RIGC/JAMSTEC	Masanori Enoki	Nutrients	MWJ
Yuichiro Kumamoto	DO/radionuclides	RIGC/JAMSTEC	Tomonori Watai	pH/total alkalinity	MWJ
Hiroshi Uchida	CTD/density/water sampling	RIGC/JAMSTEC	Yoshiko Ishikawa	DIC/pCO ₂	MWJ
Shinya Kouketsu	LADCP/ADCP/water sampling	RIGC/JAMSTEC	Miyo Ikeda	DO	MWJ
Kazuhiko Hayashi	Water sampling	RIGC/JAMSTEC	Ayaka Hatsuyama	pH/total alkalinity	MWJ
Ken'ichi Sasaki	CFCs	MIO/JAMSTEC	Hatsumi Aoyama	DIC/pCO ₂	MWJ
Moyap Kilepak	Observer	University of PNG	Masahiro Orui	CFCs	MWJ
Benjamin Malai	Observer	NWS/PNG	Makoto Takada	Water sampling/radionuclides	MWJ
Osamu Yoshida	CH ₄ and N ₂ O/water sampling	RGU	Katsunori Sagishima	CFCs	MWJ
Yuki Okazaki	CH ₄ and N ₂ O/water sampling	RGU	Shoko Tatamisashi	CFCs	MWJ
Shinichi Oikawa	CH ₄ and N ₂ O/water sampling	RGU	Kanako Yoshida	DO	MWJ
Hikari Shimizu	CH ₄ and N ₂ O/water sampling	RGU	Yuki Miyajima	DO	MWJ
Satoshi Ozawa	Chief technologist/CTD/water sampling	MWJ	Elena Hayashi	Water sampling	MWJ
Hirokatsu Uno	CTD/water sampling	MWJ	Tatsuya Ando	Water sampling	MWJ
Fujio Kobayashi	Salinity	MWJ	Hitomi Takahashi	Water sampling	MWJ
Kenichi Kato	CTD/water sampling	MWJ	Mizuho Yasui	Water sampling	MWJ
Shinsuke Toyoda	CTD/water sampling	MWJ	Daiki Hayashi	Water sampling	MWJ
Hiroki Ushiomura	Salinity	MWJ	Yusuke Ogiwara	Water sampling	MWJ
Shungo Oshitani	CTD/water sampling	MWJ	Satoshi Okumura	Chief technologist /meteorology/ geophysics/ADCP/XCTD	GODI
Kenichiro Sato	Nutrients	MWJ	Kazuho Yoshida	Meteorology/geophysics/ADCP/XCTD	GODI
Minoru Kamata	Nutrients	MWJ	Ryo Kimura	Meteorology/geophysics/ADCP/XCTD	GODI

GODI	Global Ocean Development Inc.
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
RIGC	Research Institute for Global Change
MIO	Mutsu Institute of Oceanography
MWJ	Marine Works Japan, Ltd.
RGU	Rakuno Gakuen University
PNG	Papua New Guinea
NWS	National Weather Service

Table 1.4.2. List of cruise participants for leg 3.

Name	Responsibility	Affiliation
Yuichiro Kumamoto	Chief scientist/DO/radionuclides	RIGC/JAMSTEC
Hiroshi Uchida	CTD/density/water sampling	RIGC/JAMSTEC
Katsuro Katsumata	XMP/LADCP/water sampling	RIGC/JAMSTEC
Toshimasa Doi	LADCP/water sampling	RIGC/JAMSTEC
Kazuhiko Hayashi	Water sampling	RIGC/JAMSTEC
Ken'ichi Sasaki	CFCs	MIO/JAMSTEC
Minoru Kitamura	Plankton	BGS/JAMSTEC
Eric Cruz	Plankton net dragging/water sampling	NMFS/NOAA
Nobuyoshi Yamashita	PFCs	AIST
Yuki Okazaki	CH ₄ and N ₂ O/water sampling	RGU
Shinichi Oikawa	CH ₄ and N ₂ O/water sampling	RGU
Hikari Shimizu	CH ₄ and N ₂ O/water sampling	RGU
Yoshiko Ishikawa	Chief technologist /DIC/pCO ₂	MWJ
Hideki Yamamoto	Water sampling/radionuclides	MWJ
Toru Idai	CTD/water sampling	MWJ
Kenichi Katayama	CTD/water sampling	MWJ
Naoko Miyamoto	CTD/water sampling	MWJ
Tatsuya Tanaka	Salinity	MWJ
Tamami Ueno	Salinity	MWJ
Kenichiro Sato	Nutrients	MWJ
Minoru Kamata	Nutrients	MWJ
Tomonori Watai	pH/total alkalinity	MWJ
Yasuhiro Arii	Nutrients	MWJ

Misato Kuwahara	DO	MWJ
Hatsumi Aoyama	DIC/pCO ₂	MWJ
Makoto Takada	DIC/pCO ₂	MWJ
Shinichiro Yokokawa	DO	MWJ
Katsunori Sagishima	CFCs	MWJ
Shoko Tatamisashi	CFCs	MWJ
Hironori Sato	DO	MWJ
Kanako Yoshida	DO	MWJ
Takami Mori	CTD/water sampling	MWJ
Yasumi Yamada	pH/total alkalinity	MWJ
Elena Hayashi	Water sampling	MWJ
Tatsuya Ando	Water sampling	MWJ
Rie Muranaka	Water sampling	MWJ
Shihomi Saito	Water sampling	MWJ
Emi Deguchi	Water sampling	MWJ
Erina Matsumoto	Water sampling	MWJ
Katsuhisa Maeno	Chief technologist /meteorology/ geophysics/ADCP/XCTD	GODI
Asuka Doi	Meteorology/geophysics/ADCP/XCTD	GODI
Kazuho Yoshida	Meteorology/geophysics/ADCP/XCTD	GODI
Toshimitsu Goto	Meteorology/geophysics/ADCP/XCTD	GODI

BGS Institute of Biogeosciences

NMFS/NOAA National Marine Fisheries Service, National Oceanic and Atmospheric Administration

2 Underway Measurements

2.1 Navigation

February 5, 2014

(1) Personnel

Kazuho Yoshida	(GODI)	-leg1, leg2-
Ryo Kimura	(GODI)	-leg1, leg2-
Satoshi Okumura	(GODI)	-leg2-
Katsuhisa Maeno	(GODI)	-leg3-
Asuka Doi	(GODI)	-leg3-
Toshimitsu Goto	(GODI)	-leg3-
Ryo Ohyama	(MIRAI Crew)	-leg1, leg2, leg3-

(2) System description

Ship's position and velocity were provided by Radio Navigation System on R/V Mirai. This system integrates GPS position, log speed, gyro compass heading and other basic data for navigation, and calculated speed/course over ground on workstation. Radio navigation 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) GPS system: MultiFix6 (software version 1.01), Differential GPS system.
Receiver: Trimble SPS751, with two GPS antennas located on navigation deck, starboard side and port side, manually switched as to GPS receiving state and offset to radar-mast position, datum point.
Decoder: Fugro STARFIX 4100LR
- ii) Doppler log: Furuno DS-30, which use three acoustic beam for current measurement under the hull.
- iii) Gyrocompass: Tokimec TG-6000, sperry type mechanical gyrocompass.

iv) GPS time server: SEIKO TS-2540 Time Server, synchronizing to GPS satellite every 1 second.

(3) Data period (Times in UTC)

Leg1: 04:50 4th Dec. 2011 to 00:00 20th Dec. 2011

Leg2: 06:00 20th Dec. 2011 to 02:00 12th Jan. 2012

Leg3: 23:00 12th Jan. 2012 to 00:00 9th Feb. 2012

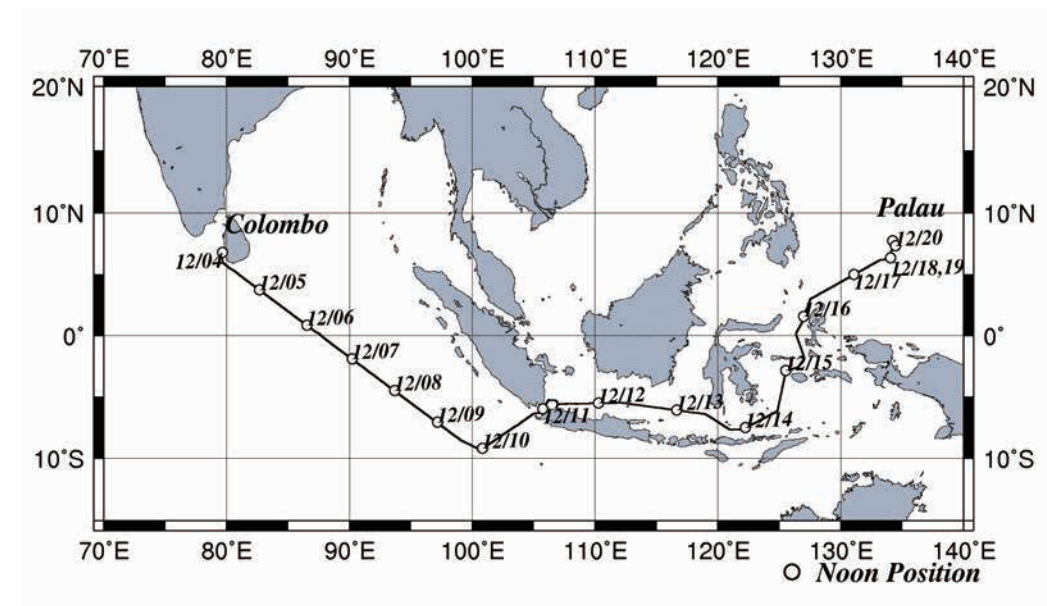


Figure 2.1.1. Cruise Track of MR11-08 Leg 1.

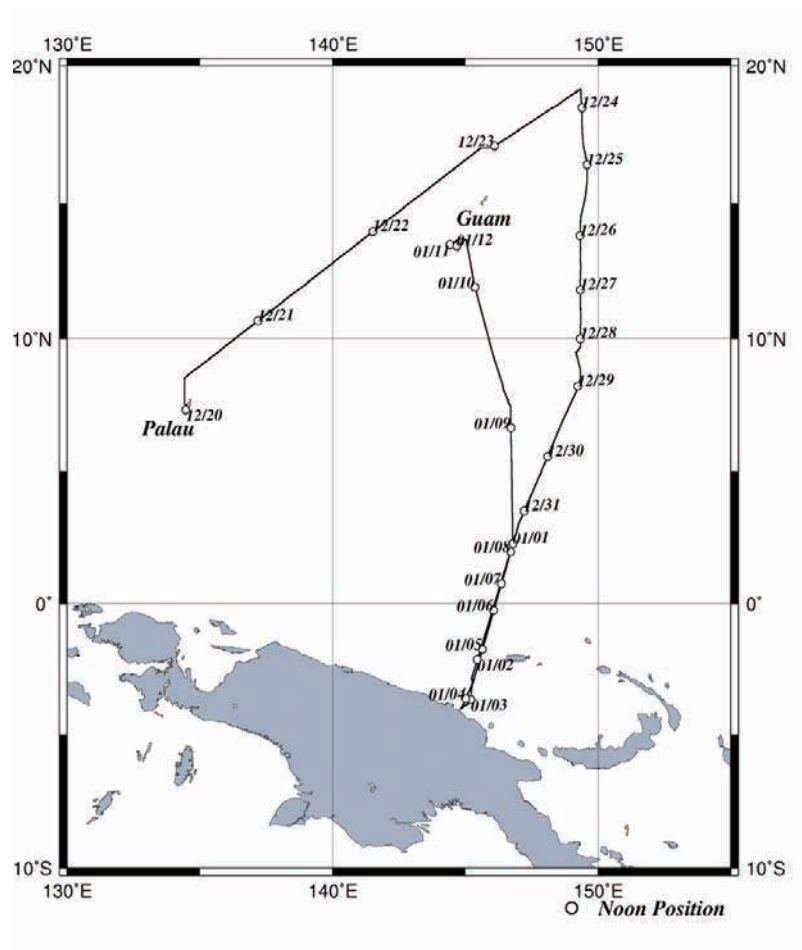


Figure 2.1.2. Cruise Track of MR11-08 Leg 2.

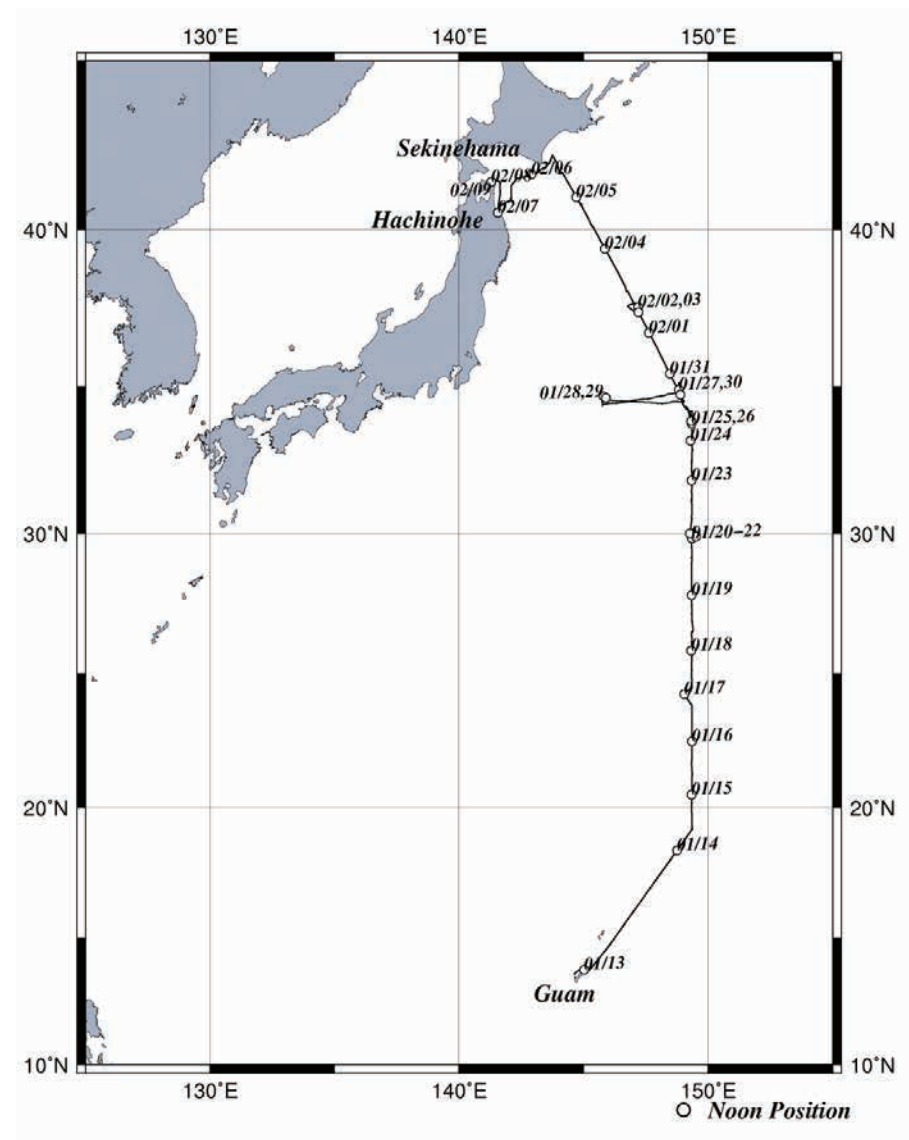


Figure 2.1.3. Cruise Track of MR11-08 Leg 3.

2.2 Swath Bathymetry

February 5, 2014

(1) Personnel

Takeshi Matsumoto	(University of the Ryukyu)	Principal Investigator (Not on-board)
Naoto Hirano	(Tohoku University)	Principal Investigator (Not on-board)
Kazuho Yoshida	(GODI)	-leg1, leg2-
Ryo Kimura	(GODI)	-leg1, leg2-
Satoshi Okumura	(GODI)	-leg2-
Katsuhisa Maeno	(GODI)	-leg3-
Asuka Doi	(GODI)	-leg3-
Toshimitsu Goto	(GODI)	-leg3-
Ryo Ohyama	(MIRAI Crew)	-leg1, leg2, leg3-

(2) Introduction

R/V MIRAI is equipped with a Multi narrow Beam Echo Sounding system (MBES), SEABEAM 2112 (SeaBeam Instruments Inc.). 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 2112" on R/V MIRAI was used for bathymetry mapping during the MR11-08 cruise from 4th December 2011 to 9th February 2012.

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 (6.2m) sound velocity, and the deeper depth sound velocity profiles were calculated by temperature and salinity profiles from CTD or XCTD or ARGO data by the equation in Del Grosso (1974) during the cruise.

Table 2.2.1 shows system configuration and performance of SEABEAM 2112.004 system.

Table 2.2.1. System configuration and performance.

SEABEAM 2112 (12 kHz system)	
Frequency:	12 kHz
Transmit beam width:	2 degree
Transmit power:	20 kW
Transmit pulse length:	3 to 20 msec.
Depth range:	100 to 11,000 m
Beam spacing:	1 degree athwart ship
Swath width:	150 degree (max) 120 degree to 4,500 m 100 degree to 6,000 m 90 degree to 11,000 m
Depth accuracy:	Within < 0.5% of depth or +/-1m, whichever is greater, over the entire swath. (Nadir beam has greater accuracy; typically within < 0.2% of depth or +/-1m, whichever is greater)

(4) Data processing

i. Sound velocity correction

The continuous bathymetry data were split into small areas around each CTD station. For each small area, the bathymetry data were corrected with a sound velocity profile calculated from the CTD data or XCTD data in the area. The equation of Del Grosso (1974) was used for calculating sound velocity. The data processing is carried out using "mbprocess" command of MBsystem.

ii. Editing and Gridding

Gridding for the bathymetry data were carried out using the HIPS software version 7.1 (CARIS, Canada). Firstly, the bathymetry data during Ship's turning was basically removed before "BASE surface" was made. A spike noise of each swath data was also removed using "swath editor" and "subset editor". Then the bathymetry data was gridded by "Interpolate" function of the software with the parameters shown as Table 2.2.2.

Finally, raw data and interpolated data are exported as ASCII data, and converted to 150m grid data using "xyz2grd" utility of GMT (Generic Mapping Tool) software.

Table 2.2.2. Parameters for interpolate of bathymetry data.

BASE surface resolution:	50m
Interpolate matrix size:	5 x 5
Minimum number of neighbors for interpolate:	10

(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)

1) The observation was carried out within following periods,

Leg1: 10:00 5th Dec. 2011 to 08:30 10th Dec.2011

Leg2: 22:10 21th Dec. 2011 to 00:00 22th Dec. 2011

19:30 23th Dec. 2011 to 04:30 1st Jan. 2012

14:00 3rd Jan 2012 to 14:09 12th Jan. 2012

Leg3: 02:48 13th Jan. 2012 to 05:13 06th Feb 2012.

2) The following period, data acquisition was suspended due to system trouble and network trouble.

15:27 to 18:22 8th Dec. 2011

21:00 to 21:37 20th Dec. 2011

08:10 to 08:34 10th Jan. 2012

21:35 to 22:03 22th Jan. 2012

15:48 to 16:15 31th Jan. 2012

3) The following period, GPS data acquisition was suspended due to GPS trouble.

03:39 to 03:52 3rd Feb. 2012

2.3 Surface Meteorological Observation

January 25, 2014

(1) Personnel

Kunio Yoneyama	(JAMSTEC)
Kasuo Yoshida	(GODI) (Legs 1, 2)
Ryo Kimura	(GODI) (Legs 1, 2)
Satoshi Okumura	(GODI) (Leg 2)
Katsuhisa Maeno	(GODI) (Leg 3)
Asuka Doi	(GODI) (Leg 3)
Toshimitsu Goto	(GODI) (Leg 3)
Ryo Ohyama	(Mirai Crew) (Legs 1, 2, 3)

(2) Objective

As basic information about general weather conditions during the cruise, surface meteorological observation had been continuously conducted.

(3) Methods

There are two different surface meteorological observation systems onboard the R/V MIRAI. One is the MIRAI surface meteorological measurement station (SMET), and the other is the Shipboard Oceanographic and Atmospheric Radiation (SOAR) system.

Instruments of SMET whose data are used here are listed in Table 2.3.1. All SMET data were collected by KOAC-7800 weather data processor made by Koshin Denki, Japan. Note that although SMET contains rain gauge, anemometer and radiometers in their system, we adopted those data from not SMET but SOAR due to the following reasons; 1) since SMET rain gauge is located near the base of the mast, there is a possibility that its capture rate might be affected, 2) SOAR's anemometer has low starting threshold wind speed (1 m/sec)

comparing to SMET's (2m/sec), and 3) SMET's radiometers has 10 W/m² resolution, while SOAR takes 1 W/m².

SOAR system was designed and constructed by the Brookhaven National Laboratory (BNL), USA for an accurate measurement of solar radiation on the ship. SOAR consists of 1) Portable Radiation Package (PRP) that measures short and long wave downwelling radiation, 2) Zeno meteorological system that measures pressure, air temperature, relative humidity, wind speed/direction, and rainfall, and 3) Scientific Computer System (SCS), that has been developed by the U.S. National Oceanic and Atmospheric Administration (NOAA) for data collection, management, real-time monitoring, etc. Information on sensors used here is listed in Table 2.3.2.

Table 2.3.1. Instruments and locations of SMET.

Sensor	Parameter	Manufacturer / type	Location / height from sea level
Thermometer ^{*1}	air temperature relative humidity	Vaisala, Finland / HMP45A	compass deck ^{*2} / 21 m
Thermometer	sea temperature	SBE, USA / SBE-3S	bow thruster room / -5 m
Barometer	pressure	Setra System, USA / Model-370	captain deck / 13 m

^{*1}: Gill aspirated radiation shield 43408 made by R. M. Young, USA is attached.

^{*2}: Thermometers are equipped at both starboard and port sides, and upwind-side data are used.

Table 2.3.2. Instruments and locations of SOAR.

Sensor	Parameter	Manufacturer / type	Location / height from sea level
Anemometer	Wind speed/direction	R. M. Young, USA / 05106	Foremast / 25 m
Rain gauge	Rainfall accumulation	R. M. Young, USA / 50202	Foremast / 24 m
Radiometer	Short wave radiation	Eppley, USA / PSP	Foremast / 25 m
	Long wave radiation	Eppley, USA / PIR	Foremast / 25 m

(4) Data processing and data format

All raw data were recorded every 6 seconds. Datasets produced here are 1-minute mean values (time stamp at the end of the average). They are mean of 8 samples (10 samples minus maximum/minimum values) to exclude singular values. Linear interpolation onto missing values was applied only when their interval is less than 4 minutes. Since the thermometers are equipped on both starboard/port sides, we adopted air temperature/relative humidity data taken at upwind side. Dew point temperature was calculated from relative humidity and air temperature data. No adjustment to sea level values is applied except pressure data.

Data are stored as ASCII format and contain the following parameters. Time in UTC expressed as YYYYMMDDHHMM, time in Julian day (1.0000 = January 1, 0000Z), longitude (°E), latitude (°N), pressure (hPa), air temperature (°C), dew point temperature (°C), relative humidity (%), sea surface temperature (°C), zonal wind component (m/sec), meridional wind component (m/sec), precipitation (mm/hr), shortwave and longwave radiation (W/m²).

Missing values are expressed as “9999”.

(5) Data quality

To ensure the data quality, each sensor was calibrated as follows. It is remarked, however, since there is a possibility that data may contain noises caused by turbulence, it is recommended to filter out such data by using smoothed data (e.g., 1-hour mean) from this 1-minute mean data sets depending on the scientific purpose.

T/RH sensor;

Temperature and humidity probes were calibrated before (Aug. 3, 2011) and after (Feb. 28, 2012) the cruise by the manufacturer. Certificated accuracy for T/RH sensors are better than ±0.2 °C and ±2 %, respectively. We also checked T/RH values using another calibrated portable T/RH sensor (Vaisala, HMP45A) before each cruise. The results are listed below.

Check date			Dec. 01, 2011	Feb. 10, 2012
Temperature (°C)	Port side	SMET	27.6	-5.7
		Portable	27.9	-5.6
	Starboard side	SMET	27.9	-5.1
		Portable	27.9	-5.0
Relative Humidity (%)	Port side	SMET	76.9	62.1
		Portable	74.0	61.7
	Starboard side	SMET	78.1	66.0
		Portable	76.2	62.1

Pressure sensor;

Using calibrated portable barometer (Vaisala, Finland / PTB220), pressure sensor was checked before/after the cruise. Accuracy is better than ±0.2 hPa.

Check date	Oct.26	Dec.01	Feb.10	Mar.30
SMET	1007.45	1008.06	1013.52	1016.51
Reference	1007.43	1008.00	1013.64	1016.40
Difference	+0.02	+0.06	-0.12	0.11

Precipitation;

Prior to the cruise, we put the water into the rain gauge to check their linearity between the indicated values and actual water amount input. Expected accuracy is better than $\pm 1\text{mm}$ which corresponds to sensor's original specification.

Calibration date	Dec. 2 (1)	Dec. 2 (2)	Dec. 2 (3)	Feb. 9 (1)	Feb. 9 (2)	Feb. 9 (3)
Min input water volume (cc)	0.00	0.00	0.00	0.00	0.00	0.00
Min measured value (mm)	0.13	0.11	0.12	0.47	0.47	0.53
Max input water volume (cc)	505.00	504.50	502.50	504.50	506.50	506.00
Max measured value (mm)	49.28	49.25	49.28	50.10	50.21	50.29

Radiation sensors ;

Short wave and long wave radiometers were calibrated by Remote Measurement & Research Company with the help of Department of Energy, Atmospheric Radiation Measurement Program prior to the cruise. Sensors used here were calibrated on June 3, 2011.

$$\text{For PSP; } y = 3.691x + 4.2$$

$$\text{For PIR; } y = 1.252x - 23.3,$$

where $y = \text{Insolation (W/m}^2\text{)}$, and $x = \text{ADC value (mV)}$.

$$1 / (T+T_0) = P_1 a^3 + P_2 a^2 + P_3 a + P_4, \text{ where } a = \ln(\text{ADC mV}), \text{ and } T_0 = 273.15 \text{ K}$$

Case temperature fit; max error = 0.000 °C

$$P_1 = 3.0273e-6, P_2 = -3.6335e-5, P_3 = 4.2203e-4, P_4 = 1.7194e-3$$

Dome temperature fit; max error = 0.000 °C

$$P_1 = 3.0297e-6, P_2 = -3.6490e-5, P_3 = 4.2347e-4, P_4 = 1.7153e-3$$

(6) Data periods

Leg-1: December 05, 2011, 1001Z – December 10, 2011, 0829Z

Leg-2: December 20, 2011, 2101Z – December 22, 2011, 0000Z

December 23, 2011, 1931Z – January 01, 2012, 0429Z

January 03, 2012, 1401Z – January 10, 2012, 1400Z

Leg-3: January 13, 2012, 0246Z – February 09, 2012, 0900Z

(7) Preliminary results

Figures 2.3.1, 2.3.2 and 2.3.3 show the time series of surface meteorological observation for each cruise. One hour mean values (time stamp at the medium of the average) instead of 1 minute mean are used to depict these figures.

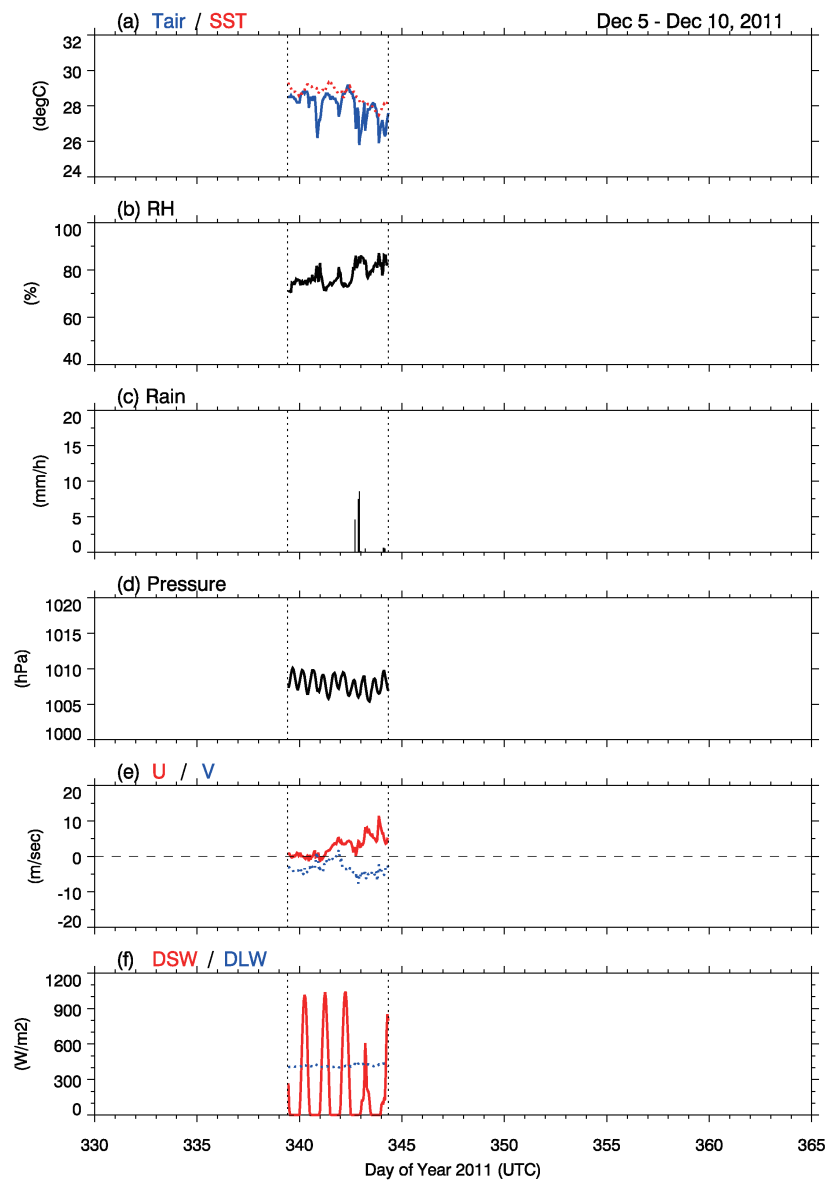


Figure 2.3.1. Time series of (a) air and sea surface temperature, (b) relative humidity, (c) precipitation, (d) pressure, (e) zonal and meridional wind components, and (e) short and long wave radiation for the Leg-1 cruise. Day-330 corresponds to Nov. 26, 2011.

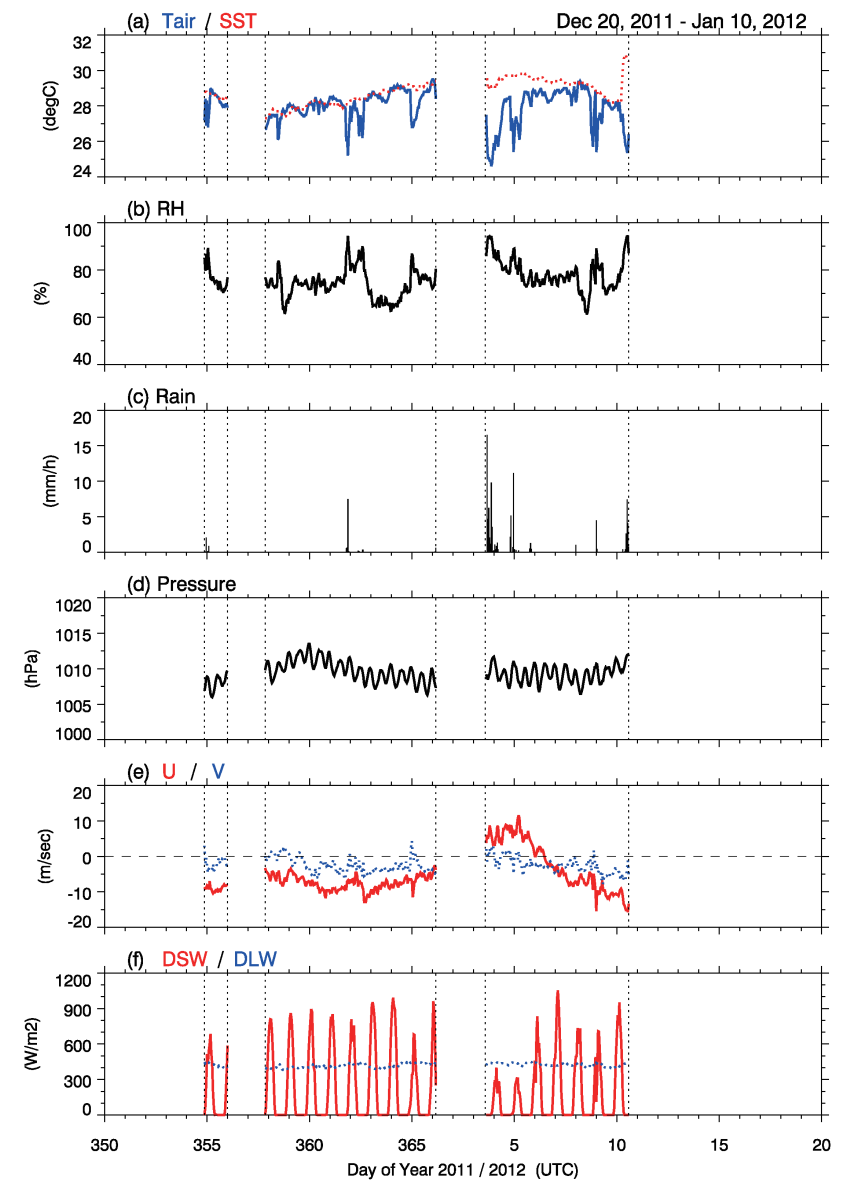


Figure 2.3.2. Same as Fig. 2.3.1, but for the Leg-2 cruise. Day-350 corresponds to Dec. 16, 2011.

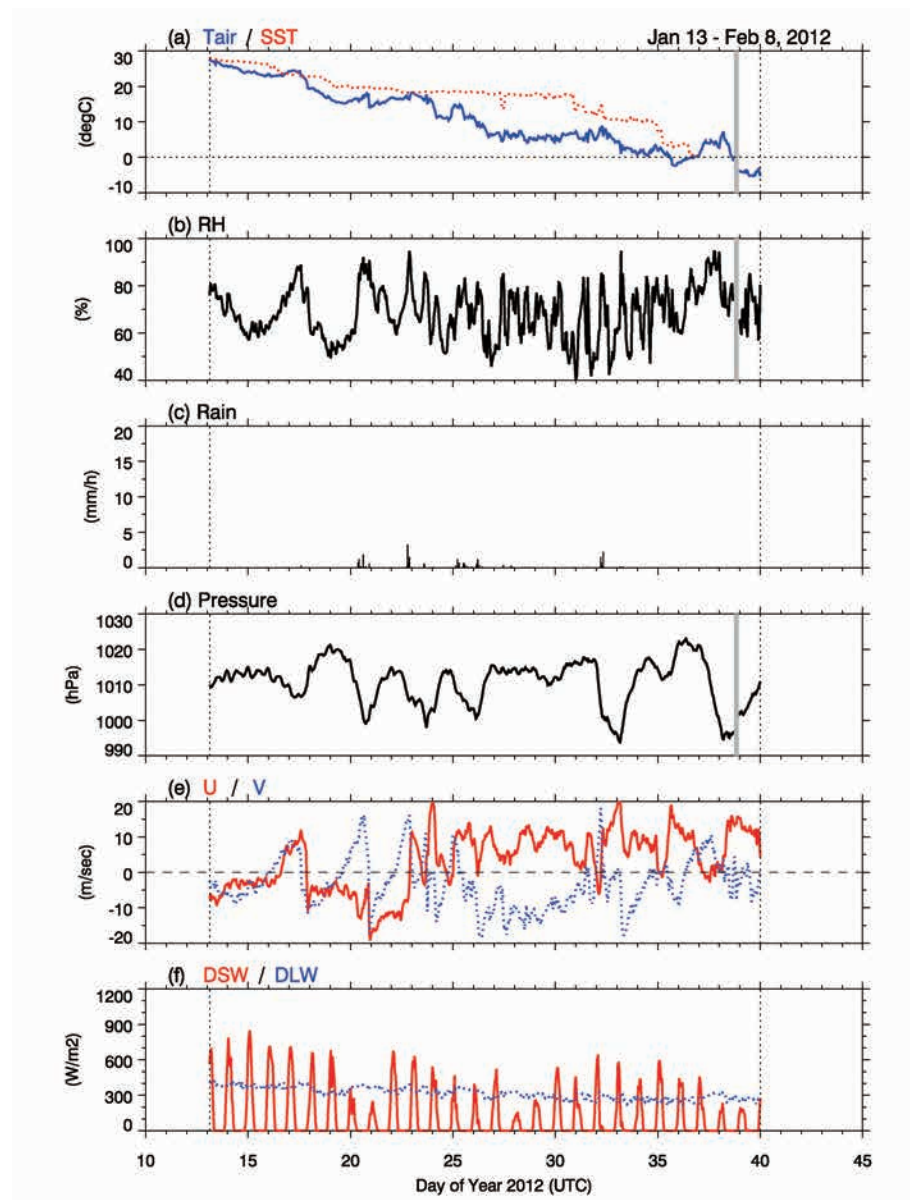


Figure 2.3.3. Same as Fig. 2.3.1, but for the Leg-3 cruise. Vertical scale for (a) and (d) are also different with Fig.

2.3.1. Day-10 corresponds to Jan. 10, 2012.

2.4 Thermo-Salinograph and Related Measurements

February 4, 2014

(1) Personnel

Hiroshi Uchida (JAMSTEC)
 Miyo Ikeda (MWJ) (Leg 2)
 Kanako Yoshida (MWJ) (Leg 2, 3)
 Yuki Miyajima (MWJ) (Leg 2)
 Misato Kuwahara (MWJ) (Leg 3)
 Shinichiro Yokogawa (MWJ) (Leg 3)

(2) Objectives

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

(3) Materials and methods

The Continuous Sea Surface Water Monitoring System (Marine Works Japan Co, Ltd.) has six sensors and automatically measures salinity, temperature, dissolved oxygen, and fluorescence in sea surface water every one minute. This system is located in the sea surface monitoring laboratory 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. The flow rate of the surface seawater was controlled to be $5 \text{ dm}^3/\text{min}$. Manufacturer's specifications of the each sensor in this system are listed below.

i. Software Seamoni-kun Ver.1.20

ii. Sensors

Temperature and conductivity sensor

Model:	SBE-45, SEA-BIRD ELECTRONICS, INC.
Serial number:	4563325-0362 (leg 1) 4557820-0319 (legs 2, 3)
Measurement range:	Temperature -5 to 35°C Conductivity 0 to 7 S m ⁻¹
Initial accuracy:	Temperature 0.002°C Conductivity 0.0003 S m ⁻¹
Typical stability (per month):	Temperature 0.0002°C Conductivity 0.0003 S m ⁻¹
Resolution:	Temperatures 0.0001°C Conductivity 0.00001 S m ⁻¹

Bottom of ship thermometer

Model:	SBE 38, SEA-BIRD ELECTRONICS, INC.
Serial number:	3857820-0540
Measurement range:	-5 to +35°C
Initial accuracy:	±0.001°C
Typical stability (per 6 month):	0.001°C
Resolution:	0.00025°C

Dissolved oxygen sensor

Model:	OPTODE 3835, AANDERAA Instruments.
Serial number:	1519
Measuring range:	0 - 500 μmol L ⁻¹

Resolution:	<1 μmol L ⁻¹
Accuracy:	<8 μmol L ⁻¹ or 5% whichever is greater
Settling time (63%):	<25 s

Fluorometer

Model:	C3, TURNER DESIGNS
Serial number:	2300123

(4) Data Processing and Quality Control

Data from the Continuous Sea Surface Water Monitoring System were processed as follows. Data gaps were linearly interpolated when the gap was ≤ 7 minutes. 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. Fluorometer data were low-pass filtered using a median filter with a window of 3 scans (3 minutes) to remove spikes. Raw data from the OPTODE oxygen sensor and the fluorometer data were low-pass filtered using a Hamming filter with a window of 15 scans (15 minutes).

Salinity (S [PSU]), dissolved oxygen (O [μmol/kg]) and fluorescence (Fl [RFU]) data were corrected using the water sampled data. Details of the measurement methods are described in Sections 3.2, 3.4, and 3.8 for salinity, dissolved oxygen and chlorophyll-a, respectively. Corrected salinity (S_{cor}), dissolved oxygen (O_{cor}), and estimated chlorophyll *a* (Chl-a) were calculated from following equations

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

$$O_{cor} \text{ [μmol/kg]} = c_0 + c_1 O + c_2 T + c_3 t$$

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

where *t* is days from a reference time, *T* is temperature in °C. The best fit sets of calibration coefficients ($c_0 \sim c_3$) were determined by a least square technique to minimize the deviation from the water sampled data. The reference times were listed in Table 2.4.1. 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 from

Figs. 2.4.1 to 2.4.6. For leg 3, sensitivity of the fluorometer to chlorophyll *a* was different between subtropical region and subarctic region. Therefore, slope (c_1) of the calibration coefficients was changed according to the temperature for each area (Table 2.4.2).

Table 2.4.1. Reference time used in the calibration equations for salinity and dissolved oxygen.

Leg	Date	Time (UTC)
2	2011/12/20	21:00
3	2012/01/13	02:47

Table 2.4.2. Calibration coefficients for the salinity, dissolved oxygen, and chlorophyll *a*.

Leg	c0	c1	c2	c3
<i>Salinity</i>				
2	1.012865e-02	0.9995585	7.254156e-04	
3	-8.713569e-02	1.002669	5.683519e-04	
<i>Dissolved oxygen</i>				
2	11.34542	1.102664	-0.6163531	-1.981512e-02
3	36.55213	0.9906656	-0.738031	-0.1868786
<i>Chlorophyll a</i>				
2	4.082381e-02	0.1021539		
3	3.746690e-02	0.1262224 (for temperature < 17 °C)		
	3.746690e-02	8.794529e-02 (for temperature ≥ 17 °C)		

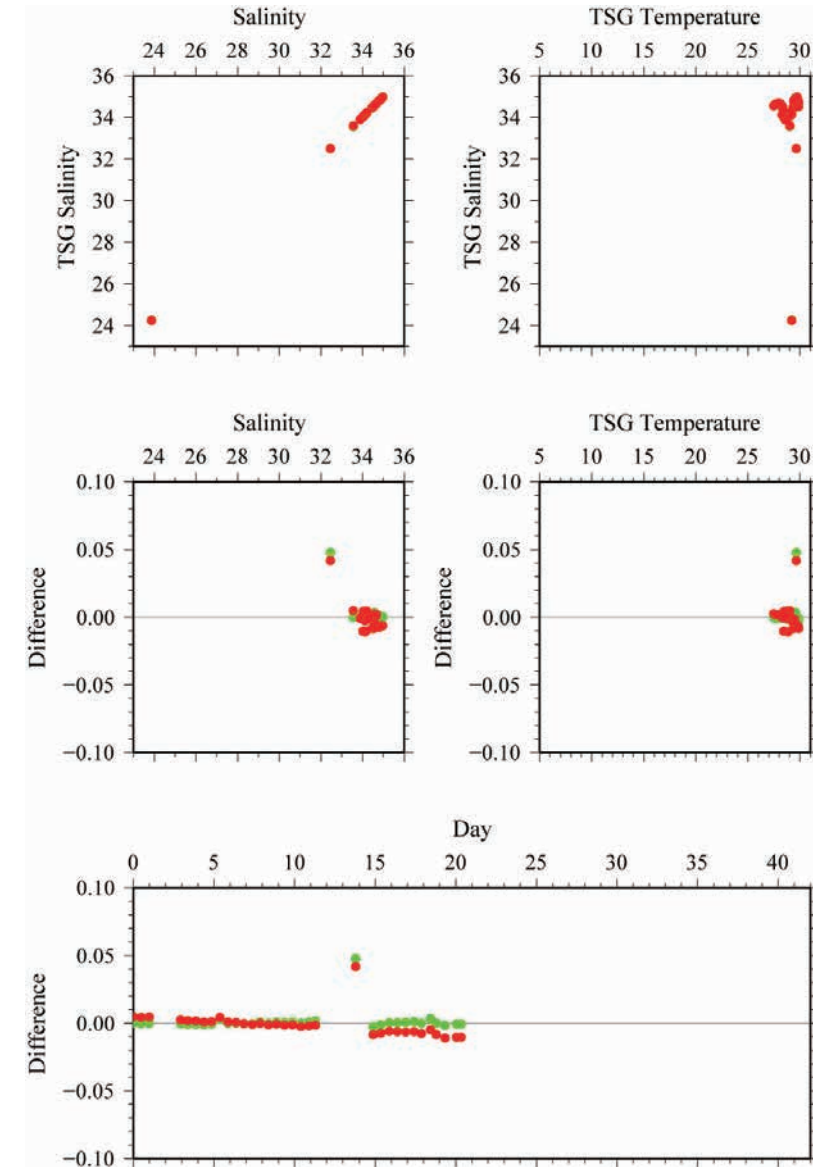


Figure 2.4.1. Comparison between TSG salinity (red: before correction, green: after correction) and sampled salinity for leg 2.

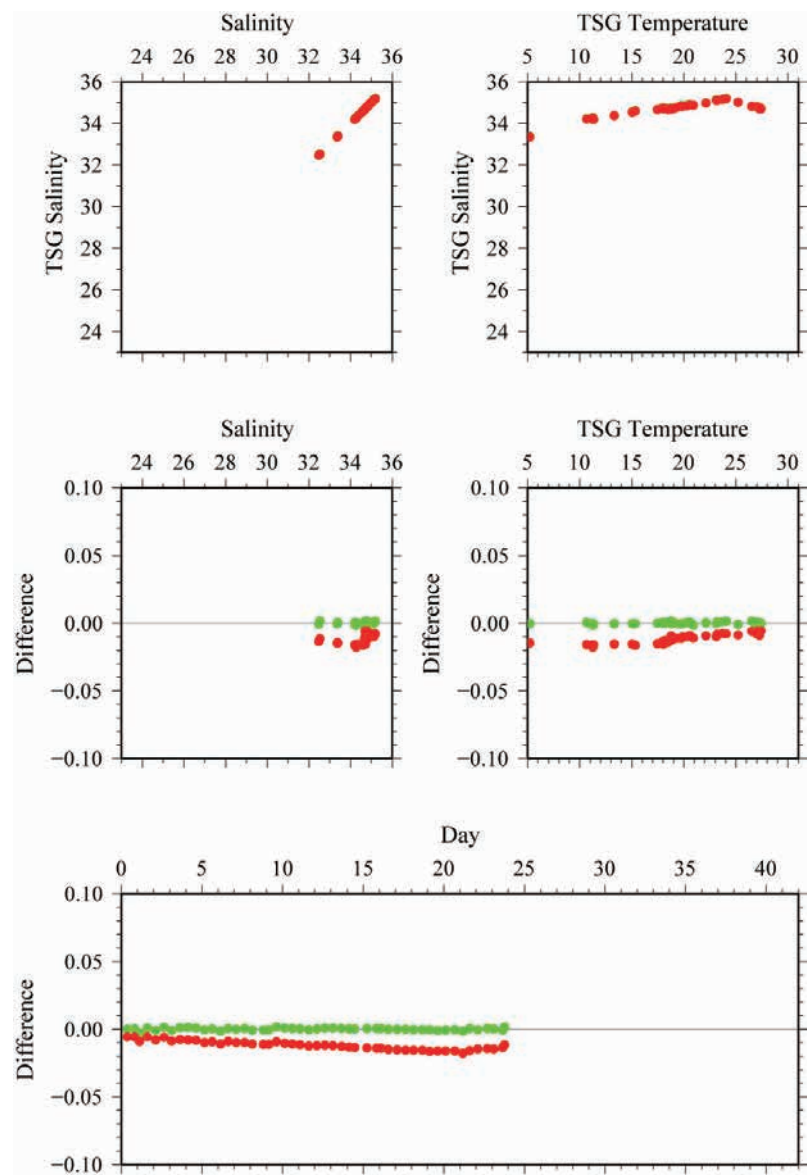


Figure 2.4.2. Same as Fig. 2.4.1, but for leg 3.

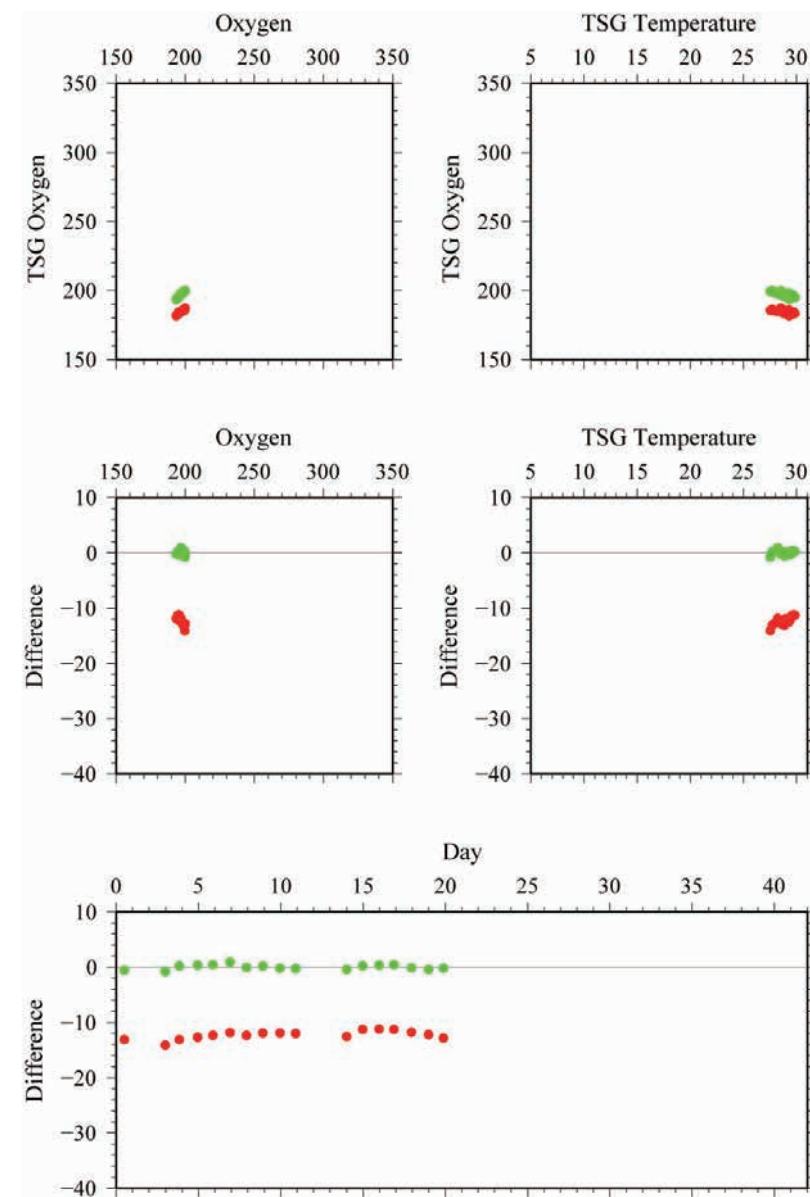


Figure 2.4.3. Comparison between TSG oxygen (red: before correction, green: after correction) and sampled oxygen for leg 2.

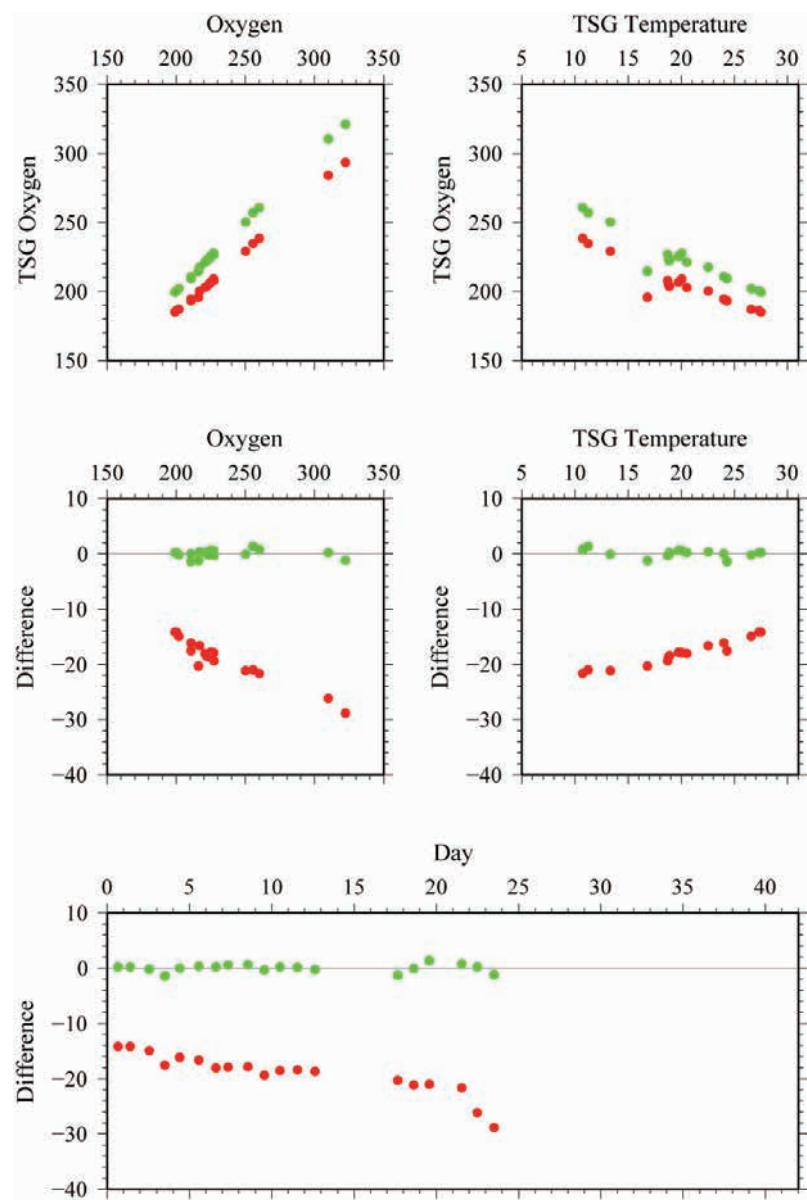


Figure 2.4.4. Same as Fig. 2.4.3, but for leg 3.

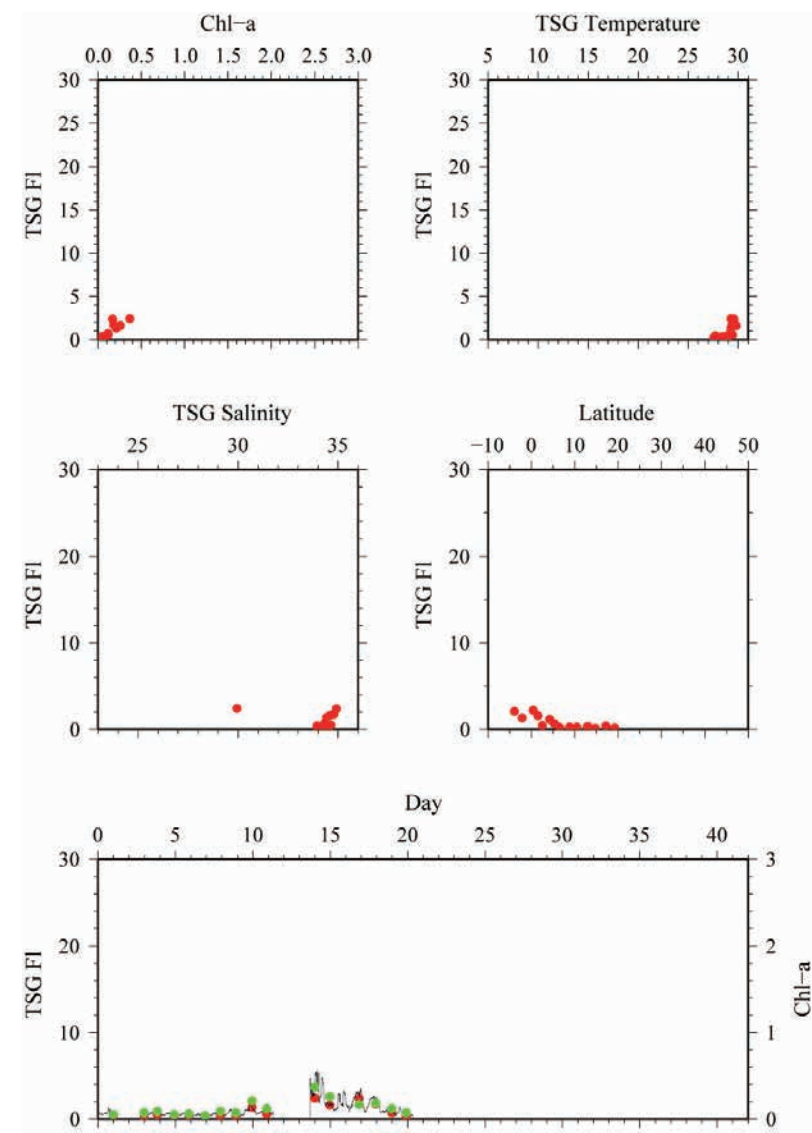


Figure 2.4.5. Comparison between TSG fluorescence and sampled chlorophyll a for leg 2. For bottom panel, red (temperature $\geq 17^{\circ}\text{C}$) and blue (temperature $< 17^{\circ}\text{C}$) dots indicate fluorescence and green dots indicate water sampled chlorophyll a. Line indicates chlorophyll a estimated from fluorometer.

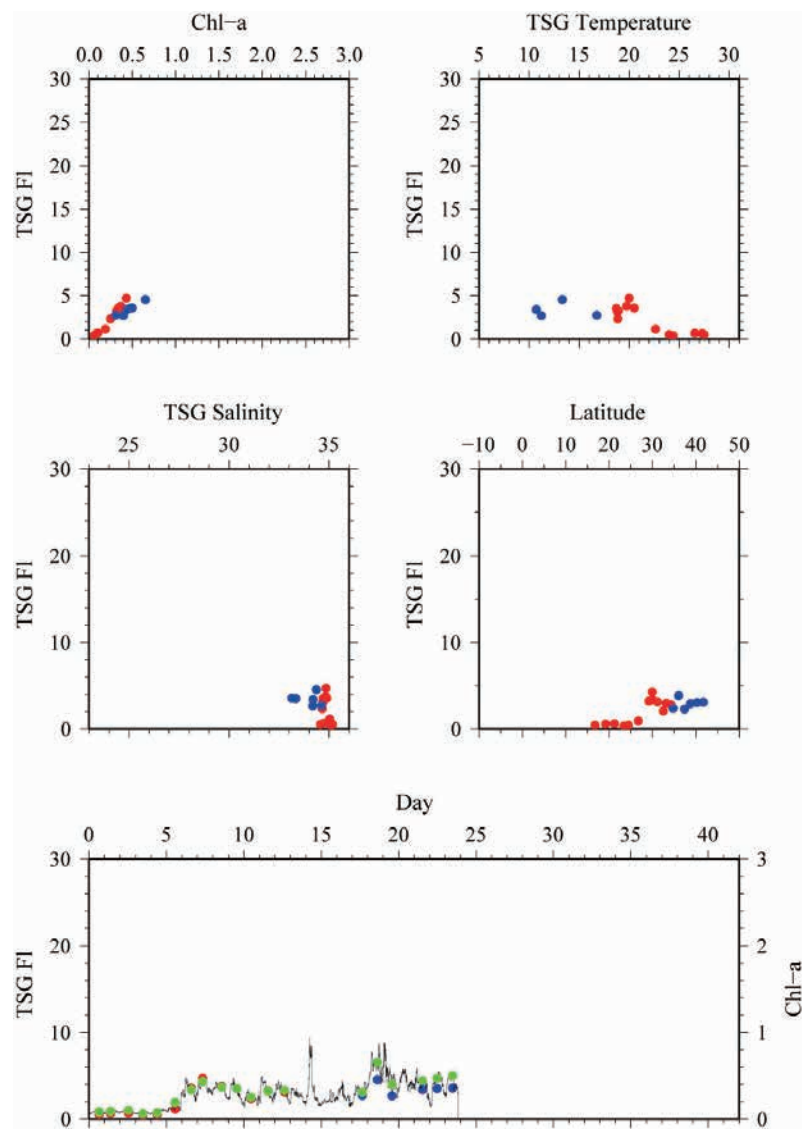


Figure 2.4.6. Same as Fig. 2.4.5, but for leg 3.

2.5 Underway pCO₂

24 September, 2013

(1) Personnel

Akihiko Murata (RIGC, JAMSTEC)

Yoshiko Ishikawa (MWJ)

Hatsumi Aoyama (MWJ)

Makoto Takada (MWJ)

(2) Introduction

Concentrations of CO₂ in the atmosphere are now increasing at a rate of 1.9 ppmv y⁻¹ due to human activities such as burning of fossil fuels, deforestation, cement production, etc. It is an urgent task to estimate as accurately as possible the absorption capacity of the ocean against the increased atmospheric CO₂, and to clarify the mechanism of the CO₂ absorption, because the magnitude of the predicted global warming depends on the levels of CO₂ 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 the P10 revisit cruise, we were aimed at quantifying how much anthropogenic CO₂ is absorbed in the surface ocean in the western Pacific. For the purpose, we measured pCO₂ (partial pressures of CO₂) in the atmosphere and in the surface seawater.

(3) Apparatus and shipboard measurement

Continuous underway measurements of atmospheric and surface seawater pCO₂ were made with the CO₂ measuring system (Nippon ANS, Ltd) installed in the R/V *Mirai* of JAMSTEC. The system comprises of a non-dispersive infrared gas analyzer (Li-COR LI-7000), an air-circulation module and a showerhead-type equilibrator. To measure concentrations (mole fraction) of CO₂ in dry air (xCO₂a), air sampled from the bow of the ship (approx. 30 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 ($\text{Mg}(\text{ClO}_4)_2$). The flow rate of the air was 500 ml min^{-1} . To measure surface seawater concentrations of CO_2 in dry air ($x\text{CO}_{2s}$), 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 $x\text{CO}_{2a}$. The flow rate of the equilibrated air was $700 - 800 \text{ ml min}^{-1}$. 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 $400 - 500 \text{ ml min}^{-1}$.

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), $x\text{CO}_{2a}$ (twice), $x\text{CO}_{2s}$ (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 after 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 $x\text{CO}_{2s}$ were adjusted based on Takahashi *et al.* (1993), although the temperature increases were slight, being ~ 0.3 °C.

We checked values of $x\text{CO}_{2a}$ and $x\text{CO}_{2s}$ by examining signals of the NDIR by plotting the $x\text{CO}_{2a}$ and $x\text{CO}_{2s}$ as a function of sequential day, longitude, sea surface temperature and sea surface salinity.

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.

Table 2.5.1. Concentrations of CO_2 standard gases used during MR11–08 cruise.

Cylinder no.	Concentrations (ppmv)
CRC00049	270.13
CRC00046	330.29
CRC00047	360.28
CRC00048	420.25

2.6 Shipboard ADCP

August 13, 2013

(1) Personnel

Shinya Kouketsu	(JAMSTEC): Principal Investigator	
Kazuho Yoshida	(Global Ocean Development Inc., GODI)	-leg1, leg2-
Ryo Kimura	(GODI)	-leg1, leg2-
Satoshi Okumura	(GODI)	-leg2-
Katsuhisa Maeno	(GODI)	-leg3-
Asuka Doi	(GODI)	-leg3-
Toshimitsu Goto	(GODI)	-leg3-
Ryo Ohyama	(MIRAI Crew)	-leg1, leg2, leg3-

(2) Objective

To obtain continuous measurement of the current profile along the ship's track.

(3) Methods

Upper ocean current measurements were made in MR11-08 cruise, using the hull-mounted Acoustic Doppler Current Profiler (ADCP) system. For most of its operation the instrument was configured for water-tracking mode. Bottom-tracking mode, interleaved bottom-ping with water-ping, was made to get the calibration data for evaluating transducer misalignment angle in the shallow water. The system consists of following components;

- 1) R/V MIRAI has installed vessel-mount ADCP (75 kHz "Ocean Surveyor", Teledyne RD Instruments). It has a phased-array transducer with single assembly and creates 4 acoustic beams electronically.
- 2) For heading source, we use ship's gyro compass (Tokimec, Japan), continuously providing heading to

the ADCP system directory. Also we have Inertial Navigation System (PHINS, iXSEA) which provide high-precision heading and attitude information are stored in ".N2R" data files.

- 3) DGPS system (Trimble SPS751 & StarFixXP) providing position fixes.
- 4) We used VmDas version 1.4.6 (TRDI) for data acquisition.
- 5) To synchronize time stamp of pinging with GPS time, the clock of the logging computer is adjusted to GPS time every 1 minute.
- 6) The sound speed at the transducer does affect the vertical bin mapping and vertical velocity measurement, is calculated from temperature, salinity (constant value; 35.0 psu) and depth (6.5 m; transducer depth) by equation in Medwin (1975).

Data was configured for 8-m intervals starting 19-m below the surface. Every ping was recorded as raw ensemble data (.ENR). Also, 60 seconds and 300 seconds averaged data were recorded as short term average (.STA) and long term average (.LTA) data, respectively. Major parameters for the measurement (Direct Command) are shown in Table 2.6.1.

(4) Preliminary results

Figs.2.6.1, 2.6.2 and 2.6.3 shows surface current profile along the ship's track, averaged four depth cells from the top, 23 m to 55 m with 30 minutes average. In the layer upper 300m, the velocity estimation were good during this cruise, because the echo intensities for each beams were over 60 counts at such depths (Fig. 2.6.4).

(5) Data

The processed data were fixed the ADCP misalignment by comparison between bottom track and ship velocities (based on GPS data) and were averaged over 10 minutes.

All the data obtained in this cruise will be submitted to the Data Management Group (DMG) of JAMSTEC, and will be opened to the public via JAMSTEC home page.

(6) Remarks (Times in UTC)

The observation was carried out within following periods

Leg1: 10:00 5th Dec. 2011 to 08:30 10th Dec. 2011

Leg2: 21:00 20th Dec. 2011 to 00:00 22th Dec. 2011

19:30 23th Dec. 2011 to 04:30 1st Jan. 2012

14:00 3rd Jan. 2012 to 14:00 10th Jan. 2012

Leg3: 02:45 13th Jan. 2012 to 00:00 9th Feb. 2012

Table 2.6.1. Major parameters.

Environmental Sensor Commands

EA = +04500	Heading Alignment (1/100 deg)
EB = +00000	Heading Bias (1/100 deg)
ED = 00065	Transducer Depth (0 - 65535 dm)
EF = +001	Pitch/Roll Divisor/Multiplier (pos/neg) [1/99 - 99]
EH = 00000	Heading (1/100 deg)
ES = 35	Salinity (0-40 pp thousand)
EX = 00000	Coord Transform (Xform:Type; Tilts; 3Bm; Map)
EZ = 10200010	Sensor Source (C; D; H; P; R; S; T; U)
	C (1): Sound velocity calculates using ED, ES, ET (temp.)
	D (0): Manual ED
	H (2): External synchro
	P (0), R (0): Manual EP, ER (0 degree)
	S (0): Manual ES
	T (1): Internal transducer sensor
	U (0): Manual EU

Timing Commands

TE = 00:00:02.00 Time per Ensemble (hrs:min:sec.sec/100)

TP = 00:02.00 Time per Ping (min:sec.sec/100)

Water-Track Commands

WA = 255 False Target Threshold (Max) (0-255 count)

WB = 1 Mode 1 Bandwidth Control (0=Wid, 1=Med, 2=Nar)

WC = 120 Low Correlation Threshold (0-255)

WD = 111 100 000 Data Out (V; C; A; PG; St; Vsum; Vsum ^ 2; #G;P0)

WE = 1000 Error Velocity Threshold (0-5000 mm/s)

WF = 0800 Blank After Transmit (cm)

WG = 001 Percent Good Minimum (0-100%)

WI = 0 Clip Data Past Bottom (0 = OFF, 1 = ON)

WJ = 1 Rcvr Gain Select (0 = Low, 1 = High)

WM = 1 Profiling Mode (1-8)

WN = 100 Number of depth cells (1-128)

WP = 00001 Pings per Ensemble (0-16384)

WS = 0800 Depth Cell Size (cm)

WT = 000 Transmit Length (cm) [0 = Bin Length]

WV = 0390 Mode 1 Ambiguity Velocity (cm/s radial)

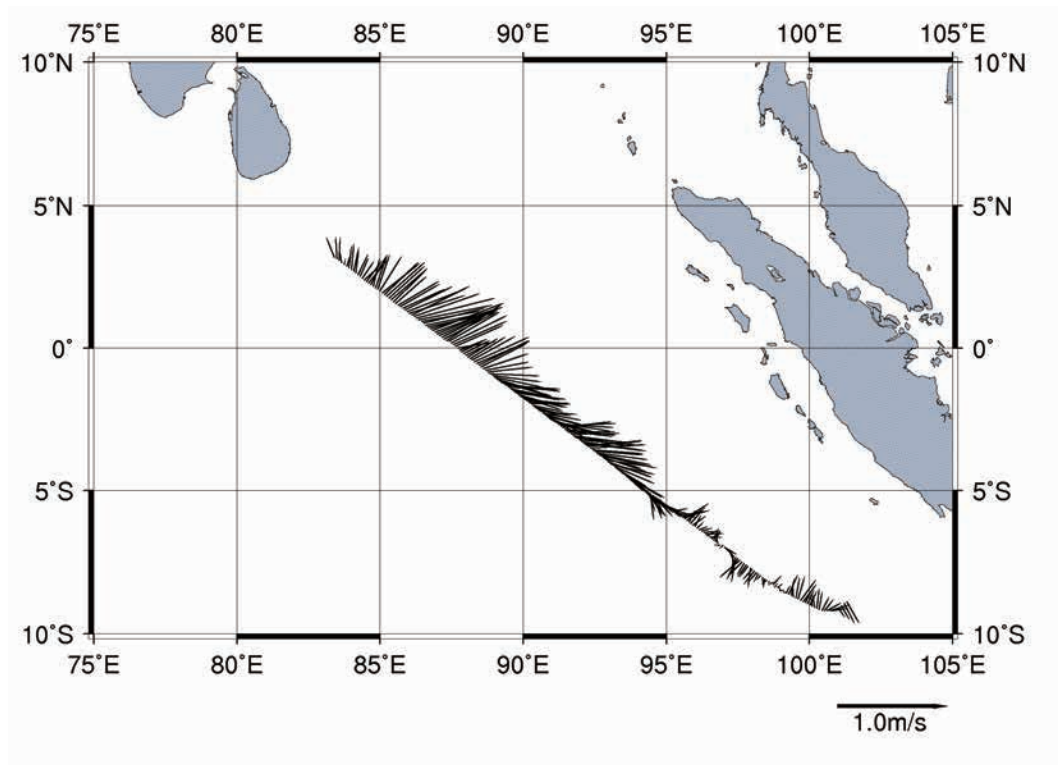


Figure 2.6.1. Current profile along the ship's track, from 23m to 55m, averaged every 30 minutes (Leg1).

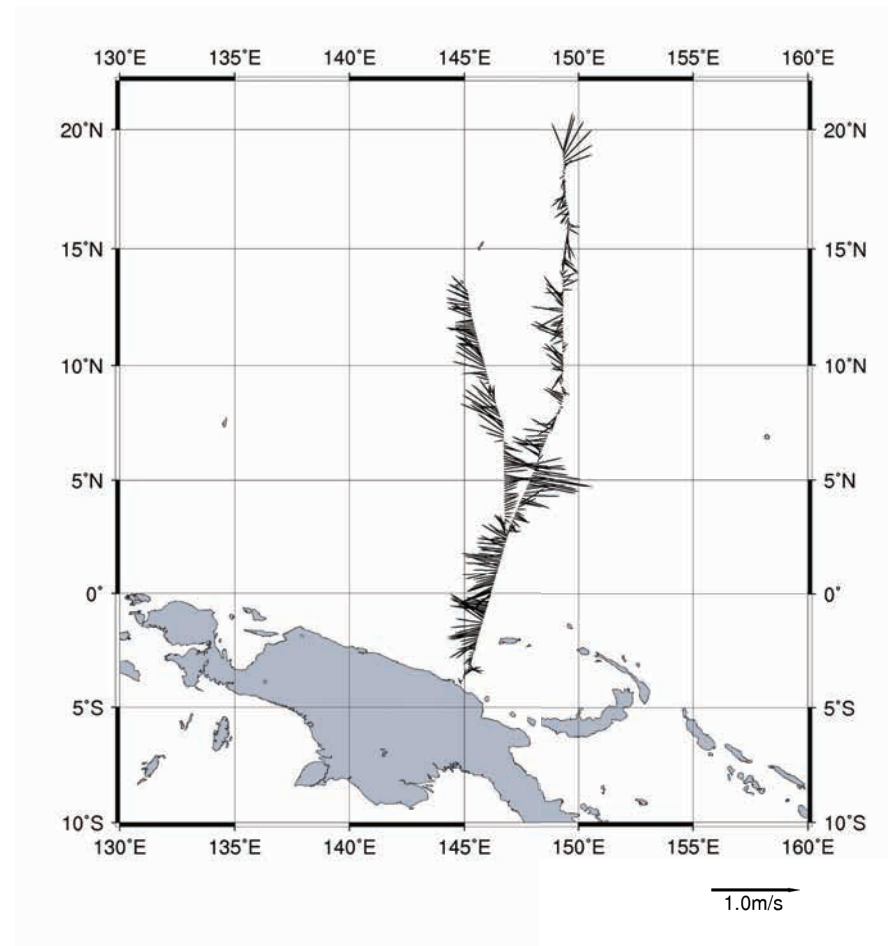


Figure 2.6.2. Current profile along the ship's track, from 23m to 55m, averaged every 30 minutes (Leg2).

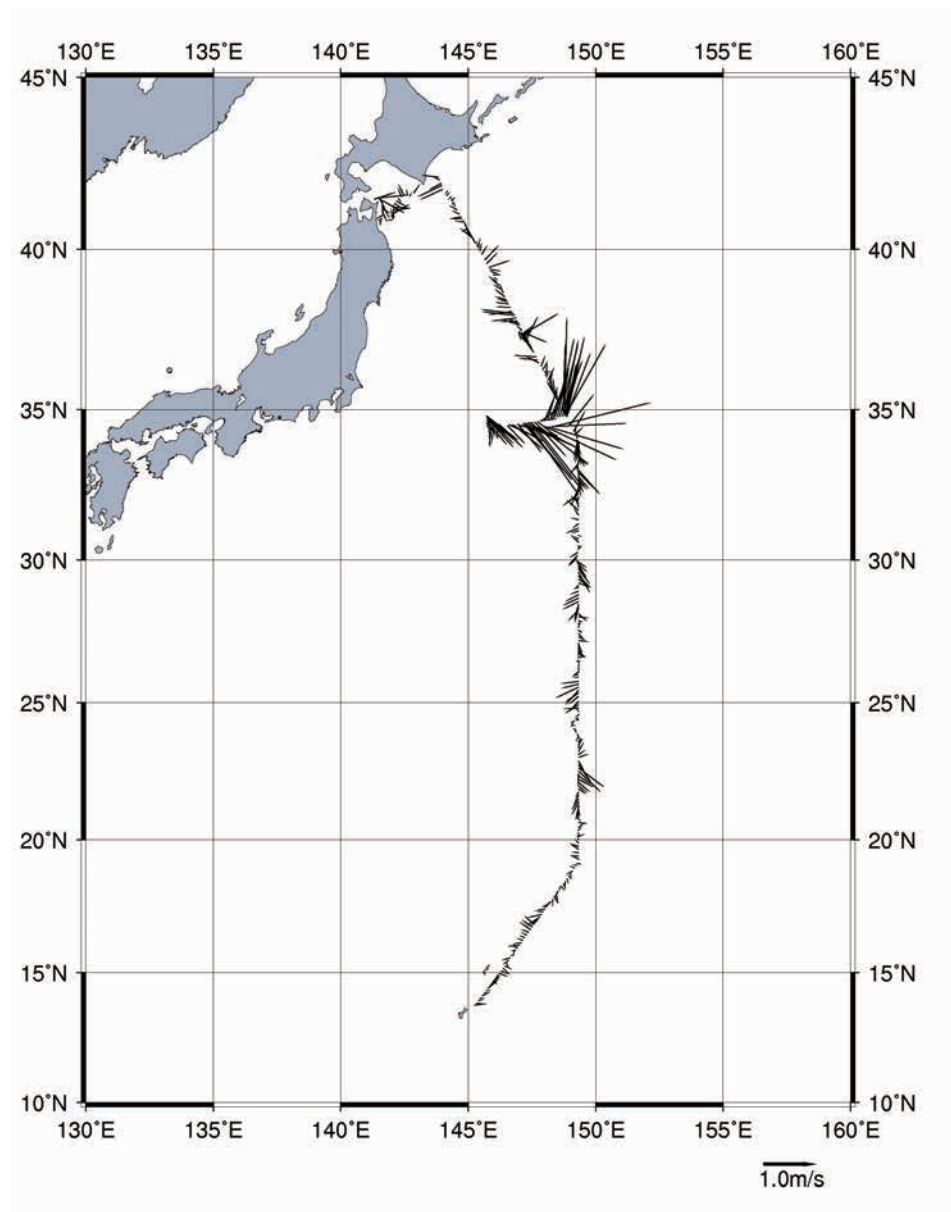


Figure 2.6.3. Current profile along the ship's track, from 23m to 55m, averaged every 30 minutes (Leg3).

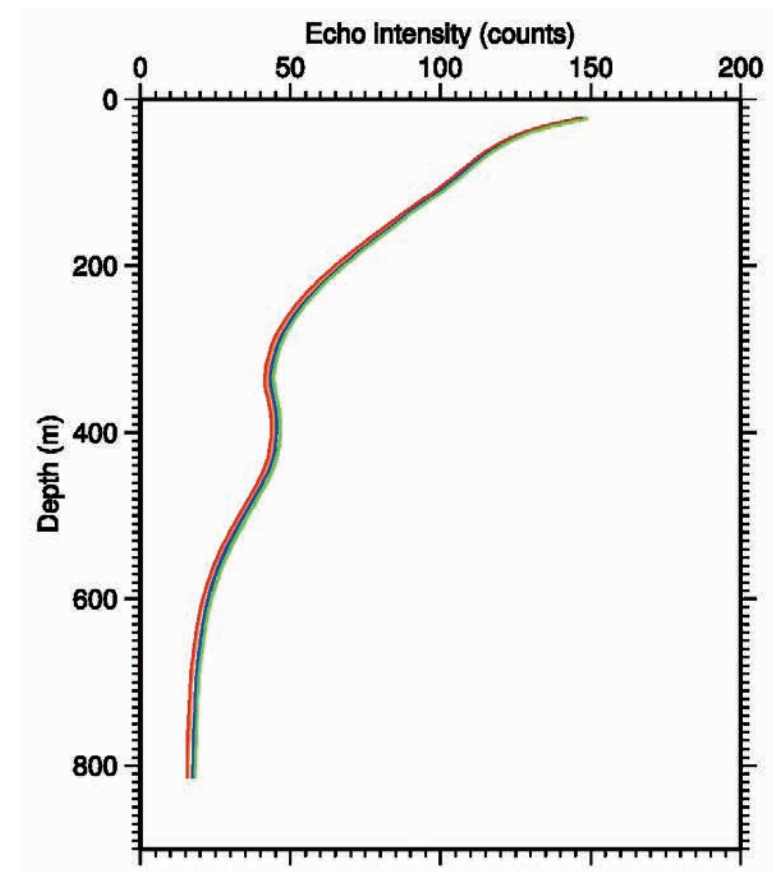


Figure 2.6.4. Echo intensity.

2.7 XCTD

February 5, 2014

(1) Personnel

Hiroshi Uchida (JAMSTEC)

Katsuhisa Maeno (GODI)

Ryo Ohyama (GODI)

Asuka Doi (GODI)

Toshimitsu Goto (GODI)

(2) Objectives

In this cruise, XCTD (eXpendable Conductivity, Temperature and Depth profiler) measurements were carried out to evaluate the fall rate equation and temperature by comparing with CTD (Conductivity, Temperature and Depth profiler) measurements, and to substitute for CTD measurements.

(3) Instrument and Method

The XCTDs used were XCTD-2 (Tsurumi-Seiki Co., Ltd., Yokohama, Kanagawa, Japan) with an MK-150N deck unit (Tsurumi-Seiki Co., Ltd.). The manufacturer's specifications are listed in Table 2.7.1. In this cruise, the XCTD probes were deployed by using 8-loading automatic launcher (stations 64, 67, 89_1, 89_2, 91, 93, 95, 103 and 105) or hand 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 (stations 64, 67, 110, 112).

(4) Data Processing and Quality Control

The XCTD data were processed and quality controlled based on a method by Uchida et al. (2011). Depth error of the XCTD data was corrected by using the estimated terminal velocity error (-0.0362 m s^{-1}) (Fig. 2.7.1). Mean thermal bias ($+0.014 \text{ }^\circ\text{C}$) of the XCTD data was estimated by comparing with the CTD data and corrected

(Fig. 2.7.2). Salinity biases of the XCTD data were estimated by using temperature and salinity relationships in the deep ocean obtained from the post-cruise calibrated CTD data (Table 2.7.2). For the XCTD data of the station P10N_89_1~4 and P10N_113_1, salinity bias could not be estimated because the maximum depth was too shallow to estimate the salinity bias.

The temperature and salinity relationships in the deep ocean obtained from the post-cruise calibrated CTD and XCTD data were shown in Fig. 2.7.3.

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.*, accepted.

Table 2.7.1. Manufacturer's specifications of XCTD-2.

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 (for XCTD-2)	5 m or 2%, whichever is greater *

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

Table 2.7.2. Serial number of the XCTD. Water depth, ship intake temperature (SST) and salinity (SSS; not corrected), and maximum pressure for the XCTD data are shown. Salinity offset applied to the XCTD data and reference salinity estimated from the CTD data are also shown.

Station	Serial number	Depth [m]	SST [°C]	SSS [PSU]	Max pressure [dbar]	Salinity offset [PSU]	Reference salinity [PSU]
64_1	11022006	5714	25.045	35.045	2018	0.025	34.6081 @ 2.1°C
67_3	11022005	5786	23.895	35.178	2018	0.022	34.6017 @ 2.0°C
89_1	11022004	6145	17.866	34.717	889	-	NA
89_2	11022001	6078	17.788	34.715	655	-	NA
89_3	11021998	6130	17.797	34.717	823	-	NA
89_4	11022002	6134	17.857	34.717	846	-	NA
91_1	11021999	6067	12.769	34.303	2021	-0.002	34.5834 @ 2.0°C
93_1	11021995	5778	14.356	34.513	2021	0.008	34.5834 @ 2.0°C
95_1	11021996	5711	12.258	34.315	2021	0.008	34.5834 @ 2.0°C
97_1	11021849	5622	15.091	34.592	1999	0.004	34.5834 @ 2.0°C
99_1	11021850	5555	10.229	34.184	2021	-0.009	34.5834 @ 2.0°C
101_1	11021851	5450	10.151	34.189	2011	0.005	34.5834 @ 2.0°C
103_1	11022000	5300	9.662	34.128	2021	0.005	34.5834 @ 2.0°C
105_1	11021846	5276	4.441	33.353	2022	0.025	34.5834 @ 2.0°C
107_1	11021848	5817	4.642	33.409	2022	0.005	34.5834 @ 2.0°C
108_1	11021847	6224	3.454	33.329	2016	0.019	34.5834 @ 2.0°C
109_1	11021844	6321	3.415	33.325	2020	0.015	34.5834 @ 2.0°C
110_2	11021843	4057	4.001	33.409	2022	0.018	34.5834 @ 2.0°C
111_1	11021840	2695	3.810	33.370	2022	0.034	34.5834 @ 2.0°C

112_1	11021841	1481	1.748	33.157	1475	0.010	34.4829 @ 2.4°C
113_1	11021842	1047	0.501	32.511	1051	-	NA

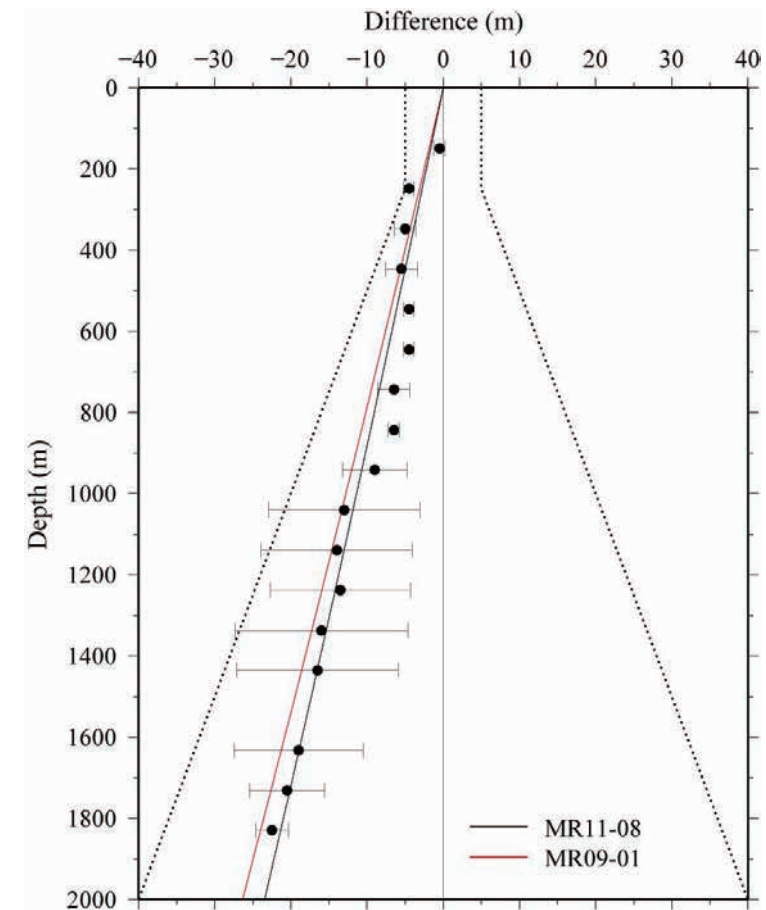


Figure 2.7.1. Differences between XCTD and CTD depths for stations 64, 67, 110 and 112. Differences were estimated with the same method as Uchida et al. (2011). Standard deviation of the estimates (horizontal bars) and the manufacturer's specification for XCTD depth error (dotted lines) are shown. The regression for the XCTD-2 data obtained in this cruise (black line) and for the XCTD-2 data obtained in the MR09-01 cruise (red line) are shown.

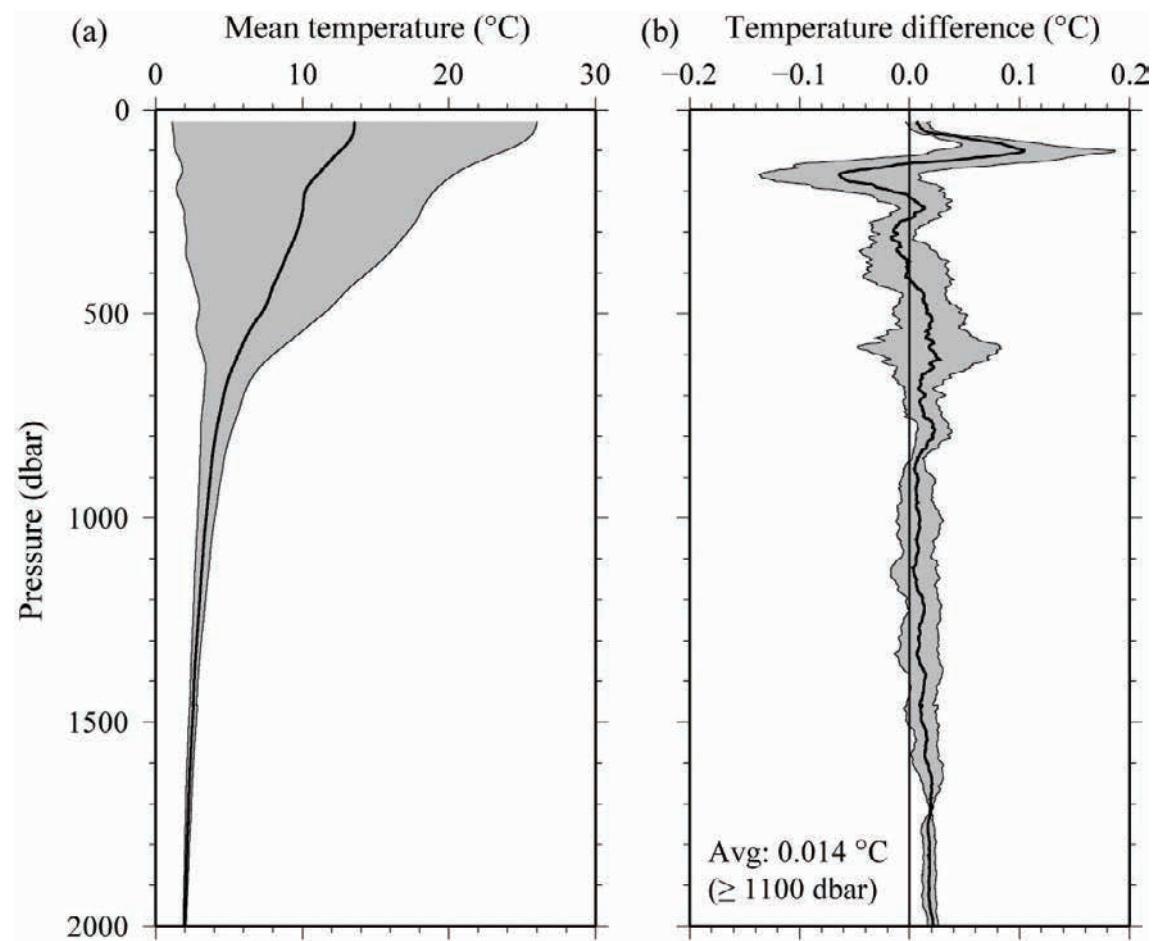


Figure 2.7.2. Comparison between XCTD and CTD temperature profiles. (a) Mean temperature profile of CTD profiles (thick line) with standard deviation (shade). (b) Mean temperature difference (thick line) with standard deviation (shade) between the XCTD and CTD.

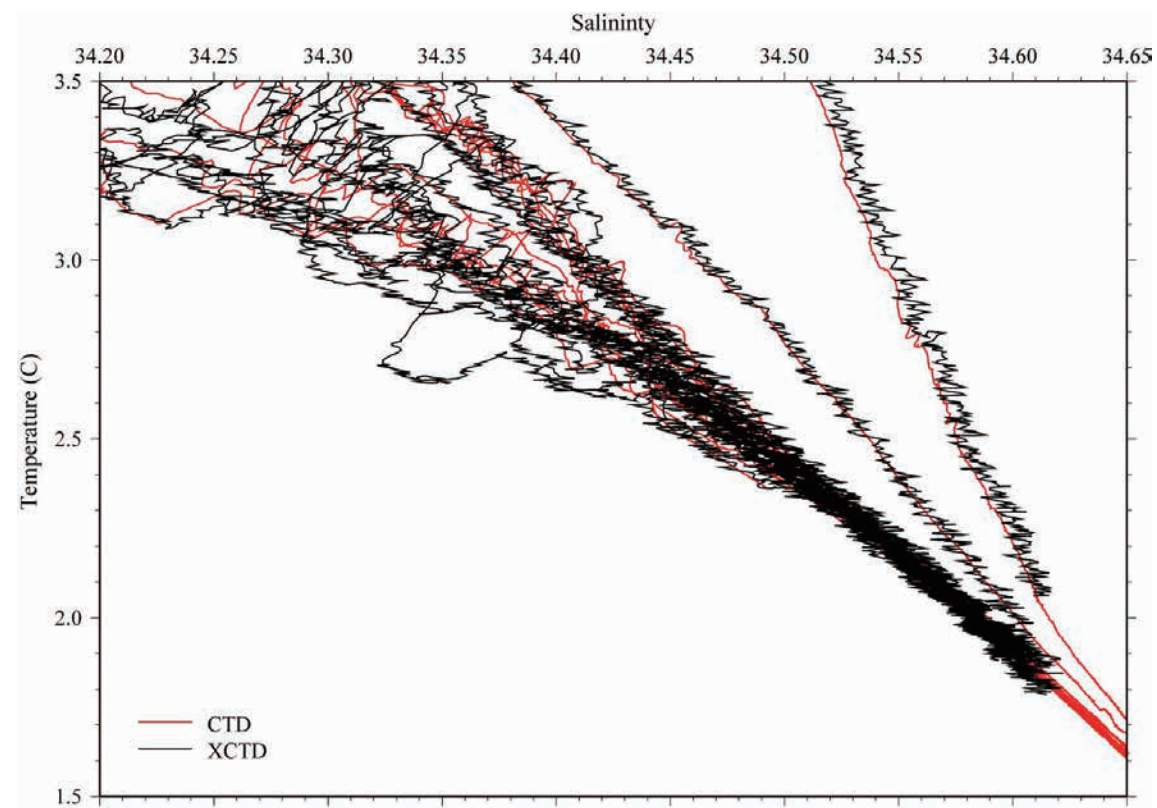


Figure 2.7.3. Comparison of temperature-salinity profiles of post-cruise calibrated CTD (red lines) and XCTD (black lines).

3 Hydrographic Measurement Techniques and Calibrations

3.1 CTDO₂ Measurements

February 10, 2014

(1) Personnel

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Shinsuke Toyoda (MWJ) (Leg 2)

Hirokatsu Uno (MWJ) (Leg 2)

Shungo Oshitani (MWJ) (Leg 2)

Kenichi Kato (MWJ) (Leg 2)

Satoshi Ozawa (MWJ) (Leg 2)

Kenichi Katayama (MWJ) (Leg 3)

Toru Idai (MWJ) (Leg 3)

Naoko Miyamoto (MWJ) (Leg 3)

Takami Mori (MWJ) (Leg 3)

(2) Winch arrangements

The CTD package was deployed by using 4.5 Ton Traction Winch System (Dynacon, Inc., Bryan, Texas, USA), which was installed on the R/V Mirai in April 2001 (Fukasawa et al., 2004). Primary system components include a complete CTD Traction Winch System with up to 8000 m of 9.53 mm armored cable (Rochester Wire & Cable).

(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 Falmouth, Massachusetts, USA), two oxygen optodes (RINKO-III; JFE Alec Co., Ltd, Kobe Hyogo, Japan), a fluorometer (Seapoint sensors, Inc., Kingston, New Hampshire, USA), a transmissometer (C-Star Transmissometer; WET Labs, Inc., Philomath, Oregon, USA), and a Photosynthetically Active Radiation (PAR) sensor (Satlantic, LP, Halifax, Nova Scotia, Canada) were also used with the SBE 9plus underwater unit. To minimize motion of the CTD package, a heavy stainless frame (total weight of the CTD package without sea water in the bottles is about 1000 kg) was used with an aluminum plate (54 × 90 cm).

An additional set of SBE 911plus CTD system with 12-position SBE 32 was also used for three deep casts (P10N 90_2, 92_1, and 94_1) in leg 3, because tension of the winch exceeded the load capacity (3 ton) of the winch system at the CTD depths deeper than 5700 dbar, although tension of the winch had not exceeded the load capacity for the maximum depth of the CTD (6500 dbar) before the calibration of the tension meter performed in April 2011. The SBE 9plus was mounted horizontally in a 12-position carousel frame.

Summary of the system used in this cruise

36-position CWS system (Set 1)

Deck unit:

SBE 11plus, S/N 0272

Under water unit:

SBE 9plus, S/N 117457 (Pressure sensor: S/N 1027)

Temperature sensor:

SBE 3plus, S/N 4815 (primary)

SBE 3plus, S/N 5329 (secondary, leg 2)

SBE 3plus, S/N 4811 (secondary, leg 3)

Conductivity sensor:

SBE 4, S/N 2854 (primary)

SBE 4, S/N 3036 (secondary)

Oxygen sensor:

SBE 43, S/N 0394

JFE Advantech RINKO-III, S/N 0024 (foil batch no. 144002A)

JFE Advantech RINKO-III, S/N 0079 (foil batch no. 160002A)

Pump:

SBE 5T, S/N 4598 (primary)

SBE 5T, S/N 4595 (secondary)

Altimeter:

PSA-916T, S/N 1100 (leg 2)

PSA-916T, S/N 1157 (leg 3)

Deep Ocean Standards Thermometer:

SBE 35, S/N 0045

Fluorometer:

Seapoint Sensors, Inc., S/N 3054

Transmissometer:

C-Star, S/N CST-1363DR

PAR:

Satlantic LP, S/N 0049

Carousel Water Sampler:

SBE 32, S/N 0391 (36-position)

SBE 32, S/N 0389 (12-position)

Water sample bottle:

12-litre Niskin-X model 1010X (no TEFLON coating)

12-position CWS system (Set 2)

Deck unit:

SBE 11plus, S/N 0272

Under water unit:

SBE 9plus, S/N 94766 (Pressure sensor: S/N 0786)

Temperature sensor:

SBE 3plus, S/N 1359 (primary)

SBE 3plus, S/N 1525 (secondary)

Conductivity sensor:

SBE 4, S/N 1203 (primary)

SBE 4, S/N 2435 (secondary)

Oxygen sensor:

SBE 43, S/N 0205

JFE Advantech RINKO-III, S/N 0037 (foil batch no. 144005A)

Pump:

SBE 5T, S/N 3118 (primary)

SBE 5T, S/N 3293 (secondary)

Altimeter:

PSA-916T, S/N 1100

Deep Ocean Standards Thermometer:

SBE 35, S/N 0022

Carousel Water Sampler:

SBE 32, S/N 0389

Water sample bottle:

12-litre Niskin-X model 1010X (no TEFLON coating)

(4) Pre-cruise calibration

i. Pressure

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

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

S/N 1027, 4 February 2011

S/N 0786, 17 November 2009

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 1027, 19 May 2011

slope = 1.00017335

offset = 0.16281

S/N 0786, 27 May 2011

slope = 0.99988759

offset = 0.05087

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 4815, 25 January 2011

S/N 5329, 11 February 2011

S/N 4811, 9 February 2011

S/N 1359, 18 May 2011

S/N 1525, 10 June 2011

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

S/N 4815, $-3.45974716e-7$ [°C/dbar]

S/N 4811, $-2.7192e-7$ [°C/dbar]

S/N 1359, $-1.8386e-7$ [°C/dbar]

Pressure sensitivities were not yet determined for S/N 5329 and 1525.

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 2854, 1 June 2011

S/N 3036, 1 June 2011

S/N 1203, 25 May 2011

S/N 2435, 2 March 2011

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 0394, 25 October 2011

S/N 0205, 27 May 2011

v. Deep Ocean Standards Thermometer

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

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

S/N 0045, 27 September 2002

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.

S/N 0045, 10 February 2011 (slope and offset correction)

S/N 0022, 23 January 2011 (slope and offset correction)

The time required per sample = $1.1 \times \text{NCYCLES} + 2.7$ 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.

From the end of 2011, the SBE has been applying a NIST correction to the fixed-point cells used for the calibration. The offset values were estimated for the above fixed-point cells as 140 μK (TPW) and 89 μK (GaMP) for the S/N 0045 and 120 μK (TPW) and 89 μK (GaMP) for the S/N 0022, and the following NIST corrected coefficients were used in this cruise.

S/N 0045: Slope = 1.000030, Offset = -0.001513

S/N 0022: Slope = 1.000010, Offset = -0.000116

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.

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

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

where V is voltage, V_0 is voltage in the absence of oxygen and K_{sv} is Stern-Volmer constant. 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 ($^{\circ}\text{C}$) 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.

$$O_{2c} = O_2 (1 + C_p p / 1000)^{1/3}$$

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 (García and Gordon, 1992). García and Gordon (1992) have recommended the use of the solubility coefficients derived from the data of Benson and Krause.

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

S/N 0024, 20 June 2011

S/N 0079, 6 December 2011

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 over a known path. 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.

Transmittance (T_r) is related to the beam attenuation coefficient c by the relationship:

$$T_r = e^{-cx}$$

$$x = 0.25 \text{ m (S/N CST-136DR)}$$

where x is the pathlength through the water volume.

x. PAR

Satlantic's Photosynthetically Active Radiation (PAR) sensors 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.

22 January 2009

(5) Data collection and processing

i. Data collection

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

The pressure windows of the transmissometer were wiped with Kimwipes wetted with ethanol before each CTD cast to clean the windows.

The package was lowered into the water from the starboard side and held 10 m beneath the surface in order to activate the pump. After the pump was activated, the package was lifted to the surface and lowered at a rate of 1.0 m/s to 200 m (or 300 m when significant wave height is 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. At each bottle firing stops, the bottle was fired after waiting from the stop for 30 seconds (or 20 seconds from station P10_78_1 to save time) and the package was stayed at least 5 seconds for measurement of the SBE 35. 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 (or 12-bottles) 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.

Data acquisition software

SEASAVE-Win32, version 7.18c

ii. Data collection problems

(a) Miss trip and miss fire

Niskin bottles did not trip correctly at the following stations.

Miss trip	Miss fire
P10_46_1, #11	P10N_106_2, #31

(b) Detaching the fluorometer, transmissometer and LADCP

At station P10_74_2 and P10N_77_2, the fluorometer, transmissometer and LADCP were detached from the CTD system, because the maximum depth of the CTD cast exceeded the pressure capacity of the sensors.

(c) Cancellation of CTD casts

At station P10_67_1, the CTD cast was cancelled at 236 dbar of down cast, because the ship maneuvering equipment was on the blink. At station P10N_84_1, the CTD cast was cancelled at 5073 dbar of down cast because of rough weather.

(d) Bottle firing without stops

At following stations, the Niskin bottles were fired without stop of the CTD package because of rough weather.

P10N_83_1: bottles #24~36

P10N_87_1: bottles #14~27, #29~36

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 7.21d

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. When the bottle was fired without bottle firing stop, the duration was set to 1.0 second and the offset was set to 0.0 second, and a quality flag of 4 (bad) was set to the SBE 35 data. 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 (or 1 second for the bottle fired without stop).

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 6 seconds advancing the SBE 43 oxygen sensor output (voltage) relative to the temperature data. Delay of the RINKO data was also compensated by 1 second advancing sensor output (voltage) relative to the temperature data. Delay of the transmissometer data was also compensated by 2 seconds advancing sensor output (voltage) relative to the temperature data.

WILDEDIT marked extreme outliers in the data files. The first pass of WILDEDIT obtained an accurate estimate of the true standard deviation of the data. The data were read in blocks of 1000 scans. Data greater than 10 standard deviations were flagged. The second pass computed a standard deviation over the same 1000 scans excluding the flagged values. Values greater than 20 standard deviations were marked bad. This process was applied to pressure, temperature, conductivity and SBE 43 output.

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

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

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

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.

DERIVE was re-used to compute salinity, potential temperature, and density (σ_θ).

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. Time series of the CTD deck pressure is shown in Fig. 3.1.1. The CTD pressure sensor offset was estimated from the deck pressure. Mean of the pre- and the post-casts data over the whole period gave an estimation of the pressure sensor offset (0.25 dbar for S/N 1027 and -0.47 dbar for S/N 0786) from the pre-cruise calibration. The post-cruise correction of the pressure data is not

deemed necessary for the pressure sensor.

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 was performed at SBE, Inc in August 2013.

S/N 0045, 15 April 2012 (2nd step: fixed point calibration)

Slope = 1.000029

Offset = -0.001423

S/N 0022, 12 March 2012 (2nd step: fixed point calibration)

Slope = 1.000012

Offset = -0.000023

Offset of the SBE 35 data from the pre-calibration was estimated to be smaller than 0.1 mK for temperature smaller than 4.5°C. So the post-cruise correction of the SBE 35 temperature data was not deemed necessary for the SBE 35.

The CTD temperature was 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 950 dbar.

The primary temperature data were used for the post-cruise calibration. 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. 3.1.2.

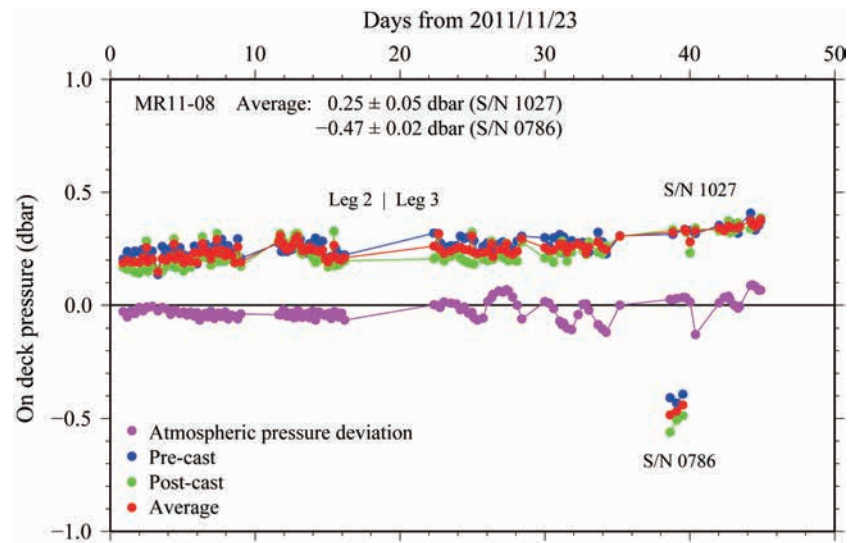


Fig. 3.1.1. Time series of the CTD deck pressure. Atmospheric pressure deviation (magenta dots) from a standard atmospheric pressure was subtracted from the CTD deck pressure. Blue and green dots indicate pre- and post-cast deck pressures, respectively. Red dots indicate averages of the pre- and the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

Table 3.1.1. Calibration coefficients for the CTD temperature sensors.

Leg	Serial number	c_0 (°C/dbar)	c_1 (°C/day)	c_2 (°C)
2	4815	-2.68889e-8	2.87072e-5	-0.0071
3	4815	-4.08124e-8	9.57543e-6	-0.0025
3	1359	1.13346e-7		0.0004

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 950 dbar. Number of data used is also shown.

Leg	Serial number	Pressure \geq 950 dbar			Pressure < 950 dbar		
		Number	Mean (mK)	Sdev (mK)	Number	Mean (mK)	Sdev (mK)
2	4815	647	0.0	0.2	1286	-0.6	7.0
3	4815	631	-0.0	0.2	1060	0.1	7.6
3	1359	36	-0.0	0.1			

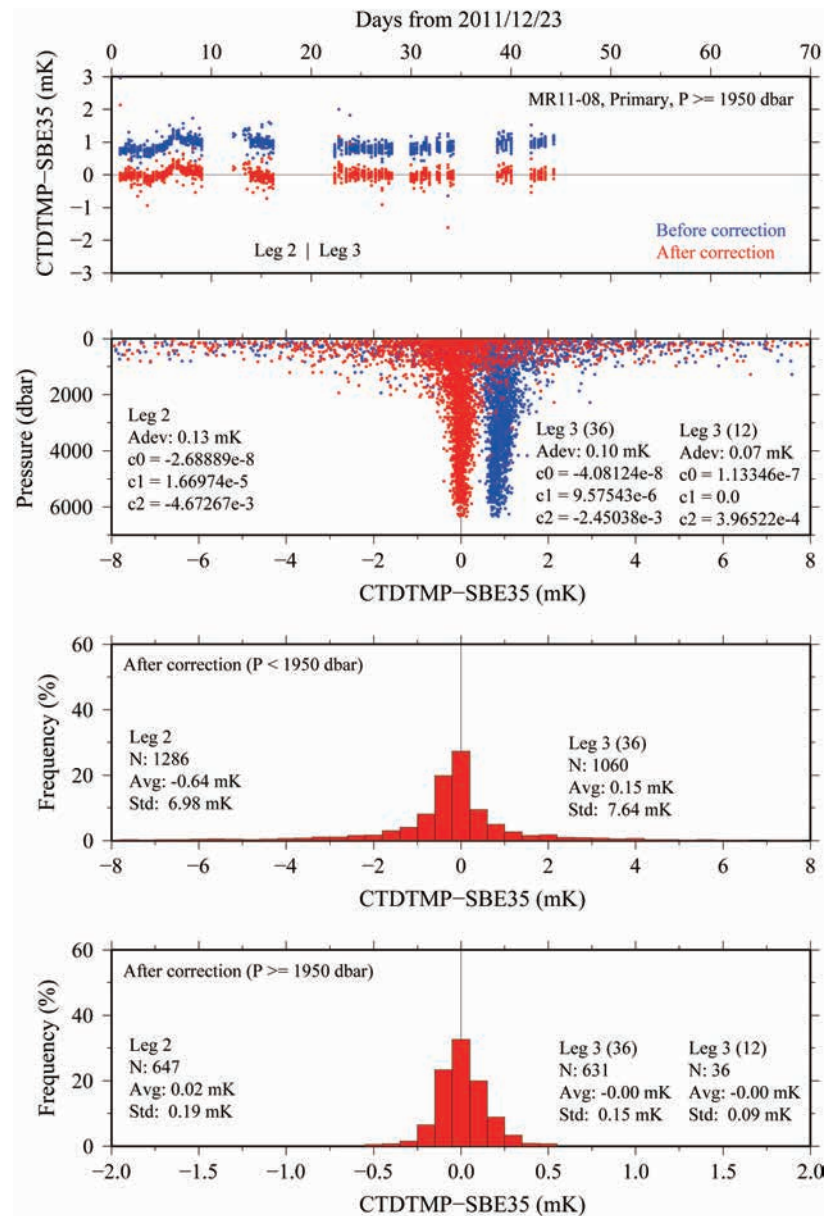


Fig. 3.1.2. Difference between the CTD temperature (primary) and the SBE 35. Blue and red dots indicate before and after the post-cruise calibration using the SBE 35 data, respectively. Lower two panels show histogram of the difference after the calibration.

iii. Salinity

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

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

where C is CTD conductivity in S/m, P is pressure in dbar, t is time in days from 23 December 2011 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 primary conductivity data created by the software module ROSSUM were basically used after the post-cruise calibration for the temperature data. The secondary conductivity sensor was also calibrated and used instead of the primary conductivity data when the data quality of the primary temperature or conductivity data was bad. The coefficients were determined for each leg. 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. 3.1.3.

Table 3.1.3. Calibration coefficients for the CTD conductivity sensors.

Leg	Serial Number	c_0	c_1 [S/(m dbar)]	c_2 (1/dbar)	c_3 [S/(m day)]	c_4 (S/m)
2	2854	0.999999	1.52141e-7	-5.00025e-8	3.69363e-6	2.68130e-4
3	2854	0.999969	-1.92594e-7	5.97695e-8	-1.20584e-6	4.13868e-4
3	120	1.00070	-1.03014e-6	2.97097e-7		-1.93434e-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 950 dbar. Number of data used is also shown.

Leg	Serial number	Pressure \geq 950 dbar			Pressure $<$ 950 dbar		
		Number	Mean	Sdev	Number	Mean	Sdev
2	2854	939	-0.0	0.6	748	0.0	4.7
3	2854	845	0.0	0.4	549	-0.0	2.8
3	1203	39	0.0	0.3			

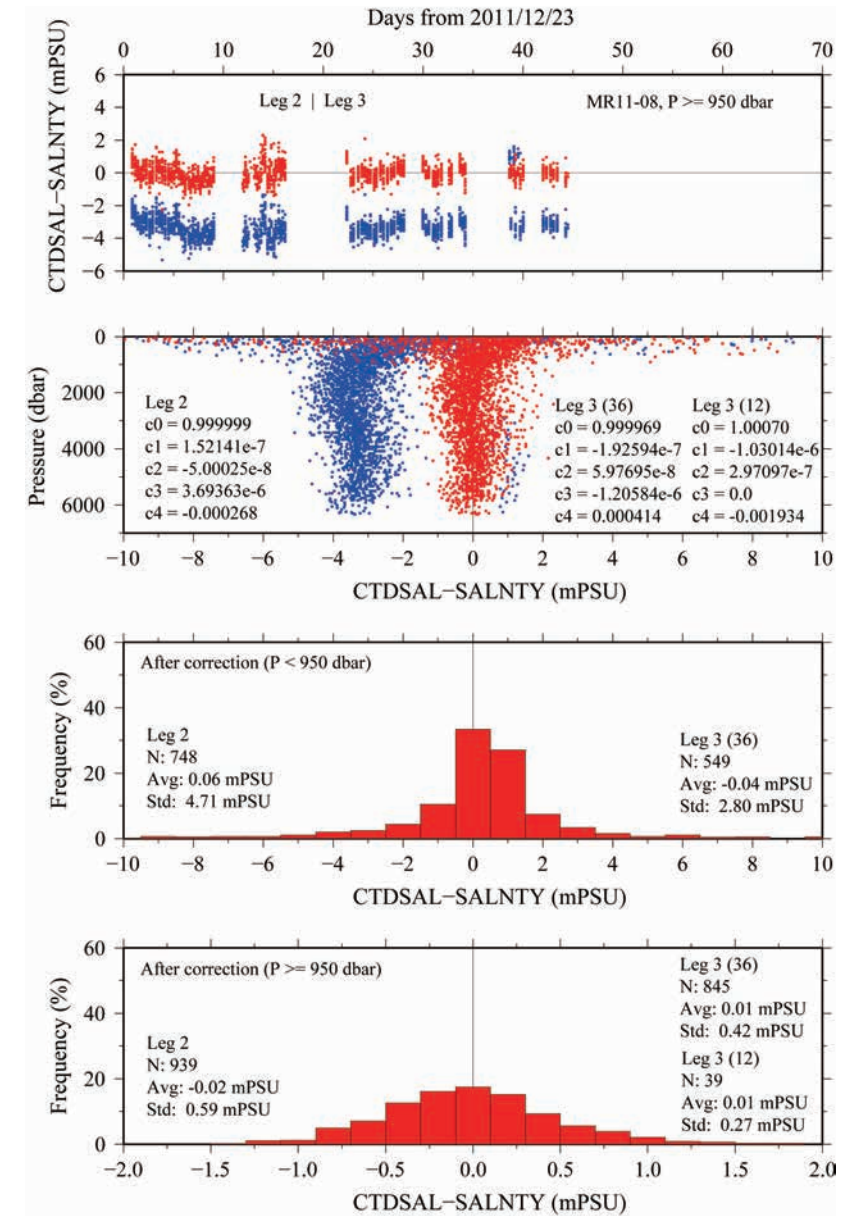


Fig. 3.1.3. Difference between the CTD salinity (primary) and the bottle salinity. Blue and red dots indicate before and after the post-cruise calibration, respectively. Lower two panels show histogram of the difference after the calibration.

iv. Oxygen

The RINKO oxygen optodes (S/N 0024 and S/N 0037) were 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 Stern-Volmer equation, basically according to a method by Uchida et al. (2010):

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

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 V_b is the RINKO output (voltage), V_0 is voltage in the absence of oxygen, T is temperature in °C, and t is working time (in days) of the RINKO sensor integrated from the first CTD cast for each leg. Time drift of the RINKO output was corrected. The pressure-compensated oxygen concentration O_{2c} was calculated as follows.

$$O_{2c} = O_2 (1 + C_p p / 1000)^{1/3}$$

where p is CTD pressure (dbar) and C_p is the compensation coefficient. 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. 3.1.4.

Table 3.1.5. Calibration coefficients for the RINKO oxygen sensors.

Leg	Serial number	c_0	c_1	c_2	c_3	c_4
2	0024	3.89290e-3	1.52171e-4	1.93156e-6	-5.08841e-4	-0.117182
3	0024	4.11419e-3	1.64439e-4	2.93308e-6	4.45790e-4	-0.140317
3	0037	3.04531e-3	1.09824e-3	-3.46770e-4	7.63642e-3	-0.146284

Table 3.1.5. Continue.

Leg	Serial number	c_5	c_6	c_7	C_p
2	0024	0.336087	5.16436e-5	2.38398e-4	0.05
3	0024	0.342439	-2.97398e-4	1.80689e-4	0.05
3	0037	0.325744			0.05

Table 3.1.6. Difference between the RINKO oxygen and the bottle oxygen after the post-cruise calibration.

Mean and standard deviation (Sdev) are calculated for the data below and above 950 dbar. Number of data used is also shown.

Leg	Serial number	Pressure \geq 950 dbar			Pressure $<$ 950 dbar		
		Number	Mean	Sdev	Number	Mean	Sdev
		[$\mu\text{mol/kg}$]			[$\mu\text{mol/kg}$]		
2	0024	890	0.00	0.23	753	0.03	0.47
3	0024	851	0.01	0.28	550	-0.09	0.81
3	0037	39	-0.03	0.27			

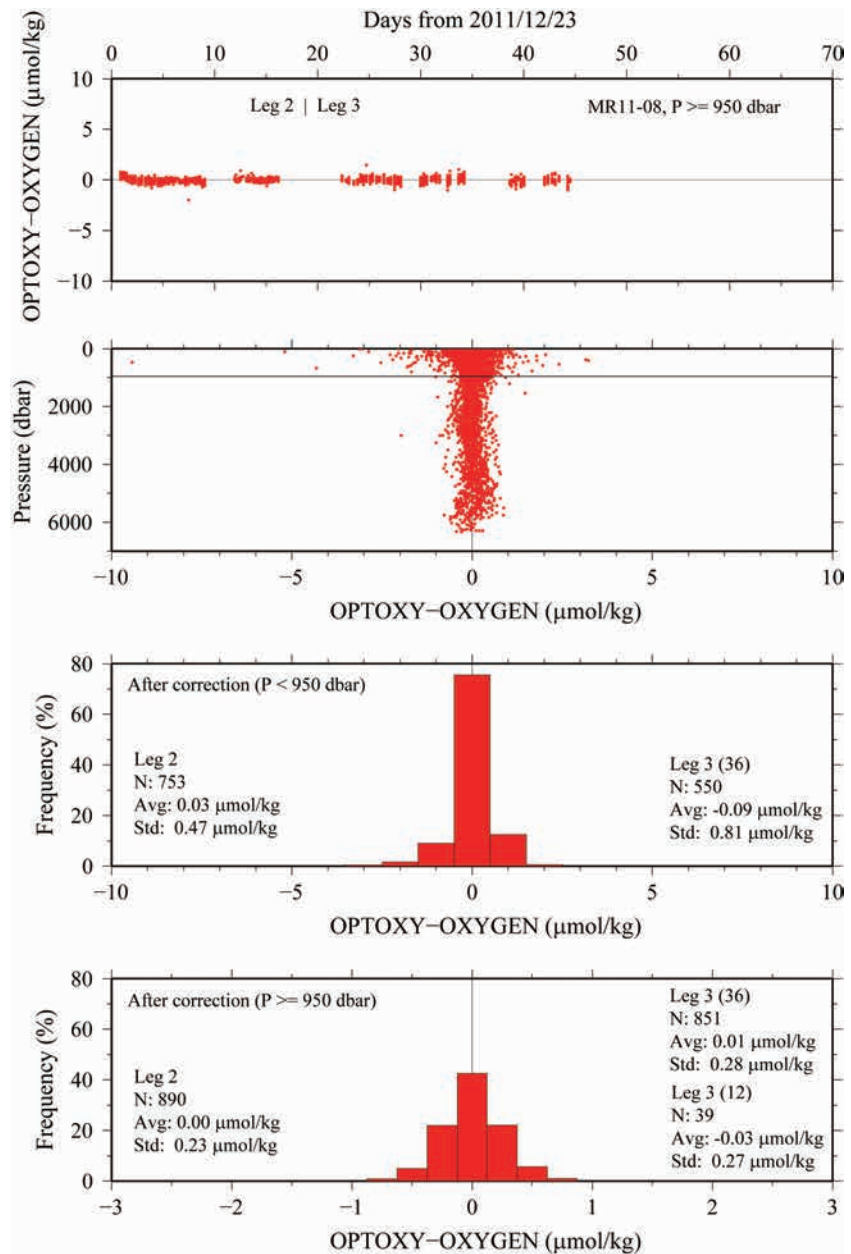


Fig. 3.1.4. Difference between the calibrated CTD oxygen and the bottle oxygen. Lower two panels show histogram of the difference.

v. Fluorometer

The CTD fluorometer (F1 in $\mu\text{g/L}$) was calibrated with the bottle sampled chlorophyll-a (Chla) as

$$F_1 = c_0 + c_1 \times \text{Chla}$$

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 (Fig. 3.1.5) and the calibration coefficients are listed in Table 3.1.7.

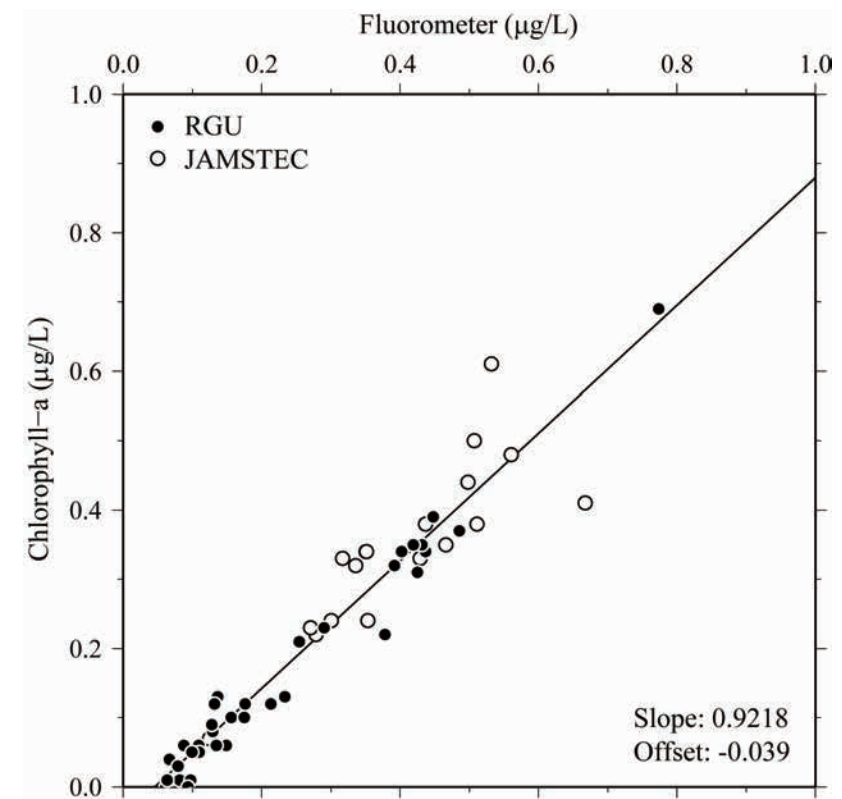


Fig. 3.1.5. Comparison of the CTD fluorometer and the bottle sampled chlorophyll-a. The solid line is the regression line.

Table 3.1.7. Calibration coefficients for the CTD fluorometer.

c_0	c_1	Standard deviation from the regression line
-0.039	0.9218	0.05 $\mu\text{g/L}$

vi. Transmissometer

The transmissometer is calibrated as

$$T_r = (V - V_d) / (V_r - V_d)$$

where V is the measured signal (voltage), V_d 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 was measured on deck before each cast and estimated to be 0.0012 during the cruise. V_r is estimated from the measured signal in the deep ocean, although the transmittance tended to decrease when the water depth was shallow (Fig. 3.1.6). Since the transmissometer drifted in time, V_r is expressed as

$$V_r = 4.84280 - 6.73551e-3 \times t + 1.78673e-4 \times t^2$$

where t is working time (in days) of the transmissometer.

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 (PAR_c) is calculated from the raw data (PAR) as follows:

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

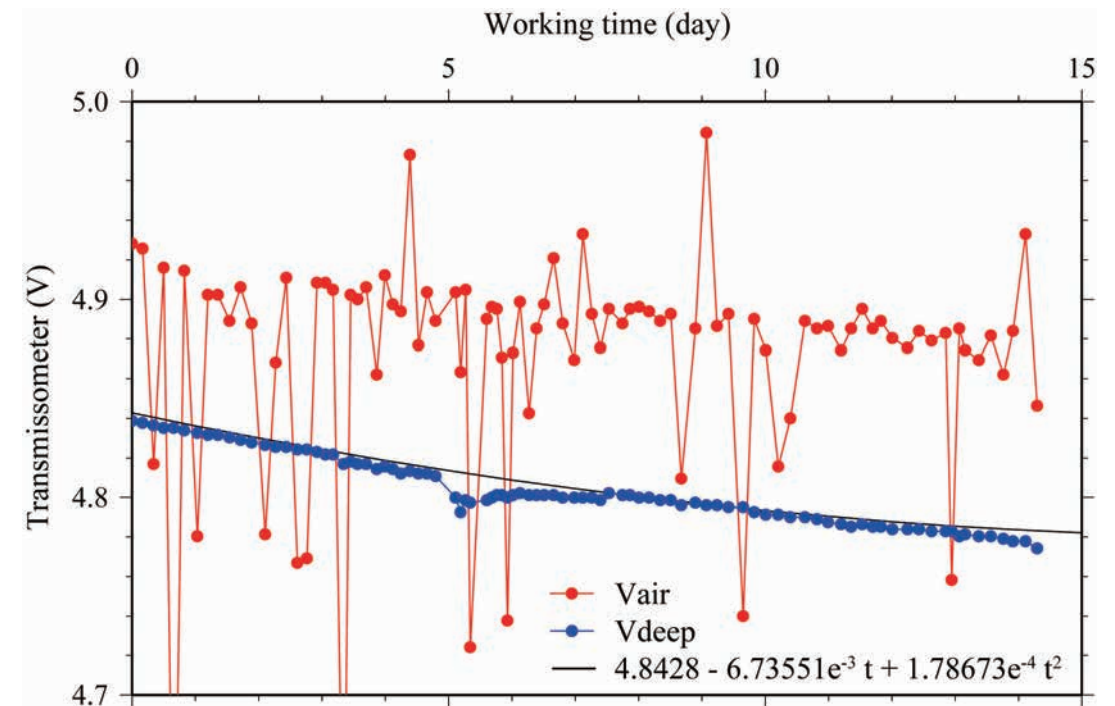


Fig. 3.1.6. Time series of an output signal (voltage) from transmissometer at on deck before CTD casts (V_{air}) and deep ocean (V_{deep}). The solid line indicates the modeled signal in the deep clear ocean.

(7) Combining of CTD profiles

Two sets of SBE 911plus CTD system with 36 and 12-position SBE 32 were used at three CTD stations (Table 3.1.8). The 12-position CWS CTD system (set 2) can be accurately calibrated with water sampled data for the depths deeper than about 3000 dbar. Therefore, the CTD profiles obtained at these casts were combined to obtain a calibrated CTD profile from surface to bottom. The data between the shallow and deep profiles were linearly interpolated for 100 dbar from the maximum depth of the shallow profile to the top of the deep profile used to combine (Fig. 3.1.7).

Table 3.1.8. List of deep double casts of CTD in leg 3. Set 1 is 36-position CWS system and set 2 is 12-position CWS system.

Station no.	Cast no.	Set of CTD system	Water sampling depth
P10N 90	2	2	3170 dbar – bottom
	3	1	Surface – 2930 dbar
P10N 92	1	2	3250 dbar – bottom
	3	1	Surface – 2999 dbar
P10N 94	1	2	3332 dbar – bottom
	3	1	Surface – 3082 dbar

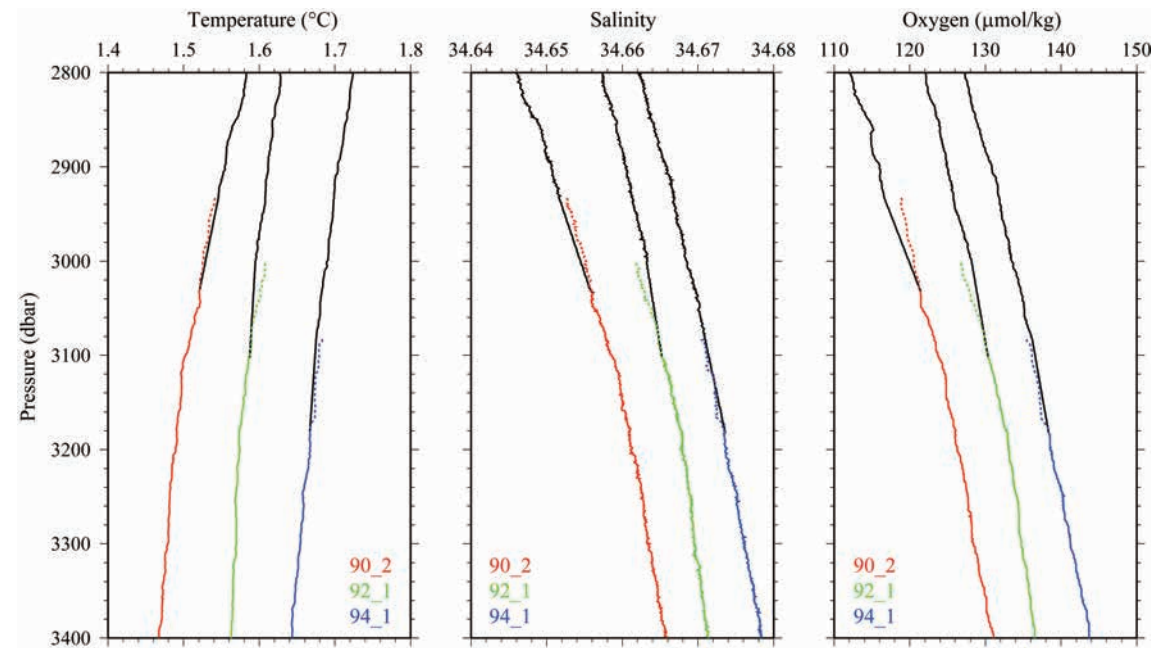


Fig. 3.1.7. Combined CTD profiles of stations P10N 90_3, 92_3, and 94_3.

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3.2 Bottle Salinity

May 10, 2012

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(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

Samples for salinity measurement were collected and stored in 250-mL brown borosilicate glass bottles with GL32 screw caps with PTFE liners (without cones). Each bottle and cap was rinsed three times with sample water, and the water was allowed to overflow the bottle. Excess water was poured out until the water was level with the shoulder of the bottle. The bottles were stored at least 12 hours in a laboratory where the salinity was to be measured for temperature equilibration with upside down in a carrying case.

ii. Instruments and Method

Salinity of water samples was measured with two salinometers (Autosal model 8400B; Guildline Instruments Ltd., Ontario, Canada; serial no. 62556 for leg 2 and serial no. 62827 for leg 3), 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 20 to 24 °C, while the bath temperature was stable and varied within ± 0.002 °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 6 to 23 hours per day and the cell was cleaned with soap after the measurement for each day. A total of about 4,000 sea water samples were measured during the cruise.

(4) Results

i. Standard Seawater

Standardization control was set to 796 (leg 2) and 482 (leg 3). The value of STANDBY was 5602 ± 0002 (leg 2) and 5408 ± 0.002 (leg 3), and that of ZERO was 0.00000 ± 0.00001 for both legs. We used IAPSO Standard Seawater (Ocean Scientific International Ltd., Havant, UK) batch P153 whose conductivity ratio was 0.99979 (double conductivity ratio is 1.99958) as the standard for salinity measurement. We measured 90 (leg 2) and 85 (leg 3) bottles of the Standard Seawater during routine measurement. Figs. 3.2.1 and 3.2.2 show the history of

the measured double conductivity ratio of the Standard Seawater during legs 2 and 3.

For leg 2, the salinometer was not stable. Therefore, an offset of the measurements was estimated by averaging the measured double conductivity ratio of the Standard Seawater for each day. The estimated offset was subtracted from the measured double conductivity ratio of the sample. After the offset correction, the average of the double conductivity ratio of the Standard Seawater became 1.99958 and the standard deviation was 0.00002, which is equivalent to 0.0003 in salinity.

For leg 3, the salinometer was slightly drifted in time. Therefore, a linear trend of the measurements was estimated by fitting the measured double conductivity ratio of the Standard Seawater for whole period. The estimated linear trend was subtracted from the measured double conductivity ratio of the sample. After the correction, the average of the double conductivity ratio of the Standard Seawater became 1.99958 and the standard deviation was 0.00001, which is equivalent to 0.0002 in salinity.

ii. Sub-Standard Seawater

We also used sub-standard seawater which was deep-sea water filtered by pore size of $0.45 \mu\text{m}$ and stored in a 20 liter cubitainer made of polyethylene and stirred for at least 24 hours before measurement. It was measured every 6 water samples in order to check the possible sudden drift of the salinometer. In this cruise, no remarkable sudden drift was detected for the salinometers.

iii. Replicate Samples

We took 323 (leg 2) and 245 (leg 3) pairs of replicate samples during the cruise. Histograms of the absolute difference between replicate samples are shown in Figs. 3.2.3 and 3.2.4. The root-mean squares of the absolute difference of replicate samples were 0.00035 (leg 2) and 0.00017 (leg 3).

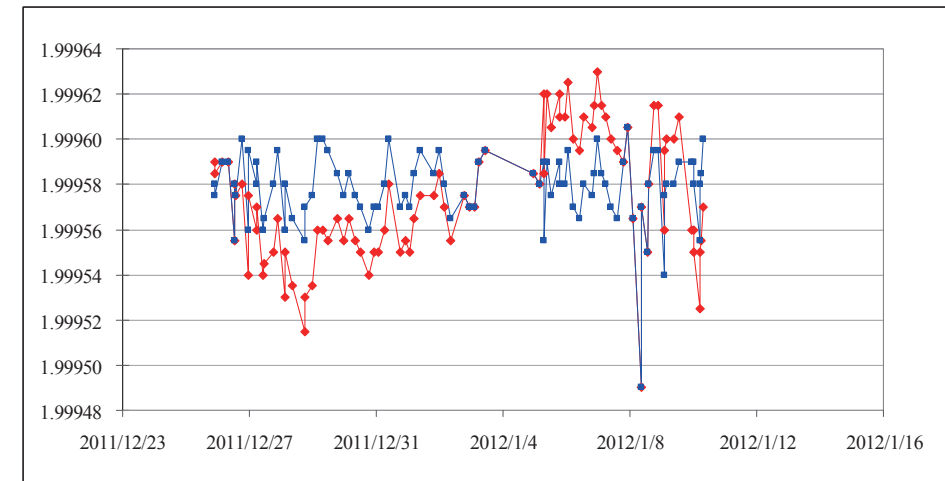


Figure 3.2.1. History of measured double conductivity ratio of the Standard Seawater (P153) during leg 2. Horizontal and vertical axes represents date and double conductivity ratio, respectively. Red dots are raw data and blue dots are corrected data.

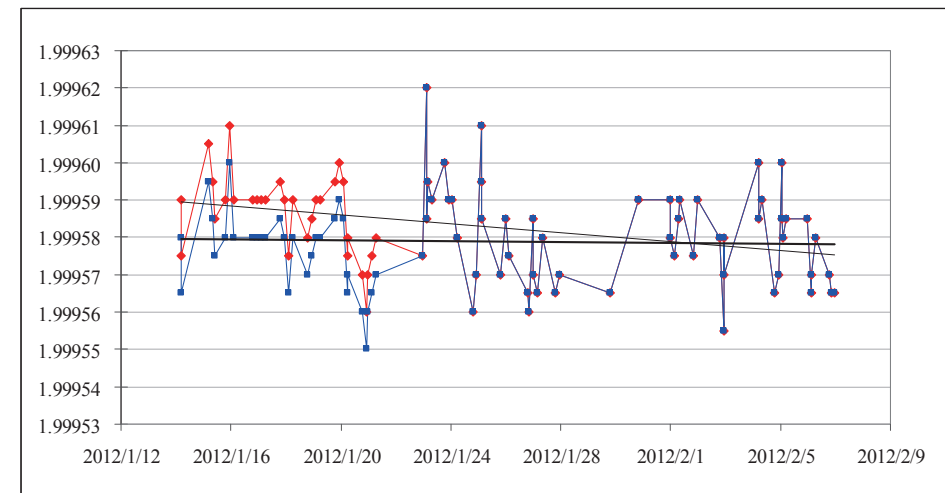


Figure 3.2.2. Same as Fig. 3.2.1, but for leg 3.

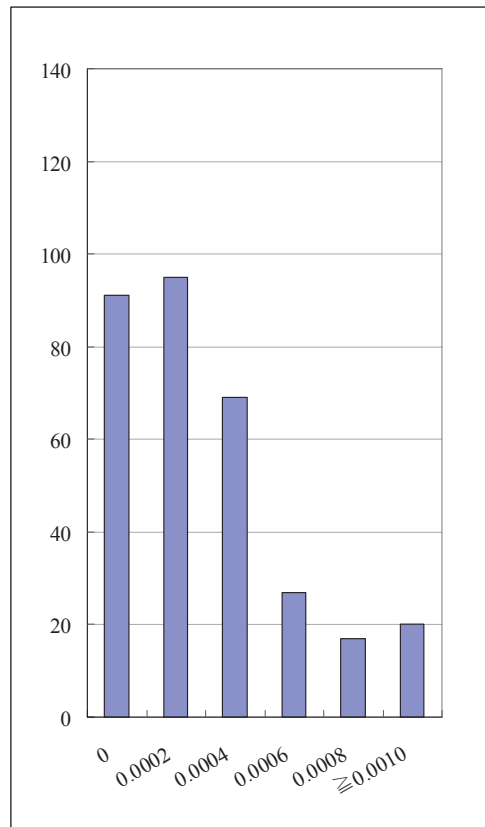


Figure 3.2.3. Histogram of the absolute difference between replicate samples for leg 2. Horizontal axis is absolute difference in salinity and vertical axis is frequency.

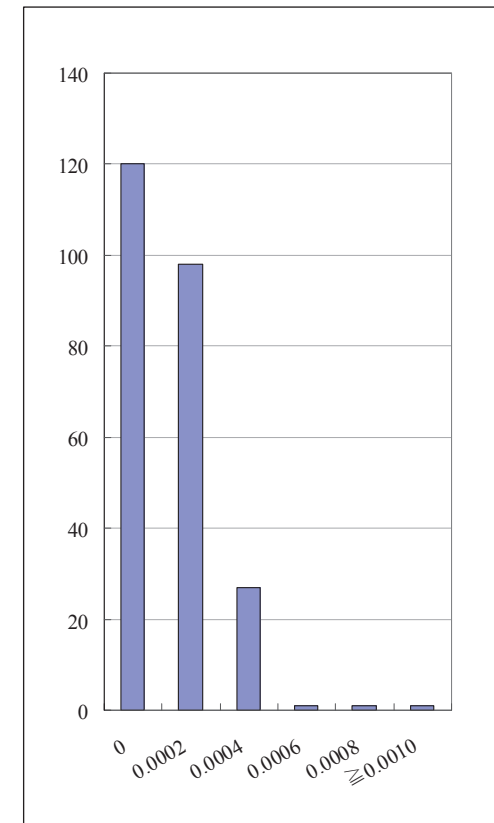


Figure 3.2.4. Same as Fig. 3.2.3, but for leg 3.

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3.3 Density

February 13, 2014

(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 and a part of the seawater samples were measured in a laboratory in the Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan, after 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. AC power was supplied to the density meter through a frequency conversion AC power supply unit (AA500F, Takasago, Ltd., Japan).

The water samples were collected in 100-mL PFA bottles (Sanplatec Co., Japan), 100-mL or 50-mL I-BOY polypropylene bottles (AS ONE, Co., Japan), and vacuum sealed with an aluminum bag (HRS, MAL or ALH, Meiwa Sanshou Co., Ltd, Japan). Densities of the samples were measured at 20 °C by the density meter from two to six times for each bottle. The glass vial was sealed with Parafilm M (Pechiney Plastic Packaging, Inc., Menasha, Wisconsin, USA) until the density was measured.

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 July 2010. The true density (ρ_{PW}) at 20 °C of the Milli-Q water was estimated to be 998.2041 kg/m³ from the isotopic

composition ($\delta D = -9.08 \text{ ‰}$, $\delta^{18}O = -58.8 \text{ ‰}$) 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 estimated from the following equation:

$$\rho_{\text{offset}} = (\rho_{\text{Milli-Q}} - \rho_{\text{PW}}) - (\rho - \rho_{\text{PW}}) \times 0.000241 \text{ [kg/m}^3\text{]}.$$

The offset correction was verified by measuring Reference Material for Nutrients in Seawater (RMNS) lot BF (Kanso Technos Co., Ltd., Osaka, Japan) along with the Milli-Q water. Reference Material for Density in Seawater (prototype Dn-RM1) developed with Marine Works Japan, Ltd., Kanagawa, Japan, and produced by Kanso Technos Co., Ltd., Osaka, Japan, was also measured at post-cruise measurements. The Dn-RM1 was similarly produced with the RMNS. Material of the bottle is not polypropylene but PFA, and vacuumed sealed aluminum bag (MAL) is not single but double.

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

The water samples collected at stations 56, 53, 49, 45, 41, 37, 34, 31, 27, 1, 5, and 10 were vacuum sealed with the HRS aluminum bag and measured within a few days after the collection. The rest of water samples were vacuum sealed with the HRS or ALH aluminum bag and stored in a refrigerator to measure in the laboratory after the cruise since the density meter was broken during the cruise.

(4) Results

List of the series of density measurement was shown in Table 3.3.1. The water samples for station 68 (#2, 5, 8, 15, 16, 22, 24, 25, and 30), 71 (#6, 10, 16, and 29), 90 (#2, 5-12, 23, 24, 27, 29, 31, 32, and 36), 92 (#8-12), and 110 (#10, 12, 13, 16, 17_2, 19, 23, and 28-32) were not measured because the aluminum bags were torn during their storage.

For the series of measurement at April 5, 2012, the density meter was largely drifted in time between the first and the last measurement of Milli-Q water (about 16 hours). In addition, magnitude of the drift was different for the Milli-Q water (+0.008 kg/m³) and the RMNS (+0.018 kg/m³). Therefore, linear time drift and offset for the sea water measurement was estimated from the result of the RMNS measurement. Density of the RMNS

was adjusted to 1024.4826 kg/m³ to match with the overall mean density of the RMNS (Table 3.3.1).

The measured density of the RMNS was smaller than twice the standard deviation from the mean for the series of measurement at January 5 and April 6, 2012. Therefore, offset for the sea water measurement was estimated from the RMNS measurement. Mean density of the RMNS at the series of measurement was adjusted to 1024.4826 kg/m³ to match with the overall mean density of the RMNS (Table 3.3.1). The estimated offsets were +0.0041 and +0.0043 kg/m³ for the series of measurements at January 5 and April 6, respectively.

To check those time drift and offset corrections by using the RMNS measurements, measured densities of the Dn-RM1 were compared (Table 3.3.2). The measured densities agreed well with each other.

A total of 26 pairs of replicate samples were measured. The root-mean square of the absolute difference of replicate samples was 0.0011 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.

Table 3.3.1. List of the series of density measurement.

Date	Stations (samples no.)	Mean density of RMNS Lot BF (kg/m ³)	Note
2011/12/25	56	1024.4847	relatively large variation #15: bad (flag 4)
2011/12/26	53	1024.4849	
2011/12/27	49	1024.4821	
2011/12/29	45	1024.4814	#12: questionable (flag 3)
2011/12/30	41	1024.4841	
2011/12/31 (1)	37	1024.4838	
2011/12/31 (2)	34	1024.4840	
2012/01/01	31	1024.4816	
2012/01/02	27	1024.4820	relatively large variation
2012/01/04	1	1024.4799	
2012/01/05	5, 10	1024.4831	frequent errors, large variation, bias correction using RMNS
2012/04/04	74, 77 (except for #6,9,10,16,27,30,36)	1024.4838	
2012/04/05	15, 21, 71 (#1,3-5,11,13,20-25,28, 31, 32,35,36), 77 (#6,9,10,16,27,30,36)	1024.4827	time drift correction using RMNS
2012/04/06	60 (#1,11,12,16-18,26), 110, 114	1024.4829	bias correction using RMNS
2012/04/09	90	1024.4810	
2012/10/15	60 (except for #1,11,12,16-18,26), 64 (except for #30-33,35)	1024.4823	
2012/10/18	102, 106	1024.4833	

2012/10/25 (1)	64 (#30-33,35), 68	1024.4836
2012/10/25 (2)	71, 79 (#1-16)	1024.4815
2012/10/26 (1)	79 (except for #1-16), 83 (except for #23,25)	1024.4825
2012/10/26 (2)	83 (#23,25), 86, 92	1024.4817
2012/10/28	94	1024.4837
2012/10/30	98	1024.4831

Average: 1024.4827 ± 0.0016

Table 3.3.2. Comparison of density measurement for the Reference Material for Density in Seawater (prototype Dn-RM1).

Date	Serial no.	Density [kg/m ³]	Note
2012/04/04	050	1024.2616	
2012/04/05	051	1024.2612	drift correction
2012/04/06	052	1024.2624	offset correction
2012/04/09	053	1024.2590	
Average: 1024.2611 ± 0.0015			

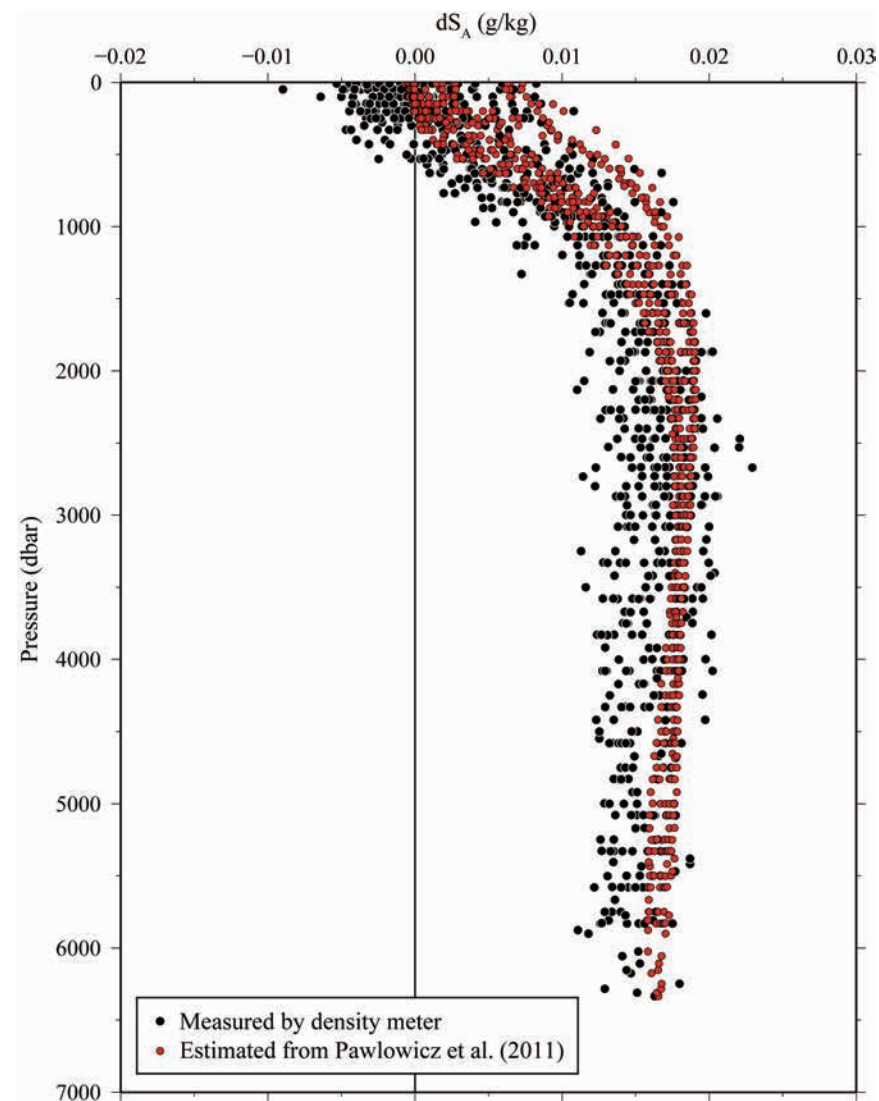


Figure 3.3.1. Vertical distribution of density salinity anomaly measured by the density meter. Absolute Salinity anomaly estimated from nutrients and carbonate parameters (Pawlowicz et al., 2011) are also shown for comparison.

Acknowledgment

The author thank Tamami Ueno (MWJ) for helping density measurement of station 83 (#23,25) and 86.

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3.4 Oxygen

September 27, 2013

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(2) Objectives

Dissolved oxygen is one of good tracers for the ocean circulation. Recent studies indicated that oxygen minimum layers in the tropical region have expanded (Stramma et al., 2008). Climate models predict a decline in oceanic dissolved oxygen concentration and a consequent expansion of the oxygen minimum layers under the global warming, which results mainly from decreased interior advection and ongoing oxygen consumption by remineralization. The mechanism of the decrease, however, is still unknown. During MR11-08 cruise, we measured dissolved oxygen concentration from surface to bottom layers at all the hydrocast stations along approximately 149°E in the western Pacific. These stations reoccupied the WOCE Hydrographic Program P10 and P10N stations in 1993 and 2005. Our purpose is to evaluate temporal change in dissolved oxygen concentration in the western Pacific between the 1993/2005 and 2011/12.

(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): Wako Pure Chemical Industries, Ltd., volumetric standard, reference material for iodometry, Lot No.EPR3227, Purity: $99.96 \pm 0.01\%$

CSK standard of potassium iodate: Lot EPJ3885, 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 cm³ 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 a CTD-system. Seawater for bottle oxygen measurement was transferred from the Niskin sampler bottle to a volume calibrated glass flask (ca. 100 cm³). Three times volume of the flask of seawater was overflowed. Sample temperature was measured by a thermometer during the overflowing. Then two reagent solutions (Reagent I, II) of 0.5 cm³ 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 cm³ 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-7 and DOT-8. Dissolved oxygen concentration ($\mu\text{mol kg}^{-1}$) was calculated by the sample temperature during the sampling, a value of bottle salinity, the flask volume, and the titrated volume of the sodium thiosulfate solution. When the bottle salinity datum is flagged to be 3 (questionable), 4 (bad), or 5 (missing), CTD salinity (primary) datum is referred in the calculation alternatively.

(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 dm³ in a calibrated volumetric flask (0.001667M). 10 cm³ of the standard potassium iodate solution was added to a flask using the volume-calibrated dispenser. Then 90 cm³ of deionized water, 1 cm³ of sulfuric acid solution, and 0.5 cm³ 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. Error (coefficient of variation) of the standardization was 0.02 %, or c.a. 0.05 $\mu\text{mol kg}^{-1}$.

(8) Determination of the blank

The oxygen in the pickling reagents I (0.5 cm³) and II (0.5 cm³) 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 cm³ of the standard potassium iodate solution were added to the flask each. Then 100 cm³ of deionized water, 1 cm³ of sulfuric acid solution, and 0.5 cm³ 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 cm³ of KIO₃) titrated volume of the sodium thiosulfate and the second (2 cm³ of KIO₃) one. The results of 3 times blank determinations were averaged (Table 3.4.1). The averaged blank values for DOT-7 and DOT-8 were -0.001 ± 0.002 (standard deviation, n=21) and 0.001 ± 0.001 (standard deviation, n=21) cm³, respectively.

(9) Replicate sample measurement

From a single routine CTD cast, a pair of replicate samples was collected at three layers of 10, 1800, and 3750 dbar. In order to estimate uncertainty including instrumental error, one and the other of a replicate pair were measured using DOT-7 and DOT-8, respectively. The total amount of the replicate sample pairs in good measurement (flagged 2) was 331. The standard deviation of the replicate measurement was 0.13 $\mu\text{mol kg}^{-1}$ that was calculated by a procedure (SOP23) in DOE (1994). A difference between measurements of a replicate pair is slightly large in samples from low-oxygen layers (Fig. 3.4.1), which is probably due to sampling error on the deck. In the hydrographic data sheet, the first of the two results from a replicate pair was presented with the flag 2 (see section 12).

(10) Duplicate sample measurement

A duplicate sampling, water samplings from two Niskin bottles that collected seawater at a same depth (deeper than 1000 dbar), were conducted at 35 stations during this cruise. Niskin numbers and sampling pressure of the duplicate pairs are shown in Table 3.4.2. One and the other of a duplicate pair were measured using DOT-7 and DOT-8 respectively in the same way of the replicate sample measurements. The standard deviation of the duplicate measurements was calculated to be 0.14 $\mu\text{mol kg}^{-1}$ that was equivalent with that of the replicate measurements (0.13 $\mu\text{mol kg}^{-1}$, see section 9), suggesting that there was no problem in a water sampling system during our CTD casts.

(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 solutions (Lot EPJ3885) against our KIO₃ standards prepared in our laboratory in 2010 and 2011 (Table 3.4.3). A good agreement among them confirms that there was no systematic shift in our oxygen analyses using our KIO₃ standards during 2010 and 2011.

(12) Quality control flag assignment

Quality flag values were assigned to oxygen measurements using the code defined in Table 0.2 of WHP Office Report WHPO 91-1 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 3.4.4). The replicate data were averaged and flagged 2 if both of them were flagged 2. If either of them was flagged 3 or 4, a datum with “younger” flag was selected. Thus we did not use flag of 6 (replicate measurements). 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. A difference between bottle oxygen and CTD oxygen (OPTODE sensor) 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 according to the steps a, b, c, and d.

Table 3.4.1. Results of the standardization and the blank determinations during MR11-08.

(UTC)	KIO ₃ No.		Na ₂ S ₂ O ₃ No.	DOT-7		DOT-8		Stations
	#	ID No.		E.P.	blank	E.P.	blank	
2011/12/22	05	20110523-05-02	20110602-01	3.953	-0.002	3.957	-0.001	P10-059,058,057,056,055,054,053,052,051,050,049,048,047,046,045
2011/12/28		20110523-05-01	20110602-01	3.952	-0.001	3.956	0.001	P10-044,043,042,041,040, 039
2011/12/29		20110523-05-07	20110602-02	3.956	-0.003	3.961	-0.001	P10-038,037,036,035,034,033,032,031,030,029,028,027
2012/01/03		20110523-05-08	20110602-02	3.963	0.000	3.964	0.003	P10-001,002,003,004,005,006,007,008,009,010,011,012,013,014,015,016,017,018,019,020,021,022
2012/1/7		20110523-05-05	20110602-03	3.959	-0.001	3.961	0.001	P10-023,024,025,026
2012/1/14	06	20110524-06-03	20110602-03	3.963	-0.001	3.964	0.001	P10-059,060,061,062,063,064,065,066,067,068,069,070,071,072,073
2012/1/19		20110524-06-05	20110602-04	4.075	-0.004	4.076	0.000	P10-074,P10N-075,076,077,078,079,080,081,082,083,084,085,088,086,087,090,092,094,096
2012/2/1		20110524-06-01	20110602-05	3.957	-0.002	3.959	0.001	P10N-098,100,102,104,106,110,112,114,115

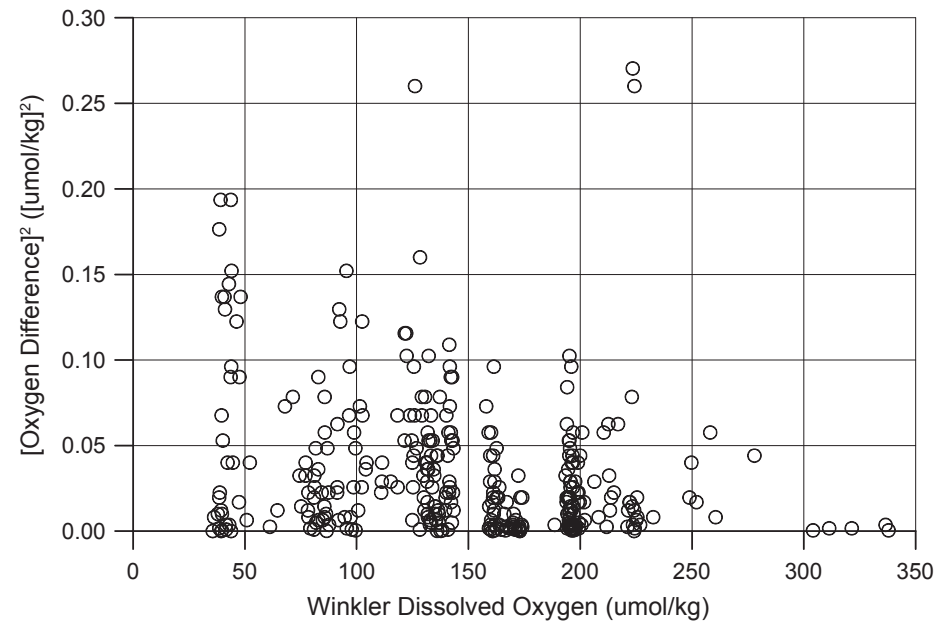


Figure 3.4.1. Oxygen difference between measurements of a replicate pair against oxygen concentration.

Table 3.4.2. Results of the duplicate sample measurements during MR11-08.

	Leg	Stations	Pres. (db)	#1 Niskin		#1 Oxygen [$\mu\text{mol/kg}$]	#2 Niskin		#2 Oxygen [$\mu\text{mol/kg}$]	Difference [$(\mu\text{mol/kg})^2$]
1	2	P10-59	5656	1	X12J01	176.21	2	X12J02	176.25	0.002
2	2	P10-58	5500	2	X12J02	174.49	3	X12J03	174.42	0.005
3	2	P10-57	5170	2	X12J02	173.25	4	X12J04	173.33	0.006
4	2	P10-56	5080	2	X12J02	172.65	5	X12J05	172.50	0.023
5	2	P10-55	4750	2	X12J02	164.09	6	X12J06	164.11	0.000
6	2	P10-54	4420	2	X12J02	164.89	7	X12J07	164.94	0.003
7	2	P10-53	4330	2	X12J02	163.54	8	X12J08	163.61	0.005
8	2	P10-52	4000	2	X12J02	155.00	9	X12J09	154.90	0.010
9	2	P10-44	3830	2	X12J02	155.70	10	X12J10	155.56	0.020

10	2	P10-43	3500	2	X12J02	149.74	11	X12J11	149.56	0.032
11	2	P10-42	3170	5	X12102	143.09	12	X12J12	143.07	0.000
12	2	P10-41	3080	2	X12103	139.96	13	X12101	140.13	0.029
13	2	P10-38	2870	4	X12104	138.17	14	X12J14	138.00	0.029
14	2	P10-37	2600	2	X12103	129.87	15	X12J15	129.92	0.002
15	2	P10-36	2330	2	X12103	119.45	16	X12J16	119.35	0.010
16	2	P10-35	2270	2	X12103	117.47	17	X12J17	116.93	0.292
17	2	P10-34	2000	2	X12103	113.64	18	X12J18	113.39	0.063
18	2	P10-33	1730	2	X12103	103.02	19	X12J19	102.90	0.014
19	2	P10-32	1670	2	X12103	101.57	20	X12001	101.45	0.014
20	2	P10-31	1400	2	X12103	96.37	21	X12J21	96.64	0.073
21	2	P10-30	1130	2	X12103	92.36	22	X12J22	92.70	0.116
22	2	P10-4	1400	2	X12103	109.34	21	X12J36	109.40	0.004
23	2	P10-5	1670	2	X12103	110.04	20	X12J35	109.89	0.023
24	2	P10-6	1730	2	X12103	109.66	19	X12J34	109.45	0.044
25	2	P10-12	1930	2	X12103	116.36	18	X12J33	116.08	0.078
26	2	P10-13	2200	2	X12103	125.37	17	X12J32	125.40	0.001
27	2	P10-15	2330	2	X12103	128.02	16	X12046	128.23	0.044
28	2	P10-16	2600	2	X12103	135.43	15	X12J30	135.42	0.000
29	2	P10-17	2870	2	X12103	139.94	14	X12J29	139.56	0.144
30	2	P10-18	2930	2	X12103	140.07	13	X12J28	139.79	0.078
31	2	P10-19	3250	2	X12103	144.23	12	X12J27	143.98	0.063
32	2	P10-21	3920	2	X12103	152.71	9	X12J25	152.57	0.020
33	2	P10-22	4500	2	X12103	156.23	7	X12J23	156.01	0.048
34	2	P10-23	4330	2	X12103	155.42	8	X12J24	155.31	0.012
35	2	P10-24	3670	2	X12103	148.59	10	X12J26	148.72	0.017

Table 3.4.3. Results of the CSK standard (Lot EPJ3885) measurements on board.

Date (UTC)	KIO ₃ ID No.	DOT-7		DOT-8		Remarks
		Conc. (N)	error (N)	Conc. (N)	error (N)	
2011/12/22	20110523-05-02	0.010008	0.000003	0.010008	0.000007	MR11-08 Leg-2
2012/01/14	20110524-06-07	0.010009	0.000002	0.010005	0.000009	MR11-08 Leg-3
Date (UTC)	KIO ₃ ID No.	DOT-1		–		Remarks
		Conc. (N)	error (N)	–	–	
2011/5/27	20100630-01-11	0.010008	0.000005	–	–	before cruise
2011/5/30	20110524-07-12	0.010007	0.000004	–	–	before cruise
2011/5/31	20110523-05-12	0.010006	0.000007	–	–	before cruise
2011/6/1	20110523-01-12	0.010006	0.000010			before cruise

Table 3.4.4. Summary of assigned quality control flags.

Flag	Definition	
2	Good	3080
3	Questionable	4
4	Bad	4
5	Not report (missing)	0
	Total	3088

(13) Preliminary Results

i. Comparison of oxygen measurements at a cross point

We compared a vertical profile of oxygen concentration at a cross point (24°N/149°E) from this cruise with that from our past cruise (MR05-05). The first and second measurements were conducted on 30-Dec.-2005 (MR05-05_P03-X10, 24.486°N/149.356°E) and 17-January-2012 (MR11-08_P10-067, 24.241°N/149.033°E), respectively. Below layers below about 2000 dbar, the vertical profiles in 2005 and 2011 agree well within the analytical error (Fig. 3.4.2).

ii. Distribution of dissolved oxygen along WHP-P10/P10N in 2011/12

Figure 3.4.3 shows that a tongue-shaped oxygen minima is lying around 500 – 1500 m depth. The highest concentration was measured in surface waters of the northernmost stations off Hokkaido. Another high-oxygen water was found in bottom waters of the north of 10°N, which corresponds to the Circumpolar Deep Water (CDW). The basin-scale distribution of dissolved oxygen in 2011/12 well agrees with those obtained in 1993 and 2005.

iii. Decadal changes in dissolved oxygen along the WHP-P10/P10N line from 2005 and 2011/12

Along the P10/P10N line, difference in dissolved oxygen concentration between 2005 and 2011/12 was large (< about 10 μmol/kg) above 1000 m depth, where the vertical gradient of dissolved oxygen is sharp. In deeper layers dissolved oxygen change less than 10 μmol/kg were also observed in some regions, implying influence of heaving and internal waves. In addition, we found 1~2 μmol/kg of oxygen decrease in near bottom waters between 10°N and 30°N.

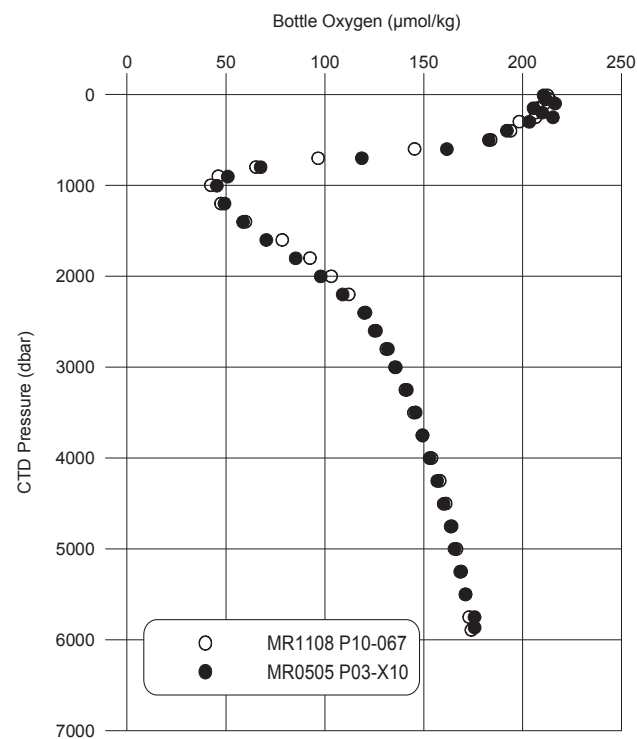


Figure 3.4.2. Vertical profiles of bottle oxygen concentration at a cross point (24°N/149°E) from MR05-05 (black circles) and MR11-08 cruises (white circles).

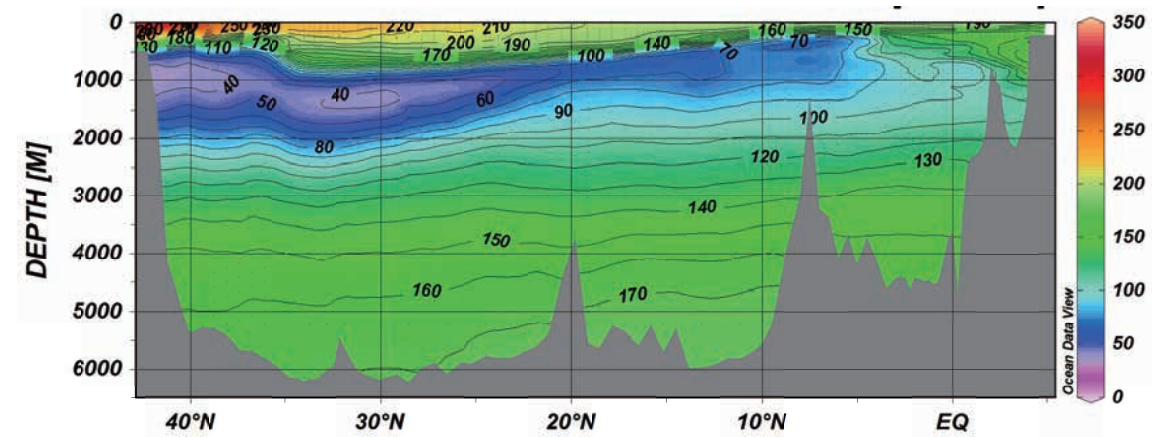


Figure 3.4.3. Transect of bottle oxygen concentration ($\mu\text{mol/kg}$) along the cruise track of MR11-08 in the winter of 2011-2012.

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3.5 Nutrients

June 13, 2012 (ver. 2.0)

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(2) Objectives

The objectives of nutrients analyses during the R/V Mirai MR11–08 cruise, WOCE P10 revisited cruise in 2011/2012, in the western Pacific Ocean are as follows;

- Describe the present status of nutrients concentration with excellent comparability.
- The determinants are nitrate, nitrite, silicate and phosphate.
- Study the temporal and spatial variation of nutrients concentration based on the previous high quality experiments data of WOCE previous P10 cruises in 1993 and 2005, GOSECS, 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 95 QuAAtro 2-HR runs for the samples at 101 stations in MR11–08. The total amount of layers of the seawater sample reached up to 3091 for MR11–08. We made duplicate measurement at all layers.

(4) Instrument and Method

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

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 stream with its equivalent nitrite was treated with an acidic, sulfanilamide reagent and the nitrite forms nitrous acid which reacted with the sulfanilamide to produce a diazonium ion. N-1-Naphthylethylene-diamine added to the sample stream then coupled with the diazonium ion to produce a red, azo dye. 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 used in this cruise are also compatible with the methods described in nutrients section in GO-SHIP repeat hydrography manual (Hydes et al., 2010). The flow diagrams and reagents for each parameter are shown in Figures 3.5.1 to 3.5.4.

(4.2) Nitrate Reagents

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

Dissolve 4 g imidazole, $C_3H_4N_2$, in ca. 1000 ml DIW; add 2 ml concentrated HCl. After mixing, 1 ml Triton(R) X-100 (50 % solution in ethanol) is added.

Sulfanilamide, 0.06 M (1 % w/v) in 1.2M 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(R)X-100 (50 % solution in ethanol) is added.

N-1-Naphthylethylene-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(R)X-100 (50 % solution in ethanol) is added.

Stored in a dark bottle.

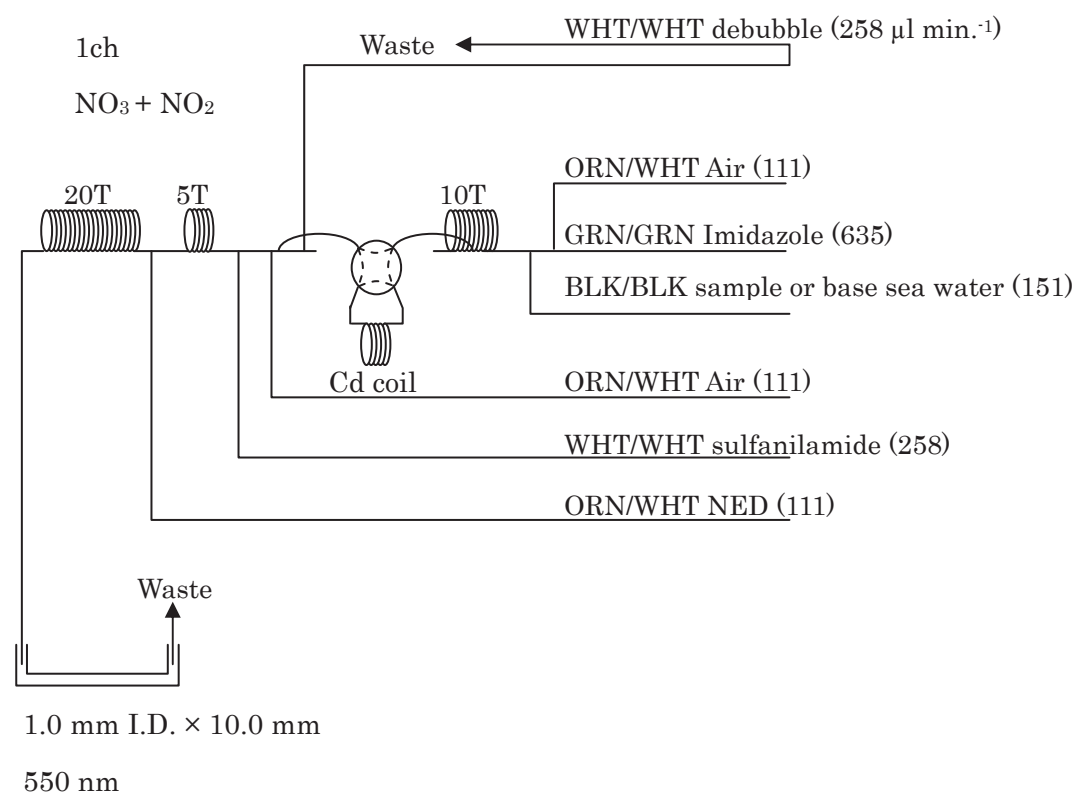


Figure 3.5.1. NO_3+NO_2 (1ch.) Flow diagram.

(4.3) Nitrite Reagents

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

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

N-1-Naphthylethylene-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(R)X-100 (50 % solution in ethanol) is added. This reagent was stored in a dark bottle.

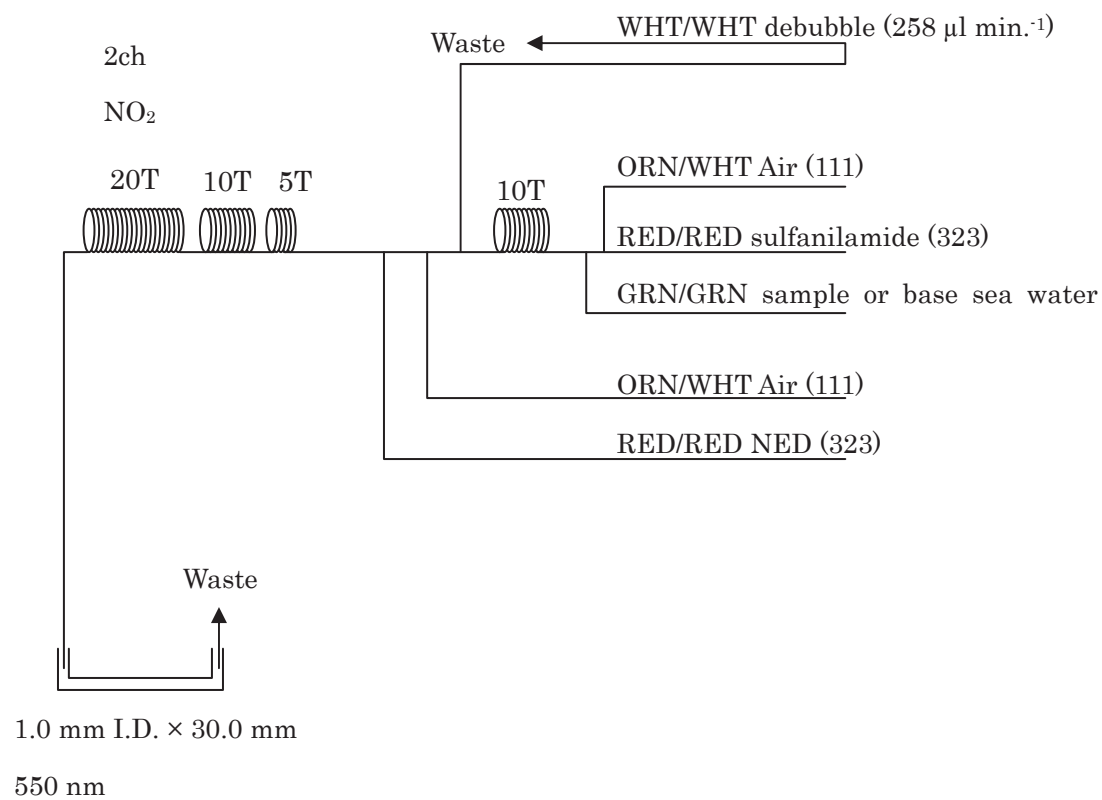


Figure 3.5.2. NO₂ (2ch.) Flow diagram.

(4.4) Silicate Reagents

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

Dissolve 15 g disodium Molybdate(VI) dihydrate, Na₂MoO₄·2H₂O, in 980 ml DIW, add 8 ml concentrated H₂SO₄.

After mixing, 20 ml sodium dodecyl sulphate (15 % solution in water) is added.

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

Dissolved 50 g oxalic acid anhydrous, HOOC:COOH, in 950 ml of DIW.

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

Dissolved 2.5g L (+)-ascorbic acid, C₆H₈O₆, in 100 ml of DIW. This reagent was freshly prepared before every measurement.

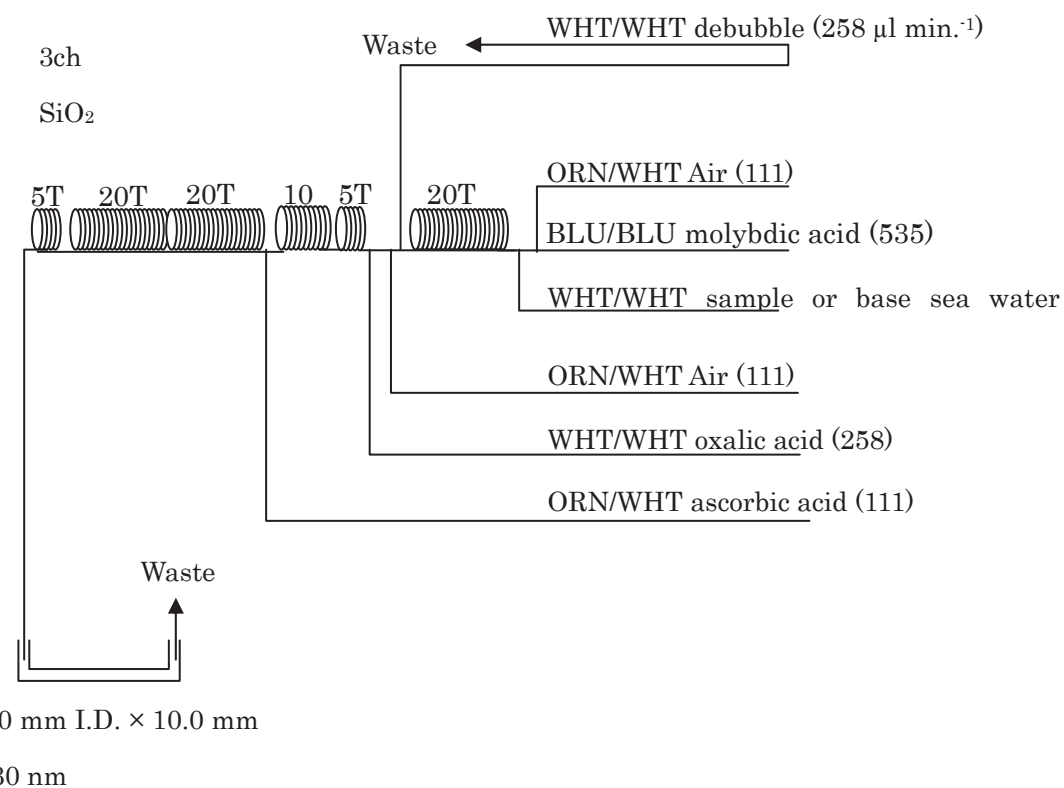


Figure 3.5.3. SiO₂ (3ch.) Flow diagram.

(4.5) Phosphate Reagents

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

Dissolved 8 g disodium molybdate (VI) dihydrate, Na₂MoO₄·2H₂O, and 0.17 g antimony potassium tartrate, C₈H₄K₂O₁₂Sb₂·3H₂O, in 950 ml of DIW and added 50 ml concentrated H₂SO₄.

Mixed Reagent

Dissolved 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 in leg3 of this cruise, 4mL sodium dodecyl sulphate (15 % solution in water) was added in leg2 because to reduce relatively noisy signals. This reagent was freshly prepared before every measurement.

Reagent for sample dilution

Dissolved sodium chloride, NaCl, 10 g in ca. 950 ml of DIW, added 50 ml acetone and 4 ml concentrated H_2SO_4 . After mixing, 5 ml sodium dodecyl sulphate (15 % solution in water) was added.

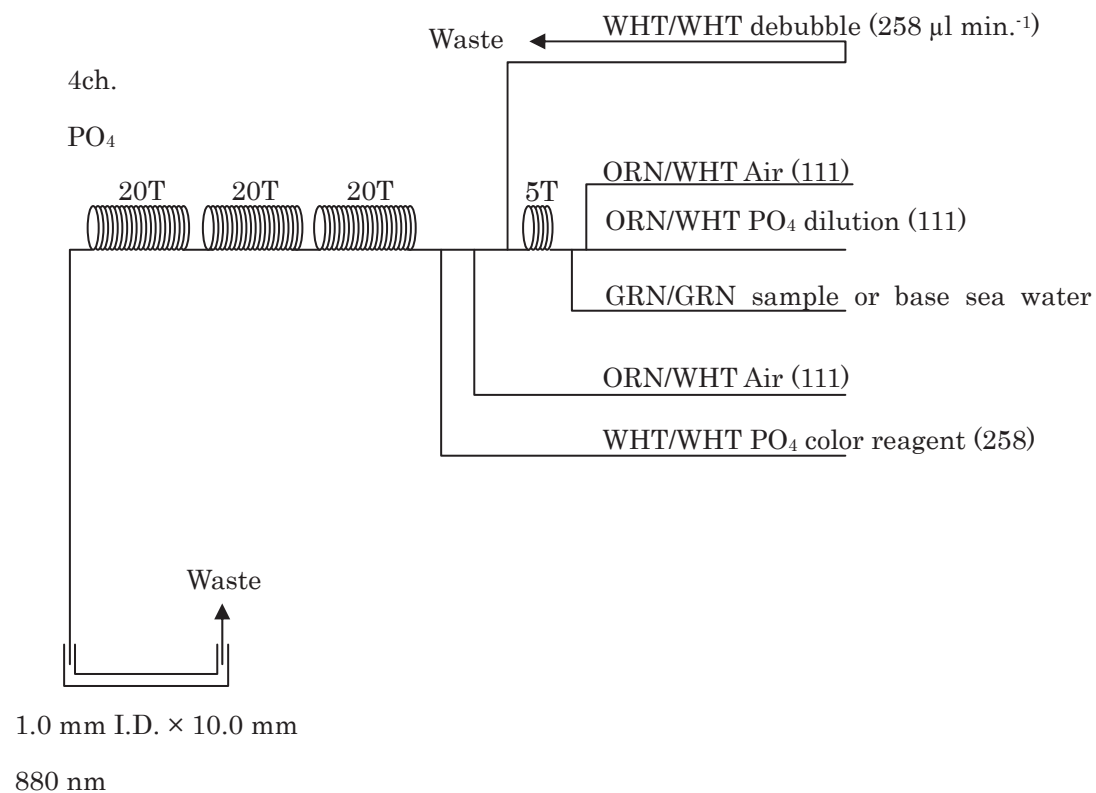


Figure 3.5.4. PO₄ (4ch.) Flow diagram.

(4.6) 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 vials were capped immediately after the drawing. The vials were put into water bath adjusted to ambient temperature, 24 ± 2 deg. C, in about 30 minutes before use to stabilize the temperature of samples in MR11–08.

No transfer was made and the vials were set an auto sampler tray directly. Samples were analyzed after collection basically within 24 hours in MR11–08.

(4.7) 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.
- 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 used were gravimetrically calibrated. Plastic volumetric flasks were gravimetrically calibrated at the temperature of use 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, CAS No. : 7757-91-1, was used.

For nitrite standard, “sodium nitrate” provided by Wako, CAS No. : 7632-00-0, was used. The assay of nitrite salts was determined according JIS K8019 were 98.31%. We use that value to adjust the weights taken.

For the silicate standard, we use “Silicon standard solution SiO₂ in NaOH 0.5 mol/l CertiPUR®” provided by Merck, CAS No. : 1310-73-2, of which lot number is HC097572 is used. The silicate concentration is certified by

NIST-SRM3150 with the uncertainty of 0.5 %. Factor of HC097572 was signed 1.000, however we reassigned the factor as 0.976 from the result of comparison among RMNS in MR11-E02 cruise.

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

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 0.45 μm pore size membrane filter. This water is stored in 20 liter cubitainer with paper box. The concentrations of nutrient of this water were measured carefully in Jan 2011.

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 MgOH₂ 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 to be about 7. After that B standard solution is used to prepare C standards.

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

Concentrations of nutrients for A, B and C standards are set as shown in Table 3.5.1. The C standard is prepared according recipes as shown in Table 3.5.2. All volumetric laboratory tools were calibrated prior the cruise as stated in chapter (i). Then the actual concentration of nutrients in each fresh standard was calculated based on the ambient, solution temperature and determined factors of volumetric lab. 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.

Table 3.5.1. Nominal concentrations of nutrients for A, B and C standards.

	A	B	C-1	C-2	C-3	C-4	C-5	C-6
NO ₃ (μ M)	45000	900	BS	BU	BT	BD	BF	55
NO ₂ (μ M)	4000	20	BS	BU	BT	BD	BF	1.2
SiO ₂ (μ M)	36000	2880	BS	BU	BT	BD	BF	167
PO ₄ (μ M)	3000	60	BS	BU	BT	BD	BF	3.6

Table 3.5.2. Working calibration standard recipes.

C Std.	B-1 Std.	B-2 Std.
C-6	30 ml	30 ml

B-1 Std.: Mixture of nitrate, silicate and phosphate

B-2 Std.: Nitrite

(5.4) Renewal of in-house standard solutions.

In-house standard solutions as stated in (iii) were renewed as shown in Table 3.5.3(a) to (c).

Table 3.5.3(a). Timing of renewal of in-house standards.

NO ₃ , NO ₂ , SiO ₂ , PO ₄	Renewal
A-1 Std. (NO ₃)	maximum 1 month
A-2 Std. (NO ₂)	maximum 1 month
A-3 Std. (SiO ₂)	commercial prepared solution
A-4 Std. (PO ₄)	maximum 1 month
B-1 Std. (mixture of NO ₃ , SiO ₂ , PO ₄)	8 days
B-2 Std. (NO ₂)	8 days

Table 3.5.3(b). Timing of renewal of in-house standards.

Working standards	Renewal
C-6 Std. (mixture of B-1 and B-2 Std.)	24 hours

Table 3.5.3(c). Timing of renewal of in-house standards for reduction estimation.

Reduction estimation	Renewal
D-1 Std. (3600 μ M NO ₃)	8 days
43 μ M NO ₃	when C Std. renewed
47 μ M NO ₂	when C Std. renewed

(6) Reference material of nutrients in seawater

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 (hereafter RMNS) are prepared (Aoyama et al., 2006, 2007, 2008, 2009). 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 μ mol kg⁻¹ for 345 crossovers at world oceans, though the maximum was 1.7 μ mol 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 2010, RMNS were used to keep comparability of nutrients measurement among the 8 cruises of CLIVAR project (Sato et al., 2010), MR10–05 cruise for Arctic research (Aoyama et al., 2010) and MR10–06 cruise for “Change in material cycles and ecosystem by the climate change and its feedback” (Aoyama et al., 2011).

(6.1) RMNSs for this cruise

RMNS lots BS, BU, BT, BD and BF, which cover full range of nutrients concentrations in the western Pacific Ocean are prepared. 80 sets of BS, BU, BT, BD and BF are prepared.

One hundred forty bottles of RMNS lot BE are prepared for MR11–08. Lot BE was used all stations. These RMNS assignment were completely done based on random number. The RMNS bottles were stored at a room in the ship, REAGENT STORE, where the temperature was maintained around 13-24 deg. C.

(6.2) Assigned concentration for RMNSs

We assigned nutrients concentrations for RMNS lots BS, BU, BT, BD, BE, and BF as shown in Table 3.5.4.

Table 3.5.4. Assigned concentration of RMNSs (in $\mu\text{mol kg}^{-1}$).

	Nitrate	Phosphate	Silicate	Nitrite
BS*	0.07	0.064	1.61	0.02
BU*	3.97	0.379	20.30	0.07
BT*	18.21	1.320	41.00	0.47
BD*	29.86	2.194	64.39	0.05
BE**	36.70	2.662	99.20	0.03
BF***	41.39	2.809	150.23 [†]	0.02

* The values are assigned for this cruise on 27 July 2011.

** The values are assigned for this cruise on 4 April 2009
(Table 3.4.4 in WHP P21 REVISIT DATA BOOK).

*** The values are assigned for this cruise on 10 October 2007
(Table 3.4.4 in WHP P1, P14 REVISIT DATA BOOK).

[†] This value is changed in MR11–03 cruise.

(6.3) The homogeneity of RMNSs

The homogeneity of lot BE used in MR11–08 cruise and analytical precisions are shown in Table 3.5.5. These are for the assessment of the magnitude of homogeneity of the RMNS bottles those are used during the cruise. As shown in Table 3.5.5 homogeneity of RMNS lot BE for nitrate, phosphate and silicate are the same magnitude of analytical precision derived from fresh raw seawater in January 2009.

Table 3.5.5. Homogeneity of lot BE derived from simultaneous 209 samples measurements and analytical precision onboard R/V Mirai in MR11-08.

	Nitrate CV %	Phosphate CV %	Silicate CV %
BE	0.17	0.28	0.17
Precision	0.12	0.20	0.14

BE: N=209

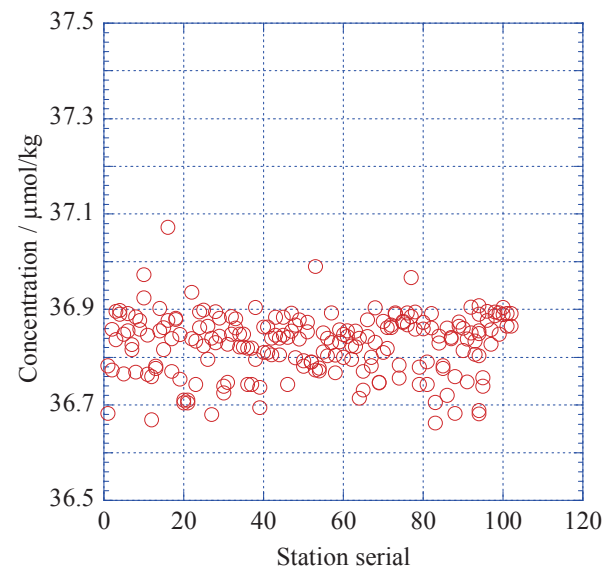


Figure 3.5.5. Time series of RMNS-BE of nitrate for MR11-08.

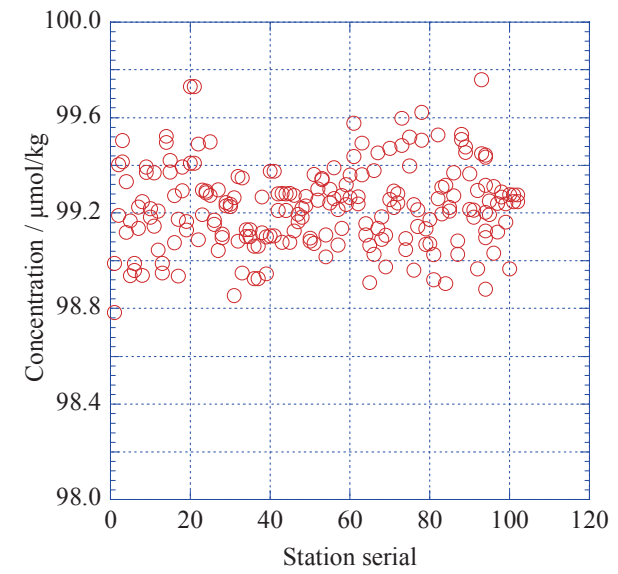


Figure 3.5.6. Time series of RMNS-BE of silicate for MR11-08.

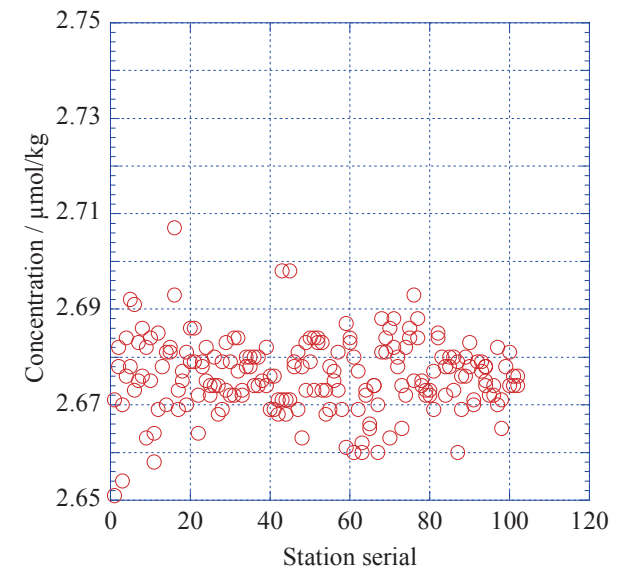


Figure 3.5.7. Time series of RMNS-BE of phosphate for MR11-08.

(6.4) Comparability of RMNSs during the periods from 2003 to 2011

Cruise-to-cruise comparability has examined based on the results of the previous results of RMNSs measurements obtained among cruises, and RMNS international comparison experiments in 2003 and 2009. The uncertainties for each value were obtained similar method described in 7.1 in this chapter at the measurement before each cruise and inter-comparison study, shown as precruise and intercomparison, and mean of uncertainties during each cruise, only shown cruise code, respectively. As shown in Table 3.5.6, the nutrients concentrations of RMNSs were in good agreement among the measurements during the period from 2003 to 2011. For the silicate measurements, we show lot numbers and chemical company names of each cruise/ measurement in the footnote. As shown in Table 3.5.6, there shows less comparability among the measurements due to less comparability among the standard solutions provided by chemical companies in the silicate measurements.

Table 3.5.6 (a). Comparability for nitrate (in $\mu\text{mol kg}^{-1}$).

Cruise / Lab.	RM Lots													
	AH	unc.	AZ	unc.	BA	unc.	AX	unc.	AV	unc.	BC	unc.	BE	unc.
Nitrate														
2003														
2003intercomp_repeorted	35.23	0.06					21.39							
MR03-K04 Leg1	35.25													
MR03-K04 Leg2	35.37													
MR03-K04 Leg4	35.37													
MR03-K04 Leg5	35.34													
2005														
MR05-02			42.30		0.07	0.02	21.45	0.07	33.35	0.06	40.70	0.06		
MR05-05_1 precruise	35.65	0.05	42.30	0.10	0.07	0.00	21.41	0.01	33.41	0.02	40.76	0.03		
MR05-05_1			42.33		0.07	0.01	21.43	0.05	33.36	0.05	40.73	0.85		
MR05-05_2 precruise			42.33		0.08	0.00	21.39	0.02	33.36	0.05	40.72	0.03		
MR05-05_2			42.34		0.07	0.01	21.44	0.05	33.36	0.05	40.73	0.06		
MR05-05_3 precruise			42.35		0.06	0.00	21.49	0.01	33.39	0.01	40.79	0.01		
MR05-05_3			42.36		0.07	0.01	21.44	0.04	33.37	0.05	40.75	0.05		

Cruise / Lab.	RM Lots													
	AH	unc.	AZ	unc.	BA	unc.	AX	unc.	AV	unc.	BC	unc.	BE	unc.
Nitrate														
2006														
2006intercomp			42.24	0.04	0.04	0.00	21.40	0.02	33.32	0.03	40.63	0.04		
2003intercomp_revisit	35.40	0.03												
2007														
MR07-04_1 precruise	35.74	0.03			0.07	0.00	21.59	0.02	33.49	0.03	40.83	0.03		
MR07-04_2 precruise	35.80	0.01			0.08	0.00	21.60	0.01	33.47	0.01	40.92	0.02		
MR07-04					0.08	0.01	21.41	0.06	33.38	0.05	40.77	0.05		
MR07-06_1 precruise	35.61	0.02			0.07	0.00	21.44	0.01	33.43	0.02	40.79	0.02		
MR07-06_2 precruise	35.61	0.04			0.06	0.00	21.43	0.02	33.54	0.04	40.79	0.05		
MR07-06_1					0.08	0.01	21.44	0.03	33.41	0.05	40.81	0.04		
MR07-06_2					0.09	0.01	21.44	0.03	33.39	0.06	40.81	0.04		
2008														
2008intercomp_report					0.08	0.00	21.44	0.02						
2006intercomp_revisit			42.27	0.04	0.07	0.00	21.47	0.02	33.34	0.03				
2003intercomp_revisit	35.35	0.04												
2009														
MR09-01_0 precruise			42.36	0.02	0.07	0.00	21.43	0.01	33.42	0.02	40.81	0.02	36.70	0.02
MR09-01_1			42.42	0.06	0.11	0.01	21.51	0.04	33.53	0.04	40.82	0.11	36.74	0.04
MR09-01_2			42.43	0.05			21.54	0.03	33.53	0.03			36.74	0.03
INSS stability test_1	35.76	0.22			0.08	0.01	21.49	0.02	33.45	0.03				
2010														
SGONS stability test_2			42.46	0.05	0.10	0.00	21.51	0.02	33.52				36.76	0.02
SGONS stability test_3			42.48		0.09		21.52		33.63				36.77	
2011														
SGONS stability test_4			42.56	0.07	0.08	0.01	21.62	0.01	33.65	0.07			36.83	0.03
SGONS stability test_5			42.49	0.05	0.06	0.00							36.87	0.06
MR11-08_2													36.83	0.07
SGONS stability test_6														
MR11-08_3													36.83	0.06

Table 3.5.6 (b). Comparability for Phosphate (in $\mu\text{mol kg}^{-1}$).

Cruise / Lab.	RM Lots													
	AH		AZ		BA		AX		AV		BC		BE	
	unc.		unc.		unc.		unc.		unc.		unc.		unc.	
	Phosphate													
2003														
2003intercomp	2.141	0.001												
MR03-K04 Leg1	2.110													
MR03-K04 Leg2	2.110													
MR03-K04 Leg4	2.110													
MR03-K04 Leg5	2.110													
2005														
MR05-02			3.010		0.061	0.010	1.614	0.008	2.515	0.008	2.778	0.010		
MR05-05_1 precruise	2.148	0.006	3.020	0.010	0.045	0.000	1.620	0.001	2.517	0.002	2.781	0.002		
MR05-05_1			3.016		0.063	0.007	1.615	0.006	2.515	0.007	2.778	0.033		
MR05-05_2 precruise			3.015		0.066	0.000	1.608	0.001	2.510	0.001	2.784	0.002		
MR05-05_2			3.018		0.064	0.005	1.614	0.004	2.515	0.005	2.782	0.006		
MR05-05_3 precruise			3.020		0.060	0.000	1.620	0.001	2.517	0.002	2.788	0.002		
MR05-05_3			3.016		0.061	0.004	1.618	0.005	2.515	0.004	2.779	0.008		
2006														
2006intercomp			3.018	0.002	0.071	0.000	1.623	0.001	2.515	0.001	2.791	0.001		
2003intercomp_revisit	2.141	0.001												
2007														
MR07-04_1 precruise	2.140	0.002			0.062	0.000	1.620	0.001	2.512	0.002	2.782	0.002		
MR07-04_2 precruise	2.146	0.002			0.056	0.000	1.620	0.001	2.517	0.002	2.788	0.002		
MR07-04					0.066	0.004	1.617	0.005	2.513	0.004	2.781	0.007		
MR07-06_1 precruise	2.144	0.001			0.066	0.000	1.617	0.001	2.517	0.001	2.790	0.001		
MR07-06_2 precruise	2.146	0.002			0.067	0.000	1.620	0.001	2.517	0.002	2.789	0.002		
MR07-06_1					0.064	0.004	1.620	0.003	2.515	0.003	2.783	0.005		
MR07-06_2					0.066	0.004	1.619	0.005	2.515	0.003	2.785	0.006		
2008														
2008intercomp_report					0.068	0.000	1.615	0.005						
2006intercomp_revisit			3.014	0.008	0.065	0.000	1.627	0.005	2.513	0.007				
2003intercomp_revisit	2.131	0.006												
2009														
MR09-01_0 precruise			3.017	0.001	0.074	0.000	1.619	0.001	2.520	0.001	2.790	0.001	2.662	0.001

Cruise / Lab.	RM Lots													
	AH		AZ		BA		AX		AV		BC		BE	
	unc.		unc.		unc.		unc.		unc.		unc.		unc.	
	Phosphate													
MR09-01_1			3.019	0.005	0.072	0.002	1.623	0.004	2.528	0.003	2.783	0.004	2.668	0.005
MR09-01_2			3.018	0.004			1.625	0.003	2.527	0.003			2.668	0.003
INSS stability test_1	2.134	0.008			0.069	0.001	1.606	0.001	2.512	0.003				
2010														
SGONS stability test_2			3.012	0.008	0.059	0.001	1.618	0.004	2.520	0.008			2.663	0.006
SGONS stability test_3			3.024		0.055		1.617		2.528				2.666	
2011														
SGONS stability test_4			3.017	0.006	0.066	0.004	1.624	0.005	2.533	0.030			2.668	0.006
SGONS stability test_5			3.011	0.004	0.003								2.665	0.002
MR11-08_2													2.676	0.008
SGONS stability test_6														
MR11-08_3													2.676	0.007

Table 3.5.6 (C). Comparability for Silicate (in $\mu\text{mol kg}^{-1}$).

Cruise	RM Lots													
	AH		AZ		BA		AX		AV		BC		BE	
	unc.		unc.		unc.		unc.		unc.		unc.		unc.	
	Silicate													
2003														
2003intercomp *	130.51	0.20												
MR03-K04 Leg1 **	132.01													
MR03-K04 Leg2 **	132.26													
MR03-K04 Leg4 **	132.28													
MR03-K04 Leg5 **	132.19													
2005														
MR05-02 #			133.69		1.61	0.05	58.04	0.11	153.92	0.19	155.93	0.19		
MR05-05_1 precruise ##	132.49	0.13	133.77	0.02	1.51	0.00	58.06	0.03	153.97	0.09	156.65	0.09		
MR05-05_1 **			133.79		1.59	0.07	58.01	0.12	154.01	0.26	156.08	0.36		
MR05-05_2 precruise ##			133.78		1.58	0.00	57.97	0.04	154.07	0.09	156.21	0.10		
MR05-05_2 **			133.88		1.59	0.06	58.00	0.09	154.05	0.16	156.14	0.15		
MR05-05_3 precruise ##			134.02		1.57	0.00	58.05	0.05	154.07	0.14	156.11	0.14		
MR05-05_3 **			133.79		1.60	0.05	57.98	0.09	153.98	0.18	156.08	0.13		

Cruise	RM Lots													
	AH	unc.	AZ	unc.	BA	unc.	AX	unc.	AV	unc.	BC	unc.	BE	unc.
Silicate														
2006														
2006intercomp [§]			133.83	0.07	1.64	0.00	58.20	0.03	154.16	0.08	156.31	0.08		
2003intercomp_revisit [§]	132.55	0.07												
2007														
MR07-04_1 precruise ^{§§}	133.38	0.06			1.61	0.00	58.46	0.03	154.82	0.07	156.98	0.07		
MR07-04_2 precruise ^{§§}	133.15	0.12			1.69	0.00	58.44	0.05	154.87	0.14	156.86	0.14		
MR07-04 ^{§§}					1.62	0.07	58.11	0.11	154.45	0.21	156.62	0.48		
MR07-06_1 precruise ^{§§}	133.02	0.09			1.64	0.00	58.50	0.04	155.06	0.11	156.33	0.11		
MR07-06_2 precruise ^{§§}	132.70	0.07			1.56	0.00	58.25	0.03	154.39	0.08	156.57	0.08		
MR07-06_1 ^{§§}					1.61	0.04	58.13	0.08	154.48	0.13	156.64	0.08		
MR07-06_2 ^{§§}					1.58	0.07	58.04	0.10	154.38	0.16	156.61	0.13		
2008														
2008intercomp [¥]					1.64	0.00	58.17	0.05						
2006intercomp_re [¥]			134.11	0.11	1.65	0.00	58.26	0.05	154.36	0.12				
2003intercomp_re [¥]	132.11	0.11												
2009														
MR09-01_0 precruise [¥]			133.93	0.04	1.57	0.00	58.06	0.02	154.23	0.05	156.16	0.05	99.20	0.03
MR09-01_1 [¥]			133.97	0.11	1.34	0.11	58.15	0.08	154.48	0.09	155.89	0.13	99.24	0.08
MR09-01_2 [¥]			133.96	0.11			58.19	0.08	154.42	0.12			99.23	0.08
INSS stability test_1 ^{¥¥}	132.40	0.35			1.69	0.02	58.18	0.02	154.43	0.09				
2010														
SGONS stability test_2 ^{¥¥}			133.89	0.12	1.58	0.02	58.15	0.04	154.43	0.21			99.20	0.07
SGONS stability test_3 ^{¥¥}			134.20		1.58		58.10		154.90				99.18	
2011														
SGONS stability test_4 ⁺			134.16	0.09	1.68	0.04	58.26	0.05	154.56	0.05			99.30	0.07
SGONS stability test_5 ⁺			133.27	0.21	1.49	0.02							98.82	0.18
MR11-08_2 ⁺⁺													99.21	0.17
SGONS stability test_6 ⁺⁺														
MR11-08_3 ⁺⁺													99.25	0.18

List of lot numbers: *: Kanto 306F9235; **: Kanto 402F9041; #: Kanto 507F9205; ##: Kanto 609F9157; \$: Merck OC551722; \$\$: Merck HC623465; ¥: Merck HC751838; ¥¥: HC814662; +: HC074650; ++: HC097572

(7) Quality control

(7.1) Precision of nutrients analyses during the cruise

Precision of nutrients analyses during the cruise was evaluated based on the 9 to 11 measurements, which are measured every 10 to 13 samples, during a run at the concentration of C-6 std. Summary of precisions are shown as shown in Table 3.5.7 and Figures 3.5.8 to 3.5.10, the precisions for each parameter are generally good considering the analytical precisions estimated from the simultaneous analyses of 14 samples in January 2009 as shown in Table 3.5.6. Analytical precisions previously evaluated were 0.18 % for nitrate, 0.14 % for phosphate and 0.08 % for silicate, respectively. During this cruise, analytical precisions were 0.12 % for nitrate, 0.20 % for phosphate and 0.14 % for silicate in terms of median of precision, respectively. Then we can conclude that the analytical precisions for nitrate, phosphate and silicate throughout this cruise became relatively bad. The reasons of the phenomenon is discussed in chapter (8).

Table 3.5.7. Summary of precision based on the replicate analyses.

	Nitrate CV %	Phosphate CV %	Silicate CV %
Median	0.12	0.20	0.14
Mean	0.13	0.21	0.13
Maximum	0.4	0.4	0.25
Minimum	0.04	0.05	0.05
N	102	102	102

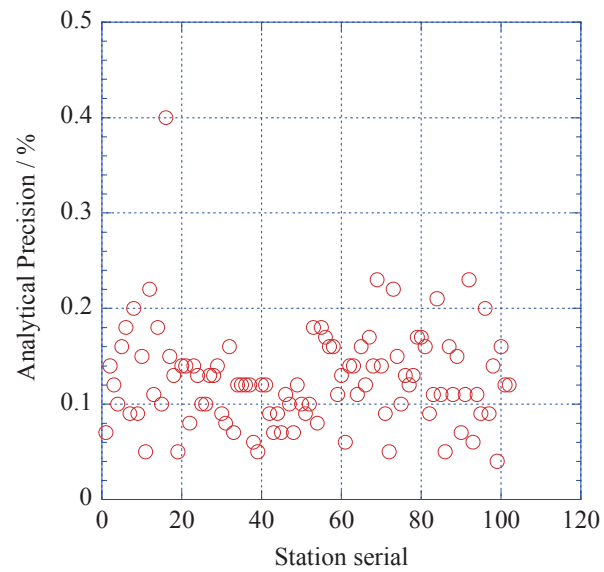


Figure 3.5.8. Time series of precision of nitrate for MR11-08.

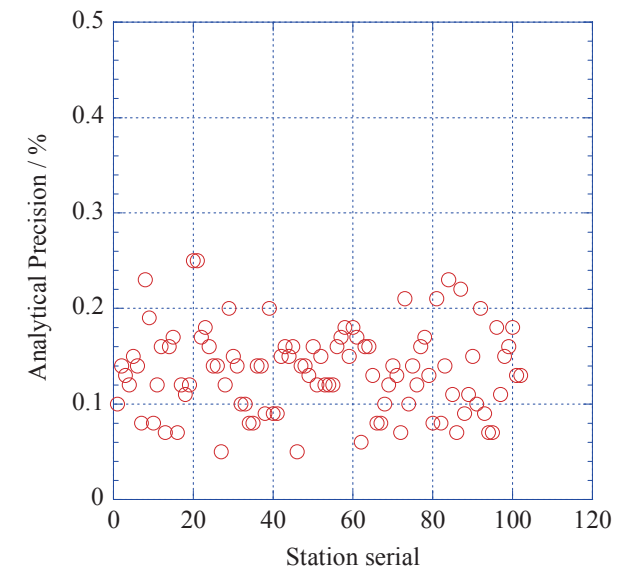


Figure 3.5.10. Time series of precision of silicate for MR11-08.

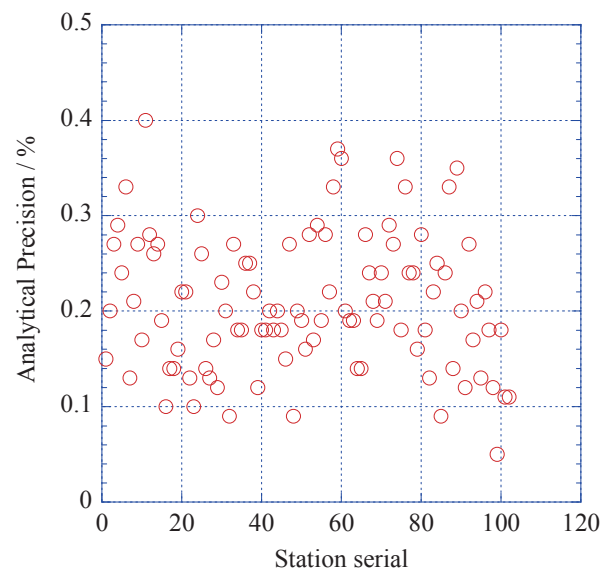


Figure 3.5.9. Time series of precision of phosphate for MR11-08.

(7.2) Carry over

We also summarize the magnitudes of carry over throughout the cruise. These are small enough within acceptable levels as shown in Table 3.5.8 and Figures 3.5.11 – 3.5.13.

Table 3.5.8. Summary of carry over through out MR11-08 cruise.

	Nitrate CV %	Phosphate CV %	Silicate CV %
Median	0.11	0.19	0.10
Mean	0.12	0.21	0.10
Maximum	0.33	0.8	0.28
Minimum	0.00	0.00	0.00
N	102	102	102

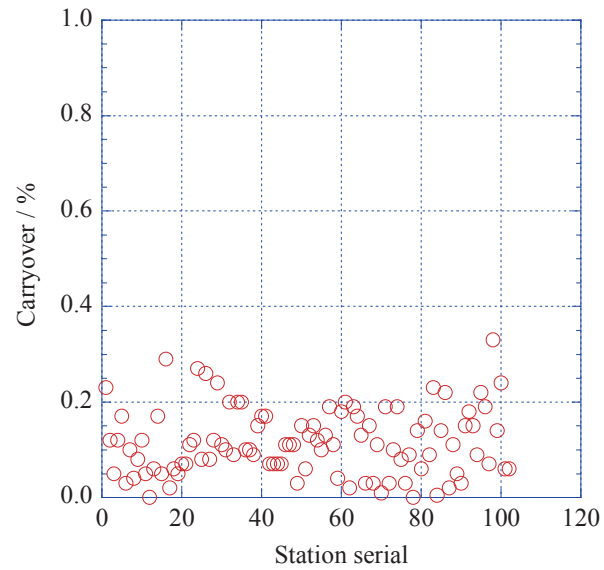


Figure 3.5.11. Time series of carryover of nitrate for MR11-08.

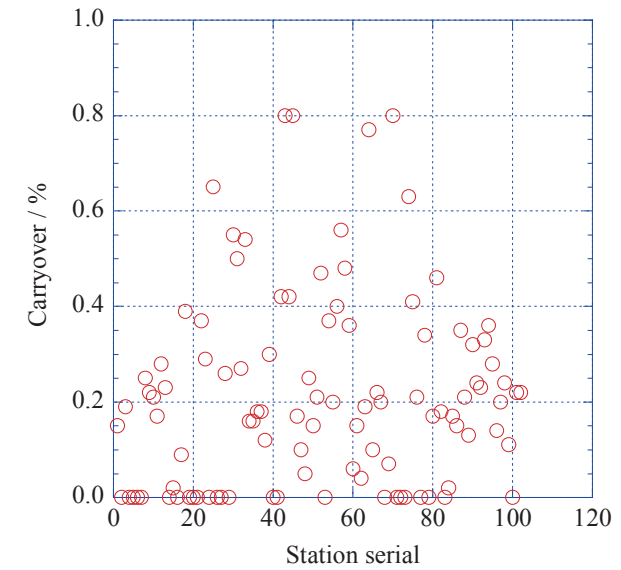


Figure 3.5.13. Time series of carryover of phosphate for MR11-08.

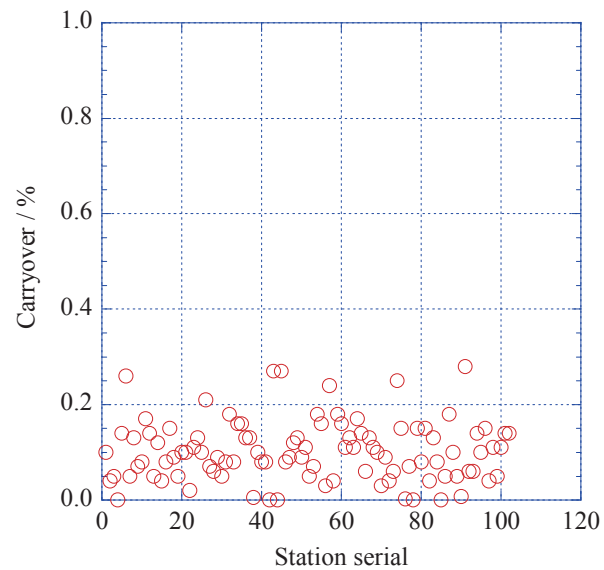


Figure 3.5.12. Time series of carryover of silicate for MR11-08.

(7.3) 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 140 sets of RMNSs during the this cruise. These empirical equations are as follows, respectively.

Phosphate Concentration C_p in $\mu\text{mol kg}^{-1}$:

$$\text{Uncertainty of measurement of phosphate (\%)} = 0.14871 + 0.61128 \times (1/C_p) + 0.02228 \times (1/C_p) \times (1/C_p) \quad \text{--- (1)}$$

where C_p is phosphate concentration of sample.

Nitrate Concentration C_n in $\mu\text{mol kg}^{-1}$:

$$\text{Uncertainty of measurement of nitrate (\%)} = 0.14629 + 2.5141 \times (1/C_n) + 0.056725 \times (1/C_n) \times (1/C_n) \quad \text{--- (2)}$$

where C_n is nitrate concentration of sample.

Silicate Concentration C_s in $\mu\text{mol kg}^{-1}$:

Uncertainty of measurement of silicate (%) =

$$0.12394 + 9.9377 \times (1/C_s) + 7.6725 \times (1/C_s) \times (1/C_s) \quad \text{--- (3)}$$

where C_s is silicate concentration of sample.

(8) Problems/improvements occurred and solutions

During this cruise, we observed noisy signals in output of QuAAtro 2-HR systems. After this cruise we investigated on this and confirmed that noisy signals were originated from Kr-lamps of the colorimeters. We did fix this problem by using LED lamps instead of Kr-lamps.

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3.6 Chlorofluorocarbons and Sulfur Hexafluoride

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(2) Objectives

Chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF₆) are man – made stable gases. These gases can slightly dissolve in sea surface water by air-sea gas exchange and then are spread into the ocean interior. These dissolved gases could be used as transient chemical tracers for the ocean circulation. We measured concentrations of three chemical species of CFCs, CFC-11 (CCl₃F), CFC-12 (CCl₂F₂) and CFC-113 (C₂Cl₃F₃), and SF₆ in seawater on board.

(3) Apparatuses

Measurement of CFCs and SF₆ were made with three gas chromatographs attached with purging and trapping systems (modified from the original design of Bullister and Weiss (1988)). One was SF₆/CFCs simultaneous analyzing system (System A). Other two were CFCs analyzing systems (System D and E). These purging and trapping systems were developed in JAMSTEC.

(3.1) SF₆/CFCs simultaneous analyzing system (System A)

Cold trap columns are 30 cm length stainless steel tubing packed the section of 5cm with 100/120 mesh Porapak T 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.

A gas chromatograph (GC-14B: Shimadzu LTD) has two electron capture detectors, ECD1 and ECD2 (ECD-14: Shimadzu LTD). A pre-column is Silica Plot capillary column [i.d.: 0.32 mm, length: 10 m, film thickness: 4 μ m]. There are two main analytical columns in GC. Main column 1 (MC1) connected up to ECD1 is MS 5A packed column [1/16" OD, 10 cm length stainless steel tubing packed the section of 7 cm with 80/100 mesh Molecular Sieve 5A] followed by Gas Pro capillary column [i.d.: 0.32 mm, length: 35 m] for SF₆ and CFC-12 analyses. Main column 2 (MC2) connected up to ECD2 is Silica Plot capillary column [i.d.: 0.32mm, length: 30 m, film thickness: 4 μ m] for CFC-11 and CFC-113 analyses.

(3.2) CFCs Systems (System D and E)

Cold trap column of the system is 1/16" stainless steel tubing packed with 5cm of 100/120 mesh Porapak T.

The GCs (GC-14B) in these systems had single ECD (ECD-14), respectively. A pre column was Silica Plot capillary column [i.d.: 0.53mm, length: 8 m, film thickness: 6 μ m]. A main column was Pola Bond-Q capillary column [i.d.: 0.53mm, length: 9 m, film thickness: 10 μ m] followed by Silica Plot capillary column [i. d.: 0.53mm, length: 14 m, film thickness: 6 μ m]

(4) Shipboard measurements

(4.1) Sampling

The marine water sampler was cleaned by diluted acetone before every CTD cast in order to remove any oils which could cause contaminations of CFCs. Seawater sub-samples were collected from 12 liter Niskin bottles to 250 ml and 400 ml of glass bottles for CFC and SF₆ measurements, respectively. CFCs sampling was made in every station and SF₆ sampling was done in every other station. The sub-sampling bottles were filled by nitrogen gas before sub-sampling. Two times of the bottle volumes of seawater sample were overflowed. The bottles filled by seawater samples were kept in thermostatic water bath (7°C). The CFC and SF₆ concentrations were determined within 24 hours.

In order to confirm stabilities of standard gases and to check saturation levels of CFCs and SF₆ in sea

surface water, mixing ratios of CFCs and SF₆ in background air were periodically analyzed. Air samples were continuously led into the Environmental Research Laboratory of R/V MIRAI by 10 mm OD Dekaron tubing. The end of the tubing was put on a head of the Compass Deck and another end was connected onto an air pump in the laboratory. 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 200 ml glass cylinder attached on the cock. Average mixing ratios of the atmospheric CFC-11, CFC-12, CFC-113, and SF₆ were 237.7 \pm 8.4 ppt, 522.8 \pm 7.4 ppt, 71.4 \pm 4.4 (n = 100) and 7.36 \pm 0.25 ppt, respectively.

(4.2) Analyses

(4.2.1) SF₆/CFCs simultaneous analyses (System A)

Constant volume of sample water (200 ml) was taken into a sample loop. The sample was sent into stripping chamber and dissolved gases were extracted by pure nitrogen gas purging for 9 minutes. The gas sample was dried by magnesium perchlorate desiccant and concentrated on a main trap column cooled 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. Following purging & trapping, the main trap column was isolated and heated to 170 °C for 1 minute. The desorbed gases were sent onto focusing trap cooled to -80 °C. Gaseous sample on the focusing trap were desorbed by heating to 170 °C for 1 minute and led into the pre-column. Sample gases were roughly separated in the pre-column. SF₆ and CFC-12 were sent onto MC1 and CFC-11 and CFC-113 still remain on the pre-column. Main column connected up to pre-column was switched to MC2 and another carrier gas line was connected up to MC1. SF₆ and CFC-12 were further separated and detected by the ECD1. CFC-11 and CFC-113 led onto MC 2 were detected by ECD2. When CFC-113 eluted from pre-column onto MC 2, the pre-column was switched onto another line and remaining compounds on the pre-column were backflushed. Temperature of the analytical column and ECD was 95 and 300 °C. Mass flow rates of nitrogen gas were 5, 32, 6 and 220 ml/min for carrier gases, detector make up gases, back flush gas and sample purging gas, respectively. Gas loops whose volumes were 0.05, 0.15, 0.3, 1, 3 and 10 ml were used for introducing standard gases into the analytical system. Calibration curves were made every several days and standard gas analyses

using largest loop (10 ml) were performed more frequently to monitor change in the detector sensitivity.

(4.2.2) CFCs analyses (System D and E)

These systems were somewhat simple compared with the system A. Volume of water sample loop was 50 ml. Gas extraction time was for 8 minutes. Cooling and heating temperatures of trap column were -50 and 140 °C, respectively. There were not focusing trap in the systems. Stripping efficiencies were more than 99.5 % of dissolved CFCs on the first purge. Temperatures of the analytical column and ECD were 95 and 240 °C. Mass flow rates of nitrogen gas were 10, 27, 20 and 120 ml/min for carrier, detector make up, back flush and sample purging gases, respectively. There were three gas loops whose volumes were 1, 3 and 10 ml, respectively.

(4.2.3) Standard gases

The standard gasses had been made by Japan Fine Products co. Ltd. Standard gas cylinder numbers used in this cruise were listed in Table 3.6.1. Cylinder of CPB15651 was used as reference gas. Precise mixing ratios of CFCs/SF₆ in the standard gases were calculated by gravimetric data. The standard gases have not been calibrated to SIO scale standard gases yet because SIO scale standard gasses were hard to obtain due to legal difficulties for CFCs import into Japan. The data would be corrected as soon as possible when we obtained the SIO scale standard gases.

(5) Quality control

(5.1) Interference peak for CFC-113

Analyzing surface layer samples (several hundred meters depth) of tropical and sub-tropical region, a large and broad peak was interfered determining CFC-113 peak area in chromatograms obtained from system D and E. Retention time of the interfering peak was slightly different from that of CFC-113. In this case, quality flag “5” was given (no data). The system A completely separated the unknown compound from CFC-113 peak. At the SF₆ stations, measurements of CFC-113 by the system A were adopted.

(5.2) Blanks

Deep water in the North Pacific which would be one of the oldest water masses in the world ocean. CFC concentrations in these water masses could be considered as overall blanks (from Niskin bottles, sub-sampling, and analytical systems). Average concentrations of CFC-11 and CFC-12 in the deep water masses ($\sigma_{\theta} > 27.7$) were 0.011 ± 0.003 , 0.005 ± 0.002 pmol kg⁻¹ ($n = \sim 700$), respectively. These values were assumed as blanks and were subtracted from all data. Significant blanks were not found in CFC-113 and SF₆ measurements.

(5.3) Precisions

The analytical precisions were estimated from replicate sample analyses ($N = 201$ pairs for CFC-12 and CFC-11, 166 pairs for CFC-113, and 103 pairs for SF₆ measurements). The replicate samples were collected from two or three sampling depths which were around 100, 400 and 600 m depths in every station. Precisions were estimated as less than ± 0.007 pmol kg⁻¹ or 0.6 % for CFC-11, ± 0.004 pmol kg⁻¹ or 0.5 % for CFC-12, ± 0.003 pmol kg⁻¹ or 2 % for CFC-113 (whichever is greater), and ± 0.05 fmol kg⁻¹ for SF₆, respectively. Although measurements of CFC-11 and CFC-12 were also obtained from the system A, the precisions were somewhat poor (± 0.016 pmol kg⁻¹ for CFC-11 and ± 0.006 pmol kg⁻¹ for CFC-12) compared with those of measurement by system D and E. Measurements of CFC-11 and CFC-12 from system A were rejected except the stations of P10-004 and P10-006 (because there was not measurements from the system D or E).

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Table 3.6.1. Standard gas cylinder list (Japan Fine Products co. ltd.).

Cylinder No.	Base gas	CFC-11 [ppt]	CFC-12 [ppt]	CFC113 [ppt]	SF ₆ [ppt]	N ₂ O [ppb]
CPB23379	Air	501	251	40.3	5.02	198
CPB17172	Air	998	519	90.0	10.0	300
CPB17174	Air	1499	750	130	10.0	502
CPB26826	N ₂	299	160	30.1	0.0	0
CPB15674	N ₂	299	160	30.0	0.0	0
CPB15651	N ₂	299	159	30.2	0.0	0

3.7 Dissolved Inorganic Carbon (C_T)

October 4, 2013

(1) Personnel

Akihiko Murata (RIGC/JAMSTEC)

Yoshiko Ishikawa (MWJ)

Hatsumi Aoyama (MWJ)

Makoto Takada (MWJ)

(2) Objectives

Concentrations of CO₂ in the atmosphere are now increasing at a rate of 1.9 ppmv y⁻¹ due to human activities such as burning of fossil fuels, deforestation, cement production, etc. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO₂, and to clarify the mechanism of the CO₂ absorption, because the magnitude of the predicted global warming depends on the levels of CO₂ 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 the cruise (MR11-08, revisit of WOCE P10 line) using the R/V Mirai, we were aimed at quantifying how much anthropogenic CO₂ is absorbed in the Pacific Ocean. For the purpose, we measured CO₂-system properties such as dissolved inorganic carbon (C_T), total alkalinity (A_T), pH and underway pCO₂.

In this section, we describe data on C_T obtained in the cruise in detail.

(3) Apparatus

Measurements of C_T were made with two total CO₂ measuring systems (systems-C and -D; Nippon ANS, Inc.), which are slightly different from each other. The systems comprise of a seawater dispensing system, a CO₂ extraction system and a coulometer (Model 3000, Nippon ANS, Inc.).

The seawater dispensing system has an auto-sampler (6 ports), which takes seawater from a 250 ml

borosilicate glass bottle (DURAN®) and dispenses the seawater to a pipette of nominal 20 ml volume by a PC control. The pipette is kept at 20 °C by a water jacket, where water from a water bath set at 20 °C is circulated.

CO₂ dissolved in a seawater sample is extracted in a stripping chamber of a CO₂ extraction system by adding phosphoric acid (10% v/v). 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 a 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 CO₂ by bubbling the nitrogen gas through a fine frit at the bottom of the stripping chamber. The CO₂ stripped in the stripping chamber is carried by the nitrogen gas (140 ml min⁻¹ for the systems C and D) to the coulometer through a dehydrating module. Both the systems have a module with two electric dehumidifiers (kept at 1–2 °C) and a chemical desiccant (Mg(ClO₄)₂).

(4) Shipboard measurement

(4.1) Sampling

All seawater samples were collected from depth with 12 liter Niskin bottles basically at every other stations. The seawater samples for CT were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into a 300 ml borosilicate glass bottle. The glass bottle was filled with seawater smoothly from the bottom following a rinse with a seawater of 2 full, bottle volumes. The glass bottle was closed tightly by a polyethylene inner cap.

At a chemical laboratory on the ship, a headspace of approx. 3 ml was made by removing seawater with a plastic pipette. A saturated mercuric chloride of 100 μl was added to poison seawater samples. The glass bottles were sealed with a greased (Apiezon M, M&I Materials Ltd) ground glass stopper and the clips were secured. 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.

(4.2) Analysis

At the start of each leg, we calibrated the measuring systems by blank and 5 kinds of Na₂CO₃ 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 2% CO₂ gas repeatedly until the measurements became stable. Then we started the calibration.

The measurement sequence such as system blank (phosphoric acid blank), 1.865% CO₂ gas in a nitrogen base, seawater samples (6) was programmed to repeat. The measurement of 1.865% CO₂ gas was made to monitor response of coulometer solutions (from UIC, Inc.). For every renewal of coulometer solutions, certified reference materials (CRMs, batch 112) provided by Prof. A. G. Dickson of Scripps Institution of Oceanography were analyzed. In addition, in-house reference materials (RM) (batch Q24 and Q25 for systems C and D, respectively) 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. As we used two systems, we had not encountered such a situation as we had to abandon the measurement due to time limitation.

(5) Quality control

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 Na₂CO₃ solutions, we calculated C_T of CRM (batch 112), 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.

Based on the averages of C_T of CRM, we re-calculated the calibration factors so that measurements of seawater samples become traceable to the certified value of batch 112.

Temporal variations of RM measurements for one coulometer solution are shown in Fig. 3.7.1. From this figure, it is evident that RM measurements had a linear trend of ~6 μmol kg⁻¹, implying that measurements of seawater samples also have the trend. The trend was also found in temporal changes of 1.865% CO₂ gas

measurements. The trend seems to be due to “cell age” change (Johnson *et al.*, 1998) of a coulometer solution.

Considering the trends, we adjusted measurements of seawater samples so as to be traceable to the certified value of batch 112.

The average and standard deviation of absolute values of differences of C_T analyzed consecutively were 0.7 and 0.5 $\mu\text{mol kg}^{-1}$ (n=96), and 0.7 and 0.6 $\mu\text{mol kg}^{-1}$ (n=85) for legs 1 and 2, respectively. The values for the entire cruises were 0.7 and 0.6 $\mu\text{mol kg}^{-1}$ (n=181).

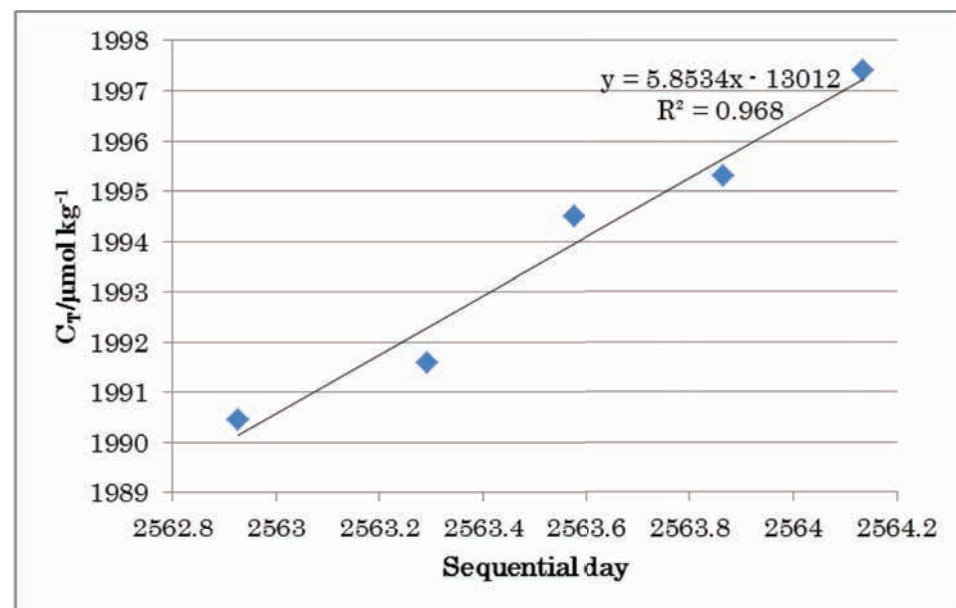


Figure 3.7.1. Distributions of RM measurements as a function of sequential day for Stns. 21 and 25 during MR11-08.

Reference

Johnson, K. M., A. G. Dickson, G. Eiseid, C. Goyet, P. Guenther, R. M. Key, F. J. Millero, D. Purkerson, C. L. Sabine, R. G. Schottle, D. W. R. Wallace, R. J. Wilke and C. D. Winn (1998): Coulometric total carbon dioxide analysis for marine studies: assessment of the quality of total inorganic carbon measurements made during the US Indian Ocean CO_2 survey 1994-1996, *Mar. Chem.*, 63, 21-37.

3.8 Total Alkalinity (A_T)

October 4, 2013

(1) Personnel

Akihiko Murata (RIGC/JAMSTEC)

Tomonori Watai (MWJ)

Ayaka Hatsuyama (MWJ)

Yasumi Yamada (MWJ)

(2) Objectives

Concentrations of CO_2 in the atmosphere are now increasing at a rate of 1.9 ppmv y^{-1} due to human activities such as burning of fossil fuels, deforestation, cement production, etc. 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 predicted 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 the cruise (MR11-08, revisit of WOCE P10 line) using the R/V Mirai, we were aimed at quantifying how much anthropogenic CO_2 is absorbed in the Pacific Ocean. For the purpose, we measured CO_2 -system properties such as dissolved inorganic carbon (C_T), total alkalinity (AT), pH and underway pCO_2 .

In this section, we describe data on A_T obtained in the cruise in detail.

(3) Apparatus

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, an auto-burette (765 Dosimat, Metrohm), and a spectrophotometer (Carry 50 Scan, Varian), which are automatically controlled by a PC. The water dispensing unit has a water-jacketed pipette and a water-jacketed titration cell. The spectrophotometer has a water-jacketed

quartz cell, length and volume of which are 8 cm and 13 ml, respectively. To circulate sample seawater between the titration and the quartz cells, PFA tubes are connected to the cells.

A seawater of approx. 42 ml is transferred from a sample bottle (brosilicate glass bottle; 130 ml) into the water-jacketed (25 °C) pipette by pressurizing the sample bottle (nitrogen gas), and is introduced into the water-jacketed (25 °C) titration cell. The seawater is circulated between the titration and the quartz cells by a peristaltic pump to rinse the route. Then, Milli-Q water is introduced into the titration cell, and is circulated in the same route twice to rinse the route. Next, a seawater of approx. 42 ml is weighted again by the pipette, and is transferred into the titration cell. The weighted seawater is introduced into the quartz cell. Then, for seawater blank, absorbances are measured at three wavelengths (750, 616 and 444 nm). After the measurement, an acid titrant, which is a mixture of approx. 0.05 M HCl in 0.65 M NaCl and bromocresol green (BCG) is added (approx. 2.1 ml) into the titration cell. The seawater + acid titrant solution is circulated for 6 minutes between the titration and the quartz cells, with stirring by a stirring tip and bubbling by wet nitrogen gas in the titration cell. Then, absorbances at the three wavelengths are measured again.

Calculation of A_T was made by the following equation:

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

where M_A is the molarity of the acid titrant added to the seawater sample, $[\text{H}^+]_T$ 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. $[\text{H}^+]_T$ is calculated from the measured absorbances based on the following equation (Yao and Byrne, 1998):

$$\text{pH}_T = -\log[\text{H}^+]_T = 4.2699 + 0.002578(35 - S) + \log((R - 0.00131)/(2.3148 - 0.1299R)) - \log(1 - 0.001005S),$$

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

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

where A_i is the absorbance at wavelength i nm.

The HCl in the acid titrant was standardized (0.050002M, 0.50002 M) on land.

(4) Shipboard measurement

(4.1) Sampling

All seawater samples were collected from depth using 12 liter Niskin bottles basically at every other stations. The seawater samples for A_T were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into borosilicate glass bottles of 130 ml. The glass bottle was filled with seawater smoothly from the bottom after rinsing it with a seawater of half a or a full bottle volume. A few hours before analysis, the seawater samples were kept at 25 °C in a water bath.

(4.2) Analysis

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 112, certified value = 2223.26 $\mu\text{mol kg}^{-1}$, respectively) were also analyzed periodically to monitor systematic differences of measured A_T . The reported values of A_T were set to be traceable to the certified value of the batch 112.

The preliminary values were reported in a data sheet on the 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. We did not encounter so serious problems as we had to give up the analyses. However, we experienced some malfunctions of the system during the cruise, which are listed in the followings:

(5) Quality control

During the cruise, 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.

On land, after making the measured values of A_T comparable to CRM, we examined vertical profiles of A_T . In doing so, we found systematic differences in A_T between 2005 and 2011. To quantify the systematic differences,

we conducted following analyses; first, we took A_T observed below 2000 dbar from both 2005 and 2011 datasets. The A_T data for 2005 were obtained by our cruise by the R/V *Mirai* (MR11-08). Then we selected A_T data collected in same or close stations for the two cruises, and found 40 pairs in total. For the selected data of each cruise, after normalizing to a salinity of 35 (nA_T), we applied a Piecewise Hermite Interpolating scheme to fixed depths to bottom with an interval of 250 dbar : 2250, 2500, 2750 Next, we compared nA_T differences of each depth in respective pairs (Fig. 3.8.1). The average of the differences was $6.0 \pm 2.6 \mu\text{mol kg}^{-1}$. Therefore we applied a value of $6.0 \mu\text{mol kg}^{-1}$ to each A_T in 2011.

The average and standard deviation of absolute values of differences of A_T analyzed consecutively were 0.5 and $0.4 \mu\text{mol kg}^{-1}$ ($n = 96$), and 0.5 and $0.4 \mu\text{mol kg}^{-1}$ ($n = 88$) for legs 2 and 3, respectively. The combined values were calculated to be 0.5 and $0.4 \mu\text{mol kg}^{-1}$ ($n = 184$).

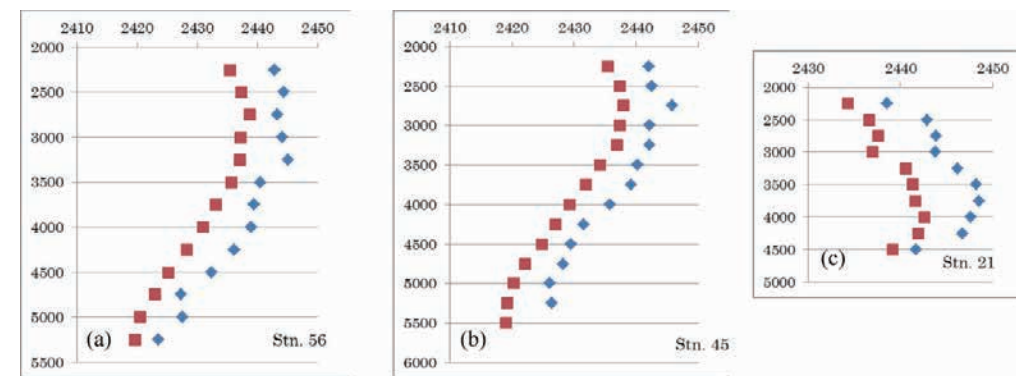


Fig. 3.8.1. Differences of nA_T between 1994 (red) and 2009 (blue) at selected stations.

Reference

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

3.9 pH

October 12, 2013

(1) Personnel

Akihiko Murata (RIGC, JAMSTEC)

Tomonori Watai (MWJ)

Ayaka Hatsuyama (MWJ)

Yasumi Yamada (MWJ)

(2) Objectives

Concentrations of CO₂ in the atmosphere are now increasing at a rate of 1.9 ppmv y⁻¹ due to human activities such as burning of fossil fuels, deforestation, cement production, etc. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO₂, and to clarify the mechanism of the CO₂ absorption, because the magnitude of the anticipated global warming depends on the levels of CO₂ 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 the cruise (MR11-08, revisit of WOCE P10 line) using the R/V Mirai, we were aimed at quantifying how much anthropogenic CO₂ is absorbed in the Pacific Ocean. For the purpose, we measured CO₂-system properties such as dissolved inorganic carbon (C_T), total alkalinity (A_T), pH and underway pCO₂.

In this section, we describe data on pH obtained in the cruise in detail.

(3) Apparatus

Measurement of pH was made by a pH measuring system (Nippon ANS, Inc.), which adopts spectrophotometry. The system comprises of a water dispensing unit and a spectrophotometer (Carry 50 Scan, Varian).

Seawater is transferred from borosilicate glass bottle (300 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 was kept at 25.00 ± 0.05 °C in a thermostated compartment. First, absorbances of seawater only are measured at three wavelengths (730, 578 and 434 nm). Then an indicator is injected and circulated for about 4 minutes to mix the indicator and seawater sufficiently. After the pump is stopped, the absorbances of seawater + indicator are measured at the respective wavelengths.

The pH is calculated based on the following equation (Clayton and Byrne, 1993):

$$pH = pK_2 + \log \left(\frac{A_1 / A_2 - 0.00691}{2.2220 - 0.1331(A_1 / A_2)} \right) \quad (1),$$

where A₁ and A₂ indicate absorbances at 578 and 434 nm, respectively, and pK₂ is calculated as a function of water temperature and salinity.

(4) Shipboard measurement

(4.1) Sampling

All seawater samples were collected from depth with 12 liter Niskin bottles basically at every other stations. The seawater samples for pH were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into a 300 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

For an indicator solution, 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. We renewed an indicator solution 3 times when the headspace of the bottle became large, and monitored pH or absorbance ratio of the indicator solution by another spectrophotometer (Carry 50 Scan, Varian) using a cell with a short path length of 0.5 mm. In most indicator solutions, the absorbance ratios of the indicator solution were kept mostly between 1.4 and 1.6 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.

Absorbances of seawater only and seawater + indicator solutions were measured 11 times each, and the last value was used for the calculation of pH (Eq. 1).

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. We did not encounter so serious a problem as we had to give up the analyses. However, we sometimes experienced malfunctions of the system during the cruise.

(5) Quality control

It is recommended that correction for pH change resulting from addition of indicator solutions is made (DOE, 1994). To check the perturbation of pH due to the addition, we measured absorbance ratios by doubling the volume of indicator solutions added to a same seawater sample. We corrected absorbance ratios based on an empirical method (DOE, 1994), although the perturbations were small. Figure 3.9.1 illustrates an example of perturbation of absorbance ratios by adding indicator solutions.

We surveyed vertical profiles of pH. In particular, we examined whether systematic differences between before and after the renewal of indicator solutions existed or not. Then taking other information of analyses into account, we determined a flag of each value of pH. The reported values, which are the total scale, were set to the values at 25°C by the CO₂ system calculation using data for pH and C_T with K₁, K₂ from Mehrbach *et al.* (1973) refit by Dickson and Millero (1987).

The average and standard deviation of absolute values of differences of pH analyzed consecutively were 0.0006 and 0.0006 pH unit (n = 116), and 0.0008 and 0.0010 pH unit (n = 109) for legs 1 and 2, respectively. The

combined values were 0.0007 and 0.0008 pH unit (n = 225). We compared observed pH and pH calculated from C_T and A_T. The average and standard deviation was 0.0102 and 0.0072 pH unit, respectively. Thus the accuracy of pH was estimated to be 0.01 pH unit at best.

References

- Clayton T. D. and R. H. Byrne (1993): Spectrophotometric seawater pH measurements: total hydrogen ion concentration scale calibration of m-cresol purple and at-sea results. *Deep-Sea Research* 40, 2115-2129.
- Dickson A. G. and F. J. Millero (1987): A Comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. *Deep-Sea Research* 34, 1733-1743.
- 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 & C. Goyet, eds.
- Mehrbach, C., C. H. Culberson, J. E. Hawley, and R. M. Pytkowicz (1973): Measurement of the apparent dissociation constants of carbonic acid in seawater at atmospheric pressure. *Limnology and Oceanography*, 18, 897-907.

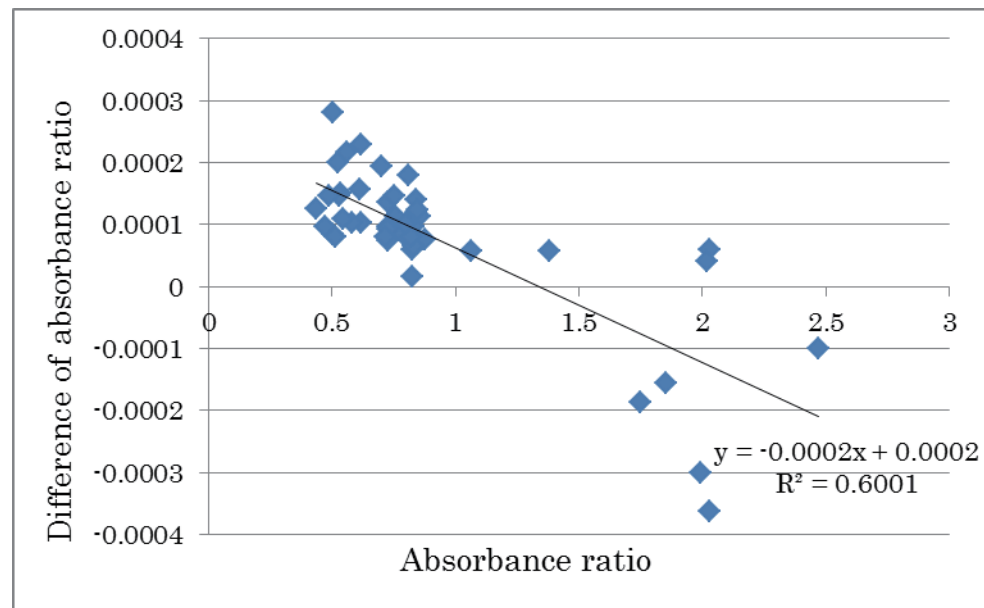


Figure 3.9.1. Perturbation of absorbance ratios by adding indicator solutions. The line was determined by the method of least squares.

3.10 Chlorophyll *a*

February 6, 2014

(1) Personnel

Osamu Yoshida¹ (Rakuno Gakuen University) (Principal Investigator)

Hiroshi Uchida (JAMSTEC) (co-Principal Investigator)

Yuki Okazaki (Rakuno Gakuen University)

Shinichi Oikawa (Rakuno Gakuen University)

Hikari Shimizu (Rakuno Gakuen University)

Chisato Yoshikawa (Tokyo Institute of Technology /

Japan Society for the Promotion of Science) (Not on board)

Shoko Tatamisashi (MWJ)

Masahiro Orui (MWJ)

Naohiro Yoshida (Tokyo Institute of Technology) (Not on board)

(2) Sampling elements

The Rakuno Gakuen University (RGU) group collected chlorophyll *a* samples at CTD/CWS stations 1, 29, 45, 58, 71, 88, and 114 for bucket and Niskin bottles of 36, 35, 34, 33 and 32. The JAMSTEC collected chlorophyll *a* samples at CTD/CWS stations 2, 9, 15, 19, 24, 59, 62, 65, 68, 77, 79, 82, 84, 90, 94, 100, 106, and 112 for a Niskin bottle closed near chlorophyll *a* maximum to calibrate CTD fluorometer data. The JAMSTEC also collected chlorophyll *a* samples from the sea surface water monitoring system once in a day at night to calibrate the fluorometer of the sea surface water monitoring system.

(3) Objective

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. The object of this

study is to investigate the vertical distribution of phytoplankton in various light intensity depth and the horizontal distribution of phytoplankton at sea surface along the cruise track.

(4) Materials and methods

Seawater samples were collected 250 mL at 6 depths from surface to about 200 m with Niskin bottles, except for the Surface water, which was taken by the bucket. For JAMSTEC stations, water samples were collected 500 mL bottle. The samples were gently filtrated by low vacuum pressure (<0.02 MPa) through Whatman GF/F filter (diameter 25 mm) in the dark room. Phytoplankton pigments were immediately extracted in 7 mL of N,N-dimethylformamide (DMF) after filtration and then, the samples were stored at -20°C under the dark condition to extract chlorophyll *a* for 24 hours or more. The extracted samples are measured the fluorescence by Turner fluorometer (10-AU-005, TURNER DESIGNS) which was previously calibrated against a pure chlorophyll *a* (Sigma-Aldrich Co.). We applied the fluorometric “Non-acidification method” (Welschmeyer, 1994).

(5) Results

The results of chlorophyll *a* at RGU sampling stations and relationship between chlorophyll *a* concentrations and chlorophyll *a* estimated from CTD fluorometer were shown in Figures 3.10.1 and 3.10.2, respectively.

Reference

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

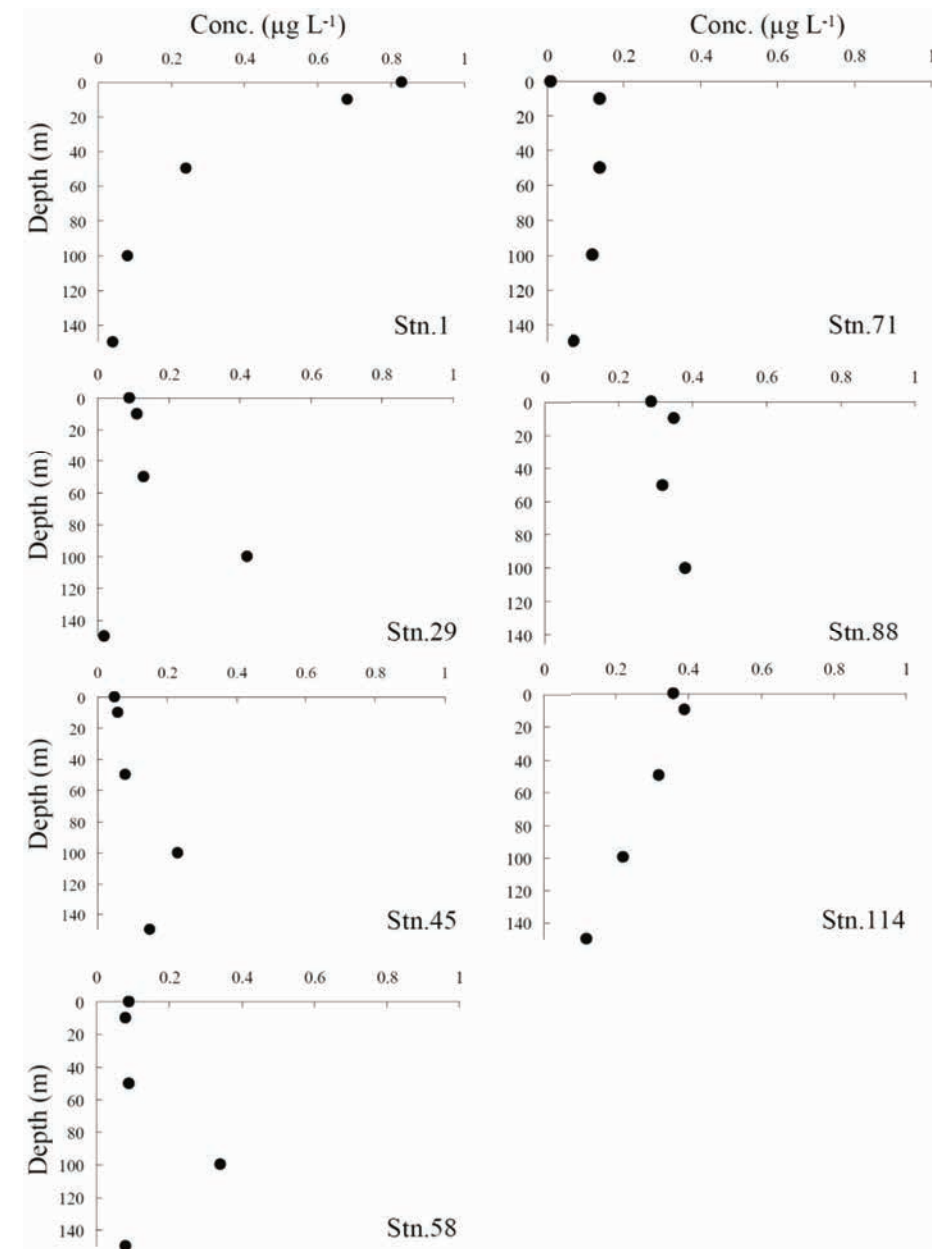


Figure 3.10.1. Vertical distributions of chlorophyll *a* at RGU stations.

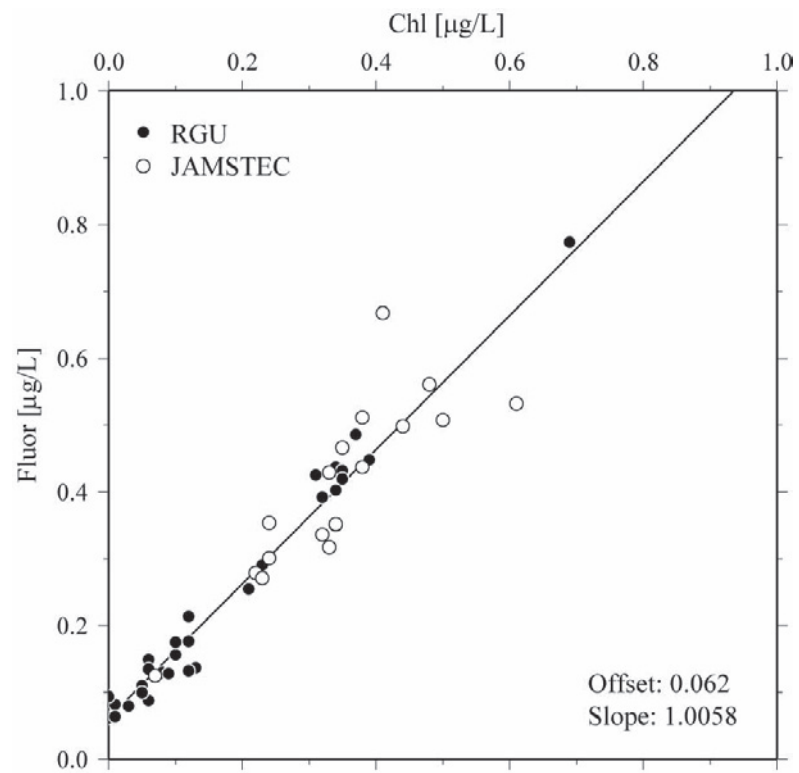


Figure 3.10.2. Relationship between fluorescent values of seawater and chlorophyll a concentrations at RGU (solid circles) and JAMSTEC (open circles) stations.

3.11 LADCP

August 13, 2013

(1) Personnel

Shinya Kouketsu (JAMSTEC)

Hiroshi Uchida (JAMSTEC)

Katsuro Katsumata (JAMSTEC)

Toshimasa Doi (JAMSTEC)

(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 50.4 volts expendable Alkali 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 were Teledyne RD Instruments, WHM300(S/N 183240).

(3) Data collection

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

Bin size: 4 m

Number of bins: 25

Pings per ensemble: 1

Ping interval: 1 sec

(4) Data collection problems

Echo intensities are sufficiently high along the section (Fig. 3.11.1), except at the stations of 9. Since the weak echo were observed for all the beams, the weakness was not due to the instrument problem.

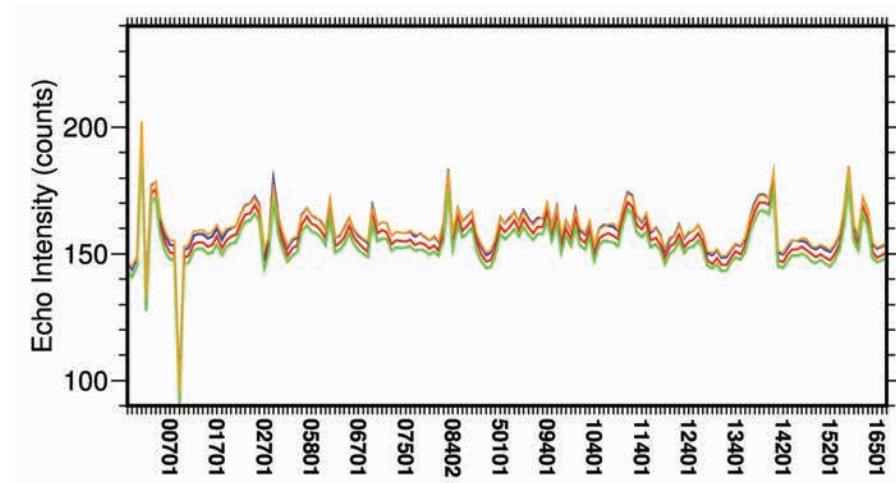


Figure 3.11.1. Cast-averaged echo intensities at the first bin. Red, blue, green and orange denote beam 1, 2, 3, and 4 respectively.

(5) Data process

Vertical profiles of velocity are obtained by the inversion method (Visbeck, 2002). Since the first bin from LADCP is influenced by the turbulence generated by CTD frame, the weight for the inversion is set to 0.1. GPS navigation data and the bottom-track data are used in the calculation of the reference velocities. Shipboard ADCP data averaged for 1 minute are also included in the calculation. The CTD data are used for the sound speed and depth calculation. The directions of velocity are corrected using the magnetic deviation estimated with International Geomagnetic reference field data.

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.

Station Summary

P10 REV R/V MIRAI CRUISE MR1108 LEG2

SHIP/CRS EXPCODE	WOCE SECT	STNNBR	CASTNO	CAST TYPE	DATE	TIME	UTC EVENT CODE	POSITION LATITUDE	LONGITUDE	NAV	UNC DEPTH	COR DEPTH	HT BOTTOM	ABOVE WIRE OUT	PRESS	MAX BOTTLES	NO. OF PARAMETERS	COMMENTS
49NZ20111220	P10	59	1	ROS	122311	2000	BE	19 10.14 N	149 20.11 E	GPS	5566	5560						
49NZ20111220	P10	59	1	BUC	122311	2009	UN	19 10.24 N	149 20.11 E	GPS	5560	5556					1	27.6C
49NZ20111220	P10	59	1	ROS	122311	2126	BO	19 10.39 N	149 20.23 E	GPS	5551	5548	9	5536	5643	36	1-8,27,93	#1=#2 DUPL BTLS
49NZ20111220	P10	59	1	ROS	122311	2345	EN	19 10.70 N	149 20.47 E	GPS	5553	5548						
49NZ20111220	P10	58	1	ROS	122411	0254	BE	18 29.95 N	149 22.94 E	GPS	5641	5643						
49NZ20111220	P10	58	1	BUC	122411	0302	UN	18 29.98 N	149 22.99 E	GPS	5640	5642					1	28.1C
49NZ20111220	P10	58	1	ROS	122411	0419	BO	18 30.08 N	149 23.14 E	GPS	5645	5645	10	5628	5739	36	1-8,23,24,26,27,31,33,34,82	#2=#3 DUPL BTLS
49NZ20111220	P10	58	1	ROS	122411	0640	EN	18 30.30 N	149 23.19 E	GPS	5641	5644						
49NZ20111220	P10	58	1	UNK	122411	0705	UN	18 25.90 N	149 23.20 E	GPS	4669	4671						AIR 13CH4/CH3D/15N2O/N218O/COS SMPL
49NZ20111220	P10	57	1	ROS	122411	0940	BE	17 50.05 N	149 23.15 E	GPS	5216	5217						
49NZ20111220	P10	57	1	BUC	122411	0948	UN	17 50.09 N	149 23.17 E	GPS	5225	5225					1	28.0C
49NZ20111220	P10	57	1	ROS	122411	1101	BO	17 50.38 N	149 23.15 E	GPS	5255	5252	9	5225	5317	35	1-8,27,93	#2=#4 DUPL BTLS
49NZ20111220	P10	57	1	ROS	122411	1309	EN	17 51.15 N	149 23.38 E	GPS	5249	5249						
49NZ20111220	P10	56	1	ROS	122411	1614	BE	17 9.83 N	149 25.94 E	GPS	5315	5316						
49NZ20111220	P10	56	1	BUC	122411	1622	UN	17 9.84 N	149 25.87 E	GPS	5322	5322					1,9,22,89	27.7C
49NZ20111220	P10	56	1	ROS	122411	1735	BO	17 9.95 N	149 25.88 E	GPS	5342	5343	10	5331	5434	35	1-8,12,13,23,24,26,27,92	
49NZ20111220	P10	56	1	ROS	122411	1950	EN	17 10.14 N	149 25.74 E	GPS	5369	5370						
49NZ20111220	P10	55	1	ROS	122411	2256	BE	16 29.84 N	149 35.01 E	GPS	5611	5611						
49NZ20111220	P10	55	1	BUC	122411	2303	UN	16 29.84 N	149 34.98 E	GPS	5609	5609					1	28.0C
49NZ20111220	P10	55	1	ROS	122511	0022	BO	16 29.82 N	149 34.99 E	GPS	5611	5610	9	5590	5703	36	1-8,27,93	#2=#6 DUPL BTLS
49NZ20111220	P10	55	1	ROS	122511	0236	EN	16 29.83 N	149 35.00 E	GPS	5611	5612						
49NZ20111220	P10	54	1	ROS	122511	0532	BE	15 50.05 N	149 35.16 E	GPS	5247	5246						
49NZ20111220	P10	54	1	BUC	122511	0539	UN	15 50.10 N	149 35.16 E	GPS	5243	5243					1,31,33	28.4C
49NZ20111220	P10	54	1	ROS	122511	0651	BO	15 50.09 N	149 35.00 E	GPS	5248	5249	10	5233	5331	35	1-8,27,31,34,93	#2=#7 DUPL BTLS
49NZ20111220	P10	54	1	ROS	122511	0903	EN	15 50.25 N	149 34.92 E	GPS	5241	5240						
49NZ20111220	P10	53	1	ROS	122511	1158	BE	15 10.03 N	149 29.98 E	GPS	5707	5707						
49NZ20111220	P10	53	1	ROS	122511	1216	BO	15 10.04 N	149 29.93 E	GPS	5717	5718	-9	825	832	18	22,89	FOR R.N.
49NZ20111220	P10	53	1	ROS	122511	1245	EN	15 10.08 N	149 29.86 E	GPS	5711	5711						
49NZ20111220	P10	53	2	ROS	122511	1343	BE	15 9.87 N	149 30.05 E	GPS	5711	5710						
49NZ20111220	P10	53	2	BUC	122511	1350	UN	15 9.89 N	149 30.04 E	GPS	5716	5715					1,9,22,89	28.1C
49NZ20111220	P10	53	2	ROS	122511	1510	BO	15 10.08 N	149 29.90 E	GPS	5713	5712	9	5699	5810	36	1-8,23,24,26,27,92	#2=#8 DUPL BTLS
49NZ20111220	P10	53	2	ROS	122511	1734	EN	15 10.41 N	149 29.76 E	GPS	5698	5697						
49NZ20111220	P10	52	1	ROS	122511	2036	BE	14 29.98 N	149 20.31 E	GPS	5330	5330						
49NZ20111220	P10	52	1	BUC	122511	2045	UN	14 29.99 N	149 20.31 E	GPS	5327	5328					1	28.4C
49NZ20111220	P10	52	1	ROS	122511	2159	BO	14 30.19 N	149 20.13 E	GPS	5303	5304	9	5296	5394	35	1-8,27,93	#2=#9 DUPL BTLS
49NZ20111220	P10	52	1	ROS	122611	0006	EN	14 30.44 N	149 20.02 E	GPS	5298	5298						
49NZ20111220	P10	51	1	ROS	122611	0307	BE	13 49.95 N	149 19.23 E	GPS	5990	5989						
49NZ20111220	P10	51	1	BUC	122611	0314	UN	13 50.02 N	149 19.18 E	GPS	5987	5987					1	28.6C
49NZ20111220	P10	51	1	ROS	122611	0418	BO	13 50.30 N	149 18.94 E	GPS	5994	5992	-9	2370	2392			CAST WAS ABORTED DUE TO WINCH TROUBLE
49NZ20111220	P10	51	1	ROS	122611	0451	EN	13 50.49 N	149 18.81 E	GPS	5991	5992						
49NZ20111220	P10	51	2	ROS	122611	0536	BE	13 50.03 N	149 19.10 E	GPS	5989	5989						
49NZ20111220	P10	51	2	ROS	122611	0712	BO	13 50.37 N	149 18.84 E	GPS	5990	5989	9	5977	6096	36	1-8,12,13,23,24,26,27	
49NZ20111220	P10	51	2	ROS	122611	0938	EN	13 50.80 N	149 18.73 E	GPS	5986	5987						
49NZ20111220	P10	50	1	ROS	122611	1243	BE	13 10.01 N	149 19.98 E	GPS	5962	5964						

49NZ20111220	P10	50	1	BUC 122611 1303	UN	13	10.03 N	149	19.96 E	GPS	5966	5966				1,9,22,89	28.5C	
49NZ20111220	P10	50	1	ROS 122611 1413	BO	13	10.02 N	149	20.02 E	GPS	5965	5967	10	5944	6069	36	1-8,27,93	
49NZ20111220	P10	50	1	ROS 122611 1637	EN	13	10.15 N	149	19.75 E	GPS	5965	5967						
49NZ20111220	P10	49	1	ROS 122611 1944	BE	12	29.80 N	149	19.92 E	GPS	5923	5922						
49NZ20111220	P10	49	1	BUC 122611 1953	UN	12	29.85 N	149	19.87 E	GPS	5924	5920				1	28.4C	
49NZ20111220	P10	49	1	ROS 122611 2115	BO	12	30.01 N	149	19.76 E	GPS	5924	5922	10	5906	6024	36	1-8,23,24,26,27,31,33,92	
49NZ20111220	P10	49	1	ROS 122611 2337	EN	12	30.34 N	149	19.66 E	GPS	5924	5921						
49NZ20111220	P10	48	1	ROS 122711 0238	BE	11	49.93 N	149	19.52 E	GPS	5815	5816						
49NZ20111220	P10	48	1	BUC 122711 0245	UN	11	49.99 N	149	19.45 E	GPS	5817	5818				1	28.6C	
49NZ20111220	P10	48	1	ROS 122711 0404	BO	11	50.13 N	149	19.48 E	GPS	5816	5816	8	5793	5912	36	1-8,27,93	
49NZ20111220	P10	48	1	ROS 122711 0626	EN	11	50.30 N	149	19.40 E	GPS	5818	5816						
49NZ20111220	P10	47	1	ROS 122711 0931	BE	11	9.51 N	149	19.93 E	GPS	5806	5807						
49NZ20111220	P10	47	1	ROS 122711 0951	BO	11	9.71 N	149	19.79 E	GPS	5811	5810	-9	826	831	18	22,89	FOR R.N.
49NZ20111220	P10	47	1	ROS 122711 1022	EN	11	10.03 N	149	19.58 E	GPS	5808	5807						
49NZ20111220	P10	47	2	ROS 122711 1117	BE	11	9.15 N	149	20.06 E	GPS	5811	5809						
49NZ20111220	P10	47	2	BUC 122711 1125	UN	11	9.20 N	149	19.98 E	GPS	5812	5812				1,9,22,89	28.3C	
49NZ20111220	P10	47	2	ROS 122711 1245	BO	11	9.42 N	149	19.99 E	GPS	5812	5813	9	5796	5911	36	1-8,12,13,23,24,26,27	
49NZ20111220	P10	47	2	ROS 122711 1509	EN	11	9.67 N	149	20.10 E	GPS	5808	5810						
49NZ20111220	P10	46	1	ROS 122711 1809	BE	10	29.93 N	149	20.03 E	GPS	5714	5713						
49NZ20111220	P10	46	1	BUC 122711 1817	UN	10	29.96 N	149	19.99 E	GPS	5715	5713				1,22,89	28.4C	
49NZ20111220	P10	46	1	ROS 122711 1936	BO	10	30.10 N	149	19.92 E	GPS	5714	5714	10	5697	5808	36	1-8,27,93	
49NZ20111220	P10	46	1	ROS 122711 2151	EN	10	30.63 N	149	19.59 E	GPS	5716	5716						
49NZ20111220	P10	45	1	ROS 122811 0015	BE	09	59.94 N	149	20.11 E	GPS	5574	5576						
49NZ20111220	P10	45	1	BUC 122811 0022	UN	09	59.97 N	149	20.10 E	GPS	5574	5574				1,31,33,34,82,92	28.7C	
49NZ20111220	P10	45	1	ROS 122811 0141	BO	10	0.02 N	149	20.03 E	GPS	5567	5568	9	5559	5668	35	1-8,23,24,26,27,31,33,34,82,92	#11 MISS TRIP
49NZ20111220	P10	45	1	ROS 122811 0402	EN	10	0.43 N	149	19.82 E	GPS	5551	5551						
49NZ20111220	P10	45	1	UNK 122811 0434	UN	09	55.90 N	149	19.90 E	GPS	5507	5505						AIR 13CH4/CH3D/15N2O/N218O/COS SMPL
49NZ20111220	P10	44	1	ROS 122811 0606	BE	09	41.76 N	149	19.99 E	GPS	5358	5358						
49NZ20111220	P10	44	1	BUC 122811 0613	UN	09	41.81 N	149	19.98 E	GPS	5359	5359				1	28.7C	
49NZ20111220	P10	44	1	ROS 122811 0727	BO	09	41.93 N	149	19.88 E	GPS	5359	5359	10	5344	5442	35	1-8,27,93	#2=#10 DUPL BTLS
49NZ20111220	P10	44	1	ROS 122811 0936	EN	09	42.42 N	149	19.84 E	GPS	5375	5373						
49NZ20111220	P10	43	1	ROS 122811 1143	BE	09	29.31 N	149	10.07 E	GPS	5225	5223						
49NZ20111220	P10	43	1	BUC 122811 1151	UN	09	29.30 N	149	10.03 E	GPS	5224	5223				1,9,22,89,90	28.6C	
49NZ20111220	P10	43	1	ROS 122811 1303	BO	09	29.38 N	149	9.97 E	GPS	5233	5232	11	5206	5304	35	1-8,23,24,26,27	#2=#11 DUPL BTLS
49NZ20111220	P10	43	1	ROS 122811 1516	EN	09	29.47 N	149	9.80 E	GPS	5225	5224						
49NZ20111220	P10	42	1	ROS 122811 1822	BE	08	49.88 N	149	19.92 E	GPS	4119	4119						
49NZ20111220	P10	42	1	BUC 122811 1830	UN	08	49.92 N	149	19.92 E	GPS	4119	4119				1	28.9C	
49NZ20111220	P10	42	1	ROS 122811 1927	BO	08	50.13 N	149	19.89 E	GPS	4122	4120	10	4116	4169	31	1-8,27,93	#5=#12 DUPL BTLS
49NZ20111220	P10	42	1	ROS 122811 2119	EN	08	50.44 N	149	19.70 E	GPS	4124	4124						
49NZ20111220	P10	41	1	ROS 122811 2303	BE	08	30.10 N	149	19.96 E	GPS	3614	3616						
49NZ20111220	P10	41	1	BUC 122811 2311	UN	08	30.15 N	149	19.92 E	GPS	3666	3666				1	28.9C	
49NZ20111220	P10	41	1	ROS 122911 0002	BO	08	30.26 N	149	19.80 E	GPS	3650	3652	9	3640	3692	29	1-8,12,13,23,24,26,27,92	#2=#13 DUPL BTLS
49NZ20111220	P10	41	1	ROS 122911 0140	EN	08	30.49 N	149	19.74 E	GPS	3679	3680						
49NZ20111220	P10	40	1	ROS 122911 0404	BE	07	59.91 N	149	9.96 E	GPS	3028	3028						
49NZ20111220	P10	40	1	BUC 122911 0411	UN	07	59.96 N	149	9.94 E	GPS	3021	3019				1	29.1C	
49NZ20111220	P10	40	1	ROS 122911 0453	BO	08	0.00 N	149	9.93 E	GPS	3020	3021	9	3012	3055	36	1-8,22,27,89,93	
49NZ20111220	P10	40	1	ROS 122911 0618	EN	08	0.20 N	149	9.92 E	GPS	3006	3005						
49NZ20111220	P10	39	1	ROS 122911 0844	BE	07	29.96 N	148	55.94 E	GPS	1315	1314						
49NZ20111220	P10	39	1	BUC 122911 0853	UN	07	29.99 N	148	55.87 E	GPS	1314	1315				1,31,33	29.0C	
49NZ20111220	P10	39	1	ROS 122911 0913	BO	07	30.04 N	148	55.84 E	GPS	1314	1313	9	1311	1324	16	1-8,23,24,26,27,31,33	
49NZ20111220	P10	39	1	ROS 122911 0959	EN	07	30.24 N	148	55.71 E	GPS	1324	1321						

49NZ20111220	P10	11	1	BUC	010512	0231	UN	01	44.89	S	145	38.54	E	GPS	1923	1923				1		29.8C	
49NZ20111220	P10	11	1	ROS	010512	0257	BO	01	45.02	S	145	38.53	E	GPS	1920	1921	10	1916	1929	21	1-8,27,93		
49NZ20111220	P10	11	1	ROS	010512	0358	EN	01	45.29	S	145	38.50	E	GPS	1915	1916							
49NZ20111220	P10	12	1	ROS	010512	0547	BE	01	29.82	S	145	42.59	E	GPS	2193	2193							
49NZ20111220	P10	12	1	BUC	010512	0554	UN	01	29.85	S	145	42.56	E	GPS	2195	2194						1	29.9C
49NZ20111220	P10	12	1	ROS	010512	0624	BO	01	29.93	S	145	42.50	E	GPS	2193	2193	9	2182	2203	24	1-8,23,24,26,27	#2=#18 DUPL BTLS	
49NZ20111220	P10	12	1	ROS	010512	0729	EN	01	30.24	S	145	42.41	E	GPS	2186	2186							
49NZ20111220	P10	13	1	ROS	010512	0933	BE	01	14.88	S	145	47.11	E	GPS	2290	2290							
49NZ20111220	P10	13	1	BUC	010512	0941	UN	01	14.88	S	145	47.04	E	GPS	2289	2290						1	30.0C
49NZ20111220	P10	13	1	ROS	010512	1013	BO	01	14.90	S	145	47.00	E	GPS	2292	2290	10	2277	2301	24	1-8,27,93	#2=#17 DUPL BTLS	
49NZ20111220	P10	13	1	ROS	010512	1119	EN	01	14.84	S	145	46.96	E	GPS	2289	2289							
49NZ20111220	P10	14	1	ROS	010512	1326	BE	00	59.80	S	145	51.31	E	GPS	2309	2310							
49NZ20111220	P10	14	1	BUC	010512	1334	UN	00	59.78	S	145	51.22	E	GPS	2309	2310						1	30.1C
49NZ20111220	P10	14	1	ROS	010512	1406	BO	00	59.83	S	145	51.23	E	GPS	2310	2310	9	2296	2331	22	1-8,23,24,26,27		
49NZ20111220	P10	14	1	ROS	010512	1512	EN	00	59.94	S	145	51.18	E	GPS	2304	2305							
49NZ20111220	P10	15	1	ROS	010512	1747	BE	00	44.81	S	145	55.80	E	GPS	2425	2424							
49NZ20111220	P10	15	1	BUC	010512	1755	UN	00	44.83	S	145	55.70	E	GPS	2424	2424						1	29.9C
49NZ20111220	P10	15	1	ROS	010512	1829	BO	00	44.89	S	145	55.54	E	GPS	2426	2425	9	2417	2438	25	1-8,23,24,26,27,34	#2=#16 DUPL BTLS	
49NZ20111220	P10	15	1	ROS	010512	1940	EN	00	45.07	S	145	55.41	E	GPS	2425	2425							
49NZ20111220	P10	16	1	ROS	010512	2215	BE	00	28.52	S	146	0.43	E	GPS	3440	3439							
49NZ20111220	P10	16	1	BUC	010512	2223	UN	00	28.54	S	146	0.37	E	GPS	3443	3442						1	29.8C
49NZ20111220	P10	16	1	ROS	010512	2312	BO	00	28.59	S	146	0.30	E	GPS	3415	3417	9	3407	3464	29	1-8,27,93		
49NZ20111220	P10	16	1	ROS	010612	0044	EN	00	28.63	S	146	0.05	E	GPS	3497	3496							
49NZ20111220	P10	17	1	ROS	010612	0322	BE	00	14.90	S	146	4.16	E	GPS	4716	4714							
49NZ20111220	P10	17	1	BUC	010612	0330	UN	00	14.91	S	146	4.09	E	GPS	4718	4719						1,9,22,89	29.8C
49NZ20111220	P10	17	1	ROS	010612	0435	BO	00	14.79	S	146	4.00	E	GPS	4718	4718	9	4700	4778	34	1-8,12,13,23,24,26,27	#2=#14 DUPL BTLS	
49NZ20111220	P10	17	1	ROS	010612	0635	EN	00	14.67	S	146	3.72	E	GPS	4725	4725							
49NZ20111220	P10	18	1	ROS	010612	0917	BE	00	0.00	S	146	8.44	E	GPS	3621	3620							
49NZ20111220	P10	18	1	BUC	010612	0925	UN	00	0.04	S	146	8.38	E	GPS	3625	3626						1,31,33,90	29.8C
49NZ20111220	P10	18	1	ROS	010612	1016	BO	00	0.00	N	146	8.29	E	GPS	3623	3625	10	3628	3673	30	1-8,23,24,26,27,31,34	#2=#13 DUPL BTLS	
49NZ20111220	P10	18	1	ROS	010612	1156	EN	00	0.00	N	146	7.88	E	GPS	3706	3705							
49NZ20111220	P10	19	1	ROS	010612	1432	BE	00	15.04	N	146	12.74	E	GPS	3727	3726							
49NZ20111220	P10	19	1	BUC	010612	1440	UN	00	14.99	N	146	12.66	E	GPS	3718	3719						1	29.7C
49NZ20111220	P10	19	1	ROS	010612	1530	BO	00	15.05	N	146	12.59	E	GPS	3728	3729	10	3707	3758	30	1-8,27,34,93	#2=#12 DUPL BTLS	
49NZ20111220	P10	19	1	ROS	010612	1706	EN	00	15.18	N	146	12.41	E	GPS	3727	3725							
49NZ20111220	P10	20	1	ROS	010612	1854	BE	00	30.06	N	146	16.95	E	GPS	4125	4126							
49NZ20111220	P10	20	1	BUC	010612	1902	UN	00	30.07	N	146	16.86	E	GPS	4132	4130						1	29.6C
49NZ20111220	P10	20	1	ROS	010612	1959	BO	00	30.13	N	146	16.79	E	GPS	4125	4126	10	4108	4171	29	1-8,27,93		
49NZ20111220	P10	20	1	ROS	010612	2221	EN	00	30.23	N	146	16.55	E	GPS	4111	4110							
49NZ20111220	P10	21	1	ROS	010712	0020	BE	00	44.97	N	146	21.29	E	GPS	4504	4504							
49NZ20111220	P10	21	1	BUC	010712	0028	UN	00	44.98	N	146	21.21	E	GPS	4489	4489						1	29.7C
49NZ20111220	P10	21	1	ROS	010712	0131	BO	00	45.05	N	146	21.26	E	GPS	4494	4495	9	4474	4548	34	1-8,23,24,26,27,92	#2=#9 DUPL BTLS	
49NZ20111220	P10	21	1	ROS	010712	0325	EN	00	45.06	N	146	21.27	E	GPS	4494	4493							
49NZ20111220	P10	22	1	ROS	010712	0518	BE	00	59.94	N	146	25.60	E	GPS	4530	4529							
49NZ20111220	P10	22	1	BUC	010712	0526	UN	00	59.94	N	146	25.54	E	GPS	4528	4529						1	29.6C
49NZ20111220	P10	22	1	ROS	010712	0629	BO	00	59.98	N	146	25.48	E	GPS	4532	4529	9	4513	4589	34	1-8,27,93	#2=#7 DUPL BTLS	
49NZ20111220	P10	22	1	ROS	010712	0821	EN	01	0.15	N	146	25.41	E	GPS	4518	4516							
49NZ20111220	P10	23	1	ROS	010712	1015	BE	01	14.94	N	146	30.13	E	GPS	4468	4468							
49NZ20111220	P10	23	1	ROS	010712	1034	BO	01	15.01	N	146	30.10	E	GPS	4469	4468	-9	825	830	28	9,22,89		FOR R.N.
49NZ20111220	P10	23	1	ROS	010712	1103	EN	01	15.15	N	146	30.07	E	GPS	4466	4469							
49NZ20111220	P10	23	2	ROS	010712	1201	BE	01	14.81	N	146	30.12	E	GPS	4475	4475							

49NZ20111220	P10	23	2	BUC 010712 1210	UN	01	14.83 N 146 30.06 E	GPS	4473	4473				1,9,22,89	29.5C	
49NZ20111220	P10	23	2	ROS 010712 1311	BO	01	14.90 N 146 30.10 E	GPS	4477	4476	9	4456	4527	33	1-8,12,13,23,24,26,27	#2=#8 DUPL BTLS
49NZ20111220	P10	23	2	ROS 010712 1508	EN	01	15.07 N 146 29.99 E	GPS	4471	4469						
49NZ20111220	P10	24	1	ROS 010712 1712	BE	01	30.08 N 146 34.26 E	GPS	4486	4483						
49NZ20111220	P10	24	1	BUC 010712 1719	UN	01	30.12 N 146 34.18 E	GPS	4482	4481					1	29.6C
49NZ20111220	P10	24	1	ROS 010712 1823	BO	01	30.18 N 146 34.21 E	GPS	4480	4479	10	4463	4538	35	1-8,27,34,93	#2=#10 DUPL BTLS, #5 CHLORA MAX
49NZ20111220	P10	24	1	ROS 010712 2026	EN	01	30.49 N 146 34.13 E	GPS	4465	4465						
49NZ20111220	P10	25	1	ROS 010712 2222	BE	01	45.00 N 146 38.55 E	GPS	4456	4455						
49NZ20111220	P10	25	1	BUC 010712 2231	UN	01	45.01 N 146 38.54 E	GPS	4453	4454					1	29.7C
49NZ20111220	P10	25	1	ROS 010712 2331	BO	01	45.05 N 146 38.65 E	GPS	4449	4454	9	4430	4502	32	1-8,23,24,26,27	
49NZ20111220	P10	25	1	ROS 010812 0124	EN	01	45.17 N 146 38.54 E	GPS	4454	4455						
49NZ20111220	P10	26	1	ROS 010812 0320	BE	01	59.81 N 146 42.94 E	GPS	4448	4448						
49NZ20111220	P10	26	1	BUC 010812 0328	UN	01	59.81 N 146 42.86 E	GPS	4441	4441					1	29.7C
49NZ20111220	P10	26	1	ROS 010812 0430	BO	01	59.83 N 146 42.98 E	GPS	4442	4441	10	4422	4495	32	1-8,27,93	
49NZ20111220	P10	26	1	ROS 010812 0620	EN	01	59.95 N 146 42.96 E	GPS	4439	4437						
49NZ20111220		802	1	UNK 011012 0310	BE	12	1.97 N 145 19.87 E	GPS	7234	7230						RELEASING EXCESS TWIST OF CTD CABLE
49NZ20111220		802	1	UNK 011012 0640	EN	12	2.55 N 145 19.21 E	GPS	7278	7275						WOUT 6500M

P10 REV R/V MIRAI CRUISE MR1108 LEG3

SHIP/CRS	WOCE	CAST		UTC EVENT		POSITION			UNC	COR	HT ABOVE	WIRE	MAX	NO. OF	COMMENTS			
EXPCODE	SECT	STNNBR	CASTNO	TYPE	DATE	TIME	CODE	LATITUDE	LONGITUDE	NAV	DEPTH	DEPTH	BOTTOM	OUT		PRESS	BOTTLES	PARAMETERS
49NZ20120113	P10	59	2	ROS	011412	0719	BE	19 10.07 N	149 20.12 E	GPS	5566	5565						
49NZ20120113	P10	59	2	BUC	011412	0727	UN	19 10.05 N	149 20.08 E	GPS	5559	5556					1	27.4C
49NZ20120113	P10	59	2	ROS	011412	0843	BO	19 10.05 N	149 19.82 E	GPS	5556	5556	9	5540	5647	36	1-8,27,93	#2 CHL MAX (130DB)
49NZ20120113	P10	59	2	ROS	011412	1107	EN	19 9.91 N	149 19.22 E	GPS	5562	5562						
49NZ20120113	P10	59	2	BIO	011412	1133	BE	19 10.11 N	149 19.31 E	GPS	5556	5556						ORI NET
49NZ20120113	P10	59	2	BIO	011412	1323	EN	19 12.85 N	149 21.16 E	GPS	5624	5623						
49NZ20120113	P10	60	1	ROS	011412	1612	BE	19 49.92 N	149 19.96 E	GPS	3752	3752						
49NZ20120113	P10	60	1	ROS	011412	1628	BO	19 49.89 N	149 19.92 E	GPS	3716	3716	-9	765	772	18	22,89	FOR R.N.
49NZ20120113	P10	60	1	ROS	011412	1658	EN	19 49.91 N	149 19.87 E	GPS	3716	3717						
49NZ20120113	P10	60	2	ROS	011412	1758	BE	19 49.85 N	149 20.06 E	GPS	3713	3714						
49NZ20120113	P10	60	2	BUC	011412	1804	UN	19 49.86 N	149 20.03 E	GPS	3695	3695					1,9,22,89	27.0C
49NZ20120113	P10	60	2	ROS	011412	1854	BO	19 49.86 N	149 19.98 E	GPS	3691	3692	11	3652	3707	28	1-8,12,13,23,24,26,27,90,92	
49NZ20120113	P10	60	2	ROS	011412	2041	EN	19 49.93 N	149 19.88 E	GPS	3723	3721						
49NZ20120113	P10	61	1	ROS	011412	2342	BE	20 29.91 N	149 20.03 E	GPS	4463	4464						
49NZ20120113	P10	61	1	BUC	011412	2350	UN	20 29.90 N	149 20.02 E	GPS	4468	4468					1	27.0C
49NZ20120113	P10	61	1	ROS	011512	0052	BO	20 29.59 N	149 19.93 E	GPS	4450	4448	10	4448	4504	30	1-8,27,93	
49NZ20120113	P10	61	1	ROS	011512	0241	EN	20 29.50 N	149 19.73 E	GPS	4553	4553						
49NZ20120113	P10	61	1	XMP	011512	0302	DE	20 29.67 N	149 19.76 E	GPS	4541	4542						RSI #0020
49NZ20120113	P10	61	2	XMP	011512	0557	DE	20 33.38 N	149 19.85 E	GPS	4629	4629						RSI #0019
49NZ20120113	P10	62	1	ROS	011512	1102	BE	21 10.88 N	149 20.56 E	GPS	5390	5392						
49NZ20120113	P10	62	1	BUC	011512	1110	UN	21 10.84 N	149 20.54 E	GPS	5390	5390					1,31,33	26.6C
49NZ20120113	P10	62	1	ROS	011512	1225	BO	21 10.85 N	149 20.53 E	GPS	5391	5391	9	5378	5480	35	1-8,23,24,26,27,31,33,34	
49NZ20120113	P10	62	1	ROS	011512	1436	EN	21 10.81 N	149 20.42 E	GPS	5389	5389						
49NZ20120113	P10	62	1	BIO	011512	1452	BE	21 10.84 N	149 20.42 E	GPS	5387	5389						ORI NET
49NZ20120113	P10	62	1	BIO	011512	1654	EN	21 13.53 N	149 21.33 E	GPS	5407	5410						
49NZ20120113	P10	63	1	ROS	011512	1946	BE	21 50.03 N	149 20.03 E	GPS	5618	5617						
49NZ20120113	P10	63	1	BUC	011512	1955	UN	21 49.99 N	149 20.02 E	GPS	5620	5619					1	26.5C
49NZ20120113	P10	63	1	ROS	011512	2113	BO	21 49.93 N	149 20.00 E	GPS	5625	5624	11	5607	5716	36	1-8,27,93	#5 UPPER AND LOWER CAPS LEAK
49NZ20120113	P10	63	1	ROS	011512	2338	EN	21 49.64 N	149 20.04 E	GPS	5628	5629						
49NZ20120113	P10	64	1	ROS	011612	0242	BE	22 29.87 N	149 20.00 E	GPS	5711	5712						
49NZ20120113	P10	64	1	BUC	011612	0249	UN	22 29.79 N	149 20.00 E	GPS	5712	5712					1	25.1C
49NZ20120113	P10	64	1	XCT	011612	0251	DE	22 29.79 N	149 20.00 E	GPS	5714	5715						TSK XCTD-2 #11022006
49NZ20120113	P10	64	1	ROS	011612	0408	BO	22 29.80 N	149 19.98 E	GPS	5712	5712	9	5695	5810	36	1-8,12,13,23,24,26,27,92	
49NZ20120113	P10	64	1	ROS	011612	0623	EN	22 29.52 N	149 20.19 E	GPS	5716	5715						
49NZ20120113	P10	65	1	ROS	011612	0930	BE	23 10.83 N	149 20.52 E	GPS	5802	5801						
49NZ20120113	P10	65	1	BUC	011612	0938	UN	23 10.85 N	149 20.53 E	GPS	5804	5803					1	25.1C
49NZ20120113	P10	65	1	ROS	011612	1058	BO	23 10.67 N	149 20.48 E	GPS	5802	5800	9	5805	5909	36	1-8,27,34,93	
49NZ20120113	P10	65	1	ROS	011612	1322	EN	23 10.71 N	149 20.67 E	GPS	5805	5803						
49NZ20120113	P10	66	1	ROS	011612	1616	BE	23 49.80 N	149 19.96 E	GPS	5829	5828						
49NZ20120113	P10	66	1	BUC	011612	1623	UN	23 49.79 N	149 19.99 E	GPS	5827	5826					1,31,33	23.6C
49NZ20120113	P10	66	1	ROS	011612	1745	BO	23 49.58 N	149 20.25 E	GPS	5808	5806	10	5841	5937	36	1-8,23,24,26,27,31,33	
49NZ20120113	P10	66	1	ROS	011612	2016	EN	23 49.44 N	149 20.35 E	GPS	5801	5801						
49NZ20120113	P10	67	1	ROS	011612	2238	BE	24 14.64 N	149 1.78 E	GPS	5789	5790						
49NZ20120113	P10	67	1	ROS	011612	2253	EN	24 14.58 N	149 1.90 E	GPS	5786	5787						CAST WAS ABORTED DUE TO STEERING TROUBLE
49NZ20120113	P10	67	2	ROS	011612	2318	BE	24 14.58 N	149 2.18 E	GPS	5783	5784						
49NZ20120113	P10	67	2	ROS	011612	2335	BO	24 14.59 N	149 2.23 E	GPS	5782	5784	-9	796	803	18	22,89	FOR R.N.

49NZ20120113	P10	67	2	ROS 011712 0004	EN	24	14.58	N	149	2.29	E	GPS	5782	5783						
49NZ20120113	P10	67	3	ROS 011712 0107	BE	24	14.54	N	149	1.76	E	GPS	5789	5789						
49NZ20120113	P10	67	3	BUC 011712 0113	UN	24	14.53	N	149	1.82	E	GPS	5788	5789				1,9,22,89	23.9C	
49NZ20120113	P10	67	3	XCT 011712 0116	DE	24	14.53	N	149	1.83	E	GPS	5786	5785					TSK XCTD-2 #11022005	
49NZ20120113	P10	67	3	ROS 011712 0234	BO	24	14.43	N	149	1.99	E	GPS	5784	5786	10	5783	5891	36	1-8,23,24,26,27,93	
49NZ20120113	P10	67	3	ROS 011712 0454	EN	24	14.21	N	149	2.07	E	GPS	5784	5785						
49NZ20120113	P10	68	1	ROS 011712 0702	BE	24	30.18	N	149	20.10	E	GPS	5773	5771						
49NZ20120113	P10	68	1	BUC 011712 0710	UN	24	30.14	N	149	20.12	E	GPS	5771	5771				1	24.1C	
49NZ20120113	P10	68	1	ROS 011712 0830	BO	24	30.02	N	149	20.10	E	GPS	5772	5772	11	5769	5876	36	1-8,23,24,26,27,34,92	
49NZ20120113	P10	68	1	ROS 011712 1054	EN	24	29.95	N	149	20.53	E	GPS	5772	5770						
49NZ20120113	P10	68	1	BIO 011712 1107	BE	24	29.94	N	149	20.67	E	GPS	5773	5774					ORI NET	
49NZ20120113	P10	68	1	BIO 011712 1252	EN	24	28.39	N	149	17.43	E	GPS	5732	5732						
49NZ20120113	P10	69	1	ROS 011712 1613	BE	25	9.99	N	149	20.00	E	GPS	5904	5904						
49NZ20120113	P10	69	1	BUC 011712 1621	UN	25	9.91	N	149	20.00	E	GPS	5902	5902				1	23.1C	
49NZ20120113	P10	69	1	ROS 011712 1743	BO	25	9.82	N	149	19.86	E	GPS	5901	5900	11	5888	6010	36	1-8,27,93	
49NZ20120113	P10	69	1	ROS 011712 2016	EN	25	9.35	N	149	19.70	E	GPS	5911	5912						
49NZ20120113	P10	70	1	ROS 011712 2347	BE	25	49.90	N	149	19.86	E	GPS	5892	5893						
49NZ20120113	P10	70	1	BUC 011812 0000	UN	25	49.91	N	149	19.67	E	GPS	5894	5894				1	22.7C	
49NZ20120113	P10	70	1	ROS 011812 0120	BO	25	49.93	N	149	19.30	E	GPS	5891	5891	11	5887	5998	36	1-8,27,93	
49NZ20120113	P10	70	1	ROS 011812 0346	EN	25	49.85	N	149	18.49	E	GPS	5877	5877						
49NZ20120113	P10	71	1	ROS 011812 0720	BE	26	29.89	N	149	19.94	E	GPS	6110	6111						
49NZ20120113	P10	71	1	ROS 011812 0738	BO	26	29.89	N	149	19.92	E	GPS	6100	6099	-9	828	831	18	22,89	FOR R.N.
49NZ20120113	P10	71	1	ROS 011812 0810	EN	26	29.91	N	149	19.93	E	GPS	6104	6104						
49NZ20120113	P10	71	2	ROS 011812 0858	BE	26	29.81	N	149	20.10	E	GPS	6081	6082						
49NZ20120113	P10	71	2	BUC 011812 0906	UN	26	29.81	N	149	20.11	E	GPS	6078	6079				1,9,22,31,33,34,82,89	22.7C	
49NZ20120113	P10	71	2	ROS 011812 1030	BO	26	29.80	N	149	19.98	E	GPS	6083	6084	11	6056	6177	36	1-8,23,24,26,27,31,33,34,82,93	
49NZ20120113	P10	71	2	ROS 011812 1303	EN	26	29.87	N	149	20.01	E	GPS	6092	6092						
49NZ20120113	P10	71	2	BIO 011812 1316	BE	26	29.98	N	149	20.15	E	GPS	6080	6079					ORI NET	
49NZ20120113	P10	71	2	UNK 011812 1450	UN	26	32.59	N	149	22.78	E	GPS	5768	5767					AIR 13CH4/CH3D/15N2O/N218O/COS SMPL	
49NZ20120113	P10	71	2	BIO 011812 1516	EN	26	33.26	N	149	23.34	E	GPS	5788	5790						
49NZ20120113	P10	72	1	ROS 011812 1825	BE	27	10.00	N	149	20.16	E	GPS	5890	5888						
49NZ20120113	P10	72	1	BUC 011812 1834	UN	27	9.97	N	149	20.16	E	GPS	5885	5883				1	21.9C	
49NZ20120113	P10	72	1	ROS 011812 1954	BO	27	9.88	N	149	20.06	E	GPS	5891	5889	11	5874	5988	36	1-8,27,93	
49NZ20120113	P10	72	1	ROS 011812 2225	EN	27	9.71	N	149	19.96	E	GPS	5889	5888						
49NZ20120113	P10	73	1	ROS 011912 0133	BE	27	50.01	N	149	19.96	E	GPS	5973	5973						
49NZ20120113	P10	73	1	BUC 011912 0141	UN	27	50.04	N	149	19.95	E	GPS	5974	5972				1	20.1C	
49NZ20120113	P10	73	1	ROS 011912 0303	BO	27	49.84	N	149	19.70	E	GPS	5970	5968	10	5963	6078	36	1-8,27,93	
49NZ20120113	P10	73	1	ROS 011912 0525	EN	27	49.79	N	149	19.72	E	GPS	5966	5966						
49NZ20120113	P10	73	1	FLT 011912 0533	DE	27	49.94	N	149	19.73	E	GPS	5968	5967					ARGO #10039/ID97950	
49NZ20120113	P10	74	1	CTD 011912 0836	BE	28	29.95	N	149	19.72	E	GPS	6221	6223					FOR FL/TRANS/LADCP	
49NZ20120113	P10	74	1	CTD 011912 0845	BO	28	29.90	N	149	19.59	E	GPS	6222	6223	-9	297	301	0		
49NZ20120113	P10	74	1	CTD 011912 0851	EN	28	29.87	N	149	19.52	E	GPS	6219	6218						
49NZ20120113	P10	74	2	ROS 011912 0959	BE	28	29.87	N	149	19.69	E	GPS	6221	6222						
49NZ20120113	P10	74	2	BUC 011912 1007	UN	28	29.83	N	149	19.58	E	GPS	6219	6219				1,9,22,31,33,89	19.6C	
49NZ20120113	P10	74	2	ROS 011912 1133	BO	28	29.84	N	149	19.68	E	GPS	6222	6222	12	6204	6334	36	1-8,12,13,23,24,26,27,31,33,92	
49NZ20120113	P10	74	2	ROS 011912 1410	EN	28	29.84	N	149	19.82	E	GPS	6224	6224						
49NZ20120113	P10N	75	1	ROS 011912 1714	BE	29	10.16	N	149	20.11	E	GPS	6093	6094						
49NZ20120113	P10N	75	1	BUC 011912 1721	UN	29	10.15	N	149	20.10	E	GPS	6095	6095				1	20.3C	
49NZ20120113	P10N	75	1	ROS 011912 1845	BO	29	10.07	N	149	20.06	E	GPS	6098	6100	10	6085	6213	36	1-8,27,93	
49NZ20120113	P10N	75	1	ROS 011912 2130	EN	29	10.08	N	149	20.08	E	GPS	6100	6101						
49NZ20120113	P10N	76	1	ROS 012012 0038	BE	29	50.10	N	149	20.12	E	GPS	6153	6153						

49NZ20120113	P10N	106	1	ROS	020412	0752	BO	40	5.02	N	145	22.21	E	GPS	5374	5374	-9	826	831	27	9,22,89	FOR R.N.
49NZ20120113	P10N	106	1	ROS	020412	0820	EN	40	4.98	N	145	22.22	E	GPS	5378	5375						
49NZ20120113	P10N	106	2	ROS	020412	0916	BE	40	5.03	N	145	22.16	E	GPS	5376	5375						
49NZ20120113	P10N	106	2	BUC	020412	0924	UN	40	5.01	N	145	22.20	E	GPS	5375	5374					1,9,22,31,33,89,91	3.6C
49NZ20120113	P10N	106	2	ROS	020412	1039	BO	40	5.09	N	145	22.12	E	GPS	5381	5380	11	5371	5469	33	1-8,12,13,23,24,26,27,31,33,91-93	#31 MISS FIRE
49NZ20120113	P10N	106	2	ROS	020412	1245	EN	40	5.09	N	145	22.27	E	GPS	5376	5375						
49NZ20120113	P10N	106	2	BIO	020412	1255	BE	40	5.09	N	145	22.29	E	GPS	5375	5376						ORI NET
49NZ20120113	P10N	106	2	BIO	020412	1355	EN	40	6.35	N	145	19.97	E	GPS	5385	5384						
49NZ20120113	P10N	107	1	XCT	020412	1550	DE	40	24.90	N	145	8.08	E	GPS	5819	5820						TSK XCTD-2 #11021848
49NZ20120113	P10N	108	1	XCT	020512	0106	DE	40	45.18	N	144	53.22	E	GPS	6239	6240						TSK XCTD-2 #11021847
49NZ20120113	P10N	109	1	XCT	020512	0258	DE	40	59.92	N	144	42.15	E	GPS	6338	6340						TSK XCTD-2 #11021844
49NZ20120113	P10N	110	1	ROS	020512	0507	BE	41	15.06	N	144	30.77	E	GPS	4041	4038						
49NZ20120113	P10N	110	1	ROS	020512	0516	BO	41	15.02	N	144	30.71	E	GPS	4045	4044	-9	340	350	30	9,22,89	FOR R.N.
49NZ20120113	P10N	110	1	ROS	020512	0539	EN	41	14.93	N	144	30.54	E	GPS	4052	4051						
49NZ20120113	P10N	110	2	ROS	020512	0628	BE	41	14.97	N	144	30.74	E	GPS	4054	4053						
49NZ20120113	P10N	110	2	XCT	020512	0639	DE	41	14.91	N	144	30.67	E	GPS	4057	4057						TSK XCTD-2 #11021843
49NZ20120113	P10N	110	2	BUC	020512	0639	UN	41	14.91	N	144	30.66	E	GPS	4059	4057						3.9C
49NZ20120113	P10N	110	2	ROS	020512	0733	BO	41	14.78	N	144	30.64	E	GPS	4110	4110	11	4064	4132	35	1,9,22,89,90 1-8,9,12,13,22-24,26,27,89,90,92,93	
49NZ20120113	P10N	110	2	ROS	020512	0910	EN	41	14.35	N	144	30.56	E	GPS	4212	4210						
49NZ20120113	P10N	111	1	XCT	020512	1038	DE	41	29.97	N	144	19.30	E	GPS	2693	2694						TSK XCTD-2 #11021840
49NZ20120113	P10N	112	1	ROS	020512	1216	BE	41	45.17	N	144	7.63	E	GPS	1472	1472						
49NZ20120113	P10N	112	1	BUC	020512	1224	UN	41	45.12	N	144	7.67	E	GPS	1482	1479						1.6C
49NZ20120113	P10N	112	1	XCT	020512	1226	DE	41	45.12	N	144	7.69	E	GPS	1479	1475						TSK XCTD-2 #11021841
49NZ20120113	P10N	112	1	ROS	020512	1244	BO	41	45.04	N	144	7.61	E	GPS	1484	1484	10	1468	1483	16	1-8,23,24,26,27,90,93	
49NZ20120113	P10N	112	1	ROS	020512	1328	EN	41	44.86	N	144	7.43	E	GPS	1497	1496						
49NZ20120113	P10N	112	1	BIO	020512	1339	BE	41	44.81	N	144	7.47	E	GPS	1502	1502						ORI NET
49NZ20120113	P10N	112	1	BIO	020512	1542	EN	41	42.50	N	144	1.07	E	GPS	1362	1362						
49NZ20120113	P10N	113	1	XCT	020512	1717	DE	42	0.17	N	143	56.22	E	GPS	1050	1048						TSK XCTD-2 #11021842
49NZ20120113	P10N	114	1	ROS	020512	1821	BE	42	10.04	N	143	48.44	E	GPS	723	723						
49NZ20120113	P10N	114	1	BUC	020512	1831	UN	42	10.02	N	143	48.46	E	GPS	723	724						0.5C
49NZ20120113	P10N	114	1	ROS	020512	1837	BO	42	10.05	N	143	48.51	E	GPS	726	726	10	714	720	33	1-8,9,22,23,24,26,27,31,33,34,82,89,90,92	
49NZ20120113	P10N	114	1	ROS	020512	1908	EN	42	10.02	N	143	48.57	E	GPS	726	726						
49NZ20120113	P10N	114	1	UNK	020512	1915	UN	42	9.90	N	143	48.45	E	GPS	727	-9						AIR 13CH4/CH3D/15N2O/N218O/COS SMPL
49NZ20120113	P10N	115	1	ROS	020512	2116	BE	42	15.18	N	143	44.42	E	GPS	484	483						
49NZ20120113	P10N	115	1	BUC	020512	2120	UN	42	15.18	N	143	44.42	E	GPS	482	484						0.6C
49NZ20120113	P10N	115	1	ROS	020512	2130	BO	42	15.18	N	143	44.43	E	GPS	484	484	11	472	477	9	1-8,27,90,93	
49NZ20120113	P10N	115	1	ROS	020512	2147	EN	42	15.13	N	143	44.37	E	GPS	481	482						
49NZ20120113	P10N	804	1	UNK	020612	0110	BE	41	46.36	N	143	12.78	E	GPS	99	-9						3-AXIS MAGNETOMETER CALIBRATION
49NZ20120113	P10N	804	1	UNK	020612	0144	EN	41	45.76	N	143	12.05	E	GPS	104	-9						

Water sample parameters:

Number	Parameter	Mnemonic	Mnemonic for expected error
1	Salinity	SALNTY	
2	Oxygen	OXYGEN	
3	Silicate	SILCAT	SILUNC
4	Nitrate	NITRAT	NRAUNC
5	Nitrite	NITRIT	NRIUNC
6	Phosphate	PHSPHT	PHPUNC
7	Freon-11	CFC-11	
8	Freon-12	CFC-12	
9	Tritium	TRITUM	
12	14Carbon	DELC14	C14ERR
13	13Carbon	DELC13	C13ERR
22	137Cs	CS-137	
23	Total carbon	TCARBN	
24	Total alkalinity	ALKALI	
26	pH	PH	
27	Freon-113	CFC113	
31	Methane	CH4	
33	Nitrous oxide	N2O	
34	Chlorophyll a	CHLORA	
82	15N-Nitrate	15NO3	
89	134Cs	CS-134	
90	Perfluorinated acids		
91	129I	I-129	
92	Density salinity	DNSSAL	
93	Sulfur hexafluoride	SF6	

Figure captions

- Figure 1 Station locations for WHP P10 revisit in 2011 cruise with bottom topography based on Smith and Sandwell (1997).
- Figure 2 Bathymetry measured by Multi Narrow Beam Echo Sounding system.
- Figure 3 Surface wind measured at 25 m above sea level. Wind data is averaged over 6-hour.
- Figure 4 (a) Sea surface temperature ($^{\circ}\text{C}$), (b) sea surface salinity (psu), (c) sea surface oxygen ($\mu\text{mol}/\text{kg}$), 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 .
- Figure 6 Surface current at 100 m depth measured by ship board acoustic Doppler current profiler (ADCP).
- Figure 7 Potential temperature ($^{\circ}\text{C}$) cross section calculated by using CTD temperature and salinity data calibrated by bottle salinity measurements. Vertical exaggeration of the 0-6500 m section is 1000:1. Expanded section of the upper 1000 m is made with a vertical exaggeration of 2500:1.
- Figure 8 CTD salinity (psu) cross section calibrated by bottle salinity measurements. Vertical exaggeration is same as Figure 7.
- Figure 9 Absolute salinity (g/kg) cross section calculated by using CTD salinity data. Vertical exaggeration is same as Figure 7.
- Figure 10 Density (σ_0) (kg/m^3) cross section calculated by using CTD temperature and salinity data. Vertical exaggeration is same as Figure 7. (a) EOS-80 and (b) TEOS-10 definition.
- Figure 11 Same as Figure 10 but for σ_4 (kg/m^3). (a) EOS-80 and (b) TEOS-10 definition.
- Figure 12 Neutral density (γ^n) (kg/m^3) cross section calculated by using CTD temperature and salinity data. Vertical exaggeration is same as Figure 7.
- Figure 13 Cross section of CTD oxygen ($\mu\text{mol}/\text{kg}$). Vertical exaggeration is same as Figure 7.
- Figure 14 Cross section of CTD chlorophyll *a* (mg/m^3). Vertical exaggeration of the upper 1000 m section is same as Figure 7.
- Figure 15 Cross section of bottle sampled dissolved oxygen ($\mu\text{mol}/\text{kg}$). Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.
- Figure 16 Silicate ($\mu\text{mol}/\text{kg}$) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.
- Figure 17 Nitrate ($\mu\text{mol}/\text{kg}$) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.
- Figure 18 Nitrite ($\mu\text{mol}/\text{kg}$) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration of the upper 1000 m section is same as Figure 7.
- Figure 19 Phosphate ($\mu\text{mol}/\text{kg}$) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 20 Dissolved inorganic carbon ($\mu\text{mol/kg}$) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 21 Total alkalinity ($\mu\text{mol/kg}$) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 22 pH cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 23 CFC-11 (pmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 24 CFC-12 (pmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 25 CFC-113 (pmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 26 Cross section of current velocity (cm/s) normal to the cruise track measured by LADCP (eastward is positive). Vertical exaggeration is same as Figure 7.

Figure 27 Difference in potential temperature ($^{\circ}\text{C}$) between results from the previous cruise and the revisit in 2011 (December 2011 – February 2012). The previous cruise is (a) WOCE (October – November 1993) and (b) the first revisit (May – June 2005). 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 Figure 7.

Figure 28 Same as Fig. 27, but for salinity (psu). CTD salinity data with SSW batch correction1 were used. On white areas differences in salinity do not exceed the detection limit of 0.002 psu.

Figure 29 Same as Fig. 27, but for dissolved oxygen ($\mu\text{mol/kg}$). CTD oxygen data were used. On white areas differences in dissolved oxygen do not exceed the detection limit of $2\mu\text{mol/kg}$.

Note

1. As for the traceability of SSW to Kawano's value (Kawano et al., 2006), the offset for the batches P114 (WOCE P10 stations from 1 to 12), P120 (WOCE P10 stations from 13 to 74), and P145 (the revisit in 2005) and P153 (the revisit in 2011) are 0.0020 , -0.0009 , -0.0009 and 0.0004 , respectively. The offset values for the recent batches are listed in Table A1 (Uchida et al., in preparation). For P120 of WOCE P10 cruise, salinity was corrected with an offset of -0.0015 (cruise report of WOCE P10). Therefore, the salinity data are corrected with an offset of 0.0006 for the stations from 13 to 74 of WOCE P10.

Table A1. SSW batch to batch differences from P145 to P155 (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	-2.2	-0.9
P146	2005/05/12	0.99979	34.9917	-2.7	-1.4
P147	2006/06/06	0.99982	34.9929	-1.8	-0.5
P148	2006/10/01	0.99982	34.9929	-1.2	0.1
P149	2007/10/05	0.99984	34.9937	-0.6	0.7
P150	2008/05/22	0.99978	34.9913	-0.5	0.8
P151	2009/05/20	0.99997	34.9984	-1.3	0.0
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	-1.1	0.2

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.
- Smith, W. H. F. and D. T. Sandwell (1997): Global seafloor topography from satellite altimetry and ship depth soundings, *Science*, 277, 1956–1962.

